Abstract

In the process of the wing design, Eugene Kim's role was to serve as Project manager, Andrew Munoz was the design engineer, and Kim Truong was the test engineer.

During the design process, three iterations of wings were designed, built and tested. For each iteration:

- The design process is discussed
- The building process is documented
- The testing data is presented and analyzed

After each iteration, the lessons learned from testing are discussed, and proposals for improving wing efficiency are addressed.

The wing in round one had efficiencies of: wing "X" 34.48 Nm/kg, and the major design feature are two right triangular spars with-in the interior structure of the wing. Wing "Y" 93.12 Nm/kg, and the major design feature are twenty 18" cylinder spars that are placed horizontally in to the interior of the wing. Wing "Z" 129.66 Nm/kg, and the major design feature is one triangular spar that fits snugly inside the wing.

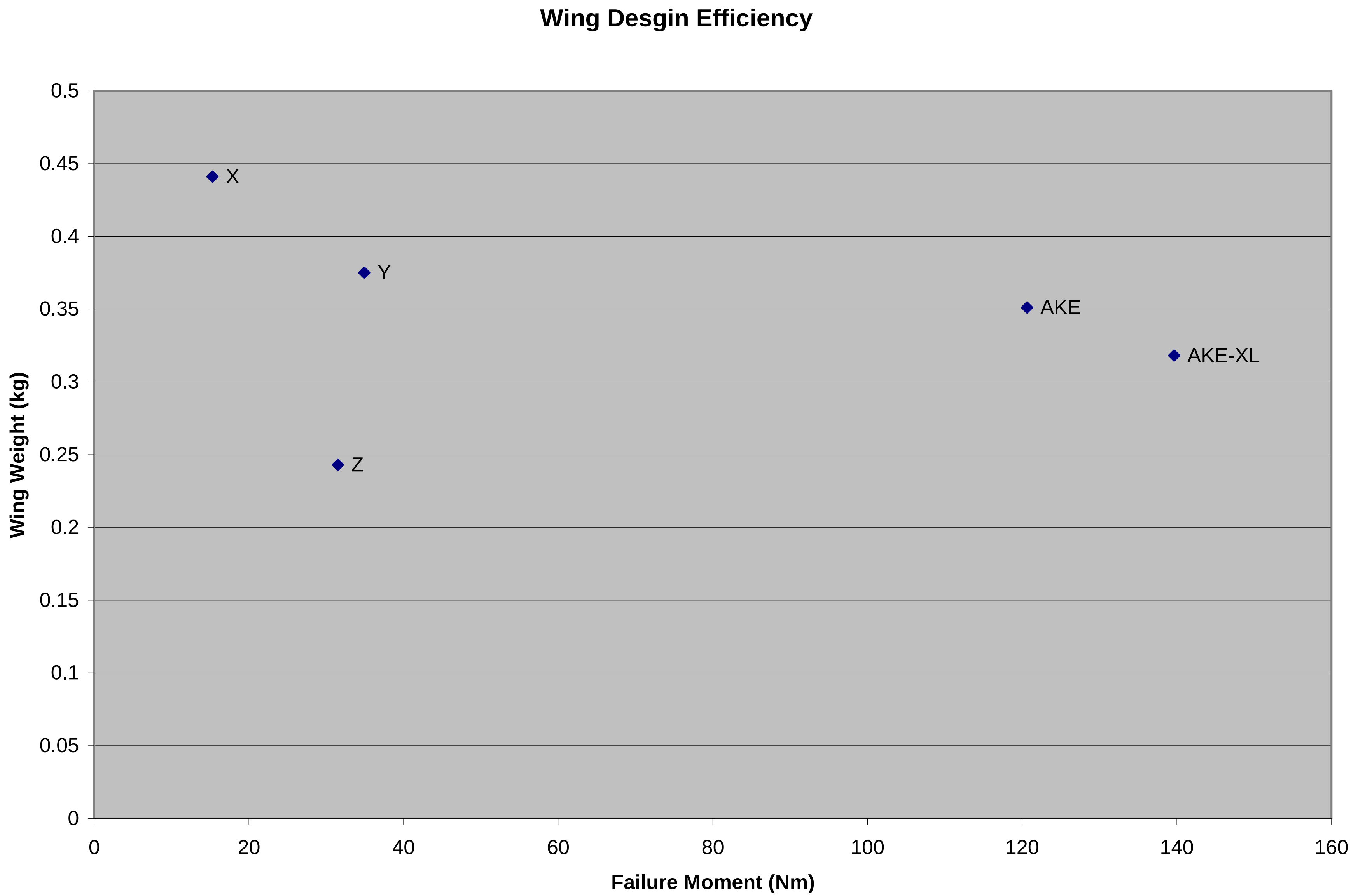
The wing in round two had an efficiency of: wing "AKE" 343.73 Nm/kg, and the major design feature are two triangular spars placed in the interior structure of the wing and two 6" rectangular spars that is placed right under the wings interface.

The wing in round three had an efficiency of: wing "AKE-XL" 439.16 Nm/kg, the major design feature are four 12"x1.3" rectangular spars that are placed evenly on both top and bottom part of the wing on the exterior and also two 22"x1.3" rectangular spars that are also placed in the same position. There is an 18"x1.5" rectangular spar that runs horizontally through the interior of the wing.

The testing model's strength and limitations are evaluated, and applications to actual wing design are discussed.

Summary of Data

Round	Wing	Wing mass (kg)	Mass of attachment (kg)	Added water						Additional weight (kg)	Total applied load (N)	Failure load shear (N)	Failure load moment (Nm)	Efficiency (Nm/kg)
				Depth (cm)	Radius (cm)	Volume (cm^3)	Density (g/cm^3)	Mass of water (g)	Mass of water (kg)					
1	X	.441	3.6	4	14.5	2642.1	1	2,642.1	2.6421	0	61.24	61.24	15.31	34.48
1	Y	.375	3.6	21	14.5	13870.92	1	13,870.92	13.87092	0	139.64	139.64	34.92	93.12
1	Z	.243	3.6	14	14.5	9247.28	1	9,247.28	9.24728	0	126.03	126.03	31.51	129.66
2	AKE	.351	3.6	28	14.5	18494.6	1	18,500	18.5	27.1	482.6	482.6	120.65	343.73
				Added sand										
				Depth (cm)	Radius (cm)	Volume (cm^3)	Density (g/cm^3)	Mass of sand (g)	Mass of sand (kg)					
3	AKE-XL	.318	3.6	24	15	16956	1.35	22,902.21	22.90221	29.81	558.59	558.59	139.65	439.14



Wing Desgin Efficiency
Wing Weight (kg)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
X
Y
AKE
AKE-XL
Z
0
20
40
60
80
100
120
140
160
Failure Moment (Nm)

First Round

During the first round phase, ideas for wing design were brainstormed. Three designs were selected. Scale drawings of these designs are included on the following pages. Predicted strengths and weaknesses of each wing are evaluated.

Design X

The following design is the first design that we built. This wing achieved an efficiency of 34.48 Nm/Kg.

After much study we found that triangles handle and distribute stress quite a bit better than most other geometric shapes. Based upon this information we made the decision to use triangles in our design.

The design interior consists of two right angle triangles place on top of each other to form a rectangle covering the entire interior of the wing.

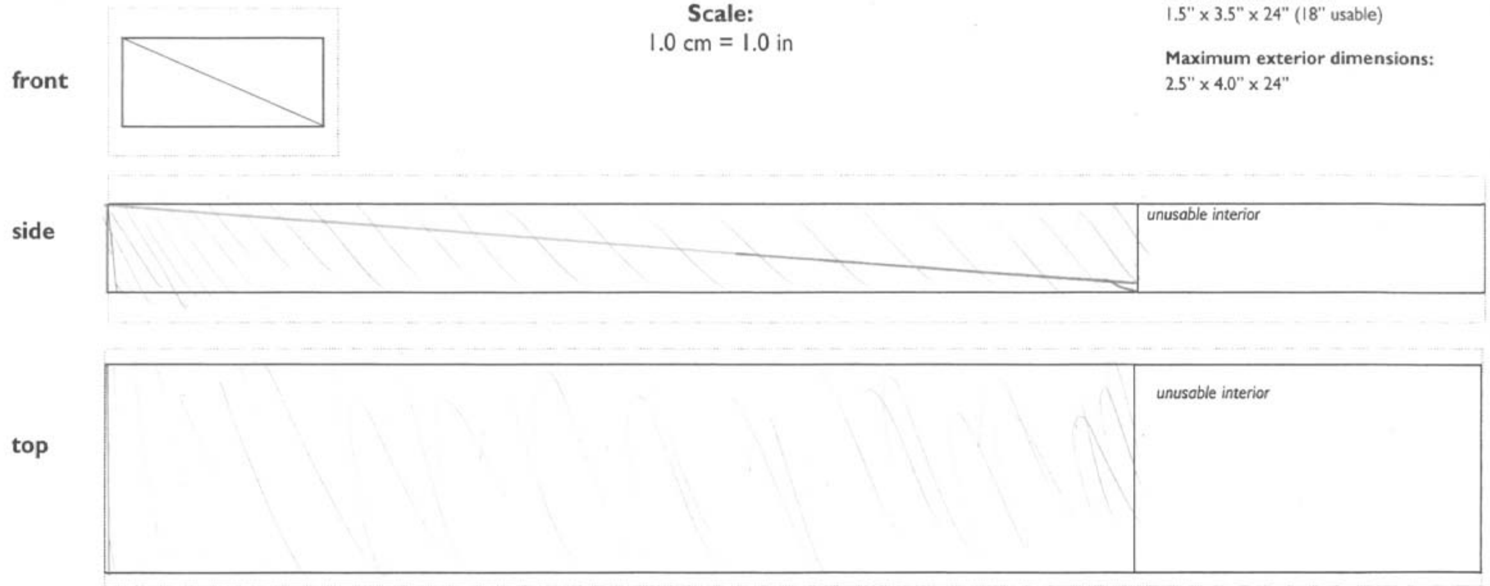
We figured that this design would distribute stress fairly well. But as the efficiency reflects it turns out we were wrong.

Date:	By Eugene/Kim	Checked	Subject **Wing Design**	Sheet ____
Job No. / Project Title **3-VIEW DRAWING** Right triangular sparred wing " x "				of ____

Scale:
1.0 cm = 1.0 in

Interior dimensions:
1.5" x 3.5" x 24" (18" usable)

Maximum exterior dimensions:
2.5" x 4.0" x 24"



Description: two giant Right triangular spar that when put together forms a rectangular is slid into the wing.

Rationale: Its gonna work because the weight on one corner will be reduced by channeling the pressure to another corner.

Design Y

After the failure of the triangle we decided to go with cylinders. This design turned out to work much better than our previous design with an efficiency of 93.12 Nm/Kg.

The design consists of ten long cylinders placed on top of each other within the interior of the wing.

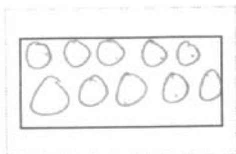
Date:	By Eugene/Kim	Checked	Subject **Wing Design**	Sheet ____ of ____
Job No. / Project Title **3-VIEW DRAWING**	bar sparred wing "Y"			

Scale:
1.0 cm = 1.0 in

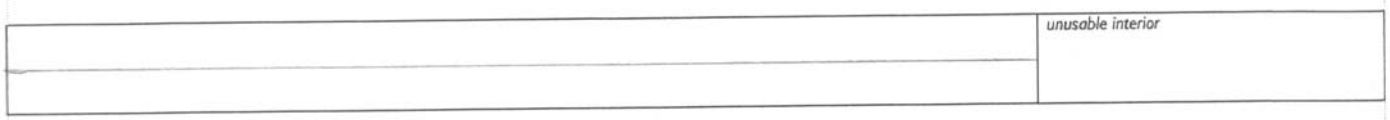
Interior dimensions:
1.5" x 3.5" x 24" (18" usable)

Maximum exterior dimensions:
2.5" x 4.0" x 24"

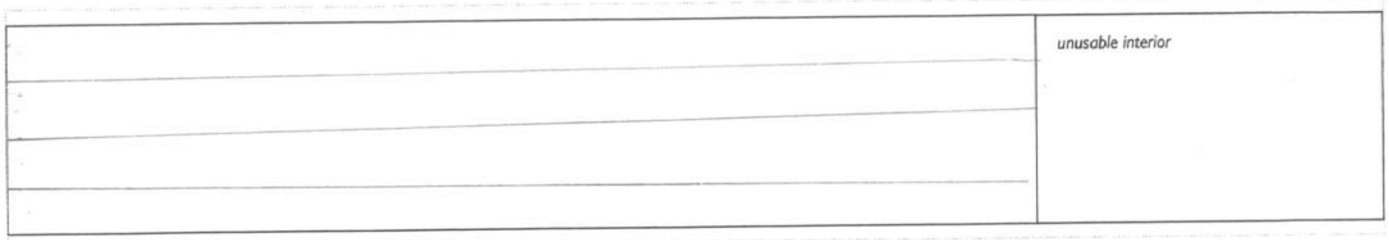
front



side



top



Description:

20 bars that are 18" long will be shoved into the wing until it's tightly fitted and then seal it in with glue.

Rationale: It will work because the thing spars shaped like bars will work to hold the weight up by having stacked bars of paper

Design Z

This design turned out to be the best of the first round (three rounds took place) with an efficiency of 129.66 Nm//Kg.

The design consists of one central triangle placed in the interior of the wing.

It is our observation that the reason this wing was so successful was because of the very low weight only .243 kg.

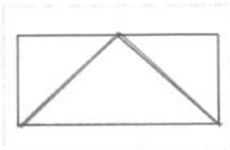
Date:	By Eugene/Kim	Checked	Subject **Wing Design**	Sheet ____ of ____
Job No. / Project Title **3-VIEW DRAWING**	Triangular sparred wing "2"			

Scale:
1.0 cm = 1.0 in

Interior dimensions:
1.5" x 3.5" x 24" (18" usable)

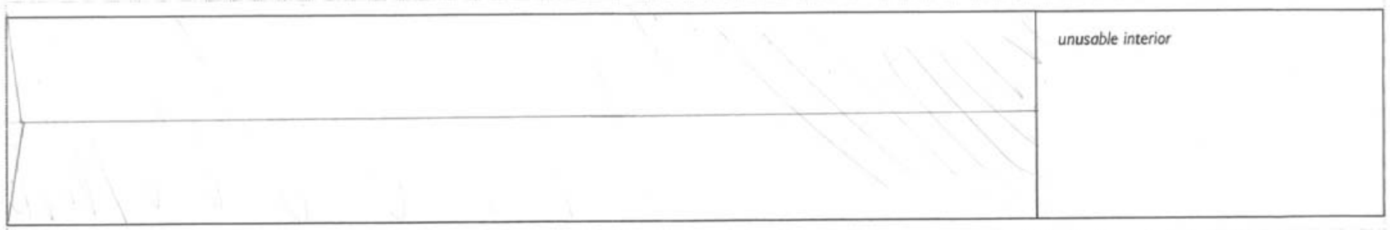
Maximum exterior dimensions:
2.5" x 4.0" x 24"

front



side

top



Description: It is a giant triangular spar fitted through the wing. The edges of the spar touches the bottom 2 corners and middle.

Rationale: Its gonna work because the weight and force applied to the middle will be reduced by channeling the pressure to the bottom 2 corners.

Building Process

Inner Shells

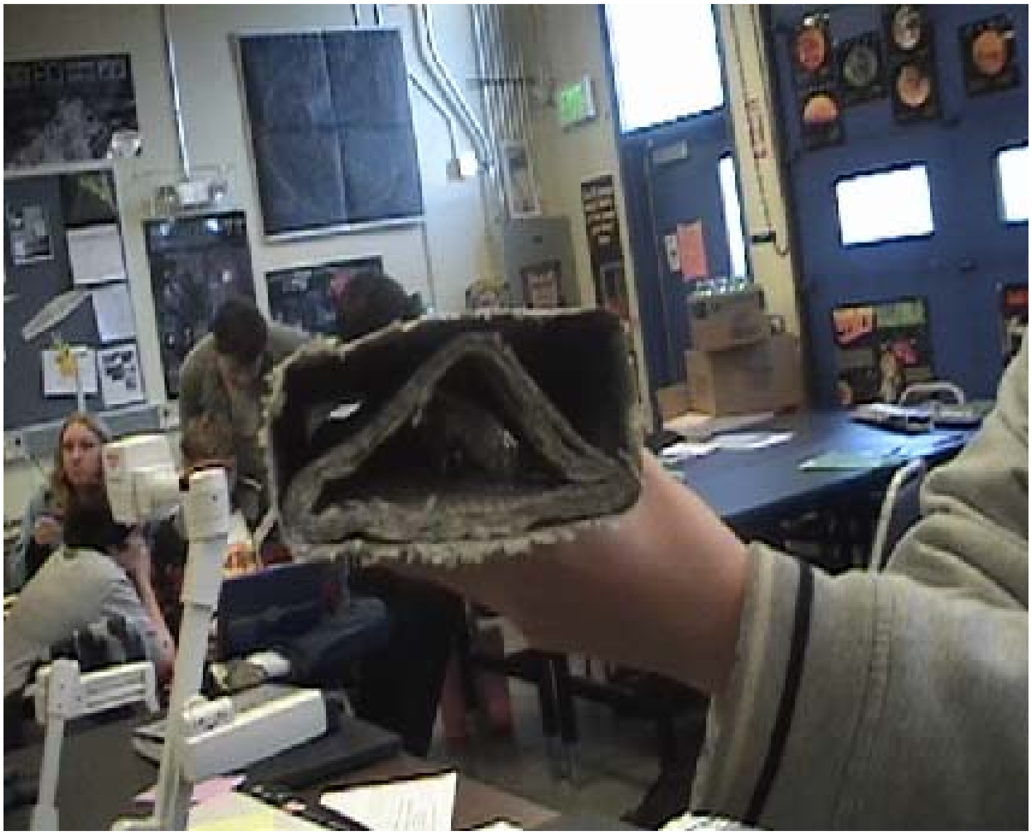
Building of the wing shells was a messy and time consuming job. There was not much experience during round one and the shells were not built as well as they should have been.

Wing X's interior structure was made of two triangular spars that ran through the wing horizontally and they were right triangular.

Wing Y had cylinder spars that ran through the whole wing horizontally.

Most of the other teams decided to cut there wings open to add supports. However we decided to leave ours whole in order to add more stability. Instead of cutting the wing open we placed cylinders triangles and rectangles in the center.

Wing Z was the best wing that the team had during the 1st round. It consisted of an interior structure of one equilateral triangular spar that runs through the whole wing.



Testing-Round 1

1. The wings were loaded 15cm onto a 2 x 4 interface.
2. Two small blocks of wood were used to clamp the wing to the interface. The blocks of wood were placed on the outside of the wing where the 2 x4 interface ended.
3. Actuators were loaded 10 cm apart; first one is placed 10 cm away from where the interface ended.
4. A lower spreader was added to the actuators.
5. A bucket was added to the lower spreader.
6. water was added to the bucket until the wing failed

Testing results are shown are shown in the chart below

Round	Wing	Wing mass (kg)	Added water						Efficiency (Nm/kg)
			Depth (cm)	Radius (cm)	Volume (cm^3)	Density (g/cm^3)	Mass of water (g)	Mass of water (kg)	
1	X	0.441	4	14.5	2642.1	1	2642.1	2.6421	34.48
1	Y	0.375	21	14.5	13871	1	13871	139.67	93.12
1	Z	0.243	14	14.5	9247.3	1	9247.3	9.2473	129.7

Qualitative Observations

Wing X: Beginning of test the wing was still wet with starch. The wing bent where the wood is at, it failed because it was not dry at all the way and also by the cause of compression. When the wing failed, it just bended slowly until the wing touched the ground.

Wing Y: The wing was dry before the test. The bending moment was 15 cm away from the root, which was caused by compression. When it failed the wing came down slowly while the wing bent.

Wing Z: The wing was dry before the test. The wing failure location was 15 cm away from the root. The cause of its failure was compression and sheer. The wing snapped immediately right at 15 cm once the water in the bucket reached 14-cm.

Probable cause of failure

Probable cause of failure for all wings was the fact that there was not enough support at the interface location.

Lesson Learned From Round 1

Based on the design, building and testing process, the following changes were implemented:

- The team learn that building a wing needs time so it does not warp while it’s dry. We had encountered having to place spars into our wing while it was still dry.
- During the building process, design engineers and project managers worked diligently to ensure quality control
- During the testing process, test engineers reviewed key formulas and variables to control

a screen with a grid was added to better quantify wing deflection a camera was placed a fixed distance away from the testing apparatus to allow consistent pictures during the tests

Second round

During the second round phase, ideas for wing design were brainstormed. One design was selected. Scale drawings of the design are included on the following pages. Predicted strengths and weaknesses of the wing were evaluated.

Design AKE

This design was a phenomenal success. In fact it won the highest efficiency in the school for round one through two with efficiency of 343.73 Nm.

This design was not only helpful to our design process but also for the rest of the school in that it was the first to incorporate outside structure.

The interior once again consisted of two triangles, but this time placed in the opposite fashion (see next page). On the exterior we place two six inch rectangular spars on the bottom intersecting the interface position.

The entire wing's mass was .351 kg

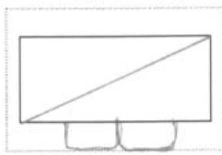
Date: 2/7/06	By Eugene Kim	Checked	Subject	Sheet ____
Job No. / Project Title **3-VIEW DRAWING** AKE			**Wing Design**	of ____

Scale:
1.0 cm = 1.0 in

Interior dimensions:
1.5" x 3.5" x 24" (18" usable)

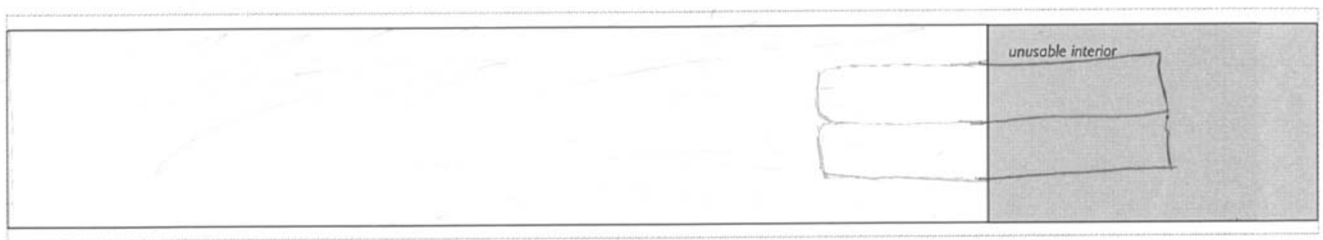
Maximum exterior dimensions:
2.5" x 4.0" x 24"

front



side

top



Description:

2 right triangular spars placed in the wing. 18 inch lon

2 6inch rectangular spars are placed under the wing between the interface.

Rationale:

This wing is going to work because we have the two triangular spars supporting the weight on the wing, while the 2 6inch spars are reducing the compression and tension where the wood and wing connects.

Building Process

Inner Shells

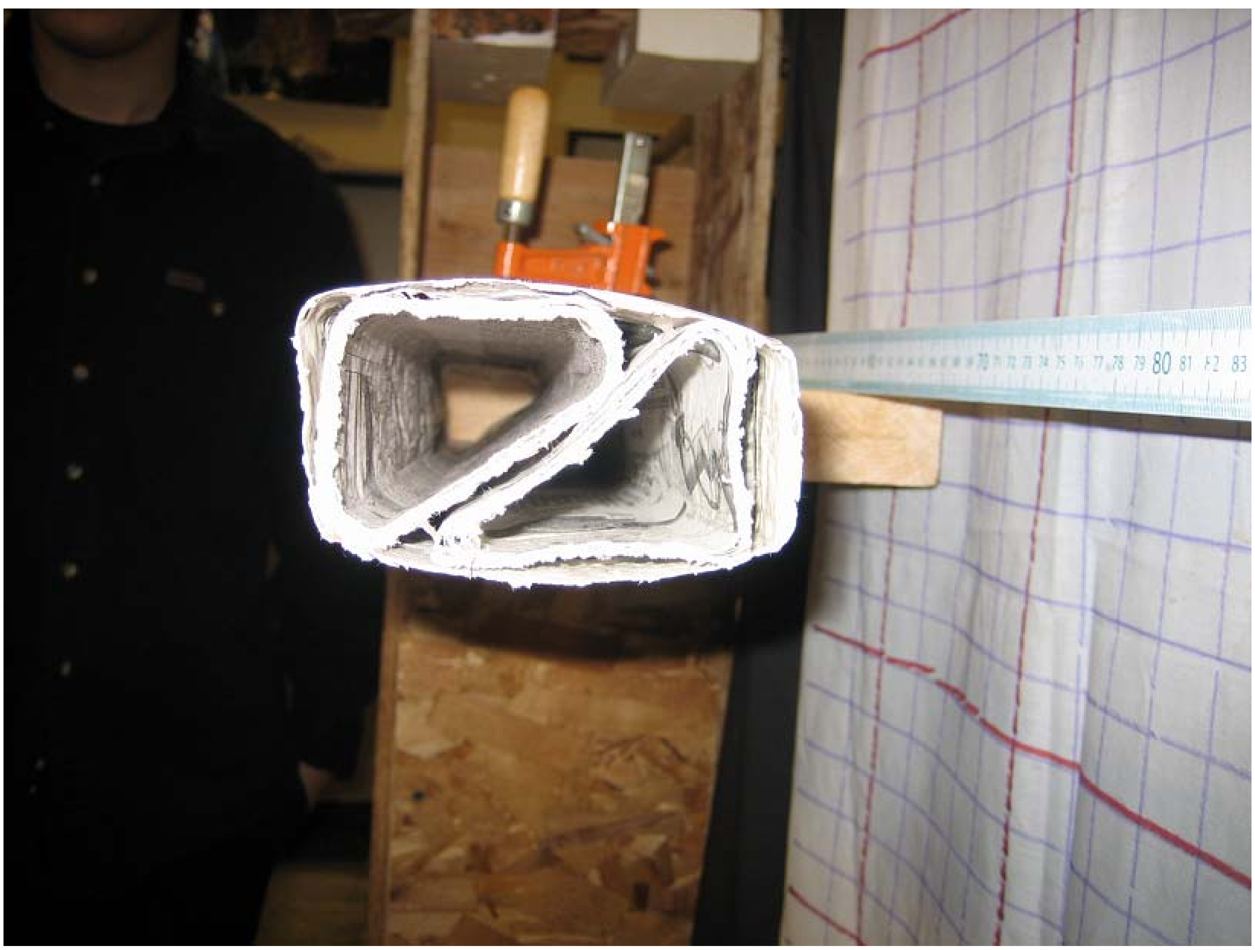
For wing AKE, building the shell was easy and proceeded according to plan. There is more newspaper at the interface, because that's where the most force is pushing down on the wing.

Support

Building papier mache support was trickier than we had anticipated.

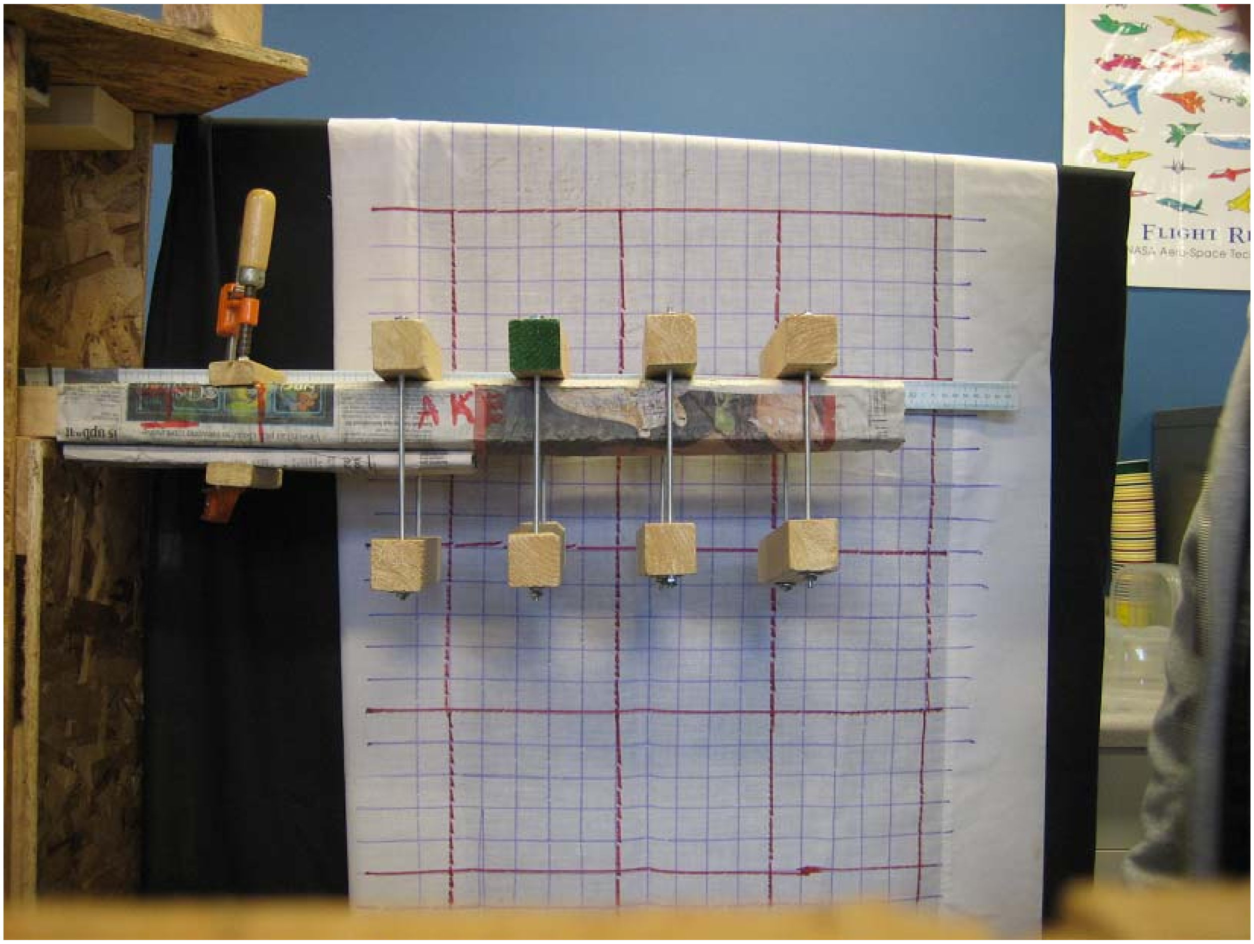
Wing AKE:

Two 18'' long triangular molds were constructed from strips of cardboard wrapped in aluminum foil for the interior structure for Wing "AKE." Then the molds were being wrapped around with 8 pieces of newspaper each. The molds had been taken out of the wing after the newspaper is dry. After that the two 18" triangular spars are inserted into the shell.



Outer Shells

Two 6” rectangular spars that is placed right under the wings interface.



Testing-Round 2

1. The wings were loaded 15 cm onto a 2 x 4 interface.
2. Two small block of wood were used to clamp the wing to the interface. The blocks of wood were placed on the outside of the wing where the 2 x 4 interface ended.
3. Actuators were loaded 10 cm apart; first one is placed 10 cm away from where the interface ended.
4. A lower spreader was added to the actuators.
5. A bucket was added to the lower spreader.
6. Water was added to the bucket until wing failed.

Testing result is shown in the chart below:

Wing name	**Wing mass (kg)**	**Total applied load (N)**	**Failure load moment (Nm)**	**Efficiency (Nm/Kg)**	**Failure load mode**
AKE	.351	482.6	120.65	343.73	Tension

Qualitative observation

Before the test, the wing was completely dried and there was no obvious defects. The interface fit perfectly into the wing. The wing had been clamp exactly 15 cm from the wing root, after clamping the wing and wood together, the actuators were placed 10 cm apart from each other. This wing was strong enough to hold 28 cm of water, which means that the bucket was full of water. So then there is extra weight added on top of the wing (16 books). Finally, wing “AKE” broke at the point where the wood and the wing meet (15 cm from wing root).

Probable Cause of Failure

The wing failed load, because of tension: first the top part of the wing ripped apart then the bottom of the wing started to compress and later at the 15 cm part of the wing start from root ripped completely. The bending moment is highest at the location 15 cm from root.

Lessons Learned From Round 2

Based on the design, building and testing process, the following changes were implemented:

- The team learned that building the exterior structure give more support to the wing than the interior structure.
- During the building process, the team learned that the simpler it is the better, because too much structure adds too much weight and that affect the efficiency in a negative way.
- During the testing process, the team learned that the interior structure beyond the interface don't take on much stress. Exterior structures at the interface are more helpful.

Third round

During the third round phase, ideas for wing design were brainstormed. One design was selected. Scale drawings of the design are included on the following pages. Predicted strengths and weaknesses of the wing were evaluated.

Design AKE-XL

This design won second place in the school for round three with an efficiency of 439.14 Nm/Kg

The design was similar to the previous in that it had outside supports. This time the interior consisted of only a single central spar, the reasoning for this was that while examining the previous design we came to the conclusion that the interior really didn't do much. However were hesitant to leave it empty because we did not want the actuators to crush the structure. The exterior consisted of 6 spars (three on top three on bottom) see next page for position.

Date: 3/11/06	By Eugene Kim	Checked	Subject **Wing Design**	Sheet ____ of ____
Job No. / Project Title **3-VIEW DRAWING**	AKE XL			

Scale: 1:2

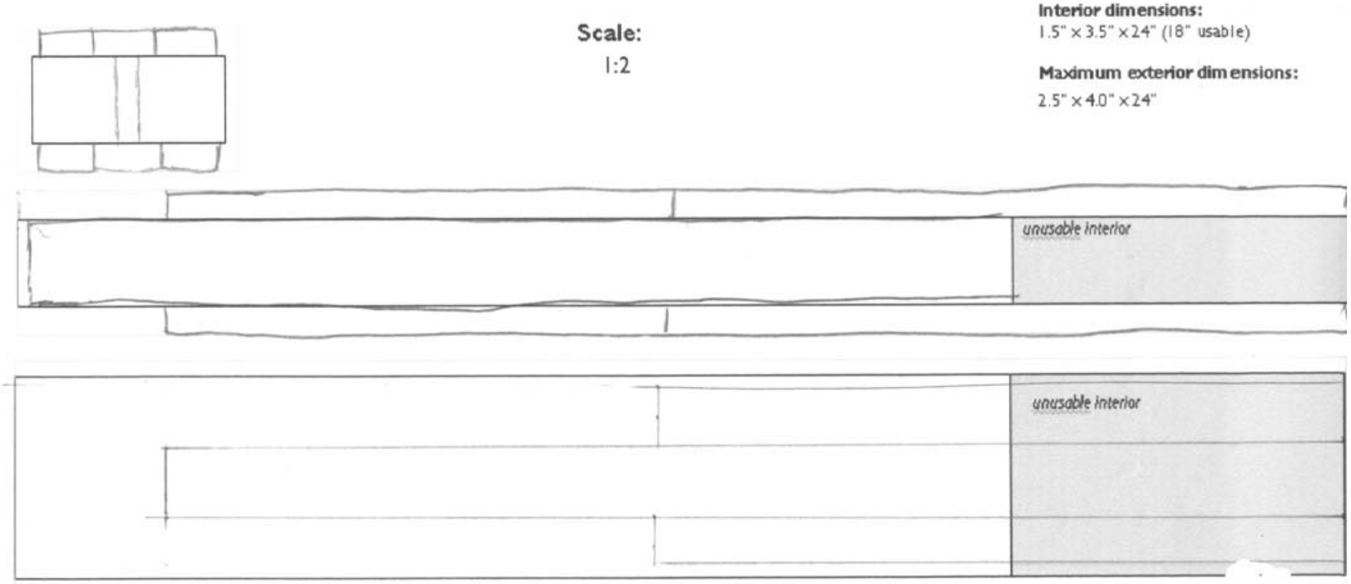
Interior dimensions:
1.5" × 3.5" × 24" (18" usable)

Maximum exterior dimensions:
2.5" × 4.0" × 24"

front

side

top



Description:
A thin 18"x 1.5" rectangular spar that is paced inside the wing horizontally. Also there is four 12" x 1.3" rectangular spars that is placed ontop and on bottom of the wing and has two 22" x 1.3" rectangular spars placed ontop and bottom of the exterior part of the wing.

Rationale:
This wing is going to work, [illegible] the are 3 spars on top and under the wing to support the wing from bending or breaking at the interface.

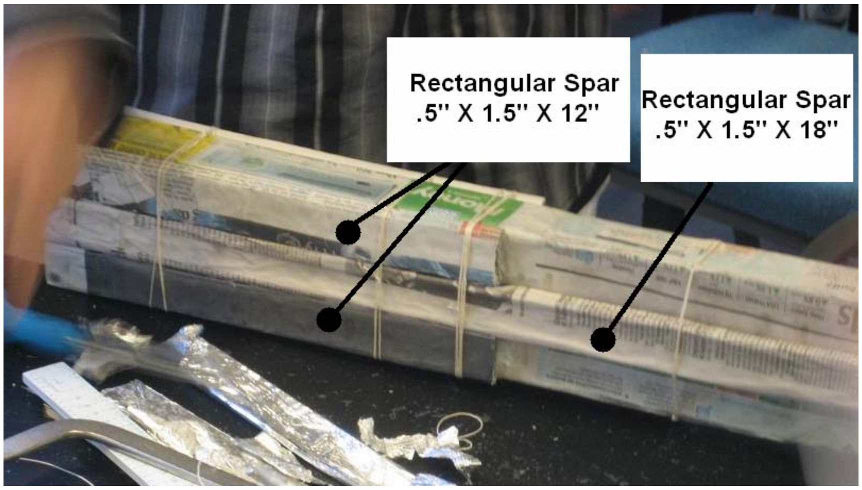
Building Process

Inner Shells

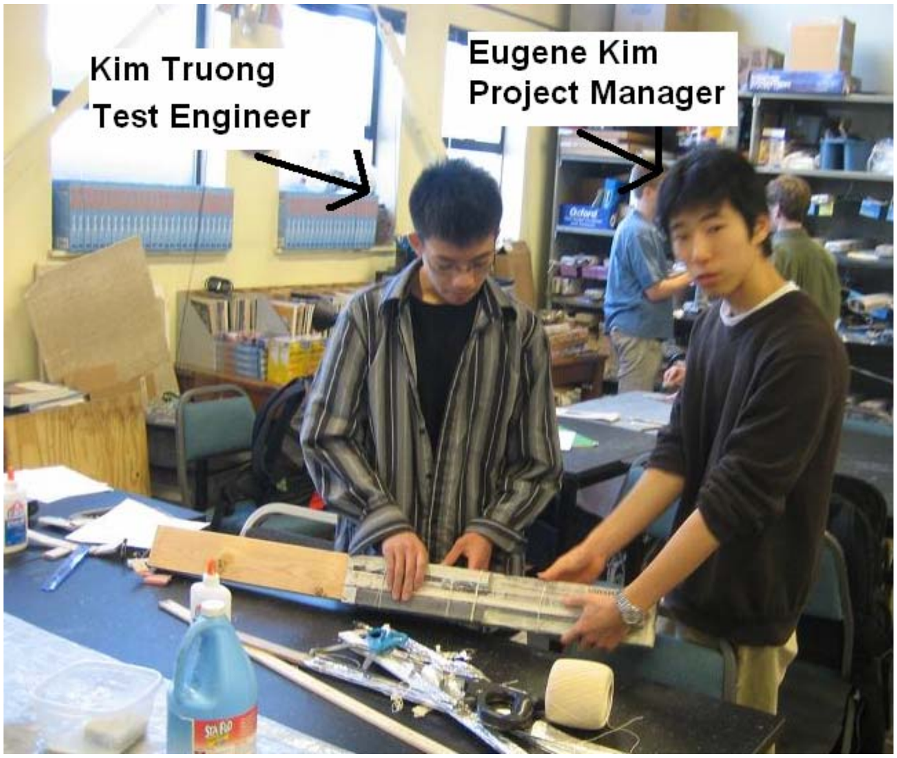
For Wing "AKE XL" the design engineer made a design to place more layers of newspaper near the interface and chose to leave the wing empty with only one spar just in case the wing collapse inwards due to too much weight.

Support

Wing AKE XL's main supports were placed on the outside of the wing because our team had found out that the interior structure of the wing does nothing at all except keep it from crumbling, which wouldn't really happen. So instead the team had placed two .5"x1.5"x12" rectangular spars and one .5"x1.5"x18" rectangular spar to support the top of the wing from tension and bottom side of the wing from compression. The spars was build by: wrapping the meter sticks with foil to create a mold, then wrapped 2 pieces of newspaper to each meter sticks with starch, and slip the meter sticks out of the spars when it's try.



The team had also taken very good care and caution during the process of attaching the supports to the wing. As you can see there are many strings used to connect the support and wing together.



Outer Shell

The outer shell of the wing perfectly fit onto the inner shell because the engineers had made precise measurements and calculations.

Testing-Round 3

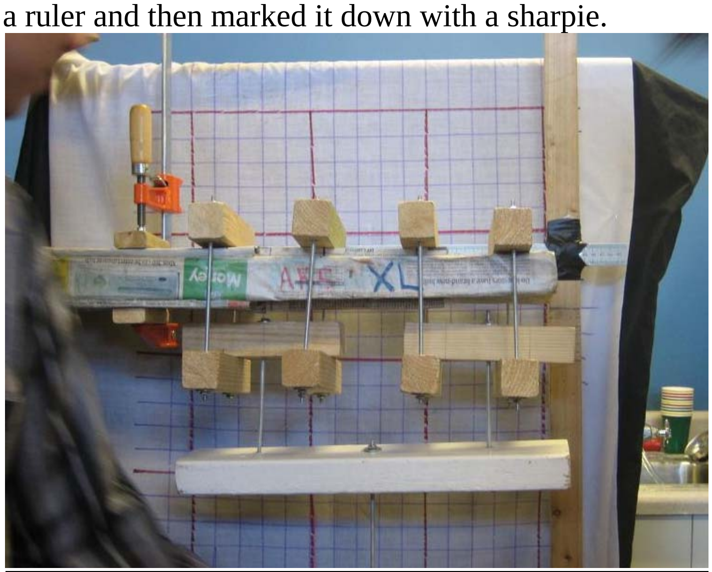
1. The wing was loaded 15 cm onto a 2 x 4 interface.
2. Two small blocks of wood were used to clamp the wing to the interface. The blocks of wood were placed on the outside of the wing where the 2 x 4 interface ended.
3. Actuators were loaded 10 cm apart; first one is placed 10 cm away from where the interface ended.
4. A lower spreader was added to the actuators.
5. A bucket was added to the lower spreader.
6. Sand was added to the bucket until the wing failed.

Testing results are shown in the chart below:

Wing name	Wing mass (kg)	Total applied load (N)	Failure load moment (Nm)	Efficiency (Nm/kg)	Failure mode
AKE XL	.318	558.59	139.69	439.14	Compressio n

Qualitative Observation

Wing AKE XL was completely dry due to the extra time that our team had. The wing was also crafted carefully and with care because it took a whole month to finish the wing. The testing was a success because the wing's efficiency had surpassed our old wings of round 1 and 2. So wing AKE XL is the team's best wing so far. The interface fit perfectly. It couldn't have been better because it was snug tight into the 2 x 4 and it was impossible to take it out with one person. The actuators were placed on the right location because our team member had measured the location more then once with a ruler and then marked it down with a sharpie.



Probable Cause of Failure

Wing AKE XL experienced buckling due to compression at the interface. The interface had the greatest bending moment and our wing could not hold any more weight so it buckled.

<u>Lessons Learned From Round 3</u>

Based on the design, building and testing process, the following changes were implemented

- If the design had changed the team would have added 2.5” x .5” x 24”rectangular spars vertically to the sides of the wing so it can greatly support compression and tension.
- We had learned that interior structure does nothing to help the wing’s durability.
- During the testing process the team had learned how to place weights and water or sand into the bucket and the key idea is to place them as gently as you can with the heaviest weights first.
- During the building process we had learned to time everything right so when one of the supports was dried we would have enough time to glue on the support to the wing.
- The project manager had learned how to keep the team on track and do what they are supposed to do so the team would be ready for test day.
- The design engineer learned how to make the wing’s design adapt to the testing station so it can get the best efficiency. Also learned the weak side of the wings interior and exterior structure.

Test engineer learned how to write down the data and calculate the problems with ease so the team will know the results quickly.

Conclusion

During each round of our experiment the efficiency of our wing improved. We attribute the improved efficiency to the following:

- Spend more time working on wing and we are aiming for quality not quantity.
- Start ahead of schedule so there is extra time for wing to dry or to fix any problems.
- Put effort and careful craftsmanship in the making of the wing.
- Discuss pros and cons with group member and make arrangements to fix any problems if necessary.
- Save as much weight as possible. Focus only on the locations that matter such as the interface and where there is high concentration of stress on the wing.

To further improve the design of the wings, the wings should….

- Weigh less.
- Be durable.
- Use less starch.
- Have a complex design to support the exterior of the wing.
- Less interior structure.

Evaluation

The paper mache model wings and testing apparatus are useful models for real wings in the following ways:

- The designs are identical because real wings are hollow on inside but on the outside there is a complex design like these wings.
- Because the real wings and this wings are light and durable with high efficiency.
- The real wings have the same intention for their structures to support their wings.

The data gathered from the paper mache model wings: and testing apparatus have the following limitations:

- There are limited in materials use, only allowed to use newspaper starch and glue. But the real wings can pretty much use anything they wish to use.
- The shape of the real wing is way more aerodynamic than these wings, which is a rectangular wing. So the dimensions are different from the two.
- The real wings are tested by being able to fit on a real fuselage.