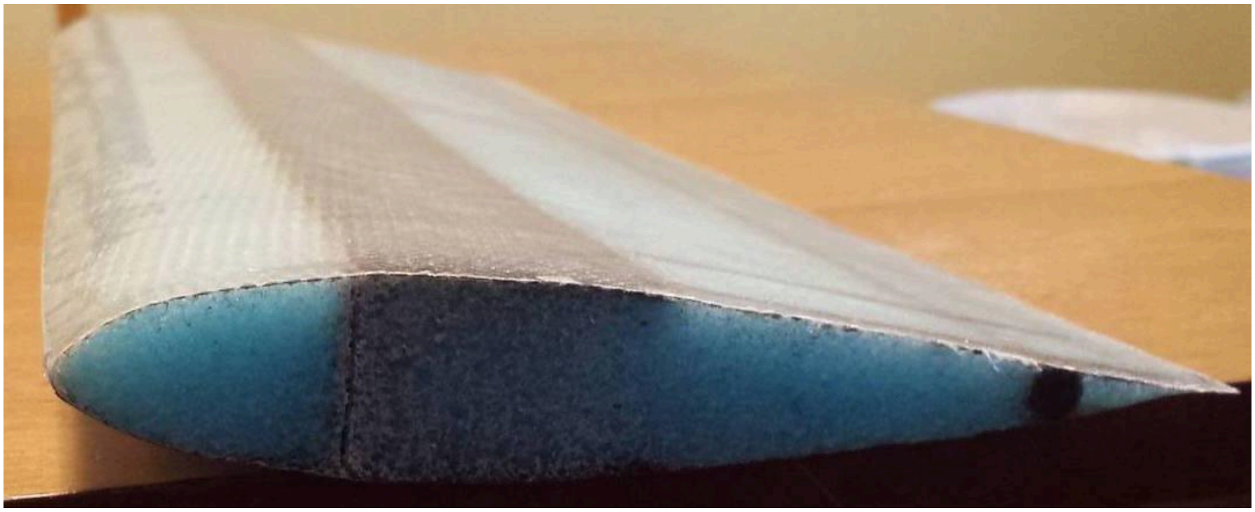
Wing Spar Project



Part 1: Engineering Analysis Report
Team 16
12/02/15

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Assumptions

- EI values (referencing the tables in the appendix) are derived for the c-channel cross section with the figure 1 configuration, so the point load applied as P does not have to be redistributed to each components of the composite; thus, directly plugging in the load value into the midspan displacement equation
- Dominant components resisting:
    - bending = flanges
    - shear = web
    - torsion = skin
    - rod = no significant contribution

Internal moment distribution (M_y)

$$M_y = -\frac{PL}{2}\left(\frac{x}{L}\right) \qquad (0 < x < L/2)$$
$$= -\frac{PL}{2}\left(1 - \frac{x}{L}\right) \qquad (L/2 < x < L)$$

Beam section distribution (EI_i)for $i = i^{th}\ ply\ from\ the\ bottom$

$EI_1 = 0in < x < 2in$

$EI_2 = 2in < x < 6in$

$EI_3 = 6in < x < 10in$

$EI_3 = 10in < x < 14in$

$EI_2 = 14in < x < 18in$

$EI_1 = 18in < x < 20in$

$L_1 = 2''$ EI1 = 2.67×10^5 lb*in^2

$L_2 = 6''$ EI2 = 4.71×10^5 lb*in^2

$\frac{L}{2} = 10''$ EI3 = 6.81×10^5 lb*in^2

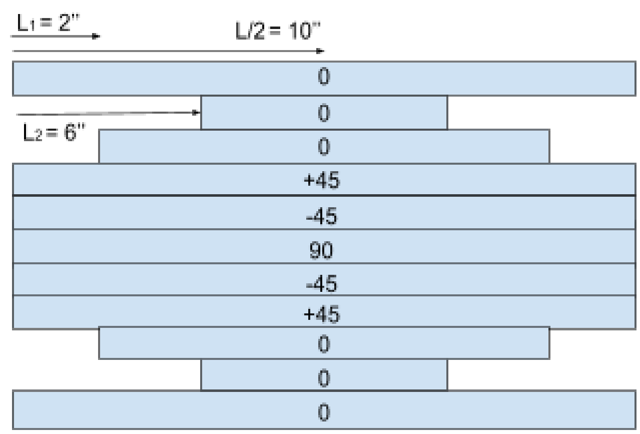

Figure 1: Team 16 Composite Configuration

After integrating the substituted equation with $M_y$and EI_iinto strain energyu^* equation…

$$u^* = \frac{P^2L_1^3}{12EI_1} + \left(\frac{P^2L_2^3}{12EI_2} - \frac{P^2L_1^3}{12EI_2}\right) + \left(\frac{P^2\frac{L^3}{8}}{12EI_3} - \frac{P^2L_2^3}{12EI_3}\right)$$

Applying the fact that $\Delta = du^*/dP$,the midspan displacement (Δ_{mid}) is…

$$\Delta_{mid} = \frac{PL_1^3}{24EI_1} + \frac{PL_2^3}{24EI_2} - \frac{PL_1^3}{24EI_2} + \frac{PL^3}{192EI_3} - \frac{PL_2^3}{24EI_3}$$

$$= \frac{P}{24}\left(\frac{L_1^3}{EI_1} + \frac{L_2^3}{EI_2} - \frac{L_1^3}{EI_2} + \frac{L^3}{8EI_3} - \frac{L_2^3}{EI_3}\right)$$

When P = 25 lbs...

$$\Delta_{mid} = \frac{25}{24}\left(\frac{2^3}{2.67*10^5} + \frac{6^3}{4.71*10^5} - \frac{2^3}{4.71*10^5} + \frac{20^3}{8*6.81*10^5} - \frac{6^3}{6.81*10^5}\right)$$

= .0017 inches

When P = 100lbs...

$$\Delta_{mid} = \frac{100}{24}\left(\frac{2^3}{2.67*10^5} + \frac{6^3}{4.71*10^5} - \frac{2^3}{4.71*10^5} + \frac{20^3}{8*6.81*10^5} - \frac{6^3}{6.81*10^5}\right)$$

= 0.0068 inches

When P = 1 lb...

$$\Delta_{mid} = \frac{1}{24}\left(\frac{2^3}{2.67*10^5} + \frac{6^3}{4.71*10^5} - \frac{2^3}{4.71*10^5} + \frac{20^3}{8*6.81*10^5} - \frac{6^3}{6.81*10^5}\right)$$

= 0.000067618 inches

Thus, the stiffness is equal to $1/d = 14789$

Composite Analysis

web [$\pm 45/\overline{90}_s$]	**Flange [$0_3/\pm 45/\overline{90}_s$]**
Ex(psi) = 4.84974E+06	Ex(psi) = 2.29559E+07
Ey(psi) = 9.02384E+06	Ey(psi) = 7.35028E+06
Gxy(psi) = 7.80896E+06	Gxy(psi) = 3.78627E+06

units all in lb and in

#	E	A	1-direction	2-direction
1	22.96	0.05169	0.758	-0.517

2	4.85	0.01574	0.00787	0
3	22.96	0.05169	0.758	0.517

$EA = 2.60 \times 10^6\ lb$
$y_c = 0.723\ in$
$z_c = 0$

#	**E**	**A**	**y**	**z**	I_{yyi}
1	22.96	0.05169	0.023	-0.517	0.013818
2	4.85	0.01574	-0.727	0	0.001312
3	22.96	0.05169	0.023	0.517	0.013818

$EI_{yy} = 681{,}000\ lb * in^2$

Load Distribution (P = 100lb)

Assumptions: continuous laminate of $[0/\pm 45/\overline{90}]s$ for web, $[\pm 45/\overline{90}]s$ for wall. Assume failure will occur in C-channel since spar provides stiffness, so it will most likely fail before the rod and the skin. Assume failure will occur at thinnest ply location, since that section will have the lowest maximum load. The thermal properties were ignored for this analysis.

$\sigma_{xx(Upper\ Flange)} = E_i * z * \frac{M_y}{EI_{yy}} = -137.18P = -13717.73psi$

$\sigma_{xx(Lower\ Flange)} = E_i * z * \frac{M_y}{EI_{yy}} = 137.18P = 13717.73psi$

$\tau_{max} = \frac{6V_z}{h^2 t}\frac{(b+h/4)}{1+6b/h} = 32.659P = 3265.850lb$

$\tau_{ave} = \frac{V_z}{ht} = 31.0812P = 3108.120lb$

Critical Locations (at root)

$N_{x(Upper\ Flange)} = \sigma_{xx} * t = -2.159P = -215.917lb/in$

$N_{x(Upper\ Flange)} = \sigma_{xx} * t = 2.159P = 215.917lb/in$

$N_{xy(Web)} = \tau_{xy} * t = 0.5141P = 51.410lb * in$

First ply failure analysis

Description	MS	Location of Failure	Failure Type	Maximum Load (MS=0)
Upper Flange	2.184127	(0°) ply	Fiber	318.4 lb
Lower Flange	5.765806	(90°) ply	Fiber	676.7 lb
Web	9.455810	(-45°) ply	Fiber	1045.6 lbs

Therefore, a failure load of 318.4lb can be predicted, with a fiber failure occurring on the upper flange of the C-channel.

First Ply Failure Survey

E-Glass Fabric @ Room Temp (E-glass/MY750) [45/-45]

Stress Direction	Mode of Failure	Ply Location of Failure	Failure Stress (psi)
+X	Shear	1	2.89440E04
-X	Shear	1	-2.89440E04
+Y	Shear	1	2.89440E04
-Y	Shear	1	-2.89440E04
XY	Transverse	1	6.35040E04

Carbon/Epoxy Pultruded Rod (T300/3501-6) [0]
Note: modeled as a single ply w/ ply thickness = diameter of rod

Stress Direction	Mode of Failure	Ply Location of Failure	Failure Stress (psi)
+X	Longitudinal	1	2.10095E05
-X	Longitudinal	1	-1.57019E05
+Y	Transverse	1	7.04170E03
-Y	Transverse	1	-1.49242E04
XY	Shear	1	1.05100E04

Carbon/Epoxy C-Channel (M55J/EX1515) [0/+45/-45/~~90~~]s

Stress Direction	Mode of Failure	Ply Location of Failure	Failure Stress (psi)
+X	Longitudinal	4	7.29544E04
-X	Longitudinal	1	-3.43719E04
+Y	Longitudinal	4	6.59082E04
-Y	Longitudinal	4	-2.37166E04
XY	Longitudinal	3	2.74975E04

Carbon/Epoxy C-Channel (M55J/EX1515) [0_2/+45/-45/~~90~~]s

Stress Direction	Mode of Failure	Ply Location of Failure	Failure Stress (psi)
+X	Longitudinal	5	1.00968E05
-X	Longitudinal	1	-4.70036E04
+Y	Longitudinal	5	5.65418E04
-Y	Longitudinal	5	-2.02794E04
XY	Longitudinal	4	2.18262E04

Carbon/Epoxy C-Channel (M55J/EX1515) [0_3/+45/-45/~~90~~]s

Stress Direction	Mode of Failure	Ply Location of Failure	Failure Stress (psi)
+X	Longitudinal	6	1.19528E05
-X	Longitudinal	1	-5.49951E04
+Y	Longitudinal	6	4.88941E04
-Y	Longitudinal	6	-1.76156E04
XY	Longitudinal	5	1.82171E04

Comment: The failure location is confirmed by the preceding table showing that the E-Glass Fabric has a greater failure stress than the other components of the wing structure, the skin and rod. This allows the previous calculation to be the assumed failure loads and location.

Appendix

[0_3/+-45/90]s	
EI_{yy} $(lb * in^2)$	6.81E+05
EI_{zz} $(lb * in^2)$	5.21E+05
EI_{yz} $(lb * in^2)$	0.00E+00

[0_2/+-45/90]s	
EI_{yy} $(lb * in^2)$	4.71E+05
EI_{zz} $(lb * in^2)$	3.76E+05
EI_{yz} $(lb * in^2)$	0.00E+00

[0/+-45/90]s	
EI_{yy} $(lb * in^2)$	2.67E+05
EI_{zz} $(lb * in^2)$	2.30E+05
EI_{yz} $(lb * in^2)$	0.00E+00

Airfoil [0_3/+-45/90]s	
EI_{yy} $(lb * in^2)$	7.41E+05
EI_{zz} $(lb * in^2)$	7.43E+06
EI_{yz} $(lb * in^2)$	0

Airfoil [0_2/+-45/90]s	
EI_{yy} $(lb * in^2)$	5.32E+05
EI_{zz} $(lb * in^2)$	6.76E+06
EI_{yz} $(lb * in^2)$	0

Airfoil [0/+-45/90]s	
EI_{yy} $(lb * in^2)$	3.27E+05
EI_{zz} $(lb * in^2)$	5.74E+06
EI_{yz} $(lb * in^2)$	0

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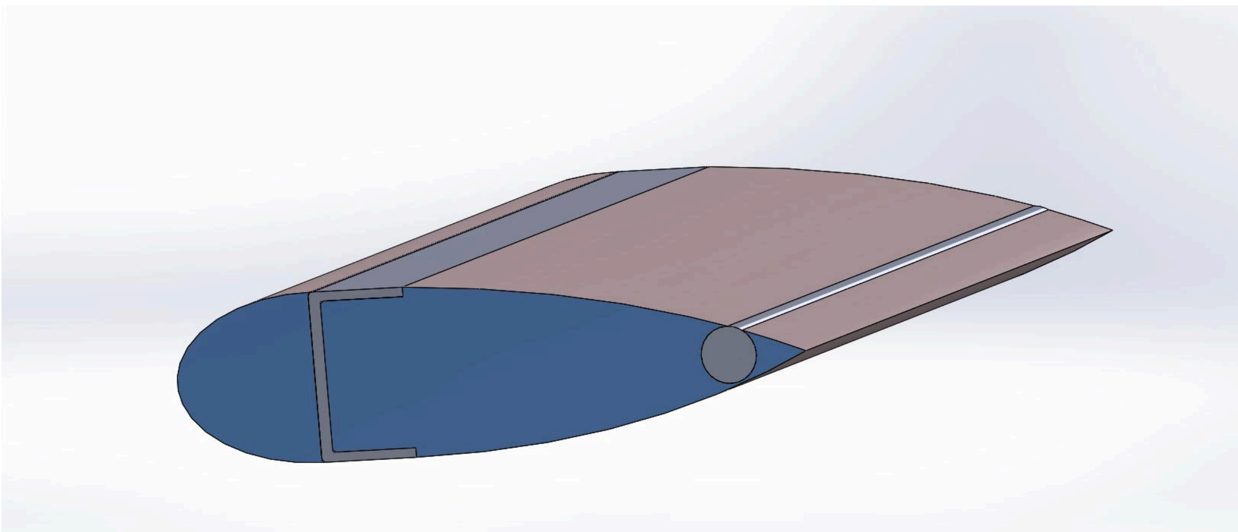

Part 2: Discussion Report
Team 16
12/04/15

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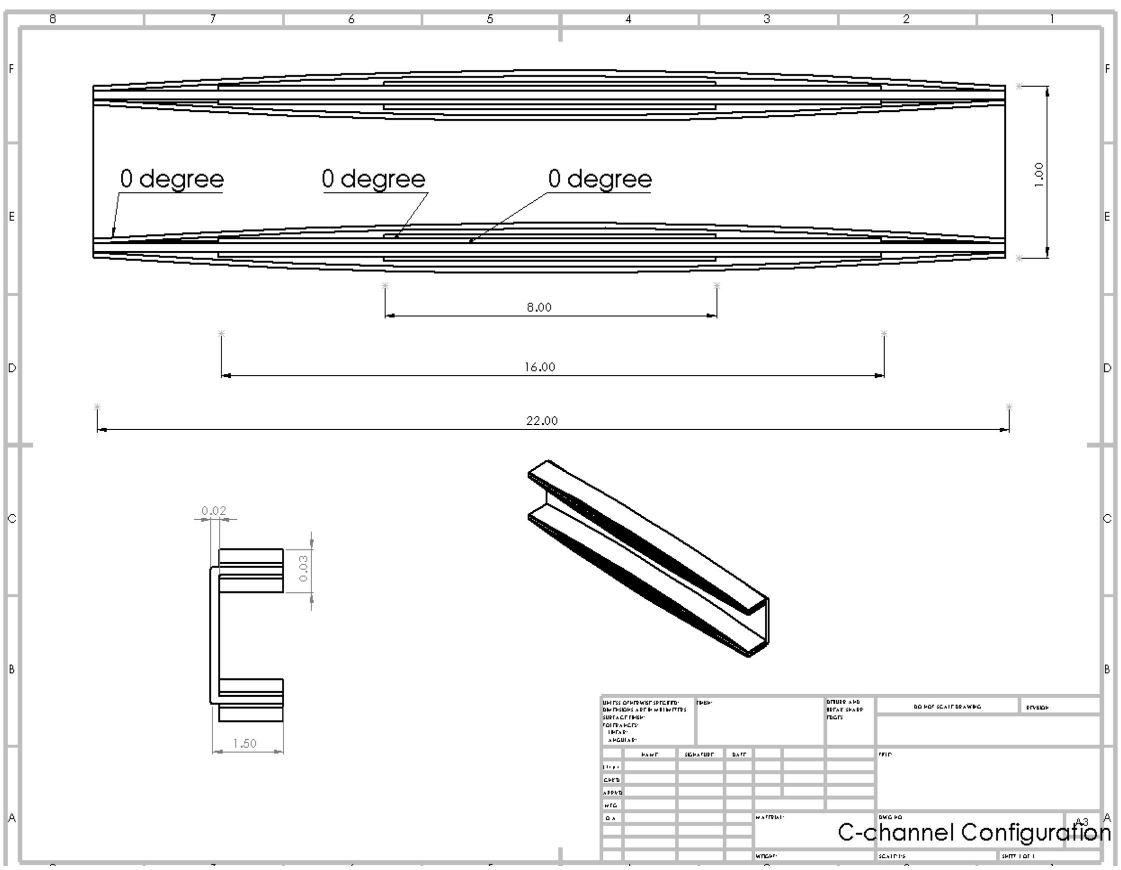
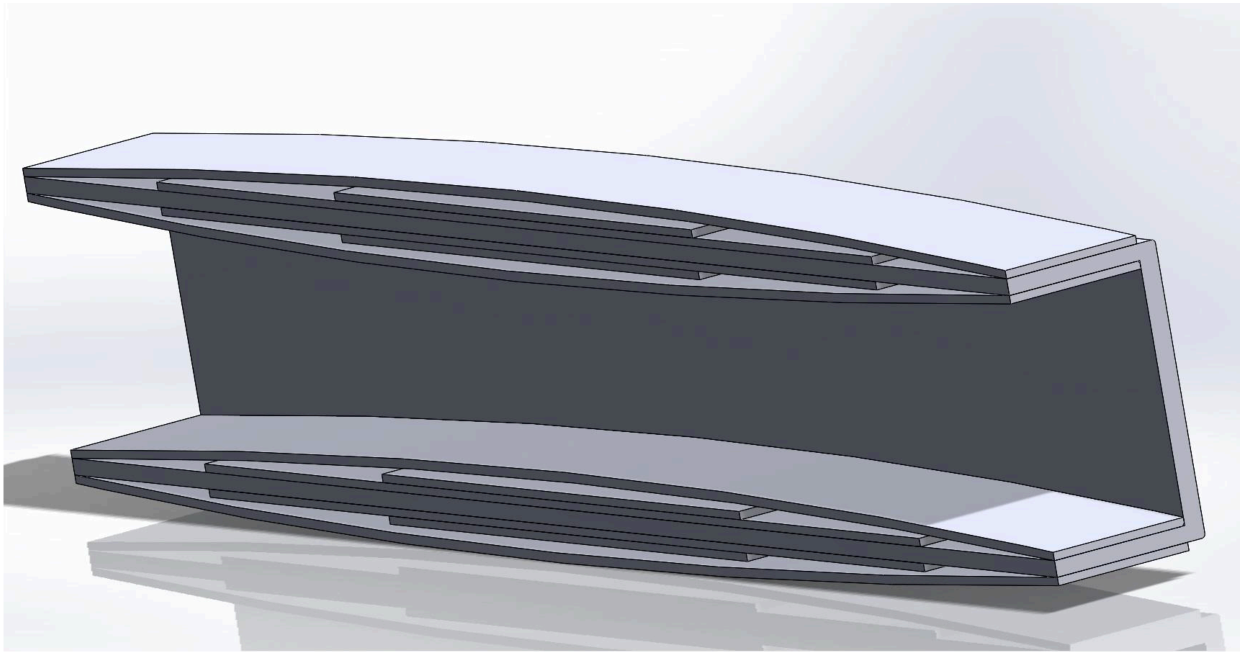
The design of the c-channel was obtained with strength in mind while maintaining awareness of total weight. The base layer of [+-45/90]s was provided. Fibers have maximum tensile strength when they are aligned in the channel flanges at zero degrees. This allows their full strength to be utilized. Also it was deemed excessive to add several full length plys along the whole c channel flange. the stress at any location is equal to My/I. With the M being moment. The moment's magnitude along the length of a simply supported beam is a triangle, with the highest value in the center. The closer to the edge of the channel the lower moment, the lower stress. Therefore the zero plys were layered as the preceeding engineering drawings depict. A total of three zero plys were added. The outermost zero ply ran the full length of the channel. The inner to were layered at 8 and 16 inches as shown. This was the most creative part of the design process. Weight, or area, of the fiber was counted in the performance index so getting the most out of the zero fibers and not using them in excess was achieved by this layering concept.





Fabrication experience

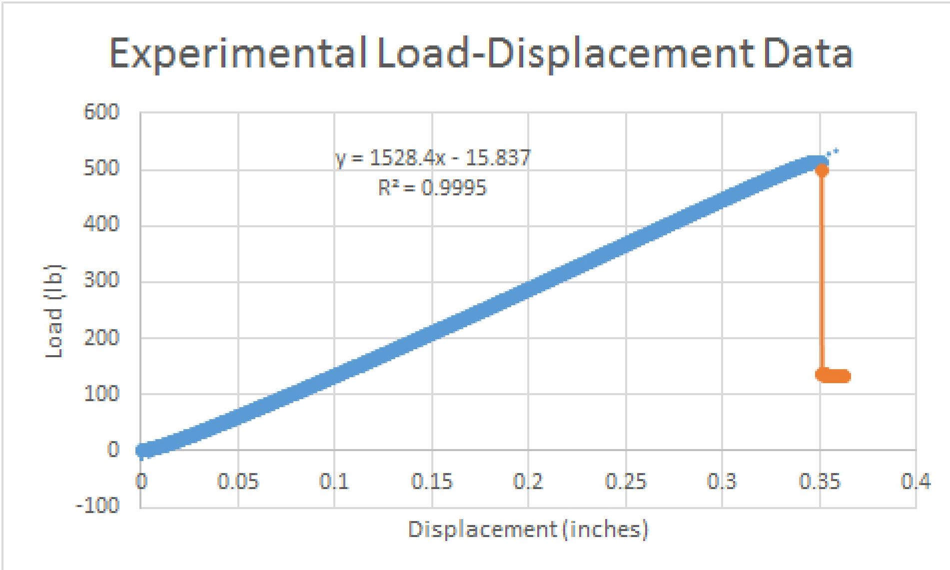
The fabrication experience was hands on from beginning to finish. The general design of the wing was, for the most part, pre determined and set up. The main load bearing part of the wing, the c channel, was left to be designed at the team's discretion.

The process begins with cutting the pre impregnated laminate at desired angles for maximum performance. Once they were cut they were placed on the c channel mold. Three additional zero plys were added to each side to greatly increase tensile and compressive strength. The c channel was baked and cured overnight.

Lastly the C channel was sandwiched between the foam containing a rod for added stiffness. This assembly was then wrapped in two 45 degree fiber-glass layers and saturated with resin. The entire wing was then cured to full strength.

The whole process was rewarding to be able to control from start to finish. It all started with deciding how to use the knowledge of laminated behavior and strengths to lay the c channel up for maximum performance. Then the ideas and drawings were created and took physical shape. The ability for such lightweight components to be combined in such a way with engineering knowledge and be so strong is an outstanding accomplishment.

Our ultimate failure load prediction was 318.4 pounds and the actual failure load was a surprising 520 pounds, an error of 39 percent. This would be abysmal if we were all professionals in the aerospace industry. Although we were not close to actual failure load, the upside was that it was a low prediction. Had it been an high prediction, the client would expect the wing to support the predicted load and it would fail before it reached the expected load. We were correct in predicting a fiber failure in compression on the top flange of the c channel. One aspect we neglected to include in the initial report was were along the c channel the fracture would happen. The channel fractured at the first drop off in layers. In retrospect it makes complete sense. The maximum compressive strength takes a drop off there due to one of the plies ending. The following graph shows an overall wing stiffness of 1528.4 lbs/inch. The failure load from testing was 514.6175 pounds with a .3509 inch deflection.



Predicted Deflection	Actual Deflection	Load	% error
0.0012	0.000067618	1.0832	1674.675
0.0017	0.024205647	25.522966	92.97685
0.0068	0.07758797	100.00223	91.23575