Mars Lander Robot Recharger

Deliverable #5 – Project Plans Update

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1.0 Problem Statement

NASA has invested heavily in the exploration of Martian surfaces. This has created a drive for a more efficient means of operation. More efficient operation of Martian rovers means that weight must be reduced on the rover as much as possible to reduce power consumption given the same mission parameters. In order to reduce the mass of the rovers, power generation, communication, and sample analysis systems currently onboard Martian rovers can be moved to a stationary lander deck. Moving these systems from the rover to the deck allows a fleet of smaller, lighter rovers to perform the tasks currently performed by or planned for larger rovers. A major task in transferring these systems to a stationary lander deck is ensuring that power can be transferred to the rovers in an efficient manner.

2.0 Project Scope/Goal

Our team is responsible for transferring power from hydrogen fuel cells (HFCs) on board a stationary lander deck to lead-acid batteries (PbACs) on board mobile rovers. This system is manifested as a robotic arm with attached umbilical connections which is capable of transferring power from the HFCs to the PbACs.

A top level functional analysis diagram of our system can be seen in figure 1. The HFCs and PbACs are provided by NASA and may not be modified by our team. The team will be designing, prototyping, and testing the remaining components of the system.

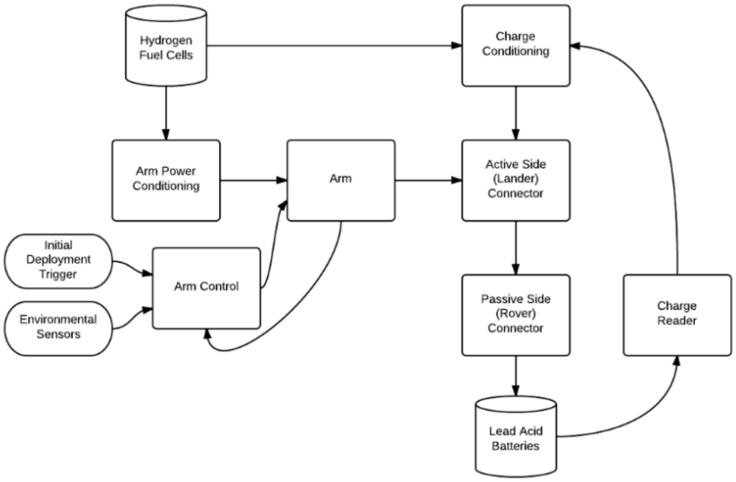

Figure 1 - Functional Analysis Diagram

3.0 Objective

The primary objective for the project is to recharge batteries onboard extraterrestrial excavators located on the Martian surface. The recharging station on the lander will function for the duration of the mission, making the teams overall objective to establish a connection using an umbilical arm from the HFC to the PbAC.

The finished prototype is to be completed no later than the end of the academic year. This dictates that the prototype must meet all of the design and performance specifications required by NASA in order to satisfy the mission objective. To accomplish this, the project must be divided into major and minor subsystems, which are to be analyzed and tested isolated from the remainder of the system.

A budget of $2000 has been approved by NASA. After completion of all major system level design, the team determined that this budget will be sufficient. The mass requirements for this project have driven the team towards a very minimal and very passive design. This has kept the total cost of the design to a minimum as well.

The team has remained in constant contact with the sponsor on site at Kennedy Space Center by hosting a conference call every one to two weeks. The purpose of these calls is to keep NASA/QinetiQ up to date on progress and changes, and to receive feedback. These calls have been instrumental in converging towards a lean and minimalist design that still meets all project specifications.

4.0 Methodology

4.1 System Breakdown

The project is divided into three major subsystems and eight minor subsystems. These subsystems can be seen in figure 2.

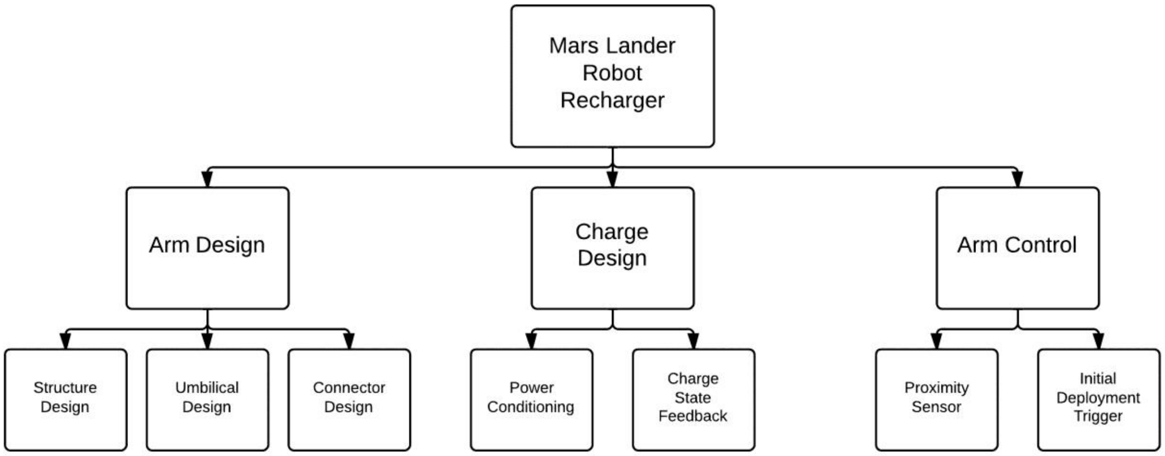

Figure 2 - Subsystem Diagram

The project is divided into three major subsystems. These subsystems are the Arm Design, Arm Control, and Charging. Within each subsystem, there are minor subsystems. The minor subsystems within the Arm Design subsystem include the umbilical design, structure design, and connector design. The minor subsystems within the Arm Control subsystem will be the proximity sensor, and the initial deployment trigger. The minor subsystems within the Charging subsystem are power conditioning and charge state feedback.

4.2 Decision Process

Design decisions will be made using the following decision matrix. Relevant criteria may be added as needed and not all criteria will be used in every decision; however, most decisions will be made using the matrix as follows and its associated weights.

Criteria	**Weighting**	**Concept #1**	**Concept #2**	**Concept #3**
Mass	.18			
Reliability/Redundancy	.18			
Volume	.14			
Robustness	.14			
Cost to NASA	.11			
Simplicity	.07			
Efficiency	.18			

After an initial design had been decided on and presented to the MEAC, a few recommendations were made that introduced an entirely new concept design to the group. From there, a few different designs arose, each more passive, simple, and efficient that the previous designs. From there, each concept was then reevaluated on the criteria described in the chart above.

5.0 Constraints

Many of the components being designed in this project will be required to meet certain constraint criteria. These constraints come from either the physical laws that govern the system or the desired operational outcomes specified by the sponsor. The three identifiable stages which the systems must be able to operate under are launch, landing, and long-term static operation. The components will need to be reliable and safe in both terrestrial testing and extraterrestrial use.

5.1 Forces

The forces exerted on a structural member, such as the desired umbilical arm depend largely on the acceleration due to gravity. The chosen design must be able to function properly in the Martian atmosphere as well as withstand the forces exerted during launch and landing. Acceleration can reach up to 3g's on manned missions, but the g-loading can be higher on unmanned missions. Because the Martian gravitational acceleration is 37.8% that of earth, the strength design of the arm will be more based upon those forces felt while in the stored position since the forces exerted on the arm on Mars will be very small.

5.2 Atmospheric Conditions

Pressure on the Martian surface is 600Pa (about 0.6% that of earth). The atmosphere is about 95% CO_2. Operation of any components using air as a dielectric, such as some capacitors, will need to be verified under these conditions. Also, any motion which uses a pneumatic piston damper or metered flow rate damper will have to be considered under the less dense Martian atmosphere.

One of the more critical atmospheric constraints which our team has to take into consideration is the frequency of dust storms. The winds on Mars can reach speeds upwards of 300mph, which can stir up the dust on the surface. Martian dust is very fine and very erosive. Any components exposed to the atmosphere on Mars will need to be capable of withstanding frequent battering by dust particles travelling at upwards of 300mph.

Lastly, an uneven Martian surface can affect the operation of the rover-lander connection. At this point, little is known about the surface characteristics of the landing site, but the team has decided on certain maximum variations from a level condition.

Maximum Elevation Change	+/- 4in.
Maximum Pitch Change	15
Maximum Roll Change	15
Maximum Yaw Change	15

5.3 Power

The transfer of power which is to be performed is a transfer from HFCs to PbACs. The HFCs are capable of producing between 24V and 32V. This power will be utilized to charge the rover and to power the arm structure. The overall efficiency of the power transfer is required by the sponsor to be at least 75% efficient, with a target efficiency of greater than 90%. Since this efficiency decreases as the arm uses more power, there is significant difficulty in designing a system which can meet this criterion.

5.4 Size

The design must be lightweight in order to be used on the mission. The sponsor has specified that all components which are attached to the lander deck must have a combined mass of under 4kg, while the components attached to the rover body must have a combined mass of under 2kg, with a target mass of under 1kg. This adds significant difficulty in design, as the parts must be as cheap as possible, while still withstanding all necessary forces, convert power efficiently, and be light enough to be practical on the Martian surface.

The design must also be compact in order to be used on the mission. The passive (rover) side of the connection must be capable of being accessible without interfering with the mission of the rover. The active (lander) side of the connection must be fully contained within a protective 3m diameter shroud provided by NASA in transport to the Martian surface.

5.5 Positioning and Accuracy

The project sponsor has indicated that the rover will be able to move to any position requested to an accuracy of 1in. in any horizontal direction (forward, backward, left, and right).

5.6 Safety

Our sponsor has specifically requested that we ensure a safety feature in designing our electrical circuits that protect the workers at NASA when working on the charger prototype. Charging should only begin when a voltage potential is present. This would keep workers in the lab safe in case of a tool or a body part accidentally making contact with the charge plates that could harm them. This will also prevent from burning out our circuit as well.

6.0 Deliverables

6.1 Work Breakdown Structure

The project can be divided into three primary subsystems. These are the arm design, charge design, and arm control subsystems. These can be further divided into secondary, tertiary, and at times, quaternary subsystems. The work breakdown structure can be seen below.

- 1 Mars Lander Robot Recharger
  - 1.1 Arm
    - 1.1.1 Umbilical
      - 1.1.1.1 Content
      - 1.1.1.2 Material Selection
      - 1.1.1.3 Location
    - 1.1.2 Structure
      - 1.1.2.1 Geometry
        - 1.1.2.1.1 Force Analysis
          - 1.1.2.1.1.1 Static Forces
            - 1.1.2.1.1.1.1 Force and Moment
            - 1.1.2.1.1.1.2 Stress and Strain
          - 1.1.2.1.1.2 Dynamic Forces
        - 1.1.2.1.2 Computer Aided Design (CAD)
      - 1.1.2.2 Material Selection
    - 1.1.3 Connector
      - 1.1.3.1 Geometry
      - 1.1.3.2 Computer Aided Design (CAD)
      - 1.1.3.3 Material Selection
    - 1.1.4 Manufacture
    - 1.1.5 Testing
  - 1.2 Charging
    - 1.2.1 Conditioning
      - 1.2.1.1 Voltage Regulation
      - 1.2.1.2 Testing/Debugging
      - 1.2.1.3 Ripple Dampening
    - 1.2.2 Charge State
    - 1.2.3 Lab Safety
  - 1.3 Arm Control
    - 1.3.1 Initial Deployment Trigger
    - 1.3.2 Lab Safety Control

6.2 Task Dependencies

Each task in our project is dependent on each of the other tasks. There is a certain workflow which must be followed in order that certain design decisions may be made which depend on previous design decisions. The task dependencies can be seen clearly in figure 3.

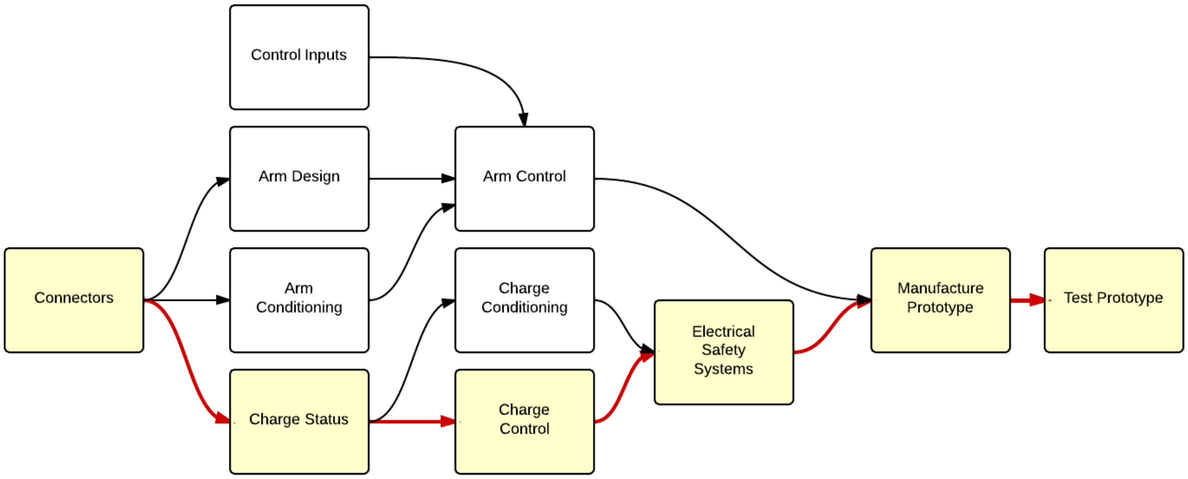

Figure 3 - Task Dependencies

The critical path is highlighted above. It was deduced by the team that these stages of development should consume the most time and therefore have no slack time. The overall timeline of the project and different stages of development are determined by this path. QinetiQ has requested a number of electrical safety systems to be designed for protection during testing in the lab. This change paired with the lack of sophisticated arm control has altered the critical path.

6.3 Gantt Chart

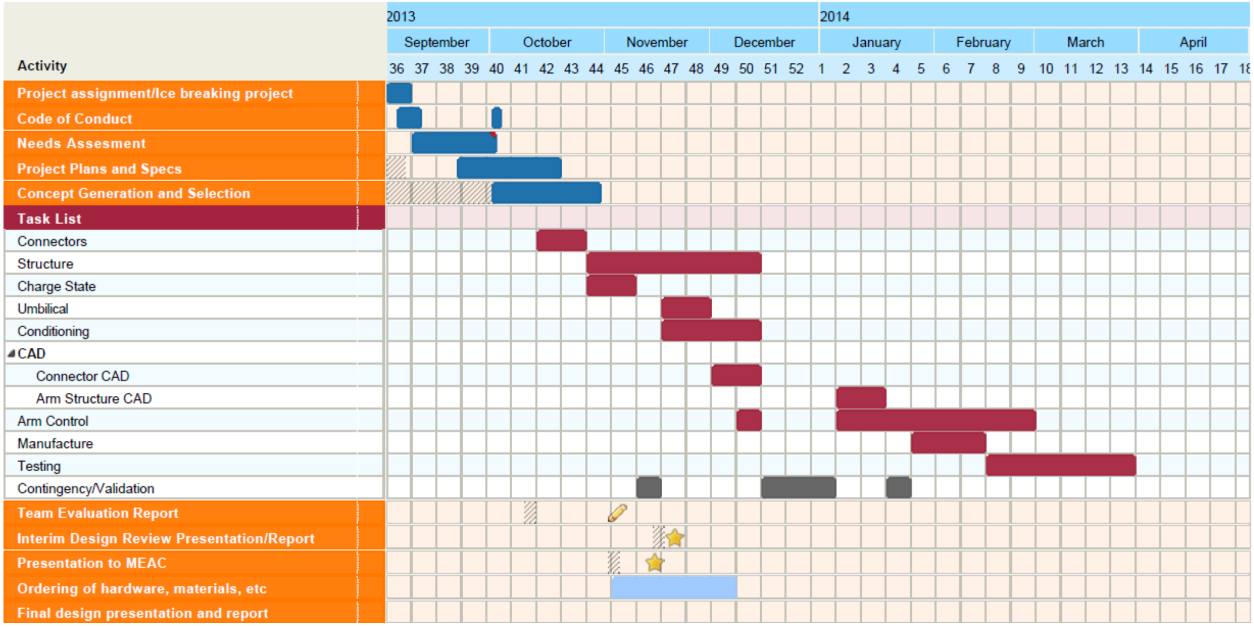

Figure 4 - Gantt Chart – Entire Team

7.0 Assignment of Resources

7.1 Human Resources

The team will be working on assigned tasks at the time stated in the Gantt Chart present in Appendix A. The tasks will be completed in the order listed on the figure 4 in section 6.3 of this report. All team members will collaborate in weekly team meetings and all deliverables will be written collectively by the team, with the members contributing data based on area of responsibility. The team will continue speaking regularly with the sponsor in order to provide status updates and receive feedback regarding status of purchase orders and other relevant issues.

7.2 Financial Resources

The current allocated budget for the project is $2,000.00. The team provided a budget proposal (found in Appendix B) to NASA in November. The budget was approved, with the only stipulation being that the team is to order all parts through NASA. The team has received the initial purchase order and has placed orders for remaining parts.

8.0 Product Specifications

Each of the specifications in this report were obtained either through contact with Ivan Townsend, our QinetiQ point of contact or our own research.

8.1 Lander and Rover Geometry

The lander deck shape is an octagon with a 9-foot distance point to point and stands 1.2 meters (3.9 feet) above the Martian surface as shown in Figure 5.

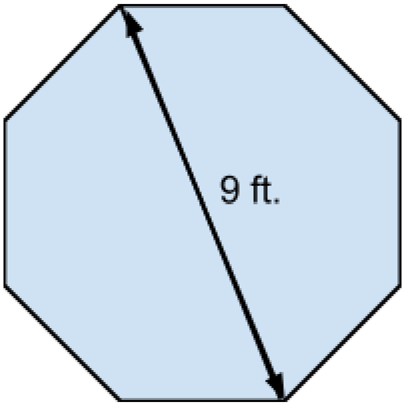

Figure 5a - Top View of Lander Deck

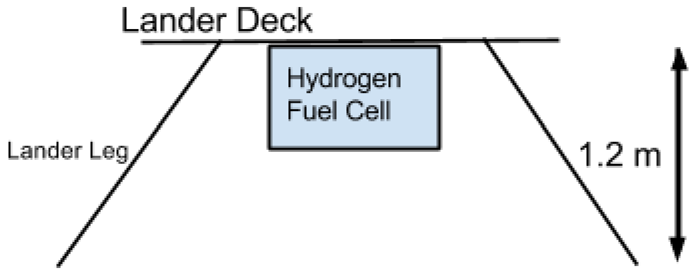

Figure 5b – Side View of Lander Deck

A hydrogen fuel cell is located in the belly of the lander and provides electrical power for the lander systems and rover recharging system. During space transit, the lander is stored inside a 3 meter diameter shroud which surrounds and protects the lander. The arm is to be stowed in transit to the Martian surface and deployed upon landing. The team is to design an arm to hang only off the top of the actual deck and cannot be attached to the side or bottom of the lander. The arm, which we are to design, will deliver power to excavators, which are approximately shin height (about 2 feet in length).

8.2 Lander and Rover Electrical Power Parameters

The lander is equipped with HFCs, capable of delivering an output voltage between 24 and 32V. The PbaCs will start at approximately 50% charge, and are required to be charged to 100% capacity in less than 8 hours. The minimum efficiency of this process is limited to 75% with a target efficiency of above 90%.

The lead length we are given with the umbilical wires coming form the hydrogen fuel cell is a maximum of 12ft. This lead will dictate how long we can make our arm to connect the umbilical to the plate connection.

8.3 Lander and Rover Connection Mass

The mass of the umbilical arm is restricted to be less than 4 kilograms. This includes the umbilical itself and any motors, motor drivers, or structural mounts. The mass of the passive side (rover connection) is restricted to be less than 2 kilograms with less than 1 kilogram preferred.

9.0 References

[1] http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html
[2] http://www.afcenergy.com/technology/advantages_of_alkali_fuel_cells.aspx
[3] http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf
[4] http://en.wikipedia.org/wiki/Atmosphere_of_Mars
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[9] http://quest.nasa.gov/aero/planetary/mars.html
[10] http://www.jpl.nasa.gov/news/press_kits/MSLLaunch.pdf

Appendix A

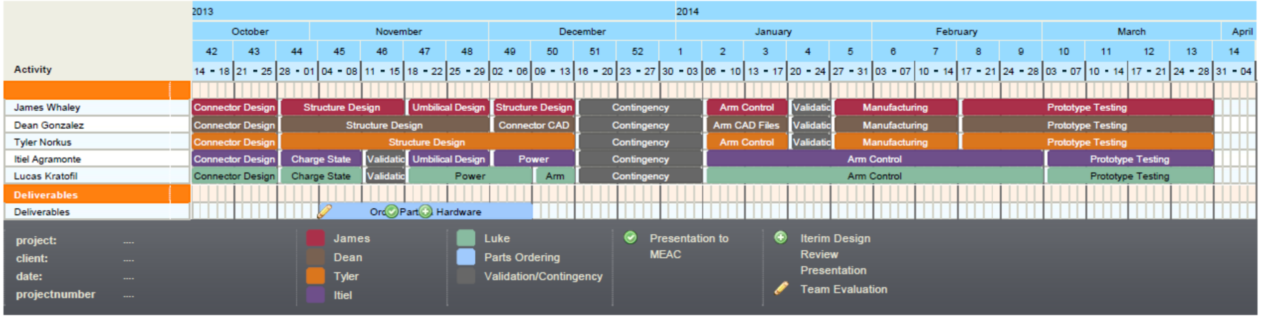

Figure 6 - Gantt Chart - Individual Division of Work

In figure 7 (above), the individual tasks are divided amongst the team members. This division of responsibility has been assigned based on expertise and item urgency. All team members have agreed on the current division of responsibility, but every team member will have full access to the work being completed by every other member.

Appendix B

PURPOSE:

To identify the monies required to fund the research, design, prototyping, and testing of a recharging apparatus for a Martian rover; and to justify the purchase of materials for the project. The current proposed budget is $2,000.00. Listed below are the materials vital to the completion of the assigned task.

	Cost (in USD) to Prototype as Designed
Prototyping	
Materials	
Carbon Fiber Tubes – 5 @ 3ft	340.00
Al6061 Plates – 3 @ 8”x8”x0.25”	44.40
Zinc plate – 2 @ 12”x12”x0.010”	13.30
Magnets	
Active Side – 2ft @ 1” wide	1.06
Passive Side – 2ft @ ½” wide	0.62
Motor	364.36
Microcontroller	199.00
Sensors	50.00
Wires – Silicone Wire – 4 @ 3ft	43.80
Integrated Circuits	15.00
Nuts, bolts, etc.	20.00
Spring	8.30
TOTAL COST TO PROTYPE	1099.84
Testing	
Lead Acid Batteries – 2@12V and 5 A-hr	43.34
Breadboards – 5	67.50
Cement – 1 large bag	8.43
TOTAL COST TO TEST	119.27
SHIPPING AND HANDLING CHARGES	250.00
UNFORESEEN EXPENSES	530.89
GRAND TOTAL	**2000.00**

JUSTIFICATION:

The team at the FAMU-FSU College of Engineering intends to create a recharging apparatus for rovers on the Martian surface. In order for this to take place, research must be completed, designs must be evaluated, and a functional prototype must be fabricated and tested. In substance, the rover will be recharged by transferring power from a Hydrogen Fuel Cell (HFC) source situated on a Lander deck, via an external physical connection with a redundant capacitive power transfer to the Lead acid Batteries (PbACs) on the rover.

The requirements for the recharging apparatus in mass and efficiency of power transfer dictate that the subsystems designed be of minimal size and weight, while maximizing power transfer. All of the larger components, therefore, must be composed of lightweight and mechanically strong materials. The decision to use Carbon Fiber tubing decreases the weight of the entire apparatus by up to 50% as compared to designs comprised of aluminum alloys of the same dimensions. However, aluminum plates are used at the connection itself due to the high conductivity as compared to Carbon Fiber and low weight as compared to other materials. A protective metal plating will be applied to the aluminum plates to increase the mechanical strength of the connection itself.

Magnetic strips are being used to help attract the active and passive sides of the design towards each other. This magnetism helps to maintain close proximity, which will increase the efficiency of the wireless transmission.

The microcontroller, motor, and sensors are being used by the charging apparatus to enable the initial release from the storage position into the charging position and to alert the active side of the charging unit that the passive side is in the vicinity. Any active controls determining the position of the unit will be run by the microcontroller.

The wires and integrated circuits are necessary in order to bring power from the Hydrogen Fuel Cell (HFC) source to the Lead Acid Batteries (PbACs) on the rover. The wires are the physical mechanism which will be carrying the voltage from the HFC to the PbACs, with the integrated circuits being used to step up and step down the voltage when and if necessary.

The nuts and bolts will be used in the securing of the various components together, both within the charging system itself and connecting the active and passive sides to the Lander deck and Rover body, respectively. The spring is to be used for passive vertical positioning of the connection to account for imperfect surface contact due to machining and possible imperfections on the Martian surface.

The breadboards and PbACs will be used in testing. These components will be used to simulate the various circuits which will be present on the final design, but which would be too expensive to purchase for the purpose of testing.

The large bag of cement mix will be used to simulate the dusty Martian environment within which the design must be capable of functioning. Due to the large dust storms on Mars, the dust will be a hazard to the components if not properly encased and protected. The cement is an artificial source of dust similar in consistency to Martian dust in structure and size.