Fall 12-10-2014

MEMS 411 Morphing Wing RC Glider Senior Design Project

Mark J. Kurtz Jr  
*Washington University in St Louis*

Erika L. Miller  
*Washington University in St Louis*

Francis K. Acquaye  
*Washington University in St Louis*

Follow this and additional works at: [https://openscholarship.wustl.edu/mems411](https://openscholarship.wustl.edu/mems411)

Recommended Citation  
Kurtz, Mark J. Jr; Miller, Erika L.; and Acquaye, Francis K., "MEMS 411 Morphing Wing RC Glider Senior Design Project" (2014).  
*Mechanical Engineering Design Project Class*. 11.  
[https://openscholarship.wustl.edu/mems411/11](https://openscholarship.wustl.edu/mems411/11)
# Table of Contents

List of Figures .................................................................................................................. 5
List of Tables .................................................................................................................... 7

## 1 Introduction ................................................................................................................. 8

1.1 Project problem statement ......................................................................................... 8
1.2 List of team members ................................................................................................. 8

## 2 Background Information Study .................................................................................. 8

2.1 A short design brief description that defines and describes the design problem ........ 8
2.2 Summary of relevant background information (such as similar existing devices or patents, patent numbers, URL’s, et cetera) ............................................................... 8

## 3 Concept Design and Specification ............................................................................... 8

3.1 User needs, metrics, and quantified needs equations. This will include three main parts: .... 8
   3.1.1 Customer Needs Interview .................................................................................. 8
   3.1.2 Identified Metrics ................................................................................................. 9
   3.1.3 Design Metrics and Happiness Equations ............................................................ 10

3.2 Four (4) concept drawings ......................................................................................... 12

3.3 A concept selection process. This will have three parts: .......................................... 16
   3.3.1 Concept scoring .................................................................................................. 16
   3.3.2 Physical Analysis ................................................................................................. 16
   3.3.3 Final summary .................................................................................................... 16

3.4 Proposed performance measures for the design ......................................................... 17

## 4 Embodiment and fabrication plan .............................................................................. 17

4.1 Embodiment drawing ................................................................................................. 17
4.2 Parts List .................................................................................................................... 17
4.3 Draft detail drawings for each manufactured part ....................................................... 19
4.4 Description of the design rationale for the choice/size/shape of each part ................ 26

## 5 Engineering analysis .................................................................................................. 27

5.1 Engineering analysis proposal ..................................................................................... 27
   5.1.1 A form, signed by our section instructor .............................................................. 27

5.2 Engineering analysis results ....................................................................................... 28
   5.2.1 Motivation. Describe why/how the before analysis is the most important thing to study at this time. How does it facilitate carrying the project forward? ............................... 28
   5.2.2 Summary statement of analysis done. Summarize, with some type of readable graphic, the engineering analysis done and the relevant engineering equations .............................. 29

   5.2.3 Methodology. How, exactly, did you get the analysis done? Was any experimentation required? Did you have to build any type of test rig? Was computation used? .......... 32
5.2.4 Results. What are the results of your analysis study? Do the results make sense? ........32
5.2.5 Significance. How will the results influence the final prototype? What dimensions and material choices will be affected? This should be shown with some type of revised embodiment drawing. Ideally, you would show a “before/after” analysis pair of embodiment drawings. ........32
5.2.6 Summary of code and standards and their influence. Similarly, summarize the relevant codes and standards identified and how they influence revision of the design .........................34

6 Working prototype ..................................................................................................................................35
6.1 A preliminary demonstration of the working prototype (this section may be left blank). ....35
6.2 A final demonstration of the working prototype (this section may be left blank). .............35
6.3 At least two digital photographs showing the prototype .................................................................35
6.4 A short video clip that shows the final prototype performing .........................................................36
6.5 At least four (4) additional digital photographs and their explanations .....................................36

7 Design documentation .............................................................................................................................40
7.1 Final Drawings and Documentation .....................................................................................................40
7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models. See Appendix C for the CAD models.................................................................40
7.1.2 All CAD Model Files ..........................................................................................................................40
7.1.3 Drawing files derived from the CAD models ......................................................................................40

7.2 Final Presentation ....................................................................................................................................52
7.1.4 A live presentation in front of the entire class and the instructors ................................................52
7.1.5 A link to a video clip version of the presentation .............................................................................52

7.3 Teardown .............................................................................................................................................53

8 Discussion ...............................................................................................................................................54
8.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result ........................................54
8.2 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects? .........................54
8.3 Discuss the overall experience: ............................................................................................................54
8.3.1 Was the project more or less difficult than you had expected? .....................................................54
8.3.2 Does your final project result align with the project description? ...............................................54
8.3.3 Did your team function well as a group? .........................................................................................54
8.3.4 Were your team member’s skills complementary? .................................................................54
8.3.5 Did your team share the workload equally? ..................................................................................55
8.3.6 Was any needed skill missing from the group? .............................................................................55
8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief? .....................................................................................................................55
8.3.8 Did the design brief (as provided by the customer) seem to change during the process? ....55
8.3.9 Has the project enhanced your design skills? ................................................................. 55
8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?... 55
8.3.11 Are there projects that you would attempt now that you would not attempt before? ....... 55

9 Appendix A - Parts List ........................................................................................................... 55
10 Appendix B - Bill of Materials .............................................................................................. 55
11 Appendix C - CAD Models .................................................................................................... 55
List of Figures
Figure 1: Concept 1- Bat wing design ................................................................. 12
Figure 2: Concept 2- Hawk wing design ............................................................... 13
Figure 3: Concept 3- Telescoping wing design ...................................................... 14
Figure 4: Concept 4- Folding wing design ............................................................ 15
Figure 5: Overall embodiment design .................................................................. 17
Figure 6: Sketch of final prototype design ............................................................ 26
Figure 7: Embodiment sketches before analysis .................................................... 33
Figure 8: Embodiment sketches after analysis ...................................................... 34
Figure 9: Initial completed prototype ................................................................... 35
Figure 10: Picture of the final completed prototype ......................................... 35
Figure 11: Initial prototype after construction ..................................................... 36
Figure 12: Final prototype nearing completion .................................................... 36
Figure 13: Finished final prototype ...................................................................... 37
Figure 14: Bare wing with frame and ribs revealed ............................................. 37
Figure 15: A wing in the construction phase with the first layer of the elastic material applied ................................................................. 38
Figure 16: Wing in the construction phase with the layer of plastic over the first layer of elastic material ................................................................. 38
Figure 17: Finished wing for the final prototype before it is connected to the main body ................................................................. 39
Figure 18: Final prototype with everything connected and place into the lower section of the body ................................................................. 39
Figure 19: Drawing of the left airfoil 1 ................................................................. 40
Figure 20: Drawing of the right airfoil 1 ................................................................. 41
Figure 21: Drawing of airfoil 2 ............................................................................ 41
Figure 22: Drawing of airfoil 3 ............................................................................ 42
Figure 23: Drawing of airfoil 4 ............................................................................ 42
Figure 24: Drawing of airfoil 5 ............................................................................ 43
Figure 25: Drawing of airfoil 6 ............................................................................ 43
Figure 26: Drawing of airfoil 7 ............................................................................ 44
Figure 27: Drawing of airfoil 8 ............................................................................ 44
Figure 28: Drawing of the left airfoil 9 ................................................................. 45
Figure 29: Drawing of the right airfoil 9 ................................................................. 45
Figure 30: Drawing of propeller support .............................................................. 46
Figure 31: Skeletal frame of right wing ................................................................. 46
Figure 32: Tail of final prototype ........................................................................ 47
Figure 33: Foam body bottom of final prototype .............................................. 47
Figure 34: Foam body top of final prototype ...................................................... 48
Figure 35: Drawing of plastic layer for wing ....................................................... 48
Figure 36: Drawing of base/connector for torsion bar to servo motor .............. 49
Figure 37: Drawing of servo back support .......................................................... 49
Figure 38: Drawing of internal body wood frame base .................................... 50
Figure 39: Drawing of vertical body support ..................................................... 50
Figure 40: Drawing of horizontal body support .......................................................... 51
Figure 41: Assembly of the final glider prototype ....................................................... 51
Figure 42: Exploded assembly of the final glider prototype ....................................... 52
List of Tables
Table 1: User Needs Table .................................................................................................................. 9
Table 2: Identified metrics table ......................................................................................................... 9
Table 3: Table of design metrics .......................................................................................................... 10
Table 4: Happiness equations data sheet ............................................................................................ 11
Table 5: Table of parts list .................................................................................................................... 18
1 Introduction

1.1 Project problem statement
Design a radio-controlled scaled model glider with a true “morphing” (shape-changing) wing. The wing’s shape changing will control the movement of the craft. The glider must stay in flight for a minimum of one minute and must successfully use the morphing wing to change its direction as well as elevation. Avoid ailerons since these parts would defeat the purpose of using the morphing wings as the source of control. Any method of takeoff is acceptable, as long as once the glider is in the air it simply glides on its own. Wingspan is no smaller than 3 feet and does not exceed 8 feet long. The model must be lightweight in order to glide with ease.

1.2 List of team members
Erika Miller
Francis Acquaye
Mark Kurtz

2 Background Information Study

2.1 A short design brief description that defines and describes the design problem
We need to design a radio-controlled glider with true “morphing” wings. The shape change of the wings will control the movement of the glider. The glider will be able to change elevation and direction as well.

2.2 Summary of relevant background information (such as similar existing devices or patents, patent numbers, URL’s, et cetera)
We researched a couple of patents relative to our design. Patent 4200253 discusses a drooping type of wing that has a pivoting section at the end. Another Patent 6834835 B1 is a telescoping design for the wings. We researched different variations of airfoils to determine which would be best for our model. We found a few videos as well that gave us a better idea of how we wanted to design our glider.

https://www.youtube.com/watch?v=8HGczYNFmfk

https://www.ted.com/talks/a_robot_that_flies_like_a_bird#t-358399

3 Concept Design and Specification

3.1 User needs, metrics, and quantified needs equations. This will include three main parts:

3.1.1 Customer Needs Interview
### Table 1: User Needs Table

<table>
<thead>
<tr>
<th>Question</th>
<th>Customer Statement</th>
<th>Interpreted Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can the RC Glider carry a load?</td>
<td>No, it does not need to carry anything.</td>
<td>Optional</td>
<td>1</td>
</tr>
<tr>
<td>RC Glider can use microprocessors to stay level in air.</td>
<td>Yes, the glider can be computer controlled.</td>
<td>Optional</td>
<td>2</td>
</tr>
<tr>
<td>How should the glider land?</td>
<td>Fine to crash on the belly.</td>
<td>Landing gear is optional.</td>
<td>1</td>
</tr>
<tr>
<td>What is the shape of the wing?</td>
<td>The wing should be one continuous surface.</td>
<td>The wing should be one continuous surface.</td>
<td>5</td>
</tr>
<tr>
<td>Can the RC glider have a towable engine?</td>
<td>Yes, that is acceptable.</td>
<td>RC glider’s mechanism does not matter.</td>
<td>1</td>
</tr>
<tr>
<td>Should the glider stay in the air for a certain amount of time?</td>
<td>It should be in the air long enough to demonstrate it can change in elevation and turn.</td>
<td>Stays in air for at least one minute.</td>
<td>5</td>
</tr>
<tr>
<td>What should the size of the RC glider be?</td>
<td>RC Glider should be large enough to be easy to work with. A glider of 3 ft. is preferable to a glider of 8 ft.</td>
<td>RC Glider should be around 5.5 ft.</td>
<td>3</td>
</tr>
</tbody>
</table>

### 3.1.2 Identified Metrics

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glider’s wing material is flexible</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Glider’s wing is continuous</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>No ailerons</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Glide ratio is at least 20</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Glider stays in air for at least 1 minute</td>
<td>5</td>
</tr>
</tbody>
</table>
6. Wingspan is between 3ft and 8ft

7. Glider’s body length is less than half the wingspan

8. Glider’s weight is minimal

3.1.3 Design Metrics and Happiness Equations

Table 3: Table of design metrics

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Min Value</th>
<th>Max Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2, 3</td>
<td>Material</td>
<td>Percentage</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Ratio</td>
<td>Integer</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Time</td>
<td>Seconds</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>6, 7</td>
<td>Length</td>
<td>Feet</td>
<td>1.5</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>Weight</td>
<td>Pounds</td>
<td>0</td>
<td>80</td>
</tr>
</tbody>
</table>
Table 4: Happiness equations data sheet.

<table>
<thead>
<tr>
<th>Need</th>
<th>Material</th>
<th>Ratio</th>
<th>Time</th>
<th>Length</th>
<th>Weight</th>
<th>Need Happiness</th>
<th>Importance Weight (all entries should add)</th>
<th>Total Happiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Glider's wing material is flexible</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.15625</td>
<td>0.09375</td>
</tr>
<tr>
<td>2 Glider's wing is continuous</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.15625</td>
<td>0.09375</td>
</tr>
<tr>
<td>3 No ailerons</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.15625</td>
<td>0.09375</td>
</tr>
<tr>
<td>4 Glide ratio is at least 20</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>0.125</td>
<td>0.125</td>
</tr>
<tr>
<td>5 Glider stays in air for at least 1 min</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>0.15625</td>
<td>0.15625</td>
</tr>
<tr>
<td>6 Wingspan between 3 and 8 ft</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>0.5454545</td>
<td>0.125</td>
<td>0.06818182</td>
</tr>
<tr>
<td>7 Glider's body length is less than half wingspan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5454545</td>
<td>0.0625</td>
<td>0.03409091</td>
</tr>
<tr>
<td>8 Glider's weight is minimal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
<td>0.0625</td>
<td>0.015625</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Units</th>
<th>Percentage</th>
<th>Integer</th>
<th>Seconds</th>
<th>Feet</th>
<th>Pounds</th>
<th>Total Happiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Value</td>
<td>100</td>
<td>60</td>
<td>300</td>
<td>5.5</td>
<td>0</td>
<td>0.68039778</td>
</tr>
<tr>
<td>Worst Value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Actual Value</td>
<td>60</td>
<td>60</td>
<td>300</td>
<td>8</td>
<td>60</td>
<td>0.6</td>
</tr>
<tr>
<td>Normalized Metric Happiness</td>
<td>0.6</td>
<td>1</td>
<td>1</td>
<td>0.5455</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Four (4) concept drawings

Figure 1: Concept 1- Bat wing design
CONCEPT 2 - "NIGHT HAWK"

MAIN WINGS:
OVERLAPPING SEGMENTS

REAR WINGS:
BENDABLE/DEFORMABLE MATERIAL

Figure 2: Concept 2- Hawk wing design
Figure 3: Concept 3 - Telescoping wing design
CONCEPT 4 - CACKLING CANARY

WINGS CAN FOLD CLOSER TO BODY

BODY VS SIZE OF WINGSPAN

OPTIONAL MOTOR TURBINES

SIDE VIEW

WINGS ALSO TILT

Figure 4: Concept 4 - Folding wing design
3.3 A concept selection process. This will have three parts:

3.3.1 Concept scoring

Concept 1 = .78

Concept 2 = .84375

Concept 3 = .6413

Concept 4 = .6804

3.3.2 Physical Analysis

Concept 1: One of the benefits to concept 1 is the material. It would be a lightweight, elastic material that wraps around the outside of the internal structure. The elasticity allows the stretching and contracting of the inner joint changing the glider’s elevation. The joints at the tip of the wings would be able to move up and down helping the glider to turn left and right. The back tails have the ability to move up and down as well.

Concept 2: This design has overlapping sections on each of the wings which resembles the wing structure of a hawk. The main segment of each wing will rotate forward and backward causing the wings to tilt, turning the glider left or right. The main wing segments will also be able to stretch or contract the overlapping sections changing the elevation. The rear wings will be of a bendable/deformable material.

Concept 3: This design uses telescoping wings. They have the ability to pivot around the center which turns the glider. In order to change elevation, the wings can stretch out fully or collapse into the center. The rear wings also pivot around their center.

Concept 4: The last design has wings that can stretch out to the glider’s sides or fold closer to the body to change the elevation. The wings also tilt back and forth to turn right or left. This concept does not have rear wings like the others.

3.3.3 Final summary

We decided concept 2 was the best design out of our four concepts. The wing structure is similar to that of a bird with the overlapping sections resembling feathers. The front segment would be able to stretch out straight as well as contract to a curved state. This motion would either expand the overlapping sections, as shown in the concept design, or condense them closer together. Expanding the sections causes the glider to fly at its current elevation whereas the condensing causes the glider to drop in elevation. The rear wings are also included to tilt the glider up or down by moving either way. The glider will also have the ability to tilt forward and backward. This action lets the glider turn left or right. We will use a lightweight, deformable material. This concept seems like the most plausible design because it satisfies our happiness equations spreadsheet the best. Concept 1 could have an issue with the elastic material stretching on its own while gliding through the air. Concept 3 could have problems when collapsing if the sections don’t stay stable and shift inside. Also, we were concerned about how
fast the wings could expand out. Concept 4 might have issues sealing the wings since the movement back and forth has to be done internally. Tilting also brings concerns since it controls the entire wing at once. Concept 2 provides more optimistic qualities for a final design than the rest of the concepts do.

3.4 Proposed performance measures for the design
   a. Have a glide ratio of at least 20 – glide 20 feet forward for every 1 foot drop.
   b. Make sure the material is as lightweight as possible.
   c. Stay in the air for 1.5 minutes (the minimum is 1 minute)
   d. Add an optional motor that could be powered on during flight to give the glider an extra boost to fly longer.

4 Embodiment and fabrication plan

4.1 Embodiment drawing

![Figure 5: Overall embodiment design](image)

4.2 Parts List
<table>
<thead>
<tr>
<th>Item</th>
<th>Dimensions</th>
<th>Material</th>
<th>Source</th>
<th>Item Number</th>
<th>Price</th>
<th>Qty</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing Skin</td>
<td>0.032&quot; thick X 36&quot; wide X 1' Long (Get 5')</td>
<td>GP Rubber</td>
<td><a href="http://www.rubbersheetroll.com/">http://www.rubbersheetroll.com/</a></td>
<td>GP RUBBER ROLL, MAXIMUM CONTINUOUS LENGTH 50 FEET .032 X 36.00&quot; X LINEAR FOOT</td>
<td>4.51</td>
<td>6</td>
<td>27.06</td>
</tr>
<tr>
<td>Transmitter &amp; Receiver</td>
<td>N/A</td>
<td>N/A</td>
<td><a href="http://www.hobbypartz.com/">http://www.hobbypartz.com/</a></td>
<td>2.4G CT6B 6-Channel Transmitter+Receiver (R6B) (Complete Radio System for RC Helicopter+Airplane)</td>
<td>39</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td>ESC</td>
<td>N/A</td>
<td>N/A</td>
<td><a href="http://www.hobbyking.com/hobbyking/store/40685_Hobby_King_30A_ESC_3A_UBEC_USA_warehouse_html">http://www.hobbyking.com/hobbyking/store/ _40685_Hobby_King_30A_ESC_3A_UBEC_USA_warehouse _html</a></td>
<td>F-30A</td>
<td>10.65</td>
<td>1</td>
<td>10.65</td>
</tr>
<tr>
<td>Battery</td>
<td>1300 mAh</td>
<td>LiPo</td>
<td><a href="http://www.hobbyking.com/hobbyking/store/u_b_viewItem.asp?idProduct=58590">http://www.hobbyking.com/hobbyking/store/u _b_viewItem.asp?idProduct=58590</a></td>
<td>Z13003S20C</td>
<td>8.5</td>
<td>1</td>
<td>8.5</td>
</tr>
<tr>
<td>Airfoil</td>
<td>1/8&quot; Thick, 4&quot; x 36&quot;</td>
<td>Balsa Wood</td>
<td><a href="http://www.mcmaster.com/">http://www.mcmaster.com/</a></td>
<td>5068K43</td>
<td>5.6</td>
<td>4</td>
<td>22.4</td>
</tr>
<tr>
<td>Body Foam</td>
<td>2&quot; thick X 48&quot; wide X 8' length</td>
<td>XPS</td>
<td><a href="http://www.homedepot.com">http://www.homedepot.com</a></td>
<td>FOAMULAR 250 2 in. x 48 in. x 8 ft. R-10 Scored Squared Edge Insulation Sheathing</td>
<td>32.52</td>
<td>1</td>
<td>32.52</td>
</tr>
</tbody>
</table>

Total = $222.40
4.3 Draft detail drawings for each manufactured part

**AIRFOIL - RG15 PROFILE**

**INNER WING SUPPORTS**

- Top View
- Side View
- Cross-Section

Supports will be made of balsa wood.
WING CONSIDERATIONS

WING SHAPE: STRAIGHT LEADING EDGE
TAPE ED TRAILING EDGE

STRAIGHT FRONT CHOSEN FOR EASY CONSTRUCTION
AND CONCERN FOR FREE ROTATION OF INDIVIDUAL
AIRFOIL CROSS-SECTION

TAPE ED TRAILING EDGE CHOSEN TO INCREASE
LIFT WHILE LIMITING DRAG

WING LENGTH L CALCULATED TO BE 0.84 M
CALCULATED BY ASSUMING LIFT MUST BE EQUAL TO WEIGHT
LIFT FORMULA:
\[ L_i = \frac{C_L V^2 S}{2 \rho} \]
\[ L = 0.625 \text{ FOR 0° ATTACK ANGLE} \]
\[ V = \text{VELOCITY} \]
\[ L^2 = 0.707555 \]
\[ L = 0.84 \text{ M} \]

\[ C = \text{DENSITY OF AIR} \]
\[ \rho = 1.331 \text{ kg/m}^3 @ 70°F, 50\% \text{ HUMIDITY} \]
\[ S = \text{SURFACE AREA} \]
\[ L = \frac{2(LWING \text{ AREA})}{2(L(\frac{1}{2}L) + \frac{1}{2}(\frac{3}{4}L)L)} \]
\[ 2L^2/5L \]
\[ L_i = \text{LIFT NEEDED} \]
\[ \rho > 5g; M \text{ DECIDED ON 1.6 KG AFTER} \]
\[ \text{LOWEST COMPARISON WITH OTHER MODEL} \]
SERVO AND TORSION AXLE CONSIDERATIONS

FRONT

0.84 m

RUBBER SKIN

FARM

END ROTATED CROSS-SECTION

LOW CROSS-SECTION ROTATED BY BAR

FREE ROTATING CROSS-SECTION

NEED TO CALCULATE REQUIRED TORQUE TO ROTATE TORSION BAR

END ON VIEW, LOOKING TOWARD PLANE AT 0.14 m SIDE CROSS-SECTION ATTACHED TO BODY

END CROSS SECTION

DEFLECTION ANGLE Φ

TO CALCULATE MOMENT, NEED STRAIN IN RUBBER

MOMENT M = \int F(x, \Phi) \, \delta \, x \, dx \, ds

\delta \text{ IS ANGLE OF FORCE WITH CROSS SECTION}

F(x, \Phi) \text{ IS FORCE AT X FOR GIVN TWIST } \Phi

\int F(x, \Phi) \, dx \, \delta \text{ IS TOTAL FORCE}

\delta = \frac{\epsilon E A}{E A}

E \text{ IS YOUNG'S MODULUS FOR SKIN}

L \rightarrow 7.4 \times 10^5 \text{ Pa}

\epsilon \text{ IS STRAIN OF MATERIAL}

\epsilon = \frac{\Delta L}{L}

A \text{ IS CROSS SECTIONAL AREA OF RUBBER}

\epsilon \approx \frac{A}{w}

w \rightarrow 0.0005 \text{ m}

\epsilon \text{ IS THICKNESS}

\Delta L \rightarrow 0.0016 \text{ m}

\Delta L = 0.0016 \text{ m}

\epsilon \rightarrow 0.0016 \text{ m}

\epsilon \rightarrow \frac{\Delta L}{L}

L \rightarrow \frac{\epsilon L}{\epsilon}

\epsilon \rightarrow \text{ EFFECTIVE LENGTH}

F \rightarrow \text{ FORCE}

\Phi \rightarrow \text{ TWIST}

\Delta \Phi \rightarrow \text{ DEFLECTION}

\Phi \rightarrow \text{ ANGLE OF DEFLECTION
SERVO AND TORSION AXLE CONSIDERATIONS CONTINUED

EXPLANATION: THE END CROSS-SECTION IS ROTATED. THE BASE CROSS SECTION AGAINST THE PLANE IS HELD STATIONARY. MIDDLE CROSS SECTIONS ARE FREE TO ROTATE ABOUT TORSIONAL AXLE. THE CROSS-SECTIONS ARE COVERED IN A RUBBER SKIN. THE RUBBER SKIN KEEPS THE FREE MOVING CROSS SECTIONS IN SHAPE.

PREVIOUSLY CALCULATED MOMENT \( M = 0.01986 \text{ N-m} \)

MADE ASSUMPTIONS THOUGH!

- APPROXIMATED WING AS FLAT BAR
- ASSUMED NO INITIAL STRAIN IN RUBBER
- ASSUMED NO FRICTION FROM CROSS-SECTIONS
- ASSUMED NO DRAG FORCE

BECAUSE OF ASSUMPTIONS USE FACTOR OF SAFETY 10

NEED SERVO OUTPUT OF AT LEAST 0.2 \text{ N-m}

\text{THIS EQUATES TO 28.3 oz-in}

THE MOMENT IS VERY SMALL, IF WE USE METAL FOR THE TORSION AXLE, THIS WILL NOT BE A LIMITING FACTOR.

LIMITING FACTOR WILL BE FORCE ON BAR FROM LIFT AND DRAG FORCES

\[
\begin{align*}
\text{WING} & \quad \text{BODY} \\
\text{MAX FORCE WILL BE FROM LIFT} & \quad \text{Each wing will support } \frac{L_i}{2} \\
\text{FOR FACTOR OF SAFETY} & \quad \text{Assume each wing and therefore torsion axle} \\
\text{MUST SUPPORT } & \quad L_i .
\end{align*}
\]

\[
\begin{align*}
\tau_{\text{max}} & = \frac{VG}{I} \\
& = 0.4(0.14) \\
I & = \frac{L_i V}{2} \\
& = 0.3 \times 1.6 \times 1.6 \times 1.6 \\
\tau_{\text{avg}} & = \frac{5.36}{1.2} \\
& = 4.45 \text{ MPa} \\
& = 0.062 \times 10^6 \text{ MPa} \\
& = 0.16 \text{ ksi} \\
& = 1.5 \text{ mm}
\end{align*}
\]

\[\text{Do not have to worry about shear, free to choose proper diameters as usual.}\]
AIRFOIL CROSS-SECTION CONSIDERATIONS

AIRFOIL SHAPE: RG15 8.9%
CLASSIC SELECTION FOR GLIDERS AND SAILPLANES. HIGH LIFT WITH SMALL DRAG
L = 81m

TAPERED TIP EFFECTIVELY REDUCES DRAG OF AIRFOIL SECTION AND ELIMINATES STALLING AT WING TIPS

AIRFOILS RANGE IN LENGTH FROM
L_{MAX} = 2.8 m to L_{MIN} = 1.4 m

HEIGHT OF AIRFOIL AT HIGHEST POINT
h_A = 8.9% OF CHORD LENGTH (L_A)

h_A = 0.089 L_A
FOR CROSS SECTION AT BODY (L_{MIN}), 

h_{MIN} = 0.02492 m

MATERIAL CHOICE:
TO ENSURE THE AIRFOIL CROSS-SECTIONS ARE LIGHTWEIGHT BUT REMAIN STRONG AND RIGID, WE CHOOSE BALSA WOOD
BODY CONSIDERATIONS & SERVO MOTORS
SIZE OF BODY DEPENDS ON SERVO MOTORS

SERVO MOTORS
NEED MINIMUM TORQUE OF 28.3 oz-in
ASSUMPTIONS FOR MINIMUM TORQUE SUGGEST ACTUAL TORQUE NEEDED IS >283 oz-in
WE CHOOSE: POWER HP CONTINUOUS ROTATION SERVOAR -3506 HB
SIZE: 40.5 mm x 20 mm x 38.00 mm
WEIGHT: 40 g
SPEED @ 7 V - 71 RPM
- 932.2 in/min
- @ 6 V - 62 RPM
- 81.02 in/min

GLIDER BODY
SIZE OF BODY DEPENDS ON COMPONENTS INSIDE, THEY ARE:
- 2 SERVO MOTORS
- RC CONTROLLER
- BATTERY
BODY'S WIDTH IS DECIDED BY SERVO MOTORS BECAUSE THEY WILL BE LAYED NEXT TO ONE ANOTHER (38.00 mm + 38.00 mm + GEAR THICKNESS)
WE ESTIMATE A BODY WIDTH OF 95.25 mm (3.75 in).
HEIGHT OF BODY 35 mm
RC CONTROLLER AND RECEIVER
NEED TO CALCULATE NECESSARY
NUMBER OF CHANNELS

1 CHANNEL FOR TOWING MOTOR POWER

1 CHANNEL FOR LEFT WING CONTROL

1 CHANNEL FOR RIGHT WING CONTROL

3 TOTAL NECESSARY CHANNELS

INCLUDE AT LEAST 2 MORE FOR SAFETY FACTOR
(COULD NEED RUDDER OR ELEVATORS
FOR ADDITIONAL CONTROL AFTER TESTING)

5 TOTAL CHANNELS DESIRED
4.4 Description of the design rationale for the choice/size/shape of each part

The equations we used to determine dimensions for each part are shown on the drawings above. We will also include more design rationale for each part listed below.

Airfoils:

We researched airfoil designs that would be suitable to our glider. We chose the RG-15 because it is recommended for first time glider builders. We chose to make them out of balsa wood since it is a light material yet is also fairly sturdy. The lengths would range from 11 inches at the side of the body and decrease in length to 5.5 inches out to the far end of the wing. Later in the design process we decided to also create airfoils out of foam. The foam piece would be in between two balsa wood airfoils all of the
same size. Both of these materials are very lightweight and will be spaced 4 inches apart from center to center. The balsa wood airfoils were ⅛ in. thick and the foam was ½ thick.

Wing:

We were able to determine the dimensions of the wings by using an equation for lift. We assumed the glider’s weight, angle of attack (to find the coefficient of lift), speed, and used the density of air in order to find an appropriate wing length to have enough lift. We then researched ratios of wing length to width to find that the far end of the wing should be ⅕ of the wing length and the end nearest to the body should be ⅓ the length of the wing. The skin to cover the wing will be an elastic material that stretches around the airfoils.

Torsion bar and servo motors:

We needed a bar made of material light enough to not pull the wings down but also strong enough to rotate the cross sections from the servo motors. We needed to find the required torque to rotate the torsion bar. To find the moment we used the skin’s Young’s modulus, strain, and cross-sectional area to calculate a moment of .01986 N-m. Using a factor of safety of 10 we needed a servo output of at least 0.2 N-m which equates to 28.3 Oz-in. Since the moment is very small, if we use metal for the torsion bar, this won’t be a limiting factor. We decided to use aluminum as our choice of material.

Body:

The body needed to be large enough to fit the battery, servo motors, receiver and ESC inside. The servo motors will be laid next to each other so the body’s width needs to as wide as the motors are. We determined the body to be 6 inches wide and 28 inches in length. We wanted to use foam as the material because it is lightweight and easy to shape.

RC controller and receiver:

We needed to use a controller and receiver with enough channels for our glider. We chose one with 3 channels; one for towing motor power for the propeller, one for left wing control, and another for right wing control.

Spacers:

These were necessary to space the airfoils at the right distance from each other. The airfoils were epoxied to the spacers which were free to rotate around the torsion bar. The material was plastic and were cut in four inch sections.

5 Engineering analysis

5.1 Engineering analysis proposal

5.1.1 A form, signed by our section instructor
5.2 Engineering analysis results

5.2.1 Motivation. Describe why/how the before analysis is the most important thing to study at this time. How does it facilitate carrying the project forward?

The before analysis allowed us to better the performance and design of our initial prototype. One major issue we had with the initial prototype was the center of mass. For an airplane, the center of mass should be towards the front of the wings, in our case the center of mass should fall just behind the torsion bars in our wing design. Another issue that contributed to the nose first dive was the lack of a
tail. The tail is necessary in airplanes to provide rear controlling surfaces further away from the center of mass. A few things that we added through experimentation rather than engineering equations during the analysis was guide wires to limit the vertical drop of the wings and wing cross sections supports to limit the bend in the wings. This analysis is now our primary focus, because without it we will not be able to build a flying prototype. The initial prototype plummeted nose first into the ground without the possibility of demonstrating control through the wings. By performing the before analysis and finishing necessary calculations, it will allow us to continue our development towards the goal of demonstrating control through the morphing wings.

5.2.2 Summary statement of analysis done. Summarize, with some type of readable graphic, the engineering analysis done and the relevant engineering equations

The analysis done, as mentioned in section 5.2.1, was to calculate the center of mass, calculate the size of the tail wings, show the addition of supports to the cross sections, and finally the string support to limit webbing in the front of the wings. The images below show the equations and rational used as well as what was determined from them.
Analysis - Center of Mass

The initial prototype was very front heavy, need to balance items on the body for a proper center of mass location.

Don't need to worry about axis in wing direction, this should be symmetric.

\[ \sum M_{cm} = 0 \]

\[ 0 = W_{motor \ prop \ assembly} \cdot D \text{ center to cm} + W_{battery} \cdot D \text{ battery to cm} - 2W_{torque \ bar} \cdot D \text{ torque bar to cm} - W_{torque \ bar} \cdot D \text{ center to cm} \]

\[ 0 = 2.83 \times 10^{-4} \times (0.1863 + (1.0)) - 2(7.52 \times 10^{-3})(0.0763) - (0.1)(0.152) \]

\[ x = 0.35.98 \text{ in} \]

\[ x = 0.75 \text{ in from center of mass} \]

Analysis - Tail wing size

After research, the tail wing surface area should be \( \frac{1}{2} \) of the surface area of the wings.

Using 8 inches as the base and a triangular length, solve for the height of the tail wings.

\[ \frac{1}{2} h B = \frac{1}{2} \text{ base} \]

\[ \frac{1}{2} h 8 = \frac{1}{2}(280) \]

\[ h = 14 \text{ in} \]
Analysis - Guide wire

Before

Support height is determined experimentally

Analysis - Wing cross-section supports

Before

Droop decreases with the supports in the first three sections.

Analysis - String support for anti-wing warping

Before

Don't worry about rear warping on wing.

Front warping is taken care of by support string.
5.2.3 Methodology. How, exactly, did you get the analysis done? Was any experimentation required? Did you have to build any type of test rig? Was computation used?

The analysis was part computation (section 5.2.2), part intuition, and part experimental determination. Even with the calculations, particularly the center of mass, experimental determination was still used. After shaping the foam body and laying all pieces in place aside from the battery, we placed the nearly assembled plane on a thin metal bar. The plane was placed so that the desired center of mass was over the top of the metal bar. The battery was then moved into place until the glider was balanced on the metal bar. The battery was started at where our calculations said it should be. We did not have to deviate too far from this initial starting point. The wings were built using the dimensions calculated as guides and then shaped using our previous experience with constructing airfoils. The height of the support for the guide wire was determined experimentally by attaching the guide wires and then applying tension at different heights of the body. A good compromise between the height of the support and the tension necessary to limit wing droop was found. The supports for the wing cross sections were determined experimentally after testing a few different designs and seeing which one was the strongest. Finally, the string did not require much analysis to put into place. The diameter of the string was chosen based on intuition for what strength was needed. No test rigs were used. All experiments and calculations were performed on our final glider design.

5.2.4 Results. What are the results of your analysis study? Do the results make sense?

The results of our analysis made sense. The position of the battery matched fairly closely with the experimental data we gathered. The addition of the tail and the shapes of the tail matched other glider and plane designs. The addition of the guide wire eliminated the wing droop completely. In fact, we ended up with some positive elevation at the wing tips when compared to the wing base. This kept the wings in tension so they wouldn’t flex as much during flight. The cross supports limited the bend in the wings. We still saw some bend at the cross sections where we did not place the cross supports; however, the bend was much less. Finally, the webbing in the front of the wings nearly disappeared completely. All these changes improved the aerodynamics and strength of the glider. The results were what we expected to happen, and they made sense.

5.2.5 Significance. How will the results influence the final prototype? What dimensions and material choices will be affected? This should be shown with some type of revised embodiment drawing. Ideally, you would show a “before/after” analysis pair of embodiment drawings.

As discussed in section 5.2.4, our results made our final prototype more aerodynamic and stronger. Overall, it made our construction of the final prototype better. The length of the glider became greater due to the addition of the tail section. Additionally, the wingspan of the glider increased with the addition of the cross section supports. Finally, the working height of the glider became less since the wing droop was decreased. In section 5.2.2 before and after comparisons are present. Below comparison images are included below for convenience.
Figure 7: Embodiment sketches before analysis
5.2.6 Summary of code and standards and their influence. Similarly, summarize the relevant codes and standards identified and how they influence revision of the design.

We found a safety code guidelines for model aircraft. They include rules such as flying a clear distance away from people and any above-ground electric utility lines. The model aircraft should be used for sport, recreation, education, and/or competition. The link to list is found here: http://www.modelaircraft.org/files/105.PDF. We just had to make sure that when we tested our glider
that we didn’t fly it when other people were around the area.

6 Working prototype

6.1 A preliminary demonstration of the working prototype (this section may be left blank).
   http://youtu.be/V0Lq2-4cuUA  Video of the initial prototype’s wings working.
   https://www.youtube.com/watch?v=k-x19gTU9Vc  Video of the initial prototypes flight

6.2 A final demonstration of the working prototype (this section may be left blank).
   This is a link to a YouTube video of our final prototype flying for the first time.
   https://www.youtube.com/watch?v=2XBKRkHOyc6&feature=youtu.be

6.3 At least two digital photographs showing the prototype

![Figure 9: Initial completed prototype](image1.png)

![Figure 10: Picture of the final completed prototype.](image2.png)
6.4 A short video clip that shows the final prototype performing
A link to the YouTube videos of the glider’s wings moving and the final prototype performing.
https://www.youtube.com/watch?v=bOiHkb6NF4I&feature=youtu.be

This is a link to a YouTube video of our final prototype flying for the second time.
http://youtu.be/o2vfyqpk5vY

6.5 At least four (4) additional digital photographs and their explanations
Below is our initial prototype after construction had been completed. In the image we can see the wings sweeping back and drooping down which was fixed in our final prototype.

![Initial prototype after construction](image)

*Figure 11: Initial prototype after construction*

Our final prototype almost done with construction. The final step was the adding guide wires. Without the guide wires we can see the wings drooping down. When comparing with the initial prototype, we see that the wings are much straighter now thanks to the changes mentioned in section 5.

![Final prototype nearing completion](image)

*Figure 12: Final prototype nearing completion*
Below is the finished final prototype. This is after the guide wire has been added and a few final details have been completed. This is the final design that was test flown.

![Finished final prototype](image1)

*Figure 13: Finished final prototype*

Below is a wing section from the final prototype. It is in the construction phase. In this stage, the cross sections have been constructed on the torsion bar with the cross section supports put into place. Also, the leading-edge string has been attached to limit the front webbing of the skin material.

![Bare wing with frame and ribs revealed](image2)

*Figure 14: Bare wing with frame and ribs revealed*
Below is a wing section from the final prototype. It is in the construction phase. In this stage, it only has one layer of the elastic fabric over the cross sections as we can see. In the front, we can see a layer of plastic and the string to fight off the webbing seen on the back of the wing.

*Figure 15*: A wing in the construction phase with the first layer of the elastic material applied.

A wing section from the final prototype. It is still in the construction phase. Here we can see the layer of plastic has been placed on it to keep the wing impermeable to air.

*Figure 16*: Wing in the construction phase with the layer of plastic over the first layer of elastic material.
A finished wing section of the final prototype before it has been attached to the glider’s body.

![Finished wing for the final prototype before it is connected to the main body.](image)

**Figure 17:** Finished wing for the final prototype before it is connected to the main body.

Below is an image of the final prototype with everything placed in the bottom foam section. Here we can see how the internal frame is made and where the internal electronics are kept.

![Final prototype with everything connected and placed into the lower section of the body.](image)

**Figure 18:** Final prototype with everything connected and placed into the lower section of the body.
7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models. See Appendix C for the CAD models. Engineering drawings including CAD model files and drawings derived from CAD models are uploaded to the “RC Glider 1” file exchange in a file entitled “Final CAD Mockups” Clicking the file should initiate download of a file entitled “Final CAD Mockup.zip”

7.1.2 All CAD Model Files
Engineering drawings including CAD model files and drawings derived from CAD models are uploaded to the “RC Glider 1” file exchange in a file entitled “Final CAD Mockups” Clicking the file should initiate download of a file entitled “Final CAD Mockup.zip”

7.1.3 Drawing files derived from the CAD models

![Figure 19: Drawing of the left airfoil 1.](image)

Figure 19: Drawing of the left airfoil 1.
Figure 20: Drawing of the right airfoil 1.

Figure 21: Drawing of airfoil 2.
Figure 22: Drawing of airfoil 3.

Figure 23: Drawing of airfoil 4.
Figure 24: Drawing of airfoil 5.

Figure 25: Drawing of airfoil 6.
Figure 26: Drawing of airfoil 7.

Figure 27: Drawing of airfoil 8.
Figure 28: Drawing of the left airfoil 9.

Figure 29: Drawing of the right airfoil 9.
Figure 30: Drawing of propeller support.

Figure 31: Skeletal frame of right wing.
Figure 32: Tail of final prototype.

Figure 33: Foam body bottom of final prototype.
Figure 34: Foam body top of final prototype

Figure 35: Drawing of plastic layer for wing.
Figure 36: Drawing of base/connector for torsion bar to servo motor.

Figure 37: Drawing of servo back support.
Figure 38: Drawing of internal body wood frame base.

Figure 39: Drawing of vertical body support
Figure 40: Drawing of horizontal body support.

Figure 41: Assembly of the final glider prototype.
7.2 Final Presentation

7.1.4 A live presentation in front of the entire class and the instructors
A live presentation was performed for the entire class as well as the instructors.

7.1.5 A link to a video clip version of the presentation
https://www.youtube.com/watch?v=W6Tmg3MJHWk&feature=youtu.be
7.3 Teardown

TEARDOWN TASKS AGREEMENT

PROJECT: RC Glider 1   NAMES: Erika Miller  
INSTRUCTOR: Professor Jakiela
Mark Kurtz
Francis Acquaye

The following teardown/cleanup tasks will be performed:

- Leftover materials and parts in the Jolley 110 machine shop will be thrown away or taken home -including foam, rubber, plastic, wood, screws, duct tape, etc.
- The glider itself will not be torn apart but taken home by the group

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: Mary Malish  
Print instructor name: Mary Malish
Date: 12/8/14

(Group members should initial near their name above.)
8 Discussion

8.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

Many of our original user needs were met from the final prototype we produced. The glider’s wing was one continuous surface, the wing skin was a flexible material, and we did not have any ailerons. The wingspan was 6 ft. long which was in our 3 foot to 8 foot range. The length of our body was less than have the length of our wingspan. We did not meet the user needs of a flight time of 1 minute or a glide ratio of 20. The materials we used were very lightweight for the most part; our servo motors could have been lighter as well as our torsion bar. Overall, we met many of our user needs originally desired.

8.2 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?

We had some issues with ordering our parts. For some reason, our order to HobbyPartz did not get placed and we weren’t informed until 4 days before our initial prototype was due. We had to drive to the store and pick up our servos and the remote controller. Unfortunately, the store did not have the same servos we originally planned on using. The servos we ended up using were more expensive and heavier as well. Other than that, we received all of the parts that we ordered. We also made some changes during the constructing process. We found that the rubber was too thick and heavy so we instead used the plastic sheet we used for our original prototype as well as an elastic fabric. We found many parts as well in the machine shops that were beneficial to our model.

8.3 Discuss the overall experience:

8.3.1 Was the project more or less difficult than you had expected?
This project was a lot more difficult and in-depth than we initially expected. A lot of this difficulty arose from the expectation that we would have a working glider by the end of the project. However, each time a test flight was performed, the RC glider was essentially destroyed and we would have to construct a new version. Also the calculations and unique factors that we needed in order to construct a flyable glider were many and difficult.

8.3.2 Does your final project result align with the project description?
Yes our RC glider aligns with the project description but it does not meet all of our user needs.

8.3.3 Did your team function well as a group?
Yes. We were a well oiled machine!

8.3.4 Were your team member’s skills complementary?
Yes all of our individual work and effort helped the overall project to move forward, and
this was because each of our individual work, complimented and added to the other group member’s work.

8.3.5 Did your team share the workload equally?
Yes. We each contributed to the different parts of the project equally.

8.3.6 Was any needed skill missing from the group?
During testing, it would’ve been nice to have a member with experience in piloting RC gliders.

8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?
No we did not. We established early in the project the customer’s needs and we worked off of those through the entire process.

8.3.8 Did the design brief (as provided by the customer) seem to change during the process?
No it did not change. We stayed true to the initial customer provided design brief.

8.3.9 Has the project enhanced your design skills?
Yes, we would all say that over the course of this project we developed and reinforced our skills in design and also the manufacturing of that design. Our team skills were likewise enhanced.

8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?
Absolutely. We now understand the requirements and the amount of work that goes into a design project and our experience in designing an RC glider will have

8.3.11 Are there projects that you would attempt now that you would not attempt before?
Because of the difficulty and involvement required for this project, we are more confident in our design skills and are willing to tackle projects we once saw as intimidating.

9 Appendix A - Parts List
Parts list located in Section 4.2.

10 Appendix B - Bill of Materials
Bill of Materials located in Section 4.2.

11 Appendix C - CAD Models
2D versions are located in Section 7.1. As described in Section 7.1, Engineering drawings including CAD model files and drawings derived from CAD models are uploaded to the “RC Glider 1” file exchange in a file entitled “Final CAD Mockups”. Clicking the file should initiate download of a file entitled “Final CAD Mockup.zip”
Annotated Bibliography


