Critical Design Review

Rensselaer Rocket Society (RRS)
Project Red Gemini

System Level Design

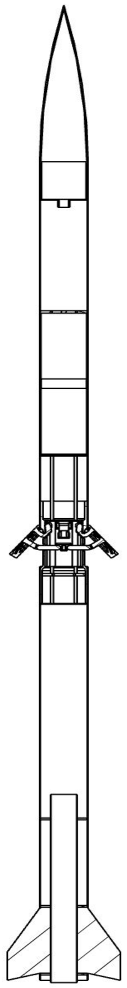
Tasks: Aerodynamic Analysis, Atmospheric Measurements

Three Subsystems:

- Recovery
- Structural
- Aerodynamics and Flight Stability

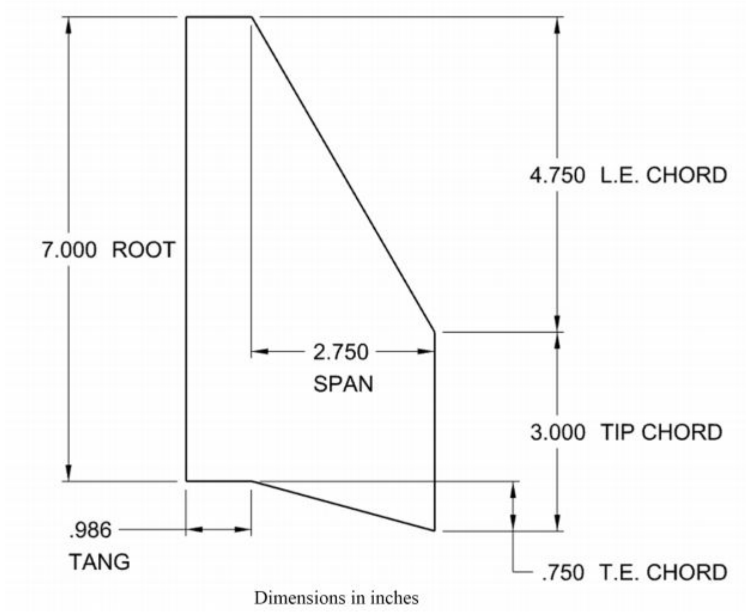
Changes Since PDR:

- Recovery System
- Electrical Schematics
- Camera Guidance System



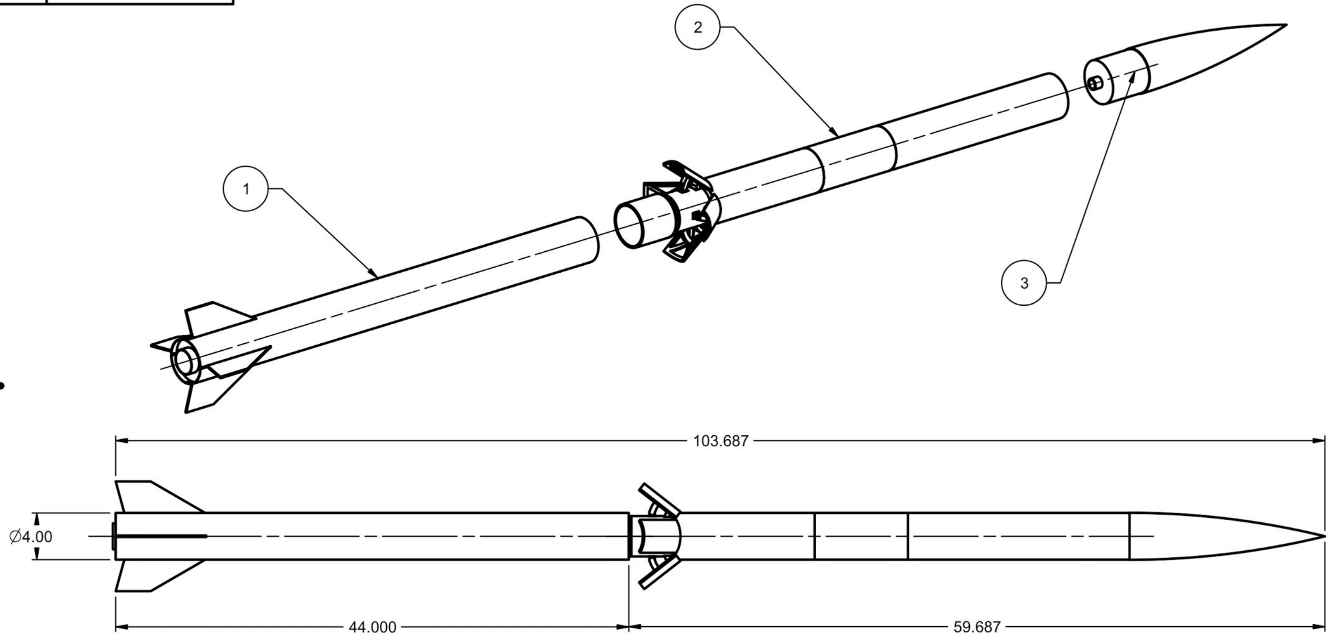
Vehicle Dimensions, Materials, and Justifications

- Final Height: 104 inches
- Final Diameter: 4.02 inches
- Mass: 13.176 lbm
- Body tube material: phenolic resin tubing
- Fin material: G-10 fiberglass (PML)
- Fin Thickness: 0.125 inches



PC NO	PART NAME
1	LOWER AIRFRAME
2	MAIN AIRFRAME
3	NOSE CONE

MODEL REV	SHEET REV	DESCRIPTION	DATE(YEAR-MO-DA)	APPROVED
	A	INITIAL_REVISION		



DRAWING NOTES (UNLESS OTHERWISE NOTED)
1. ALL DIMENSIONS IN INCHES

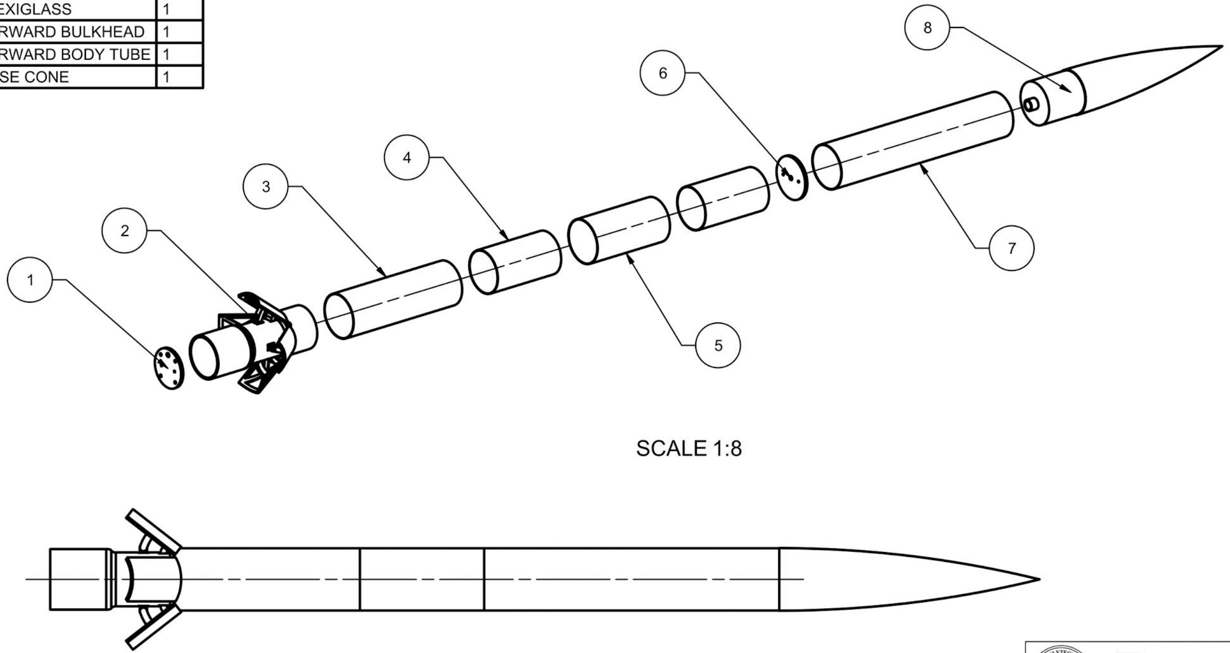
TOL. (UNLESS NOTED)	
DECIMAL:	X.X: ± 0.015
	X.XX: ± 0.01
	X.XXX: ± 0.005
FRACT.:	± 1/32

Rensselaer

TITLE	RED GEMINI FULL ASSY		
MATERIAL	VARIOUS		
AUTHOR	TUCKER BABCOCK		
SIZE B	CAD FILE __Rocket Full Assy_dwg1		QTY. REQUIRED
	SCALE 1:8	SHEET 1 OF 13	1

PC NO	PART NAME	QTY
1	AFT BULKHEAD	1
2	DRAG FLAPS ASSY	1
3	MIDDLE BODY TUBE	1
4	COUPLER	2
5	PLEXIGLASS	1
6	FORWARD BULKHEAD	1
7	FORWARD BODY TUBE	1
8	NOSE CONE	1

MODEL REV	SHEET REV	DESCRIPTION	DATE(YEAR-MO-DA)	APPROVED
	A	INITIAL_REVISION		



DRAWING NOTES (UNLESS OTHERWISE NOTED)
1. ALL DIMENSIONS IN INCHES
2. DRAG FLAPS DISCUSSED EXTENSIVELY IN SECTION 5.1
3. NOSE CONE IS PML PNC-3.9 WITH TANGENT OGIVE SHAPE

TOL. (UNLESS NOTED)	
DECIMAL:	X.X: ± 0.015
	X.XX: ± 0.01
	X.XXX: ± 0.005
FRACT.:	± 1/32

Rensselaer

TITLE	MAIN AIRFRAME ASSY
MATERIAL	VARIOUS
AUTHOR	TUCKER BABCOCK
SIZE	B
CAD FILE	_Rocket Top Section_dwg1
QTY. REQUIRED	1
SCALE	1:6
SHEET	7 OF 13

Mass Statement

Lower Airframe:

- Total: 6.603 lbm
- Motor: 54.42 ounces
- Body Tubing: 18.7 ounces

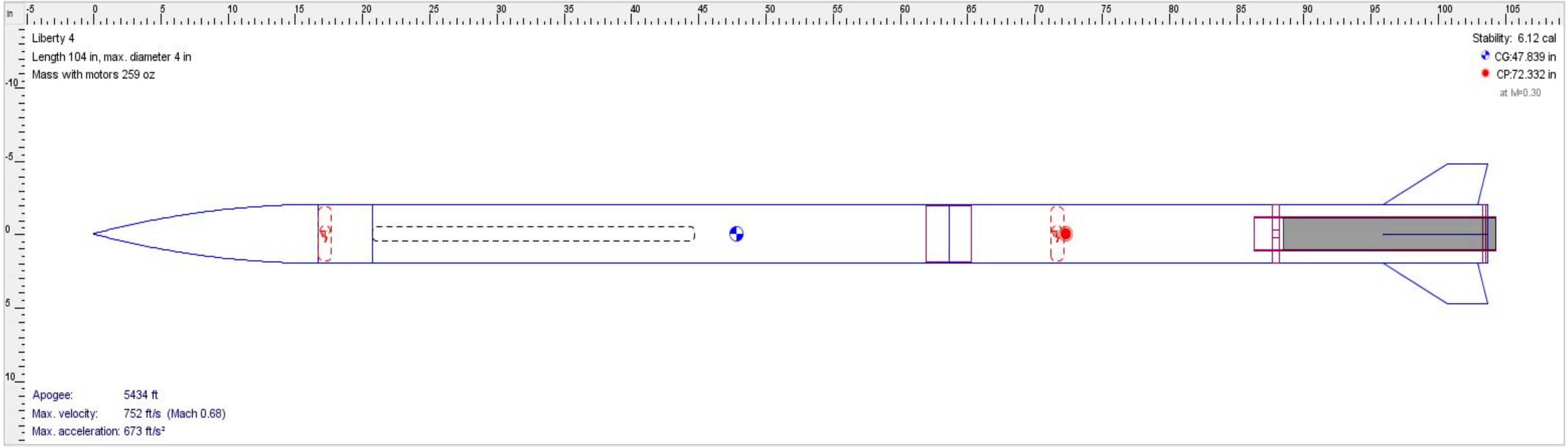
Main Airframe:

- Total: 6.573 lbm
- Tubing: 13.18 ounces
- Lexan Polycarbonate Tubing (camera sub.): 8.48 ounces
- Drag Flap System: 17.39

Total: 13.176 lbm

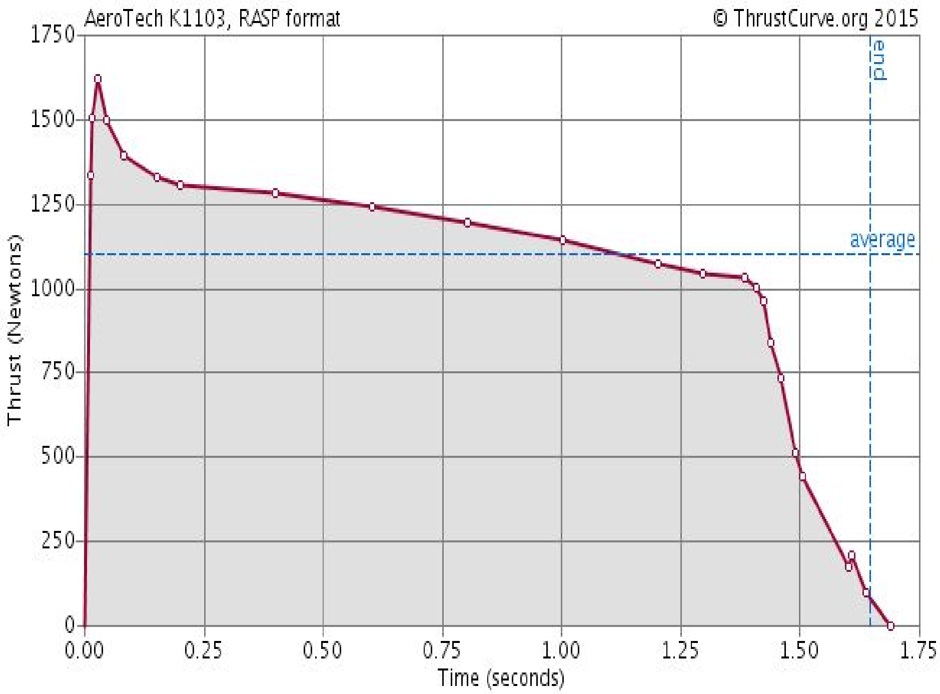
Static Stability Margin

- Margin: 6.12 cal with motor, 9.14 cal without motor
- Simulation: OpenRocket, drag flap models included
- CP and CG on diagram; 72 and 48 inches from nose tip respectively



Baseline Motor Selection and Justification

- Selected Motor: Aerotech K1103X Motor
- Class: K
- Propellant: APCP
- Average Thrust: 1,044 N
- Maximum Thrust: 1620 N
- Total Impulse: 1763 N-s
- Thrust Duration: 1.688 s



Important Notes:

- Apogee: 5431 feet without flaps
- TWR: **24.42 maximum**
- TWR: **15.74 average**
- Rail exit velocity: **63.6 ft/s**
- Rail length: **39.37 inches**

Major Components and Subsystems

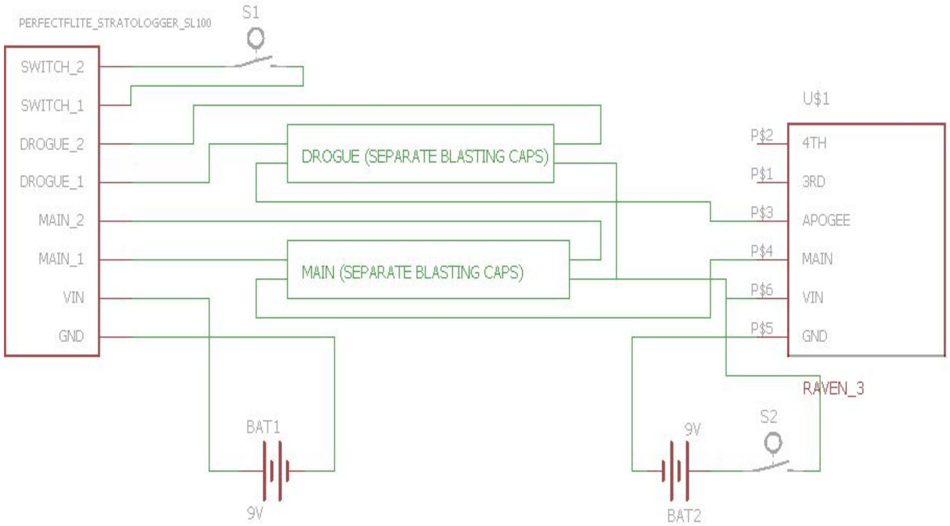
Recovery System

- Main parachute: SkyAngle Classic-II 42
- Drogue parachute: SkyAngle Cert-3 Drogue
- Suspension lines for each rated at 2250 lbf, attached to swivel joint rated for 1500 lbf
- Descent velocity:
  - After dogue deployment: 50 ft/s
  - After main deployment: 14.5 ft/s
- Three body sections attached by 250’’ of Kevlar shock cord each

Major Components and Subsystems

Recovery System

- Electronic Components
  - StratoLogger CF altimeter
  - Raven3 altimeter
- Two altimeters provide redundancy
- Ignite black powder charges mounted in aluminum blast caps
  - First charge (2.1 g): apogee
  - Second charge (1.7 g): 800 feet AGO



Recovery system electronics

Kinetic Energies and Drift

Kinetic Energies:

- Nose cone: 3.78 ft-lb
- Upper body: 52.2 ft-lb
- Lower body: 29.4 ft-lb

Drift:

(PDR)

Wind Speed	Drift Value
5 mph	856 ft
10 mph	1712 ft
15 mph	2567 ft
20 mph	3423 ft

(Final)

Wind Speed	Drift Value
0 mph	211 ft
5 mph	782 ft
10 mph	1209 ft
15 mph	1912 ft
20 mph	2150 ft

Verification Plan: Status Summary

In accordance with the Statement of Work; 2016 SL Handbook:

- Projected apogee: minimum 5280 feet, maximum 5600 feet unaltered
- Approved barometric altimeters with designated power supplies and arming switches, electronically separate from payload
- Launch vehicle separates into three independent sections, reusable after launch
- Single stage with commercially available motor (Aerotech K1103X, K-class)
- Recovery: electronic dual-deploy with drogue and main parachutes
- Independent sections fall with kinetic energy less than 75 ft-lbf

Verification Plan

Requirement	Design Feature	Verification that Design Meets Requirements
Apogee between 5,280 ft and 5,600 ft if left unaltered	Rocket Mass, Rocket Motor, Design	OpenRocket Simulations based on a 5 lb payload mass with the selected motor projects the rocket design to reach an apogee of 5,440 ft.
Reusable	Body Strength (fins, airframe, parachutes, etc.)	A strength, materials, and buckling analysis of vulnerable components was conducted to determine the rocket strength with respect to launch and landing forces. These analyses used a factor of safety of at least 1.4 in critical components During initial construction, the use high-strength epoxies has been followed. Components inspected upon order arrival show no signs of damage. The subscale rocket design showed a distinct ability to withstand the launch forces, even with a similar length and fin structure.
Four or fewer Independent Sections	General Design	Three independent sections (nosecone section, payload/avionics section, lower body section) were designed (and mirrored in the subscale launch).

Verification Plan (continued)

Requirement	Design Feature	Verification that design meets requirements
Single Stage	General Design, Motor Design	Rocket designed with only a single stage motor. Initial construction follows this design, and the subscale launch mirrored this full-scale design.
Commercially available solid motor propulsion system under Class L	Motor	OpenRocket Simulations based on a given 5 lb payload mass with the selected rocket design allow for a motor well under Class L motor approved by the TRA and NAR An Aerotech K1103X motor was selected.
Capable of Launch by 12 V DC firing system	Motor, motor retainer	An Aeropack motor retainer that allows for access to motor was selected, and the selected motor is fully capable of being launched with 12 V DC firing system. The subscale launch mirrored this requirement with an Aerotech G80 motor that was launched on a 12 V DC firing system

Verification Plan (continued)

Requirement	Design Feature	Verification that Design Meets Requirements
Electronic Dual Deploy	General Recovery Design (parachutes, shock cord, ejection charges, etc.)	The general design is dual deployment, and it uses a drogue and main parachute with design for multiple separation points. Initial calculations and simulations are run with these design parameters. The subscale launch mirrored this recovery system.
Drogue Deploys at Apogee, Main Parachute Deploys at much lower altitude	Parachutes, ejection charges, General Rocket Design, Altimeters	The general design has the drogue parachute at first separation point and the main parachute at another. OpenRocket simulations were run with these deployment locations. The subscale launch mirrored these deployments with parachute deployment at similar locations to the full-scale design.

Verification Plan (continued)

Requirement	Design Feature	Verification that Design Meets Requirements
Shear Pins hold rocket sections together until Parachute Deployment	Shear Pins, Ejection Charges	In the overall launch vehicle design, the shear pin strength was accurately calculated and inserted into the recovery design. The ejection charge strengths were also accurately calculated for the full scale rocket design. Ejection charge strengths for the subscale rocket were calculated in the same way as the full-scale rocket design, and successfully deployed the recovery system.
Independent Sections have less than 75 ft-lb of KE at Landing	General Rocket Design (Mass), Parachutes	The kinetic energy of each independent section was analyzed accurately. A major focus of the initial construction has been to stay as close as possible to original mass estimates for the full-scale rocket build., Parachutes and Recovery system components show no signs of damage upon order arrival. The subscale rocket launch landed safely with no signs of independent sections landing with more than 75 ft-lb of KE at landing in relatively difficult launch conditions.
Redundant, Safe Altimeters	Altimeters, Supporting Recovery Electronics	The full-scale launch vehicle has selected 2 commercially available altimeters, the Raven3 and Stratologger CF altimeters. The electronics design has an independent power supply to each altimeter. These altimeters are being stored safely, along with all other supporting electronics components. The subscale recovery system operated as expected with installation similar to what will be done on the full-scale launch vehicle.

Status/Plan for Launch Vehicle Testing

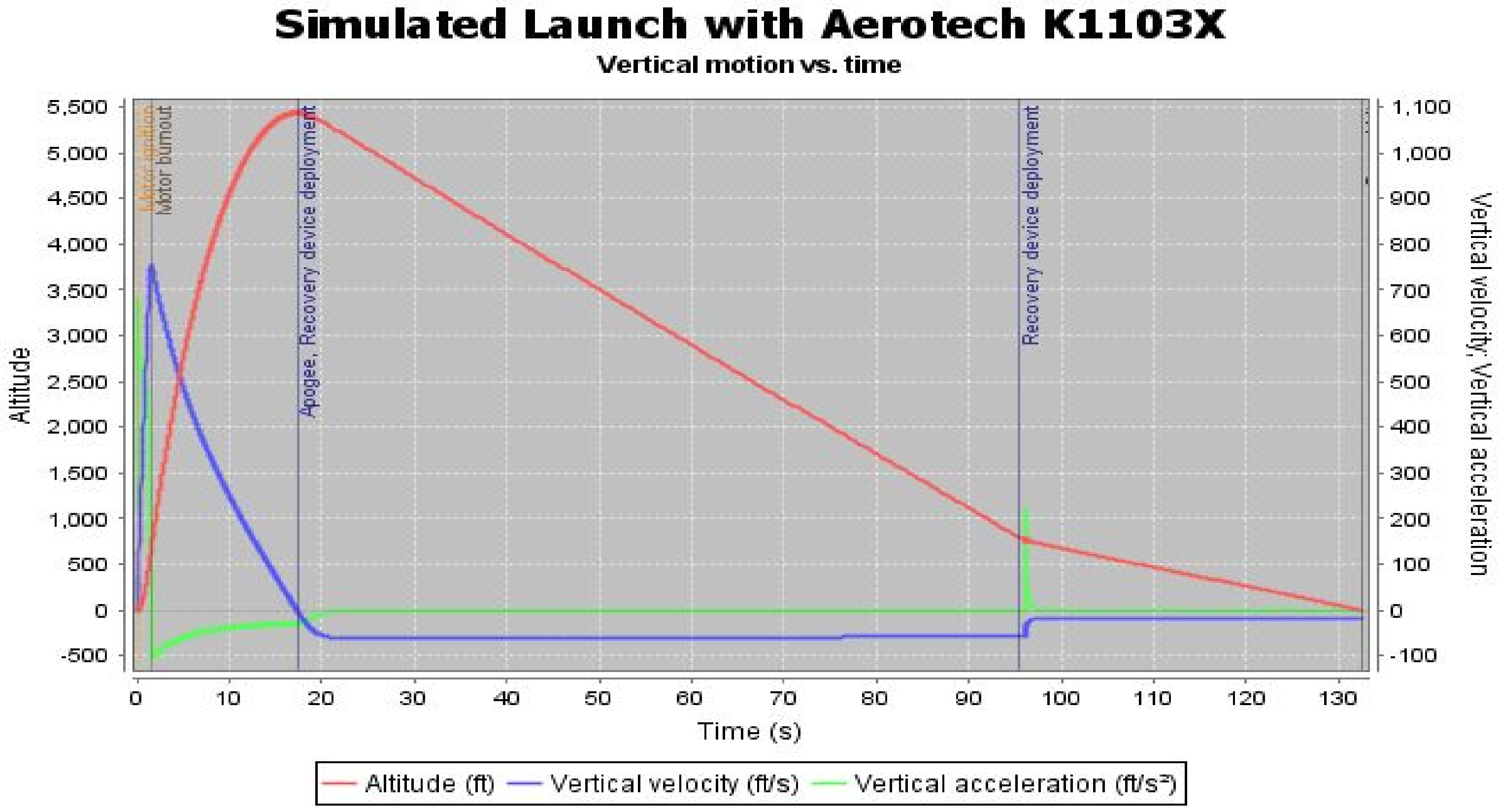
Vehicle verification summary:

- Several calculations performed to reinforce critical design points
- Simulations conducted during design phase to make informed decisions and models
- Designs and safety practices closely followed during the construction phase
- Modular construction and assembly of vehicle that allows for several verification checkpoints

Testing plans:

- Static load testing of major structural components
- Several scale and full test launches to verify all systems perform as expected

Launch Vehicle Verification - Simulated Launch



Sub-Scale Flight Results

Projection:

- Apogee: 1000 ft
- Recovery Deployments

Results:

- Apogee: 1237 ft
- Recovery Deployments
- Success!

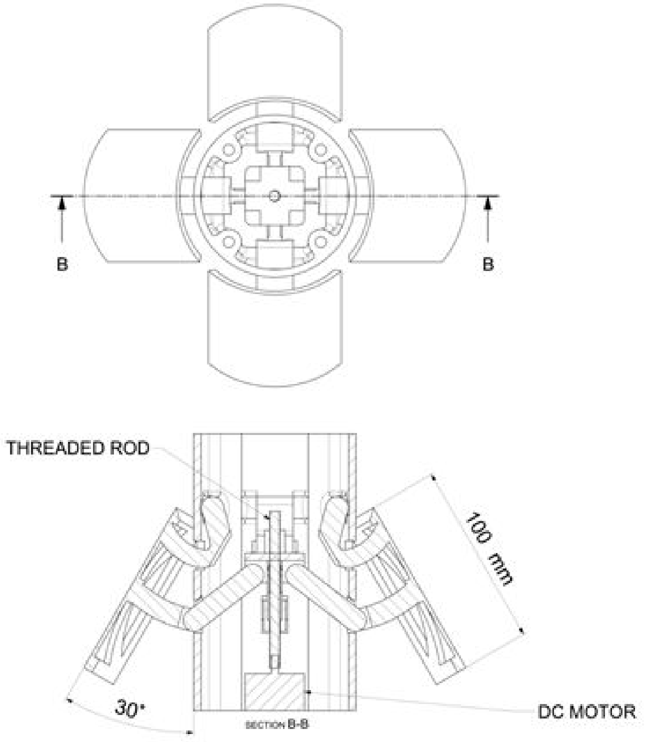
Impact:

- Vehicle Design Verification
- Recovery Design Verification

Major Components and Subsystems

Drag Flap Subsystem

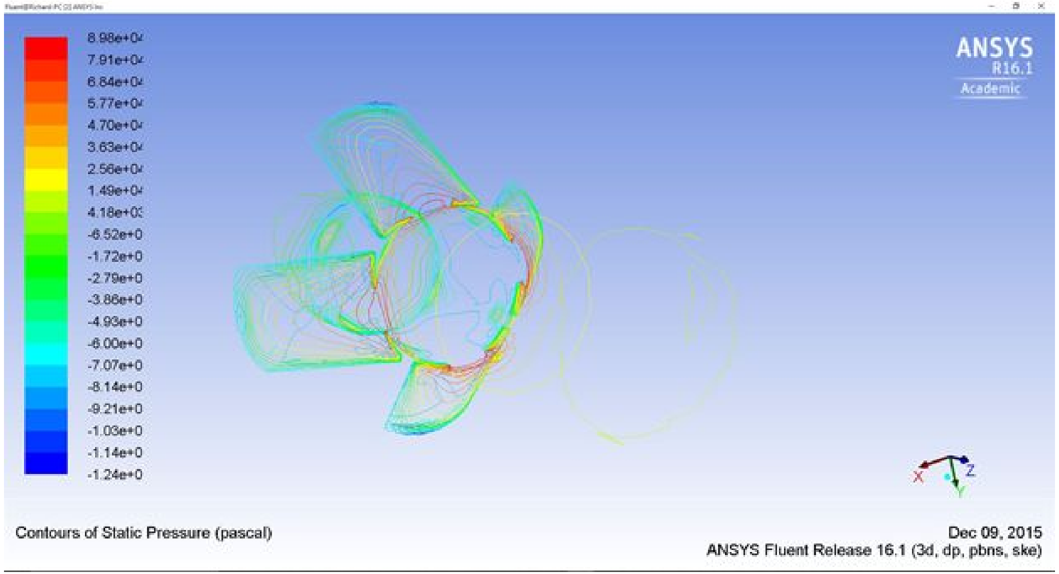
- Four quarter-cylinder elements fan out to create drag force
- Controlled simultaneously via threaded rod attached to single DC motor
- Twelve 3D-printed plastic pieces
- Control Algorithm/Modeling



Major Components and Subsystems

Drag Flap Subsystem

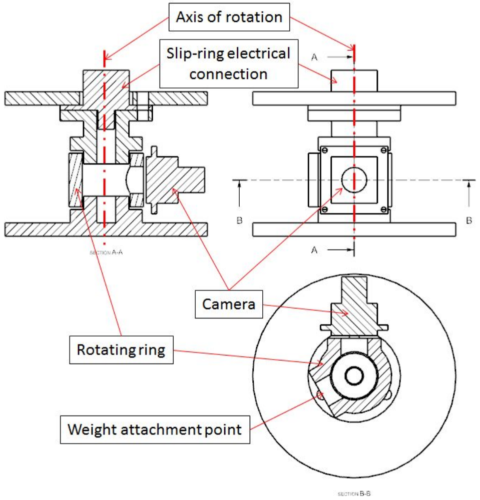
- Dynamically controlled to reduce vertical velocity to reach apogee of 5,280 feet
- Barometric pressure measured above and below flaps in order to fulfill payload requirement 3.1.6, “Aerodynamic Analysis of Structural Protuberances.”



Major Components and Subsystems

Payload - Camera

- Body tube with transparent Lexan Polycarbonate section (PDR - Plexiglass)
- Camera system freely rotates about rocket vertical axis
- Camera system keeps image frame in proper orientation with counterweight



Major Components and Subsystems

Payload - Avionics and Science

- Two Arduino microprocessors
- XBee radio data relay
- GPS / triple-axis accelerometer

Science package:

- Two barometers located above and below drag flaps to characterize flow
- UV and humidity sensors, solar irradiance measurement
- Camera system

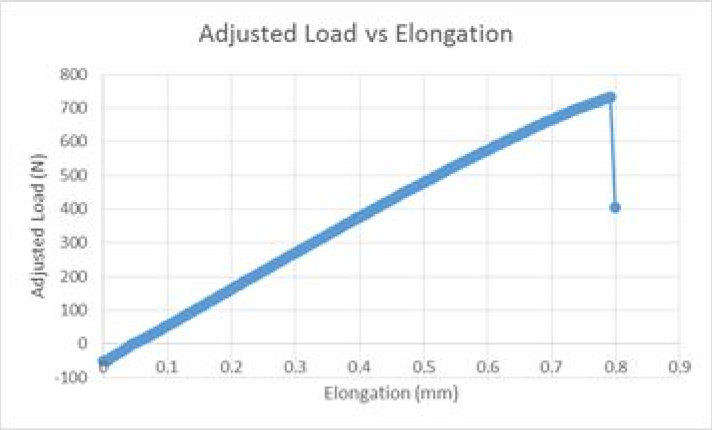
Plan for Payload Verification and Testing

Payload verification summary:

- Tasks: Aerodynamic Analysis, Atmospheric Measurements
- Radio relay of both pictures and data

Test Plan/Status:

- Static load testing on drag flaps
- CFD analysis of drag flaps
- Software testing of data relay
- Electronics testing of payload systems
- Orientation testing of camera



Plan for Vehicle Safety Verification and Testing

Safety verification summary:

- Risk analysis conducted, checklists created, testing plans drafted
- Launch failure modes, hazards identified, ranked for severity, and analyzed

Testing plans:

- Ground testing of flight avionics. Static load testing of drag flap system.
- Body separation testing for separation charges (parachute deployment failure, loss of vehicle)

Safety Officer: *Special Election*

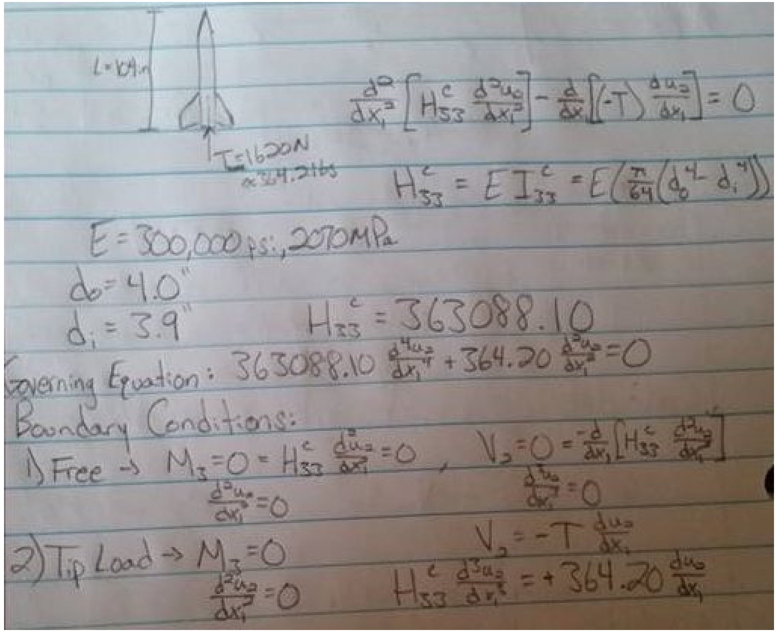
Analysis of Failure Modes

Launch Failure Analysis Factors:

- Stress-Strain
- Material
- Buckling

Failure Modes:

- Motor
- Computer/Control Systems
- Recovery
- Structural
- Launch Operations/Transportation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$$\frac{d^2}{dx_1^2}\left[H^c_{33}\frac{d^2u_2}{dx_1^2}\right] - \frac{d}{dx_1}\left[(-T)\frac{du_2}{dx_1}\right] = 0$$

T=1620N ≈364.2lbs

$$H^c_{33} = E I^c_{33} = E\left(\frac{\pi}{64}\left(d_o^4 - d_i^4\right)\right)$$

E = 300,000 psi, 2070 MPa

$d_o = 4.0''$

$d_i = 3.9''$ $\quad H^c_{33} = 363088.10$

Governing Equation: $363088.10\frac{d^4u_2}{dx_1^4} + 364.20\frac{d^2u_2}{dx_1^2} = 0$

Boundary Conditions:

1) Free → $M_3 = 0 = H^c_{33}\frac{d^2u_2}{dx_1^2} = 0$, $\quad V_2 = 0 = -\frac{d}{dx_1}\left[H^c_{33}\frac{d^2u_2}{dx_1^2}\right]$

$\frac{d^2u_2}{dx_1^2} = 0 \qquad \frac{d^3u_2}{dx_1^3} = 0$

2) Tip Load → $M_3 = 0 \qquad V_2 = -T\frac{du_2}{dx_1}$

$\frac{d^2u_2}{dx_1^2} = 0 \qquad H^c_{33}\frac{d^3u_2}{dx_1^3} = +364.20\frac{du_2}{dx_1}$

Personal Hazard Analysis

Potential Risks:

- Machine Shop Tools (Drill Press, Band Saw, etc.)
- Power Tools (Power Drill, Dremel, etc.)
- Hazardous Materials (Epoxies, Paint Fumes, Propellant, etc.)

Mitigation:

- Personal Protective Equipment
- First Aid Kit
- Eyewash Station

Environmental Concerns

Risk	Mitigation	Likelihood
Inoperable Wind Conditions / Cloudy	Launches will be planned in advance according to weather forecasts to ensure timely completion.	2
Rainy Conditions	All electromechanical and electrical parts will be shielded. Body structure will be able to retain integrity in damp conditions.	2
Operable Wind Conditions	Launch rod angle will be adjusted. Parachute deployment altitude will be recalculated and adjusted due to higher-than-expected drift.	3
Vehicle Cannot be Found	All charges will be detonated by flight computer before landing to ensure that it is inert. Vehicle will have identifiable, bright paint scheme.	1

Launch Procedures

- Recovery Preparation
- Motor Preparation
- Launcher Setup
- Igniter Installation
- Troubleshooting
- Post-Flight Inspection

Budget

Income:

- Membership Dues ($1,600)
- School of Engineering ($1,500)
- WeR Gold Fundraising ($3,000)

Expenses:

- Vehicle Design Team ($490.58)
- Recovery Design Team ($289.95)
- Payload Design Team ($336.59)
- Travel ($5,070.00)
- Sub-Scale Launch ($101.99)

Income	$7,630.00
Spending	$6,289.11
Difference	$1,340.89

Timeline

RPI USLI Gantt Chart

Plan | Actual | % Complete | Actual (beyo

Task	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	Owner	Date 7-Aug 1	8-Aug 2	9-Aug 3	10-Aug 4	11-Aug 5	12-Aug 6	13-Aug 7	14-Aug 8	15-Aug 9	16-Aug 10	17-Aug 11	18-Aug 12
Complete Preliminary Recovery Design	1	59	1	59	100%	Jon												
Complete Preliminary Payload Design	1	59	1	59	100%	Matt												
Complete Preliminary Vehicle Design	1	59	1	59	100%	Charlie												
Complete Proposal	1	35	1	35	100%	David												
Web Presence Established	36	43	36	43	100%	Ryan												
Vehicle, Payload, and Recovery Parts Ordered	58	34	58	34	100%	Shane												
Preliminary Design Review	62	30	62	62	100%	David												
All Payload Electronics Components Selected	88	3	88	3	100%	Ryan												
Completed CAD Models of Drag Flaps	88	3	88	3	100%	David												
Completed CAD Models of Camera System	88	3	88	3	100%	Matt												
Completed CAD Models of 3D Printing Stress Testing	88	1	88	1	0%	David												
Pseudo Code Completed for All Systems	88	8	88	8	50%	John												
Initial Construction of Drag Flaps	90	19	90	19	5%	David												
Initial Construction of Camera System	90	19	90	0	0%	Matt												
Initial Construction of Electronics	90	12	90	0	0%	Ryan												
Analysis of Feasibility of 3D Printing	92	6	92	0	0%	David												
Preliminary Vehicle Constructed	92	29	92	0	0%	Charlie												
Order Parts	94	14	94	0	0%	Joe												
Initial Code Completed for Camera System	95	14	95	0	0%	Brian												
Initial Code Completed for Drag Flaps	95	14	95	0	0%	Chris												
Initial Code Completed for Science Payload	95	7	95	0	0%	John												
PDR Video Teleconference	98	1	98	0	0%	David												
Ground Testing of Electronics	99	10	99	0	0%	Ryan												
Receive Parts - Inspect/Clean/Prep	101	7	101	0	0%	Charlie												
Make Fin Alignment Guide	101	14	101	0	0%	Shane												
All Payload Parts Delivered	105	5	105	0	0%	Jon												
Ground Testing of Drag Flaps	106	10	106	0	0%	David												
Ground Testing of Camera System	106	10	106	0	0%	Matt												
Prepare Fin Can/Install Fins	108	21	108	0	0%	Charlie/Tim												
Preliminary Recovery System Constructed	113	11	113	0	0%	Jon												
Payload Structure Finalized and Built	113	16	113	0	0%	Jon												
Prepare Body for Install	115	14	115	0	0%	Tucker/Shane												
Critical Design Review	120	43	120	0	0%	David												
Launch Test Vehicle and Recovery Design	121	7	121	0	0%	Chris												
Complete Recovery Final Design	121	18	121	0	0%	Jon												
Complete Vehicle Final Design	121	18	121	0	0%	Charlie												
Complete Testing of Electronics	128	18	128	0	0%	Matt												
Install Fin Can	129	7	129	0	0%	Charlie/Shane												
Complete Total Payload System Testing	130	9	130	0	0%	Matt												
CDR Video Teleconference	166	10	166	0	0%	David												
Install Motor Retainer	171	7	171	0	0%	Tim												
Prepare Nosecone	171	7	171	0	0%	Tucker												
Full Rocket Test	177	15	177	0	0%	Chris												
Complete System Improvements	177	40	177	0	0%	Shane												
Build Payload Section	178	21	178	0	0%	Charlie/Tucker												
Flight Readiness Review	181	40	181	0	0%	David												
Drill Holes for Shear Pins	199	7	199	0	0%	Tucker/Shane												
Connect and Install All Components	206	6	206	0	0%	Charlie/Tim												
Second Complete System Launch	206	7	206	0	0%	Chris												
FRR Video Teleconference	224	13	224	0	0%	David												
Trip to Huntsville for Launch	251	4	251	0	0%	Shane												