Team Members

Atalla Buretta ............ Materials
Ryan Fowler .............. Propulsion
Matt Germroth .......... Weights, Materials
Brian Hayes .............. Structures
Timothy Miller .......... Aerodynamics, Stability & Control
Evan Neblett ............. Configuration Design
Matt Statzer ............. Leader, Systems, Mission analysis
The Lemming Concept

Premise:
• Provide a low-cost, expendable reconnaissance platform
• Alternative to more expensive existing UAV systems
• Incorporate aerial launch capability
• Designed for the US Navy

Rationale:
• UAV will be used for high risk missions
• Current UAVs have high loss rates
• Aerial launch allows greater service range & extended time on station
• Not returning to base provides greater time over target
Request for Proposal (RFP)

To create a “cheap” UAV with the following characteristics:

• Launch or drop via air vehicle
• Carry 50 pound payload
• Fly for 5 hours on a circuit (pre-determined or directed)
• Crash
Design Team Requirements

- Navy aircraft Launch capability (primary or secondary)
- Cruise altitude of 5,000 feet
- Minimum ceiling of 10,000 feet
- Speed range of 65 - 140 knots
- 30-minute positioning time (launch to station)
- 5-hour loiter time
- 200 fpm ROC at 5,000 feet
Project Drivers

- Cost – (UAV must be expendable)
- Aerial Launch Capability
- Endurance Requirements
- Payload Requirements
UAV Concepts

Delta Wing

Team Lenning

Dimensions in inches

Delta Concept

February 2, 2003
UAV Concepts

Folding Wing
UAV Concepts

Scissor Wing

<table>
<thead>
<tr>
<th>Team Lemming</th>
<th>Scissor Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions in Inches</td>
<td>February 2, 2003</td>
</tr>
</tbody>
</table>
Selection of Preferred Concept

Detailed analysis of the 3 concepts yielded the following data

<table>
<thead>
<tr>
<th>FOMs</th>
<th>Delta</th>
<th>Folding</th>
<th>Scissor</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Weight (lbs)</td>
<td>193</td>
<td>187</td>
<td>187</td>
<td>189</td>
</tr>
<tr>
<td>Manufacturing Costs</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5.7</td>
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<tr>
<td>( C_d ) at Loiter</td>
<td>0.0861</td>
<td>0.0498</td>
<td>0.0498</td>
<td>0.0619</td>
</tr>
<tr>
<td>Power Required (hp)</td>
<td>7.29</td>
<td>4.21</td>
<td>4.21</td>
<td>5.24</td>
</tr>
</tbody>
</table>

**Normalized Selection Matrix**

<table>
<thead>
<tr>
<th>FOMs</th>
<th>Delta</th>
<th>Folding</th>
<th>Scissor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(4) Weight (lbs)</td>
<td>1.021</td>
<td>0.989</td>
<td>0.989</td>
</tr>
<tr>
<td>(5) Manufacturing Costs</td>
<td>1.059</td>
<td>1.235</td>
<td>0.706</td>
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<tr>
<td>(2) ( C_d ) at Loiter</td>
<td>1.392</td>
<td>0.804</td>
<td>0.804</td>
</tr>
<tr>
<td>(3) Power Required (hp)</td>
<td>1.392</td>
<td>0.804</td>
<td>0.804</td>
</tr>
<tr>
<td>Total</td>
<td>16.338</td>
<td>14.155</td>
<td>11.508</td>
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</table>

**Conclusion:** Scissor wing concept is preferred design
Deployment

Parachute Assisted Drop Launch

1. Aircraft Ejection
2. Chute Stabilization Region
3. Nose Down Attitude
4. Controlled Descent Region
5. Chute Release
   Flight Surface Deployment
6. Pullout Region
7. Self-sustained Flight
Deployment

Boom Launch

1. Boom Storage
2. Boom Extension
3. UAV Release
4. Freefall Region
5. Flight Surface Deployment
6. Flight Entrance Region
7. Self-sustained Flight
Deployment

Tow Line Launch

1. UAV Release
2. Descent Region
3. Self-sustained Flight
Final 3-view

Dimensions in Inches

Team Lemming

Revision: 4

February 23, 2003
Final Inboard Dimensions

Team Lenning
Fuselage Dimensions
Revision 1.6
April 8, 2003

02/25/03
Final Inboard Profile

SECTION A - A
- 2-cycle Gasoline Engine
- Tail Servos
- Receiver
- 28V Batteries

SECTION B - B
- Payload
- Wing Pivot & Rotation Spring
- Transmitter
- Flight Control

SECTION C - C
- Fuel Tank

SECTION D - D

SECTION E - E

SECTION F - F

Team Lemming
Revision 6
Inboard Profile
April 17, 2003
Full Configuration

Structure
Flight Control
Payload
Electrical Power
Propulsion
Fuel
Wing Pivot
Communication
Aerodynamics

Mission:

- Airfoil Design and Selection
- Wing Optimization
- Drag / Climb estimation
Aerodynamics

Airfoil:

• Desired Characteristics
  • Flat Bottom
  • $C_{ICR} \geq 0.8$
  • Low $C_d$ at $C_{ICR}$
• Team designed Airfoil
  • Xfoil MDES used to shape pressure distribution
• Compared Drag Polars
  • Xfoil OPER viscous polar accumulation used ($Re = 8.8e5$, $M = 0.1231$)
• Considered Structural Acceptability
Aerodynamics

Airfoil Drag Comparison:

Drag Comparison of three CUAV airfoils

- Clark Y
- Midnight
- Last
Aerodynamics

Airfoil Profile Comparison:

<table>
<thead>
<tr>
<th></th>
<th>Midnight 1</th>
<th>Last</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>0.08643</td>
<td>0.08124</td>
</tr>
<tr>
<td>thick.</td>
<td>0.12428</td>
<td>0.11633</td>
</tr>
<tr>
<td>camber</td>
<td>0.04016</td>
<td>0.03535</td>
</tr>
<tr>
<td>( c_{LE} )</td>
<td>0.01331</td>
<td>0.01575</td>
</tr>
<tr>
<td>( \Delta \theta_{TE} )</td>
<td>7.52(^\circ)</td>
<td>14.08(^\circ)</td>
</tr>
</tbody>
</table>
Aerodynamics

Airfoil Selection Conclusion:

• Midnight
  • $C_{L/D_{\text{max}}}$ = 0.889
  • $C_{\text{Lmax}}$ = 1.58
  • Highest L/D = 155.4
  • Best structural characteristics
Aerodynamics

Wing Optimization:

• \( C_{L/D_{\text{max}}} = 0.889; \ V = 135 \ \text{fps} \)
• \( S_{\text{req.}} = \frac{W}{(\_\_V^2C_L)} = 11.27\text{ft}^2 \)
• \( S_{\text{actual}} = b \times c = 10\text{ft} \times 14\text{in} = 11.67\text{ft}^2 \)
• Conclusion
  • Wing size kept same, to accommodate weight growth during design
Aerodynamics

Trimmed CUAV Lift Estimation:

- Used Midnight Airfoil Polar to produce $C_l$ for both wing and tail

\[
C_{\text{cuav}} = C_{\text{Mwb}} + C_l \cdot \frac{h}{c} \cdot e \cdot \frac{S_t \cdot l_t}{S \cdot c}
\]

- $C_{\text{cuav}} = C_{\text{lwing}} + C_{\text{ltail}}$
Trimmed CUAV Drag Estimation:

- Program “Friction” used to find $C_{d_0}$ of Airframe (wing not included)
  - $C_{d_{0\text{airframe}}} = 0.0156$
- Used Midnight Airfoil Polar to produce $C_{d_0}$ and $C_l$ for both wing and tail
  - $C_d = C_{d_{0\text{airframe}}} + C_{d_{0\text{airfoil}}} + KC_l^2$
Aerodynamics

Trimmed CUAV Polars:

![Graphs showing aerodynamic properties](image)

Cd

Alpha (deg)
Stability and Control

Mission:

- Size Surfaces
- Calculate Aileron Hinge Moments
- Validate Tornado Code
- Verify Stability of Aircraft
Stability and Control

Surface Sizing:

• Tail Surfaces sized in Preliminary
  • $b_{\text{actual}} = 2.21\text{ft}$
  • $C = 0.5\text{ft}$

• Aileron Sizing using Raymer’s traditional aileron vs percent chord
  • $c_{\text{ailerorn}} = 25\%$
  • $b_{\text{ailerorn}} = 2\text{ft}$ (per aileron)
Hinge Moment Calculations:

- Used Xfoil OPER menu, and FMOM command
- Maximum Speed and S.L. used for analysis

<table>
<thead>
<tr>
<th></th>
<th>Hinge Moment (ft-lb)</th>
<th>X-Force (lb)</th>
<th>Y-Force (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>0.2375</td>
<td>1.7376</td>
<td>6.7001</td>
</tr>
<tr>
<td>Bottom</td>
<td>0.3326</td>
<td>-4.3973</td>
<td>6.7001</td>
</tr>
</tbody>
</table>
Stability and Control

Tornado Verification:

- Used 2D viscous lift curve and pitch moment of airfoil and Raymer 3D conversion
- Enter wing dimension and estimated camber line slope of Midnight airfoil into Tornado
  - Analysis
    - Central Difference Analysis used
    - $V = 45.156 \text{ m/s} = 135 \text{ fps}$
Stability and Control

Tornado Verification:

3-D Wing configuration

Wing x-coordinate

Wing y-coordinate

Wing z-coordinate
Stability and Control

Tornado Validation:

<table>
<thead>
<tr>
<th></th>
<th>( C_L )</th>
<th>( C_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tornado Results</td>
<td>4.80</td>
<td>0.0350</td>
</tr>
<tr>
<td>Xfoil Results</td>
<td>4.43</td>
<td>0.0335</td>
</tr>
<tr>
<td>Error</td>
<td>8.47%</td>
<td>4.64%</td>
</tr>
</tbody>
</table>

Conclusion:

- Tornado provides good approximation of stability parameters
- Only Use Tornado for all derivatives
Stability and Control

Tornado Verification:

<table>
<thead>
<tr>
<th></th>
<th>Longitudinal</th>
<th>Lateral-Directional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>C_L_ = 5.1404</td>
<td>C_m_ = -1.4376</td>
</tr>
<tr>
<td>Control Deflection</td>
<td>C_m_e = -2.7082</td>
<td>C_l_a = 0.3145</td>
</tr>
<tr>
<td>Static Margin</td>
<td>23.31%</td>
<td>C_l_r = 0.0398</td>
</tr>
</tbody>
</table>

Conclusion:

- Tornado provides good approximation of stability parameters
- Aircraft is statically stable, and stable w.r.t. control deflections
Performance

Performance was not defined in RFP

Team Defined Performance Parameters:

• Cruise altitude of 5,000 feet
• Minimum ceiling of 10,000 feet
• Speed range of 65 - 140 knots
• 30-minute positioning time (launch to station)
• 5-hour loiter time
• 200 fpm ROC at 5,000 feet
• 100 fpm ROC at 10,000 feet

The CUAV easily exceeds all performance requirements
Rate of Climb

Maximum rate of climb occurs at $V_{mp}$

$$V_{mp} = \sqrt{\frac{2W}{k} \sqrt{\frac{k}{3} C_{Do}}}$$

$$ROC = \frac{550bhp[\rho]p}{W} \frac{DV}{W}$$

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Max Rate of Climb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td>2211 fpm</td>
</tr>
<tr>
<td>5,000 ft</td>
<td>1684 fpm</td>
</tr>
<tr>
<td>10,000 ft</td>
<td>1277 fpm</td>
</tr>
</tbody>
</table>
Flight Envelope

For stall boundary: \( C_{l_{\text{max}}} = 1.57 \)

For \( V_{\text{max}} \) boundary: \( P_a = P_r \)

\[
V_{\text{min}} = \sqrt{\frac{W}{C_{l_{\text{max}}}}} \cdot 0.5 \sqrt{S}
\]

\[
P_r = C_{d_0} + k \sqrt{\frac{W}{0.5 \cdot V^2 \cdot S}} \cdot 0.5 \sqrt{V^2 \cdot S}
\]
## Loiter Performance

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Min Power</th>
<th>Vel</th>
<th>Drag</th>
<th>Power Req'd</th>
<th>Est. Fuel Cons.</th>
<th>Endurance</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td>111 fps</td>
<td>9.05 lbs</td>
<td>1.83 Hp</td>
<td>0.28 gal/hr</td>
<td>11.7 hr</td>
<td>880 mile</td>
<td></td>
</tr>
<tr>
<td>5,000 ft</td>
<td>120 fps</td>
<td>9.09 lbs</td>
<td>1.98 Hp</td>
<td>0.37 gal/hr</td>
<td>8.6 hr</td>
<td>705 mile</td>
<td></td>
</tr>
<tr>
<td>10,000 ft</td>
<td>129 fps</td>
<td>9.029 lbs</td>
<td>2.12 Hp</td>
<td>0.48 gal/hr</td>
<td>6.7 hr</td>
<td>590 mile</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing mission profile for different altitudes.]

- **Distance, miles**
  - Sea Level
  - 5k Feet
  - 10k Feet

**Mission Profile for Cheap UAV**

<table>
<thead>
<tr>
<th>Distance, miles</th>
<th>0</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5k Feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10k Feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Engine Selection

<table>
<thead>
<tr>
<th>Engine</th>
<th>Weight (lbs.)</th>
<th>Power (hp)</th>
<th>Electric Starter</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tecumseh Power Sport</td>
<td>55</td>
<td>10</td>
<td>No</td>
<td>$495.99</td>
</tr>
<tr>
<td>Honda GX270 QAE2</td>
<td>62</td>
<td>9</td>
<td>Yes</td>
<td>$742.50</td>
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<tr>
<td>Saito FA-450R3-D</td>
<td>6.5</td>
<td>7</td>
<td>No</td>
<td>$1069.95</td>
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<tr>
<td>Fuji BT-86 Twin</td>
<td>6.2</td>
<td>7.5</td>
<td>No</td>
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<tr>
<td>Radne Raket 120 Aero ES</td>
<td>15</td>
<td>14.8</td>
<td>Yes</td>
<td>$1100.00</td>
</tr>
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</table>
Propeller Sizing

Raymer’s Method

Assume: Activity Factor = 100 (typical for light-aircraft)
Blade design \( C_L = 0.5 \)

Extract propeller efficiency \( \eta_p \) from figure 13.12 in Raymer
using equations: \( J = \frac{V}{nd} \)
\( c_p = \frac{(550 \text{ bhp})}{(\_n^3D^5)} \)

Other parameters and coefficients:
\( T = \frac{P_{\text{\_P}}}{V} \)
\( c_T = \frac{T}{\_n^2D^4} \)
\( c_S = V(\_/Pn^2)^{1/5} \)
Altitude Power Adjustments

\[ \text{Power} = \text{Power}_{SL} \times \left( \frac{1}{\text{Altitude}} - \frac{1}{\text{Sea Level}} \right) \times 7.55 \]

<table>
<thead>
<tr>
<th>Height (ft)</th>
<th>Adjusted Power (hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td>14.80</td>
</tr>
<tr>
<td>1000</td>
<td>13.62</td>
</tr>
<tr>
<td>2000</td>
<td>13.17</td>
</tr>
<tr>
<td>3000</td>
<td>12.73</td>
</tr>
<tr>
<td>4000</td>
<td>12.30</td>
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<tr>
<td>5000</td>
<td>11.87</td>
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<tr>
<td>6000</td>
<td>11.46</td>
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<td>8000</td>
<td>10.67</td>
</tr>
<tr>
<td>9000</td>
<td>10.29</td>
</tr>
<tr>
<td>10000</td>
<td>9.91</td>
</tr>
</tbody>
</table>
## Propeller Sizing

<table>
<thead>
<tr>
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<th></th>
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<th></th>
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<tr>
<td>2.0</td>
<td>66.67</td>
<td>1.0125</td>
<td>0.3610</td>
<td>0.53</td>
<td>1.2048</td>
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<td>0.2194</td>
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<td>2.0</td>
<td>75.00</td>
<td>0.9000</td>
<td>0.2536</td>
<td>0.68</td>
<td>1.1493</td>
<td>41.00</td>
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<td>83.33</td>
<td>0.8100</td>
<td>0.1848</td>
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<td>1.1019</td>
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<td>1.1493</td>
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<td>83.33</td>
<td>0.7714</td>
<td>0.1448</td>
<td>0.78</td>
<td>1.1019</td>
<td>47.03</td>
<td>0.1700</td>
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<td>0.2327</td>
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<td>66.67</td>
<td>0.9205</td>
<td>0.2242</td>
<td>0.73</td>
<td>1.2048</td>
<td>44.02</td>
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<td>58.33</td>
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<td>0.75</td>
<td>1.2709</td>
<td>45.22</td>
<td>0.2319</td>
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<tr>
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<td>0.8804</td>
<td>0.1795</td>
<td>0.83</td>
<td>1.2048</td>
<td>50.05</td>
<td>0.1965</td>
</tr>
<tr>
<td>2.3</td>
<td>75.00</td>
<td>0.7826</td>
<td>0.1261</td>
<td>0.83</td>
<td>1.1493</td>
<td>50.05</td>
<td>0.1552</td>
</tr>
</tbody>
</table>
Propeller Selection

• To avoid losing thrust at high speeds or RPMs, the helical tip speed of the propeller should not get too close to the speed of sound

\[ M_{\text{tip}} = \left( V^2 + (\omega nD)^2 \right)^{1/2}/a \]

• At sea level, the calculated tip Mach is 0.4675, well below the speed of sound.

• Materials: Metal, Carbon Fiber, Glass Fiber, Plastic, Wood

• Wood is the ideal material for our design.

• Zinger Propellers: 25 – 8 wood propeller costing $31.39.
Engine Installation

- Mount engine upside-down. 5.1" _ 6.1" _ 0.25" Flat plate to mount to firewall, 1.5" from top of fuselage.

- Connect fuel feed to carburetor inlet.

- Connect throttle servo to throttle shaft.

- Run exhaust to outside of fuselage.

- Extension for engine shaft.
Materials

• COMPOSITES
  Bi-directional Kevlar

• ALUMINIUM
  6061T6
Skin material is Bi-directional Kevlar

- Good resistance to corrosion and fatigue
- Elimination of part interface
- High damping characteristics
- Low coeff of Thermal Expansion
Materials

- Stress analysis using FEPC suggests reinforcement for composite frame
- Failure at 90 degree joints may occur
Materials

Aluminum 6061T6 Airframe

• Abundant and Low Cost
• Versatile
• Good formability
• Resistance to corrosion
• Ductile
Materials

Material Designation

• Complete skin construction of Composites
• Aluminum beams for reinforcement
• Fuselage and wings 0.03”
Structures
Structures Overview

- Wing loading
  - Shearing force
  - Bending moment
- V-n diagram
  - Maneuver loading
  - Gust conditions
- Spar designs
  - Shearing stress
  - Compressive stress
  - Deflection
- Aileron integration
  - Rear wing spar attachment
- Tail integration
  - Offset bearing system
Wing loading

- Max shear force
  - Level flight: 84.5 lbs
  - 3g turn: 277.5 lbs

- Max bending moment
  - Level flight: 174.8 ft-lbs
  - 3g turn: 584.3 ft-lbs
V-n Diagram

- Max structural loading 3
- Min structural loading -1.2
- Gust conditions
  - 66 ft/sec – stall
  - 50 ft/sec – cruise
  - 25 ft/sec – max velocity
V-n Diagram
Wing Spar Design

• Designed to withstand 3g maneuver
• Constructed from 6061T6 aluminum
  – Yield strength of 35,000 psi in compression
  – Yield strength of 20,000 psi in shear
• Designed with 2 C-beams
  – Height of 1.54 in
  – Width of 0.6 in
  – Thickness of 0.1 in
  – Combined weight of 6.03 lbs
  – Tip deflection of 0.024 in
Tail Spar Design

- Designed for 3g turn requirement: 67 lbs
- Constructed from 6061T6 aluminum
  - Yield strength of 35,000 psi in compression
  - Yield strength of 20,000 psi in shear
- Designed with C – beam at quarter chord
  - Height of 0.51 in
  - Width of 0.40 in
  - Thickness of 0.10 in
  - Weight of 0.27 lbs each
  - Tip deflection of 0.50 in
Tail Spar Design
Tail Integration
UAV Systems

Systems to be incorporated into UAV:

- Navigation
- Autopilot
- Control
- Communication
- Electrical
- Deployment
Navigation and Autopilot Systems

• Micropilot MP1000SYS autopilot
• Originally designed for model airplanes
• Combines navigation and stability functions
• Integrated GPS and GPS antenna
• Designed to interface with standard RC servos
• Operates with RC transmitter or other data link

Micropilot MP1000SYS Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS Accuracy</td>
<td>± 25 ft</td>
</tr>
<tr>
<td>Altitude Accuracy</td>
<td>± 5 ft</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>255 fps</td>
</tr>
<tr>
<td>Altitude Limit</td>
<td>25,000 ft</td>
</tr>
<tr>
<td>Dimensions</td>
<td>6&quot; x 3.2&quot; x 1.5&quot;</td>
</tr>
<tr>
<td>Weight</td>
<td>0.33 lbs</td>
</tr>
<tr>
<td>Antenna Length</td>
<td>48 in</td>
</tr>
<tr>
<td>Current Draw</td>
<td>0.30 Amps @ 8 V</td>
</tr>
<tr>
<td>Unit Cost</td>
<td>$1,500</td>
</tr>
</tbody>
</table>
Control System

• _ Scale Radio Control Model Airplane Servos
• Inexpensive, readily available, variety of choices
• Off-the-shelf integration with autopilot system
• Number and type of servos determined by hinge moment calculations

<table>
<thead>
<tr>
<th>1/4 Scale RC Servo Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
</tr>
<tr>
<td>Torque</td>
</tr>
<tr>
<td>Avg Current</td>
</tr>
<tr>
<td>Unit Cost</td>
</tr>
</tbody>
</table>
Communication System

• In 1991 the DOD made the Tactical Common Data Link (TCDL) the standard for military imaging and signals intelligence
• UAV was initially designed to use a TCDL
• Use of standard link would facilitate use of existing control stations
• Cost of TCDL is prohibitively expensive

<table>
<thead>
<tr>
<th>L-3 Communications TCDL Specifications</th>
<th>TCDL from L3 Comm.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td>120 nm</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td>up to 45 Mbps</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>3&quot; x 6.75&quot; x 10&quot;</td>
</tr>
<tr>
<td></td>
<td>3&quot; x 12&quot; x 10&quot;</td>
</tr>
<tr>
<td><strong>Current Draw</strong></td>
<td>5.89 Amps at 28 V</td>
</tr>
<tr>
<td><strong>Unit Cost</strong></td>
<td>200,000 +</td>
</tr>
</tbody>
</table>
Communication System

• CUAV will use data link built by AACOM communication systems.
• Range will be 50 miles
• Cost will be 7.5 % of TCDL cost

<table>
<thead>
<tr>
<th>Data Link Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AACOM AT6420 Transmitter</strong></td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Voltage Input</td>
</tr>
<tr>
<td>Current Draw</td>
</tr>
<tr>
<td>Dimensions</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Power Output</td>
</tr>
<tr>
<td>Antenna</td>
</tr>
<tr>
<td>Total Unit Cost</td>
</tr>
</tbody>
</table>
Electrical System

- 2 Choices for the electrical system: (generator, batteries)
- Use of go-kart engine makes incorporation of generator infeasible

### UAV Electrical Requirements

<table>
<thead>
<tr>
<th>System</th>
<th>Amps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autopilot</td>
<td>0.30</td>
</tr>
<tr>
<td>Servos (times 5)</td>
<td>0.50</td>
</tr>
<tr>
<td>Receiver</td>
<td>0.20</td>
</tr>
<tr>
<td>Transmitter</td>
<td>6.00</td>
</tr>
<tr>
<td>Payload</td>
<td>10.00</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20.00</strong></td>
</tr>
</tbody>
</table>

20 Amps x 5.5 hrs = 110 Ah

### UAV Battery Selection

<table>
<thead>
<tr>
<th>Type</th>
<th>Manufacturer</th>
<th>Voltage</th>
<th>Capacity</th>
<th>Weight</th>
<th>Dimensions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium-Ion</td>
<td>Ultra-Life</td>
<td>28 V</td>
<td>11 Ah</td>
<td>2.9 lb</td>
<td>5”x4.4”x2.45”</td>
<td>$125</td>
</tr>
<tr>
<td>Zinc - Air</td>
<td>Electric Fuel</td>
<td>28 V</td>
<td>56 Ah</td>
<td>5.9 lb</td>
<td>12.2”x7.3”x2.4”</td>
<td>$290</td>
</tr>
<tr>
<td>Zinc - Air</td>
<td>Electric Fuel</td>
<td>28 V</td>
<td>30 Ah</td>
<td>3.1 lb</td>
<td>12.2”x3.7”x2.7”</td>
<td>$210</td>
</tr>
</tbody>
</table>

Electric Fuel Zinc-Air BA-8180/U
Deployment System

UAV will be designed for 3 deployment options:

• Parachute Deploy
  – Design of chute packaging, opening, and release systems
  – Sizing of parachute

• Boom Deploy
  – Design of boom and related systems
  – Integration of boom attachment points into UAV design

• Tow-line
  – Placement of tow-line attachment point
  – Design of tow-line release mechanism
Cost Analysis

Summary of Fly-Away Cost

• Engineering Costs
• Airframe Costs
• Assembly Costs
• Systems Costs
Cost Analysis

Engineering Cost

- 7 member team
- 3 months concept evaluation
- 3 months detailed design
- 3 months of flight test evaluation & redesign
- Total cost = $ 300,000
- Cost per unit for 200 units = $ 1,500
Airframe Cost

Study of composite kit-planes indicated that airframe materials could be acquired for $3,000.

The group allowed $2,000 for airframe assembly.

Total airframe cost = $5,000
Assembly Costs

Assembly Includes:

- Joining airframe components
- Mounting and integration of UAV systems
- Final testing and quality assurance

32 man-hours at $20 per hour

Assembly Cost = $ 640
## Systems Cost

<table>
<thead>
<tr>
<th>System</th>
<th>Cost per Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Link</td>
<td>$15,000</td>
</tr>
<tr>
<td>Autopilot / Navigation</td>
<td>$2,000</td>
</tr>
<tr>
<td>Servos</td>
<td>$70 x 6</td>
</tr>
<tr>
<td>Batteries</td>
<td>$580</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$18,000</strong></td>
</tr>
</tbody>
</table>
## Cost Summary

<table>
<thead>
<tr>
<th>UAV Cost Summary per Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Engineering</td>
<td>$1,500</td>
</tr>
<tr>
<td>Airframe</td>
<td>$5,000</td>
</tr>
<tr>
<td>Systems</td>
<td>$18,000</td>
</tr>
<tr>
<td>Assembly / Testing</td>
<td>$640</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$25,140</strong></td>
</tr>
</tbody>
</table>

Total production estimated at $25,140

With a profit margin, units could be sold for less than $30,000
Weights and CG

= pt. load
Weights and CG

• Moment summation
  • $\sum M_{cg} = 0$;
  • $\sum M_{cg} = 0 = \sum [weight_i \times (localcg_i - cg)]$

• Features of MATLAB code
  • Amount of fuel (input function)
  • Reads data file with over 80 specifications, explanation
  • Individual weights and cg’s displayed
  • Weight of skin (Kevlar), airframe (Al), and UAV displayed
  • UAV CG displayed
  • $I_{xx}$, $I_{yy}$ displayed
  • Accepts airfoil geometry
Weights and CG

• Key Contributing Factors
  • Skin thickness = 0.06”, Bi-directional Kevlar
  • Aluminum tail boom
  • Full fuel tank of 15 lb
  • Payload of 50 lb
  • Forward engine of 15 lb
  • Most internal components behind spring
Weights

• Results
  • Skin (Kevlar) weight = 10.61 lb
  • Airframe (Aluminum) weight = 36.07 lb
  • Total UAV weight = 159.39 lb
  • \( I_{xx} = 216129 \text{ in}^4; I_{yy} = 759934 \text{ in}^4 \)

The total weight of the skin (Kevlar only) is 10.61 lb
The total weight of the airframe (Aluminum only) is 36.07 lb
The total weight of the UAV is 159.39 lb

The cg is 0.57 inches in front of rotational spring and shaft. - OR -
The cg is at 0.3426 of the airfoil chord. - OR -
4.83 inches behind the airfoil LE.

<table>
<thead>
<tr>
<th>WEIGTHS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing skin</td>
<td>5.10 lb</td>
</tr>
<tr>
<td>Forward wing spar</td>
<td>3.00 lb</td>
</tr>
<tr>
<td>Aft wing spar</td>
<td>3.00 lb</td>
</tr>
<tr>
<td>Tail airfoil skin</td>
<td>0.51 lb</td>
</tr>
<tr>
<td>Tail spar</td>
<td>0.50 lb</td>
</tr>
<tr>
<td>Fuselage 4 skin</td>
<td>18.36 lb</td>
</tr>
<tr>
<td>Fuselage 3 skin</td>
<td>2.38 lb</td>
</tr>
</tbody>
</table>

Sample Output

<table>
<thead>
<tr>
<th>CENTERS OF GRAVITY</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing skin</td>
<td>26.82 in</td>
</tr>
<tr>
<td>Forward wing spar</td>
<td>26.12 in</td>
</tr>
<tr>
<td>Aft wing spar</td>
<td>31.20 in</td>
</tr>
<tr>
<td>Tail airfoil skin</td>
<td>85.28 in</td>
</tr>
<tr>
<td>Tail spar</td>
<td>85.28 in</td>
</tr>
<tr>
<td>Fuselage 4 skin</td>
<td>64.10 in</td>
</tr>
<tr>
<td>Fuselage 3 skin</td>
<td>53.78 in</td>
</tr>
</tbody>
</table>
• Results
  • For full fuel and payload, cg is 0.57” in front of shaft
  • Acceptable cg is from 17.9 % chord to 49.4 % chord
Conclusions

• CUAV design meets or exceeds all RFP requirements
  • Maximum Payload
  • Endurance
  • Autonomous Operation
  • Expendability

• Cost
  • Lowest of all UAVs of similar performance
Questions?