



Pathfinder Lander Rover Recharge System, and MARCO POLO Controls/ACME Regolith Feed System Controls and Integration Regolith Resources Robotics Intern

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Pathfinder Lander Rover Recharge System

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The next huge step in the National Aeronautics and Space Administration (NASA) is to land humans on the Mars – otherwise known as the infamous “Journey to Mars”. This is a colossal undertaking by the governmental agency that is going to require some brand new innovation and breakthroughs. Mars is rich with history that is very useful to the extraterrestrials here on Earth because they are hoping to study the atmosphere, terrain, etc. of the red planet because it could very well help them with their own planet’s history and future since it is seemingly similar to Earth. However before humans can be sent to explore the mysterious planet, Landers and Rovers must be sent first to help pave the way for the future, such as the Curiosity Rover. As part of the initiative to ensure the rover’s use is maximized, the goal of the robotics intern was to create a trade study that would look into various ways to utilize the arm of the Lander and design and develop a way to take power from the Lander, allow the Martian rovers to dock to the station, and recharge the various kinds of batteries.

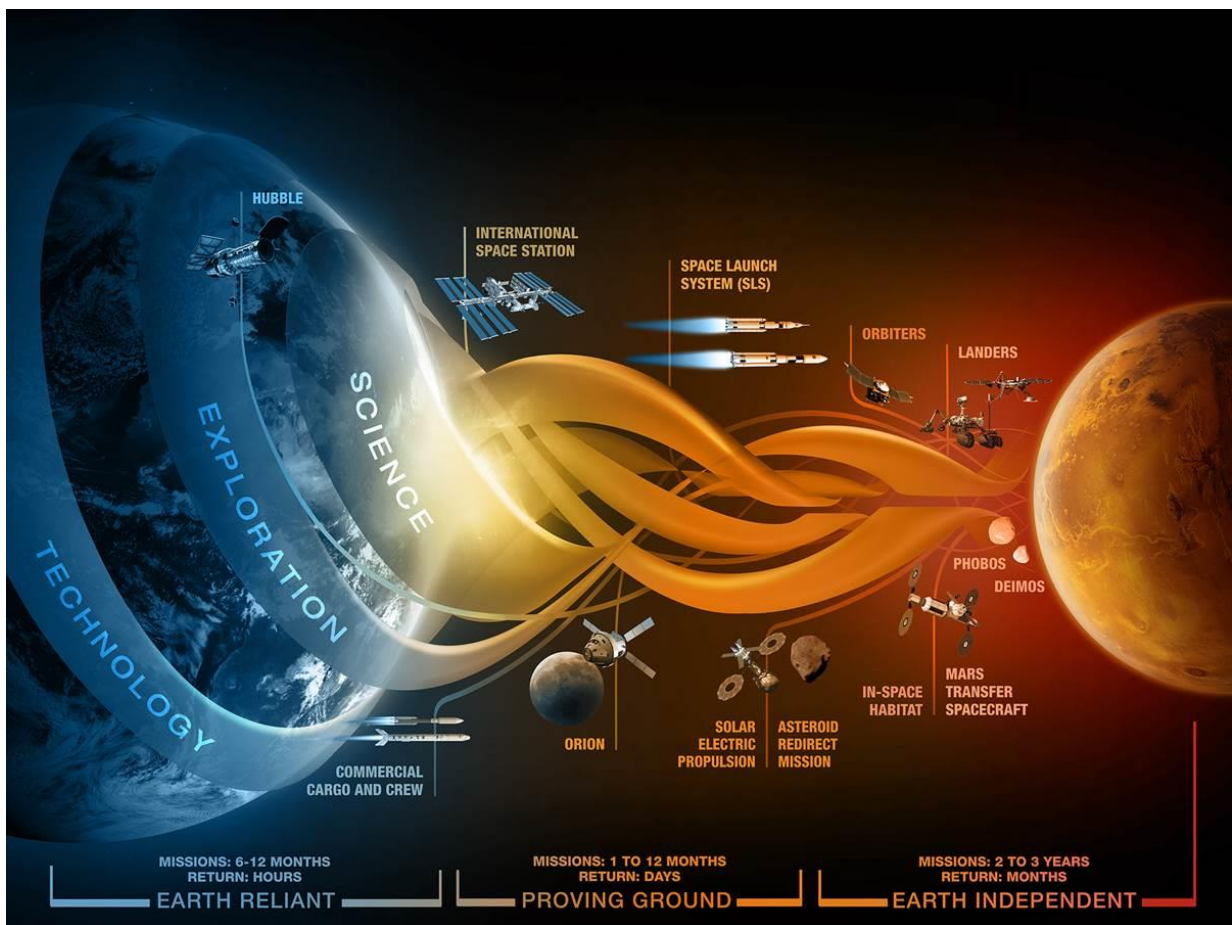
Nomenclature

<i>FAMU</i>	= <i>Florida A&M University</i>
<i>GMRO</i>	= <i>Granular, Mechanics, Regolith, and Operations Laboratory</i>
<i>KSC</i>	= <i>Kennedy Space Center</i>
<i>NASA</i>	= <i>National Aeronautics and Space Administration</i>
<i>NE</i>	= <i>Engineering Directorate</i>
<i>PbAC</i>	= <i>Lead- Acid</i>
<i>RASSOR</i>	= <i>Regolith Advanced Surface Systems Operations Robot</i>
<i>UB</i>	= <i>Exploration Research and Technology Directorate</i>

I. Introduction

This project stems from the Exploration, Research, and Technology Directorate (UB) Projects Division, and one of their main initiatives is the “Journey to Mars”. Landing on the surface of Mars which is millions of miles away is an incredibly large challenge. The terrain is covered in boulders, deep canyons, volcanic mountains, and spotted with sand dunes. The robotic lander is a kind of spacecraft with multiple purposes. One purpose is to be the protective shell for the Martian rover and absorb the impact from the landing forces; another purpose is to be a place where the rovers can come back to, actively communicate with, and recharge their batteries from. Rovers have been instrumental to the Journey to Mars initiative. They have been performing key research on the terrain of the red planet, trying to unlock the mysteries of the land for over a decade. The rovers that will need charging will not

all have the same kind of internal battery either. RASSOR batteries may differ from the PbAC batteries inside Red Rover’s chassis. NASA has invested heavily in the exploration of the surface of Mars. A driving force behind further exploration is the need for a more efficient operation of Martian rovers. One way is to reduce the weight 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. Positioning these systems from the rover to the Lander deck allows a taskforce of smaller, lighter rovers to perform the same 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.



II. Objective

The objective behind this project involves the completion of the deliverables which include the research and design/development of the Rover Recharge System utilizing the Lander arm and hydrogen fuel cell power supply. This project has multiple success benchmarks in order to be considered complete:

1. Generate a List of Requirements for the Rover Recharge System
2. Research various ways to charge several kinds of batteries
3. Gather data and input from experts within space industry
4. Harvest useful data and information from the FAMU student's reports
5. Create and Present a Trade Study for the different designs of the recharge system.
6. Formulate and decide which design to continue the project with.

III. Technical Approach

It all began with intensive research into various ways to recharge several kinds of batteries (Lithium-Ion, PbAC, etc.). There have been many others who have paved the way for recharging systems/docking stations; it became a matter of deciphering which one was the most appropriate fit for the project purpose.

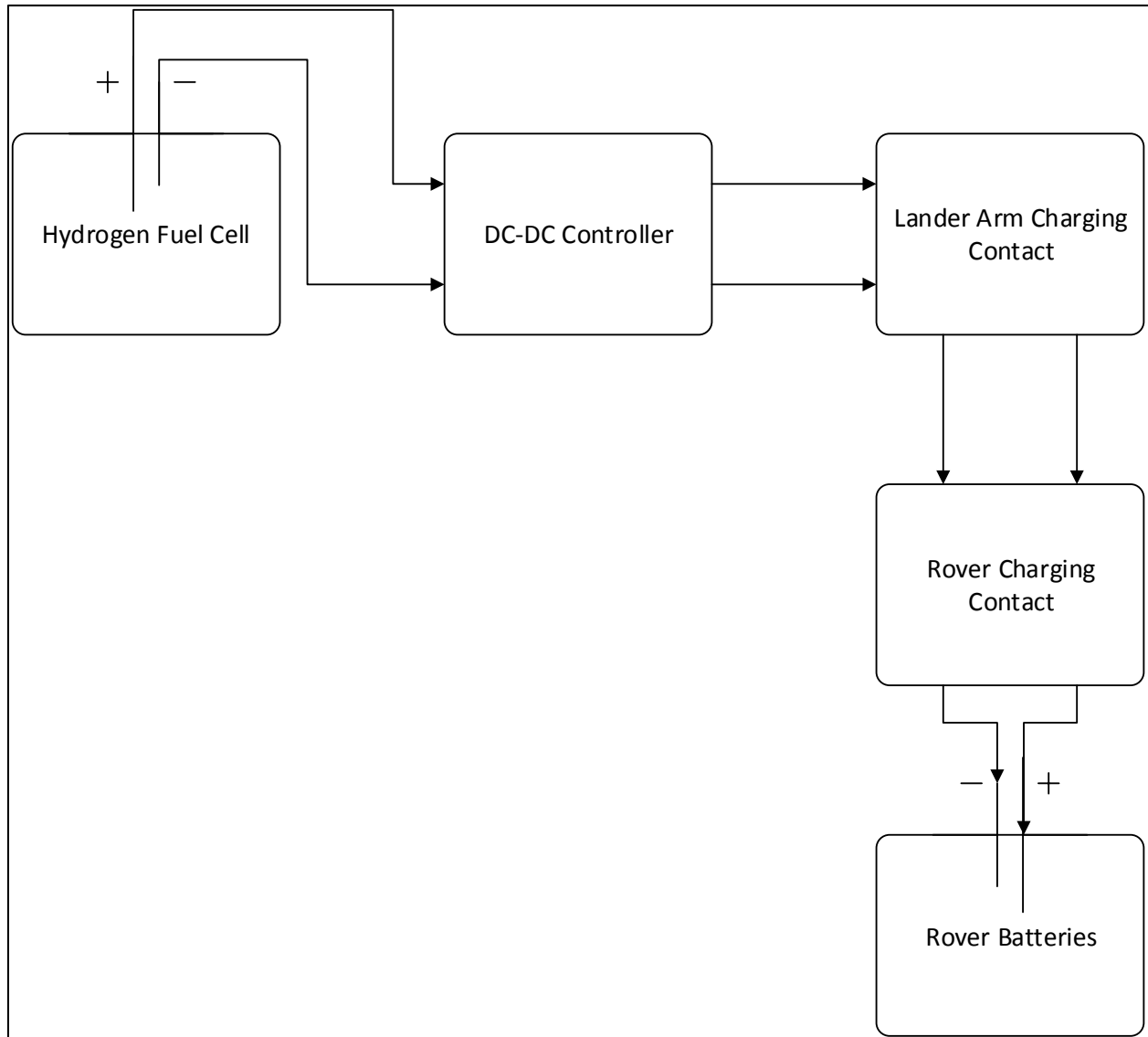
The next milestone was to gather all the information, brainstorm new ideas, and develop several different concepts for the design. Then to create a trade study that looks deeper into the history of the application and the design concepts.

IV. Trade Study Characteristics

The project's end goal is to design a system that the Martian rovers can dock to and recharge its batteries. The rover must be able to find the arm attachment from the Lander and attach itself with room for alignment error because the terrain on Mars is not a flat surface. The flow of power/current from the Lander to the rover is shown in Figure 1. The list of requirements for the system are:

- Withstand Launch & Landing & Operate Long-Term Operation
- Dust/Vibration Resistant
- Active Communication System
- Safety Feature Design
- Fail-Safe Feature
- X,Y,Z Max Change: 1 inch
- Max Pitch, Roll, Yaw Change: 15 Degrees, Max Elevation Change: +/- 4 inches
- Power Supply 24-32V
- Lightweight – Entire System under 8 kg

Figure 1.



When the project gets into the ore in-depth design stage, then the following standards will need to be followed in order to be in compliance with KSC standards for prototypes/designs:

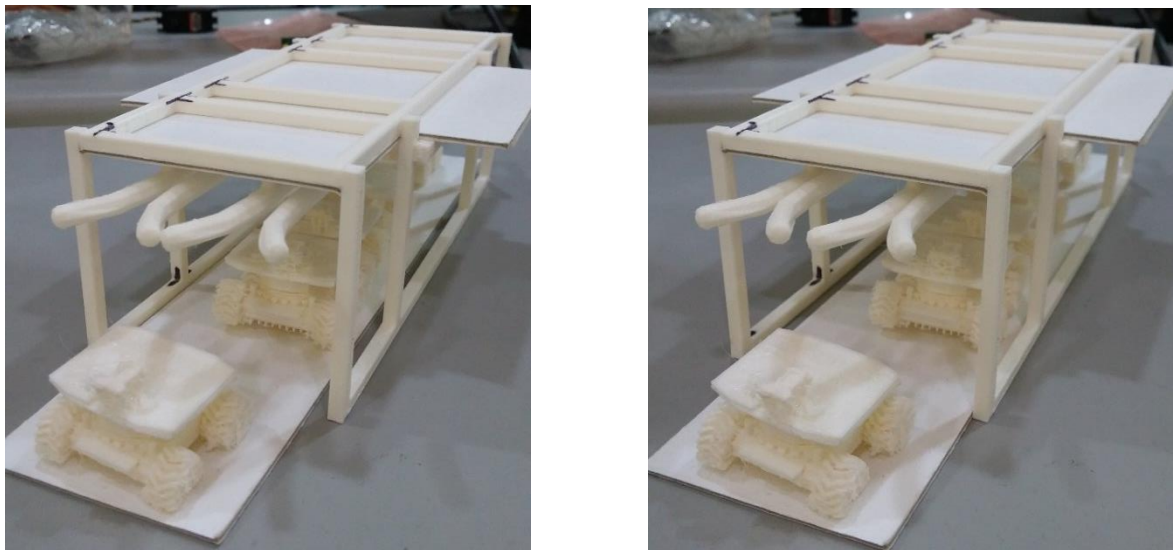
- KDP 2723
- NEMA ICS 61800-2
- NEMA MG 1
- MIL-STD-1541A
- NFPA 70
- 29 CR 1910, 29 CFR 1926, NPR 8715.3
- 120E3100003

As part of the trade study, there will be a weighted trade matrix to determine which design concept is the most efficient fit for the project goals. Some of the qualities that will be judged are:

- Mass
- Reliability
- Room for Alignment Error
- Volume
- Cost
- Simplicity of Design
- Dust Tolerant
- Communication Reliant
- Vibration Tolerant (Rover-Side)
- Overall Efficiency

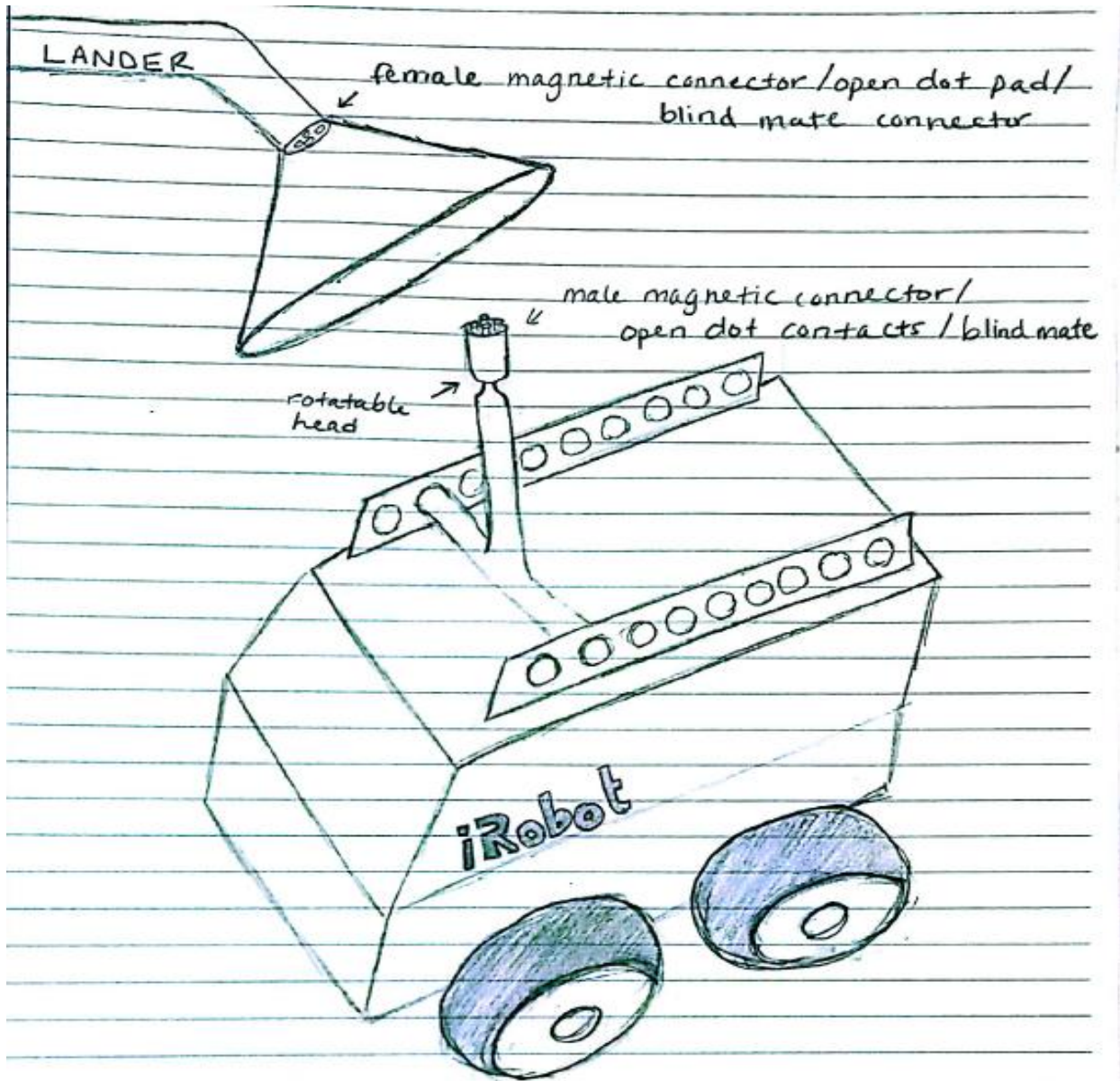
The research of past solutions involved looking into different ways to connect power and docking stations with power contacts. Some of the kinds of electrical connectors that were researched were open dot alliance, magnetic alignment, and blind-mate. The various “charge-and-dock systems” were explored as well such as the Self-Aligning Docking Bay, IRobot Vacuum Dock, and the Mobile Robot Autonomous Charging Port. Other existing power ideas that were investigated were the conductive floor & brush connection (bumper cars), wireless inductive charging, and wireless conductive charging. Kurt Leucht’s (NASA-KSC-NE) Kickstarter project for the novel/robust way to charge the *Swarmie* robots was also studied (See Figure 2). All of the data was gathered and compiled into 4 separate designs. One of the chosen conceptual designs was Kurt’s *Swarmie* Charging System.

Figure 2



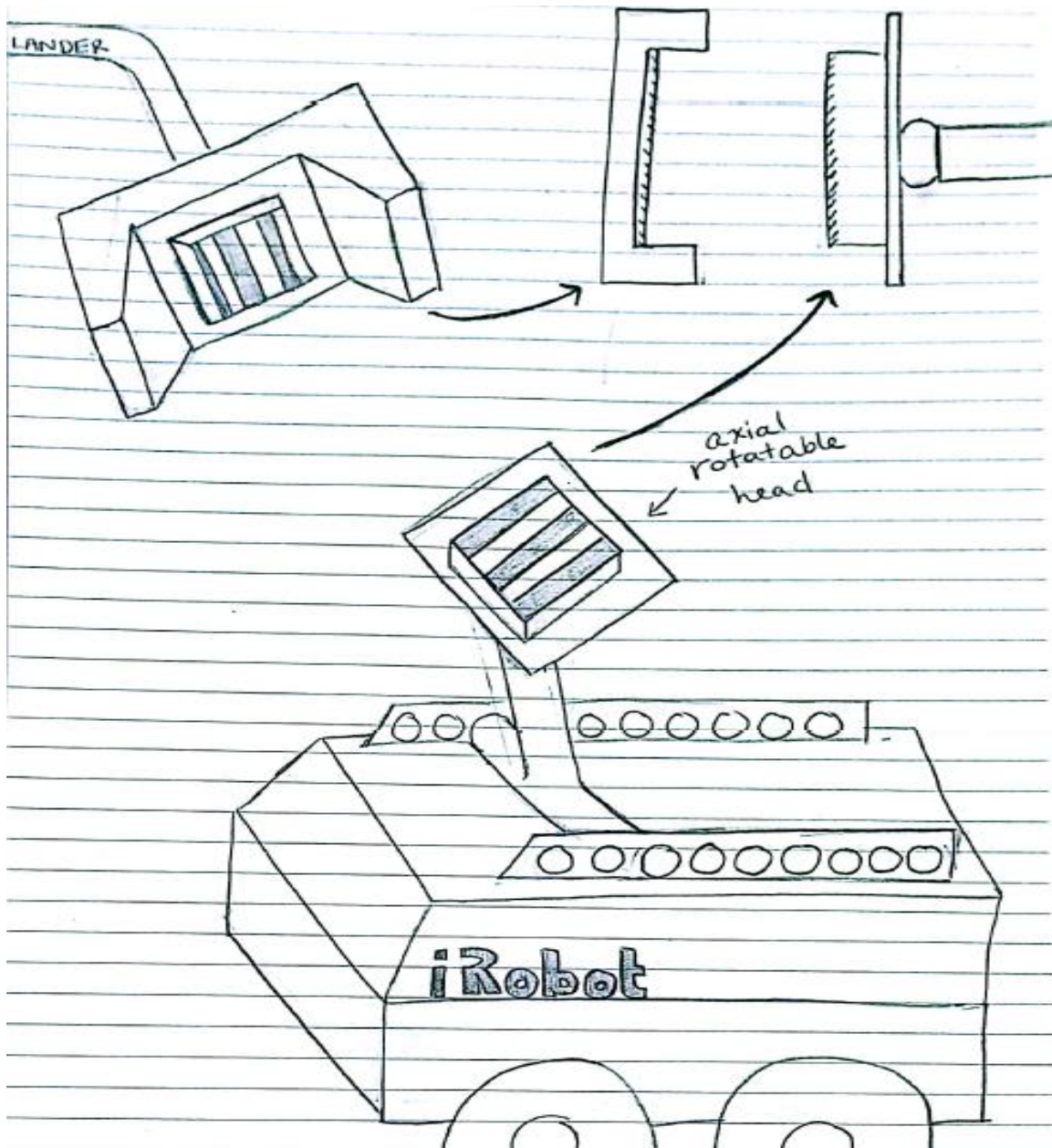
The author came up with a *Conical Connection* Design. The Lander arm has a funnel at the end of it, and at the top of the funnel is the female side of the connector (whether it be a magnetic connector, open dot, or blind-mate). The rover will have an arm with a rotatable ball head (male side of the connector), and the funnel will guide the rover arm into the arm, so a solid connection can be made (See Figure 3).

Figure 3



The third design that was created features the concept of the Self-Aligning Docking Bay. Its shape allows the rover side of the connection to slide into the Lander side, and it will insert into the extrusion. Both sides of the connector will have copper strips for charging, and the rover connection head will be on a rotatable ball head, allowing room for axial alignment errors. The rover head will also be on an angled arm that attaches to the top of the rover (See Figure 4).

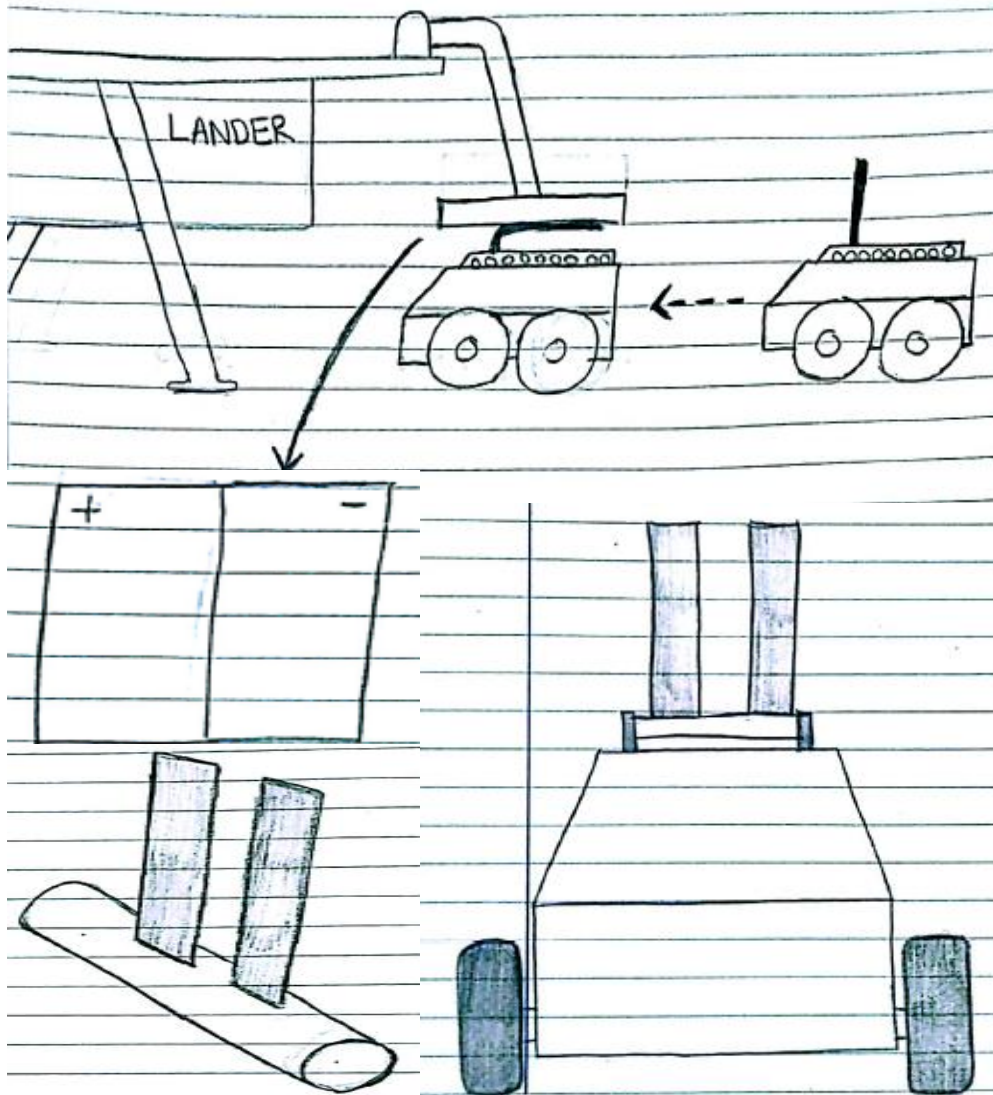
Figure 4



The fourth design was made by the Florida A&M University Students. They were initially given this project, and they were tasked to explore wireless charging vs. physical contact charging and to find a DC-DC Controller that will be able to communicate with the system and charge various kinds of batteries. They concluded that a physical contact solution was the best option because wireless, inductive charging had too large a loss in energy (<30% efficiency). They were also able to find a DC-DC controller that has a 4-stage algorithm that can protect the batteries from over-charging and to detect what kind of battery (thus current to output). Their solution features two copper plates attached to the top of the rover (one

positive plate, one negative plate). The Lander deck has an L-shaped arm with a charging plate on the end of that is parallel to the ground. It is divided into a positive/negative side as well. When the rover drives under the charging plate, then the two copper plates will bend down to ensure a solid connection has been made, and the transfer of power will ensure (See Figure 5).

Figure 5



V. Results

The next step of the trade study was that each design concept be graded on a scale of 1-5 for each quality (1 being the best and 5 being the worst). If there was not enough data or information, then a 2.5 was given as a neutral value. This was the graded results based on the author's research (See Figure 6).

Figure. 6.

DESIGN DECISION MATRIX												
Group											Project	Pathfinder Recharge System
UB-R1 - Swamp Works Lab											Date	#####
	Mass	Reliability	Room for Alignment Error	Volume	Cost	Simplicity of Design	Simplicity of Use	Dust Tolerant	Vibration Tolerant (Rover-Static)	Active Communication Needed?	Efficiency	Totals
Kurt's Swarmies Recharge Design	2.5	1	1.5	3	2	3.5	2	1	1	2.5	1	21
Conical Connector Design 2	1	2.5	1	1	2.5	2	2	1.5	3	2.5	2.5	21.5
Plug and Play Design 3	5	2.5	2.5	4	2.5	2	2.5	2	4	2.5	2.5	32
FAMU Copper Plate Design 4	1	2.5	3	1	2	1	2.5	1	2	2.5	2.5	21
**1 Being Most Ideal, 5 Least ** No Information is 2.5											Chosen Design	Kurt's Swarmies Recharge Design or FAMU Copper Plate Design 4

As one can see from the trade matrix, Kurt's Swarmies Recharge Design and the FAMU Student's Copper Plate Design were the two that had the lowest scores – 21. After presenting the trade study to key members of the GMRO and UB-R1 teams, everyone agreed that the two winning design concepts were the most fitting for the application. However after much discussion, an idea was brought forth that a combination of both designs would be the most ideal because it would mix the pros of both solutions and it would lessen the cons as well. It was also brought up that the trade matrix should be on a weighted scale, so other qualities could be graded more heavily than others.

VI. Conclusion

The entire team has decided that the best solution to further the design of is a combination of Kurt's Swarmies Recharge Design and the FAMU's Copper Plate Design. It should be noted that a new trade matrix will be made after the next designs are generated that will have qualities that are more heavily weighted than others. The milestone of the project of furthering the design has been met.

MARCO POLO Controls/ACME Regolith Feed System Controls and Integration – Controls Engineer

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As we expand into more of our galaxy, the premier focus of NASA’s human exploration program has become “Journey to Mars”. An ambitious but passionate goal of the program is to send humans onto the red planet by the 2030s. However, there is a lot of groundwork that needs to be laid down by scientific discovery and robotic exploration before we will be able to send humans. In light of this initiative, In-Situ Resource Utilization (ISRU) will be the driving force to enable the future endeavors of these missions. ISRU aims to take the resources from Mars and turn it into necessities for missions/temporary habitation such as rocket propellant, shelters, and other consumables. The Pathfinder Lander plans to harness these ISRU technologies on its deck, and this project involves the integration of the electrical controls within two separate portions of the Mars Atmosphere and Regolith Collector/Processor for Lander Operations (MARCO POLO) project – the Regolith Feed System and the Soil Processing Module (SPM).

Nomenclature

<i>ACME</i>	= <i>Additive Construction with Mobile Enhancement</i>
<i>APM</i>	= <i>Atmospheric Processing Module</i>
<i>CAD</i>	= <i>Computer-Aided Design</i>
<i>ISRU</i>	= <i>In-Situ Resource Utilization</i>
<i>JSC</i>	= <i>Johnson Space Center</i>
<i>GMRO</i>	= <i>Granular, Mechanics, Regolith, and Operations Laboratory</i>
<i>KSC</i>	= <i>Kennedy Space Center</i>
<i>MARCO POLO</i>	= <i>Mars Atmosphere and Regolith Collector/Processor for Lander Operations</i>
<i>NASA</i>	= <i>National Aeronautics and Space Administration</i>
<i>SPM</i>	= <i>Soil Processing Module</i>
<i>UB</i>	= <i>Exploration Research and Technology Directorate</i>

I. Introduction

“Each spacecraft, crewed or robotic, encounters an extraordinary spectrum of vast resources throughout its journey. From the first space missions onward, space architects and scientists have considered incorporating these space resources into their designs to improve efficiency and guarantee the survival of hardware and people in space.” – NASA. This process of utilizing these resources is called ISRU. The Additive Construction with Mobile Emplacement (ACME) project has the same goals of developing technology to build 2D and 3D structures on planetary surfaces using the resources around them; it is separate from the MARCO POLO project. ACME is a joint venture from NASA and the Army Core of Engineers (USACE) with intent of utilizing 3D printing of structures using the environmental

material in efforts to reduce personnel and time to build infrastructures. The MARCO POLO project was created to demonstrate the methane and oxygen production system in a Mars-simulated environment. “Living off the Land” or ISRU will enable missions to take other irreplaceable equipment on these long journeys to the red planet, instead of having to take excessive amounts of water, fuel, and other necessary resources. Before NASA can use these technologies, they must be able to prove the practicality of them first. Then in the future MARCO POLO’s space mining and other technologies will be vital in truly achieving ISRU for Mars.

II. Objective

The primary goals of this project is the completion of the following tasks which are focused on the design and integration of the electrical components onto various portions of the Lander/ACME project. The success criteria are:

1. Create a more accurate CAD model of Red Rover for Visual Presentation
2. Become familiar with the existing controls
3. Develop electrical schematic for integration of encoder and auger motor for the ACME project
4. Implement the design into the existing controls
5. Test the solution
6. Develop electrical schematic for integration of relay, digital input module, and control valves into the SPM project of the MARCO POLO Lander deck.
7. Implement the design into the existing controls
8. Test the solution
9. Model the Power Supply of the Lander Deck

III. Technical Approach for ACME Regolith Feed System

The first step of the project was to understand the larger picture of how the ACME Regolith Feed System worked. The author was tasked to implement an encoder and motor combination to help the feed system operate. The Martian rovers are going to be excavating regolith from the terrain, and they will proceed to dump it into the bucket of the Lander hopper arm. Then a motor will be utilized to sift the larger rocks out of the bucket, until it is only fine dirt which will be fed into the 3D printing arm by another motor. The 3D printing arm will be utilized in the future for pavers, shelters, etc.

The next step was to research and find the datasheets for all the parts that are involved. Then to study those datasheets to acquire the information needed to make them work for the project. Once that is learned, then to utilize Microsoft Visio and Microsoft PowerPoint to design the electrical layout for how to connect the motor and the encoder to the electrical servo drive using military specification connectors. That was the most difficult part because they are so many different kinds of connectors that fit into one another, finding the right match was tedious because of how obscure the datasheets were..

Before physical production of the wiring was done, other experts in controls/robotics/electrical engineering looked over the diagrams and double-checked that they were accurate and would properly power the system. Once it got the approval, the task involved learning how to use military specification power connectors. The tools and process of inserting the wires into the separate pins was taught to the author by the experts.

IV. Testing Results for ACME Regolith Feed System

After the electrical wiring diagrams were approved by the experts in the GMRO Laboratory and the connectors physically wired up then testing of the connections was the next step. Safety is critical to the operations around NASA and especially KSC. All of the necessary precautions were taken before turning the system on, such as enclosing the system in a casing, having a way to emergency shut-off the power, and standing away from the system as it runs.

The results was that everything was operational, and the auger was moving the regolith through the feeder so the finer dirt could be utilized. The only issue that came up was the auger seemed to run backwards, however the team ended up switching the polarity of it within the software of the Elmo servo drive, and it fixed the problem immediately.

V. Technical Approach to MARCO POLO SPM

The Soil Processing Module (SPM) is a portion of the MARCO POLO project that Johnson Space Center (JSC) is in charge of. The SPM's purpose is to take the refined dirt from the Regolith Feed System (same concept as the ACME Regolith Feed System), and it will dry the dirt and extract the water out of it. Then the water will go to another module on the MARCO POLO Lander deck to be processed further. The goal of this project was to integrate an electromechanical relay and a universal digital input module to the soil processing module's, which will be here on referred to as the dryer, to the two control valves that regulate the flow of regolith through the system. The water that is extracted will be cleaned and utilized for many other types of purposes for the future crew

The next steps in this process were very similar to the approach for the ACME Regolith Feed System. First one must understand how the whole system works, find the datasheets for the electrical components needed, and then create an electrical schematic for the wiring of the system to show how it will be integrated. Again, it was vital to ensure that before the physical aspect of the design was implemented that the schematics were checked by one of the expert engineers in the GMRO Laboratory.

This time the military specification power connectors didn't have push pins, but they have solder holes where the wires would need to be soldered straight in for a connection to be made. This was a little more difficult than the push-pins because the solder had to melt down into the holes, then heated up again so the wired could be pushed down in it. It all had to be done in a relatively quick manner so that the solder didn't cool off before the wires were able to be pushed down there.

VI. Testing for the MARCO POLO SPM

After all the components are physically assembled, the proper terminal blocks are created, and all the diagrams have been checked off, then a physical test of the solution is required. At this point in the project, the team is waiting for some more parts to come in and as soon as they do, the assembly can be completed in short matter of time. That is the next deliverable to be met before December 18, 2015. A successful implementation test will include checkmarks to see the following:

- Control Valve 1 Indicator Light On
- Control Valve 1 Physically Move

- Control Valve 2 Indicator Light On
- Control Valve 2 Physically Move

VII. Additional Tasks

Another objective given was to create a more accurate Computer-Aided Design (CAD) model of one of the rovers in the GMRO Laboratory because there is a coalition of engineers and scientists that are creating a full-scale computer model of MARCO POLO Lander Deck and all its components in CAD. The author utilized their ability with AutoDesk Inventor to create the model in Creo Parametric, another type of 3D modeling software. This task involved a lot of reverse engineering principles and taking measurements and inputting them into the system. See Figure 14 for the 3D model of the Red Rover.

Figure 14



Another task was to model the current power supply for the Regolith Feed System and the Dryer Portion of the SPM. The overall objective is to collaborate with other KSC groups and JSC groups to develop a model of the entire power system for the MARCO POLO Integration, so that safety can be ensured during operation. See Figure 15 for the Power Supply Model.

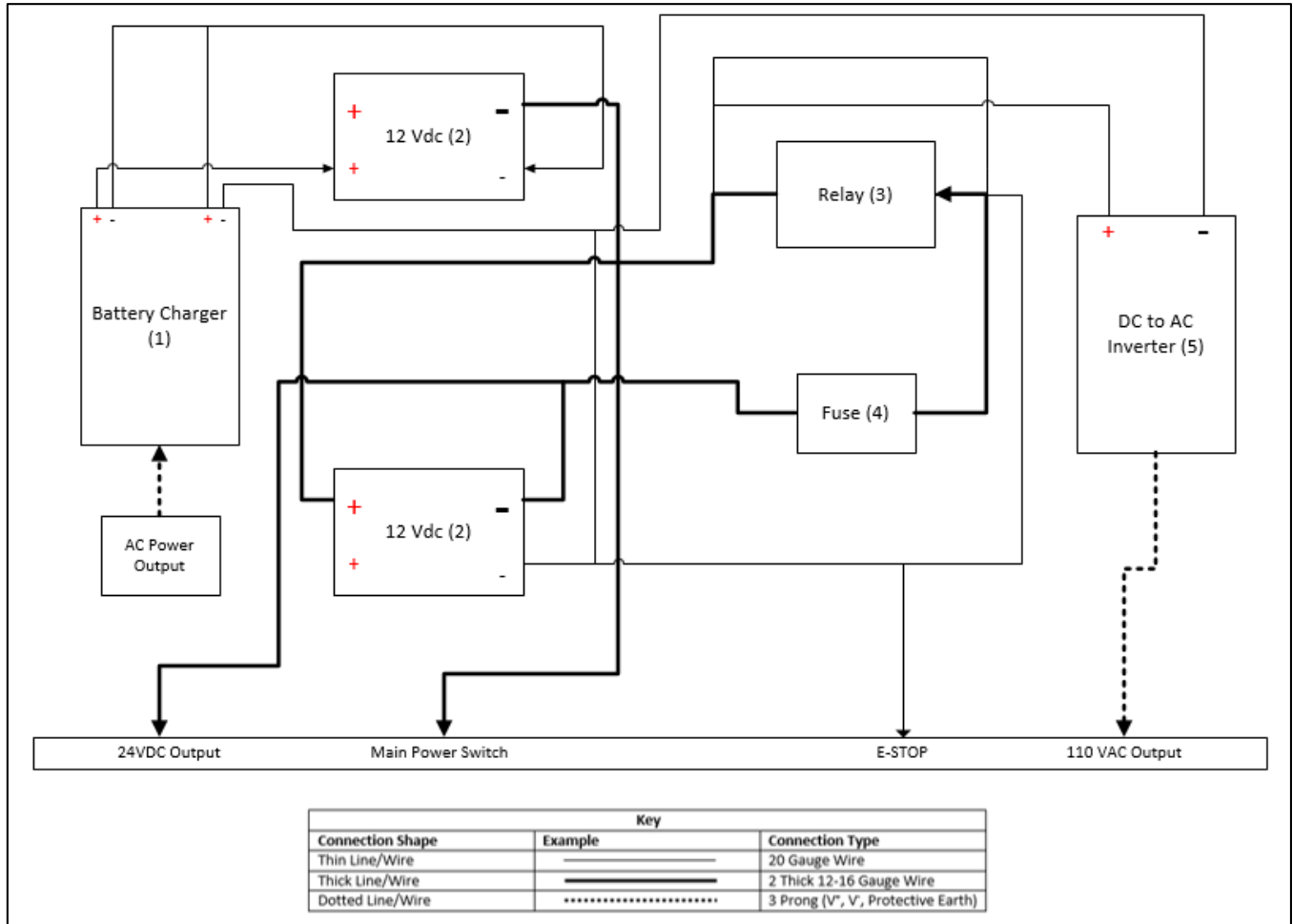
VIII. Conclusion

The major milestones for this project have been completed for the ACME Regolith Feed System. The major milestones for the MARCO POLO SPM are halfway completed, and they will be 100% complete before the December 18, 2015 deadline signaling the end of the internship. Further work in

programming the Lander Arm in LabVIEW and modeling the entire electrical system for the MARCO POLO Lander Deck will also be performed up until the end of the internship as well.

Special Thanks to all the Mentors who have contributed to this project: Khoa Vo, Gabor Tamasy, Van Townsend, A.J. Nick, Kurt Leucht, Rob Mueller, Luke Setzer, Christopher Reeves, Kim Shepherd, and Tom Lippitt.

Figure 15



References

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