WKU

Western Kentucky University

ARTEMIS

Lunabotics Mining: Evolution of *A.R.T.E.M.I.S. PRIME*

Sarah Bertke
Christine Gries
Amanda Huff
Brittany Logan

Kaitlin Oliver
Erica Rigney
Whitney Tyree
Maegan Young

Faculty Advisors
Dr. Julie Ellis
Dr. Kevin Schmaltz
Dr. Stacy Wilson

Western Kentucky University

A leading American university with international reach

Photo: Brian Powell

Located in Bowling Green, KY

- Between Louisville (110 miles) and Nashville (70 miles)
- Home of the Corvette Plant and National Corvette Museum
- Home of the minor league baseball Hot Rods

20,000+ WKU students

450+ Undergraduate Engineering students in CE, EE, and ME programs

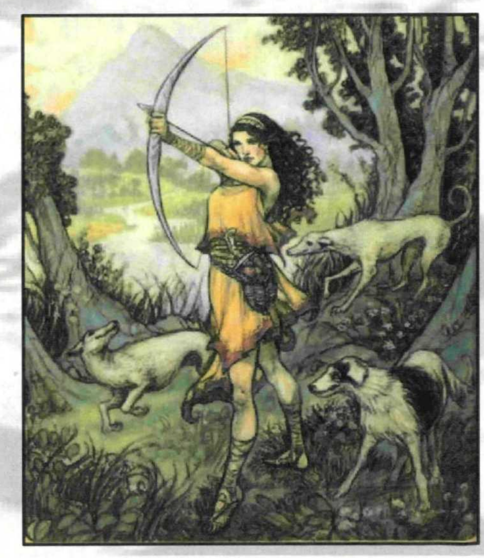
Home of the ***Carol Martin Gatton Academy of Mathematics and Science in Kentucky***

ARTEMIS

Amassing
Regolith
with
Topper
Engineers
eMploying
Innovative
Solutions

- **A Multidisciplinary Team**
  - Electrical Engineering
  - Mechanical Engineering
  - Civil Engineering
  - Physics
  - Mathematics and Science (Gatton student)

- **All Female Members**
  - Unusual in Engineering
  - Name inspired by the powerful Greek moon goddess, Artemis



A.R.T.E.M.I.S. PRIME

Excavator Name: ***A.R.T.E.M.I.S. PRIME***

Mass: **76.5 kg**

Max height: **1.5 meters**

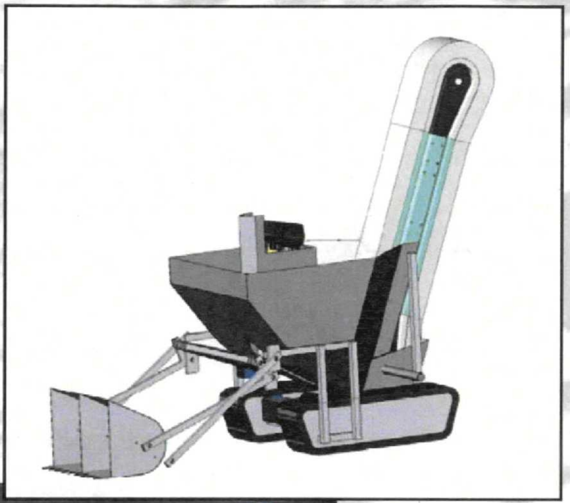
Max width: **0.75 meters**

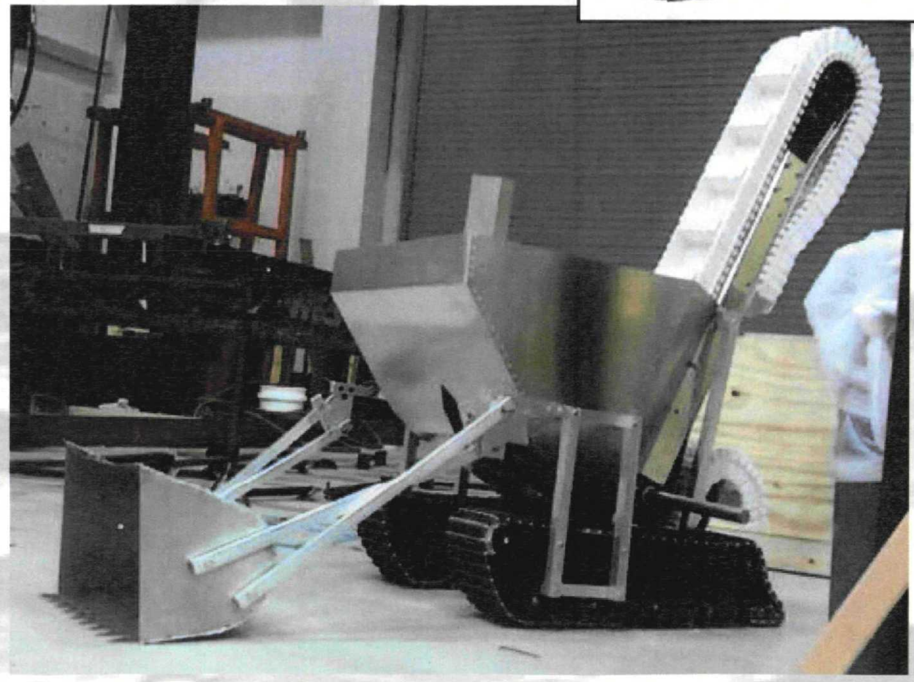
Max length: **1.5 meters**

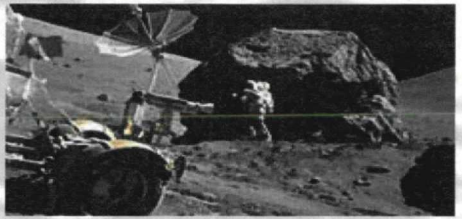
Regolith capacity: **113 kg**

Born: **Spring 2010**

Hobbies: **Lunar Mining**







Lunabotics Mining Competition

"The purpose of the Lunabotics Mining Competition is to engage and retain students in science, technology, engineering, and mathematics, or STEM, in competitive environment that may result in innovative ideas and solutions, which could be applied to actual lunar excavation for NASA."

-NASA Exploration Systems Mission Directorate Higher Education Project and the National Space Grant College and Fellowship Program

Student Design Team

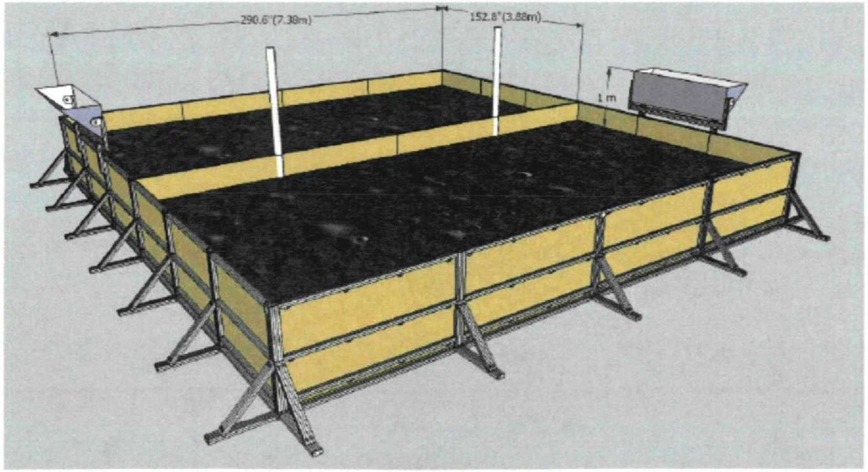
WKU's A.R.T.E.M.I.S. team was formed in response to the announcement of the inaugural NASA Lunabotics Mining Competition. Competing will allow WKU engineering students to develop and be engaged in project-based learning activities by fulfilling the competition requirements, to proudly represent WKU at the Kennedy Space Center, contributing innovative ideas and solutions through a systems engineering approach, and to advance the fields of engineering through K-12 outreach programs.

Statement of Lunabotics Problem

•Design, build, and operate a remotely controlled device that is capable of excavating, transporting, and discharging lunar regolith simulant in a lunar environment over a 15-minute period.

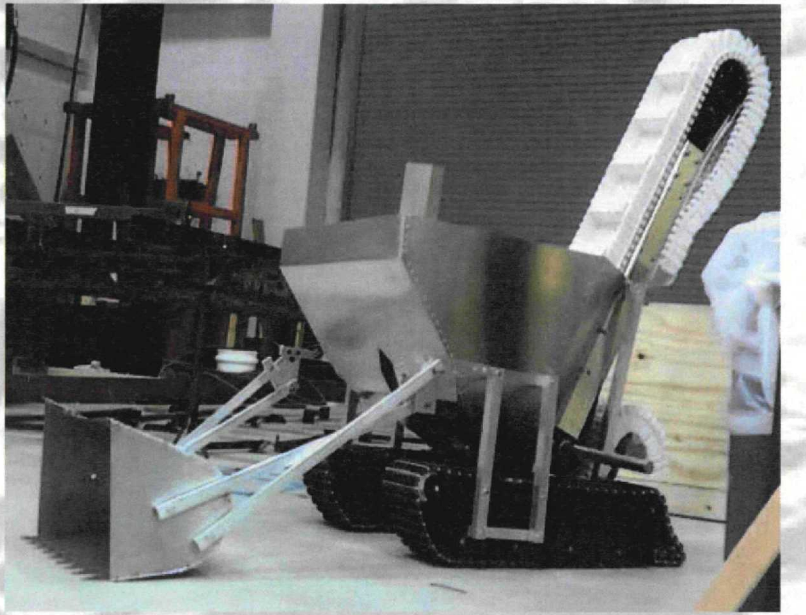
Key NASA Specifications:

- ✓ Maximum dimensions: 2m x 0.75m x 1.5m
- ✓ Maximum hardware mass: 80.0 kg
- ✓ Communication bandwidth: <5.0 Mbps
- ✓ All power must be provided onboard
- ✓ Hardware may not change the physical or chemical properties of the simulant
- ✓ Processes or materials used must be appropriate for the lunar surface



Sandbox Diagram (side view)

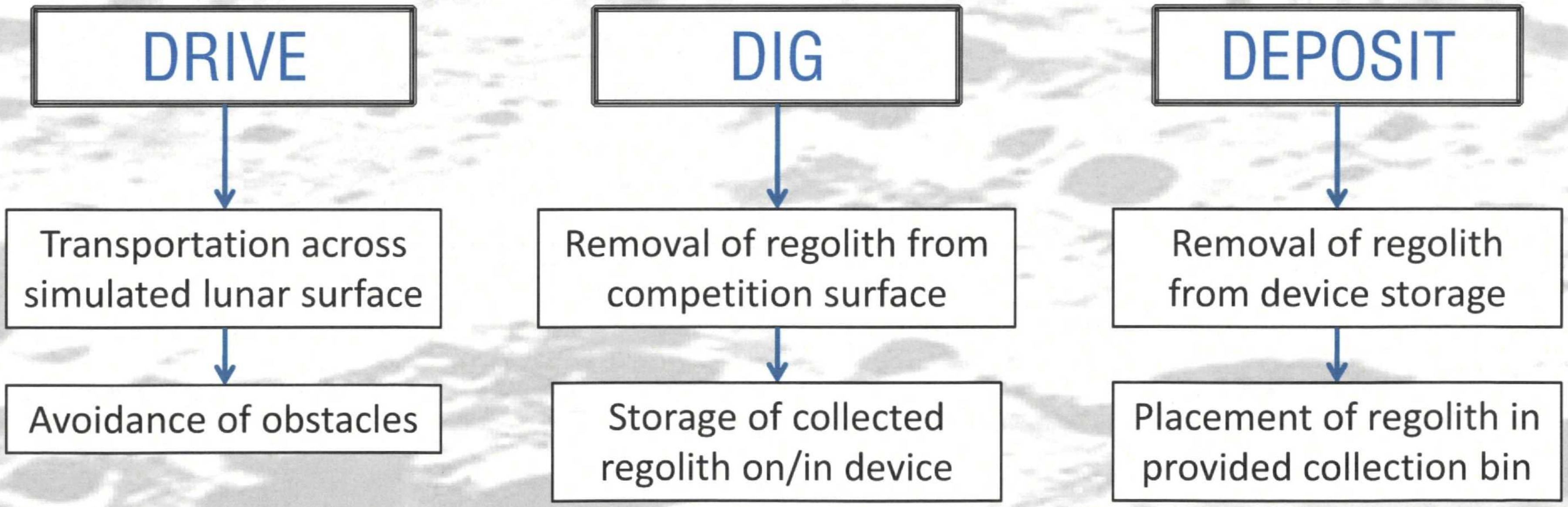
Statement of Lunabotics Problem



A.R.T.E.M.I.S. Criteria:

- ✓ Maximize regolith carrying capacity
- ✓ Minimize complexity of system
- ✓ Minimize regolith contamination of moving and electrical components
- ✓ Minimize regolith loss
- ✓ Optimize battery capacity/weight
- ✓ Reduce costs if quality is not sacrificed

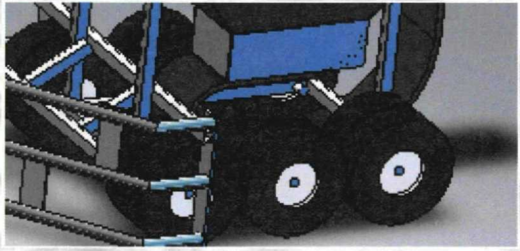
The Major System Functions



- DRIVE
  - Transportation across simulated lunar surface
  - Avoidance of obstacles
- DIG
  - Removal of regolith from competition surface
  - Storage of collected regolith on/in device
- DEPOSIT
  - Removal of regolith from device storage
  - Placement of regolith in provided collection bin

Drive Function Decisions

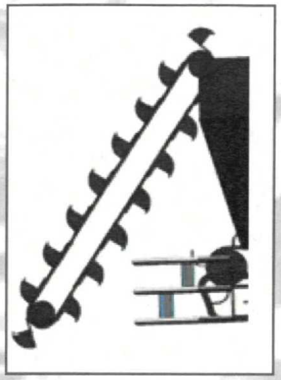
- Wheels vs. Track Systems
- Required power
- Maneuverability; ability to handle obstacles
- Fabricate at WKU vs. professional manufacturing with enhanced reliability



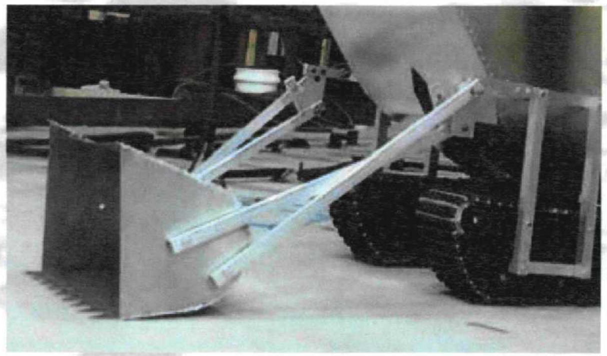
Evaluation Matrix

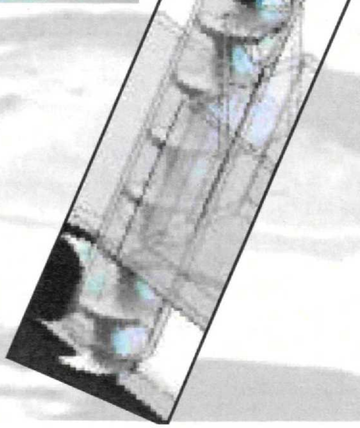
Wheels vs. Tracks	Cost	Weight (3x)	Time	Resources	
Wheels	+	-	-	-	-4
	$1,300	~65 lbs	>1 week		
Tracks	0	0	0	0	0
	$2,000	~52 lbs	1 week	none needed	

Dig Function Decisions



- Auger vs. conveyor vs. scoop
- Regolith excavation and storage in hopper
- Required power
- Weight and integration challenges



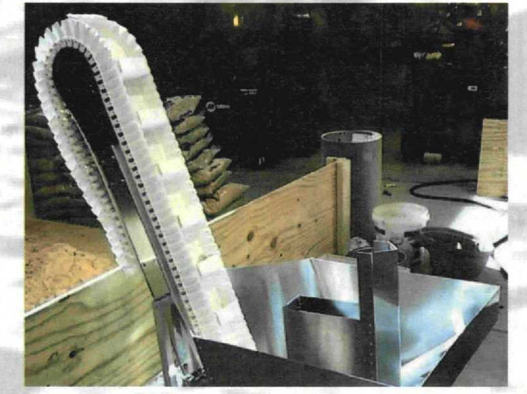


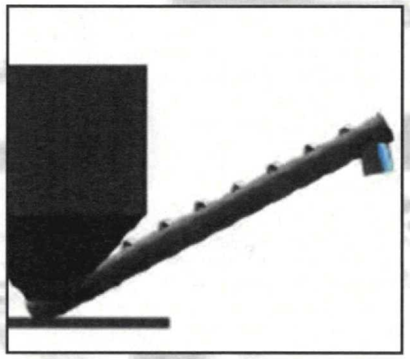
Evaluation Matrix

DIG	Cost	Efficiency (2x)	Weight (2x)	Design Time	Construct Time	Power Needs	TOTAL
Auger	0	0	0	0	0	0	0
Conveyor	+	+	-	+	0	0	2
Scoop	**0**	**+**	**+**	**-**	**-**	**+**	**3**

Deposit Function Decisions

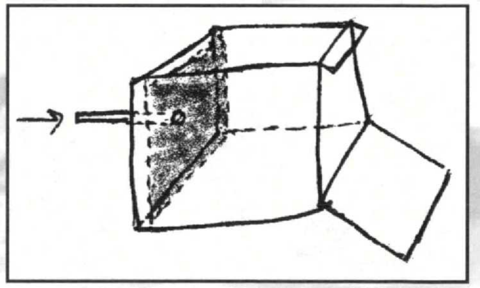
- Piston vs. Auger vs. conveyor
- Integration into hopper
- Weight
- Enhanced reliability, professional manufacturing
- Decreased construction time
- Required power



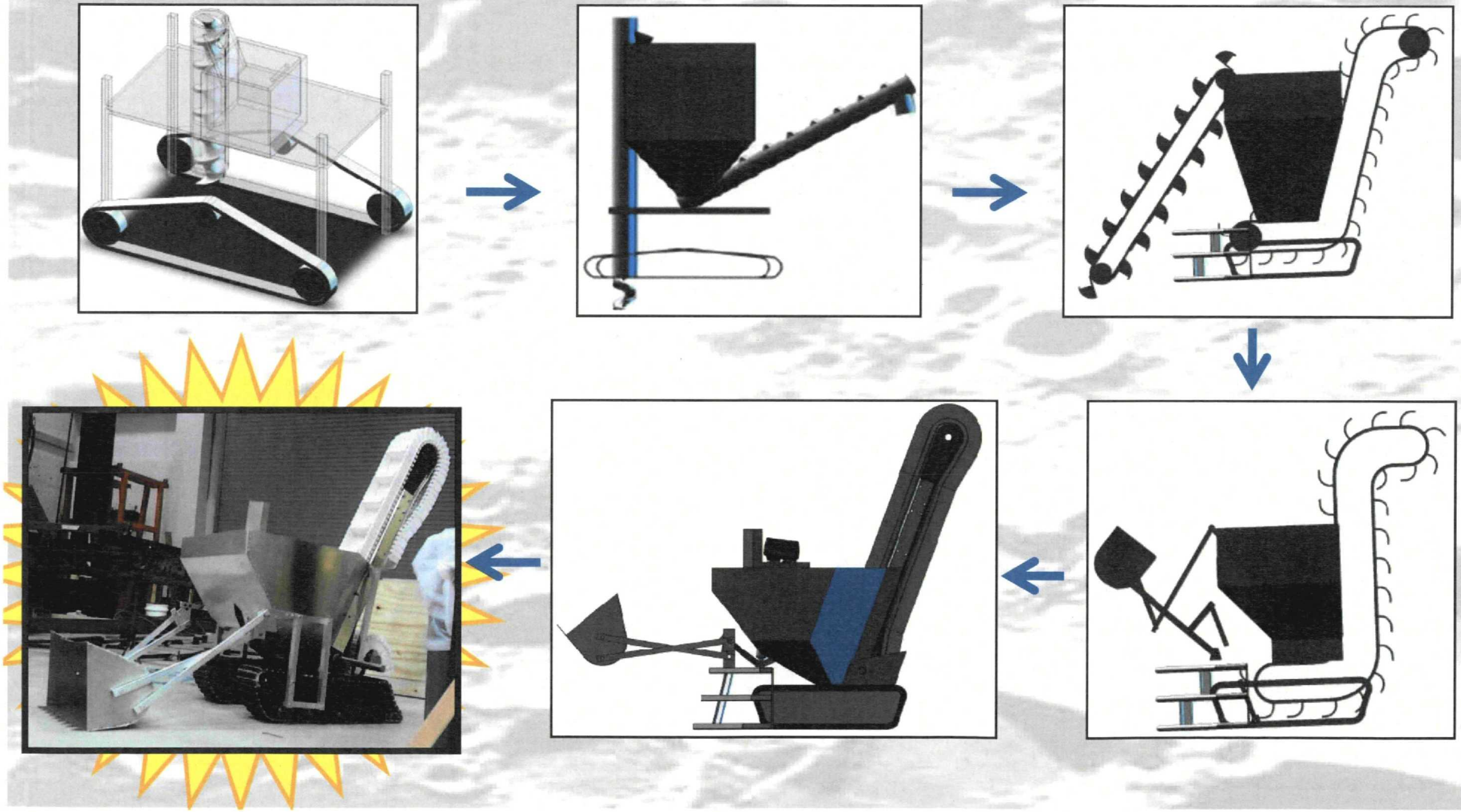


Evaluation Matrix

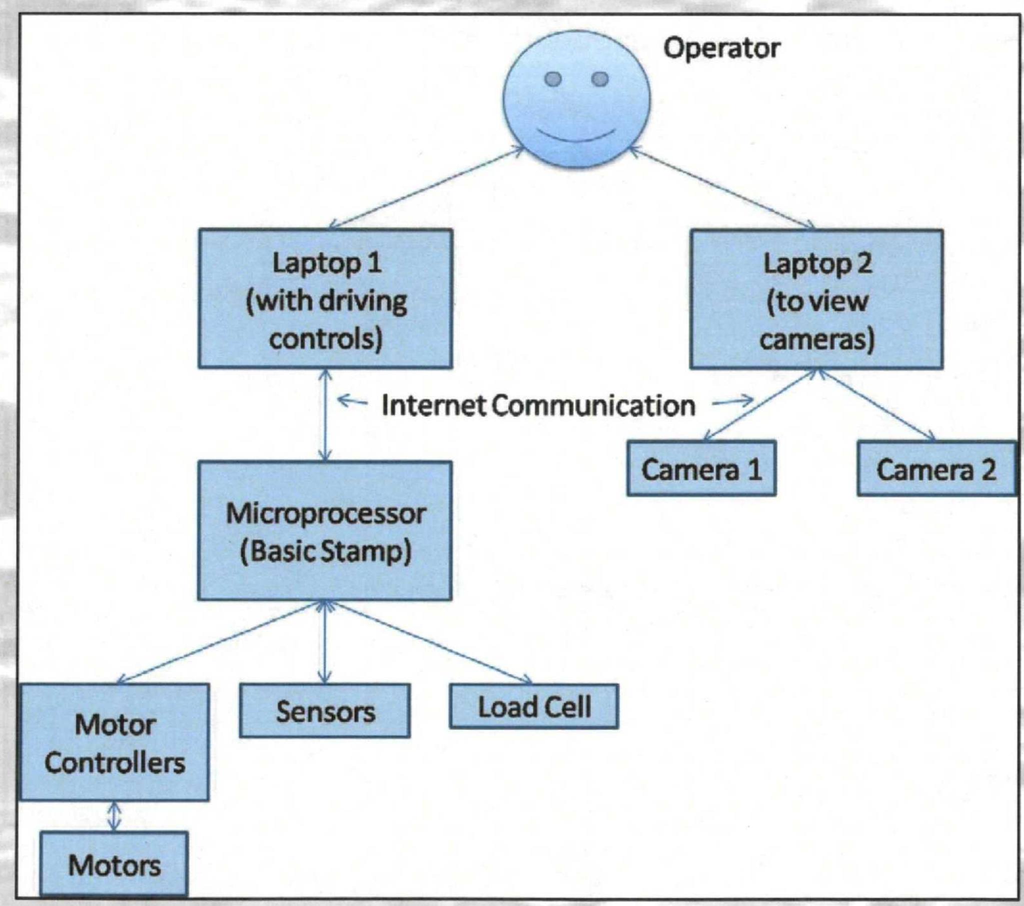
DEPOSIT	Cost	Efficiency (2x)	Weight (2x)	Design Time	Construct Time	Power Needs	TOTAL
Auger	0	0	0	0	0	0	0
Conveyor	**+**	**0**	**-**	**+**	**+**	**0**	**1**
Push Out	0	-	+	-	-	+	-1



Mechanical Design Iterations



Iterative Design Process: Electrical System Design



Operator

Laptop 1 (with driving controls)

Laptop 2 (to view cameras)

← Internet Communication →

Camera 1

Camera 2

Microprocessor (Basic Stamp)

Motor Controllers

Sensors

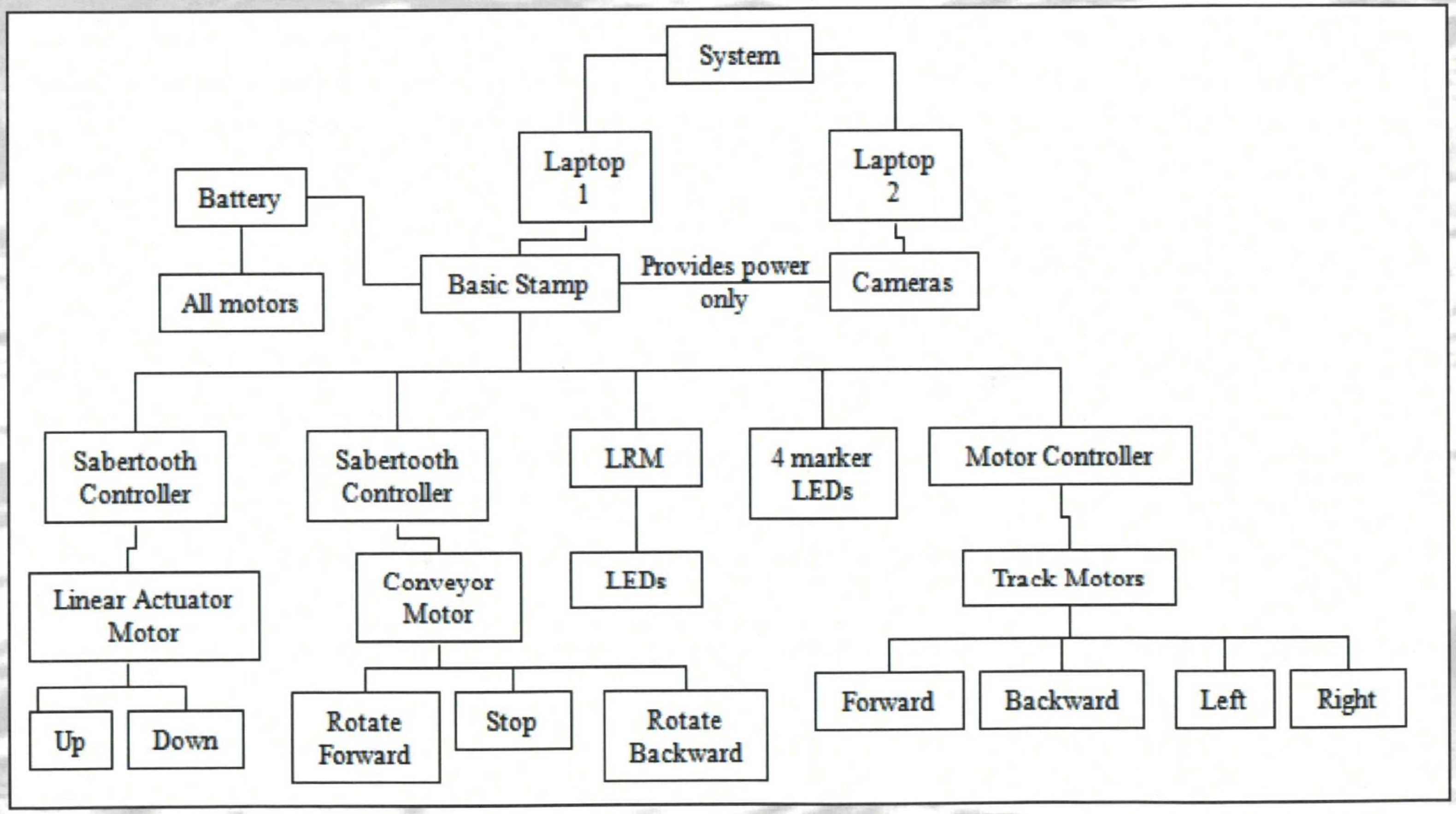
Load Cell

Motors

Design Decisions:
Considering the distance between the operator and the device at the competition, an IP control system was chosen over a remote control system for reliability.

Before the mechanical system was complete, electrical design began with a schematic of the basic communication process.

Electrical System Design



- System
  - Laptop 1
    - Basic Stamp
  - Laptop 2
    - Cameras
- Battery
  - All motors
  - Basic Stamp
- Basic Stamp — Provides power only — Cameras
- Basic Stamp
  - Sabertooth Controller
    - Linear Actuator Motor
      - Up
      - Down
  - Sabertooth Controller
    - Conveyor Motor
      - Rotate Forward
      - Stop
      - Rotate Backward
  - LRM
    - LEDs
  - 4 marker LEDs
  - Motor Controller
    - Track Motors
      - Forward
      - Backward
      - Left
      - Right

After mechanical components were chosen, the final schematic of control system was created.

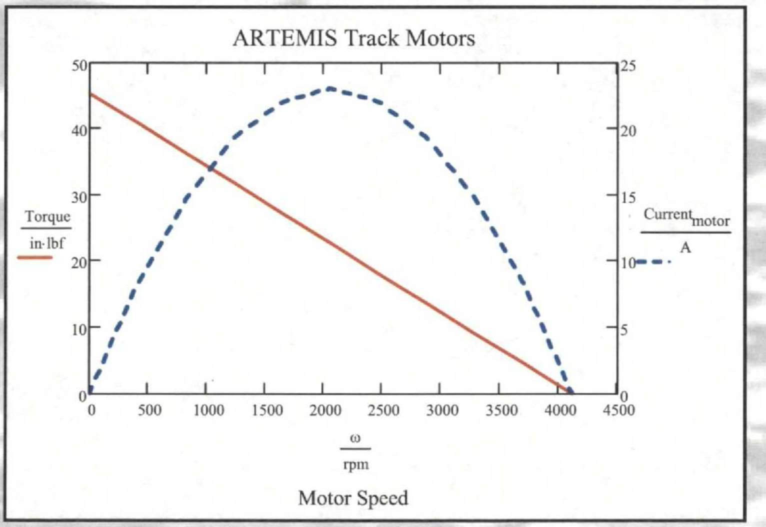
Hardware Requirements

Objective: Simplicity of system

Solution: Uniform voltage in system

Implementation: Track motors (24V) dictated the voltage of linear actuator and conveyor motors.

Evaluation: Voltage was easily accommodated for the linear actuator and conveyor motors.



Objective: On-board power system

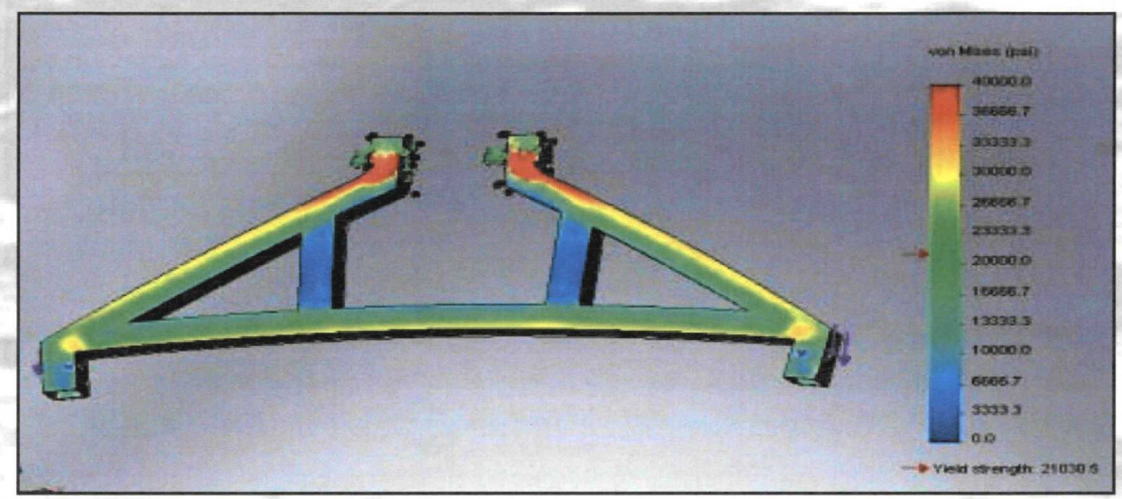
Solution: Rechargeable battery

Implementation: Design parameters included max drawn current, operation time of each component in a cycle, and ultimate amp-hour requirements.

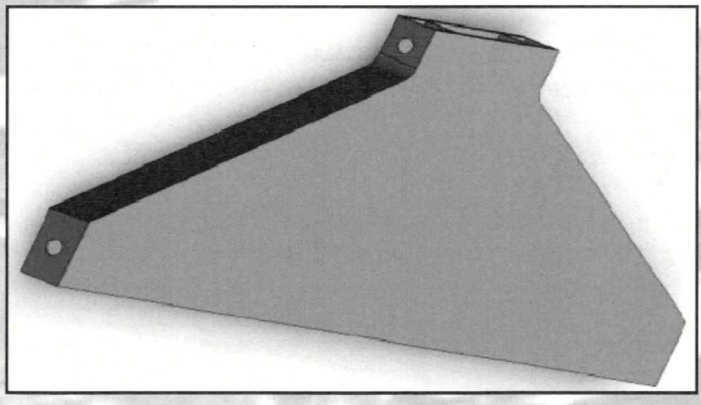
Evaluation: Initial battery choice proved adequate but exceeded the weight budget. Lithium ion battery was chosen for weight, amp-hour reliability, and peak current accommodation, as these design factors were more significant than cost.


Left: Lead Acid
Below: Lithium Ion

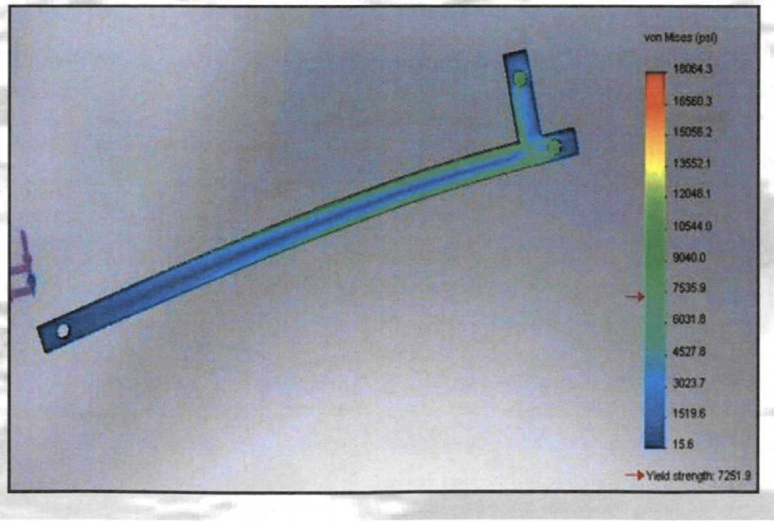
System Modeling



A finite element analysis (FEA) was performed using *SolidWorks* to determine maximum stresses the supports must withstand. Analysis of the initial design led to the manufacture of the final support brace.

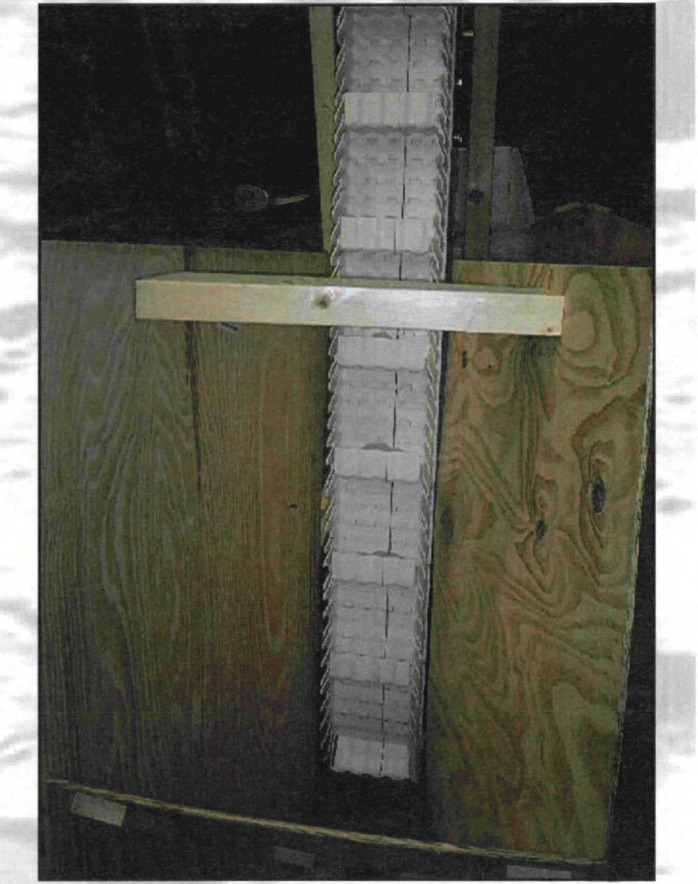


Left: Final support brace
Right: FEA of scoop arm confirmed the design was adequate.

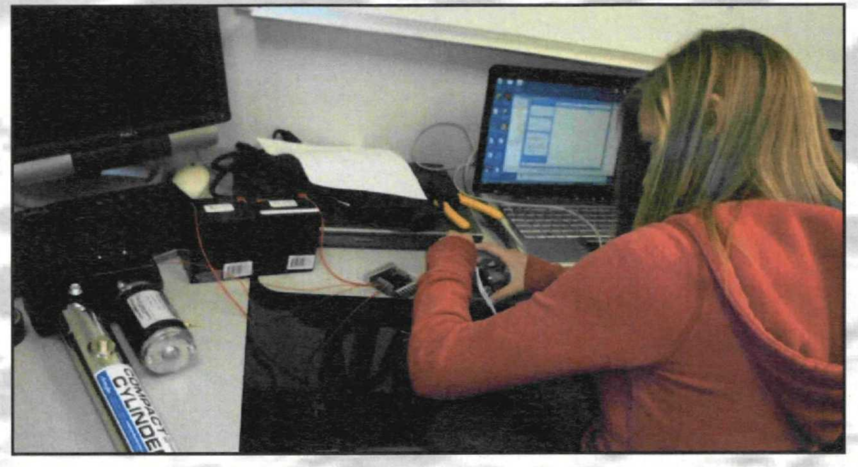


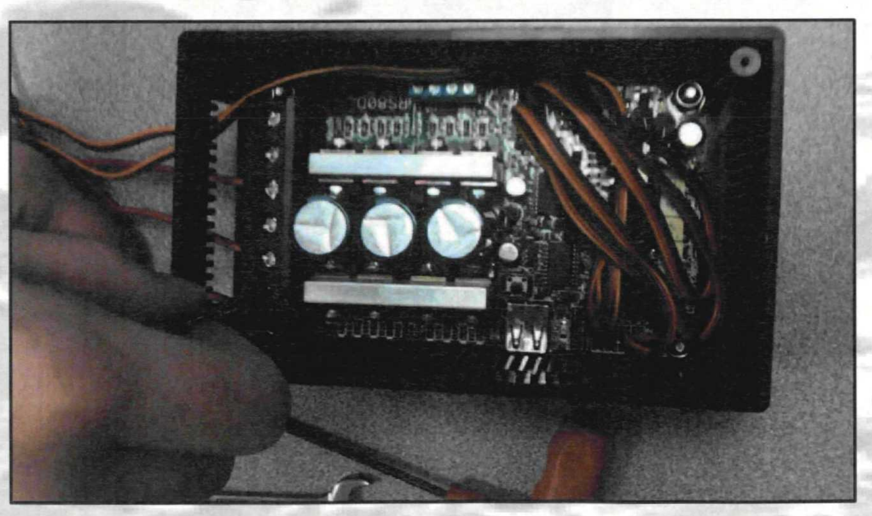
Preliminary Testing

A mock-up of the conveyor/ hopper assembly was created for regolith retention tests. The team also experimented with various delivery angles for the conveyor deposit system.



Preliminary Testing



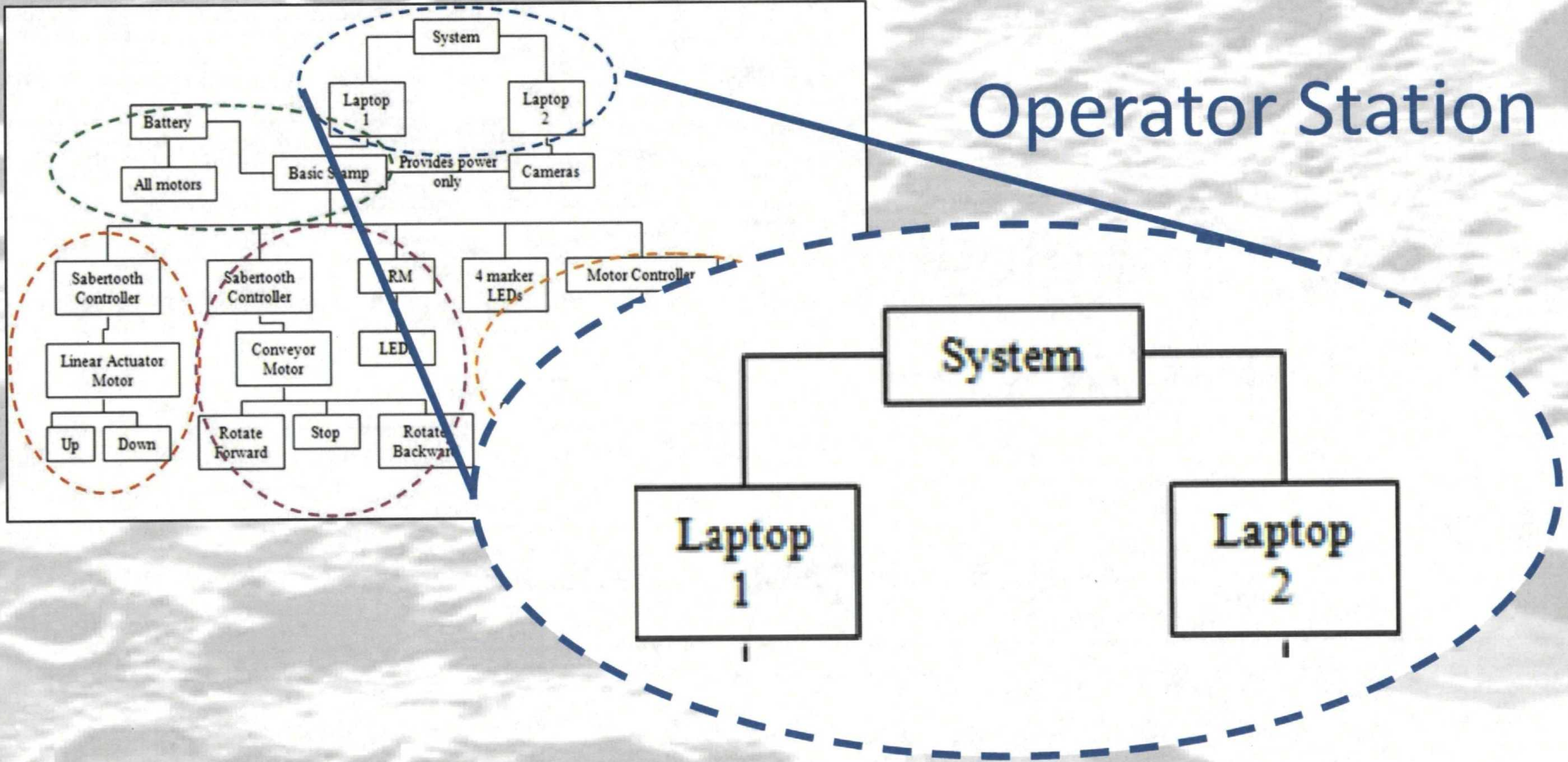


Top left: A platform was assembled to test the tracks for uniform speed and power.

Top right: Testing Sabertooth motor controller for compatibility with the linear actuator motor.

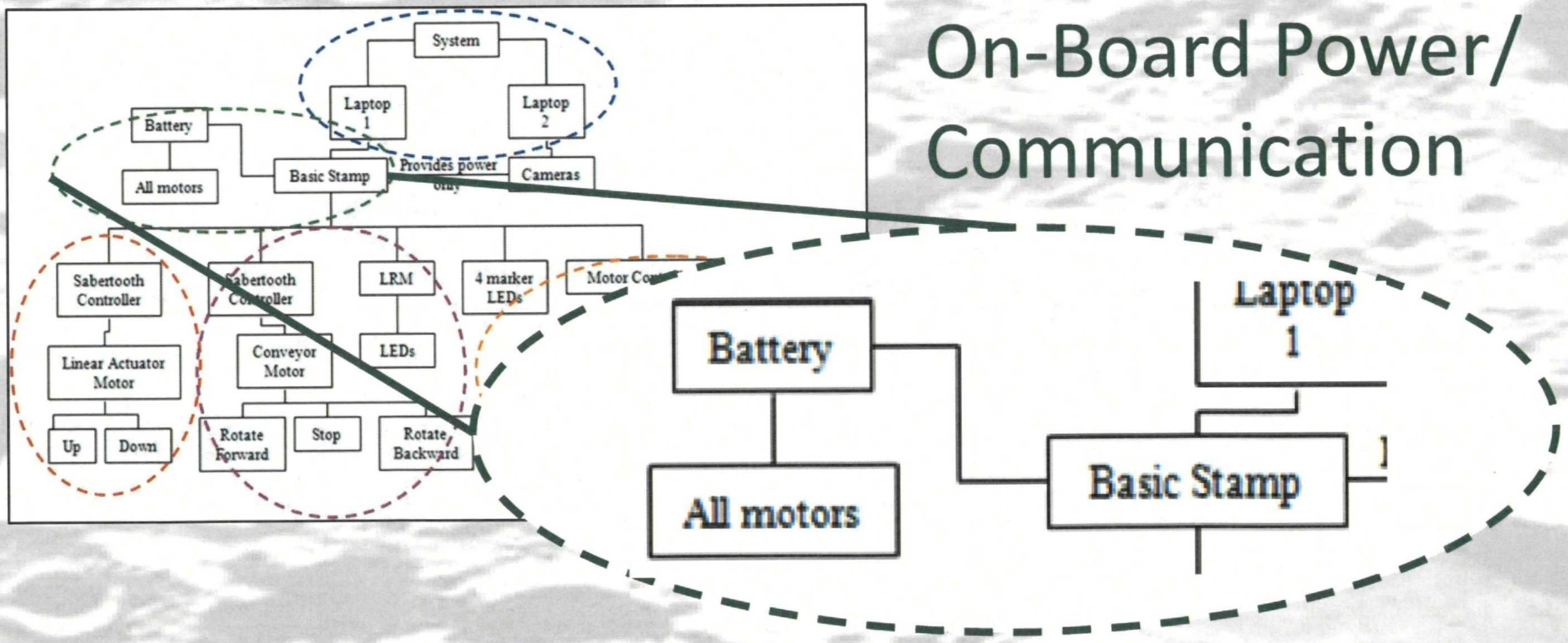
Left: Wiring RS80D motor controller for tracks compatibility testing

System Integration



Operator Station

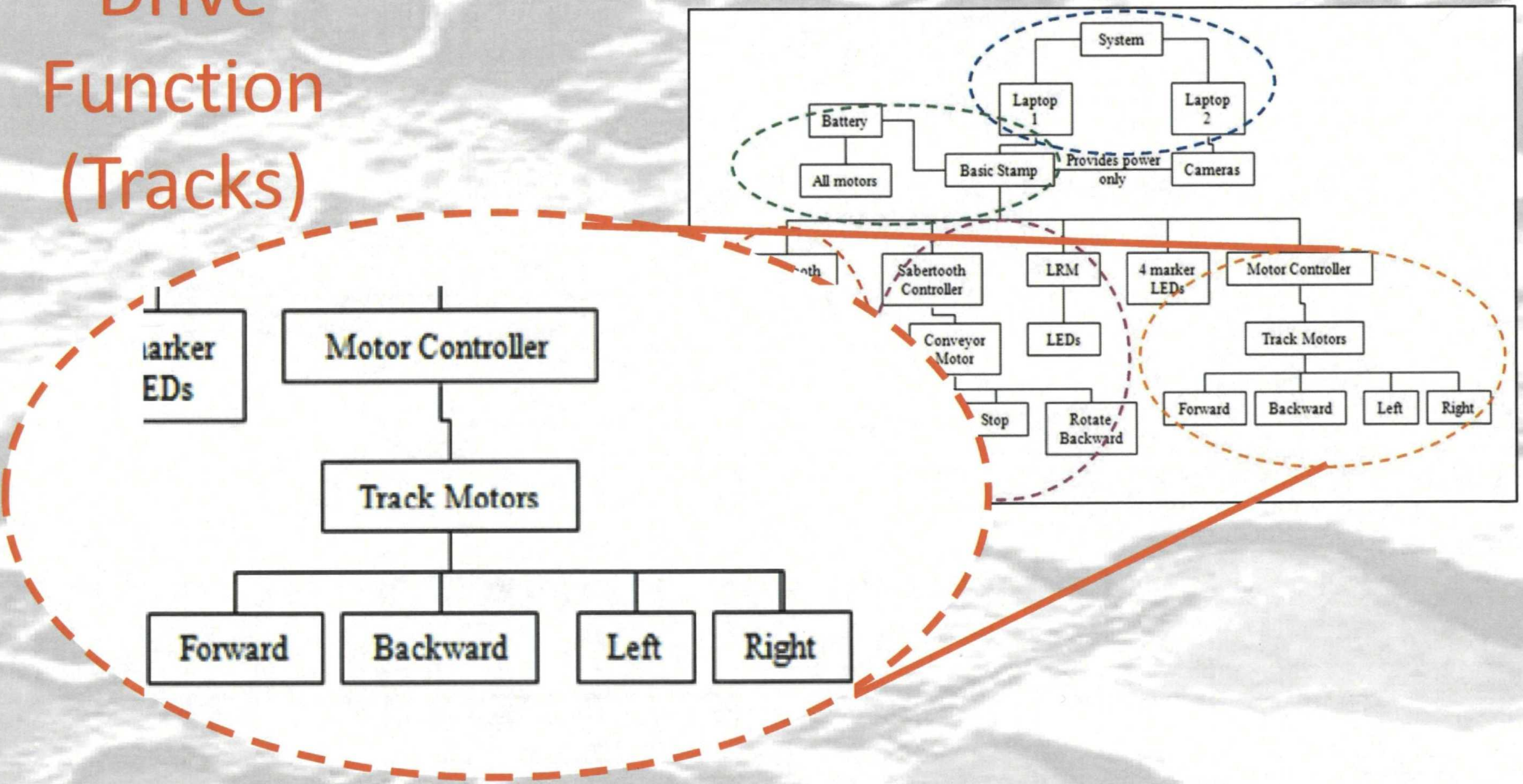
System Integration



On-Board Power/ Communication

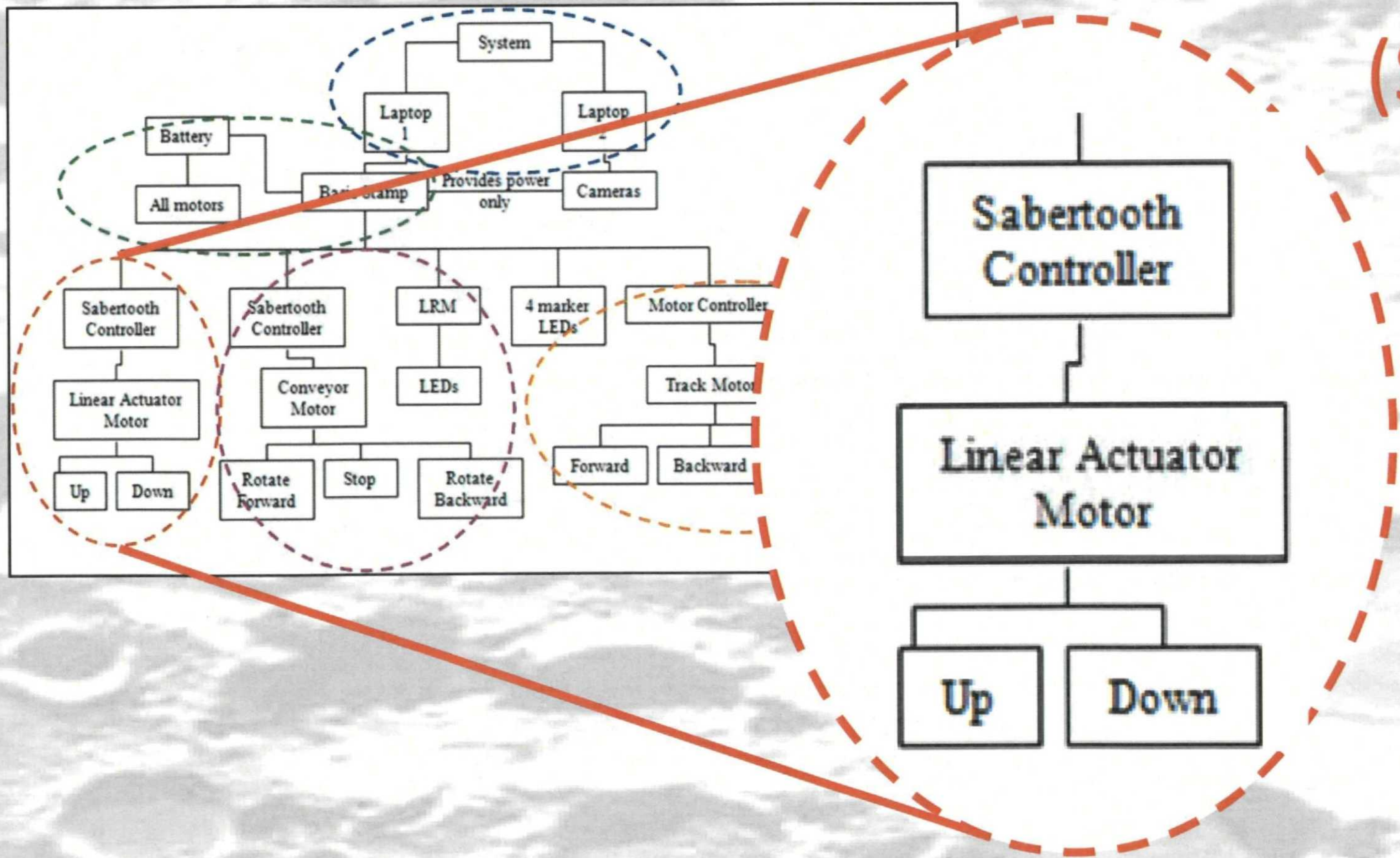
System Integration

Drive Function (Tracks)



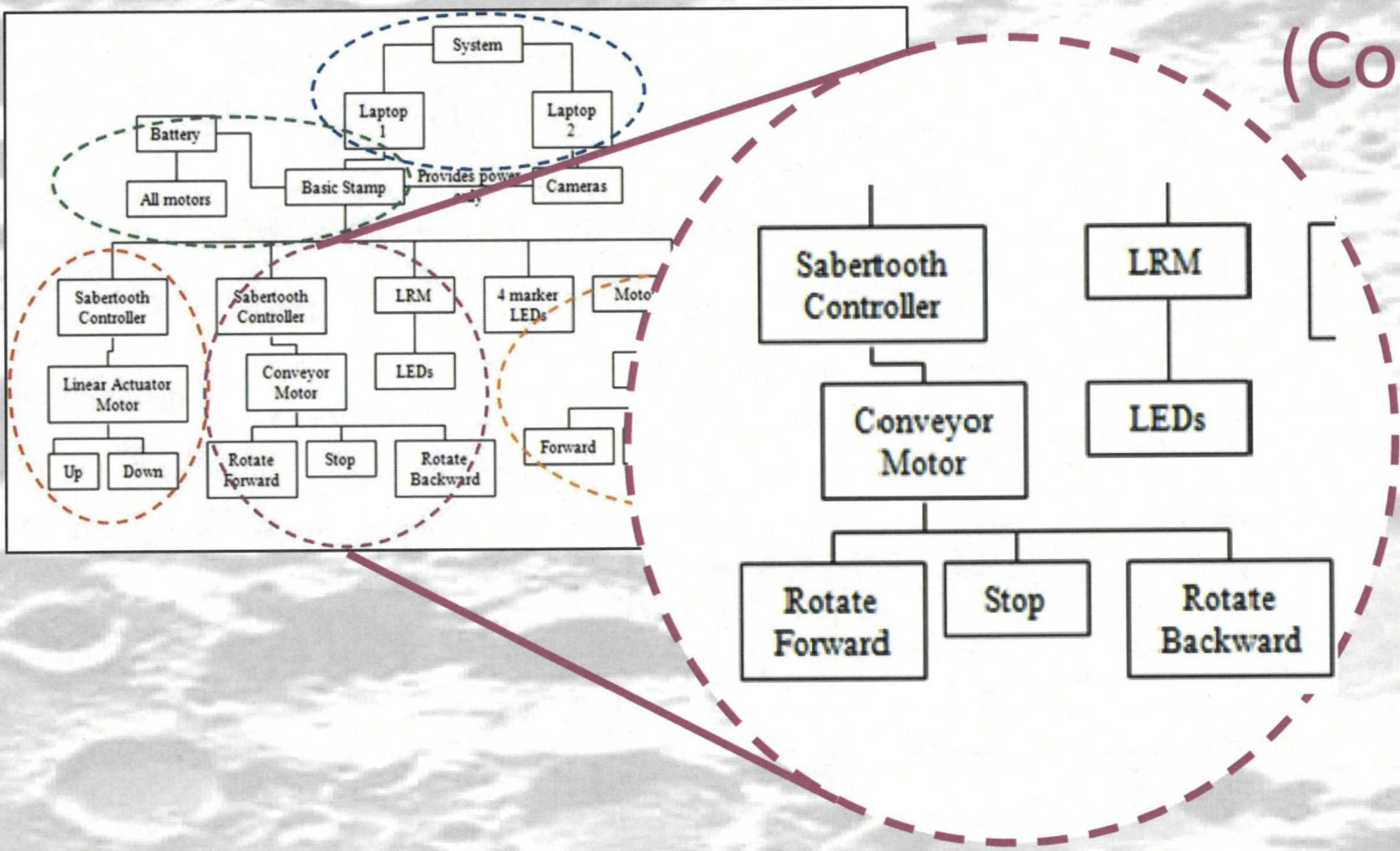
System Integration

DIG Function (Scoop)



System Integration

Deposit Function (Conveyor)



Risk Assessment

System Model:

Excavator is primarily a series system
Limited redundancy due to weight constraints
Virtually every component is a single point failure

Potential Failure Modes:

Yielding
Current overload
Motor torque overload

Risk Minimization:

Professional vs. onsite fabrication
Safety factor of at least 1.5 for each component
Conservative load estimates
Familiarity with motor controllers
Safety factor for maximum current
Derating of purchased components

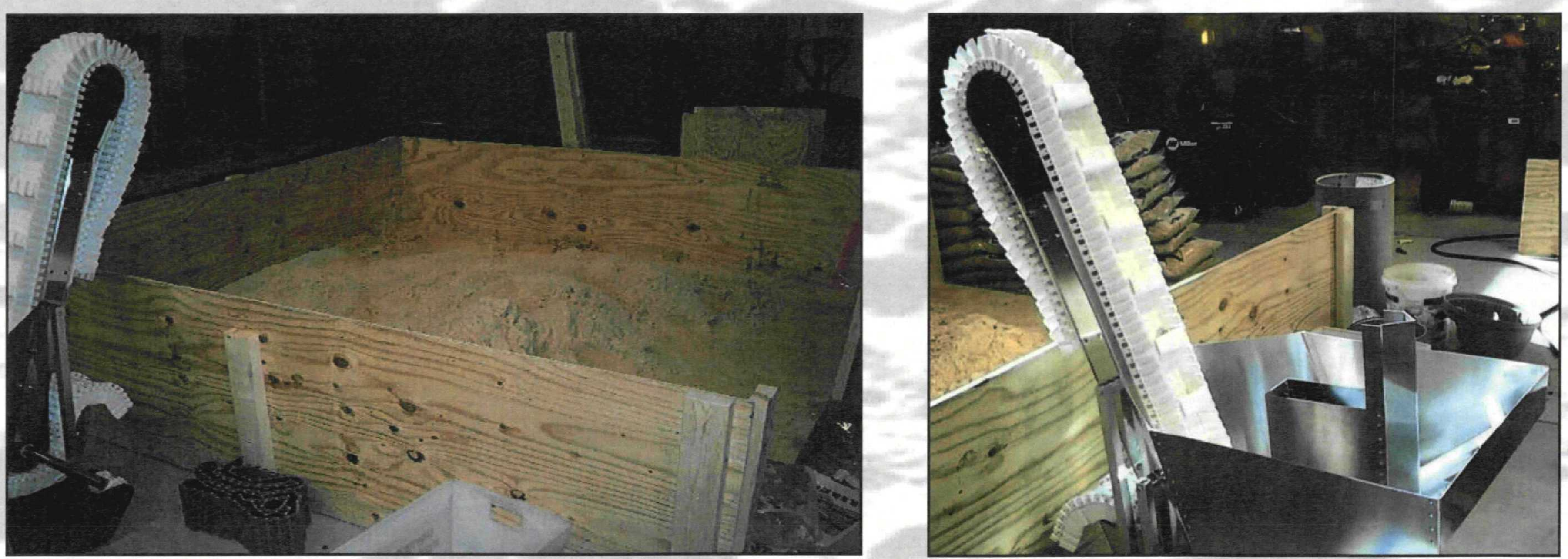
Reliability Ratings for Key Components

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

R = Reliability
β = Shape Parameter (0.8; indicates wear-in period)
η = Scale Parameter (Expected Life) (700 hours)
t = operation time (10 hours)

Two-Parameter Weibull Distribution equation yields a reliability rating of **96.7%** for the linear actuator based on device information.

Performance Evaluation Plan



Subsystems integration is completed as expected, with weight and size dimensions within specification. CE sub-team has constructed a 1:4 scale practice box to test excavator operation. Sufficient re-design time has been allotted in the project schedule for components that must be re-engineered for improved performance.

Sources

- NASA. 2010 Lunabotics Mining Competition Official Rules. Revised January 2010. <http://www.nasa.gov/offices/education/centers/kennedy/technology/lunabotics.html >
- Dovich, Robert and Wortman, Bill. *CRE Primer*, 4th Ed. October 1, 2009. P. V-77
- Powerizer 25.9V, 40Ah battery. <http://www.batteryspace.com/highpowerpolymerlionbattery259v10ah259wh70aratewithpcmafireretardantbag.aspx>
- Powerizer Battery Charger. http://www.batteryspace.com/smartcharger60afor259vliionpolymerrechargeablebatterypack-110v-240v.aspx
- Sabertooth 25A Motor Controller. http://superdroidrobots.com/shop/item.asp?itemid=822
- Dovich, Robert and Wortman, Bill. *CRE Primer*, 4th Ed. October 1, 2009. Section V
- O'Connor, P.D.T. (2002). *Practical Reliability Engineering*, 4th ed. Hoboken, NJ: John Wiley
- Axis 207W Wireless Network Camera. <http://www.axis.com/files/manuals/um_207w_mw_33158_en_1208.pdf>
- SpanTech LLC. http://www.spantechllc.com
- SpanTech straight conveyor. http://www.spantechllc.com/straight_conveyor.asp
- V2 track modules, Evolution Model Technology http://www.evolutionmodeltechnology.ca/platforms.html
- Photo by Brian Powell <www.wku.edu>
- Image from <www. corvettemuseum.com>
- Image from <www.bghotrods.com>
- Image from <www.nasa.gov>
- Huff Technology. <http://www.huff-tech.com/index.php>
- Ability Robotics. <http://abilityrobotics.com/index.html>
- *TFHRC*. <*http://www.tfhrc.gov/hnr20/recycle/waste/cfa51.htm*>
- Quickrete <http://www.quikrete.com/PDFs/MSDS-B4-Playsand.pdf>