Final Presentation for the Morphing Wing Design Team

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The goal for this semester was to build a R/C airplane with a morphing wing wing.

The wings will be able to morph to loiter, maneuver, dash, and landing.

This will be accomplished with chord, sweep, and span changes.

Last semester’s results help our team in the design process.
The work presented identifies the process used to design and build a morphing aircraft.

Actuation → Sizing and structures → Aerodynamics
The span extension is operated using a pull-pull method actuated by a winch servo and fishing line.

A large control horn is counter wrapped with fishing line.

When rotated, one line unwraps while the other winds up.

Which ever side winds up pulls the extension in or out of the wing.
The span extension is operated using a pull-pull method actuated by a winch servo and fishing line.
The change in camber is produced by a flap that is actuated by a servo

The flap rotates downward and increases the camber

A servo moves a flexible pushrod in or out

The flexible pushrod extends or retracts the Fowler flap
The sweep is actuated by a motor driven power screw

A DC motor drives a power screw through a Hooke’s coupling

A transverse nut travels up or down the screw length

Push rods retract, rotate and increase the sweep angle
The electric motor was sized using power screw equations

The approximated maximum load on the power screw was 20 lbs

\[ T_{\text{raise}} = \frac{Fd_m}{2} \left( \frac{l + \pi f d_m}{d_m - fl} \right) \]

If the screw was self locking no holding torque would be required

\[ \pi f d_m > l \]

[www.towerhobbies.com]
The sweep actuation electrical system is made possible through use of Zener Diodes

An electronic speed controller regulates the speed of the motor

Zener diodes act as check valves allowing current to flow one way

This allows the motor to reverse direction with the kill switches engaged
The core of the sweep actuation is located within the carbon fiber wing box

The wing box was cut from 1/8” plywood

One side of each plate was covered with carbon fiber

The plates are separated by 1 1/2” long PVC spacers

A carbon fiber rod was added across the pivot points to increase strength
The wing box and power screw are combined to form the sweep mechanism

The motor mounts were made from prefabricated sheet metal

The transverse nut travels 6 1/2” to sweep the wing a full 45°

With the motor running at 1200 RPM it takes 5.5s to sweep

The carbon fiber plates are connected with nylon bolts
The wing box and power screw are combined to form the sweep mechanism.

The motor mounts were made from prefabricated sheet metal.

The transverse nut travels 6 1/2” to sweep the wing a full 45°.

With the motor running at 1200 RPM it takes 5.5s to sweep.

The carbon fiber plates are connected with nylon bolts.
After final assembly the wing can sweep back to a maximum angle of 45 degrees
The aircraft was divided into seven components to estimate the total weight.

The seven components which make up the aircraft are:

1. Propulsion
2. Main wing
3. Fuselage and tail
4. Landing gear
5. Radio control system
6. Actuation system
7. Instrumentation system

The weight of each component is estimated by obtaining the weight of each part which make up the component. If the weight of a part cannot be obtained, an estimation was made using a similar part.

Note: Part names followed by * indicate weight estimations
The estimated total aircraft weight was between 12.91 – 14.91 lbs

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>3.65</td>
</tr>
<tr>
<td>Main wing</td>
<td>3.63</td>
</tr>
<tr>
<td>Fuselage and Tail</td>
<td>1.56</td>
</tr>
<tr>
<td>Landing gear</td>
<td>1.41</td>
</tr>
<tr>
<td>Radio control system</td>
<td>1.13</td>
</tr>
<tr>
<td>Actuation System</td>
<td>1.53</td>
</tr>
<tr>
<td>Instrumentation System</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The total aircraft weight varies depending on the use of the instrumentation system for data acquisition.
Aircraft engine sizing based on data for existing aircraft

Engine size vs. Weight

To achieve a similar performance as the scale model planes used in this plot, an O. S. 1.4 engine is ideal. However, the engine that is currently available can be used with a reduced performance.
Wing airfoil and geometry selection

The Clark-Y airfoil was chosen for its flat lower surface.

Geometric properties of the Clark-Y airfoil

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chord</td>
<td>c</td>
</tr>
<tr>
<td>Maximum camber</td>
<td>0.03435 c</td>
</tr>
<tr>
<td>Location of max camber</td>
<td>0.42 c</td>
</tr>
<tr>
<td>Maximum thickness</td>
<td>0.117 c</td>
</tr>
<tr>
<td>Location of max thickness</td>
<td>0.29 c</td>
</tr>
<tr>
<td>Circumference</td>
<td>2.04 c</td>
</tr>
<tr>
<td>Circumference to Chord ratio</td>
<td>2.04 c</td>
</tr>
</tbody>
</table>
The wing dimensions were calculated based on specific goals and constraints

Goals, requirements and constraints:

Take-off speed range: 30 – 35 mph
Take-off velocity equation:

\[ V_{LO} = 1.2V_{stall} = 1.2 \sqrt{\frac{2W}{\rho \infty SC_{L,max}}} \]

where: \( W = 14.91 \text{ lb} \) (from weight estimation)
\( C_{L,max} = 1.3 \) (estimation based on WT data + flap effect)

Aspect ratio \( \sim 5 , 6 \) \( \text{AR} = b^2/S \)

Wing loading limit: \( W/S < 2.6 \text{ lb/ft}^2 \)

→ Result: span \( b = 5’6” \), chord \( c = 13” \) which gives:

\( V_{LO} = 33.9 \text{ mph} \); \( \text{AR} = 5.08 \) and \( W/S = 2.50 \text{ lb/ft}^2 \)
The wing dimensions were calculated based on specific goals and constraints.
The span extension was designed to achieve a high aspect ratio for loiter configuration

- Constraint: chord of extension \( c_e \) limited to 8.625 in (66% of the wing chord) by space necessary for ailerons, flaps and structure

- Objective: 50% increase in span or more likely \( AR_l \sim 9 \)

\[
AR_l = \frac{b^2}{S_l} = \frac{[(1 + x)b]^2}{bc + xb(0.66c)} \quad \Rightarrow \quad \frac{(1 + x)^2}{1 + 0.66x} = \frac{AR_l}{AR}
\]

solving for \( x \) with \( AR_l/AR = 9/5.08 \) gives: \( x = 0.56 \)

\( b_l = 8'7" \) \( \rightarrow \) span increase: 56% , AR increase: 77%

Result: extension dimension: \( c' = 8.625" \) and \( b' = 21" \)
- when fully extended: 18.5" out and 2.5" in
- when fully retracted: 4" free space for actuations
## Resulting wing dimensions

<table>
<thead>
<tr>
<th>Wing Area $S$ (in²)</th>
<th>Span $b$ (in)</th>
<th>Mean Geometric Chord $c'$ (in)</th>
<th>Aspect Ratio $AR$</th>
<th>Mean Aerodynamic Chord $c_a$ (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span-extension fully in</td>
<td>858</td>
<td>66</td>
<td>13</td>
<td>5.08</td>
</tr>
<tr>
<td>Span-extension fully out</td>
<td>1177.1</td>
<td>103</td>
<td>11.43</td>
<td>9.01</td>
</tr>
</tbody>
</table>
The pivot point location was determined to align the wing LE with the casing at maximum sweep.

Distance from pivot point P to root chord:

\[ x = \frac{c / 4}{\tan(67.5^\circ)} = 1.346" \]

Also from geometry, the distance from the root TE for 45° sweep to the root chord line for 0° sweep is: \( d = 7.289" \)

→ thus we opted for a wing casing width of 16"
Tail sizing was based on empirical techniques and refined by stability analysis

- An initial estimation of the tail size was obtained using the “tail volume coefficient” method given by Raymer:

\[ S_{VT} = c_{VT} b_w S_w / L_{VT} \quad S_{HT} = c_{HT} \bar{c}_w S_w / L_{HT} \]

- The results were refined using VLMpcjective: 50% increase in span or more likely ARi ~ 9
After the analysis the final fuselage dimensions could be determined.

![Diagram of fuselage with dimensions labeled: Engine compartment, Forward compartment, 5", 2", 5", 62.5", 40", 10.5".](image)
An all-moving tail was chosen to trim the backward shift of the aerodynamic center in sweep

- The all-moving tail provides a tremendous down load necessary to balance the aircraft in its swept configuration.

- The other control surfaces were sized based on historical guidelines:
  - the aileron extends from about 50% to 90% of the wing span, has a span of 14” and a chord of 3” (23% of the wing chord).
  - the rudder is 40% of the tail chord, begin at the side of the fuselage and extends all the way to the tip of the tail.
The fuselage was designed to support the wing, the tail, the landing gear and the engine.

The main purpose of a conventional fuselage is to carry cargo.

In this case the fuselage was designed to support the morphing wings.
The wing was supported by a series of three bulkhead pairs

The bulkhead pairs were connected by nylon bolts

These bolts also attached the wing box to the fuselage

The forward, center and aft bulkheads used 6, 7 and 4 nuts respectively
The tail loads were carried by the aft fuselage

Four balsa bulkheads support the aft fuselage

The loads are transferred between the bulkheads by 1/8 inch balsa sheets and sticks

The tail is connected to the fuselage by a ¼ inch carbon fiber rod

The rod passes through two 1/8 inch balsa sheets positioned 2 inches apart
The landing loads were carried by the baseboard and the landing gear

The landing loads are shared by the baseboard and the gear

The corners of the main gear are reinforced to provide greater shock control

The main landing gear was attached --- in. from the nose
The engine loads were carried by the firewall

The engine mount was attached to the firewall by four 1/8” bolts

The firewall was made from a ¼” plywood sheet

The firewall was attached to the baseboard, a 1/8” plywood sheet, as well as to the 1/8” balsa siding
As the wing morphs the AC and CG location move

Wing Extended Conf.:
- CG: Static
- AC: Moves forward

Wing Swept Conf.:
- CG: Slight Shift aft
- AC: Large Displacement aft
The mass of the swinging wing induces the displacement of the CG

\[ x_{cg}(\Lambda) = \frac{x_{fuselage} \times m_{fuselage}}{m_{total}} + \frac{[x_{w0} + r(sin(\Lambda + \theta) - sin(\theta))] \times m_{wing}}{m_{total}} \]

The locus of wing CG is displaced due to the rotation of the wing.
The morphing wing alters longitudinal stability characteristics

In the loiter configuration the aircraft will reach its least stable state

In dash configuration the aircraft will become heavily stable
The wing was designed to limit the negative impact on longitudinal stability

<table>
<thead>
<tr>
<th>Wing design Characteristic</th>
<th>Impact on Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Outboard pivot point</td>
<td>• Lower AC displacement by keeping a section of the wing static</td>
</tr>
<tr>
<td>• Wing Heavy (Relative to fuselage)</td>
<td>• This characteristic induced by the extension increases the CG displacement</td>
</tr>
</tbody>
</table>
Fuselage and tail design decisions were driven by the stability constraints

<table>
<thead>
<tr>
<th>Driving Stability Characteristic</th>
<th>Design Decision</th>
<th>Effects</th>
</tr>
</thead>
</table>
| Displacement of AC in sweep | • Large wing/tail distance | • Increased level arm for longitudinal control  
• Lower forces required by HT to trim. |
| Important static margin in sweep | • Full deflecting HT  
• Large HT surface | • Increased force range for control and trim  
• Capacity to balance moment induced by static margin in sweep |
| Variable CG location | • Fuel tank placed at 0 sweep CG location | • No effect in loiter and maneuver configuration  
• Positive effect in dash conf. (displacement aft of CG with fuel usage) |
In conclusion, the aircraft will be flight ready by Wednesday morning

The fuselage is nearly complete

The control surfaces are built and ready to fly

The actuation must be added last