A Modular Excavator Targets Planetary Surface Operations for Space Exploration

Planetary Surface Excavator

*sys*RAND Corporation

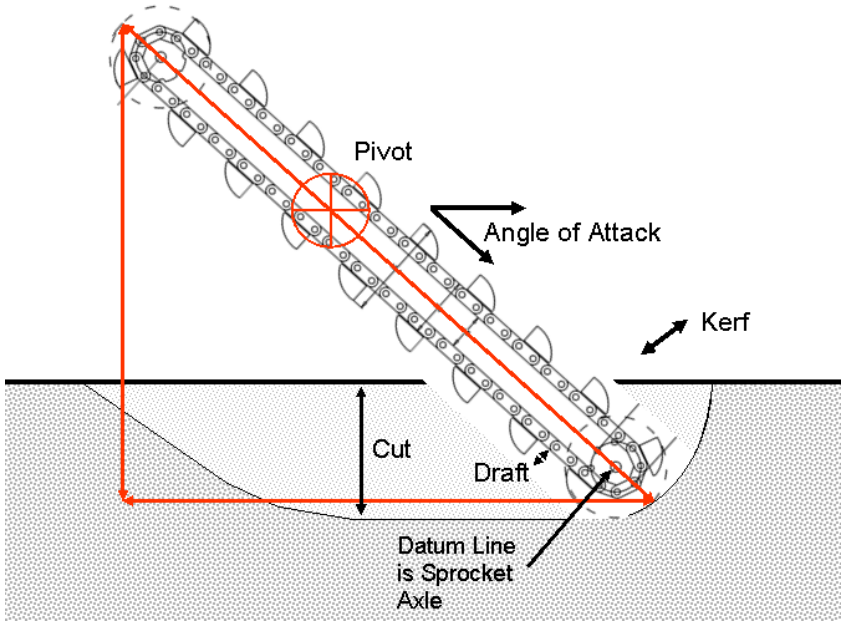
COLORADOSCHOOLOFMINES
EARTH ENERGY ENVIRONMENT

SPACE ENVIRONMENT TECHNOLOGIES
Infrastructure and Standards Division

Top Level View

- Planetary Surfaces such as the Moon and Mars will require civil engineering and ISRU mining activities in order to sustain long-term exploration efforts
- Intelligent, Modular Tools will be required to operate:
  - in hard vacuum,
  - at cryogenic temperatures,
  - with low-energy
  - at a high reliability
  - and be easy to repair (including remotely) or self-repair
- ISRU and Civil Engineering activities may employ an architecture which features:
  - interchangeable modular tools
  - numerous small platforms

Realization



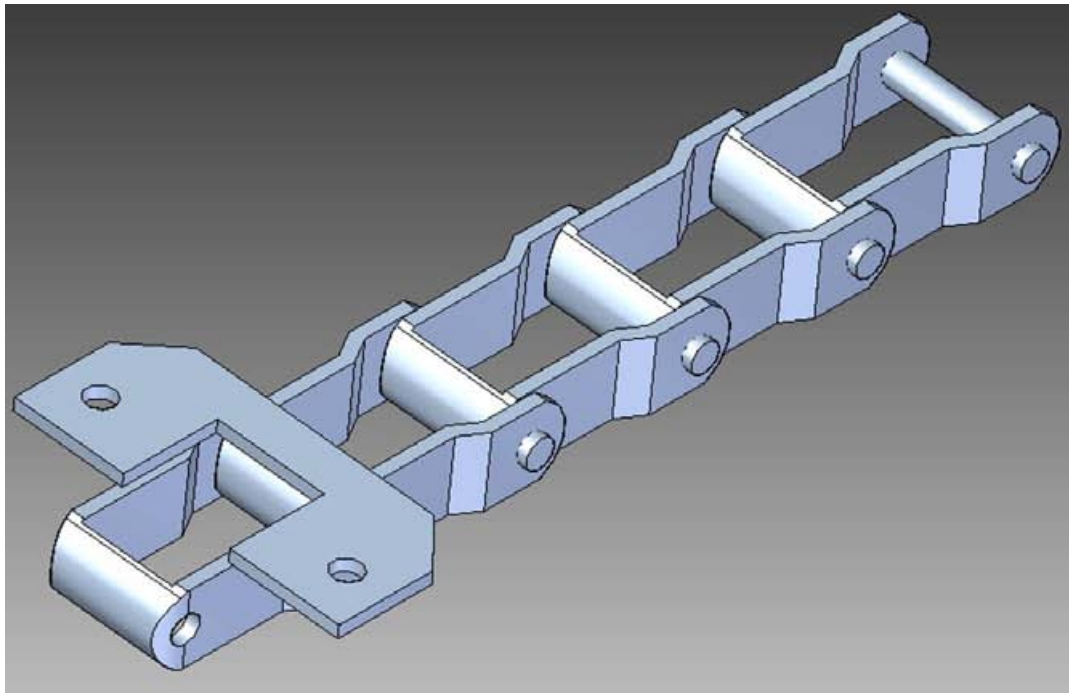
Bucket Ladder Excavator

- ✧ Front-to-Back Excavation System
- ✧ Enables the Science of Digging

Sizing

- NASA provided specifications
  - 500kg/hr
  - 4” wide trench
  - Cut of 2’ below ground level
- Resulting Excavator Dimensions
  - 6’ long due to midpoint mounting
  - 2.5” wide structure

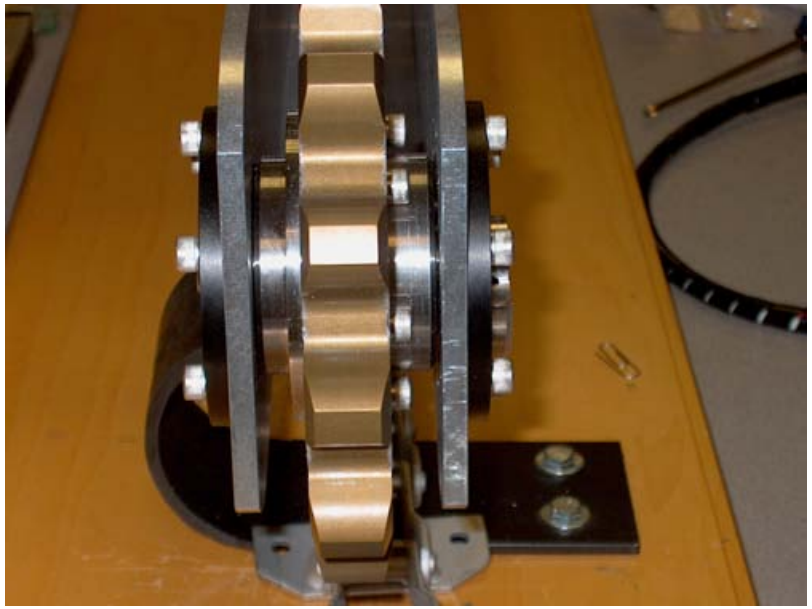
Chain



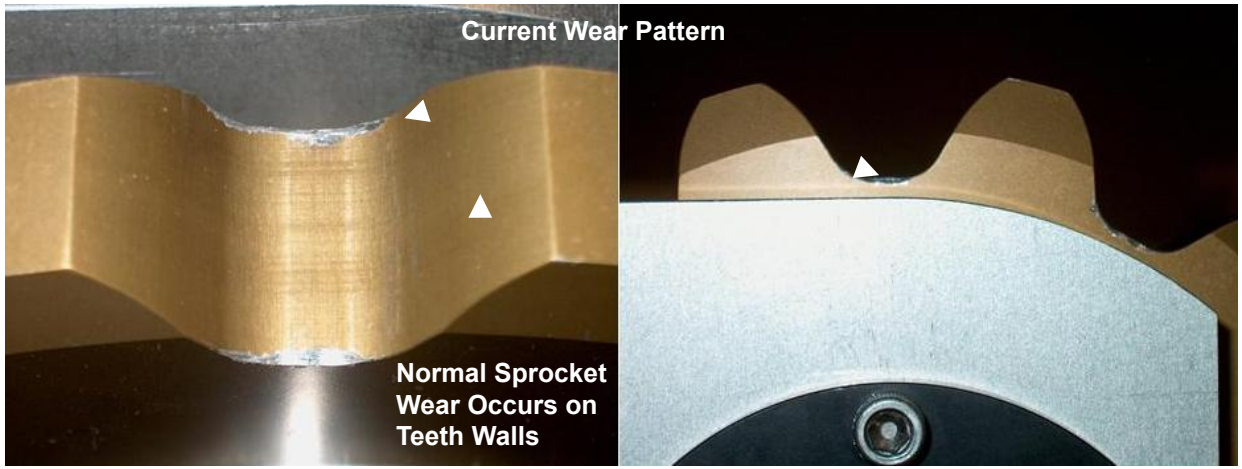
- Pintle Chain
  - Agricultural/industrial application heritage
  - Lightest COTS chain per length
  - K-1 mounting platform every five links
  - 16 segments making a total of 80 links
  - Complete transport with a single chain

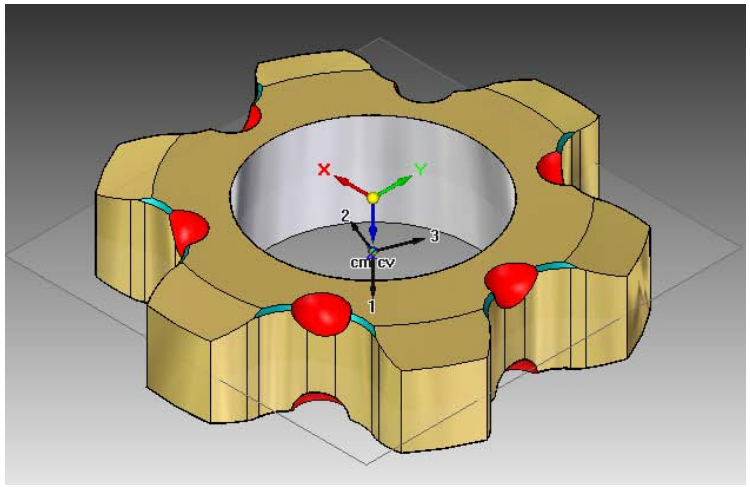
Sprocket Design

- All sprockets designed using ASME standards
- Original sprockets made of aluminum and anodized with non-organic dyes.
  - The anodizing hardens the exterior.
  - Provides a visual contrast for the wear patterns.



Redesigned Sprockets

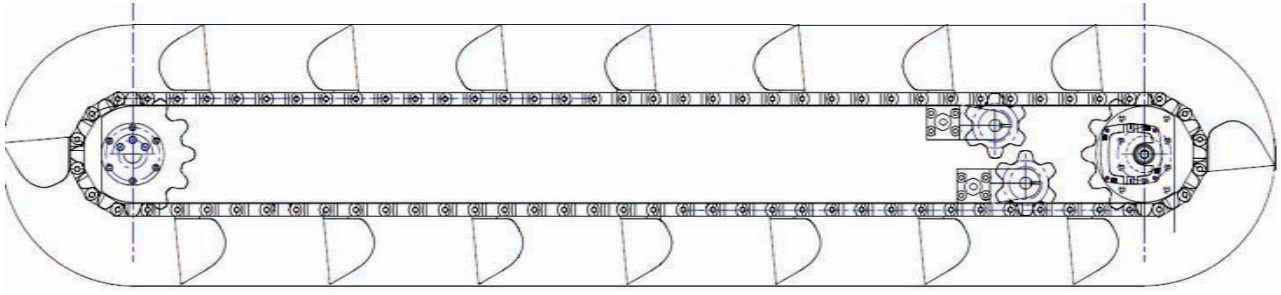




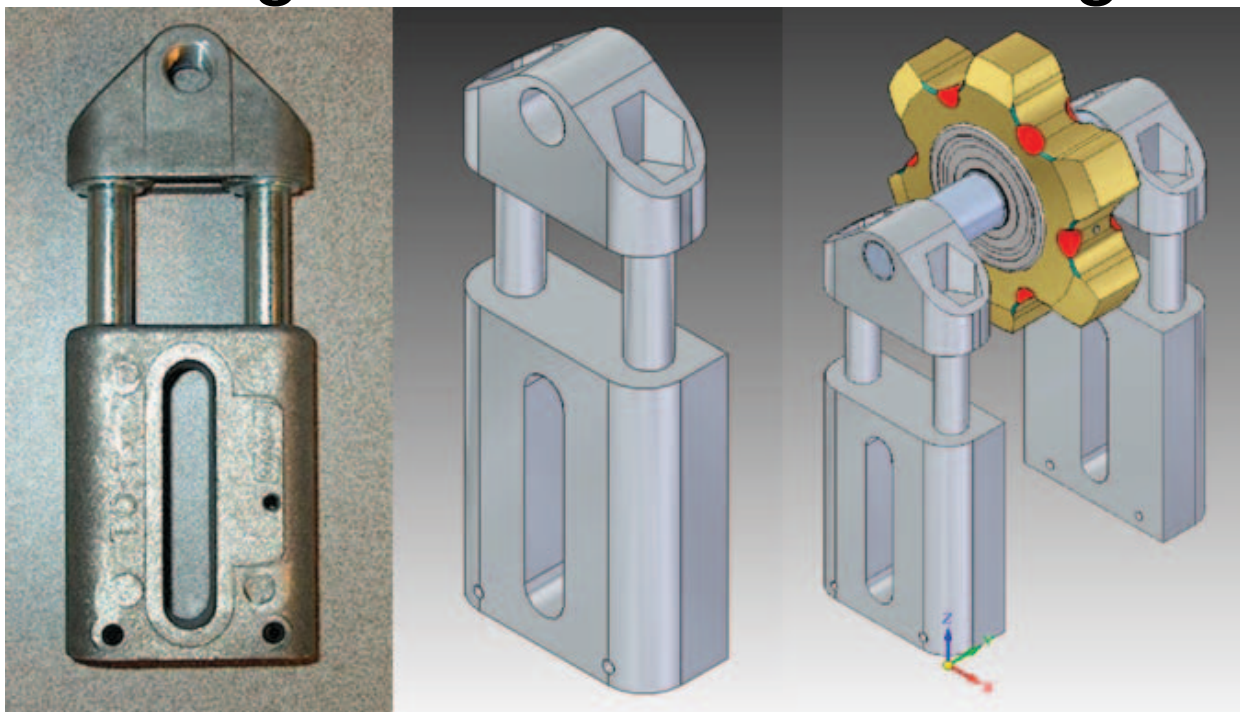
- Excessive wear at unexpected location
- Lack of wear at expected locations
- Sprockets modified to include “mud groove”
- Teeth reformed and beveling added to minimize the observed wear on the original units

Chain Tensioning

- Original Tensioner
  - Two sprockets on single mount
- Difficulties Encountered
  - Insufficient tension
  - Long lever arm causes rocking
  - Incorrectly spaced sprockets caused chain slippage and induced vibration into the system



Redesigned Chain Tensioning

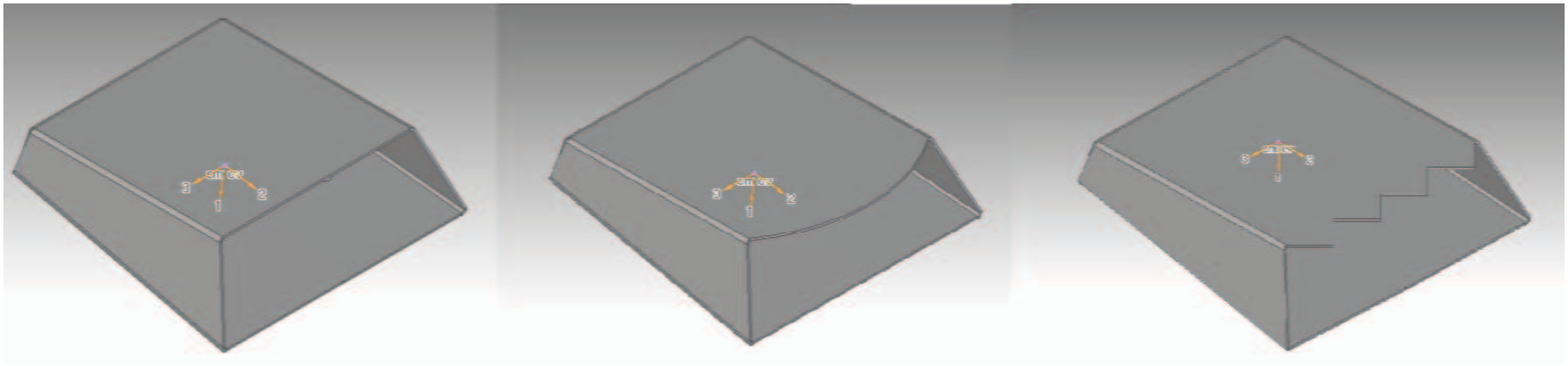


- Redesigned Tensioner
  - Use COTS spring loaded chain tensioners
  - Max of 100 lbf tension on the chain at full retraction
  - Tensioner placed at the slack end of the chain, at the bottom of the excavator

Motor

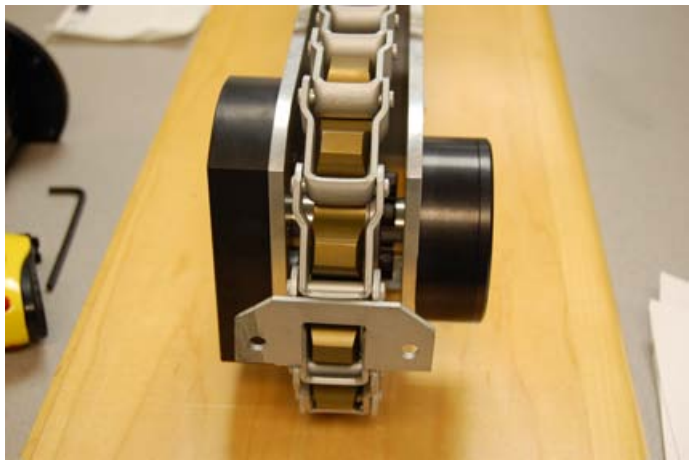
- Bodine Motor
  - High Torque: 180:1
  - Operates on 24V and 3.3A (Maximum)
  - 14 rpm max rotation at the motor
  - 7 rpm nominal
  - Motor/drive sprocket coupling hub first unit to yield at system stall condition, generally recoverable

Bucket Designs



- Folded and Welded Sheet Steel
- 3 Designs
  - Standard flat edge
  - Curved edge for soft ground
  - Serrated edge for consolidated ground
- Chain holds 16 buckets
- Nominal production rate >500 kg/hr

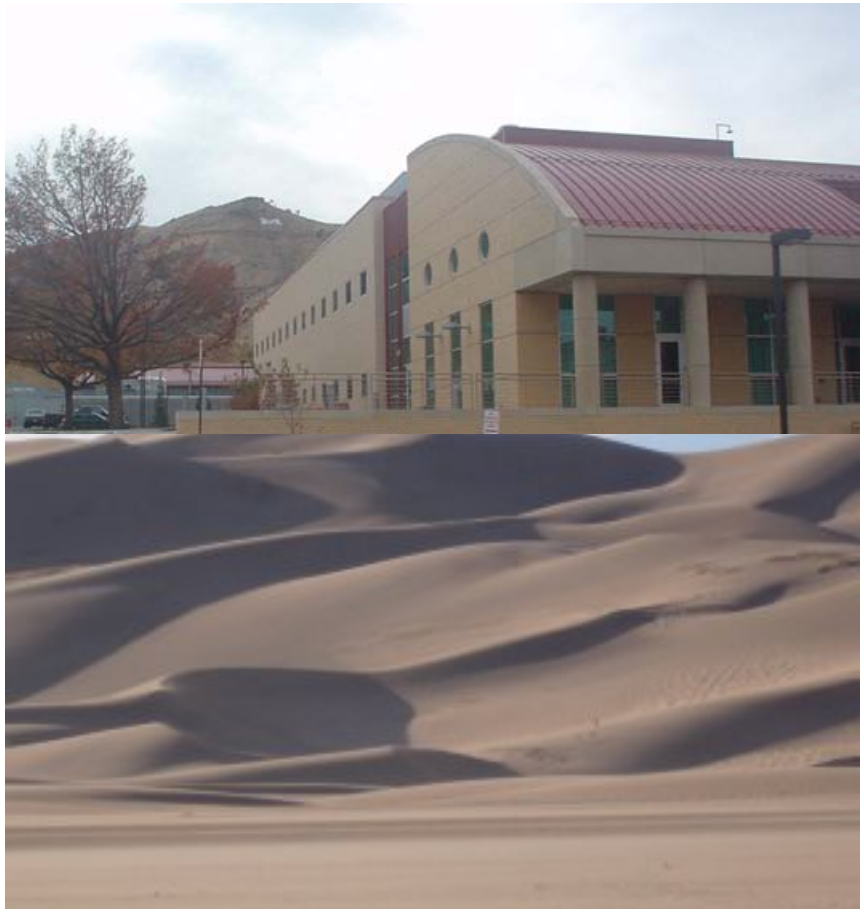
Dust Contamination Mitigation



- O-rings to seal bearings/axle interface
- Delran dust excluders
- Current bearings are double sealed against contamination internally.

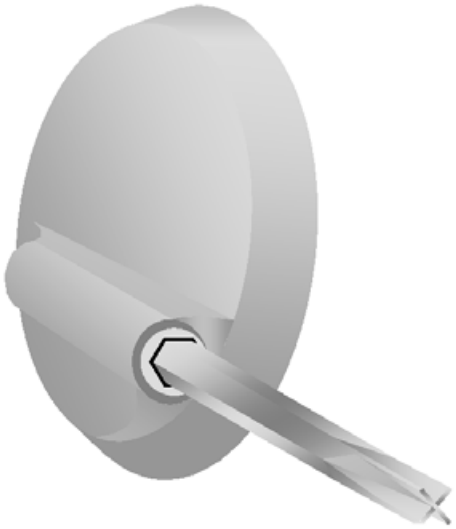
- Current model is for Earth demonstration and does not have the dust mitigation devices currently installed

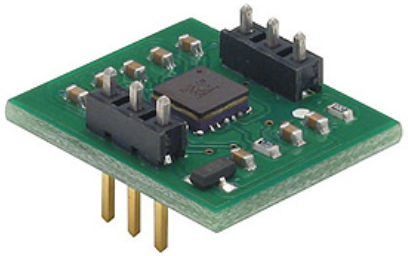
Laboratory and Field Testing



- Once the Excavator is working properly in *sys*RAND's lab, a unit will be delivered to Colorado School of Mines' Center for Space Resources
- A testing program will commence which seeks to improve the art and science of digging with the excavator, at several scales
- The data will be used to improve the fidelity of existing models and explore their completeness
- When a mobility platform is available, the testing program will be taken to the field

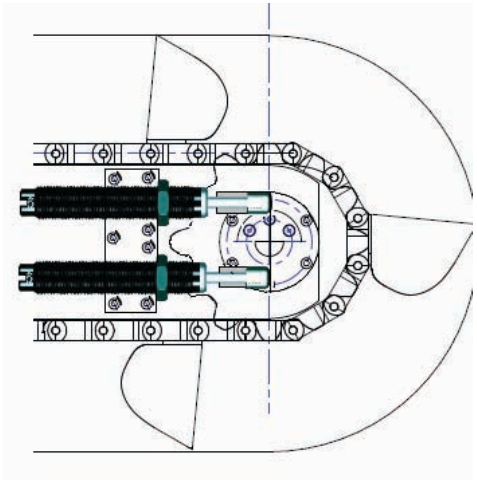
Possible Enhancements

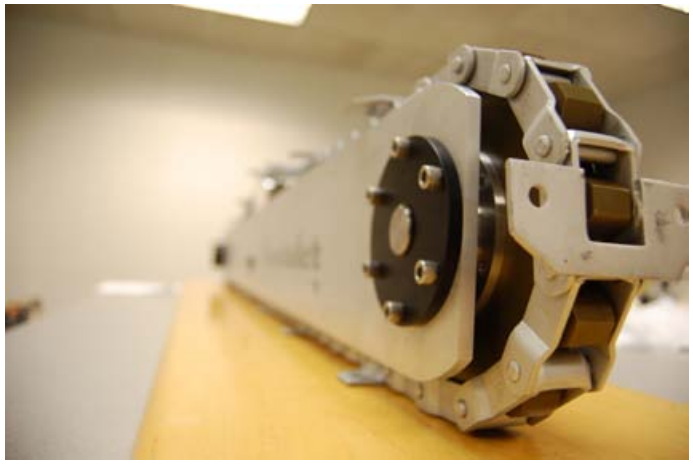




- Star Hammer Drill
- Electrodynamic Proximity Sensing
- Angular Rate Sensors (MEMS Accelerometers) provide positional data
- Discriminating Blade Mechanical Noise from spatial movements through Angular Rate Sensors

Nose Shock Absorber

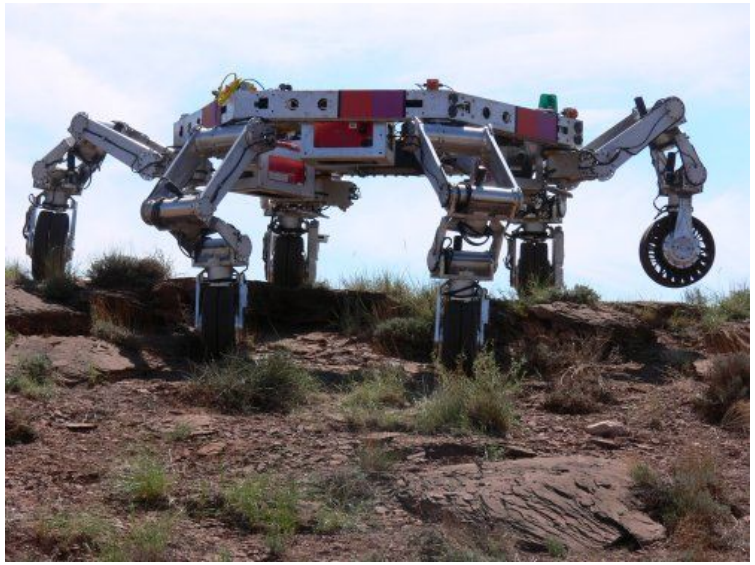


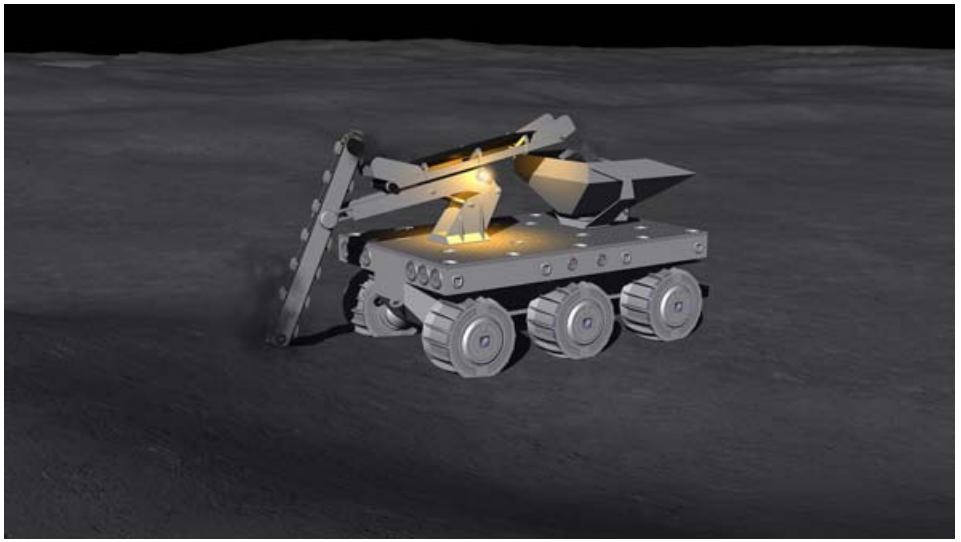


- A shock absorber/strut is needed on the nose of the blade
  - 2 COTS struts per side
  - The nose sprocket assembly will provide dynamic response to incoming system disturbances (*i.e.* rocks, harder material)

Mobility Platforms

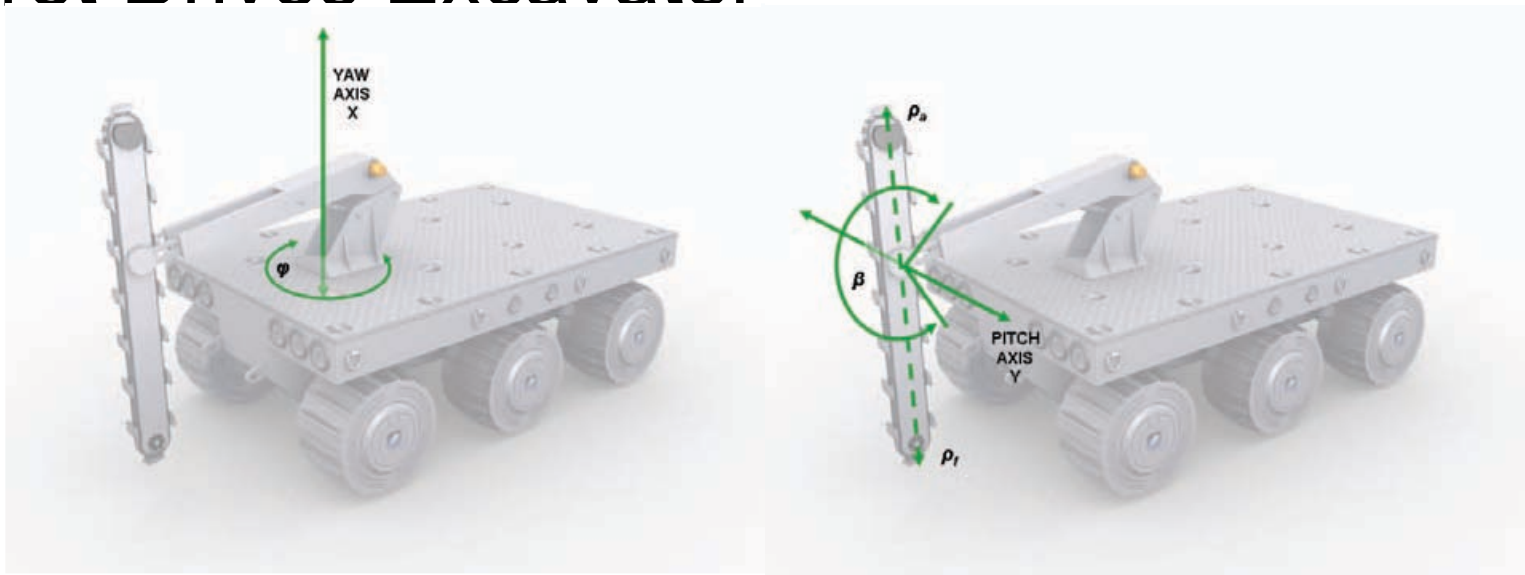
- NASA Platforms
  - Chariot
  - Athlete
  - Norcat Juno
- TUG – *sys*RAND conceptual design





R&D which endeavors to leapfrog the rocket equation by solving the logistics equation

Turret Drives Excavator

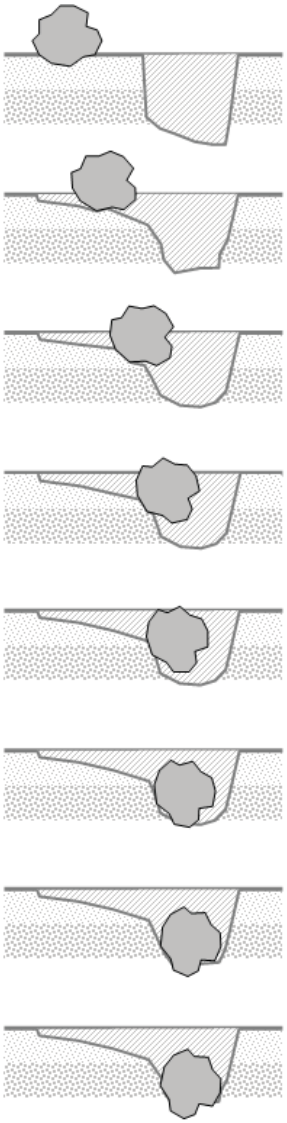


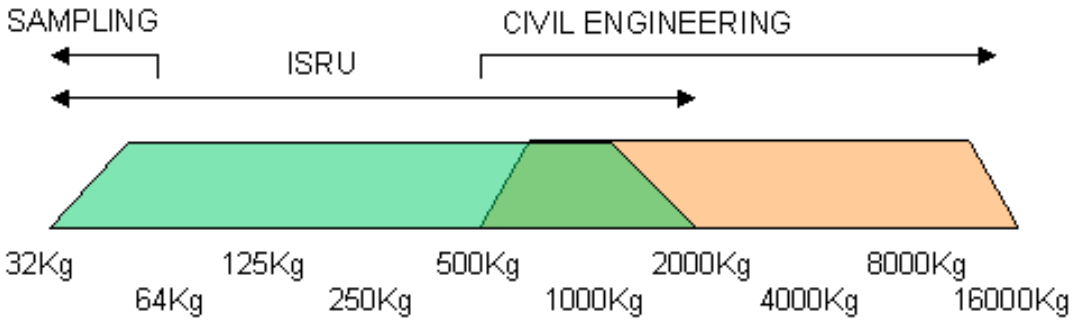
TUG wheels apply continuous pressure against the excavation workface

Turret sweeps the Excavator through its work volume

Work can be precise or coarse

Excavator Applications





Trenching for Cable and Pipe

Structure Emplacement

Postholes

Structure Burial & Footings

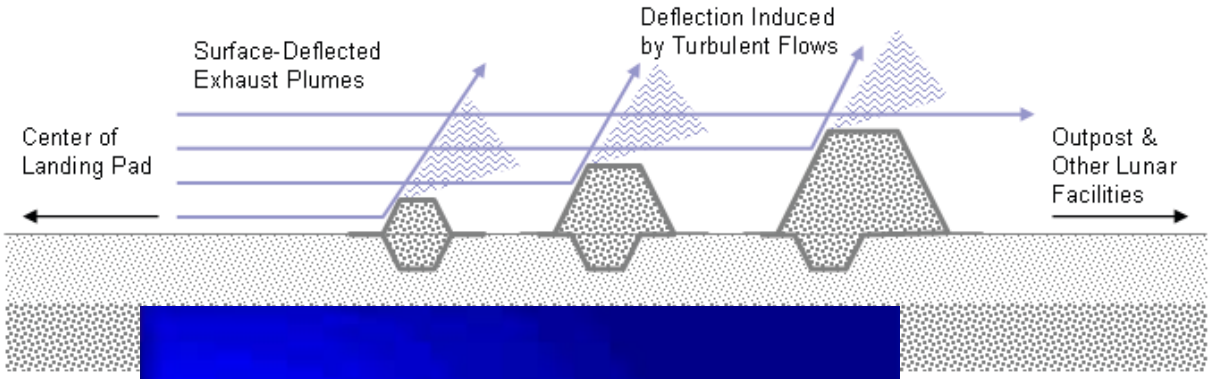
Berm Construction

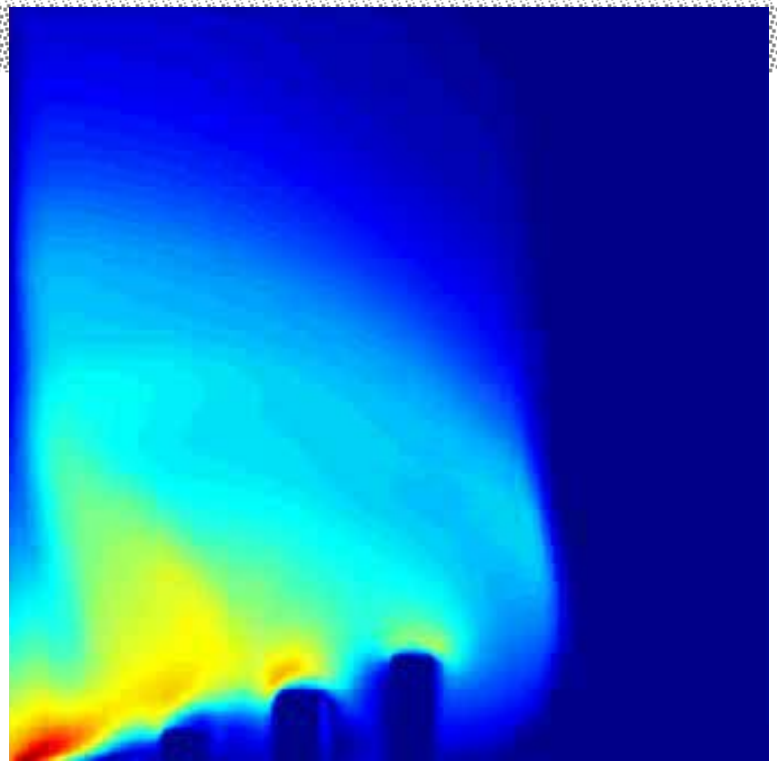
Rock Mitigation

Landing Pad Preparation

Trenching for A.C. Power Cables

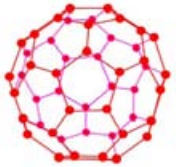
Excavator Applications: Ripple Berms





- Software Model shows that induced turbulence disrupts deflected exhaust plumes
- A series of small berms has the effect of a very large berm
- Has the potential to protect surface assets

A Sketch of *sys*RAND



- Incorporated 14 Dec 1989 in Colorado
- Started as a systems consultancy, work with oil, industrial, avionics and systems manufacturers
- 1998 downturn: product development increasingly moved offshore along with manufacturing (the IT bust)
- 2001: entered space industry with a paper on ISRU applications of Silicon
- 2004: assembled and managed a winning $14.3M NASA ISRU contract for Colorado School of Mines
- 2006: awarded existing NASA and AF SBIRs, where both advanced to Phase 2
- Today, we actively develop technologies in two domains:
  - Foundational Systems and Tools
  - Translating Low-Energy Industrial Processes to Space-based ISRU
- Our new facility at Centennial Airport combines our offices and laboratory facilities into a suite which includes an integration bay and technical library