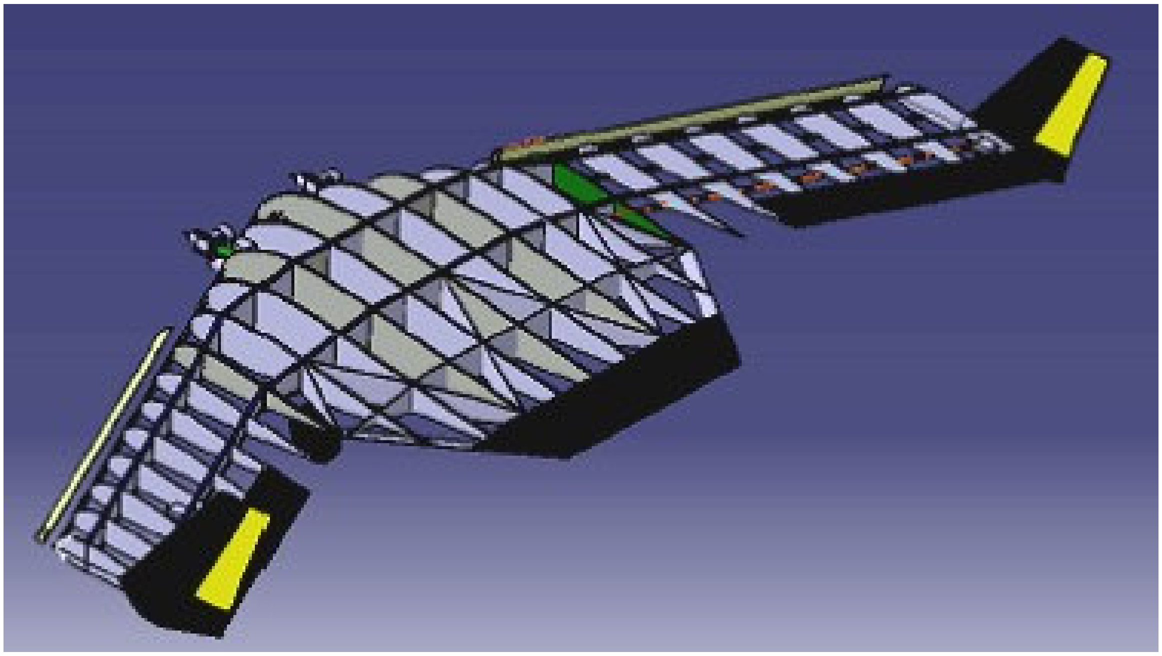
No. 255 OCTOBER 2007

T.W.I.T.T. NEWSLETTER



3D CAD image of Team CSULB's flying wing entry in the SAE Heavy Lift Contest. See page 3 for Dan Dougherty's presentation.

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., **0710** means this is your last issue unless renewed.

Next TWITT meeting: Saturday, November 17, 2007, 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).

TABLE OF CONTENTS

PRESIDENT'S CORNER

I know some of you, especially those without an Internet connection, will be disappointed that none of the Boeing 306 article is being published in this issue. I felt it would be of more interest to have all of Dan Dougherty's presentation in one issue versus splitting it up over a couple of months. For those of you with Internet access, hopefully you have already found that the entire Boeing article is in the member's only section and you are seeing it in full color, which makes a lot of difference. I will publish the last seven pages next month.

If you weren't in southern California over Labor Day weekend and missed the ESA Workshops make sure to mark you calendar for 2008 and plan on attending. This year contained a wide variety of topics including our own Phil Barnes showing the group practical computer graphics for sailplane design. Bruce Carmichael did a presentation on one of his favorite subjects, laminar flow and, Gerry Merrill followed that up with a practical application of laminar flow on a prototype personal transportation aircraft that included a flying wing type. I will put some of his material in a future issue, but this issue will include the start of Al Bowers dissertation the ultimate open class sailplane and how flying wings could fit into that picture. Hopefully, by the time the next issue comes out Al will have published more of it that I can include.

I am pleased to report we are growing again, but very slowly. We are back to 85 members with some new members coming in from overseas areas. We welcome all our new members and hope they enjoy the newsletter and get a lot of information from the web site.

We have received some new material and I have run across some items that need to be on the web site, so hopefully I will get them posted in the coming weeks.

Andy

SEPTEMBER 15, 2007
MEETING RECAP

Dan Dougherty opened his presentation by explaining the criteria for this design contest. He also noted that although this was a team event, most of the development work and design parameters were done by Dan. This was the first year for CSULB to enter the competition so it was new territory for everyone.

SAE holds an annual Aero Design competition in which the goal is to produce a flying model capable of lifting the maximum payload up to 55 lbs gross takeoff weight. For the 2007 competition, California State University Long Beach has entered the Open Class with a flying wing design named ‘A Tailless Tale’. The 2007 Open Class rules require that a fixed wing aircraft may not weight more than 55 lbs including payload and fuel. There are no restrictions on payload size and shape. A maximum of two 0.61 cubic inch gasoline engines may be used in which gearboxes and non-standard fuel may be used to provide enhanced performance. The aircraft must takeoff within 100 ft and complete one 360-degree circuit of the flying field. The aircraft must then land within a 400 ft landing zone. In addition to the flight score, the total team score includes a written report and an oral presentation.

Configuration Selection

FOM	Weight	Conventional	Bi-Plane	Flying wing	Canard	Theoretical Ideal
Ease of Construction	0.80	3	2.5	3.5	2.5	5
Cost	0.40	3	2.5	3	3	5
Empty Weight	0.90	2.5	2	4	2	5
Handling Qualities	0.90	4	3.5	3.5	3	5
Historical Data	0.60	4	3.5	3	3	5
Total		**11.85**	**10.05**	**12.55**	**9.5**	**18**

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). Each FOM was weighted with percentage importance and scored from 1 to 5. The matrix is presented above. Since Dan was putting together the matrix and some of the values were subjective he figures he probably biased the results toward the flying wing since that is what he really wanted to do.

Once the scores were tabulated it was seen that the flying wing design was at least 6% better than any of the other configurations. The main benefit of the flying wing type is its reduced empty weight due to inherent ‘span loading’ capability, which reduces the maximum spar bending moment and thus structural weight. Another benefit is the ease of construction due to an inherently lower part count; there are no fuselage or tail surfaces to attach since the wing alone houses the payload while providing stability and control. It should be noted that a flying wing is a highly integrated design, each of the disciplines – aero, stability and control, structures, etc – are coupled to a larger extent than a conventional aircraft.

Planform Selection

Before aerodynamic, stability and control, or structural analysis can be carried out, an initial planform must be selected and then iterated upon through the various design disciplines. A self-imposed span requirement of 12 feet was chosen – mainly driven by transport, stowage, cost and build schedule concerns.

The planform area was then determined based on an assumed C_{lmax} of 1.0, which is a reasonable assumption given historical data on flying wings (reference 1, page 423). In reference 2, page 10, the calculated mean acceleration was 9.72 ft/sec^2. For our model, it was assumed that the mean acceleration on takeoff ground roll was 8 ft/sec^2.

Now that the team had calculated an initial planform area, span, and AR; it was time to choose the leading edge sweep (LE sweep). A survey of existing swept flying wing models and previous production flying wings such as the B2 and B49 show the LE sweep to vary from 18 deg for competitive sailplanes such as the CO5 to 33 deg for the B2. When comparing various LE sweeps, one parameter used was the effective ‘tail length’ due to sweep.

An increase in tail length will benefit two key areas: 1) increase the longitudinal control power of the elevons and 2) facilitate a larger CG envelope. However, increased sweep decreases C_{lmax} and increases span wise flow which causes tip stall. Therefore, a LE of 25 degrees (an average of the surveyed flying wings) was chosen as a good balance between stability and control and performance.

The leading edge now designed, the team focused on the trailing edge of the planform. It was laid out such that there was an aft extension in the middle portion of the wing. This served the dual purpose of 1) moving the aerodynamic center of the planform aft, thus allowing easier packaging of payload, and 2) allowing an effective longitudinal pitch control surface since it is relatively far aft of the CG. The outer wing panels were then designed as un-tapered sections to facilitate ease of construction.

Aerodynamics

Once the planform was designed, an airfoil needed to be selected and analyzed. The main requirements of the airfoil were high C_{lmax}, gentle stall and neutral to positive (nose up) pitching moment. The first two items, high C_{lmax} 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 1) airfoil 'reflex' (s-shaped camber line with negative camber at the trailing edge), 2) negative trailing edge deflection (TE up), or 3) washout at the wing tips (LE twisted down). Often a combination of these methods is used for longitudinal trim, however there are larger performance penalties for methods 2) and 3). Negative TE deflection is essentially a 'reflexed airfoil', but the surface deflection creates a discontinuous airfoil shape that compares unfavorably in drag. While wing washout greatly reduces the total lifting capability of the wing since the outer wing sections are at a lower angle of attack and thus are producing less lift at a given alpha. This can be understood as an effective decrease in wingspan. For these reasons, a positive pitching moment airfoil was deemed most desirable.

The University of Illinois at Urbana-Champaign aerodynamics website, http://www.ae.uiuc.edu/m-selig/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 analysis for 3D effects.

The MH78 airfoil was chosen, however, in order to attain a higher C_{lmax}; the airfoil was modified by increasing the camber at the trailing edge by 2 degrees at 75% chord. Figure 3 shows the MH78M (modified) vs. the original MH78 section. MH78M has increased max lift by 6% to 1.75, and reduced the pitching moment to 0.02.

It should be noted that the MH78 airfoil requires a trip strip at 12.5% chord to reduce the possibility of laminar flow and the attendant instantaneous separation at high AOA.

The airfoil now chosen, two key aerodynamic parameters for the 3D wing were zero lift angle of attack, C_{lo}, and change in lift with change in alpha, $dC_L/d\alpha$. C_{lo} is mostly dependant on airfoil camber. $dC_L/d\alpha$ is essentially linear up to stall and is strongly affected by quarter chord sweep and aspect ratio. Both of these parameters directly determine the lifting performance of the aircraft. The planform points were entered in XFLR5, panel mesh was created, and vortex lattice results calculated at the T.O. speed of 25 kts.

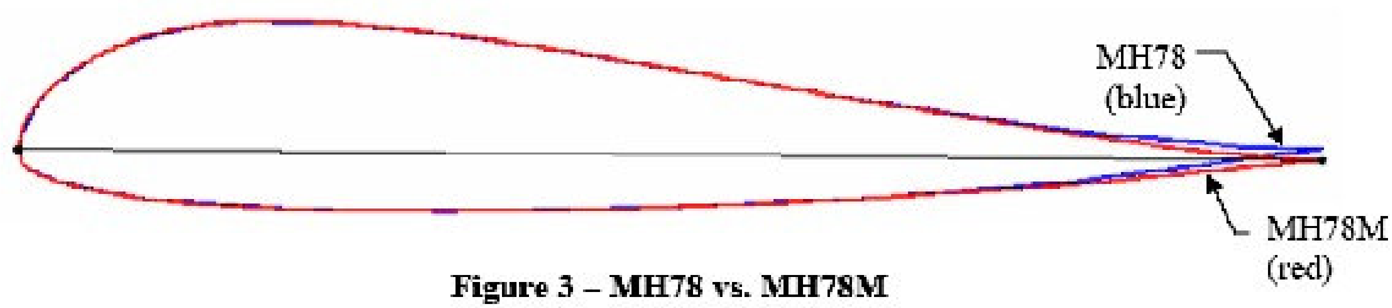


Figure 3 – MH78 vs. MH78M

The next aerodynamics challenge to be tackled was protecting against tip stall. LE sweep, as mentioned in Section III, helps increase longitudinal control and CG envelope. However, increased LE sweep also increases span-wise flow, which can cause tip stall. In order to keep the flow attached over the outer wings, fixed slats were utilized forward of the span section with elevons (see Section X). In this way, the center section will stall first, creating a nose down pitching moment. Meanwhile, due to slats, the outer elevons are operating in fully attached flow, allowing full pitch control through the stall. This effect is confirmed in reference 1, page 423. Slat shape and placement were roughly based on the successful PZL-104 Wilga design per reference 4, page 1.

Lastly, 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 AR4 to

AR5 (reference 3, page 324). This directly increases the lifting capability of the aircraft by increasing the slope of the $C_{L\alpha}$ curve from .065 to .071.

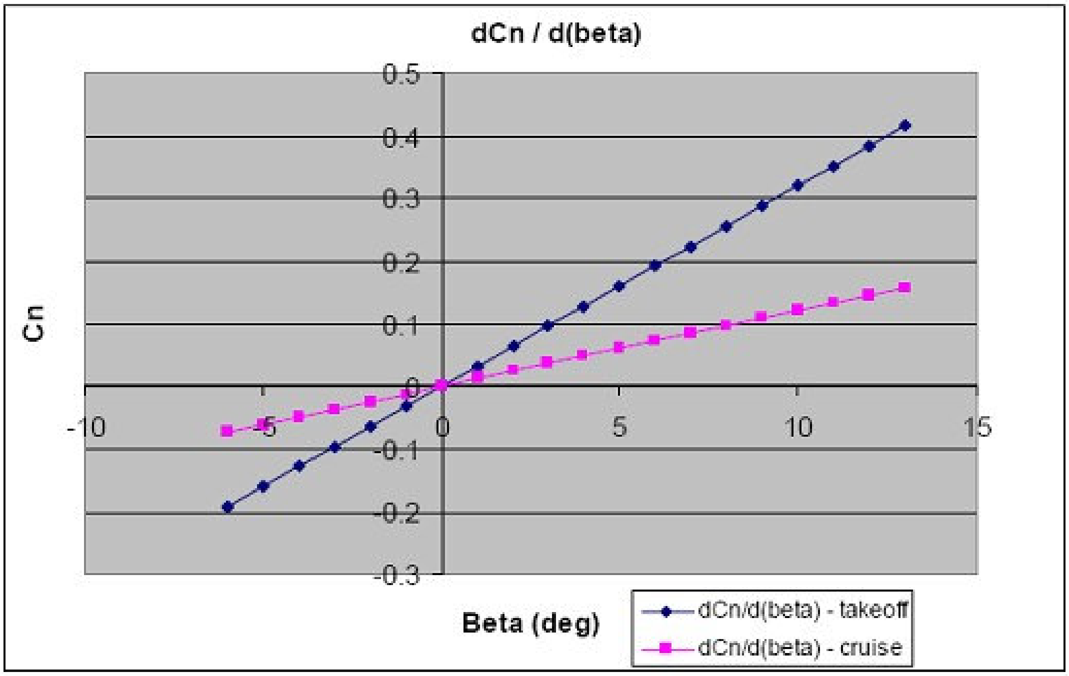
Stability and Control

Static longitudinal stability, dC_m/dC_L, is the change in pitching moment vs. change in lift coefficient. In order for an aircraft to be statically stable, the slope of this curve should be negative such that the aircraft pitches nose down with increasing lift coefficient. The team quickly decided that the aircraft would be statically stable in order to achieve good flying qualities and reduce electronics cost and complication. This requires that the 'static margin' (SM) must be positive, or, put another way, the CG must be forward of the aerodynamic center (AC).

XFLR5 was used to calculate the AC location on the planform, in order to determine where the CG should be placed for positive SM. The AC was calculated at approximately 24.2% of the MAC, which is in agreement with general theory that holds that the AC is roughly 25% of MAC. In our case, the aircraft must maintain a static margin of no less than 5%, requiring the CG to be forward of 21.75 inches. This was determined to be a good compromise between flying qualities and performance since an increased static margin improves stability, but reduces performance due to greater trailing edge deflections required for trim.

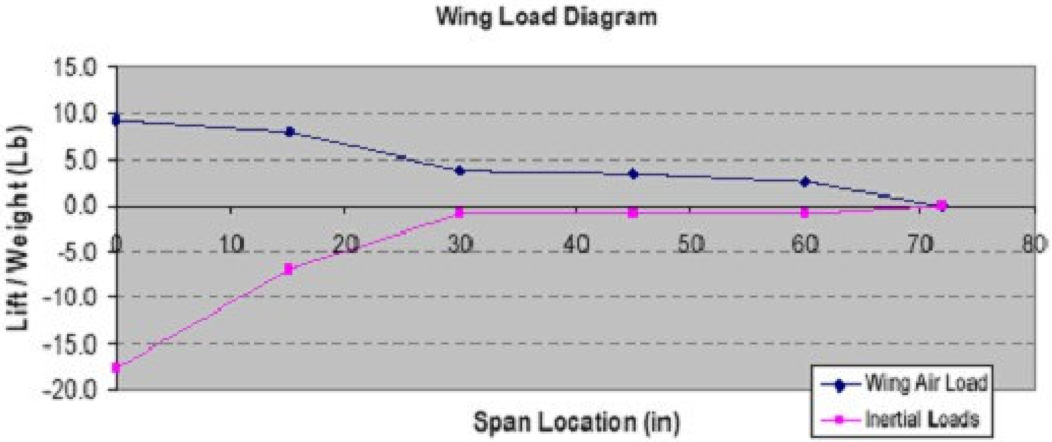
It should be noted that the static margin is affected by power as well as CG placement. For tractor layout flying wings, it is recommended that the AC of the wing sections immersed in the slipstream are forward of the CG (reference 1, page 424). Also, it is desirable to have the thrust line going through the CG or be slightly above the CG. Both of these features will produce a stabilizing effect with the addition of power. A destabilizing effect will occur if the AC of the 'immersed' wing sections are forward of the CG. Essentially the entire center section of our planform directly aft of the propellers is immersed in prop wash. The resulting 'immersed' wing has an AR = 0.5, and span = 30 inches.

Directional stability, dCn/dβ, is another important factor in the aircrafts' flying qualities. This term can be described as change in yawing moment vs. change in sideslip angle and should have a positive slope for static directional stability. Sweep and C_L largely affect wing directional stability such that increasing sweep or C_L will increase wing alone directional stability. An Excel spreadsheet was created to calculate the $dC_n/d\beta$ of the entire aircraft at varying C_L's both at takeoff and cruise conditions. The target for adequate directional static stability was a $dC_n/d\beta >$ 0.001/deg (reference 1, pg 428). As seen in Figure 5, $dC_n/d\beta$ is 0.012 at cruise and 0.032 at takeoff. Due to the dihedral effect of sweep, dihedral was deemed unnecessary.



As a final check for adequate longitudinal and directional stability margin, a test glider of 20% scale (36 inch span) was cut out of foam sheet, and the CG placed at 20% MAC (5% stable) to confirm that the correct AC location had been calculated. The glider had no dihedral, and was a 'flat plate' airfoil section. This glider exhibited excellent longitudinal and directional stability, and provided validation of the theoretical calculations. Other speakers have commented about keeping test models simple and Dan's was a good example. Everything was held in place using duct tape, which made any repairs easy, plus it made for quick initial construction.

Finally, it was necessary to determine whether the aircraft had adequate longitudinal and directional control power. First, longitudinal control power at takeoff was analyzed. XFLR5 was used to calculate

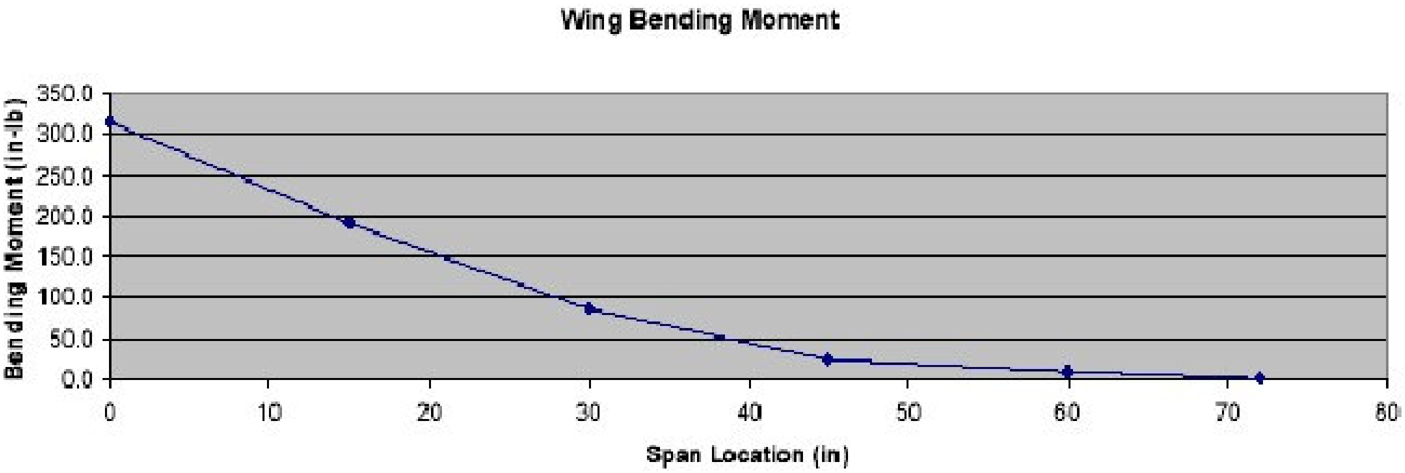


the change in pitching moment vs. change in TE deflection. It was also used to calculate change in lift coefficient vs. change in TE deflection. These values are critical in determining the control power and trimmed lift coefficient for the aircraft.

The MH78M airfoil was modeled with 10 deg TE deflection at 75% 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. This analysis found that the TE deflection was well within the linear range and showed that the initial configuration had the right combination of sweep and control sizing to rotate at 55 lbs Max T.O. weight.

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 bays. Outboard of the payload are the engines, and outboard of the engines are the landing gear. See Section X for the structural layout details.



An XCEL 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 wing load diagram is shown in Figure 9 for a 2G load.

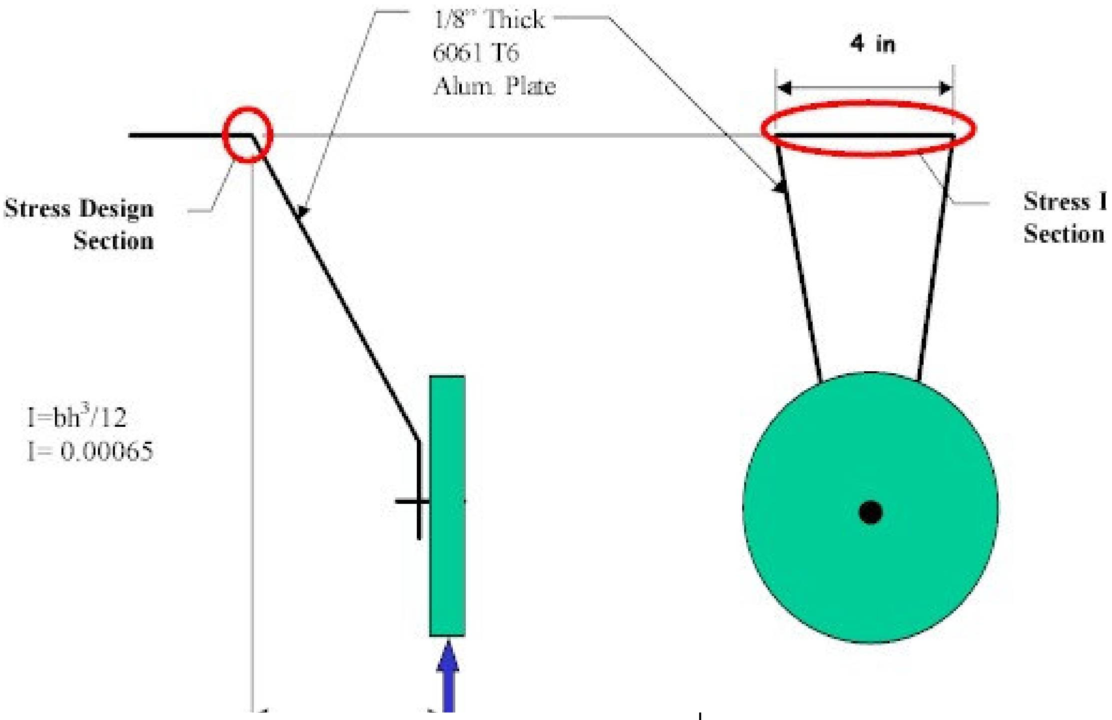
Of note in the wing loading diagram is the span-wise distributed inertial loads from 0 to 30 inches in the payload bay section. Also, due to the increased section chord across the payload section, the wing lift is well located above the inertial loads. This is important in reducing the root bending moment on the spar, thus reducing structural weight.

Next, the shear and bending moment diagrams can be calculated in order. Figure 10 and 11 show the shear and bending moment diagrams for the 2G loads.

Since the spars are roughly located equidistant from the center of lift, each was sized equally.

The ½ inch x ¼ inch spruce spar caps with 1/8 inch balsa shear webs were selected for their ease of construction, excellent strength to weight ratios and low cost. There were plywood shear webs located in the payload, engine and gear bays to form stiffer, more durable structure to attach the various required fittings.

Next to be sized was the landing gear. 1/8" thick, 6061 T6 aluminum plate stock was chosen for its excellent strength to weight ratio and ease of machining. The gear was stressed such that on the worst case landing load, a single main gear takes 2 x 55lbs load. The bending stress was analyzed using the following figure:



The stress is concentrated as shown in the red area (circles at the top of the gear leg) since this is the clamped portion of the beam, and the gear leg will act like a cantilevered beam.

The gear was found to have a max section stress of 39,000 psi. The max allowable stress for 6061T6 is 45,000 psi, so there is a 1.15 safety factor for the worst case 2G condition.

Finally, a structural attach method was devised for the outer wing panels. These needed to be removable in order to store and transport the aircraft economically. In order to create a stiff box structure at the wing attach joints, the outboard bays of the center section and inboard bays of the wing panels were reinforced with plywood gussets and shear webs. Then the outer ribs of the center body and wing panels were reinforced with plywood and an aluminum piano hinge was bolted in a vertical orientation between the upper and lower spar caps of the forward and aft spars. In this way, the load is driven primarily to the upper and lower spar caps and the stiffened 'box' sections at the wing joint. The primary concern is pull through load of the bolts through the plywood reinforced ribs, so aluminum plate was used to in-lieu of washers for the nut clamp up to the rib. Also, to ensure minimum mechanical play in the joint, a slightly oversized 1/8" pin was used in the piano hinge.

Propulsion

The rules dictate that no more than two 0.61 engines are allowed on unlimited class aircraft. The team did a survey of the performance of available 0.60 engines using reference 6, and chose the Tower Hobbies .61BB ABC engine. It had the highest brake horsepower of 1.59 at 14,150 RPM and the highest BHP to weight ratio of 1.08. For balance, the engines were arranged in a tractor configuration. They are close to centerline to minimize thrust induced yawing moment due to engine out or asymmetrical thrust. The static thrust of the engine/propeller combination can be seen in Table 14.

Based on this data, the APC 11x7 propeller was chosen as it had the maximum static thrust of 11.3 lb. Given the static thrust, we were now able to calculate the dynamic thrust. Dynamic thrust decreases linearly with forward airspeed. This relation is also found in reference 3, page 397. Figure 15 shows dynamic thrust vs. airspeed for the APC 11x7 propeller.

Prop Dia	Prop Pitch	RPM	Torque (lb-ft)	Static Thrust (lb)
11	6	14450	0.54	10.7
11	7	14150	0.57	11.3
11	8	12850	0.53	10.2
11	11	10950	0.56	7.2
12	6	12150	0.53	9.7
12	7	11250	0.54	9.3
13	7	10450	0.58	9.6
12.5	9	9750	0.55	9.8

Weights and Balance

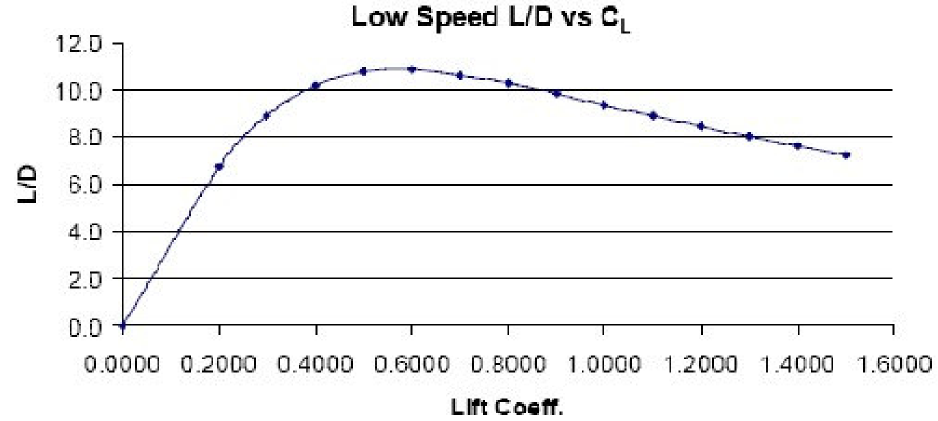
In order to get an accurate weight and CG location of the aircraft, the team modeled everything in a 3D CAD program. This included assigning densities to all of the structural members, electronics, engines, landing gear, fuel, payload, etc. This took a bit of effort, but since the CG location is so critical on this aircraft, it was felt the effort was warranted.

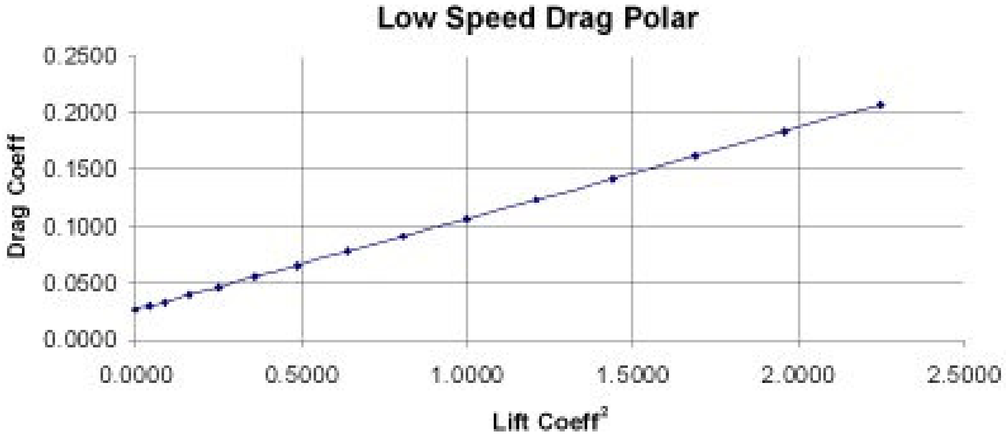
The empty weight of the aircraft was calculated to be about 25 lbs. This allowed for 30 lbs of payload to be carried for a payload to GTOW ratio of 1.375. Also based on the CAD model, the CG of the aircraft with no payload was found to be at X = 22.05, with a static margin of 4.3%. This is within 1% of the 5% stable requirement. With full payload, the CG moves from X=22.05 to X=21.87, thus the aircraft becomes more stable and is very close to the 5% stable goal. It should be noted that the engines were designed such that they can slide forward and aft within the engine mounting structure. This was done in order to allow fine-tuning of the CG before first flight. An image of the 3D CAD model used to calculate the weights and CG is shown in Figure 16.

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 21 kts per section I.

An Excel spreadsheet was utilized to sum the drag, then the low speed L/D vs. C_L and C_D vs. C_L^2 polars were created. The drag vs. available thrust was calculated to be 19 : 9.4 or roughly 2:1. Thus the aircraft has adequate thrust margin at takeoff to avoid mushing back into the runway at high AOA's.





Fabrication

The build took place at the team captain's home in Long Beach. Each part template was printed from CAD for accuracy and speed of fabrication. The center section ribs were balsa with foam core sandwich for strength. The spars were spruce and the shear webs were 1/8-inch balsa sheet. All hard attach points such as the gear floors, payload bay floors and outer wing attach joints were 1/8 inch plywood / foam sandwich structure. First the center section was jigged by taping VHS cassettes to a table, then sliding the ribs in between the cassettes. The spars were spliced using a coping saw and protractor to get accurate fit. They were then bonded in place using epoxy.

The outer wings were initially going to be made from foam, but the weight penalty was at least 2 lbs. The team then went with standard built up spruce spar caps and balsa shear webs with balsa ribs for the outer wings. This resulted in a very light and strong structure similar to the center section. The fixed slats were cut from a CNC foam machine using a CAD model transferred into CNC code.

The gear, motor tubes and wing attach fittings were aluminum. Overall, the project took 3 – ½ months from design freeze to first flight. The cost of materials was roughly $1500. The cost was kept down by a generous donation of a 6-channel radio.

Payload Prediction Chart

In order to calculate an accurate payload prediction chart, the team created a spreadsheet that allowed drag and lift to vary with altitude. The takeoff speed is increased due to reduced density therefore, the velocity must be increased to produce the same amount of lift. This increases the ground roll on takeoff. Also, the thrust produced by the propeller is reduced in the same way due to reduced density. The power of the engine is also reduced since the mass flow into the engine is reduced due to lower air density. All of these factors were allowed to vary in the spreadsheet in order to determine the payload prediction equation.

Conclusion

The design and build of this flying wing model was very challenging. The team found that no item could be taken for granted since the configuration was so sensitive to changes in CG, planform shape, airfoil section and propulsion integration. Overall, designing and building a tailless aircraft gave us deeper insight into the design compromises that are a part of aircraft design and construction. We look forward to demonstrating our ‘unusual’ configuration to the rest of our competitors.

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LETTERS TO THE EDITOR

September 1, 2007

Andy:

Here is the most recent response from one of the younger foreign builders. Some photos and a video of his "bird", and my response to the message. Thanks for keeping the activity going. I'll try to remember to cc: you on other similar messages.

Bob Hoey
<bobh@antelecom.net>

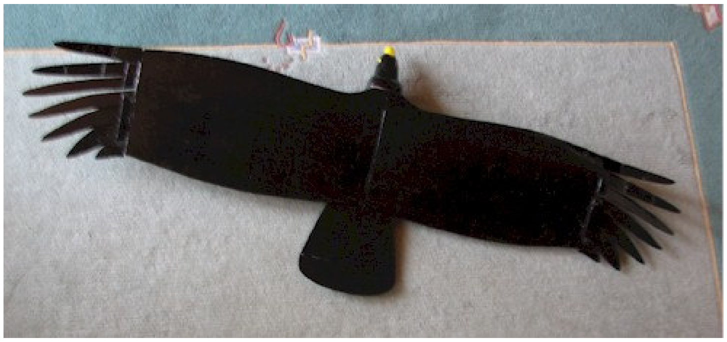
(ed. – I had an opportunity to talk with Bob at the ESA Western Workshop over Labor Day and asked him to copy us when he was answering inquiries or comments on his bird models. This way we all learn a little bid more about what he and others are up to with radio controlled birds. This is one of his messages.)

Hello:

I just finished my bird, which you sent me a plan. And I have to tell you, it isn't fly good on slope (just like you said) because it was too windy. But I fly with bird just a few times and it wasn't completely tested.

So, I made my "buzzard" (in Latin: buteo buteo) that birds live in our country. Some technical data:

Wingspan -- 1400mm
Weight -- 350g



I changed your plan a little (I hope you don't angry). I made a little smaller and from styro foam and cover with black tape. Other stuff is the same.

I add pictures of bird and one video of maiden flight (sound background is real and first flight I made in calm).

Thanks again for sketches! Best regards

JureVidmar

Hello Jure:

Thanks for the photos and video. Seems to fly well, and very much like my models (a bit sensitive in pitch, due to the short coupling) .

You have used all of the good features of the Raven and Vulture models, and the foam construction should make it more durable. Congratulations! Your workmanship is very good!

I am not, at all, angry for any changes you made. I published these model drawings for the purpose of stimulating modelers to do some experimenting with bird flight. I'm sure you will learn new things about how birds fly as you test and develop your bird model. Please keep me posted on your experiences.

Bob Hoey

September 4, 2007

Attached is a picture I found on the internet and was wondering what I would need to be able to cut that design out myself from foam. I wanted to purchase a finished product from the company that manufactures the wing, but they do not ship to South Africa.

I would appreciate any advice you may have to offer, or website referrals that may help me.

Many thanks,

Peter Vergeer
<peter@vergeer.co.za>

(ed. – I replied to him with several options and got the following back. Hopefully we will hear back from him with the photos and some more information on how well it flies.)

Morning Andy:

Thanks for getting back to me. I did email the company some time back, but they did not get back to me. I have since then started a new *Wing* project. It is a small foam core wing that I am covering with balsa. Not sure what it is called, but I will send some photos of the progress and finished product when I am done.

Thanks again,

Peter Vergeer

September 4, 2007

Hello Andy:

The newsletter came in today. I've another question: Has Chuck Tucker been heard from recently? I've some questions for him and do not want to bother if conditions are bad. Had you seen or spoken with Don Hunsaker?

Regards,

Henry Whittle
<gulfrose@Juno.com>

The following is directed to Edwin Sward of Worcester, Ma. Please print in newsletter as the fellow seems to be computer less.

Edwin- Everything current regarding Hang Glider and Para Glider may be researched at: http://www.ushga.org/. Should you be without a computer the local public library should be able to let you use one if you are a cardholder.

Regards

Hank

(ed. – I responded that we haven't heard from either Chuck or Don in a long time, so I couldn't really point Hank in the right direction.)

(ed. – This came from the Nurflugel bulletin board, but covers the subject that Al talked about at the ESA Western Workshop in September. The next part will get into why even a flying wing won't help get better results, but this has laid out the background.)

So I saved the presentation I did for last. A year ago, I was thinking out loud (never do this in front of Bruce Carmichael, he will hold you to your word!). It seemed to me that we still had a LOT of performance we had not taken advantage of in the open class yet. I was mulling over the presentation by Leo Benetti-Longhini on Dick Butler's Concordia super-sailplane. Leo is a member of the "team" helping to build this aircraft, along with Gerhard Waibel (the "W" in "ASW"), Loek Boermanns (the airfoil wizard from Delft University in the Netherlands), and Butler himself.

The only "stock" piece on the whole aircraft is the pod part of the fuselage. It's out of an ASW-27, but they cut-off the boom just aft of the cockpit (they even had to recontour the wing root fairings). The wings are 28m span, and there are MANY different airfoils along the span, the wing root area has a continuously variable airfoil to maintain the maximum run of laminar flow near the fuselage. In years past, sailplane designers would run the same wing airfoil all the way in to the wing root fairing on the fuselage. This is inherently a poor idea, as the contamination from the fuselage pressure distribution causes large drag increases and possibly even separation (both the wing and the fuselage are trying to recover pressure at the same time, resulting in the boundary-layer not being to able to remain attached for either). The boom is a custom one-off piece built-up from balsa for the form and then covered with carbon fiber. The tail is also all custom, a HUGE vertical made from Kevlar (all the radio antennas are internal to the vertical) and the bitty horizontal is carbon also. The tail wheel retracts (unusual in a sailplane), this is a one-off mechanism made by Waibel (he's sorta proud of it too). The aspect ratio is a hugely impressive 51.7 (the best open classers are in the sub-40 range right now). And the ship has a HUGE wing loading range with the water ballast it can legally carry (many folks overload their open class sailplanes for better performance in strong lift conditions, limited to 850 kg by the rules). The high aspect ratio is pushing the limits of airfoil capability, and the performance is sensitive to Reynolds number; at light wing loading (low speed) the max L/D is 72 (!) and at heavy wing loading (high speed) the max L/D is 75 (!!!). The only thing Butler & team did wrong was they were trying to elliptical span load (we ALL know bell shaped is ideal if span is not the constraint, right?). The target to beat was ETA, the German ultra-span super-sailplane (30.9m span, two seats, 920 kg max TOGW, self-launch, max L/D 70:1).

So I'm thinking about this, and I blurt out that the limit to max L/D for the open class must be up around 100-110. But that would be for conventional sailplanes, a flying wing must be up around max L/D 120-135. Anyone within earshot at the time should have BET ME MONEY. I would have LOST MY SHIRT! BIG!

So I started gathering the data. And I got busy. Way busy. The data sat. And sat. And sat. For 11 months, nothing happened. Bruce called to confirm I was still presenting. "Uh, yeah..." Bruce doesn't take no for an answer. And like I would be the guy to let BRUCE down!?!

So I started putting the data in and doing the analysis. Hmmm. ETA is right up against the optimal limit of what can be done. There are some things that can be improved, like maximize laminar flow over the fuselage, and the wing root problem. The huge verticals are needed to prevent spin entry, and the small horizontals are good to minimize trim drag (you only need to overcome pitching moment from the wing). But the elliptical vs bell-shaped will give us an edge :-) I am SO confident that the L/D is going to go way up. But you only get HALF the savings in drag if you only affect induced drag without doing anything to profile drag, and conversely. And I did the analysis two ways and got my answer.

And I am assuming that nobody is doing any solar-powered laminar flow control (Bruce is a strong supporter of this idea, I accuse Bruce of cheating ;-).

Q: What's the size limit for standard class sailplanes?
A: 15m span.
Q: What's the size limit for "racing" class sailplanes?
A: 15m span.
Q: What's the size limit for open class sailplanes?
A: It's a weight limit of eight-hundred and fifty kilograms.

That doesn't sound like a size limit, but if you go back to Klein and Viswanathan's paper in 1975 in AIAA Journal of Aircraft, it IS a size limit. And though we can make things a LOT stiffer than carbon fiber (by using things like boron fiber, about 3x stiffer than carbon) you can't make it much STRONGER. And STRENGTH is the limitation; for a given mass.

And I plotted up many open classers made in the last 40 years. The trends are very progressive and predictable. There are no great surprises or major jumps in performance or in the mass characteristics.

You can see groupings of the early all fiberglass open classers ("gummiflugel"), and a slow convergence to the all carbon ships of today.

So we're limited to about 36m span (for a conventional) with a max L/D of about 84:1 (this is using everything Butler has in his arsenal, if you're only going as far as ETA, you end up at 78:1). And even if you pulled out all the stops with a flying wing, you only end up at 94:1 with a 40-42m span (again using all the tricks Butler is using, if you're doing the ETA. approach you end up at 84~86:1).

Result: We're pretty close to the ultimate limit of what can be done with open class sailplanes now. Someone is going to have to do something radical and revolutionary to break out of the limits we have now.

Al

AVAILABLE PLANS & REFERENCE MATERIAL

Coming Soon: **Tailless Aircraft Bibliography**
Edition 1-g

Edition 1-f, which is sold out, contained over 5600 annotated tailless aircraft and related listings: reports, papers, books, articles, patents, etc. of 1867 - present, listed chronologically and supported by introductory material, 3 Appendices, and other helpful information. Historical overview. Information on sources, location and acquisition of material. Alphabetical listing of 370 creators of tailless and related aircraft, including dates and configurations. More. Only a limited number printed. Not cross referenced: 342 pages. It was spiral bound in plain black vinyl. By far the largest ever of its kind - a unique source of hardcore information.

But don't despair, Edition 1-g is in the works and will be bigger and better than ever. It will also include a very extensive listing of the relevant U.S. patents, which may be the most comprehensive one ever put together. A publication date has not been set yet, so check back here once in a while.

Prices: To Be Announced

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Books by Bruce Carmichael:
Personal Aircraft Drag Reduction: $30 pp + $17 postage outside USA: Low drag R&D history, laminar aircraft design, 300 mph on 100 hp.
Ultralight & Light Self Launching Sailplanes: $20 pp: 23 ultralights, 16 lights, 18 sustainer engines, 56 self launch engines, history, safety, prop drag reduction, performance.
Collected Sailplane Articles & Soaring Mishaps: $30 pp: 72 articles incl. 6 misadventures, future predictions, ULSP, dynamic soaring, 20 years SHA workshop.
Collected Aircraft Performance Improvements: $30 pp: 14 articles, 7 lectures, Oshkosh Appraisal, AR-5 and VMAX Probe Drag Analysis, fuselage drag & propeller location studies.

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VIDEOS AND AUDIO TAPES

(ed. – These videos are also now available on DVD, at the buyer's choice.)

VHS tape containing First Flights "Flying Wings," Discovery Channel's The Wing Will Fly, and ME-163, SWIFT flight footage, Paragliding, and other miscellaneous items (approximately 3½+ hours of material).
Cost: $8.00 postage paid
Add: $2.00 for foreign postage

VHS tape of Al Bowers' September 19, 1998 presentation on "The Horten H X Series: Ultra Light Flying Wing Sailplanes." The package includes Al's 20 pages of slides so you won't have to squint at the TV screen trying to read what he is explaining. This was an excellent presentation covering Horten history and an analysis of bell and elliptical lift distributions.
Cost: $10.00 postage paid
Add: $ 2.00 for foreign postage

VHS tape of July 15, 2000 presentation by Stefanie Brochocki on the design history of the BKB-1 (Brochocki,Kasper,Bodek) as related by her father Stefan. The second part of this program was conducted by Henry Jex on the design and flights of the radio controlled Quetzalcoatlus northropi (pterodactyl) used in the Smithsonian IMAX film. This was an Aerovironment project led by Dr. Paul MacCready.
Cost: $8.00 postage paid
Add: $2.00 for foreign postage

An Overview of Composite Design Properties, by Alex Kozloff, as presented at the TWITT Meeting 3/19/94. Includes pamphlet of charts and graphs on composite characteristics, and audio cassette tape of Alex's presentation explaining the material.
Cost: $5.00 postage paid
Add: $1.50 for foreign postage

VHS of Paul MacCready's presentation on March 21,1998, covering his experiences with flying wings and how flying wings occur in nature. Tape includes Aerovironment's "Doing More With Much Less", and the presentations by Rudy Opitz, Dez George-Falvy and Jim Marske at the 1997 Flying Wing Symposiums at Harris Hill, plus some other miscellaneous "stuff".
Cost: $8.00 postage paid in US
Add: $2.00 for foreign postage

VHS of Robert Hoey's presentation on November 20, 1999, covering his group's experimentation with radio controlled bird models being used to explore the control and performance parameters of birds. Tape comes with a complete set of the overhead slides used in the presentation.
Cost : $10.00 postage paid in US
$15.00 foreign orders

FLYING WING SALES

BLUEPRINTS – Available for the Mitchell Wing Model U-2 Superwing Experimental motor glider and the B-10 Ultralight motor glider. These two aircraft were designed by Don Mitchell and are considered by many to be the finest flying wing airplanes available. The complete drawings, which include instructions, constructions photos and a flight manual cost $140, postage paid. Add $15 for foreign shipping.

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