The Montana MULE: A Case Study In Interdisciplinary Capstone Design

Dr. Brock J. LaMeres
Assistant Professor
Electrical & Computer Engineering Dept
Montana State University - Bozeman
Overview

• In May of 2010, NASA conducted the first annual *Lunabotics Mining Competition* at the Kennedy Space Center.

• This event was put on by the NASA ESMD Higher Education Project with the intent to

  “*retain students in Science, Technology, Engineering and Math (STEM)*”
Competition Overview

- Students were to design a wireless-controlled robot to excavate lunar regolith simulant.

- The robot had 15 minutes to collect the regolith and deposit as much as possible into a collector.

- A minimum of 10kg of regolith needed to be deposited into the collector to qualify. The team with the most regolith deposited above 10kg wins.
Competition Overview

• The sandbox was divided into two zones:
  1) the obstacle zone
  2) the mining zone

• The robot needed to traverse the obstacle zone (craters and rocks), pick up regolith from the mining zone, then return through the obstacle zone to deposit the regolith into the collector.

• A "sandbox" was constructed that allowed two robots to compete at a time.

• The robot was controlled using an 802.11 network from an isolated room that showed a real-time view of the sandbox using cameras.
Competition Overview

- Constraints were given for the robot design:

1) Size
   - Width = 1.5m
   - Length = 0.75m
   - Height = 2m
   Note: these dimensions were dictated by a wheelchair elevator in the pit area that was used to move robots between the 1st and 2nd levels.

2) Mass
   - 80kg
   Note: each robot was weighted prior to competition.

3) Technology
   - nothing could be used that couldn’t be used on the moon
     - for example: pneumatic tires, non-enclosed combustion engines, vacuums.
Competition Overview

• What it really looked like…

The sandbox was housed in a ventilated tent.

Tyvex suits and ventilation masks had to be worn inside the tent to prevent contact with the regolith

(Paul Dallapiazza, Steve Pemble, Ben Hogenson)

(Chris Ching)

(Steve Pemble)
Competition Overview

• What it really looked like…

Robots were loaded into the sandbox using a forklift.

The robot was driven from a control room that showed the sandbox on a monitor.

(Jack Ritter, Chris Ching, Jenny Hane)
• The Lunabotics opportunity was introduced at a NASA faculty workshop on capstones in June of 2009. This workshop was attended by Dr. LaMeres.

• Funds from NASA became available in August of 2009 to help with the material cost of the robots (up to $5k/team, total pool $50k).

• The Montana MULE team consisted of 8 students from 4 different departments

Ben Hogenson (EE)
Jennifer Hane (EE)
Phillip Karls (EE)
Chris Ching (CS)
Steve Pemble (MET)
Craig Harne (MET)
John Ritter (ME)
Paul Dallapiazza (ME)

(Pemble, Dallapiazza, Ching, Hane, Hogenson, Harne, Ritter)
Design Process

• **1) Mechanical System**

  The mechanical system consisted of the following sub-systems:
  a) Locomotion
  b) Digging
  c) Dumping

• **1.a) Locomotion**

  - The MULE used two motors to propel itself. Each motor controlled the two wheels on each side of the robot with a chain system.

  - The MULE used skid steering to turn.

  - Custom aluminum wheels on spindles were used that had fins for grip in the regolith.
• **1.b) Digging**

- The MULE used a bucket system to dig. This consisted of 26 individual buckets on a chain system.

- The chain system was mounted to a digging head that could be actuated to lower the buckets into the regolith.

- The buckets carried the regolith up and poured it into a hopper which stored the regolith for dumping (similar to a water wheel).

(John Ritter)
1. Design Process

- Once the hopper was full of regolith, a pulley system tipped it up for dumping.

- The dimensions of the hopper were designed so that the regolith could be dumped over the edge of the sandbox into the collector.
• **2.a) Motor Control**

- There were 6 motors/actuators that need to be controlled.

1x motor to run the pulley system

2x linear actuators to raise/lower the digging head

2x motors for locomotion

1x motor for running the bucket system
Design Process

- **2.a) Motor Control**

Each motor/actuator was controlled using an H-bridge circuit. Each H-bridge was controlled with a Pulse Width Modulated Signal that was generated depending on the RS232 packet received from the computer controller.
• **2.b) Power System**

- The motors were powered using two, 12v, lead-acid car batteries connected in series to produce 24v. The batteries were charged each time the robot returned to the pit.

- The electronics were powered using AA batteries and linear regulators. The batteries were changed each time the robot returned to the pit.

(Ben Hogenson & Steve Pemble)
Design Process

- **Fabrication**

  - The entire mechanical system was custom fabricated at MSU with the exception of chains and sprockets.

(Steve Pemble Welding Frame)  
(Wheel Cutting)  
(Craig Harne Holding Cut Wheel)
Design Process

• **Fabrication**

- The electrical system was prototyped in the lab using signal generators prior to attaching to the robot frame.
• **Testing**

- The mechanical system was tested without the control electronics using a relay switch box. This allowed all of the mechanical systems to be verified. The testing was conducted in a volleyball course at MSU.

(Hogenson, Hane, Dallapiazza, Ritter, Pemble, Ching, Harne)

(Hogenson, Ching, Pemble, Dallapiazza, Ritter)
Outreach Events

- **Event #2** – Presentation to 30 students from Mrs. Pool’s 4th grade class from Morning Star Elementary School.

Paul Dallapiazza (ME)  
Steve Pemble (MET)  
Chris Ching (CS)  
Craig Harne (MET)  
MSU Excavator  
Mrs. Pool’s 4th Grade Students
Outreach Events

- **Highlight Video** – The team worked with the MSU news service to create a video highlighting the design process and what this competition entails. The video was turned into NASA for points toward the Joe Kosmo Award. The video is now being used as a promotional tool for recruiting students into the college of engineering.
Outreach Events

• **Hallway Outreach** – 3 year old Alexis LaMeres gets a VIP driving lesson from Craig Harne and Ben Hogenson.
In May of 2010, Dr. LaMeres and 6 students traveled to NASA’s Kennedy Space Center to participate in the 1st annual Lunabotics Mining Competition.

The students on the travel team were:

- Ben Hogenson (EE)
- Jennifer Hane (EE)
- Chris Ching (CS)
- Steve Pemble (MET)
- John Ritter (ME)
- Paul Dallapiazza (ME)

Craig Harne and Phillip Karls could not attend due to already working in industry.

- The competition was held at the Astronaut Hall of Fame.
- Prior to leaving for the competition, the University and local news picked up the story about a student team going to NASA for a robot competition.

- The outpouring of support was the first time the students began to realize how big of an event they were apart of.

MSU Website Main Page
May 21, 2010
Competition Event

- Local Support cont...

Bozeman Chronicle Newspaper Article
May 27, 2010

MSU student robot to dig ‘moon dirt’ in NASA contest

By EVELYN BOSWELL
MSU News Service

A Montana State University robot that sometimes had a spooky mind of its own is at the Kennedy Space Center to see if it can dig more moon dirt than any other student-built robot. In a May 27-28 competition sponsored by NASA, an MSU engineering student will remotely steer the 120-pound robot through a giant sandbox so it avoids craters and rocks then removes as much simulated moon dirt as possible in 15 minutes.

The simulated dirt — officially called ‘regolith’ — is different from the sand on a Florida beach or the outdoor volleyball court where the MSU students tested their robot in a May snowstorm. Since erosion doesn’t occur on the moon like it does on Earth, the top layer will be like powdery glass that’s extremely loose and super fine. The soil beneath will be small, sharp, jagged particles that can clump together. It’s almost as hard as concrete.

If MSU wins NASA’s first Lunar Regolith Excavator Student Competition, it will receive $5,000 and the opportunity to return to the Kennedy Space Center to watch a launch. If MSU’s robot, “Montana MULE,” doesn’t dig the most dirt and the MSU team doesn’t dazzle with its spirit, robot design, videos and project presentations — other contest categories — the students said they will still have gained valuable experience from the project.

John Ritter observes “Montana MULE” to see what needs to be done before the robot competes in a national contest at the Kennedy Space Center. Six MSU students and a faculty adviser will be in Florida for the NASA competition.
Competition Event

- Local Support cont…

Billings Gazette
Newspaper Article
May 25, 2010
• Local Support cont…

KBZK News Story
5/19/10
Competition Event

• **Shipping**

- 22 teams from across the nation participated in the mining competition.

- MSU traveled the furthest distance. The robot was shipped to the Kennedy Space Center the week prior to the event.

(Ben Hogenson and Steve Pemble fasten down the MULE in a custom crate)

(Jenny Hane, Steve Pemble, and Ben Hogenson stand by the sealed crate)

(The MULE and its crate weight for the shipping truck to arrive on the MSU loading dock)
• **Shipping**

- Upon arrival, the MULE was waiting at the Astronaut Hall of Fame.

- There was some minor damage during shipping, but nothing that couldn’t be repaired.

(Steve Pemble and Ben Hogenson open the MULE crate)  
(The team tries to figure out where all the broken wood came from?)
**Setup**

- Each team was given a *pit area* where they could setup the robot and start getting ready to compete.

(Jenny Hane and Ben Hogenson get the motor controller electronics ready)  
(Chris Ching begins talking to the robot via the practice wireless network)  
(John Ritter, Paul Dallapiazza, and Steve Pemble make mechanical adjustments)
• **Practice Day**

- Each team was given a trial run in the sandbox prior to the official competition days.

- Very few robots moved. The MULE was one of them.

(Jenny Hane and Ben Hogenson try to get the motor controller electronics turned on)

(Steve Pemble, Ben Hogenson, and Paul Dallapiazza lift the MULE into the sandbox for its practice run)

(Chris Ching comes into the sandbox from the control room trying to figure out why it didn’t move)
• Testing outside of the tent (Test #2)

- Since there was no more time to test inside the tent, the team decided to start digging in the grass near the tent.

- This test revealed a 2\textsuperscript{nd} round of issues…
• **Test #3 Outside Test**

- everything seemed to work solidly
• **Competition Day #1**

- The MULE was called late in the afternoon for its competition run. No team had dumped any regolith and very few robots even moved.

- The MULE moved, the buckets spun, and the hopper could dump

  **BUT…..**

  a broken wire prevented the digging head from actuating and getting the buckets into the regolith.
• **Competition Day #2**

- All wires were checked and the MULE made its 2\textsuperscript{nd} competition attempt.

- Still, no other team had put any regolith in the collector….

- It was loaded………………………It moved…………………………….…It dug…………

- It was loaded………………………It moved…………………………….…It dug…………
Competition Event

- **Competition Day #2**

- It dumped……………………………………….21.6kg !!!!!!
Competition Event

• **Competition Day #2**

  - The team then waited for the rest of the teams to go.

  - The waiting was **excruciating!!** but………..
- In the end, no other team was able to dump the required 10kg of regolith.
THE BIG SKY

MSU robot moon-digger wins NASA competition

By MICHAEL BECKER
Chronicle Staff Writer

A robot moon-digger designed by Montana State University engineering students bested 21 other robots in a competition at Kennedy Space Center on Friday, earning the student team $5,000 and an invitation to a NASA rocket launch.

The Lunar Regolith Excavator Student Competition was held at the Astronaut Hall of Fame in Florida on Thursday and Friday and featured teams from universities around the country.

The goal: to see which student-designed and built, remote-controlled robot could pick up the most simulated moon dust.

The MSU robot, dubbed Montana MULE, picked up about 22 kilograms of dust — roughly 45 pounds. The MSU robot was the only one at the competition to meet NASA’s 10-kilogram minimum, said the team’s faculty adviser, MSU professor Brock LaMeres.

“They’re freaking out. It’s incredible,” he said. “We went third, so we’d been sitting here for 120 pounds, 5-foot-tall robot was designed last fall by eight students from three MSU engineering departments. It was built and tested on campus over the past year.

I don’t know how long, six hours, waiting while other teams went.”

The competition was intended as part of an effort to keep university students around the country enrolled in science, engineering and mathematics courses, according to the its website. NASA also hopes that the students will come up with innovative ideas that could be used on future moon missions.

Michael Becker can be reached at 582-2657 or becker@daily-chronicle.com.

$5,000 prize and will get V.I.P. seating at a future NASA launch, LaMeres said.
KBZK News Story
May 29, 2010
MSU students win NASA moon dirt-digging contest

BY EVELYN ROSEWELL
MSU NEWS SERVICE

A Montana State University student-built robot won a national contest at the Kennedy Space Center Friday by digging the most simulated moon dirt in 15 minutes. Competing from 21 other colleges and universities, Montana MULE removed 23.8 kilograms of regolith from a giant sandbox. That was far above the 10 kilograms required to qualify in the contest and far ahead of the nearest competitor at NASA's first Lunar Regolith Executive Student Competition.

A robot from Auburn University dug 6.6 kilograms. The University of South Carolina robot dug 2.4 kilograms. Montana MULE was the only robot that met and surpassed the minimum requirement, beating out others, larger universities such as Virginia Tech, Iowa State University and the University of North Carolina Charlotte.

The victory gives the MSU students $5,000, the chance to return to the Kennedy Space Center for a month and plenty of thrills. Additionally, the team won the $10,000 Robert Warren Award for their combined work in engineering, outreach and presentation.

"I'm so proud of everyone who worked on the competition," said team member Chris Ching said by telephone from Virginia. "I'm so proud of everyone who worked on the competition," said team member Chris Ching said by telephone from Virginia.

"I'm so proud of everyone who worked on the competition," said team member Chris Ching said by telephone from Virginia.

Students representing three departments and five majors in the College of Engineering built Montana MULE. The team consisted of Ben Wagner and Eliza Bax from Billings. Team Leader Craig Harper and Paul Dallalas from Florence. Their faculty advisors were LaMere in the Department of Electrical and Computer Engineering, Shee in the Department of Computer Science, and Bob Lesley in the Department of Mechanical and Industrial Engineering.

"After 354 performance, Lloyd received an email from NASA telling him that NASA would pay for him to travel there to fly for the introduction of next year's contest, a planetary research vehicle.

"This team is all graduating, so we'll be looking for a new group of students in the fall," Lloyd said.

The students built Montana MULE in out of recycled aluminum. They used wireless technology and the controls for an X-Box 360 computer games to talk to the robot's electronics system. The electronics system turned a motor on and off. The motor turned a chain that caused small plastic balls before the end of the tunnel.

"The heavy - moving like a bat on a Fwitt wheel - dug the dirt, talked along the run while it dug into the dirt to put it into the hopper. The robot then emptied the dirt into a 10-kilogram container where it was cooled down."

"The robot was very simple in terms of the robot's electronics system. The electronics system turned a motor on and off. The motor turned a chain that caused small plastic balls before the end of the tunnel.

"The heavy - moving like a bat on a Fwitt wheel - dug the dirt, talked along the run while it dug into the dirt to put it into the hopper. The robot then emptied the dirt into a 10-kilogram container where it was cooled down."

Belgrade Newspaper
June 1, 2010
Competition Event

• **Award Ceremony**

- All teams were invited to an awards banquet at the Saturn V visitor center.

(MULE Team standing by Saturn V rocket Ritter, Pemble, Dallapiazza, Ching, Hane, Hogenson, LaMeres)

(Chris Ching standing in front of banquet tables setup under the Saturn V rocket)
Competition Event

- **Award Ceremony**

  - The Montana MULE team won the overall mining competition and was the ONLY team to meet the 10kg minimum qualifying mark. The team won $5000 and VIP launch passes.

  - The Montana MULE team won the Joe Kosmo Award for Excellence for accumulating the most overall competition points. The team won an all expenses paid trip to NASA’s Dessert RATS robotics demonstration.
Other Highlights

(MULE Team at Atlantis Landing Site)

(Delta IV rocket launch May 27, 2010)

President Cruzado’s Inauguration

Desert RATS

Highlighted in MSU KidZone Publication
Other Highlights

**Bobcats dig moon “gold”:** MSU students won a national contest held by NASA when their robot moved the most regolith, or simulated moon dirt.

**Staying in touch:**
MSU and Advanced Acoustic Concepts, Inc. build a smart antenna to keep emergency workers connected in rugged terrain.

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**IN THE NEWS**
- Touroff receives NSU fellowship to turn waste into product
- Nehir named fellow of IFF
- Dickensheets and Nehir receive 2010 faculty awards
- Guelzene awarded Phi Kappa Phi Fellowship
- Skydive has story published in national scholarly journal
- Albert receives IEEE individual achievement award

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**FROM THE DEAN**
As you read this issue, you’ll see reflections of our core values and our desire that we are moving forward toward our strategic goals.

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**ALUMNI SPOTLIGHT**
Maury Irvine, ’40, Engineering Physics, a life-long learner, hasn’t retired in retirement.

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**EXCELLENCE**

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**CALENDAR**

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**GIVE TO COE**

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**ARCHIVES**

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**CONTACT US**

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• The team was interviewed by KBZK upon return about the experience
• **What did this experience cost?**

**Materials & Supplies** $4,200
- Mechanical System ($1,650)
- Electrical System ($2,050)
- Computer System (used existing HW)
- Printing & Media ($500)

**Travel** $8,900
- Airfare ($4,200)
- Motel ($2,050)
- Rental Car ($600)
- Per Diems & Miscellaneous ($2,050)

**Shipping** $2,100

**Total** $15,200
Conclusion

Go Cats!!!

Go MULE!!!