**Targets and Metrics**

**Introduction**

The targets and metrics were developed by analyzing the subsystems functions that were defined during the functional decomposition phase. The lowest level functions were assigned targets and metrics. The targets and metrics found can be used as a determinant in the success and effectiveness of the project. All the targets and metrics for the project are tabulated in the chart below.

|  |  |  |
| --- | --- | --- |
| **Functions** | **Metric** | **Target** |
| Operates redundant C02 charges | Volume | 23-35 g CO2  |
| Separates rocket bays | Force | 64-80 lbf on sheer pins |
| Retains and deploys parachutes | Altitude | 1500 m |
| Calculates acceleration | G-force | 0-100 g sensor range |
| Initializes flight events | Latency | Max 10 ms delay |
| Tracks live system location | GPS connectivity | Min 4 satellites  |
| Transmits telemetry | Frequency | 433 MHz |
| Records sensor data | Polling rate | 10 Hz – 100 Hz (variable) |
| Performs RT calculations for flight events | Latency | Max 10 ms delay |
| Reduces vibrations | Velocity | Max Velocity below 1500 ft/s |
| Reduces mass | Mass | Max 55 pounds |
| Withstand propulsion | Force | Min 480 lbf |
| Reduces drag forces | Drag force | Max 43 lbf |
| Increases stability | Stability ratio | 3-5  |
| Generates thrust | Force | Min 382 lbf |
| Ignite under external excitation | Voltage | 12V |
| Houses payload design | Diameter | 5 in |
| Designed for human metrics | Length | ~65x STEMnaut height |

Table 1, *Full Targets and Metrics List*

**Critical Targets and Metrics**

Some critical targets and metrics were identified for the project. Each of these critical targets and metrics must be achieved to ensure success of the project. Meeting these will allow the vehicle to reach the altitude requirement and descend/be recovered without any structural failures during flight. The targets and metrics deemed critical for the rocket are tabulated in the chart below.

|  |  |  |
| --- | --- | --- |
| **Critical Functions** | **Metrics** | **Target** |
| Separates rocket bays | Force | 64-80 lbf on sheer pins |
| Retains and deploys parachutes | Altitude | 1500 m |
| Calculates acceleration | G-force | 0-100 g sensor range |
| Records sensor data | Polling rate | 10 Hz – 100 Hz (variable) |
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| Generates thrust | Force | Min 382 lbf |
| Houses payload design | Diameter | 5 in |

Table 2, *Critical Targets and Metrics*

### **Testing Methods and Validation**

A significant testing and validation milestone for the project is the subscale flight. This flight will involve designing, fabricating, and launching a 60% scale model that matches all systems of the full-scale vehicle. This subscale test will test various systems, design ideas, and components intended to be used on the main rocket and mitigate risks to project budget and timeline. Discussed below are validation and testing methods for the deemed critical targets and metrics.

Our team has developed and is in the process of developing new testing methods to validate our design. Retaining and deploying the parachutes can be validated and tested in a few different ways. The validation can be done by visual inspection and looking up to see that the parachutes deployed during flight. Onboard computers will also record flight events, such as separation and deployment. Sharp changes in velocity and altitude are indicators of parachute deployment so events can be derived from data. Testing methods for parachute deployment are employed before the flight. The recovery team will do experiments with parachute folding methods and restraining methods to test reliability and determine the best packing method. The CO2 ejection charges will also be tested in a low-friction cradle to ensure that separation reliably occurs, enabling the parachutes to deploy during an actual flight.

Generating thrust is simulated, tested, and validated in multiple stages. Preliminary projections can use the motor specification sheet to base our design on to ensure our motor retaining system can withstand the motor’s force during flight. These projections provide a generalized thrust profile throughout motor burn. Simulation will also be performed through OpenRocket using the motor thrust profile to create flight projections to inform our design decisions. Flight data will also be collected by the flight computers including altitude, velocity, and acceleration data. This data will be analyzed after launch with mass details to confirm the motor thrust was obtained within reasonable margins.

Drag reduction of the launch vehicle will be tested and verified through OpenRocket simulations. The drag coefficient of the vehicle is calculated based on certain atmospheric conditions. The output value of these calculations and simulation will be compared to the target value to verify the feasibility of the design. Additionally, some backup hand calculations will be performed to verify the simulation.

Measuring velocity and altitude can be done by the required altimeters onboard collecting flight data. This data can be reviewed to validate that the target apogee and vehicle velocity was met. This testing method will also be used to validate, test and measure the storing of flight data target outlined in the critical targets above.

Excess vibrations will be evaluated using OpenRocket simulations. Like the drag coefficient, the damping coefficient will be determined after loading the rocket model and setting the atmospheric conditions for launch. This calculated damping coefficient will then be compared to the target value and validated through manual calculations.

Housing payload design will be tested with the subscale rocket. The payload team will test that their integration methods are valid and work with the space provided to them and the points of attachment. After the subscale launches the condition of the payload and whether it moves around in the rocket will validate whether the method for housing the payload has to be altered in any way.

**Derivation of Metrics**

To calculate the force needed to separate rocket bays, there are shear pins connecting each bay that are broken by pressure build up inside the rocket, this pressure buildup induces shear forces on the shear pins as the rocket wants to lower this pressure by expanding the volume inside the separation bay. The shear force needed to break the pins is governed by the equation

$$τ=\frac{F}{A}$$

where the area here is the cross-sectional area of the pin. 64-80 lbf was stated as the target which came from the material properties of the shear pins and calculating the minimum force needed to cause failure in the pins.

 The parachutes are both expected to be house in their respective parts of the rocket, with the drogue shoot being housed under the nosecone and payload and main parachute being above the fins. With a target apogee of, as outlined by NASA, between 4,000 and 6,000 feet, or between 1219.2 and 1828.8 meters, the goal is for the drogue shoot to be opened at apogee. This will use the onboard altimeters which will send a signal to open the 25g, immediately followed by the 35g Co2 charge for each parachute. The drogue shoot will be opened at apogee, which in OpenRocket is currently simulated at 5,200 feet, 1,585 meters. This will keep the rocket from falling strictly at freefall. The current plan is to utilize the same drogue and main parachutes because of their associated cost, but drift is taken into account where there is the possibility of downsizing the main parachute if necessary. The NASA student launch handbook states that the main parachute shall not be deployed any lower than 500 feet, or 152.4 meters. Using the onboard altimeters and current OpenRocket Simulations, the current projected deployment of the main parachute is at 574 feet, or 175 meters where the charge will be sent from the altimeters to the charges for the final separation stage.

Altitude is derived from the altimeter device which uses the change in pressure to calculate its height compared to sea level. OpenRocket also provides an expended apogee based on mass; however, this is not the most accurate as the physical mass of the rocket typically differs from the software. The NASA handbook requires the rocket to have an apogee ranging from 3500-6500 feet. Our rockets apogee is roughly 5000 feet which is in the range of NASA’s guidelines.

 We can calculate the rockets altitude by using an altimeter as mentioned above. Another feature of altimeters is that they keep a record of time stamps during flight. We can then derive a velocity by taking the derivative of change in altitude(height) with respect to time such that:

$$\dot{X}=V=\frac{dx}{dt}$$

Software’s such as MATLAB can handle derivates of data points. Next, we simply take another derivate but with change in velocity with respect to time such that:

$$\ddot{X}=\dot{V}=a=\frac{dv}{dt}$$

Finally, we can use this calculated acceleration to fine g force by simply dividing acceleration by earths gravitational acceleration. It is important that the acceleration is in meters per second squared. G-force is expressed as:

$GForce=\frac{a}{g}$ where g is 9.81$\frac{m}{s^{2}}$

There will be some latency between the flight computer and launch event systems (i.e. separation for drogue and main parachute). The greatest descent speed is expected to be less than 150 ft/s based on simulation and real-world rocket flight data. Therefore, flight event latency that does not exceed 10 ms will maximally result in a 1.5 ft error for altitude-based flight events. This is an acceptable error and provides a sufficient margin for safe operation.

 Per NASA competition guidelines and to improve post-landing recovery, the avionics bay will have GPS capabilities with wireless transmission to a ground station. To track the rocket, a GPS module will locate and use a minimum of 4 satellites during the complete launch sequence to maintain accurate tracking. We can expect to have connectivity with at least 6 satellites at our selected launch locations.

 The avionics system will transmit data to a ground station to provide real time monitoring of flight status. This data will be transmitted on the amateur radio technician range near 433 MHz. This is the frequency our ground station receiver is optimized for. Telemetry transmission also includes GPS location data to assist in locating the rocket.

 The avionics system must operate sensors to collect, record, and process flight data. The device must have a sufficiently high polling rate to provide an accurate flight profile while still producing small file sizes to permit repeat launches without offloading data. A 10 Hz polling rate during descent is sufficient for this task. Descent is more gradual than ascent and can use this rate to provide a good profile of the stage. The polling rate will be increased for ascent to record further details. Changing the polling rate depending on the stage increases the resolution when it provides sufficient improvements to flight profile and decreases the rate to save storage space when the resolution improvements would be marginal. The file size should not exceed 300 kB to permit reuse of the rocket system.

 The rocket flight computer must perform calculations in real time to record the flight profile and initiate critical launch events. The greatest descent speed is expected to be less than 150 ft/s based on simulation and real-world rocket flight data. Therefore, calculation latency that does not exceed 10 ms will maximally result in a 1.5 ft error for altitude-based flight events. This is an acceptable error and provides a sufficient margin for safe operation even combined with event initiation latency.

There exists a velocity of the vehicle above which the frequency of vibrations experienced on the fins becomes greater than the natural frequency, causing what is known as fin flutter. When fin flutter begins, it almost certainly results in catastrophic failure. Fin flutter velocity was calculated to generate a hard limit to ensure fin flutter does not occur during flight. The equation is written out below featuring the fin flutter velocity $V\_{f}$ as a function of many rocket fin parameters which were found on our OpenRocket simulations or calculated for by hand.

$$V\_{f}=a\sqrt{\frac{G}{\frac{39.3A^{3}}{(\frac{t}{c})^{3}\*(A+2)}\*\left(\frac{λ+1}{2}\right)\*(\frac{p}{p\_{0}})}}$$

This equation confirmed that fin flutter will begin to occur at about 1500 ft/s which is more than twice the maximum velocity of our rocket.

The mass of the rocket is important as it pertains to the flight profile as well as apogee. Most of the mass of the rocket exists at the fore and aft sections. Since the back of the rocket is likely not to change nearly as much as the front due to payload integration, it is important that this front region does not get too heavy. Mass at the front although good for stability can be detrimental to apogee. A mass limit of 55 lbs for the entire rocket ensures a satisfactory flight with the current motor selection.

The force and impulse are two motor functions that determine how much thrust the motor generates and how capable the rocket body is of housing the motor securely. Using Open Rocket simulation, a minimum thrust was selected, and an impulse was calculated using a factor of safety to ensure the rocket body can withstand the force the motor exerts on it.

Drag force was another metric attained from Open Rocket that likely will not change much since the major components of the rocket responsible for producing drag are almost fully designed. If it does change, it would only be to optimize the rocket to a lower drag force than what it currently is.

Stability on a rocket is calculated by the distance between the center of gravity and center of pressure or by the following equation

$$Stabilty=|Center of Gravity-Center of Pressure|$$

To derive a stability factor, OpenRocket software is used to calculate both center of gravity and center of pressure. To convert this distance into a non-dimensional number the diameter of the rocket is used such that

$$Stabilty Caliber=\frac{Stabilty}{Diameter\\_rocket}$$

In applications a stability caliber between 2-5 is seen adequate. Our stability of 4.77 was calculated by using the OpenRocket software

 The rocket motor will be ignitable by a 12V direct current firing system, per the NASA Student Launch Handbook. This is a common firing system that is used throughout high-powered rocketry.

 One of the requirements for our NASA competition is that we successfully fly with a payload. While the payload itself is not our project, we have told the payload team they will have a 5in diameter within the rocket body to work with. They also have a substantial length within the body to work with, however an exact number was not set for that dimension.

To keep in spirit with the inspiration for our launch mission, the Artemis program, we have kept our rocket’s size roughly proportional to that of the real SLS rocket which will be used for the Artemis II mission. With an average human height of 5ft 6in and the SLS rocket’s height of 321ft, that gives us a rocket height of roughly 100in for a STEMnaut height of 1.5in. This is not required by NASA, but it gives our rocket a more realistic feel for our own mission and gives the payload team a more accurate size for the STEMnauts on board.

**Other Needs Addressed**

Aside from the listed functions, NASA requires that the rocket must be able to be fully assembled and primed for flight in a 2-hour window. This is being addressed by our team’s new design philosophy compared to last year; design for assembly. All parts are created to fit together as a system first, not just for their general purpose within the system. NASA requires that the rocket must also have a stability margin of 2 off-the-rail. Off-the-rail referring to when the last rail connector on the rocket loses contact with the launch rail. This will be studied in our OpenRocket simulations and can be altered, if need be, by our rocket’s airframe design and our motor selection. Lastly, the rocket must be “flight ready” for at least 3 hours after assembly. Historically, Launch Day flight times are usually behind schedule on the magnitude of hours so we will be designing our avionics bay electronics to draw lower levels of power, when needed, to elongate its battery life.

One of the secondary objectives of the NASA launch challenge is to develop a reusable rocket, meaning that nonexpendable parts do not need to be replaced in between flights. This includes all components besides sheer pins, the rocket motor, and separation energetics (e-matches, black powder, and CO2). Our design must complete a safe landing to avoid damage and be designed to withstand all flight forces.

**Summary**

The targets and metrics determined were all optimized with the goal of safely launching and recovery a high-powered rocket. In addition to these targets the vehicle should adhere to the NASA student launch guidelines highlighted in the handbook. The targets that were deemed required to meet the functions needed are all measurable and defined based off benchmarking and research. If these quantitative guidelines found are followed, the ricket will launch and be recovered successfully, achieving the goal of qualifying for the competition.