ENEAS Rocket
Capstone Project Presentation

Team Eneas:
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Martin Tangari
Joshua Solberg
Ray Colquhoun

Instructor: Dan Larson (Space X)

4/21/16
Complete Design Intent

1st OpenRocket Simulation

SRR 9/28/15

PDR 11/3/15

CDR 12/15/15

dCDR 2/9/16

NAR L1 Certification 2/13/16

Dual Deployment Test 3/12/16

Flight Readiness Review 4/7/16

Launch 4/16/16

Electronics Bay Complete

CF-Balsa Fins Complete

CFRP Components Complete

Electronics Bay

CFRP Components

Primary Launch 4/9/16

Complete Electronics Bay

Complete CFRP Components

Launch 4/16/16

Primary Launch 4/9/16
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Parameter</th>
<th>Estimated Capability</th>
<th>Tested Capability</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocket shall achieve an apogee of 3000'</td>
<td>3000'</td>
<td>3256'</td>
<td>3556'</td>
<td>18.5%</td>
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<tr>
<td>Rocket must utilize dual deploy recovery methods with main parachute deployment between 500 and 800 ft.</td>
<td></td>
<td>Comply</td>
<td>Complied – 15” drogue, 60” main, altimeter successfully programmed</td>
<td>N/A</td>
</tr>
<tr>
<td>Rocket system shall demonstrate full reusability.</td>
<td>2 flights completed</td>
<td>Comply</td>
<td>Not Compliant – 1 flight completed, in-flight anomaly resulted in catastrophic damage</td>
<td>-50%</td>
</tr>
<tr>
<td>At least 1 team member must be NAR L1 certified</td>
<td>Team members certified ≥ 1</td>
<td>Comply</td>
<td>Complied – Ray Colquhoun NAR L1 certified on 2/13/16</td>
<td>N/A</td>
</tr>
<tr>
<td>The rocket shall carry at least 1 payload, separate from the altimeter and electronics bay, which shall be recovered and returned to ground safely.</td>
<td></td>
<td>Comply</td>
<td>Not Compliant – Egg module not recovered</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Design Overview

Rocket motor: Cesaroni I-216-CL(I)

- Ejectable Egg Module
- Alternative motor retention
  - 3D Printed Engine Block
  - Concentric alignment control
- Triple output altimeter
- Kevlar shock cord
- Shear pins (x3)
- Removable rivets (x4)
- CFRP Trapezoidal Fins (x4)
- Go Pro Camera bay
- Main Parachute
- Drogue Parachute
- Ejection Cap
- CFRP Ogive Nosecone
- "Dragon Egg" Ejectable Egg Module
- CFRP Removable Tailboat

Diameter: 4in
Weight: 6.78 lb (3077g)
Length: 62.13 in
Cost: $1,678.60
Build Milestone 1 – Electronics Bay

- To Drogue Charge
- To Payload Charge
- To Main
- To Drogue
- To Payload

 Rotary Switch accessible through static port hole

Testing altimeter barometric function
Build Milestone 2 – CFRP Components (1/3)

**Materials Required:**
- Chromate tape
- Carbon fiber fabric (bidirectional)
- Resin (Hexion 784-7978 vinyl ester resin, PEEK catalyst)
- Vacuum bagging film
- Peel ply
- Perforate ply
- Breather cloth
- Vacuum pump
- Vacuum port
- Release wax
- PVA mold release
- Flat plate/table
- Machined, primed, and surfaced molds (female molded monocoque parts)
- HVLP spray gun & compressor
- Hard polyester surfacing primer
Build Milestone 2 – CFRP Components (2/3)

- Vacuum bag film
- Breather cloth
- Peel ply
- Perforate ply
- Carbon fiber fabric (wet)
- Chromate tape
- 1/16” Balsa core
- Surfaced 2-piece mold (released)
Build Milestone 2 – CFRP Components (3/3)

- Remove edge irregularities
- Sand to fit
- Clear coat

- Remove PVA residue
- Cut shoulder to length & square
- Sand surface irregularities
- Clear coat
- Fairing buildup for transition
- Add tip (nose cone only)
Build Milestone 3 – Motor Retention

Engine Block

Shear load transfer via epoxy
Primary Load Transfer Area

Shear load transfer via epoxy
Secondary Load Transfer Area

Thrust

Tail Retainer Plate
Rear centering ring (CFRP-Phenolic honeycomb)

1st Centering ring (0.20 laser cut plywood)

2nd Centering ring (0.20 laser cut plywood)

Mounting method
Build Milestone 3 – Motor Retention

**Tensile Testing**

- Heat bar stock to approx. 400°F, then press against block for >1min
- No noticeable loss of mechanical integrity

**Thermal Testing**

**Low-cycle Fatigue Testing**

- Ramp to 160lbs in 2s, relax to 0, repeat.
Flight Preparation

- Wire electronics
- Pack black powder charges
- Connect shock cord
- Pack parachutes and payload
- Connect rocket sections with removable rivets and shear pins
- Move to launch pad and attach igniter
- Arm electronics
- Launch!
Flight Profile
Post-Flight Analysis
Drogue Charge Firing No separation 3556 ft (t=13.85s)

Payload Deployment 900 ft (28.15s)

Main Chute Deployment 800 ft (28.20s)

Max Ascent Velocity 389 mph (t=2.10s)

Tube separation (t=28.45s)

Lift off

Landing (t=53.20s)

Wind Conditions: 13mph gusting to 17mph
Post Flight Analysis

Root cause: Drogue charge failed to separate nose cone @ apogee (3556ft)

Independent failure: Exhaust & hot motor casing caused epoxy fillet securing rear centering ring temperature to exceed $T_g$, made bond with tail cone extremely brittle, fractured during handling after recovery.
Lessons Learned & Recommendations

• Rigorous testing & quality assurance of flight articles must not be overlooked
• Carbon fiber composites are hard and messy – but yield awesome results!
• Traditional motor mounting is the standard for a reason
• Be careful of requirement creep!
• Make sure proposed increases to budget are justified by improved performance
Acknowledgements

ADM-Works (Santa Ana, CA): Eric Schwartz & Jimmy Garcia, for donating carbon fiber, release wax, perforate ply, mold machining, and an enormous amount of time & knowledge on how to fabricate carbon composite components. Thank you so much!!!!

Plastic Materials Inc. (Ontario, CA): Nicole Ketchum, for donating all of our vacuum bagging film, peel ply, and breather cloth, half of our chromate tape, and also for sourcing the resin and tooling board.

Aerospace Corporation (El Segundo, CA): Dr. Jim Nokes, for lending use of a vacuum pump, as well as a second opinion on CFRP fabrication techniques and invaluable insight on the fundamentals of vacuum bagging composites.

Loyola Marymount University (Los Angeles, CA): Tom Boughey, for preparing an awesome workspace in the form of the Engineering Design Lab and for sourcing the odd tools we never thought we would need; Joe Foyos for running the Instron tensile testing machine so we could validate our design; John McLennan for machining our tensile test tooling and providing general advice.

SpaceX (Hawthorne, CA): Daniel Larson, for keeping us honest and motivated and working tirelessly to make this singularly awesome project a reality.

Johann Kim: For graciously providing all the money shots.
Thank you!
such shiny
much bright
wow
very rocket
omg amaze
many fast
CFRP Components – Failed Layups
## Budget Analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost ($)</th>
<th>% of Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFRP Components</td>
<td>835.07</td>
<td>50%</td>
</tr>
<tr>
<td>Motor &amp; Motor Retention</td>
<td>192.49</td>
<td>11%</td>
</tr>
<tr>
<td>Fuselage/Other</td>
<td>131.12</td>
<td>8%</td>
</tr>
<tr>
<td>Recovery System</td>
<td>360.04</td>
<td>21%</td>
</tr>
<tr>
<td>Shipping, Tax, &amp; Fees</td>
<td>159.88</td>
<td>10%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>1,678.60</td>
<td>100%</td>
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</tbody>
</table>
Testing

Engine Block
• Prototype 1
  • Survived 800 lbs. (Tooling failure)
• Prototype 2
  • Reduced weight to 47g
  • Survived 400 lbs.
• Future
  • Survived high load rate (160lb/s) testing & 10 cycles @ 80lb/s ramp

Ejection System
• Ejection Test on 3/12
Fore End Assembly

- Nose Cone
- Bulkhead
- Eye Bolt
- Drogue Chute
- Egg Module
- Chute Protectors
- Ejection Caps
- Bulkheads
- Body Tube
- Shear Pin
- Launch Lug
- **Altimeter:** RRC3 Sport
- **3 Outputs - Dual Deployment + Payload ejection**
- **Battery:** Energizer 522 9V
- **Switch:** Rotary switch
- **Housing:** 8 inch long 4 inch Blue tube coupler
- **Bulkheads & Sled:** ¼” Pine Plywood
- **Connections**
  - To front end: Removable Rivets (4)
  - To aft end: Shear Pins (4)
- **Eyebolts:** ¼”-28
- **Rods:** 8.5” 10-32 Aluminum fully threaded rods (2)
Ejection Charges

- 4F Black Powder
  - Estimated Charge Sizes
    - Drogue Chute: 0.51g
    - Payload: 0.34g
    - Main Chute: 0.66g
- PVC Ejection Caps (3)
- Igniters: Quest Low-current igniters
Aft End Assembly

- Chute Protector
- Main Chute
- Camera Assy.
- Fins
- Motor Retention Assy.
- Motor Casing
Altitude & Stability vs. ascent time
Flight Sims

AOA VS. Ascent time
<table>
<thead>
<tr>
<th>Potential Failure Mode</th>
<th>Parachute failure to deploy</th>
<th>Payload Recovery Failure</th>
<th>Zippering</th>
<th>Motor Retention Failure</th>
<th>Tailboat and Fin Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity</td>
<td>9 - Danger to those on the ground, damage to all rocket components</td>
<td>8 - Failure to meet &quot;intact egg&quot; requirement.</td>
<td>9-Failure of reusability requirement</td>
<td>9 - Danger to those on the ground, damage to all rocket components</td>
<td>8 - Failure to meet reusability requirement</td>
</tr>
<tr>
<td>Occurrence</td>
<td>8-Successful parachute deployment requires interaction of 3 systems</td>
<td>8- Successful ejection requires interaction of 3 systems</td>
<td>5-Occurs with moderate frequency, but can be easily prevented</td>
<td>5 – Engine block was tested and withstands 400 lb.</td>
<td>5 - Fin and tailboat cracking is a frequent event</td>
</tr>
<tr>
<td>Detectability</td>
<td>5- Deployment errors would be observed during test.</td>
<td>5 – Payload recovery errors would be observed during test.</td>
<td>5-Ejection system errors would be observed during test.</td>
<td>3– No engine block fracture observed before 300 lb</td>
<td></td>
</tr>
<tr>
<td>Risk Priority Number</td>
<td>360</td>
<td>320</td>
<td>225</td>
<td>135</td>
<td>120</td>
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<tr>
<td>Future Action</td>
<td>Ground test of dual deployment system</td>
<td>Ground test of egg recovery system</td>
<td>Ground test of dual deployment system</td>
<td>Fatigue and thermal testing of engine block</td>
<td>Proper carbon fiber layup</td>
</tr>
</tbody>
</table>
Egg Module

- Payload: Egg
- 3-D Printed ABS Plastic
- Rubber foam padding
- Nylon Parachute

Cutout for ejection cap

Cutout for shock cord

Slots for parachute tie-in
Camera Assembly

- Go Pro Hero3 Camera
- Carbon Fiber/Balsa Bulkheads