University of Colorado
Colorado Springs

CONOP-02
05/02/2022

SOUNDING ROCKET CONCEPT OF OPERATIONS

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Document Change History

Date	Rev	Description	Status
11/22/21	CONOP-00	Initial Draft	Graded
02/07/22	CONOP-01	Post Initial Grade Revision	Pre PDR
03/14/22	CONOP-02	Implementation of Cis	Post PDR/Pre CDR

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1 Introduction

In the 21st century, scientific and technological innovations have become increasingly important as we face the benefits and challenges of both globalization and a knowledge-based economy. To succeed in this era, education programs in schools and other areas have strived to develop their capabilities in STEM to levels much beyond what was considered acceptable in the past.

STEM education provides individuals with a well-rounded foundation of skills to help them understand a wide range of concepts and thrive in many industries. Several projects that are commonly utilized are understanding the fundamentals of Rocketry, Robotics, Programming, Navigation etc.

A Popular STEM project is in the realm of Rocketry such as the design and build of a sounding rocket. Sounding rockets typically are used for the purpose of taking measurements for geographical observations, test components for larger payloads implementations and zero gravity experiments. With schools and organizations teaming together to do their own projects to participate in future space efforts, they often run into issues such as Federal Aviation Administration (FAA) constraints, Increasing costs and time delays. The goal of this project is to team up with sponsors and lay the foundation for these organizations to help achieve their goals from a Systems Engineering perspective.

1.1. Purpose

This Document describes the Concept of Operations (CONOPS) for the Sounding Rocket developed for the PTSD Foundation and Kino Junior High School

1.2. Scope

The Sounding Rocket will be developed to consist of a Rocket and Payload. The primary focus of the rocket is to launch a provided payload to a pre-determined altitude, collect video and telemetry with the ability to land back and retrieve the data for post-flight feedback to the users. In addition, this document describes the intended operations for pre-launch, launch, ascent, descent, and recovery operations. This document is also a source for high level functional requirements on a Higher Level.

1.3. System States

The Sounding Rocket system operations covers 6 chronological phases called system states beginning with Assembly/Preparation and ending after Landing and Recovery of the payloads.

- Pre-Flight: The rocket is prepared for flight by configuring the motor installation and recovery system. The payload bay will be loaded and armed for mission use prior to motor and recovery preparation. With the payload loaded, the rocket will be set up on a provided launch pad. Any payloads that are powered, will be powered on at the time of the rocket's installation on the launch pad. The rocket's motor igniter will be installed on the launch pad.
- Launch: At the launch controller, once all personnel have cleared the pad area, the launch circuits will be armed once a range all-clear has been given.
- Ascent: After timed countdown, the rocket will launch, at which time it will enter powered ascent to a precalculated altitude governed by the motor thrust.
- Descent: The rocket will reach apogee (the maximum altitude) where the payloads shall function and/or be deployed depending on mission requirements.
- Recovery: After apogee, the rocket will begin freefall descent until the recovery system ejects the parachute to provide a controlled descent and recovery of the rocket.
- Post Launch: After landing, all powered payloads will be shutoff and data collected from them shall be retrieved by the mission sponsors.

2 Capability Need

Due to extreme costs, FAA (Federal Aviation Administration) constraints, and the desire for low-scale science organizations to participate in Space efforts, a Junior High School has approached us to design and build a Sounding Rocket System. With advances in high power and amateur rocketry technology, and experience from certified flyers of these same rockets, it is feasible to produce a Sounding Rocket for these purposes.

2.1 Business Need(s)

The Junior High School has approached us to design and build a Sounding Rocket System that would have the following benefits:

- Permit flight-borne science experiments to be launched.
- A fraction of the cost of well-known Sounding Rocket providers.
- Flight and mission capabilities as close to well-known Sounding Rocket providers as possible.
- FAA regulation compliance.
  Flexibility to test advanced space technologies (either now or later) by building in design features that allow for modular updates.

2.2 Business Need Capability Gap

Several crowd and privately funded efforts have shown that this is feasible, so now the effort is to do the same and permit science experiments by organizations that possess lower budgets. Sounding Rockets that have been built already will be examined for relevant system blocks that can be ported into this offering, leveraging existing technologies and experiential success to produce this rocket offering. The effort here is to provide a Sounding Rocket via direct donation and not solicit them for funding. This is for a charitable cause and to forward STEM education for the customer. There are current rockets that could perform the scientific payload launch but are limited on size and launch payload size. The plan is to customize a Sounding Rocket for specific payloads versus using existing models that may not accommodate the type of payloads that the customer may want.

2.3 Current Situation

Presently, the school does not have the infrastructure, skills, and certifications needed to build and fly a Sounding Rocket on their own. They need those who possess these to provide the Sounding Rocket on their behalf. What they need is a launch vehicle that can deliver their scientific payloads to prespecified and calculated altitudes.

3 Reference Documents

This System CONOPS document is a stand-alone description of how the system operates. The following additional references are provided as courtesy to the readers and users of this document who may desire greater insight into specific operational aspects.

PRM-00	Risk and Management Plan
PPN-001	Project Plan
SSD-02	Systems Specification Document
MBSE-00	MBSE Model Overview Document

4 System Description

4.1 Mission Description

The primary mission of the sounding rocket is to launch scientific payloads for educational purposes. This includes the launch of cameras, altimeters, GPS, and other non-biological payloads. The rocket shall be of sufficient size to be used beyond the current manifest of sponsor.

4.2 System Architecture

The sounding rocket consists of Nose Cone, Payload Bay (Experiment), Body, Fins, Motor Mount, and Recovery system. The purpose is to fly scientific payloads in the payload bay to a precalculated altitude.

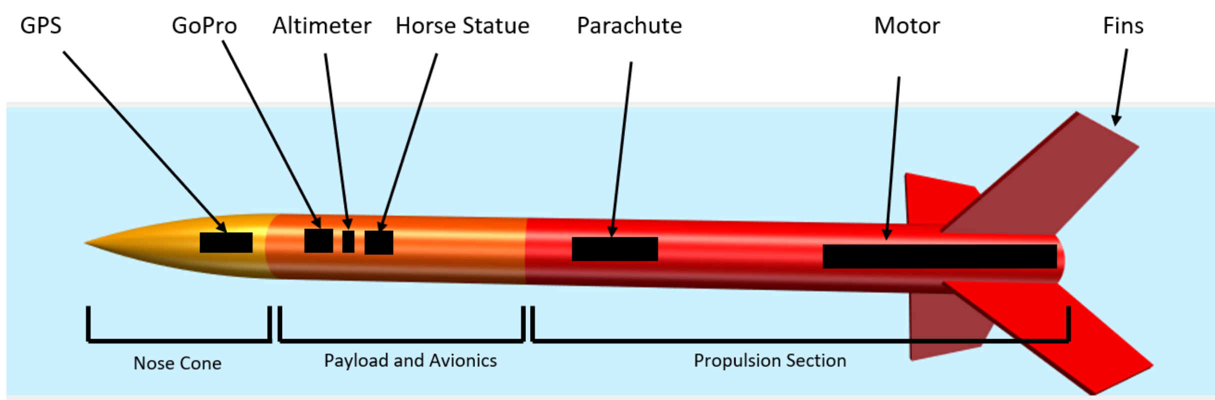


Figure 4-1 Sounding Rocket Layout

Table 1.1

Subsystem/Functional Area	Key Functions
Structure	• The body of the rocket will withstand aerodynamic and acceleration forces. • Consists of nosecone, payload bay, recovery bay(s), avionics bay, tailfins, boattail, and motor mount. • Ascends at a rate of acceleration that permits maximum altitude yet does not exceed the force handling of the payload. This will determine the motor used and whether regressive or progressive thrust is utilized. • The fins Permit stable, unguided vertical flight. • Permit RF transmission of the avionics providing data back to the ground tracking station
Propulsion	• Provides the thrust necessary to launch the vehicle and sustain an acceleration and velocity required to reach the desired altitude. • Houses the motor and is ran on a non-toxic propellent and is a single stage system.
Avionics	• Permit staging function of the rocket • Survive the stresses of the rocket ascent and flight at both altitude and temperature.
Recovery	• Deploy at either motor ejection delay altitude or electronic ejection system that is altimeter and accelerometer based to recover the rocket intact.
Payload Bay	• Ensures that the payloads carried are preserved • Ensures payload is fully functional throughout the flight as designed • Preserves avionics at the G-force and aerodynamic loads present during flight.

4.3 Functional Capabilities and Configuration items

The Functional capabilities of the rocket have been gathered into a excel matrix format to identify what is required during pre-flight, flight and post flight operations. Assembly, Launch Pad Setup, Procedures checks, arming and firing are part of the pre-flight operations.

The Configuration Items were then developed based upon the functional capabilities and architecture of the overall system. The descriptions below identify the CIs and how they will be used during operations and the matrix is shown after the listing of CIs.

Structure

- **Nose Cone** – The nose cone is the upper portion of the rocket. It houses the GPS that will send tracking data back to the ground station.
- **Body-** The body encompasses the major components within the rocket. It houses the payload, and propulsion system and Recovery Parachutes.
- **Fins –** the fins provide the stability of the rocket to ensure the body and nosecone remain in a vertical orientation after it's guided off the launch rails.

Avionics

- **Altimeter** – The altimeter is used by the flight computer to log flight altitude data for the sake of tracking and staging events. This is used during all phases of flight
- **Accelerometers** – The accelerometers are sensors that detect acceleration and help the flight computer to determine forward ascent air speed.
- **GPS** – The GPS detects geographical location and altitude of the rocket and is used to provide the ground station telemetry data on the location of the rocket during flight and recovery operations.
- **Timer** – The timer is used by the flight computer in tandem with the altimeter and accelerometers to determine the best time to deploy the drogue and main parachutes for recovery. After apogee is determined via the altimeter and accelerometers, a calculated timer count is compared to these values to determine when to deploy the recovery functions of the rocket which include the drogue and mains.
- **Servos** – The servos are used for deployment of deployable payload items should any be chosen in the future for the rocket. For the sake of Kino Junior

High (the sponsor), this is not needed but is reserved for future payloads needing to be deployed from the payload bay.

- **Power Supply** – The power supply provides power to all onboard avionics. It is battery operated and is capable of providing all voltage and current power to the onboard avionics.
- **Arming switch** – The arming switch provides power to the onboard power supply and is also used to arm the energetics used to deploy the parachute and drogues for recovery. It is only switched on when the rocket is on the launch pad and ready for flight to protect the ground crew of an inadvertent pyrotechnic event.
- **Flight Computer** – The brain of the avionics system. It's primary function is to monitor onboard flight status of the rocket and to make determination of when to deploy the recovery parachute and drogues after apogee is reached.

Recovery

- **Drogue** – The drogue is the first parachute that is deployed and is meant to slow the rocket's descent yet keep the speed up on descent as to help the rocket descend close to the launch pad prior to deployment of the main parachute.
- **Parachute** – The main parachute that is deployed after the drogue to slow the descent of the rocket to a safe recovery descent speed. It is deployed by the flight computer and stage charge.
- **Stage Charge** – The pyrotechnic load that opens the rocket and deploys both the drogue and main parachute after the flight computer detects the rocket has reached apogee

Propulsion

- **Motor -**The propulsion system of the sounding rocket is comprised of a solid motor running on nontoxic propellant that provides the thrust necessary to reach the desired minimum altitude. This motor is a common of the shelf

(COTS) specifically designed for Class I rockets which integrates into the rocket design appropriately.

Payload

- **GoPro-** The GoPro Hero 9 with a GP2 Processer camera will record the rocket flight through an opening in the payload bay so that the customer can view the recording after retrieving the camera post flight. This GoPro camera provides Hyper Smooth 4.0 video recording, Super View field of view, and plenty of memory space to record the entire flight. The GoPro Hero 9 is also housed in a protective case providing security during flight.
- **Horse Figurine-** The horse figurine provided by the customer is a representation of the school's mascot and is a fun way for the students to connect with the project. The horse figurine does not have any contributions to the sounding rocket system in a technical sense but does fit within the payload bay secured by the payload bay insulation.
- **Customer Provided Altimeter** - The customer provided altimeter is an air-pressure sensor that detects the altitude through the change in air pressure as the rocket ascends. This is a separate altimeter than the one used by the flight computer and is purely for data collection for the customer to view after recovery

Ground Station

- **Featherweight GPS Tracking App (iPhone)** – The Featherweight GPS tracker app will be used as the Realtime data tracking mechanism during Launch. It will provide continuous feedback on altitude and location of the rocket.

The way this is displayed in the matrix below is that the matrix runs through every part of the rocket at a certain point in time and identifies what needs to be performed at that moment. Those details are then ingested in a MBSE tool which captures use cases, scenarios and requirements which will be described in more detail in section 5.1.2

	t - 2 hours	t - 5 min	t - 4 min	t - 2 min	t + 0.4 sec	t + 1 sec	t + 3 sec
General	Assembly	Launch Pad Setup	Procedures Check	Arming	Firing	Takeoff	Motor burnout
Passing Criteria	Complete "Assembly Procedure"	Rocket on pad with right launch angle	Complete "Rocket Preparation"	Complete "Arming Checklist"	Motor ignites	Rocket leaves rail	Motor has finished burning
Avionics	Join connectors between systems, insert into rocket		System check	Arming rocket, data acquisition and downlink starting	-	Detect launch, start altitude measurements	Altitude prediction calculations
Propulsion	Motor assembling, insertion into rocket	Igniter Insertion	Check igniter conductivity	-	Firing	-	Stop burning
Structure	Securing of each subsystem, rocket closing and verticated onto pad	Launch lugs slide nominally, structure is stable	Check coupler tightness	-	-	-	-
Recovery	Parachute folding, insertion in the rocket	-	-	Check buzzer feedback for nominal recovery system arming	-	-	-
Payload	Assembling, insertion in the rocket, payload ready for flight	Go-Pro turned on	System check	-	-	Payload wakes up	-
Ground Station	Set up ground station app	-	System check	Initialize downlink, data acquisition and GPS start	-	Display event: takeoff (alt numbers update)	-

t -+10 sec	t + 13 sec	t + 36 sec	t + 120 sec	t + 180 sec	t + 5 min	t + 30 min	t + 60 min
Altitude control	Apogee	Primary Recover (Drogue)	Secondary Recovery (Main)	Ground Arrival	Ground arrival Payload	Recovery	Disassembly
Rocket velocity reaches 0	Rocket starts descent	Drogue Parachute Deployed	Main parachute unreefed	Rocket lies stable on the ground	Rocket lies stable on the ground	All rocket and payload parts are recovered	All rocket and payload parts are stored for shipping
-	Wake up recovery systems	Give ejection signal	Give parachute unreefing signal	-	Turning off systems (except trackers)	Data saving and system packing	-
-	-	-	-	-	-	-	System cleaning and packing
-	-	-	-	-	-	-	Packing parts
-	-	-	Cut reefing line	-	-	-	Cleaning and packing
-	-	Deploy payload drone parachute	-	-	-	Turn systems off	Datasaving, system packing
-	Display event: apogee (alt update)			Display event: rocket landing (alt update)		Data saving and system packing	Packing

4.4 Functional Capabilities Delivered by Alternatives

There are no other sounding rocket launch vehicles available to specifically launch the required payloads of the sponsors, hence the reason for architecting, designing, and building this system.

5 Operations

5.1 Operations Scenarios

The Sounding Rocket Scenario is divided into the phases shown in Figure 5-1 that also integrate into the system states and employment modes as discussed in paragraph 1.3.

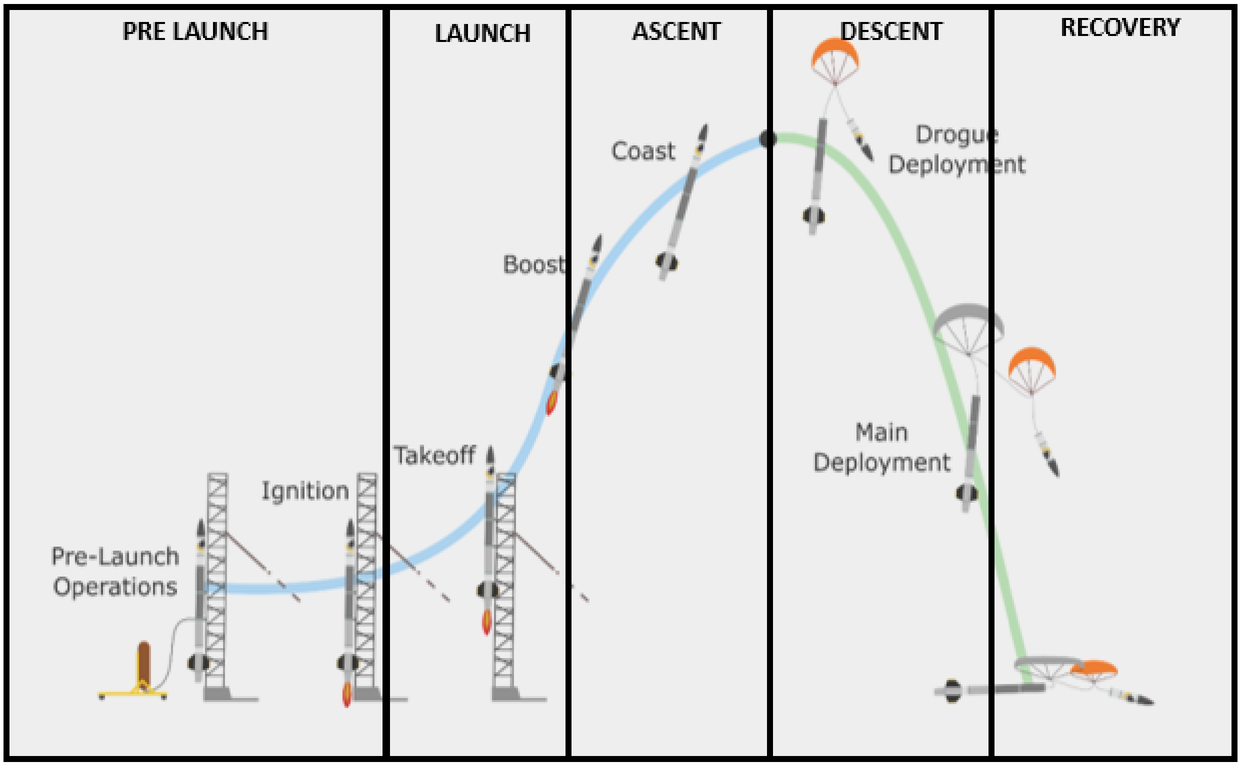
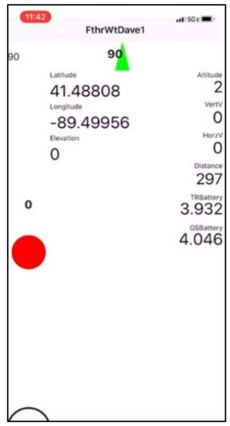


Figure 5-1 Operational Scenarios

1. Pre-Launch Phase

The Pre-Launch Operations Phase begins at T-2 hours when assembly is performed (avionics body will be connected, parachute deployment module will be turned on ad set to 1000ft AGL, go pro powered up and payload and avionics bay closed back up), the launch tower is raised to the vertical position and the launch operations team begins final launch preparations. The rocket will be launched off a pre-selected launch pad that is already in place. Final launch preparations will begin once the tower is raised. An all clear will be given to all non-essential personnel in the hazard area. The crew will insert the Igniter within the motor assembly, connect to the launcher cables and verify igniter conductivity. The Launch lugs will be verified, and the crew will ensure structure is stable and applicable parts such as the lugs are nominally sliding. The couplers will also be checked and verified secure. The crew will verify the Launch controller is powered on and all switches and safety mechanisms are set. Avionics will be initialized including the GPS, altimeter, accelerometer, etc and controller. As part of the comm checks on the ground station, the downlink, data acquisition and GPS will be enabled and verified operational with continuous feedback when queried. This will be done via Bluetooth via the Eggtimer software .



Featherweight GPS App Synchronization

Arming will occur around T-2 minutes in which the crew will verify ground station and avionics are providing continuous feedback. The Launch control operator will remove the safety and verify rocket is ready to fire when the ignition is commanded from the starter. Buzzer feedback will be verified nominal for the recovery system to ensure parachute ready for deployment when commanded.

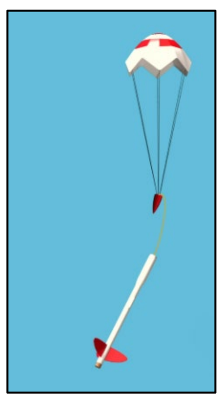
2. <u>Launch</u>

At T-10 seconds, the launch crew will begin the countdown. At T-0, the Launch Control Operator will initiate the start command to ignite the rocket. The ignition signal is sent to the primary ignition puck. The puck must ignite successfully, building up sufficient pressure and heat to ignite the motor grains. The rocket begins accelerating along the launch rail and departs the rail at sufficient velocity and a static stability margin of at least 1.0 cal. When the rocket is launch and ascends, the flight crew will be reading and verifying telemetry from the Eggtimer GPS avionics with Eggtimer software on the ground.

The engine continues burning for a few seconds, accelerating the rocket to several hundred miles an hour climbing to precalculated altitude. Burnout then occurs once all the propellant is “burnt up”. During this period, the stability margin of the rocket increases as the motor reduces mass due to the decreasing propellant within the rocket. This also shifts the rocket’s center of gravity forward. The ground station verifies the altitude and speed of the rocket during flight.

3. Ascent/Descent

The Coast Phase begins following burnout and lasts for the remainder of the ascent. As the engine is no longer producing thrust, the rocket begins to decelerate and will eventually reach apogee (when velocity equals zero). The ground station will also verify altitude count starting to slow down. The recovery altimeters detect that the apogee has been reached and trigger the first deployment event.The deployment charge is activated and will open the rocket nosecone/payload section from the airframe and push the main parachute out.



4. Recovery

The Main Recovery Phase begins when Sounding Rocket descends to 1000 ft AGL. The Jolly Logic parachute release will keep the parachute wrapped until the rocket reaches the appropriate altitude and will then release to slow the rocket to a safe descent rate in accordance with requirements. The rocket and payload will then land back on the ground in which GPS location will verify location of both items. The stored flight data will be retrieved with the same software which includes GPS, altimeter, accelerometer, speed, etc. Once the articles are retrieved, the avionics will be powered down via Bluetooth enabled arming switch as well as the chute release system (Jolly Logic). The GoPro camera will also be powered down and the power supply battery will be disconnected. Pack-up then occurs with wrapping the parachute up and removing the motor, the parachute will be stored inside the airframe of the rocket, and everything will be closed up and verified ready for transportation.

5.2 Operating Concept (OpCon)

Model Based Systems Engineering has been used to support the requirements, design, analysis, verification, and validation associated with the development of the sounding rocket. Interface block diagrams have been developed to demonstrate use case scenarios for the sounding rocket. Starting with the top-down approach, the team developed diagrams for the three stages including, Pre-Flight, Flight, and Post-Flight. These diagrams help capture the system architecture of the rocket as well as captured all of the requirements needed to satisfy the customers' needs and the needs of the rocket to meet the requirements.

Figure 5-2 shows the pre-flight stage in an MBSE format. Arming, Launch Pad Setup, Assembly, and system checks are identified as the use cases required to complete the operation. If required, the use cases are taken a step further to identify what needs to be done for assembly, setup, and arming. Ground Operations is responsible for the tangible set up items prior to launch, the ground station is responsible for system checks and tracking and the feedback from the commands required during pre-flight are feeds from the Avionics or Payload portion of the vehicle.

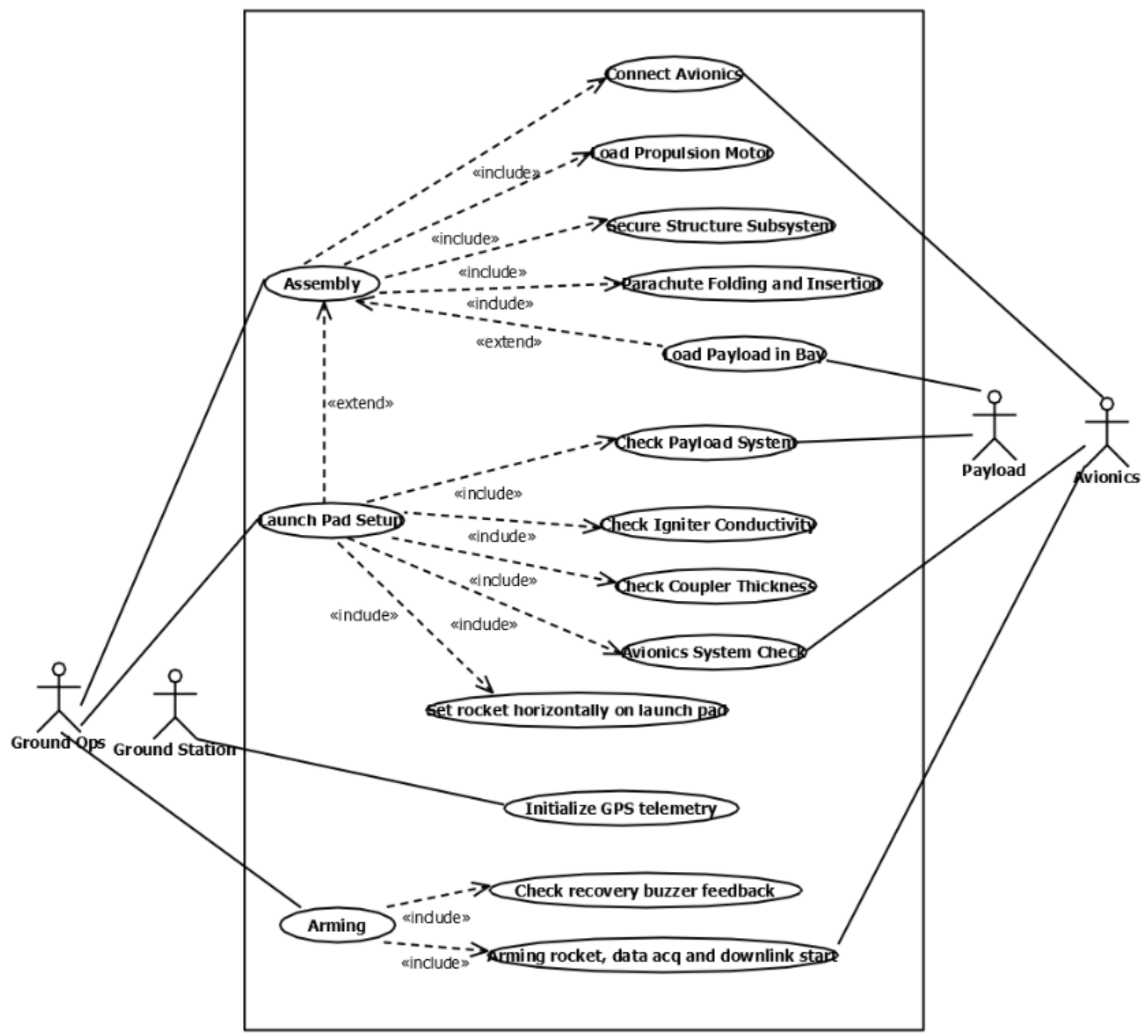


Figure 5-2 Pre-Flight Use Cases

Figure 5-3 shows the flight stage. Firing the rocket, launching the rocket, monitoring flight status, descent and parachute deployment are captured in this stage.

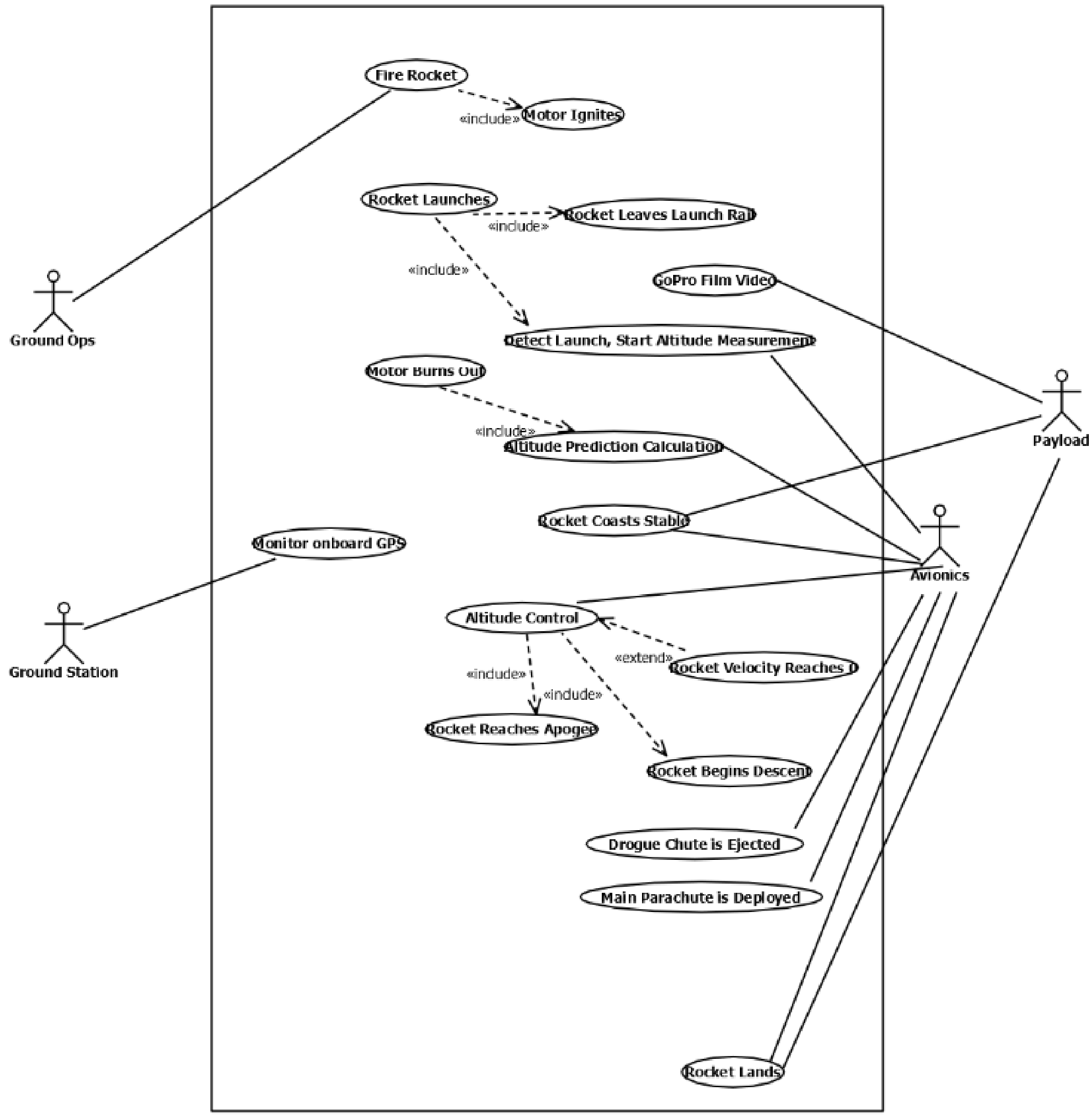


Figure 5-3 Flight Use Cases

Figure 5-4 shows the post- flight stage. Post flight consists of the ground station tracking the rocket back to the landing site, the avionics system powering down the rocket, ground ops disassembling the rocket, which consists of unloading the motor and disassembling the structure as well as folding the parachute. They will also unload the payload and retrieve the data.

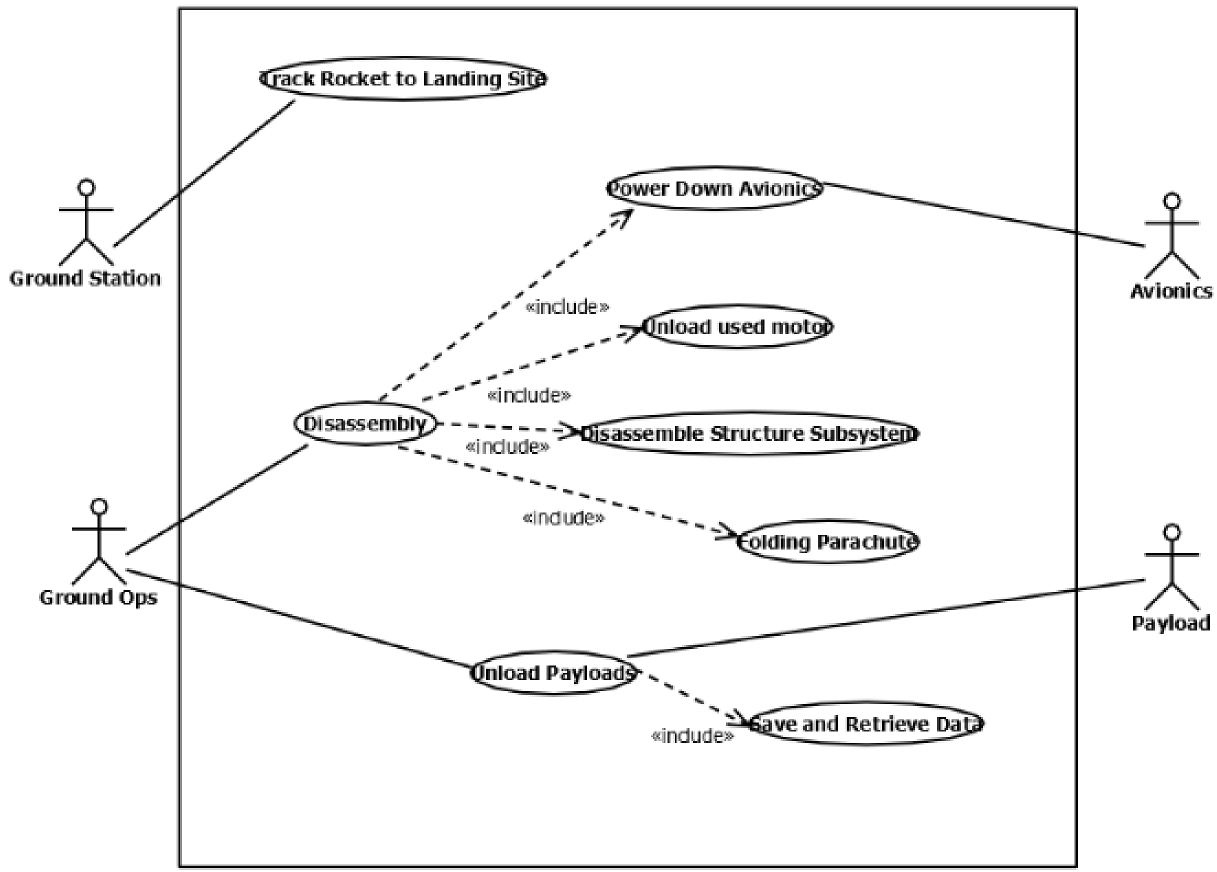


Figure 5-4 Post Flight Use Cases

As stated, the next step of the MBSE was to take it a step down and identify additional use cases and relate them back to the requirements. Based on the gathering of data, the system architecture block diagram was also developed as a guide to show all the systems related to the rocket. The requirements were then divided into the same sections. All of the data was then referred back to the MBSE models to document it all in a single source.

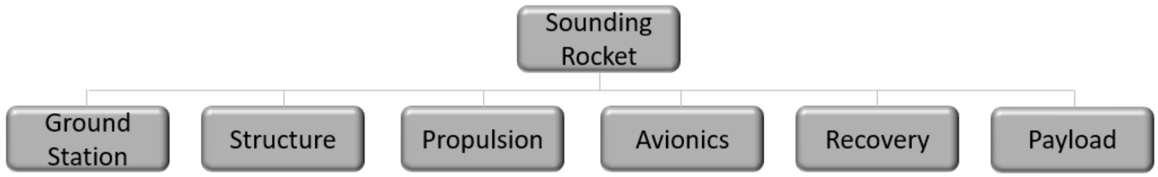


Figure 5-5 System Architecture Block Diagram

5.2.1 Employment Modes

The sounding rocket has various steps and modes in its operation. There is ground preparation involving the recovery system and loading of the payloads. There is transport to the launch site and mounting at the launch pad. There is flight enable where the igniter is committed to flight. Then there is the flight of the rocket where the motor is ignited, and it ascends in flight. There could be staging where the first stage separates from the sustainer (upper stage) and ignited via electronic timer and altimeter detection. The payload which consists of electronics operates throughout flight to capture both video of the flight and altitude recording. Finally, at apogee, the recovery system is deployed which enables the recovery of the rocket.

5.2.2 Scheduling and Operations Planning

Prior to flight, the sponsor/customer will request a flight of the rocket. The rocket shall be available to fly payloads and well maintained in between flights and meant for as much reuse as possible. The rocket shall be transported to the launch pad after specific flight waivers are secured from the FAA in accordance with Federal Aviation Administration Regulation on Aeronautics and Space Title 14, Chapter 1, Subchapter F, Part 101 involving rocket size, altitude, launch location, trajectory, and mission duration.

5.2.3 Operating Environment

Normal flight operations shall be performed in the environments specified in accordance with Federal Aviation Administration Regulation on Aeronautics and Space Title 14, Chapter 1, Subchapter F, Part 101 and the constraints listed therein.

5.2.4 Geographic Area(s)

Normal flight operations shall be performed in the geographic location types specified in accordance with Federal Aviation Administration Regulation Aeronautics and Space Title 14, Chapter 1, Subchapter F, Part 101, Sections 101.23 and 101.25 and the constraints listed therein. Specific locations that fit this criteria include flight locations southwest of both Phoenix and Aquila, AZ and also at Black Rock, NV and Spaceport America in New Mexico. There could be more locations granted they are in accordance with Federal Aviation Administration Regulation Section 101 and the constraints listed therein.

5.2.5 Environmental Conditions

Normal flight operations shall be performed in the environments specified in accordance with Federal Aviation Administration Regulation Section 101.23 and 101.25 and the constraints listed therein.

5.2.6 Interoperability with Other Elements

This rocket shall be its own standalone system and is not meant to interoperate between other rocket systems. The payload section of the rocket could theoretically be used on other rockets, but this rocket is meant specifically for the sponsor-supplied payloads.

5.2.7 Product Support Description

Rocket product support shall be provided by the rocket design engineering staff on behalf of the sponsors. This includes providing access to the payload bay for the sake of loading electronic and other payloads.

5.2.8 Potential Impacts

The sounding rocket shall be designed with sections that are built for update and interchangeability to meet changing needs of the sponsors for the purpose of scientific payload and flights. Rocket programs are known for adaptation

5.3 Users and Other Stakeholders

The users shall consist of team members that own the payload, range safety officers, launch control officers, and rocket handlers. Those who build and launch the rocket shall be certified at least through Level 2 through either Tripoli Rocketry Association or National Association of Rocketry, sufficient to launch rockets with Class 2 motors. Data handlers for the payloads shall also interact with the rocket where appropriate.

5.4 Policies, Assumptions and Constraints

5.4.1 Policy

The design and construction of the rocket vehicle, its motors, and launch operations shall be governed by NFPA 1127 and Tripoli Safety Code. Exemption from elements of NFPA 1127 may apply due to the rocket being designed for use by Federal, state, and local government, colleges, universities, and licensed for-profit businesses engaged in high power rocketry activities. The design and construction should support flight within the constraints of Federal Aviation Administration Regulation Aeronautics and Space Title 14, Chapter 1, Subchapter F, Part 101, Sections 101.23 and 101.25 and the constraints listed therein.

5.4.2 Assumption

There are three additional assumptions worth mentioning at the outset. First, the estimate that sounding rocket technology is feasible is a reasonable one. Second, a fiscally constrained environment will continue. Third, the launch vehicle shall be designed to support growth and development of a customer base beyond the current sponsors to encourage dual-use, or perhaps triple-use, of related facilities and systems. This latter one means that the rocket shall be of sufficient size and launch capability to be used beyond the current manifest of sponsors, thereby increasing the opportunities for other missions and customers.

5.4.3 Constraint

The design and construction of the rocket vehicle, its motors, and launch operations shall be governed by standard NFPA 1127 and Tripoli Safety Code. Exemption from elements of standard NFPA 1127 could apply due to the rocket being designed for use by Federal, state, and local government, colleges, universities, and licensed for-profit businesses engaged in high power rocketry activities. Also, the operating clearances for flying the rocket must comply with standards NFPA 1122, NFPA 1127, and Federal Aviation Administration Regulation on Aeronautics and Space Title 14, Chapter 1, Subchapter F, Part 101.

5.5 CONOPS Development Team

The CONOPS Development Team consists of three members who are all students of University of Colorado at Colorado Springs pursuing their Master's Degree. For the purpose of their Senior Design Project, this CONOPS was generated to meet the program objectives.

- Ben Faltinowski
- Cindy Judd
- Austin Galley

6 Appendix

6.1 Acronyms and Abbreviations

Acronym	Meaning
STEM	Science Technology Engineering Mathematics
FAA	Federal Aviation Administration
GPS	Global
AGL	Above Ground Level
CONOPS	Concept of Operations

6.2 Citations References

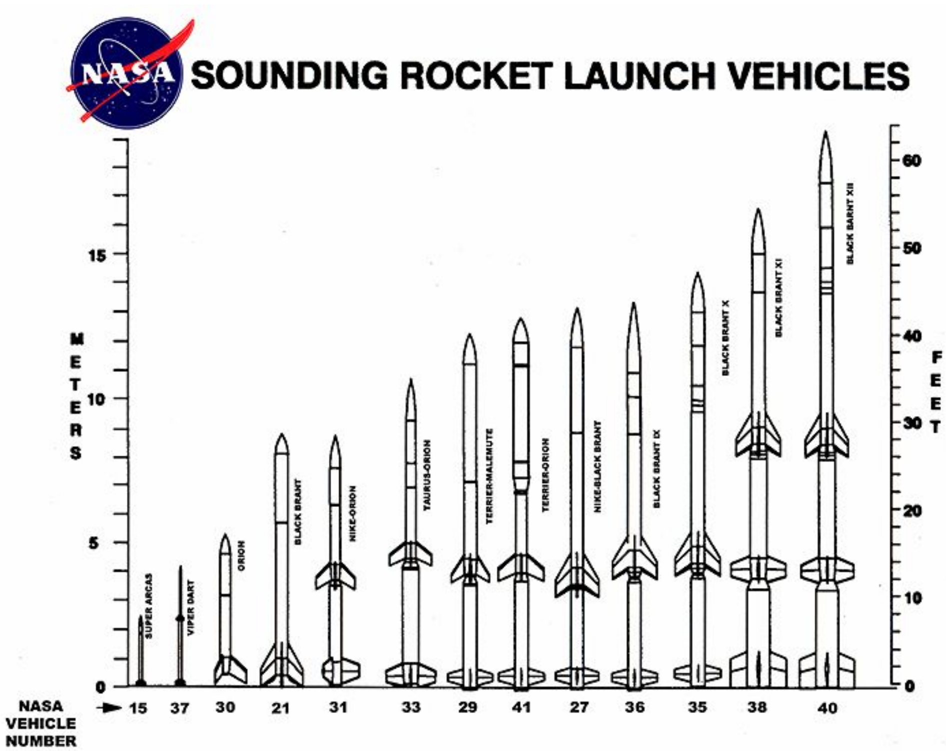
1. NFPA 1122: Code for Model Rocketry; Edition 2018.
2. NFPA 1127: Code for High Powered Rocketry; Edition 2018.
3. Federal Aviation Administration Regulation Aeronautics and Space Title 14, Chapter 1, Subchapter F, Part 101, Sections 101.23 and 101.25 and the constraints listed therein.

6.3 TPMs

Launch Vehicle

Given that there is no given requirement by the sponsors for stage configuration, a list of TPMs was derived for 14 well-known sounding rocket programs to determine the best overall configuration to use.

The diagram below shows 13 of the 14 sounding rockets and configurations used commonly by NASA both in the past and present.



An additional one not pictured is from UP Aerospace. The weighted measures given the most important characteristics were derived upon review of the rocket configurations. The weighted measure categories were rated from the highest to lowest importance with the higher number equating to the higher level of importance. Then, each rocket was scored from the highest score to lowest score in each of the categories, with the highest number equaling the number of rocket options and ranked in lower number from that point across the launch vehicles. The weight of each category was then added to the score in each category to produce a weighted score in each category and then the totals were added.

After performing the analysis, there were two sounding rocket configurations that were down selected. They were the Super Arcas single stage and the Taurus-Orion two-stage. These had the highest overall TPMs given their ranking in each category. The key difference between the two was the complexity of each. A single-stage rocket has less complexity than a multi-stage rocket so although the TPM total for Super Arcas was slightly smaller than Taurus-Orion, its single-stage configuration is desirable given the less complexity required. Also, the Super Arcas happens to be the lightest rocket option of the sounding rocket options and happens to have the payload size capacity needed to fly the payloads required by our sponsor's sounding rocket. The Super Arcas configuration is capable of a maximum 32-mile altitude and given that our sponsors have no defined altitude requirement, there is leeway in determining a configuration that can fly to an altitude limited only by the classification of the rocket (Class 1 or 2) and the need for an FAA waiver to fly to high altitude (if it is a Class 2 rocket). The altitude of Arizona (e.g.) flight locations is between 4500 ft AGL or 48,000 ft AGL, and the sponsors are most interested in having a rocket they can readily fly thus making for an altitude requirement in the lower end of this range which means smaller motors could perform the task.

Technical Performance Measures

Rocket Vehicle		Super Arcas				Viper Dart				Orion			
	Weight	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score
Payload Mass	11	9.9	lbs	4	15		lbs	3	14	149	lbs	6	17
Altitude	10	32	miles	1	11	74	miles	3	13	52	miles	2	12
Stages	9	1	stage	4	13	1	stage	4	13	1	stage	4	13
Thrust	8	336	lbf	5	13	6069	lbf	8	16	1573	lbf	7	15
Mass	7	76	lbs	13	20	881	lbs	10	17	880	lbs	11	18
P/M Ratio	6	0.130	P/M Ratio	10	16	0.000	P/M Ratio	1	7	0.169	P/M Ratio	11	17
T/W Ratio	5	4.4	T/W Ratio	3	8	6.9	T/W Ratio	4	9	1.8	T/W Ratio	2	7
Years of Use	4	33	years	10	14	16	years	5	9	34	years	11	15
Length	3	7.5	ft	12	15	7.2	ft	13	16	18.3	ft	11	14
Diameter	2	4	in	13	15	7.087	in	12	14	13	in	9	11
Reusability	1	0	times	0	1	0	times	0	1	0	times	0	1
Total					**141**				**129**				**140**
Data Reference		http://www.astronautix.com/a/arcas.html				http://www.astronautix.com/v/viper-dart.h				https://en.wikipedia.org/wiki/Orion_(rock			

Rocket Vehicle		Black Brant				Nike-Orion				Taurus-Orion			
	Weight	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score
Payload Mass	11	150	lbs	7	18	149	lbs	6	17	500	lbs	11	22
Altitude	10	140	miles	7	17	80	miles	4	14	120	miles	6	16
Stages	9	1	stage	4	13	2	stage	3	12	2	stage	3	12
Thrust	8	25000	lbf	9	17	48783	lbf	10	18	102737	lbf	12	20
Mass	7	1610	lbs	9	16	2400	lbs	8	15	4400	lbs	5	12
P/M Ratio	6	0.093	P/M Ratio	6	12	0.062	P/M Ratio	5	11	0.114	P/M Ratio	8	14
T/W Ratio	5	15.5	T/W Ratio	8	13	20.3	T/W Ratio	10	15	23.3	T/W Ratio	11	16
Years of Use	4	4	years	3	7	24	years	8	12	24	years	8	12
Length	3	24.3	ft	9	12	29.5	ft	8	11	37.4	ft	7	10
Diameter	2	10	in	11	13	16	in	8	10	23	in	8	10
Reusability	1	0	times	0	1	0	times	0	1	0	times	0	1
Total					**139**				**136**				**145**
Data Reference		http://www.astronautix.com/b/blackbrant				http://www.astronautix.com/n/nikeorion.l				http://www.astronautix.com/t/taurusorion			

Note: Super Arcas chosen over Taurus-Orion due to less complexity (1 stage) and it's size is comparable to the sponsors' payload need.

Rocket Vehicle		Terrier-Malemute				Terrier-Orion				Black Brant IX			
	Weight	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score
Payload Mass	11	396	lbs	10	21	639	lbs	12	23		lbs	3	14
Altitude	10	260	miles		10	118	miles	5	15	190	miles	8	18
Stages	9	2	stage	3	12	2	stage	3	12	2	stage	3	12
Thrust	8	58000	lbf	11	19	58000	lbf	11	19		lbf	4	12
Mass	7	3456	lbs	6	13	2800	lbs	7	14	4800	lbs	4	11
P/M Ratio	6	0.115	P/M Ratio	9	15	0.228	P/M Ratio	12	18	0.000	P/M Ratio	1	7
T/W Ratio	5	16.8	T/W Ratio	9	14	20.7	T/W Ratio		5	0.0	T/W Ratio	1	6
Years of Use	4	30	years	9	13	18	years	6	10	39	years	13	17
Length	3	41.6	ft	5	8	41.9	ft	4	7	40	ft	6	9
Diameter	2	18	in	6	8	18	in	6	8	18	in	6	8
Reusability	1	0	times	0	1	0	times	0	1	0	times	0	1
Total					**134**				**132**				**115**
Data Reference		http://www.astronautix.com/t/terriermale				https://en.wikipedia.org/wiki/Terrier_Oric				https://en.wikipedia.org/wiki/Black_Brant			

Rocket Vehicle		Black Brant X				Black Brant XI				Black Brant XII			
	Weight	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score	Metric	Unit	Score	Weighted Score
Payload Mass	11	200	lbs	8	19	710	lbs	13	24	240	lbs	9	20
Altitude	10	560	miles	9	19	800	miles	10	20	930	miles	11	21
Stages	9	3	stage	2	11	3	stage	2	11	4	stage	1	10
Thrust	8	58000	lbf	11	19		lbf	4	12	116000	lbf	13	21
Mass	7	5700	lbs	3	10	11600	lbs	2	9	11700	lbs	1	8
P/M Ratio	6	0.035	P/M Ratio	3	9	0.061	P/M Ratio	4	10	0.021	P/M Ratio	2	8
T/W Ratio	5	10.2	T/W Ratio	6	11	0.0	T/W Ratio	1	6	9.9	T/W Ratio	5	10
Years of Use	4	37	years	12	16	22	years	7	11	33	years	10	14
Length	3	47.6	ft	3	6	55	ft	1	4	49	ft	2	5
Diameter	2	17	in	7	9	30	in	9	11	30	in	9	11
Reusability	1	0	times	0	1	0	times	0	1	0	times	0	1
Total					**130**				**119**				**129**
Data Reference		https://en.wikipedia.org/wiki/Black_Brant				https://en.wikipedia.org/wiki/Black_Brant				https://en.wikipedia.org/wiki/Black_Brant			

SpaceLoft XL			
Metric	Unit	Score	Weighted Score
79	lbs	5	16
140	miles	7	17
1	stage	4	13
8240	lbf	6	14
780	lbs	12	19
0.101	P/M Ratio	7	13
10.6	T/W Ratio	7	12
15	years	4	8
20	ft	10	13
10.45	in	10	12
0	times	0	1
			138
https://en.wikipedia.org/wiki/SpaceLoft_XL			

Camera

A camera needed to be selected for one of the requests of the user. The camera would give the user the ability to view the rocket during flight and be able to retrieve video post flight. A go pro was decided as an option as many vendors have used this capability for suborbital rocket launches. The decision point what what type of go-pro. Three potential options were selected that consist of a Hero 8, 9 or 10. Hero 8 is the older version, Hero 10 is the newest version. The quality type, Video, horizon leveling, duration captures were all analyzed and weighted. Hero 9 and 10 were pretty similar but off by 2 points. Hero 9 ended up getting selected as the price was a little cheaper and the GP2 processer was an additional upgrade for what we were looking for. Our goal was to find something decently priced with the best technology that could be used time and time again.

	Weight	HERO8	Score	Weighted Score	HERO9	Score	Weighted Score	HERO10	Score	Weighted Score
Cost	17	$ 279.00	3	20	$ 349.00	2	19	$ 399.00	1	18
Photo	16	12MP + SuperPhoto with HDR	1	17	20MP + SuperPhoto with HDR	2	18	23MP + SuperPhoto with HDR	3	19
Video	15	4K60	1	16	5.3K60	2	17	5K30	3	18
100Mbps Bit Rate	14	4K / 2.7K	3	17	5.3K / 4K / 2.7K	2	16	5K / 4K / 2.7K	1	15
Video Stabilization	13	HyperSmooth 2.0	1	14	HyperSmooth 4.0	3	16	HyperSmooth 3.0	2	15
Horizon Leveling	12	With the Quik App	1	13	In-Camera	2	14	In-Camera	2	14
Digital Lenses / FOV	11	SuperView, Wide, Linear, Narrow	1	12	SuperView, Wide, Linear, Linear + Horizon-Leveling, Narrow	2	13	SuperView, Wide, Linear, Linear + Horizon-Leveling, Narrow	2	13
Front Screen	10	Status-only Screen	1	11	1.4" Color LCD with Live Preview and Status	2	12	1.4" Color LCD with Live Preview and Status	2	12
Mods	9	Media Mod (HERO8 Black)	1	10	Media Mod (HERO10 Black)	1	10	Media Mod (HERO9 Black)	1	10
TimeWarp Video	8	TimeWarp 2.0	1	9	TimeWarp 3.0	2	10	TimeWarp 3.0	2	10
Slo-Mo	7	8x (1080p)	1	8	8x (2.7K, 1080p)	2	9	8x (1080p)	1	8
Hind Sight	6	—	1	7	Yes	2	8	Yes	2	8
Scheduled Capture	5	—	1	6	Yes	2	7	Yes	2	7
Duration Capture	4	—	1	5	Yes	2	6	Yes	2	6
Wake on Voice	3	Yes	2	5	—	1	4	Yes	2	5
Compatible Housing	2	Protective Housing (HERO8 Black)	1	3	Protective Housing (HERO10 Black)	1	3	Protective Housing (HERO9 Black)	1	3
Processor	1	GP1	1	2	GP2 (New!)	2	3	GP1	1	2
				175			185			183
		Note: HERO9 Chosen due to a balance of technology and cost found during trade.								