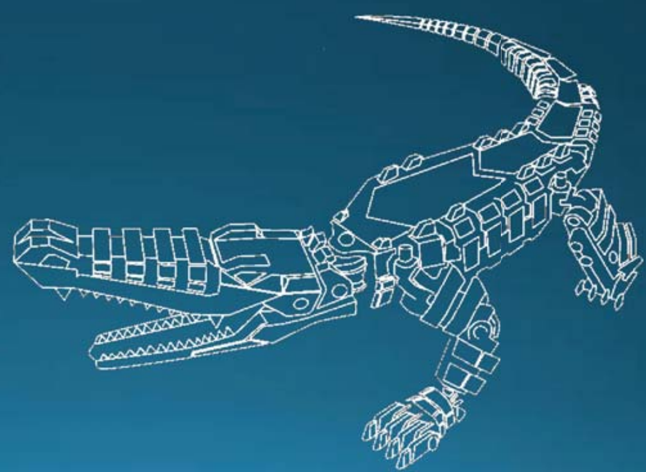
Space Resource Technologies

Rachel Hardy, NASA Kennedy Space Center

Who we are and what we do

Swamp Works



Swamp Works is a lean development lab

that strives to use rapid, innovative, and cost effective approaches.

- High bay lab area
- Technology incubator area – spaces for new project ideas to grow
- Lunar Regolith (moon dirt) Test Bin
- Machine Shop
- Innovation Space – loft area with white boards for brainstorming
- Outdoor rock yard for testing robots

NASA/KSC

Areas of Focus

Our mission is to provide government and commercial space ventures with the technologies they need for working and living on the surfaces of the Moon, planets, and other bodies in our solar system.

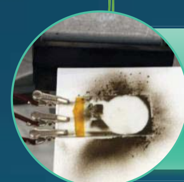
We have four labs with different focuses, and plans to expand to more labs.

Granular Mechanics and Regolith Operations

Explores ways to use regolith (dirt, gravel, rocks) on the surfaces of other planets for ISRU. Studies blasting effects of rocket plumes; robotics; mining; regolith transportation; additive manufacturing; physics and geology.

Applied Chemistry

Studies ISRU chemical processes: toxic vapor detection; hydrogen detection; self-healing wire insulation; prospecting for water on the moon; resource extraction methods; ground water cleaning.



Electrostatics and Surface Physics

Electrostatic charging solutions; high density, rapid charging energy storage devices; dust repulsion off surfaces, such as solar panels.

Advanced Life Support

Develops technologies for human exploration life support and habitations. Water recovery systems; ammonia removal; microbial characterization; in-situ production of advanced biological materials and composites; advanced environmental control.

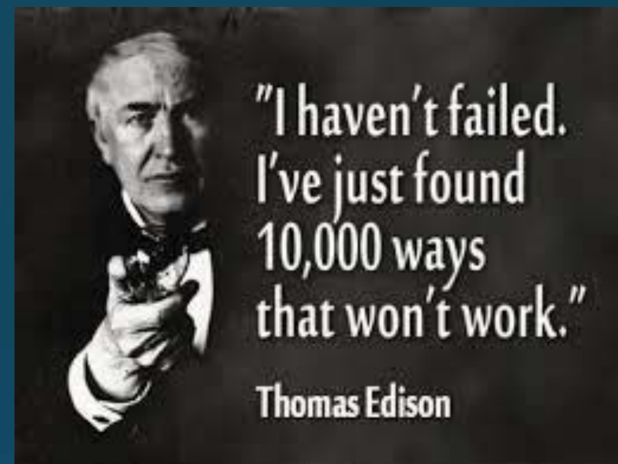

mks
MASS-FLO CONTROLLER

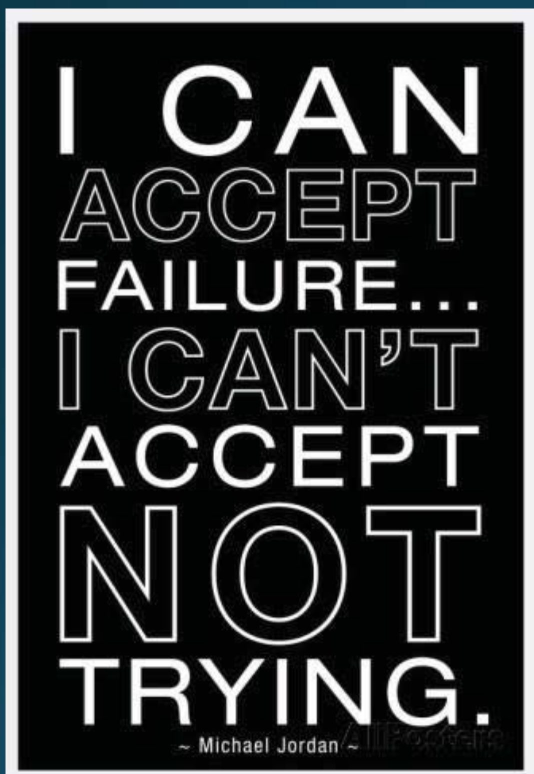

Simulated Moon Hazard Field

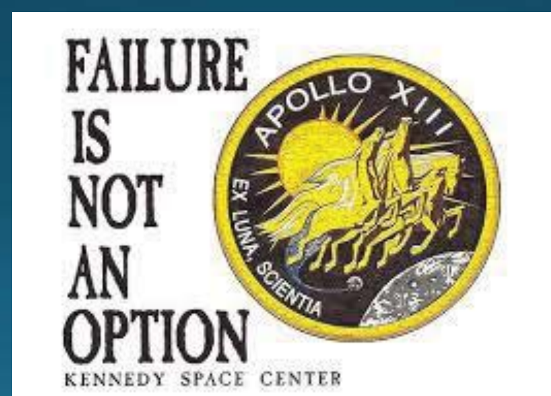

Shuttle
Landing
Runway
aerial view

Failure?


NO
FAILURE
ZONE


"I haven't failed.
I've just found
10,000 ways
that won't work."
Thomas Edison


I CAN
ACCEPT
FAILURE...
I CAN'T
ACCEPT
NOT
TRYING.
~ Michael Jordan ~


FAILURE
IS
NOT
AN
OPTION
APOLLO XIII
EX LUNA, SCIENTIA
KENNEDY SPACE CENTER


Failure
is an option...
if things are not failing
you are not
innovating


August 9, 2012
May 28, 2014
FAIL EARLY
FAIL FAST
FAIL FORWARD

Technology Readiness

NASA has a scale to measure how far along a technology is in its development lifecycle. They call increments on the scale Technology Readiness Levels, or TRLs.

Swamp Works project generally fall around TRLs 1-5, though occasionally they are higher and even make it to flight.

1. Transition from scientific research to applied research
2. Applied research
3. Proof-of-concept validation
4. Standalone prototyping implementation and test
5. Thorough prototype testing in relevant environment
6. Prototyping on full-scale realistic problems
7. System functions in operational environment
8. System completed and "mission qualified"
9. Mission/ground operations

Efficiency

Not too many people.

Small teams — fast and agile decision-making

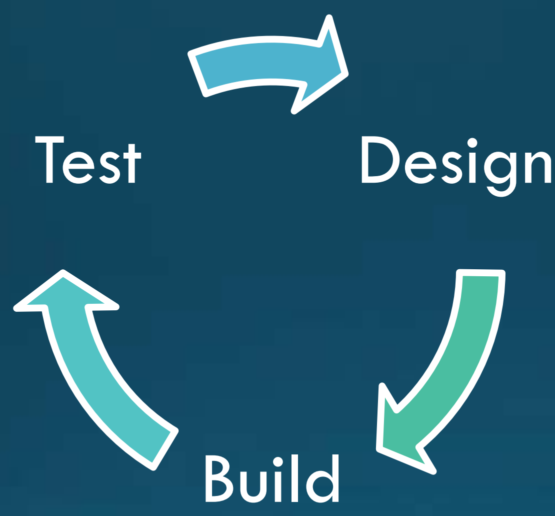
Not too much money.

Small budgets. No massive programs.

Not too much time.

Quick prototypes — build up fast, learn & move on

Design-build-test conducted iteratively with increasing knowledge of the operating environment will result in an end product that optimizes safety and performance.



Begin with a clear vision of what the technology will do and won't do

By the Preliminary Design Review (PDR), we will know exactly what we want, how we're going to build it, and how we're going to operate it

Credit: Astronaut Mike Gernhardt, NASA JSC

Select Projects

Space Technology Portfolio

“ The absolute least efficient way to get air, water, and fuel into space is the way that we currently do it: by packing as much of it as we can into rockets on Earth, and then firing it off into orbit. If this is how we have to get supplies to the moon, or Mars, it's going to be ludicrously expensive and time consuming. ”

Evan Ackerman, IEEE

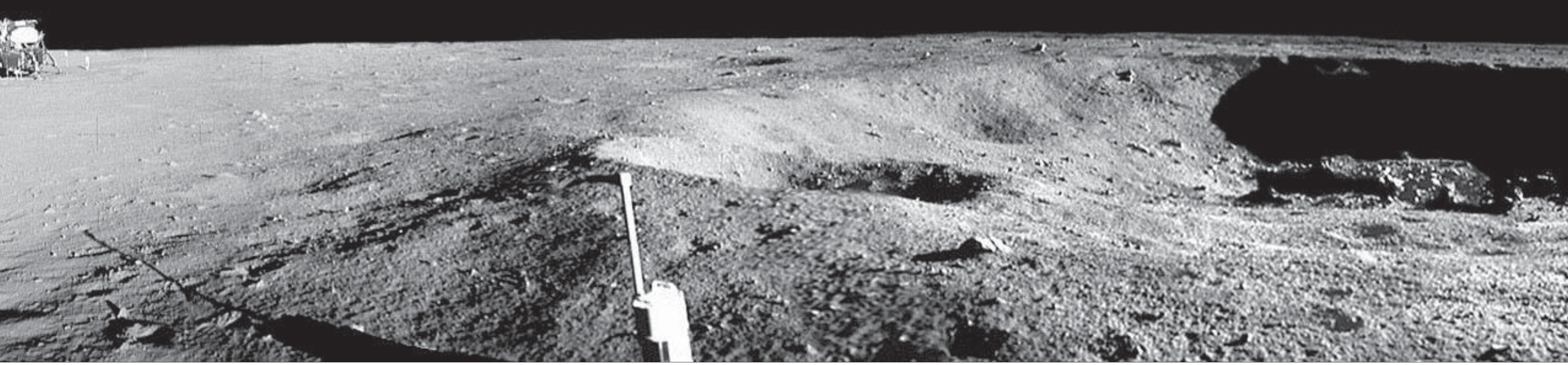
Source: **NASA Training 'Swarmie' Robots for Space Mining.**

http://spectrum.ieee.org/automaton/robotics/military-robots/nasa-training-swarmie-robots-for-space-mining

In-situ resource utilization

Like explorers before us, we don't need to carry everything with us. In-situ resource utilization, or ISRU, is the idea of harnessing resources available at our destination, whether it is Mars, the Moon, an asteroid, or elsewhere.

LUNAR REGOLITH AS A RESOURCE

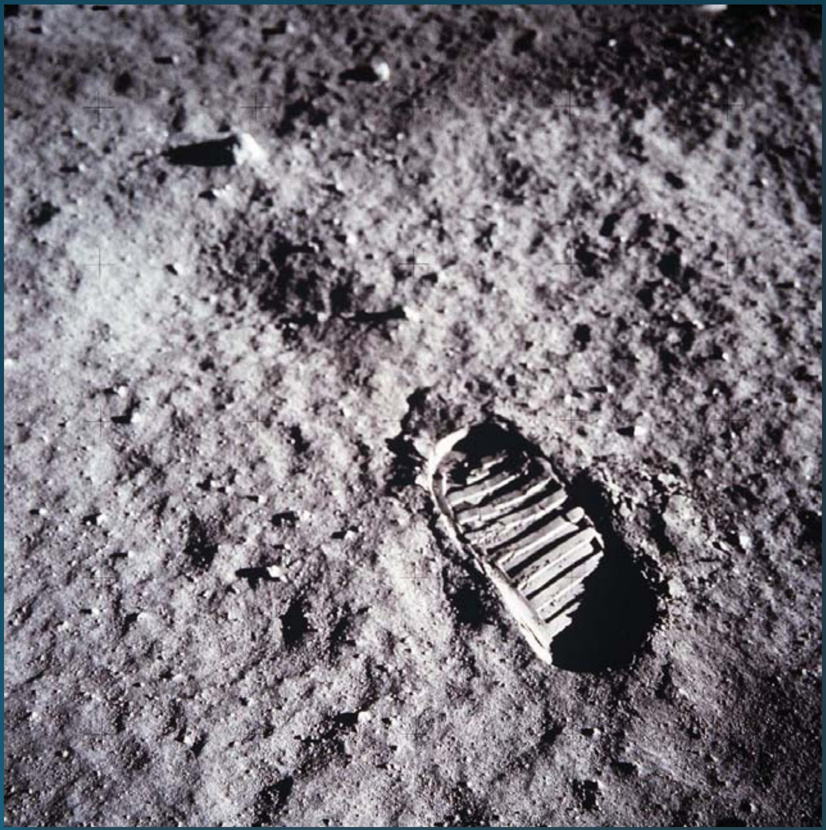


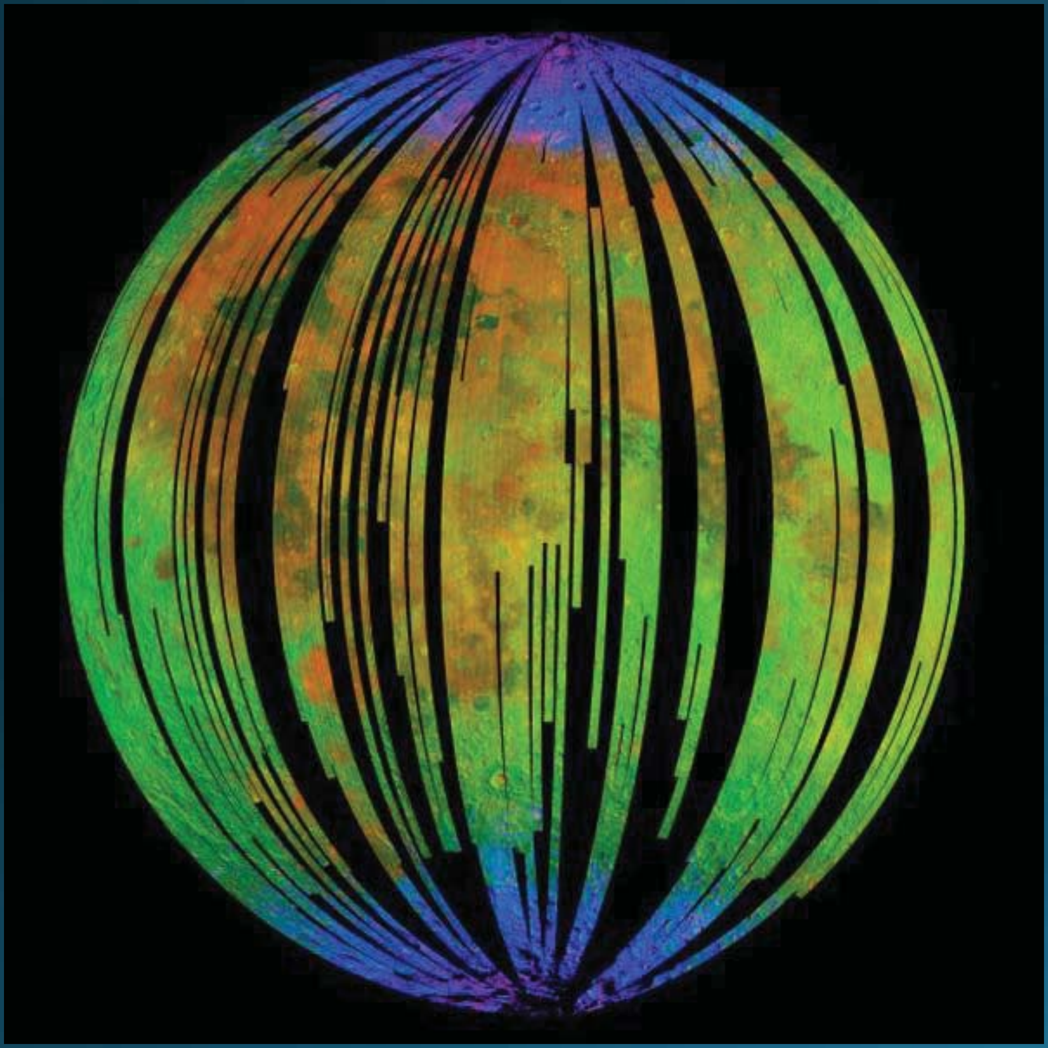
Regolith

Regolith is the surface layer of loose material that sits on top of bedrock. It includes all the rocks, gravel, and dust – from large boulders to tiny particles. It exists on Earth, other planets, moons, and asteroids.

Swamp Works is exploring ways to exploit the regolith for as many uses as possible. We take one of two approaches:

1. Extracting resources out of the regolith, usually with chemical processes
2. Using the regolith as a raw material for building structures





blue = water signature

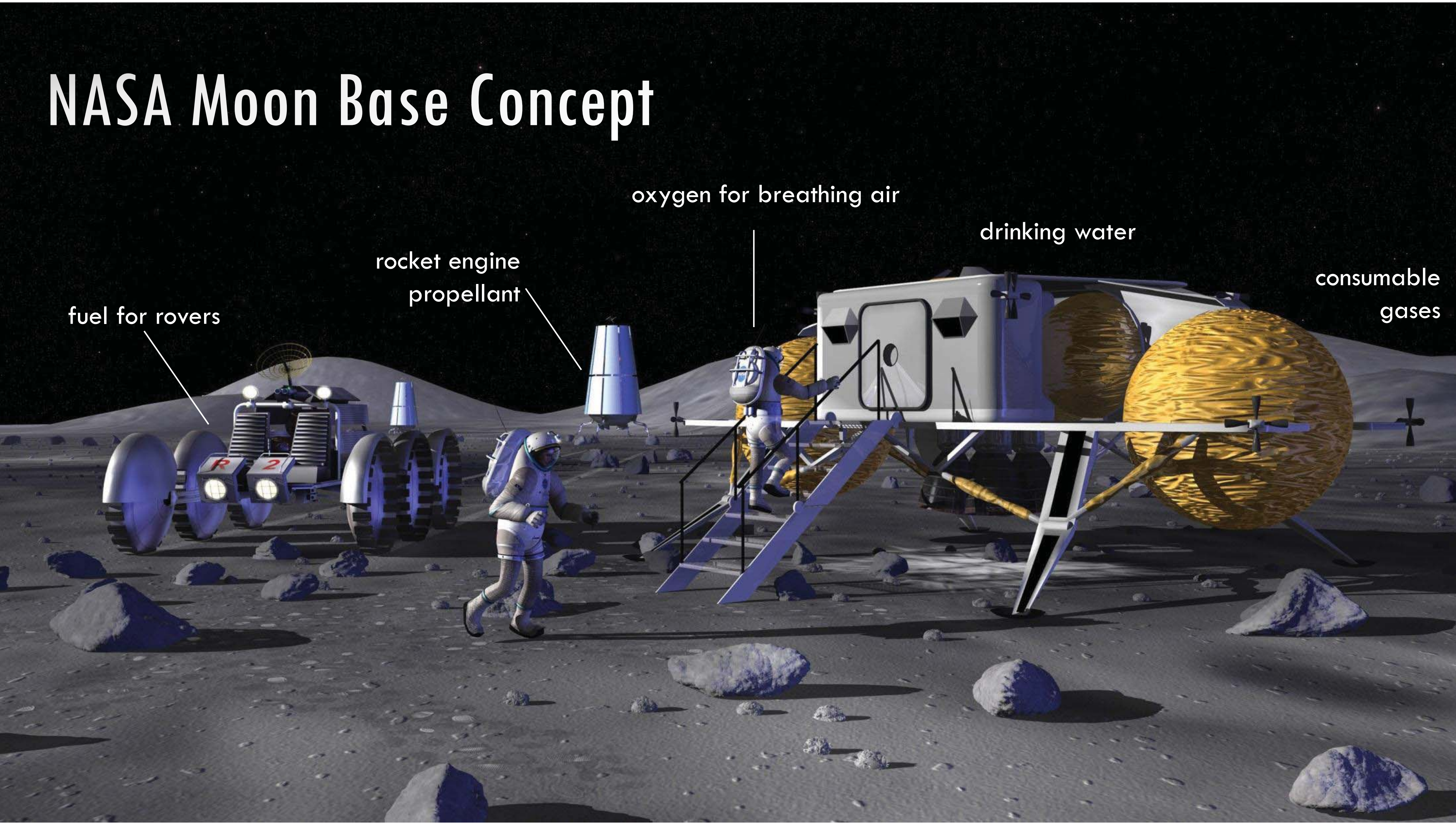
Moon Mineralogy Map. NASA/JPL

Lunar Regolith Composition

- 42% oxygen by mass
- Water
- Hydrogen
- Helium & helium 3
- Carbon monoxide
- Metals (aluminum, titanium, iron…)
- Silica → glass, optical communication fibers

Chemical composition of surface regolith (dirt, gravel, rocks)			
Compound	Formula	Composition (wt %)	
		Maria	Highlands
silica	SiO_2	45.4%	45.5%
alumina	Al_2O_3	14.9%	24.0%
lime	CaO	11.8%	15.9%
iron(II) oxide	FeO	14.1%	5.9%
magnesia	MgO	9.2%	7.5%
titanium dioxide	TiO_2	3.9%	0.6%
sodium oxide	Na_2O	0.6%	0.6%
Total		99.9%	100.0%

NASA Moon Base Concept

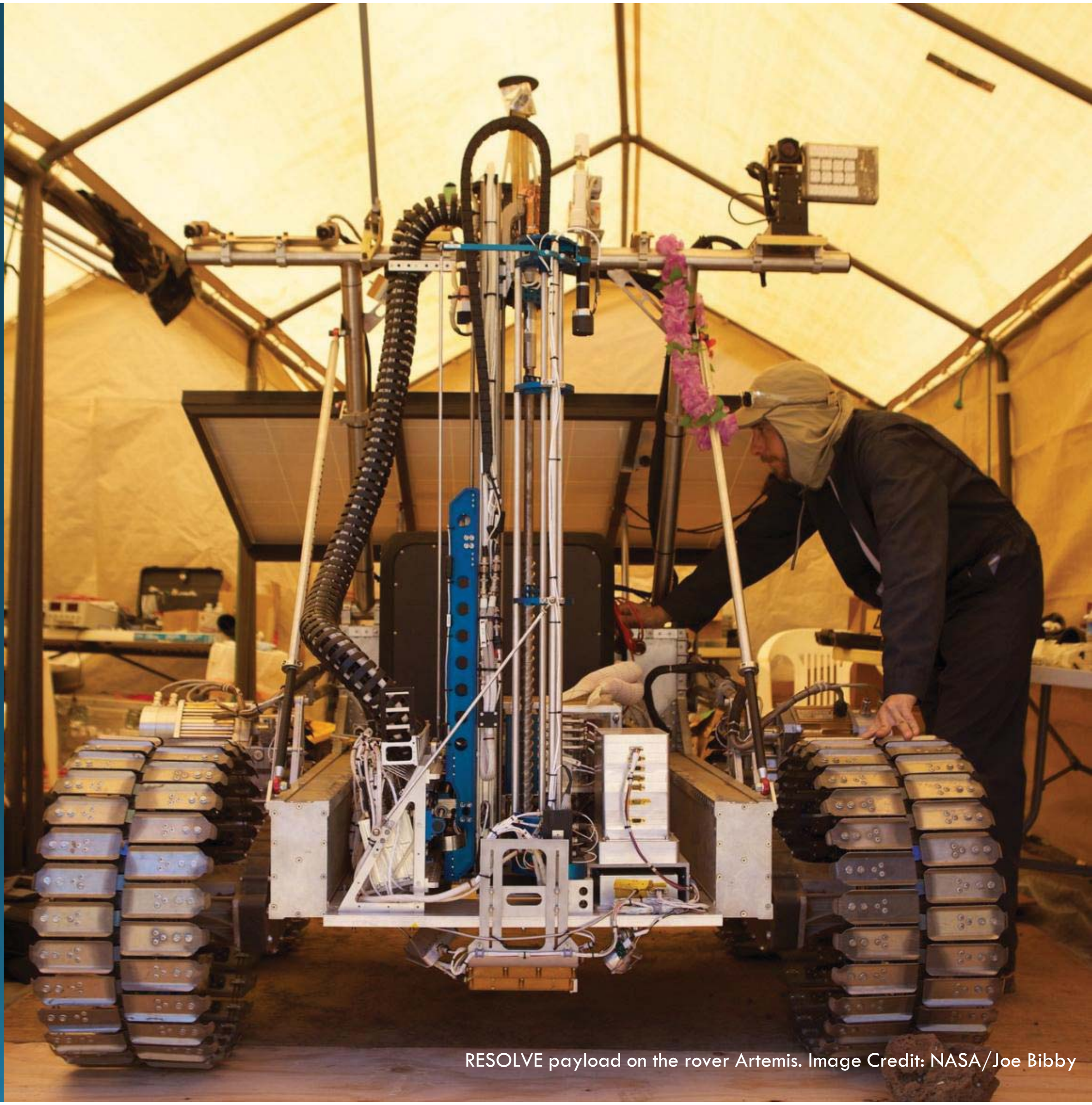


Prospecting at the Poles

This scientific instrument called RESOLVE (short for Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction) will sit onboard the Canadian rover Artemis to prospect on the moon for water ice.

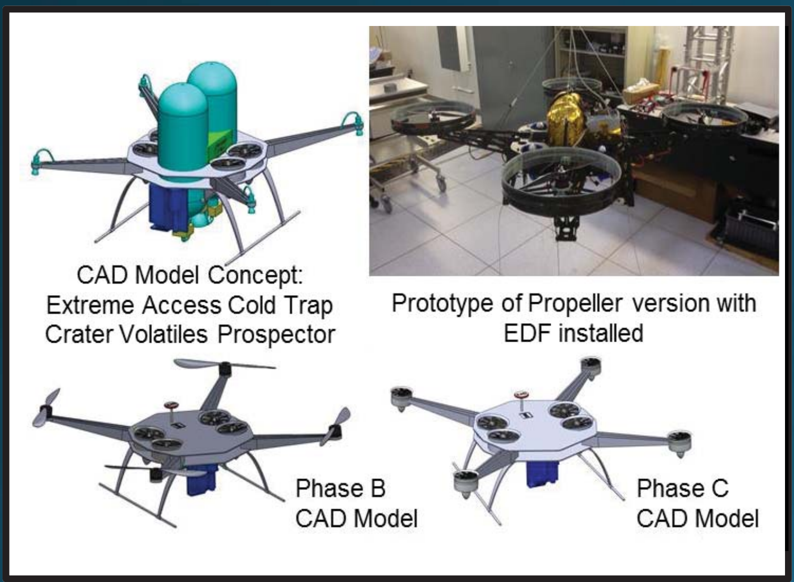
RESOLVE instruments:

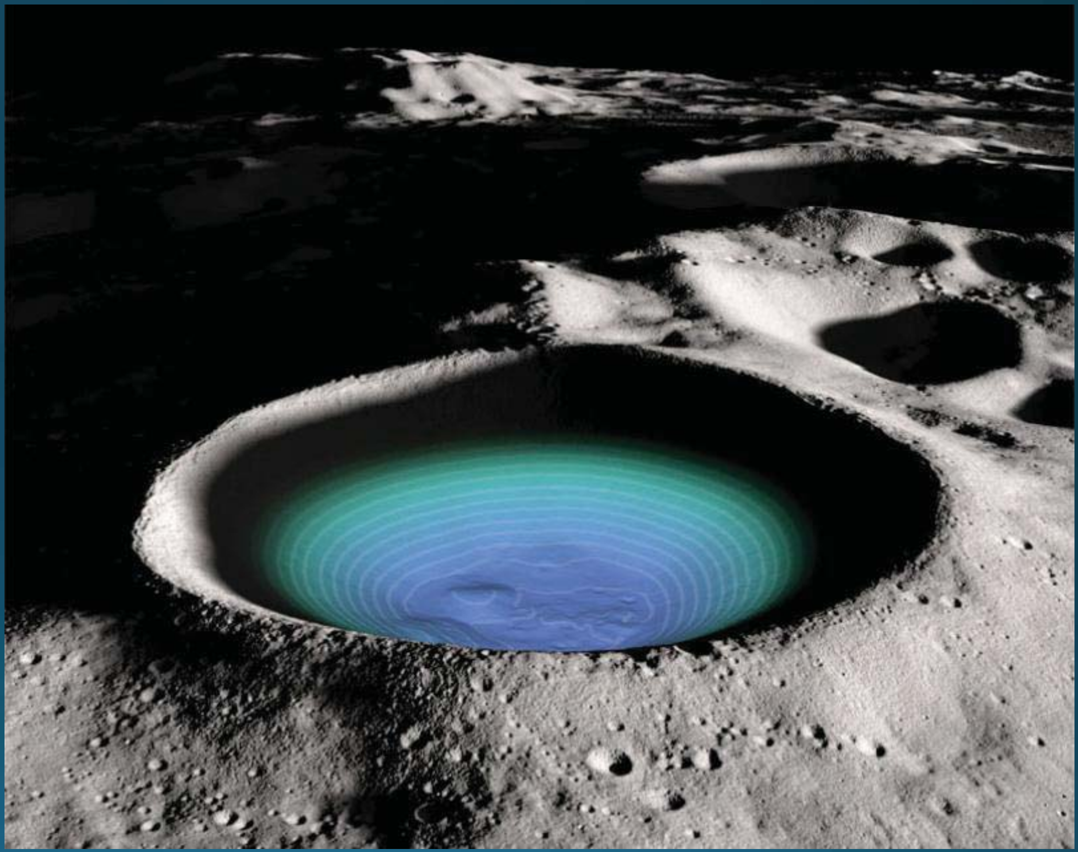
- A neutron spectrometer and near infra-red spectrometer for selecting sample sites
- A drill and core transfer mechanism for sampling
- A heating oven for processing the sample
- A gas chromatograph/mass spectrometer to capture water and other volatiles

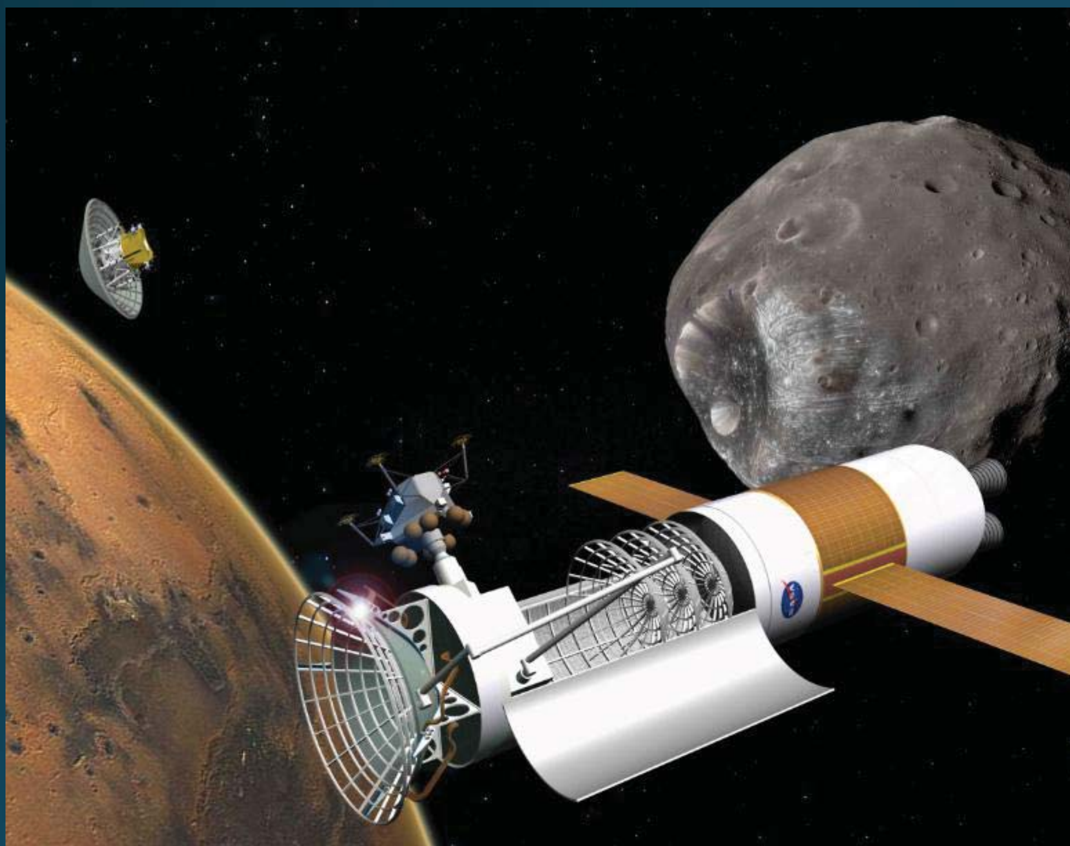


RESOLVE payload on the rover Artemis. Image Credit: NASA/Joe Bibby

Sampling Permanently Shadowed Crater Regions







Artist concept of heat shield fabrication. NASA/KSC

Regolith Heat Shields

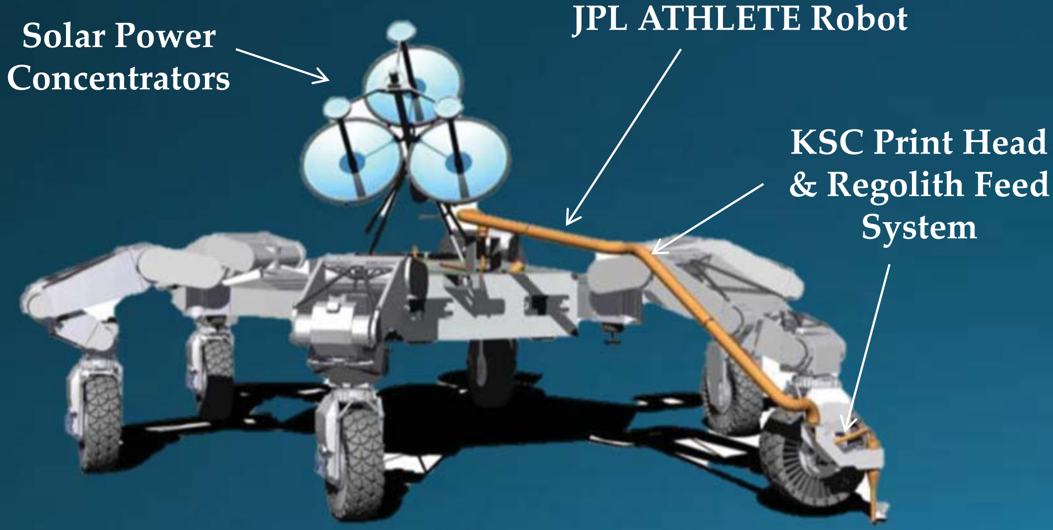
When spacecraft enter an atmosphere, like when landing on Mars or upon returning to Earth, the atmosphere creates a high amount of friction and heat on the fast-moving vehicle. If the vehicle did not have thermal protection, it would burn up upon (re)entry.

Heat shields are very heavy and therefore costly to launch from the gravity well of Earth. Fabricating heat shields in space, like shown in the concept to the right, could make the missions more affordable.

Clockwise from top left: Regolith-derived heat shield sample undergoing flame testing; regolith samples post-test; artist concept. Image Credit: NASA/KSC

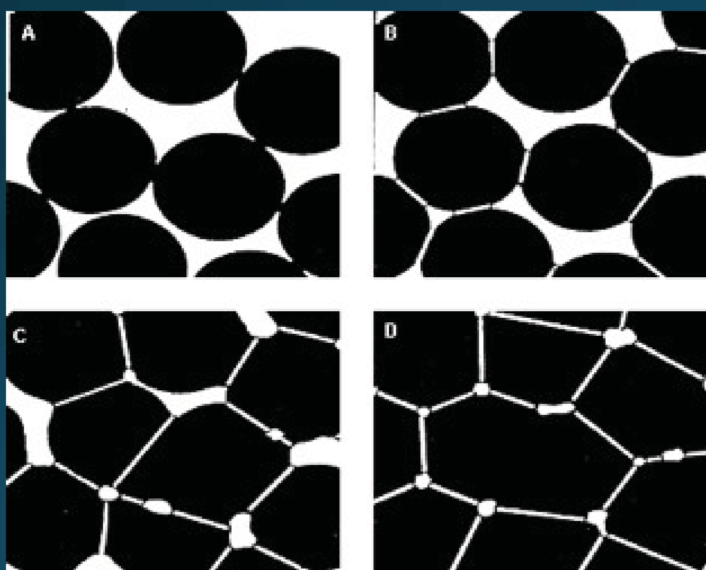
Regolith 3-D Printing/Additive Manufacturing

Swamp Works is investigating methods of using robotic construction technologies to build structures using Lunar and Marian regolith.



Regolith 3-D Printing/Additive Manufacturing

Heating the moon dirt to just-below-melting temperatures (1200-1500 °C) makes the dirt stick together. Robotic 3D printers can then build walls of a habitat.



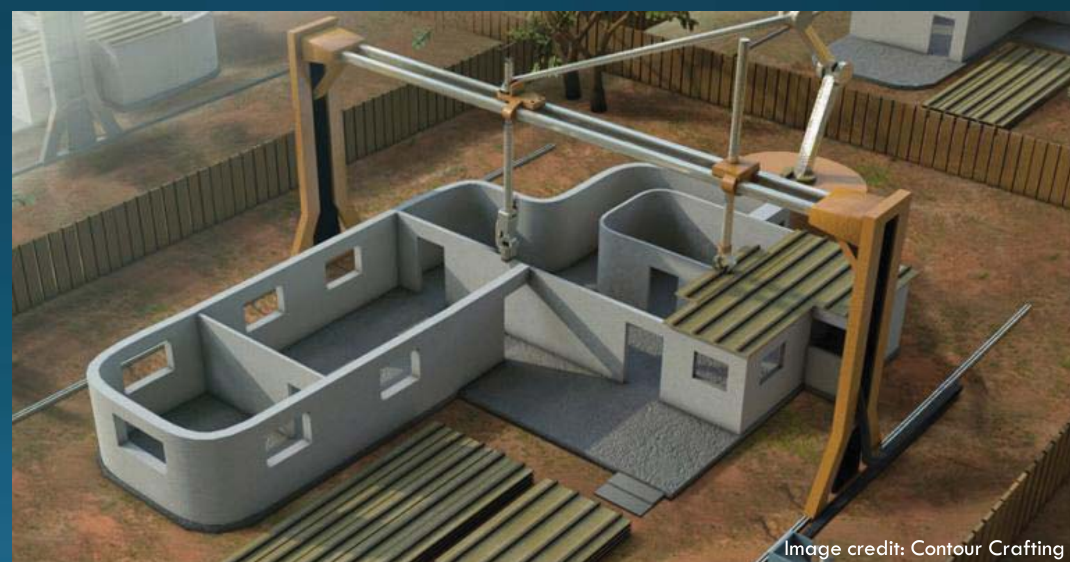


Image credit: Contour Crafting

Regolith Mining and Delivery

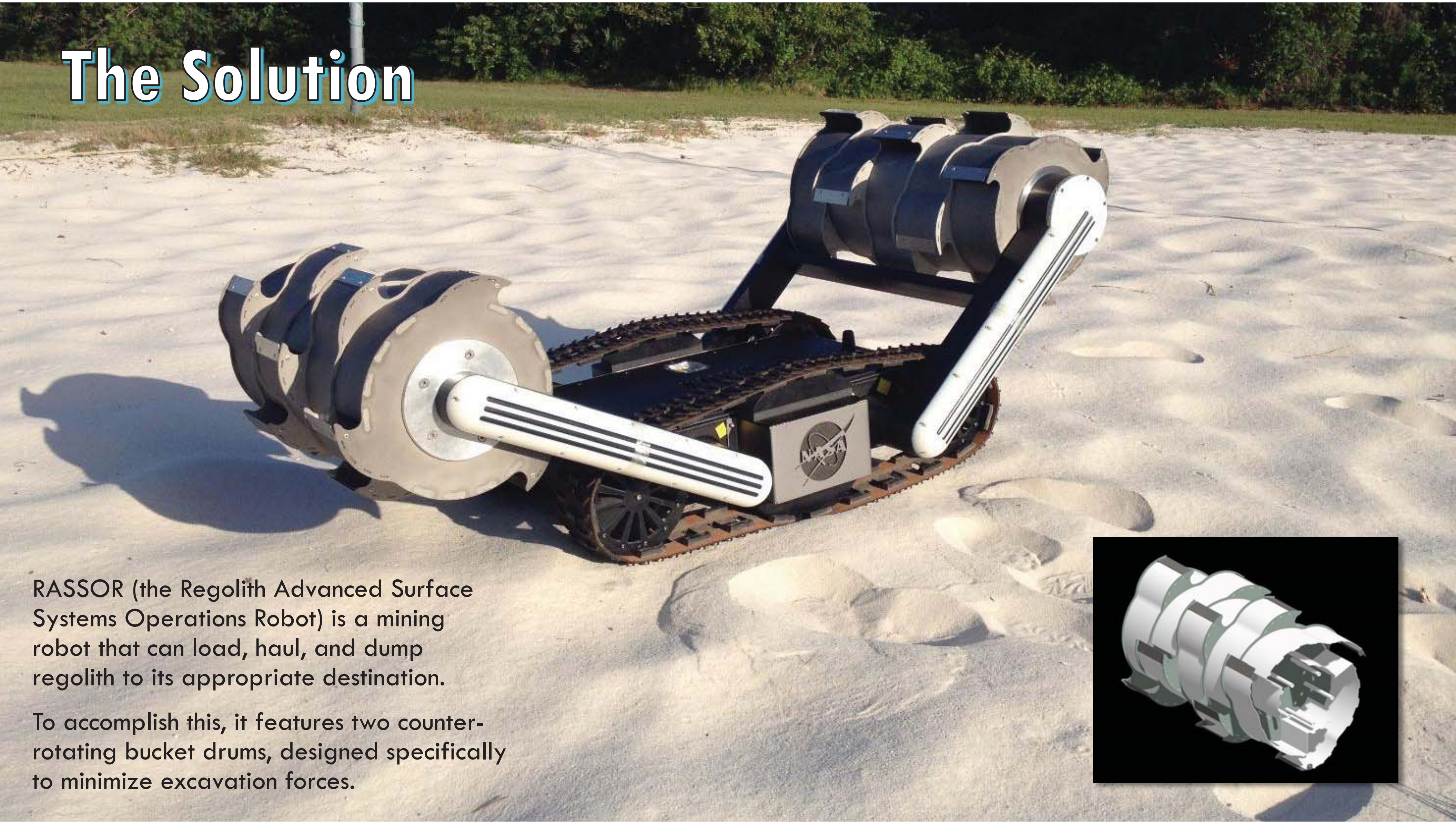
In order to get the regolith feedstock into chemical processing plants (to extract metals, oxygen, hydrogen, etc.), we need a mining and delivery system.

Traditional Earth excavation methods are not ideal. They take advantage of weight and traction to counter high digging reaction forces.

- Reduced gravity corresponds with increase in mass (6x's for moon) to produce the same weight
- Launch costs (~$4,000/kg)
- Packaging constraints

Image Credit: heavyequipment.com

The Solution



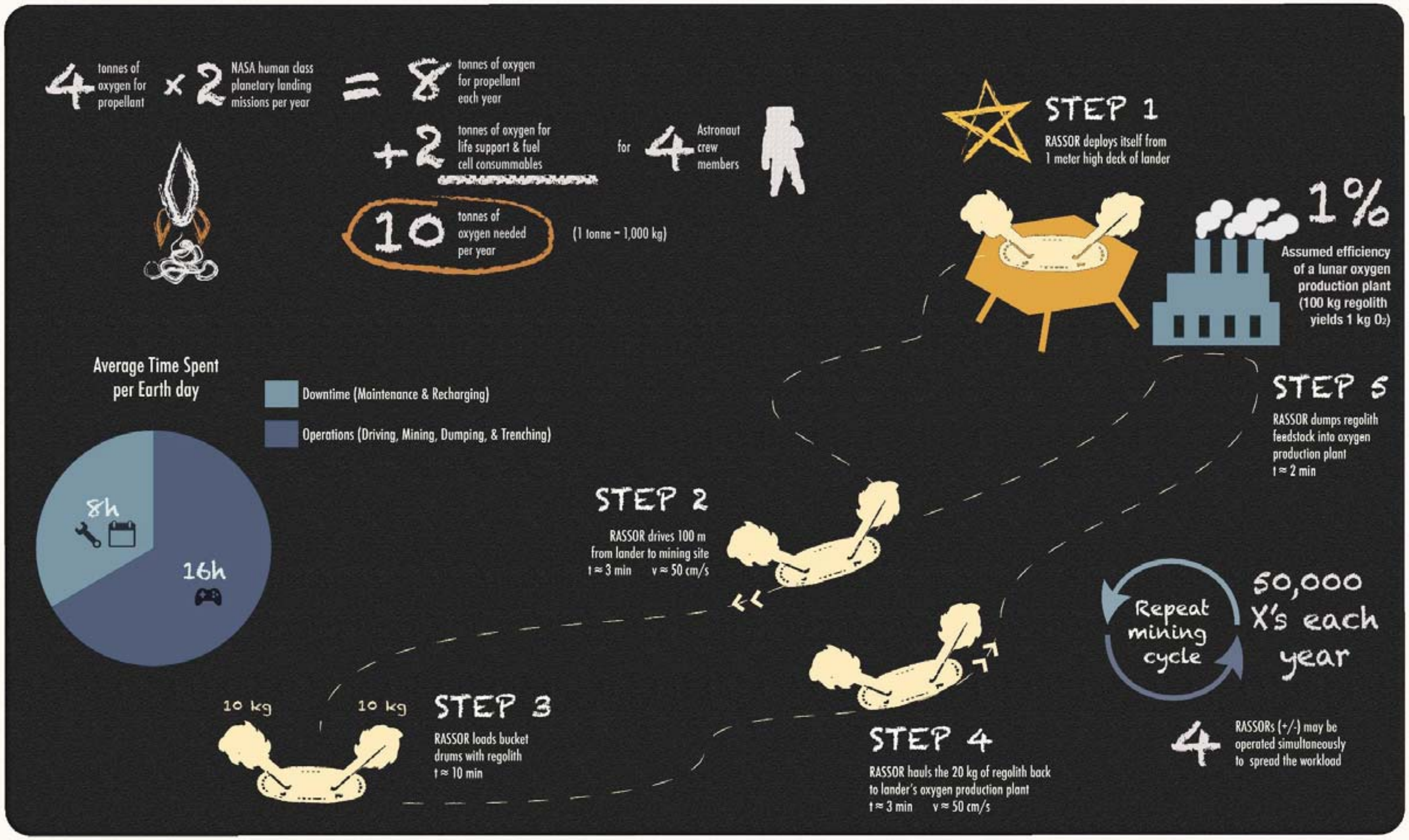
RASSOR (the Regolith Advanced Surface Systems Operations Robot) is a mining robot that can load, haul, and dump regolith to its appropriate destination.

To accomplish this, it features two counter-rotating bucket drums, designed specifically to minimize excavation forces.

RASSOR Concept of Operations

MISSION: Mine Regolith & Deliver to a Hydrogen Reduction Reactor for Oxygen Production

DURATION: 5 Years



created by Rachel Hardy
NASA KSC Swamp Works

Robust Robotics

RASSOR also needs to be reliable and self-sufficient if it is to survive on the moon for five years. It is prohibitively expensive to send astronauts up to repair it.

So RASSOR was designed to do "acrobatics" – assuming various positions to clear its tracks, somersault out of holes, or climb its way out of trouble.

RASSOR Acrobatics. Image Credit: NASA/Rachel Hardy

RASSOR Lunar Testing. Image Credit: Gina Chitko/NASA/KSC

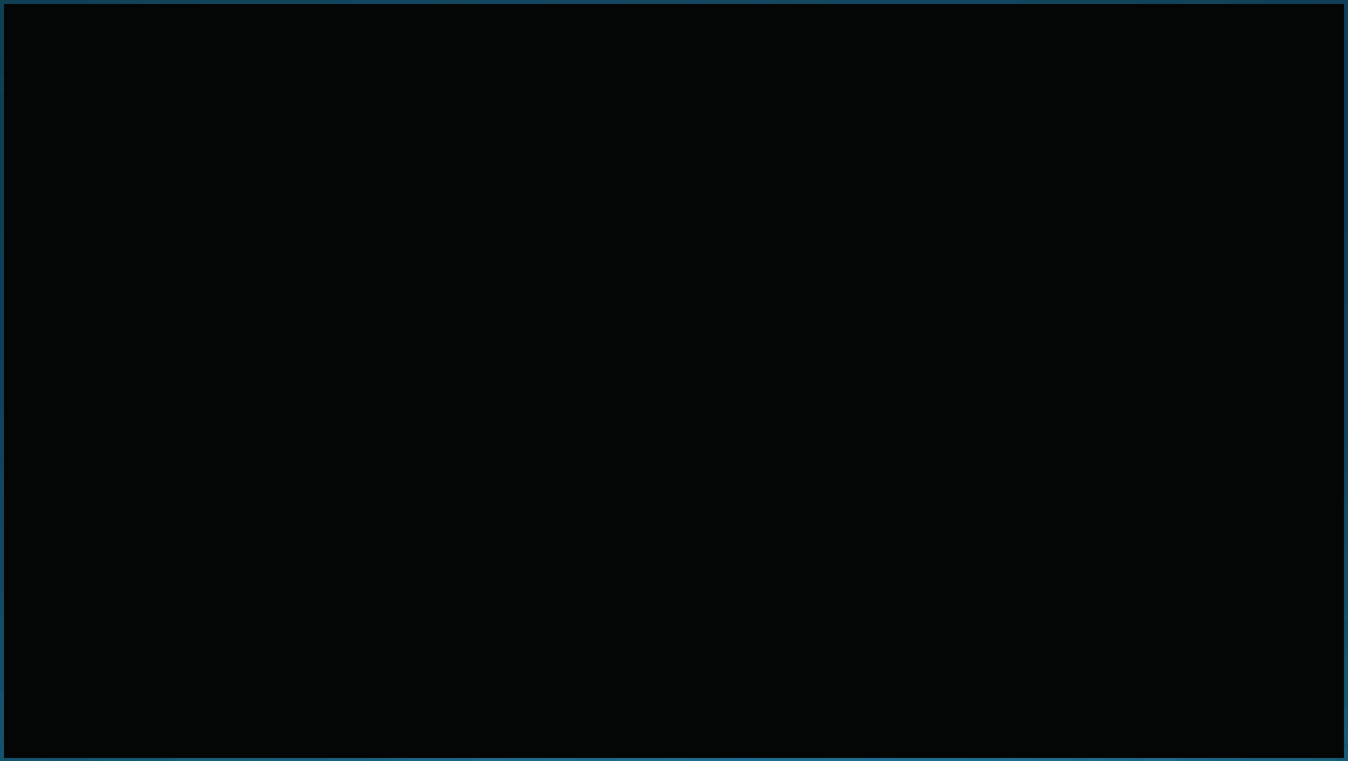
Simulating the Moon

RASSOR must be able to operate in the reduced gravity of the Moon (1/6 G). And it must be able to dig frozen regolith at temperatures as low as 40 K.

RASSOR is seen here on a “gravity offload” system to counterbalance its weight while performing digging and traction tests. It is digging in a cryogenically frozen lunar simulant (77 K) to mimic lunar conditions.

RASSOR Video

Computer Modeling and Simulation



FUTURE RASSOR TECHNOLOGY

SWARMING ALGORITHMS


Questions?