Advanced Logistics Delivery System
Glider Design Team

Final Design Review
May 3, 2005
Team Members

- Chris Imhof – Stability & Control
- Laura Morgan – Leader & Launch System
- David Rogers – Aerodynamics
- Adam Russell – Design Configuration
- Andy Tuggle – Structures
- Sean Tully – Wing Deployment/Design
- Lesley Walcourt – Avionics & Power
- Charles Walston – Aerodynamics
- Patrick Williams – Structures
- Brian Mohns – Glider Construction
Presentation Outline

- Introduction
- Initial Glider Configurations
- Final Glider Configuration
- Analysis of Glider Design
  - Glider Aerodynamics
  - Structures Analysis
  - Wing Deployment
  - Stability and Control
  - Weights
  - Avionics Packages
  - Ship Storage
  - Total Cost Estimates
- Conclusions
Project Objectives

- To provide a low cost, disposable glider to carry supplies to troops in hostile territories.
- Ship launch design is an alternative to flying planes to drop supplies over hostile territories.
- Designed premise from Carderock Innovation Center and the Center of Innovations in Ship Design.
To design an expanding wing glider with the following characteristics:

- Payload = 1000 lbs
- Range = 50 miles
- Launch Speed = 500 knots
- Launch Acceleration = 30g
- Cruise Speed = 60 knots
- Launch Pod Dimensions = 10 ft span
Project Drivers

- Range Requirements
- Payload Requirements
- Cost (glider must be disposable)
- Inflatable Wings/Size Requirements
Initial Glider Configurations
Design Decision Tree
Payload

Airbag Fuel

Wing Ribs

Avionics Package

Inflated Spars

Payload
Final Configuration
Payload

- **Volume**
  - Dry payload
  - Wet payload

- **Dimensions**
  - 2 X 2 X 4 ft.
  - 1.5 X 1.5 X 9 ft.
Payload Continued
Fuselage

- Frontal profile shape change.
  - Squared sides
  - Circular

- Added tank to regulate pressure on descent.
Fuselage

- Total length change.
  - 15 ft.
  - 18 ft.
- Elevated rear section.
Sodium Azide tank

- Required volume changes.
- Frontal tank section becomes unnecessary.
- Allows for access to the payload through the noescone.
Solid Wing Section

- Added structural support.
- Delivery of reacted sodium azide to inflatable wings.
- More room provided for inflatable wings during launch phase.
Inflatable Wings

- Inflatable spars with solid ribs filling a soft skin.
- Completely inflatable wings with segmented inflation sections.
Servo Motors

- Servo Motors are used to physically move the control surfaces on the tail.
  - 3 servo motors, for the rudder and 2 horizontal stabilizing surfaces.
Glider Aerodynamics and Performance

Launch Phase
Glide Phase
Launch Characteristics

- launch speed = 500 knots
- 50 mile goal
  - Range=(L/D)\_height
  - Assumed L/D of 33 for a calculations
- 8000ft goal
  - Exceeding this height will allow us to either travel further than 50 miles or allow us to lower the L/D which would result in reduced manufacturing costs.
Constant Flight Angle

Free Body Diagram:

Sum of Forces:

\[ F_x : -D - mg \sin \alpha = m \frac{d^2 x}{dt^2} \]
\[ F_y : L - mg \cos \alpha = 0 \]

Equations of Motion:

\[ \frac{d^2 x'}{dt^2} = -\frac{mg^2 \cos^2 \alpha}{2} - g \sin \alpha - \frac{\rho \left( \frac{dx'}{dt} \right)^2 S\pi AR e}{2m} \]
\[ \frac{1}{2} \rho \left( \frac{dx'}{dt} \right)^2 S\pi AR e \]
\[ \frac{dy'}{dt} = 0 \]
Launch Angle Determination

- With a $C_{\text{max}} = 1.0$, a launch angle between $30^\circ$ and $35^\circ$ is needed to reach 8000ft.
- Chose $30^\circ$ because of the reduced stress with the intention of optimizing.
Sensitivity Analysis

- Initial wing span of 9.5ft
- Reduced to 8.25 to gain approximately 50ft
Sensitivity Analysis

- Initial chord length of 3.5ft
- Maximum altitude with chord length of 2ft
  - This reduces the space for internal structure and affects glide properties
Sensitivity Analysis

- Initial Temperature of 520ºR → 60ºF
- In order to reach 8000ft, sea level temperature needs to be above 525ºR
**Friction** Results

CASE TITLE: Glider

<table>
<thead>
<tr>
<th>COMPONENT TITLE</th>
<th>SWET (FT)</th>
<th>REFL(FT)</th>
<th>TC</th>
<th>ICODE</th>
<th>FRM</th>
<th>FCTR</th>
<th>FTRANS</th>
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<tr>
<td>Fuselage</td>
<td>117.0071</td>
<td>18.131</td>
<td>0.138</td>
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<td>1.0952</td>
<td>0.0000</td>
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<tr>
<td>Wings</td>
<td>68.8914</td>
<td>4.622</td>
<td>0.174</td>
<td>0</td>
<td>1.3587</td>
<td>0.0000</td>
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<td>Horiz. Tail</td>
<td>57.5000</td>
<td>2.875</td>
<td>0.200</td>
<td>0</td>
<td>1.4400</td>
<td>0.0000</td>
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<tr>
<td>Vert. Tail</td>
<td>25.0000</td>
<td>2.750</td>
<td>0.200</td>
<td>0</td>
<td>1.4400</td>
<td>0.0000</td>
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</table>

TOTAL SWET = 268.3985

REYNOLDS NO./FT = 0.480E+07 Altitude = 4000.00 XME = 0.756

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>RN</th>
<th>CF</th>
<th>CF*SWET</th>
<th>CF<em>SWET</em>FF</th>
<th>CDCOMP</th>
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<tr>
<td>Fuselage</td>
<td>0.871E+08</td>
<td>0.00202</td>
<td>0.23659</td>
<td>0.25911</td>
<td>0.00568</td>
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<tr>
<td>Wings</td>
<td>0.222E+08</td>
<td>0.00248</td>
<td>0.17080</td>
<td>0.23207</td>
<td>0.00509</td>
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<tr>
<td>Horiz. Tail</td>
<td>0.138E+08</td>
<td>0.00267</td>
<td>0.15368</td>
<td>0.22130</td>
<td>0.00485</td>
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<tr>
<td>Vert. Tail</td>
<td>0.132E+08</td>
<td>0.00269</td>
<td>0.06730</td>
<td>0.09691</td>
<td>0.00212</td>
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</table>

SUM = 0.62837

FRICTION DRAG: CDF = 0.01377 FORM DRAG: CDFORM = 0.00397

SUMMARY

<table>
<thead>
<tr>
<th>J</th>
<th>XME</th>
<th>Altitude</th>
<th>RE/FT</th>
<th>CDF</th>
<th>CDFORM</th>
<th>CDF+CDFORM</th>
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<tr>
<td>1</td>
<td>0.756</td>
<td>0.400E+04</td>
<td>0.480E+07</td>
<td>0.01377</td>
<td>0.00397</td>
<td>0.01774</td>
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</table>
Post Wing Deployment Glide

- Drag and Performance Analysis
  - XFOIL Boundary Layer Analysis
    - Inflatable wing analysis
  - Fuselage and Tail Friction Analysis
    - Turbulent flow over the fuselage and airfoils
  - Performance Analysis for Maximum and Minimum Weight
Glide Characteristics

- Minimum Requirements for a 50 Mile Range
- Primary Area of interest for the glide was the Inflatable Wing
  - 50% of the Overall Zero Lift Drag on the glide can be associated with wing airfoil
    - $C_{D0W} = 0.00892$
  - Root Foil: Wortmann FX 67-K-170
  - Tip Foil: Wortmann FX 67-K-150

### Advanced Logistics Delivery System Glider Design Requirements

<table>
<thead>
<tr>
<th>Weight (lbs.)</th>
<th>$C_{L_{\text{max}}}$</th>
<th>Range (ft.)</th>
<th>$V_{\text{max}}$ (ft/s)</th>
<th>L/D$_{\text{max}}$</th>
<th>Mach Number</th>
<th>Minimum Altitude (ft.)</th>
<th>$C_{D0}$</th>
<th>Aspect Ratio</th>
<th>$C_{D_{\text{i}}}$</th>
<th>Span (ft.)</th>
<th>$C_{D}$</th>
<th>Root/Tip Chord (ft.)</th>
<th>Glide Angle (deg.)</th>
<th>Wing Area (sq. ft.)</th>
<th>Minimum Sink (ft/s)</th>
<th>Efficiency Factor</th>
<th>Root Reynolds Number</th>
<th>Taper Ratio</th>
<th>Tip Reynolds Number</th>
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<tbody>
<tr>
<td>1500</td>
<td>1.1775</td>
<td>264000</td>
<td>88.106</td>
<td>33</td>
<td>0.0811</td>
<td>7750</td>
<td>0.01784</td>
<td>25.77</td>
<td>0.01786</td>
<td>67</td>
<td>0.0357</td>
<td>3.852/1.348</td>
<td>-1.74</td>
<td>174.2</td>
<td>-2.68</td>
<td>0.96</td>
<td>1780000</td>
<td>0.35</td>
<td>623000</td>
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</tbody>
</table>
Inflatable Wing Analysis

- Contour Modification to simulate pressure loss
  - Sine wave adjustment for a 1% pressure loss
  - On board tank and actuator to restore pressure
- Use of a material that will provide laminar flow
  - Use of $n_{\text{crit}}$ value of 9 in XFOIL Analysis

Wortmann FX 67-K-170

![Graph showing thickness vs. length](image)
Inflatable Wing Analysis

\[ M_a = 0.0810 \quad \alpha = 5.5000^\circ \quad C_L = 1.0645 \quad T: \chi_{tr}/c = 0.4669 \]
\[ Re = 1.784 \times 10^6 \quad N_{cr} = 9.00 \quad C_D = 0.00764 \quad B: \chi_{tr}/c = 0.8410 \]
Inflatable Wing Analysis

- Separation Bubble Formation
  - Tripped the flow before bubble formation
- Comparison of Rigid Wing and 1% deflated Wing
  - Below max $C_{D0W}$ of 0.00892

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>Type</th>
<th>$C_{D0W}$</th>
<th>% Change</th>
<th>$C_L$</th>
<th>% Change</th>
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<tbody>
<tr>
<td>Wortmann FX 67-K-170</td>
<td>Rigid</td>
<td>0.00629</td>
<td>21.62</td>
<td>1.0651</td>
<td>0.16</td>
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<tr>
<td></td>
<td>Deflated</td>
<td>0.00765</td>
<td></td>
<td>1.0634</td>
<td></td>
</tr>
<tr>
<td>Wortmann FX 67-K-150</td>
<td>Rigid</td>
<td>0.00852</td>
<td>-6.34</td>
<td>1.0367</td>
<td>9.59</td>
</tr>
<tr>
<td></td>
<td>Deflated</td>
<td>0.00798</td>
<td></td>
<td>0.9373</td>
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</tr>
</tbody>
</table>
ALDS Lift and Drag Estimate

- **Friction Code**
  - Analyzed the fuselage, horizontal, and vertical stabilizers
  - Inputted wetted area, reference length, mach number, and altitude
  - Assumed flow turbulent over entire area to maximize drag
  - Body Zero Lift drag of 0.00461

- **Lifting Line Theory**
  - Determined Lift Coefficient and induced drag coefficient

- **Overall Drag**
  - Combined Friction CD0 and CD0 of the wing to get total
  - Increased by 20% to account for track attachment and wing interference

<table>
<thead>
<tr>
<th>Finite Airfoil Type</th>
<th>CL</th>
<th>Cdi</th>
<th>CD</th>
<th>L/D</th>
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<tbody>
<tr>
<td>Rigid</td>
<td>0.97813</td>
<td>0.01354</td>
<td>0.02796</td>
<td>34.984</td>
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<tr>
<td>One Percent Deflation</td>
<td>1.02219</td>
<td>0.01479</td>
<td>0.02970</td>
<td>34.418</td>
</tr>
</tbody>
</table>
## ALDS Glide Performance

- **Maximum Weight**
  - Increases Velocity and the overall Wing Loading

- **Minimum Weight**
  - Low Velocity
  - Fly with ballast to increase speed

### Performance of ALDS Glider with One Percent Deflated Wing

<table>
<thead>
<tr>
<th>Constants</th>
<th>Calculations</th>
<th>Minimum Weight (1400 lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude(ft)</td>
<td>7750</td>
<td></td>
</tr>
<tr>
<td>Density(slugs/ft³)</td>
<td>0.001884</td>
<td></td>
</tr>
<tr>
<td>Viscosity(lb s/ft²)</td>
<td>3.58318E-07</td>
<td></td>
</tr>
<tr>
<td>Weight(lbs)</td>
<td>1759</td>
<td>99.79</td>
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<tr>
<td>Eff. Factor, e</td>
<td>0.96</td>
<td>1.6642</td>
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<tr>
<td>L/D Max</td>
<td>34.42</td>
<td>10.10</td>
</tr>
<tr>
<td>Mean Wing Chord(ft)</td>
<td>2.6</td>
<td>Min Sink(ft/s)</td>
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<tr>
<td>Wing Span(ft)</td>
<td>67</td>
<td>50.5 Range(miles)</td>
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<tr>
<td>Wing Area(ft²)</td>
<td>174.2</td>
<td>2.021E+06</td>
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<tr>
<td>Aspect Ratio</td>
<td>25.77</td>
<td>0.0919 Mach</td>
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</tbody>
</table>

### Performance of ALDS Glider With Rigid Wing

<table>
<thead>
<tr>
<th>Constants</th>
<th>Calculations</th>
<th>Minimum Weight (1400 lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude(ft)</td>
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<tr>
<td>Density(slugs/ft³)</td>
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</tr>
<tr>
<td>Viscosity(lb s/ft²)</td>
<td>3.58318E-07</td>
<td></td>
</tr>
<tr>
<td>Weight(lbs)</td>
<td>1759</td>
<td>100.63</td>
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<tr>
<td>Eff. Factor, e</td>
<td>0.96</td>
<td>1.6373</td>
</tr>
<tr>
<td>L/D Max</td>
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<td>10.10</td>
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<tr>
<td>Mean Wing Chord(ft)</td>
<td>2.6</td>
<td>Min Sink(ft/s)</td>
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<tr>
<td>Wing Span(ft)</td>
<td>67</td>
<td>51.3 Range(miles)</td>
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<tr>
<td>Wing Area(ft²)</td>
<td>174.2</td>
<td>2.038E+06</td>
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<tr>
<td>Aspect Ratio</td>
<td>25.77</td>
<td>0.0926 Mach</td>
</tr>
</tbody>
</table>
Glider Structural Analysis

Solid Structures
Inflatable Wing Structures
Non-Inflatable Structural Design

Critical Structural Issues:

- Fuselage must be able to support payload under loads during launch
- Stub wing supports must resist bending moments acting on wing due to loads resulting from lift

Solution methods:

- Optimize structural components for minimum weight using structural theory
- Use factor of safety of 1.5 for all calculations
- Use excel solver for all optimization routines
Glider Structural Overview
## Materials

### Carbon Reinforced Carbon Fiber:
Graphitized SIGRABOND type 1501 G

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Flexural Strength (ksi)</td>
<td>37.0 - 46.2</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength (ksi)</td>
<td>49.3 – 58</td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity (10^6 psi)</td>
<td>10.15 – 12.33</td>
<td></td>
</tr>
<tr>
<td>Bulk Density (lb/in^3)</td>
<td>0.05238 – 0.05599</td>
<td></td>
</tr>
<tr>
<td>Shear Strength (ksi)</td>
<td>9.86</td>
<td></td>
</tr>
</tbody>
</table>

**Pros:**
- Light weight
- High strength
- Resistant to thermal deflections

**Cons:**
- Expensive
- Tough to manufacture
- Shear strength is based on an estimated value
Damping Composites:
ISODAMP C-3002 (E-A-R Specialty Composites)

Pros:
- Made specifically for skin design
- High resistance to shear
- Low weight

Cons:
- High manufacturing cost
- Only available in certain thickness
- Expensive

<table>
<thead>
<tr>
<th>Shear Strength (lb/in)</th>
<th>1504</th>
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<tbody>
<tr>
<td>Tensile Strength (ksi)</td>
<td>11.9</td>
</tr>
</tbody>
</table>
| Weight (lb/ft²)        | t = 0.125 in, 0.07  
                         | t = 0.250 in, 0.14  
                         | t = 0.500 in, 0.28  |
Major Loads Due to Payload

Load due to acceleration
Down track = 33\(m\)\(g\)\(n\)
= 5500 lbs/support (frame and payload supports)

Load due to centripetal force at curved
Portion of track = \(\frac{nmv^2}{r}\)
= 15,734.66 lbs/support (frame and payload supports)

Blue squares represent payload supports

Mounting apparatus (mounts glider to track)

Edge of glider fuselage

Moment Due to Track Acceleration
= 49,500 ft-lbs (skin and stringers)
## Structural Design (Fuselage)

<table>
<thead>
<tr>
<th>Component</th>
<th>Payload Supports</th>
<th>Frame</th>
<th>Stringers</th>
<th>Skin</th>
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</thead>
<tbody>
<tr>
<td><strong>Function</strong></td>
<td>Connect payload to frame</td>
<td>Support load due to payload at T.O.</td>
<td>Carry longitudinal stress in fuselage</td>
<td>Carry shear stress in fuselage</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>Carbon Fiber</td>
<td>Carbon Fiber</td>
<td>Carbon Fiber</td>
<td>Skin Composite</td>
</tr>
<tr>
<td><strong>Cross Section</strong></td>
<td><img src="image1" alt="Cross Section" /></td>
<td><img src="image2" alt="Cross Section" /></td>
<td><img src="image3" alt="Cross Section" /></td>
<td>Thin Panel</td>
</tr>
<tr>
<td><strong>Loads</strong></td>
<td><img src="image4" alt="Load Diagram" /></td>
<td><img src="image5" alt="Load Diagram" /></td>
<td><img src="image6" alt="Load Diagram" /></td>
<td>Shear flow In each panel (increases at X-axis)</td>
</tr>
<tr>
<td><strong>Analysis Method</strong></td>
<td>Beam analysis</td>
<td>Beam analysis</td>
<td>Stringer idealization</td>
<td>Panel shear flow</td>
</tr>
<tr>
<td><strong>Constraints</strong></td>
<td>( \sigma_i = \frac{M_i y_i}{I_i} )</td>
<td>( \sigma_i = \frac{M y}{I} &lt; \sigma_y )</td>
<td>( \sigma_i = \frac{n(F.O.S) M y_i}{I x x} &lt; \sigma_y )</td>
<td>( \tau_{\text{max}} = \frac{q_{\text{max}}}{t} &lt; \tau_{\text{all}} )</td>
</tr>
</tbody>
</table>
Major Loads Due to Lift

Assume loading is elliptical

\[ P_y(z) = \left( \frac{2W}{\pi L} \right) \sqrt{1 - \left( \frac{z}{L} \right)^2} \]

Moment at root of wing
Due to lift = 10,743 ft-lbs

This elliptical lift results in a large Moment that acts at the root of the Wing. Our solution is to create a Fuselage that gives extra support To counteract this moment
Solution to Wing Problem
Optimized Structural Dimensions

Frame:

- $t = 0.1$ in
- $b = 1.42$ in
- $h = 4.0$ in
- Weight per Frame = 25.83 lbs

Estimated total structural weight (no skin) = 193.62 lbs

Payload supports:

- $b = 1.04$ in
- $h = 2.98$ in
- Weight per support = 3.12 lbs

Stringers:

- $t = 0.1$ in
- $b = 1$ in
- $h = 0.5$ in
- Weight per Stringer = 1.66 lbs

Optimal skin thickness is 0.005 in → 0.02 in
Inflatable Structures

- Percentage of cross sectional area that is inflated is low. Loss of structures.
- Non-webbed indiv. spars have different load reactions.
- Added weight and prevention of spars from filling up outer skin where ribs are located.
- Outer skin will bubble up and disturb laminar flow.
- “Accordion” effect when inflated, losing desired airfoil shape.
- No inner tangential skin supports to smooth surface, or inner webbing to reduce torsion.
Combined Cross-Sectional Design

- From “Big Blue”: Inflated Glider Developed by KU.
- Entirely Inflated: better structural stability.
- Several internal webbed connections to maximize rigidity without exceeding maximum deflated area and weight.
- Outer skin wrap: layer of Dacron to fill in gaps caused by “bubbles.” W=7.4 lbs/wing
- Inner fabric: TBD from internal pressure and aerodynamic loads.
Lift Profile Based on Pressure Coefficients Along Chord
Wrinkling Pressure $P_w$

- Known as the minimum pressure required inside the inflated wing to keep both the upper and lower surface in tension, minimizing deflection.
- For an inflated cylinder: 
  \[ P_w = \frac{2M_w}{\pi r^3} \] (Webber)
Pressure to Prevent Wrinkling

Required Pressure in Each Sub Section to Prevent Wrinkling

\[ P_{\text{max}} = 1450 \text{ psi} \]

\[ P_w = 1000 \text{ psi} \]
Material Selection

- Burst Pressure $P_b = 2tS/d$  
  (must be $> P_w$)
- Vectron: used in Mars Pathfinder. Strong enough but too heavy. (~840 lbs/wing)
- Vela Carb 335U: carbon fiber fabric used to strengthen masonry structures.
  - If double wrapped, $P_b = 1760$ psi and $W = 87$ lbs/wing.
Wing Deployment
Chosen Inflation Method

- **Primary Inflation**
  - Use chemical reactions to produce enough nitrogen gas to satisfy pressure requirements
  - Pressure required to be at a minimum of 1,000 PSI
  - Wing deployment is required to have a rapid, smooth deployment

- **Reserve Inflation**
  - Keep wings inflated at required pressure during entire glide phase
  - Use direct inflation method
Primary Inflation Method

- Process uses car airbag technology described in reactions below
- Benefits include fast deployment times and easy storage
- Problems arise using sodium azide, a harmful chemical which increases cost and safety concerns during manufacturing
- Sodium azide is highly volatile
- Small electrical charge is required to begin chemical reactions

\[ 2NaN_3 \rightarrow 2Na + 3N_2 \]

\[ 2Na + \frac{2}{5}KNO_3 \rightarrow \frac{1}{5}K_2O + Na_2O + \frac{1}{5}N_2 \]

\[ K_2O + Na_2O + SiO_2 \rightarrow \text{alkaline silicate(glass)} \]
Primary Inflation Analysis

- Deployment mixture is linearly related to pressure required.
- Optimum amount of airbag mixture is found at 105 pounds.
- Temperature affects required amount of airbag deployment mixture.
- Temperature increase will cause pressure increase in wings.
Primary Inflation Analysis

- Deployment time is based on the weight, size, and pressure.
- By increasing pressure inflation times decrease.
- Maximum inflation time is found out 0.022 seconds.
Reserve Inflation Method

- Can not use chemical reactions because they only allow for one time inflation
- Solution is to use nitrogen gas stored in tanks set above the payload
- Tanks are sized similar to commercial scuba gear
- Stored gas is controlled using a spring actuator
Reserve Inflation Analysis

Actuator sensitivity is compared in the above equation.

- \( P_U \) = under inflated pressure
- \( P_S \) = stable inflation pressure
- \( K, \_x \) = actuator sensitivities
- \( D \) = actuator size
Reserve Inflation Analysis

- With the given spring constant sensitive control of wing pressure is obtained.
- Pressure is added to the inflated structures at pressure losses at 1% of required pressure.
- Reserve inflation will compensate for leaks long enough to last for glide phase.

![Actuator Movement vs. Pressure loss](chart.png)

\[ k = 50 \text{ lb/in}, \ D = 1 \text{ in} \]
Additional Thoughts

- Chemical Reaction requires physical experimentation to refine chemical reactions
- Reserve inflation system requires testing for various inflation problems
- It is also possible to use controlled reserve inflation/deflation to gain more controllability for rolling and yaw maneuvers
Weights & CG
Glider Weight Distribution

- **STRUCTURES GROUP:**
  - *Tail:*
    - Horizontal
    - Vertical
  - *Body:*
    - Main Fuselage
    - Nose
    - Rear Fuselage
  - *Wing (Including Stub):*

- **EQUIPMENT GROUP:**
  - *Avionics package*
  - *Servo Motors*
  - *Wing Deployment Ignition System*

- **LOAD GROUP:**
  - *Cargo*
  - *Airbag fuel*
  - *Sodium Azide Tank*
  - *Nitrogen Tank*
# Weight Breakdown

<table>
<thead>
<tr>
<th>Component (Count)</th>
<th>Individual</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs</td>
<td>kg</td>
</tr>
<tr>
<td><strong>Main Fuselage:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stingers (12)</td>
<td>1.66</td>
<td>0.75</td>
</tr>
<tr>
<td>Frame Support (6)</td>
<td>26.83</td>
<td>12.16</td>
</tr>
<tr>
<td>Skin Material</td>
<td>3.68</td>
<td>1.67</td>
</tr>
<tr>
<td><strong>Rear Fuselage:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stringers (12)</td>
<td>2.41</td>
<td>1.09</td>
</tr>
<tr>
<td>Frame Support (2)</td>
<td>1.28</td>
<td>0.58</td>
</tr>
<tr>
<td>Skin Material</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Tail Assembly:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>26</td>
<td>11.79</td>
</tr>
<tr>
<td>Horizontal (2)</td>
<td>22.19</td>
<td>10.06</td>
</tr>
<tr>
<td><strong>Wing Stub:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stub Frame support (6)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Stub Lateral Support (8)</td>
<td>4.95</td>
<td>2.24</td>
</tr>
<tr>
<td>Stub Skin Material</td>
<td>3.81</td>
<td>1.72</td>
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<tr>
<td>Wing (2)</td>
<td>87</td>
<td>39</td>
</tr>
<tr>
<td>Nose Cone</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sodium Azide Tank</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Nitrogen Tank</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Servo Motors (3)</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>Avionics &amp; Battery Pack</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Payload</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sodium Azide Fuel</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

**TOTAL WEIGHT (with payload & fuel):** 1,759 lbs 798 kg  
**TOTAL WEIGHT (without payload & fuel):** 654 lbs 297 kg
Weight Distribution **With** Payload & Fuel

- **Payload**: 56%
- **Wings**: 10%
- **Main Fuselage**: 10%
- **Rear Fuselage**: 2%
- **Tail**: 3%
- **Servo Motors**: 3%
- **Wing Stub Assembly**: 6%
- **Nose Cone**: <1%
- **Sodium Azide Tank**: 3%
- **Nitrogen Tank**: 1%
- **Fuel**: 6%
- **Nitrogen Tank**: 1%
Weight Distribution Without Payload & Fuel

- Main Fuselage: 27%
- Rear Fuselage: 6%
- Tail: 8%
- Wings: 26%
- Wing Stub Assembly: 15%
- Sodium Azide Tank: 7%
- Nose Cone: <1%
- Nitrogen Tank: 3%
- Servo Motors: 8%
# CG Location: Moment Analysis

<table>
<thead>
<tr>
<th>Weight Component</th>
<th>Moment about the nose (lb*in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal tail</td>
<td>17,736.9</td>
</tr>
<tr>
<td>Vertical tail</td>
<td>5,240.46</td>
</tr>
<tr>
<td>Wing</td>
<td>8,392.56</td>
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<tr>
<td>nitrogen tank</td>
<td>1,402.74</td>
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<tr>
<td>sodium azide tank &amp; fuel</td>
<td>10,428.2</td>
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<tr>
<td>payload</td>
<td>81,013</td>
</tr>
<tr>
<td>motor 1</td>
<td>2,794.62</td>
</tr>
<tr>
<td>motor 2</td>
<td>2,882.6</td>
</tr>
<tr>
<td>main fuselage</td>
<td>15,538.8</td>
</tr>
<tr>
<td>rear fuselage</td>
<td>6,372</td>
</tr>
<tr>
<td><strong>Total Moment</strong></td>
<td><strong>151,802</strong></td>
</tr>
</tbody>
</table>
Final CG Location

- **With Payload and sodium azide fuel:**
  - CG ≈ 40 % C-bar (86 in from nose)

- **Without Payload and sodium azide fuel:**
  - CG ≈ 45 % C-bar (97 in from nose)

**NOTE:** The CG locations are taken in reference to the nose of the glider.
Constraints

- Due to launch method
  - Height: 10 ft
  - Span: 10 ft
  - Length: 18.5 ft
- No control surfaces available on wings due to inflatable structure.
Requirements

- Withstand large launch loads.
- Stable and controllable during wing deployment.
- Stable and controllable during glide.
- Navigated without the aid of an onboard pilot.
Tail Selection

- Tail types considered
  - Conventional
  - T-Tail
  - V-Tail
  - Inverted V-Tail
  - Y-Tail

- The conventional tail was selected for its reliability and the ability to provide adequate stability and control at the lightest weight.
Tail configuration

- The tail contains very little sweep.
  - Due to low glide velocity.
  - To maximize tail volume.
- The horizontal and vertical tails are staggered.
  - The effectiveness of increased moment arm was greater in the horizontal tail and thus is mounted aft of vertical tail.
- Control surfaces.
  - Control surfaces are mounted on the trailing edges at half the length of the chord.

<table>
<thead>
<tr>
<th>TAILS</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airfoil</td>
<td>FX 67-K-170/17</td>
<td>FX 67-K-170/17</td>
</tr>
<tr>
<td>Span</td>
<td>10 ft</td>
<td>3.5 ft</td>
</tr>
<tr>
<td>Root Chord</td>
<td>3.00 ft</td>
<td>3.50 ft</td>
</tr>
<tr>
<td>Tip Chord</td>
<td>2.75 ft</td>
<td>2.50 ft</td>
</tr>
<tr>
<td>Sweep Angle</td>
<td>2.86 degrees</td>
<td>4.09 degrees</td>
</tr>
</tbody>
</table>

Tail modeled by Athena Vortex Lattice Code
The Neutral Point of glider is located at 39.2% of the overall length of glider.

The desired Center of Gravity of glider is located at 33.5% of the overall length of glider.

The CG location can be shifted forward and aft depending on payload and still maintain trim and a minimum L/D of 33.2.

Maximum CG positions (percentage of glider length):
- Forward: 32.5%
- Aft: 34.1%
Longitudinal Trim

- Trim example:
  - At desired CG location
  - Can easily handle angles of attack from -5 to 5 degrees with elevator deflections of -5 to 3 degrees.
  - Constraint lines represent Coefficients of Lift that correspond to L/D values of 33.2
**Yaw Control**

\[
C_{nB} B + C_{n\delta r} \delta r = 0
\]

\[
B = - \left( \frac{C_{n\delta r} \delta r}{C_{nB}} \right) \quad \text{(Yaw angle)}
\]

**Maximum Yaw Angle induced is approximately ± 30 degrees**

![Graph of Yaw Control](image)
Roll effectiveness

\[ p = (-2 \ V \ C_{lB} \ B) / (C_{lp} \ b) \]  
\[ B = - (C_{n\delta r} \ \delta r) / C_{nB} \]  

(Roll Rate)

(Yaw angle)

Maximum roll rate: of 0.1 radians/sec, or 5.85 degrees/sec
Avionics
Avionics Package

Piccolo Plus

By

www.cloudcaptech.com
Key Features

- Flight planning system (FalconView)
- End-user Programmability
- Autonomous operation
- Integrated avionics systems, i.e.
  - Autopilot, flight sensors, navigation etc...
- Updated inertial and air data sensors
Key Components

- **CPU** - The brain of the Piccolo is the MPC555 microcontroller. It delivers 40Mhz of power and can handle a wide range of interfaces.
- **Sensors**
  - Air data sensors
  - Inertial – features 3 gyros and 3 accelerometers
- **GPS** - Motorola M12 provides basic ground speed and position
- **Navigation** - Uses the Motorola M12 GPS to command and control the autopilot
System Layout

MPC555
40MHz Embedded Power PC with 448K Flash, 26K SRAM and a host of integrated peripherals

PiccoloPlus

www.cloudcaptech.com
Communications

- Data Stream – Data transfer is done through a network of wireless channels
- Wireless Link – Provided by MHX 910/2400 frequency hopping radio (Microhard Systems Inc.)
- Flow Control – For support of multiple aircraft, also prevents multiple radio transmissions
Flight Planning...

- Flight plans are made with waypoints that are linked together, i.e. like vectors
  - 100 waypoints stored in avionics
- Each waypoint encodes latitude, longitude, altitude, etc...

Flight Planning page:

<table>
<thead>
<tr>
<th>Index</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude [m]</th>
<th>W/F [km]</th>
<th>Preburn</th>
<th>Right</th>
<th>Radius</th>
<th>Orbit [m]</th>
<th>Camera</th>
<th>Lights</th>
<th>Chute</th>
<th>Drop</th>
<th>Slope</th>
<th>Land</th>
<th>To</th>
<th>Length [km]</th>
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</thead>
<tbody>
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<td>-122.355326</td>
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<td>U</td>
<td>U</td>
<td>1.02</td>
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<tr>
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<td>200</td>
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<td>U</td>
<td>U</td>
<td>U</td>
<td>0.57</td>
<td></td>
</tr>
</tbody>
</table>
More on flight planning...

- Autopilot Page:
  Displays the current autopilot command status

- Can easily be changed from one command to another
Example flight plan

- Map Page:
  - Provides interface for flight planning
  - Gives up-to-date vehicle location
  - Displays vector shape plans
Avionics Overview

- Direct and control unmanned glider aircraft to deliver a 1,000 lbs payload 50 miles off the sea base.
- Ignite Sodium Azide fuel for wing deployment
Onboard Ship Glider Storage
Glider Storage

- 233 gliders per storage room
  - 2000 square feet by 8 feet high
- Only 206 fit by volume
- Actual configuration will fit less

Assumptions
- Square Storage Rooms
- No damage dealt sustained by stacked components
Component Stacks

3 Separate Components

• 4 layers of fuselages
  Layers 1 and 3 have 35 gliders
  Layers 2 and 4 have 30 gliders
  Place to right

• 6 cones in a stack
  17 stacks in a column
  Stacks stand on end
  Placed to left

• Tails will be stored in middle of room
Final Configuration

- Each glider is broken down into 3 components
- 130 gliders will fit in each storage room
- 64% of volume occupied
Cost Analysis
## Total Cost Estimates

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structures: Fuselage (110 lbs. Al Alloy and Carbon Fiber)</td>
<td>$2,500</td>
</tr>
<tr>
<td>Avionics Package</td>
<td>$6,197</td>
</tr>
<tr>
<td>Airbag System</td>
<td>$5,500</td>
</tr>
<tr>
<td>Inflatable Wings: Material</td>
<td>$8,383</td>
</tr>
<tr>
<td>Control Motors</td>
<td>$6,042</td>
</tr>
<tr>
<td><strong>Total (per glider)</strong></td>
<td><strong>$28,622</strong></td>
</tr>
<tr>
<td>One time cost (Avionics Ground Station)</td>
<td>$7,566</td>
</tr>
</tbody>
</table>
## Cost Comparison to Existing Payload Delivery Methods

<table>
<thead>
<tr>
<th>Delivery Method</th>
<th>Cost per Unit</th>
<th>Max Payload (lb)</th>
<th>Cost/Pound Deliverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glider</td>
<td>$28,622</td>
<td>1000</td>
<td>$42.67</td>
</tr>
<tr>
<td>C-130 Hercules</td>
<td>$44.1 million</td>
<td>42,000</td>
<td>$7.43</td>
</tr>
<tr>
<td>Chinook Heavy Lift Helicopter</td>
<td>$26.1 million</td>
<td>3,038</td>
<td>$48.67</td>
</tr>
</tbody>
</table>
Conclusions

- We have provided a design for a disposable glider that will deliver supplies to troops in hostile territories.
- The glider satisfies all of the following RFP constraints.
  - Payload = 1000 lbs.
  - Range = 50 miles
  - Launch Speed = 500 knots
  - Launch Acceleration = 30g
  - Launch Pod Dimensions = 10 ft span