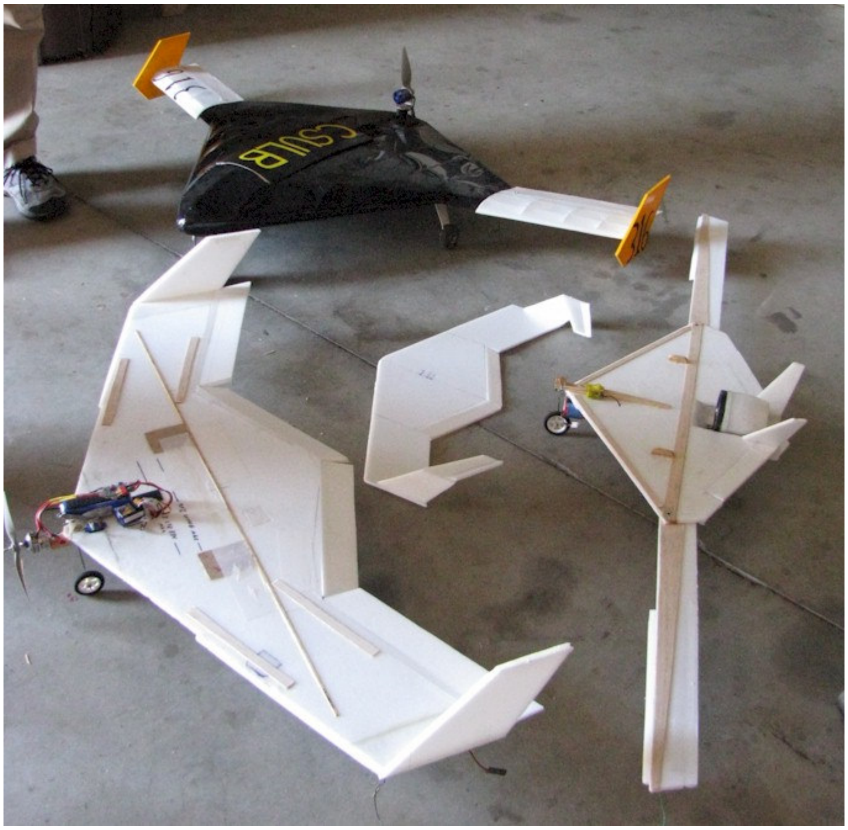
No. 268 OCTOBER 2008

T.W.I.T.T. NEWSLETTER



The fleet of models Dan Dougherty brought with him for the September meeting. See the presentation recap inside, along with more photos these aircraft and his winning entry in the SAE Eastern Contest.

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., **0810** means this is your last issue unless renewed.

Next TWITT meeting: Saturday, November 15, 2008, 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.

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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 has turned our to be a good issue. Gavin came across an article on flying wing stability by Reimar Horten that may not have been published in any previous issues. Then we have Dan Dougherty's presentation at the September meeting including all the hardware he brought along.

Although there were only a few of there to enjoy the presentation we had a great time questioning Dan on the various models. The videos he had of many of them flying added to our enthusiasm of, especially when he did some hand launches of the C-Wing model shown in the center of the cover photo. Although C-Wings are not new (you can find them in the blended wing body section of our web site) there hasn't been a lot said about them recently. However, they do offer an alternative method for reducing the wingspan to get aircraft into the current airport infrastructure. The down side is the public probably still isn't ready to fly in something this radical in appearance.

Although the cover page indicates a meeting date in November, I am not planning on pulling together a program. Based on the turn out for September I don't feel it is fair to a speaker to often travel a long distance to talk to 4-5 people. Pre-meeting publicity isn't having the impact it used to have with the folks from the Los Angeles area and there are fewer members in the San Diego area than in the past.

With that said, I am pleased that our membership has been growing slowly with some new enthusiasts. We welcome them to TWITT.

Andy

SEPTEMBER 20, 2008 MEETING RECAP

For those of us who were at the hanger on Saturday we were treated to a presentation on Dan Dougherty's Cal State Long Beach team entry in the AIAA East micro-lift competition. He brought along a lot of models for us to go over and that became a big part of the day's activities.

After our initial ogling of the models, Dan put on his PowerPoint that was used for their oral briefing to the judging committee, which is part of the competition. The material below comes from this presentation.

For the 2008 SAE Aero Design competition entered the Micro Class category with a flying wing design named after the northern constellation, Aquila, the swan of Eagle of Greek myth.

The 2008 Micro Class rules require a fixed wing aircraft scored on the basis of the payload fraction (Payload / Aircraft Takeoff Weight). The payload bay must accommodate an 8" x 3" x 4" payload block. The aircraft must fit inside a carrying case that is 36" x 60" x 8" with a shoulder strap for portability. The aircraft can be powered by gas or electric type motors. The team will be scored on the time that it takes to remove the model from the carrying case and assemble the aircraft to flight condition. The flight score is given by the following equation: Flight Score = (10 – Empty Wt) * [Payload / (Payload + Empty Wt)] * 13. The aircraft must takeoff within 100 ft and complete one 360-degree circuit of the flying field. The aircraft must then land within a 200 ft landing zone. In addition to the flight score, the total team score includes a written report, an oral presentation, and an aircraft quick assembly demonstration within a fixed timeframe.

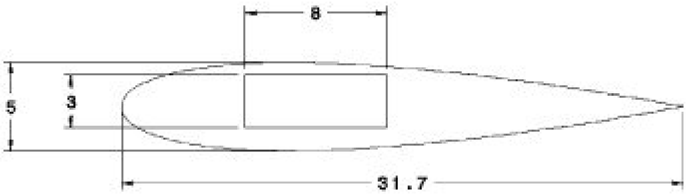
Configuration Selection

Once the requirements for the competition were thoroughly understood, the team analyzed various configurations to determine the one that could best meet the mission requirements. In order to quickly determine the relative advantages and disadvantages of various configurations, the configurations were placed in a matrix and scored based on various Figures of Merit (FOM's) from 1 to 5. The weightings and rankings listed in the FOM table were qualitatively based on the team's collective model construction experience; aircraft design knowledge, and a thorough understanding of the competition requirements.

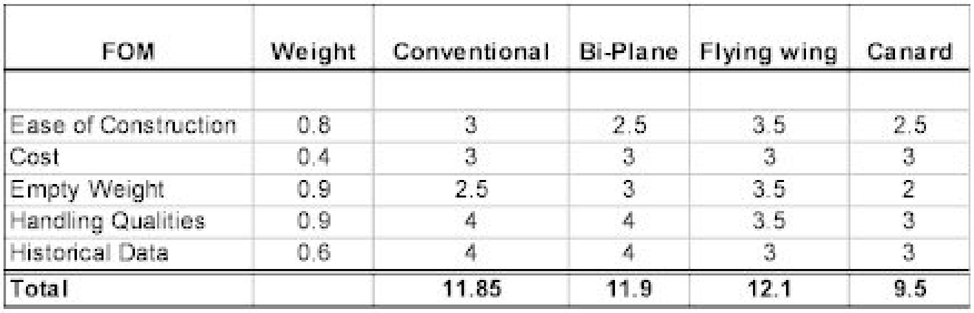
Once the scores were tabulated it was seen that the flying wing design had the highest score, by 1.7%, over the biplane. The main benefit of the flying wing type is its reduced empty weight due to lack of horizontal tail and the attendant tail boom. Also, lack of a tail reduced the length of the aircraft making it easier to package into the carrying case. Based on the FOM scores, the team chose to move forward with a flying wing design.

Planform Selection

In order to fit that payload block into the wing section, the team determined that it was necessary to have the largest possible airfoil thickness to chord ratio (t/c). Once the maximum t/c was determined, the center wing chord could be determined by multiplying t/c * airfoil thickness required to package payload. The payload height is 3", assuming a 1" clearance above and below the payload, this results in an airfoil section that is 5" high. Figure 2 shows the cross section chosen to package the 3" x 8" payload envelope. The airfoil is NACA0018 (below), a symmetric 18% airfoil section that provides a tight packaging envelope, low drag and relatively benign stall at low Reynolds numbers.

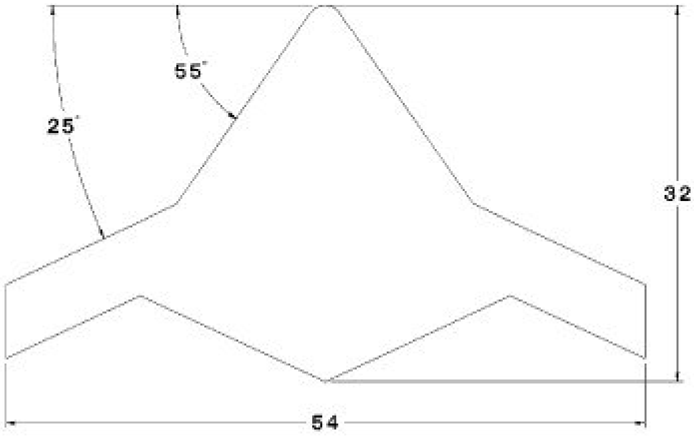


Now that the center chord length was determined, the planform span was maximized to fit inside the carrying case envelope. Assuming 1" clearance from the inside of the case, the maximum span is 58". The team decided to conservatively size the wingspan at 54", allowing for equipment movement inside the case. The aircraft dimensions were then 32" x 54", resulting in roughly 3" clearance to the boundaries of the box. In order to get some 'tail volume' or move the control surfaces far enough aft of the C.G. to effectively control the aircraft during flight, some amount of wing sweep was needed. The center



FOM	Weight	Conventional	Bi-Plane	Flying wing	Canard
Ease of Construction	0.8	3	2.5	3.5	2.5
Cost	0.4	3	3	3	3
Empty Weight	0.9	2.5	3	3.5	2
Handling Qualities	0.9	4	4	3.5	3
Historical Data	0.6	4	4	3	3
Total		11.85	11.9	12.1	9.5

section would be relatively higher sweep, while the outer wing section would be lower sweep to increase the lifting performance of the aircraft. After many iterations with simple 20" hand-launch foam gliders, the planform shown below was arrived at.



Once the planform was selected, airfoils needed to be designed and analyzed. The main requirements of the airfoil were high Clmax, gentle stall and neutral to positive (nose up) pitching moment. The first two items, high Clmax and gentle stall are desirable regardless of configuration; however, a neutral to positive pitching moment airfoil is unique to flying wing design. For a statically stable flying wing, trim can be achieved through airfoil 'reflex' (s-shaped camber line with negative camber at the trailing edge).

The University of Illinois at Urbana-Champaign aerodynamics website, http://www.ae.uiuc.edu/mselig/ads/coord_database.html, was used to survey the existing flying wing airfoils. Many airfoils were downloaded and analyzed in XFLR5, a publicly available airfoil analysis program that provides fully viscous 2D section analysis and vortex lattice method for 3D wing analysis. Assuming a typical wing loading of 1.5 lb/ft2, based on historical R/C aircraft literature, this gives a maximum takeoff weight of 1.5 lb/ft2 x 4.95 ft2 = 7.5 lbs. Now the velocity could be calculated and therefore the Reynolds number can be calculated.

Various airfoils were analyzed at Re = 150,000 and Mach = .03. The reason for analyzing at a lower Re number is that the outer wing panels have a significantly reduced chord length and will stall before the center chord since they will have a higher aerodynamic loading. Therefore the outer wing panels dictate stall behavior at takeoff so the local Re number at the outer panels is the key design point. All airfoils analyzed were neutral or positive pitching moment airfoils designed for relatively low Reynolds numbers.

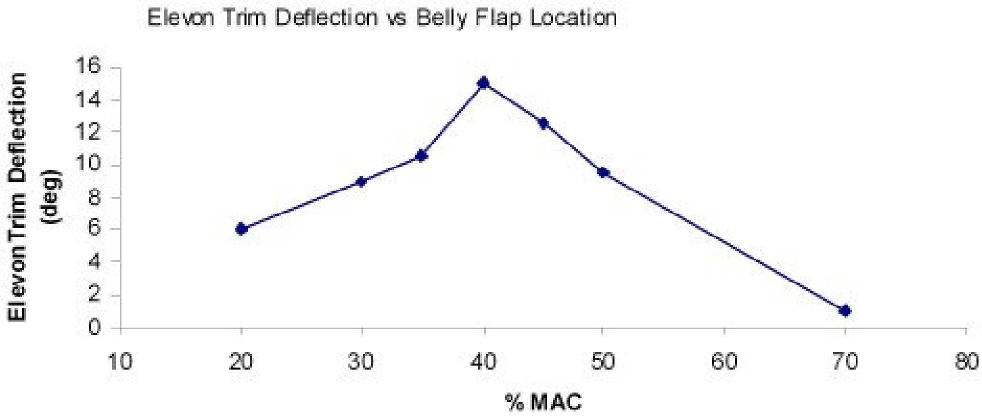
The results of some of the airfoils analyzed in XFLR5 are shown in Figure 4, Cl vs. Alpha.

The chosen airfoil was 'D12_28_2' shown in here. This was a custom airfoil designed by the team to meet the challenging requirements of producing high lift and neutral pitching moment while operating at a low Reynolds number. The D12_28_2 has a Clmax of 1.3, which is 10% higher than the next best airfoil, the LRHL1. The airfoil is 12.24% thick, with the maximum camber location at 28%, and a camber of 4%. It was decided that winglets would be added to the wing tips. These provided increased yaw stability and control and increased the effective span. Based on empirical data, the addition of winglets increases the aspect ratio by roughly 20% from AR = 4 to AR = 4.8.

The D122802 airfoil was modeled with +10 deg TE deflection at 65% chord. These airfoils were then laid into the planform and a vortex lattice analysis was conducted comparing change in pitching moment and lift coefficient between the faired and deflected planforms. The resultant answer showed the elevon deflection was too large, well outside the accepted linear range of 15 degrees. This is a common issue for tailless aircraft, since they are usually short coupled, and thus do not have a large tail moment arm for takeoff rotation.

A different method or device for takeoff rotation was needed. The team researched the web, looking for any data dealing with control devices on tailless aircraft. It is known that the ME-163 (a tailless German fighter designed by Alexander Lippisch in the early 1940's) had under wing flaps located at 50% chord in order to slow the aircraft down on landing approach. This flap had to be trimmed with down deflection of the trailing edge flaps because it caused a nose up pitching moment. Further research showed a paper written on a 'belly flap' device to increase nose up pitching moment at takeoff

In order to test the flap device, a 40% scale (20" span) flat plate foam glider was constructed and various size belly flaps were attached under the center wing. CG was located at 5% static margin. The test flight procedure was as follows: a reasonably sized belly flap (height = 15% MAC, length = 20% bref) was attached to the underside of the wing at 90 deg deflection. Then the elevators were deflected down (belly flap causes nose up pitching moment which required down elevator to trim) until a trimmed flight was achieved. Then the elevator deflection required for the belly flap at that chord location (%MAC) was recorded on paper. The figure of merit was nose up pitching moment. Therefore the % MAC belly flap position that required the largest elevator down trim deflection was the optimal location for the belly flap.



The 40% MAC was the optimal location for the belly flap as it required the largest amount of down elevator to trim (15 deg). Therefore, the nose up pitching moment of the belly flap can be found by multiplying dCm/dη * 15 deg = -.0045 * 15 = -.0675. Thus, at 90 deg deflection, 40% MAC location, the belly flap is creating a Cmbelly flap = .0675 (nose up). The belly flap provided a 35% reduction in control deflection required for takeoff rotation! While still large at 30 deg, this was a much more reasonable deflection and the aircraft should have no difficulty rotating at takeoff with 5 deg of ground incidence built into the landing gear.

Structures

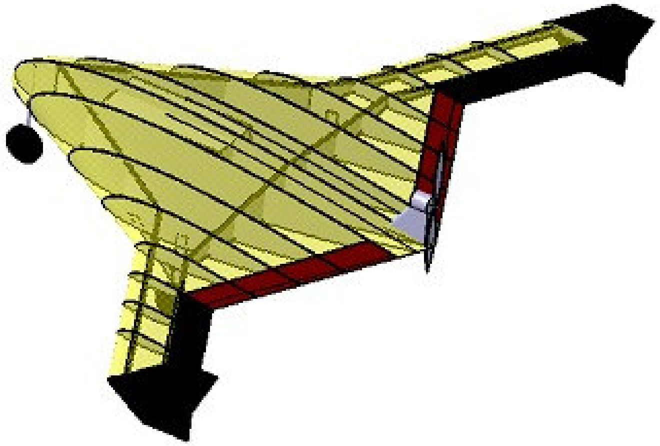
The structure was laid out such that there was a forward and aft spar. Due to the long chord of the center section and the necessity to remove the torsion inherent in swept wing structure, the structure employs a 2-spar layout. The structure was arranged such that the CG was in between the forward and aft spar, thus providing a very strong box structure to incorporate the payload bay. An Excel spreadsheet was created to calculate the inertial loads, wing air loads, shear diagram and bending moment diagram for the spars. It was assumed that the wing has a roughly elliptical span load, which was confirmed in XFLR5. The inertial loads were calculated based on estimated structures, hardware and payload weights at the given preliminary structural layout locations. The aft spar is straight across the span, while the forward spar has a large amount of sweep. Therefore, the aft spar will take the majority of the bending load, as it is the shortest, most direct load path.

Propulsion

The team decided to power the aircraft with a brushless electric motor powered by a lithium polymer battery. This was easy to integrate, had a similar power to weight ratio as a gasoline engine, and was easy to operate. Based on this data, the APC 10x10 propeller was chosen as it had the maximum static thrust of 3.0 lb. This value is close to other published static thrust tests of similar engine/propeller combinations. Given the static thrust, we were now able to calculate the dynamic thrust. Dynamic thrust decreases linearly with forward airspeed.

Weights and Balance

In order to get an accurate weight and CG location of the aircraft, the team modeled everything in a 3D CAD program. This included assigning densities to all of the structural members, electronics, engines, landing gear, fuel, payload, etc. The empty weight of the aircraft was calculated to be about 3 lbs. This allowed for 4.5 lbs of payload to be carried. Also based on the CAD model, the CG of the aircraft with no payload was found to be at X = 15.7 in, yielding a static margin of 5%. With full payload, the CG stays constant at 5%. An image of the 3D CAD model used to calculate the weights and CG.



Performance

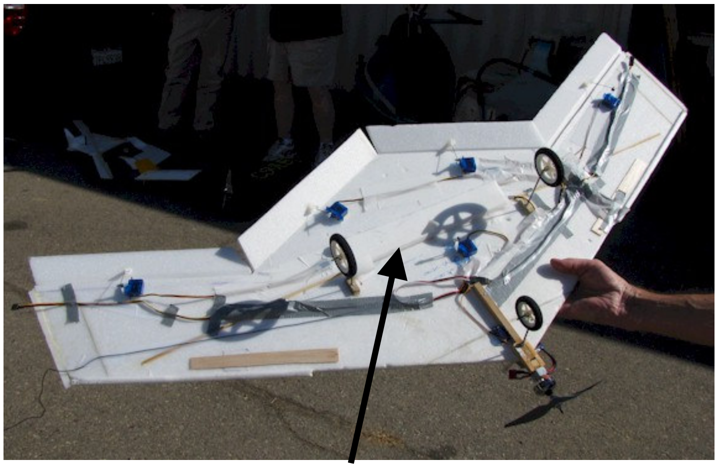
Once all of the key disciplines had confirmed the validity of the design, a performance analysis was run on the configuration to determine the aircraft closes on the mission requirements. The key performance parameter is takeoff distance with max payload. For this condition, the velocity of the aircraft was assumed to be 19.2 kts. The aircraft's drag is the sum of the skin friction drag and the induced drag. Skin friction drag was calculated assuming fully turbulent flow. The aircraft components consisted of the wing, vertical tails, landing gear, engines, and flaps.

Fabrication

The build took place at Dan's home in Long Beach. Each part template was printed from CAD for accuracy and speed of fabrication. The former ribs were 1/16" balsa, while structural ribs were constructed of 1/64" ply and 1/16" balsa core. The spars were spruce and the shear webs were 1/32" balsa sheet. All hard attach points such as the gear floors, payload bay floors and outer wing attach joints were vacuum bagged epoxy 1/32" plywood / 1/8" balsa sandwich. First the center section was jigged and the spars were tacked in place using CA glue. The spars were spliced using a lap joint construction with a 4" overlap at the joint. Overall, the project took 3 – ½ months from design freeze to first flight. The cost of materials was roughly $400.

Here are some pictures of the models Dan brought to the meeting.

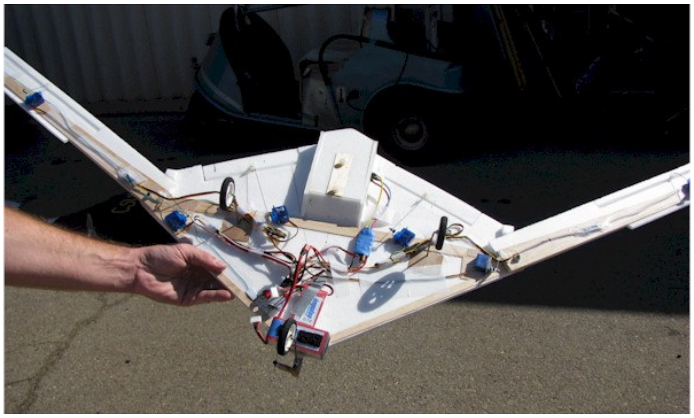
Top view of the scale prototype of the 2009 competition.



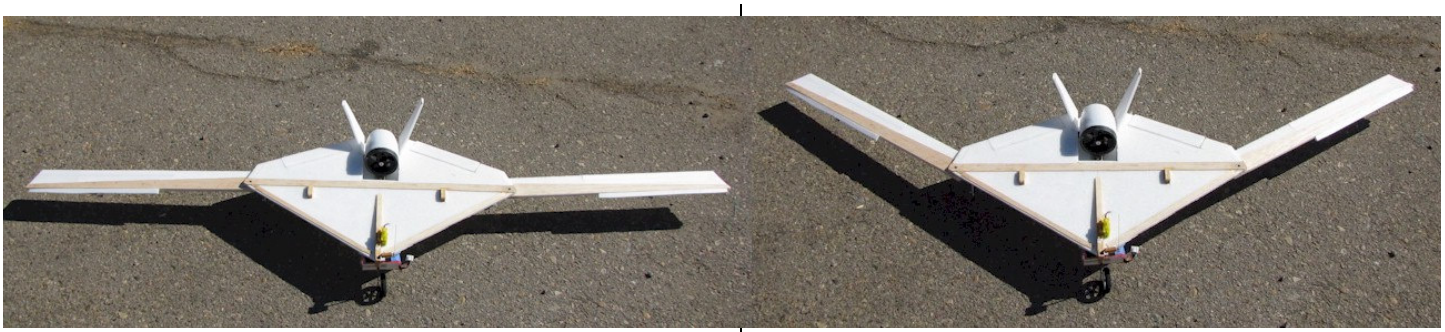
Bottom of the 2009 prototype showing that things don't have to look pretty in order to proof of concept testing. It is hard to see in the view but the arrow points at the belly flap location.

This is Dan holding the 2008 model that shows the belly flap deployed in the 90 degree position.

Shots of the 2008 competition model that took second place at the SAE Eastern event. The wing tips plug in quickly on two extension shafts versus having to install a wing on a more conventional design.



Bottom of the swing wing testing model that Dan has been working on in his spare time. You can see the extended and sweep views in an image on the next page. He explained that this configuration is pitch neutral during the sweep action. He showed a shot video of a similar model being flown from an vacant parking lot in the El Segunda area of Los Angeles. The pilot reported that he did not have to make any pitch adjustments as the wings were swept aft. The video seemed to confirm this as there was no big pitch movements evident.



(ed. – This paper by Reimar Horten was in our archives and I don't recall having ever published it an issue of the newsletter.)

THE STABILITY AND CONTROLLABILITY OF ALL-WING AIRCRAFT

Fifty years ago, with the decision to realize the flying wing, patented by Junkers (German Reich Patent 253,788 of 1 February 1910), the theme that dominated research carried out between 1925 and 1931 at the Forschungsanstalt Prof. Junkers (Prof. Junkers Research Center) made its appearance. The flow mechanics division was to establish what flight possibilities existed in the unstable region, that is with the c.g. behind the neutral point, as Doepp reported in Lilienthal Advance Report 164 in 1943. This research now seems quite modern, since the control of fast airplanes requires low, nearly neutral static stability in order to keep actuation forces to a minimum; in slow airplanes too this neutral stability is desirable in order to suppress large-amplitude flight path oscillations, or phugoids.

With the flight tests of my first airplane in 1933 there appeared additional, surprising insights: while Doepp's research concerned itself primarily with stability and control about the lateral axis, I ascertained that it was the vertical axis that determined the flying qualities of the all-wing airplane. Hence, moments and controllability about all axis must be discussed here, the vertical axis foremost; the aft c.g. envelope, i.e. the permissible range of rearward c.g. travel and the lift range, or rather angle-of-attack range, appear as parameters. Mach number and forward c.g. travel are excluded; these require special research.

Vertical Axis: Directional stability must be distinguished from weathercock stability. Directional stability means that the airplane maintains its heading when disturbed by a lateral gust, as is usually practiced in model airplane flight, while weathercock stability refers to aerodynamic moments which arise in a crosswind or in yaw and turn the airplane. Negative weathercock stability is unflyable; the airplane immediately becomes unstable on all axis. Neutral weathercock stability is a prerequisite of directional stability and is desired for that reason. Increasing weathercock stability causes an oscillation of the airplane about the vertical axis in gusty weather. Since low or even neutral weathercock stability is sought and a clear dividing line must be drawn between this and negative stability, this specifies the aft limit of c.g. travel; and indeed it is with tail-heavy loading that a "swimming" motion, i.e. movement about the vertical axis, increases and becomes uncomfortable for the pilot. Now the all-wing airplane has the advantage, due to its span wise loading, that c.g. movement is small; in sailplanes the pilot can even be placed at the c.g. so that different pilot weights produce no c.g. movement.

At this point moments about the e vertical axis must be discussed. Unlike the conventional airplane, the flying wing experiences little or no moment from fuselage and empennage, at least to the extent that it is a true flying wing; but another consequence of this is that aerodynamic side forces are very small.

The result from, the pilot's point of view is that ball in the yaw indicator, which: is supposed to show apparent force by swinging outward when a side force is acting, is ineffective; the aerodynamic side force lacks the surface on which to act. A less tightly curved glass tube for the ball to move in would be helpful, but could not he manufactured due to standardization. In order to give the pilot a means of checking his piloting form it is possible to show him the stream direction directly by means of a woolen tuft glued to the front of the cockpit canopy. It turns out that this tuft indicates very effectively, jumping from left to right, provided that the canopy has a well-rounded shape. The first flights of the H.I revealed that the weathercock stability was slightly negative, for which reason the front of the canopy was shortened. Since Plexiglas canopies were not commercially available in 1933, the part housing the pilot's head was angular, hence particularly unsuitable.

Another moment acting on a swept wing in yaw is caused by friction drag. If the wing boundary layer is turbulent, we can consider it to be acting at about 40% of the wing chord that is behind the c.g., which is at 25% of chord. Friction drag therefore affects weathercock stability. If one uses airfoil sections with S-shaped mean lines having no center-of-pressure movement, such as the 8 or [9--?] NACA series, the flow on the underside of sailplane wings can remain laminar to nearly 100% of chord. In that case, the friction drag is considered to act at 20% of chord, that is forward of the c.g. At high angles of attack the pressure gradient is strong, and with smooth construction the flow is laminar and the weathercock stability consequently lower. So it is that in slow flight the "swimming" motion increases, decreasing again at maximum lift if flow separations having long moment arms in yaw occur on both sides. With a laminar/turbulent boundary layer, 50/50% for instance, the overall friction drag should be considered as acting at about 60% of chord, hence in a very stabilizing way. On the upper surface of the wing, where airfoil sections with S-shaped mean lines can have just such a transition point, we find on the rear half, that is on 25% of the wing's surface, about 75% of the friction drag; the remaining 25% of the drag appears on the lower surface and the front half of the upper surface, that is to say on 75/'0 of the wing surface. If the transition point, hence the friction drag, is different on the right and left panels due to yaw, unsymmetrical forces and moments arise. The determination of the boundary layer transition point is therefore relevant to stability about the vertical axis.

If the friction drag appears to be concentrated on the aft part of the upper wing surface, the location of the overall drag must also be placed there. On the high-performance sailplane Altostratus I (Soaring, Feb. 1981), the transition point is eliminated through suction provided by solar energy and laminar separation is taken into account, successfully it seems, since the sailplane's glide ratio--nearly 100--had never previously been achieved by any other airplane. Perhaps in the future the transverse pressure gradient in this zone could in be employed to replace solar energy. Besides flight performance, stability in yaw would also be improved.

In connection with powered airplanes it must be noted that a propeller in front of the c.g. is destabilizing in yaw; hence the flying wing must have a pusher propeller, not only because of its stabilizing effect about the vertical (and the lateral) axis, but also because the propeller rpm and the side force interact to produce different moments in takeoff and landing, which is to say that stability is present.

The rudder must give the pilot the ability to produce moments, which cause angular accelerations about the vertical axis for entering and leaving a turn, to compensate the aileron yawing moment and to compensate for unilateral engine failure on a multi-engine airplane. It makes no difference whether the steering moment is produced by airbrakes on the wingtips or, as for instance in the case of short-span Delta wings, by fins with a vertical rudder. It should be noted that the drag rudder is effective at all angles of attack, whereas vertical stabilizers can be influenced by the wing center-section or fuselage and a Delta easily loses rudder effectiveness at high angles of attack.

How then do we use these three requirements to dimension the rudder effectiveness? For multi-engine airplanes with asymmetric propeller rotation, requirements are established in detail by the design standards of the various countries. At a minimum takeoff speed, with extended landing gear and flaps in takeoff position, the direction of flight must be maintained even in a climb; permissible deviations are also specified. With these data, the lateral controls can be precisely dimensioned. For sailplanes, compensating the aileron yawing moment is usually the controlling consideration. Through use of a bell-shaped lift distribution the adverse yaw can be minimized, leaving only the desired angular acceleration for the rudder to produce. This acceleration is not prescribed and is left to the pilot's taste. The rudder on a flying wing can therefore be quite small, but in the interest of pure flying form cannot be left off entirely. There may also be special considerations such as spin entry or control in a crosswind landing which rudder effectiveness must satisfy.

Dynamic stability, too, about the vertical axis, which is supposed to appear as a periodic motion, sometimes shows slow oscillations instead. The motion, which would otherwise take a long time to damp out, can be stopped by a brief deflection of the rudder. The motion can also be quickly stopped by deflecting drag rudders on both wingtips at the same time. The fact, observed again and again, that lateral stability is higher in a turn explained.

Longitudinal Axis: All movement about the longitudinal axis is strongly damped by the wing. Asymmetrical moments besides those due to gusts arise due to unilateral flow separation, that is at maximum lift, as well as through yaw at all angles of attack. The tendency to fall off on a wing at max. lift can be mitigated by the bell-shaped lift distribution; or it can be flown out of using aileron because the local lift coefficient at the wingtip is low and the aileron remains effective. A Handley Page-Lachmann slat at the wingtip is unnecessary with this lift distribution. It should be added that airfoil sections with an S-curve have a gradual rather than a catastrophic stall, leaving the pilot the necessary reaction time.

The problem is rolling moment due to yaw. Sweep and dihedral are clearly understood to be features of an all-wing airplane, dihedral being incorporated for the sake of ground clearance. At high angles of attack, sweep causes most of the rolling moment due to yaw; dihedral increases it at all lift coefficients, even in a dive at zero lift. A coupling therefore takes place with the vertical axis, becoming stronger at high angles of attack. This is a given fact for the flying wing, which cannot be altered by design changes. If the wingtips are given a local negative dihedral, as in Wenk's Weltensegler and some Northrop airplanes, this measure can eliminate rolling due to yaw, but only at one C, not through the entire range, particularly not at high values. In landing or in a turn, always at high C, a wobbling motion called Dutch roll can occur. Because it is, as we have said earlier, linked to rotation about the vertical axis, it can be stopped by a brief rudder deflection or by the extension of drag rudders on both wingtips. If however static stability about the vertical axis is low, the necessary resonance does not occur. Recovery from roll angles caused by gusts requires that the ailerons cause only rotation about the longitudinal axis and (to avoid a harmful effect on the vertical axis) no negative yawing moment. The lift distribution should have a horizontal tangent at the wingtip so that a negative curvature prevails on the outer wing panel which produces an induced thrust at local positive lift coefficients, which in turn reverses the aileron yawing moment in this region, that is reduces or even nullifies the negative yawing moment.

Coupling of rotation of the airplane about the vertical axis with moments about the longitudinal axis is only noted in large-span sailplanes in circling flight. Even so it was possible to ensure trouble-free turning characteristics even in extreme cases, as for instance in the H III (10 kg/m wing, loading and 20 meters wingspan), which not only refers to wing-dropping properties in a turn but is so defined that the airplane maintains its bank angle and turn rate with the ailerons and rudder both neutral, that is neither tightens its turn nor straightens out. This is important when flying blind inside cumulus clouds, since it reduces the load on the pilot while the sailplane flies itself; even the artificial horizon could be dispensed with.

Control about the longitudinal axis takes place with a combination of flaps so arranged that the sum, of their deflections produces an elevator effect, while the difference in deflections between the right and left sides serves as the ailerons. The right and left flaps, each with up and down travel, require four stops, while the stick with fore and aft, left and right travel also requires four stops. The effect of having eight stops in all is to change the usual stick movement rectangle into an octagon. So it is that with the stick hard back only one-third of the aileron travel is available, while all of it is available when the stick is pulled back halfway. At full elevator deflection, too, the aileron travel is reduced, so that in aerobatics (roll), the aileron power should whenever possible be augmented by yaw.

The effectiveness of flaps on a swept wing is perhaps somewhat lower than on a straight wing, since the boundary layer flows toward them. This disadvantage can be reduced by increasing the percentage flap chord toward the wingtips. Frise type flap leading edges are especially helpful in this combined aileron-elevator arrangement.

Rotation about the longitudinal axis is a periodic; oscillations have never occurred, due to the strong damping.

Transverse axis: Static stability about the transverse axis is always present in a swept and tapered wing, because the lift curve slope is high at the tips, that is to say the neutral point lies to the rear. Then, too, the wing center section forward of the center of lift, that is forward of the c.g., has a lower lift-curve slope because of the kink in the planform. If the c/4 line is rounded off' by increasing the chord at the center-section, the reduction in lift is no longer noticeable, as in the H IV. In the H VI, the c/4 line was even swept forward [at the center-section] to determine whether the local lift-curve slope would then be higher than for an upswept wing, that is, whether the neutral point would move forward. Results of this kind are important to the layout of high-speed airplanes in order to keep the static stability low and minimize control forces.

Because the local lift coefficient is kept low by the practice of increasing chord to round off the c/4 line, flow separation at the center section is not to be expected. In other words, the swept wing neither pitches down by the nose, nor falls off on a wing, nor pitches back over the two wing tips. The tips are protected from flow separation by the bell-shaped lift distribution; hence the wing remains controllable at and beyond maximum lift. Flow separation should occur near the trailing edge at 30-40% of semi-span.

Near the ground, that is during takeoff and landing, all wings experience additional lift which depends on the ratio of the altitude to the wing chord. The center section of a swept tapered wing could then have 50-60% additional lift, while the tip might have only 10% because of its smaller chord. The lift distribution thus changes in near the ground in such a way that the center of pressure migrates in front of the c.g., creating a tail-heavy moment. As it happens, the airplane rotates easily for takeoff and flares automatically for landing and floats for a long time. One could hardly find any disadvantage in this.

In order to determine the stick free neutral point, I assumed that the control surfaces have been removed. A new neutral point is then found by computing the normal lift distribution based on the wing chord minus the control surfaces. This neutral point must also lie behind the c.g. The result is stability not only with the stick fixed but also stick free; also control movement stability in that each stick position corresponds to a distinct C; and finally both aspects of control force stability--for instance in steady flight as in a turn the force increases with increased C, and with constant acceleration there is decreased dynamic pressure at higher lift coefficient, as in landing. There, however, again because of ground effect, control force increase is not certain.

Landing aids are very important for the moment balance of a flying wing. In 1936 I chose for the H V a combination of split and hinged flaps extending to 0.5 semi-span and was thereby able to increase the maximum lift coefficient to about 1.8. There remained however a slight nose-heavy moment which could be balanced an elevator deflection. In 1938 I built a 90-degree split flap extending to 0.12 semi-span into the H IIIb; designed as a brake, it nevertheless produced very strong lift and a tail-heavy moment. The moment and lift were reduced again by an additional spoiler on the upper surface of this region; the braking effect was not affected. Dr. Krashinsky in Argentina has again studied this question in a wind tunnel and found that a flap extending only 0.15 of the semi-span must suffice to increase lift 60-65% without producing a moment. He therefore recommended for sailplanes a kind of Fowler flap in this zone to allow the plane to fly slowly through lifting air while creating a slight tail-heavy moment similar to an elevator deflection. On the strength of this a test with a Junkers type auxiliary airfoil was improvised with the two-seat I. Ae. 34, which Scheidhauer flew with Nickel as observer.

Concerning dynamic stability it should be mentioned that the moment of inertia of Delta wings about the lateral axis is higher than that about the longitudinal axis; the opposite is true of large-span sailplanes. For these, movements about the lateral axis are faster, an advantage in dolphin flight. The rotational damping of a swept wing is about a third that of the horizontal stabilizer of a conventional airplane of similar size. Because the c.g. range, and hence the static stability, can be kept small, the phugoid oscillation is usually a periodic, hence trouble-free. This however requires a stiff airplane.

A new phenomenon made its appearance on the H IV and H VI: wing bending. Because of the sweep, it causes a change in wing washout in the outer panels, and during oscillation of the wing it produces a periodic change in washout, which in turn causes a change in flight path. This could not be flown through using the controls, but the critical speed could be displaced to higher values by extending the drag rudders on both sides. Reinforcement of the center-section and lightening of the tips to raise the fundamental frequency of oscillation caused no visible improvement. Dr. Haener in Argentina studied the problem mathematically in 1956 with the result that only the outer wing panel is significant, not the fundamental frequency, and the stiffness of the wing region around 0.6 semi-span is decisive. In this way, Dr. Haener solved the problem of critical speeds in high aspect ratio all-wing airplanes.

Cordoba, September 1982

[signed]
Reimar Horten

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