The Wright Stuff

UGRADS Technical Presentation
April 26, 2013

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Agenda

• Competition Overview
• Team Process
• Budget
• Configuration Selection
• Preliminary Analysis
• Performance Analysis
• Flight Testing
• Competition Objectives & Results
• Lessons Learned
Competition Overview

• Customer
  – Society of Automotive Engineers (SAE)

• Project
  – Aero Design West Competition
  – Self-motivated, self-funded project
  – Test of individual and group capabilities
Problem Statement

• Needs Identification
  – Current remote controlled aircraft do not carry sufficient payload

• Goals
  – Introduce precision manufacturing techniques into RC aircraft design
  – Maximize the payload capacity of an aircraft within the requirements laid out by SAE
Design Constraints

• **Mission Objectives**
  – Technical Presentation
  – Flight Demonstration

• **Design Limitations**
Design Limitations

<table>
<thead>
<tr>
<th>R1</th>
<th>Aircraft must lift from the ground within a take-off distance of 200 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>Aircraft must successfully complete one 360 degree circuit of the field</td>
</tr>
<tr>
<td>R3</td>
<td>Aircraft must touch down and land within 400 feet</td>
</tr>
<tr>
<td>R4</td>
<td>Aircraft must remain intact during takeoff and landing</td>
</tr>
<tr>
<td>R5</td>
<td>Aircraft shall not exceed a combined length, width and height of 225 inches</td>
</tr>
<tr>
<td>R6</td>
<td>Aircraft may not weigh more than 65 pounds with payload and fuel</td>
</tr>
<tr>
<td>R7</td>
<td>Aircraft components may not consist of any fiber-reinforced plastic or lead</td>
</tr>
<tr>
<td>R8</td>
<td>Either an O.S. 61FX or a Magnum XLS-61A engine must be used</td>
</tr>
</tbody>
</table>
Team Process

• Design Philosophy
  – Sound conceptual design
  – Thorough engineering analysis
  – Precision manufacturing techniques
Team Process

The Wright Stuff

Design & Construction
- Aerodynamics
- Propulsion

Structural
- Manufacturing

Management
- Budgeting
- Scheduling
## Team Process

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
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</thead>
<tbody>
<tr>
<td>Senior Design</td>
<td>Wed 8/1/12</td>
<td>Sat 5/4/13</td>
</tr>
<tr>
<td>Conceptual Design Phase</td>
<td>Mon 9/24/12</td>
<td>Fri 10/19/12</td>
</tr>
<tr>
<td>Register for Competition</td>
<td>Tue 10/2/12</td>
<td>Tue 10/2/12</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Fri 10/19/12</td>
<td>Thu 1/10/13</td>
</tr>
<tr>
<td>Meet Fundraising Goal</td>
<td>Mon 10/29/12</td>
<td>Mon 10/29/12</td>
</tr>
<tr>
<td>Preliminary Design Review</td>
<td>Sun 11/11/12</td>
<td>Sun 11/11/12</td>
</tr>
<tr>
<td>Construction</td>
<td>Fri 1/11/13</td>
<td>Fri 3/1/13</td>
</tr>
<tr>
<td>Critical Design Review</td>
<td>Fri 3/1/13</td>
<td>Fri 3/1/13</td>
</tr>
<tr>
<td>Flight Test</td>
<td>Sat 3/2/13</td>
<td>Sat 3/2/13</td>
</tr>
<tr>
<td>Flight Test 2</td>
<td>Sat 3/30/13</td>
<td>Sat 3/30/13</td>
</tr>
<tr>
<td>SAE Aero Competition</td>
<td>Thu 4/11/13</td>
<td>Mon 4/15/13</td>
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## Budget & Expenses

<table>
<thead>
<tr>
<th>Type</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Budget</td>
<td>$1,835</td>
</tr>
<tr>
<td>Travel Budget</td>
<td>$2,250</td>
</tr>
<tr>
<td>Competition Budget</td>
<td>$870</td>
</tr>
<tr>
<td><strong>Total Budget</strong></td>
<td><strong>$5,000</strong></td>
</tr>
<tr>
<td>Expenses</td>
<td>$4901</td>
</tr>
<tr>
<td>Remaining Budget</td>
<td>$98.57</td>
</tr>
</tbody>
</table>
Configuration Selection

- **Wing**
  - Hybrid square/elliptical
  - High placement
  - Aspect Ratio = 7.5
  - Dihedral
  - Acrylonitrile Butadiene Styrene (ABS) additive manufactured ribs
Configuration Selection

• Tail
  – Conventional
  – Minimize weight without sacrificing stability

  ![T-Tail](image1.png)  ![No tail](image2.png)  ![Conventional](image3.png)

• Landing Gear
  – Tail Dragger
  – High propeller clearance
  – Induces natural angle of attack
  – Minimizes weight

• Propulsion Installation
  – Front mounted
  – Induces desired center of gravity
  – “Clean” air intake
Preliminary Analysis

- Based on legacy documentation [3]
  - Airfoils: E423 and S1223
  - Traveling velocity = 30 ft/s
  - Re = 200,000
  - Elevation = 800 ft
  - Air density = 0.0023 slug/ft$^3$
  - Total plane weight = 35 lb
Preliminary Analysis

- L/D ratio up to 15% higher for S1223
- Optimal L/D ratio at approximately 5°
- $c_L$ ranges between 1.2 and 1.5

**Lift Coefficient Comparison**

**Lift-to-Drag Comparison**
Vehicle Sizing

- Wing Sizing (Airplane Width)
  - Input assumed values for $c_L$, $\rho$, and $V$ into below equations [5]

$$L' = c_L \times \frac{1}{2} \times \rho \times V^2 \times \text{chord}$$

$$L = L' \times \text{wingspan}$$

- Iterate chord and wingspan values until desired result is met
  - Lift matches target airplane weight (35 lb)
  - Aspect ratio is acceptable (7.5)
Vehicle Sizing

- Fuselage Sizing (Airplane Length)

- Mimic the profile of a NACA 0012 [6]
Vehicle Sizing

• Landing Gear Sizing (Airplane Height)
• Results
  – Width = 90 in
  – Length = 56 in
  – Height = 17 in
  – Total = 90 + 56 + 17 = 163 inches < 225 inches
Propulsion

- Magnum XLS-61A engine selected per SAE requirements
- Propeller manufacturer guidelines for choosing diameter range [6]
Propulsion

- Static thrust testing
- 14X4 provided the most static thrust
  - Seemed to stress the engine a bit
- When in motion, the thrust will decrease
- 14X4 propeller will be used

<table>
<thead>
<tr>
<th>Propeller</th>
<th>RPM</th>
<th>Thrust (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11X7</td>
<td>11,400</td>
<td>5.51</td>
</tr>
<tr>
<td>12X7</td>
<td>10,000</td>
<td>5.22</td>
</tr>
<tr>
<td>13X4</td>
<td>10,500</td>
<td>7.28</td>
</tr>
<tr>
<td>14X4</td>
<td>9,300</td>
<td>8.16</td>
</tr>
</tbody>
</table>
Performance Analysis

• Drag Estimation

\[ C_D(C_L) = \sum C_{D_{\text{min}}} + K'C_L^2 + K''(C_L-C_{L_{\text{min}}})^2 \] [7]

\[ C_D = 0.07559 + 0.0475C_L^2 + 0.01715(C_L - 1.1221)^2 \]
Performance Analysis

• Takeoff Performance

\[ S_{LO} = \frac{1.44W^2}{g\rho_{\infty}SCL_{max}\{T-[D+\mu_r(W-L)]_{ave}\}} \]  [5]

\[ W_{max} = 12.78 - (2.273 \times 10^{-4})h \]

\[ W(800 \text{ ft}) = 12.60 \text{ lb} \]

– Iterative MATLAB code solves for airplane weight for a sweep of air density values
– After subtracting the empty airplane weight, the payload weight is found
Stability

• Pitch
  – $V_H$ of 0.3-0.6 is needed [8]
  – Our $V_H = 0.55$

• Roll
  – Dihedral angle of 3° provides spiral stability
Control

- Control Surfaces
  - Based on ratios between wing/stabilizers and respective control surface
    - Planform Area (S)
    - Total Span (b)
    - Chord Width (C)
Control

- Aileron

<table>
<thead>
<tr>
<th></th>
<th>Typical [9]</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_a/S$</td>
<td>0.05-0.1</td>
<td>0.11</td>
</tr>
<tr>
<td>$b_a/b$</td>
<td>0.2-0.3</td>
<td>0.38</td>
</tr>
<tr>
<td>$C_a/C$</td>
<td>0.15-0.25</td>
<td>0.29</td>
</tr>
<tr>
<td>$\delta_{A_{max}}$</td>
<td>$\pm 30^\circ$</td>
<td>$\pm 25^\circ$</td>
</tr>
</tbody>
</table>
Control

• Elevator

<table>
<thead>
<tr>
<th></th>
<th>Typical [9]</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_E/S_h$</td>
<td>0.15-0.4</td>
<td>0.26</td>
</tr>
<tr>
<td>$b_E/b_h$</td>
<td>0.8-1</td>
<td>1</td>
</tr>
<tr>
<td>$C_E/C_h$</td>
<td>0.2-0.4</td>
<td>0.39</td>
</tr>
<tr>
<td>$\delta_{E_{max}}$</td>
<td>±20°</td>
<td>±20°</td>
</tr>
</tbody>
</table>
Control

- Rudder

\[ \frac{S_R}{S_V} \]

<table>
<thead>
<tr>
<th>Typical* [9]</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{S_R}{S_V} )</td>
<td>0.19-0.24</td>
</tr>
<tr>
<td>( \frac{C_R}{C_V} )</td>
<td>0.2-.25</td>
</tr>
<tr>
<td>( \delta_{Rmax} )</td>
<td>±30°</td>
</tr>
</tbody>
</table>

*Empirically derived
Control

• Servo Sizing
  – Torque Equation

\[ T(oz - in) = 8.56 \times 10^{-6} \left( \frac{C^2 V^2 L \sin(S_1)}{\tan(S_2)} \right) \] [10]

- \( C \) = Control Surface Chord
- \( V \) = Max Velocity
- \( L \) = Control Surface Length
- \( S_1 \) = Maximum Control Surface Deflection
- \( S_2 \) = Max Servo Deflection

<table>
<thead>
<tr>
<th></th>
<th>Calculated (oz-in)</th>
<th>Actual (oz-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aileron</td>
<td>31.4</td>
<td>42.0</td>
</tr>
<tr>
<td>Elevator</td>
<td>28.7</td>
<td>42.0</td>
</tr>
<tr>
<td>Rudder</td>
<td>47.27</td>
<td>72.0</td>
</tr>
</tbody>
</table>
Weight Buildup

- Initial weight estimate = 10 lb
- Final airplane weight = 10 lb
- Use of commercial-grade Al honeycomb as fuselage centerpiece
- Cut holes in stabilizers, bulkheads, and ribs to reduce weight
- Center of Gravity was placed at 22% of the wing chord
  - Slightly forward from standard 25% approximation
  - Highly-cambered airfoil [11]
Materials

• Acrylonitrile Butadiene Styrene (ABS)
  – Used for ribs, cowling, and ailerons
  – 3D printed for precise manufacturing and customization

• Aluminum Honeycomb
  – Connection point between fuselage, wings, landing gear, and payload
  – High strength-to-weight ratio
Stress Analysis

- **Spars**
  - Treated as cantilevered beam with distributed load

- **Landing Gear**
  - Utilized COSMOS FEA software
Flight Testing

• Initial
  – Location
    • Flagstaff, AZ
  – Elevation
    • 7,000 ft
  – Inspired several design changes:
    • Larger horizontal stabilizer
    • Reduced angle of attack
    • Added dihedral angle
    • Propeller size increased
Flight Testing

- Final
  - Location
    - Leupp, AZ
  - Elevation
    - 4,400 ft
  - Multiple test flights with varying weights
    - Empty to 10.5 lbs
Competition Objectives

• Mission Strategy
  – Empty weight flight
    • 10 points
  – Flight with a load very near to prediction
    • FS + PPB = 74.0336
  – Empty flights for remainder to maximize Ao ➔ i
    • i = 1.15
Competition

• Flight Results
  – Flight 1: Empty
  – Flight 2: 13.8lb
  – Flight 3: Empty
  – Flight 4: 6.9lb
  – Flight 5: 13.8lb
  – Flight 6: 6.9lb
Competition

- 1st place Technical Presentation
- 14th Overall Score
Lessons Learned

• Start design & build processes early
• Research fundamentals of aircraft design
  o Center of gravity location and aircraft stability
• Emphasize testing over conceptual perfection
• Problem Identification
  o Thorough understanding of aircraft components
  o Effective communication between pilot and crew
• Take advantage of allotted dimensions
Acknowledgements

• Pilot
  – Chuck Hebestreit

• Academic Advisors
  – Dr. John Tester
  – Dr. Tom Acker

And our sponsors...
References


Questions?

“The exhilaration of flying is too keen, the pleasure too great, for it to be neglected as a sport”
-Orville Wright
Performance Analysis

- **Takeoff Performance**

\[ S_{LO} = \frac{1.44W^2}{g\rho_\infty SC_{Lmax}\{T-[D+\mu_r(W-L)]_{ave}\}} \]  \[ [5] \]

\[ W = \sqrt{\frac{S_{LO}g\rho_\infty SC_{Lmax}\{T-[D+\mu_r(W-L)]_{ave}\}}{1.44}} \]

- Iterative MATLAB code solves for airplane weight for a sweep of air density values
- After subtracting the empty airplane weight, the payload weight is found

\[ S_{LO} \equiv \text{Takeoff Distance} \]
\[ W \equiv \text{Airplane Weight} \]
\[ g \equiv \text{Acceleration due to Gravity} \]
\[ \rho_\infty \equiv \text{Air Density} \]
\[ S \equiv \text{Wing Planform Area} \]
\[ C_{Lmax} \equiv \text{Maximum Lift Coefficient} \]
\[ T \equiv \text{Static Thrust} \]
\[ D \equiv \text{Total Drag} \]
\[ \mu_r \equiv \text{Rolling Friction Coefficient} \]
\[ L \equiv \text{Total Lift} \]
Stability

• Longitudinal

\[ V_H = \frac{S_H l_H}{S c} \] [8]

- \( V_H \) of 0.3-0.6 is needed [8]
- Our \( V_H = 0.55 \)

• Spiral

- Dihedral angle of 3° provides spiral stability