Flight Readiness Review

5/16/2019

Agenda:

1. Introduction
2. System Overview Requirements
3. Sub-system Analysis
   a. Structures - Nose Cone
   b. Payload
   c. Avionics
   d. Recovery
   e. Motor
   f. Structures - Fin can
4. Launch Operations
5. Outstanding Risks
6. Closing Statements

Rocket Team’s Mission:

To design, build, test, launch, and recover a rocket
—flying an engaging scientific experiment—
beyond the Kármán Line

Spaceshot Risk Categories
Mitigated by Hermes II

Mathematical and Numerical Models	Component Selection	Manufacturing Methods	Operation Logistics
• Nose cone tip thermal model • Parachute deployment loads • Drag model • Motor thrust curve	• Avionics • Ground communications • Parachute Materials • Recovery deployment mechanism	• Nose cone and fincan layup • Motor case manufacturing and tolerancing • Rocket integration	• FAA Waivers • Transportation • Budgets • Team structure

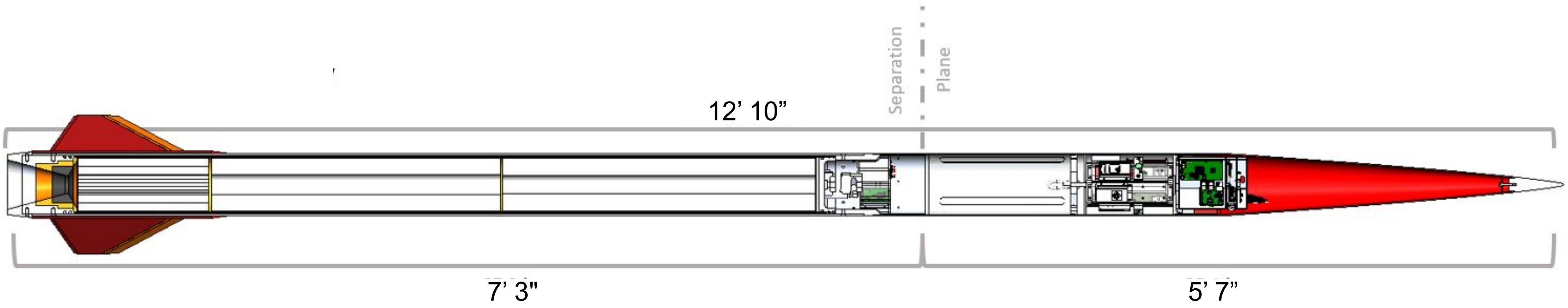
Hermes II Mission Objectives:

- To bridge the gap between the intercollegiate competitions to spaceshot in 2020

- To validate our current manufacturing and design methods

- To reduce the risks of the spaceshot

The Rocket



P Class Motor
Total Impulse: 74 kNs
Isp: 227 s

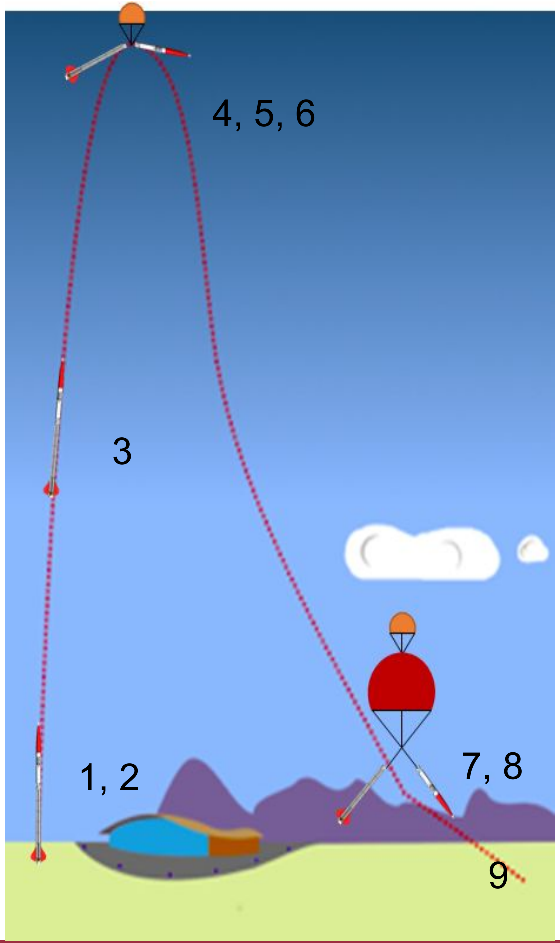
Total mass: 167 lbs (measured)
Propellant mass: 73.3 lbs (measured)

4 Composite Fins
Passively stabilized

Payload
Custom Flight Computer
5 IMUs
10 Thermocouples
1 Load Cell
5 Cameras
3 Barometric Altimeters
2 GPS

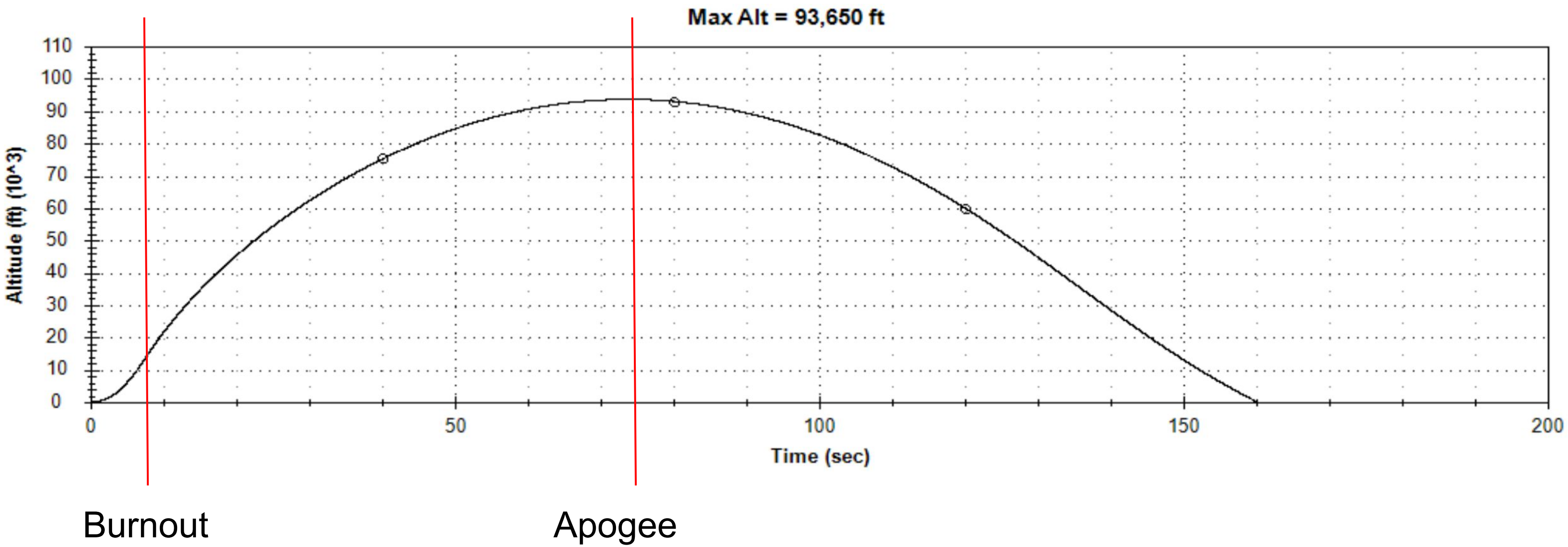
Expected Flight Profile

ID	Time	Event	Altitude (ft)
1	-5:00	Arm Avionics	0
2	0:00	Go/No Go, Ignition	0
3	0:08	Burnout	15,000
4	1:15	Apogee	93,000
5	1:15	Recovery Separation	93,000
6	1:25	Drogue Inflation	90,000
7	6:00	Main Parachute Release	2,000
8	6:10	Main Parachute Inflation	1,800
9	7:00	Impact	0



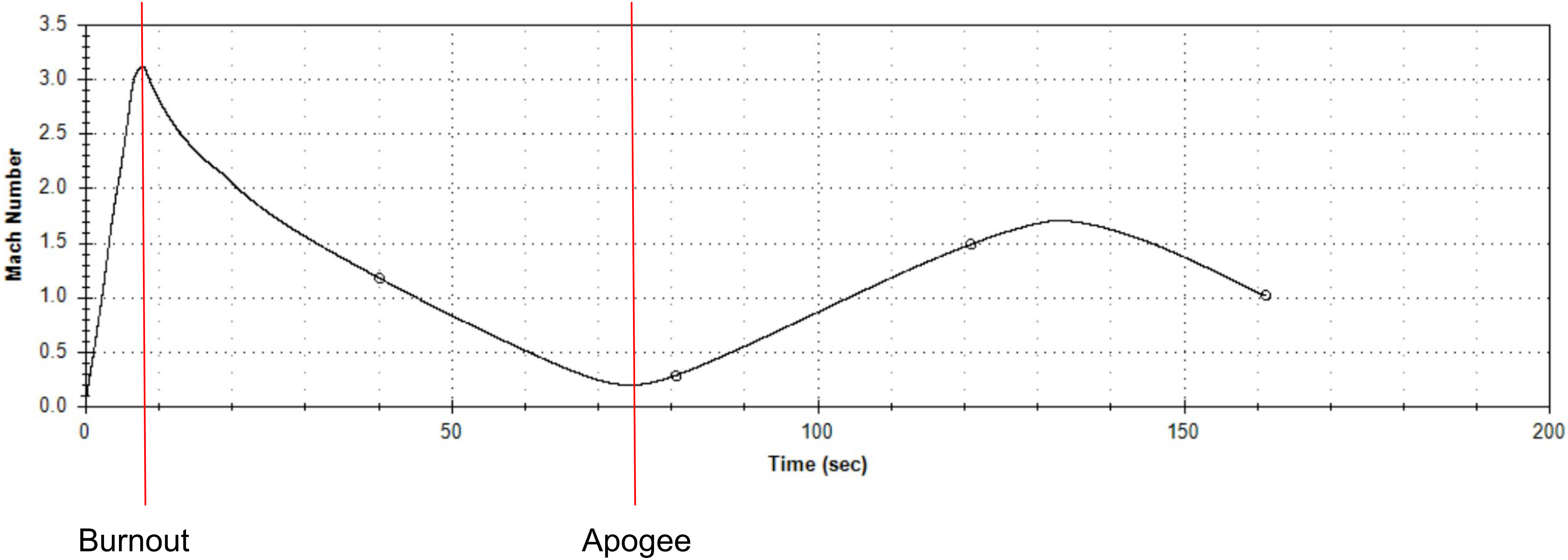
Altitude Requirement

- Performance of larger motors
- Parachute deployment in a rarefied atmosphere
- Accuracy of telemetry
- Verify drag model



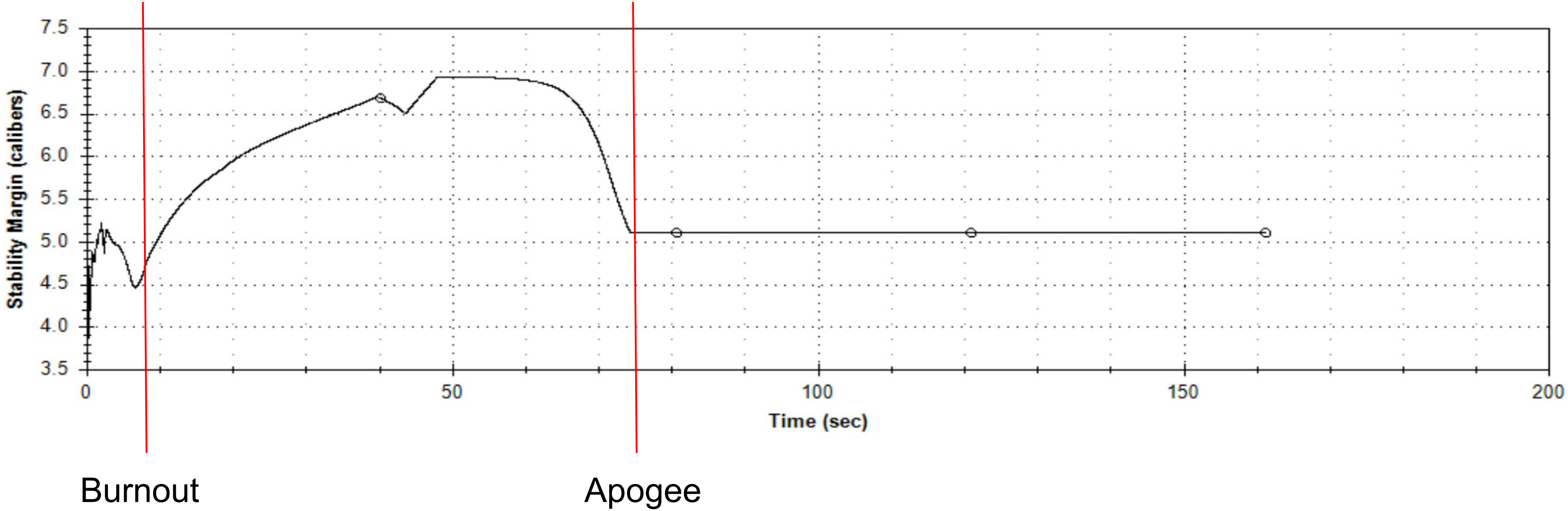
Mach Requirement

- Go fast enough to test thermal protection and verify thermal simulations



Stability Requirement

- Verify stability is at least 2 calibers off the pad and the rocket remains stable throughout the entire flight

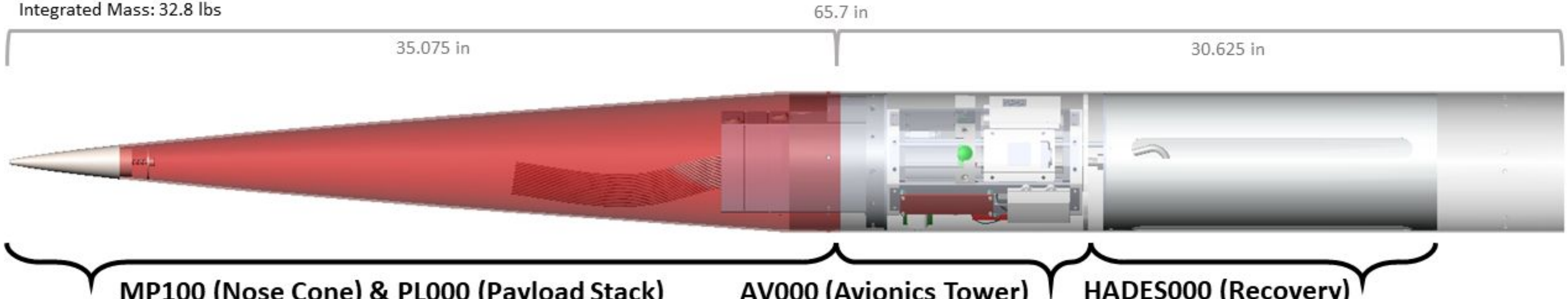


Sub-system Verification

Mission Package (MP) – Overview

MP000 (Mission Package)

April 19, 2019 – Launch Rehearsal
Integrated Mass: 32.8 lbs



MP100 (Nose Cone) & PL000 (Payload Stack)
PL100 (Thermal DAQ)
PL200 (Video Downlink System)
PL300 (Outreach Payload)
MP101 (Nose Cone Tip)

AV000 (Avionics Tower)
AV100 (Pyxida)
AV200 (Marsa)
AV600 (TeleMega)
Cameras

HADES000 (Recovery)
HADES001 (Piston)
Tender Descenders
Main Parachute
Drogue Parachute

Part Name

Challenges/Requirements

Design Overview

Verification & Validation

Risks & Mitigations

Reqs.	
Design	
Verify	
Open Risks	

Separation Mechanism

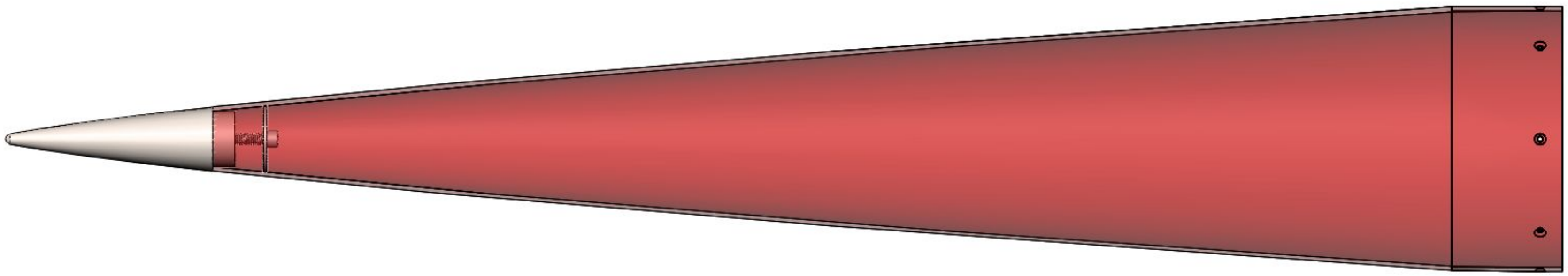
Challenges/Requirements: Works in vacuum, scalable to 4” rocket diameters, can be qualified for vacuum operation without a vacuum chamber

Design Overview: An electric match ignites black powder inside a sealed piston. A diaphragm on the end of the throw pushes against a coupler tube and severs shear pins. This imparts enough energy into the bodies to deploy the drogue.

V&V: Piston was tested alone 4 times. During initial testing 1 in 7 Firebolt ignitors burst out. This was mitigated by strict process control and hydrostatic testing of all Firebolt ignitors. Then tested with the shear pins 12 times, and in the fully integrated rocket in ground tests 6 times.

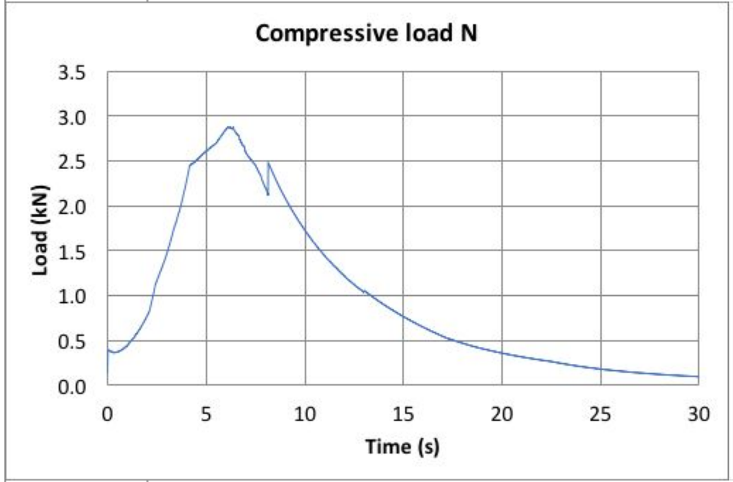
Nose Cone Structural

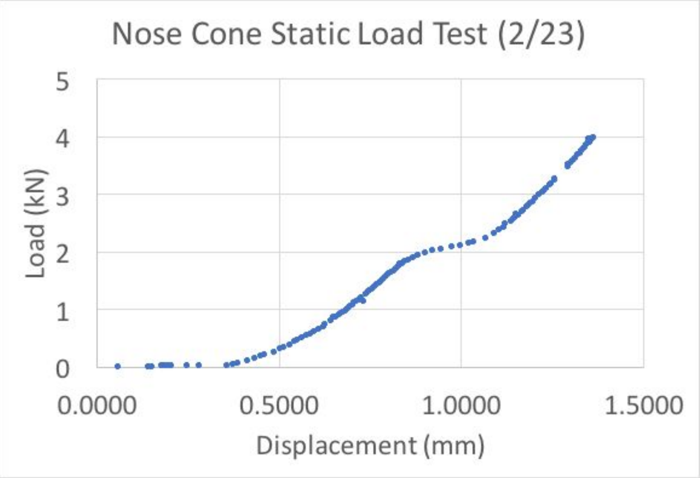
Reqs.	Withstand the compressive forces of flight, especially with respect to buckling.
Design	NC: ¾ Power Series geometry. 10-layer 5.6 oz twill weave fiberglass (S-glass) layup. 316 Stainless Steel tip with 3mm radius.

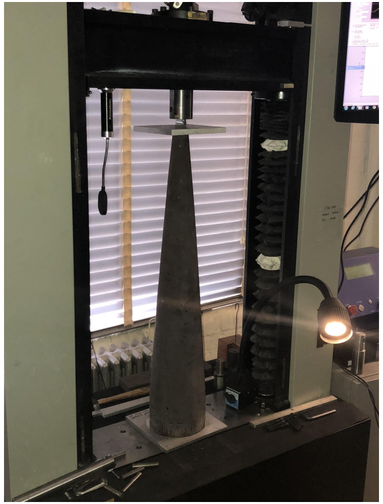


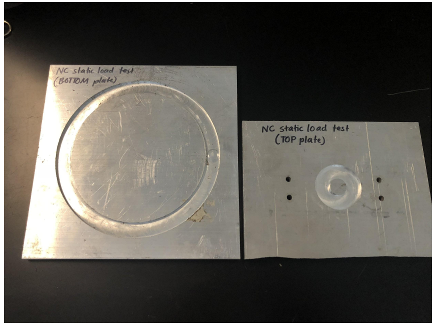
Nose Cone Static Load

Verify	• Calculated maximum load expected on nose cone • Max expected compressive load = 2.9kN • Nose Cone tested in Instron to 4kN (1.4x safety factor)









Above: nose cone static load test in progress (top), nose cone jig (bottom)

Open Risks	Lateral loads are unknown. Thermal effects are unaccounted for in this test. Need test that applies load on entire surface of NC, not just ends

Nose Cone Thermal

Reqs.	Demonstrate that ablatives can be used to withstand aerothermal heating without melting tip.
Design	10-layer fiberglass nose cone painted with 0.03” of Systems 3000 epoxy with 15%wt phenolic microballoons. 4” 316 Stainless Steel tip with 3mm tip radius. Center hole for attachment and 2 holes (one on either side of center) for thermocouple insertion

Nose Cone Thermal Test

Series of thermal tests conducted on fiberglass samples with ablative coating

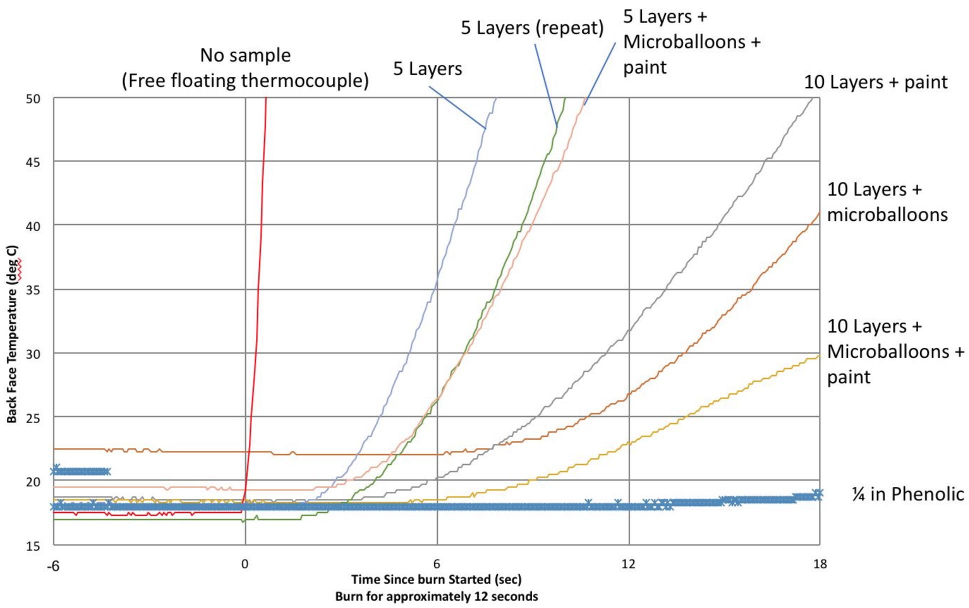
- Ablative coating: Systems 3000 epoxy + 15% by weight phenolic microballoons
- Other combinations of composites/ablatives also tested

Test setup:

- Propane blowtorch attached to jig positioned 10cm from test sample
- Test conducted in blast chamber

Future work:

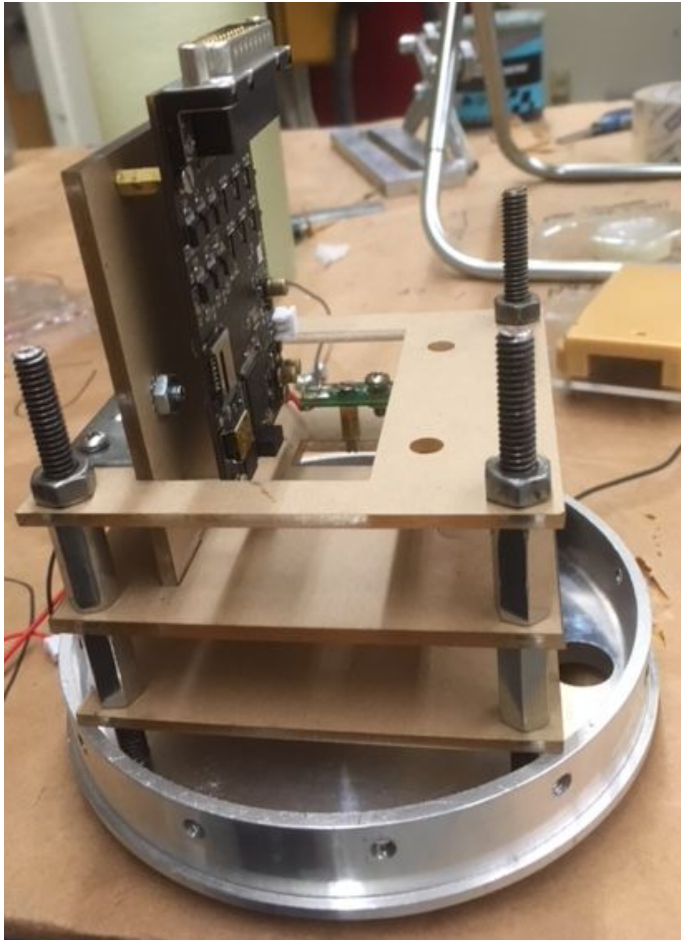
- Use heat gun instead of propane torch (to avoid offgassing)
- Increase precision of sample manufacturing (consistent fiberglass/ablative coating thickness)

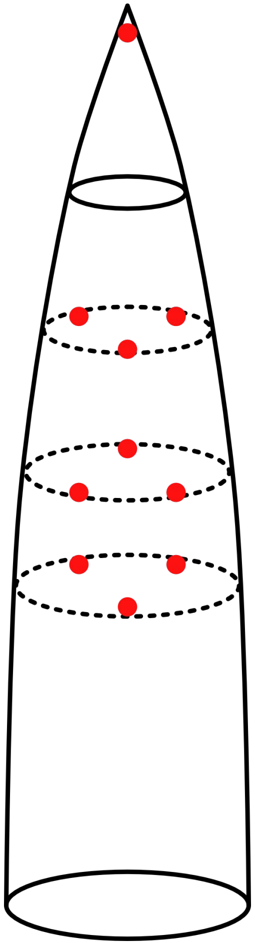


Payload Overview

- **Primary Objective**: Determine peak temperatures of the nose cone tip and thermal profile along the inner surface of the nose cone
- **Secondary Objectives**:
  - Characterize vibration environment of Hermes II
  - Measure recovery deployment forces
  - Characterize parachute deployment
- Custom data acquisition system that reads and logs data from:
  - Thermocouples
  - Resistance Temperature Detectors
  - 3-axis accelerometer

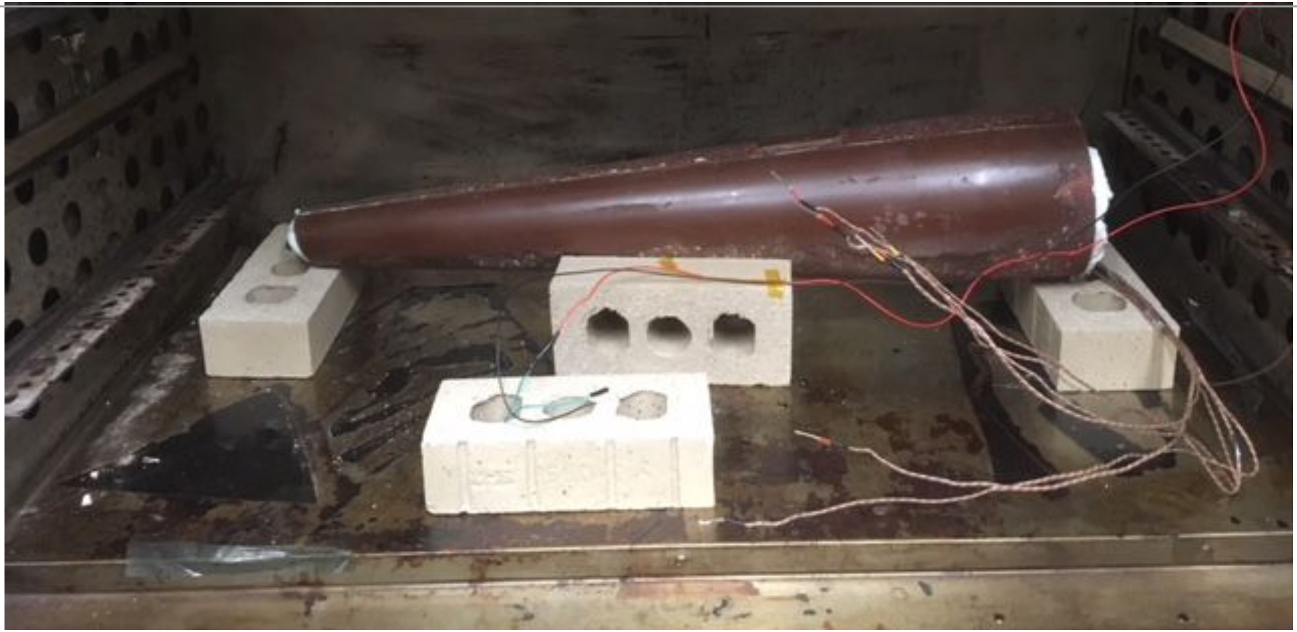
Configuration



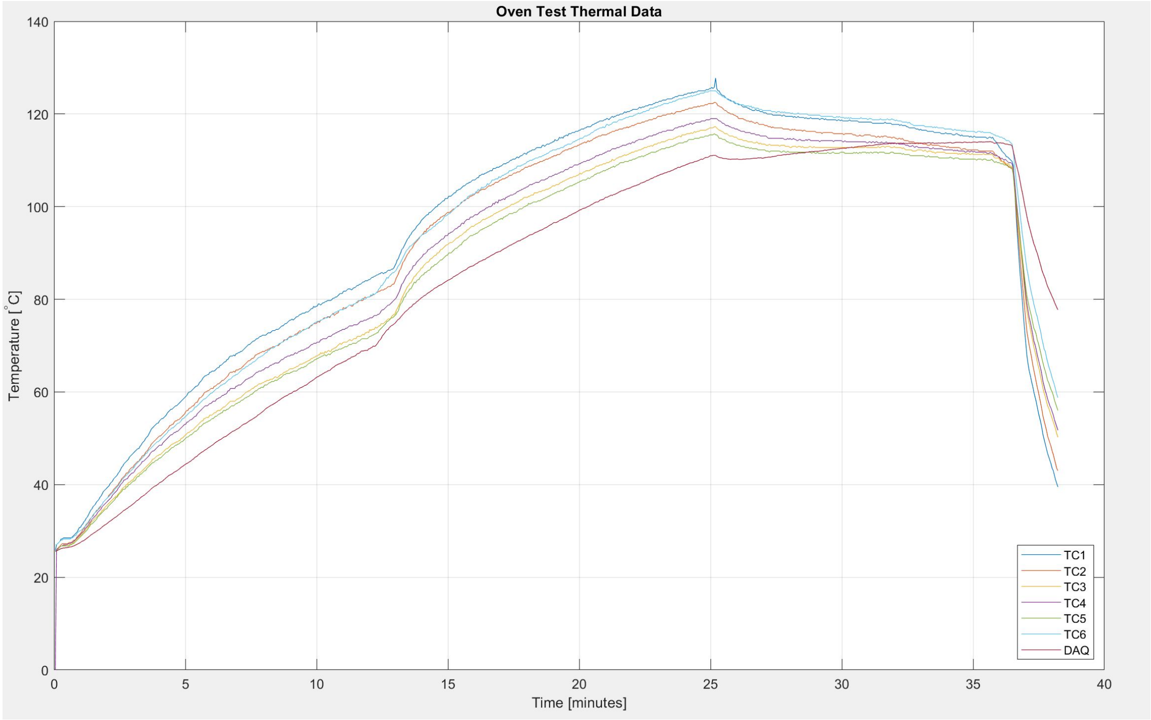


Payload Thermal Test

Verify	System operates nominally under high temperatures (250 F) for over 7 min.



Thermal Test Data

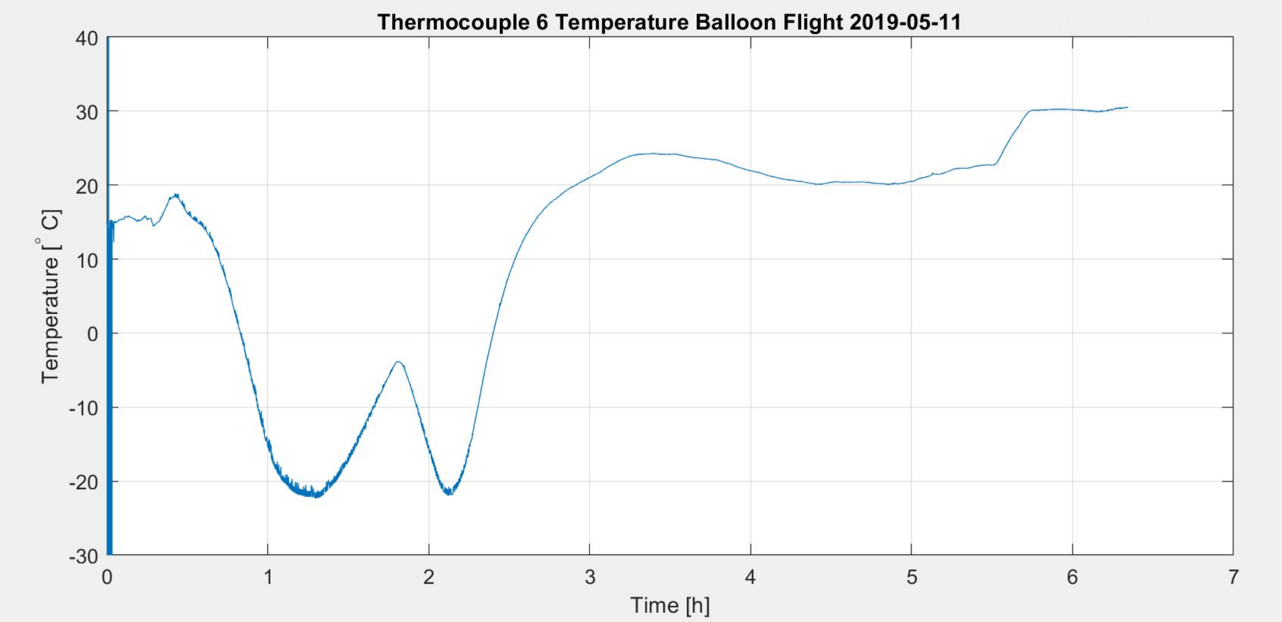


Test successful. Nominal operation up to 120 C for over 10 minutes

Payload Balloon Test

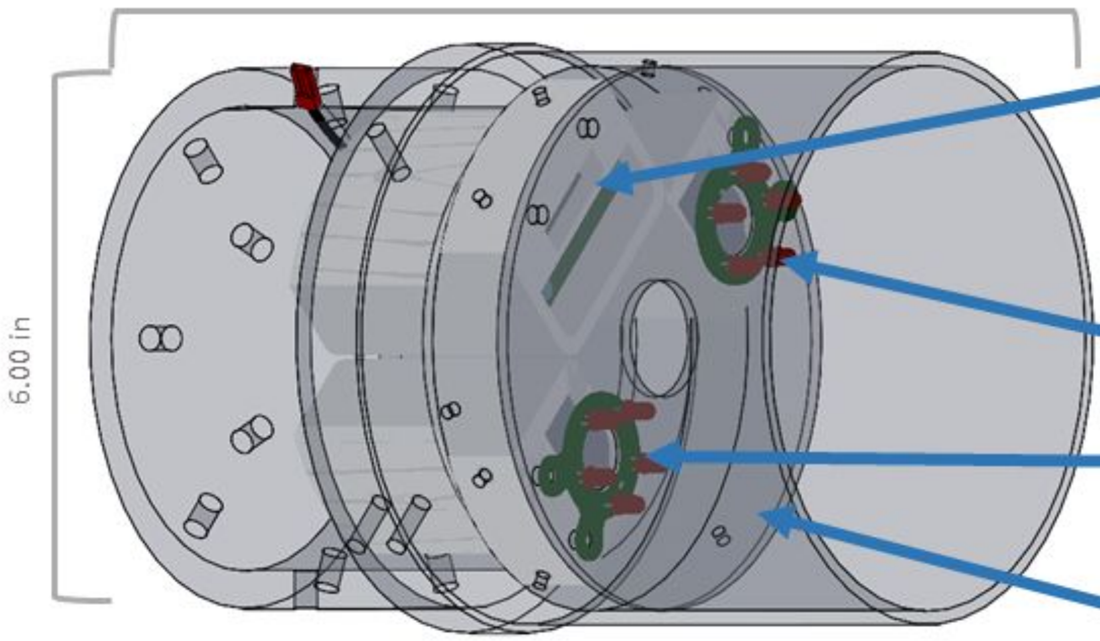
Verify	System operates nominally under high-altitude conditions and survives extreme time duration Effects from off-gassing of materials at high-altitude do not impact sensor readings

Flight Thermal Data



Test successful. Nominal Operation over 100,000 ft, over 3 hrs.

Lower Electronics – Overview



LE100 (Motor DAQ)

- LE101 (DAQ Holder)
- LE102 (DAQ Cover)
- Minerva (DAQ)
- 800 mAh LiPo

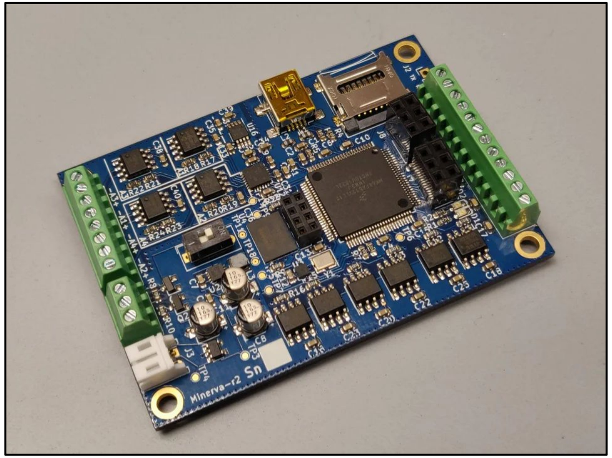
LE200 (Camera) x2

- LE201 (Camera Holder)
- LE202 (LED Ring)
- Firefly Q6 Camera

LE102 (Recovery Guard)

Lower Electronics - Validation

Verify	Nominal readings and performance from all associated sensors: ● Load Cell ● Pressure Transducer



Validated in series of integrated recovery tests.

Position and Telemetry

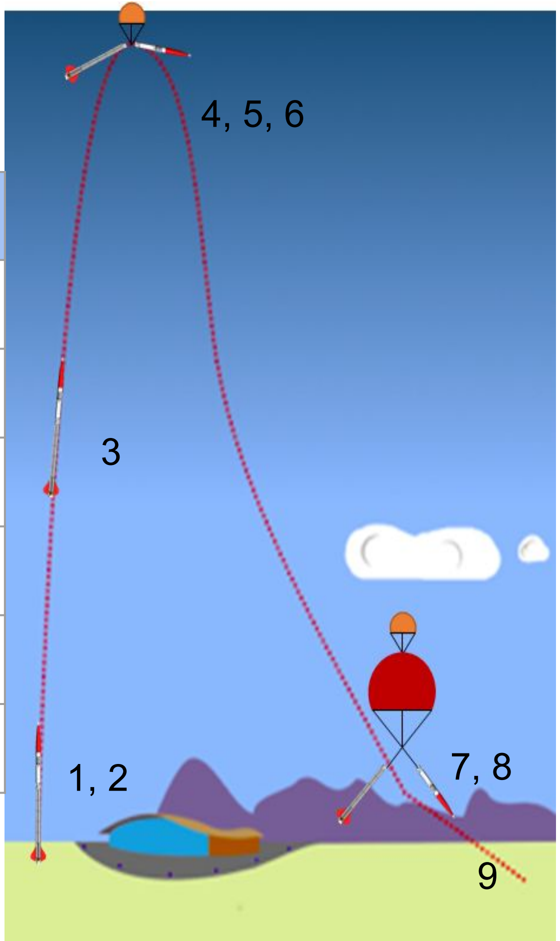
Reqs.	Get accurate altitude and position data from the flight Maintain a radio link with the rocket throughout the flight
Design	Custom flight computer Pyxida Telemega (commercial-off-the-shelf) for redundancy
Verify	Radio range tested from green building to northeastern (3km) Unit and HOOTL tests for software GPS spoofing test Balloon test
Open Risks	Radio will not work at higher mach numbers, and 30km vertical range

Parachute Deployment

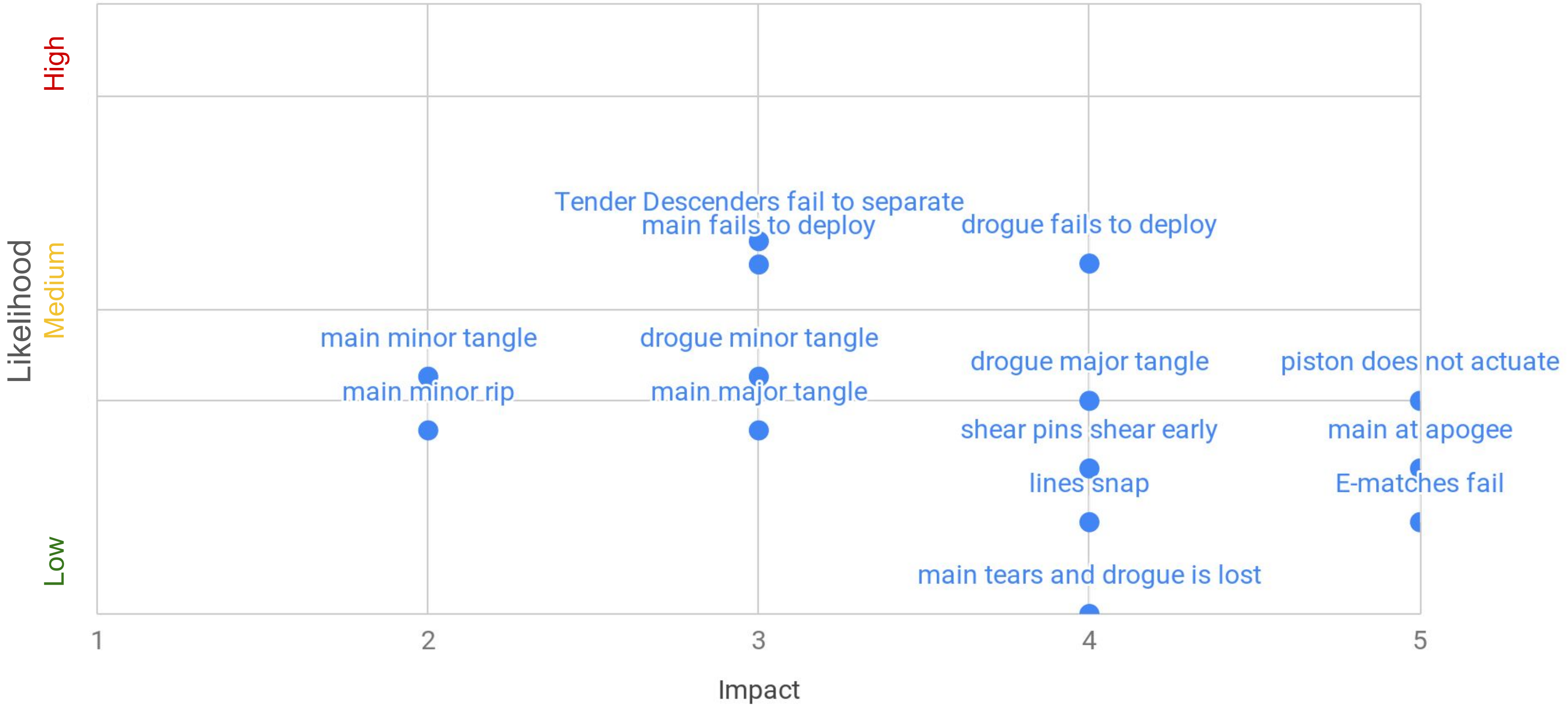
Reqs.	Detect apogee and deploy the drogue parachute. Detect altitude at 2000ft and deploy the main parachute.
Design	Telemega (commercial-off-the-shelf) fires the parachutes. Pyxida (not in command) reports when it wants to fire the parachutes.
Verify	Vacuum chamber tests showed telemega fires the parachutes at the right time. We verified manual deployment works from the ground.
Open Risks	Reliability of Telemega (COTS).

Recovery Overview

ID	Event	Time	Altitude	Key Parameter
4	Apogee	1:15	93,000 ft	0-400 ft/s
5	Piston Separates Rocket	1:15	93,000 ft	0-400 ft/s
6	Drogue Inflates	1:25	90,000 ft	25-400 lbs
7	Tender Descenders Release Main	6:00	2,000 ft	94-97 ft/s
8	Main Parachute Inflates	6:10	1,800 ft	1550-1630 lbs
9	Impact	7:00	0 ft	29-30 ft/s

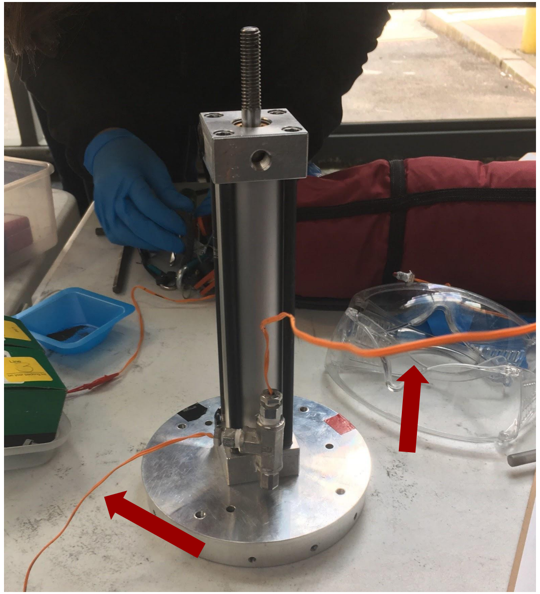


Hermes II Recovery Risk Matrix



Firebolts: Actuate Piston & Main Release

Reqs.	Firebolts must actuate the piston to allow rocket separation and to release the main
Design	Hex head bolts are drilled through on the lathe, then an e-match is epoxied through the head and degassed in a vacuum chamber
Verify	Hydrostatic test for quality Continuity checks when integrating Process control through logging every step of manufacturing and test ● Quantified reliability
Open Risks	Epoxy blows out E-match is a dud

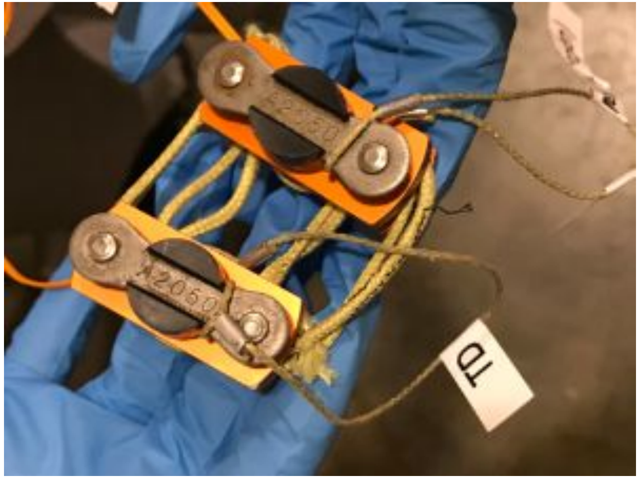


Piston Separation at Apogee

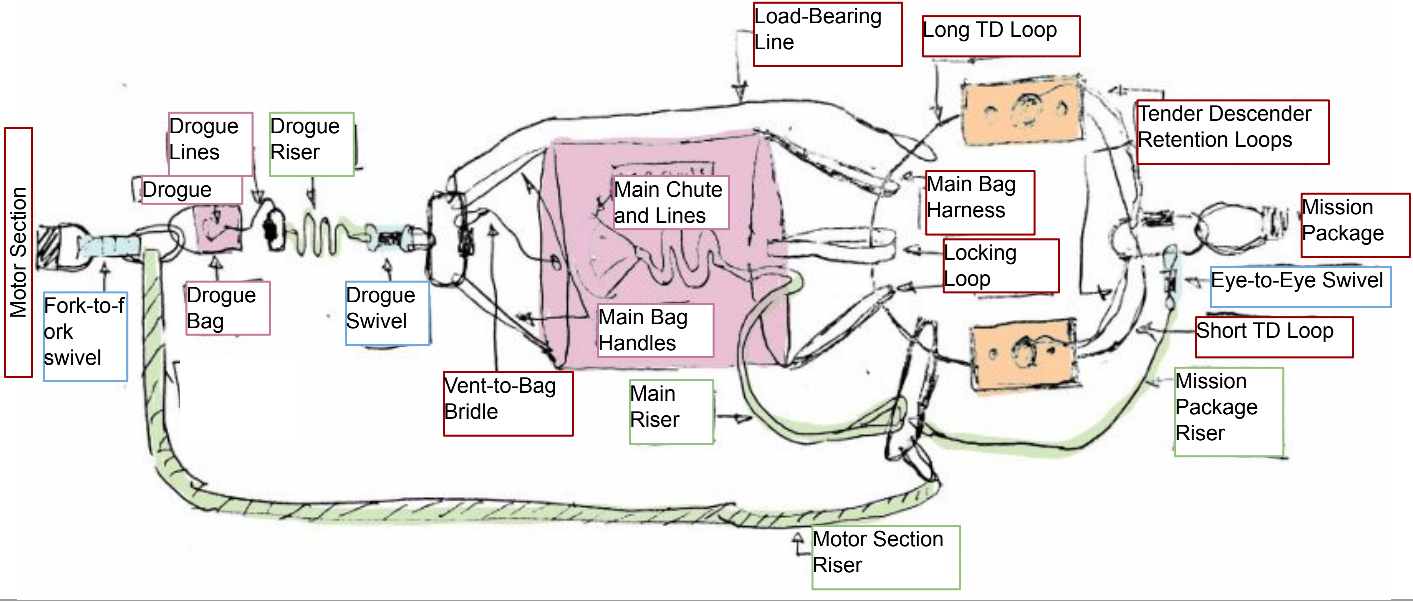
Reqs.	Piston must fire with enough force to break the shear pins in order to separate the rocket to deploy the drogue
Design	Dual redundant charges connected to two different flight computers
Verify	4x Solo piston test in blast chamber 10x Integrated test in tubes in blast chamber 6x Ground test

Main Deployment

Reqs.	Main must be restrained from deploying until 2000 ft AGL.
Design	Frangible connections, Tender Descenders, are connected in parallel with two separate charges to two different flight computers for redundancy.
Verify	Tender Descender Tests: Integrated with 0.2g black powder each in blast chamber Successful separation
Open Risks	Tender Descenders squeezed and cannot separate



Recovery - Soft goods

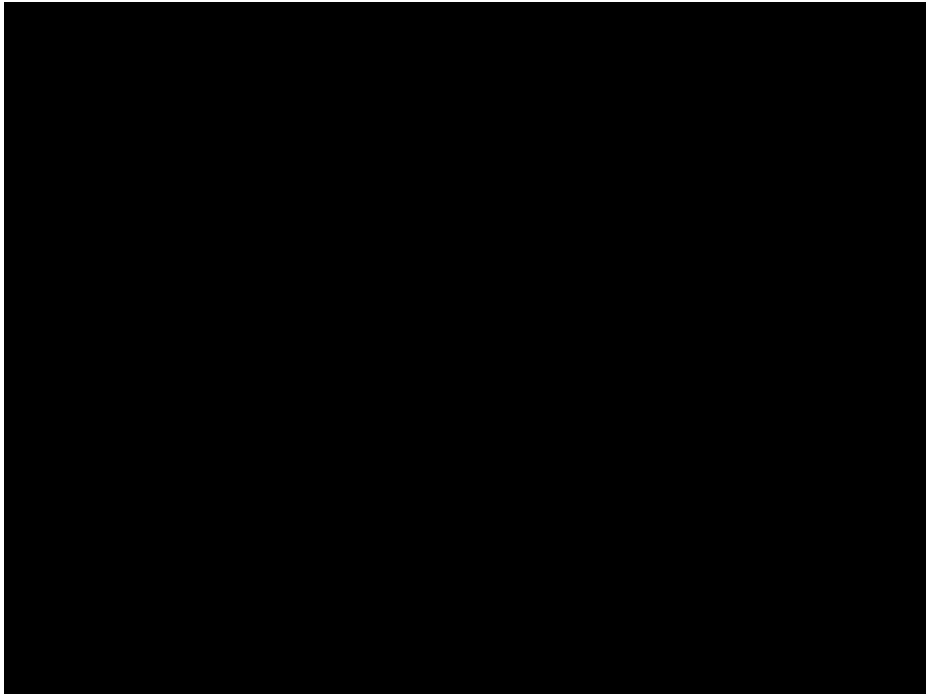
Reqs.	Parachutes must deploy and inflate properly, and lines cannot break
Design	

Recovery- Soft goods

Verify	Parachutes: • Tow test behind a car • Drop test at minimum load to check inflation Lines: • Safety factors and load path analysis • Drop test with load cell
Open Risks	Line tangling

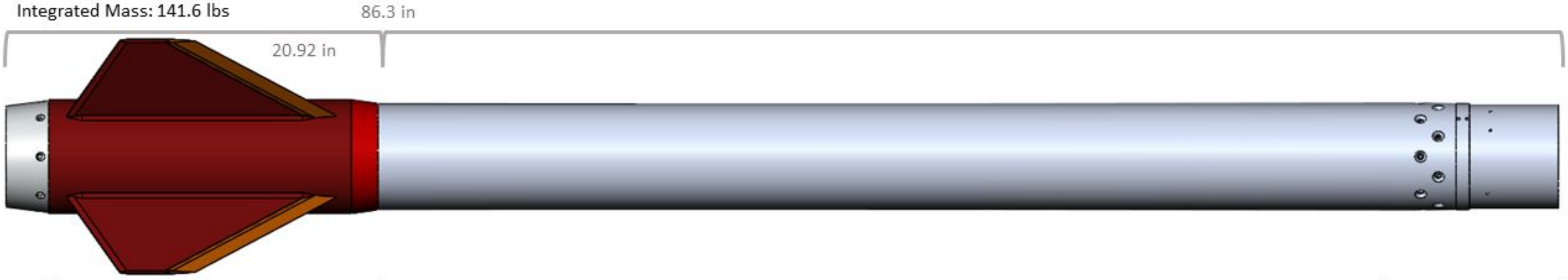
Mission Package – Ground Test

Reqs.	The mission package tube must integrate the payload, the avionics tower, and the recovery system.
Design	Soft goods are contained in a fiberglass cup at the end of the piston. The piston and tender descenders are wired to the avionics tower. The avionics are also wired to the payload stack.
Verify	Integration and separation test Piston and tender descenders ignited with avionics Multiple successful tests
Open Risks	Faulty integration



Booster - Overview

April 19, 2019 – Launch Rehearsal
Integrated Mass: 141.6 lbs



FC000 (Fin Can)
FC001 (Fin Collar)
FC002 (Fin Preform) x4
FC004 (Fin Can Retainer)

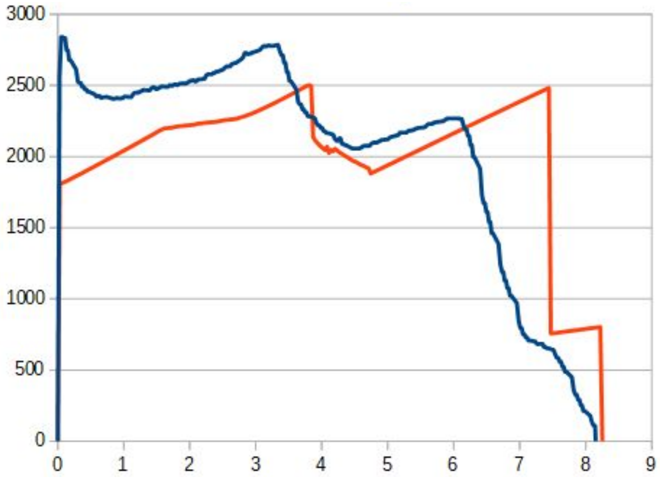
MT000 (Motor)
MT100 (Nozzle)
MT200 (Forward Closure)
MT300 (Propellant)

LE000 (Lower Electronics)
LE100 (Motor DAQ)
LE200 (Camera Mount)
LE002 (Recovery Guard)

Motor – Key Features

- 73.3 lbs of ammonium perchlorate composite propellant
    - 82.5% solids, 7.5% aluminum
    - Three grains: one finocyl at the aft end and two BATES at the forward end
- Convolute wound canvas phenolic liner for thermal insulation
- 6061-T6 aluminum case and closures retained by 16 alloy steel bolts
    - 3.4x calculated safety factor
    - Hydrostatic tested to 1600 psi (2x operating pressure)
- Nozzle assembly contains a significant amount of linen phenolic
    - Sacrificial layer that prevents erosion of aluminum components
    - Lighter than a fully aluminum nozzle
    - Graphite throat has low coefficient of thermal expansion and does not erode

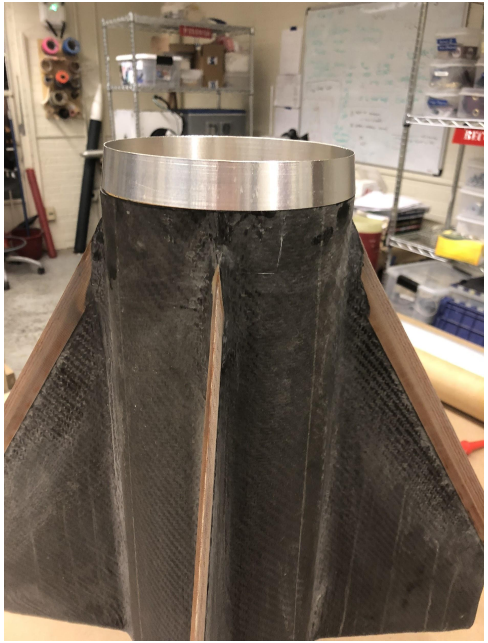
Static Fire



	Simulated	Actual
Impulse	74014 Ns	74042 Ns
Average thrust	8950 N	9095 N
Peak thrust	11120 N	12500 N
Peak pressure	5.17 MPa	6.3 MPa
Specific Impulse	226s	227s

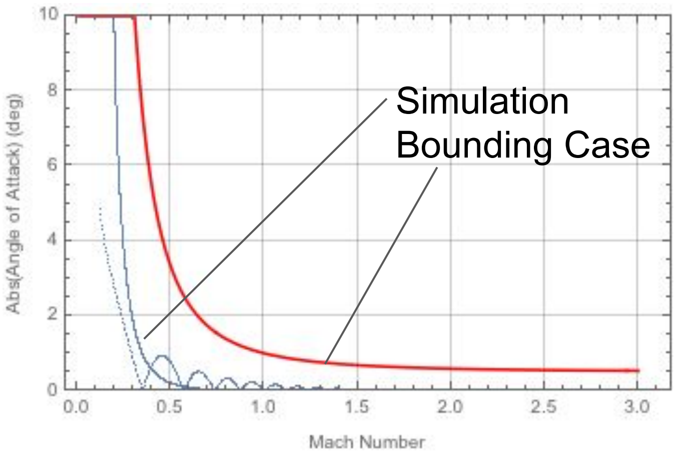
Fin Can - Overview

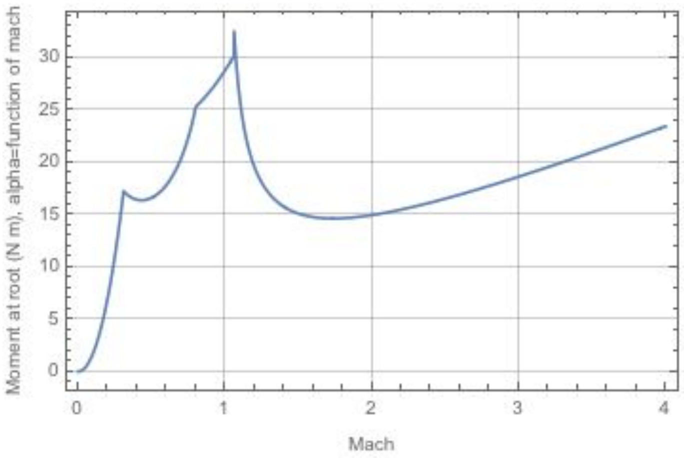
- Four fins (planform shown)
- 4.5 calibers minimum stability from 18’ rail (Requirement: 2.0 calibers)
- 12 ply CF sandwich panel with G10 core
- Phenolic leading edges with 15 degree taper
- Design supported by heritage from:
  - Hermes I
  - USC



Fins Structural

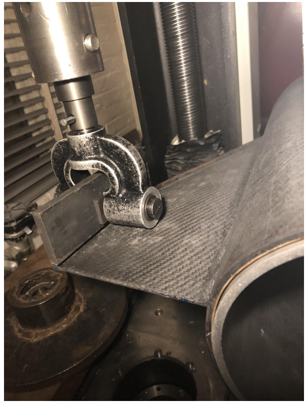
Reqs.	Fins must survive launch and flight loads: (1) bending, (2) torsion, (3) flutter, (4) thermal
Design	6 layer tip-to-tip CF (0-90 config), ⅛” G10 core with phenolic leading edge
Verify	Flat-plate aero model indicates max root bending moment as function of mach number. AoA-mach number bounded from flight simulations. Peak moment ~30Nm. Static load test to 100Nm (3x)



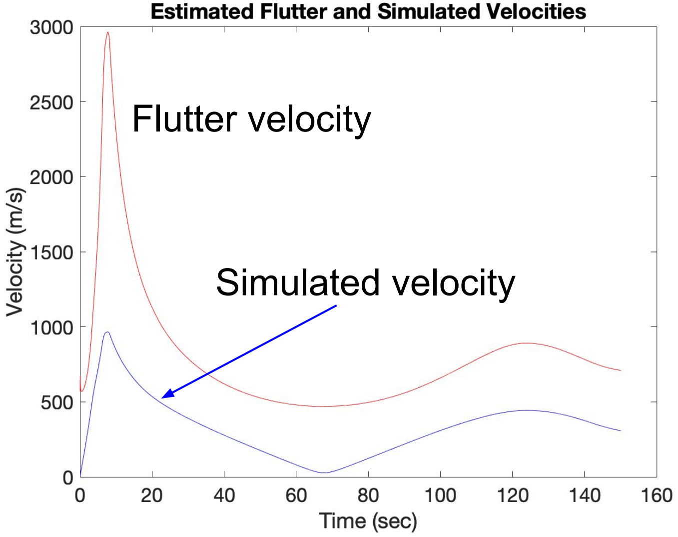


Fins Structural

Reqs.	Fins must survive launch and flight loads: (1) bending, (2) torsion, (3) flutter, (4) thermal
Verify	*Deflection is not accurate due to jig movement



Fins Structural

Reqs.	Fins must survive launch and flight loads: (1) bending, (2) torsion, (3) flutter, (4) thermal
Verify	NACA TN4197 allows flutter velocity estimation Calls for 15% margin Successfully used by collegiate teams Using estimated bending stiffness from static load test 2x safety factor on flutter velocity across entire flight Bending Stiffness used is a lower bound Flutter velocity will be higher 
Open Risks	Hard to verify aero model for for fins. Torsional and flutter modes not rigorously addressed → **need better modeling for fin can loads**. Difficult to discern test setup deflection from fin deflection in test Phenolic leading edge should be sufficient based on heritage

Launch Operations

Flight Assembly

- Highly detailed procedures for reference
- Integration checklists highlight single-point failures
  - Require signatures from two members

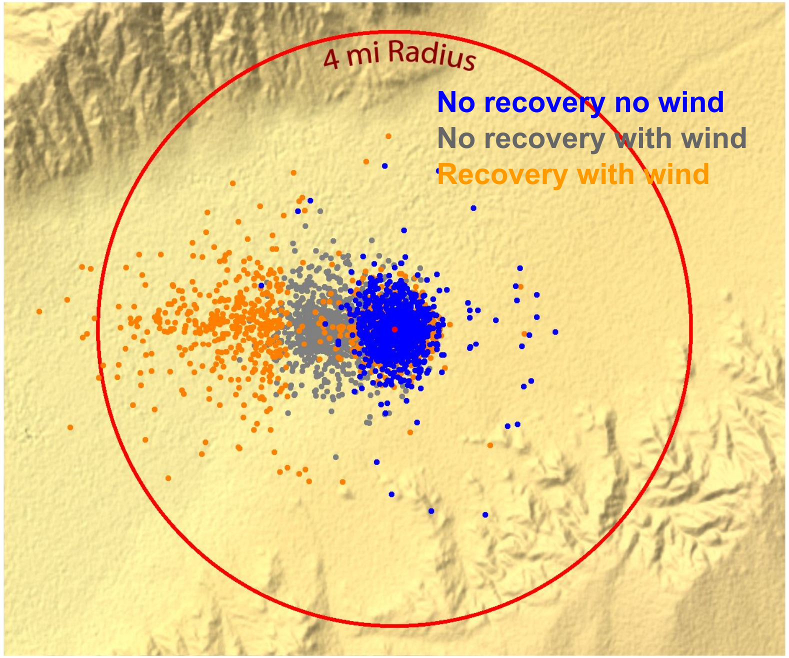
Completed rehearsals of assembly and launch operations

- Simulated adverse scenario of changing a battery on-site (95 minutes)
- Completed two full-up ground tests after flight assembly completed
- Successful piston and TD actuation during ground test

Outstanding risks:

- Assembly procedures and integration checklists not yet combined
- Clearly integrate roles & responsibilities of non-flight assembly

Dispersion Analysis

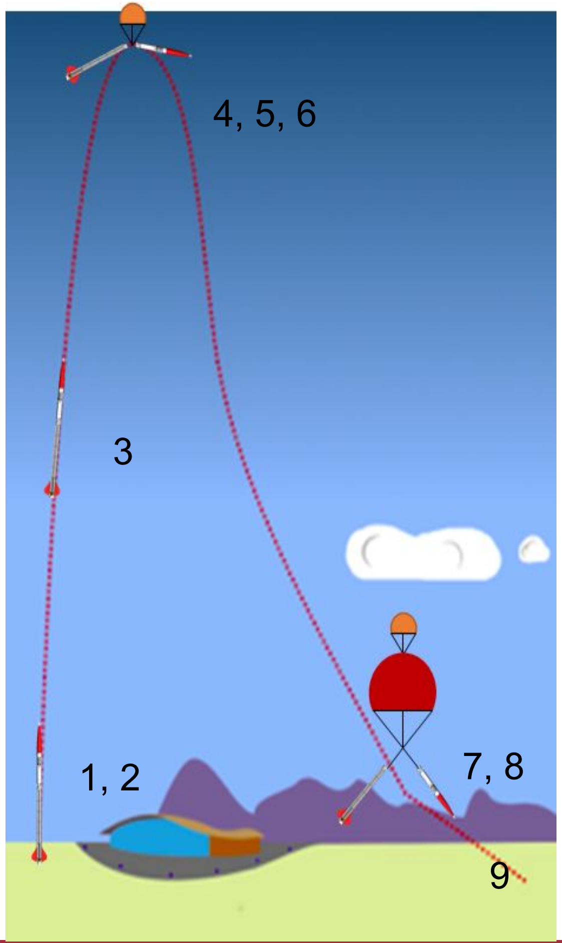


Key Outstanding Risks

- Fin can stiffness
- Off-nominal recovery
- Loss of radio link

Conclusion

ID	Time	Event	Altitude (ft)
1	-5:00	Arm Avionics	0
2	0:00	Go/No Go, Ignition	0
3	0:08	Burnout	15,000
4	1:15	Apogee	93,000
5	1:15	Recovery Separation	93,000
6	1:25	Drogue Inflation	90,000
7	6:00	Main Parachute Release	2,000
8	6:10	Main Parachute Inflation	1,800
9	7:00	Impact	0



Thank you!

Team Leadership

Exec

Julia Gaubatz
Katie Kutina
Andrew Reilley

Recovery

Maggie Zheng

Structures

Dayna Erdmann

Payload

Juan Salazar

Propulsion

Ethan Sit

Avionics

Zack Holbrook

Other Presenters

Jakob Coray - Spaceshot Chief Engineer
Luka Govedič - Spaceshot Avionics Lead
Devansh Agrawal - Structures

Launch Operations, cont.

Preflight simulations

- Estimate landing location in case no data is returned

Away team

- Team of ~6 monitors flight from ¼ mile from launch line

Čontingencies

- Hangfire, Battery out, Main at Apogee, Ballistic Recovery, CATO

Outstanding risks:

- Combine assembly procedures with integration checklists to streamline
- Clearly integrate roles and responsibilities