

Swamp Works 10th Anniversary 2013-2023

Space Resources Roundtable (SRR-XXIII)

Colorado School of Mines

GOLDEN, COLORADO

JUNE 6-9, 2023

Rob Mueller

Senior Technologist / Principal Investigator

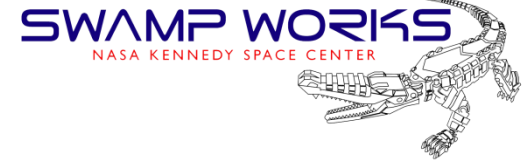
Exploration Systems & Development Office

NASA

Kennedy Space Center, Florida, USA



Innovation Environment

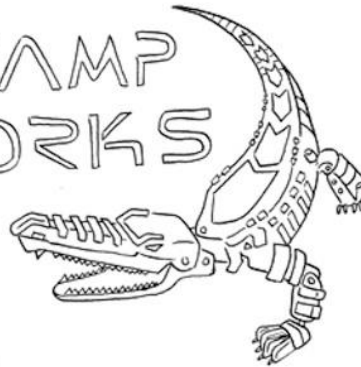


OH MAN. SWAMP WORKS.

AN ENTIRE BUILDING DEDICATED TO IN SITU RESOURCE UTILIZATION AND INVESTIGATION ON OTHER PLANETS AND ASTEROIDS! SCIENTISTS AND ENGINEERS FIGURING OUT HOW TO TEST THE LUNAR SURFACE FOR WATER AND MINE THE REGOLITH OF MARS FOR FUEL!



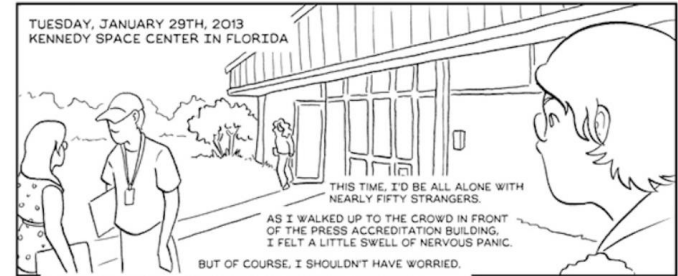
SWAMP
WORKS



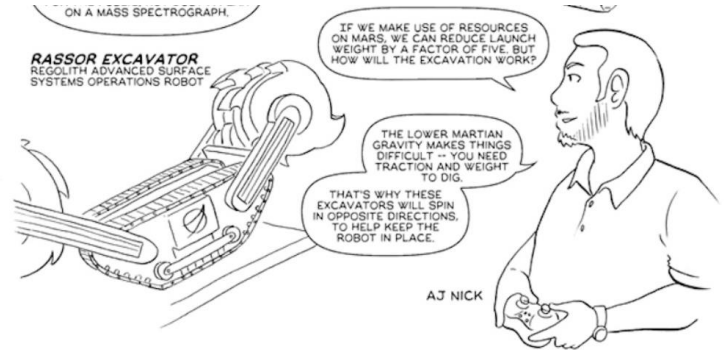
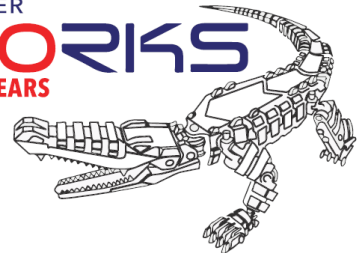
"WE'RE TRYING TO CLOSE THE LOOP ON LIFE SUPPORT," THEY SAID.

"TELL ME MORE!" I SAID.

AND THEY DID.



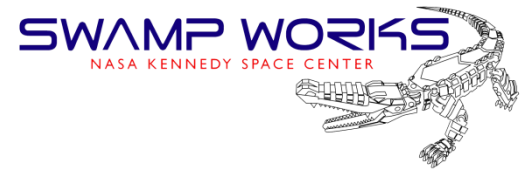
NASA KENNEDY SPACE CENTER
SWAMP WORKS
YEARS



<http://www.tor.com/stories/2013/07/nasa-comic-alison-wilgus>



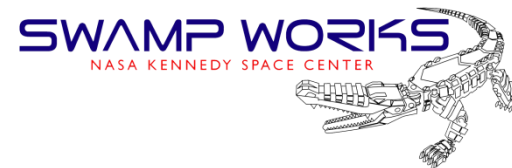
History & Purpose



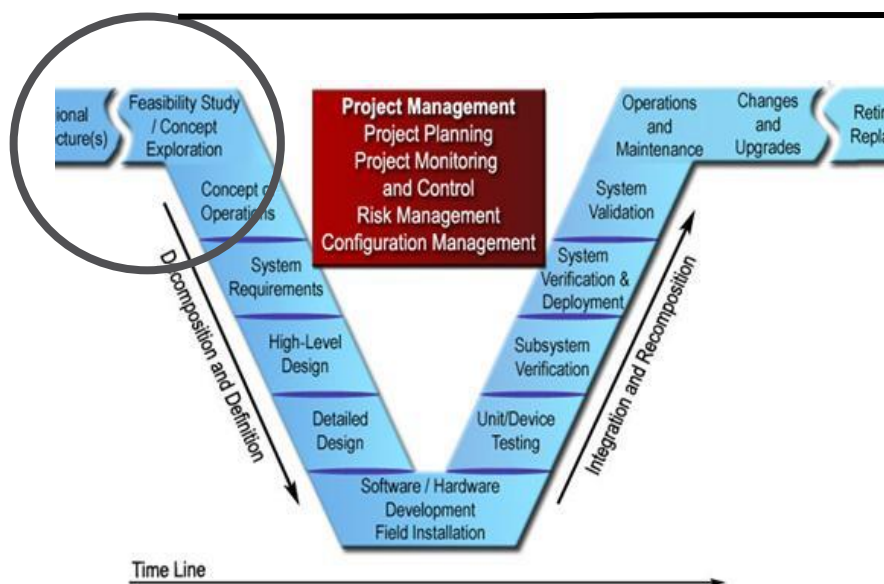
- The **KSC Swamp Works** was established in January, 2013 as a lean research & technology development environment for **efficient, innovative and cost effective** exploration mission solutions for NASA in collaboration with commercial space industry
- Philosophies aligned with those used in *Kelly Johnson's Skunk Works* and *Werner von Braun's development shops*
- **Hands-on approach:** start small and cheap - build up momentum
- **Testing performed in early stages**, fail forward allowed and drive design improvements in a helical process
- **Leveraging partnerships** across NASA, government, industry & academia



Status Quo



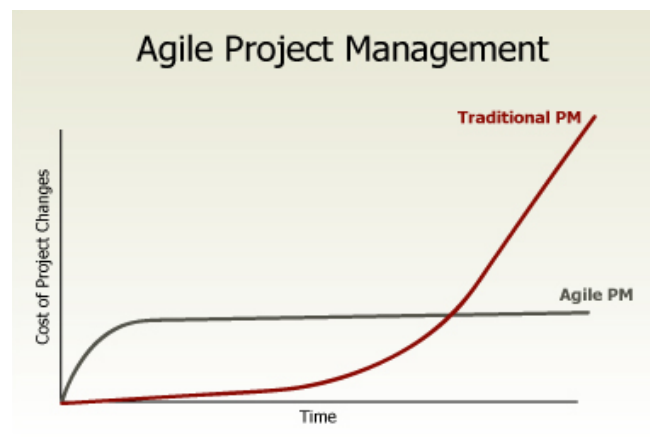
NASA Status Quo



One-size-fits-all development process

- All changes go to Control Boards
- Detailed design & analysis before any procurements
- Testing can begin a year after start
- Risk averse environment

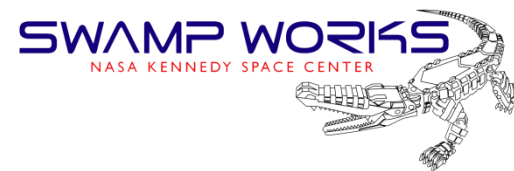
Innovation Methods



- Lean Development with Agile Project Management enables innovative solutions for sustainable exploration
- Stretch goals with revolutionary potential – technical risk accepted
- Reduced Cost – Better Results

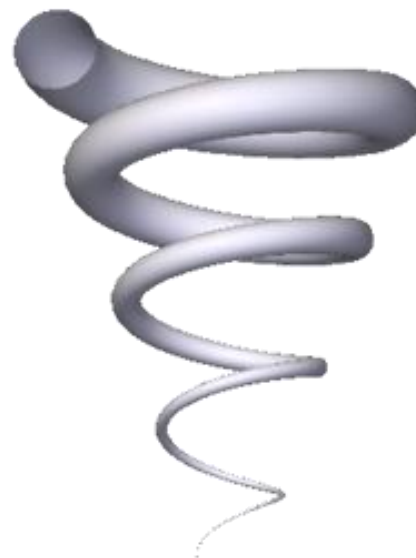


Swamp Works Method



Swamp Works Helical Development

TRL 6: Flight Project: Preliminary
Design Review (PDR)



TRL

Start Small, Safe, Cheap & Fast

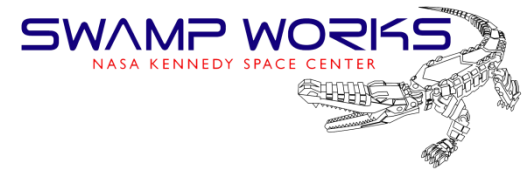
Game Changing Ideas

Culture of Innovation

Learn Fast – Prototyping -Test

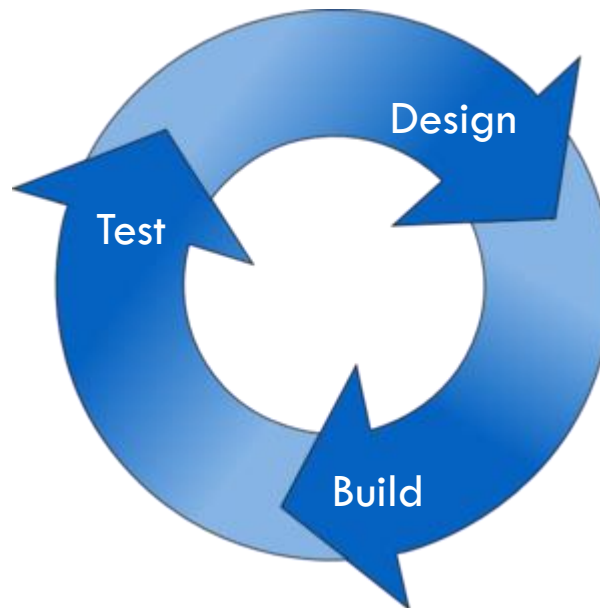


Swamp Works Method



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



Generation 1

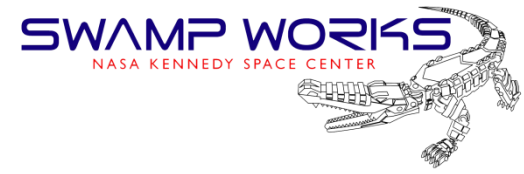
Generation 2

Generation 3

Flight



Lunar Excavator Example



Generation 1
RASSOR 1.0



Since 2010 > 650 University Teams

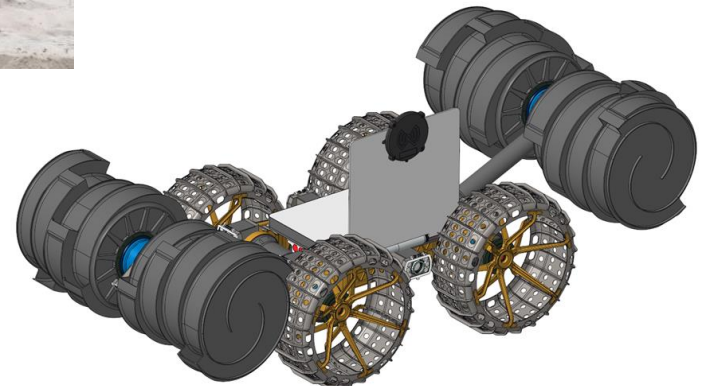


Generation 2
RASSOR 2.0



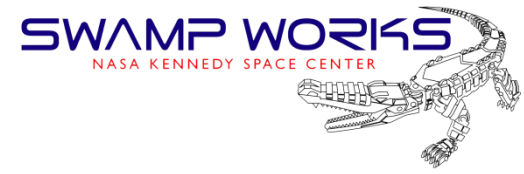
314 Entries

Generation 3
ISRU Pilot Excavator
(IPEX)





Collaboration Examples (not all are shown)



HONEYBEE ROBOTICS

SPACEX

OFFWORLD

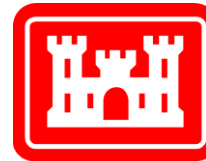
SIERRA
S P A C E



LOCKHEED MARTIN



BLUE ORIGIN



US Army Corps
of Engineers®



JPL



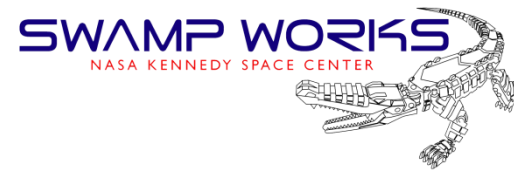
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Applied Chemistry Lab

Project Examples

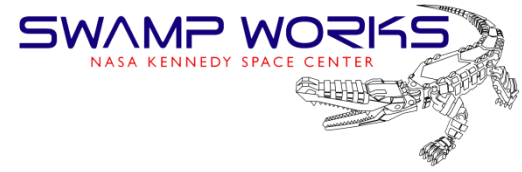


- Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE)
- Water analysis and volatile extraction (WAVE)
- Resource Prospector Mission Prototype
- Mass Spectrometer observing lunar operations (MSolo)
 - MSolo-1
 - MSolo-2
- Polar Resources Ice Mining Experiment-1 (PRIME-1)
- Trash to Gas for In-Situ Resource Utilization (ISRU)
- Carbothermal Reduction Demonstration (CaRD)
- Terrestrial Environmental Remediation



Electrostatics and Surface Physics Lab

Project Examples

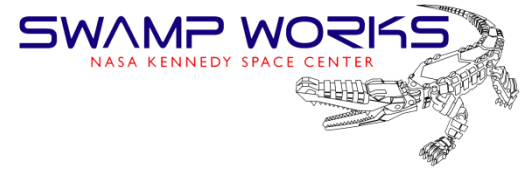


- Electrodynamic Dust Shield for IM1 CLPS mission (EagleCam)
- Electrodynamic Dust Shield for 19D CLPS mission
- Electrodynamic Dust Shield for IPEX Rover
- Lunar Terrain Vehicle (Boeing, Lockheed Martin)
- VSAT (Astrobotics, Lockheed Martin, Honeybee)
- Electrostatic Discharge Testing for Blue Origin, Virgin Orbit, Space X
- MISSE-15 and MISSE-11 Flights of Electrodynamic Dust Shield (EDS) samples
- ERIE Flight Opportunity
- CIF: Modelling LIGGGHTS, Thermal Radiator EDS, Glass EDS, and Regolith Conveyor, EDS for solar cells, Electrospray Technologies
- Commercialization of Aeroponics Electrospray on International Space Station (ISS)
- HLS Blue Origin Testing and EDS Development
- HLS Dynetics EDS Development
- Electrostatic Precipitation for Mars



Electrostatics and Surface Physics Lab

Project Examples

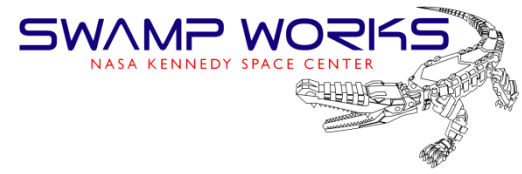


- Vertical Lunar Regolith Conveyor
- Lunar Extreme Environments Guidebook
- NASA Dust Test Standard
- Space Launch System (SLS) Broken Firing Line Project
- SLS LT-80 Tape Project
- Gateway Dust Mitigation Working Group
- Electrostatic Beneficiation of Environmental Control & Life Support Systems (ECLSS) Brines on International Space Station (ISS)
- Astronaut tool for Electrostatics and Dust Mitigation
- Exploration Upper Stage Testing
- P-static testing of space vehicles
- Electrostatic Dust Lofting experiment
- Electrostatic Regolith Interaction Experiment
- Secondary Electron Emission Experiments
- Volatiles Investigating Polar Exploration Rover (VIPER) Rover Electrostatics Testing



Granular Mechanics & Regolith Operations

Lab Project Examples

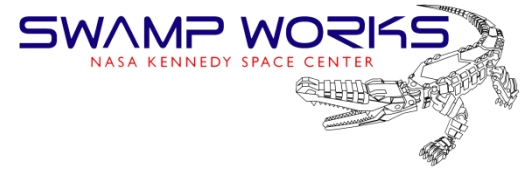


- Project Morpheus Landing Pads – Lunar Lander prototype with automated hazard detection
- Badger – Percussive Excavator Implement
- VIPER – Percussive Excavator Implement
- RASSOR – Lunar Regolith Surface Excavator
- Mars gypsum pick testing
- Plume Surface Interaction (PSI) – Earth, Moon & Mars
- DTAU – Dust Tolerant Automated Umbilical Interface
- ACME – Additive Construction w. Mobile Emplacement
- PISCES landing pad prototype – Hawaii in-situ regolith sintered robotic laid pavers
- Lunar Exploration Rover (LER) Quick Attach
- LANCE lunar bulldozer blade implement
- Voxel Based Regolith Manufacturing
- Teleoperation sensors testing in a dusty environment
- Regolith Test Beds with various regolith simulants
- Gravity Offload beam for testing excavators
- 3D printed Polymer Regolith for Robotic Construction
- NIAC – Mars Molniya Atmospheric Resource Mining
- NIAC – Regolith Derived Heat Shield
- NIAC – In-Space Propulsion Engine Architecture based on Sublimation of Planetary Resources
- NIAC – TransFormers for Extreme Environments



Granular Mechanics & Regolith Operations

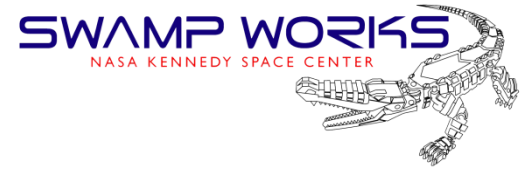
Lab Project Examples



- In Situ Resource Utilization (ISRU) Pilot Excavator
- Florida League of Cities In-Situ Construction Materials Development
- BMG – Bulk Metallic Glass gearbox environmental testing
- Dusty Motors for Extremely Cold and Dusty Environments
- Mini-RASSOR – sub scale 3D printed RASSOR excavator
- SSERVI Center for Lunar & Asteroid Surface Science - collaborations
- COLdarm Scoop Geotechnical Testing
- MMPACT, Moon to Mars Planetary Autonomous Construction Technologies
- Low Separation Force Quick Disconnect (QD)
- Dust Mitigation technology development for surface systems
- ISRU Pilot Excavator
- Space X ACO - Large Vehicle Lunar Landing Surface Interaction and In-Situ Resource Based Risk Mitigation: Landing & Launch Pads
- Molten Regolith Electrolysis (MRE)
- Relevant Environment Additive Construction Technology
- Moon Tycoon Virtual Reality Lunar Surface Simulator
- University Robotic Mining Competition (RMC): Lunabotics
- “3D Printed Mars Habitat” Centennial Challenge
- “Break the Ice” Centennial Challenge
- NASA Swarmathon - Swarming Robots Competition for universities



Success Ingredients



- ✓ Swamp Works methods have been used for 10 years on a variety of NASA Research & Technology Development (R&TD) projects
- ✓ Not all projects were successful – but that was acceptable
- ✓ A few projects were able to make it to a flight selection
- ✓ Seed money from IR&TD funding is essential
- ✓ Management support is essential
- ✓ A culture of innovation is essential
- ✓ Create a sphere of psychological safety – No fear zone
- ✓ Think Big - don't waste resources and time on incremental items
- ✓ Aim for the stars and you might reach the Moon!
- ✓ **Clear Purpose and Vision - with buy in from all stakeholders**