On to Mars:
Engineering for the Unknown

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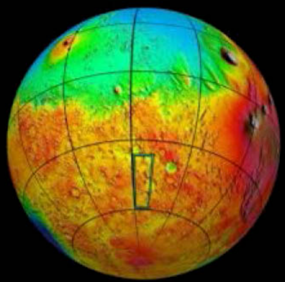
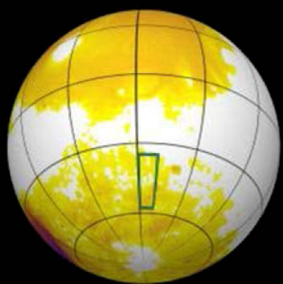
Introduction

- On November 26th, 2011 JPL launched the Mars Science Laboratory mission
  - Largest rover ever be leave the earth
  - Advanced science payload
  - Superior roving capability
- MSL represents the pinnacle of robotic space exploration
  - Effort stands of the shoulders of the missions before, VIK, MPF, MER, and PHX
- Engineering for success in Mars exploration is a challenging task
  - Only ~1/3 of missions to Mars have been successful
  - Success on the surface, and more challengingly, just getting there, requires great care and effort
- Stacking the odds in our favor requires anticipating a wide range of possible Martian challenges
  - Engineering for the unknown

The Mars Challenge

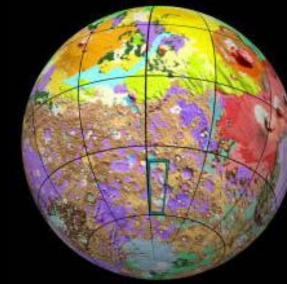


Topography

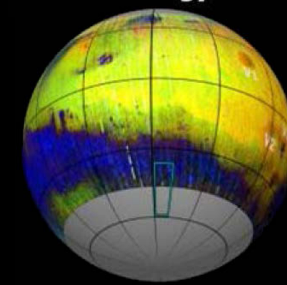


Density

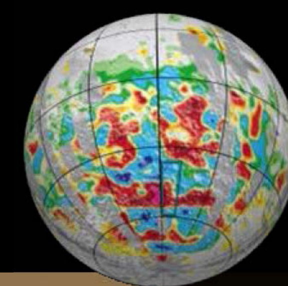
- Gravity
  - $3/8^{ths}$ of Earth gravity
- Atmosphere
  - $1/100^{th}$ of Earth atm density, mostly C02
- Topography
  - Surface elevation between -5 km and +2.5 km
- Terrain
  - Rocky, cratered, sandy surface features
- Risk
  - About 2/3 of missions to Mars have failed



Geology

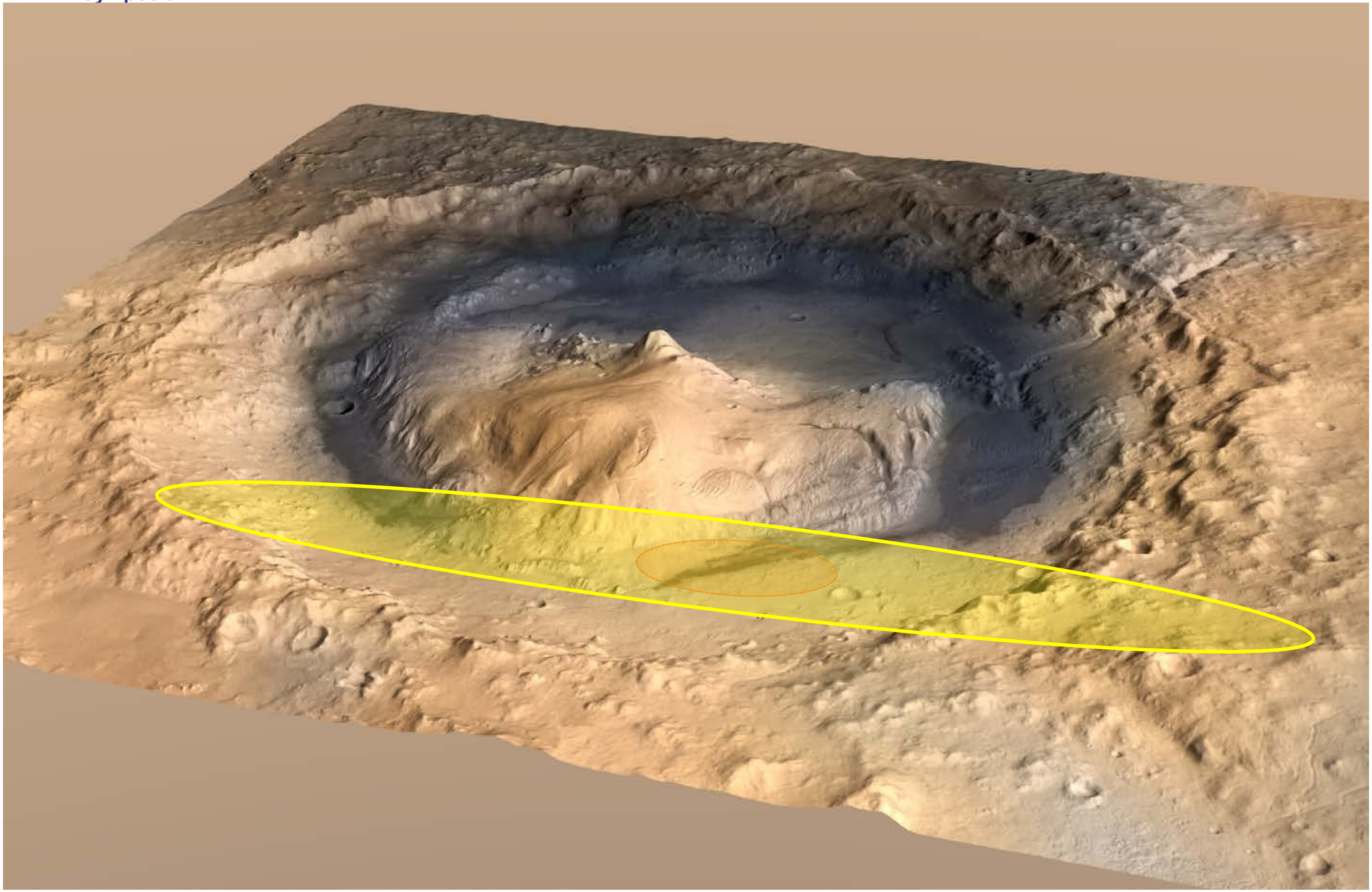


Minerals

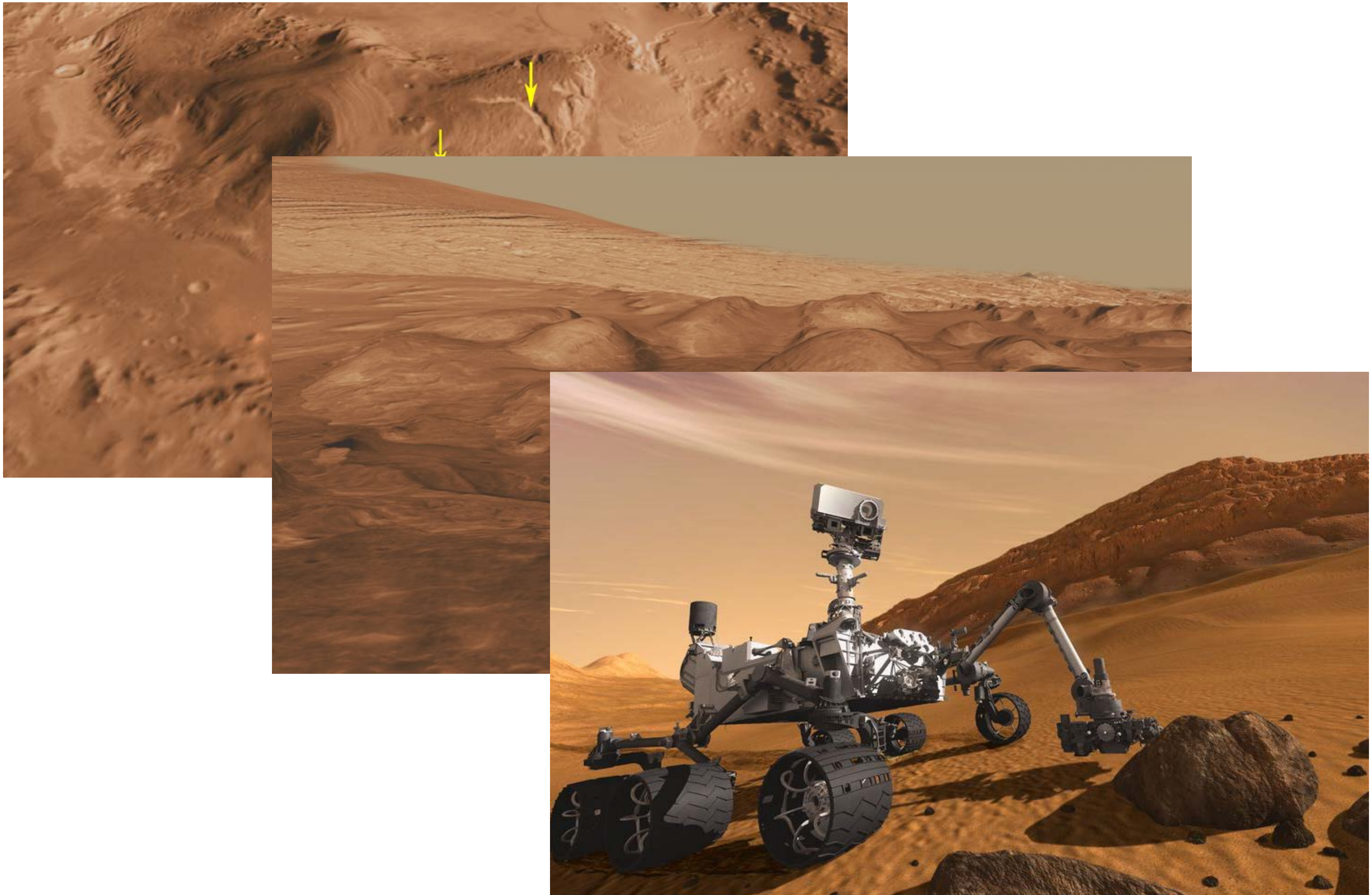


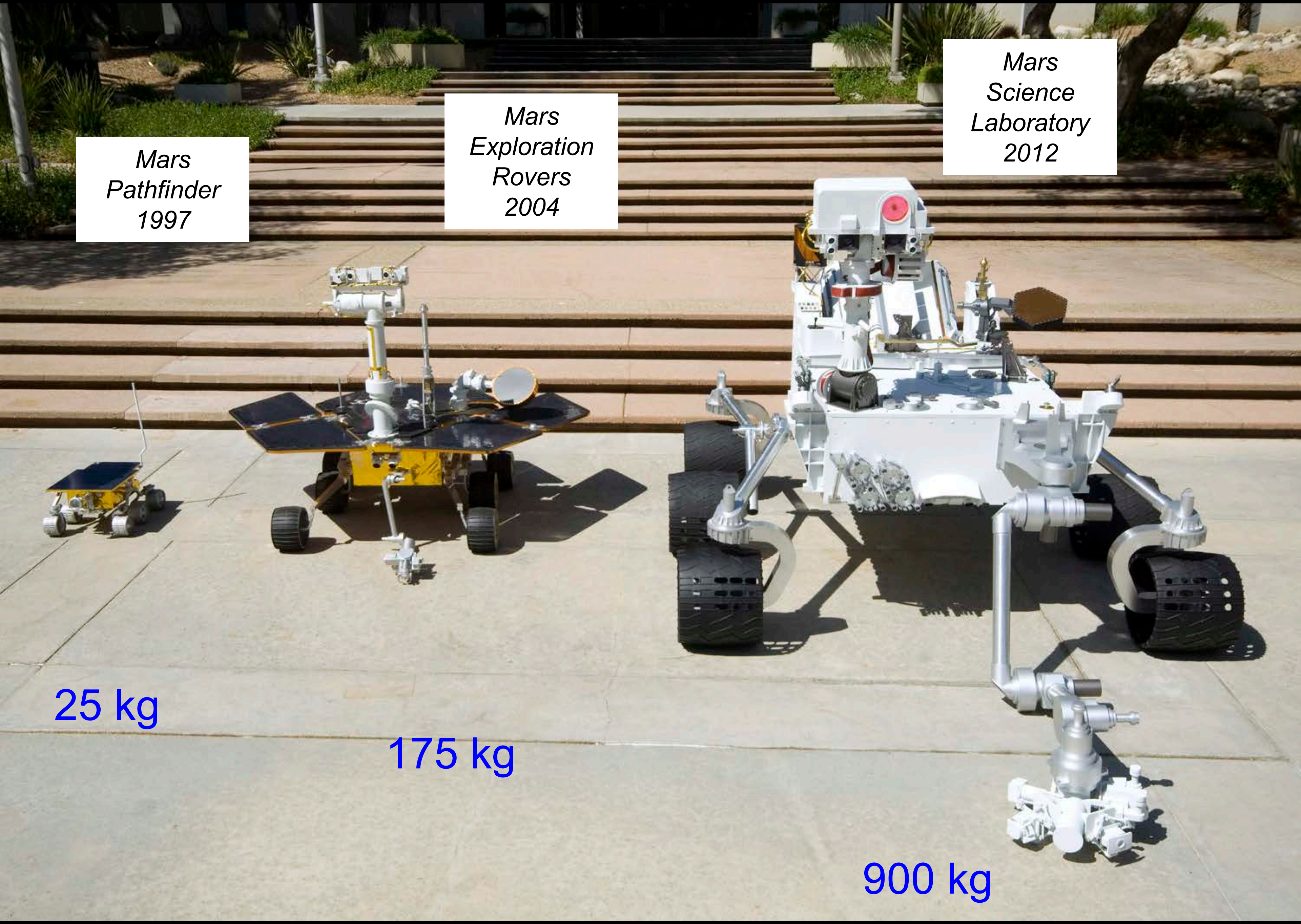
Magnetism

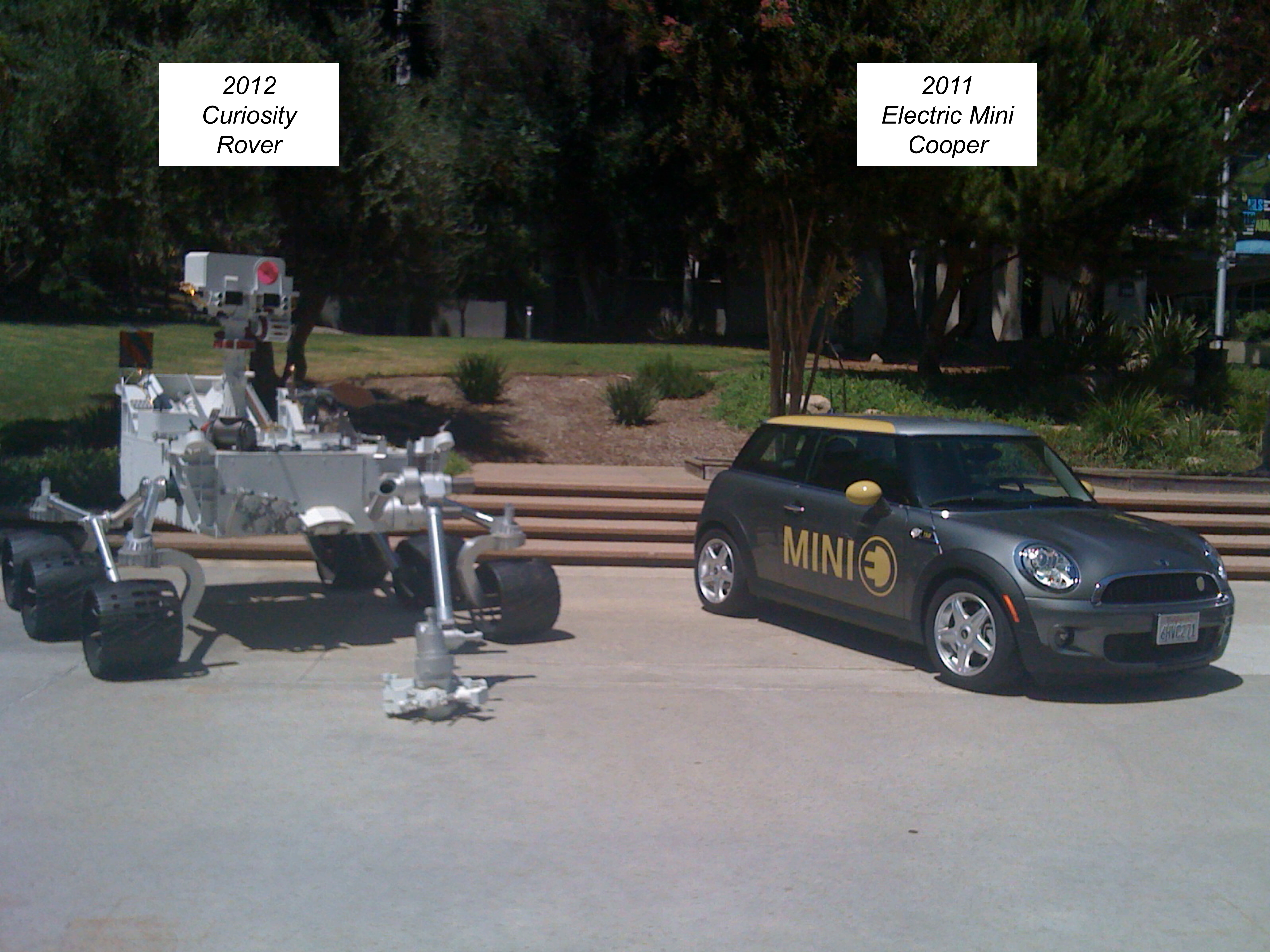
Gale Crater



The Drive to Science at Gale

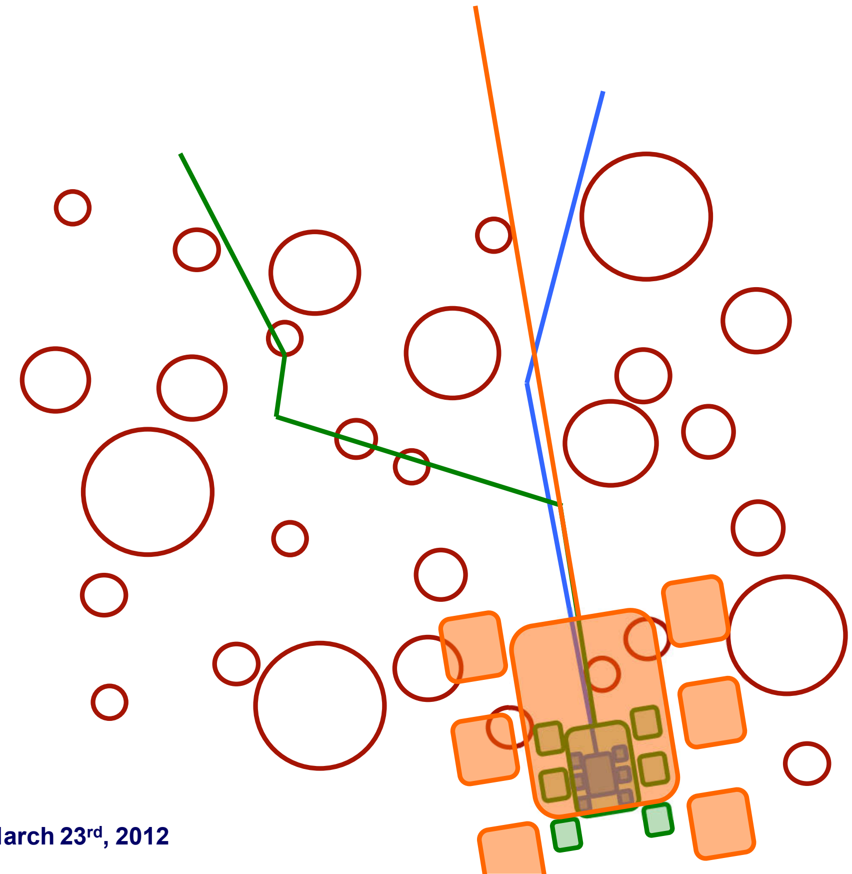


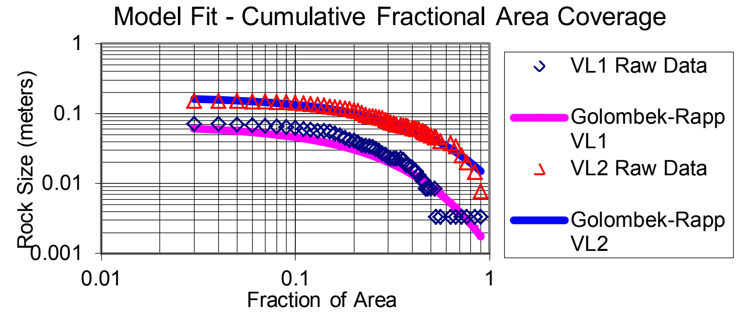

Mars Pathfinder 1997
Mars Exploration Rovers 2004
Mars Science Laboratory 2012
25 kg
175 kg
900 kg

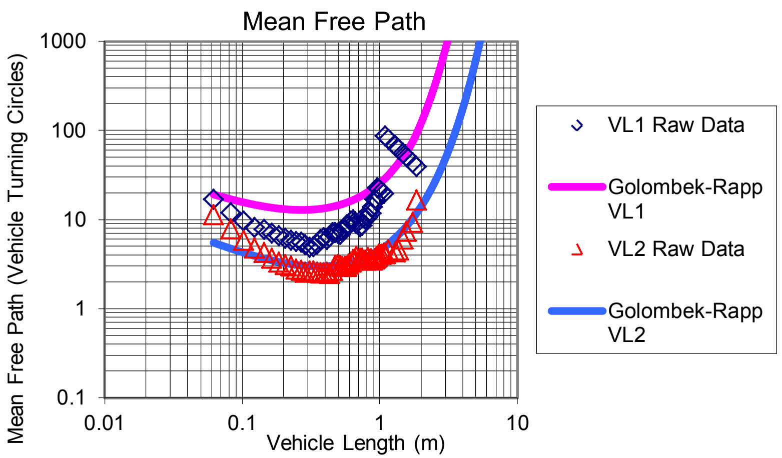

2012
Curiosity
Rover
2011
Electric Mini
Cooper
MINI

Roving the Surface of Mars (1/2)

- The bigger the rover, the easier the driving, less turning for obstacles
- The vehicle size determines the drive efficiency



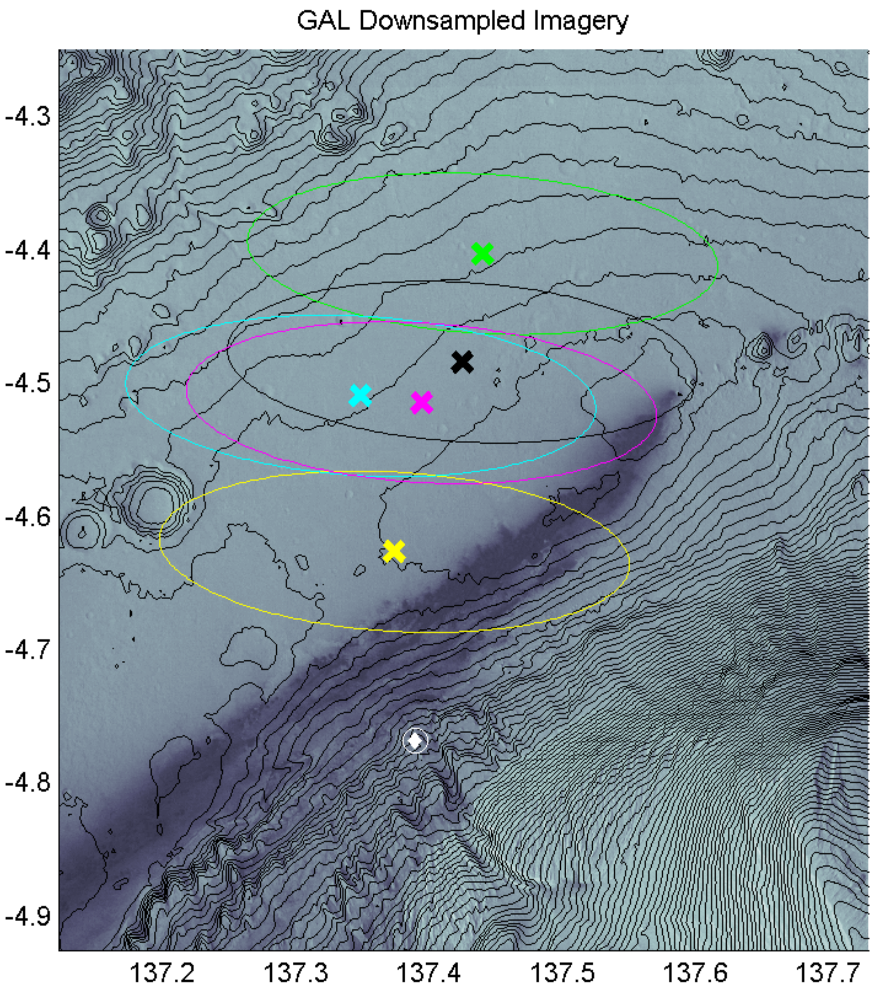


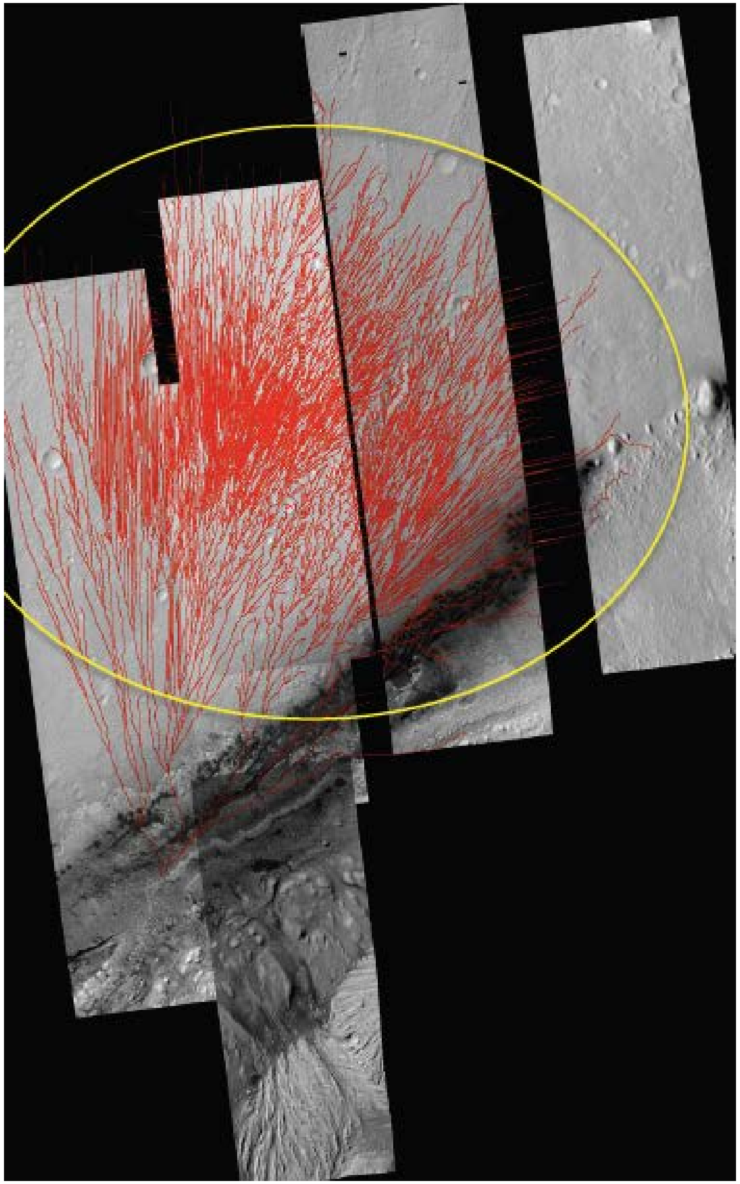


Roving the Surface of Mars (2/3)

- Then we test and test and test……

Roving the Surface of Mars (2/2)

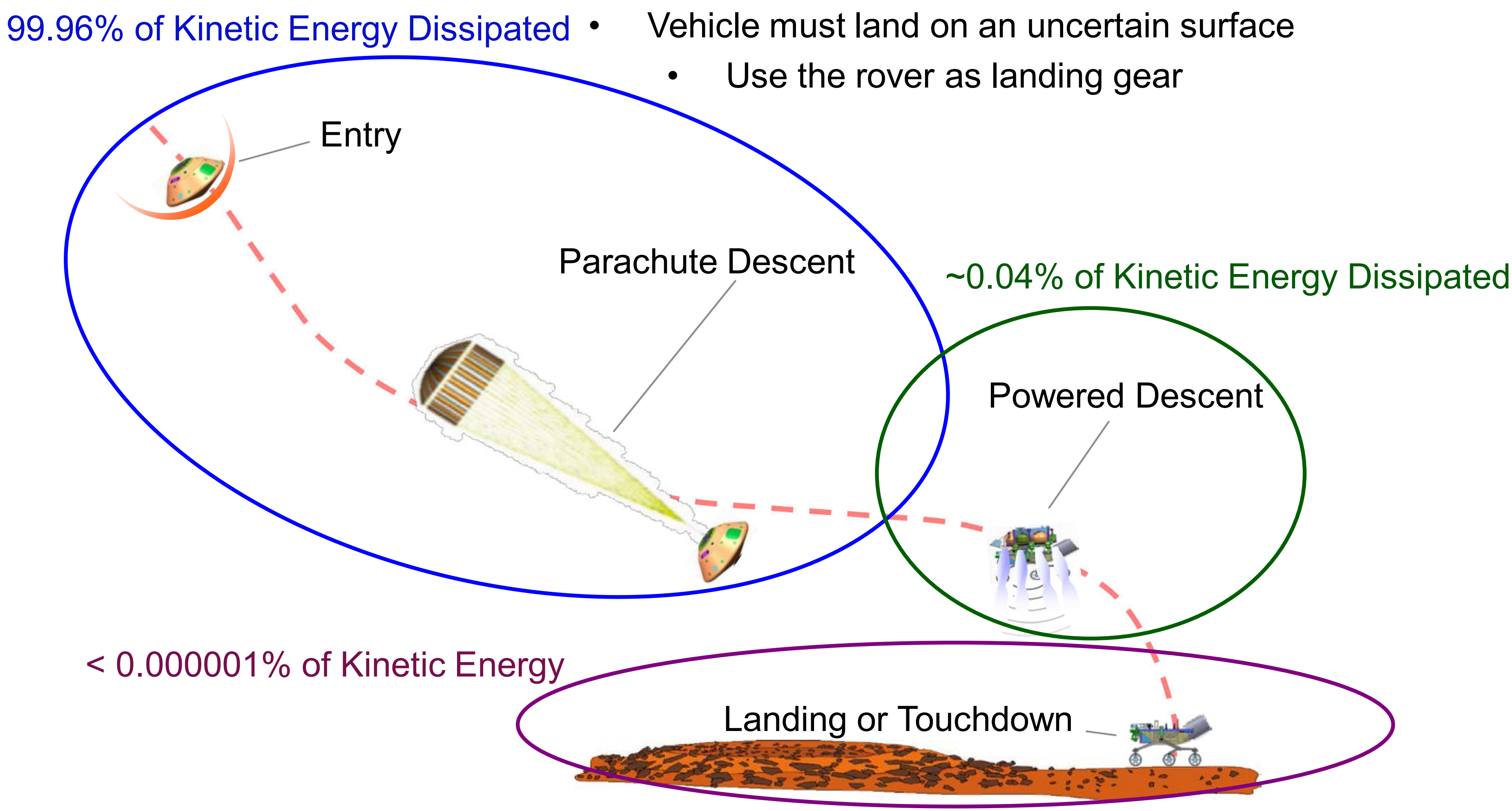




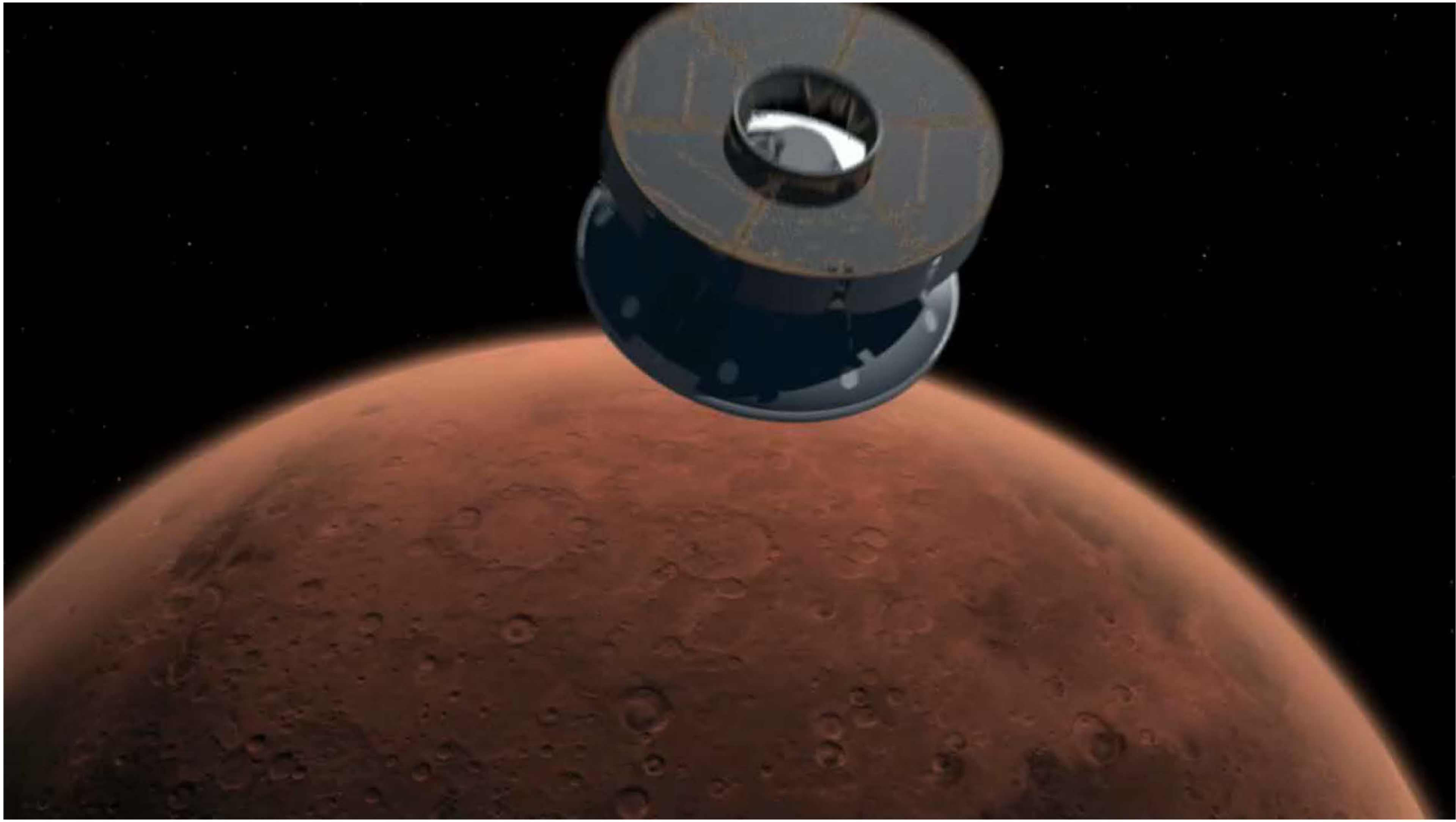
The Challenge of Landing a 900 kg Rover

Entry Descent and Landing for Curiosity:

- Must hit a very tight target
  - 21x7 km ellipse
- Vehicle must land on an uncertain surface
  - Use the rover as landing gear



Entry, Descent and Landing: Curiosity Style



EDL Touchdown System Trade Space

- The touchdown system must perform three tasks:
  - Remove kinetic energy remaining from powered descent condition
  - Land safely on uncertain terrain
  - Allow rover to “egress” or drive away from the landed state
- Four major families of touchdown system exist
  - Airbags, Legs, Pallet, and Direct Placement

Touchdown Systems

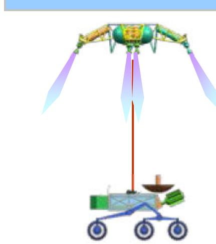
- Open Loop 1-DOF Propulsion (10-20 m/s vert., ~ 10 m/s hori.)
  - Airbags
- Closed-loop 6-DOF Propulsion (1-3 m/s vert., <1 m/s hori.)
  - Airbags
  - Legs
  - Pallet
  - Direct Placement

Airbags

Legs

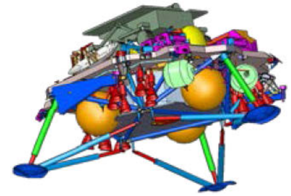
Pallet

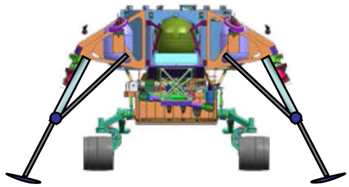
Direct Placement

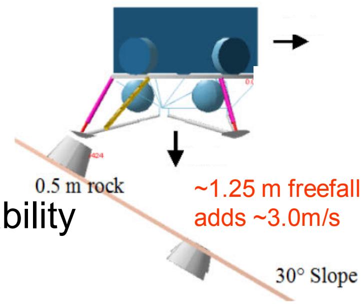


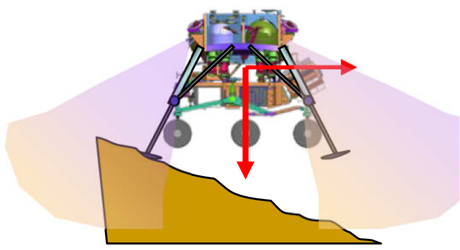
Legged Landers

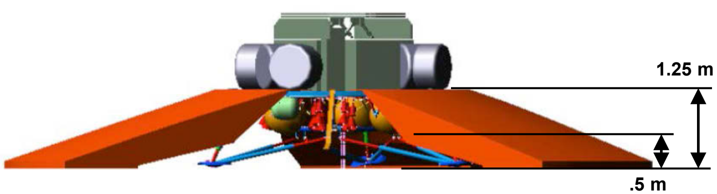
- **Description**
  - Rover top mounted or bottom mounted
  - Landing legs plastically absorb touchdown energy
  - Stability augmenting outriggers for slopes
  - Ramps (top-mounted) or short bridle deployment (bottom-mounted) used for egress
- **Pros**
  - Exploits Viking and Apollo landing technology
  - Single body control at all times
- **Cons**
  - Ground/plume interaction
  - High CG and post engine shut-off free fall reduce stability
  - Touchdown sensing and high rate engine shut-off
  - Validation of terrain interaction difficult
  - Egress system mass and development
- **Observation**
  - Family of architectures potentially feasible for use on MSL
  - Landing stability, touchdown sensing, ground/plume interaction are challenges

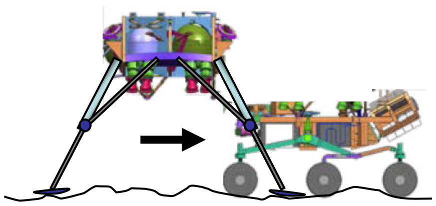






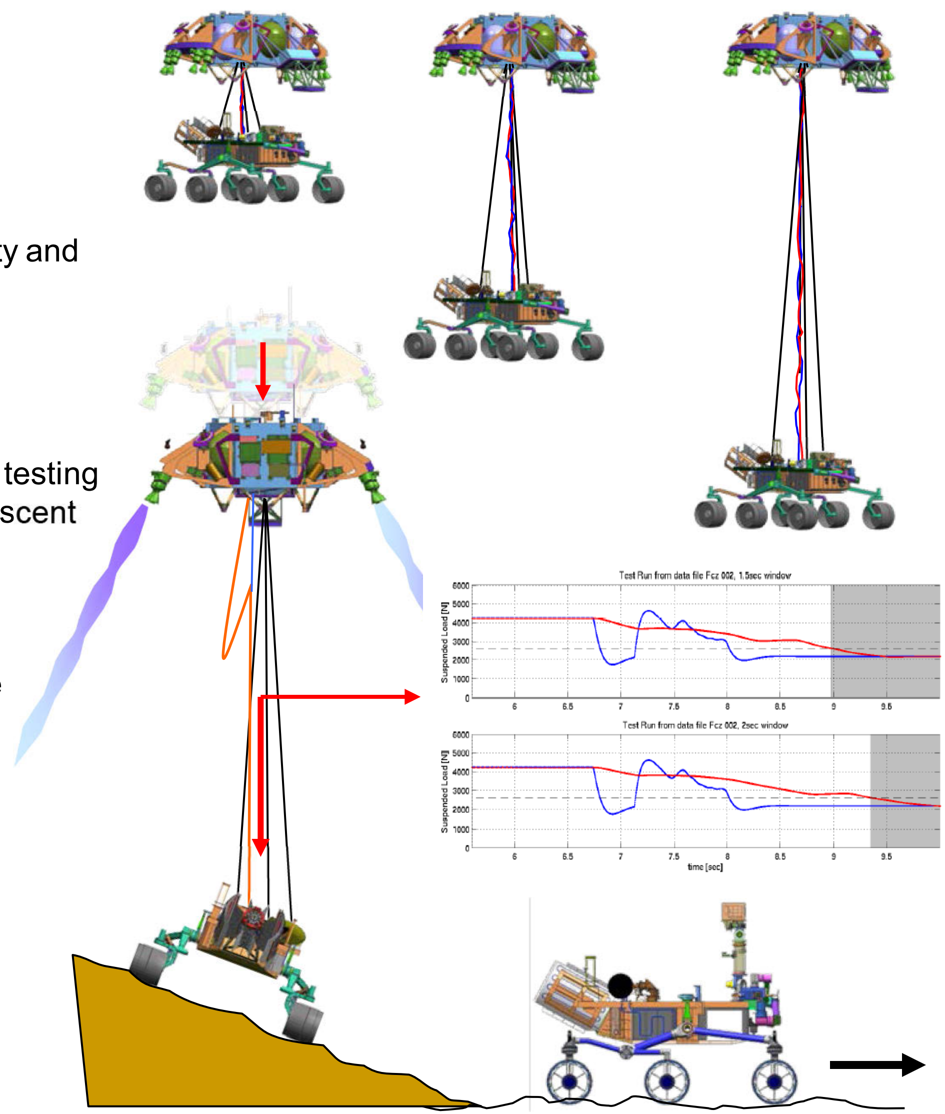






Direct Payload Placement (e.g. Sky Crane)

- **Description**
  - Propulsion module with bridle suspended rover.
  - Rover placed directly in mobile configuration
- **Pros**
  - Reduced ground-plume interaction
  - Slower touchdown and lower CG allows greater stability and hazard tolerance
  - Utilizes rover's inherent terrain interaction capabilities
  - Touchdown signature is persistent and unambiguous
  - Rover does not need to egress from lander
  - Validation can be decomposed into surface interaction testing (rover) and closed loop propulsion/GNC simulation (descent stage)
- **Cons**
  - New architecture
  - Additional pendulum and multi-body dynamics must be addressed
- **Observations**
  - Architecture is feasible for MSL
  - Significant advantages for this architecture



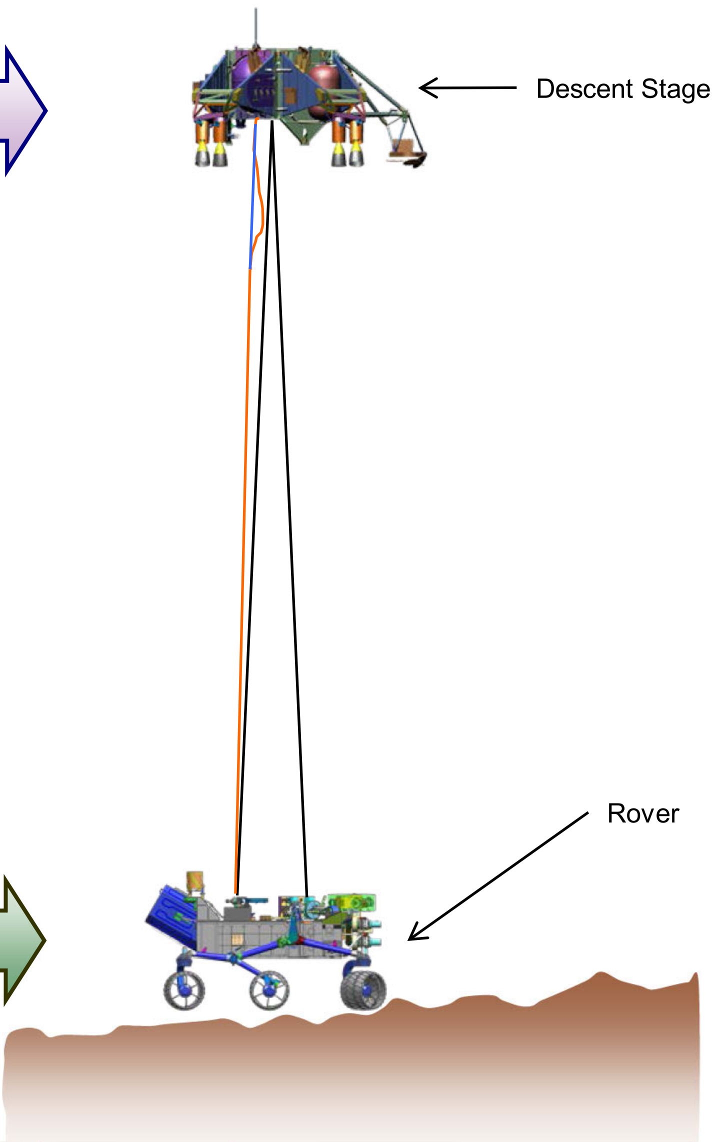
Key Validation Features of Sky Crane

Descent Stage:

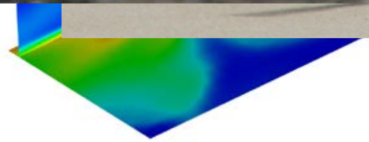
- Environmental interaction is analyzable
  - Unit/subsystem testing
  - System simulation
- Key features
  - CG located tension-only bridle interface
  - Wide spectral separation in GNC, structural modes and prop/engine performance
  - Touchdown signature is the post-touchdown state of the vehicle
  - Descent stage interaction with environment is very simple (F = ma)

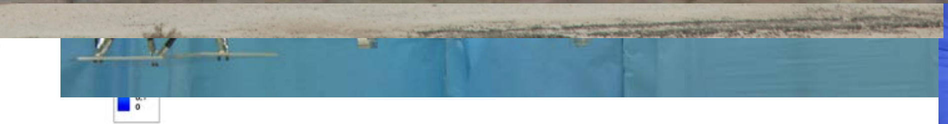
Rover:

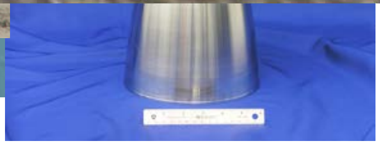
- Terrain interaction more testable
  - Rover dropped onto Mars analogs
  - Descent stage function represented by a crane
- Acknowledges difficulty in simulation of rover-terrain interaction
  - Rover interaction with environment is very complex ($\Sigma F = \Sigma(ma)$)



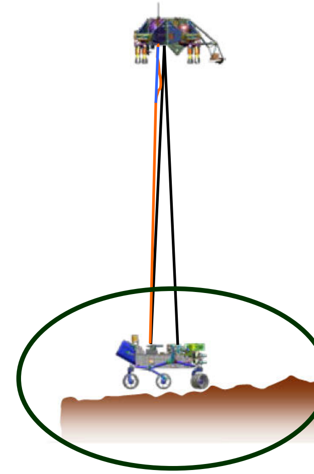
Sky Crane Engineering (1/3)







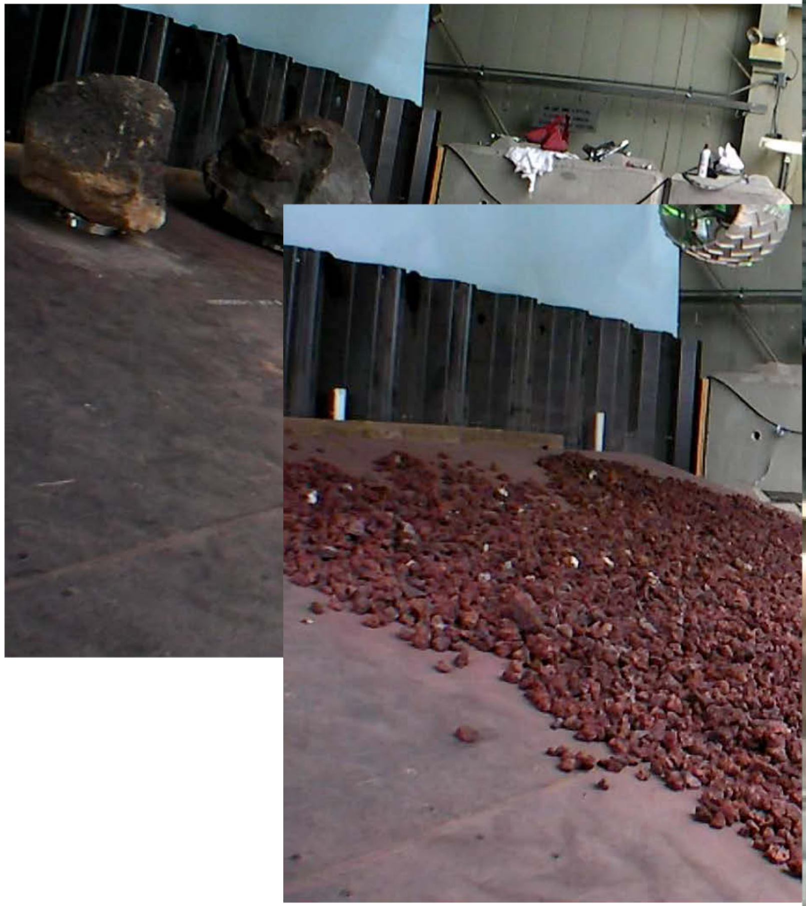
Sky Crane Engineering (2/3)



Testing, testing, testing…….

Sky Crane

NAE Mini-Symposium



Closing thoughts…

- JPL/NASA has been learning to better our engineering efforts with each expedition to Mars
  - MSL represents the current summation of that process
- Curiosity is the biggest, most science equipped and longest lived (planned) rover to visit the Martian surface
- Getting Curiosity to the surface has involved the development of next generation EDL architecture
  - MSL EDL architecture resulted from extended trade study
  - Approach is an evolutionary outgrowth of past Mars missions
- The resulting touchdown system design is novel
  - Analysis and test results suggest design is sound and very robust
- The final test for this engineering system awaits on Mars, on Sunday night, August 5th…….wish us luck!