Flight Readiness Review

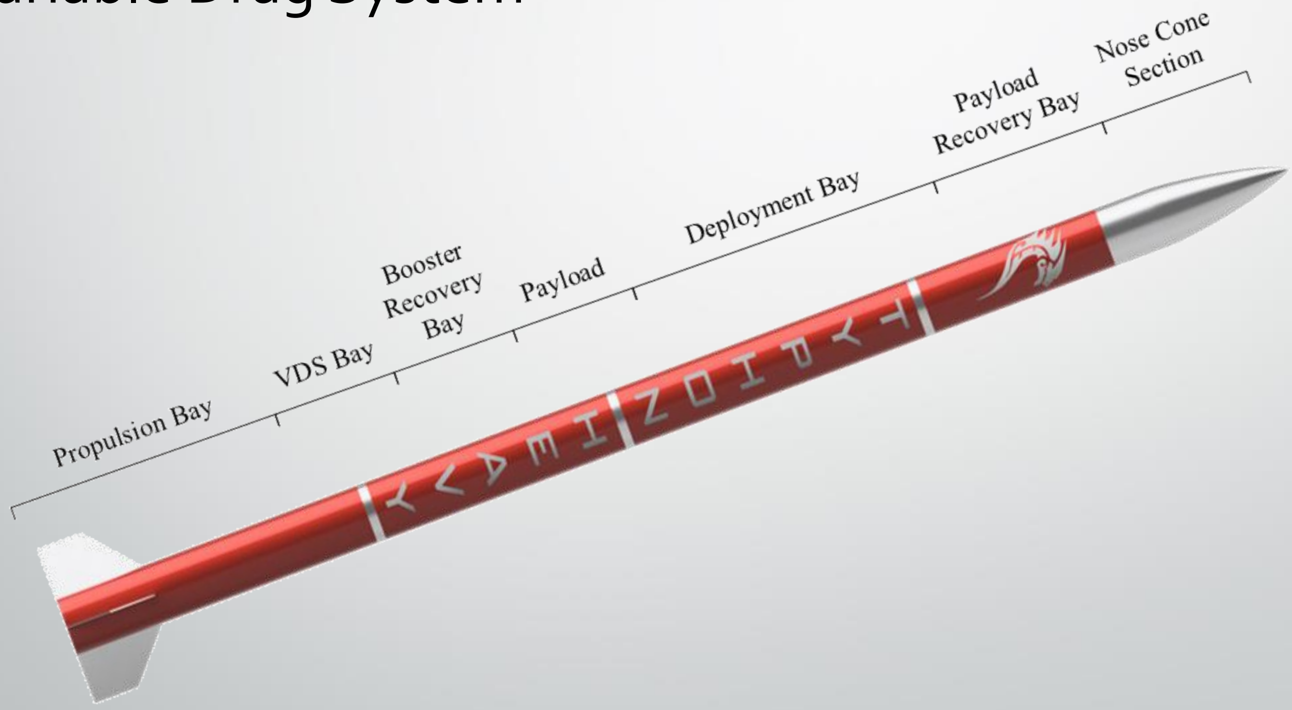
University of Louisville
River City Rocketry
2016-2017

FRR Presentation Agenda

- Launch Vehicle
- Variable Drag System
- Recovery
- Full-Scale Flight Results
- Payload
- Safety
- Educational Outreach
- Budget

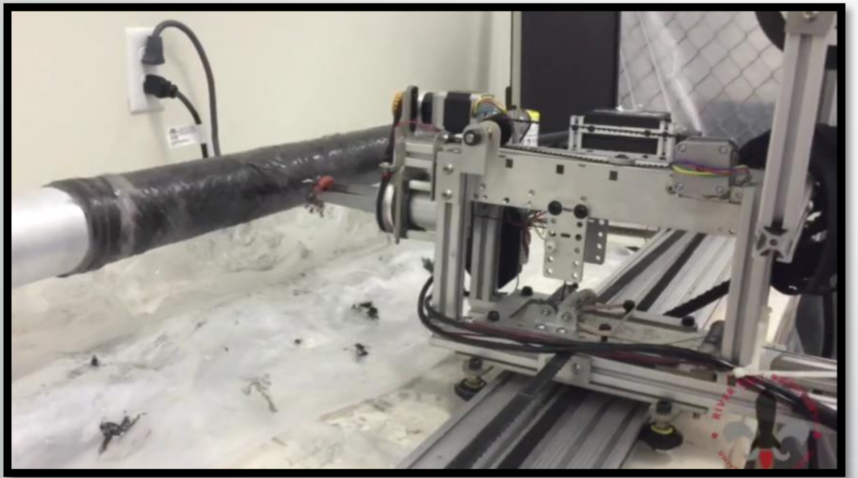
Overall Vehicle Design

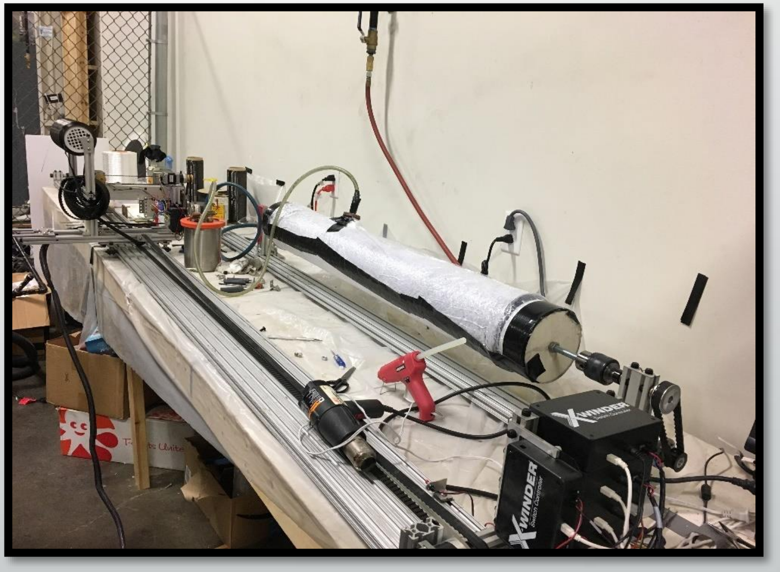
- 6.1 inch diameter, 141 inch long, carbon fiber airframe
- Custom manufactured carbon fiber nose cone
- Removable Fin System
- Variable Drag System



Airframe

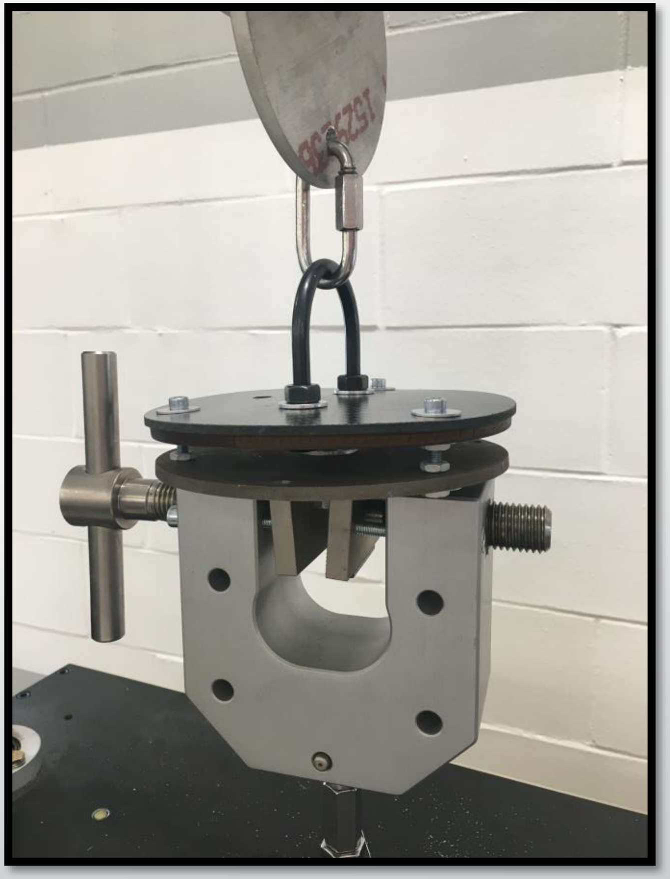
- 6K carbon fiber filament wound airframe
- X-Winder Desktop Filament Winder
- Vacuum bagging and heat-shrink tape methods





Launch Vehicle Component Tests

Airframe Tensile Strength Test



Bulkplate Tensile Strength Test

Nose Cone

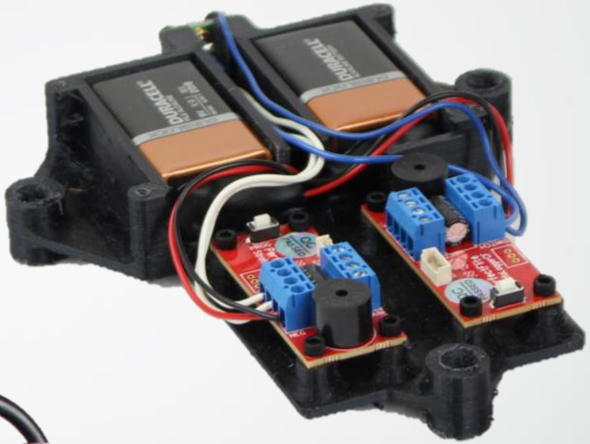
- Carbon Fiber LD Haack nose cone
- Positive and negative mold used to create nose cone

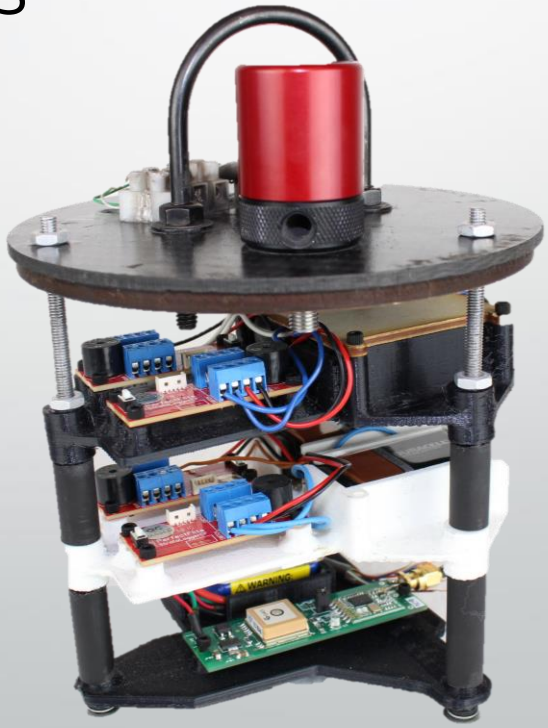
Nose Cone

- Carbon fiber nose cone cone vacuum formed
- 3D printed nose cone tip
- Painted and epoxied coupler tube

Avionics

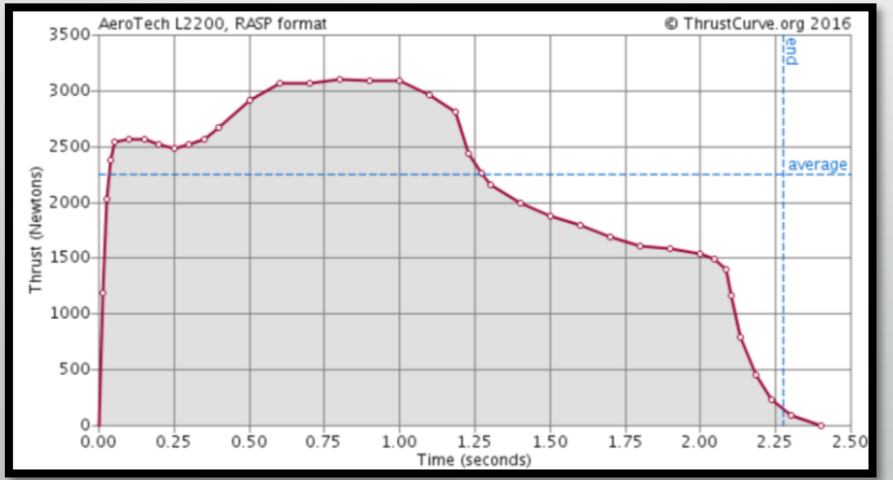
- Six PerfectFlite Stratologger CF altimeters
- Three Eggfinder GPS tracking system



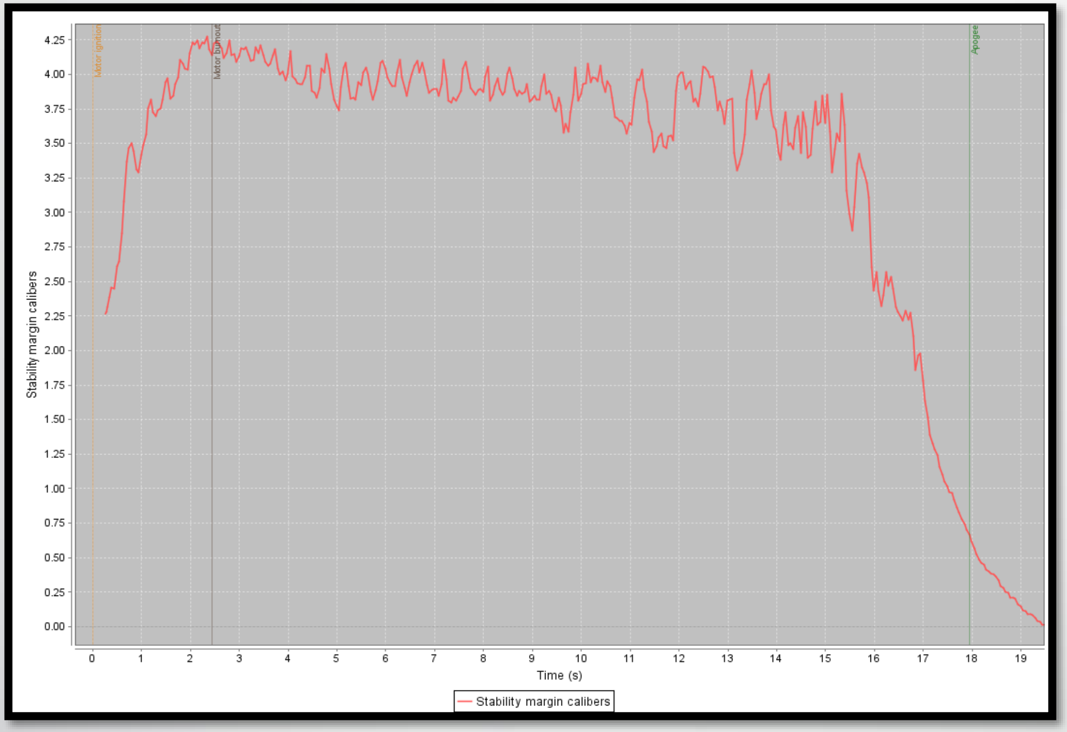


Motor Selection

Motor	AeroTech L2200-G
Diameter	75.0 mm
Total Weight	167.59 oz
Propellant Weight	88.75 oz
Average Thrust	2200.0 N
Maximum Thrust	3101.8 N
Total Impulse	5104.1 N-sec
Burn Time	2.3 sec



Stability Margin



- Overall Length: 141 in
- Overall Diameter: 6.1 in
- Overall Weight: 50.7 lbs
- Stability Margin (off the rail) : 2.2
- CG Location at rail exit (from tip): 102.11 in
- CP Location at rail exit (from tip): 115.30 in

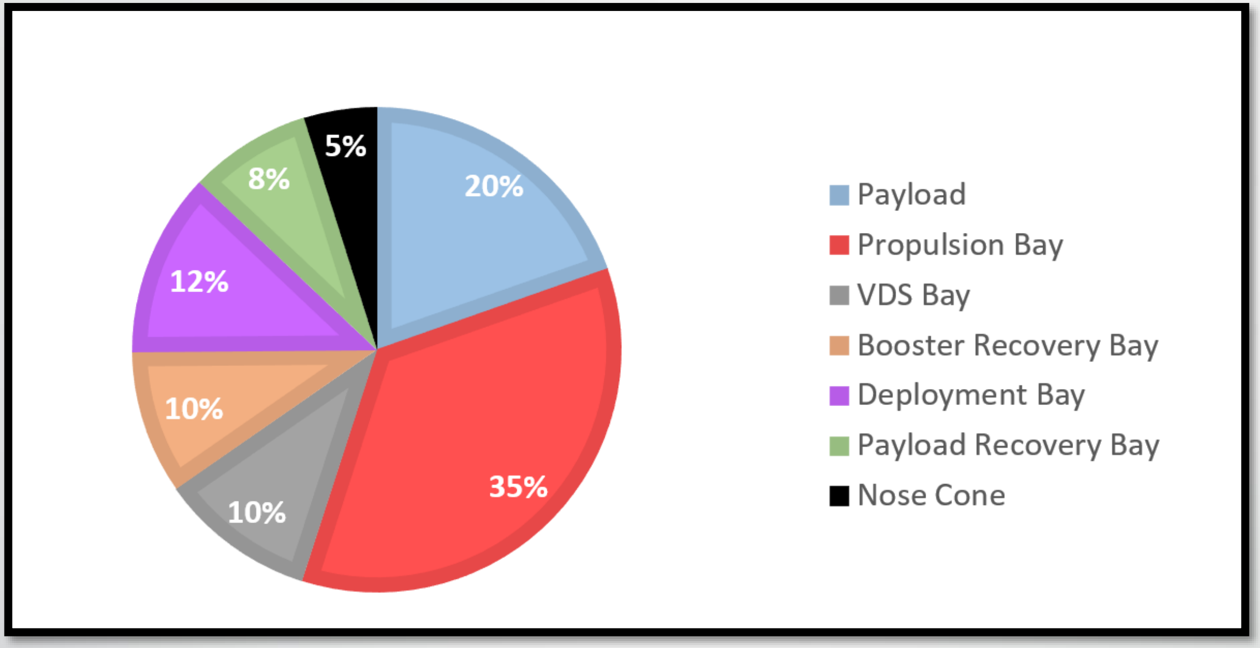
Full-Scale Launch Vehicle Flight Characteristics

Property	Value
Predicted Apogee Altitude (ft)	5,561 (no VDS)
Thrust-to-Weight Ratio	14.65
Burnout Velocity (ft/s)	721 (0.61 Mach)
Maximum Acceleration (ft/s^2)	469
Exit Rail Velocity (ft/s)	96.8

Mission Performance Predictions

Wind Speed (mph)	OpenRocket Simulated (No-brakes) Apogee Altitude (ft)	VDS Simulation (No-brakes) Apogee Altitude (ft.)	VDS Simulation (VDS Active) Apogee Altitude (ft.)
0	5,594	5,419	5,287
5	5,556	5,416	5,288
10	5,498	5,410	5,288
15	5,460	5,394	5,287
20	5,383	5,338	5,287

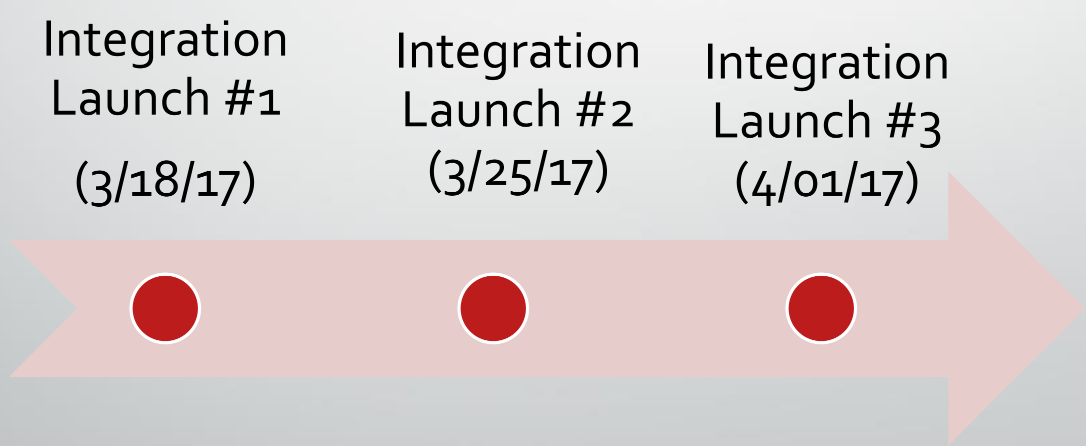
Mass Margin



- Launch vehicle overall weight for first two test flights was 45.5 lbs, compared to 43.95 lbs predicted in CDR
- A thicker paint job will be added to increase overall mass of launch vehicle to 50.7 lbs

Launch Vehicle Verification Status

- 34/40 team-derived requirements verified
- Remaining verifications include:
  - Full Scale Integration Launch Vehicle Tests



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- Launch Vehicle
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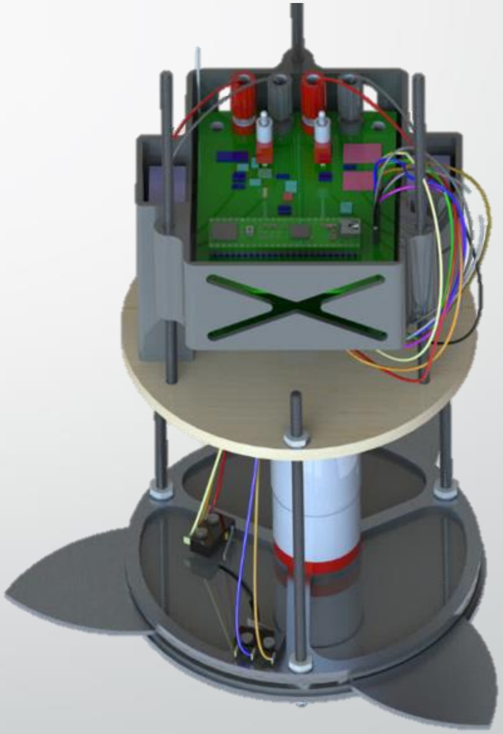
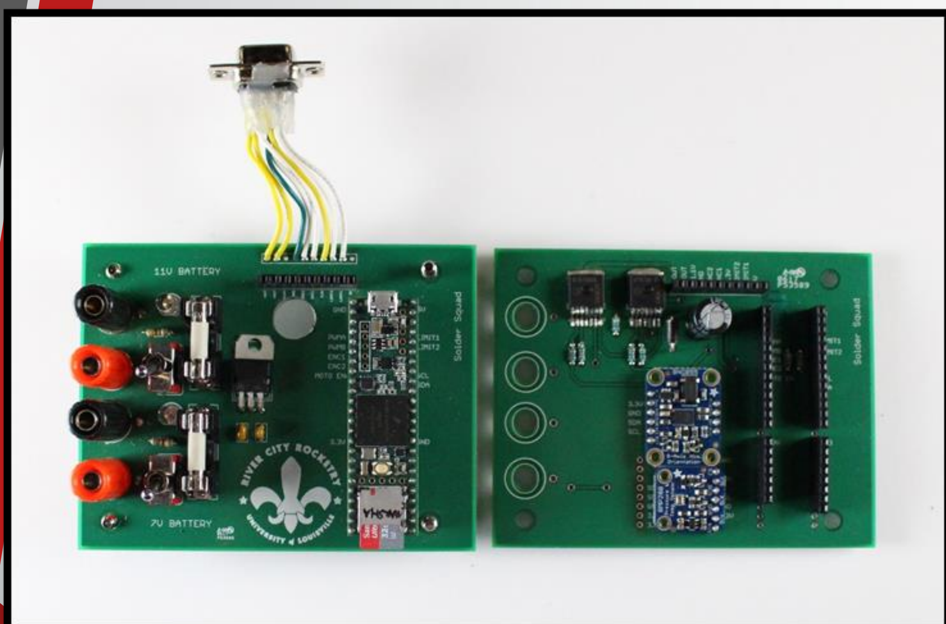
VDS Agenda

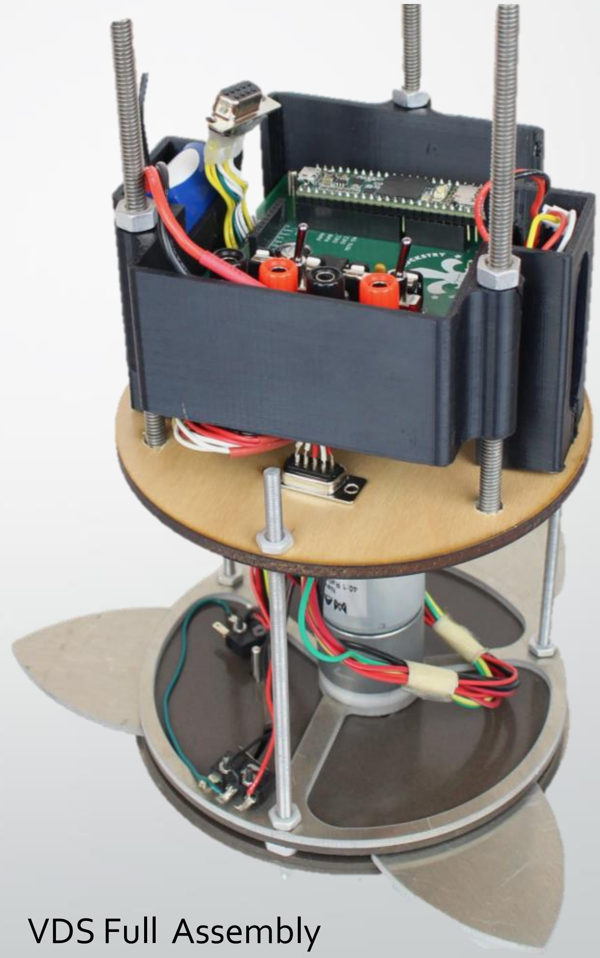
- Manufacturing Complete
- Braking Power Test
- VDS Demonstrations
- VDS Verification Status



Manufacturing Complete



VDS Electronics PCBs



VDS Full Assembly

Braking Power Test: Overview

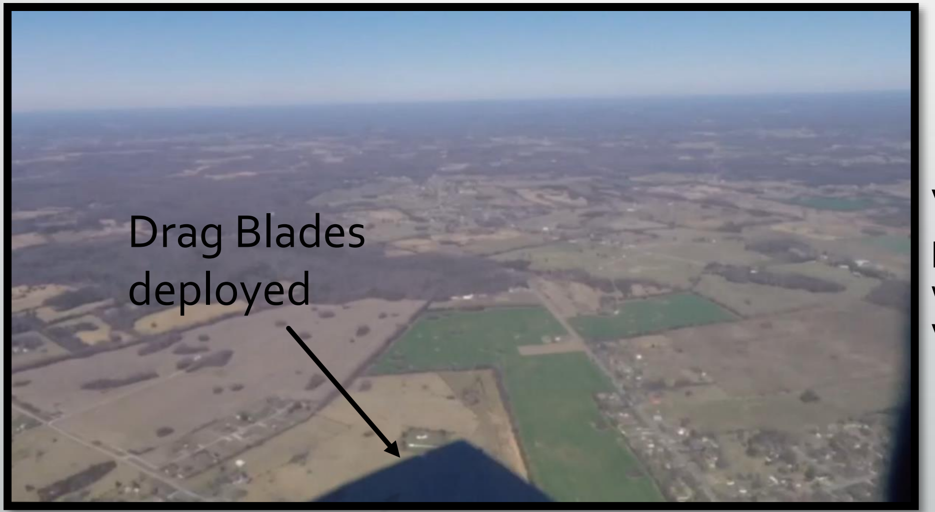
Purpose: To demonstrate the system's ability to reduce the apogee of the vehicle.

Procedure Overview: Fly two full scale launches:

1) Control Launch: To characterize the behavior of the vehicle without the VDS active.

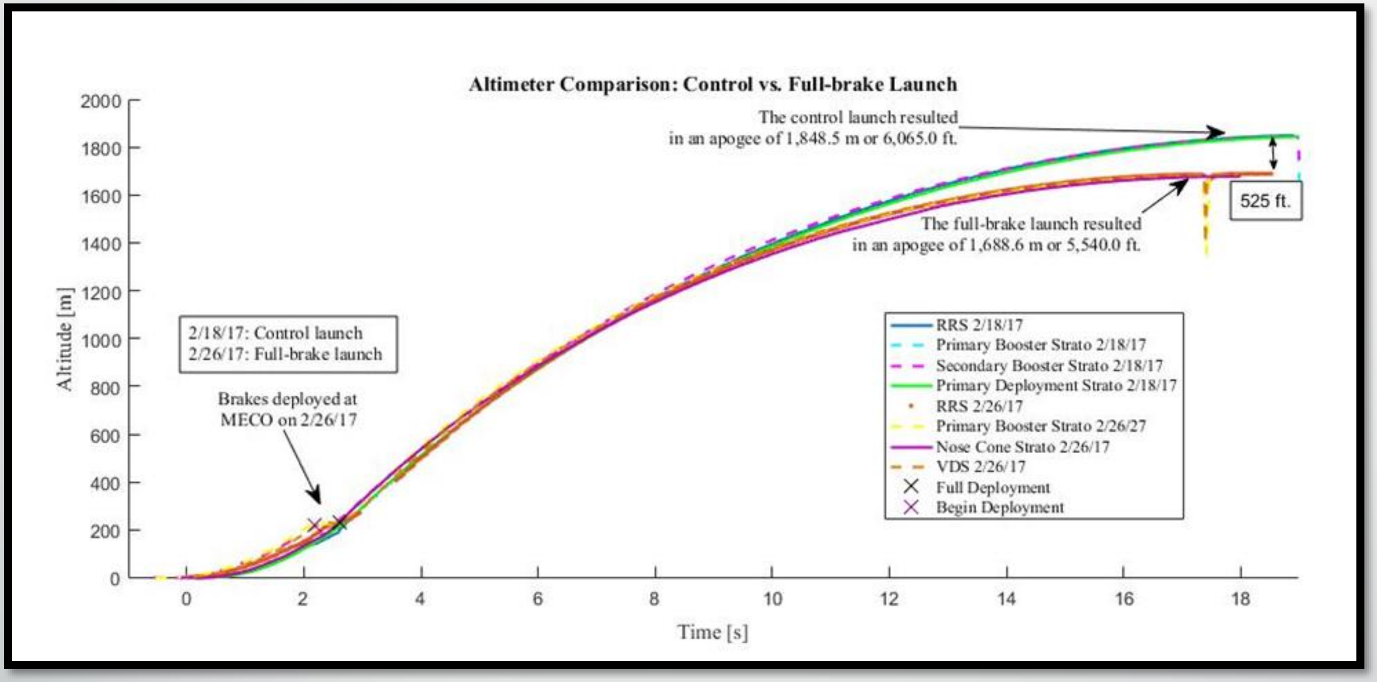
2) Full-deploy Launch: To fully extend the drag blades at motor burnout to characterize the vehicle drag with the brakes.

Results: Pass. The VDS was able to reduce apogee of vehicle by 525 ft.



View from propulsion bay window above VDS on 2/26/17

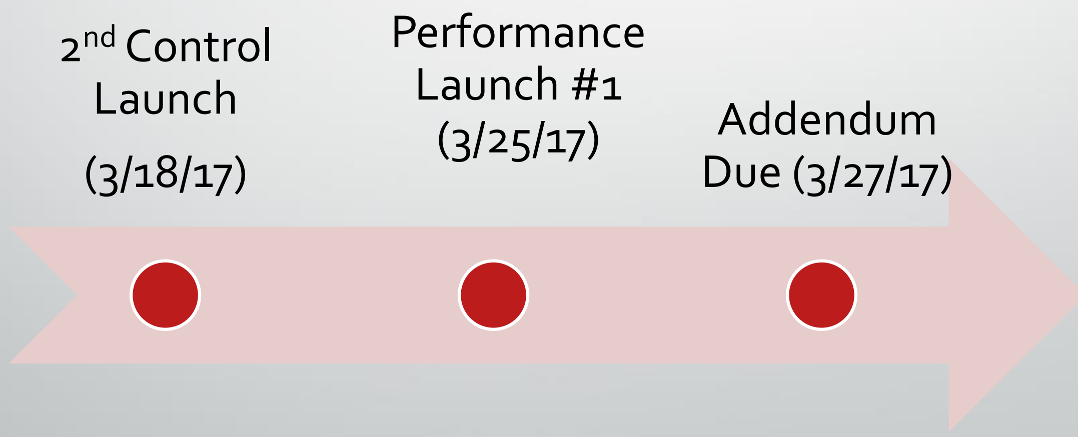
Braking Power Test: Results



- First two launches served to demonstrate VDS braking power
- VDS reduced vehicle apogee by 525 ft.
  - Despite lower skin friction from paint job
  - Despite higher winds during control launch

VDS Verification Status

- 29/30 team-derived requirements verified
- Coefficient of drag requirement remains
- Will be verified before addendum on March 27th

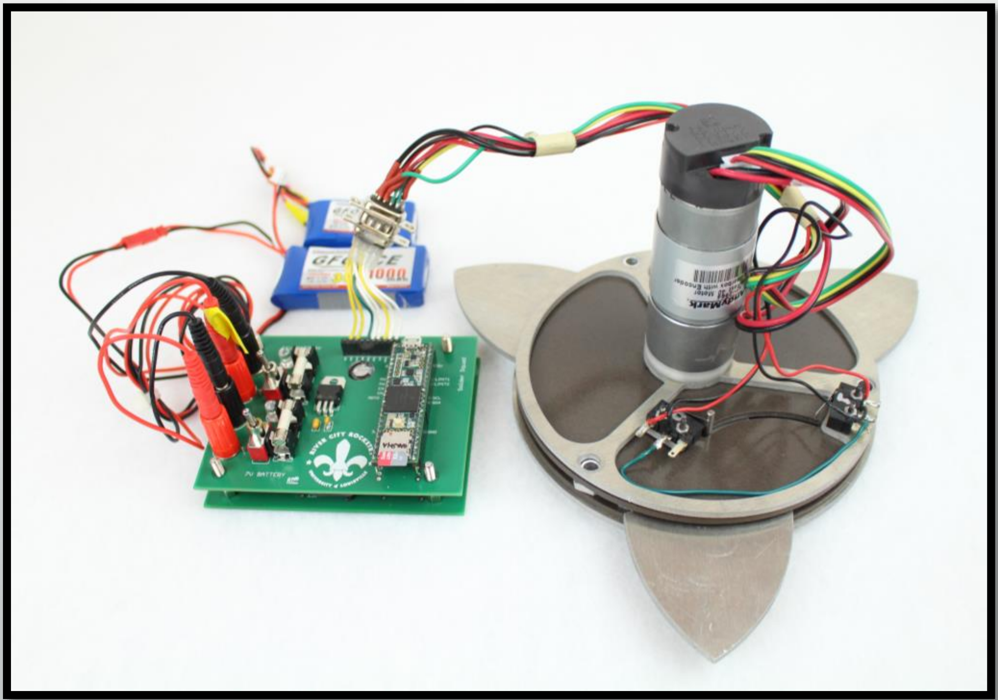


VDS Demonstrations

- Duration demonstration: Capable of operating for > three hours
- Motor-Sensor Interaction demonstration: DC motor actuation does not affect sensor readings
- GPS-sensor interaction demonstration: GPS transmitter in adjacent bay does not affect sensor readings
- Actuation demonstration: VDS has robust control over its drag blade position

Outlook

- Perform 2nd control launch with:
  - Ballast
  - Working accelerometer
- Perform three performance launches before competition



VDS components

FRR Presentation Agenda

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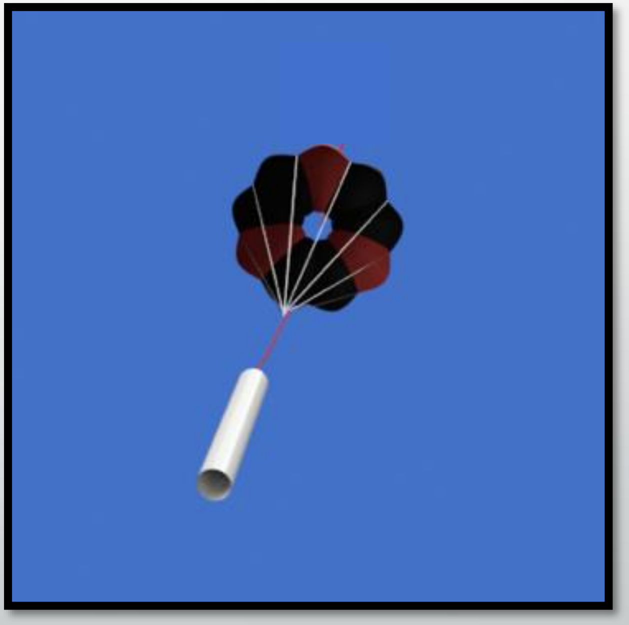
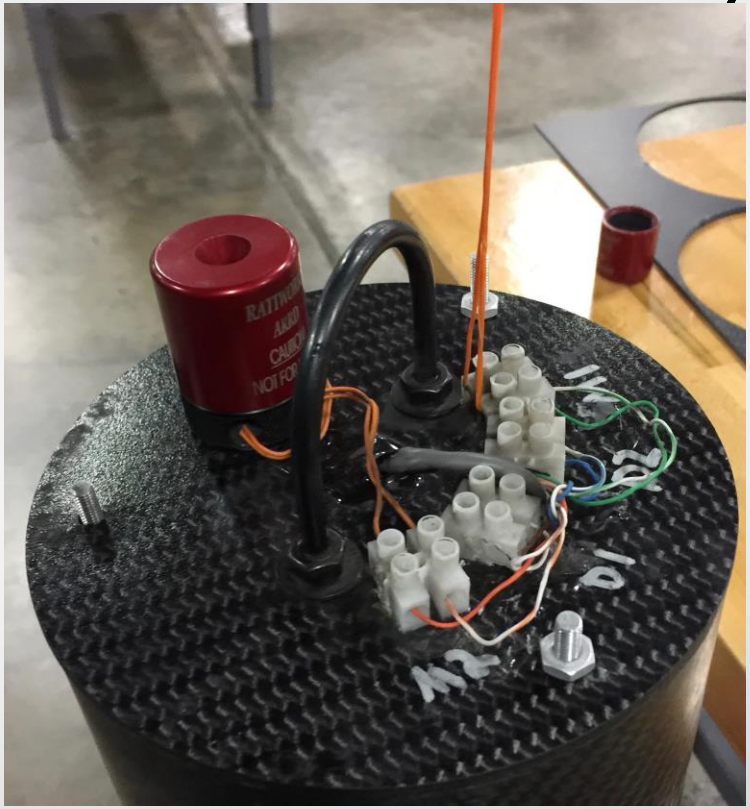
Recovery Overview

- Dual deploy from single bay using ARRD
- Crucifrom drogues for both sections
- Toroidal main parachute for both sections as well as multirotor deployment parachute

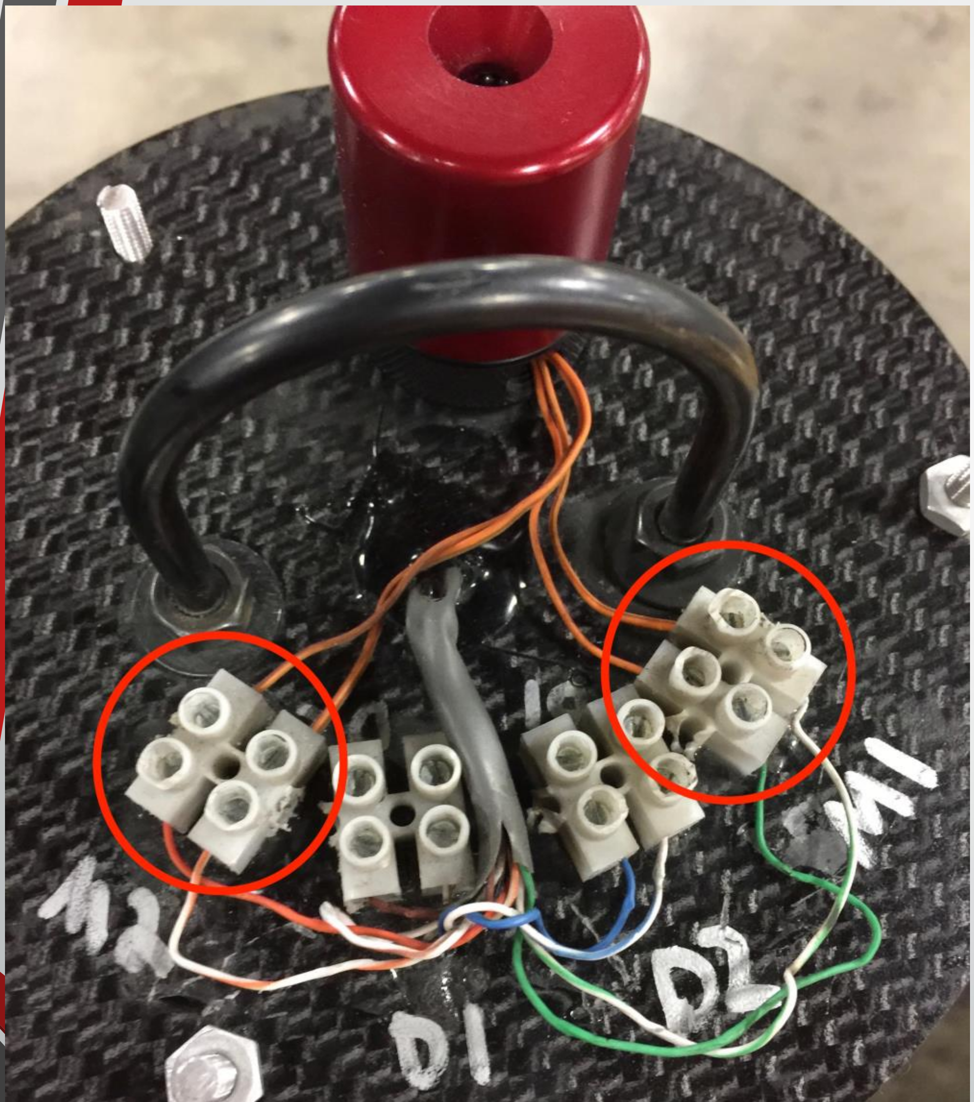


Tender Descender Redundancy



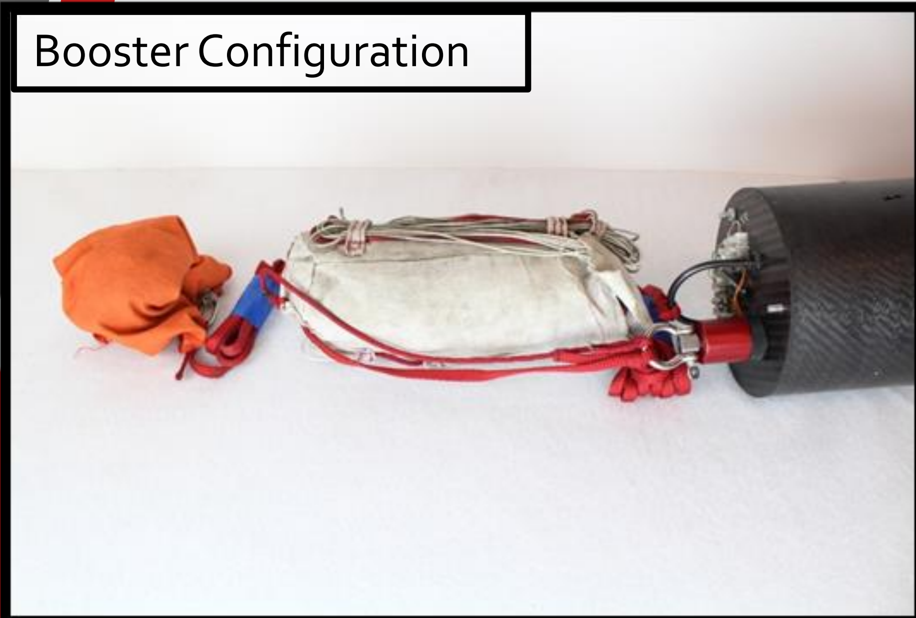
- Tender descender creates additional points of failure in system
- Device tends to snag and creates issues with e-matches and terminal blocks

ARRD Redundancy Plan



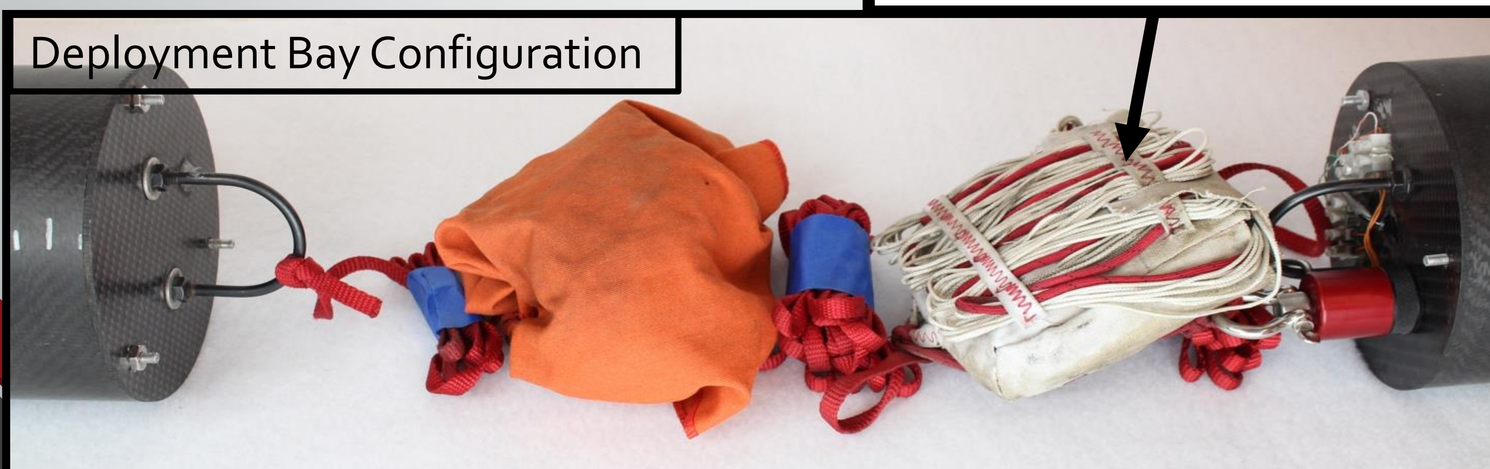
- Using ARRD with dual e-matches
- ARRD has had 100% success in all test campaigns

Final Recovery Bay Configurations



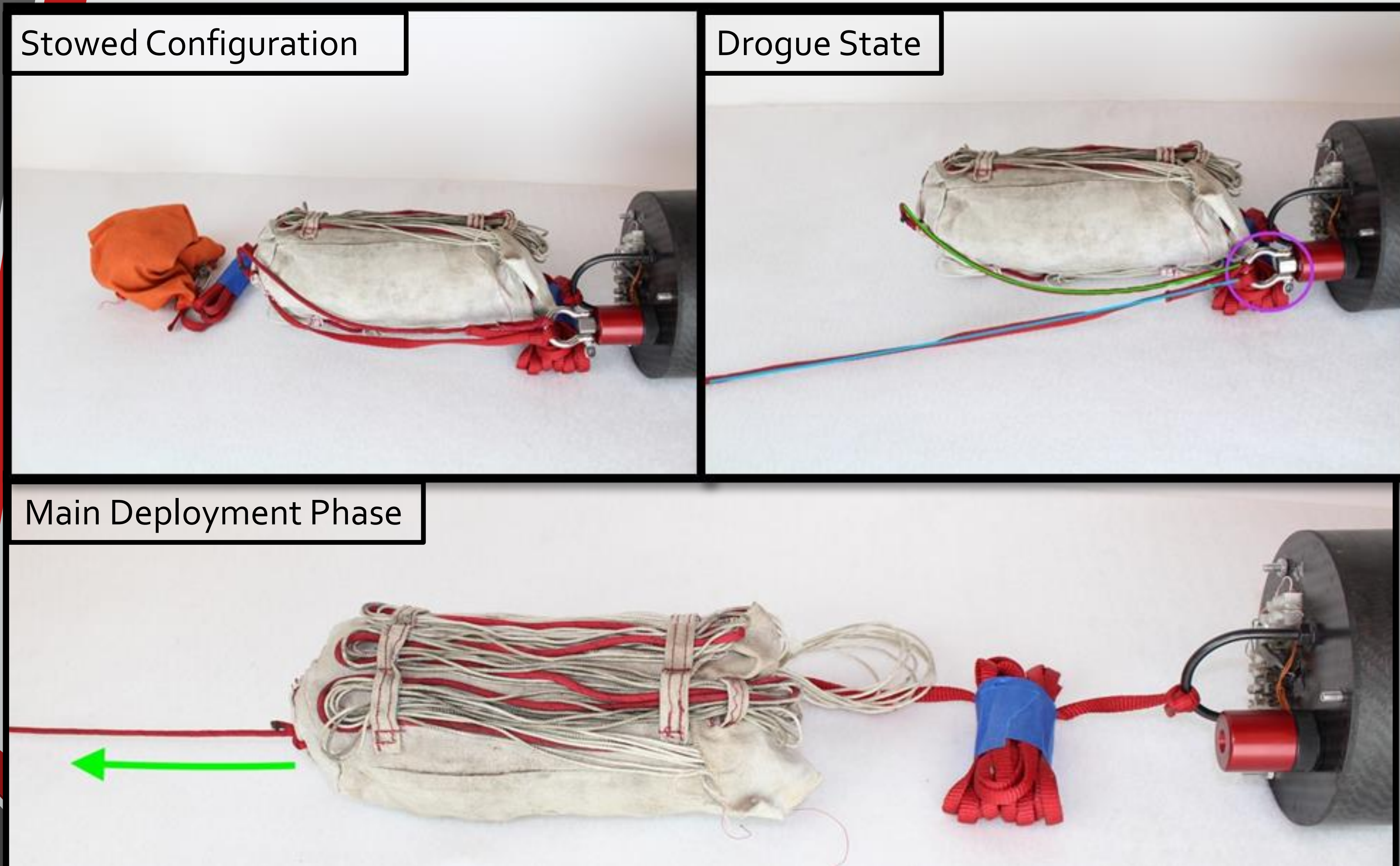
Booster Configuration

Bag locking loops prevent premature deployment during extraction



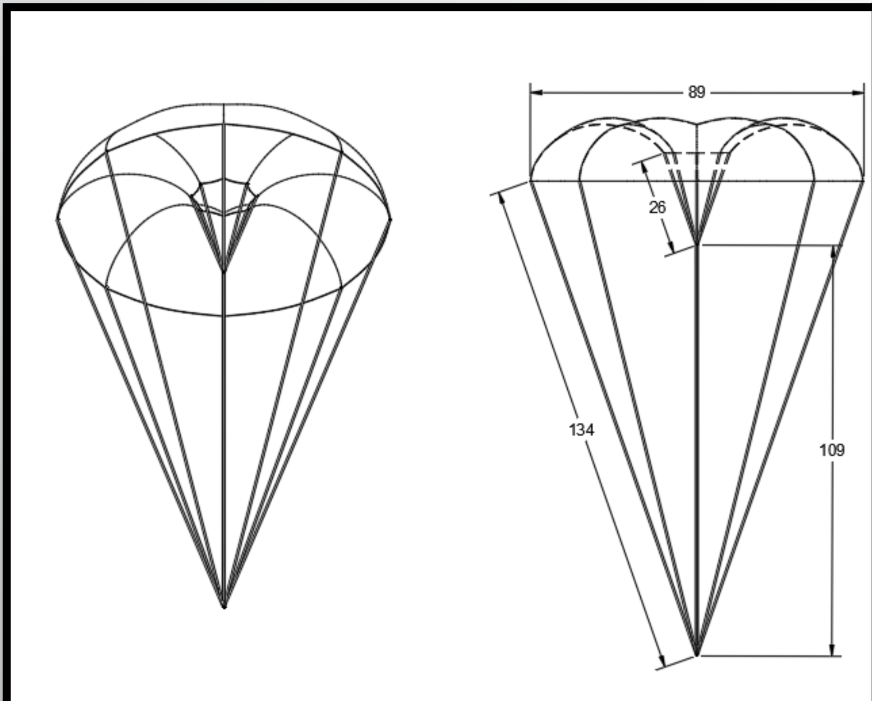
Deployment Bay Configuration

ARRD Deployment

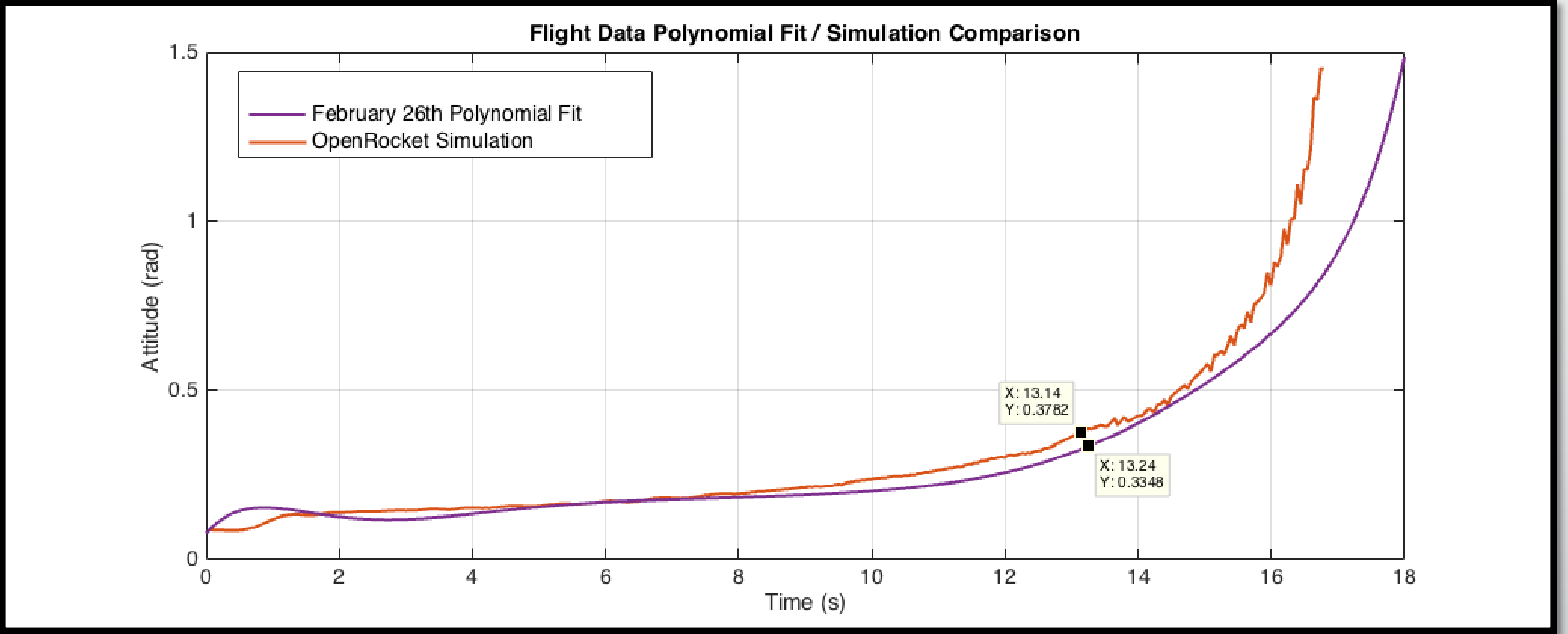


Recovery Specifications

Section	Average Descent Velocity (ft/s)	Kinetic Energy (ft-lb)
Booster	10.2	30
Deployment Bay	14.03	22
Multirotor Payload	23.02	78
Nose Cone	Data acquisition failure	Data acquisition failure

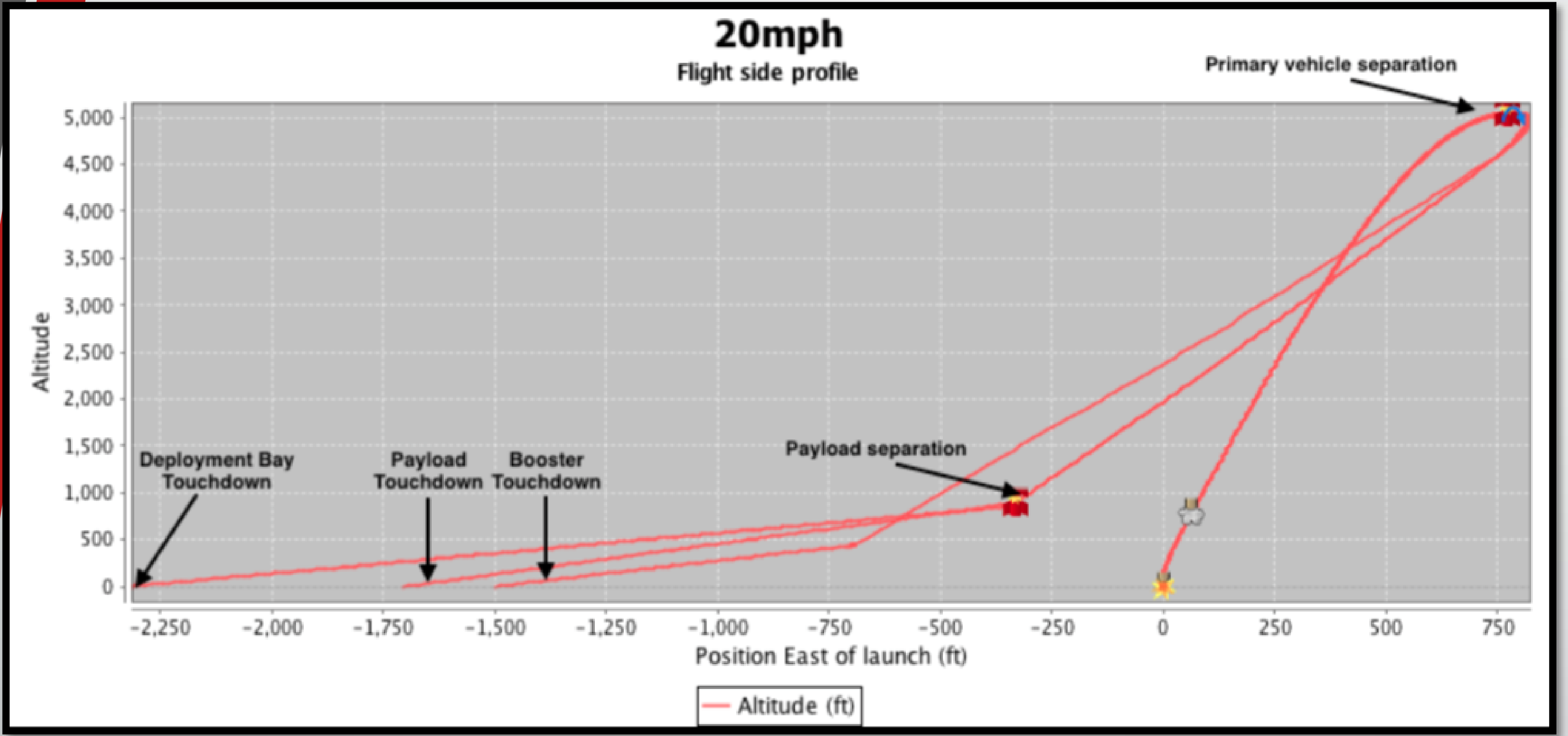


Drift Predictions – Simulation Verification



- Accuracy of OpenRocket weathercocking model verified
- Max variance in attitude of 2.5° between flight data and simulation data

Simulations



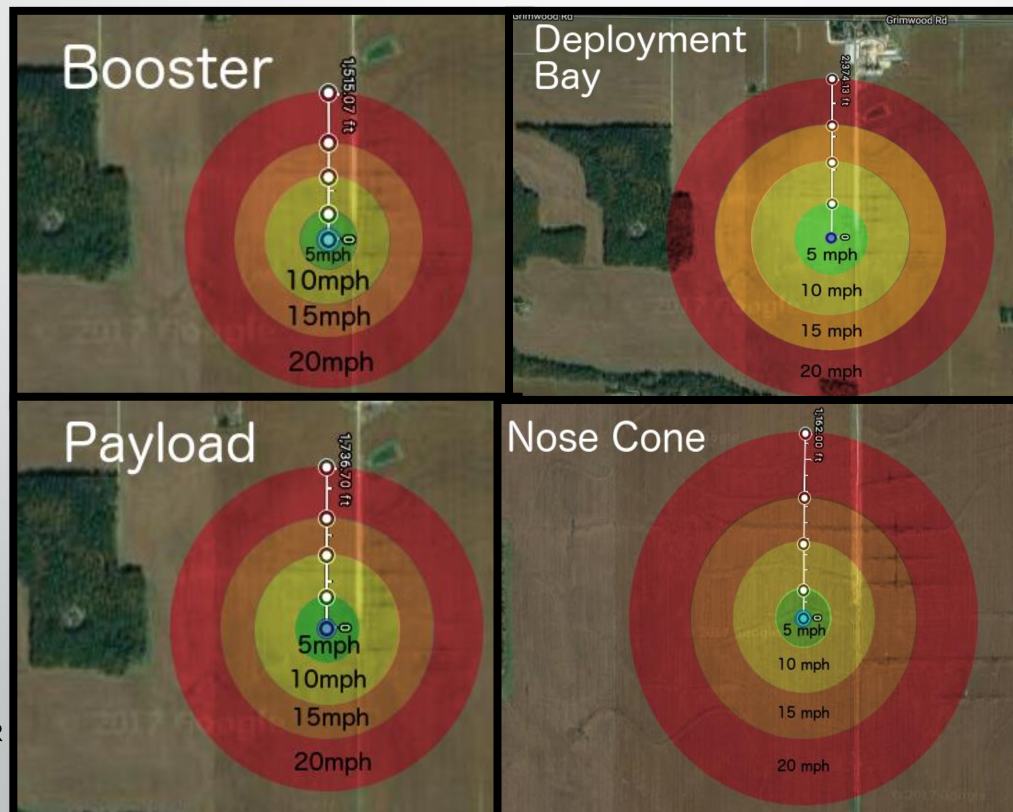
- Assumes vertical launch angle
- New model accounts for weathercocking
- Nose cone drift calculated by hand due to OpenRocket staging limitations

Drift Predictions

Wind Speed (mph)	Drift Distance (ft)			
	Booster	Deployment Bay	Payload	Nose Cone
0	~7	~7	~7	~7
5	270	504	334	173
10	652	1,119	790	467
15	1,010	1,678	1,185	758
20	1,515	2,374	1,736	1,162

- Calculated using vertical launch rail angle

Grimwood Rd
Grimwood Rd
100
Grimwood Rd
100
Murphy Hill Rd
Murphy Hill Rd
Murphy Hill Rd
Bragg Farms
Approximate launch location
Madison County Co-Op



Booster
1,515.07 ft
0
5mph
10mph
15mph
20mph
Deployment Bay
2,374.13 ft
0
5 mph
10 mph
15 mph
20 mph
Payload
1,736.70 ft
0
5mph
10mph
15mph
20mph
Nose Cone
1,162.00 ft
0
5 mph
10 mph
15 mph
20 mph

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Full Scale Flight Test

- Two full scale test flights were conducted.

Date: February 18^{th}
Location: Elizabethtown, KY
Apogee Attitude: 6,071 feet

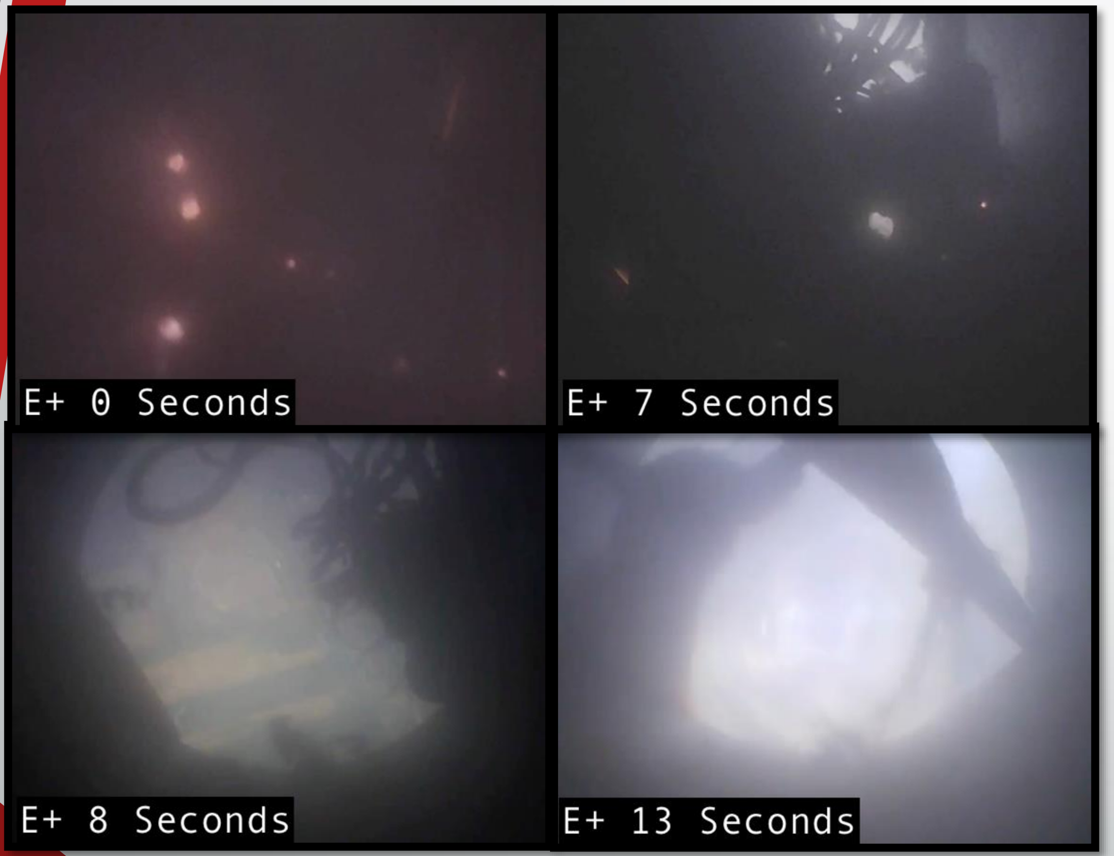
Date: February 26^{th}
Location: Bowling Green, KY
Apogee Altitude: 5,514 feet

Full Scale Test Flight Results

Property	February 18th Launch Data	February 26th Launch Data	Average
Deployment Bay Drogue Velocity (ft/s)	96.4	93.0	94.7
Deployment Bay Main Velocity (ft/s)	16.7	11.36	14.0
Booster Drogue Velocity (ft/s)	81.7	87.3	84.5
Booster Main Velocity (ft/s)	10.16	Main deployment failure	10.16
Nosecone Descent Velocity (ft/s)	Data logging device failed	Data logging device failed	N/A
Payload Deployment Parachute Velocity (ft/s)	Data logging device failed	23.3	23.3

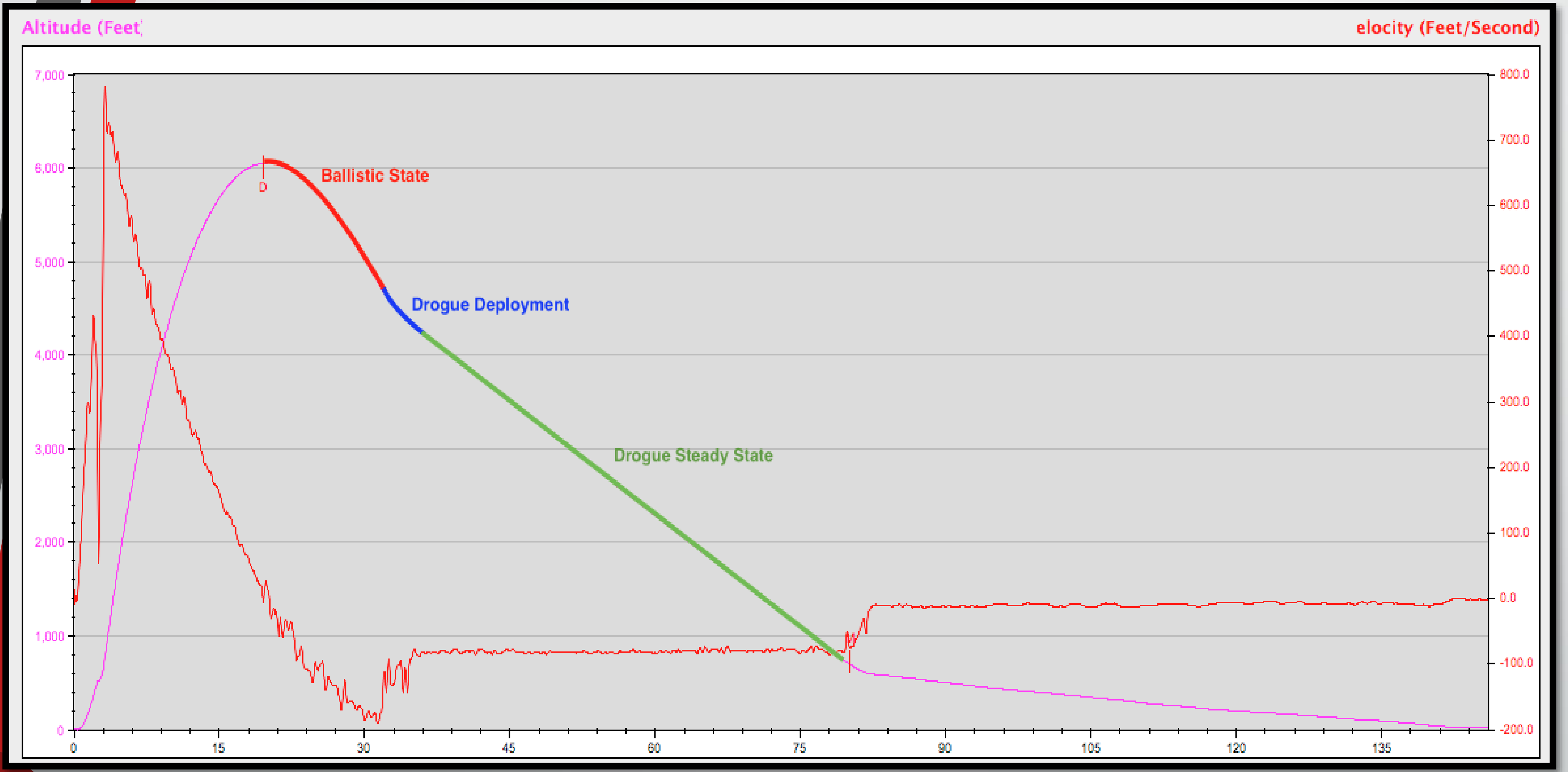
February 18th Flight

- Successful flight apart from 2 anomalies



Time (E+ Apogee)	Event
0 seconds	Apogee separation charge is ignited
7 seconds	Drogue parachute obscures recovery bay opening of separated booster
8 seconds	Aerodynamic turbulence shifts recovery gear. Ground is visible – booster is oriented fins up and is ballistic
13 seconds	Drogue is extracted by high velocity aerodynamic turbulence

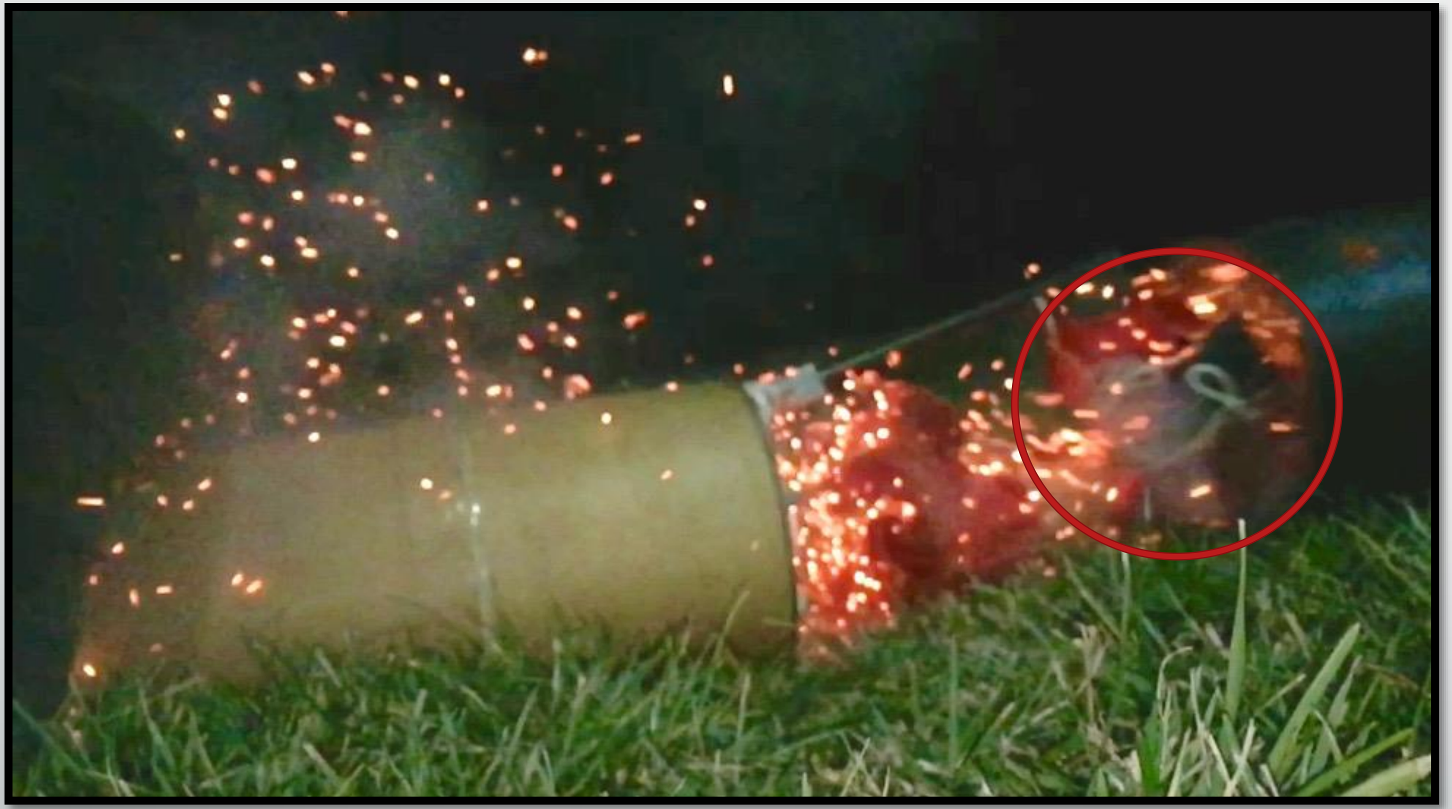
Ballistic Anomaly



Ballistic Anomaly Damage Assessment

- No damage to recovery system.
- Slight zippering damage (.43 in fracture) present on launch vehicle air frame. Does not affect integrity of vehicle.

Ballistic State Mitigation



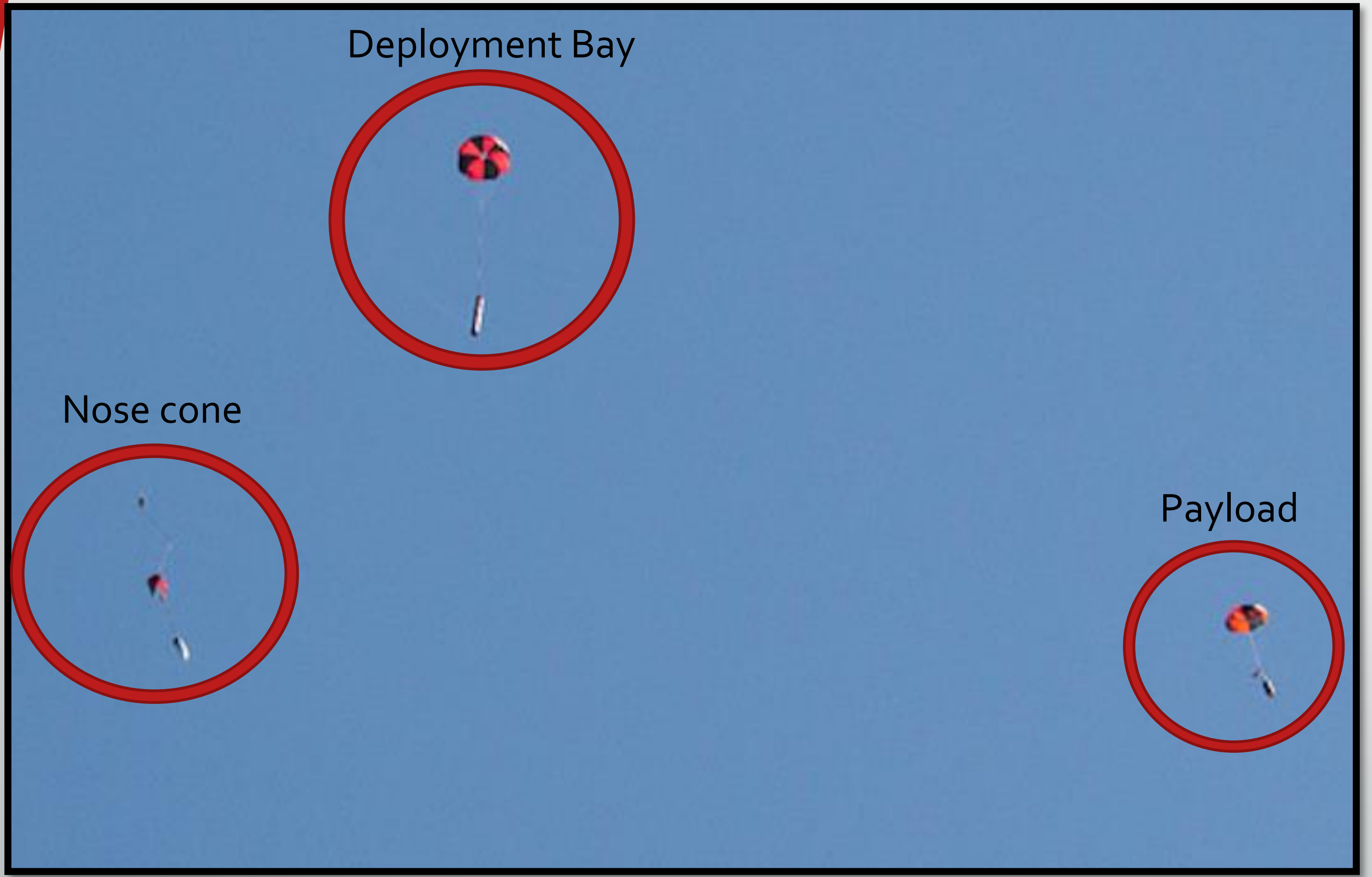
- Black powder tests confirm that drogue parachute exits airframe when packed loosely

Anomaly #2: Premature Payload Separation

- High opening force from deployment bay main forced premature shearing and ejection of payload
- Was deemed to be an enormous benefit – is now implemented as primary deployment method with triplicate redundancy from original two BP charges

February 26th Flight

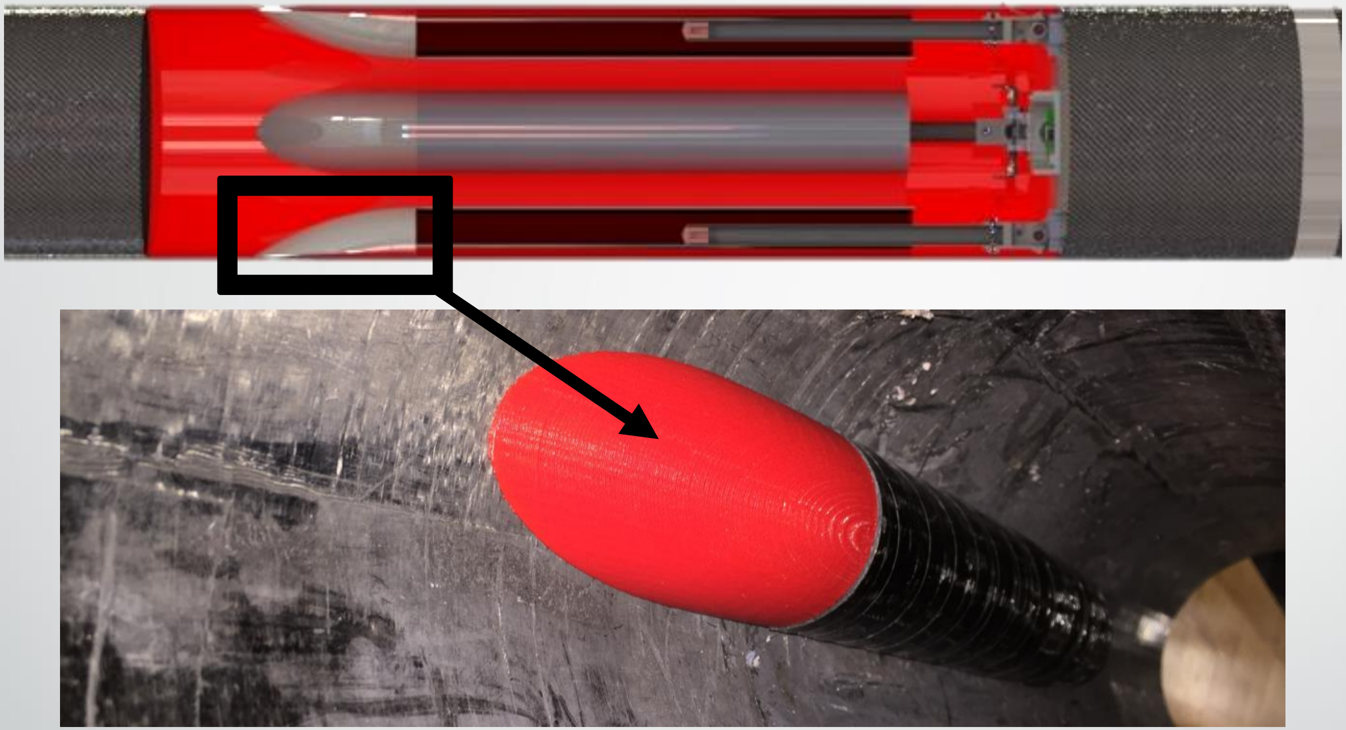
- Successful deployment bay recovery
- Booster main failure


Deployment Bay
Nose cone
Payload

Booster Main Failure Diagnosis

- Suspected to be result of combination of crippled drogue parachute and deployment interference from payload leg sheathes

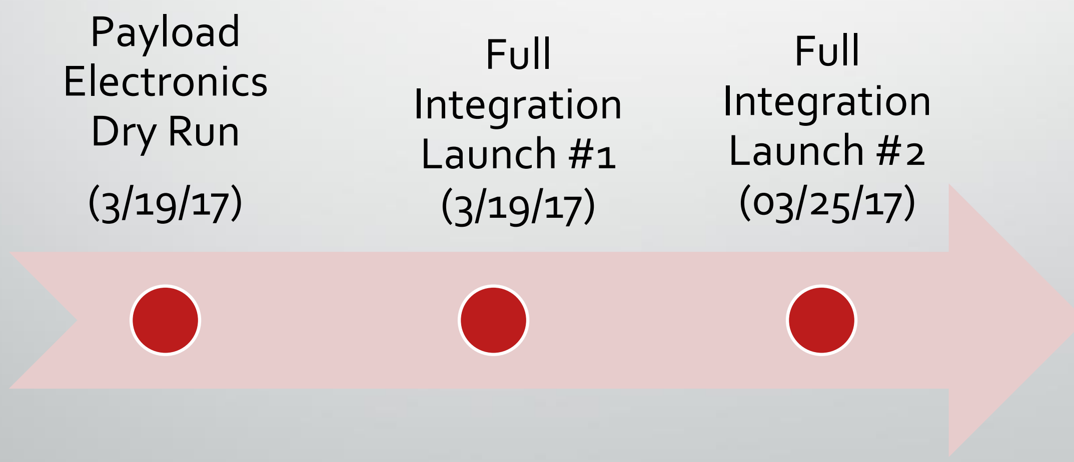
Deployment Failure Mitigation



- Sheathes no longer mate with bulkplate
  - Have been redesigned with terminating fillets to eliminate any potential snag points for recovery harnessing

Recovery Verification Status

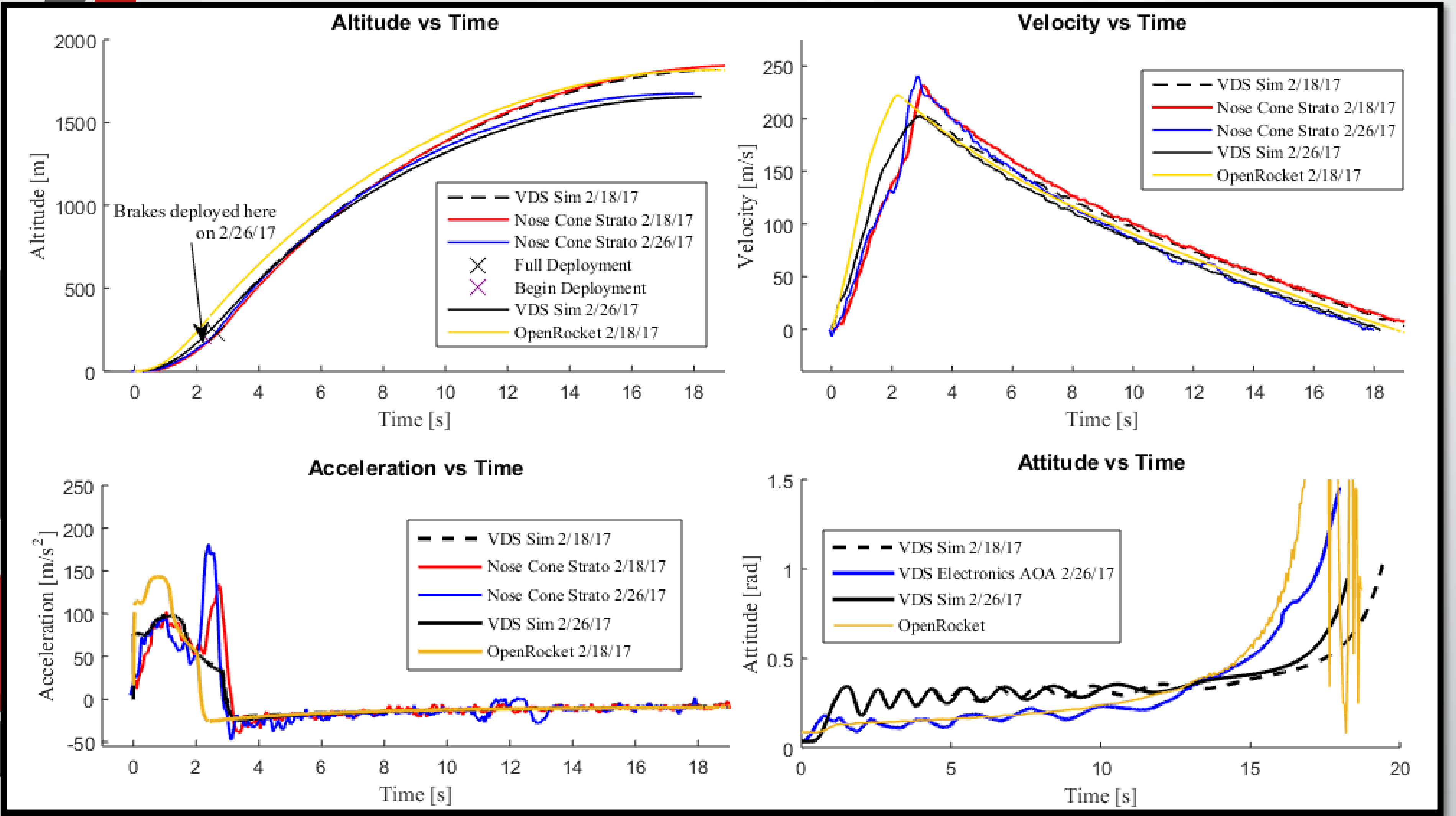
- 9/10 team-derived requirements verified
- Collision avoidance requirement remains
- Will be verified before addendum on March 27th



Outlook

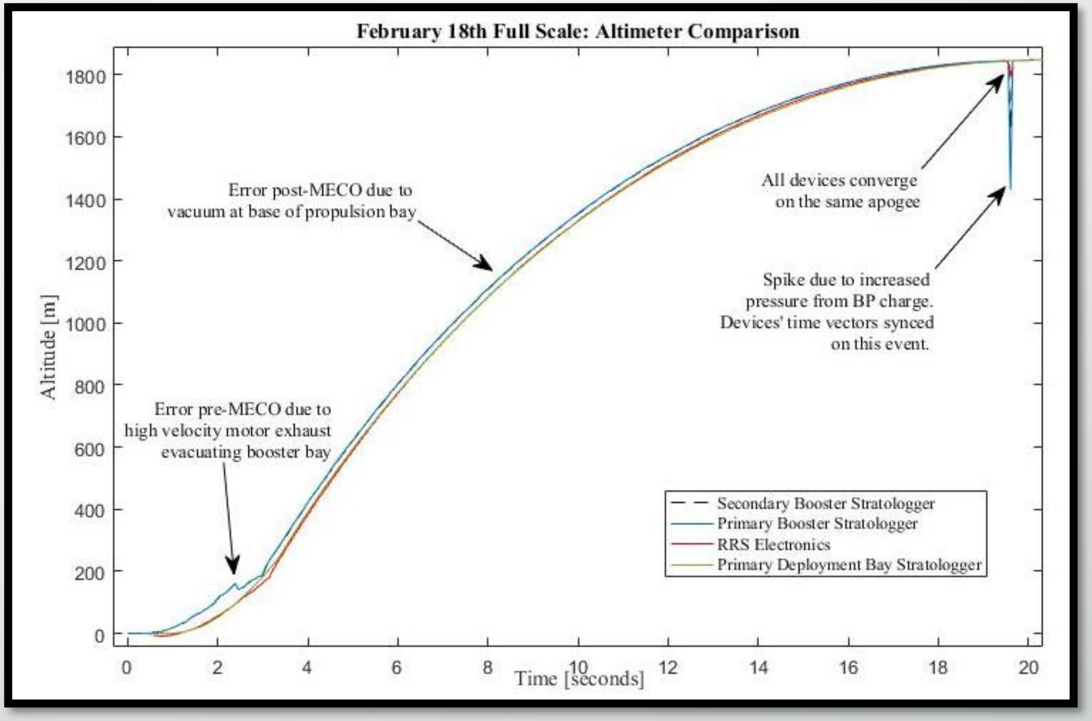
- Perform additional full scale launches with:
  - Precise nose cone descent data
  - Precise payload opening force data
- Perform two fully integrated launches before competition

Full Scale Flight Test Results

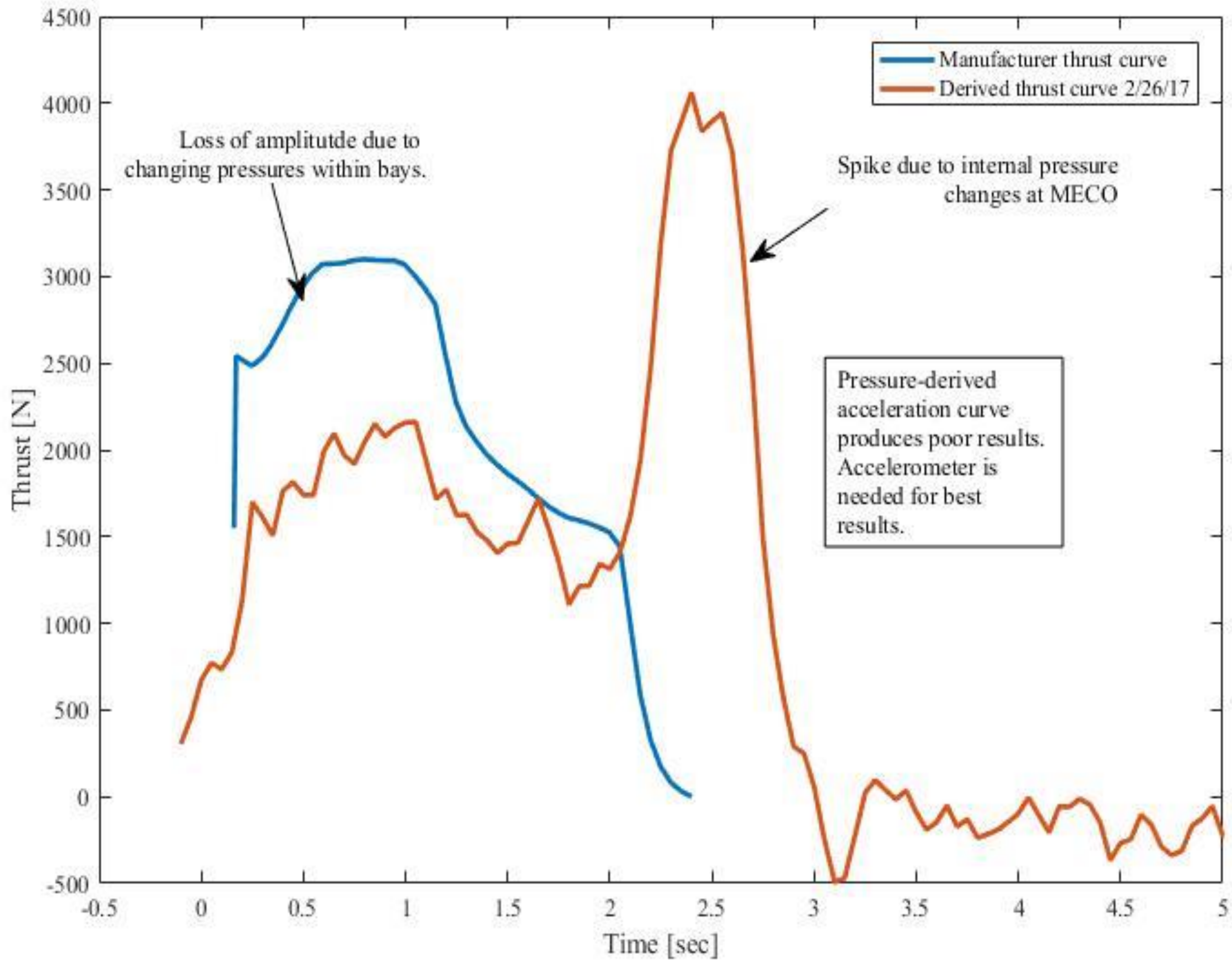


Pressure Anomaly

- Pressure anomaly in VDS coupler
- Current prediction of cause of pressure drop is from motor burn
- Wooden plate epoxied into propulsion bay to seal VDS coupler from motor



Motor Thrust Curve

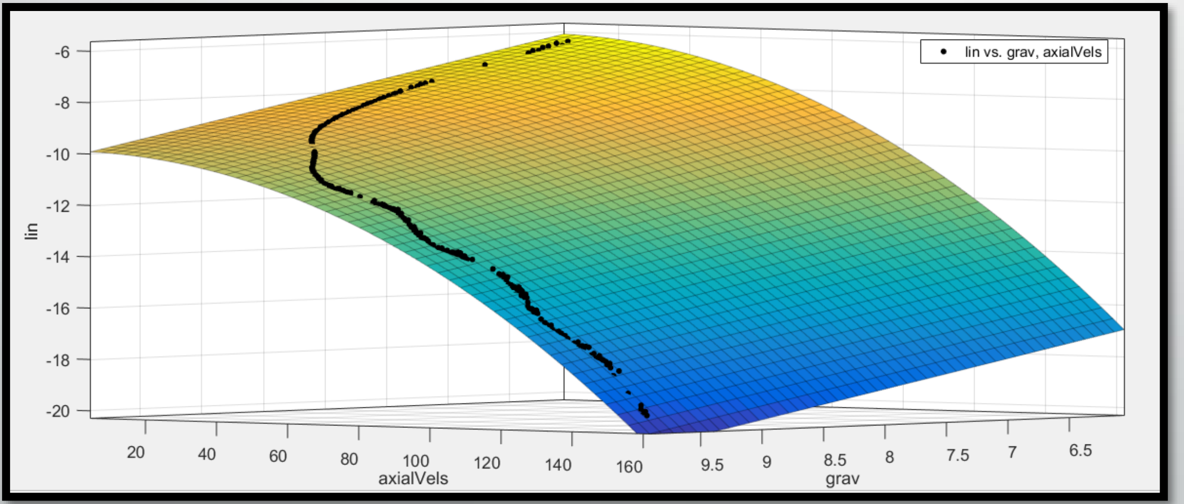


Coefficient of Drag Estimation

- Estimated coefficient of drag using Matlab
- Fit February 26th accelerometer flight data to the following equation:

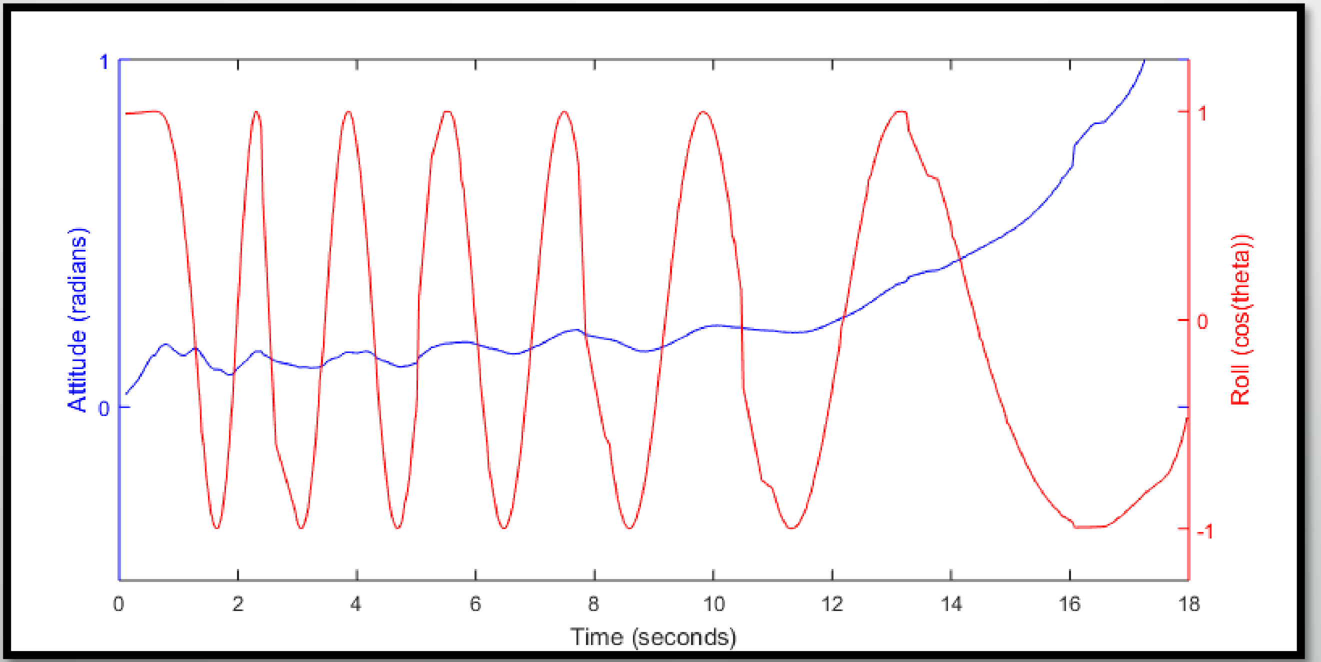
$$a_a = -g - \frac{C_d \rho A_r v_a^2}{2m}$$

- Estimation : 0.4494

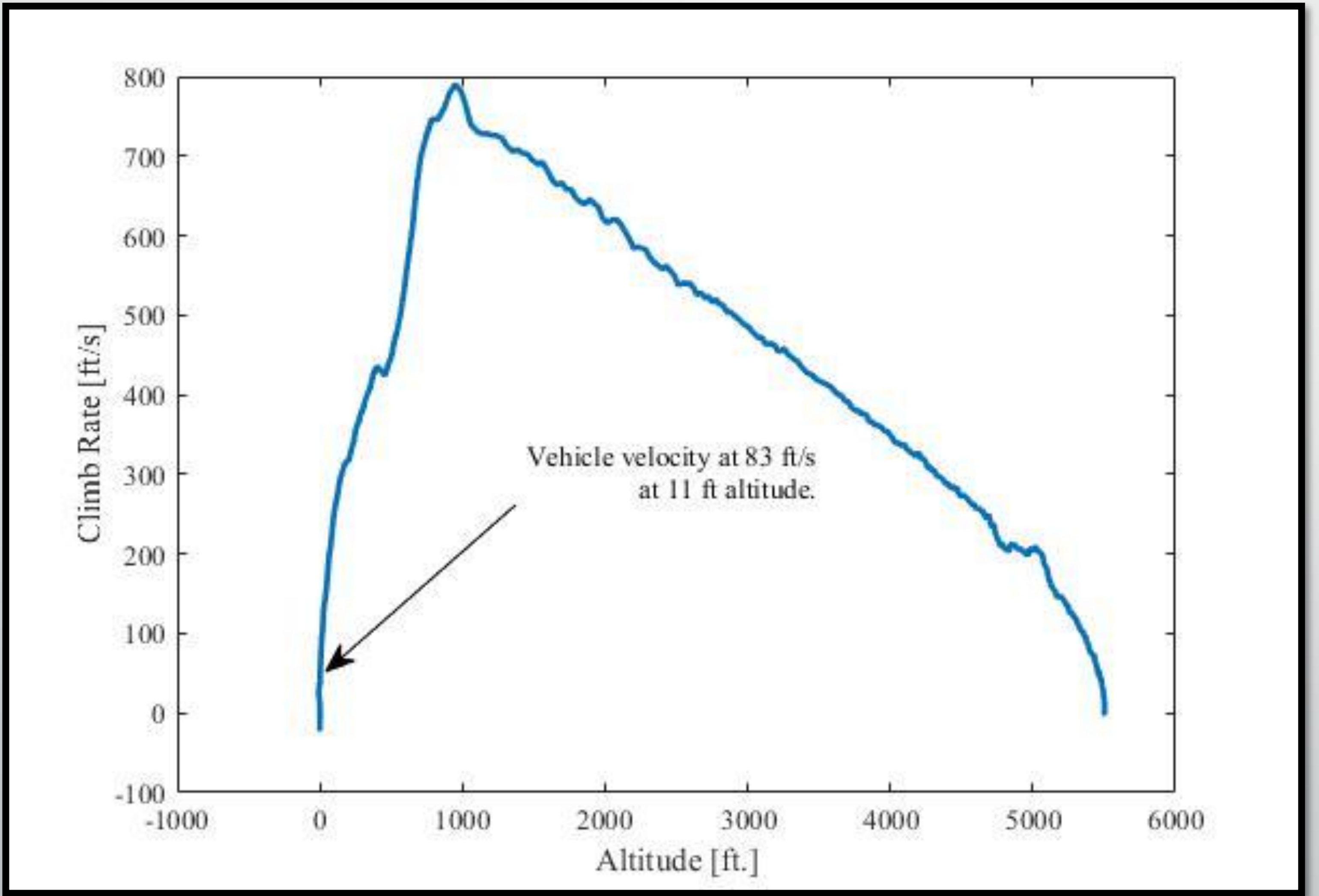


Inertial Roll Coupling

- Roll and attitude natural frequencies similar
- Caused by flexing between coupler joints and misalignment of fins



Exit Rail Velocity Calculation



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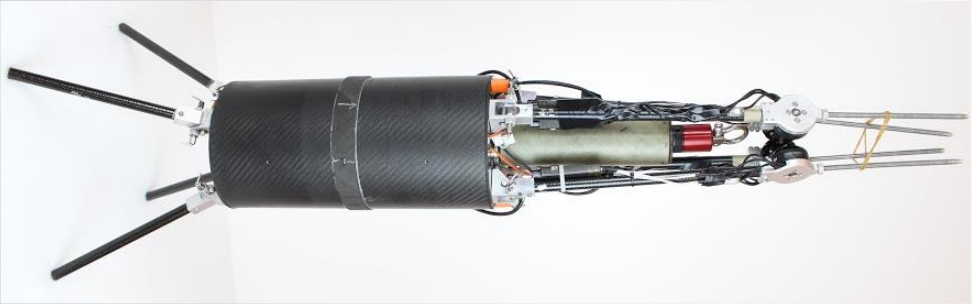
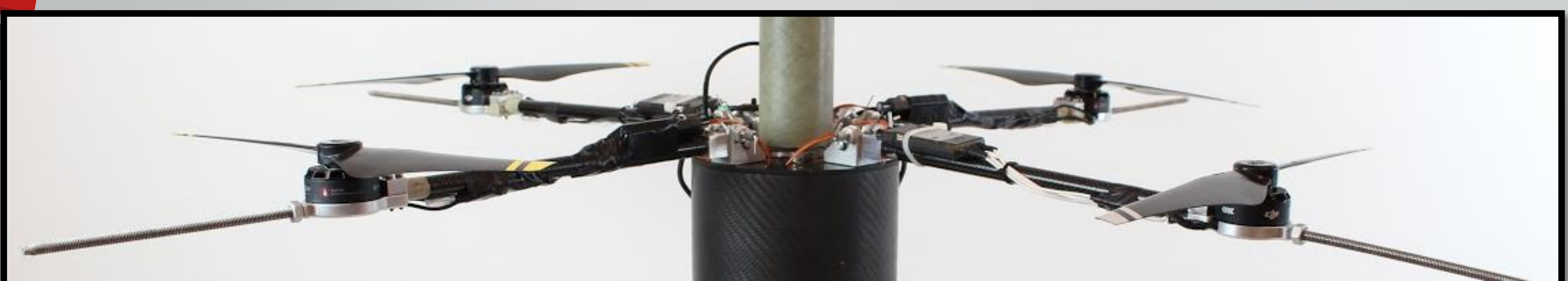
Payload Design Overview



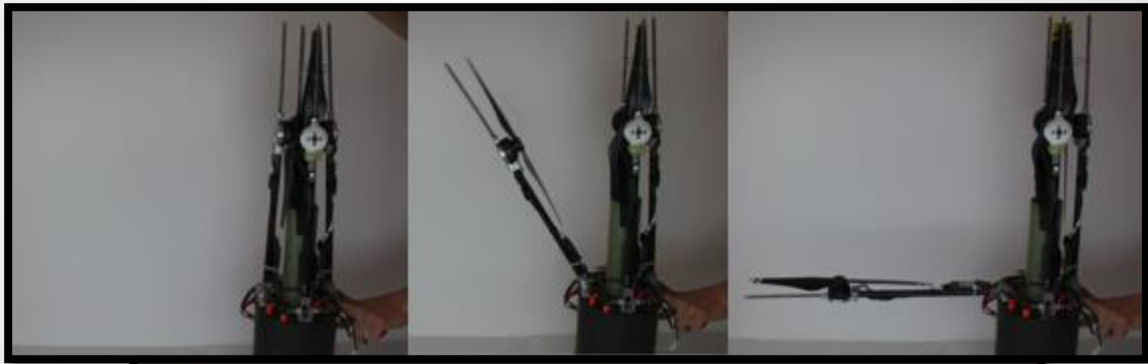
Mass (lb)	Motor to Motor (in)	Overall Deployed Width (in)	Height (in)	
			Stowed	Deployed
9.5	29.0	42.0	40.8	36.0

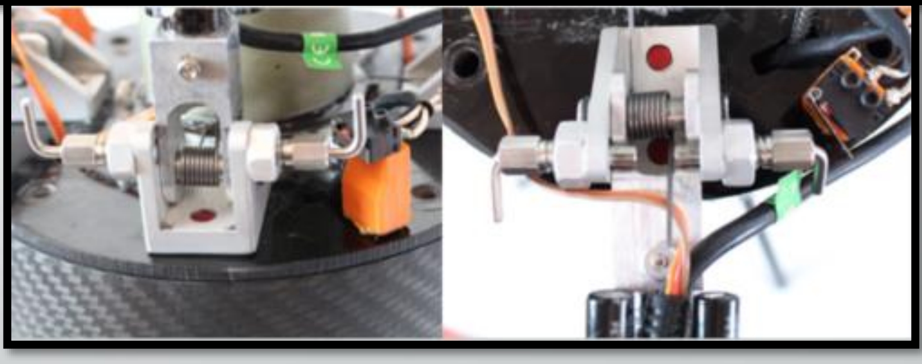
Multirotor Recovery System (MRS)

- Primary recovery system
- Fully Autonomous Propulsion system



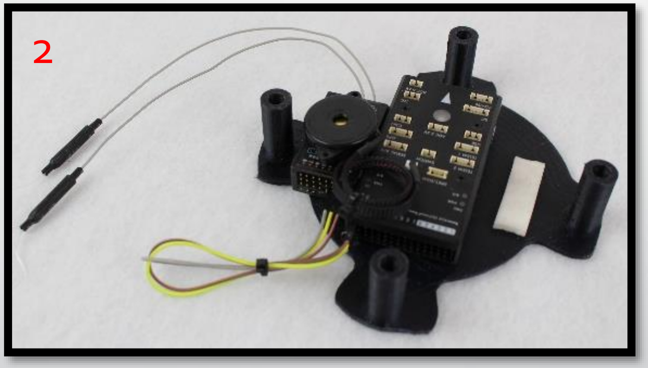
Propulsion System





MRS Electronics

- GPS coordinates and velocity set-points handle autonomous flight of Payload
- General Purpose Input/Output (GPIO) on flight computer handles low-level communication with RRS and monitoring of arm deployment using limit switches

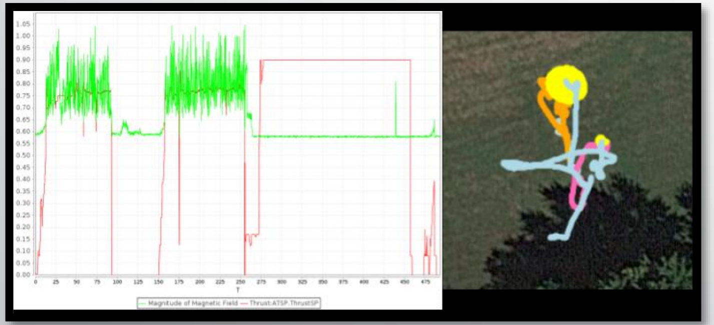


Flight Testing

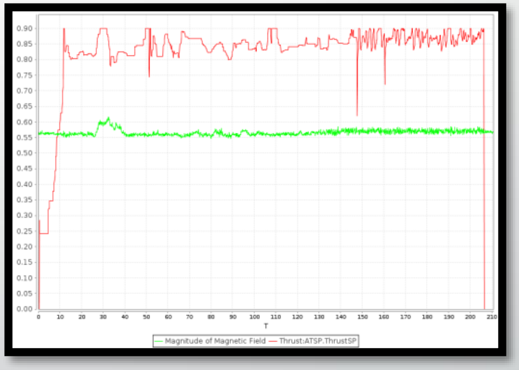
- Manual Flight Testing
  - Controlled by trained operator
- Autonomous Flight Testing
  - Controlled by onboard flight computer
- Fully Integrated Flight Testing
  - Integration of MRS, RRS, TDS
  - In progress

Flight Testing Results

- Issues with electromagnetic noise from motors when GPS/Compass module was mounted internally on the Payload
- Solved by moving GPS/Compass module to an external location



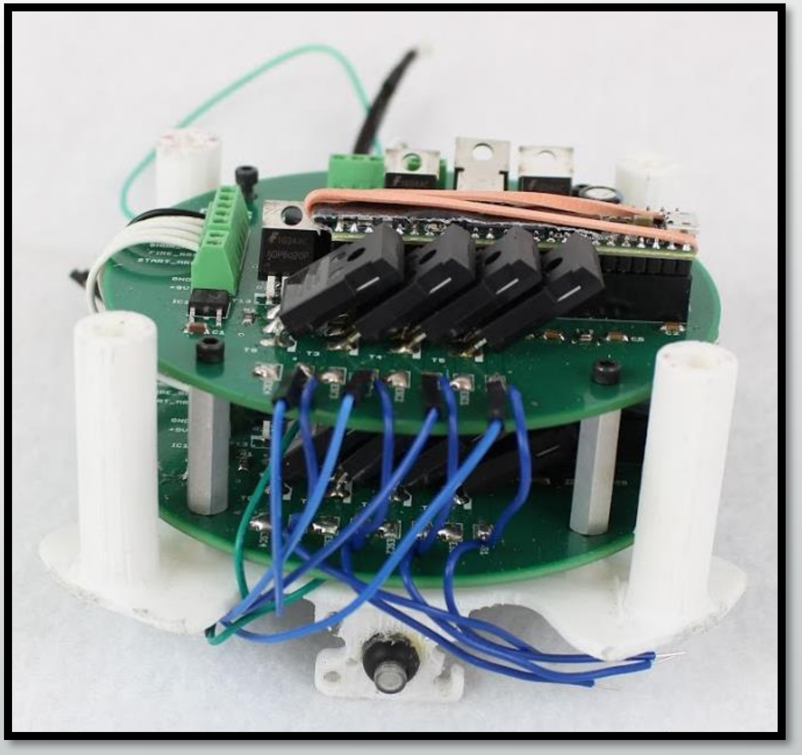
Compass noise vs. thrust (left), Oscillation around a central point (right)



Noise eliminated after GPS/Compass module moved

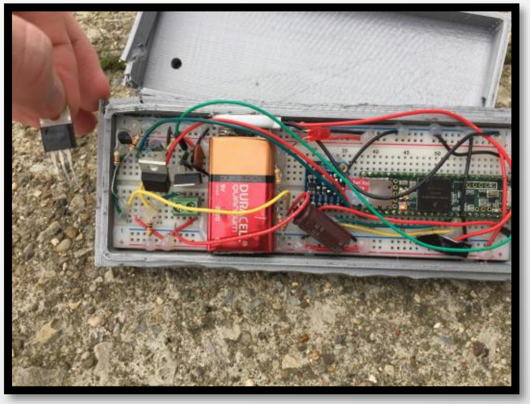
Redundant Recovery System (RRS)

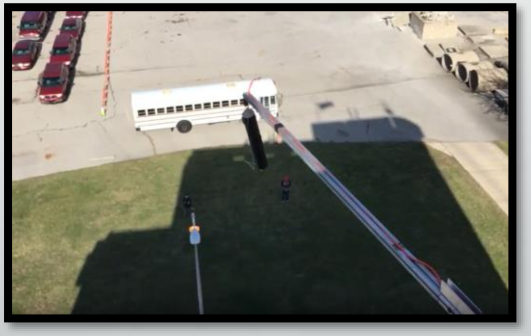
- Cut away from deployment parachute
- Monitor flight conditions
- Deploy recovery parachute if max KE is exceeded or from manual deployment



RRS Testing

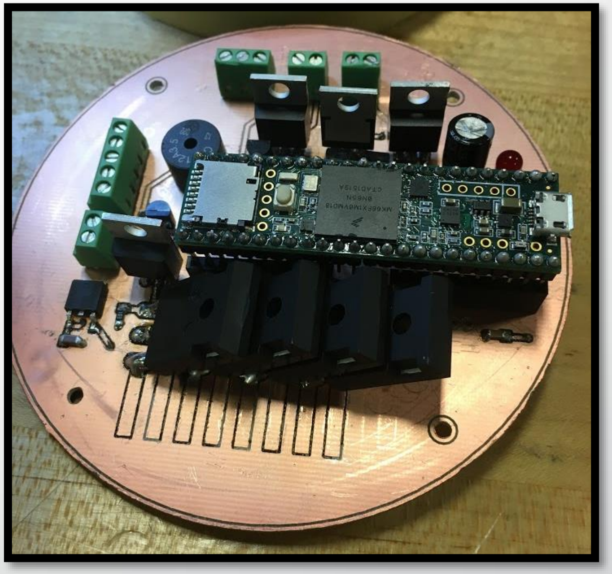
- Drop Test from 65 ft. AGL
- Deploy recovery parachute upon exceeding kinetic energy threshold
- Test result: <u>Success</u>

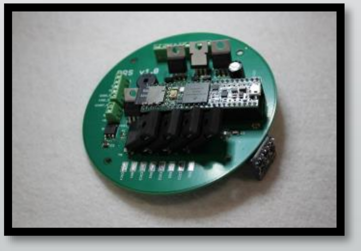


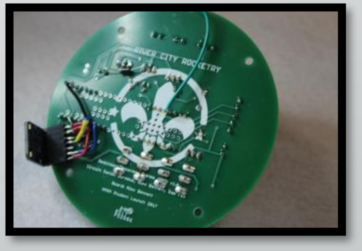


RRS Prototype and Changes

- RRS prototype used to verify circuit and logic functionality
- Flown on two full scale vehicle test flights and recorded accurate data
- Changed to grounding throttle control line for MRS motors
- Upgraded receiver and transmitter for increased range
- Upgraded to BMP280 commercial barometer





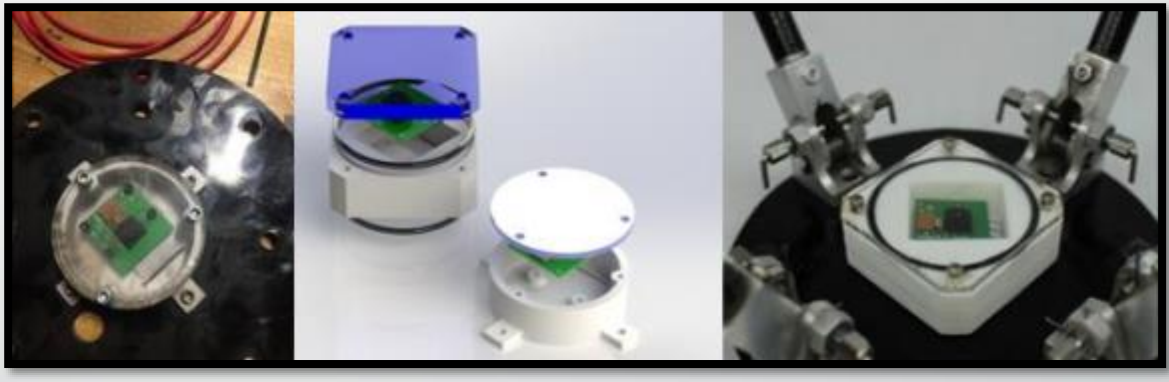


Target Detection System (TDS)

- Preliminary testing has been successful
- Payload test flights have been utilized to obtain pictures for TDS testing
- Since CDR improvements have been made to account for more scenarios such as lighting changes

TDS Housing

- Camera housing redesigned
  - Incorporate seals
  - Increase rigidity



Payload Structural System (PSS)

- Houses all flight electronics
- Reacts all flight loads
- Doubles as coupler for the vehicle

Coupler Body

- 6" Carbon Fiber Coupler
- All thread Mounting System for 3D printed electronic sleds
- All thread rods preload's Coupler for structural stability during flight

Upper Bulkplate Assembly

- Contains RRS tube, ARRD cutaway mechanism, Limit Switches, and Propulsion Arms.

RRS Tube Redesign

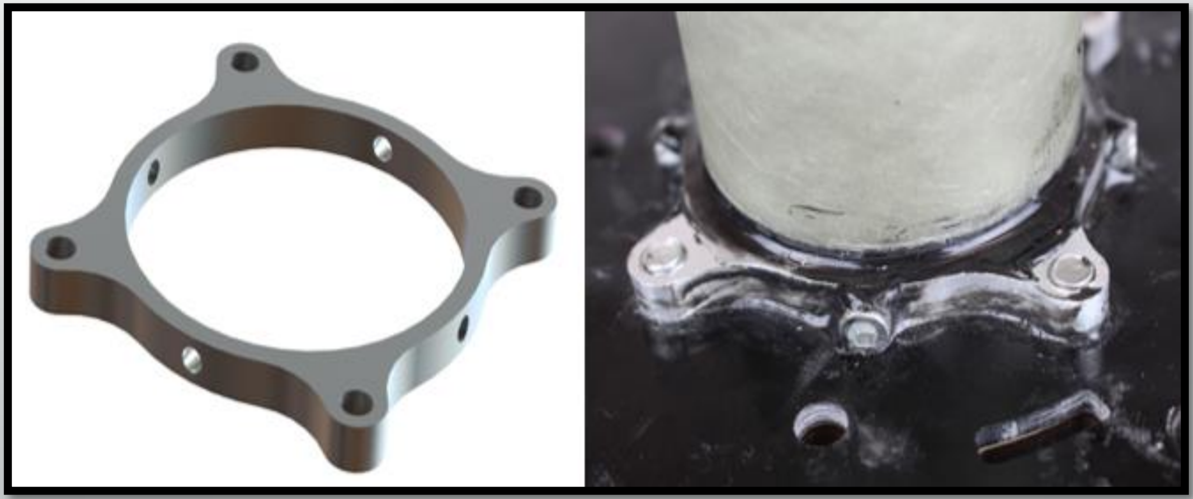
- RRS Cap
- Improper seal; failed RRS demonstration
- Part Fracture upon landing

Redesigned RRS Cap

RRS Tube Joint Redesign (cont.)

Broken Epoxy Joint due to landing

Redesigned RRS Shear Collar



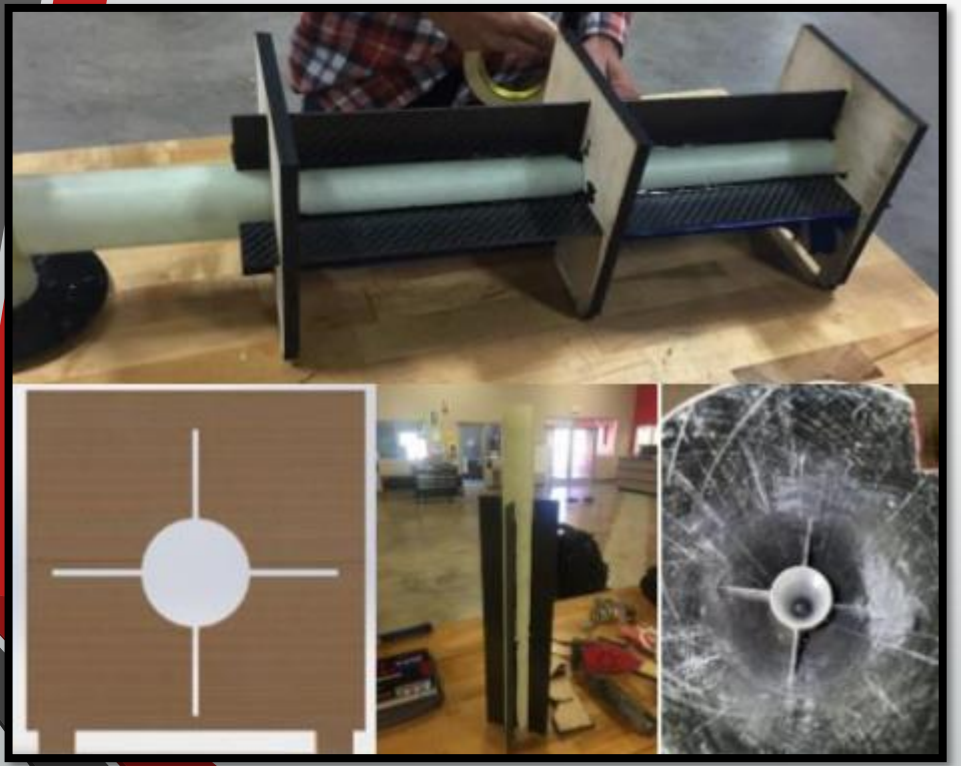
Landing Leg System (LLS)

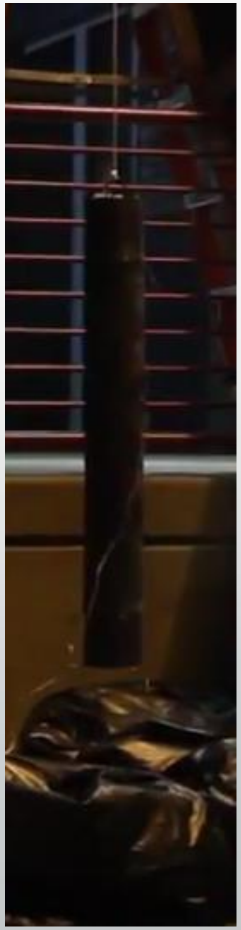
- Similar Design to MRS Propulsion Arms
- Successful Deployment Verification
- Successful flight deployment

Deployment System

- Deployment Bay
- Main opening force primary separation
- Redundant black powder charges still present

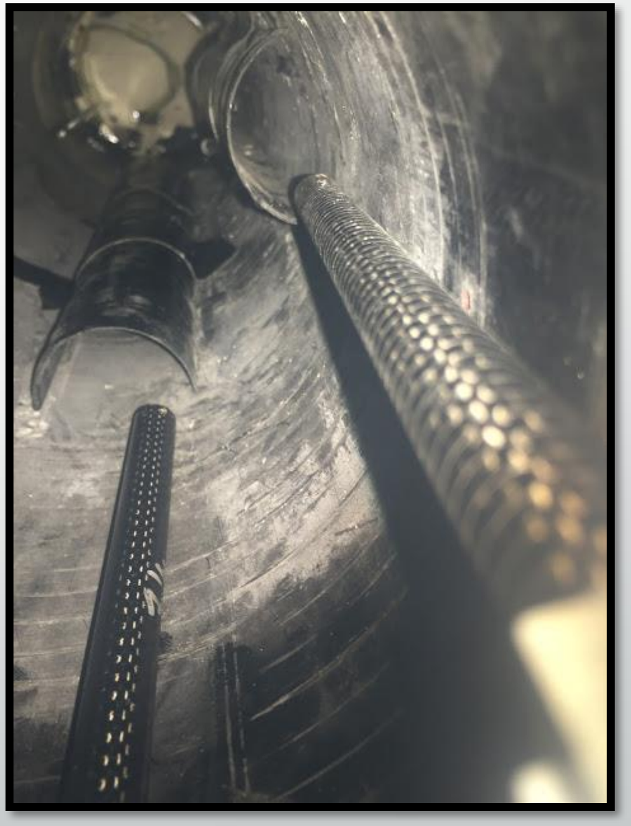
Deployment Bay Manufacturing and Testing





Deployment System

- Main Recovery Bay
- Added leg sheath close-offs to prevent recovery interference.



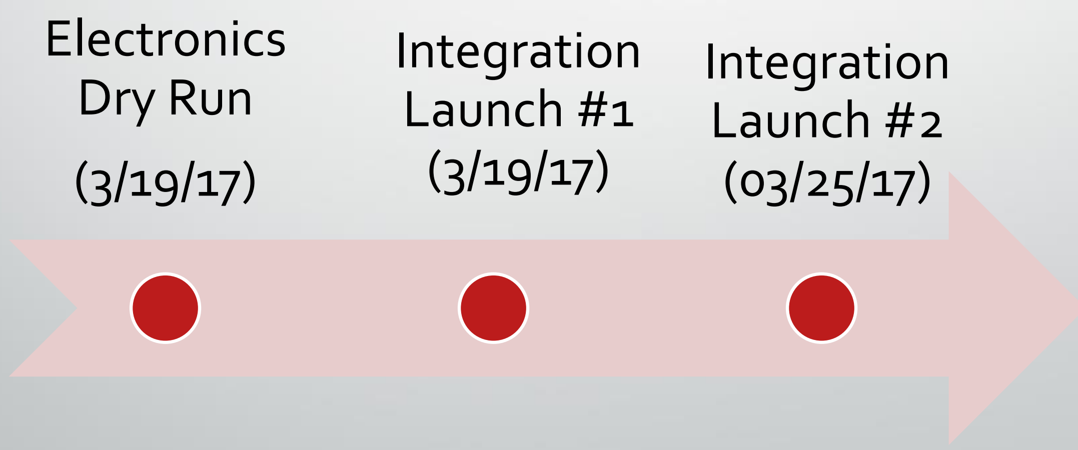
Main Recovery Bay Deployment Verification

- No interference between LLS and recovery gear
- Successful leg actuation
- LLS flew on full scale flight 02/18/2017 and successfully deployed.



Payload Verification Status

- 66/90 team-derived requirements verified
- Remaining verifications include:
  - Full Scale Integration Launch Vehicle Tests



FRR Presentation Agenda

- Launch Vehicle
- Variable Drag System
- Recovery
- Full-Scale Flight Results
- Payload
- Safety
- Educational Outreach
- Budget

Launch Operations

6 Launch Concerns and Operations Procedures

6.1 Launch Operations Checklist

6.1.6 Overall Final Assembly Checklist (requirement 1.7)

Required Equipment:

- *Allen Wrench Set – SAE*
- *Phillips Head Screwdriver (large)*
- *Flat Head Screwdriver (Large)*
- *Small Screwdriver Set (Small)*
- *Masking tape*
- *Socket Cap Screws*
- *4-40 shear pins*
- *Socket Wrench Set for ¼-20 Nuts and 10-32 Nuts*

1. ___ Attach propulsion bay to VDS coupler using 3x 8-32 metal bolts.
2. ___ Attach upper VDS coupler to the booster recovery bay using x3 8-32 shear pins.
3. ___Connect the ejection charge canisters to the VDS coupler bulkplate by attaching the e-matches to the respective terminal blocks.
4. ___ Attach booster recovery bay to the payload coupler using x3 4-40 nylon shear pins.
5. ___ Attach the payload coupler to deployment bay using x3 4-40 nylon shear pins.
6. ___Connect the ejection charge canisters to the deployment coupler bulkplate by attaching the e-matches to the respective terminal blocks.
7. ___ Attach the deployment bay to the payload recovery bay using x3 8-32 nylon shear pins.
8. ___ Attach the payload recovery bay to the nose cone using x3 4-40 nylon shear pins.
9. ___ Check that the coupling does not allow for any flexing of the rocket between any airframe and coupler tubes. Should this occur, add layers of painters tape to the coupler tubing on the payload bay until sufficient coupling is achieved.
10. ___ Tape motor igniter to the outside of the lower sustainer in a place easily seen by the field RSO.
11. ___Ensure all screw switches to altimeters on the interior of the launch vehicle are visible and accessible from the exterior of the launch vehicle.
12. ___ A final visual inspection will need to be done to ensure all systems are go.

Final Assembly Representatives Signatures:

1. ______________________ 2. ______________________

6.1.7 Clear to Leave for Launch Pad

All sections of the safety checklist preceding must be complete and signed prior to leaving for the launch pad. A signature from every lead, co-captains, and safety officer must sign off to proceed to the pad.

Vehicle Lead: ______________________

Recovery Lead: ______________________

VDS Lead: ______________________

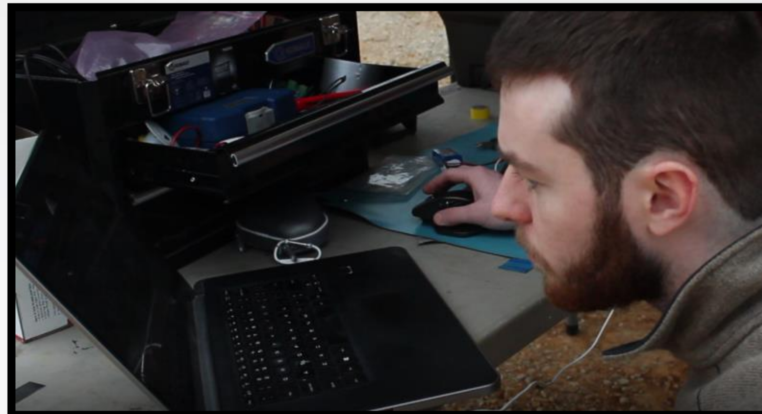
Payload Lead: ______________________

Signatures indicating the rocket is a "Go" for launch:

Team Co-Captain: ______________________

Team Co-Captain: ______________________

Safety Officer Signature: ______________________

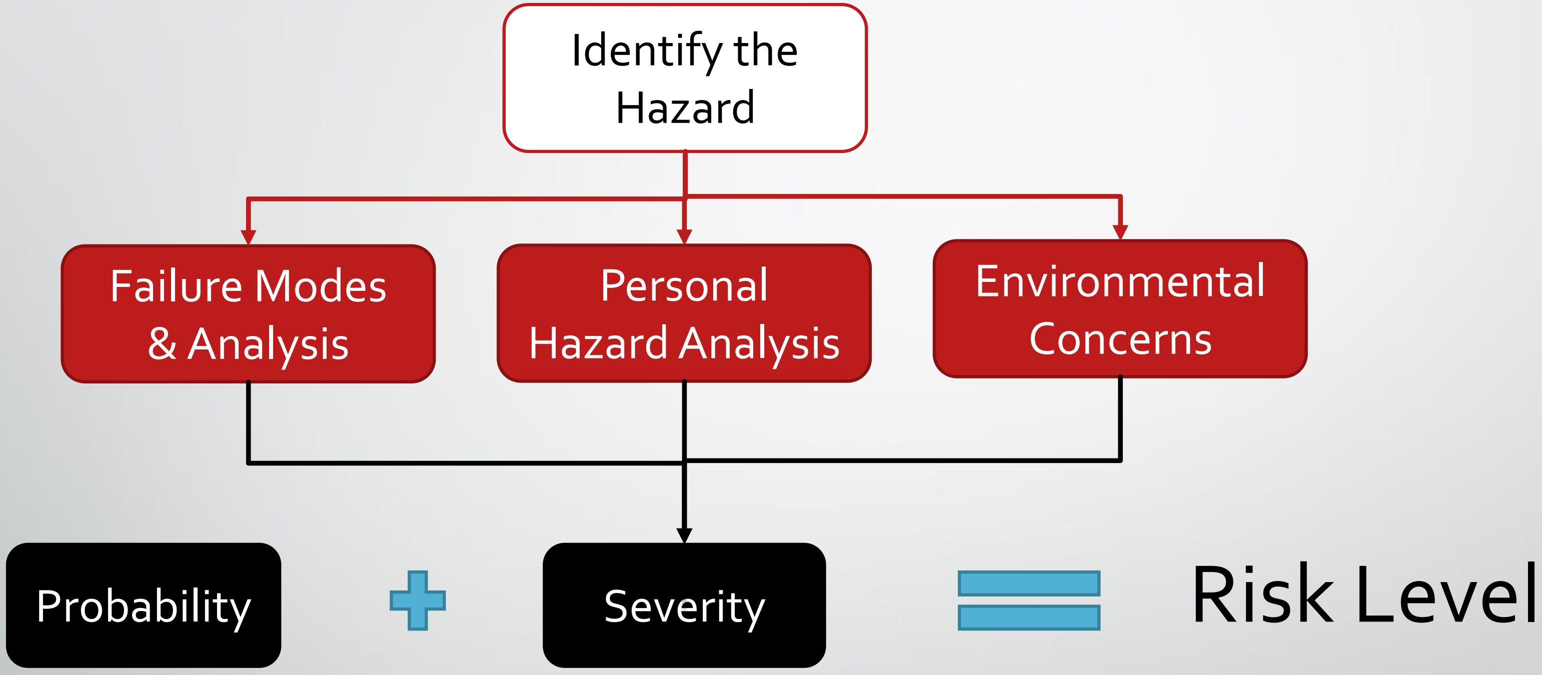


Safety Overview

Risk Assessment Matrix

Risk Assessment Matrix				
Probability Value	**Severity Value**			
	(XXX)-(1)	(XXX)-(2)	(XXX)-(3)	(XXX)-(4)
Almost Certain- (1)	2-High	3-High	4-High	5-Moderate
Likely-(2)	3-High	4-High	5-Moderate	6-Moderate
Moderate-(3)	4-High	5-Moderate	6-Moderate	7-Low
Unlikely-(4)	5-Moderate	6-Moderate	7-Low	8-Low
Improbable-(5)	6-Moderate	7-Low	8-Low	9-Low

Human Safety Hazard Analysis



FRR Presentation Agenda

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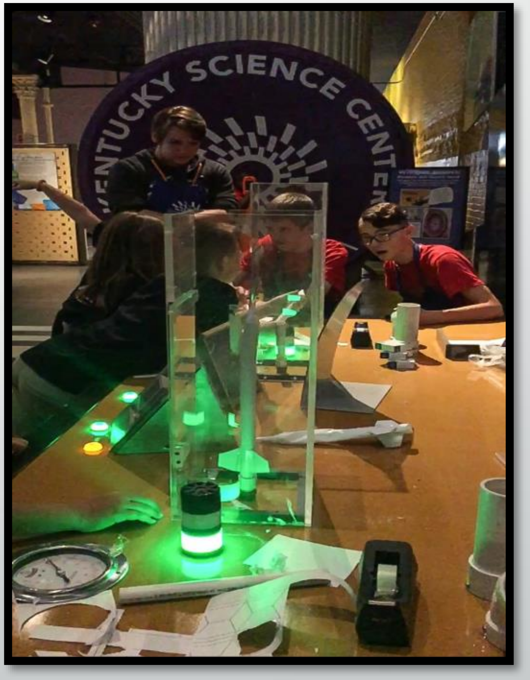
Educational Outreach

Educational Outreach Student Count			
	NASA Requirement	*Our Requirement*	
Requirement to reach	200	2000	
Students yet to be reached	Complete	Complete	
Students reached at CDR	**1226**	**Current Total**	**3,176**



FRR Presentation Agenda

- Launch Vehicle
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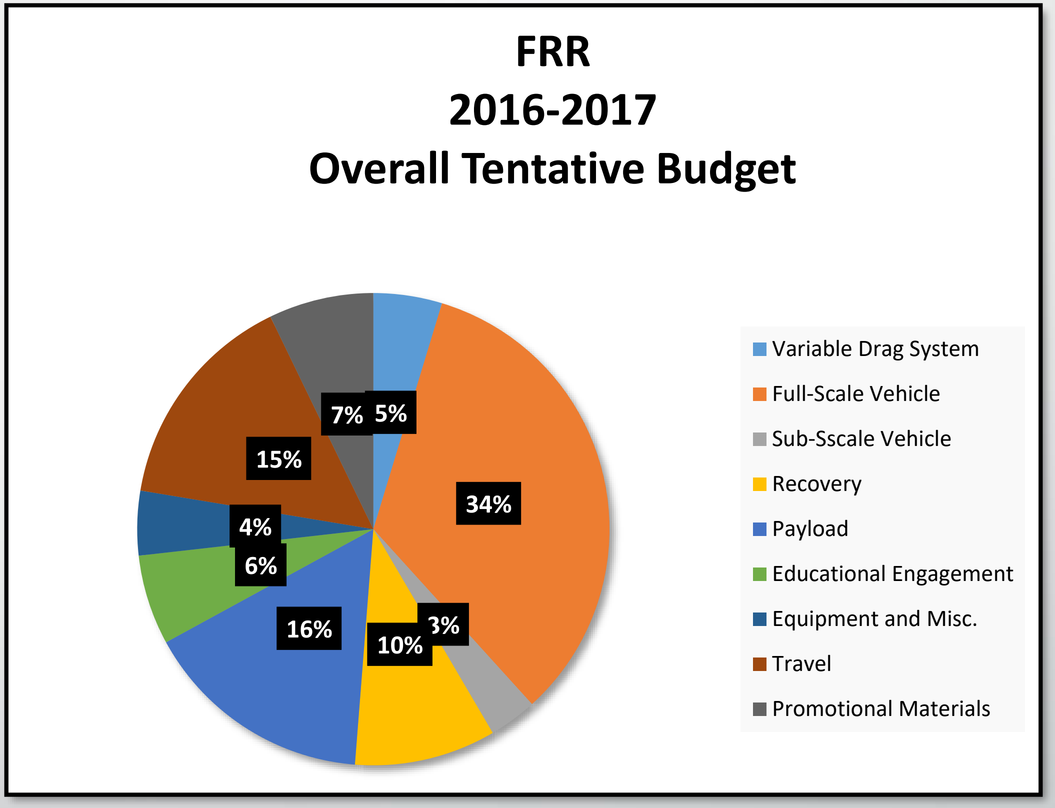
2016 – 2017 Overall Budget

Overall Tentative Budget		
Budget	Increase from CDR	**Total Cost**
Variable Drag System	$352.30	$1,431.75
Full-Scale Vehicle	$5,163.66	$10,232.49
Sub-Sscale Vehicle	0	$1,000.34
Recovery	$1,266.09	$2,951.84
Payload	$1,957.59	$4,815.73
Educational Engagement	0	$1,877.03
Equipment and Misc.	0	$1,344.88
Travel	0	$4,632.30
Promotional Materials	0	$2,187.50
Overall Cost		**$30,473.86**



Sustainable Budget

Sustainable Budget					
Inflow					
Donor	**Description of Donation**	**Date Submitted**	**Date Received**	**Amount Requested**	**Accepted**
2015-2016 RCR Remaining Balance	Remaining balance of the teams expenditures from the 2015-2016 NASA Student Launch Competition	N/A	N/A	$23,799.00	Y
J.B. Speed School	The University of Louisville J.B. Speed School donates based off presentation of materials and amount requested/needed by the organization, including money from the JB Speed school student council.	Thursday, September 22, 2016	Friday, October 28, 2016	$5,300.00	Y
Raytheon Missle Systems	Assistance in outreach event MathMovesU.	Thursday, October 13, 2016	Thursday, October 27, 2016	$1,000.00	Y
U of L, Department of Mechanical Engineering	The Department of Mechanical Engineering donated to the team for continued success in the NASA SL competition and persevering of River City Rocketry	Saturday, November 12, 2016	Monday, December 5, 2016	$2,000.00	Y
Anonymous Donations	Various anonymous donations made through the river city rocketry website	Wednesday, May 3, 2017	Wednesday, May 3, 2017	$125.00	Y
Dr. Kelly Donation	An alumni of the University of Louisville who has worked in the aerospace industry and expressed continuous interest in the team.	Thursday, December 8, 2016	TBD	$10,053.27	Y
			Overall Income	**$42,277.27**	
Outlfow					
			Expected Team Expenses	**$30,473.86**	
			End of the Season Expected Total	**$11,803.41**