On the ’Wing... #150

Penumbra.5

After a respite of several years, we’ve decided to commence the design, construction, and eventual test flying of what will be the fifth iteration within our Penumbra project.

Project Penumbra originated as an exercise in developing a tailless sailplane for thermal duration events, and possibly for F3B. The planforms for Penumbra.1 through Penumbra.4 were derivations of Hans-Jürgen Unverferth’s CO2, the best performing swept wing sailplane then in existence. As swept wings must have both strength along the span and torsional rigidity, the series has consisted of much experimentation focused on construction materials and methods.

The basic planform for the series up until now uses a span of around 110 inches, a chord of nearly 12 inches, and 18 degrees of sweep. We’ve consistently used the EH 1.0/9.0 airfoil and one degree of twist starting at the mid point of the semi-span. Since we’re designing for thermal flying, winglets have always been added.

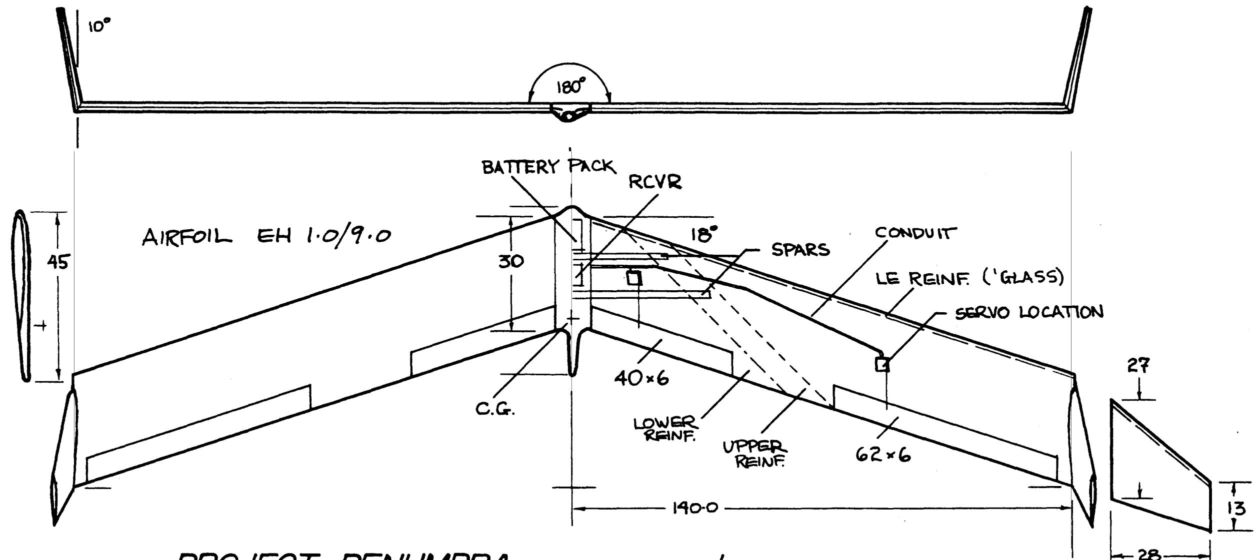
For those relatively new to *RCSD*, here’s a brief overview of the Penumbra series thus far:

Penumbra.1

The first of the Penumbra series was constructed almost immediately after attending the 1989 MARCS Symposium and devouring Dr. Walter Panknin’s presentation on the design and construction of swept wing tailless aircraft. Like all of the Penumbra series thus far, it was constructed of pink foam with a vacuum bagged fiberglass skin. We used the spar system advocated by Dr. Panknin for his balsa skinned Flying Rainbow series, and this turned out to be a major error. The fiberglass we applied was not sufficiently strong in compression, and the first winch launch buckled the upper surface of the wing a short distance outboard of the end of the main spar. Despite the structural failure, the first and only test flight was an unqualified success. The winch launch using a single tow hook was otherwise uneventful, and the ’wing was downright docile in flight.

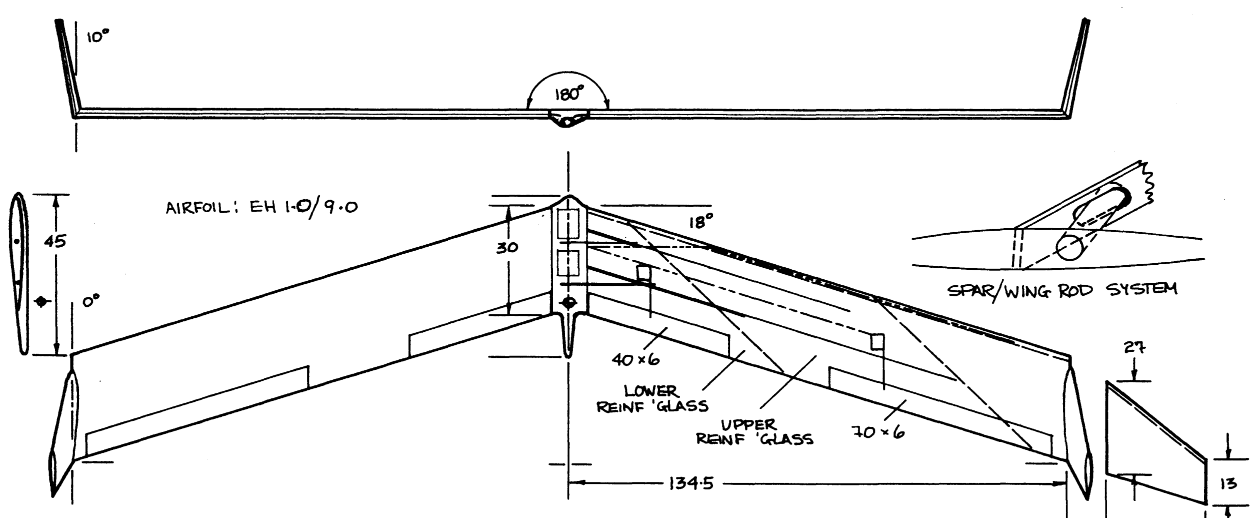
Penumbra.2

Built with a better spar system than Penumbra.1, Penumbra.2 was flown several times at 60 Acres in Redmond Washington during and after Bruce Abell’s visit to America in 1990. The tow hook was initially mounted too far back, leading to what can only be described as a “flat spin” from a height of about 50 feet. It suffered no damage. The wing-fuselage joints were retaped and the tow hook was moved slightly forward. Subsequent launches exhibited no such difficulties, and Penumbra.2 was thermalled later that day. A strong launch resulted in a few cycles of flutter, but none was seen during flight, despite some high speed passes. Flap deflection was extremely effective at markedly slowing the ’wing.



PROJECT PENUMBRA ·1

ENTIRE WING USES '150' PINK STYROFOAM; VACUUM BAG TECHNIQUE:
- COVERED WITH TWO LAYERS 3oz 'GLASS
- CENTER PANEL USES 3 LAYERS 6oz
- LE REINFORCEMENT 6 oz 2" TAPE
- TAPERED ROOT REINF. ONE LAYER 3oz
- SPARS OF BALSA & PLYWOOD
- WING RODS OF 5/16" DRILL ROD, & 3/16" MUSIC WIRE



PROJECT PENUMBRA ·2, ·3

- "150" PINK STYROFOAM 'CORE'
- 2 LAYERS 3.14 oz/YD² FIBERGLASS WING SKIN
- LE REINFORCEMENT = 6 oz/YD² 'GLASS TAPE 2" WIDTH
- 1 LAYER 3.14 oz/YD² 'GLASS TO DIAG'S
- SPAR MAT'L = 3/32" PLYWOOD, DOUBLED NEAR ROOT
- WING RODS = REAR = 5/16" DRILL ROD
  = FRONT = 3/16" MUSIC WIRE
- VACUUM BAG TECHNIQUE
- FUSELAGE OF PINK FOAM WITH 3 LAYERS 6oz/YD² 'GLAS

Bill setting up Penumbra.2 at 60 Acres

Penumbra 3

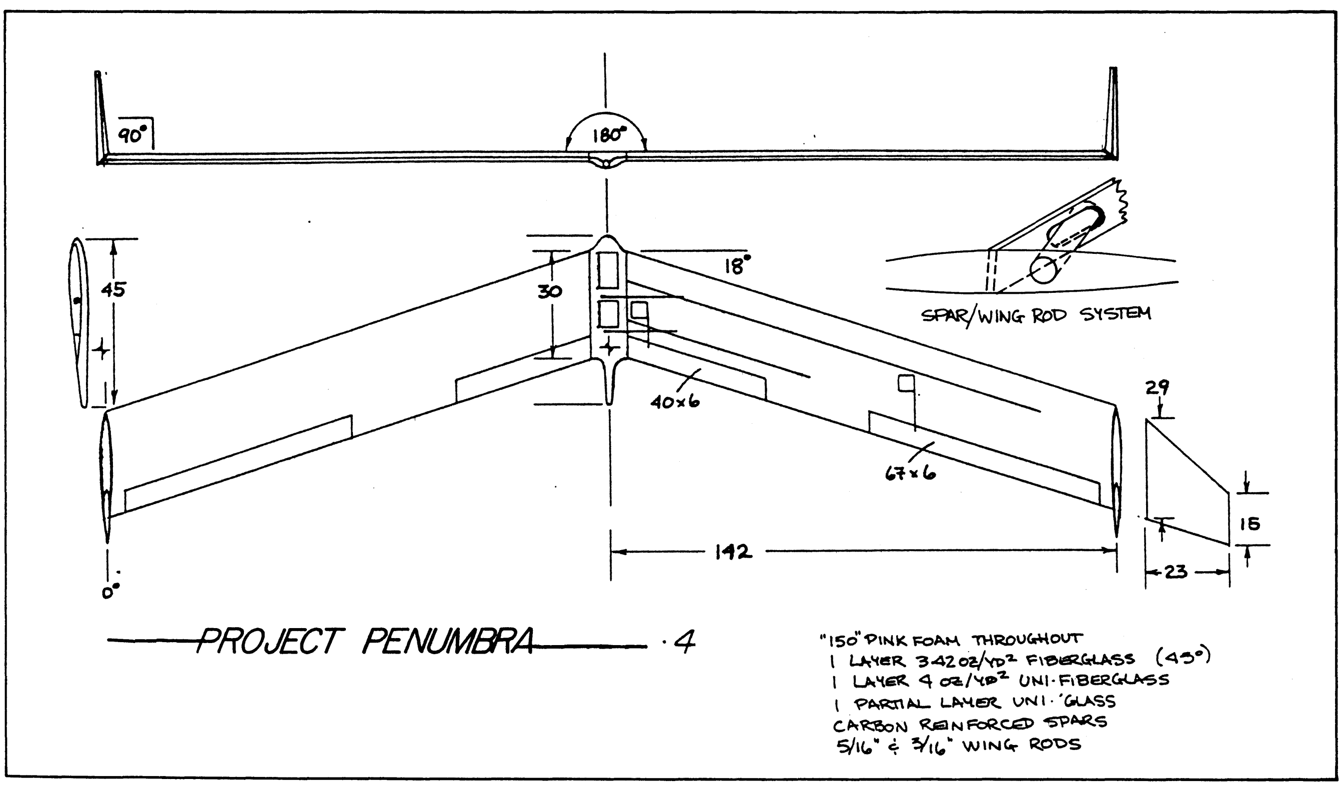
This wing, with spars extending slightly outboard from those used in Penumbra.2, did not have what we considered to be sufficient strength in the spanwise direction. It was also our first experience with applying paint to the mylar sheets before vacuum bagging, and so was slightly heavier than we thought it should be. Penumbra.3 was never flown.

Penumbra.4

Tapered carbon spar caps were fabricated using the vacuum bag technique, and this wing is very strong along the span and in torsion as well. First flights were made April 20th 1991, during Dr. Panknin's visit while on his way back to Germany. The first winch launch was a replay of that of Penumbra.2, with a flat spin shortly after release. Again no damage, so everything was retaped and the tow hook moved forward. Subsequent launches were without problem, and the tow hook was moved back a bit on later launches. This 'wing does not seek out lift, but will thermal even in light lift, despite weighing 100 ounces. Once circling in rising air it flies very nearly hands off with a bit of up trim. It has no tendency to spiral in, and no corrective aileron is needed.

The strength of this wing is amazing, as attested to by an experience in Richland Washington. Penumbra.4 was flying fairly far out when, without warning, the transmitter battery went dead. The aircraft made a wide semi-circle while slowly pitching down. It was coming down at high speed and at about a 60 degree angle when last seen. We found it in a front yard, flat on the ground, with a large piece of cactus next to it. The only damage was to the right wing which had a

Penumbra.4 circling in a thermal at 60 Acres



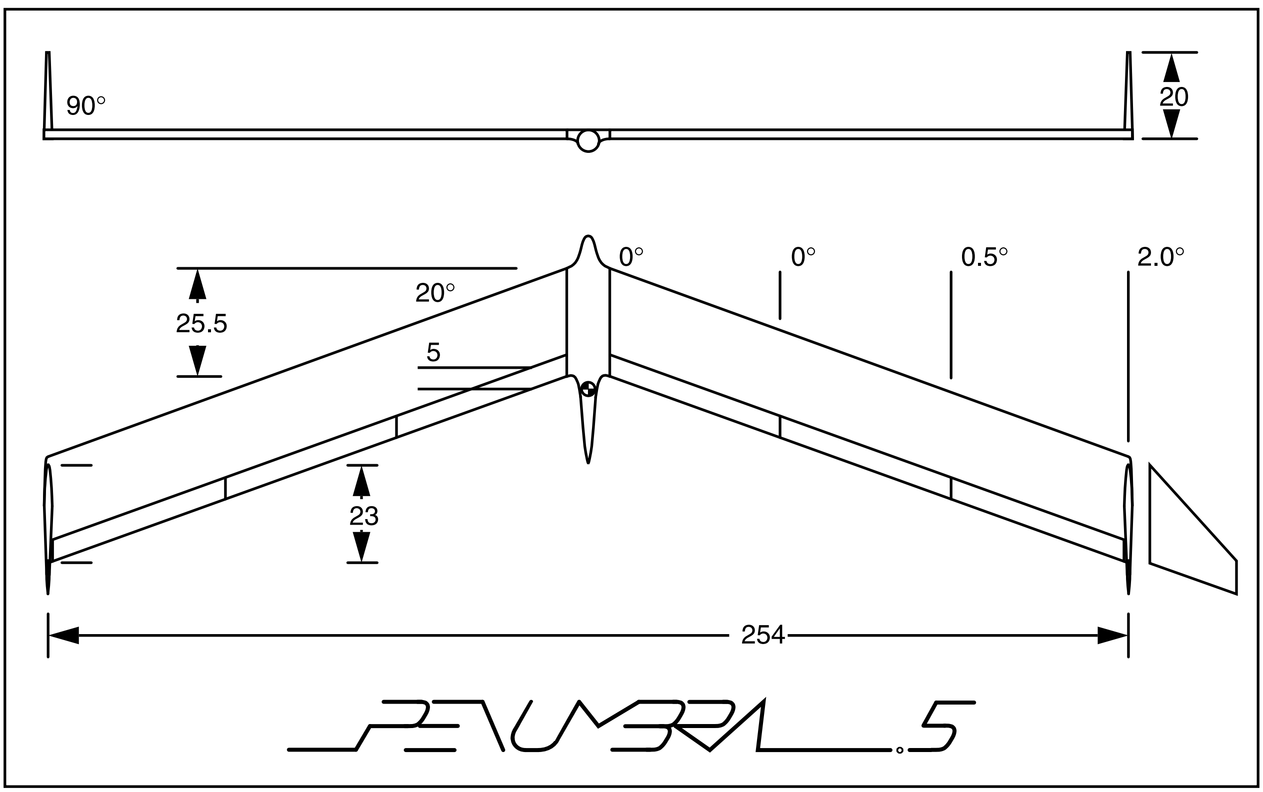
three inch section of its leading edge punched back in a bow of about a quarter inch in depth. This ding was easily repaired. Damage to the cactus was more severe. Penumbra.4 is still in flyable condition, but has not been in the air for several years.

Between then and now, we’ve been flying our various Blackbird 2M models and a couple of Ravens. But having a swept wing tailless soarer flying overhead, searching out the elusive thermal, still resides in our minds. Their ability to climb out in light lift, travel rapidly between thermals, and just look good in the air has always been just too much to disregard.

<u>Penumbra.5</u>

The impetus to build another swept wing tailless sailplane has come from several sources.

First, there is the recent discussions on the internet nurflugel e-mail list concerning various wing twist paradigms. Of special interest to us are the pros and cons of the Horten and Culver methods of distributing the twist along the wing span. In brief, the Horten method has most of the twist in the outer portion of the wing, and there is a bell-shaped lift distribution. It is possible to set up the twist distribution such that there is proverse yaw during turns, despite lack of a rudder function. The Culver method, on the other hand, concentrates most of the twist over the inboard portion of the wing, and the lift distribution is elliptical. Inhibiting adverse yaw may require some sort of rudder control. (We’re currently working on articles which will examine both of these twist distribution methods, along with other paradigms.)



Second, and along these same lines, we read the condensations of presentations given by Al Bowers at meetings of TWITT (The Wing Is The Thing) in which he described various twist distributions, planforms, and control surface placements. This reinforced some ideas we had about incorporating a “six flap” control system in a new design.

The successes of Glyn Fonteneau and Dave Camp — Vitesse and CO8 2M — certainly increased our confidence. And we got some news about the RS004A from Aaron Coffey.

> “...I've been learning to use Xfoil in order to eventually figure out an airfoil for a flying wing, starting with examining the RS004A. It's a very interesting ’foil. The maximum L/D occurs at almost the same C_l as on the widely used MH-32, although the MH-32's L/D is theoretically 3.5 points better. Close though. What really caught my attention was the fact that as the C_l approaches stall, the C_{m0} of the RS004A approaches zero! So, after plugging the C_{m0} into the Panknin twist formula I found that the CO8 can be flown at least as slow as 13.5 mph and the wing twist (not linear, so this is a little off) remains within 0.1 degree of exactly the right amount: 2.9. If this matches with reality... amazing.
>
> “I think this is a result of a combination of the shape of the camber line near the TE and the separation bubble. Following the flows along the top and bottom boundary layers, the effective airfoil is one that possesses increasing reflex as the C_l increases. So if all this is true, this C_{m0} reduction is a very desirable property for a flying wing airfoil.
>
> “I still have to figure out how to do flap deflection calculations, so it'll be awhile before I can calculate what the max C_l possible is. And longer still ’til I can use the program's results with confidence. Oh, the MH-32 also exhibits the same C_{m0} reduction, though not as great.”

Our visit to the Puyallup Model Expo in February was the real trigger, however. We found some very small but powerful servos at the Thermal-Gromit Works booth. These MPI (Maxx Products, Inc.) servos are powerful, putting out 47 in.-oz., about the same as the standard JR servos we’ve used previously, yet they are a small 31.0 mm x 16.1 mm x 30.0 mm (1.22” x 0.63” x 1.18”) and weigh just 0.85 ounces. The rotational speed is fairly fast as well, 0.18 sec/60°. We bought six, already mentally configuring a swept wing of 100” span with flaps and elevons outboard and at mid-span.

MPI MX-100 Specifications

Size, L x H x W	Weight	Torque, at 4.8V	Speed
31.0 mm x 16.1 mm x 30.0 mm 1.22” x 0.63” x 1.18”	0.85 oz.	47 in.-oz	0.18 sec/60°

Penumbra.5 will depart from our previous tack in several respects — sweep angle, airfoil, and control system.

We used Joa Harrison’s Excel spreadsheet of the Panknin formula to set up the initial design. We’ve included two screen shots which show the required twist values for lift coefficients of 0.1

(cruise) and 0.6 (thermalling). The Panknin formula assumes a constant rate of twist from the root to the tip. We're going to construct our wing so that the twist is concentrated in the outboard third of the wing. The inner third of the wing will have no twist at all; at two-thirds span the twist will be one half degree; the tip will be set at an angle of -2.0 degrees. The additional one half degree will compensate for the difference in the twist distribution. The outboard elevons should be in their neutral position for cruising between thermals. The trim for thermalling will be a few degrees of up trim so that the effect is similar to increasing the twist to about four degrees.

Control surfaces for this new machine will consist of inboard flaps, mid-span elevons, and outboard elevons, with each control surface taking up one third of the semi-span. We've not yet decided on the initial mixing percentages, and probably will not achieve a good balance of aileron and elevator authority and elimination of adverse yaw until well into flight testing.

As we already have several other projects in various stages of completion, we have no way of establishing a time frame for Penumbra.5 progress at this time. But the airframe is pretty much fixed, and construction will begin as soon as the building table is clear once more.

Topic suggestions for future “On the ’Wing...” columns can be sent to us at P.O. Box 975, Olalla WA 98359-0975 USA, or <bsquared@halcyon.com>.

References:

Bowers, Al. About the Horten H Xc. TWITT Newsletters #148-150, October-December 1998.

de Piolenc, F. Marc. Flying wing design flowchart. TWITT Newsletter #2, July 1986.

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__. An update on project Penumbra. *RC Soaring Digest*, October 1990. Available as a reprint in “On the ’Wing... the book.”B^{2}Streamlines, Olalla WA.

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__. Glyn Fonteneau and Dave Camp’s CO8 2M. *RC Soaring Digest*, October 1999.

__. Glyn Fonteneau and Dave Camp’s Vitesse. *RC Soaring Digest*, July 2000.

Panknin, Dr. Walter. Flying Rainbows. MARCS Symposium, 1989. Contact Al Scidmore, 5013 Dorset Drive, Madison WI 53711 USA concerning availability of the 1989 Symposium Proceedings.

Thermal-Gromit Works, <http://www.tgworks.com>, 1-866-wlaunch.

PROJECT PENUMBRA

	Penumbra.1 1990	**Penumbra.2** 1991	**Penumbra.3** 1991	**Penumbra.4** 1991	**Penumbra.5** ~2001
Span	110”	106”	106”	112”	100”
Chord (constant)	11.8”	11.8”	11.8”	11.8”	10”
Airfoil(s)	EH 1.0/9.0	EH 1.0/9.0	EH 1.0/9.0	EH 1.0/9.0	RS004A to 2/3 semi-span, RS004AT at tip
Sweep angle	18°	18°	18°	18°	20°
Twist	0° at root and 1/2 semi-span, 1°at tip	0° at root and 1/2 semi-span, 1°at tip	0° at root and 1/2 semi-span, 1°at tip	0° at root and 1/2 semi-span, 1°at tip	0° at root and at 1/3 semi-span, 0.5° at 2/3 semi-span, 1.5° at tip
Controls	Outboard elevons, inboard flaps	Outboard elevons, inboard flaps	Outboard elevons, inboard flaps	Outboard elevons, inboard flaps	Outboard ailerons, elevons, inboard flaps
Winglets	11” high 100° to wing	11” high 100° to wing	11” high 100° to wing	9” high 90° to wing	Yes
Spar system	0.125”x0.5” spruce spar caps with balsa webbing. 6.0” front, 15” rear	0.125” plywood full height spar. 30” front 8” doubled, 42” rear 18” doubled	0.125” plywood full height spar. 34” front 9” doubled, 46” rear 16” doubled	0.5” wide unidirectional carbon fiber, tapered in thickness from root to tip, 48” front, 18” rear	unidirectional carbon fiber, tapered in thickness from root to tip, 48” front and rear
Fuselage	1.75” deep, 4” wide with wing root filleting, 6” tail	1.75” deep, 4” wide with wing root filleting, 6” tail	1.75” deep, 4” wide with wing root filleting, 6” tail	2.0 deep, 4” wide with wing root filleting, 5” tail	2.0” deep, 4” wide with wing root filleting, 7” tail
Wing structure	Failed in compression outboard of end of spar	Weak due to insufficient fiberglass thickness	Weak in spanwise direction, flutter on strong launch	Very good, but some flutter on very strong zooms	
Performance	Launched easily, excellent glide, docile handling	Launch height limited due to flutter, docile handling, thermalled well	Not flown due to poor wing strength in bending	Launches easily, excellent glide, docile handling, can be thermalled nearly hands off	

RS004A

1.00000	0.00000
0.99726	0.00027
0.98907	0.00118
0.97553	0.00281
0.95667	0.00504
0.93301	0.00771
0.90451	0.01080
0.87157	0.01431
0.83457	0.01823
0.79389	0.02242
0.75000	0.02687
0.70337	0.03167
0.65451	0.03674
0.60396	0.04189
0.55226	0.04678
0.50000	0.05126
0.44774	0.05520
0.39604	0.05823
0.34549	0.06020
0.29663	0.06101
0.25000	0.06053
0.20611	0.05869
0.16543	0.05553
0.12843	0.05111
0.09549	0.04554
0.06699	0.03894
0.04323	0.03142
0.02447	0.02317
0.01093	0.01453
0.00274	0.00640
0.00000	0.00000
0.00274	-0.00487
0.01093	-0.00931
0.02447	-0.01379
0.04323	-0.01805
0.06699	-0.02196
0.09549	-0.02521
0.12843	-0.02754
0.16543	-0.02894
0.20611	-0.02950
0.25000	-0.02936
0.29663	-0.02862
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0.39604	-0.02574
0.44774	-0.02382
0.50000	-0.02179
0.55226	-0.01961
0.6039	-0.01693
0.65451	-0.01385
0.70337	-0.01087
0.75000	-0.00811
0.79389	-0.00563
0.83457	-0.00355
0.87159	-0.00188
0.90451	-0.00066
0.93301	0.00010
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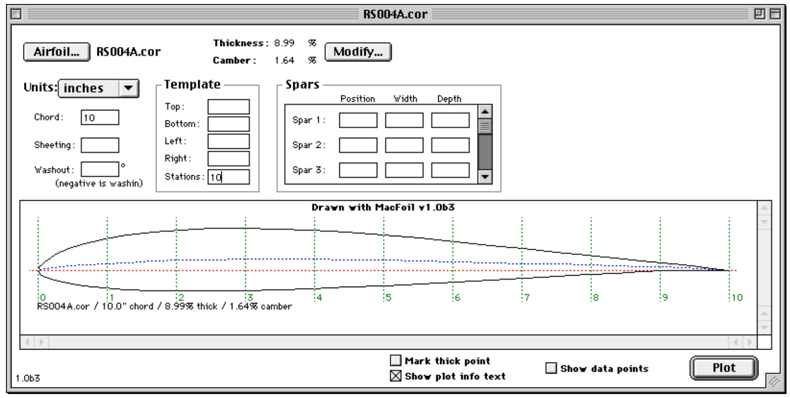
1.00000	0.00000



$C_m = -0.0418$
$\alpha_{0L} = -1.8066°$

RS004AT

1.000000	0.000000
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0.989070	0.000465
0.975530	0.001190
0.956670	0.002306
0.933010	0.003805
0.904510	0.005730
0.871570	0.008095
0.834570	0.010890
0.793890	0.014025
0.750000	0.017490
0.703370	0.021270
0.654510	0.025295
0.603960	0.029410
0.552260	0.033195
0.500000	0.036525
0.447740	0.039510
0.396040	0.041985
0.345490	0.043785
0.296630	0.044815
0.250000	0.044945
0.206110	0.044095
0.165430	0.042235
0.128430	0.039325
0.095490	0.035375
0.066990	0.030450
0.043230	0.024735
0.024470	0.018480
0.010930	0.011920
0.002740	0.005635
0.000000	0.000000
0.002740	-0.005635
0.010930	-0.011920
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0.095490	-0.035375
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0.296630	-0.044815
0.345490	-0.043785
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0.447740	-0.039510
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0.654510	-0.025295
0.703370	-0.021270
0.750000	-0.017490
0.793890	-0.014025
0.834570	-0.010890
0.871590	-0.008094
0.904510	-0.005730
0.933010	-0.003805
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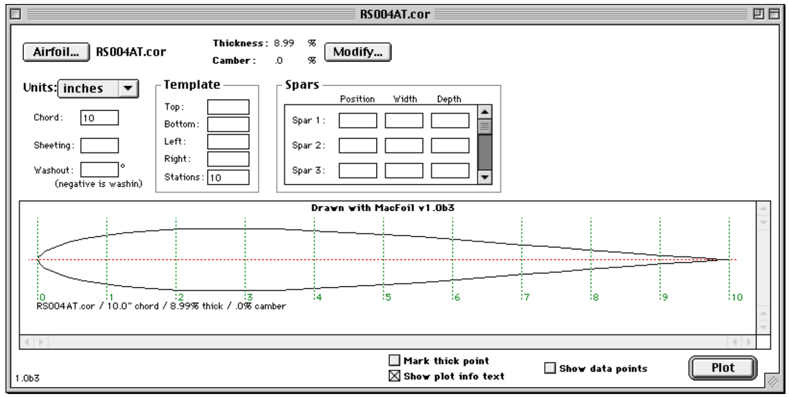

$C_m = 0.0000$
$\alpha_{0L} = 0.0000°$