The Montana MULE:
A Case Study In Interdisciplinary Capstone Design

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Overview

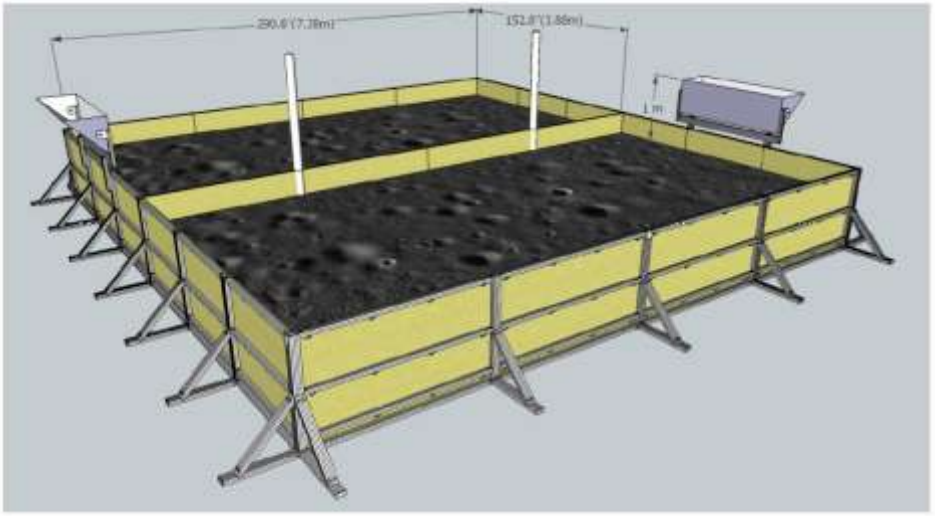
- In May of 2010, NASA conducted the first annual *Lunabotics Mining Competition* at the Kennedy Space Center.

- 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.

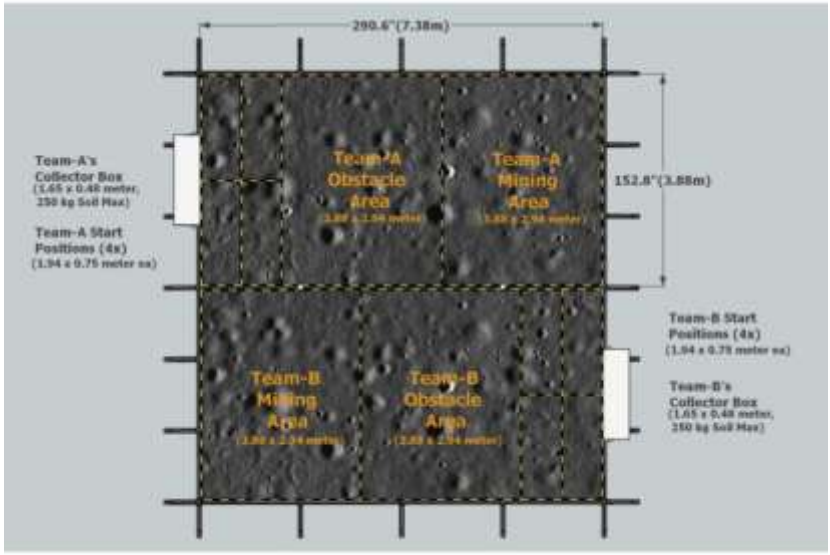


Sandbox Diagram (side view)

Competition Overview

- The sandbox was divided into two zones:

  1) the obstacle zone
  2) the mining zone



Sandbox Diagram (top view)

- 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.

(Chris Ching)

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

(Paul Dallapiazza, Steve Pemble, Ben Hogenson)

(Steve Pemble)

Competition Overview

- What it really looked like…

Robots where loaded into the sandbox using a forklift.

(Jack Ritter, Chris Ching, Jenny Hane)

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

Interdisciplinary Capstone Logistics

- 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

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

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

Design Process

- **1) Mechanical System**

  The mechanical system consisted of the following sub-systems:

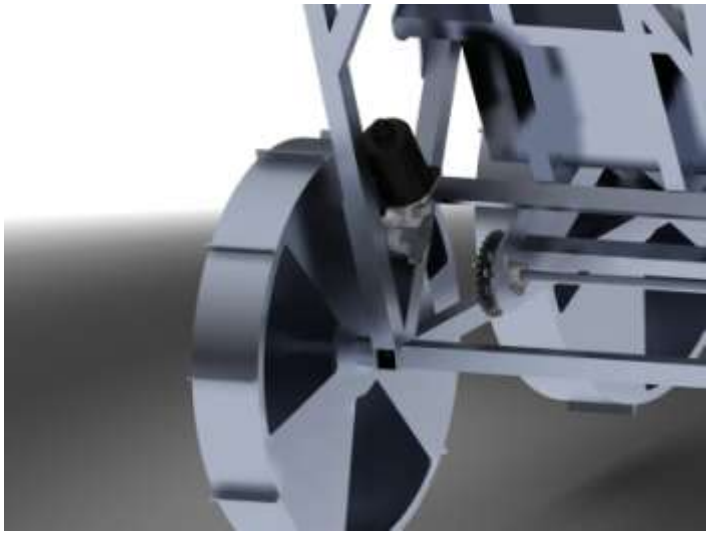
  a) Locomotion
  b) Digging
  c) Dumping

- **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.



Design Process

- **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)

Design Process

- **1.c) Dumping**

  - 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.

Pulleys lift the hopper.

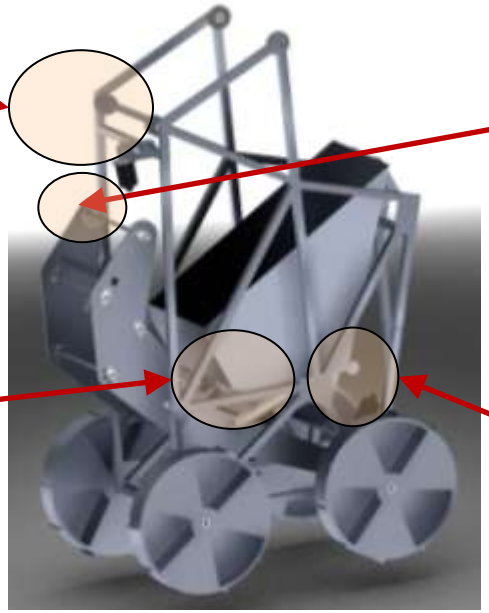
The hopper is shaped to dump over the edge of the sandbox.

Design Process

- **2.a) Motor Control**

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

1x motor to run the pulley system



1x motor for running the bucket system

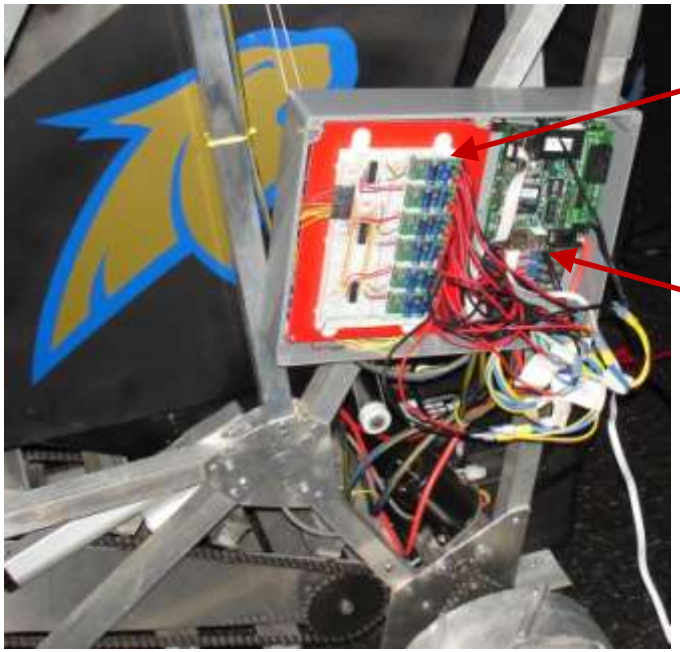
2x linear actuators to raise/lower the digging head

2x motors for locomotion

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.



6x H-bridge circuits that send signals to DC motors/actuators

An FPGA board receives RS232 commands from the computer control and converts the instructions into PWM signals for the H-bridges

Design Process

- **2.b) Power System**

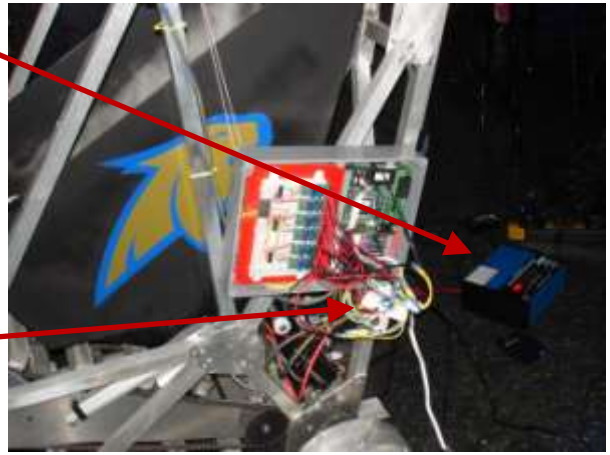
  - The motors were powered using two, 12v, lead-acid car batteries connected in series to produce 24v. The batteries were charged each time the robot returned to the pit.

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

12v, lead-acid car batteries

Battery Charger

AA battery pack and linear regulators.



(Ben Hogenson & Steve Pemble)

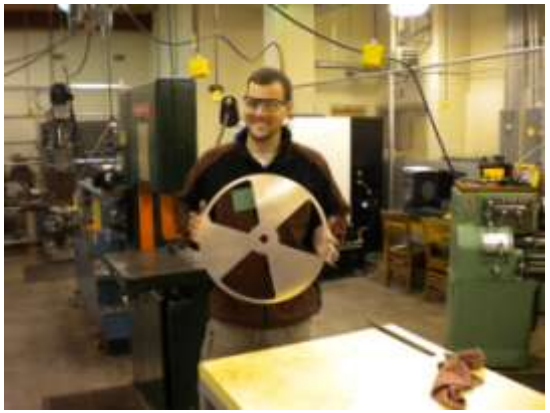
Design Process

- **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.

Design Process

- **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.

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.

Competition Event

- 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.

Competition Event

- **Local Support**

  - 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

BOZEMAN DAILY CHRONICLE

THE BIG SKY

THURSDAY, MAY 27, 2010

CITY DESK: 587-4491 OR E-MAIL: CITYDESK@DAILYCHRONICLE.COM

MSU student robot to dig 'moon dirt' in NASA contest

By EVELYN BOSWELL
MSU News Service

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.

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, video and project presentations — other contest categories — the students said they will still have gained valuable experience from the project that spanned two semesters.

Representing three departments and five majors in the College of Engineering, the team of eight students said the project taught them how to communicate their ideas across specialties — a skill they'll need when they become practicing engineers. They also worked together to design and build a robot that MSU faculty said is much more complex than senior capstone projects in past generations.

(More **Robot**, Page C2)

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.

MSU PHOTO BY KELLY GORHAM

Competition Event

- **Local Support cont…**

MSU team digs into 'moon dirt' in contest

Billings Gazette
Newspaper Article
May 25, 2010

Competition Event

- **Local Support cont…**

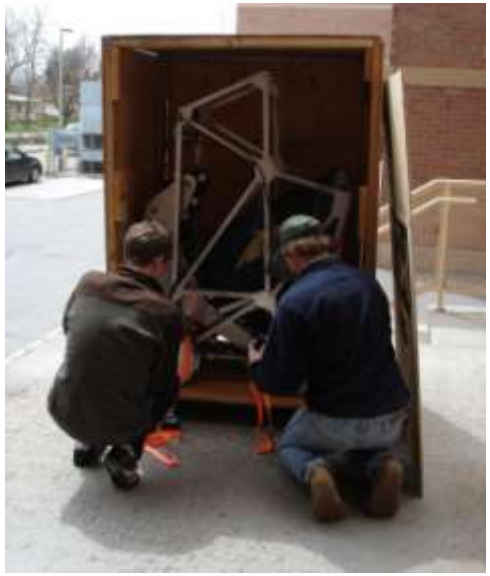
KBZK News Story
5/19/10

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)

Competition Event

- **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?)

Competition Event

- **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)

Competition Event

- **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)

The Competition

University of Alabama

Virginia Tech

Southern Indiana

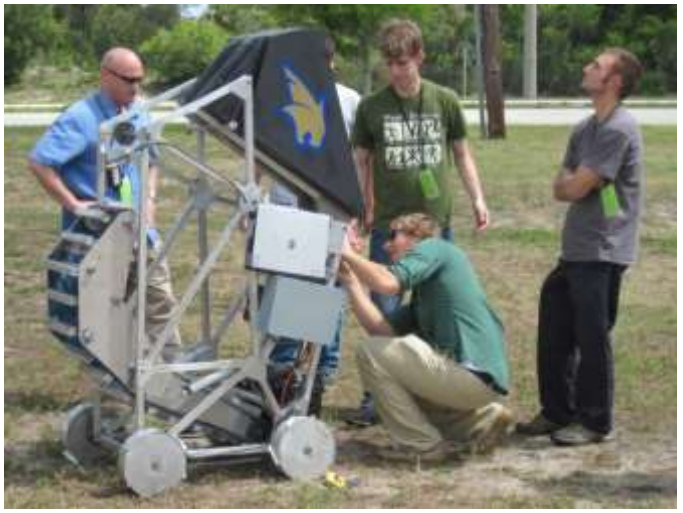
Carnegie Mellon

Western Kentucky

Competition Event

- **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 2nd round of issues…

Competition Event

- **Test #3 Outside Test**

  - everything seemed to work solidly

Competition Event

- **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 Event

- **Competition Day #2**

  - All wires were checked and the MULE made its 2nd competition attempt.

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

  - It was loaded……It moved……It dug……

Competition Event

- **Competition Day #2**

- It dumped.....**21.6kg !!!!!!!**

Competition Event

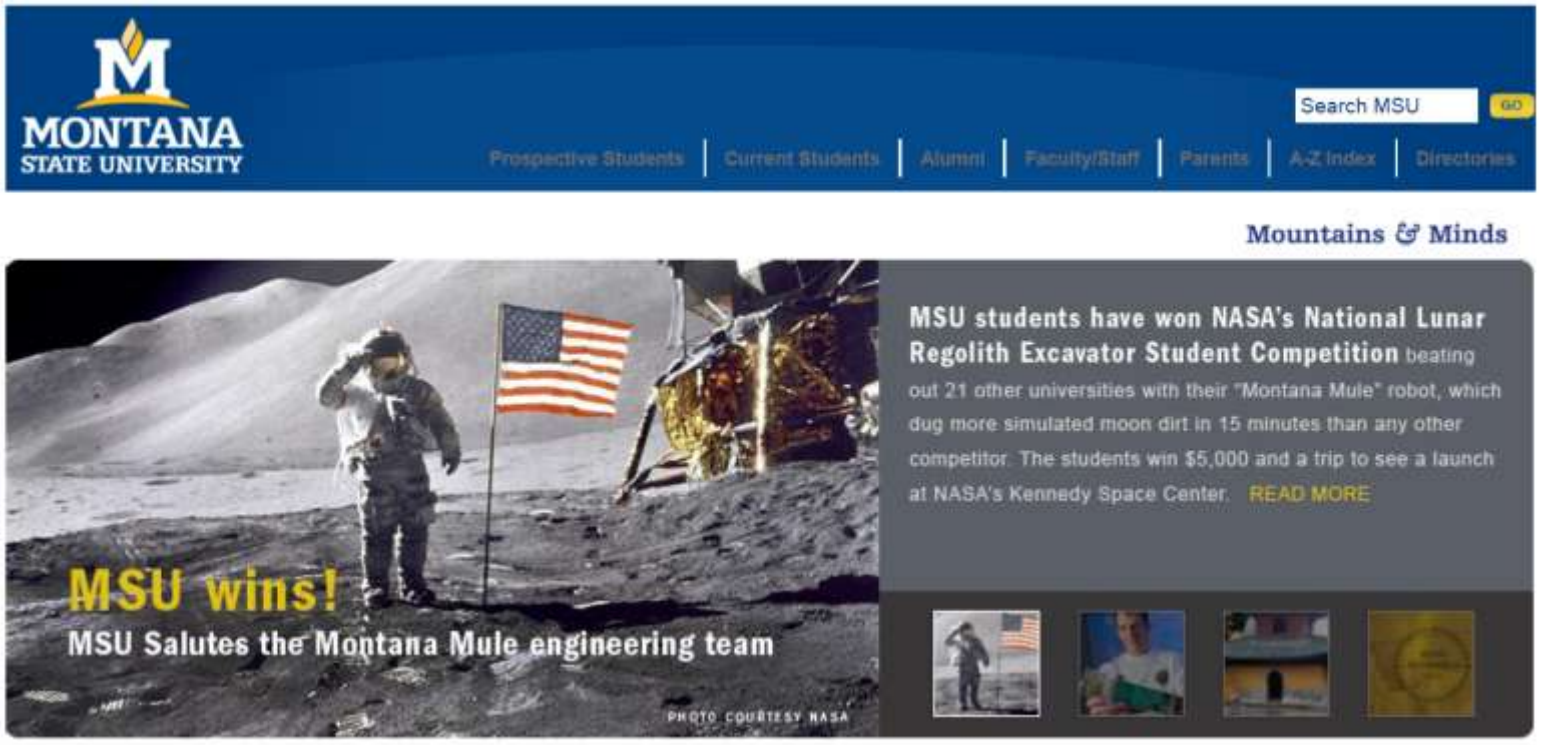
- **Competition Day #2**

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

  - The waiting was **excruciating!**!! but……..

Competition Event

- In the end, no other team was able to dump the required 10kg of regolith.



MSU News Service Article
May 29, 2010

Competition Event

BOZEMAN DAILY CHRONICLE

THE BIG SKY

SATURDAY, MAY 29, 2010

CITY DESK: 587-4491 OR E-MAIL: CITYDESK@DAILYCHRONICLE.COM

MSU robot moon-digger wins NASA competition

By MICHAEL BECKER
Chronicle Staff Writer

The 120-pound, 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.

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 I don't know how long, six hours, waiting while other teams went."

The 120-pound, 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.

The students will split the $5,000 prize and will get V.I.P. seating at a future NASA launch, LaMeres said.

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@dailychronicle.com.

Bozeman Chronicle Newspaper Article
May 29, 2010

Competition Event

KBZK News Story
May 29, 2010

Competition Event

BELGRADE NEWS JUNE 1, 2010

MSU students win NASA moon dirt-digging contest

Some of the MSU team members who designed and built Montana MULE test their robot at MSU before heading to the Kennedy Space Center. From left are Chris Ching, Steve Pemble, Paul Dallaplazza and John Ritter.

BY EVELYN BOSWELL
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.

Defeating robots from 21 other colleges and universities, Montana MULE removed 21.6 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 in NASA's first Lunar Regolith Excavator Student Competition.

A robot from Auburn University dug 6.6 kilograms. The University of Southern Indiana's robot dug 2.4 kilograms. Montana MULE was the only robot that met and surpassed the minimum requirement, beating out other, 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 launch, and plenty of thrills. Additionally, the team won the Joe Kosmo Award for their combined work in engineering, outreach and presentation.

"I'm supposing my parents won't have much problem with how many video games I played as a kid," Chris Ching said by telephone from Florida.

Ching from Belgrade, an MSU senior in computer science, remotely steered Montana MULE to victory by using the controls of an X Box 360 computer game and wireless technology. Ching sat inside a building that was isolated from the arena, so he controlled Montana MULE by watching the robot on a screen.

Helping him watch were teammates Jennifer Hane of Fort Shaw and John

more on Mules Dirt, + next page

JUNE 1, 2010 BELGRADE

continued from page A18

Ritter of Idaho Falls, Idaho. Ching said the screen refreshed at a low rate, which meant there were lags between what he was doing and seeing.

"It was pretty nerve-wracking," Ching said.

Loud cheers and applause interrupted a NASA talk show Friday morning when the 120-pound MSU robot became the first robot in the contest to dig more than 10 kilograms of simulated moon dirt. The competition began Thursday, but no robots were able to dig 10 kilograms the first day.

A few teams were disqualified. As a result, NASA gave the remaining teams three hours to fine-tune their robots, then started the competition over on Friday.

Brock LaMeres, faculty adviser for the MSU team, said a loose wire was the reason Montana MULE wasn't digging on Thursday. Ching could move the robot across the dirt and into the mining area, but he couldn't lower the bucket into the dirt. The students fixed the wire, taped down all their wires and recharged the battery that night.

LaMeres said he believes the robot finally did so well because the students incorporated the right combination of systems into their robot. They probably had three or four alternatives to choose from for each system, but they apparently chose the best combination, he said.

Montana MULE had wheels, for example, instead of moving like a Caterpillar as some other robots did. It also had a bucket-digging system and a hopper. The robot itself contained a computer system.

Ching and LaMeres said MSU also benefitted from some extra practice time. Since MSU still had a few minutes left in its 15-minute allotment on Thursday, Ching used the time to practice running the robot through the course and give the audience a show. He got Montana MULE to do a doughnut. He got it to dodge rocks and craters. He turned it so people could see the MSU Bobcat on its side.

"It handled fantastic," Ching said.

Students representing three departments and five majors in the College of Engineering built Montana MULE this school year. Besides Ching, Hane and Ritter, the MSU team consisted of Ben Hogenson and Phillip Karls from Billings, Steve Pemble of Culbertson, Craig Harne of Corbank and Paul Dallaplazza from Florence. Their faculty advisers were LaMeres in the Department of Electrical and Computer Engineering, Lloyd in the Department of Computer Science, and Robb Larson in the Department of Mechanical and Industrial Engineering.

After MSU's performance, Lloyd received an e-mail from NASA, telling him that NASA would pay for him to travel there in July 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 mostly out of recycled aluminum. They used wireless technology and the controls for an X Box 360 computer game to talk to the robot's electronics system. The electronics system turned a motor on and off. The motor turned a chain that moved small buckets below the axel of the wheels.

The buckets — moving like seats on a Ferris wheel — dug the soil, took it along for the ride and dumped it into the robot's hopper. The robot then emptied the hopper into a NASA cost saver where the regolith was weighed.

Pemble said every system on the robot failed at least once in the development stages.

"We finally got to the point where all our weak links got weeded out," he said. "On a wing and a prayer, it worked."

An awards ceremony was held Friday evening in Florida. Besides the dirt digging competition, other categories included team spirit, robot design, video and project presentations.

Montana Mule will be displayed in MSU's Engineering Physical Sciences building this summer.

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.

(MULE Team with $5000 Check)

(MULE Team with KSC Director and ESMD Higher Education Program Director)

Other Highlights

(MULE Team at Atlantis Landing Site)

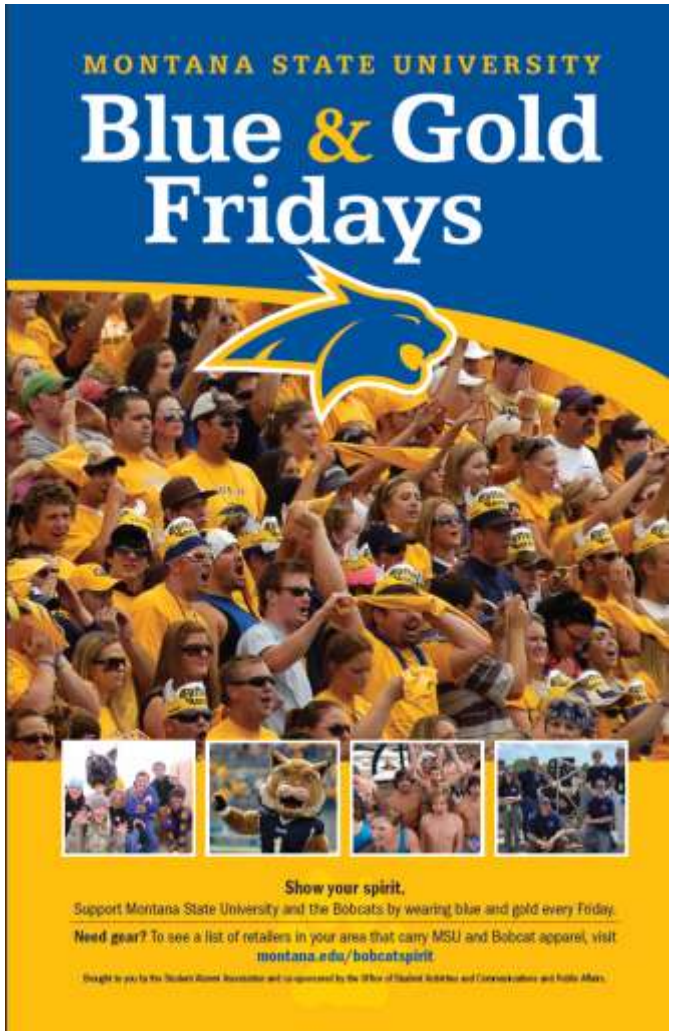
(Delta IV rocket launch May 27, 2010)

President Cruzado's Inauguration

Desert RATS

Highlighted in MSU KidZone Publication

Other Highlights



Competition Event

- **The team was interviewed by KBZK upon return about the experience**

Budget

- **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**

Go Cats!!!

Go MULE!!!