Mars Lander Robot Recharger

Deliverable #3 – Midterm Report 1

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1.0 Executive Summary[1]

NASA has invested heavily in the exploration of Martian surfaces. This has created a drive for a more efficient means of operation. Achieving this goal requires higher fuel efficiencies and a lower rover mass. Since a large percentage of a spacecraft's mass comes from fuel, reducing fuel mass reduces the total rover mass and allows the rover to operate more efficiently. Other large contributors to the mass of mobile rovers are charging and energy storage systems. Large solar arrays and radioisotope power generation systems can be heavy. A mission that includes a stationary charging base trades rover mobility for efficiency. One drawback of this strategy is that the rovers must stay within a predetermined radius of their charging station, but gain efficiency by reducing the amount of onboard power storage. Moving the power generation, communication, and sample analysis systems to the stationary lander base significantly reduces rover mass. NASA has an existing Martian lander with several technologies on the deck. The lander will remain stationary and generate power via a bank of hydrogen fuel cells. This power must be transferred to excavators on the surface to charge batteries aboard excavators[2].

2.0 Project Overview[1]

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.

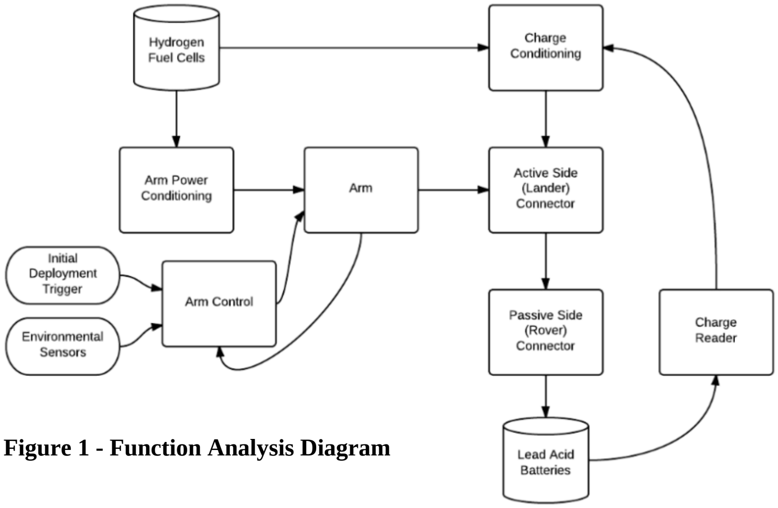

Figure 1 - Function Analysis Diagram

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[1] Sections 1.0 and 2.0 of this report are taken from sections 1.0 and 2.0 of the Project Plans and Product Specs produced by this team.

[2] The excavators being used are the commercially available ATRV-Jr., which are purchased from iRobot Corporation.

3.0 Design and Analysis

The team has identified three key subsystems which will need to be designed in order to complete the directed task. These subsystems are the Connection, Arm, and Charge. The connection subsystem is the primary subsystem to be designed. The connection and all considerations which that design entails will dictate what designs for the arm and charge may be considered and which must be discarded.

3.1 Function Analysis

The top level function analysis diagram for the system to be designed can be seed in figure 1 in section 2.0 of this report. Task dependencies, workflow, and critical path can be seen in figure 2 below.

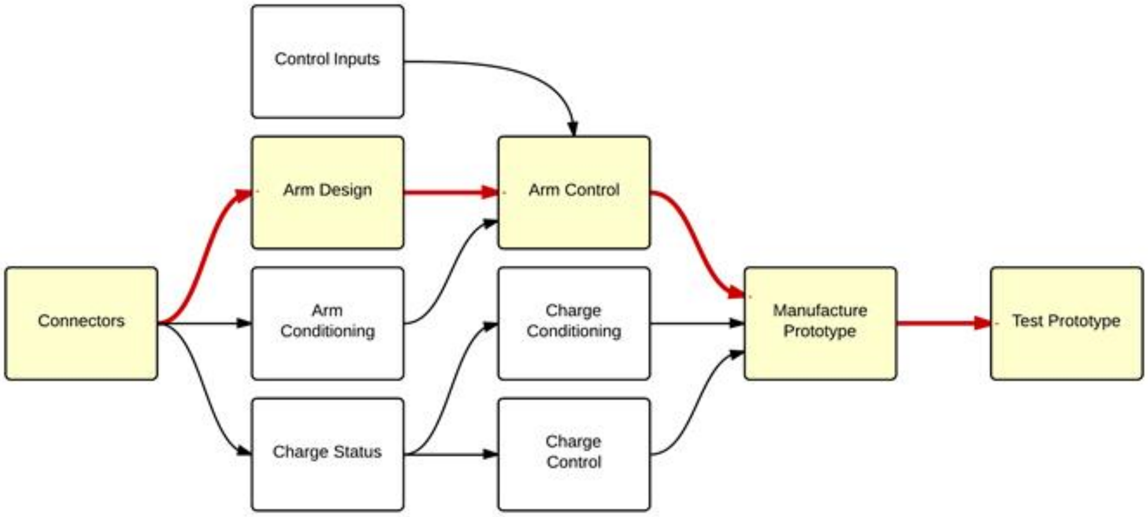

Figure 2 - Task Dependency and Critical Path (Highlighted)

Due to the critical path, the team has spent a majority of time thus far working on a design for the connection between the robotic arm and the rover. This design is crucial to the success of the project as a whole and will mandate what designs in both arm design and charge must be considered and which may not.

3.2 Design Process

In designing the connection, the team determined that the most crucial design decision to be made was the type of power transfer that was to take place at the connection point. The two choices apparent to the team were contact and wireless power transfer. Contact power transfer was defined to be the traditional method of power transfer with a typical male and female plug of various shapes and sizes. Wireless power transfer involves many different methods. The team initially considered three methods of wireless power transfer, which included inductive, laser, and microwave power transfer.

While researching additional methods of power transfer, the team began research on capacitive power transfer (CPT), which led to a unique solution, which is an external contact with CPT backup system. Based on scholarly papers researched and preliminary tests performed by our team, this method of power transfer is capable of producing between 65% and 90% efficiency. Since the power transfer efficiency requirement given to the team is a minimum of 75% with a target goal of 90%, this power transfer method will be capable of producing the desired power transfer, given optimal design of other components.

A decision matrix (found in Appendix A of this report) was used to determine the best form of power transfer. Due to the large ranges present when considering many design possibilities within each method of power transfer, a clear choice was not found; however, wireless power transfer was determined to be the weakest eliminate the lowest performer amongst the three methods of power transfer. All designs considered from this point onward fall only into the categories of a contact connection or the contact/CPT hybrid.

3.3 Design Concepts and Evaluation

The six remaining design concepts[3] (three for each method of power transfer) were compared using the following decision matrix.

	Weight (%)	Single Pin Plug	Paddle with Slot	Paddle with Clamp	Blunted Cone	Moving Plate	POCCET[4] Station
Mass	20	8.5	6.5	6	6.5	8	8
Reliability	16	7.5	8	8.5	8.5	9	8.5
Volume	12	9	8	7	7.5	8	7.5
Robustness	12	3.5	7	6.5	8	7	8
Simplicity of Design	8	9	8	7	7	8	7
Simplicity of Use	12	4	4	5	9	7.5	8.5
Efficiency	20	10	10	10	7	7	7
Total[5]	100	7.6	7.5	7.34	7.56	7.8	7.78

It was initially desired that this decision matrix would make the final decision about the connection, however it was seen that there is not much separation between the first and second or

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[3] Images and brief descriptions for each design can be seen in Appendix B of this report.

[4] POCCET is an acronym for Passively Operated Contact CPT-hybrid Energy Transfer

[5] All totals for individual designs are the weighted totals. The maximum possible score is 10.

the third and fourth ranked concepts. The team then did qualitative analysis of the four best concepts. This qualitative analysis took the form of a pro versus con list for each of the concepts. The pro versus con lists can be seen in Appendix C of this report. After considering the two decision matrices and the qualitative list of pros and cons for each concept, the POCCET system was chosen as the final design.

4.0 Programming Needs and Control

In accordance with the name of the system chosen, the arm will be mostly passively operated. The majority of programming and control will be within the rover itself. The main idea behind this design decision is that the rover comes with precise control onboard which allows the operator at NASA to drive the rove to a very precise location on the Martian surface. The plate attached to the lander deck will not move from its position unless forced to by the passive controls. The passive controls are magnets which will attract the two plates, moving the lander side connection as necessary. The plate will have certain limited movements allowed in the lateral, longitudinal, and vertical directions, as well as a certain degree of yaw which will be permitted.

The only active control which the arm has is the control which will be the deployment from the transit position to the usage position. The transit position will need to be stored within the 3m shroud which is provided for all components on the lander deck, while the usage position will need to be capable of reaching the rover outside and below the lander deck. The usage position will be permanent due to the lander deck remaining on the Martian surface.

5.0 Procurement

Our team has scheduled ordering of parts to be done during the month of November (see Gantt chart in section 8.0 of this report). In order to order parts for the completion of the project, the team needs a final budget from NASA. The tentative budget has been set at $2,000.00, but the team has been instructed to determine what the necessary budget is. The team therefore set out to find the funds necessary to finish the project by the given deadline of the end of the academic year. Appendix D of this report includes the proposed budget for the team and justification for all expenses. The team has determined that $2,000.00 should be sufficient to complete the project as desired. The budget proposal will be sent to the sponsor during the week of October 28, 2013; the team will begin purchasing funds as soon as the budget has been allocated for our use by the sponsor.

All parts will be purchased from vendors which provide the desired item at the best price by a reasonable date of delivery. The team expects to purchase most items from McMaster-Carr, Jameco, and Home Depot.

6.0 Conclusions

The team has been instructed to create a recharging apparatus present on a Martian lander deck which is capable of recharging the batteries onboard Martian rovers. The central design on which all other design decisions must be based is the connection design. The connection design incorporates both the connection type (physical or wireless) and the connection geometry. All other design considerations depend on the design of the connection.

The connection designed by the team uses contact with a CPT backup as the power transfer method and square plates as the connection geometry. These decisions dictate what may and may not be done as the team divides work on other designs over the next few weeks as defined in section 7.0 of this report.

7.0 Future Work

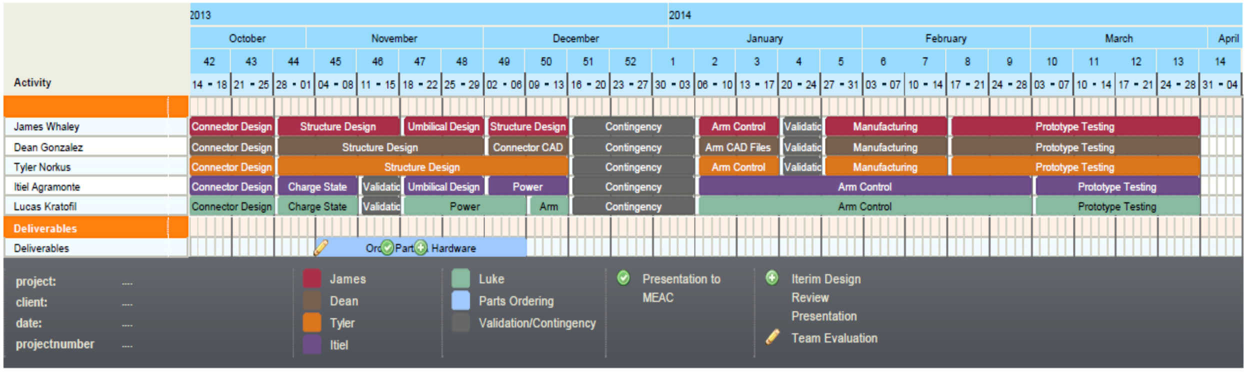

Figure 3 - Individual Work Gantt Chart

The future work for the team as a whole is broken down individually into assigned specific tasks as shown above in Figure 3 above. As planned, the choice for a connector design has been made. The team is currently in the process of making final decisions on the connection to include the material and dimensions. The team is beginning work on the arm structure design and the charge state. The team will make decisions to include dimensions, materials selections, and connections between the various subsystems over the next couple of weeks.

The next step is to come to a structural geometric decision for the moving arm that is holding the connector plate. This task will be handled by strictly the mechanical engineers on the team. The movement and degrees of freedom of the moving arm will be a major decision at this step of this process. The types of joints, dynamic and static force analysis, leading to the materials selection for the arm as well will be affected by the how the arm moves dynamically through space. CAD programs will be used heavily in this stage of the process to further visualize as well as further analyze the design. During this stage, the electrical engineers on the team will develop the charge state of the connector to the rover, as well as the umbilical power to the rover. The design for the umbilical connections running along the arm that connect the connector from the lander to the rover connector on the arm will be handled as well. All of the above tasks are predicted to take just over a month in duration and are expected to be completed by the end of November. Time for contingency is allotted for all members to finish their tasks and integrate the smaller parts into the larger whole at the completion of each task.

At the start of January, once the arm structure and umbilical decisions are established, the arm control will be the major task. The type of structural design and the movement chosen, governs the control analysis of the arm. The team as a whole will all have major individual tasks based on specialty involving the circuitry, software programming, and implementation of various mechanisms such as specific motors and sensors to control the arm to be able to move properly in order to dock and make a connection with the rover.

Overall manufacturing will be conducted once the arm is fully designed and analyzed thoroughly. This is predicted to begin at the start of February at the latest. Materials for the manufacturing of the arm will be previously ordered before the end of the December and are expected to arrive well in time to begin building the overall design. Prototyping of the manufactured designed will be tested, analyzed and adjusted due to results found. This is the last step for the team until the final goal desired for the project is reached by the end of April.

8.0 Gantt Chart

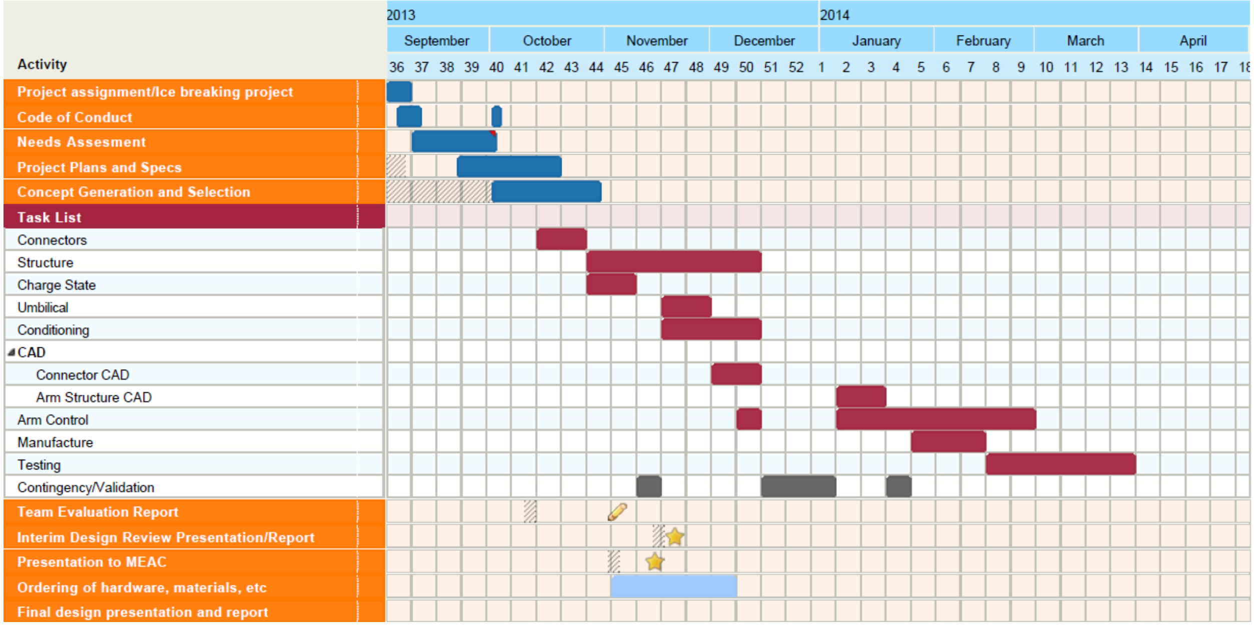

Figure 4 - Overall Gantt Chart

The Gantt chart in figure 4 above shows the way that all individual tasks fit into the whole scope of the project. The team is using this aggressive pace in order to catch up with the timeline which we feel allows adequate time for testing of the final design.

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
[5] http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1554624&tag=1
[6] http://www.jameco.com/Jameco/Products/ProdDS/178597.pdf
[7] http://www.space.com/16907-what-is-the-temperature-of-mars.html
[8] http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/What_Is_the_Temperature.html
[9] http://quest.nasa.gov/aero/planetary/mars.html
[10] http://www.jpl.nasa.gov/news/press_kits/MSLLaunch.pdf

10.0 Appendices

Appendix A – Power Transfer Method Decision Matrix

	Rank (%)	Wired	CPT	Wireless
Mass	20	8-10	6-9	4-8
Reliability/Redundancy	16	6-7	7-9	10
Volume	12	8-10	5-8	7-9
Robustness	12	4	6-9	6-9
Simplicity – Design	8	10	7	6
Simplicity - Use	12	6	8-9	8-9
Efficiency	20	10	7-8	5
Total	100	7.23-8.0	6.31-8.19	6.15-7.62

The above Decision Matrix includes ranges in some categories due to the variety of concepts which are present in that power transfer method.

Appendix B – Design Concepts

Figure 5 (to right) is a simple representation of a single pin and socket design. This charge connection represents the simplest iteration of the physical connection. The male end and female end would fit together to bring power from the lander deck to the rover. Problems with this concept included the ease of stressing the male end and the very difficult arm control.

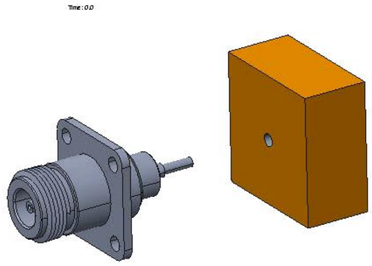

Figure 5 - Single Pin and Socket

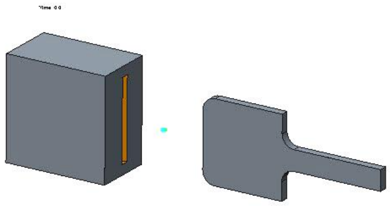

Figure 6 (to left) is a representation of a modified physical connection. This iteration sought to alleviate the stress issue present in the single pin concept (figure 5). This concept still had the problem of very difficult arm control, however.

Figure 6 - Paddle with Slot

Figure 7 (to right) is a representation of the third physical connection concept. This concept takes the paddle with slot concept (figure 6) and attempts to eliminate the issues regarding the difficult arm control. The clamps can press together against the paddle, which can then rotate to achieve perfect contact points. This concept has a significant amount of problems regarding the Martian dust which is so prevalent. That dust can get in the grooves that the clamp travels in. This could cause problems with this design.

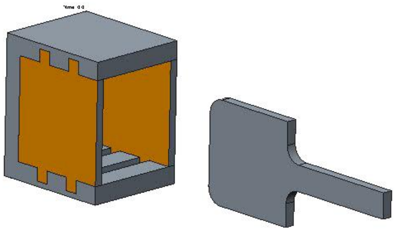

Figure 7 - Paddle with Clamp

Figure 8 (to right) is a representation of the first concept utilizing the Contact-CPT hybrid method of power transfer. The cones do not allow dust to gather on any surface, but in analyzing this design, it became immediately apparent that the largest issue with this design is the difficulty in manufacture. The rounded edges and desire for near perfect contact causes very small tolerances in manufacture.

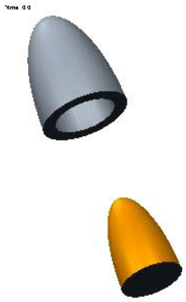

Figure 8 - Blunted Cone

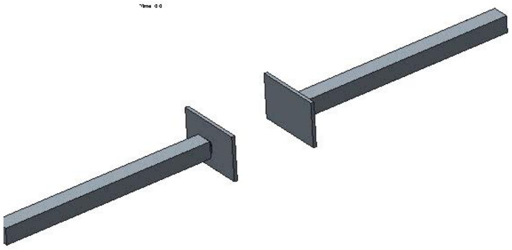

Figure 9 - Moving Plate

Figure 9 (to left) is a representation of the second concept utilizing the Contact-CPT hybrid method of power transfer. The two plates are flat, nearly eliminating the tight geometric tolerances in manufacture, but reintroducing the arm control difficulties present in concepts 1 and 2 (figures 5 and 6).

Figure 10 (to right) is a representation of the third concept utilizing the Contact-CPT method of power transfer. This concept is a derivative of the moving plate concept. The primary difference is the outsourcing of active control to the rover body. The plate connected to the lander deck is semi-stationary, utilizing only passive controls to ensure proper contact can be achieved.

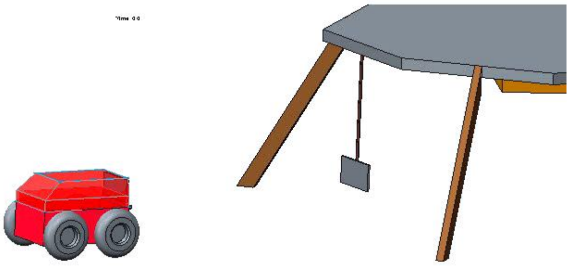

Figure 10 - POCCET station

Appendix C – Pro versus Con Lists

	Single Pin Socket	Blunted Cone	Moving Plate	POCCET Station
Pros	- Simple - Light - Symmetric - Efficient	- Symmetric - Resistant to dust - Simpler Arm Control	- Resistant to dust - Easy to manufacture	- Minimal Arm Control - Easy to Prototype and Test - Resistant to dust
Cons	- Dust - Sophisticated Arm Control - NASA/QinetiQ says to avoid if possible	- Difficult to manufacture - Requires Strict Dimensional Tolerances	- Sophisticated Arm Control - Wind - Not Symmetric	- Not symmetric - Requires static Martian surface - Wind

The above pro versus con lists are the qualitative analysis used to choose between the top four concepts taken from the decision matrix in section 3.3 of this report. The design chosen was the POCCET Station by unanimous agreement of the team.

Appendix D – Budget Proposal

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	182.18
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	917.66
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	200.00
UNFORESEEN EXPENSES	500.00
GRAND TOTAL	**1736.93**

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.