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Launch and Landing Infrastructure on the Moon

Robert P. Mueller
NASA

Phillip T. Metzger
NASA

Wayne G. Finger
PE, RS&H

Steve W. Moore
PE, RS&H

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Launch and Landing Infrastructure on the Moon

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Robert P. Mueller, NASA
Phillip T Metzger, PhD, NASA
G. Wayne Finger, PhD, PE, RS&H
Steve W. Moore, PE, RS&H

NASA, Surface Systems Office,
Kennedy Space Center, FL 32899
(321) 867-2557 www.nasa.gov

Reynolds, Smith & Hills
2235 N. Courtenay Parkway, Suite C, Merritt Island, FL 32953
(321) 453-0212 www.rsandh.com

Agenda

- Launch and Landing Functions
- Example Earth based sites
- Characteristics of the Lunar Environment
- Lunar Site Planning
- Lunar Design Approaches
- Summary

What does a "Launch Pad" really do ?

- Structural Support & Stability for the Rocket:
  - During assembly, processing and transit.
  - During weather events.
  - During Flight Readiness Firings.
  - During prelaunch engine thrust buildup.
  - At launch:
    - Hold up and hold down
    - Release or rebound.

Photos Credits: Atlas V Rollout (US Air Force); Flight Readiness Firing (NASA), Shuttle Launch (NASA)

What does a "Launch Pad" really do ?

- Provide Exhaust Management:
  - Overpressure waves
  - Blast forces
  - Splash forces
  - Acoustic vibrations
  - High Temperatures
  - Thermal cycles
  - Manage to within the limits of:
    - The launch vehicle & payload
    - The ground infrastructure

Photos Credits: Titan IV launch (NASA)

What does a "Launch Pad" really do ?

- FOD & Abrasive Management:
  - Foreign / Flying Objects and Debris can cause extensive damage to the infrastructure and the vehicle.
  - Certain rocket exhaust products are abrasive and erode materials, obscure camera lenses, etc.
  - Manage to eliminate FOD.
  - Manage to withstand abrasion.

Photos Credits: LC 39 Fence Damage (CBS News)

FOD

FOD Shields

What does a "Launch Pad" really do ?

- Fluid, Power and Communication Services:
  - Provide storage and transfer for all liquids which cannot be loaded early (non storable liquids) or are consumed prior to launch – Liquid Oxygen, Liquid Hydrogen, Hypergols, etc.
  - Provide storage and transfer for all gasses which cannot be loaded early or are consumed at the pad – Nitrogen, Helium, Environmental Control Air, Breathing Air, etc.
  - "Umbilical Connections" must disconnect immediately upon launch at T-0, but not before. Premature disconnect can result in dangerous conditions.

Photos Credits: STS 119 Umbilical (CBS News)

What does a "Launch Pad" really do ?

- System Verification and Site Safety Services:
  - Verification that "All systems really are go" via direct communications and situational awareness.
  - Protection of Surface Assets and personnel from:
    - Detonation
    - Conflagration
    - Fragmentation
    - Overpressure
    - Toxic hazards.

Photos Credits: Operational TV typical views (NASA); Delta II launch failure, Jan 1997 (Aerospace Corp/Gazur)

What about a terrestrial "Landing" ?

- Structural Support:
  - Stable and secure support to the vehicle upon touchdown.
  - Withstands impact, shear, wear.
  - Accommodates location uncertainty:
    - Launch point is known.
    - Landing occurs within a zone.

- Exhaust Management:
  - Earth landings occur with and without powered exhaust.
  - If powered, must be managed to within the limits of the vehicle and ground infrastructure.

Photos Credits: DC-X (NASA); Delta II launch failure, Jan 1997 (Aerospace Corp/Gazur)

What about a terrestrial "Landing" ?

- FOD and Abrasive Management:
  - Retro rocket exhaust or landing contact (tires) can generate high velocity FOD which can damage the vehicle or the surrounding area.
  - The landing zone must be free of loose materials and able to withstand the contact without generating FOD.

- Fluid Power and Communications Services
- System verification and Site Safety Services

Photos Credits: Orbiter tile damage (NASA)

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Example: Terrestrial Launch Pad: LC 39

- Structural Support
  - Provided via Mobile Launch Platform
  - Load path goes through SRB aft skirt, into MLP, through columns, into piles.
  - Hold-down-release by explosive bolts.

- Exhaust Management
  - Exhaust routed through MLP, guided with side deflectors into main deflector.
  - Ignition Overpressure and acoustic abated with 1 Million GPM water.
  - Structures designed to withstand exhaust forces and thermal exposure.

Photos Credits: Shuttle on Pad (NASA), LC 39 Flame Deflector (RS&H)

Example: Terrestrial Launch Pad: LC 39

- FOD
  - Managed with personnel awareness, procedures and designs.
  - Abrasive wear accommodated with allowances.
- Fluid, Power and Communications
  - Provided via Tail Service Masts and Swing Arms.
- System Verification and Site Safety
  - Extensive network of cameras, sensors; Command and Control Centers.

Photos Credits: Shuttle Launch NASA), Shuttle on Pad (NASA)

Example: Terrestrial Landing: SLF

- Structural Support
  - Provided via extra wide, extra long and extra thick runway.
- Exhaust Management
  - Not an issue due to winged landing.
- FOD Management
  - Includes clearing the runway of alligators
- Fluid, Power and Communications
  - Provided by Mobile Support Equipment
- Verification & Site Safety
  - Extensive network of cameras, sensors; Command and Control Centers.
  - Weather support includes alternate landing sites.

Photos Credits: Shuttle on Pad (NASA), LC 39 Flame Deflector (RS&H)

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Comparison of Earth – Lunar Differences

Characteristics	Earth Conditions	Lunar Conditions
Atmosphere	Nitrogen, Oxygen, etc.	None
Gravity	1 G	1/6 G
Raw Materials: Water, Hydrocarbons	Abundant	Rare
Industrial Supply Chain	Established	Not Present

Photos Credits: Orbiter tile damage (NASA)

Comparison of Earth – Lunar Differences

- Absence of Atmosphere
  - No aerodynamic drag: FOD flies farther and maintains high velocities.
  - No aerodynamic lift: Wings and parachutes cannot slow you down or enhance the landing. This indicates retro rocket type landings.
  - No local weather pattern: No worries about wind, rain or thunderstorms.
  - No protection from the solar system's weather events: Solar flares and disturbances can create unsafe situations for unprotected crew.
  - No convection heat transfer: Must only use conduction and radiation.
  - No mechanism to manage humidity or deliver water: Dry soils, without natural binders.

Photos Credits: Orbiter tile damage (NASA)

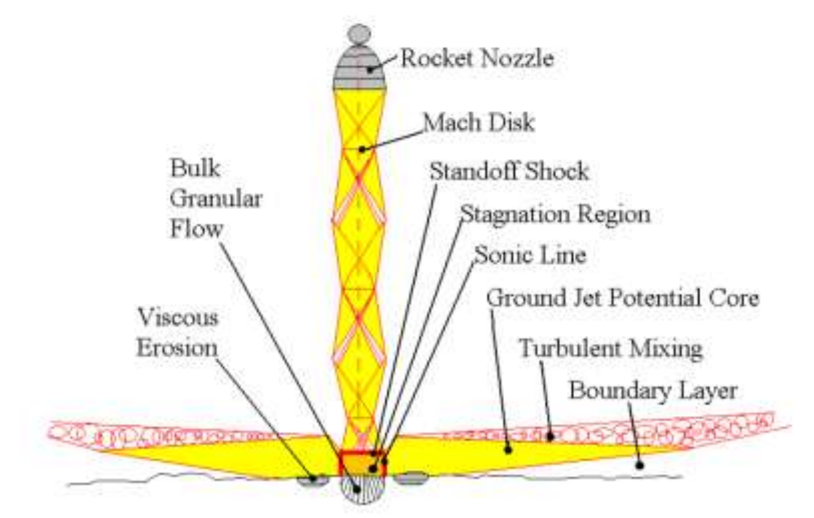
Comparison of Earth – Lunar Differences

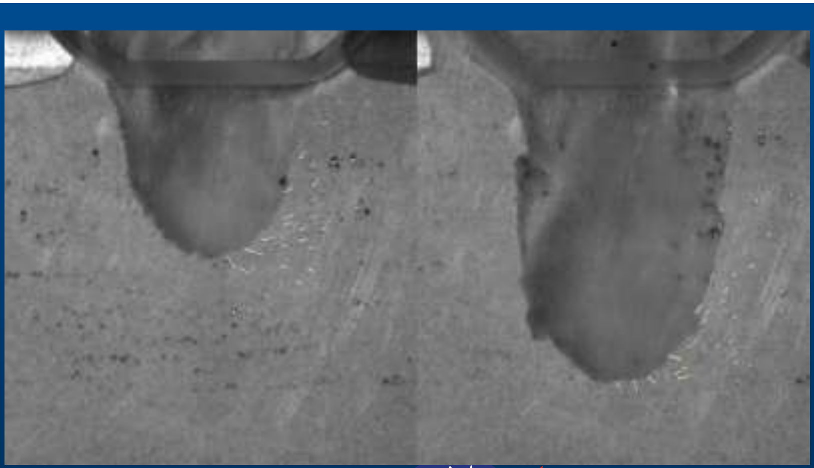
- Reduced Gravity
  - Reduced “gravity well” for Spacecraft: Less energy required to reach lunar orbit for returning spacecraft. It can be smaller than earth bases equivalent with much less propellant.
  - Reduced “gravity well” for FOD: Less energy required to reach lunar orbit for returning anything put in motion during launch or landing. FOD could become ballistic, even completing an orbit before impact.

Photos Credits: Orbiter tile damage (NASA)

Comparison of Earth – Lunar Differences

- Combining These Primary effects:
  - Viscous Erosion
  - Bearing Capacity Failure
  - Diffused Gas Eruption
  - Diffusion Driven Flow





Credit: : Dr. Phil Metzger

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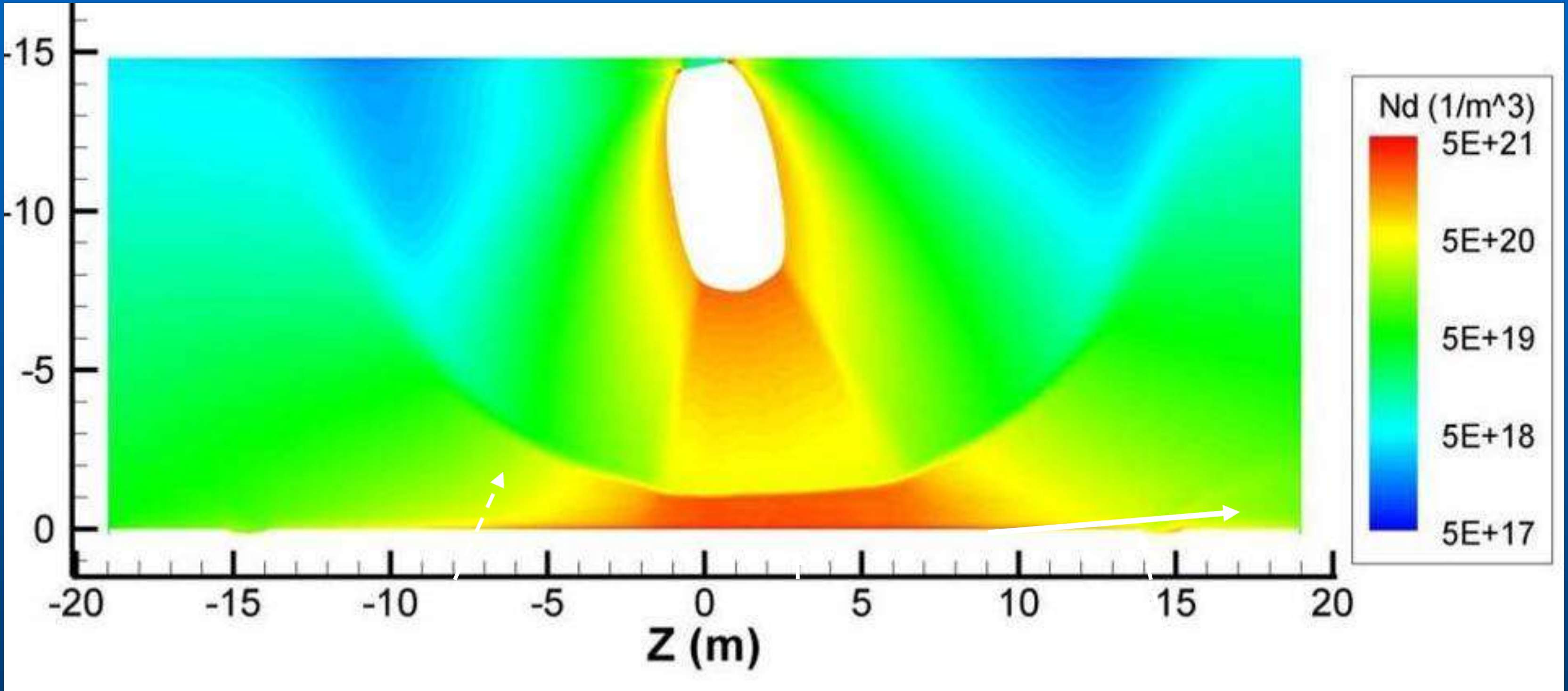
Characteristics of Exhaust Plume



Standoff Shock

Stagnation region

Supersonic, horizontal jet

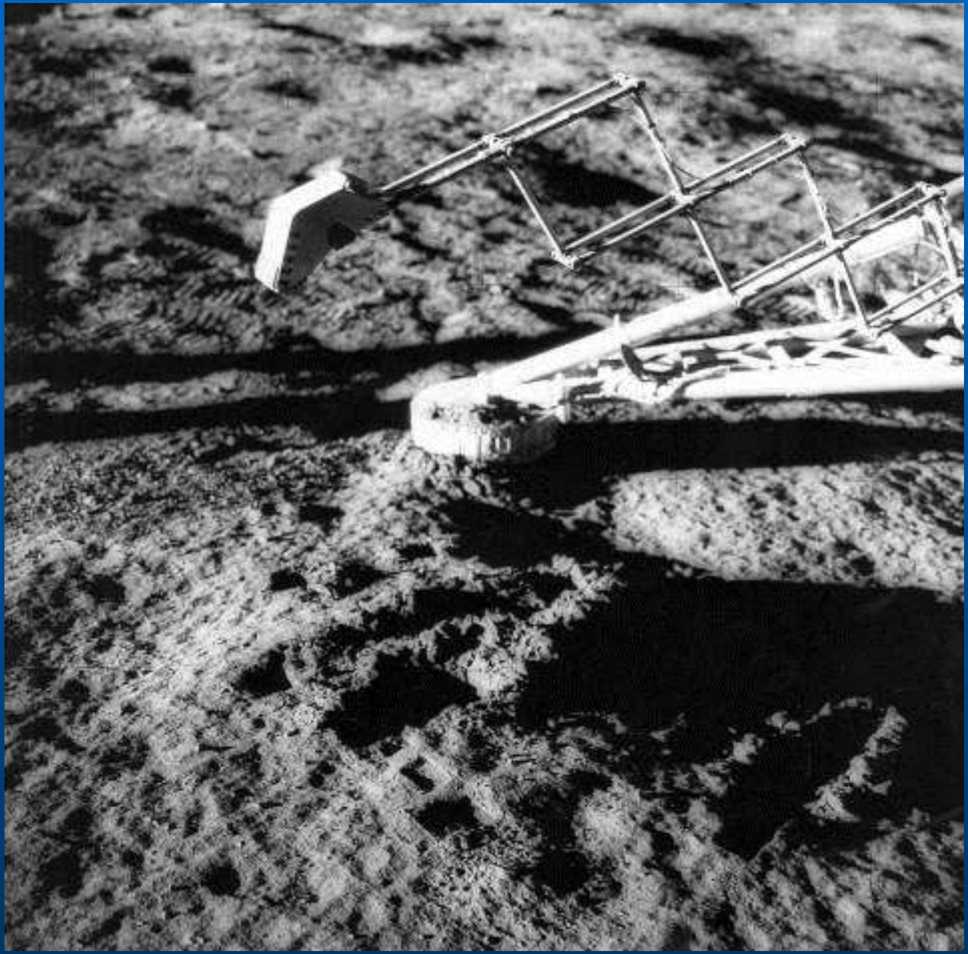
CFD and DSMC simulations by Forrest Lumpkin (NASA/JSC) and Jeremiah Marichalar (Jacobs/JSC), "Plume Impingement to the Lunar Surface: A Challenging Problem for DSMC," in *Direct Simulation Monte Carlo Theory, Methods & Applications*, Santa Fe, NM (2007).

Lunar Case: Background

- During the Apollo and Viking programs, NASA needed to know how the rocket exhaust would affect the soil on the Moon and Mars.
- A number of studies were done during the 50's through 70's
- Existing models are crude and do not predict mass-rate or trajectories of ejected material

Must Protect Spacecraft from Itself

- Landing visibility
- Contamination of mechanisms
- Jamming or spoofing sensors
- Erosion of coated surfaces
- Pitting of optics

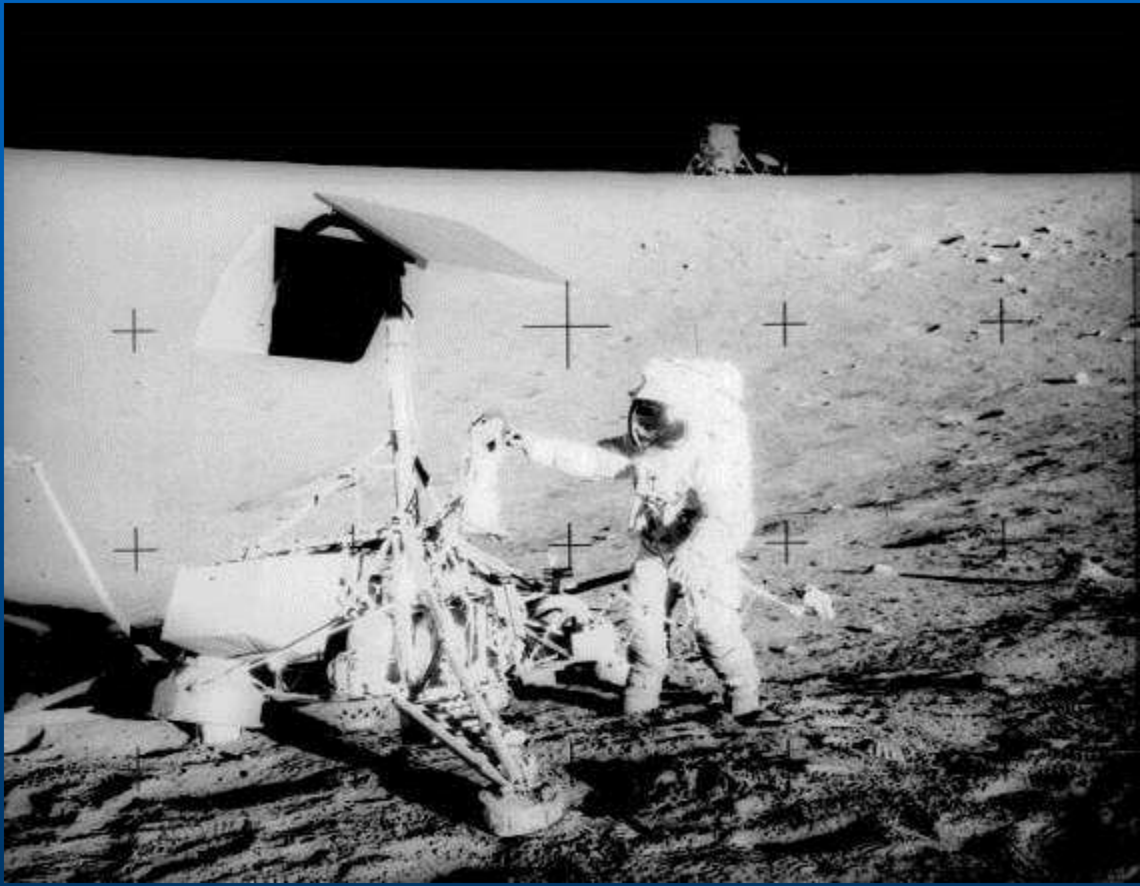


Credit: : Dr. Phil Metzger

Must Protect Surrounding Hardware

Apollo / Surveyor:

- Damage
- Erosion of coatings
- Contamination with dust
- Jamming mechanisms
- Excessive blast hardening required



Credit: : Dr. Phil Metzger

Damage to Surveyor III by Apollo 12 LM

- Apollo 12 LM landed 160 to 180 meters from deactivated Surveyor 3 spacecraft
- Effects:
    - Scoured the surface off metal components and other materials [1]
        - Due to the smallest and most numerous particles, traveling the fastest
    - Numerous pits in the exposed surfaces [1,2]
        - Due to fewer, larger particles that were traveling slower
    - Fractured paint surface into a "mud cracking" pattern [2]
    - Injected grit into the inspection hole of the camera [1,2]
    - Glass or plastic would also sustain surface damage in these conditions
- Larger particles were traveling 400 m/s and possibly up to 2 km/s [3]
    - This agrees with theory and with recent plume modeling

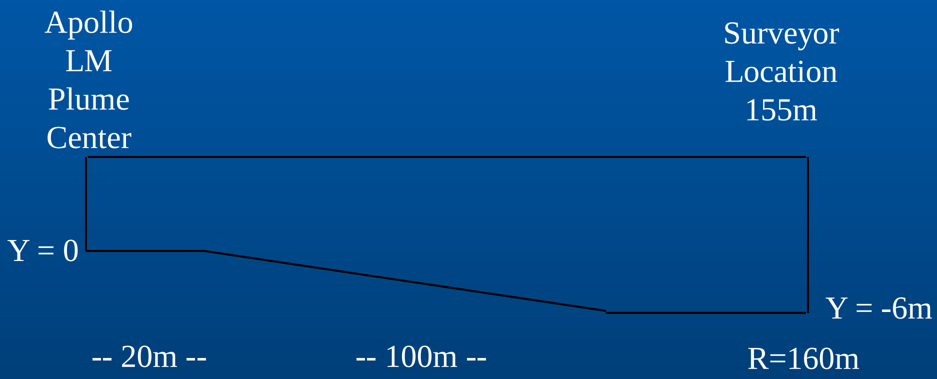
Sources:[1] Cour-Palais, B.G., *et al.*, "Results of examination of the returned Surveyor 3 samples for particulate impacts," in *Analysis of Surveyor 3 material and photographs returned by Apollo 12*, (NASA SP-284, 1972), p. 161.

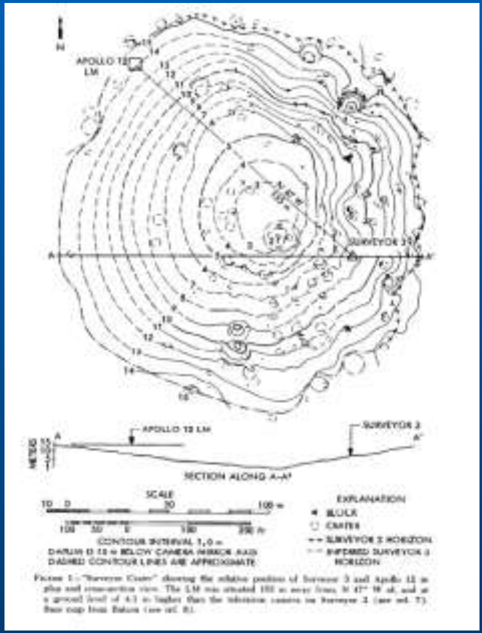
[2] Hughes Aircraft Technical Journal (in lunar material repository, JSC), reviewed by P. Metzger 04/23/07

[3] Katzan, Cynthia M. and Jonathan L. Edwards, *Lunar Dust Transport and Potential Interactions with Power System Components*, NASA Contractor Report 4404, (Sverdrup Technologies, Nov. 1999), p. 17, and references therein.

Demo of Lunar Plume Debris Transport

- Apollo-12 LEM Descent Engine Plume Sandblasted Surveyor-3 Spacecraft at 155m Distance
- Surface Pits Indicated Debris Particle Impact Velocities in Excess of 2000 m/s for Partial Power (Hover) Plume
- Demo Simulation With Standalone Particle Tracker Predicts 3000 m/s Debris Velocity (Simulation Was Run With Full Power LEM Plume)

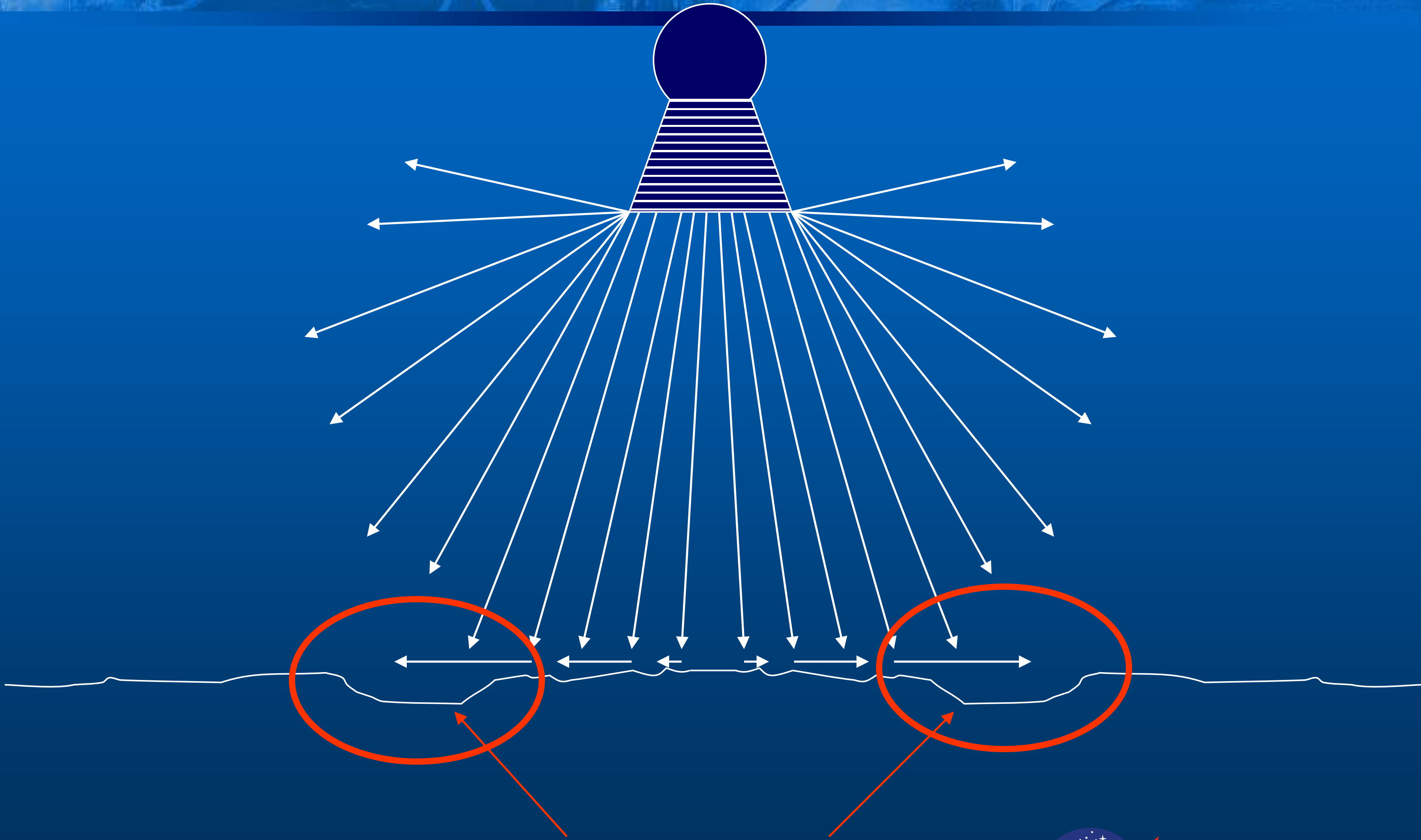




Particle Trajectories Colored by Velocity (m/s) for Apollo – Surveyor Debris Scenari

Credit: : Dr. Phil Metzger

Viscous Erosion



Regions of maximum traction

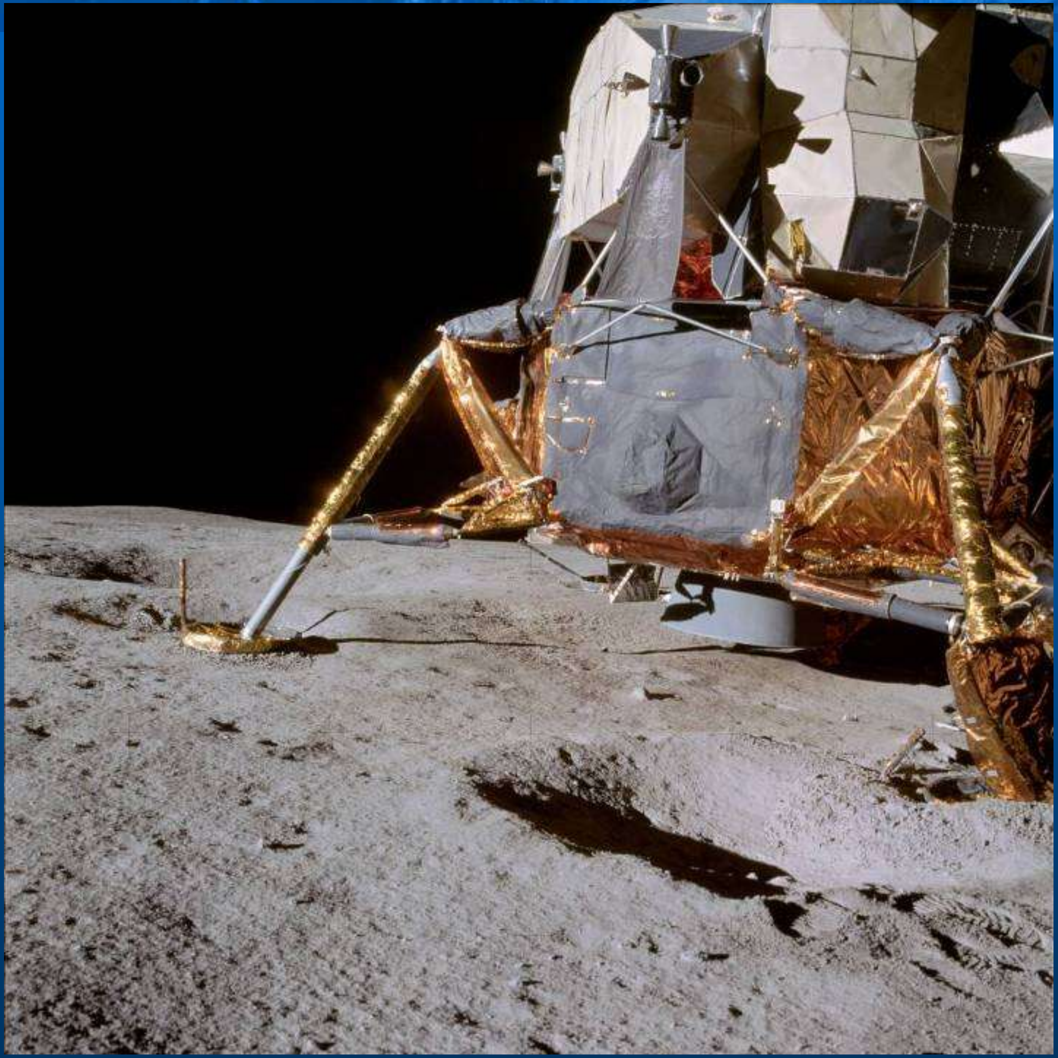
Credit: : Dr. Phil Metzger

"Swept clean" appearance under nozzle indicates no occurrence of bearing capacity failure or diffused gas eruption

Credit: : Dr. Phil Metzger

Viscous Erosion + Diffusion

Eroded volume of 440 liters under LM [1]

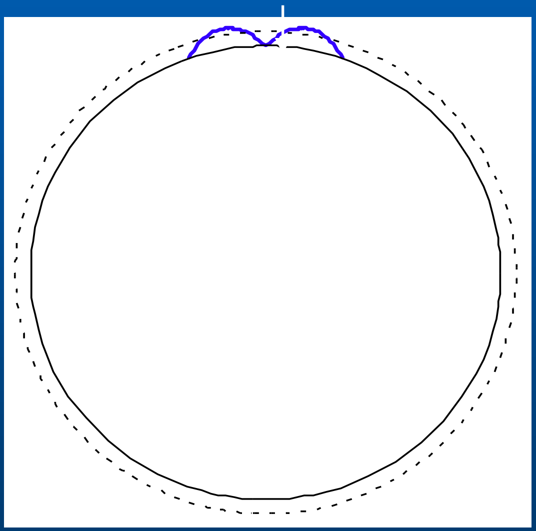


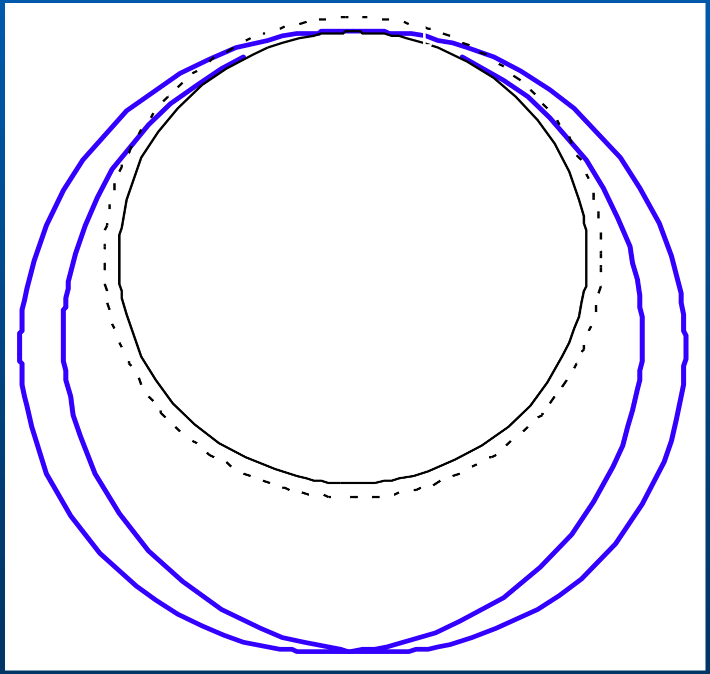
Credit: : Dr. Phil Metzger

Source [1]: Katzan and Edwards, p. 9.

Characteristics of Landing Plume Ejecta

- Spray reaches orbital altitudes and encompasses the entire Moon
  - Flux in orbit very low but preliminary modeling indicates significant chance of some impacts if spacecraft flies through the spray
  - Net velocity may be >4000 mps (hypervelocity regime)





Credit: : Dr. Phil Metzger

JSC-1A Impacting Glass

Source: Luke Roberson (NASA/KSC), Ryan Clegg (FIT), Philip Metzger (NASA/KSC)

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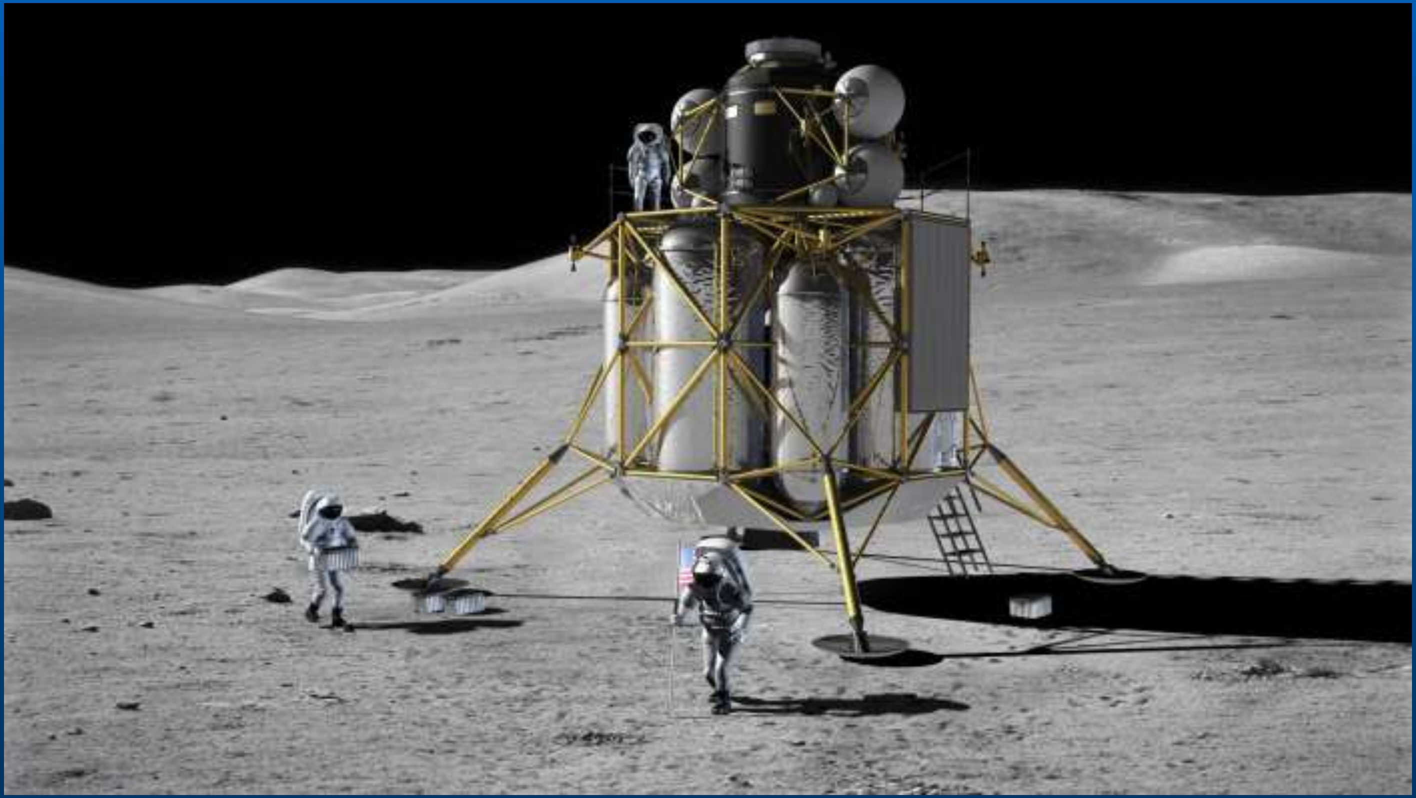
Goal

- Successfully land a crew of four and cargo on the moon at a lunar outpost on a repeatable basis with safe operations and reasonable life cycle costs



Lunar Site Planning

1. Identify primary Lunar functions and operational conditions.
2. Group the functions and identify the logical functional areas.
3. Develop adjacency diagrams and notional site plans.
4. Identify technology approaches which can abate the anticipated problems.

Lunar Site Planning – Major Areas

Permanent Installation Areas for Lunar Base	10 Day Mission	1 Month Mission	1 Year Mission
Lunar Base Long Duration Habitat (LDH) Interconnect Module (Un)Pressurized Cargo Carrier (U/PCC)		X	X
Surface Power Module (SPM)		X	X
Landing/Launch Facility			X
Hydrogen Storage		X	X
Oxygen Storage		X	X
Human Exploration Rover (HER)	X	X	X
Mobile ISRU Plant (MIP)		X	X
Maintenance Facility			X
Regolith Mover		X	X
Water Storage		X	X
Agricultural Facility			X

Reference: RS&H and Andrews Space

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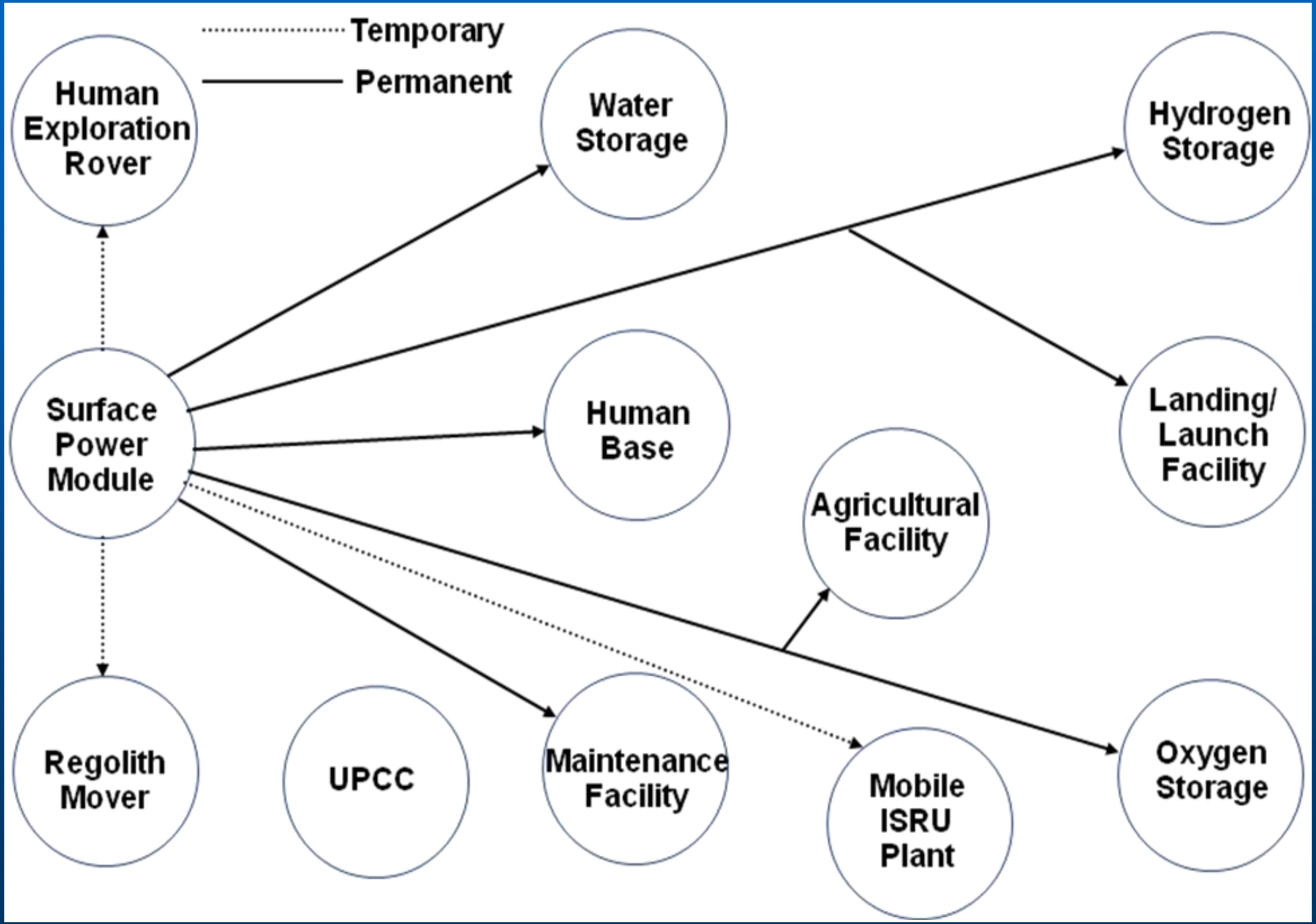
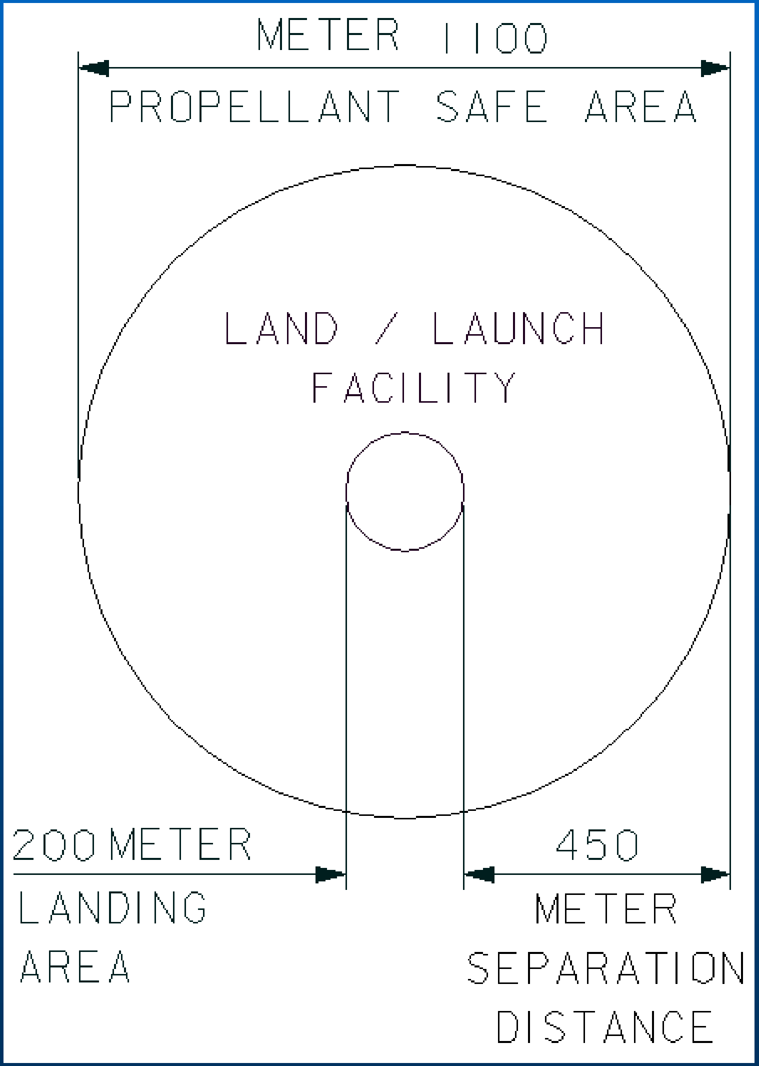
Lunar Site Planning – Power



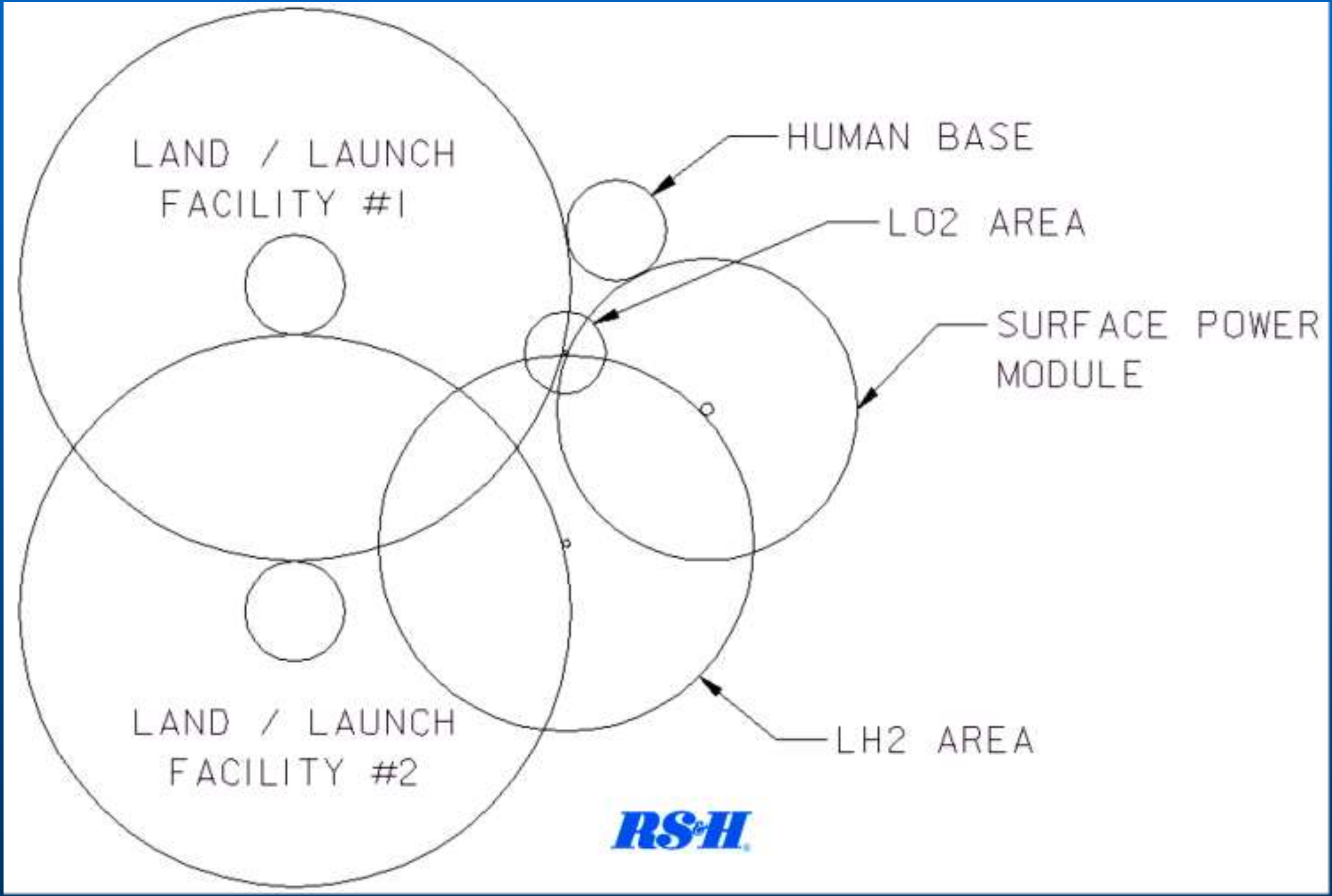
Reference: RS&H and Andrews Space

Lunar Site Planning – Launch & Landing



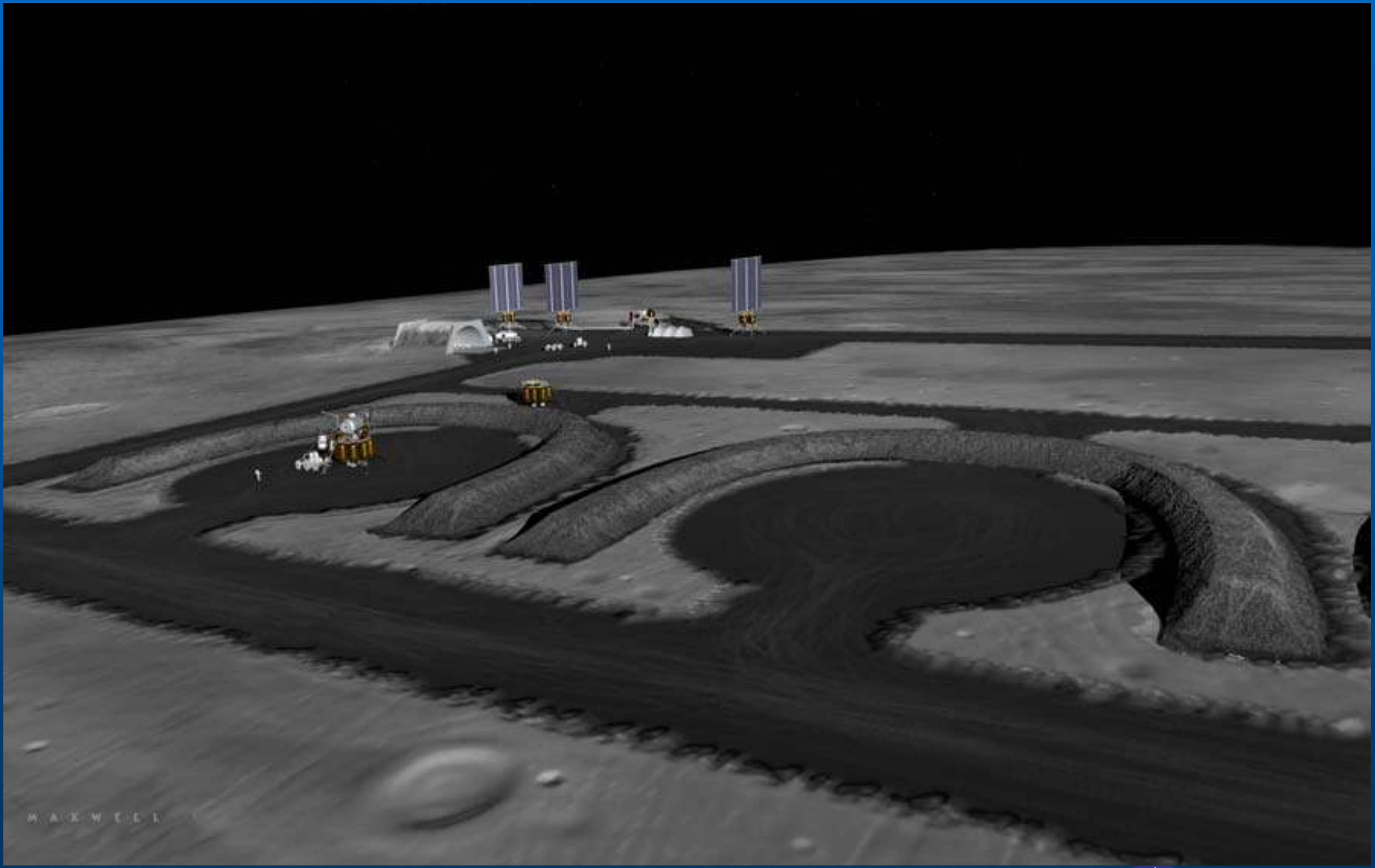
Reference: RS&H and Andrews Space

Lunar Site Planning – Surface Use Plan

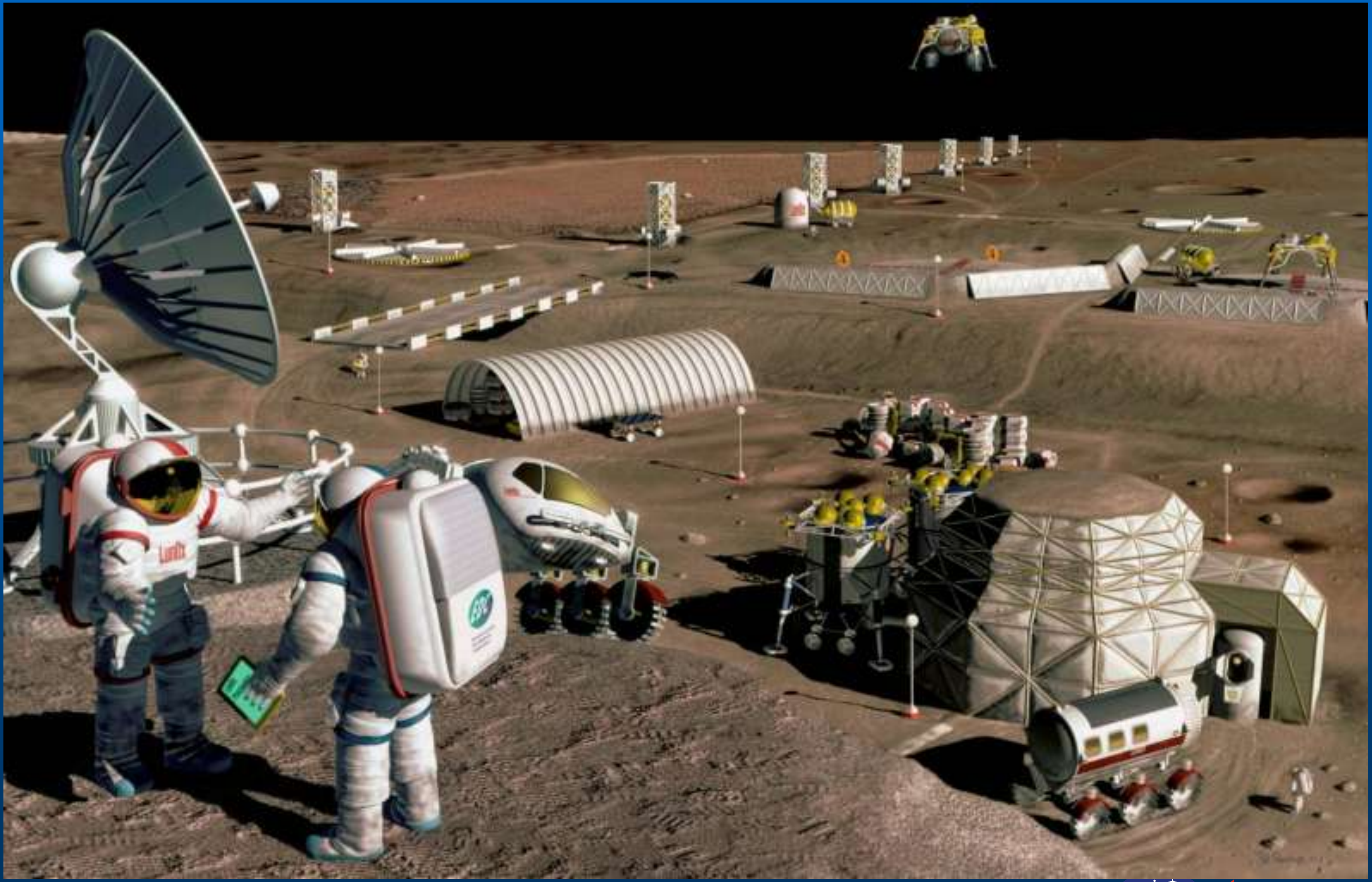


Reference: RS&H and Andrews Space

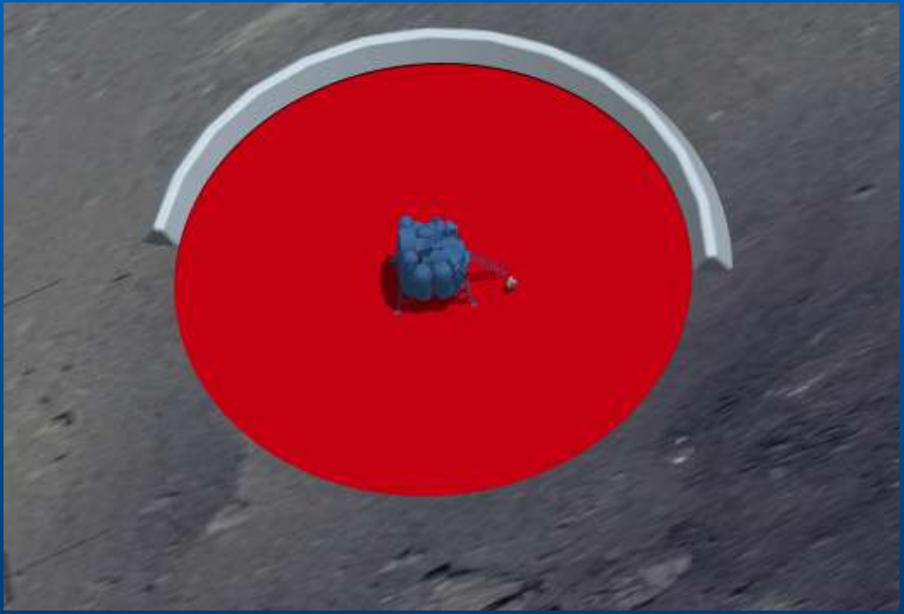
Lunar Outpost Concept (Artistic)



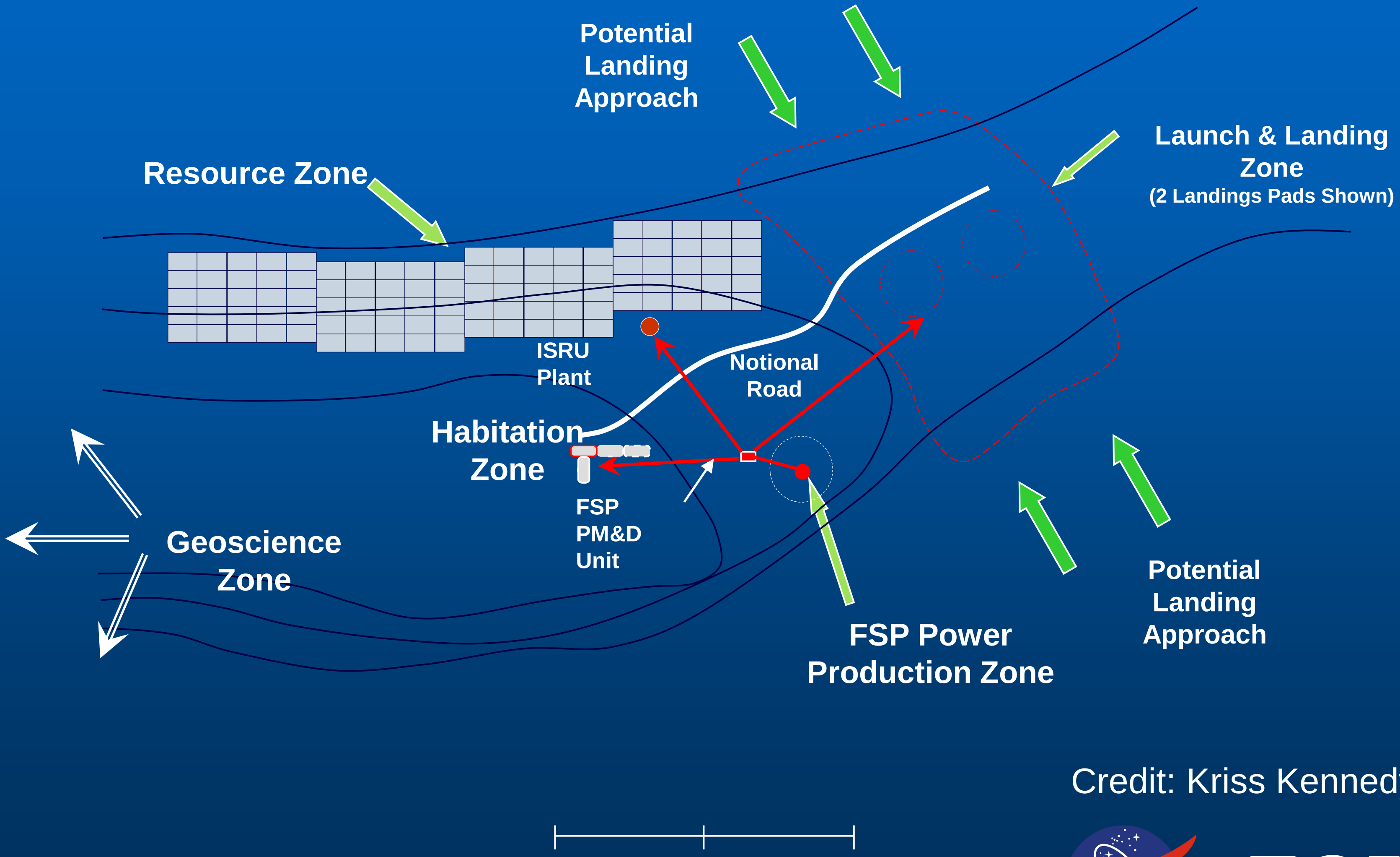
Lunar Outpost Concept (Artistic)



Aerial Views of Landing Pad



Outpost *Notional* Master Planning [LS-5.0]



Credit: Kriss Kennedy

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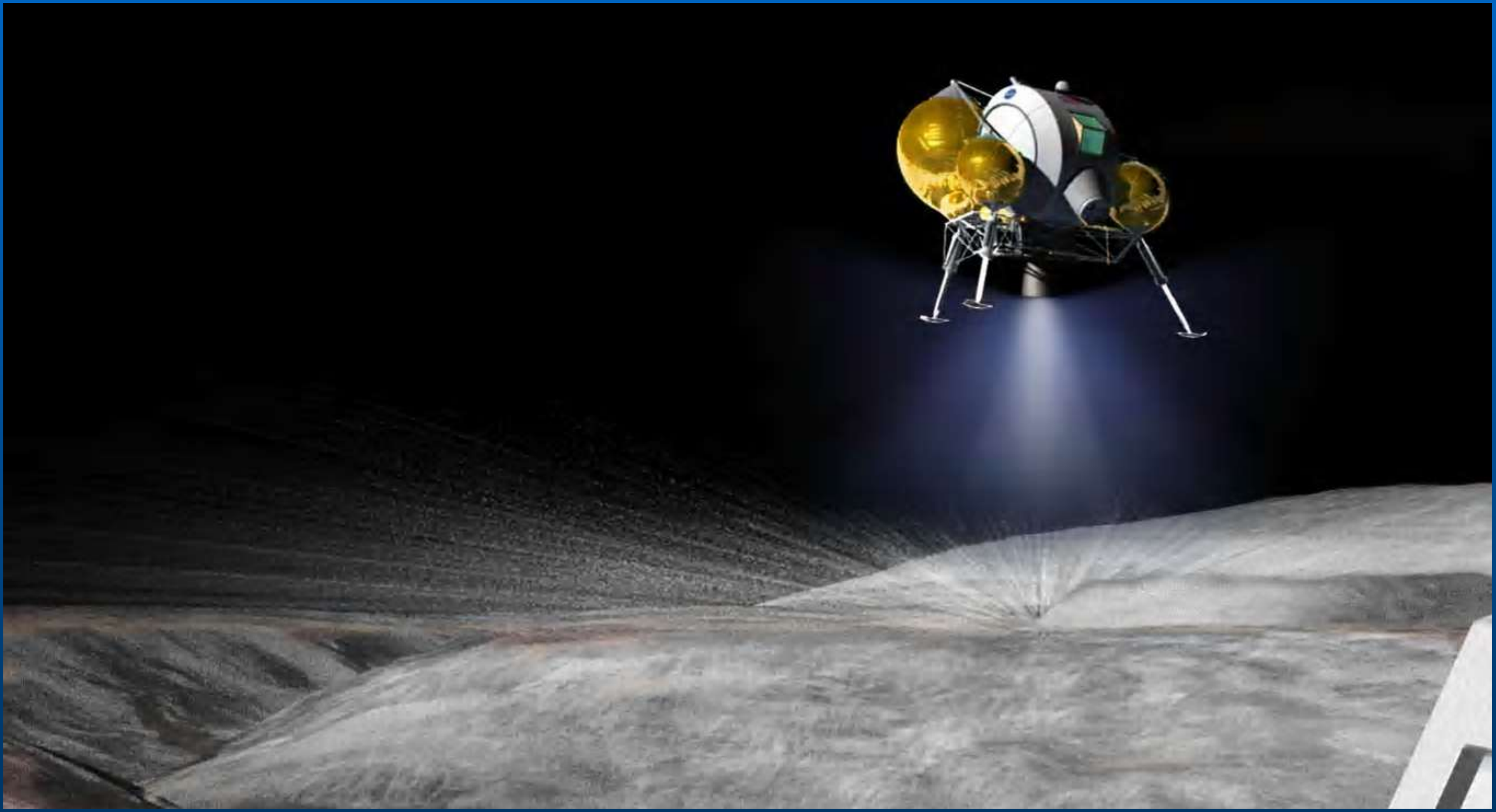
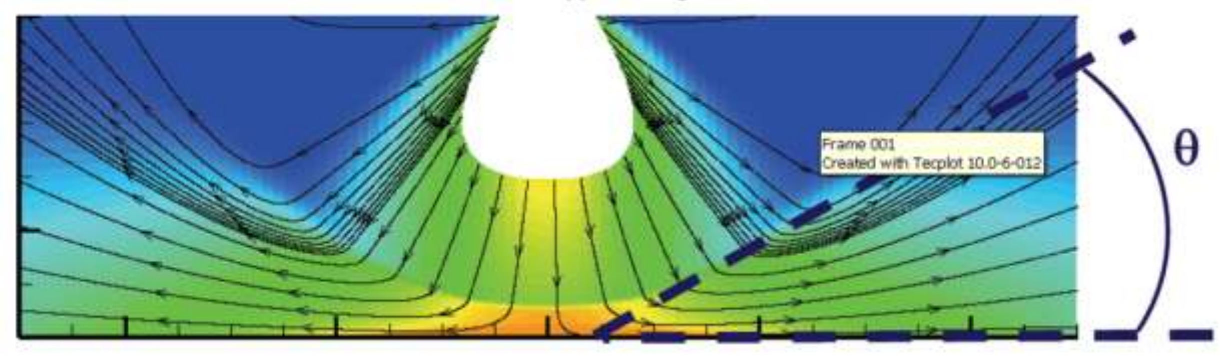
Visualization of Landing Effects



Plume Impingement Details

1. Regolith spray is primarily at a low elevation angle (~ 3 degrees)
2. Terrain features such as craters can ramp the spray up at higher angles (we saw 12 degrees on Apollo 15 because they landed on the edge of a wide crater)
3. Plume reflection planes can rooster-tail the soil up at high angles. this is only within the symmetry planes between engines, so for a 4 engine lander there will be four directions in yaw that have these rooster tails of soil. Any other yaw angles have just the 3 degree horizontal spray.
4. Spray will shoot up the center of the vehicle between the engines
5. Particles that are sprayed will have a broad size distribution between 10 microns and 1 millimeter (rough approx). Much larger particles like gravel will not be lofted
6. Small particles will go faster than large ones because the inertia of the larger ones keep them from getting up to speed before they run out of the region of dense gas
7. Small particles will go the speed of the gas, which will be very fast (1 or 2 km per second, perhaps)
8. There are vastly more small particles (10 microns) in the spray than large ones

3 Degree Ejecta Angle (from Apollo)



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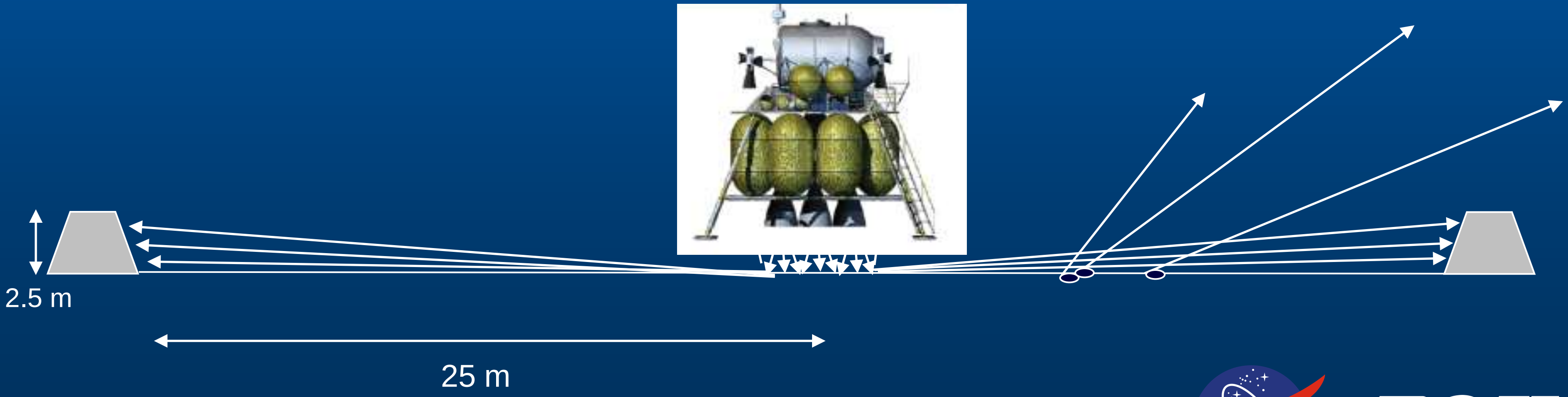


Lunar Plume Management

- Need a top-level, integrated plan
  - Analogy of blast management at terrestrial launch pads
- Prevent it?
  - Prepared landing surface
  - Flight hardware design
- Block it?
  - Berms
  - Curtains
  - etc.
- Harden assets to live with it?
  - Derive requirements
  - Coatings
  - Sealed mechanical joints
  - etc.
- Surface operations
  - Put surface assets into safe config for launches & landings
  - Scheduled inspections of hardware for accumulated damage
  - *In situ* maintenance & repairs

What We Know

- Particles travel at ultra-high velocity and low angles
- Terrain features may make the problem worse
  - By blowing the larger material into higher angles to "rain down" on the outpost
- The plume itself may "unlevel" the soil unless it is stabilized
- We have physical evidence of real damage on the Surveyor III hardware returned to Earth
  - Different size soil particles caused a variety of effects
- We can't cure the problem by landing farther away

What We *Don't* Know

- Parts of the physics

Turbulence in the boundary layer of the plume
Structure of the boundary layer in the plume
Lift forces on particles in these conditions
Cohesion forces that clump particles together
Scattering properties of the blowing soil
Physical processes that contribute to erosion rate
Role of particle collisions after erosion
Affect of two-way coupling between the soil & gas

Therefore,

- Accurate trajectory & velocity for all particle sizes
  - So we can design mitigation strategies & technologies
- Hardness requirements for assets exposed to spray
  - Rate of soil erosion = no. of particle strikes per cm^2 per landing
  - How big a divot is caused by a certain size/velocity particle?
- Loss of landing visibility with engines larger than Apollo
- What conditions make the lunar regolith fail & form a scour hole?
  - Will Altair scour out holes more readily than the Apollo LM?
  - How important is it to stabilize the regolith?

What We Need

- Early predictions
  - In work
- Trade study of mitigation techniques
- Drive Mars requirements into Lunar program objectives
- High-fidelity fluid flow code
  - In work via STTR
  - Requires high-fidelity data to calibrate & benchmark
- Benchmark code
  - Vacuum chamber tests
  - Large-scale test in desert?
  - Mars data?
  - Lunar Flight Instrument develop & fly

Lunar Design Approaches

- Structural Support:
  - Regolith Stabilization
  - Fabric Mats
- Exhaust Management:
- FOD Control:
  - Regolith Stabilization
  - Berms
  - Inflatable Screens
  - Use of naturally occurring morphological features

Concepts for Blast Protection

- Lunar regolith “in-situ” berms
- Deployable fabric fence
- Inflatable blast barrier
- Deployable protection blankets
- Eliminate the ejecta source regolith (sky crane, lander skirt)
- Spent descent stage structure wall
- Gimballing of the Lander engine nozzle upon landing
- Build a flame trench type of topography where the blast is re-directed away from the Outpost and Lander
- Use natural topography as a blast shield
- Shut down the engines early and drop-land on airbags
- Blanket to drape over critical hardware or critical surfaces
- Inflatable landing pad
- Land 20 km from outpost and use a pressurized rover for crew transfer
- Submerge Habitat below grade level (in crater or by excavation)

Concepts for Surface Stabilization

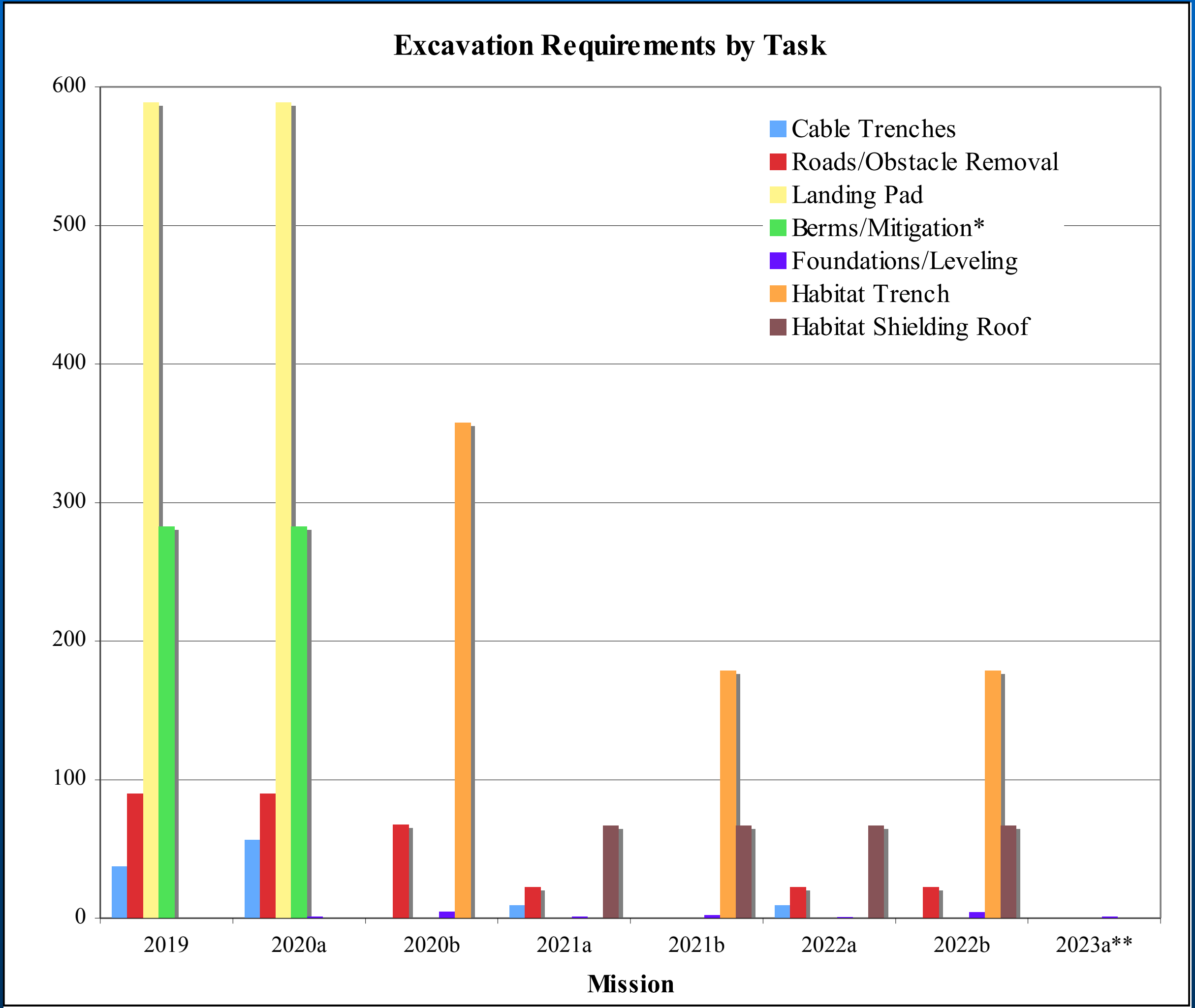
- Regolith surface sintering
- Palliatives
- Lightweight Surface mats
- “In-Situ” regolith paver bricks
- Gravel bed
- Polymer stabilization
- Gossamer textile bonded to surface
- Scrape off the loose top 30 cm's of regolith and compact the surface
- Lunacrete paving of entire pad area
- Pre-blast it with a rocket engine to the hard regolith

Benefits of Excavation and Surface Preparation

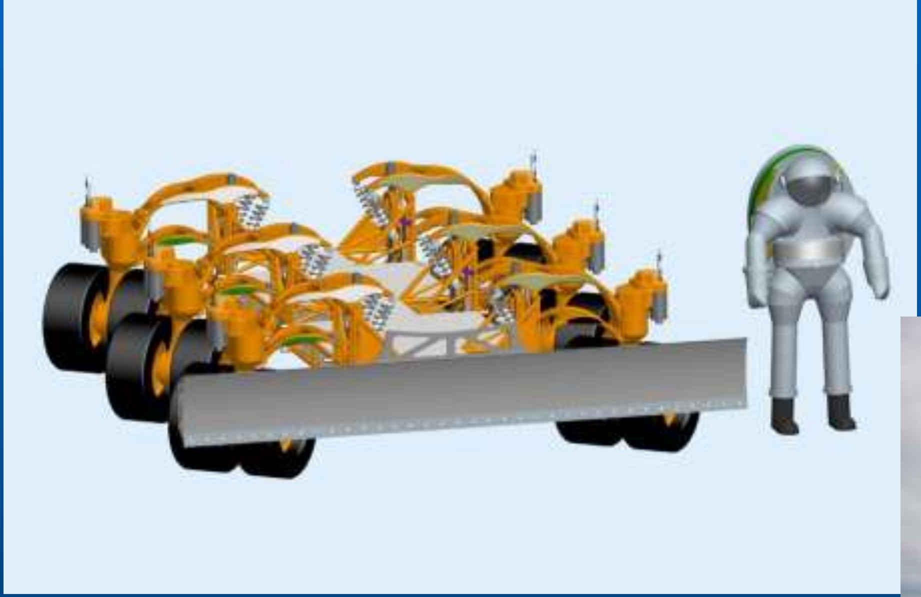
- Surface Systems:
  - Protect emplaced assets from subsequent blast damage during landings
  - Provide a better surface capability for Outpost deployment
  - Reduce life cycle cost and operations risk of operating an outpost
  - Dust Mitigation
- Altair Lander:
  - Provide an enhanced landing capability
  - Reduce landing risk
  - Reduce turnaround issues / potential damage to lander
  - Provide a landing facility with associated support equipment
  - Level surface and controlled launching conditions
- Science:
  - Provide a trenching capability for Lunar Stratigraphy studies
  - Provide a surface and sub-surface sample collection capability
  - Provide geotechnical methods for deploying instruments
- Mars Forward
  - DRM 3.0 has predicted Mars Landers of 50-60 MT mass

Excavation by Task

- Time sequence of tasks based on LAT II Option 1 Concept of Operations



Lightweight Chariot Bulldozer Blade

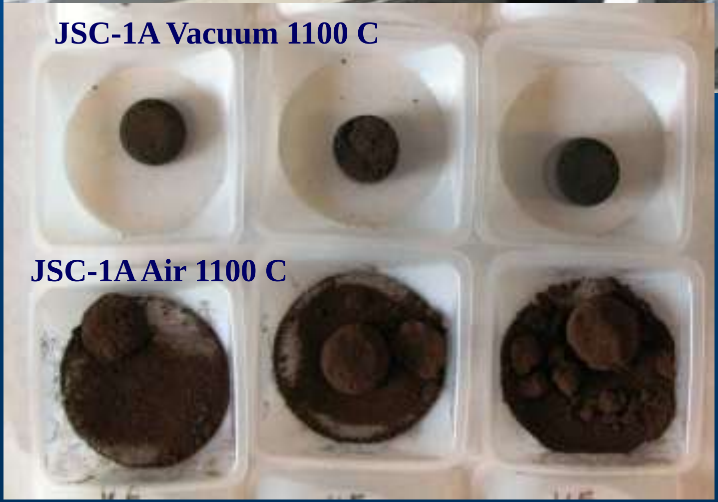


Carbon Fiber/Epoxy/Aluminum
Blade Mass ~ 285 Lbs (129 Kg)

Blade on Chariot Mobility Platform (JSC)

Bulldozer Blade on Chariot Mobility Platform (JSC) Testing at Moses Lake, Wa.

Surface Stabilization: Solar Sintering



Credit: Dr. Paul Hintze, KSC

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Summary

Surface systems will be required on the moon to perform similar functions to their earth analogs.

However, the methods used to perform these functions and the problematic conditions are still being understood.

Much analysis, design and testing are still required.

The current work being performed by NASA, RS&H and others is contributing to the accelerated development of Lunar Based Surface systems.

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Robert P. Mueller, NASA
Phillip T Metzger, PhD, NASA
G. Wayne Finger, PhD, PE, RS&H
Steve W. Moore, PE, RS&H

NASA, Surface Systems Office,
Kennedy Space Center, FL 32899
(321) 867-2557 www.nasa.gov

Reynolds, Smith & Hills
2235 N. Courtenay Parkway, Suite C, Merritt Island, FL 32953
(321) 453-0212   www.rsandh.com