Design of A Micro-Aircraft Glider

Major Qualifying Project Report
Submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for
The Degree of Bachelor of Science

Submitted by:

____________________  ____________________
Zaki Akhtar            Ryan Fredette

____________________  ____________________
Phil O’Sullivan        Daniel Rosado

Approved by:

____________________  ____________________
Professor David Olinger  Professor Simon Evans
Certain materials are included under the fair use exemption of the U.S. Copyright Law and have been prepared according to the fair use guidelines and are restricted from further use.
Abstract

The goal of this project was to design an aircraft to compete in the micro-class of the 2013 SAE Aero Design West competition. The competition scores are based on empty weight and payload fraction. The team chose to construct a glider, which reduces empty weight by not employing a propulsion system. Thus, a launching system was designed to launch the micro-aircraft to a sufficient height to allow the aircraft to complete the required flight by gliding. The rules state that all parts of the aircraft and launcher must be contained in a 24” x 18” x 8” box. This glider concept was unique because the team implemented fabric wings to save substantial weight and integrated the launcher into the box to allow as much space as possible for the aircraft components. The empty weight of the aircraft is 0.35 lb, while also carrying a payload weight of about 0.35 lb. Ultimately, the aircraft was not able to complete the required flight because the team achieved 50% of its desired altitude during tests. However, improvements were made over the glider showcased at the 2012 SAE competition by Cedarville University. By following a standard aircraft design process and performing testing on each component of the system, the team created a design that can be further developed to make a competition-ready glider. This report details the competition goals and constraints, design process, aircraft configuration, and recommendations for future development.
Acknowledgements

The team would like to thank Professors David Olinger and Simon Evans for their direction and guidance in this project. We would also like to thank WPI’s Dean of Engineering Office and the Mechanical Engineering Department for their assistance throughout the project.
# Table of Contents

Acknowledgements ........................................................................................................... 4
List of Figures........................................................................................................................ 6
List of Tables.......................................................................................................................... 6
1.0 Introduction ...................................................................................................................... 7
2.0 Research ............................................................................................................................ 8
  2.1 Cedarville University SAE Competition Glider ............................................................... 9
  2.2 WPI’s 2012 Entry ........................................................................................................ 9
  2.3 2012 Georgia Tech Design .......................................................................................... 10
  2.4 MAV Literature Research ............................................................................................ 12
3.0 Design Process ................................................................................................................ 13
  3.1 Decision Process .......................................................................................................... 14
  3.2 Initial Design .............................................................................................................. 16
  3.3 Low Weight Design ................................................................................................... 17
  3.4 Launcher .................................................................................................................... 18
4.0 Analysis ........................................................................................................................... 20
  4.1 Aircraft Sizing ............................................................................................................ 20
    4.1.1 Weight Estimate .................................................................................................. 21
    4.1.2 Wing Sizing ....................................................................................................... 21
    4.1.3 Tail Sizing .......................................................................................................... 22
  4.2 Pitch Stability ............................................................................................................. 24
  4.3 Wind Tunnel Testing .................................................................................................. 25
  4.4 Launcher Analysis ...................................................................................................... 30
    4.4.1 Capabilities ........................................................................................................ 30
    4.4.2 Performance ....................................................................................................... 30
    4.4.3 Challenges ......................................................................................................... 31
5.0 Fabrication ...................................................................................................................... 31
  5.1 Final Assembly ........................................................................................................... 31
  5.2 Construction Materials ............................................................................................ 32
  5.3 Tools Utilized ............................................................................................................ 32
6.0 Flight Testing.................................................................................................................. 33
List of Figures

Figure 1: Schematic of Flight Course .................................................................................. 7
Figure 2: Full plane, called "Tina" ...................................................................................... 10
Figure 3: 2012 Georgia Tech Micro-Class Aircraft ............................................................. 11
Figure 4: Final Aircraft ........................................................................................................ 15
Figure 5: First Prototype of Glider ...................................................................................... 16
Figure 6: Folding Mechanism Design ............................................................................... 18
Figure 7: Shuttle used for launching system ......................................................................... 19
Figure 8: Launcher Prototype .............................................................................................. 20
Figure 9: Initial Tail Sizing .................................................................................................. 23
Figure 10: Force Balance Arrangement for Drag (Calibration Configuration) ..................... 25
Figure 11: Force Balance Arrangement for Lift ................................................................... 26
Figure 12: Lift Coefficient vs. Angle of Attack for Semi-circular Wing ................................. 28
Figure 13: Lift Coefficient vs. Angle of Attack for Rectangular Wing ................................. 29

List of Tables

Table 1: Weight Estimates .................................................................................................. 21
Table 2: Full-scale Wing Dimensions .................................................................................. 26
Table 3: Trial 1 Wind Tunnel Data ....................................................................................... 27
Table 4: Trial 2 Wind Tunnel Data ....................................................................................... 28
Table 5: Trial 3 Wind Tunnel Data ....................................................................................... 28
Table 6: Wind Tunnel Test Results ..................................................................................... 29
1.0 Introduction

The goal of this project is to design and build an aircraft for entry in the Society of Automotive Engineers (SAE) Aero Design West 2013 competition in Van Nuys, CA in April 2013. There are three distinct classes for this competition: Advanced, Regular, and Micro. Our aircraft will be entered in the micro class and our design will be driven by the micro class requirements:

1. All aircraft and launcher components must fit into a box with the interior dimensions of 24” x 18” x 8”.
2. The aircraft must be capable of assembly in three minutes by only two people.
3. The aircraft must be able to complete at least one flight around a marked course.

(schematic of the course shown below in Figure 1)

4. The aircraft must be capable of carrying and enclosing a rectangular block of dimensions 2” by 2” by 5”.

Figure 1: Schematic of Flight Course
Our overall performance will be evaluated in three distinct areas: Design Score, Tech Presentation, and Flight score. Our main focus is the flight score, which is calculated from the aircraft’s empty weight and payload fraction, which is the payload weight divided by the gross weight (payload plus empty weight). Therefore, our design goal is to construct the lightest aircraft which can carry the most weight. The flight score is calculated based on the following formula:

\[
\text{Flight Score} = (2 - EW) \times PF \times 120
\]

(1)

Where EW is the empty weight and PF is the payload fraction, and 120 is a constant.

Given that the flight score is directly proportional to the aircraft’s empty weight, we have decided to adopt a less conventional aircraft design: a glider. A glider does not operate on a propulsion system, like a motor or propeller, commonly found in the competition. Thus, it has potential for a lower empty weight than its powered counterparts. The team’s early efforts were focused on improving the performance of our design. Once a final aircraft design was agreed upon and the manufacturing process started, focus shifted towards the development and construction of the launching apparatus.

2.0 Research

For familiarity with the methods of a full design and manufacturing process, the team investigated recent competition gliders and the model from last year’s WPI team. Reports from other recent teams in the competition, such as Georgia Tech (2012 winner) and Cedarville University, are not available to others outside those respective institutions. But, short descriptions of a team’s aircraft can usually be found in a university press/promotional release.
2.1 Cedarville University SAE Competition Glider

At the 2012 Aero Design East Competition, Cedarville University entered a glider. A glider allows the removal of the motor, propeller, speed controller, flight battery, and associated wiring. Keeping the same payload weight, this potentially allows for a greater payload fraction and a higher flight score, all else being equal. However, there are some unique challenges presented by a glider, primarily regarding the launch. Video footage from the competition allowed for closer examination of these challenges. Cedarville chose to launch with their wings extended, which seemed to restrict the force they could put on the aircraft in their launch configuration. This resulted in the aircraft landing only a few feet away from the launcher, as it only gained about 10 feet in total altitude and never attained flying speed. Cedarville claims to have completed successful flight testing inside their recreational center and that the results at the competition were due to less than optimal flight conditions. Cedarville’s aircraft proved to the team that stability in the launcher and flight off of the launcher are the most critical parts of that system.

2.2 WPI’s 2012 Entry

Last year marked the first time WPI has entered the SAE Aero Design Competition in over a decade. The team placed 6th overall, while competing in a field with organizations and universities who are perennial competitors. The WPI team chose to build a powered aircraft. Their final aircraft had an empty weight of 0.8 lbs and could carry a maximum payload of 2.17 lbs. This resulted in a payload fraction of 0.71. In comparison the overall winner, Georgia Institute of Technology, had a payload fraction of 0.78.
The main design features of the aircraft were a collapsible boom tail and removable wings. The team determined their wingspan by the maximum dimension of the carrying case. The wings were tapered and constructed of full airfoil ribs and half ribs to conserve weight but maintain aerodynamic stability. The fuselage was built with formers and longerons to provide an aerodynamic profile with minimum weight. The aircraft mainly comprised of balsa wood, carbon fiber, skin coating, and various glues. The team also manufactured a custom case with a precisely cut foam interior to house all components. Every component of the aircraft was designed to minimize weight, while meeting aerodynamic and structural requirements.

While materials were ordered from various suppliers, the aircraft was built locally at WPI. The team used the laser cutter and machine shop on campus. They also built a jig to ensure accurate construction of the wing assembly.

**2.3 2012 Georgia Tech Design**

Georgia Tech earned 1st place in the SAE East Micro-Class Aircraft Design Competition in April of 2012. They bested all other competitors in the Micro-Class due to high marks in their design report and presentation. Their delta wing airframe established the highest standards in
competition, which we are up against. They attained an exceptional flight score, which is based on the following equation:

\[
\text{Flight Score} = (2 – \text{EW})\times\text{PF} \times 120
\]

Where:

\[
\text{EW} = \text{Empty Weight in pounds}
\]
\[
\text{PW} = \text{Payload Weight in pounds}
\]
\[
\text{PF} = \text{Payload Fraction} = \frac{\text{PW}}{\text{PW} + \text{EW}}
\]

The Final Score was calculated by:

\[
\text{Final Flight Score} = i \times (\text{Best Flight Score})
\]

Where:

\[
i = 1 + (A_0-40\%) \times .25
\]

\[
A_0 = \frac{(\text{Successful flights})}{(\text{Total flights})}
\]

**Figure 3: 2012 Georgia Tech Micro-Class Aircraft**

The outstanding performance of the aircraft can be directly attributed to three main factors: the payload fraction of the aircraft which allowed it to be able to successfully lift 3.5
times its own weight (Blair, et al), the aerodynamics of the delta wing airfoil and onboard controls allowing the aircraft to reach high speeds resulting in greater lift, and the extensive flight testing prior to the competition with 11 prototypes undertaking over 100 flights prior to the competition (Blair, et al). The latter factor enabled the team to fully understand flight capability, which ensured a high $A_0$ value. This attests to the fact that necessary preparations and trials need to be made prior to competing.

Specifications of Georgia Tech’s winning aircraft remain undisclosed. But, knowing WPI and Georgia Tech’s flight scores and payload fractions helped the team establish goals for those parameters in order to be competitive.

2.4 MAV Literature Research

The SAE micro-aircraft is a type of micro air vehicle (MAV). The Defense Advanced Research Projects Agency (DARPA) defines a micro air vehicle as having a maximum dimensional size of 15cm or 6 inches in length, width, or height (McMichael). The popularity of model aircrafts in the 1980s and RC planes in the 1990s helped contribute to the development of micro air vehicles. The RAND corp. first raised the possibility of such vehicles for military use in 1992. Today, small unmanned aircraft have VTOL capability (Honeywell T-Hawk), catapulted launch systems (Boeing ScanEagle), or can be hand launched (Aerovironment Wasp). The versatility and potential of gliders ultimately attracted the team to the concept for the competition.

For the deployable wing concept, one of the most helpful resources was a paper titled “Development of Deployable Wings for Small Unmanned Aerial Vehicles Using Compliant Mechanisms” written by Steven Landon of Brigham Young University. From this paper, the
team acquired design ideas for the wing, knowledge on how different launches affect performance, and ideas on some of the main parts to be built. The team’s inspiration was actually the batwing design that DaVinci and others originally used for human flight exploration. From the paper, the team tracked the evolution of the design, particularly use of spars and tapering of the wings (Landon 11). The paper examined gun and tube launched MAV’s such as the WASP (19). The ideas helped mold our final launcher design and the team learned that stable flight off the launcher would largely determine success of the flight. The paper also discussed varying assortments of pivoting joints, which would help in the assembly phase of the mechanism (28). This paper and others provided a good database of knowledge to implement in designing deployable wings.

Although the team referenced other respected texts, Daniel P. Raymer’s book, *Aircraft Design: A Conceptual Approach*, served as a guideline while the design process was underway. With this book, the team was able to quickly reference how to determine lift coefficients, stability specifications, and complete numerous other steps toward creating an airworthy glider.

### 3.0 Design Process

This section outlines the overall design process, describing the evolution of the aircraft design, design considerations, and design of the launcher. The aircraft’s design has gone through significant changes throughout the process. Initially, the team’s primary design goal was to carry as much payload weight as possible, with low empty weight as a secondary goal. This led to an extremely large aircraft, which the team deemed not feasible for competition because it would exceed the limits of any potential launcher. After quantifying the capabilities of the launcher, the team redesigned the aircraft with lowest empty weight as the primary design goal. This led to
the team’s final design, shown in figure 4 with all of the aircraft components. After the aircraft was resized, it underwent wind tunnel testing. A prototype launcher was constructed and flight tests occurred soon after.

3.1 Decision Process

The competition guidelines were the first factors taken into account for the design process. The team had a dimension limit and based on the data from the 2012 WPI aircraft, the team determined a rough weight and payload fraction goal. The 2012 aircraft carried a two pound payload and so we used that as a baseline weight to start. These core guidelines and the project directive of having a glider entry and the use of a launcher focused the team on two main objectives. Since the airframe was going to be under extreme forces upon the launch, the team followed in the footsteps of last year’s WPI SAE Aero Design competition entry. The primary objectives are durability and simplicity. Durability plays a major factor in flight-testing because a solid airframe requires less maintenance in the event of a crash. Ultimately, a low maintenance airframe allows for aggressive testing and saves time in the manufacturing process. Simplicity in the design cuts down on overall cost and manufacturing time while making repeatability and immediate adjustments or improvements very feasible.
These basic goals narrowed down the design options. A folding fabric-wing concept or a folding fixed-wing concept were chosen based on the necessity of gaining as much altitude of the launch as possible. While folded the aircraft would have aerodynamic properties of a rocket and at the peak of its trajectory, the wings would expand and maintain high lift values based on the wing design. The fixed wing concept would require large solid wings that would be difficult to conform to a folded body and they would be considerably heavy. Fabric wings are light and wing area does not constrain the ease of folding the wings. The benefits of the folding wing characteristics greatly outweighed those of the fixed-wing design so the team decided to pursue the former.
Wind tunnel tests provided the necessary data to determine the shape of the wing. The drag and lift of a rectangular and semi-circular wing shape were analyzed using force balances. The rectangular wing was selected due to its high area and aspect ratio. It also yielded more favorable experimental results from the wind tunnel testing which can be seen in later sections.

3.2 Initial Design

The initial mindset was to push the size limits established by the guidelines, because a larger wingspan and wing area would result in greater lift forces. Last year’s WPI entry carried a two pound payload and so we decided to use the same payload as a baseline. A combination of the payload determination and weight build up gave us a gross weight to input as the minimum lift required for flight in the lift equation. The team decided that using collapsible carbon fiber rods as a leading edge could result of a wingspan of up to 2 meters. The first prototype constructed had a total wing area of 1 square meter and a length of 1 meter. The wing of this first design is shown in Figure 5.

![First Prototype of Glider](image)

This design focused on achieving the highest payload possible through the utilization of a large wing area and high lift forces. Properly tensioning the fabric wing proved to be the most
challenging aspect of this concept. Carbon fiber ribs were placed from the center of the leading edge to the corners and midpoints of the trailing edge and held in place by Dacron pockets to maintain a rigid airfoil. The team conducted multiple hand launches once a solid balsa tail was attached. This design was proved itself to be airworthy and stable, even at the low speeds produced from a hand launch.

3.3 Low Weight Design

The dimensions of the aircraft changed drastically with a new target weight. The wingspan decreased to 0.5 meters and an overall length of 0.45 meters. A fuselage able to contain the required payload volume of 2”x2”x5” was attached to the aircraft body and electronic components were added bringing the final weight to 0.149 kg. A new folding mechanism was drafted but before its incorporation, the team tested fixed wing launches to determine if the aircraft was capable of withstanding the launch forces. A preliminary draft of the folding mechanism is shown below:
The team ultimately decided that the benefit of the reduced drag does not offset the added weight of such a mechanism, and it was not included on the final aircraft.

3.4 Launcher

A prototype launcher was constructed using basic carpentry tools and skills. The main surface, which houses the attached rail mirrors the dimensions of the top of the box and is placed on the longest axis (24” plane). The rail extends a few inches past the edge; this distance can be varied depending on slack of tubing. The speargun tubing is tied and secured around two arms that run parallel to the guide rail. The pieces were assembled to give a 45 degree angle of
launch, which is the most allowable by competition rules. A launch shuttle was designed to house the fuselage of the aircraft and provide protection from shock forces during launch. The shuttle was machined from Delrin stock and was designed to be as light as possible to maintain as much energy as possible for the launch. The shuttle is attached to the rail by low friction rail buttons.

![Shuttle used for launching system](image)

*Figure 7: Shuttle used for launching system*
4.0 Analysis

This section explains all important calculations made to size the aircraft as well as analyze its performance. The process we used to perform the analysis’ shown in this section is similar to the traditional design process with the exception that we only performed the steps applicable to gliders.

4.1 Aircraft Sizing

This segment describes the methods used to size the aircraft wing, tail, and overall weight.
4.1.1 Weight Estimate

The table below illustrates the weight buildup for the aircraft, which was used in preliminary lift calculations. Weights for all of the radio components were taken from the manufacturer specifications. Weights for the fuselage, wings and spar were calculated based on volume and material densities.

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver</td>
<td>6.5</td>
</tr>
<tr>
<td>Tail</td>
<td>1.8</td>
</tr>
<tr>
<td>Fuselage</td>
<td>42.6</td>
</tr>
<tr>
<td>Servo</td>
<td>7.5 (x2)</td>
</tr>
<tr>
<td>Battery</td>
<td>63.9</td>
</tr>
<tr>
<td>Fabric</td>
<td>4</td>
</tr>
<tr>
<td>Spar</td>
<td>7</td>
</tr>
<tr>
<td>Payload</td>
<td>≈76</td>
</tr>
<tr>
<td><strong>Empty Weight</strong></td>
<td><strong>140.8</strong></td>
</tr>
<tr>
<td><strong>Gross Weight</strong></td>
<td><strong>216.8</strong></td>
</tr>
</tbody>
</table>

To validate the glider concept we investigated the difference between the weight of our aircraft and the weight of a conventional aircraft (with propeller and motor). The team looked at the data for an 8 inch, plastic propeller and a motor from HobbyKing.com which are 20 grams and 21 grams respectively. The addition of those weights would bring the empty weight up to approximately 181.8 grams (0.4 lbs). The increase in weight would then lead to an increase in wing size to obtain enough lift to carry the new weight, which would also add weight. Using this analysis, we can conclude that a successful glider at the weight we have chosen can potentially obtain a higher flight score than a conventional aircraft.

4.1.2 Wing Sizing

The wingspan of 0.5 meters was decided upon to work around the challenge of fitting the aircraft within the box dimensions. The chord of 0.125 meters was chosen to maintain the same
aspect ratio as our initial design (2 meter wingspan). This resulted in an area of 0.0625m$^2$ and an aspect ratio of 4. The next step was to determine an estimated flight velocity in order to obtain a lift coefficient. Equation 5 was used to calculate the flight velocity:

$$V_{max} = \frac{K}{\sqrt{c_{D,0} \rho S V^2}}$$  \hspace{1cm} (5)

The unknowns in the equation above are K and $c_{D,0}$, the parasitic drag coefficient. The parasitic drag coefficient was estimated to be 0.07 as that is a reasonable assumption for most aircrafts. The variable K was calculated using the following equation:

$$K = \frac{1}{\pi AR e_0}$$  \hspace{1cm} (6)

The Oswald efficiency factor, $e_0$, is usually estimated to be approximately 0.9 for most aircraft yielding a $K= 0.088$. Using this as well as the density of air and the aircraft weight and wing area we were able to obtain a flight velocity of 8 meters per second. With these parameters set, a lift coefficient was found using equation 7:

$$c_{L,required} = \frac{2L}{\rho SV^2}$$  \hspace{1cm} (7)

Assuming the aircraft glides at the calculated flight speed, the required coefficient of lift is 0.89. The airfoil was chosen as a flat plate to ease construction, and it provides enough lift for this aircraft.

**4.1.3 Tail Sizing**

After determining the wing geometry and general sizing of the aircraft, the tails can be sized. We used equations found in Raymer’s Aircraft Design textbook and obtained the variables
necessary to evaluate these equations using historical data tables also found in Raymer. The horizontal tail volume coefficient, $c_{HT}$, and vertical tail volume coefficient, $c_{VT}$, were estimated to be 0.50 and 0.02 respectively as shown by Table 6.4 in Raymer for a sailplane. We assumed that values for a sailplane were the closest estimation to what they would be for our glider. The horizontal and vertical tail lengths were measured on the actual aircraft and approximated using Figure 9 taken from Raymer:

![Figure 9: Initial Tail Sizing](image)

Equations 8 and 9 were used for sizing the tails:

$$S_{VerticalTail} = \frac{c_{VT} b_w S_w}{L_{VT}} \quad (8)$$

$$S_{HorizontalTail} = \frac{c_{HT} c_w S_w}{L_{HT}} \quad (9)$$

These equations resulted in a vertical tail area of 25.81 cm$^2$ and a horizontal tail area of 149.7 cm$^2$. From these areas, the dimensions of the tail surfaces were determined through simple geometric manipulation.
4.2 Pitch Stability

Evaluating the stability of our aircraft during flight involves the calculation of two critical points. These are the center of gravity, $X_{CG}$, and the neutral point, $X_{NP}$. The center of gravity is determined by:

$$X_{CG} = \frac{1}{M} \sum(W \cdot d) \quad (10)$$

$W$ is weight and $d$ the distance from the aircraft nose. These values were measured once a preliminary model was completed. Using these measurements and equation 10, $X_{CG} = 12.5$ cm from the nose cone. The equation for the neutral point is:

$$0 = (X_{CG} - X_{ACW}) - \eta \cdot \frac{S_h}{S_w} \cdot \frac{C_{Law}}{C_{Law}} \cdot \frac{d_{alh}}{d_a} \cdot (X_{ACH} - X_{CG}) \quad (11)$$

where $X_{CG}$ is set equal to $X_{NP}$ when solving the equation. In the case of this aircraft,

$$S_w \equiv Wing Area = 0.0625m^2$$

$$S_h \equiv Horizontal Tail Area = 0.0175m^2$$

$$\eta = 0.9$$

$$\frac{d_{alh}}{d_a} = 1 - \frac{2}{\pi AR_w} \cdot C_{Law} \quad (12)$$

$$X_{ACW} = 0.15 + \frac{c}{4} = 0.08m \text{ (measured)}$$

$$X_{ACH} = 0.40m \text{ (measured)}$$

Solving for $X_{CG}$ gives a neutral point of $X_{NP} = 13.9$ cm. With this data we used equation 13 to calculate the static margin:

$$Static Margin = \bar{X}_{NP} - \bar{X}_{CG} = \frac{X_{NP} - X_{CG}}{c} \quad (13)$$

$$\bar{c} = Mean \ Aerodynamic \ Chord$$
The mean aerodynamic chord is simply the chord of the wing as it is not tapered. This yields a static margin of about 11.4%. Because the center of gravity is forward of the neutral point, the aircraft is stable during flight.

4.3 Wind Tunnel Testing

After preliminary calculations indicated the necessary lift coefficient needed for flight, tests were begun to determine how experimental data would match theoretical results. The team used the subsonic wind tunnel in the Fluids Lab in Higgins Laboratory which has a 2’x2’ cross section. A force balance mechanism [1] was used to collect lift drag and data, as depicted below:

![Figure 10: Force Balance Arrangement for Drag (Calibration Configuration)](image-url)
Because the initial design for our aircraft had a two meter span, we had to scale down the size of the wing for our wind tunnel models. At the time of testing, we were still unsure on which wing design we were going to move forward with and so we made both semi-circular and rectangular wing models. The dimensions of the full-scale wings are shown in Table 2:

<table>
<thead>
<tr>
<th></th>
<th>Rectangular Wing</th>
<th></th>
<th>Semi-Circular Wing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Span</td>
<td>2 m</td>
<td>1.5 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord</td>
<td>0.5 m</td>
<td>0.75 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>1 m²</td>
<td>0.883 m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>4</td>
<td>2.55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Full-scale Wing Dimensions

The rectangular wing was scaled down to a quarter of its size and the semi-circular wing was scaled down to a third of its size in order to fit in the wind tunnel cross-section. The team ultimately decided to move forward with the rectangular wing design as it has a higher aspect
ratio and output the best data of the two during wind tunnel testing. Once we had decided to scale down our aircraft to a 0.5 meter wing span we concluded that the raw wind tunnel data was still valid because the model used was also 0.5 meters.

Three wind tunnel tests were carried out for different angles of attack using the procedure found in the report for the Human Powered Helicopter MQP. The tunnel velocity was set to 6 hertz (approx. 6.5 meters per second). That velocity was chosen because the initial flight velocity calculation yielded a velocity of 6.5 meters per second. The resulting data is tabulated below:

<table>
<thead>
<tr>
<th>AOA (°)</th>
<th>F1 (g)</th>
<th>F2 (g)</th>
<th>Lift (N)</th>
<th>Cl</th>
<th>F3 (g)</th>
<th>Drag (N)</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>23.9</td>
<td>-28.5</td>
<td>1.15</td>
<td>0.54</td>
<td>-14.4</td>
<td>1.02</td>
<td>0.48</td>
</tr>
<tr>
<td>3</td>
<td>19.9</td>
<td>-40</td>
<td>0.89</td>
<td>0.42</td>
<td>-23.2</td>
<td>0.66</td>
<td>0.31</td>
</tr>
<tr>
<td>5</td>
<td>36.8</td>
<td>-72.2</td>
<td>1.48</td>
<td>0.70</td>
<td>-37.2</td>
<td>0.60</td>
<td>0.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Semi-circular Wing</th>
<th>Lift Data</th>
<th>Drag Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOA (°)</td>
<td>F1 (g)</td>
<td>F2 (g)</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>0</td>
<td>41.2</td>
<td>-68</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
<td>-77</td>
</tr>
<tr>
<td>5</td>
<td>52.6</td>
<td>-90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rectangular Wing</th>
<th>Lift Data</th>
<th>Drag data</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOA (°)</td>
<td>F1 (g)</td>
<td>F2 (g)</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>0</td>
<td>26</td>
<td>-25</td>
</tr>
<tr>
<td>3</td>
<td>30.9</td>
<td>-48.1</td>
</tr>
<tr>
<td>5</td>
<td>33.1</td>
<td>-54.8</td>
</tr>
</tbody>
</table>

Table 3: Trial 1 Wind Tunnel Data
### Table 4: Trial 2 Wind Tunnel Data

<table>
<thead>
<tr>
<th>AOA (°)</th>
<th>F1 (g)</th>
<th>F2 (g)</th>
<th>Lift (N)</th>
<th>Cl</th>
<th>F3 (g)</th>
<th>Drag (N)</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24.6</td>
<td>-21.4</td>
<td>1.01</td>
<td>0.48</td>
<td>-26.1</td>
<td>0.76</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>29.3</td>
<td>-44.3</td>
<td>1.09</td>
<td>0.52</td>
<td>-64</td>
<td>0.52</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>31.9</td>
<td>-56.5</td>
<td>1.20</td>
<td>0.57</td>
<td>-69.5</td>
<td>0.32</td>
<td>0.15</td>
</tr>
</tbody>
</table>

### Table 5: Trial 3 Wind Tunnel Data

<table>
<thead>
<tr>
<th>AOA (°)</th>
<th>F1 (g)</th>
<th>F2 (g)</th>
<th>Lift (N)</th>
<th>Cl</th>
<th>F3 (g)</th>
<th>Drag (N)</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24</td>
<td>-31.7</td>
<td>1.22</td>
<td>0.69</td>
<td>-52</td>
<td>0.75</td>
<td>0.56</td>
</tr>
<tr>
<td>3</td>
<td>22.3</td>
<td>-43.4</td>
<td>0.98</td>
<td>0.72</td>
<td>-64.3</td>
<td>0.41</td>
<td>0.31</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>-47.1</td>
<td>0.94</td>
<td>0.90</td>
<td>-72.7</td>
<td>0.17</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Figures 12 and 13 show the linear relation between the lift coefficient and angle of attack of our rectangular and semi-circular wing designs:

![C_L vs. AOA for Semi-circular Wing](image-url)
An average of the lift and drag coefficients for the rectangular wing at a five degree angle of attack is shown in the table below:

<table>
<thead>
<tr>
<th>Trial</th>
<th>$C_L$</th>
<th>$C_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>1.43</td>
<td>0.660</td>
</tr>
<tr>
<td>Trial 2</td>
<td>0.740</td>
<td>0.160</td>
</tr>
<tr>
<td>Trial 3</td>
<td>0.69</td>
<td>0.130</td>
</tr>
<tr>
<td>Average</td>
<td>0.715</td>
<td>0.145</td>
</tr>
</tbody>
</table>

Table 6: Wind Tunnel Test Results

The team decided to exclude trial 1 from the average because it is an obvious outlier, given the magnitude of the values obtained in the following two trials. The team used equation 14 to substantiate the lift coefficient of 0.715:

$$c_{L\text{, measured}} \geq \frac{c_{L\text{, required}}}{(1 + \frac{A_D}{4})} = 0.593 \quad (14)$$

The result of the calculation of equation 14 led us to conclude that the lift coefficient obtained from our experimental data was sufficient.
4.4 Launcher Analysis

This section explains design, construction, and performance of the team’s prototype launcher.

4.4.1 Capabilities

Since this aircraft is a glider and has no on-board power source, it must achieve sufficient initial height from the launch. The absolute minimum travel distance around the course would be about 213.4 meters. The team chose a target altitude of 21.3 meters as a reasonable value to launch the aircraft to, based on expected glide ratios. To determine the amount of weight that could be launched to this height required knowledge of how much energy the tubing used in the launcher can store. The spring constant of the material was found experimentally by measuring the deflection of a length of tubing when a known weight was placed on it. This spring constant was found to be 73 N/m. The potential energy in a linear spring is:

\[ \frac{1}{2} kx^2 = mgh \quad (13) \]

Solving for the mass, \( m \), resulted in a weight of 0.159 kg. To test the performance of the launcher with this magnitude of load, a baseball weighing 0.145 kg was substituted in place of the aircraft. From reviewing videos of the test, the team estimated that the baseball reached 21.3 meters of altitude while also traveling about 45.72 meters horizontally. Thus, the team decided to build an aircraft with empty weight of 0.136 kg to carry a payload of 0.181 kg, resulting in an estimated total gross weight of 0.317 kg.

4.4.2 Performance

The maximum height attained from the team’s constructed launcher was close to 30 feet. This was only about 50% of the required altitude to complete the course. The launcher was
stable and no parts were damaged during repeated tests. The launch shuttle moved with very little friction and survived repeated impacts with the ground. It protected the aircraft well and as a result, the plane saw very little damage throughout flight testing.

4.4.3 Challenges

The team attained 25 to 30 feet of altitude from its launcher prototype. Much of this performance is due to the constraints placed on launcher design by the competition rules. The rules stated that the elastic must be a single tube, with maximum diameter of 0.5” and no parallel configurations allowed. Also because everything had to fit in the box, this limited our launcher size, more specifically how much stretch and energy we could fully harness from the elastic. These and other constraints make designing a fully capable launcher something to be explored further.

5.0 Fabrication

This section details the manufacturing process of the aircraft. It describes the final product, all materials used to make the models, and specialized tools that aided in the process.

5.1 Final Assembly

The size of the aircraft allows it to fit within the required dimensions without removing or changing any part of the configuration. Thus, the assembly process is reduced to installing the payload and battery, attaching the nose, and plugging in the receiver.
5.2 Construction Materials

The materials used throughout the aircraft are cheap, lightweight, and easy to work with. The wing spars and stiffeners are various diameter carbon fiber rods. The fuselage, tail, and control surfaces are all sheet balsa wood. The pull-pull lines connecting the servos to the control surfaces are sewing thread. The fuselage and tails are covered in a light weight heat shrink material. The wing is constructed from a combination of rip-stop nylon material and Dacron tape. Both of these materials are very common in the construction of kites. Hot glue was used extensively in the construction of the aircraft due to its ease of use and its cure time, allowing parts to be aligned before setting solid. Cyanoacrylate (CA) glue was used to fasten the vertical stabilizer to the horizontal stabilizer because the hot glue beads along the inside corners of the joint proved ineffective at bonding to the covering material. A small amount of the covering material was removed along the centerline of the horizontal surface, allowing the CA to soak into the balsa to provide a strong bond.

5.3 Tools Utilized

The only specialized tool required for producing this aircraft is a laser cutter, which the team had access to on campus. This was used to cut out the balsa shapes for the tails, control surfaces, and fuselage sides. While it is within the realm of possibility to construct the aircraft with careful application of a ruler and a hobby knife, the laser tool allowed for rapid, repeatable production of parts within very small tolerances. A heat-shrink iron is required to attach the coating to the balsa before shrinking it with a heat gun, although a soldering iron would be acceptable as well. A hot glue gun is also required, along with myriad other common items, such as a utility knife, scissors, a ruler, and a pen or pencil.
6.0 Flight Testing

After a prototype aircraft was completed, flight tests were conducted with it. First a lasso test was performed, in which the aircraft is tied to a string that extends along the span of one wing for several feet. The model is then swung around in a circle, which allows the pitch stability and control to be analyzed. After passing this test with adequate elevator control, free flight tests were performed. The aircraft was hand-tossed from an indoor balcony to a team member waiting below. During these glides, the aircraft exhibited good stability and control both longitudinally and laterally. The space used for testing was not large enough for turns to be attempted comfortably, so turning flight was not investigated.

7.0 SAE Deliverables

This section summarizes the design report that was submitted to the team’s advisors for entry into the SAE competition in accordance with its rules and regulations.

7.1 SAE Design Report

To complete a valid entry in the SAE competition, a specialized design report is submitted to SAE roughly a month before the event is to take place. The report is limited to a maximum of thirty pages. It contains information regarding the aircraft, the design process, construction, and expected performance. The design presented in the SAE report must be identical to the aircraft flown at the event; else points are deducted from the team’s score. The team used the SAE reports from last year’s WPI entries as guidance to formulate a report for this aircraft.
8.0 Lessons Learned and Improvements

There are many details and methods seen in the project that future teams could build upon in order to facilitate the design process of creating a micro-class glider.

It is important to realize that the launcher and aircraft should be built in conjunction with each other rather than designing a glider and subsequently building a launcher for it. The team found the launcher to be the most integral part of a successful flight. Gaining altitude is the main driver for a glider and attaining the appropriate altitude should be the first priority.

The focus on having a folding wing mechanism turned out to be not nearly as important as originally thought. The lightest weight possible was necessary to determine maximum potential altitude. The added weight estimated at 22.2 grams would increase the empty weight by 15 percent. Furthermore, design and manufacturing complexity would require time to focus on construction while simultaneously reducing available flight-testing opportunities. The team determined that the small size of the aircraft produced minimal drag therefore the additional weight of a folding system would hinder the maximum possible altitude gain. Future improvements include incorporating the folding mechanism to understand its flight performance, differential elevators on the tail for better turning stability, and redesigning the nose cone to be able to withstand impact more effectively.

The use carbon fiber rods for the spars and of fabric for the wings were both exceptional weight savers. The high wing design contributed to a very stable aircraft as well. The glider’s simple design contributed to both its durability and its ease of manufacture. These characteristics allowed many launch tests to be conducted for each given model without. The strength and
durability of the materials successfully prevented structural failure from the significant launch and impact forces.

Based on comparisons to the performance of Cedarville University the designed glider showed more potential for total attainable height and flight performance. There are still many changes and improvements that need to be made to this design in order to create a viable competitor for the SAE design competition.

9.0 Conclusions

The purpose of this project was to design and manufacture a micro aircraft glider and launcher with a high payload fraction that met the design criteria set by the SAE Aero design competition guidelines.

At the conclusion of the project, the team’s final design did not attain the necessary altitude required to successfully navigate through the SAE flight course. This shortcoming can be directly attributed to the constraints of the launcher design. The use of a single elastic tube and the size limitation of the launcher were the foremost obstacles the design team had to overcome. The maximum height reached by the launcher was near 30 feet, which was close to 50% of the desired altitude. The final flight test data proved that the current launcher design had to be radically changed and improved in order to double the maximum height.

The aircraft itself was very successful in terms of weight and performance. The design called for a small and durable aircraft capable of achieving a high glide ratio and able to withstand the extreme launch forces. Our aircraft met both of these standards with a final empty weight of 0.35 pounds and a glide ratio of about 6.
Due to time constraints, the team was not able to redesign the launcher however; the results and conclusions drawn from the project can be built upon in continuing years if the gilder design concept sustained.
References


