1.4 Targets and Metrics

1.4.1 Targets

After defining the ultimate goal of this project and decomposing each of the system's functions, the design process was followed by identifying targets. Each of the targets and their respective functions are based directly off of customer needs. Targets are the goal for each function, which then add constraints and conditions to the functions, allowing us to determine possible solutions to the problem.

Following the hierarchy chart created in the functional decomposition, we identified each function that our design should have to satisfy the customer needs. Each function has a respective target defined with it, allowing us to view the relationship with the function goal and how to accomplish it. The targets were chosen through asking questions to our technical contacts at NASA and by standards set by previous missions, such as Apollo, that work well and take customer and users' needs into consideration. Targets are shown in Table 1, including the critical targets which are highlighted in yellow.

FUNCTIONS	TARGETS
Absorb Impact Energy	All Kinetic Energy (~145 kJ) is transferred into system
Absorb Structural Shock	Endures ≤ 3 g's of impact acceleration
Support Mass	~25,000 kg
Return to Original State	Time ≤ 10 hours
Indicate Reusability	Shock absorber proves its return to 100% of original parameters

Table 1: Critical functions and defined targets.

1.4.1.1 Critical Targets

1.4.1.1.1 Absorb Impact Energy

To land safely without a risk of failure, the system must be able to absorb, store, and then dissipate the energy safely. Therefore, the first critical target for this system is that it must be able to absorb the impact energy, which we calculated our target to be approximately 145 KJ of kinetic energy. This value was calculated by using the simple mass spring damper equation for kinetic energy,

$$KE = \frac{1}{2}mv^2$$

1.4.1.1.2 Absorb Structural Shock

Structural shock is the shock that the system experiences from its own deceleration. The target for this function must be less than or equal to 3 Earth g's, since this is NASA's limit for a safe landing for a human. This was chosen because the system must be as safe as possible and prevent the HLS from falling apart upon landing.

1.4.1.1.3 Support Mass

The target for this system to is to support the mass of the HLS, which according to NASA, is expected to be around 25,000 kg. However, this is an estimation and not final mass value because the lander is still in the design process. This estimation includes the mass of the lander, the legs, and all the passengers and equipment on board.

1.4.1.1.4 Return to Original State

For the shock absorber system to be reusable, it must return to its original state that it was in before being used. One of the most crucial functions that makes this problem different from previous shock absorption systems is that it must be reusable. Therefore, it is only a matter of how long it takes for it to be reused. The target time for the system to return to its original state after landing was chosen to be 10 hours. This number was chosen because it is low enough to allow the HLS to hop to another site during the same mission and long enough to allow the system to dissipate energy.

1.4.1.1.5 Indicate Reusability

The target for indicating reusability is that the shock absorber clearly proves to its user(s) that it has completed return to 100% of original parameters. This means it cannot be up to interpretation if the shock is ready to be used again.

1.4.1.2 Additional Targets

1.4.1.2.1 Prevent excessive rebound

The target for preventing excessive rebound from the surface was decided to be a rebound height of less than 0.5m. Ideally, the system will have no rebound, but this is limiting. Instead, by restricting the maximum rebound height to 0.5m, it allows for prioritizing other critical targets while keeping the entire system safe.

1.4.1.2.2 Transform and Store Energy

The target for transforming energy of the system is a final kinetic energy of zero. This indicates that all the energy created during landing has been transformed. The target for storing energy is that the system is capable of storing ~145KJ of energy. The target for dissipating energy is that all stored energy can be dissipated within 10 hours.

1.4.1.2.3 Dampen Vibrations

The target for dampening of vibrations is to have a settling time of less than 2 seconds. This is a value that is standard in controls that is used as a starting point for the metrics.

1.4.1.2.4 Withstand Lunar Conditions

The target for withstanding lunar conditions is about 10 years. Mission Artemis is centered around developing and maintaining a human presence on the moon (and eventually Mars) and ultimately the search for water. It is expensive and wasteful to use single-use shocks, such as the crushable shocks from Apollo. Reusability of this device is crucial, not only to be used twice, but to be used for years. The goal is a 10-year lifespan.

1.4.2 Metrics

Metrics can be defined as the methods that we are going to use to test our established targets. Some of our testing is validated with physics, math, and/or engineering equations. Table 2 shows the functions and metrics, with the most important functions highlighted in yellow.

1.4.2.1 Critical Metrics

1.4.2.1.1 Absorb Impact Energy

The metric for deriving impact energy and stored energy may be calculated using the equation for kinetic energy. This was the simplest solution for obtaining these metrics and it gave us a clear sense of how we are satisfying one of our critical functions. The value calculated for absorbing impact energy is critical to know because that is the total amount of energy in the system that must be conserved or properly dissipated.

1.4.2.1.2 Absorb Structural Shock

One of the functions is for our system to absorb structural shock upon landing. In order to absorb the structural shock, the system must remain elastically ductile when subjected to up to 3 g's of acceleration given the materials, mass, and geometry chosen in the final design. This was deemed to be one of our critical functions because if this target is not met, the entire system would catastrophically fall apart.

FUNCTIONS	METRICS
Absorb Impact Energy	All kinetic energy from impact is absorbed into the system as it brings the structure to rest.
Absorb Structural Shock	System remains elastically ductile when subjected to up to 3 g's of acceleration given materials, mass, and geometry.
Support Mass	Materials and geometry of the structure statically supports the mass under Earth and Moon gravity without plastic deformation.
Return to Original State	Through dissipation of stored energy and/or active reversion, the system returns exactly to original parameters within the time limit.
Indicate Reusability	Sensors monitor parameter values over time including when parameters return to initial values.

Table 2: Critical functions and methods of testing.

1.4.2.1.3 Support Mass

To support the mass of the HLS, the materials and geometry of the structure must statically support the mass under Earth and Moon gravity without plastic deformation. This is also deemed to be one of our critical targets and metrics because failure could result in the loss of human life.

1.4.2.1.4 Return to original state

One of the critical functions of the shock absorber system is for it to be able to return to its original state before the module takes off for another landing. This will be verified by comparing the parameters of the shock absorber before and after use. If the parameters are the same, then the function has been satisfied.

1.4.2.1.5 Indicate Reusability

Since the shock absorber must be reused safely, it must prove it has returned to its original parameters. Therefore, the shock absorber must recognize its current state, which would involve the use of sensor. This sensor would monitor parameters over time, including when parameters return to initial values. To achieve this, we may use concepts of mechatronic systems and dynamics to create a system to indicate whether the shock absorber is ready to be used, shows warnings, and shows when it is not ready/safe to be used. It must clearly indicate its status for the safety of the passengers.

1.4.2.2 Additional Metrics

1.4.2.2.1 Prevent excessive rebound

To prevent excessive rebound, the shock absorber system should be designed so that any energy from landing that is not transformed is insufficient to launch the HLS past the target rebound height.

1.4.2.2.2 Transform Energy

Another function of the shock absorber system is to be able to transform the kinetic energy of the module from landing into energy that is either stored or dissipated through the shock absorber system. This will be verified when the module is brought safely to rest and thus its kinetic energy is zero, and the system has reached its steady state value.

1.4.2.2.3 Dampen & moderate vibrations

Another function of the shock absorber system is to dampen any vibrations that may result from landing. The module, if vibrating at all, will settle to its steady state value within 2 seconds. This will be verified through graphing software such as MATLAB that will allow us to see the point in time that the system settles.

Resonate frequencies within the shock absorbing system will be a concern before the lunar module even reaches the moon. The entire launch vehicle will be subjected to many low frequencies as it traverses from the surface of the Earth to the Moon. It is important that the natural frequency of the shock absorber system does not fall in the range of expected launch frequencies, because dangerous vibrations could result. Our project sponsor has advised us that there should be no problems with resonance so long as the shock absorber system's natural frequency is above 50 Hz.

1.4.2.2.4 Store and Dissipate Energy

Dissipating and storing energy are shown as two different functions in the table, but they are inversely related to each other in the sense that whatever is not dissipated must be stored. This is based upon the phenomena that energy cannot be created nor destroyed. The system must be capable of storing all the impact energy in forms such as compressed spring energy, material elastic energy, heat storage, and/or electricity. Then the entirety of the stored energy must leave the system through spring decompression, elastic deformation, thermal radiation, and/or usage of the stored electricity.

1.4.2.2.5 Withstand Lunar Conditions

The LM is planned to be reused for a period of 10 years. To achieve this, we must investigate the material strength properties under lunar and space conditions. Then, we must choose materials that will ensure a long lifespan while still being able to meet the requirements of the other targets. Extreme temperatures and extreme changes in temperatures must be considered because this condition affects material properties.

The shock must be resistant or shielded to regolith, meaning the system must be able to withstand impact of small, glass-like particles, shooting at the HLS at high speeds. We will use material science concepts, such as particulate size and diffusion, to determine the features of the shock absorbing system.

Appendix C: Targets and Metrics

FUNCTIONS	TARGETS	METRICS
Absorb Impact Energy	All Kinetic Energy (~145 kJ) is transferred into system	All kinetic energy from impact is absorbed into the system as it brings the structure to rest.
Absorb Structural Shock	Endures ≤ 3 g's of impact acceleration	System remains elastically ductile when subjected to up to 3 g's of acceleration given materials, mass, and geometry.
Support Mass	~25,000 kg	Materials and geometry of the structure statically supports the mass under Earth and Moon gravity without plastic deformation.
Return to Original State	Time ≤ 10 hours	Through dissipation of stored energy and/or active reversion, the system returns exactly to original parameters within the time limit.
Indicate Reusability	Shock absorber proves its return to 100% of original parameters	Sensors monitor parameter values over time including when parameters return to initial values.
Prevent Excessive Rebound From Surface	Rebound Height < 0.5m	The spring is designed so that the spring energy from compression is insufficient to launch system to stated rebound height when converted to its equivalent potential energy.
Transform Energy	Final Kinetic Energy = 0	Kinetic Energy from impact is completely converted into various forms of energy to be stored within the system.
Dampen Vibrations	Settling Time: 2 s	Structure becomes stationary by 2 seconds after impact.
Dissipate Energy	All stored energy leaves the system within 10 hours	The entirety of the stored energy leaves the system through spring decompression, elastic decompression, thermal radiation, and/or usage of stored electricity.
Store Energy	System has capacity to store ~145 kJ of energy	System is capable of storing the entirety of the impact energy in forms such as compressed spring energy, material elastic energy, heat storage, and/or electricity.

Figure C-1. Full targets and metrics