Swamp Works Technology Development 10th Anniversary: 2013-2023

Innovative Research & Technology Development Summary

AIAA ASCEND CONFERENCE

LAS VEGAS, NEVADA

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NASA KENNEDY SPACE CENTER

SWAMP WORKS

10 YEARS

Goals

- Focus on innovation
- Focus on high potential impact
- Focus on technology gaps
- Be nimble and efficient
- Embrace collaboration
- Technical excellence
- Focus on Moon to Mars
- Align with the mission
- Visionary thinking
- End state drives strategy

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 ***Wernher von Braun's development shops***

- **Hands-on approach**: start small and cheap - build up momentum

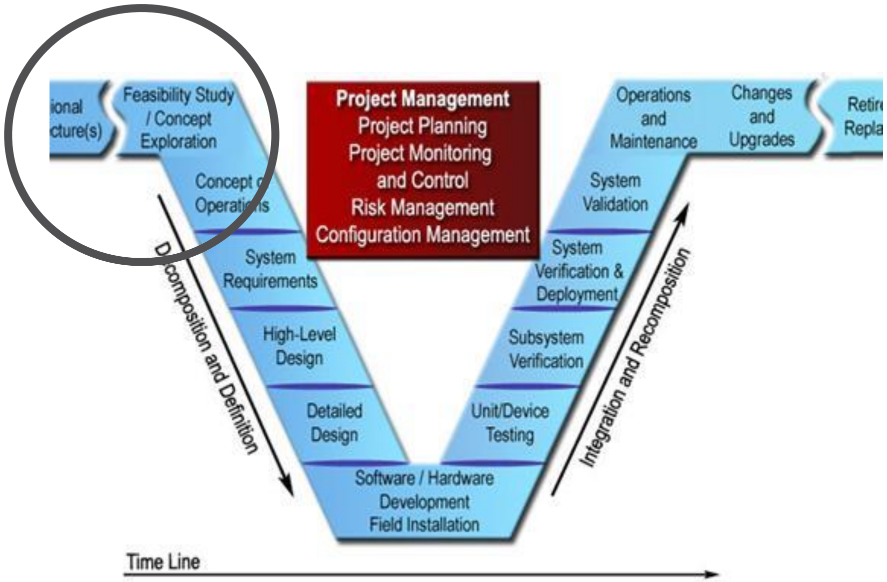
- **Testing performed in early stages**, fail forward allowed and drive design improvements in a helical process

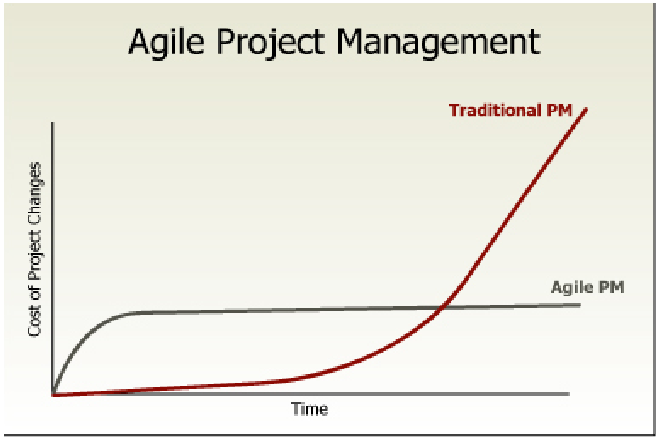
- **Leveraging partnerships** across NASA, government, industry & academia

Status Quo

NASA Status Quo

Innovation Methods





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

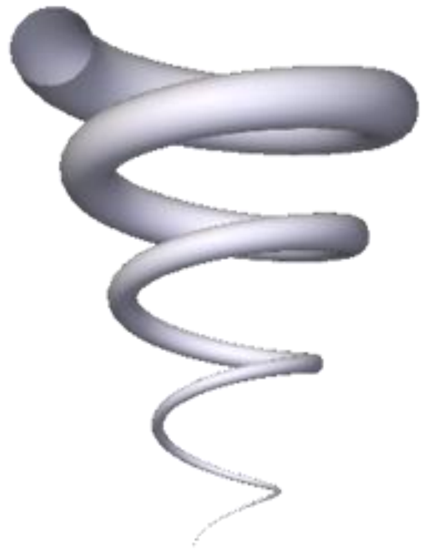
Flexible development process

- 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

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

Swamp Works Helical Development



Start Small, Safe, Cheap & Fast

Game Changing Ideas

Culture of Innovation

Learn Fast – Prototyping -Test

TRL

Swamp Works Method

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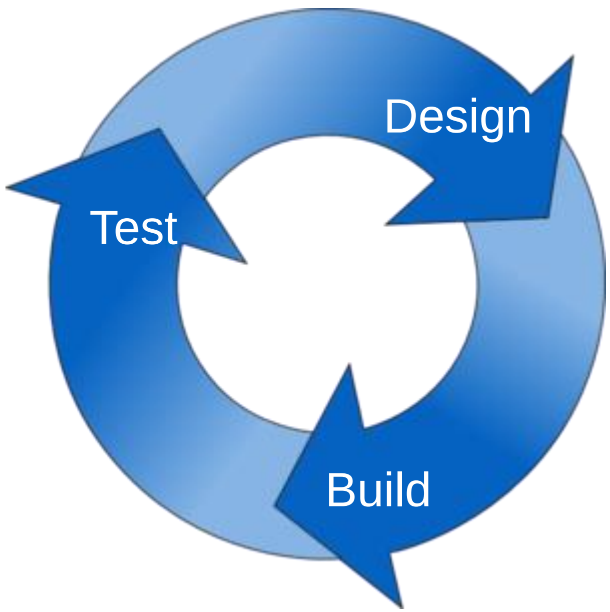
<u>Design-build-test</u> conducted iteratively with increasing knowledge of the operating environment will result in an end product that optimizes safety and performance.

Begin with a <u>clear vision</u> of what the technology will do and won't do



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

Functional Requirements → Expanded Functional Requirements → Preliminary Design Requirements → Flight Design Requirements

Generation 1 | Generation 2 | Generation 3 | Flight

Credit: Astronaut Mike Gernhardt, NASA JSC

Lunar Excavator Example

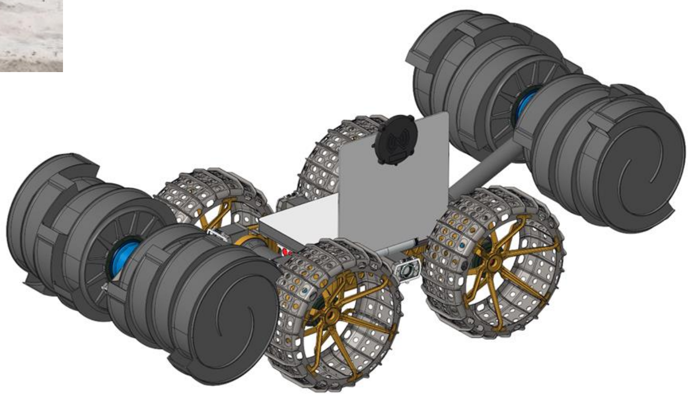
314 Entries

Generation 1
RASSOR 1.0

Since 2010 > 650 University Teams

Generation 2
RASSOR 2.0

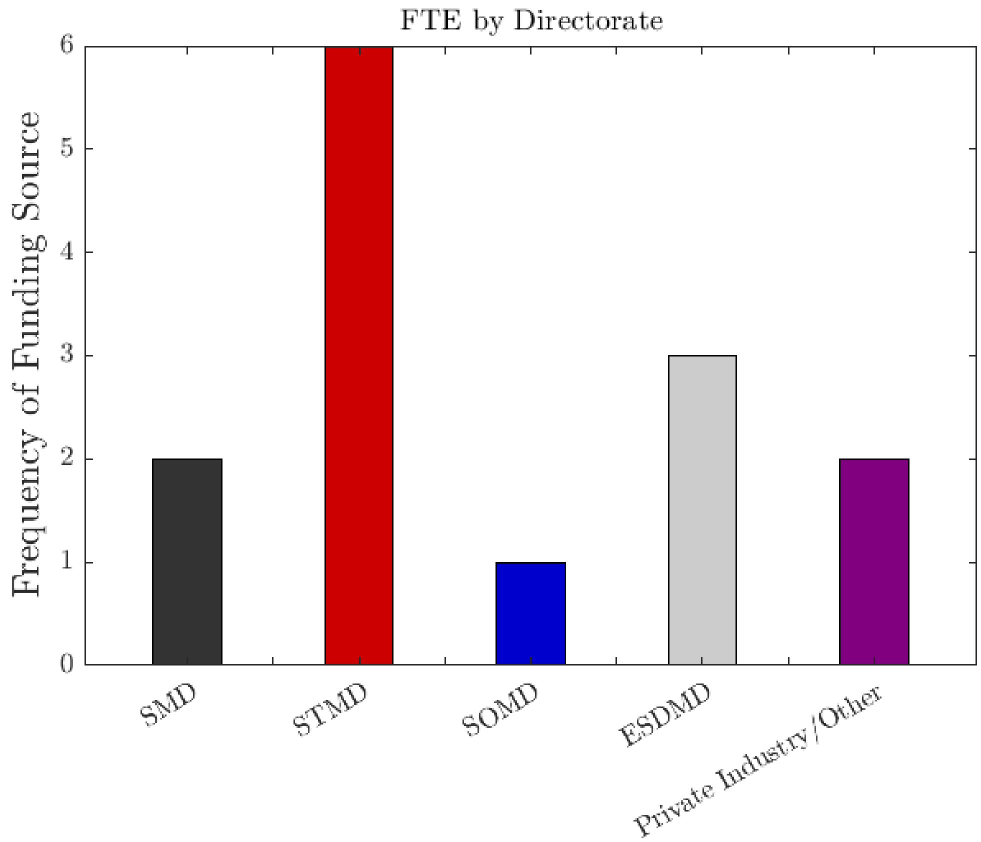
Generation 3
ISRU Pilot Excavator
(IPEX)



FTE by Directorate

Diverse selection of R&T Projects

- Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE)
- Mass Spectrometer observing lunar operations (MSolo)
- RASSOR – Lunar Regolith Surface Excavator / ISRU Pilot Excavator
- Vertical Lunar Regolith Conveyor
- Electrodynamic Dust Shield for IM1 CLPS mission (EagleCam)
- Dusty Motors for Extremely Cold and Dusty Environments



Work Source

On-Center

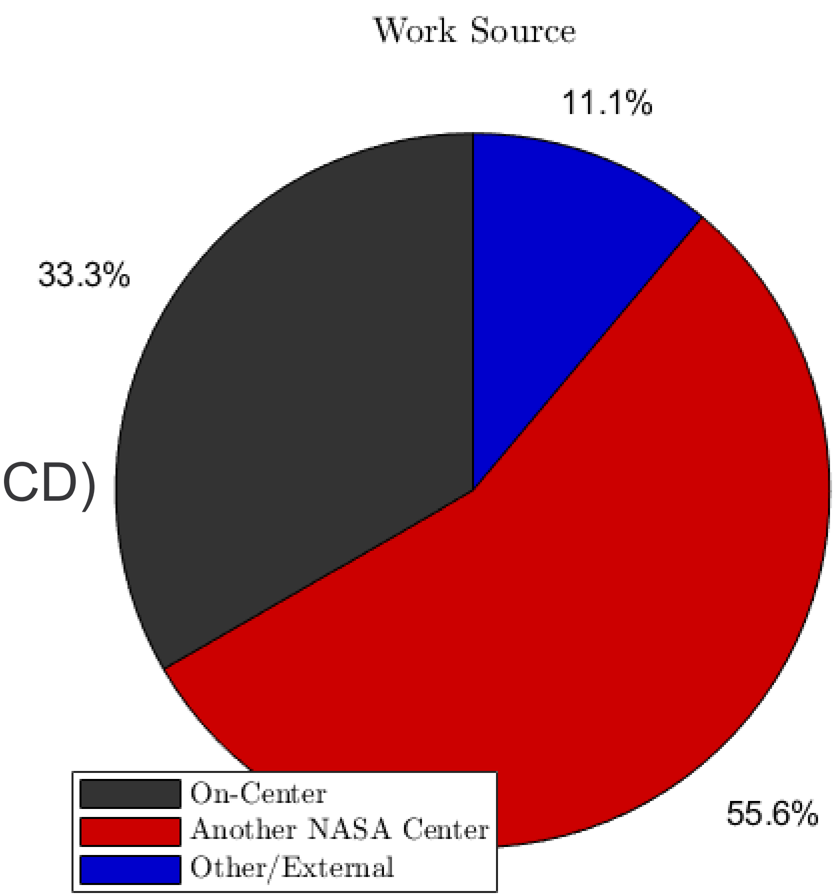
- Center Innovation Fund (CIF)
- LSP Technology Advancement Program (TAP)

Other Centers / Agency

- PICCASO
- Game Changing Development (GCD)
- Early Career Initiative (ECI)
- NASA Innovative Advanced Concepts (NIAC)

External

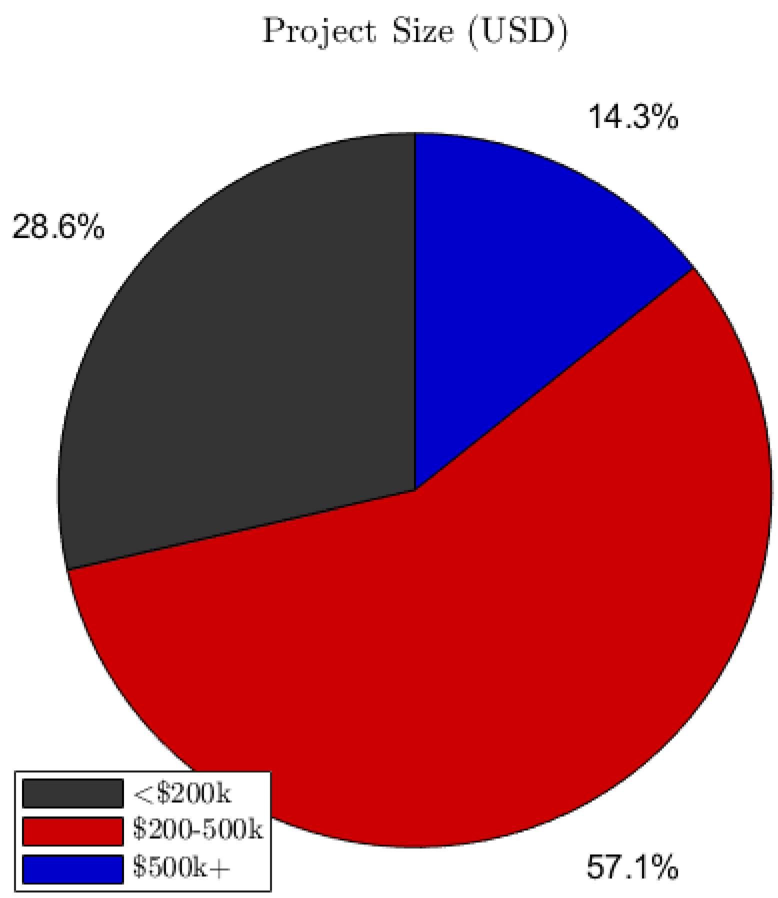
- Florida League of Cities



Project Size

Specialize in low-TRL concept development

- Projects tend to be lower-budget
- Work tends towards lean and agile development
- Utilize existing hardware, experience, and technology

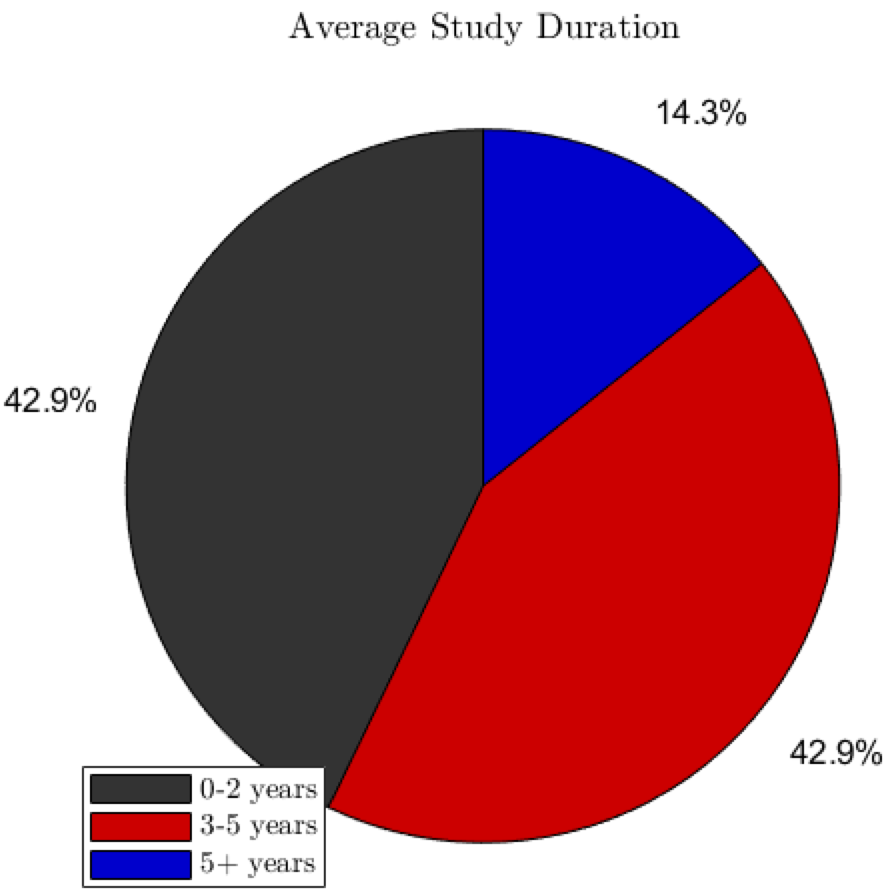


Average Study Duration

Many short-term, Low-TRL projects

Funnel down to the projects with the most promising results

Expand into Mid-TRL projects with longer development lifetimes if successful

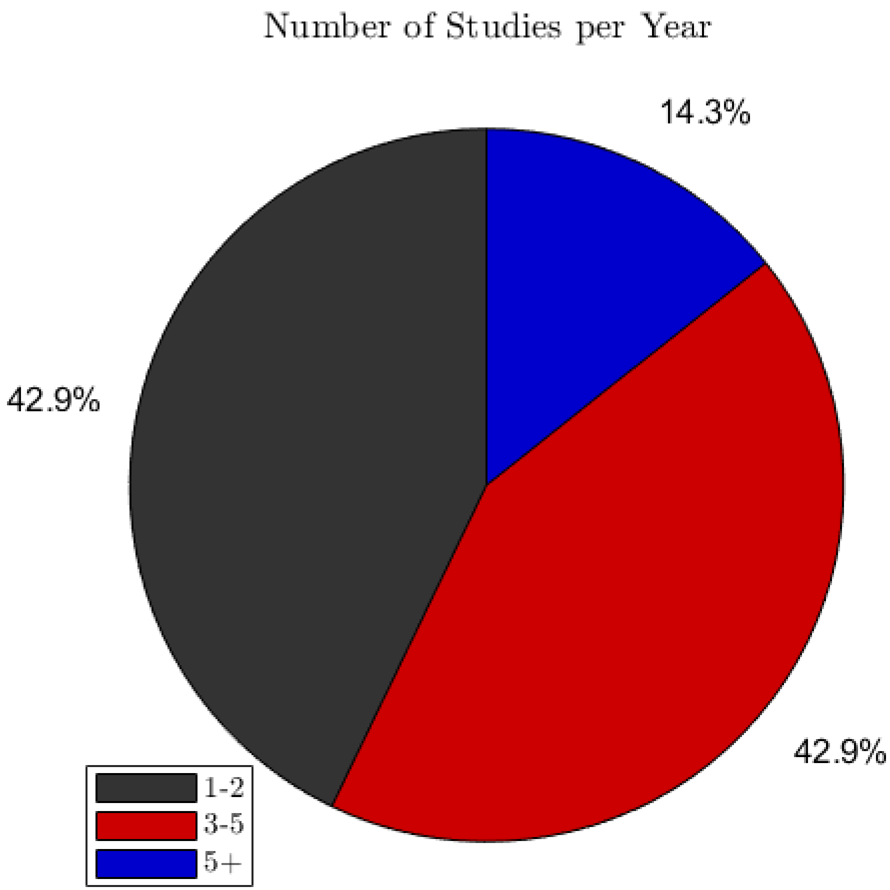


Number of Studies

Most researchers are on fewer projects, with some involved with many studies.

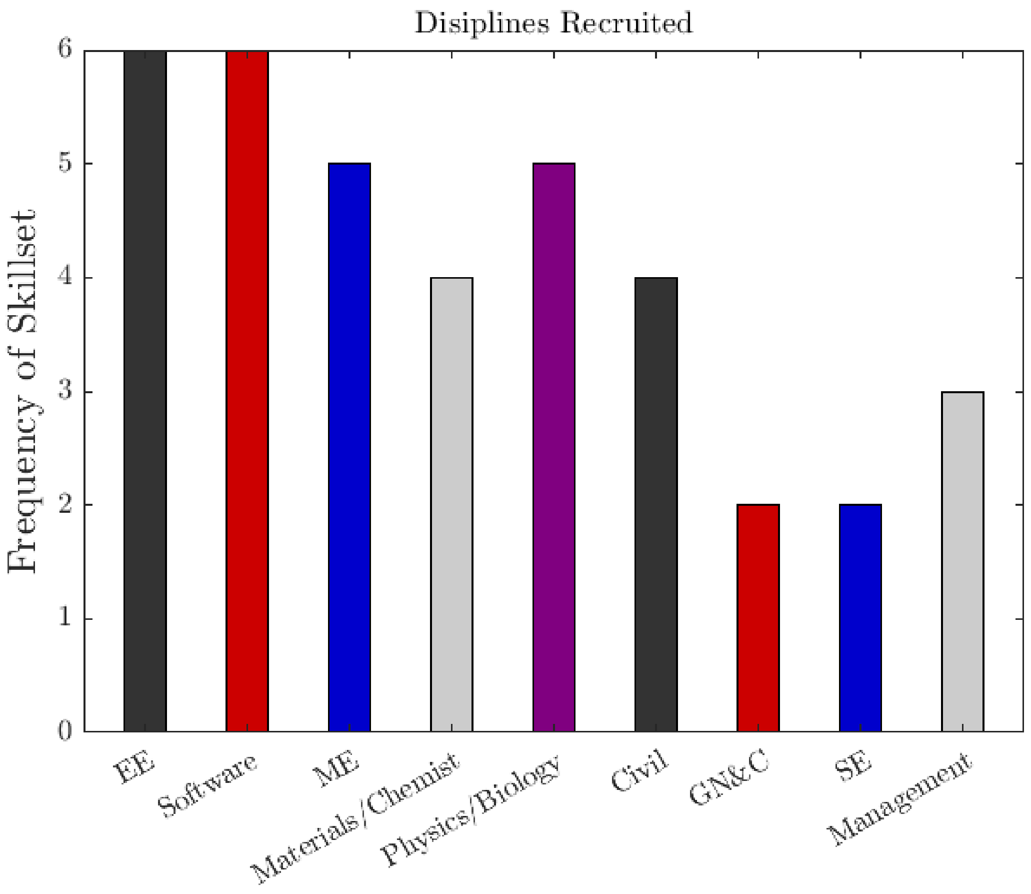
PI's tend to focus and have only 1-2 projects.

Support staff, Systems Engineers (SE), and specialists tend to support many projects at once.



Skillsets

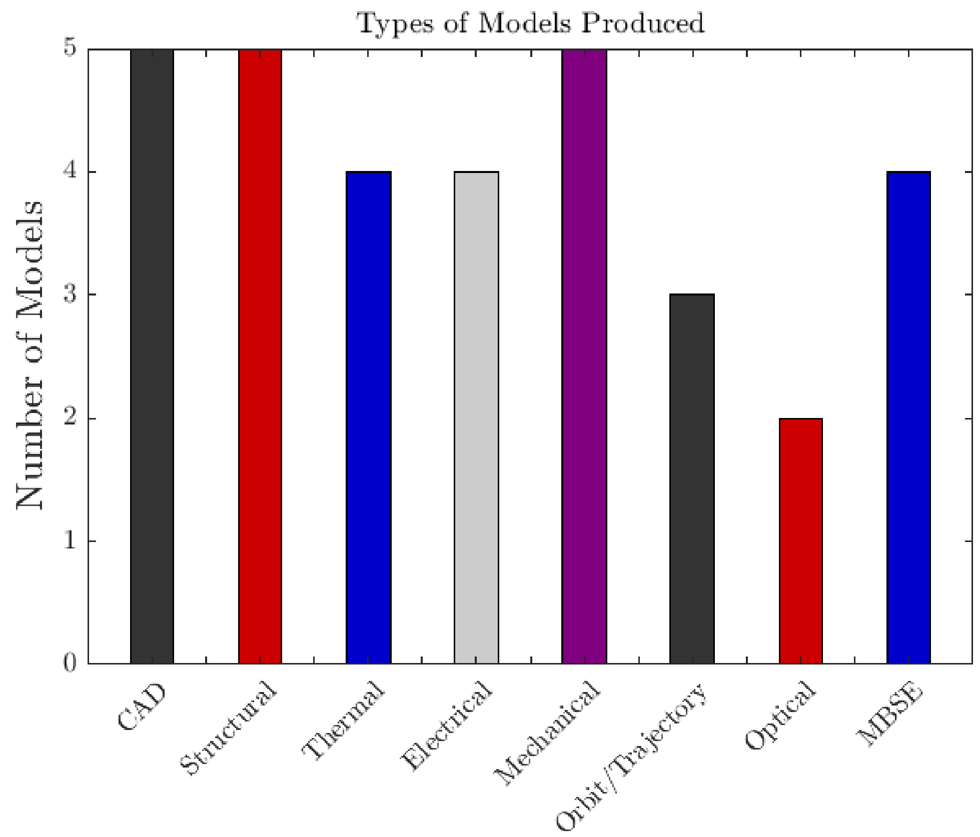
- Diverse skillset available at KSC Swamp Works
- Most studies are multi-disciplinary, with expertise required especially for mission integration during higher TRLs



Models and Views

- CAD/Structural models are most frequently produced (nearly all projects produce CAD models that double as structural models)

- Optics the most specialized skills set at Swamp Works



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!
- ✓ **<u>Clear Purpose and Vision</u> - with buy in from all stakeholders**

Backup Slides

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