No. 310 APRIL 2012

T.W.I.T.T. NEWSLETTER

The Tuscar H-71was a side-by-side two-seat tailless flying wing design with several rudders mounted along the trailing edge of the wing. The aircraft was powered by a 95-hp Menasco B-4 pusher prop located at the rear of the fuselage. Source: http://www.aerospaceweb.org/question/history/q0029b.shtml

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., **1204** means this is your last issue unless renewed.

Next TWITT meeting: Saturday, May 19, 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).

TWITT NEWSLETTER **APRIL 2012**

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.

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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).

TABLE OF CONTENTS

President's Corner 1
Letters to the Editor... 2
Nurflugel Threads 3
Wing Tips of Tailless Aircraft – Weyl................ 6
Available Plans/Reference Material 11

PRESIDENT'S CORNER

On page 2 I have included a picture and description of a tailless sailplane we would like to identify along with its designer. So if you have any idea of what it may be please drop me a line and fill me in with what you know about it. As I note in comments it appears to be something from the Don Mitchell string of designs. Unfortunately, Richard Avalon who had most of that knowledge has passed away so I am depending on our members to fill in the blanks.

There will be one more installment of the Weyl wing tips article coming to you in the May issue. There are some very interesting graphics that go along with the text so I think you will enjoy finishing this story. I hope everyone had gotten a lot of information out of these old articles and can see the progress we have made in the ensuing years to make flying wings more efficient and safer. I think I still have another one of his papers to post in the newsletter, then I will try to find some of the other more historical papers we have in the archives and pass them along.

As the weather continues to get warmer I hope you will send me some photos and a little information on what you flying and/or building. I really enjoy seeing what others are doing with new designs and how successful they have been.

Andy

LETTERS TO THE EDITOR

(ed. – I wrote to Serge Krauss to ask him how I should update his Tailless Aircraft Bibliography advertisement in the classified section of the newsletter. Here is his edited reply that has resulted in making a change to the ad in this and future issues.)

Hi Andy,

I have been thinking about this for some time. I have only entered a part of what I have accumulated and have not kept up with publications over the last decade. So, with other events in my life at present I no longer see an up to date bibliography emerging. What I'd like to do is catch it up on disk and illustrate it with the techniques I've developed from newsletter editing so that a pre-21st century PDF edition could emerge from what's in that huge file now. I only have a million copyright concerns on illustrations, since it appears that the entire world is owned. Anyway, that looks like an achievable goal. Meanwhile, I'm available to people who have questions and can for some more serious inquiries search and print out citations in specific subject areas, as I have been doing.

So maybe something like this is in order for the newsletter:

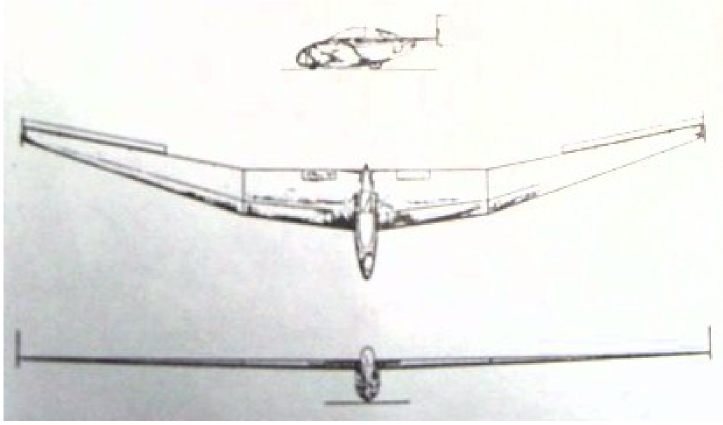
> ***Tailless Aircraft Bibliography*:** My book containing several thousand annotated entries and appendices listing well over three hundred tailless designers/creators and their aircraft is no longer in print. I expect *eventually* to make available on disc a fairly comprehensive annotated and perhaps illustraterd listing of pre-21st century tailless and related-interest aircraft documents in PDF format. Meanwhile, I will continue to provide information from my files to serious researchers. I'm sorry for the continuing delay, but life happens. Serge Krauss, skrauss@ameritech,net, (216) 321-5743.

The Internet has usurped a good bit of the up-to-date usefulness, although only the TWITT and a couple other sites really carry good history. I think the lessons of the 20th century are still important, especially since we keep reading of people - even the technically well-educated with computers - making the same old mistakes. However, I see my work as more historical than technical now. So there are four boxes here, partially filled with "stuff" for the bibliography, and some of it's pretty "cool". I think my generous friend Philippe Vigneron is the outstanding historical researcher now. How he keeps tracking down information from his multitudinous postings around the world is still a source of amazement to me.

Serge

(ed. – I got an e-mail from a friend who was trying to find out the designation of the flying wing described and shown below. I am not sure what publication it was in originally, but it looks like something for either the Vintage Sailplane or Experimental Soaring associations.

It appears to be from the Don Mitchell collection based on the fuselage profile being almost identical to his Goodyear Racer proposal many years ago. However, the wing span is obviously not for a racer, so what is it?)



Specifications:

Wing span	46’
Length	11’ 3”
Height	4’ 6”
Weight empty	250#
Gross weight	450#
Wing	high, wood-covered wooden spar
Fuselage	wood-covered semi monocoque
Landing Gear	two-wheel tandem

Noteworthy Features: Single place Class I tailless sailplane, using external “ailevators” for longitudinal and lateral control. Airfoil is modified Gott-549 with an aspect ratio of 17.9 and zero wing twist. Canopy is molded Lucite. Available in kit form. This ship was built in 1950.

Thought you might like to know a source for some but not all Horten models on the Internet. On the Internet go to Fiddlers Green.com and look under the sections for gliders and Nazi X Planes. These are paper card models that come to you via the Internet and are printed out on card stock on your color printer.

Possibly enough encouragement from TWITTers might persuade Fiddlers Green to produce other Horten varieties.

Hope this helps.

David Bogart
<dave.bogart@yahoo.com>
El Campo, TX

(ed. - Thanks for the link to the paper gliders. I did find that the link is really:
https://www.fiddlersgreen.net/shop/category/name/Gliders.html

since FiddlersGreen.com is golfing equipment. These look like interesting short term projects that might be fun for indoor flying.)

Bob (Hoey),

I am very interested in your efforts with the seagull. Do you have any plans and a building guide.
I can see the page from the 2002 TWITT meeting http://www.twitt.org/2partdrib.html#top

Regards

Trevor Hornby

Hello Trevor,

The Raven and Turkey Vulture plans were published in RCM and Model Airplane News, respectively, but the Seagull plans have never been published. I have working drawings, which I would be glad to send you, no charge. If you have done any scratch building, I'm sure you could build a successful Seagull model. Send me your snail mail address and I will mail you a copy of the Seagull drawings. I can also send you some photos of the model during construction, which should help.

You might check out the following video clip sent to me by Evert Kleinhans in South Africa, who built his model from my plans.

http://www.youtube.com/watch?v=srxLGIdx5_M

I'd be glad to answer any questions you have about the construction.

Good luck,

Bob Hoey
<bobh@antelecom.net>

(ed. – I am always glad to see people want to experiment with R/C bird flight and are contacting Bob for more information on his great models. Our thanks to Bob for being so responsive and willing to assist with more information.)

NURFLUGEL Bulletin Board Threads

I am just now reading the book, quite interesting. The book is "The Horten Brothers And Their All-Wing Aircraft", written by David Myhra. It deals with their lives and planes.

Dave Sinme

Two other books you need are

Nurflugel by Reimar Horten, Peter Selinger, and Jan Scott

Only the Wing by Russ Lee

These have excellent information on the Hortens. Other books by Myhra are also good.

Al Bowers

Tailless Tale by Ferdinando Galè lists hundreds of tailless models and has some good technical information.

It looks like you can still get it:
http://www.b2streamlines.com/books/booktitles.html

Norm Masters

Agree with that. And anything B^2 writes. And

Tailless Aircraft Theory and Practice by Wolfarht and Nickel

I like some of the model designs on Andy MacDonald's web page. Particularly Hans Unverferth's CO series.

Al Bowers

Having made quite a few swept flying wing models now, one problem keeps cropping up. Getting the C of G where you want it. Simple, you say - add some weight in the right place. But what if that place is outside the structure? Let me explain. The models I am talking about have very high aspect ratios, considerable taper, 16 degrees sweep, vestigial central pods for fuselages and winglets/tip fins. For these I often encounter the need to add weight behind the CG, not in front. They usually turn out very nose heavy. Given that the CG starts out being behind the trailing edge of the wing at the root, it follows that weight must be added further back than that. Either I must make the fuselage longer or add weight on a rod sticking out the back of it! This has implications in terms of rotating inertia especially at the stall and aerodynamic consequences if the fuselage is extended far behind the leading edge at the root. Making the tips heavier is not a place I want to go.

I have often wondered where the Hortens put their C of Gs. As some of their gliders were not dissimilar to mine (think somewhat north of HVI) I wonder if they encountered the same problem. Any pearls of wisdom, Nurflugelers?

Chris

Just a thought, although I have only made a few wings, I use 20 degrees sweep back as recommended in one of many articles in "On the Wing". This will give you a more rearward CG.

Another thought: highly tapered wings above taper ration 0.6 are not recommended owing to problems with tip stall from the lack of the resulting Reynolds numbers at the reduced chord tip.

I expect some experts will chime in here and argue with me about my lack of knowledge but that's what this site is all about.
Best wishes

Ken Baker. Bristol, U.K.

Is there some particular reason you can't place weights in, on, or under the wings at the right distance from the AC to get the proper CG?

For most models I have dealt with this could be done by jurist placement of the servos. Of course this means you have to think a little more about the structure loadings in particular when maneuvering and with really thin wings. You don't want to end up adding twist when all you are asking to do for a simple banking maneuver.

Warren Bean

When I am working with flying wings, I usually start with 25 degrees and a high aspect ratio. The c.g. can be found by using descriptive geometry. I mount the engine amidships, using an extended shaft for a pusher, and I don't use weight (pure). The engine is, usually, laying flat, buried in the wing. I use a small impeller, to draw air over the engine until the wing is moving thru the air. I use drag tips for yaw control and no fin. Flying wings must have retracts, it cleans then up. The wing, I have just finished, is 9 ft. using a .61 and weighs about 7 lbs. Jump in with comments.
Sincerely,

Dave Sinme

A couple of things to keep in mind:

On big swept wings, if you run much more than 20 degrees of leading edge wing sweep, the flow will not want to stay laminar. As you exceed 20 degrees of LE sweep designers are forced to accommodate less forgiving airfoils to maintain laminar flow, and accept less forgiving stall characteristics.

If your CG is too far forward, you can move equipment outboard to move mass aft. This can result in problems with glitter and spin recovery though.

And a pusher prop aft of the CG on powered aircraft is stabilizing both in yaw and pitch. Tractors with props forward of the CG are generally discouraged...

I think (though a good argument might convince me otherwise)...

Al Bowers

Glitter? Autocorrect is funny. I was just corresponding with a modeler about mass distribution and body freedom flutter earlier today. Standard practice now that servos are so small is to put them in the wing so that there's only one bar linking the servo output arm to the aileron control horn. However on a high AR 'wing like the Horten 4 you need to use every flutter avoidance trick you know and moving some of the massive items, like elevon servos, to the nodes is a simple thing even if it means devolving to more complex linkages. The hard part is figuring out exactly where the bending node of the half span is. I just guess.

Norm Masters

Yes, auto correct is maddening. Apologies to all. The switch from a BlackBerry to an iPhone hasn't been as seamless as I had hoped.

And I would surmise your "guess" is pretty good about the nodes on the Wong shape vibration modes. Intuition can be a very good guide when coupled with experience.

Al Bowers

OK. I will put up a shot of my latest model to show you what I mean. It actually flies really well with a very good glide performance and no tendency to act like a propeller. It uses a twist layout that accelerates as the tip is approached. I was deliberately trying to push the envelope with this series of designs and I thought this one would simply not fly but, happily, I was wrong! It seems to have adequate stability in all three axes but especially in yaw, which is encouraging. The design has tip fins and spans over two meters. At the moment, the C of G is most of the way down towards the rear fuselage tip, perhaps two cms behind the trailing edge and needs to go further aft. In terms of MAC, that's about -10 to -12 per cent! Of course, as the C of G goes aft I will find out what it is really like.

A couple of points. This is a chuck glider, so no controls or engines yet. However, I am working on a 5-metre carbon version of this design where the wing, even at that scale, is still so thin that a servo will only fit in the thickened root with a long straight snake down to bell cranks and short push rods at the elevon. The simple way to cure the CG problem would be to let the tip get a bit heavier than one would like but this invites, as Al says, problems with spin recovery. You run out of control power to correct things and the tendency to go on rotating, once started, is overpowering. The next step is to design a longer fuselage to cope but that may spoil some of the stability. But that is what it is all about. Keep trying.

Chris Bryant

>The c.g. can be found by using descriptive geometry.

I am assuming that this refers to finding the a.c. of the wing and then using a chosen static margin to place the c.g. Aside from variances due to twist, RN, and cambers in swept wings, which I'm assuming you folks have handled already in your adventures, I've found significant problems with accuracy of the popular drawn geometrical method itself due to fairly large variance of drawn line intersections for small initial drawing errors. While this appears less important in context of other uncertainties, it seems best to minimize input errors and know the nature/sources of errors in results.

If the equations for MAC (MGC) and a.c. location are not the most convenient, they're not that bad for straight tapers (or elliptical chord distributions), but, why not just go here...

http://www.palosrc.com/index.php?option=com_content&view=article&id=50:cg&catid=41:ic&Itemid=50

or here:
http://www.palosrc.com/index.php?option=com_content&view=article&id=51:mac&catid=41:ic&Itemid=50

...and just read the answer?

'sorry if I have failed to interpret correctly.

Serge Krauss

It is not so much intuition as a series of lucky encounters. There was a thread about flutter on RC Groups and Mark Drela mentioned that the bending node is at about 1/3 of the half span and that mass there drops out of the BFF picture. Some time later, while I was plotting the CG range of a flying wing, I realized that the pitch axis for sin^3 crosses the 1/4 chord line at that point also.

So: from Ferdinando Galè I learned how to plot the

CG range of a swept 'wing and from Isaac Newton I learned that energy increases as velocity squared and from Mark Drela I learned approximately where the bending node is which I should have realized years earlier because I have seen many articles about flutter testing that SHOW the bending node and wave form of BFF

Random, self directed, learning is a slow process. Stay in school kids.

Norm Masters

September, 1945 AIRCRAFT ENGINEERING

Wing Tips for Tailless Aeroplanes

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

Characteristics of Diffuser Tips

Diffuser-type tips are thus not simply tilted-down tips; their characteristics are:

(a) deflection of the plane of the wing tip against the plane of the wing, in combination with:
(b) axis of the deflection of the plane of the wing tip arranged under such an angle to the plane of symmetry of the aeroplane that the two axes of deflection of both tips intersect forward of the leading edge of the wing. This results in a twisting distortion of the wing at the tip.

In characterizing the significant features of a wing tip of the diffuser type, it is inessential whether the angle of deflection is a proper angle (i.e. axis of deflection lying within the plane of the wing) or if it is the result of a gradual bend in the wing (axis of deflection lying below the plane of the wing). Also, the axis of deflection may or may not be parallel to the plane of the Wing. Thus an immense variety of wing tips of the diffuser type is possible. Only a few of these Shapes have been experimented with up to now.

The angle of skew which the axis of tip deflection forms with the plane of symmetry of the aeroplane is aerodynamically essential. At first sight, it might appear that this feature amounts to not much more than a washing-out twist of the wing. It seems, however, nearer to the truth to assume that by means of the skew, the effect obtained for lateral stability, corresponds to that of a toed-in fin disk located at the wing, tip (to which we have referred already, viz. – "Stability of Tailless Aeroplanes", AIRCRAFT ENGINEERING, April, 1945, p. 107).

A diffuser-type tilt which seems to deviate somewhat from the shapes outlined in our definition, but which is in principle equivalent, is the "hollow half-cone" fitted to the ends of an otherwise normal wing, as experimented with by V. Schill.

Consider a plain wing provided with a primitive diffuser tip in a side-slip to starboard (Fig. 4), i.e. flying under an angle of yaw β. The angle of yaw $\beta = \sin^{-1} v/V$ is thus positive, the starboard wing is leading and the port wing trailing. The velocity V of the resultant air flow can be resolved into two components, one of velocity U parallel of the plane of symmetry, and the other of velocity V_y with a span wise direction. In our assumption, the transverse flow component V_y is positive--being from starboard to port. It affects the wing tips differently: at the leading wing (starboard), it decreases the effective angle of incidence, while at the trailing tip, tile effective incidence is increased. The rolling moment resulting from this tends to depress the leading wing. In accordance with the standard system of body axes used, the moment is positive, hence

$$L_v = \partial L / \partial \beta > o$$

i.e., the tip makes the wing unstable in roll, due to anhedral effect, and the wing thus equipped would appear to have the tendency to "dig in" when side-slipping, unless the wing part outside the tip can, due to effective dihedral, neutralize this tendency.

This simple consideration of the stability in roll is, however, far from being complete. First of all, it neglects influences such as those due to boundary-layer flow at or near the tips. The span wise movement of boundary-layer material toward the trailing wing is obviously of some importance on the lift there and hence on the rolling moment. Possibly the boundary layer is thickening near the trailing tip on the dorsal surface of the wing, and partial separation will decrease the lift force. Further, the tilted tip facing the relative wind forms a heavily cambered aerofoil section which gives relatively large lift forces even at negative geometric angles of incidence, besides large drag and span wise components within the boundary layer on it, will make premature separation unlikely. A separation of the boundary layer on the leading wing will, if at all, occur in parts only, which are inboard, while at the trailing tip, stalling phenomena may set in early at the tip itself (contrary to corresponding disturbances produced by the marginal vortices of a plain wing with square-cut straight tips).

Other less explored effects (e.g. the "oblique attack") may be contributing to an extent which really seem to be worth some painstaking research and tile application of appropriate theoretical methods, before the characteristics of diffuser tips could be considered as known.

But even without such detailed knowledge, it does not seem unreasonable to assume that the deficiency in rolling stability as induced by a diffuser tip is, at the least, small and in any case smaller than the anhedral alone would lead one to believe.

In general, however, diffuser tips are used with wing systems which possess some effective dihedral in the inner part (though Dunne and some other tailless experimenters have made no use of this feature). As a sort of countermeasure, Dunne placed the centre of gravity of his monoplane very low beneath the aerodynamic centre of the wing.

In the wing system considered above, the drag in side-slip is obviously unequal at both wing tips. The leading tip presents a large frontal area to the relative air flow, the drag of which (heavily-cambered section) must be in excess of that of the trailing tip. The yawing moment *N* resulting from this drag difference tends to turn the wing into the relative wind, hence:—

$\partial N / \partial \beta < 0$, i.e. positive weathercock stability.

But again that is only part of the story. The drag on the leading tip depends largely upon the relative incidence, far more than the, in comparison, smaller drag component caused by the trailing tip. The weathercock stability will thus greatly vary with the incidence. And when we assume the existence of the "oblique-attack" effect claimed by Budig giving negative drag components at large angles of side-slip, then a diffuser tip may even give zero or negative weathercock stability, i.e. yaw the aeroplane so that it is flying with the relative wind. Dunne presumed that the Zanonia seed-leaf (as opposed to his "negative" tips) had this quality.

The whole problem is moreover complicated by the scale effect. With cambered sections, and the effective tip sections in side-slip are always cambered, the scale effect is much evident when the effective incidence becomes negative. According to British and to N.A.C.A. tests, large variations of the down-lift occur in a critical range of Reynolds numbers between 0.45 and 1.8×10^6, so that differences can be expected to occur between high speed and landing speed, and with small and slow tailless aeroplanes and models. For experiments with scaled-down tailless aircraft this should be borne in mind. It may not only affect the longitudinal stability and the trim, but also the yawing stability.

In general, model experience indicates, that diffuser tips tend to keep the aeroplane on its original course, i.e. that the weathercock stability is either zero or very small, while a Zanonia type wing tends to turn against the relative wind. It was stated that Northrop had to reduce the tilt of his diffuser tips, because the weathercock stability in flight had become excessive, in comparison to model experiments.

When a wing with diffuser tips yaws, i.e. turns about its *z*-axis in a positive sense (port (wing advancing), the leading tip (port) will commonly experience more drag and increased down-lift, in comparison with tile trailing tip. Thus damping in yaw

$$N_r = \partial N / \partial v$$

and a reduced value of the derivative of the rolling moment due to yawing

$$L_r = \partial L / \partial v$$

can be expected. The latter property is, as mentioned before, conducive to comfort and steadiness in flight. Both qualities are largely responsible for the steadiness of the flight path which is exhibited by glider models provided with diffuser-type wing tips.

Another stability derivative which may be influenced by a diffuser wing tip, is the yawing moment due to rolling

$$N_v = \partial N / \partial p$$

It is also conceivable that the roll damping L_v is not only beneficially influenced at incidences below the stall, but that it might not change its sign for some range of incidences above the stall, i.e. that a diffuser tip could render a wing safer against an inadvertent spin. How far freedom from auto-rotation could be achieved by appropriate shapes of diffuser tips, would certainly be worth an investigation, as possibilities in this direction seem to exist.

Diffuser tips may also have effect on the rotary derivative of the pitching moment due to pitching

$$M_q = \partial M / \partial q$$

When discussing the longitudinal stability of isolated wing systems ("Stability of Tailless Aeroplanes", Aircraft Engineering, Marc 1945, p. 79), we found that the damping in pitch (M_q) made the main difference in the flying qualities of the tailless aeroplane, as compared with conventional types. We then pointed out that any improvement of the aerodynamic damping would be beneficial for the problem of the flying wing. The diffuser wing tip might bring about such an improvement. It would seem that the span-wise flow component induced by this device is tending to increase the mass of air which will be set in motion by a pitching oscillation of the wing. Admittedly, this effect may also express itself as an apparent increase in the moment of inertia. about the lateral axis. But if the diffuser tip itself is considered, it would appear obvious that, in pitch, its air damping qualities will differ greatly when the angle of incidence of the wing is increased to that when it is decreased. This unilateral damping assisted by the air flow at the tip and unaffected by the phenomena of unsteady lift permit one to suppose that the diffuser tip will be beneficial for the aerodynamic damping in pitch.

Due to its inherent wash-out, the diffuser tip also influences the static longitudinal stability; in the extreme case, it is possible to render any, in itself unstable wing into a longitudinally stable system by fitting appropriate diffuser tips.

From this it is evident that a diffuser tip exerts a profound bearing on the stability qualities of an isolated wing system, and that this influence is far greater than that which can be expected from an equivalent ordinary can wash-out or anhedral. It can therefore be assumed that it forms an excellent device for tailless aeroplanes and flying wings, and its adoption at modern Northrop tailless aeroplanes is evidence that designers begin to awake to this fact.

Suitability of Diffuser Tips

With every stability device two main aspects deciding adoption present themselves to the designer: the effect on performance and the structural implications. For the diffuser tip, the structural disadvantages are obviously those that to a purely lift-generating wing, tips are added which do not conform to the plain constructional lines of this wing and which may be subject to considerable forces and moments of their own. Compared with wing-tip disks, such structural disadvantages do not seem great; moreover, parts of diffuser tips may well replace control surfaces or trimming tabs otherwise necessary, so that it will on the whole be reasonable to assume that for tailless aeroplanes, from the structural point of view, the designer might well favor the device.

Aerodynamically, the diffuser tip is, of course, an element which by itself causes drag and, in the general case, also down-lift. But since it can take the place of wing-tip disks (fins and rudders) and also that of wing twist (as required for longitudinal stability), the deficiency in performance caused by it, can be considered to be tolerable. Beyond this, however, the diffuser tip could even become superior in performance to all other devices applicable to isolated wing systems. The utilization of span wise flow components may well permit the achievement of stability and trim without the expense of additional drag.

When considering the possibilities of wing tips of the diffuser type, the application of boundary layer suction methods at such tips should not be overlooked. Ordinarily (closed) diffusers can obtain a greatly improved efficiency, by making in this way, the flow adhere to the wall. Accordingly, with shaped wing tips, the sucking away of the boundary layer would possibly help to suppress the periodic shedding of vortices (which is a direct result of premature separation of the boundary layer from the surfaces forming expanding passages). The marginal vortices are not only dissipative, but also cause, as a reaction upon the wing, induced vibrations in the structure, and may impair the steadiness of the flight, too, when shed by an elaborate wing tip.

Moreover, such manipulation of the boundary layer at shaped wing tips might constitute a practical form of aerodynamic control. The suction energy required would not be prohibitive, and the mechanical complications might well be tolerable with large Flying Wings.

The Rams-Horn Vortex and Related Phenomena

When surveying the problem of diffuser wing tips, it is worthwhile to recall former (generally overlooked or forgotten) research on bird flight which, though originally based on mistaken assumptions, seem to have yielded results which may have some bearing on the subject.

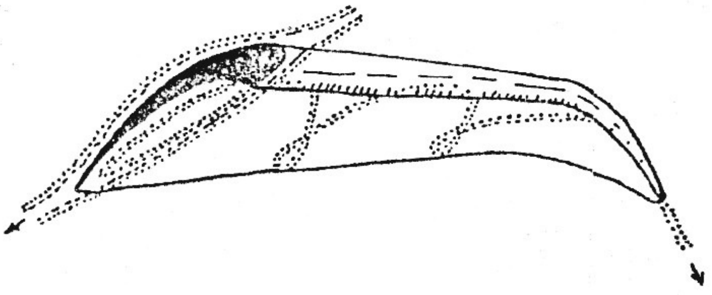


FiG. 8 —The "Rams-horn" vortex.

Wings of soaring birds show aerofoil sections with rather thick, rounded leading edges and pronounced camber which forms a concave lower surface. Phillips and Goupil have based the conception of the "dipping" leading edge on observations with such aerofoil sections. Phillips conceived that the airflow in front of a lifting wing has an ascending tendency.

A. Goupil experimented in 1883 with a large bird-like monoplane glider of 20 ft. span in natural wind and claimed to have observed the appearance of "negative drag" on virtue of its cambered thick aerofoil section.

In 1896, L. Hargrave investigated flow phenomena on heavily cambered aerofoils; he observed and described the formation of a standing vortex in the cavity of the lower surface when experimenting in flowing water to which ochre had been added. He concluded from this discovery that this vortex must have something to do with sustentation in flight such as is exhibited by soaring birds.

Fr. Ahlborn, the Hamburg school teacher, who has already been mentioned as the father of the Zanonia wing, checked up on Hargrave's observation in 1901 and experimented with a corresponding aerofoil in a water tank; he obtained flow photographs which clearly showed the presence of this vortex in the cavity.

In 1911-12, Gustav Lilienthal (brother of the great pioneer of flying) conducting experiments in natural wind, not only observed a pronounced span wise flow along the concave lower surface of bird-like wings, but gave a clear description of the character of the vortex formation which he termed "WidderhornWirbel" (rams-horn vortex).

Lilienthal had made his flow observations in free wind on complete bird models of 13 ft, span, having a maximum wing chord of 2.64 ft.; the section camber amounted to one-tenth of the chord. The flow direction was indicated by tiny flags mounted on thin needles, hence not dissimilar to the modern Haslam method of silk tufts. Lilienthal also noticed that the flow over the smooth upper surface was approximately undeflected in plan, i.e. was following the direction of the wind, and that this also applied to that part of the lower surface which was near the bird-like fuselage; beyond this relatively narrow region, the airflow was directed more or less toward the tips. The spiral shape of the tip-ward progressing vortex gave cause for the name.

Unfortunately, Lilienthal drew somewhat precipitate conclusions from his observations. He stubbornly contended that the vortex formation gave to the bird wing a negative drag, and that this phenomenon was responsible for the soaring flight of birds. Living in a country of experts where amateurish views are severely frowned upon, the pugnacious discoverer of the rams-horn vortex and his discovery went into oblivion.

Commenting later upon Lilienthal's contentions, J. Ackeret (of the Goettingen Circle) agrees that there is a large stationary vortex in the aerofoil cavity, but emphasizes that this vortex formation is purely dissipative Goett. 462 aerfoil section compared with Goett. 535 section. He doubted if the plan shape of Lilienthal's bird wing could render "rams-horn vortex" sections more useful for flying, and he also disclaimed the possibility of diminishing the induced drag by the aid of such devices.

Years afterwards (in 1921), P. ldrac investigated in a wind tunnel at St. Cyr the wing of a vulture which had Hankin's patagial depression at its lower surface behind the leading edge. He observed normal flow over the dorsal surface with a regional deflection toward the centre of the body, while at the lower surface, the flow was strongly deflected toward the body, after having been normal when flowing over the first third of the chord; this deflection was restricted to the boundary layer region. This inwards deflection in or near to the boundary layer may have been caused by the extending passage formed at the wing body-joint.

Friedrich Harth, the tenacious pioneer of soaring flight, who experimented with bird-like aerofoil sections, did not believe in the benefits of the rams-horn vortex. In his view, the air being deflected by the wedge-like leading edge, impinges on the concave lower surface, instead of forming a cylindrical vortex.

Nearly 20 years afterwards, the existence of Lilienthal's rams-horn vortex was experimentally confirmed in a wind-tunnel investigation made by E. Saenger at the Aerodynamic Laboratory of the University of Vienna.

Saenger argued that the induced drag is caused by eddies which originate from the equalization of pressure at the wing tips, and that an appropriate deflection of the flow at the tips might suppress, at least partially, the formation of these dissipative vortices. He also assumed that the profile drag which is mainly surface friction, might be reduced by the effect of a rotating air mass underneath a wing, similar in action to that of a roller bearing. In his view, the birds obtained far better lift/drag ratios than ordinary aerofoils, by the use of devices of such a character.

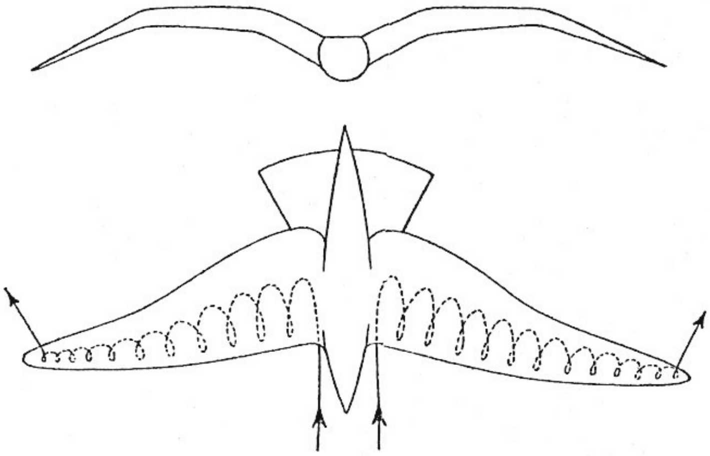


FiG. 9.--The "Rams-horn vortex" as observed in 1911 by Gustav Lilienthal. He investigated the air-flow on the lower surface of this model of as bird in natural wing.

If one adopts G. Lilienthal's conception of the rams-horn-vortex (Fig. 9), the following flow phenomena becomes apparent: a streamline entering at the lower surface separates from the wing surface at or near the point when the section curvature becomes concave, since the centrifugal forces acting upon the flow particles, will prevent it adhering to the surface in the cavity. That this actually takes place is beyond question, and A. Betz refers (in one of his patents on boundary-layer suction) expressively to boundary layer separation under such circumstances. Due to friction of this separated air layer (free vortex layer) with the dead air enclosed within the cavity, the latter will begin to rotate, i.e. forms a vortex in the cavity which has a span wise axis. This also is in agreement with observations other than those by G. Lilienthal on bird-like wings. (The presence of such vortex formed behind a dipping leading edge was observed by L. Prandtl who published excellent flow photographs of it in the “The Generation of Vortices in Fluids of Small Velocity,” *Journal of the Roy. Aer. Soc.,* 1927, p. 727, fig 15.) Now Lilienthal claimed that this vortex, by way of its centrifugal force, contributed to the lift. Even, if such effect were present at all, it will be negligibly small. Lilienthal also contended that, when the surface within the cavity was rough, energy from this vortex gave, by losing part of its kinetic energy, thrust to the wing, i.e. at least decreased the profile drag materially. This also is mere speculation and seems scarcely probable. The vortex shifts axially in a span wise direction. This is so because of the pressure gradient along the, span. Its span wise translational velocity increases toward the tip. At the tip, the translating and rotating vortex air encounters, at a bird's wing, the tilted-down parts; it is deflected downward and thus causes a lift force as reaction. Finally, the vortex leaves the nozzle-shaped tip with a velocity which is still greater than that of the surrounding air; hence it is able to suppress the formation of eddies at the tips.

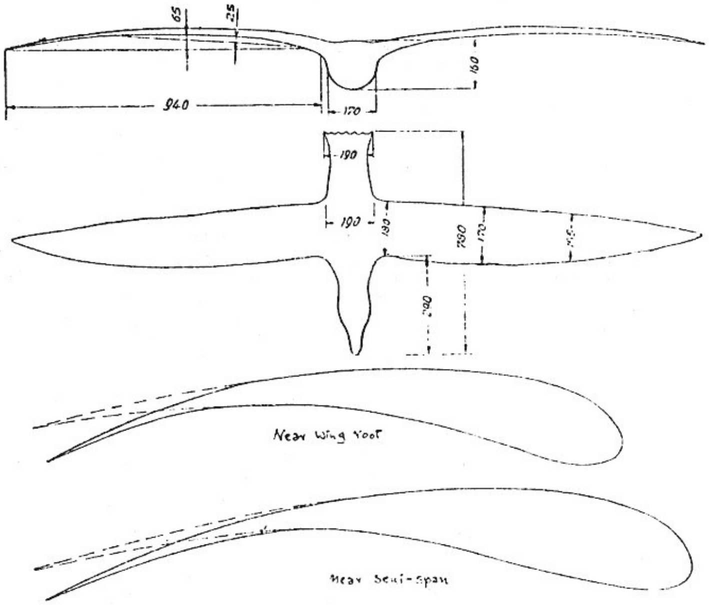


FIG. 10.— Wing shape and wing sections of a grey albatross. The dotted lines indicate the presumed deflections under air load in soaring flight. Measurements in millimeters. (Front "Flugsport").

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