"The only hope is the sweet release of D.R.O.P."

LUMA: Long-range Universal Mission Administrator

2024 Mission Concept Review

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Team

Member	Subteam	Role
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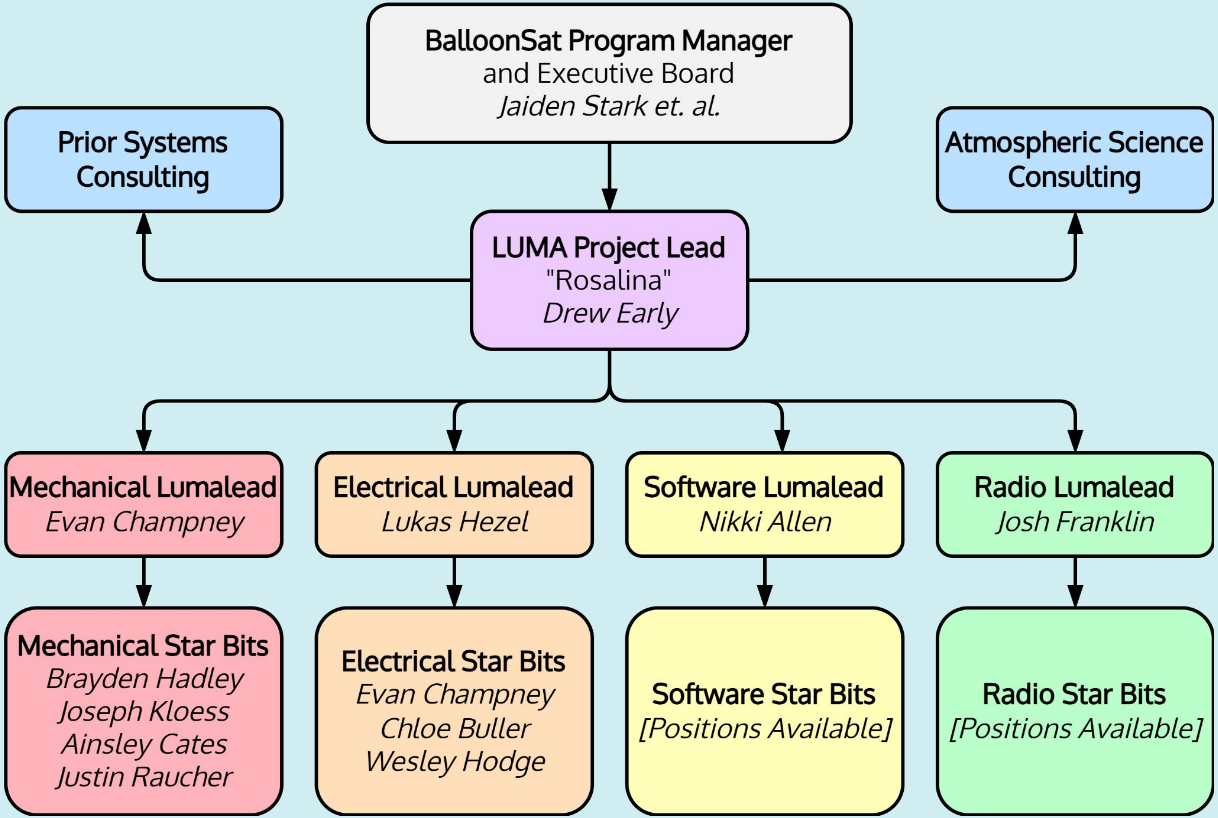
Overview

Structure and Proposed Program



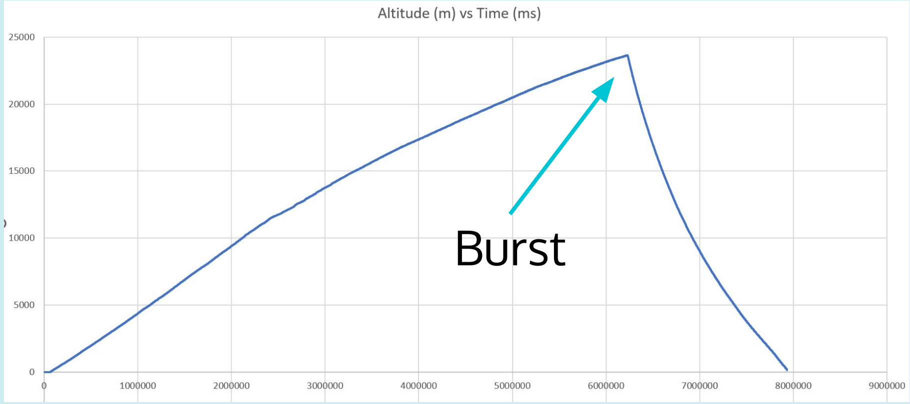
Acronyms and Terminology

- The LUMA System:
  - **LUMA** - Long-range Universal Mission Administrator
  - **LRC** - Long-Range Communications subsystem
- Prior Technologies and Space Hardware Club Projects:
  - **D.R.O.P.** - Designated Release Of Payload (a balloon cutdown system)
  - **NEBP** - National Eclipse Ballooning Project
  - **GHOUL** - Generalized Helium Outflow Unit for Latex balloons
  - **HAVOC** - High Altitude Visual Orientation Control
  - **HELEN** - High Energy Lightning Emissions Network
- Mission Nomenclature:
  - **Demo** - Demonstration
  - **PLDM** - Payload Demonstration
  - **CoMET** - Controlled Mission for Experimental Technologies
- Design Reviews:
  - **MCR** - Mission Concept Review
  - **PDR** - Preliminary Design Review
  - **CDR** - Critical Design Review
  - **MRR** - Mission Readiness Review
  - **ORR** - Operational Readiness Review
- Other:
  - **C&C** - Command and Control
  - **SHC** - UAH Space Hardware Club
  - **MCU** - Microcontroller Unit
  - **PCB** - Printed Circuit Board
  - **UAH** - University of Alabama in Huntsville
  - **UMD** - University of Maryland

Command and Control Theory (1/2)

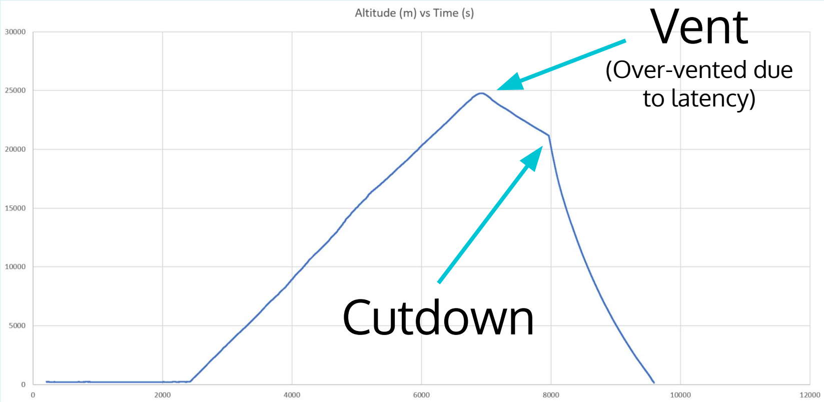
- Balloon flights typically rise at a nearly constant rate before reaching an altitude where they burst, followed by a period of free fall and landing.
- By venting helium from a balloon, a payload can lower or zero the ascent rate.
- By cutting down from the balloon, a payload can enter free fall without a burst. Commanded cutdown also removes the uncertainty of balloon-burst prediction.

Typical balloon flight



RCS Two-Month, October 2022

Manually-controlled vent with latency



UMD Snoopy, May 2023

Command and Control Theory (2/2)

- Balloon flights typically rise at a nearly constant rate before reaching an altitude where they burst, followed by a period of free fall and landing.
- By venting helium from a balloon, a payload can lower or zero the ascent rate.
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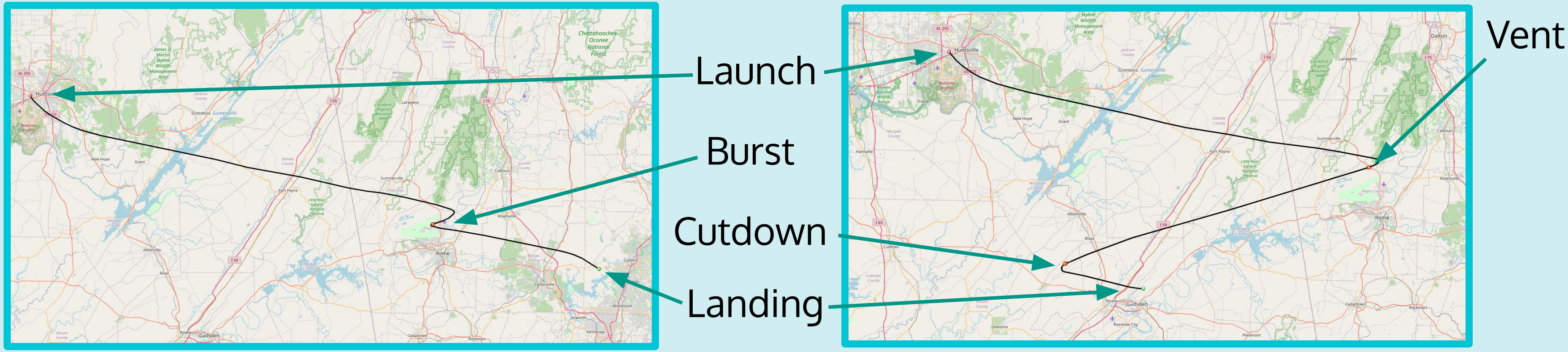
Typical balloon flight | Flight with vent and cutdown capability



Flights simulated with the same launch time and parameters using Sondehub Predictor

Purpose

The purpose of the LUMA System is to provide command-and-control capabilities for the full duration of a high-altitude balloon flight.

- This will be accomplished with the combination of two subsystems that the BalloonSat Program has researched in the past, as well as a new subsystem.

The purpose of the LUMA Project is to centralize and maintain the design and understanding of balloon command-and-control within the BalloonSat Program of the Space Hardware Club.

- This will be accomplished by bringing together the club's existing knowledge, extending it, and ensuring that the result is useful across a wide variety of mission profiles suitable for other balloon payloads.

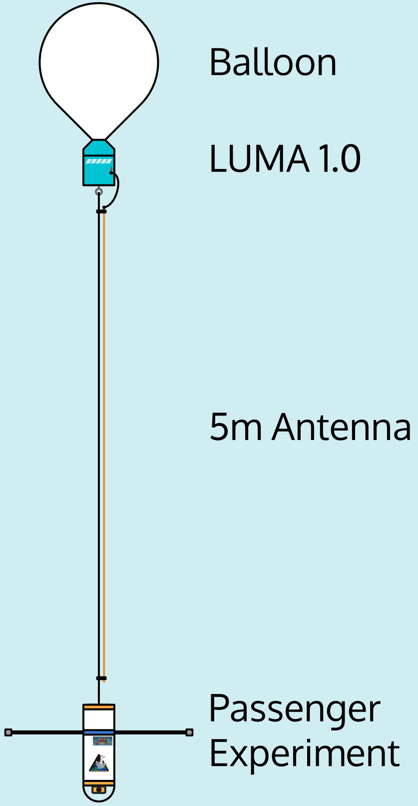
Objectives

The objectives of the LUMA Project, therefore, are to further develop and maintain the following capabilities within the club:

- **Develop** a helium venting subsystem for altitude control.
- **Develop** a balloon cutdown subsystem for flight termination.
- **Develop** a long-range communication subsystem for constant telemetry and direct control of the flight.
- **Integrate**, **test**, and **maintain** these capabilities within the BalloonSat Program, so that other projects may use the capabilities LUMA provides.

The LUMA System

- **The LUMA System** refers to one or more interoperable payloads that serve to provide command and control of balloon flights as a service to other experimental technologies.
- **LUMA 1.0**, the first phase of development for the LUMA System, will consist of a single payload and will contain a Vent subsystem, a Cutdown subsystem, and a Long-Range Communications (LRC) subsystem.
- **This presentation** will primarily cover the conceptual design of LUMA 1.0 as a proof-of-concept, and will provide insight into additional capabilities of future project phases.

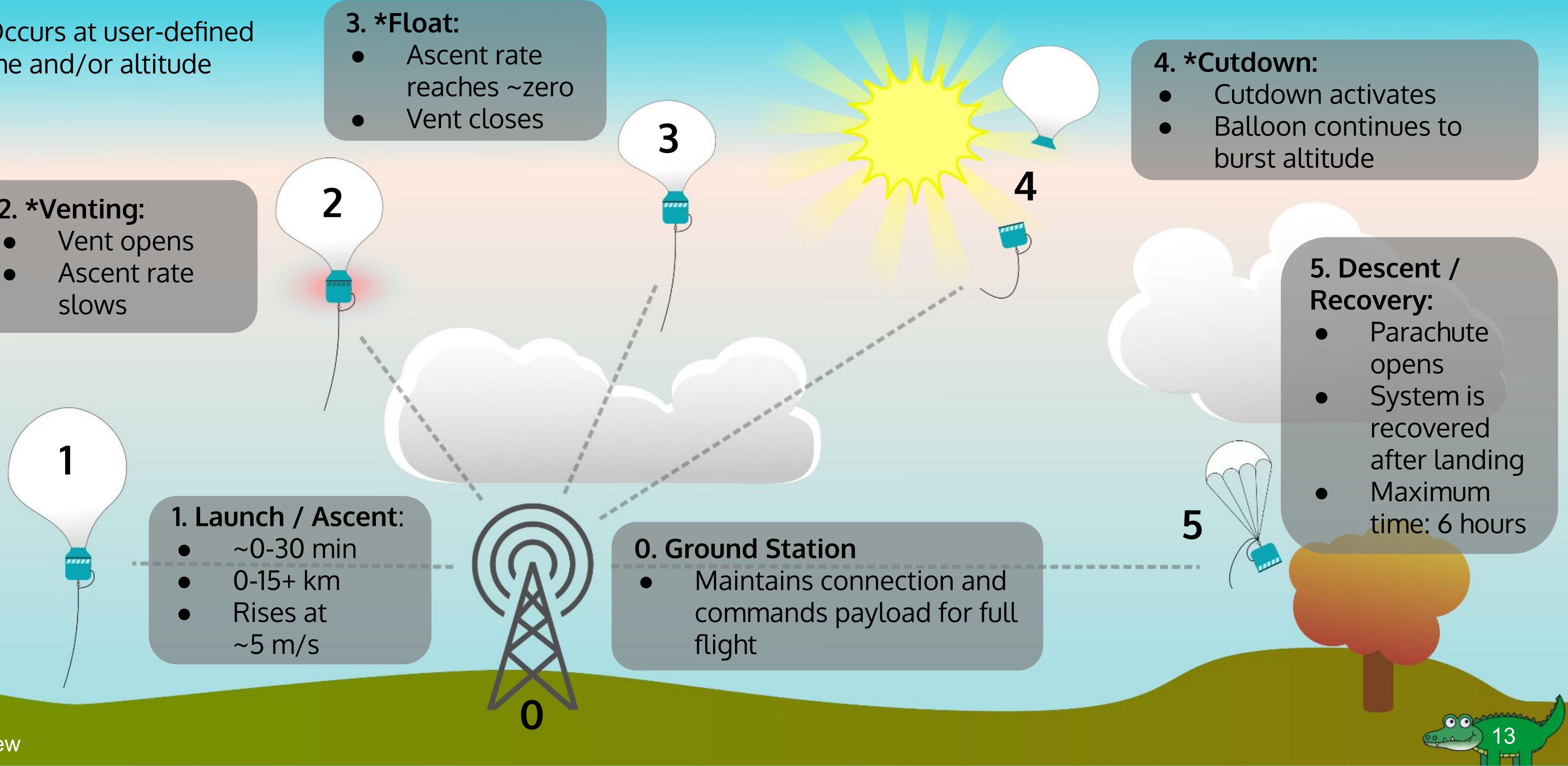


LUMA Project Phases

- **LUMA 1.0**
  - The first functional LUMA System, a single payload with only necessary C&C capabilities
  - *Scheduled for completion in Fall 2024*
- **LUMA 1.1**
  - A suite of upgrades to the LUMA 1.0 System, using as much of the same hardware as possible
  - Addition of ballast subsystem, as well as the possible addition of satellite communications
  - *Scheduled for completion in Spring 2025*
- **LUMA 2.0**
  - A full redesign of the LUMA System based on the lessons learned from the previous phases
  - *Scheduled for completion in Fall 2025*

LUMA 1.0 Concept of Operations

*Occurs at user-defined time and/or altitude



1. Launch / Ascent:
- ~0-30 min
- 0-15+ km
- Rises at ~5 m/s

2. *Venting:
- Vent opens
- Ascent rate slows

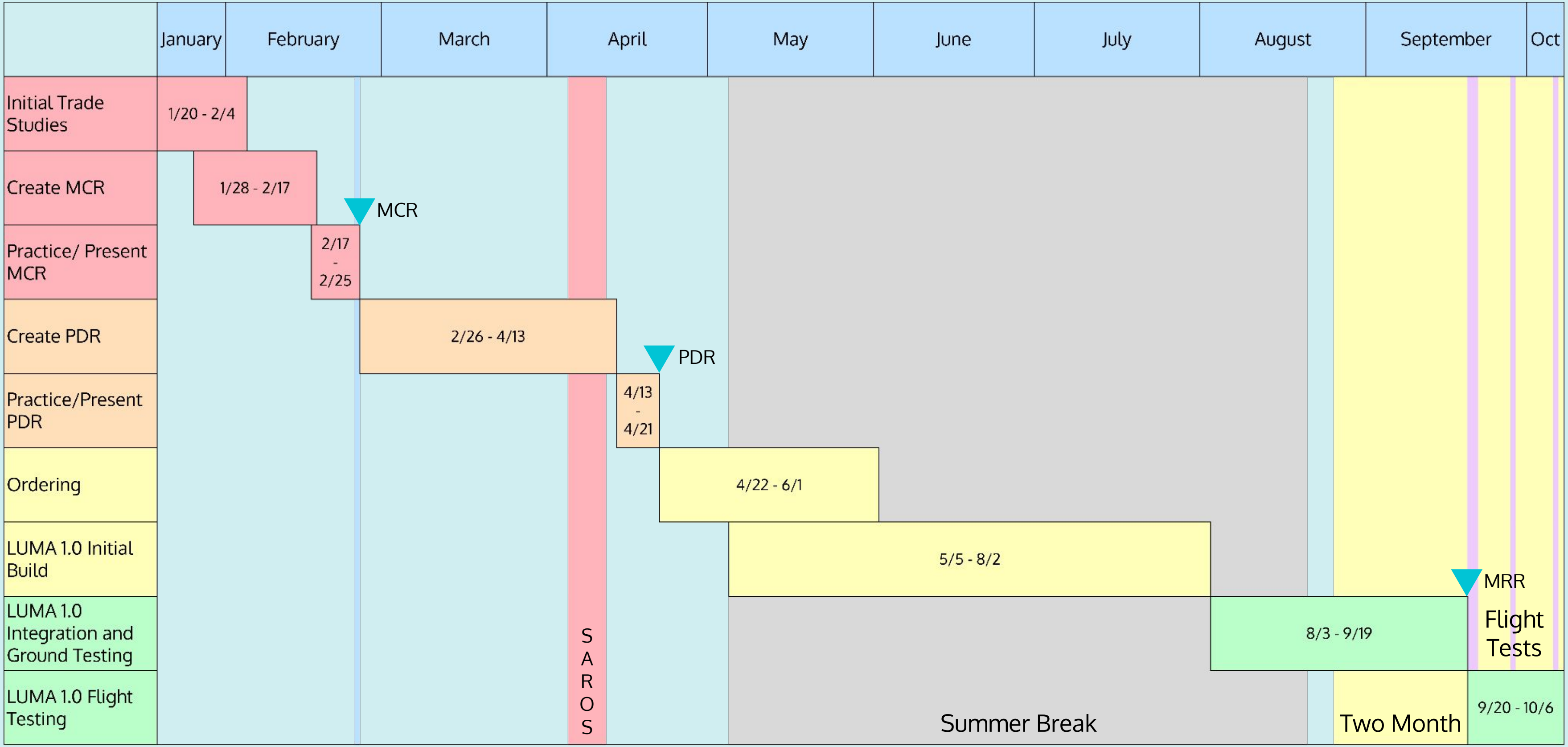
3. *Float:
- Ascent rate reaches ~zero
- Vent closes

4. *Cutdown:
- Cutdown activates
- Balloon continues to burst altitude

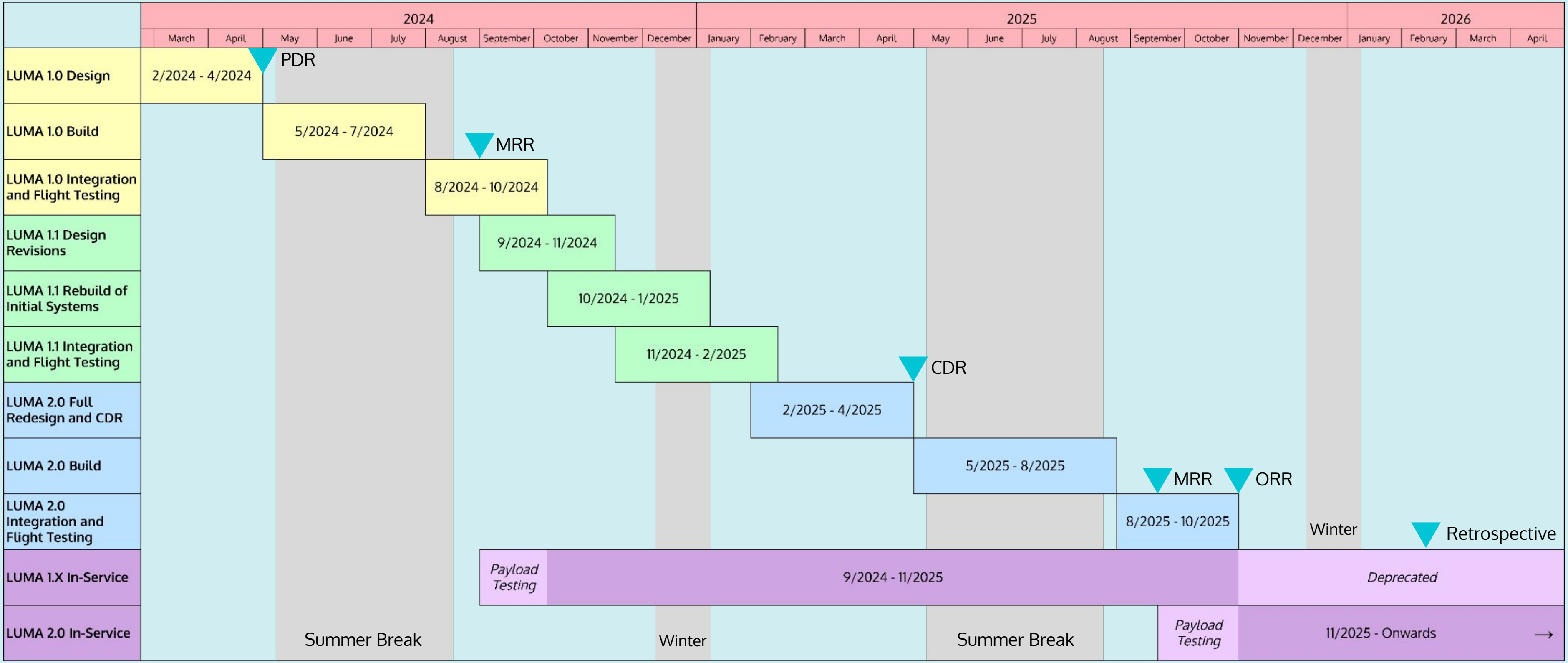
5. Descent / Recovery:
- Parachute opens
- System is recovered after landing
- Maximum time: 6 hours

0. Ground Station
- Maintains connection and commands payload for full flight

LUMA 1.0 Timeline

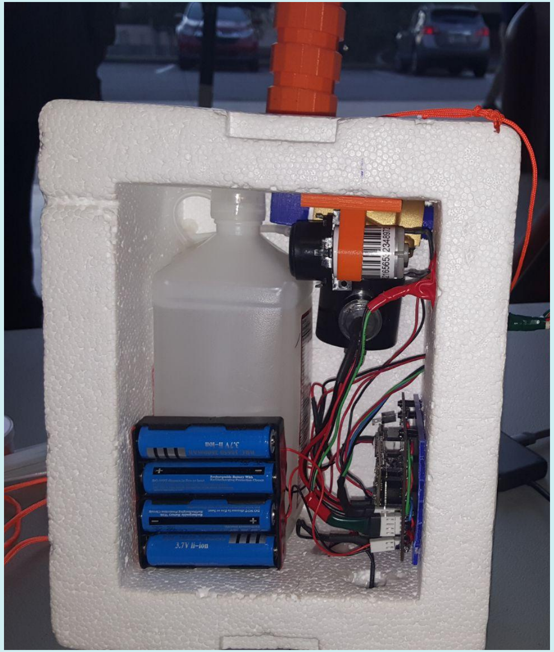


LUMA Extended Timeline



BalloonSat Control Legacy

Smart Balloon (Two Month 2021)



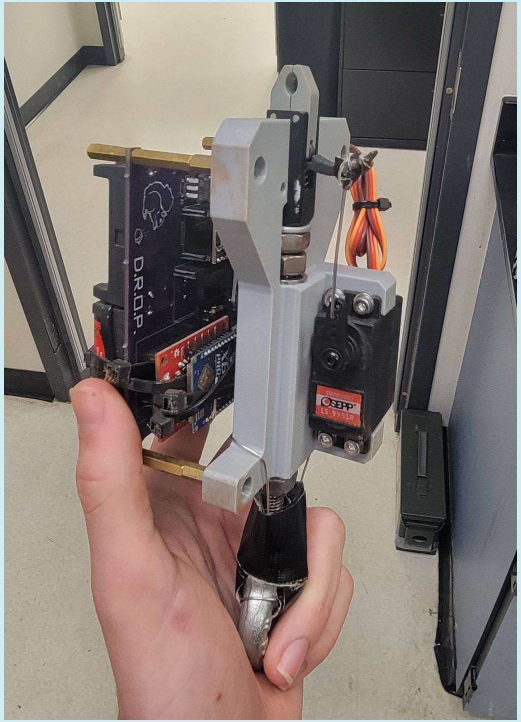
Smart Balloon - Red Pill Payload

Image Courtesy of Jackson Lee

- First SHC payload with vent capability
- Payload designed to control altitude via expelling helium or ballast
  - Similar mission profile to ours, but operated only in the troposphere (0-10 kilometers altitude)
  - At lower altitudes, payloads can use a pump for venting of helium, but operating conditions in the stratosphere (10-50 kilometers) make this infeasible, as demonstrated by the ASH Project
- Can be drawn on for design inspiration in some circumstances, but little direct design reuse is possible due to the differences in scope
  - For LUMA 1.1 and beyond's ballast subsystem, pumping metered amounts of isopropyl alcohol may serve as a good starting point due to its low freezing point and quick vaporization in the upper atmosphere

D.R.O.P. - Designated Release of Payload

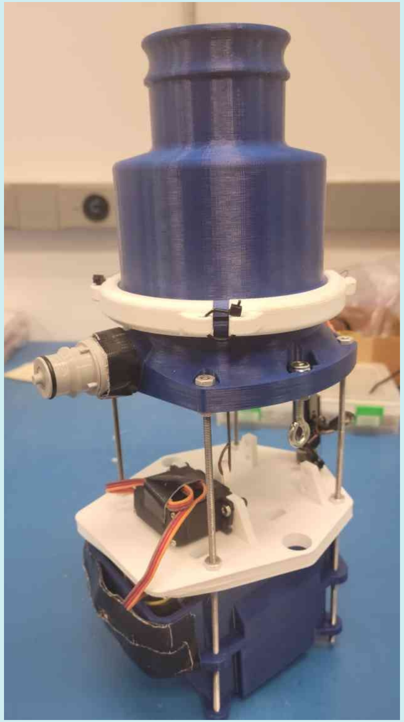
- Flight proven cutdown system
  - Flown multiple times successfully: SAROS DEMO-2 and DEMO-3, Two Month 2023, and more
  - Designed by highly experienced SHC members
- Mechanically robust
  - All load on the payload is transferred through an archery release and a threaded rod, both of which are more than capable of holding any weight SHC could design
- Communications unreliable
  - Ground communications via XBees are unreliable at long range, which can make manual cutdown unavailable
  - Chase team is required for manual recovery operations due to the short command range



D.R.O.P.

GHOUL - Generalized Helium Outflow Unit for Latex balloons

GHOUL with balloon attached



Close-up

- UAH GHOUL is a flight-proven venting payload inspired UMD GHOUL
    - Developed as part of the National Eclipse Ballooning Project (NEBP)
- Current implementation leaves much to be desired
    - Release mechanism is multi-stage and its setup and tensioning procedure is complex in comparison to D.R.O.P.
        - Prone to minor failures or leaks due to imperfect setup and tensioning.
    - Open-air servos and electronics may be significantly affected by cold
- Serves as a useful starting point for our balloon interface design
    - PLA balloon neck insert is biodegradable and lost on release, which will be carried over to our design

Requirements

LUMA System Requirements

Requirement		Reasoning
L.1	**The LUMA System shall be capable of venting helium from the balloon to stabilize at a specified altitude.**	Requirement generated from initial mission concept.
L.2	**The LUMA System shall be capable of cutting down from the balloon automatically or upon command.**	Requirement generated from initial mission concept.
L.3	**The LUMA System shall be capable of receiving commands and reporting telemetry over a long-range radio link.**	Requirement generated from initial mission concept. Additionally, the prior requirements are inherently more useful with live control.
L.4	**The LUMA System should be user-friendly, robust, and extensible.**	In order to effectively utilize the LUMA System in other missions, it must act as a “finished product.”
L.5	**The LUMA System should have a mass and cost that is not prohibitive for use with large additional payloads.**	In order to effectively utilize the LUMA System in other missions, it must not be cost-prohibitive or use a significant portion of the legal maximum mass.

Vent Requirements

Requirement		Reasoning
L.1.1	**Helium reservoirs shall be properly sealed in all locations.**	Helium leaks will cause minor issues at best, and complete mission failure in most cases.
L.1.2	**All seals shall be stationary.**	We are not capable of the tolerances required for sliding seals within the budget.
L.1.3	**Helium shall not be allowed to leak into electronics, even when venting.**	Helium prevents MEMS oscillators from functioning, which disables most microcontrollers.
L.1.4	**Helium reservoirs shall contain no electronics.**	Helium prevents MEMS oscillators from functioning, which disables most microcontrollers.
L.1.5	**Helium flow should not be overly restricted by the vent mechanism when open.**	A large venting area is necessary to ensure that useful flow rates are achieved across low pressure differentials. The size of the balloon neck determines the minimum cross sectional area.
L.1.6	**The LUMA System shall allow balloon fill through an onboard helium port.**	Helium fill will likely be infeasible prior to the attachment of the balloon to the LUMA System.

Cutdown Requirements

Requirement		Reasoning
L.2.1	**The Cutdown Subsystem shall not use hotwires or pyrotechnics.**	The UAH Space Hardware Club's BalloonSat Program has a historical precedent that prohibits the use of pyrotechnics on balloon flights for safety purposes.
L.2.2	**The Cutdown Subsystem should have as few points of failure as possible.**	Additional complexity in such a vital system may add numerous unnecessary failure modes.
L.2.3	**The Cutdown Subsystem's balloon interface should be of negligible cost and easy to mass-produce.**	As this is ideally the only unrecovered part, it is paramount that its cost is low and rebuilding it is a smooth process.
L.2.4	**LUMA shall be capable of commanded, altitude-based, timed, or geofenced cutdown.**	These modes of cutdown should be available as basic operations, such that more complex mission plans may make use of them.
L.2.5	**The Cutdown Subsystem shall be robust and shall remain solidly connected during the rigors of normal flight or minor extremes, except when cutdown is explicitly attempted.**	A cutdown system that activates prematurely or allows an uncommanded cutdown to occur has the potential to cause mission failure.

Radio Requirements

Requirement		Reasoning
L.3.1	**The Long Range Communications (LRC) Subsystem should have a minimum operating range of 300 km.**	A range of 300+ km will ensure constant communication with the ground station, and will ensure the payload receives commands should something go wrong.
L.3.2	**The LRC Subsystem shall be capable of interfacing with other systems onboard, especially the command and control systems.**	These systems need to be able to interface with the long range comms to be able to receive commands and send data in realtime.
L.3.3	**The LRC Subsystem shall not be exposed to the external environment with the exception of the antenna and its connectors.**	The system must not be exposed to outside elements, including, but not limited to wind and water to ensure complete functionality and to mitigate damage.
L.3.4	**The LRC Subsystem should have an antenna that is capable of attaching to a balloon line.**	Having an antenna that can attach to the balloon line allows for a longer antenna that does not have to be supported by the LUMA structure.
L.3.5	**The LRC Subsystem shall adhere to the FCC's guidelines for amature radio transmissions as well as class limits and the ARRL Band Chart.**	Following these guidelines ensures for a safe and legal operation of LUMA's LRC system.

Usability Requirements

Requirement		Reasoning
L.4.1	**Standard Operating Procedures for flight use should be simple and repeatable.**	If the LUMA System is to see extensive use, its procedures should have minimal overhead and high reliability.
L.4.2	**System configurations and mission profiles shall be editable in-flight and capable of being saved to and loaded from computer files.**	To allow a wide range of missions with little overhead, the LUMA System's software and ground station should be designed both for precision and ease of use.
L.4.3	**The LUMA System should be robust and error-tolerant.**	If the LUMA System is to see extensive use, it should be designed in a way that ensures mission success.
L.4.4	**The LUMA System shall be able to survive normal balloon flights with minor extremes.**	If the LUMA System is to see extensive use, it should be designed in a way that ensures its reusability.
L.4.5	**The LUMA System shall have an operational runtime of greater than six hours.**	The LUMA System must be capable of facilitating longer-than-typical balloon flights to accommodate extended periods of floating.

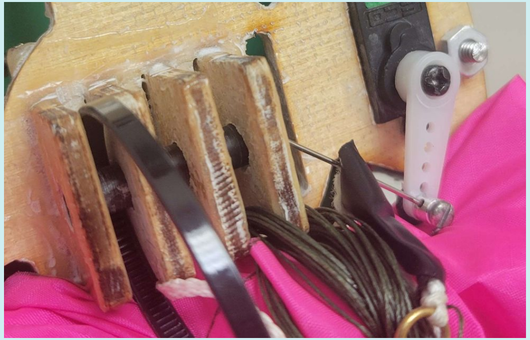
Budget Requirements

Requirement		Reasoning
L.5.1	**The LUMA System shall have a mass budget of 1360 grams (3 pounds).**	A reasonable maximum LUMA System mass is 1/4 of the maximum total mass (12lbs).
L.5.2	**The LUMA System shall have a monetary budget of less than $1000 per final flight unit.**	The cost of the LUMA System should be negligible in comparison to the cost of flight. Ideally, over 10 flights, the amortized cost-per-flight should be less than $110.
L.5.3	**The LUMA System shall have a monetary budget of less than $10 per flight.**	The cost of the LUMA System should be negligible in comparison to the cost of flight. Ideally, over 10 flights, the amortized cost-per-flight should be less than $110.

Mechanical Overview

Cutdown Trade (1/3)

Initial Release Concepts:	Benefits	Drawbacks
Pin Release	• Preferred method of release by SHC CanSat teams • Highly reliable and well-tested within SHC • Easy to implement with servos or motors	• High friction under load, which may cause failure • Linear pins require horizontal space, which may be limited • Difficult to tension without breaking parts, making seals difficult
Archery Release	• Current method of release for D.R.O.P. and UAH GHOUL • Designed to release cleanly under high tension • Small, vertical form-factor; can be tensioned directly	• Trigger-pulling actuators may be clunky or hard to implement

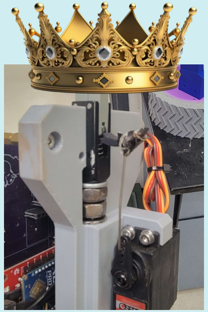


Cutdown Trade (2/3)

Initial Release Concepts:	Benefits	Drawbacks
Single Stage Release	• Has significantly fewer possible points of failure • Simpler actuator design	• Difficult to design within helium requirements • More difficult to tension
Multi-Stage Release	• Easier to design around helium requirements due to more freedom of design • Additional stages can lessen need to tension the release mechanism	• More complex series of actions • More points of failure

Cutdown Trade (3/3)

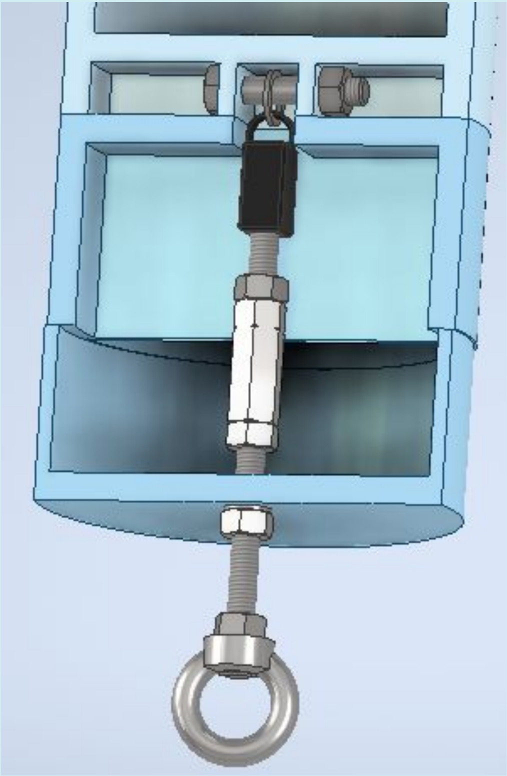
Criteria	Weight	Pin Release		Archery Release		Single-Stage		Multi-Stage	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Failure Points	8	4	**32**	8	**64**	4	**32**	2	**16**
Ease of Tensioning	4	2	**8**	8	**32**	4	**16**	2	**8**
Flight Tested	4	4	**16**	8	**32**	8	**32**	4	**16**
Design Freedom	2	2	**4**	1	**2**	2	**4**	8	**16**
Weighted Sum		61		138		88		60	



Cutdown Trade Selection

Archery Release, Single Stage

- Single stage separation removes points of failure, ensuring a more reliable and user friendly design
    - While possibilities for single stage separation designs are more constrained, clever designs of the vent system can allow for it to fit within the payload
- Archery Release has been proven to work in both D.R.O.P. and UAH GHOUL
    - Archery Releases are designed to hold onto forces of 100+lbs* and let go very easily, so they work well in these applications
- Equivalent to D.R.O.P., and thus will be referred to as such for the remainder of the presentation

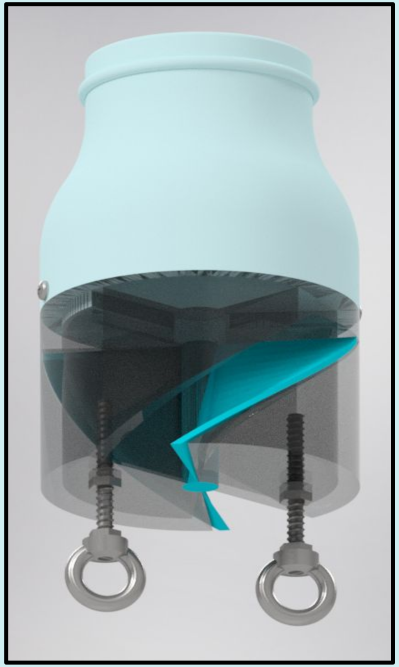


*According to the clerk we spoke to at an archery shop

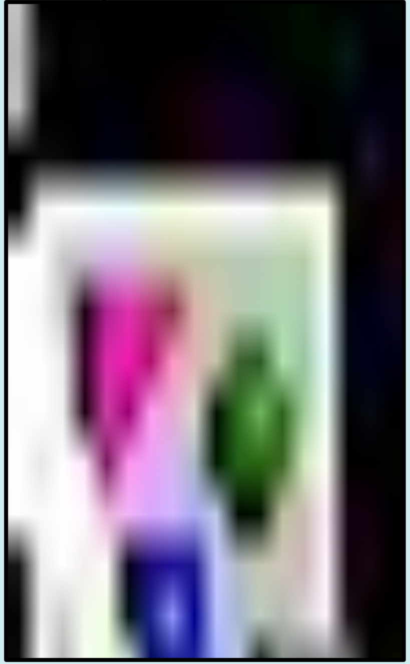
Vent Trade (1/4)

Initial Vent Concept	Helical
Benefits	• Mechanics are internal and are not exposed to the outside environment ○ Unlikely to break from outside forces • Single-degree-of-freedom rotation lends itself nicely to servo actuation
Drawbacks	• No room for central D.R.O.P. ○ Requires two separate single-stage releases on opposite sides, negating the benefits of single stage release • Difficult to manufacture

Open



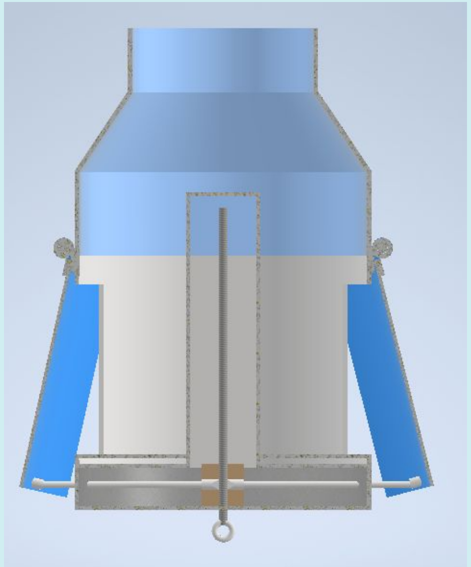
Open/Closed



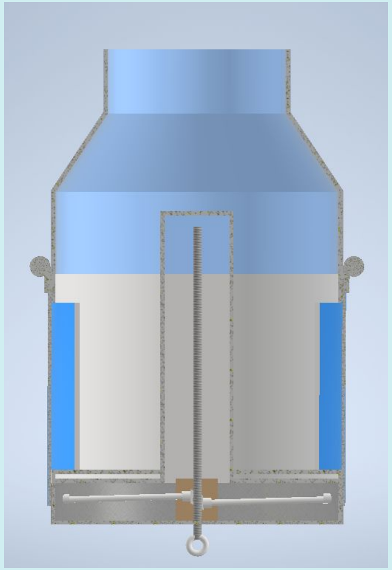
Vent Trade (2/4)

Initial Vent Concept	Flaps
Benefits	- Ample room for central D.R.O.P. - Large internal cavity means helium can be routed easily without impeding D.R.O.P. - Simple to implement - Single-actuation opening - Lever motion means small motion on servo results in large change in opening
Drawbacks	- Fins external to payload - Easily damaged on hard landings - Could get caught on trees - Actuation mechanisms are necessarily exposed to the outside of the payload

Open

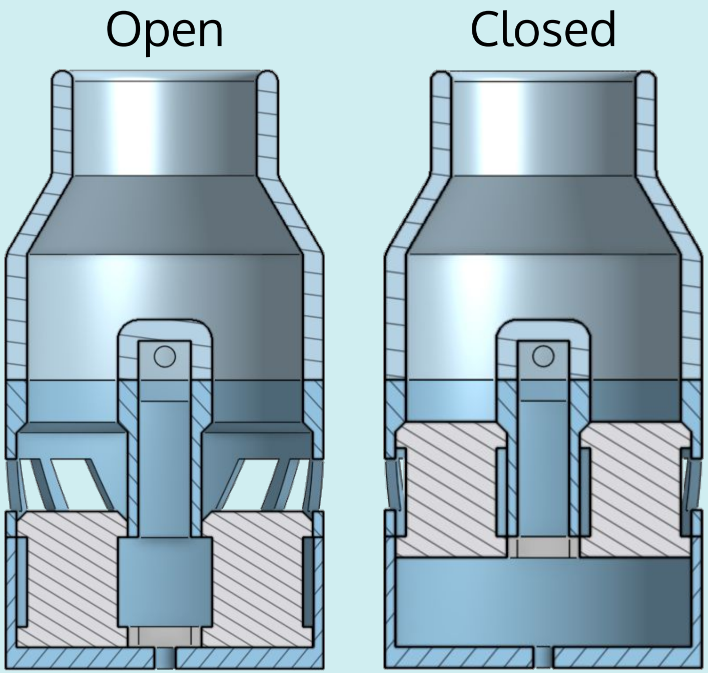


Closed



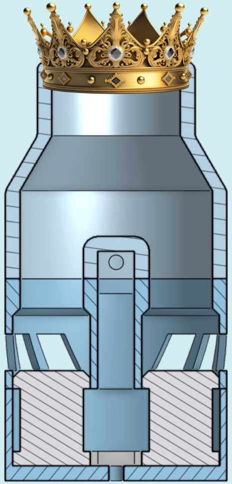
Vent Trade (3/4)

Initial Vent Concept	Plunger
Benefits	● Ample room for central D.R.O.P. ● Simple to implement ○ Linear motion with one degree of freedom, single seal at the top ● Mechanically robust ○ All moving parts internal to enclosure ○ High strength linear actuator can ensure tight seal
Drawbacks	● Feedback response more difficult with linear actuator ● Off-center linear actuation due to central D.R.O.P. may misalign seals



Vent Trade (4/4)

Criteria	Weight	Helical		Flaps		Plunger	
		Raw	Weighted	Raw	Weighted	Raw	Weighted
D.R.O.P. Compatible	8	4	**32**	8	**64**	8	**64**
Mechanisms are Internal	4	4	**16**	2	**8**	8	**32**
Sealable	8	4	**32**	4	**32**	8	**64**
Manufacturable	4	1	**4**	8	**32**	4	**16**
Controllable	2	8	**16**	8	**16**	4	**8**
Weighted Sum		100		152		**184**	



Vent Trade Selection

Plunger

- Room for Central D.R.O.P.
  - Plunger can be shaped to allow room for central D.R.O.P., significantly decreasing design complexity and increasing reliability by removing potential points of failure
- Moving parts internal to payload
  - Keeping the moving parts of the design entirely within the design entirely within the payload housing prevents damage from external factors
- Actuation more complex than other designs
  - Off axis linear actuator may cause challenges in the mechanical and electrical design

Balloon Neck Insert
Balloon neck attaches around top opening to allow helium to flow to the vent

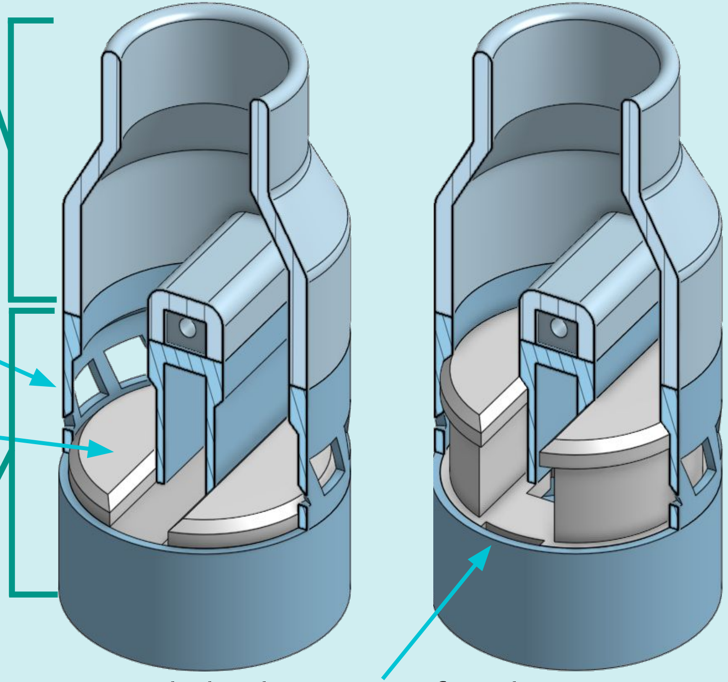
Helium Vent Holes

Vent Plunger
Stops helium flow when closed

LUMA Payload Body

Open

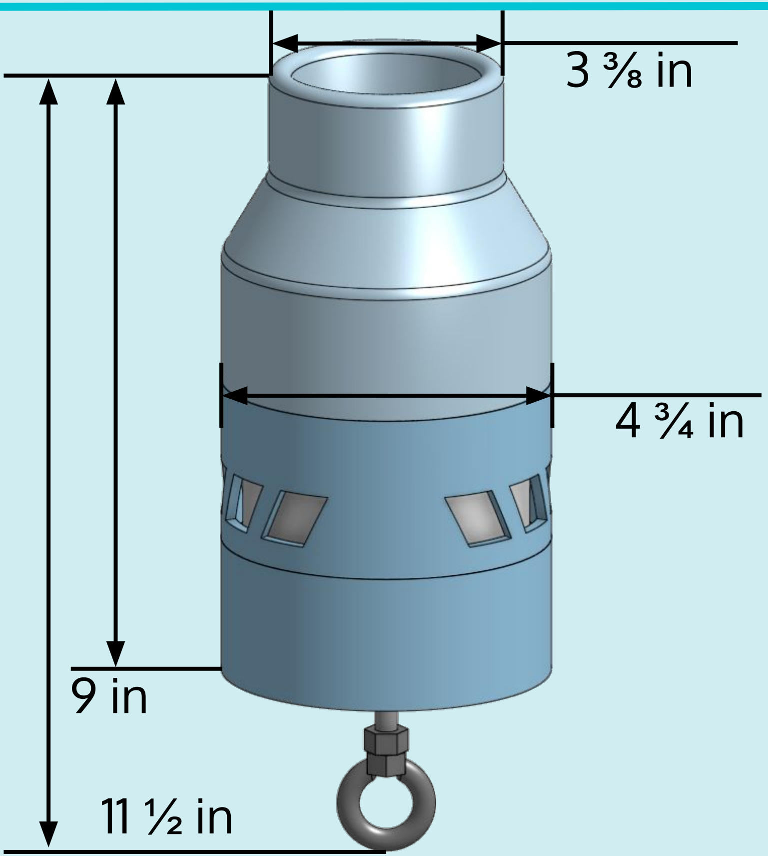
Closed



Central slot has space for electronics, linear actuator, and DROP

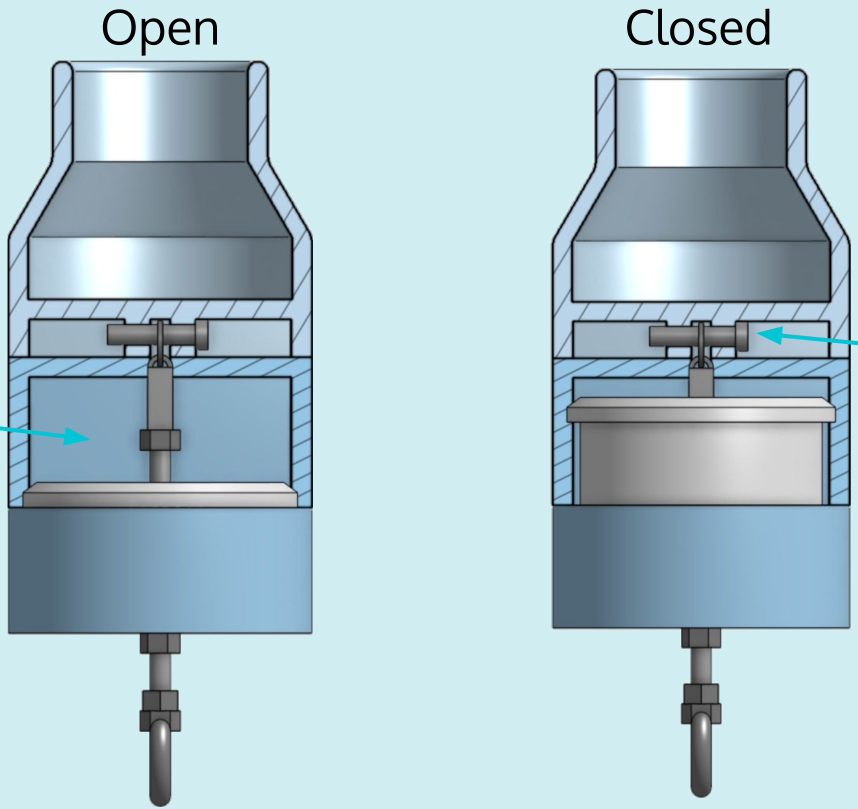
Payload Dimensions

All dimensions shown are approximations based on initial design. Further research and development are likely to change them



Banana for Scale

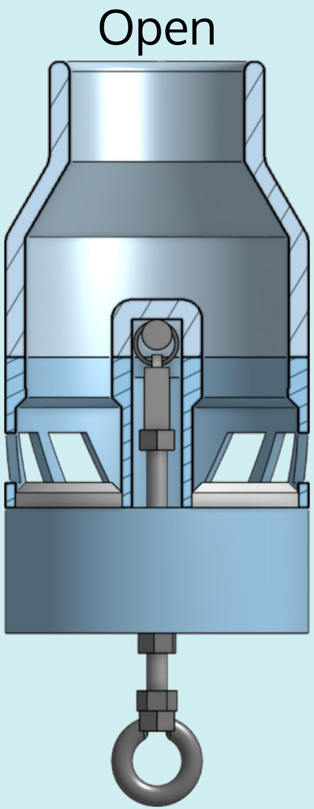
Initial Payload Design (Front View)



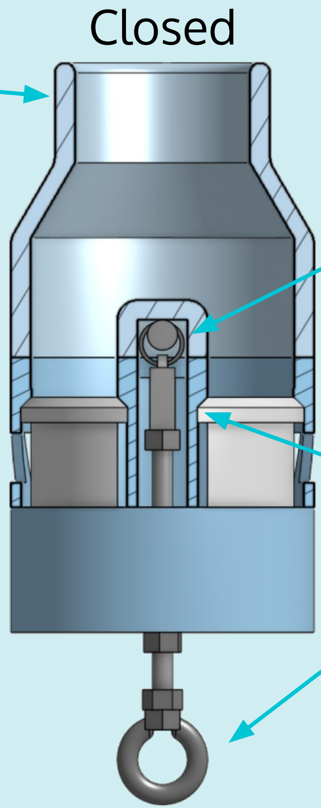
Cavity between the two vent halves contains space for actuation mechanisms, entirely separate from helium flow

Bolt and ring transfer all load from the archery release directly to the balloon interface, leaving the bottom shell free of load

Initial Payload Design (Side View)



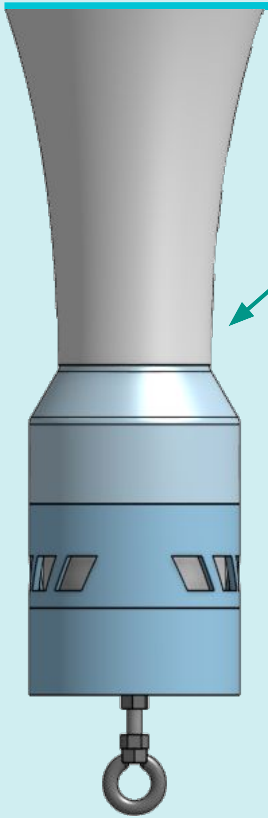
Load through the balloon interface is transferred to the balloon neck



Bolt and ring transfer all load from the archery release directly to the balloon interface, leaving the bottom shell free of load

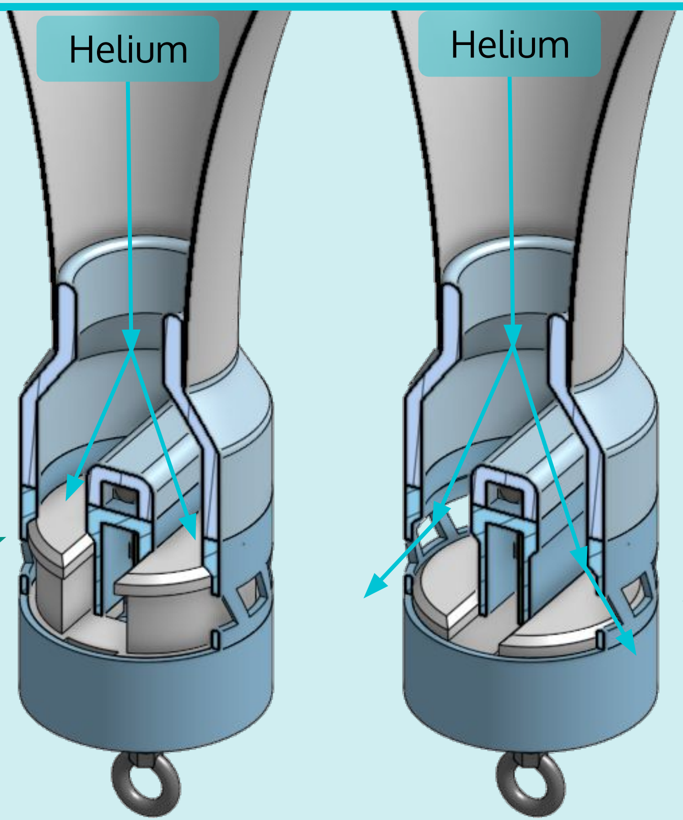
All load from the eye nut is transferred through its threaded rod to the archery release and the balloon interface

Initial Payload Design (Balloon Attached)



Balloon neck attaches to the top of the payload. (Balloon extends upward out of view)

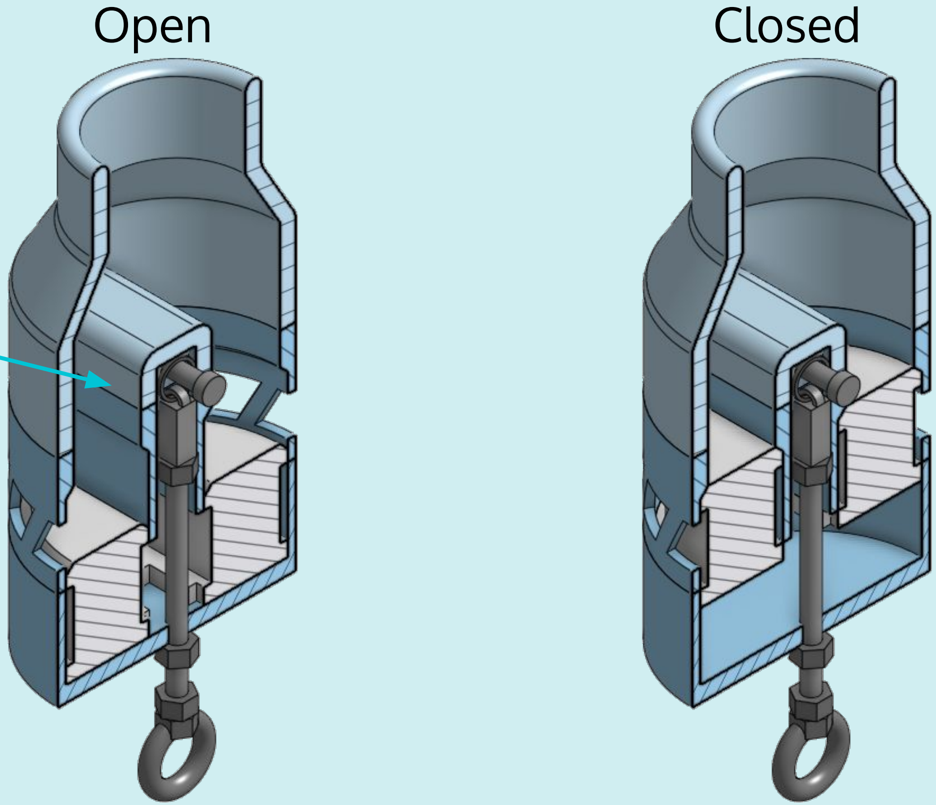
When the plunger is sealed, helium is prevented from exiting the balloon



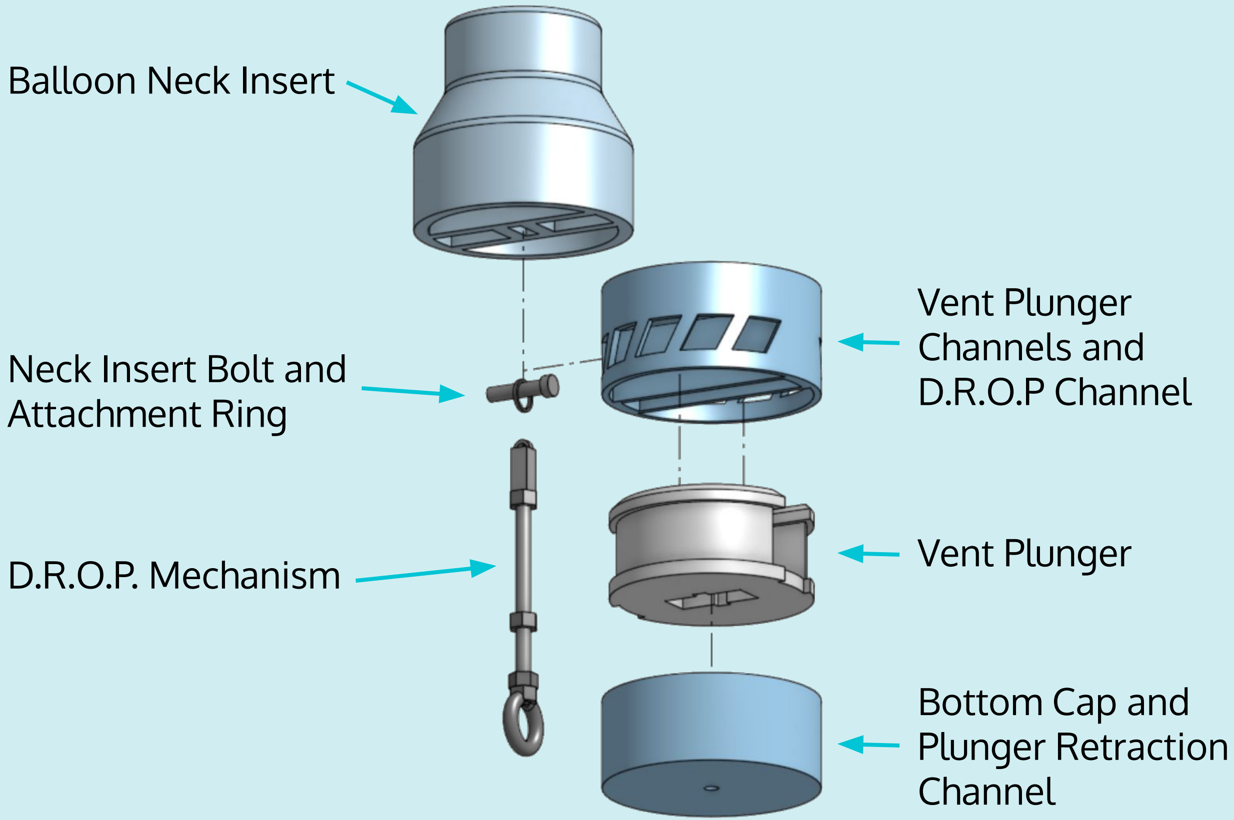
When the plunger is unsealed, helium is free to escape through the vents

Initial Payload Design (Isometric View)

The interface between the parts will contain indentation that prevents the parts from meshing incorrectly or sliding laterally, as well as a sealant to prevent helium from leaking

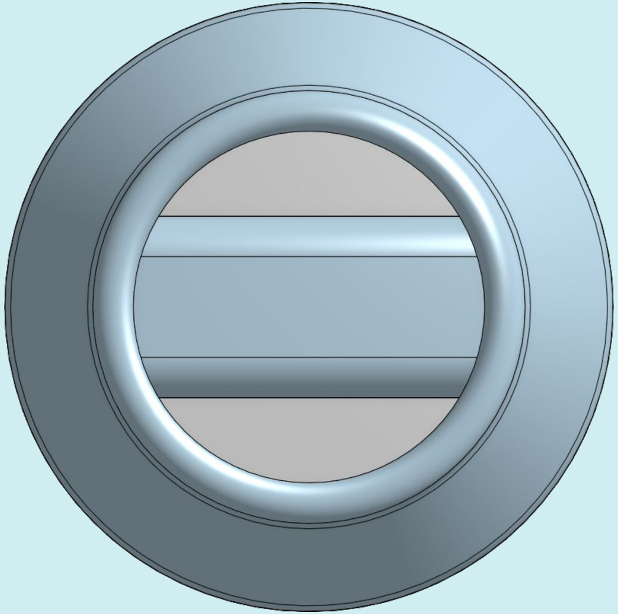


Initial Payload Design (Disassembled View)

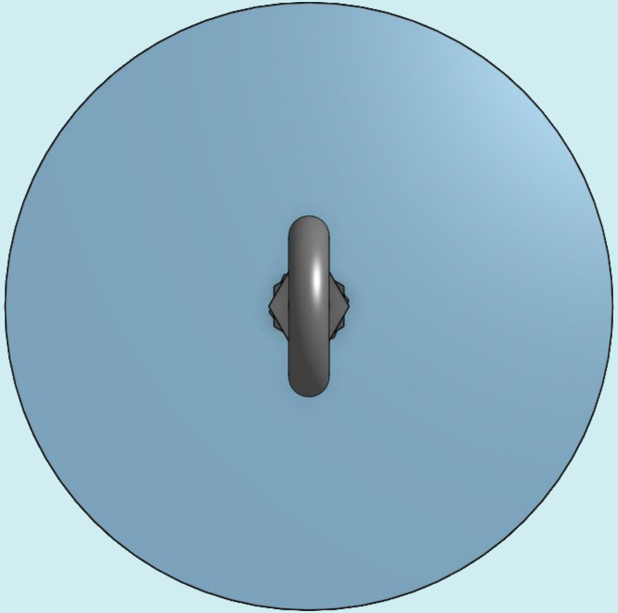


Initial Payload Design (Vertical View)

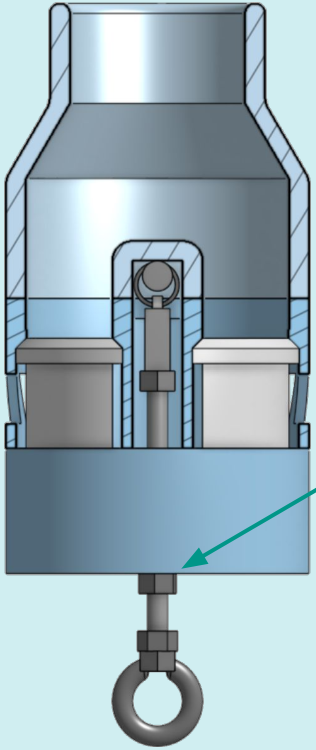
Top



Bottom



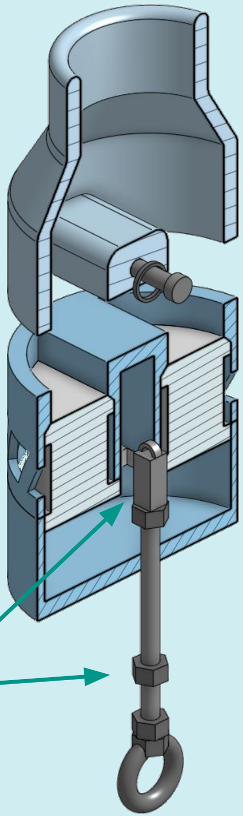
Initial Payload Design (Separation)

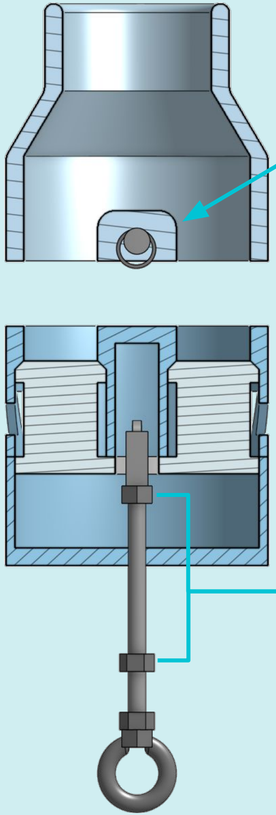


Tension holds seal closed for full duration of flight. Gasket material is used at the interface between the parts

Nut/washer at bottom of payload tensions full system before flight

When the archery release is triggered, tension on the D.R.O.P. mechanism is released and the payload separates





Two small metal pieces and a PLA neck-insert are unrecoverable

The remainder of the payload is freed from the balloon, but constrained between the release and the tensioning nut

Estimated Mass Budget (1/4)

Mechanical

Item	Quantity	Single Mass	Total Mass
PLA Balloon Neck Insert	1	~100 g	100 g
PETG Housing	1	~150 g	150 g
Foam/O-ring	1	~10 g	10 g
Screws/Fasteners	1	~75 g	75 g
PETG Plunger	1	~100 g	100 g
Valve	1	~50 g	50 g

Estimated Mass Budget (2/4)

Electrical

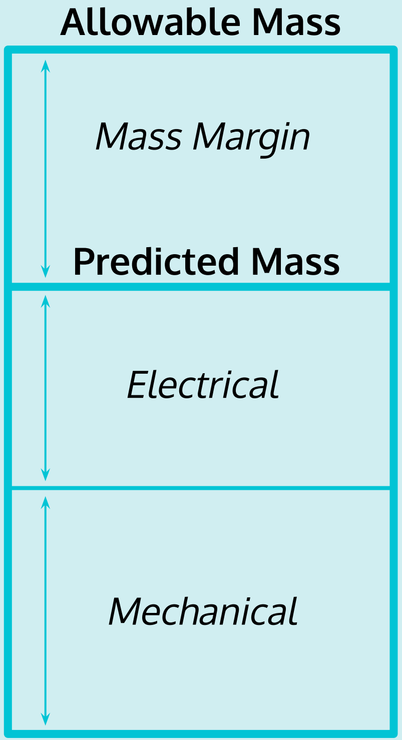
Item	Quantity	Single Mass	Total Mass
Teensy 4.1	1	~ 14 g	14 g
18650 Lithium Ion	4	~45 g	180 g
GPS	1	~2 g	2 g
Radio	1	~80 g	80 g
Additional Electronics	1	~50 g	50 g
Servo	2	~30 g	60 g
900 MHz Antenna	1	~17 g	17 g

Estimated Mass Budget (3/4)

Subsystem	Total Mass	Mass Breakdown
Mechanical	485 g	54.61%
Electrical	403 g	45.38%
Total Combined Mass	888 g (1.96 lb)	100%

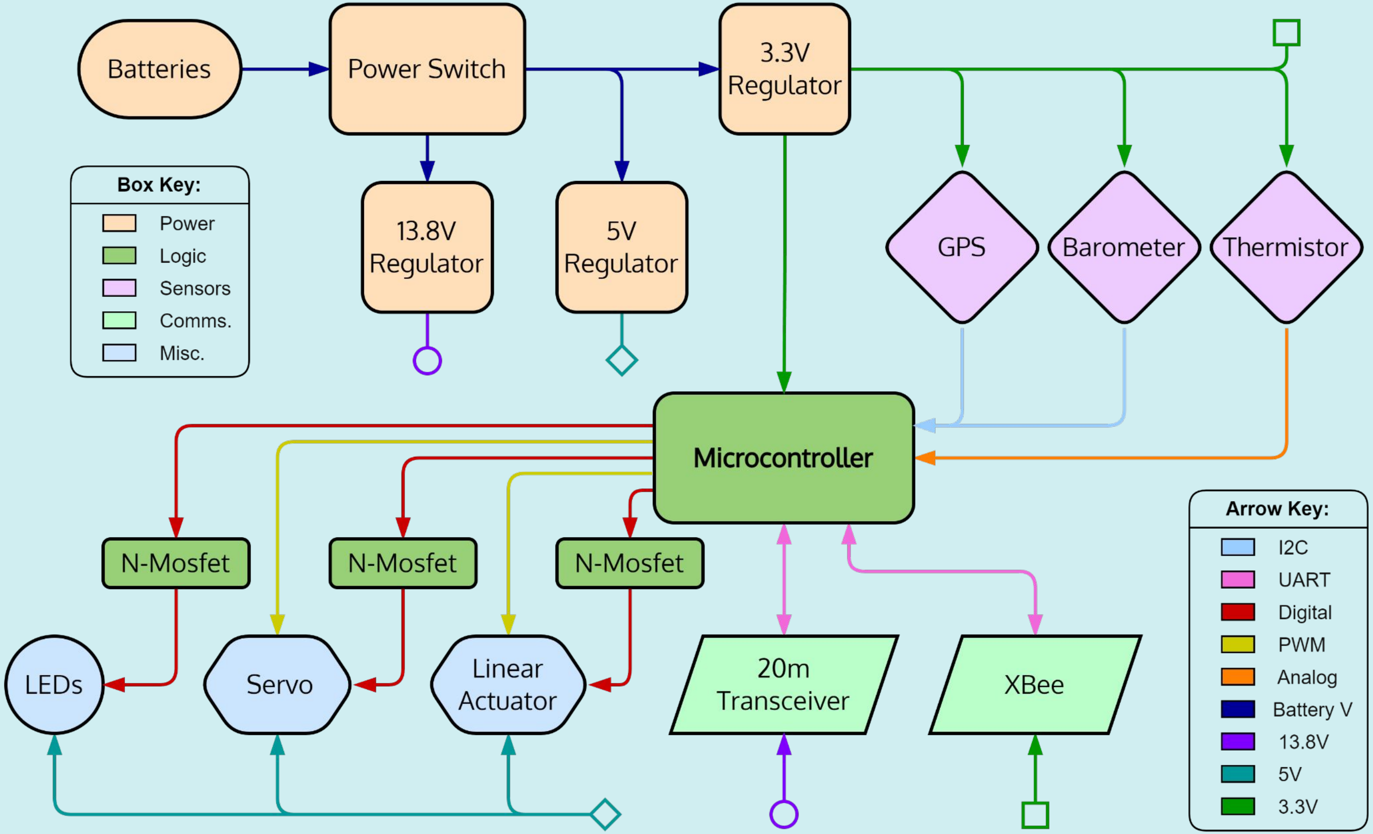
Estimated Mass Budget (4/4)

Subsystem	Mass	Allowed Mass	Mass Growth Allowance
Mechanical	485 g	885 g	45.2%
Electrical	403 g	475 g	15.12%
Total	**888 g (1.96 lb)**	**1360 g (3 lb)**	**34.71%**



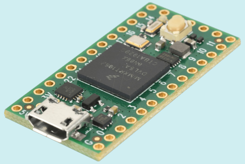
Electrical Overview

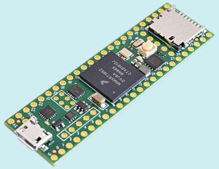
Block Diagram

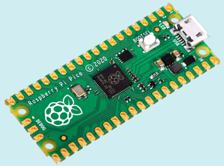


MCU Trade (1/2)

Name	Teensy 4.0	Teensy 4.1	Feather HUZZAH 32	Pi Pico
Cost ($)	23.80	31.50	19.95	4.0
Pins	21	55	21	26
Clock Speed (MHz)	600	600	240	133
Flash (MB)	2	8	4	2

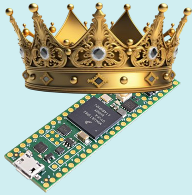






MCU Trade (2/2)

Criteria	Weight	Teensy 4.0		Teensy 4.1		Feather HUZZAH 32		Pi Pico	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Cost	4	1	**4**	1	**4**	2	**8**	8	**32**
Pins	4	2	**8**	4	**16**	2	**8**	2	**8**
Clock Speed	8	8	**64**	8	**64**	4	**32**	2	**16**
Flash	2	2	**4**	8	**16**	4	**8**	2	**4**
Weighted Sum		80		100		56		60	



Barometer Trade (1/2)

Name	MS560702 BA03-50	MS561101 BA03-50	MS580301 BA01-00	325540009-00
Sampling Time (ms)	2.1	2.1	2.1	35
Accuracy (±Pa)	250	250	250	200
Comm Lines	I2C, SPI	I2C, SPI	I2C, SPI	I2C, SPI
Cost ($)	8.69	9.33	20.53	30.31



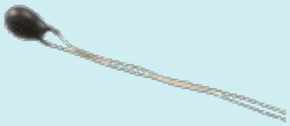
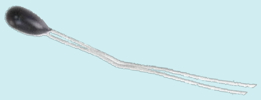

Barometer Trade (2/2)

Criteria	Weight	MS560702BA03-50		MS561101BA03-50		MS580301BA01-00		325540009-00	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Sampling Rate	4	4	**16**	4	**16**	4	16	2	**8**
Accuracy	8	4	**32**	4	**32**	4	32	8	**64**
Comm Lines	1	2	**2**	2	**2**	2	2	2	**2**
Cost	4	8	**32**	8	**32**	2	8	1	**4**
Weighted Sum		**82**		82		58		78	

Thermistor Trade (1/2)

Name	EC95F502WN	EC95F502VN	701003	PT103J2
Time Constant (s)	10	10	< 10	10
Accuracy (± °C)	0.2	0.1	0.2	0.2
Cost ($ / 10 units)	3.79	5.31	17.69	1.95
Flight-Proven by SHC	Unknown	Unknown	Unknown	SAROS has flown many



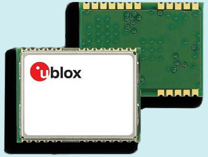



Thermistor Trade (2/2)

Criteria	Weight	EC95F502WN		EC95F502VN		701003		PT103J2	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Time Constant	2	4	**16**	4	**16**	8	**32**	4	**16**
Accuracy	4	4	**8**	8	**16**	4	**8**	4	**8**
Cost	4	8	**32**	4	**16**	1	**4**	8	**32**
Flight Proven	1	1	**1**	1	**1**	1	**1**	8	**8**
Weighted Sum		57		57		37		**64**	

GPS Trade (1/2)

Name	NEO-M9N	SAM-M8Q	SAM-M10Q	ZOE-M8Q
Protocol	UART, SPI, I2C, USB	UART, I2C	UART, I2C	UART, SPI, I2C, SQI
Polling Rate (Hz)	25	10 - 18	4 - 20	5 - 18
Circular Error Probability (m)	2	2.5	1.5	2.5 - 4
Cost ($)	27.00	31.50	31.50	29.00



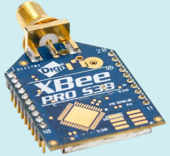
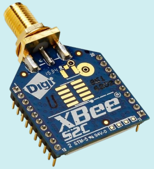
GPS Trade (2/2)

Criteria	Weight	NEO-M9N		SAM-M8Q		SAM-M10Q		ZOE-M8Q	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Protocol	2	4	**8**	2	**4**	2	**4**	4	**8**
Polling Rate	4	8	**32**	4	**16**	2	**8**	4	**16**
CEP	8	4	**32**	1	**8**	8	**64**	1	**8**
Cost	2	2	**4**	1	**2**	1	**2**	2	**4**
Weighted Sum		76		30		**78**		36	

Short-Range Radio Trade (1/2)

Name	Digi XBee 3 PRO 802.15.4 RF Module	Digi XBee 3 Zigbee 3 RF Module	XBee-PRO 900HP	Digi XBee S2C Zigbee
Serial Interface	UART, SPI, I2C	UART, SPI, I2C	UART, SPI	UART, SPI
RF Data Rate (Kbps)	250	250	10-200	250
Line of Sight Range (km)	3.2	1.2	15.5	1.2
Cost ($)	38.25	23.52	54.97	29.33



Short-Range Radio Trade (2/2)

Criteria	Weight	Digi XBee 3 PRO 802.15.4 RF Module		Digi XBee 3 Zigbee 3 RF Module		XBee-PRO 900HP		Digi XBee S2C Zigbee	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Serial Interface	2	4	**8**	4	**8**	2	**4**	2	**4**
Data Rate	4	4	**16**	4	**16**	2	**8**	4	**16**
Line of Sight Range	8	2	**16**	1	**8**	8	**64**	1	**8**
Cost	1	2	**2**	4	**4**	1	**1**	4	**4**
Weighted Sum		42		36		**77**		32	

Power Overview

- The highest voltage needed is 13.8 Volts for the Long-Range Communications
  - However, given the minor drops in voltage once batteries start to deplete, we aim for the battery source voltage to be a bit higher (ideally over 14.0 volts)
- The calculated power consumption (as will be shown in the power budget) is about 6.67 Watts
  - Since our required runtime for the system is 6 hours, this means that the batteries need a minimum capacity of 40 Wh (though a large margin from the minimum capacity is ideal)
- Given the high energy requirements yet tight mass requirements, our current plan for power is to have 4 high-capacity 18650 batteries in series
  - A specific model of 18650 is yet to be decided

Total Voltage	Capacity	Total Energy	Total Mass	Total Price
~14.4 Volts	~4000 mAh	~57.6 Wh	~200 g	~$88.00

Power Budget (1/2)

Component	Voltage (V)	Active Draw (mA)	Active Duration (h)	Idle Draw (mA)	Idle Duration (h)	Energy (Wh)
Microcontroller	3.3	100	6	~	0	1.980
Barometer	3.3	1.4	6	~	0	0.028
GPS	3.3	150	6	~	0	2.970
Thermistor	3.3	0.05	6	~	0	0.001
Long Range Radio	13.8	362	6	~	0	29.974
Short Range Radio	3.3	150	6	~	0	2.970
Cutdown Servo	5	250	~0	10	~6	0.300
Vent Linear Actuator	5	680	0.2	10	5.8	0.970
LEDs (4)	5	20	0.3	10	5.7	1.260
					Total:	**40.45 Wh**

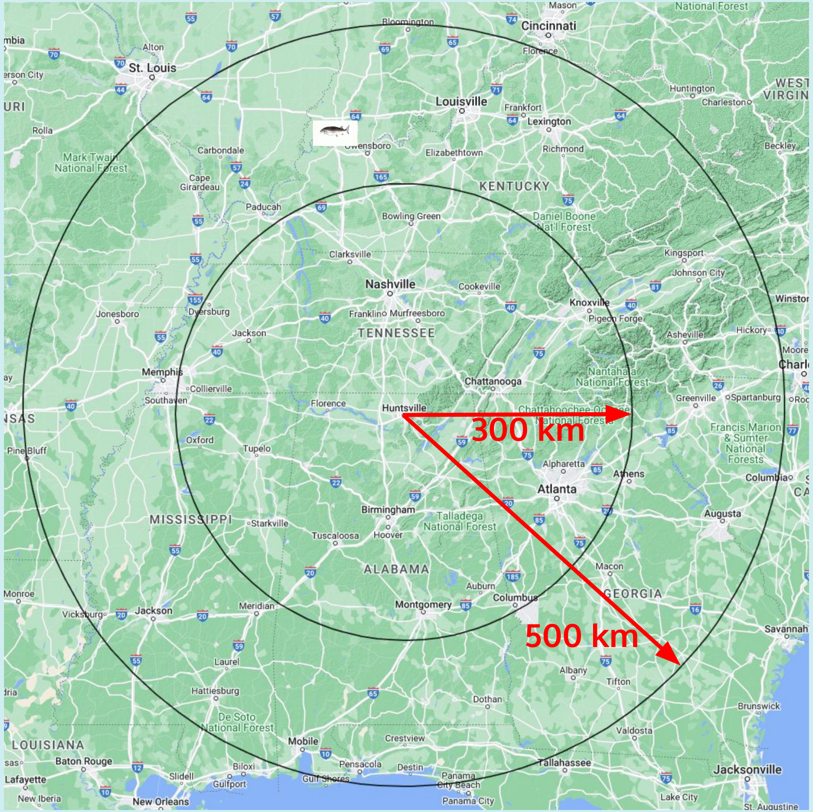
Power Budget (2/2)

Available Battery Capacity:	57.60 Wh
Total Energy Consumption:	40.45 Wh
Energy Margin:	17.15 Wh
Maximum Runtime:	8.54 h
Planned Runtime:	6.00 h
Runtime Margin:	142%

Radio Overview

Radio

- <u>20-meter wavelength</u>
  - Best distance while keeping the best data transfer rate
- <u>Antenna attached to balloon line</u>
  - 5m antenna length
  - 0.13 lbs
  - Round Copper
- <u>300-500 km range</u>
  - Large range ensures balloon never loses connection even if it does not travel very far
- <u>Small and light transceiver</u>
  - Capable of fitting inside the LUMA payload without compromising structural integrity
- Looking at <u>RTTY (Radioteletype) using a higher baud than normal</u>, as well as a few other alternative protocols
- <u>A General license will be required</u> for 20m radio
- HAM Radio Committee approves this project and is willing to help with licensing and comms



Long-Range Radio Trade (1/2)

Name	AFP-FSK Digital Transceiver III	MFJ-9320K, QRP CUB TRANSCEIVER KIT	Rockmite 20m Transceiver	QMX multi-band multi-mode transceiver	QCX-mini
Power (W)	5	2	0.5	4-5	3-5
Size (In)	3.5 x 3.5 x 1	5 x 3 x 3	2 x 2.5 x 1	3.75 x 2.5 x 1	3.75 x 2.5 x 1
Mode	FT8, FT4, JS8, WSPR, RTTY	CW	CW	WSJT-X, JS8CALL, RTTY, Olivia, WSPR, CW	CW
Cost	$100	$119.95	$50	$95	$55
Data Transfer	Medium	Low	Low	High	Low

Long-Range Radio Trade (2/2)

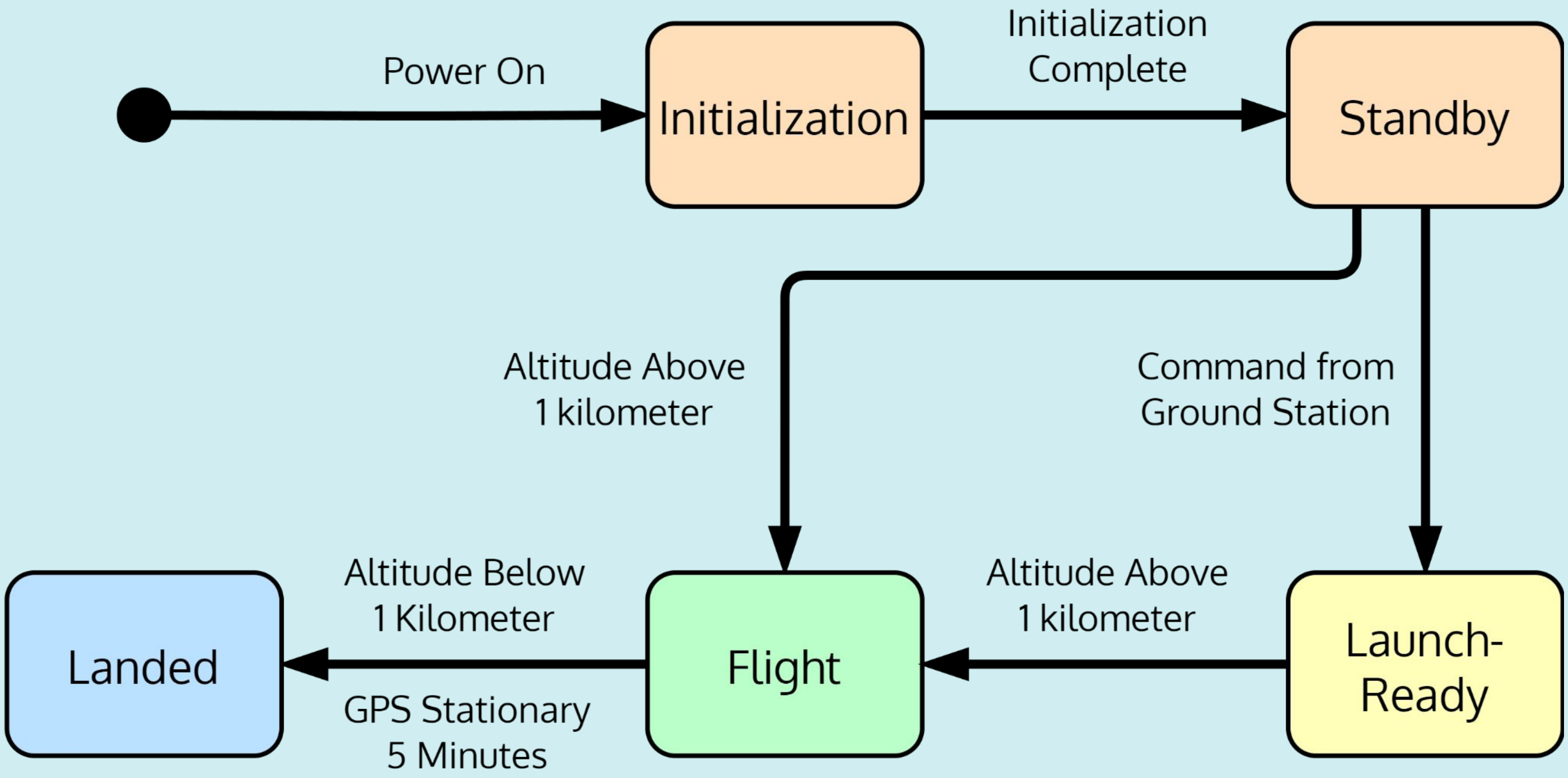
Criteria	Weight	AFP-FSK Digital Transceiver III		MFJ-9320K, Transceiver KIT		Rockmite 20m Transceiver		QMX Transceiver		QCX-mini	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Power (W)	4	8	32	2	8	1	4	8	32	8	32
Size	4	4	16	1	4	8	32	4	16	4	16
Mode	8	8	64	2	16	2	16	8	64	2	16
Cost	2	2	4	2	4	8	16	4	8	8	16
Data Transfer	2	4	8	1	2	1	2	8	16	1	2
Weighted Sum		124		34		70		136		82	

Ground Station Hardware

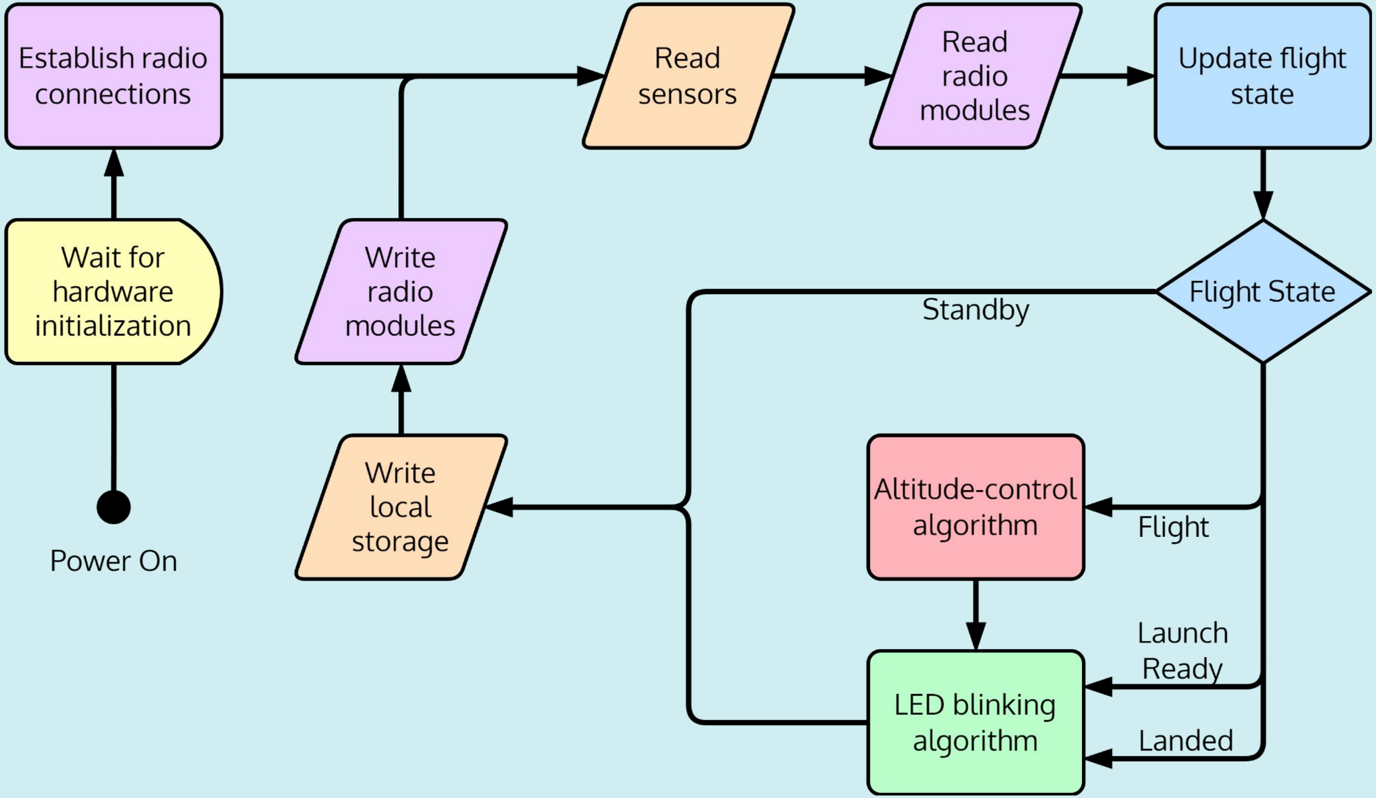
- Due to the range of the selected radio hardware, the ground station location can be nearly anywhere
- **SHC Space Communications Lab**
  - The Space Hardware Club has a lab dedicated to radio communications with roof access suitable for a 20-meter radio antenna
  - The lab also has the ability to host an internet server
  - <u>Thus, the primary ground station hardware will be in the Comms Lab, and will allow field access via the Internet</u>
    - A dedicated mission controller may reside in the lab during launch, if necessary or desired
- **Field hardware**
  - A laptop with a mobile internet hotspot, or a mobile phone, may be used as a field station

Software Overview

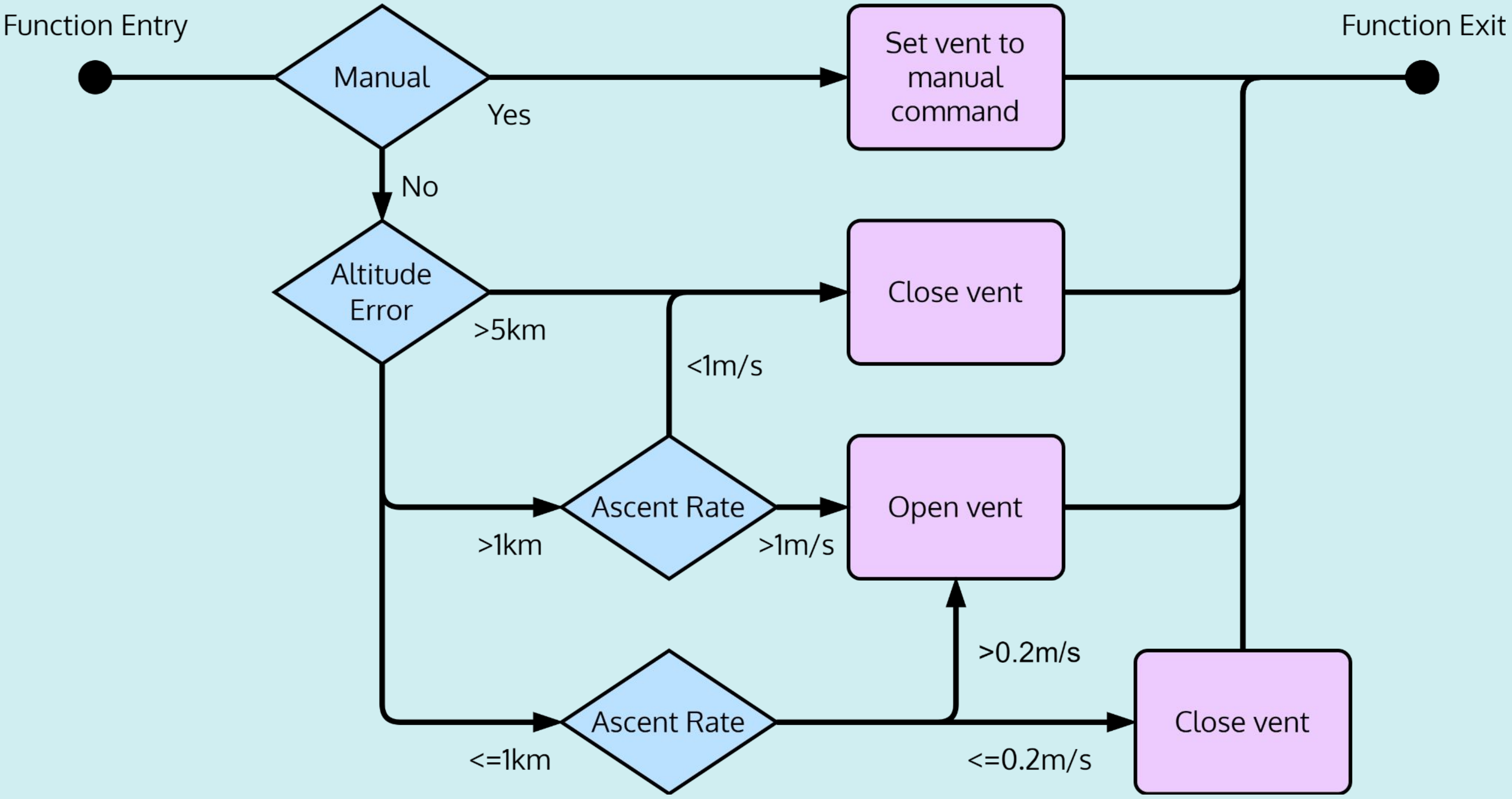
Flight State Diagram



Control Flow Diagram



Altitude-Control Algorithm



Minimum Feasible Data Packet

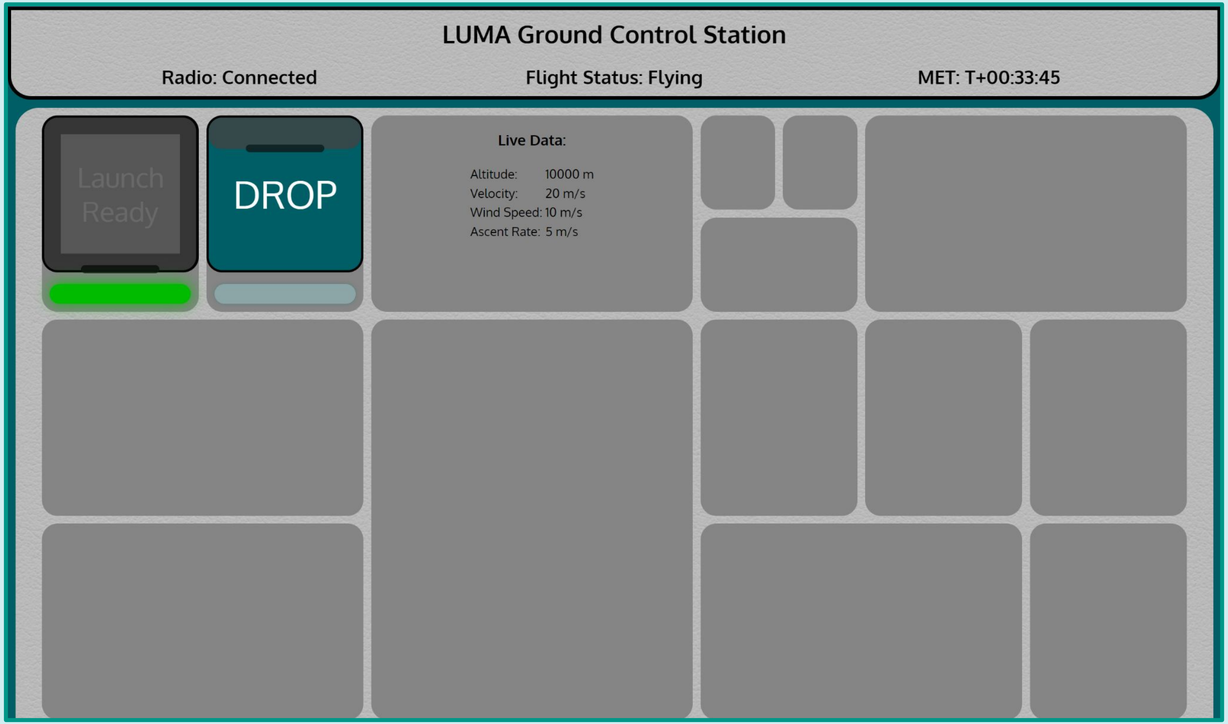
Item	Size	Format	Precision	Range
GPS Latitude (deg)	3 bytes	Signed fixed point	2.3 (m)	Full
GPS Longitude (deg)	3 bytes	Signed fixed point	2.3 (m)	Full
GPS Altitude (m)	2 bytes	Unsigned fixed-point	0.5 (m)	0 - 32,767.5 (m)
Barometric Altitude (m)	2 bytes	Unsigned fixed-point	0.5 (m)	0 - 32,767 (m)
Ascent Rate (m/s)	1 byte	Signed fixed-point	0.125 (m/s)	±15.875 (m/s)
Payload State	1 byte	Software (3 bit), Actuators (2 bit), Connections (3 bit)	Exact	Full
Battery Voltage	1 byte	Floating-point offset by -3.75 V	Variable, highest around offset	Full
Additional data and error correction	3 bytes	Forwarded from carried payloads / generated	N/A	N/A
Total	**16 bytes**			

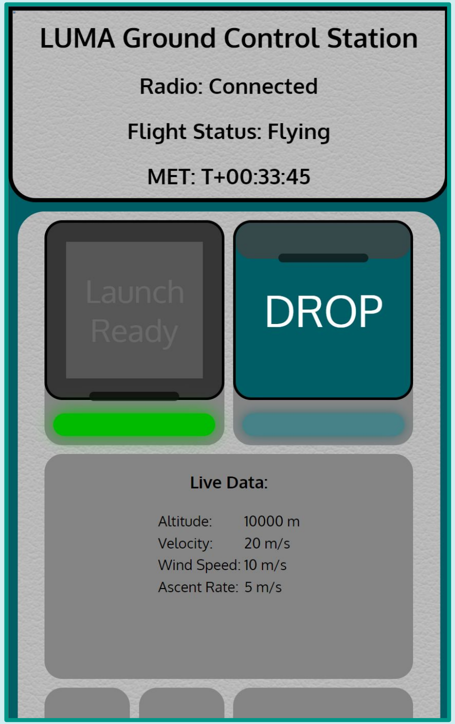
Notes:

- If either altitude goes out of range, set barometric altitude to high, and lower GPS altitude precision to 1 meter
- If ascent rate is out of range, set ascent rate to -16
- Error correction and XOR-masking with alternating bits will be used to ensure proper transmission

Ground Station Software Concept

- Ground station interface is browser-accessible and reflows to fit device





Testing and Validation

Mechanical Testing

Determine largest feasible balloon neck diameter

- Larger neck insert means more flow rate when venting, but neck inserts that are too large don't easily accommodate stretching the balloon neck over them
    - 3D print several different sizes of neck insert and test fit with the common sizes of balloons that the club uses to ensure that they all fit

Ensure helium is sealed correctly

- Helium is a notoriously leaky gas, so ensuring that all seals are tight is of the utmost priority. Choosing proper sealant for use in the Vent and D.R.O.P. mechanisms is important
    - Long duration leak test to ensure that no gas can escape from the payload when vent is closed

Electrical Testing

"Standard" Electrical Development Testing

- Verify that all components function expectedly
  - Make sure that the batteries have the advertised voltage and capacity
  - See if components function as we need them to with our planned power accommodations
- Systematically test each component's functionality as we make progress in development
  - Each time we make substantial changes, we will run commands through the microcontroller to see if we get the expected feedback
  - As we move further into the development, we will need to test commanding the system remotely as well

All testing will be thoroughly documented both for the sake of our development and for the sake of newcomers and onlookers to understand our progress

Radio Testing

Ensuring LRC functions for flight

- Test radio connectivity from payload to ground station on the ground
  - Make sure data transfers
  - Test internet ground station
  - Test cutdown
- Test systems communication to radio
  - Make sure all data can be routed through the radio
- Verify radio functions over distance
  - Drive to 5, 10, 20, and 30 km distances
  - On demo flights log distance covered and connection stability

Flight Testing

Demo-1 through PLDM-1 will be used to confirm flight readiness of all primary subsystems prior to controlled missions.

Further testing will validate optional features before they are used by controlled missions.

Flight Test	Date	Demonstrations
Demo-1	9/20/2024	Small flight test of vital systems, leak-free seals, and cutdown at low, predetermined altitude
Demo-2	9/21/2024	First full flight test of venting and cutdown at predetermined altitudes or times
Demo-3	9/28/2024	Vent and cutdown with in-flight modification of mission plan using LRC
PLDM-1	10/5/2024	Vent and cutdown with any payload*
Demo-4	TBD	Vent and cutdown with pre-targeted landing site
PLDM-2	TBD	Vent and cutdown with payload* which uses LRC

*Payload Demonstration (PLDM) test flights will carry payloads from informed and consenting teams.

Controlled Missions

- Following testing, the LUMA System will be considered validated and will begin its CoMET (Controlled Mission for Experimental Technologies) campaign
- CoMET-1 will likely occur shortly following the end of the testing campaign, and may occur during SHC's Two Month Flight Day
- Further Controlled Missions may carry other existing SHC BalloonSat Projects on mission profiles previously not possible:
    - HAVOC may fly a Controlled Mission to target a specific location with its directed camera system
    - HELEN may fly a Controlled Mission to help navigation or emergency recovery during thunderstorms
    - The LUMA System opens up mission concepts that previously would have been dismissed as impossible, and thus the breadth of other possibilities is difficult to predict

Budget and Funding Source

Budget: Mechanical (1/2)

Item	Unit Cost	Quantity	Total Cost
Archery Release	~$20	1	~$20
Eye Nut	$6.74	1	$6.74
Threaded Rod	$5.31	1	$5.31
Lock Nuts	$8.57 / 25	5	$8.57
Washer	$0.88	1	$0.88

Budget: Mechanical (2/2)

Item	Unit Cost	Quantity	Total Cost
Coupling Nut	$0.73	1	$0.73
Gasket Material	~$5	6 x 6 in	~$5
Helium Valve	~$20	1	~$20
PETG Plunger	~$0.02/g	~150g	~$3
PETG Housing	~$0.02/g	~200g	~$4
Total:	**~$75**		

Budget: Electrical (1/2)

Item	Unit Cost	Quantity	Total Cost
Teensy 4.1	$31.50	1	$31.50
MS560702BA03-50	$8.00	1	$8.00
PT103J2	$8.00	1	$8.00
GPS	$31.50	1	$31.50
Battery	$21.95	4	$87.80
Battery Holder	$5.34	4	$21.36
Linear Actuator	~$60.00	1	~$60.00
Servo	$4.00	1	$4.00

Budget: Electrical (2/2)

Item	Unit Cost	Quantity	Total Cost
LED	$2.75 / 10	4	$2.75
12V Regulator	$5.30	1	$5.30
5V Regulator	$5.30	1	$5.30
3.3V Regulator	$5.30	1	$5.30
MOSFET	~$0.20	3	~$0.60
Power Switch	~$0.70	1	~$0.70
PCB	~$20 / 10	1	~$20
Total:	**~$290**		

Budget: Radio

Item	Unit Cost	Quantity	Total Cost
Short Range Radio	$54.97	1	$54.97
Half Wave Dipole 900 MHz Antenna	$24.20	1	$24.20
Long Range Radio	$90.00	1	$90.00
5m antenna	~$0.92 / m	5 m	~$4.60
Total	**~$175**		

Budget: Preliminary Totals and Timeline

Item	Total Cost	Allowed Cost	Budget Growth Allowance
Mechanical	$75	$150	50%
Electrical	$290	$500	42%
Radio	$175	$350	50%
Total	**$540**	**$1000**	**46%**
The budget and totals expressed here are the cost of one LUMA 1.0 payload. Development costs are estimated to be approximately this amount, and no more than $1000, per academic semester, beginning in late April 2024.			

Budget: Per Flight

Item	Unit Cost	Quantity	Total Cost
Attachment Ring	$1.32	1	$1.32
Neck Insert Bolt	$12.09 / 25	1	$0.48
Lock Nut	$8.57 / 25	2	$0.34
PLA Neck Insert	~$0.016/g	150g	~$2.40
LUMA System	$540	*Amortized over an assumed minimum of ten flights*	$54
Total	**~$58.24**		

Flight Cost Comparison

All balloon flights use these materials, regardless of the presence of C&C systems

The LUMA System adds costs to the flight, but the increase is negligible, especially given the increased freedom that C&C payloads provide

Item	Cost Per Flight	Percent of Total Cost
Helium	$256	50.6%
Balloon	$130.00	25.7%
Line	$4	00.8%
Attachment Ring	$1.32	00.3%
Neck Insert Bolt	$0.48	00.1%
Lock Nut	$0.34	00.1%
PLA Neck Insert	$2.40	00.5%
LUMA System (10 Flights)	$54	10.6%
Total Balloon Cost	**$447.90**	**88.6%**
Total LUMA Cost	**$58.24**	**11.4%**

Funding Source

- The Space Hardware Club has received a donation of $15,000 from Bill Brown (WB8ELK), a ham radio and high-altitude ballooning expert
  - This donation contains a condition that the Club must work on a balloon command-and-control payload
  - A portion of the budget may be directed toward development of the LUMA System
- Further funding in future years will be determined by the Alabama Space Grant Consortium
- No budget will be used until after the LUMA 1.0 PDR in April 2024

Bill Brown (WB8ELK) and a pico-balloon

Conclusions and the Future

Conclusions and the Future

- It is desirable and possible to improve upon existing Space Hardware Club balloon flight command-and-control techniques
  - A new vent design improves upon existing flap designs with a plunger-based vent
  - The direct combination of the D.R.O.P. and vent systems leads to a simpler and more reliable cutdown mechanism as opposed to the existing multi-stage mechanism
- Further improvements and changes will be made to all subsystems before the Preliminary Design Review
  - More research will be done on optimal vent placement and dimensioning, and the LUMA mechanical structure will be fully designed
  - Specific components will be finalized and a PCB will be designed for the electrical subsystem
  - Radio protocols and designs will be further researched and developed
  - Fine-tuning of control software to incorporate more complete mission planning capabilities
  - Minor changes to system architecture are being discussed that could increase modularity and overall design flexibility

Questions?