# FAMU-FSU College of Engineering

# Department of Mechanical Engineering

# Evidence Manual

## Team 516: Lunar Transport Design Group

**Jacob Hackett**

**Caleb Jansen**

**Noah Lang**

**Kyle Nulty**

**Hannah Rodgers**

**Date:**

**January 10, 2020**

**Table of Contents**

# Project Scope

## Project Description

NASA wants the ability to relocate their lunar bases to different areas on the surface of the Moon. However, achieving this is difficult because unlike on Earth, all materials must be either sent to the Moon fully assembled or must be assembled on the lunar surface.  NASA is set to begin the Artemis mission in 2020. A critical initial step of preparing for the journey is to deliver preliminary equipment to the lunar surface. This will be accomplished through the Commercial Lunar Payload Services (CLPS) initiative. It is in NASA’s interest develop a mobility tool that can transport payloads from a lunar lander to nearby locations on the lunar surface. Therefore, the objective of this project is to develop a full-scale simulation and scaled version of the mobility tool to transport CLPS payloads on the surface of the Moon.

## Key Goals

The key goal of the project is to develop a mobility tool that can move a scaled version of NASA's CLPS equipment. Additionally, it will be able to traverse obstacles that are present on the lunar surface. It will also be able to be controlled via remote control with the functionality defined by SAE level 1 autonomy. A full-scale simulation of the mobility tool will be delivered, as well.

The mobility tool will be capable of moving a scaled payload from one location to another nearby location through the means of translation and rotation. In order to relocate the payload, it will be capable of lifting and removing the payload from the platform. With this functionality, the mobility tool can properly transport the payload to its new desired location.

To ensure the CLPS payload will arrive at the desired destination, the mobility tool will be capable of traversing difficult terrains and obstacles found on the lunar surface. The mobility tool will be able to safely transport the life support system while also navigating obstacles such as: rocks, uneven terrain, and other conditions found on the path to the destination.

The assembly tool will be operator-controlled and in compliance with SAE 1 autonomy standards. Based on these guidelines, the mobility tool will be capable of sustained and consistent safe operations. Due to the control interface, operators will be able to visually monitor the mobility tool's movement.

Along with a scaled prototype of the mobility tool used to transport the CLPS payload, a full-scale simulation will be developed. This will be done for full validation of the conceptual design and prototyping. In order to decrease computing cost, main subsystems will be simulated individually.

**Primary Market**

The primary market of the project will be NASA - Marshall Space Flight Center. NASA is interested in establishing a lunar base, so it will be necessary to have the appropriate supplies in the desired location.

**Secondary Market**

A secondary market of this project will be the military. This technology will be useful in various missions involving logistics readiness operations. The military would benefit from the mobility tool because it would allow for transportation of base supplies and materiel throughout non permissive arid desert regions. The benefits gained by this technology will ensure increased protection and safety for military personnel deployed in combat areas. Due to the remote-piloted nature of this mechanism, overall human safety will be enhanced.

Research groups and humanitarian efforts would greatly benefit from this technology as well. For example, research teams based in Antarctica would find the easier transportation of supplies and base materials beneficial. Volunteer organizations such as the Red Cross or Doctors Without Borders would benefit from the mobility tool because supplies could be expediently and safely moved to the areas affected by natural disasters and/or disease. These areas are difficult to traverse, making the mobility technology most suitable for the task.

Within the commercial industry this mechanism will have wide-spread benefits. As an example, businesses that rely on shipping yards, train yards or warehouses would greatly benefit from this technology. The versatile load-carrying capability of the mobility tool will enable logistics and shipping companies to transport cargo containers more efficiently than standard forklifts. As seen with the emergence of companies such as Space X and Blue Origin, space travel is becoming a larger market. By utilizing the mobility tool, time, money, and other resources can be saved.

**Assumptions**

The team is only responsible for the design of the mechanism to move the CLPS payload or other similarly sized payloads; it is not responsible for the transportation of the mobility tool to the lunar surface. The design of the system will assume that some assembly is required on the lunar surface, but the components will be sent to the Moon. All testing and verification will be done under Earth's atmospheric conditions in similar terrain with consideration for the Moon's atmosphere. The team will consider the power usage of the system, but the generation will be left to the sponsor. Existing software and hardware components will be utilized as needed. The mobility tool will be built to operate under typical lunar conditions.

The mobility tool does not have to be fully constructed upon shipment to the Moon. The mechanism may have some degree of assembly on the lunar surface in order to optimize the space provided in the transportation vehicle.

Testing will be conducted on the Earth's surface under its conditions. Verification will be accomplished using specialized technology.

.

Existing software and hardware components will be utilized in the design of the project when applicable. Development of specialized hardware and software will only be implemented when no existing solution is found. Customization of existing software and hardware will be used when necessary.

Lunar anomalies will not be considered and designed for. The assembly tool will be designed for normal lunar conditions only.

**Stakeholders**

The stakeholders of this project are NASA: Marshall Space Flight Center, CLPS Providers (Lockheed Martin, SpaceX, Blue Origin, etc.), FAMU-FSU College of Engineering, senior design coordinator Dr. Shayne McConomy, and the academic advisor Dr. Christian Hubicki

NASA is the sponsor of the project and has interest in the outcome of the project due to their financial support. It will supply them with possible ideas and solutions to an mobility tool, which will be needed for future missions.

The CLPS Providers may be interested in using the mobility tool to transport their payloads. While it is their responsibility to design a lander, it may be beneficial to rely on a third-party mobility tool.

The FAMU-FSU College of Engineering has interest in the project becomes this project is a representation of the college of engineering.

Dr. Shayne McConomy has invested time into the project and oversees each senior design project, as the senior design coordinator, in order to ensure successful and positive outcome of the project.

Dr. Christian Hubicki is the team's faculty advisor on the project and has invested both time and knowledge into the project.

## Code of Conduct

### Mission Statement

Team 516 is committed to ensuring a work environment that supports honesty, integrity, respect, and positivity amongst its members. Every member of this team will be supported by each other, so that the resulting atmosphere will facilitate creativity and innovation. Each member will contribute as much as possible to this goal, and to the project.

### Roles

Each team member is delegated a specific role based on their experience and skill sets and is responsible for all here-within:

### Team Lead and Robotics Engineer - Hannah Rodgers

The team leader engineer will manage the team, develop a plan and timeline for the project, delegate tasks among group member according to their skill sets, finalize all documents, and provides input on other positions where needed.  The team leader is responsible for promoting synergy and increased teamwork. If a problem arises, the team leader will act in the best interest of the project. The team lead engineer will maintain an atmosphere of open communication, both between team members and the project sponsor, and will oversee delegation of tasks as they are deemed necessary. The robotics engineer will lead the design of the robotic and automated components of the mobility system.

**Systems and Simulation Engineer - Jacob Hackett**

The simulation engineer will be responsible for dynamic modeling and controlling of the full-scale simulation. The systems engineer will work to make sure that each discrete component will work in tandem.

**Vehicle Design Engineer - Noah Lang**

The vehicle design engineer is responsible for the design of the vehicle involving the suspension and chassis. This includes the design of the CAD model and wheel selection.

**Communications Engineer - Caleb Jansen**

The communication engineer will design and manage the resource requirements for the communication system, if applicable, and coordinates budgeting and design for the entire project. The communication engineer will calculate requirements of the communication system and plan for the needs of the sponsor and any other stakeholders.

**Logic and Image Processing Design Engineer - Kyle Nulty**

The logic and image processing design engineer will be responsible for writing the software and firmware for the functionality of the device, including but not limited to microcontrollers, microprocessors, and processing units. They will also be responsible for the image processing used in the design.

**Department Member Leads**

**Lead ME: Hannah Rodgers**

The lead mechanical engineer will take charge of the mechanical design aspects of the project and maintain the line of communication with the lead ECE and their team. The lead mechanical engineer is responsible for knowing the details of the design and presenting the options for each aspect to the team for the decision process. The lead ME will keep all design documentation for record and is responsible for gathering all reports and submitting assignments.

**Lead ECE: Caleb Jansen**

The lead electrical/computer engineer is responsible of the EE, IE, or CE design part in support of the project. The lead ECE engineer will maintain line of communication with the lead ME, keep all design documentation for record, and act as the main liaison between the ECE Senior Design instructor and the team. As necessary, the lead ECE engineer will submit relevant assignments and reports to the ECE Senior Design instructor.

For all duties not directly assigned, lead team members may delegate tasks to their respective team members and form positions as needed.

**All Team Members**

Each team member will be required to work on certain tasks of the project, as determined by the needs of the project, and actively contribute to the project as much as possible. Each member will buy into project goals and successes, deliver on commitments, adopt a team spirit, and listen to others. Criticism by team members will be constructive, not harmful or mean-spirited. Communication by each team member will be respectful, active, and open-minded. Each team member will take initiative when project issues occur.

**Communication**

The main form of communication will be in-person meetings consisting of the whole team and our respective advisors/sponsors, if available. This meeting must be attended by a simple majority of members. For the passing of information, i.e. files and presentations, OneDrive and email will be the main form of file transfer and proliferation.

Each group member must have a working email for the purposes of communication and file transference. Members must check their emails at least twice a day to check for important information and updates from the group. Although members will be initially informed via a text message, meeting dates and pertinent information from the sponsor will additionally be sent over email; therefore, it is very important that each group member checks their email frequently. Meeting agendas will be distributed through emails. All messages in the team communications must be addressed by team members at most 24 hours from the message sent time.

If a meeting with a sponsor or academic advisor must be canceled, an email must be sent to the group at least 24 hours in advance. Any team member that cannot attend a meeting must give advance notice of 24 hours informing the group of his/her absence, preferably through text message. Reason for absence will be appreciated, but not required if personal. Repeated absences in violation with this agreement will not be tolerated.

The team's communication methods are subject to the requirements given by the project sponsor, which may/or may change during the duration of the project.

**Team Dynamics**

The team members will work together, while allowing one another to feel free to make any suggestions or constructive criticisms without fear of being ridiculed and/or embarrassed. If any member on this team finds a task to be too difficult, it is expected that the member should ask for help from the other teammates and/or meet with the faculty advisor for assistance. If any member of the team feels they are not being respected or taken seriously, that member must bring it to the attention of the team for the issue to be resolved. Emotions will NOT dictate actions. Everything done is for the benefit of the project and together everyone achieves more.

**Ethics**

Team members are required to be familiar with the NSPE Engineering Code of Ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics by all team members. The team will also be subject to whatever requirements or contracts are required by the sponsor group.

**Dress Code**

Team meetings and meetings with the team academic advisor will be held in casual attire or, if required, business casual. Sponsor meetings and group presentations will be professional attire, as decided by the team per the event.

**Weekly and Biweekly Tasks**

Team members will participate in all meetings with the sponsor, advisor and instructor. During the meeting, ideas, project progress, budget, conflicts, timelines and due dates will be discussed. In addition, tasks will be delegated to team members during these meetings. Repeat absences will not be tolerated.

**Attendance**

Team members will participate in weekly meetings and blocked work times. The weekly meetings will take place between 3:30 and 7:30 pm Tuesdays and Thursdays. The required blocked project work time will take place on Fridays between 12:00 and 5:00 pm.

**Decision Making**

Decision making will be conducted by consensus and majority of the team members. Should ethical/moral reasons be cited for dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. Individuals with conflicts of interest should not participate in decision-making processes, but do not need to announce said conflict. It is up to everyone to act ethically and for the interests of the group and the goals of the project. Achieving the goals of the project will be the top priority for each group member. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss with team.
- Tentative Solutions – Brainstorms possible solutions. Discuss among group most plausible.
- Data/History Gathering and Analyses – Gather necessary data required for implementing Tentative Solution. Re-evaluate Tentative Solution for plausibility and effectiveness.
- Design – Design the Tentative Solution product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for Tentative Solution and gather data. Re-evaluate for plausibility and effectiveness.
- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

**Conflict Resolution**

In the event of discord amongst team members the following steps shall be respectfully employed, as needed:

- Communication of points of interest from both parties which may include demonstration of active listening by both parties through paraphrasing and other tools acknowledging clear understanding.
- Administration of a vote, if needed, favoring majority rule.
- Rock paper scissors (best 2 out of 3) for unimportant but conflicting decisions.
- Team Leader intervention.

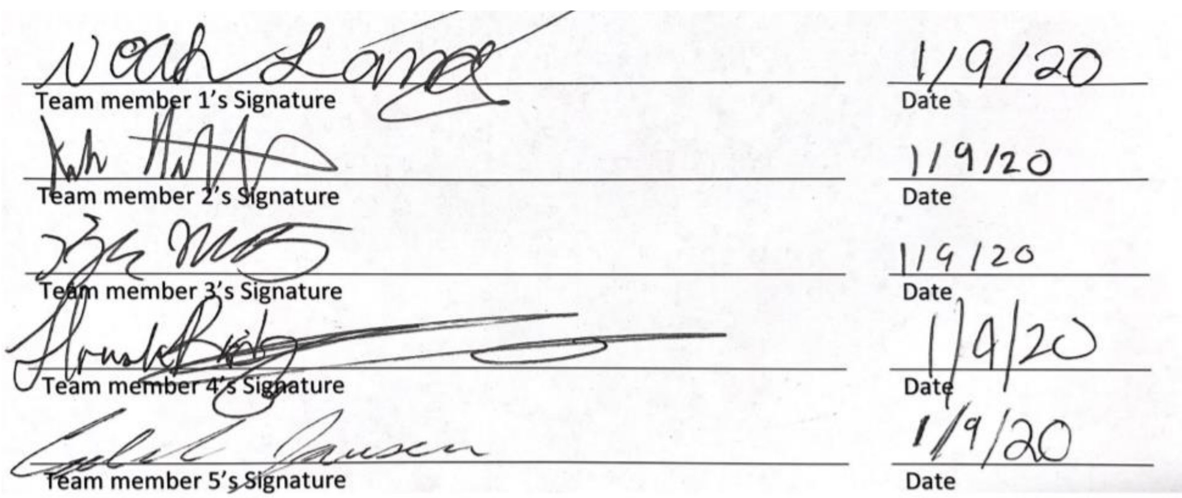
- Upon dissent about critical design decision, super majority vote will rule.
- For issues or conflicts that cannot be resolved within a week, they will be taken to our team advisor and senior design instructor for resolution.

**Process for Amending the Code of Conduct**

If changes must be made to the code of conduct, the entire team will meet and agree upon the changes. After agreeing upon the changes, the document will be amended. After amending the document, the document will be reuploaded to the OneDrive so the date of change will be shown.

**Statement of Understanding**

By signing this document, the members of Team 516 agree to all the above and will abide by the code of conduct set forth by the group.


Team member 1's Signature — Date 1/9/20
Team member 2's Signature — Date 1/9/20
Team member 3's Signature — Date 1/9/20
Team member 4's Signature — Date 1/9/20
Team member 5's Signature — Date 1/9/20

## Customer Needs

NASA is in search of alternatives to the ATHLETE life support system assembly tool. The question found in the table were emailed to the sponsor stand-in, Dr. Shayne McConomy. Until a NASA liaison is appointed to the team, these interpreted needs will be the direction that the project follows.

Table 2: Customer Responses and Interpretations

| Questions | Response | Interpretation |
|---|---|---|
| 1. How big is the payload we will be lifting? | "300 kg in earth's gravity" | The mobility tool lifts a payload with a mass of 300 kilograms. |
| 2. What are the size constraints of the system? | "4m x 4m" | The mobility tool fits in an area of 16 meters squared, fully assembled. |
| 3. What scale of a model do you expect? | "I would like this to be truly parametric which I can use a slider gain to scale down the model." | The simulation has various scaled models available for the customer. |
| 4. How detailed of a simulation? | "As a customer I would answer this with I want a full animated simulation including full physics model." | A full physics model is needed for the simulation- it lifts and transport the payload. |
| 5. Do we need to worry about how to power the system? | "This is going to be heavy machinery on the moon so I am looking for you to determine how this would be powered. I assume solar." | Powering the mobility tool will be the responsibility of the team. |
| 6. Do you want it to be fully assembled when we get there? | "As a customer of course, I want it fully assembled. My expectation would be that the any assembly needed would only require the hand tools." | Upon arrival to the Moon, the mobility tool will be able to begin lifting/transporting payloads, disregarding minor hand tool adjustments. |
| 7. Will the operator be on the Moon or on Earth? | "The operator would be on same 'planet' as the machine" | The operator of the mobility tool will be relatively close to the system. |
| 8. Do we have mass constraints? Material requirements? | "Less than 805 kg. No specific requirements on materials." | The mobility tool is less than 805 kilograms of mass. There |

| | | |
|---|---|---|
| | | are no specific materials that need be used. |
| 9. Will the system need to lift the payload and then attach it to another part of the lunar base (a docking mechanism)? | | |
| 10. Besides lifting and transporting the payload, should the mobility tool do anything else? | | |
| 11. What range do you desire? | | |
| 12. How high is the platform that we will be moving the payload from/to? | | |
| 13. Are you concerned about regolith? | "TBD, assume yes until clarified" | The design accounts for locomotion over regolith. |
| 14. Is there a specific program or software package the simulation should be done in? | "One that is industry friendly and can be shared if necessary." | Until further notice, the team will use the simulation tool recommended by our faculty adviser. |
| 15. Is there a preferred controller for the "driver" to use? | "No." | The control system to be used by the driver is at the discretion of the team. |
| 17. Is there a concern for the time needed to move a payload? | "Yes, but this will be determined later." | This is not the current focus of the design. |

After the initial needs were provided, contact was made with the stand-in sponsor. Questions were written by the team to determine the needs of the project, then sent to the stand-in sponsor through email. Based upon the responses of the contact, the interpreted needs were specifically stated and synthesized. The synthesized needs are found in the table above; however, the main needs are noted in the following discussion. These customer needs were as follows: the mobility tool will need to lift and transport the payload to other locations on the lunar surface very soon after landing on the Moon and the full-physics simulation of the model will need to vary in scale. It should be noted that the mass of the mobility tool and payload were determined to be less than 805 kilograms and 305 kilograms, respectively. The customer requires that the full-scale mobility tool fit within an area of sixteen meters squared. The power generation for the system will be the responsibility of the team, per the customer. Also, the operator of the system, since it is to be remote controlled per project scope, will be on the same planetary body as the system itself.

Overall, the contact with the stand-in sponsor, Dr. McConomy, provided valuable insight into the specific needs of the project. With the responses from the customer, the team can begin to consider how to achieve what needs to be accomplished for a successful project in terms of the customer.

## Functional Decomposition

Guided by the key goals and interpreted needs of the customer, a functional decomposition was constructed. The goals and needs were broken down into the smallest possible function accomplishable. After they were broken down, they were categorized under different overarching functions. By undergoing this task, the team can determine clear expectations of what the project must accomplish. In addition, it allows for multiple functions to be achieved with as few features as possible, therefore simplifying the final design.

Using the customer responses and project brief, table 3 was constructed to analyze the mobility tool's elementary functions.

Table 3: Functional Decomposition Cross Reference Table

| System Functional Decomposition | | | | | |
|---|---|---|---|---|---|
| *Function* | *Measure* | *Transfer* | *Control Magnitude* | *Provide* | *Convert* |
| Transmit Power | | + | | | |
| Store Power | | | | + | |
| Receive Power | | + | | | |
| Regenerate Power | | | + | | + |
| Send Communication Signals | | + | | | |
| Broadcast Signal | | + | + | | |
| Receive Signal | | + | | | |
| Process Signal | | + | + | | + |
| Identify Signal | + | + | | | |
| Detect Signal | + | + | | | |
| Translate Vehicle | | + | | | |
| Rotate Vehicle | | + | | | |
| Convert Electricity to Translational Motion | | | | | + |
| Convert Electricity to Rotational Motion | | | | | + |
| Traverse Terrain | | + | | | |
| Take Angle Input | + | | | | |
| Indicate Angle Change | | + | | | |
| Translate Payload | | + | | | |
| Secure Payload | | + | | | |
| Rotate Payload | | + | | | |
| Convert Electricity to Payload Rotation | | | | | + |
| Convert Electricity to Payload Translation | | | | | + |
| Lift Payload | | + | | | |

Having rigorous definitions for the categories of the reference table ensures that the functions can be systematically compared resulting in a comprehensive understanding of the project's priorities and goals. Using the clear and concise language defined in *Development of a Functional Basis for Design* by Robert Stone and Kristin Wood, five categories were constructed to group the functions by type: measure, transfer, control magnitude, provide, and convert. A function fell under the measure category if its purpose is to determine an information type.

Transfer designated functions that “move either material or energy from one place to another” (Stone & Wood, 2000). A function was assigned to control magnitude if it ”regulated the size or amplitude of a material or energy“  (Stone & Wood, 2000). Provide involved all functions that” accumulate material or energy” (Stone & Wood, 2000). Convert included all functions that” change one form of energy or material to another” (Stone & Wood, 2000). The primary functions relating to the vehicle movement system and the payload movement system fell under the transfer and convert category. Most of the communication system’s signals fell exclusively under the transfer category except for identify, detect, process, and broadcast signal. Identify and detect signal also fell under the measure category. Process and broadcast signal were also a part of the control magnitude category. The power system’s functions fell under the widest range of categories. The only function to fall under the provide category was the store power function.

It is crucial to properly allocate resources in order to ensure completion of the project. Using the reference table, a high-level priority list was made. The transfer category encompasses the most functions. As a result, this category and its functions take top priority as it accounts for most of the assembly tool. Convert takes the next major priority whereas measure, control magnitude, and provide are all relatively ranked the same.

As a result, the reference table was able to categorize the functions for better optimization of the assembly tool system. By identifying all functional relationships, a deeper understanding of the project’s goals was accomplished. Furthermore, a flow chart and a hierarchy can be created to break down the system into its smallest parts. In doing this, similarities in function branches can be identified. This can lead to optimizing the system to streamline its functions as much as possible by saving resources.

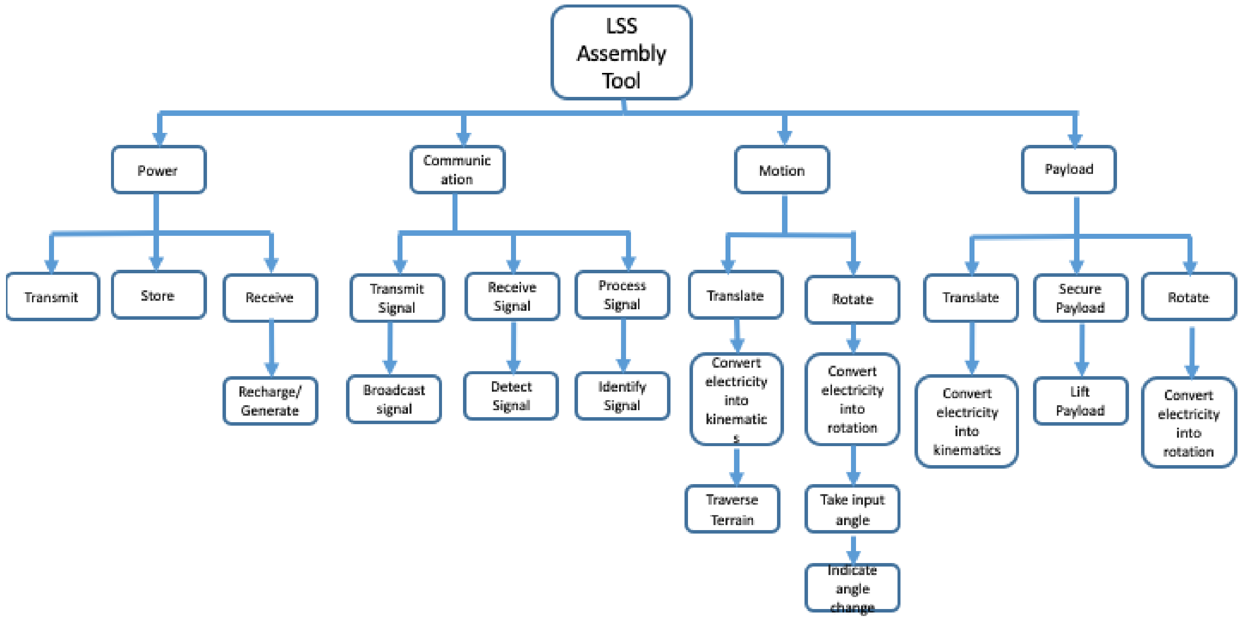



Figure 1: The functional decomposition hierarchy chart.

**Discussion of Data**

From the project objective and needs of the customer, the four primary functions of the system were identified: power, communication, motion, and payload.

In the power branch three subfunctions were identified: transmit power to the assembly tool, store the energy to be transmitted, and receive power from a source. The power reception portion of the assembly tool also requires some form of repowering. The assembly tool will be equipped with a form of energy storage allowing for continual use of the system. In addition, the assembly tool will be capable of transmitting power to its various parts and components from the storage device. The storage device will also have the capability to be replenished.

Communication is responsible for the identifying, sharing, and conversion of information between components within the mobility tool and the user. The communication branch is defined into three subfunctions: receive, transmit, and process signals. As a result, the communication system of the mobility tool will be able to detect relevant signals which will be processed for identification and then transmitted to the correct destination whether that be a system in the assembly tool or the user.

The motion branch is concerned with the assembly tool's movement on the lunar surface. The motion branch is defined by two subfunctions: translate and rotate. The mobility tool will be able to achieve translation by converting electricity from the power system into the kinetics needed to move the system forwards and backwards. The assembly tool will also be able to rotate itself by converting electricity from the power system into the kinetics needed to rotate the system with respect to the desired angle of rotation. As a result, the assembly tool will be able to provide the motion and direction to traverse over the lunar terrain.

The payload branch is comprised of three functions: translate, secure payload, and rotate. The mobility tool will be equipped with a mechanism to secure the payload to the payload movement system. The assembly tool will be able to translate the payload by converting electricity from the power system into the kinetics needed to move and lift the payload. The assembly tool will also be able to rotate the payload by converting electricity from the power system into the kinetics needed to rotate the payload with respect to the desired angle of rotation. In addition, the assembly tool will be able to rotate the payload independently from the rest of the assembly tool.

## Targets and Metrics

Based on the key goals, benchmarking of other lunar mechanisms, and the functional decomposition, targets and metrics were established. The targets are numerical values that must be achieved in order to successfully hit the goals for the mobility tool. The metrics for the assembly tool are the testing methods used to ensure that the targets are met. Not all the targets and functions of the system are independent of each other. The targets that were found to satisfy more than one function or have interconnectivity between functions were deemed to be critical functions. These critical functions are later noted and discussed in greater detail.

Table 4: Target and Metrics

| **Attributes** | **Target (Simulation)** |
|---|---|
| Transmit Power | 4kW |
| Store Power | 1-hour max stress operation / 8-hours normal operations |
| Receive Power | 16-hour recharge time |
| Send Communication Signal | 100 m |
| Broadcast Signal | 100 m |
| Receive Signal | 100 m |
| Process Signal | 0.250 ms (Response Time) |
| Identify Signal | 0.250 ms (Response Time) |
| Detect Signal | 100 m |
| Translate Vehicle | 100 m |
| Rotate Vehicle | 360° |
| Convert Electricity to Rotational Motion | 500 Nm |
| Traverse Terrain | 5 $km^2$ |
| Take Angle Input | 0-360° |
| Indicate Angle Change | 0-360° |
| Translate Payload | 2 m |
| Secure Payload | 1500 N |
| Rotate Payload | 360° |
| Convert Electricity to Payload Rotation | 500 Nm |
| Convert Electricity to Payload Translation | 500 Nm |
| Lift Payload | 300kg |
| Size | 16$m^2$ |
| Remote Controlled | 100m |
| Autonomy | SAE Level 1 |
| Power port | 120V/230V |

**How Targets Were Established**

Based on benchmarking other lunar mechanisms and the functional decomposition previously completed, targets were established. As seen in the table, the key as is follows "simulation metric/prototype metric." It is important to discern the prototype and full-scale simulation targets because they will greatly differ base on budget and dynamic scaling factors. Currently, the project targets are based solely on objective measurements; targets involving specifications of the prototype have yet to be determined fully. These objective measurements are nominal- the tolerances for success are plus or minus five percent. In order to properly determine the nominal targets for the prototype, the selected concept design should be scaled to achieve the necessary dynamic movements, thus providing the parameters of the design. As the project continues, more subjective targets, such as aesthetic, can be addressed as desired by the customer. Many of the targets for the mobility tool functions were determined from industry standards and existing technology; for example, the Apollo Lunar Roving Vehicle (LRV) had a range of five kilometers and a payload of 490 kilograms (Williams, 2016).

**Detailed Description of Targets**

The targets portion of the table only provides numerical values for the simulation. The prototype targets will be identified once the scale ability factors are determined and appropriate electronics specified. It is important to discern different targets for the prototype and full-scale simulation because they will greatly differ base on budget and dynamic scaling factors. The target's numerical measurements are nominal; the tolerances for success are plus or minus five percent of the target's numerical value. As the project continues, more subjective targets, such as aesthetic, can be addressed as desired by the customer. Many of the targets for the mobility tool functions were determined from industry standards and existing technology; for example, the

Apollo Lunar Roving Vehicle (LRV) had a range of five kilometers and a payload of 490 kilograms (Williams, 2016).

Transmitting power's target, 4 kilowatts, is a scaled benchmark based on the power necessities of an electric forklift. Storing power's target was chosen with the assumption the device will be used heavily in a short amount of time. One hour is the benchmark for using the assembly tool at max stress operation. This will allow the user enough time to move anything. 8-hours is the benchmark for use of the assembly tool under normal operations. To charge the device, a conservative 16-hour recharge time was chosen. This will allow the device to be used daily while the cost to recharge is kept low.

Sending, broadcasting, receiving, processing, identifying, and detecting a signal were all chosen based on the typical ranges for remote controlled heavy machinery (Hetronic, 2019). As a result, an identical communication metric of 100 meters was chosen.

The requested size for the device was given as 4 by 4 meters. Therefore, 16 meters squared was chosen as the target size for the completed model.

The full-scale vehicle is meant to move payloads around the lunar surface, which will require the vehicle to move a significant distance on the surface. In order to account for this, the target area to travel over was set at 5 kilometers squared. This was also chosen to match the signal range. The simulated vehicle and prototype will each achieve 360 degrees of rotation.

The assembly tool will be able to be lift, translate, and rotate the payload. To successfully complete this, the vehicle will be able to exert a force of 1500 newtons. This value accounts for a factor of safety of 3 as defined by NASA structural standards (National Aeronautics and Space Administration, 1996). With this amount of force, the full-scale simulation vehicle will be targeted to lift 300 kilograms of mass; the prototype mass will be determined through dynamic scaling. The simulated vehicle and prototype will both rotate the payload 360 degrees.

The remote-control target of 100m was established to coincide with the rest of the range goals specified by the signaling goals of the assembly tool.

SAE level 1 autonomy was not one of the functions outlined by the functional decomposition. However, it is a key goal established with the project brief. SAE level 1 autonomy includes automatic braking when objects are detected in the path of the vehicle, as well as lane detection. The lane detection will keep the assembly tool from veering off of the set path and colliding with other obstacles in the terrain.

The power port is another attribute outside of our functions. It will have capability for 120V and 240V to accommodate to different countries powering standards. The two chosen being the US and European standard power outlets.

**Explanation of Metrics**

The metrics were determined based on two different parts of the project, the full-scale simulation and the scaled prototype. These are listed in the appendix and detailed in the report below. The prototype will be tested with actual hardware, using experimental testing and validation techniques. Electrical designs, such power transmission, will be checked by a multimeter. The signal communication will be tested by oscilloscopes, to ensure that the correct signal is being sent and received. The full-scale simulation will be validated in Simscape. Simscape, a subset of Simulink, is a MATLAB program that allows the user to model physical systems. The following section describes how the prototype will be tested as the simulation will provide this information in an accessible data window. It is relevant to note that while the next section reports on the techniques used to validate the prototype's targets. The numerical values stated are the simulation's targets acting as place holders for when the prototype's targets are identified.

**Detailed Description of Metrics**

For transmission, storage, and reception of power a multimeter will be used when testing the prototype. The multimeter will be used on all electrical components to ensure the target values were met.

Testing of the send communication and broadcast signal for the prototype will be completed by using a device that will able to receive the outgoing signal. The communication and broadcasting signal will be continuously sent while the receiving end is placed at varying distances away until the signal is lost all together.

Reception and processing of the signal for the prototype will be tested using an oscilloscope. Signals will be passed into the assembly tool using an oscilloscope. Constant and varying signals will be continuously sent out from the oscilloscope. These signals will be taken in by the assembly and checked for correct reception and correct processing of the signal within the target time response of 0.250ms.

Identification and detection of signal for the prototype will be tested by broadcasting a test signal. For the identification of signal, the broadcasted signal will be checked for the desired time response. The detection of the signal will be handled in a similar manner to the testing of the send communication and broadcast signal. A test signal will be broadcasted at various distances from the signal detection function.

Translation of the vehicle will be tested by sending an input signal to the assembly tool and seeing if the it reaches the targeted value. The assembly tool will be given a path or desired destination 5 kilometers away. This desired destination will contain various obstacles indicative of terrain found on the moon's surface. For the target to be met, the assembly till traverse through the path set in place.

Rotation of the vehicle will be tested by checking the resulting angular change from an input. The rotation of the assembly tool will be measured by comparing the initial angular position to the final angular position with an encoder.

Testing of the conversion of electricity to rotational motion will occur when testing for the rotation of the vehicle. Voltage will be sent to the motors; this voltage will be checked to ensure proper power delivery. After the voltage has been provided to the motor, observation for the rotational motion will be observed. To check that the target is being obtained, a load equivalent to the target of 500 newton-meters will be subjected to the motor. A successful test will result in the applied load being moved.

Input angle testing will be completed by giving an input angle and then checking the bit signal from the interrupt. If the signal requires an output an interrupt will be sent to the CPU, executing the code for the resulting angle. The angle change will be checked by using a gyroscope to ensure for full 360° range.

Translation of the payload will be completed by measuring the difference of the starting and ending positions of the payload. An input signal will be provided to the assembly tool. The length of total translation will be measured. The test will involve translating the payload to its max distance of 2 meters to be considered successful.

Testing of the secure payload function will be done by giving an input signal to the assembly tool. The securing force of the assembly tool will be measured by applying a load of 3900 newtons to the payload system. For the testing of the target to be considered successful, the payload will not be able to move.

Payload rotation will be tested in the same manner as the vehicle angular rotation test.

Conversion of electricity to payload rotation and translation will be handled the same as the previous tests. The electrical signal will be provided to the motors. The torque output will be measured by applying the target load. For the test to be successful, a 500 newton-meter torque will be observed from both the rotational and translational motors.

Payload lift will be tested by measuring the difference of the starting and ending positions of the payload. The lifting of the payload will be considered successful if it can lift the payload 2 meters.

The size of the payload will be checked by using a tape measure for testing with the prototype.

The remote-control target will be tested similarly to signal testing. Inputs will be given to the controller at different ranges until there is no longer a response from the assembly tool.

Testing the SAE Level 1 autonomy of the assembly tool will be completed using a verity of tests. Lane checking will be completed by giving a set path and making sure it can maintain and autocorrect its pathing if there is an interference from an obstacle. Additionally, the auto-braking feature will be tested by placing a non-traversable obstacle in its path and seeing if the assembly tool stops.

Testing of the power port will be accomplished by first using a voltmeter to check the power and voltage capabilities. After the capability is ensured, standard US and European power connections will be used.

**Critical Targets and Metrics**

The critical targets are the lifting force, traversing terrain, and the distance of the communications system, as per the project brief provided by the sponsor. The purpose of the mobility tool is to move a payload about the lunar surface; to complete this task, the mobility tool must successfully lift the payload, traverse the lunar surface, and maintain steady communications between its internal components and the operator. These, as previously explained, will be tested through Simscape, experimental testing of the prototype, and an oscilloscope.

**Conclusion**

In conclusion, the targets and metrics were determined based on the project requirements, background research into similar technology, and the engineering experience of the team. As the project progresses and the sponsor is contacted, some of the targets are subject to change potentially resulting in different corresponding metrics. Overall, the goal of identifying the targets and metrics for the mobility tool is essential in determining what is needed for the success of the project.

**References**

Stone, R. B., & Wood, K. L. (2000). Development of a Functional. *Journal of Mechanical Design*, 359-370.

# Appendix A

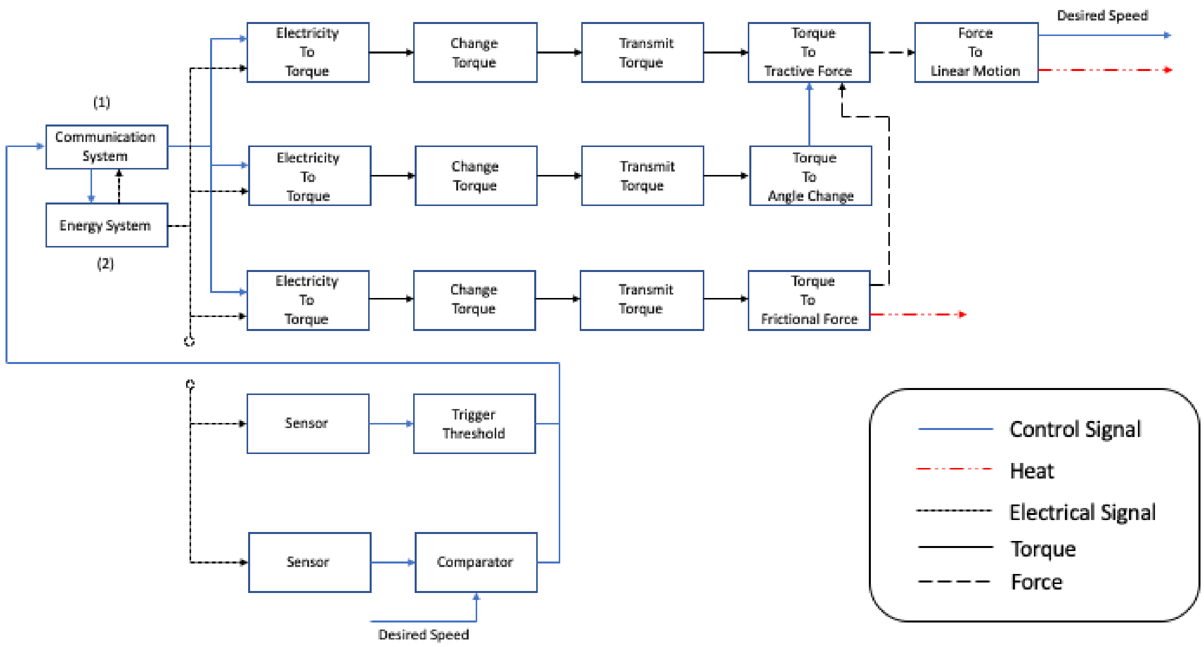



Figure 2: Functional decomposition flow chart of motion system.

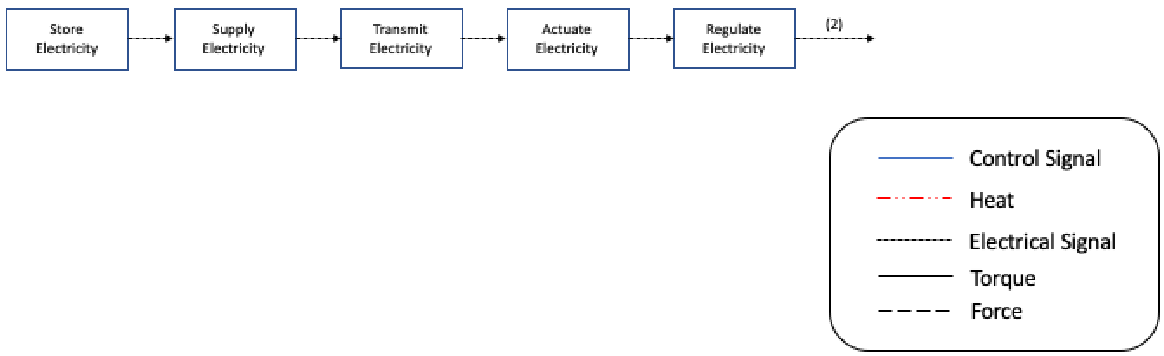



Figure 3: Functional decomposition flow chart of energy system.

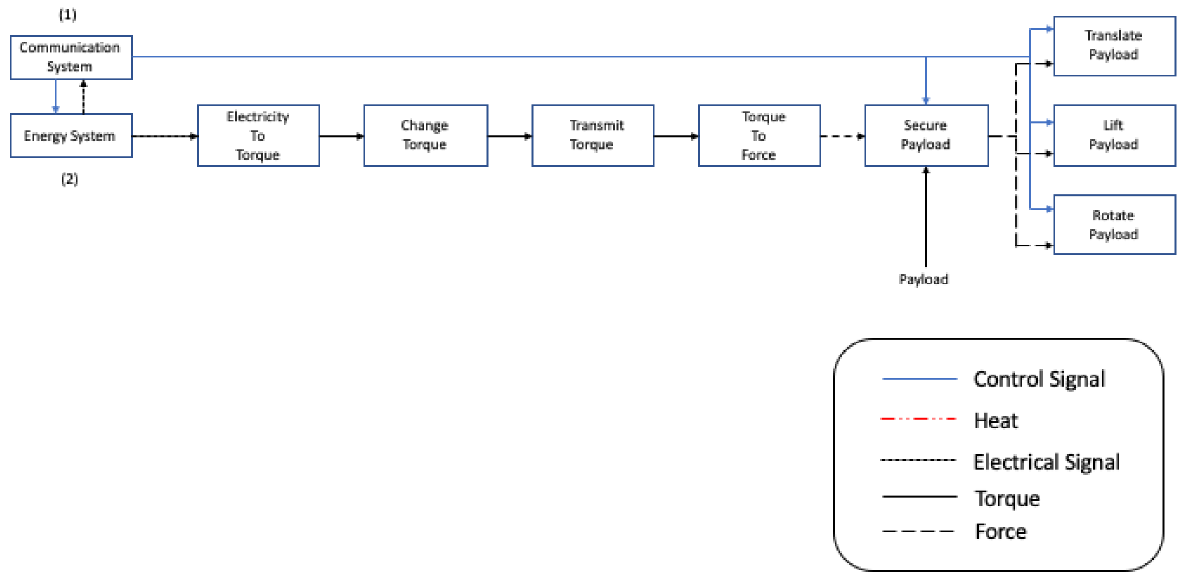



Figure 4: Functional decomposition flow chart of payload motion system.

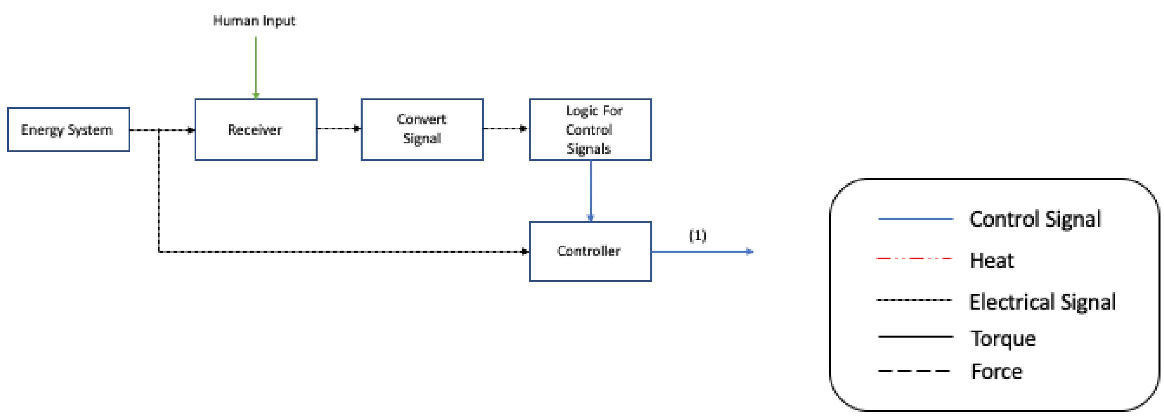



Figure 5: Functional decomposition flow chart of communication system.

The charts outline the function of each system found on the assembly tool. These systems, as mentioned previously, include motion, power, communications, and payload.

Table 1: Targets and Metrics

| Attributes | Target (Simulation) | Metric (Simulation/Prototype) |
|---|---|---|
| Transmit Power | 4kW | Simscape/Multimeter. Based off requirement for electric motor of typical forklift and requirement to lift 300 kg payloads |
| Store Power | 1-hour max stress operation / 8-hours normal operations | Simscape/Multimeter, Clock |
| Receive Power | 16-hour recharge time | Simscape/Multimeter, Clock |
| Send Communication Signal | 5 km | Simscape/Test signal at varies range until no signal is found |
| Broadcast Signal | 5 km | Simscape/Test signal at various increasing ranges until no signal is found |
| Receive Signal | 5 km | Simscape/Test signal at various increasing ranges until no signal is found |
| Process Signal | 0.250 ms (Response Time) | Simscape/Oscilloscope attached to circuit that encodes the signal |
| Identify Signal | 0.250 ms (Response Time) | Simscape/Broadcast test signal and test if it was properly processed |
| Detect Signal | 5 km | Simscape/Broadcast test signal and test if it was properly received |
| Translate Vehicle | 5 km | Simscape/Send forward signal, observe if vehicle moves forward |
| Rotate Vehicle | 360° | Simscape/Send forward signal and angular velocity desired, observe if vehicle turns |
| Convert Electricity to Rotational Motion | 500 Nm | Simscape/Send voltage to system motors, observe if motors spin |
| Traverse Terrain | 5 $km^2$ | Simscape/Send forward signal while vehicle is on |

| | | |
|---|---|---|
| | | Moon-like surface, observe if vehicle moves forward |
| Take Angle Input | 0-360° | Simscape/Check bit signal from interrupt |
| Indicate Angle Change | 0-360° | Simscape/Check gyroscope output |
| Translate Payload | 2 m | Simscape/Send forward signal to system, measure the change of distance of the payload |
| Secure Payload | 1500 N | Simscape/ Send grab signal to system, observe if system remains stable while grasping payload |
| Rotate Payload | 360° | Simscape/Send rotate payload signal to system, observe if system can rotate payload |
| Convert Electricity to Payload Rotation | 500 Nm | Simscape/Send voltage to system motors, measure torque output |
| Convert Electricity to Payload Translation | 500 Nm | Simscape/Send voltage to system motors, measure torque output |
| Lift Payload | 300kg | Simscape/Send grab signal to system, observe if system remains stable while picking up payload |
| Size | $16m^2$ | Simscape/Tape Measure |
| Remote Controlled | 100m | Give controller input at various ranges, observe response |
| Autonomy | SAE Level 1 | Check systems to meet all criteria of SAE standards |
| Power Port | 120V/230V | Use voltmeter to check capability of port |