T H E   W A D D E L O W   D E S I G N

T R I - Q   S T R A I G H T   C A N A R D

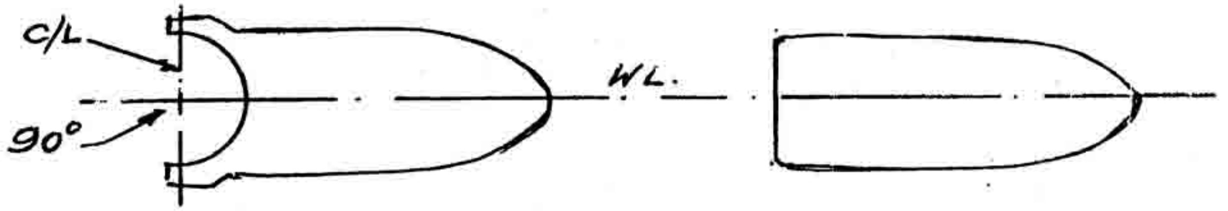
MANUFACTURING SEQUENCE

Foam block layout is identical to plans Page 5-2 and 5-3 of LS1 Canard, except all ends are cut at 90° thus making all blocks rectangles that is all corners are 90°.

Shear web is cut at 90° to waterline, not half round - there is no round spar -

Proceed to layout and hot wire cut the cores per plans on page 5-2 and 5-3.

The shear web is cut at exactly the centre of the round spar cut out



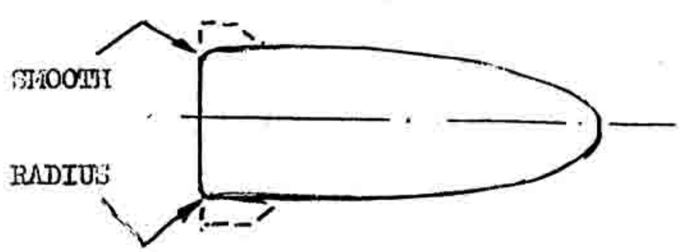
Cut center core BL 15 R to BL 15 L
from one piece 30" long

Cut inboard cores BL 15 to BL 48.8
from one piece 33.8" long

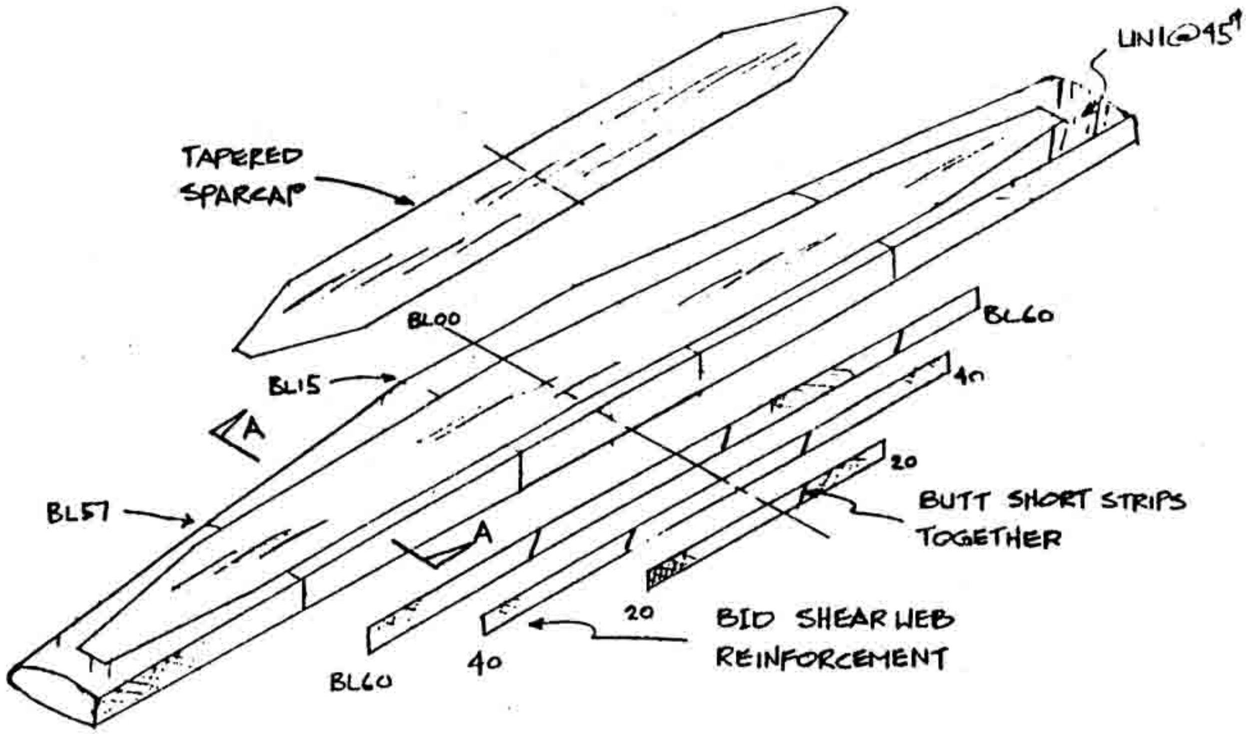
Cut outboard cores BL 48.8 to BL 100
from one piece 51.2" long

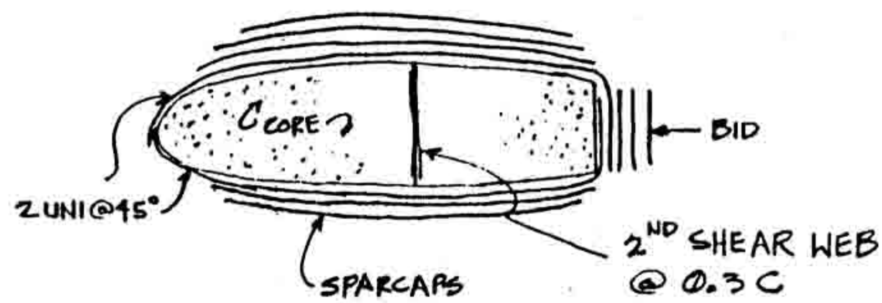
Mark and identify all BL and Level lines on each core

Sand/cut off fish tail on all cores to produce a smooth radius at the top and bottom of the shear web face



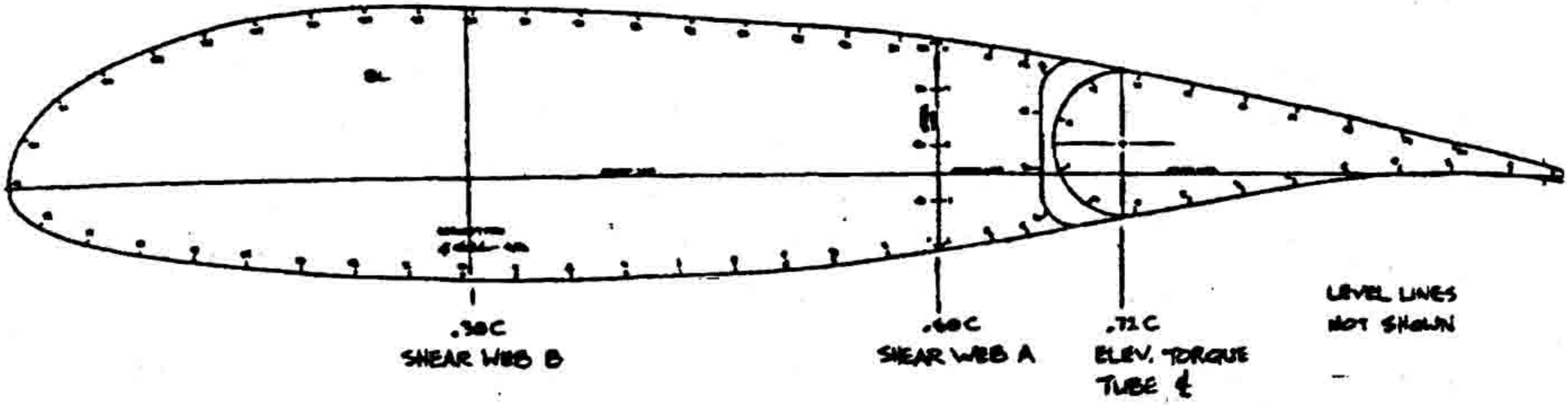
CANARD LAYUP- EXPLODED VIEW



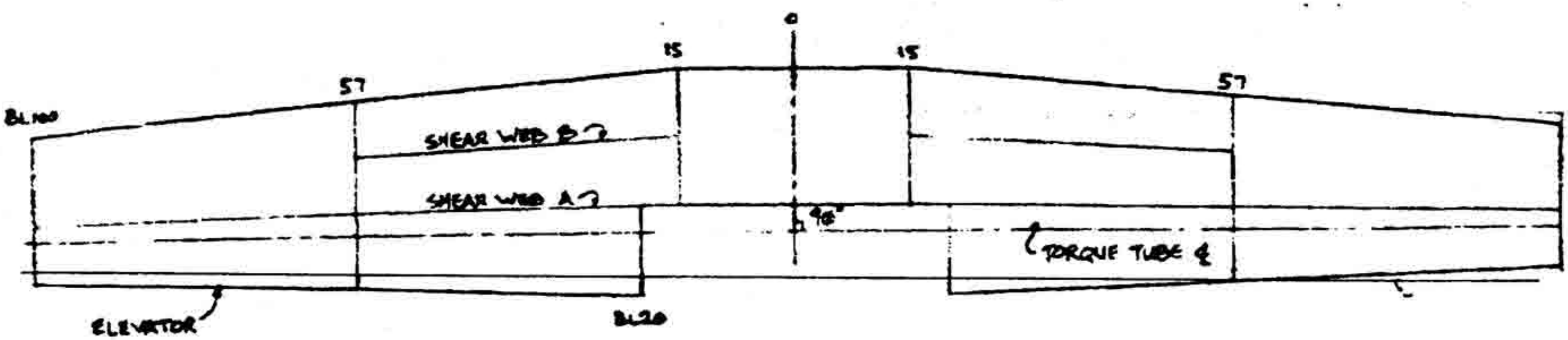


SECTION A-A

M. Waddelow
4/86



CANARD LS(1)0417MOD AIRFOIL



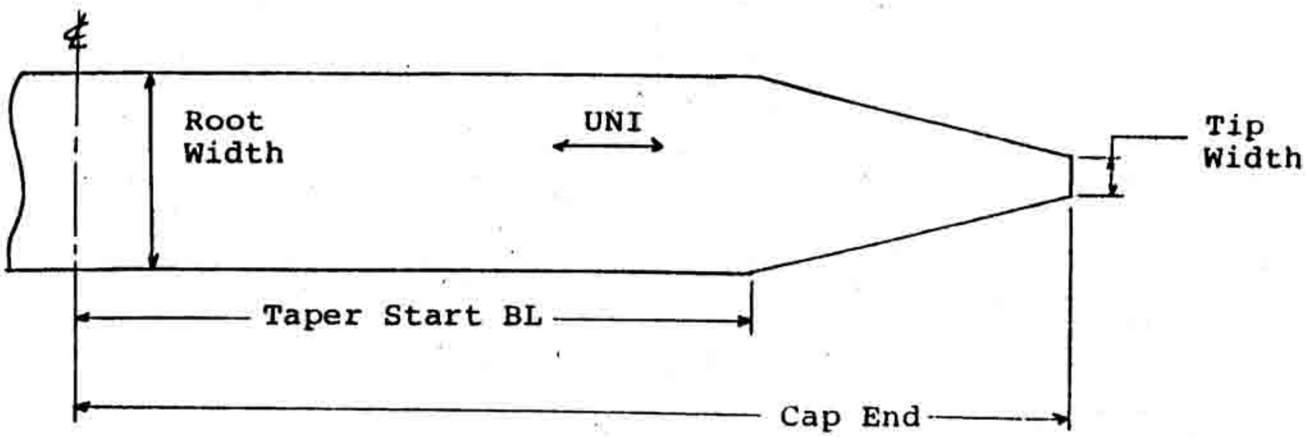
TRI-Q CANARD PLANFORM

SCALE: 1:20

M. Waddelow
May '86

ACTUAL SPAR CAP DIMENSIONS

These values describe the actual spar cap dimensions, in inches, to be used in the analysis function. Each spar cap is described as shown below.



GENERAL NOTES ON THE Q2ANALYSIS PROGRAM

The Q2ANALYSIS program calculates the spanwise loads using a simplified computer model of the wing. The simplifying assumptions used are described below.

1. The wing planform is limited to rectangular or straight taper.

2. The lift provided by the wing at any point is proportional to it's chord. The effects of tip washout are not considered. This results in a conservative layup schedule as the real loads would be slightly lower than the calculated loads.

3. No structural credit is given to the two 45 degree UNI plies beneath the spar caps. This results in a conservative layup schedule. The two 45 deg. plies are needed to carry the torsional (twisting) loads but they are very weak for spanwise loads at that orientation.

4. The weight of the wing itself is not considered. This results in a conservative layup schedule as the real loads would be slightly lower than the calculated loads.

5. The tapered sparcap design is important to match the cap strength to the bending loads. Wide, square ended caps create a large stress concentration where they end; i.e. there is too much cloth just inboard and not enough just outboard of where they stop. The actual loads increase smoothly going inboard along the span; good engineering practice dictates the wing's strength should also increase smoothly. The object is to keep the STRESS in the wing constant at the design level. Cut the tapers with a rotary "pizza cutter" blade and a straightedge.

TABULATED VALUES

The Q2ANALYSIS program will generate tabulated output data in one of two formats depending on whether a design or an analysis was performed. The design function is used to compute the expected spanwise loads and the "equivalent width" of sparcap required. The analysis function is used to see the actual spanwise stresses for a given layup schedule.

DESIGN FUNCTION

1. BL
   This is the BL number along the wingspan for the calculations. The BL number is in inches from the centerline of the wing. Calculations begin just outboard of the fuselage.

2. SHEAR
   This is the vertical shear load in pounds.

3. MOMENT
   This is the bending moment in inch-pounds.

4. SPAR THICKNESS
   This is the calculated average airfoil thickness in inches.

5. EQUIVALENT CAP WIDTH
   This gives the width in inches of a single ply of sparcap needed to carry the calculated moments. In practice, this width is divided among several sparcap layers. For example, an equiv cap width of 60" can be built of 6 plys each 10" wide, or 5 plys each 12" wide, etc.

ANALYSIS FUNCTION

1. BL
   As above.

2. MOMENT
   As above.

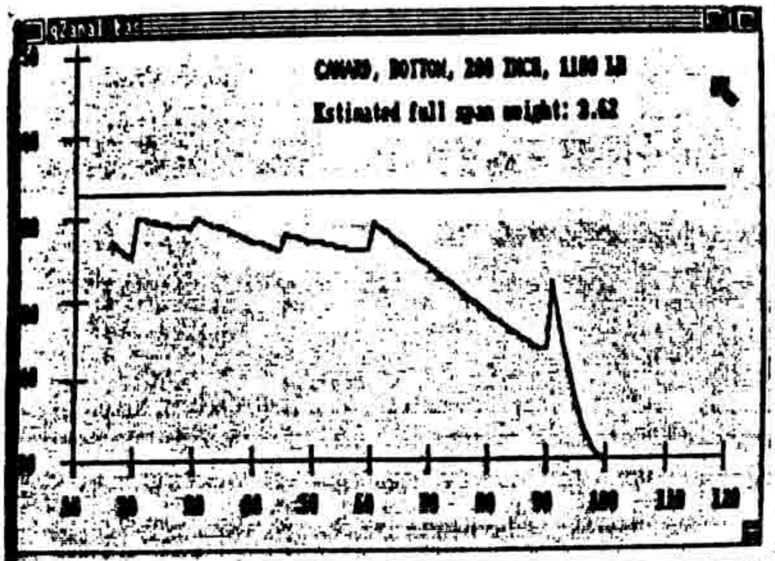
3. CALC WIDTH
   Same as equivalent cap width above.

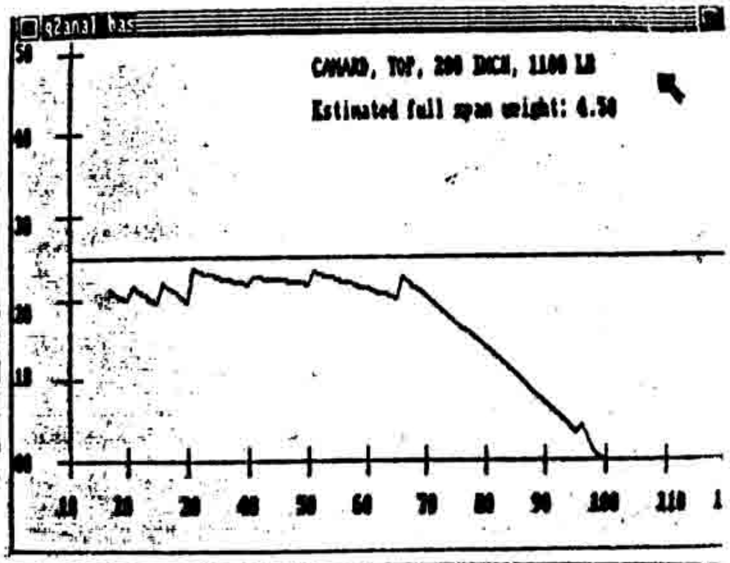
4. ACTUAL WIDTH
   The computed equivalent width provided by the actual layup schedule. This width should be equal to or greater than the calc width. Calculated by adding up the width of each cap layer.

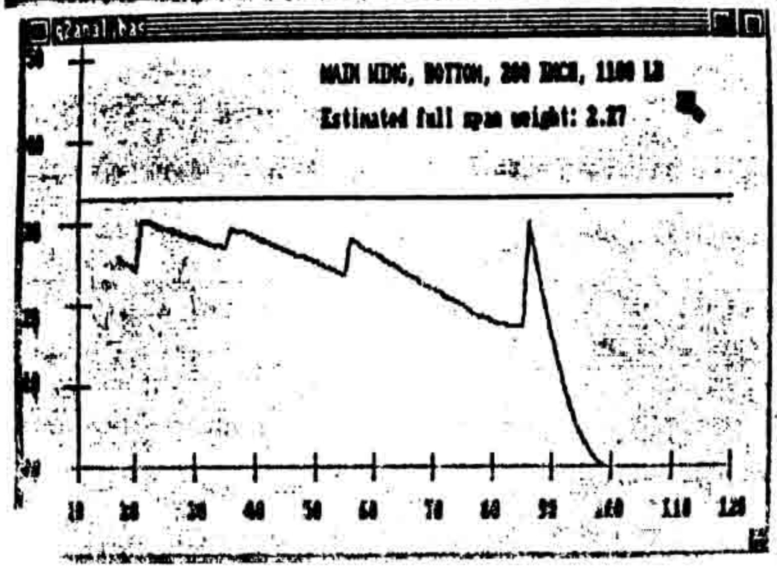
5. ACTUAL STRESS
   The computed stress actually seen in the layup. Should be equal to or less than the design allowable stress.

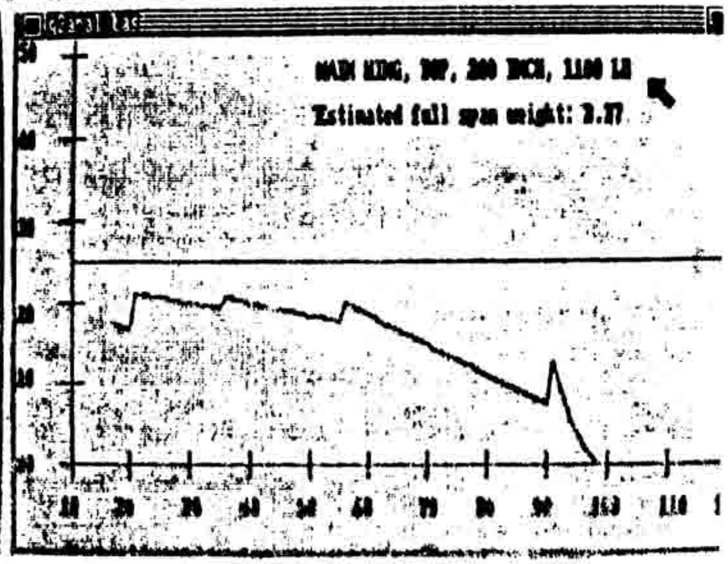
6. OVERSTRESS
   A graphic indicator of an overstress condition. One asterick indicates a 0% to 10% overstress; two astericks 10%-20%, etc.

STRESS (KSI) VS. BL - TAPERED CAPS

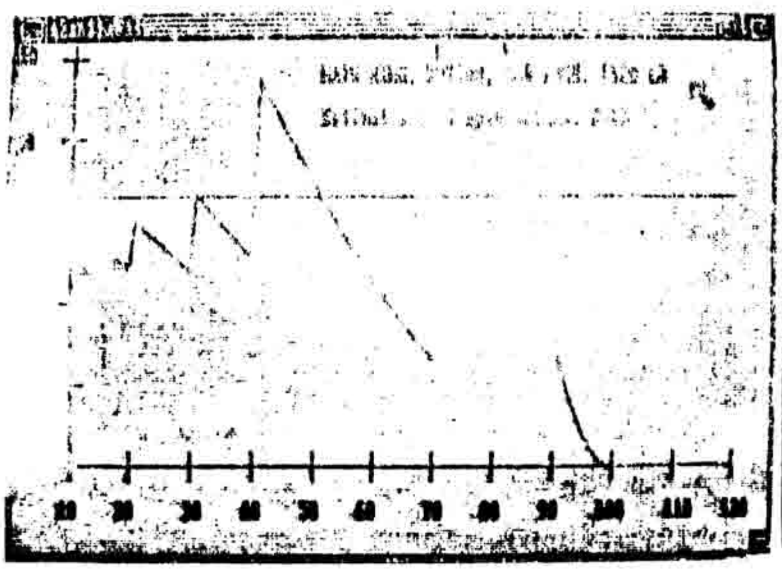


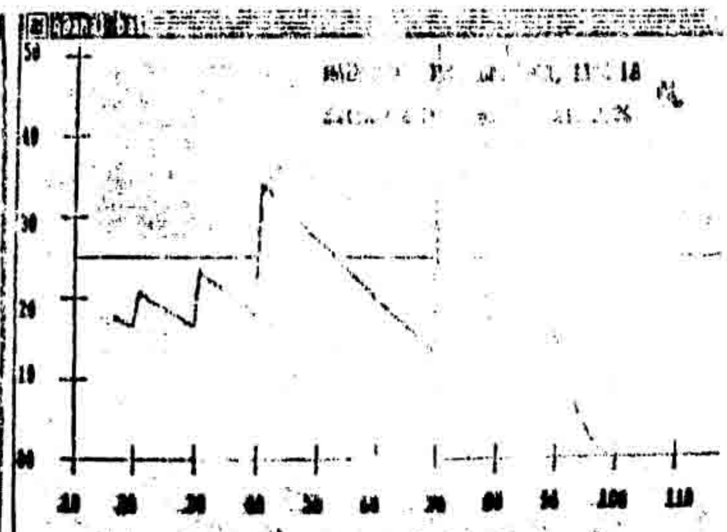






LAYUP PER QAC PLANS





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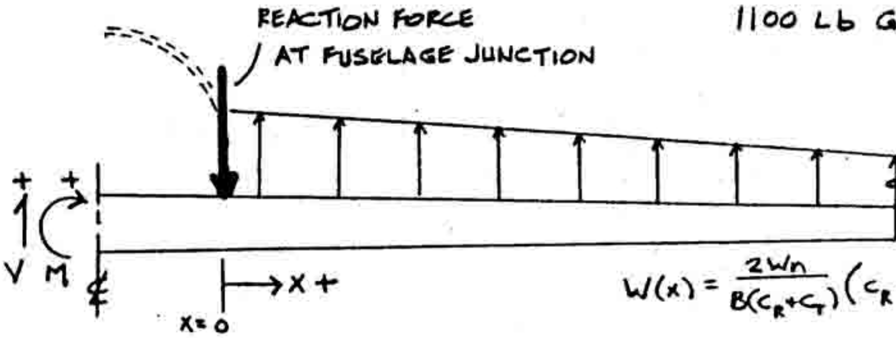
5/14/86

CANARD FREE BODY DIAGRAM

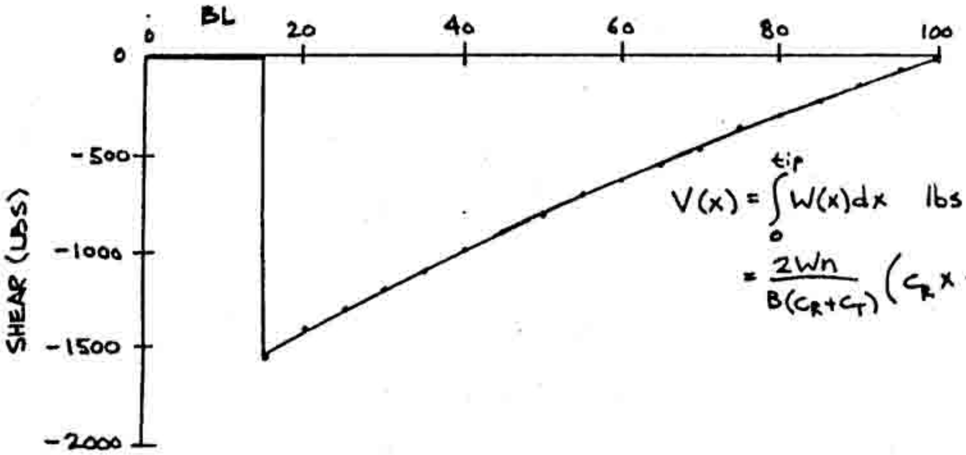
1100 Lb Gross, 200" Span



$$W(x) = \frac{2Wn}{B(c_R+c_T)}\left(c_R - \frac{2x}{B}(c_R-c_T)\right) \text{ lbs/in}$$

where W = gross weight x % carried (lb)
n = design G load
B = total exposed span (in)
c_R = chord at X = 0 (in)
c_T = chord at wingtip (in)

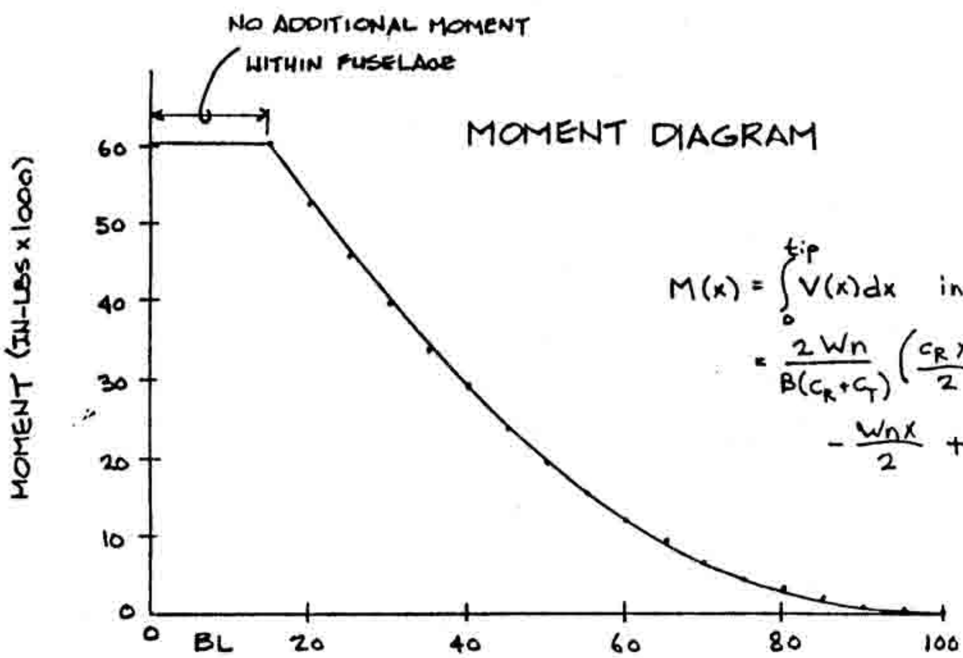
SHEAR DIAGRAM



$$V(x) = \int_0^{tip} W(x)\,dx \quad \text{lbs}$$

$$= \frac{2Wn}{B(c_R+c_T)}\left(c_R x - \frac{x^2}{B}(c_R-c_T)\right) - \frac{Wn}{2}$$

MOMENT DIAGRAM



$$M(x) = \int_0^{tip} V(x)\,dx \quad \text{in}\cdot\text{lbs}$$

$$= \frac{2Wn}{B(c_R+c_T)}\left(\frac{c_R x^2}{2} - \frac{x^3}{3B}(c_R-c_T)\right) +$$

$$- \frac{Wnx}{2} + \frac{WnB}{12}\left(3 - \frac{(2c_R+c_T)}{(c_R+c_T)}\right)$$

EXPLANATION OF PARAMETERS and GENERAL NOTES on the Q2ANALYSIS PROGRAM

by Marc Waddelow

The Q2ANALYSIS program was originally designed to investigate the effects of increasing the wingspan and gross weight limit of a Tri-Q experimental aircraft. It will calculate the bending and shear loads along the span and evaluate stresses in a given layup schedule.

INPUT PARAMETERS

The various input parameters used in the Q2ANALYSIS program are described below.

1. HALF SPAN
   Wingspan in inches measured from centerline to tip.

2. CENTERLINE CHORD
   Airfoil chord length in inches measured at wing centerline.

3. TIP CHORD
   Airfoil chord length in inches measured at wing tip.

4. GROSS WEIGHT
   Aircraft maximum gross weight in pounds.

5. FRACTION CARRIED BY WING
   This parameter is used to compute the portion of the gross weight carried by each wing. The value ranges from 0 (no load carried by the wing) to 1 (all load carried by wing). For the Tri-Q canard, this value should be at max forward CG. For the wing, it should be at max aft CG. Typical values: .69 for the canard, .38 for the wing.

6. FUSELAGE LIFT FACTOR
   This parameter is used to give partial credit to that portion of the wing buried within the fuselage. The value ranges from 0 (no credit) to 1 (full credit). The pressure carryover across the fuselage will provide some lift but not as effectively as a fully exposed wing. Typical value is .5.

7. FUSELAGE WIDTH
   Fuselage width in inches at wing intersection. Used to determine wing area buried within fuselage. Typical value is 33.

8. MAX G LOAD
   Design maximum load factor, positive G´s. Typical value is 4.4 for an aircraft in the utility category.

9. AVERAGE AIRFOIL THICKNESS
   This is the average airfoil thickness as a fraction of the chord. It is used to determine the average distance from the center of the airfoil to the spar caps for the structural calculations. To determine this value, average the airfoil thickness at 10, 30, and 60 percent chord points. Be conservative here, a smaller value will produce a stronger wing than a larger one. Typical values are .152 for the LS(1)0417MOD canard and .16 for the main wing.

10. ALLOWABLE SPAR CAP STRESS
This is the DESIGN stress limit for the spar caps in psi. The design stress is the ultimate (failure) stress divided by the factor of safety. Typical values for UNI spar caps are 33,000 psi in tension (bottom surface) and 25,000 psi compressive (top surface). These are based on an ultimate tensile stress of 66,000 psi with a safety factor of 2.0. Compressive strength is 75% of tensile.

11. SPAR CAP CLOTH THICKNESS
Thickness of UNI cloth in inches. Typical value is .009.

12. LAYUP DENSITY
Density in pounds per cubic inch of UNI/epoxy layup. Used to estimate spar cap weight. Not used in structural calculations. Typical value is .076.

OUTPUT PARAMETERS

The various output parameters from the Q2ANALYSIS program are described below.

1. TOTAL WING AREA
Computed total wing area in square feet including that part buried within the fuselage.

2. EXPOSED WING AREA
Computed wing area excluding that part buried within the fuselage.

3. TOTAL LOAD - 1 G
Total load in pounds carried by the wing at 1 G. Computed by multiplying the gross weight by the fraction carried by wing.

4. LOAD CARRIED BY WING
Load in pounds carried by the exposed wing.

5. LOAD CARRIED BY FUSELAGE
Load in pounds credited to fuselage lift.

6. LOAD CARRIED BY WING - MAX G
Load in pounds carried by the exposed wing at maximum G loading.

7. WING LOADING
Wing loading in pounds per square foot computed by dividing the load carried by the exposed wing by the exposed wing area. This gives the wing loading actually seen by the airfoil.

8. EXPOSED SPAN
Exposed wingspan in inches calculated by subtracting the fuselage width from the total wingspan.

9. ASPECT RATIO
Span divided by chord. Computed by squaring the total wingspan and dividing by the total wing area.

LOAD TESTING

Begin by building a stand such as the one shown on the enclosed sketch. It is vital that the "saddles" match the top airfoil contour. Use a different set of saddles for the main wing and canard. The saddle must be padded - some 1/2" Clark foam or a 2" thick piece of seat cushion foam will do. Loading the wing directly on the hard wood is likely to cause local compression damage; then you'll get to build another wing.

Place the wing upside down in the padded saddles. Weight is loaded on the BOTTOM wing surface to simulate positive G loads. Weigh, and record, each sandbag placed on the wing. See enclosed weight schedule and sketches. Do not apply any weight between the saddles. And don't support the tips with a jack! The wing isn't designed to handle loads applied in that fashion - besides, there won't be any "helping hand" in the air. Just load the wing evenly, with layer by layer of sandbags, until the correct totals are reached. (I'm referring here to the "Q-Tip" in the Sept/Oct '85 Quicktalk; it's generally good info except for the jacks idea). Measure the wingtip height above the floor before, fully loaded, and after the test. The before and after heights should be the same. Any permanent deformation indicates structural failure. After the test, carefully examine both sides of the wing for damage - particularly the top wing surface near the saddle.

My own feeling is to load test to the 4.4 G's the wing was designed to carry. If it shows ANY sign of failure at this loading it's not safe to fly. Overloading to 125% (5.5 G) is probably OK, maybe even a good idea, but in no case would I go over 150%. Concerning negative G loads, the wing is designed to withstand 75% of the positive G limit, or -3.3 G. Since this is almost double the FAA required -1.76 G, load testing is not really necessary. If you do test for negative G loads, it will require new saddles and a new load schedule.

Repairs:

I have strong misgivings about repairing damage to primary structure. I recently learned of a fatal Q2 accident where the main wing failed in compression near the fuselage. The builder had previously repaired major structural damage in that area resulting from a landing accident. It is far better to discard the damaged wing and build a new one as fiberglass loses much of its strength when damaged (even dropping a wrench on it can cause local failure of the glass). It is critical that each strand of UNI in the sparcaps be continuous without separations or splices, especially on the bottom surfaces. The foam/glass bond is important too, especially on the top surfaces.

Controversy:

The "controversy" began in August, 1985 when I first "reverse engineered" QAC's main wing lay-up schedule. What I learned concerned me enough to write Sheehan and alert him (and then hopefully other builders) of what I considered a serious, and easily correctable, weakness in the area of BL 40. His rather rude response refused to acknowledge any such weakness. After two other attempts, I finally gave up trying to convince him. If you're really into gore, for a $0.39 self-addressed stamped legal envelope I will return copies of our correspondence. They provide some interesting first hand insights into the personality behind QAC.

The numerical printouts included here are listed every 5" to conserve mailing weight (computers are great for overwhelming you with paper). If you really want greater detail, send your request and the postage. The graphs, however, were calculated every 0.5" and so provide, qualitatively at least, greater resolution. Referring to those graphs, I invite you to compare the actual stresses in my tapered cap main wing design against the per QAC plans design. Please note that the input parameters are identical; only the lay-up schedule is different. While the exact magnitude of the numbers may be open to discussion (see General Notes in the Explanations section), they do provide a valid RELATIVE comparison. Note the almost 2:1 stress concentration (a sharp jump in stress) in the QAC wing at BL 40. I'm sure by now we've all seen pictures of, or worse, experienced, a broken GU canard after a hard landing. Have you ever wondered why they always break in the same place, right at BL 49 where the trough stiffener ends? Stress concentration. I need to comment on the "FAIL" indication of the QAC wing at BL 70. This is another area of stress concentration but the actual cap stresses are not as great as calculated near the wingtips. The anomaly is caused by my not giving any structural credit to the two 45 degree UNI plies. Since UNI has only about 15% of its strength at this orientation, it was not considered in my design, effectively building in an extra safety factor (about 7%). It does, however, introduce some error (on the conservative side) in the spar cap analysis ranging from small near the root to moderate near the tips. If there was no sparcap, i.e. only the two 45 degree UNI, a 1" width was assumed to prevent divide by zero in the calculations. In other words, the sparcap analysis is fairly accurate in the critical first half of the wing where the loads are large but does cause the sparcaps near the tips to appear more heavily stressed than they actually are; take that into consideration when comparing. Note that the QAC design does depend exclusively on the crossed UNI plies to carry the outboard 30" of wing stresses. Note the relatively small stress variations, from root to tip, in the tapered sparcap design. Note the 12 ounce difference in estimated sparcap weights (that's for the ENTIRE wing).

I have not performed a detailed analysis of the Q2 or Q200 canard, and really don't plan to since I'm not building one. Remember, these lay-ups schedules are not intended, and must not be used, for "wheel on the wingtip" designs.

Present Status:

At this writing, I have completed construction of my main wing incorporating 20" tip extensions, tapered sparcaps, and reinforced shear web. My Tri-Q canard, using the LS(1)0417MOD airfoil, 20" tip extensions, tapered sparcaps, and an additional shear web, is under construction. I intend to load test both wings together sometime late this summer.

Closing Remarks:

The lay-up schedules presented here are overly conservative - they were designed with my neck in mind. I have tried improving the computer model by taking more factors into account (like the two 45 UNI, wing weight, washout, etc.). As it turned out, it didn't make much difference in the lay-up schedule and the small reduction in sparcap weight (about 1 lb) did not, in my opinion, offset the added safety margins of the more conservative approach presented here. I hasten to add, however, that there is a balance between strength and weight, and that it's easy to go too far in adding cloth. I also caution against exceeding the 1100 lb gross weight with the 200" span tapered caps based primarily on wing AREA considerations, rather than wing strength.

I concede that a main wing using the QAC lay-ups will not break at 4.4 G's when new. However, fiberglass is notoriously weak in fatigue strength - that's why glass designs use a safety factor of 2.0, or more, while most aluminum aircraft are designed with a safety factor of about 1.5. In QAC's design, flex and fatigue are concentrated at the end of each cap layer instead of being spread evenly throughout the span as with the tapered sparcaps. I urge anyone with a high time Q2 to frequently and carefully inspect their main wing at BL 40, and especially the canard at BL 49, for signs of fatigue.

Some other things to consider: A Q2, sitting on its wingtips in the hanger, has as much bending moment at the fuselage junction as the Tri-Q does in a 3 G pullout. Using the sparless canard will SAVE about 9 lbs over the carbon tube design (this includes the extra shear web reinforcement). Subtract the 1.9 lb increase in the main wing (again including the reinforced shear web) for a total wing weight savings of 7.1 lbs. I don't know exactly how much extra (if any) the Tri-Q gear weighs but let's say for argument it's 7.1 lbs. The net result is an airplane with the SAME empty weight as the stock Q2, but you've gained an even stress distribution in both wings, lower stresses in the shear webs, $720 in your pocket (for not having to buy QAC's carbon spar), and of course the safer ground handling of the tricycle gear.

Redesigning aircraft primary structure is not something to be taken lightly. There are many critical and interrelated factors to consider - some can be approximated, even neglected, but all must be considered. I have slept with this work for many months, and I would not be building my own wings this way, or be writing this paper, if I did not believe these designs were truly superior. But I insist that each builder carefully examine this work and draw their own conclusions about its integrity. By providing the engineering data, my intent is to allow other builders to sleep as well as I do. I believe it's important to explain how and why these designs evolved; I want your understanding, not your faith.

I wish to avoid the impression that I am "recommending" how to build your aircraft; I'm simply sharing information on how I'm building mine. Even though the tips presented here are written using active voice (to keep it interesting) they must not be construed as "instructions" - they are suggestions only. If you have any doubts at all, do not modify your primary structure; stay with QAC's "safe", "proven", and "approved" per plans Q2. By the way, if you do make any modifications, don't call your airplane a Quickie - we don't want to give credit where it's not due.

This work is being provided without charge to advance the free exchange of ideas relating to experimental aircraft. To this end I will gladly share anything I have learned with other individuals. If you find this work of value, your support is appreciated. I would also appreciate taking a moment to write with your ideas, questions, and feedback on these designs and the issues I've raised here. Let me know what you decide to do and how it turns out.

See you at Oshkosh!

350 Clemens, New Braunfels, TX 78130 (512) 629-5281

MAIN WING: TOP SURFACE

ANALYSIS

********** INPUT PARAMETERS **********	
HALF SPAN (INCHES)	100
CENTERLINE CHORD (INCHES)	26.5
TIP CHORD (INCHES)	17.5
GROSS WEIGHT (LBS)	1100
FRACTION CARRIED BY WING	.38
FUSELAGE LIFT FACTOR (CL-FUSE/CL-WING)	.5
FUSELAGE WIDTH (INCHES)	33
MAX G LOAD	4.4
AVERAGE AIRFOIL THICKNESS (FRACTION OF CHORD)	.16
ALLOWABLE SPAR CAP STRESS (PSI)	25000
SPAR CAP CLOTH THICKNESS (INCHES)	.009
LAYUP DENSITY (LBS/IN^3)	.075

********** COMPUTED PARAMETERS **********	
TOTAL WING AREA (FT^2)	30.5556
EXPOSED WING AREA (FT^2)	24.6528
TOTAL LOAD - 1 G (LBS)	418
LOAD CARRIED BY WING - 1 G (LBS)	373.308
LOAD CARRIED BY FUSELAGE - 1 G (LBS)	44.6917
LOAD CARRIED BY WING - MAX G (LBS)	1642.56
WING LOADING (LBS/FT^2)	15.1428
EXPOSED SPAN (INCHES)	167
ASPECT RATIO	9.09091

ACTUAL SPAR CAP DIMENSIONS (INCHES)

ROOT WIDTH	TIP WIDTH	TAPER START	CAP END
14	2	55	90
13	2	35	55
12	2	20	35
11	11	20	20
10	10	12	12
9	9	9	9
8	6	5	5

BL	MOMENT (IN-LBS)	CALC WIDTH (INCHES)	ACTUAL WIDTH (INCHES)	ACT STRESS (PSI)	OVERSTRESS (** 10X)
20	29464.2	33.1356	50	16567.8	
25	25701.1	29.44	35.6667	20635.5	
30	22218.5	25.9319	32.3333	20050.4	
35	19011.1	22.6161	29	19496.7	
40	16073.9	19.4977	24.25	20100.7	
45	13401.6	16.582	21.5	19281.4	
50	10988.9	13.8749	18.75	18499.9	
55	8830.76	11.3638	16	17785.6	
60	6921.87	9.11252	12.2857	18542.9	
65	5257.04	7.07162	10.5714	16[illegible]33.4	
70	3931.09	5.26827	8.85714	14[illegible]70.1	
75	2638.79	3.71137	7.14286	12[illegible]39.8	
80	1674.94	2.41068	5.42857	11101.8	
85	934.349	1.37688	3.71429	9267.44	
90	411.795	.621672	2	7770.89	
95	102.053	.157975	1	3545.37	
100	0	0	1	0	

ESTIMATED FULL SPAN SPAR CAP WEIGHT (LBS): 3.36665

MAIN WING; BOTTOM SURFACE

ANALYSIS

********** INPUT PARAMETERS **********	
HALF SPAN (INCHES)	100
CENTERLINE CHORD (INCHES)	26.5
TIP CHORD (INCHES)	17.5
GROSS WEIGHT (LBS)	1100
FRACTION CARRIED BY WING	.38
FUSELAGE LIFT FACTOR (CL-FUSE/CL-WING)	.5
FUSELAGE WIDTH (INCHES)	33
MAX G LOAD	4.4
AVERAGE AIRFOIL THICKNESS (FRACTION OF CHORD)	.16
ALLOWABLE SPAR CAP STRESS (PSI)	33000
SPAR CAP CLOTH THICKNESS (INCHES)	.009
LAYUP DENSITY (LBS/IN^3)	.076

********** COMPUTED PARAMETERS **********	
TOTAL WING AREA (FT^2)	32.5556
EXPOSED WING AREA (FT^2)	24.6528
TOTAL LOAD - 1 G (LBS)	418
LOAD CARRIED BY WING - 1 G (LBS)	373.308
LOAD CARRIED BY FUSELAGE - 1 G (LBS)	44.6917
LOAD CARRIED BY WING - MAX G (LBS)	1642.56
WING LOADING (LBS/FT^2)	15.1426
EXPOSED SPAN (INCHES)	167
ASPECT RATIO	9.09091

ACTUAL SPAR CAP DIMENSIONS (INCHES)

ROOT WIDTH	TIP WIDTH	TAPER START	CAP END
10	2	55	85
9	2	35	55
8	2	20	35
7	7	20	20
6	6	13	13
5	5	10	10

BL	MOMENT (IN-LBS)	CALC WIDTH (INCHES)	ACTUAL WIDTH (INCHES)	ACT STRESS (PSI)	OVERSTRESS (** 10X)
20	29464.2	25.1029	34	24364.4	
25	25701.1	22.303	25	29440	
30	22216.5	19.6454	23	28186.9	
35	19011.1	17.1334	21	26924	
40	16073.5	14.771	17.25	28257.5	
45	13401.6	12.5621	15.5	26745.2	
50	10988.9	10.5113	13.75	25227.1	
55	8830.76	8.62332	12	23714.1	
60	6921.87	6.90342	8.66667	26286.1	
65	5257.04	5.35729	7.33333	24107.8	
70	3831.09	3.99111	6	21951.1	
75	2636.79	2.81165	4.66667	19882.4	
80	1674.94	1.83627	3.33333	18080.1	
85	934.349	1.04309	2	17211	
90	411.795	.470363	1	15541.8	
95	102.083	.119678	1	3949.37	
100	0	0	1	0	

ESTIMATED FULL SPAN SPAR CAP WEIGHT (LBS): 2.26814