27th annual INCOSE international symposium

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NASA's Robotic Mining Competition Provides Undergraduates Full Life Cycle Systems Engineering Experience

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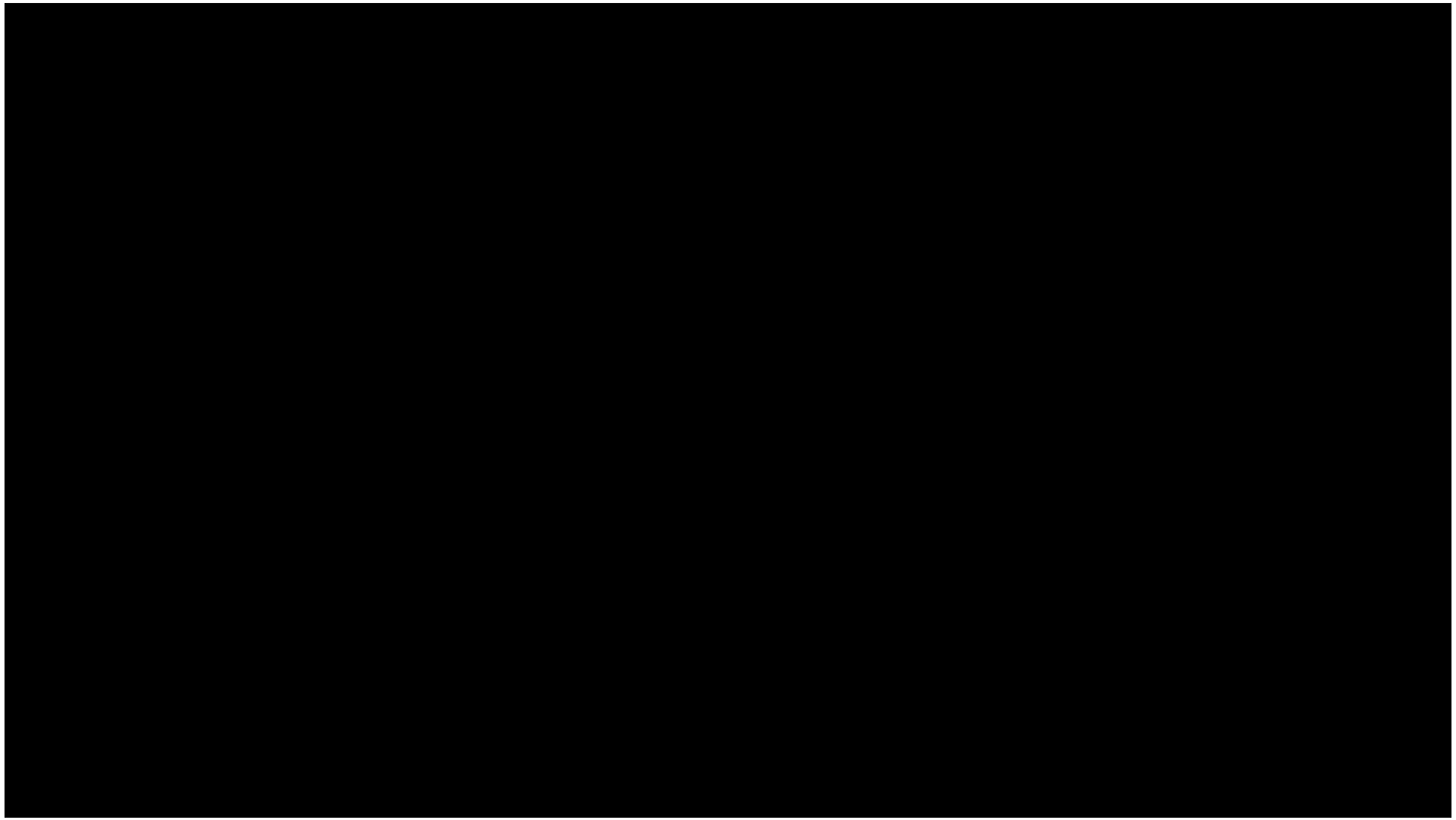
RMC 2015 Recap



2’16”

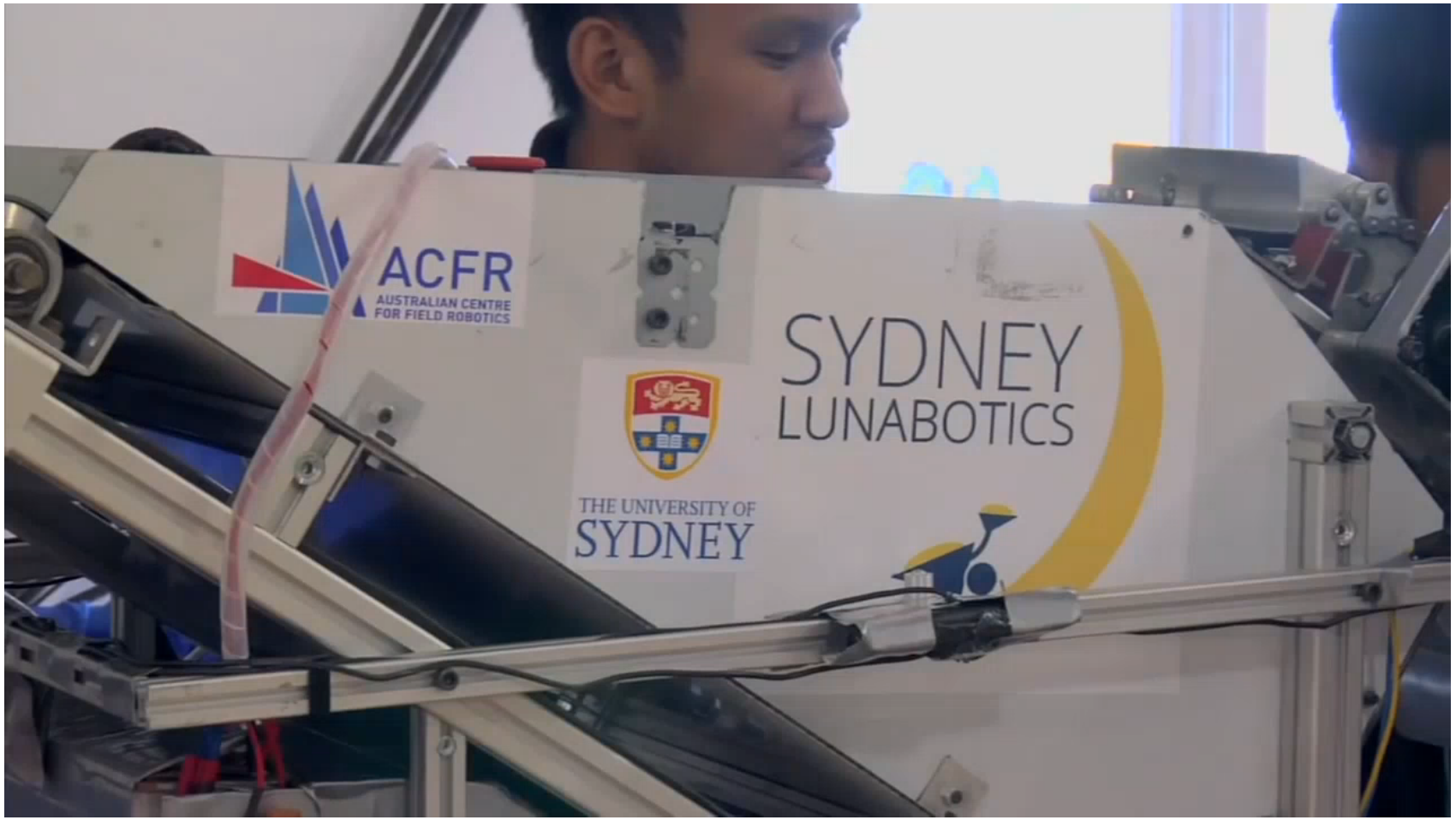
The Annual NASA Robotics Mining Competition

- University level competition – to design, build, and operate a robot remotely to excavate simulated Martian regolith.
  - Full Life cycle, from ideation to decommissioning.
  - Started in 2010 as Lunabotics Mining Competition.
  - NASA purpose:
    - To encourage development of innovative robotic excavation concepts (NASA may use these approaches on a future In-Situ Resource Utilization mission).
    - To advance STEM education and inspire students to become the type of engineers NASA needs.
- NASA has hosted over 340 different robots and 3500 students.
- Up to 50 teams per competition year.
  - 3-70 students and faculty.
  - Major universities, college teams, and even community college and club teams.
  - Teams responsible for all their own funding.
  - Full year effort starting in August with final week long competition in late May at KSC.
  - Some schools use the RMC as a capstone design project.

Participating Countries in Lunabotics/Robotic Mining Competition

Competition Year	Team Countries
2010 Lunabotics	USA
2011 Lunabotics	USA, Bangladesh, Canada, Colombia, India, Spain
2012 Lunabotics	USA, Bangladesh, Canada, Colombia, India, Mexico, Romania, South Korea
2013 Lunabotics	USA, Australia, Bangladesh, Canada, Colombia, India, Mexico, Poland
2014 – 2017 RMC	USA

Australia Competed in 2013



Teams 2017

Auburn University
Case Western Reserve University
Colorado School of Mines
Embry-Riddle Aeronautical University
Florida Institute of Technology
Illinois Institute of Technology
Iowa State University
John Brown University
Kent State University
Milwaukee School of Engineering
Mississippi State University
Montana State University
Montana Tech
New York University's Tandon School of Engineering
North Dakota State University
Oakton Community College
Polytechnic University of Puerto Rico Purdue
South Dakota School of Mines & Technology
Temple University
Texas A & M International University
The University of Akron
The University of Alabama
The University of North Carolina at Charlotte
The University of Utah
University of Alaska Fairbanks
University of Arkansas
University of Central Florida
University of Colorado Boulder
University of Florida
University of Hawaii-Hilo
University of Illinois at Chicago
University of Illinois at Urbana-Champaign
University of Kentucky
University of Michigan
University of Nebraska-Lincoln
University of New Hampshire
University of North Dakota
University of North Florida
University of Virginia
University of Washington Bothell
University Wisconsin – Madison
Virginia State University
Virginia Tech
West Virginia University
Worcester Polytechnic Institute
Wright State University
York College

RMC Sponsorship

- NASA
- Stellar Sponsor – Caterpillar.
- Boeing, Harris Corporation, Moon Express.
- Honeybee Robotics, Space Florida, Astronaut Memorial Foundation.
- Sponsors often hire student competitors, some interview and hire at KSC competition.
- Great opportunity for sponsors.

Role of Systems Engineering (SE) in RMC

- Required SE Paper to describe the SE used on the project.
  - Counts 25% of overall score, as much as any other competition element.
  - Required submission, or team not eligible to compete in the arenas at KSC in May.
  - To explain what SE was performed, not to describe the robot system.
  - 25 pages overall, including 5 pages of appendices.

RMC – Systems Engineering Awards

- SE Paper
  - Minimum score of 80% to be eligible for awards
  - First Place: $500 Scholarship and Plaque
  - Second Place: Plaque
  - Third Place: Plaque
- New in 2018: Systems Engineering Leaps and Bounds Award
  - Awarded to the team that made a significant improvement over the previous years in the application of SE to the development of their robot as demonstrated by their SE Paper.
  - $250 Scholarship

- Goal: Increase SE Prize Awards (Scholarships)

RMC Major Awards

Award Level	Major Required Elements		Special Prizes	
	Systems Engineering Paper	Robotic On-Site Mining	Caterpillar Autonomy Award	Joe Kosmo Award of Excellence (Grand Prize)
1st Place	$500 Scholarship	$3,000 Scholarship	$1,500 Scholarship	$5,000 Scholarship
2nd Place	Plaque	$2,000 Scholarship	$750 Scholarship	
3rd Place	Plaque	$1,000 Scholarship	$250 Scholarship	

SE Paper Rubric – Format and Intrinsic Merit

- Format – 12% of SE Paper Score
  - Professional appearance
  - Page limit: 20 for body, 5 for appendices
  - Statement of purpose for using SE
- Intrinsic Merit – 32% of SE Paper Score
  - Project schedule
  - Project Budget
  - Major Reviews (SRR, PDR, CDR)
  - Statement of design philosophy or objectives

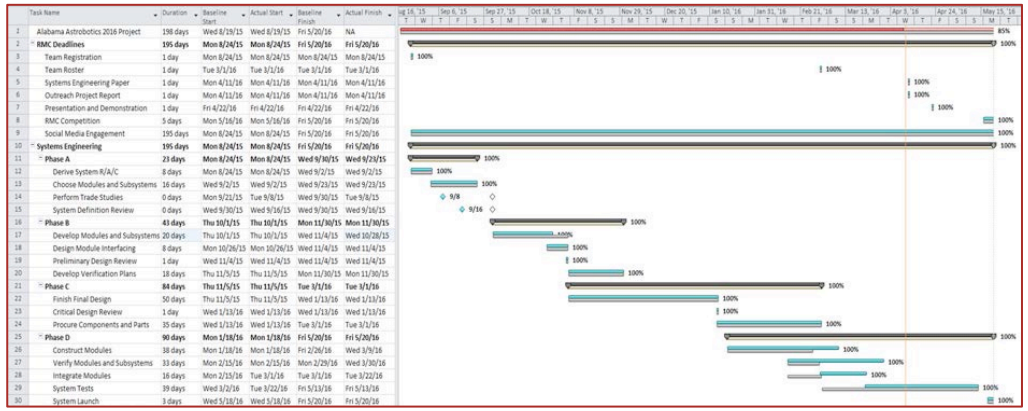
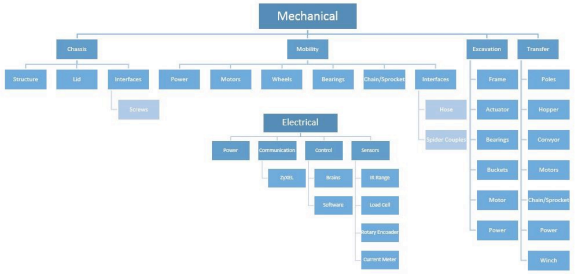


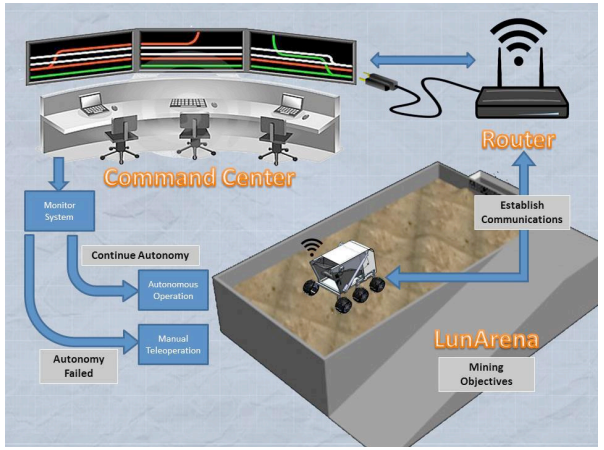
Table 13: Financial Budget

Item Description		Estimated/Allocated Credit	Actual Credit	Estimated/Allocated Debit	Actual Debit
Oakton Educational Foundation Grant		$8000	$16,000		
Mechanical Subsystem	Chassis			$800	$760
	Locomotion & Wheels			$2,000	$1,550
	Excavation & Collection Module			$2,200	$2,050
	Replacement Parts			$500	$600
Electrical Subsystem	Power			$1,500	$1,250
Computer & Autonomy Subsystem	Navigation & Obstacle Avoidance			$700	$800
	Excavation & Deposit			$200	$200
	Computer Hardware			$100	$200
Transportation & Hotel				$8,000	$7,700
Actual Totals		$16,000		$15,120	
Final Total		**$880 Under Budget**			

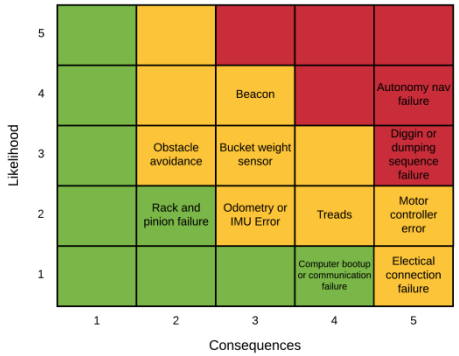
SE Paper Rubric – Technical Merit

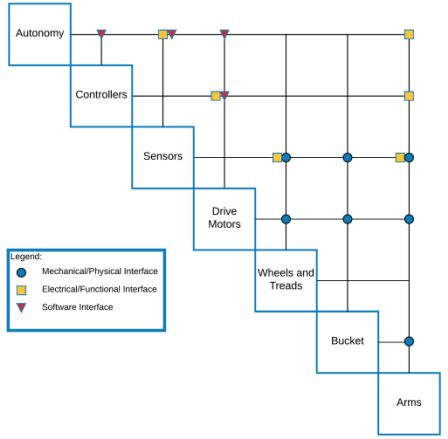
- Technical Merit
  - Comprises 56% of total SE Paper Score
  - 8 required SE elements to be discussed
    - System hierarchy
    - Concept of Operations
    - Interfaces
    - Technical Budgets
    - Trade Studies
    - Reliability
    - Requirements
    - Verification
  - Additional SE Elements discussed may earn bonus points





Robot Design Decision Matrix:		RMC Max Scores				Long Term Mission Max Scores				
Measures	Weight	Scraper	Auger	Single HERMES	Multi HERMES	Weight	Scraper	Auger	Single HERMES	Multi HERMES
Mining Effectiveness (BP-1)	3	3	1	3	9	3	3	1	3	9
Mining Effectiveness (Icy Regolith)	9	1	9	1	1	9	3	3	3	9
Robot Weight Below 80kg	9	1	1	1	1	3	1	1	1	1
Weight-To-Effectiveness Ratio	9	1	3	9	9	9	1	3	9	9
Durability of Design	1	1	1	3	3	9	1	1	3	3
Limit Dust Production	3	9	3	3	3	3	9	3	3	3
Autonomy Capable	9	3	3	3	1	9	3	3	3	1
Design Risk	-3	3	9	1	3	-9	3	3	1	3
Weighted Score (TOTAL)		82	130	144	138		84	78	174	210
Percent of Max Score		57%	90%	100%	96%		40%	37%	83%	100%





SEP Judging Process

- **Screening Round** – Screening for required content, papers with sufficient judgeable content qualify for Round 1 judging (usually around 20-30).
- **Round 1** – Scored numerically per rubric.
  - Minimum 3 judges per paper, each judge typically evaluates 3-4 papers
  - Scores discussed among all judges after scoring in telecon
  - Papers that did not make round 1 scored by screening judge
  - Judging comments provided to teams post competition
- **Round 2** – Top scoring papers and judge nominated papers from Round 1 (typically 6-8 papers make the cut).
  - Select set of volunteer judges from round 2 read all papers
  - Rank ordering by each judge of all papers and documented rationale
  - Rank orders discussed and consensus established on paper awards in telecon

RMC SE – Lessons Learned & Improvements

Year	Desired Outcome	Actions
2014	Improvement in Identification of Round 2 Worthy Papers	3 judges per paper (previously 2 judges)
		No two judges score multiple papers together
2015	Increase Student Understanding of SE	Webcast/Video – "Applying SE for your NASA RMC Project"
2016	Improve Consistency in SE Paper Judging	Developed SE Paper Scoring Guidelines
	Improve Faculty and Student Understanding of SE	Established SE Roundtable Meetings for Faculty and for Students at KSC Event
2017	Emphasize Importance of SE in Robot System Development	Increased Contribution of SE Paper Score for Grand Prize
2018	Encourage Improvement in Low/Mid-scoring Teams for SE Paper	Establish New Award: "Systems Engineering Leaps and Bounds Award"
	Provide Deeper Knowledge/Context of SE Principles	Develop Educational SE Video Series (Ten 15-minute videos on SE Paper Rubic Topics)

NASA SE Support to Student Teams

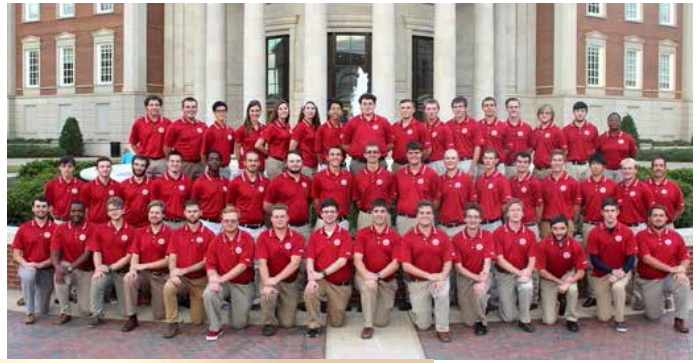
- Bibliography of SE materials provided
- SE Paper Webinar and Video 2015
- Faculty SE Roundtable at KSC competition since 2016
- Student SE Roundtable at KSC competition since 2016
- Upcoming SE educational videos for 2017-2018 school year

SEP Observations since 2010

- Most schools have very little if any SE content in curriculum
- Few schools have faculty advisors with any SE experience or knowledge
- Students mostly self-learn and apply SE
- SE Papers have improved every year
  - Noted improvement after Webinar in 2015
  - Noted significant improvement after faculty and student roundtables in 2016
- RMC accomplishing INCOSE goals
  - Educating undergraduates and graduate students in systems engineering
  - Reaching out to non-standard Industry (Mining)

2017 RMC Winners – Systems Engineering Paper

- First Place:
  - Case Western Reserve University
- Second Place:
  - The University of Alabama
- Third Place:
  - The University of Utah



2017 RMC Winner – Grand Prize

And the

2017 NASA Robotics Mining Competition

Joe Kosmo Award of Excellence

is awarded to …

Summary

- Significant SE element in university competition produces SE experience for students comparable to that gained in first five years of working as an engineer.
- Other university engineering design competitions (students) would benefit from adding System Engineering Paper as significant judging element.
- RMC sponsorship has many tangible benefits to sponsor.
- NASA's RMC is creating SE's out of students who would never see SE in their curriculum.

Call for INCOSE Participation

- NASA's Robotic Mining Competition worthy of INCOSE Support.
- Sponsorship
- INCOSE Chapters can get involved
  - As Team SE mentors
  - As outside reviewers for Teams' SRR, PDR, and CDR
- INCOSE members can get involved
  - As SE Paper judges

Contact and Links

- NASA's RMC - for more info
  - www.nasa.gov/nasarmc
  - https://www.facebook.com/RoboticMiningCompetition

- Contact RMC Lead Systems Engineering Judge, jonette.m.stecklein@nasa.gov
  - To support Systems Engineering in RMC
  - To mentor an RMC team in systems engineering
  - To volunteer as an RMC Systems Engineering Paper Judge