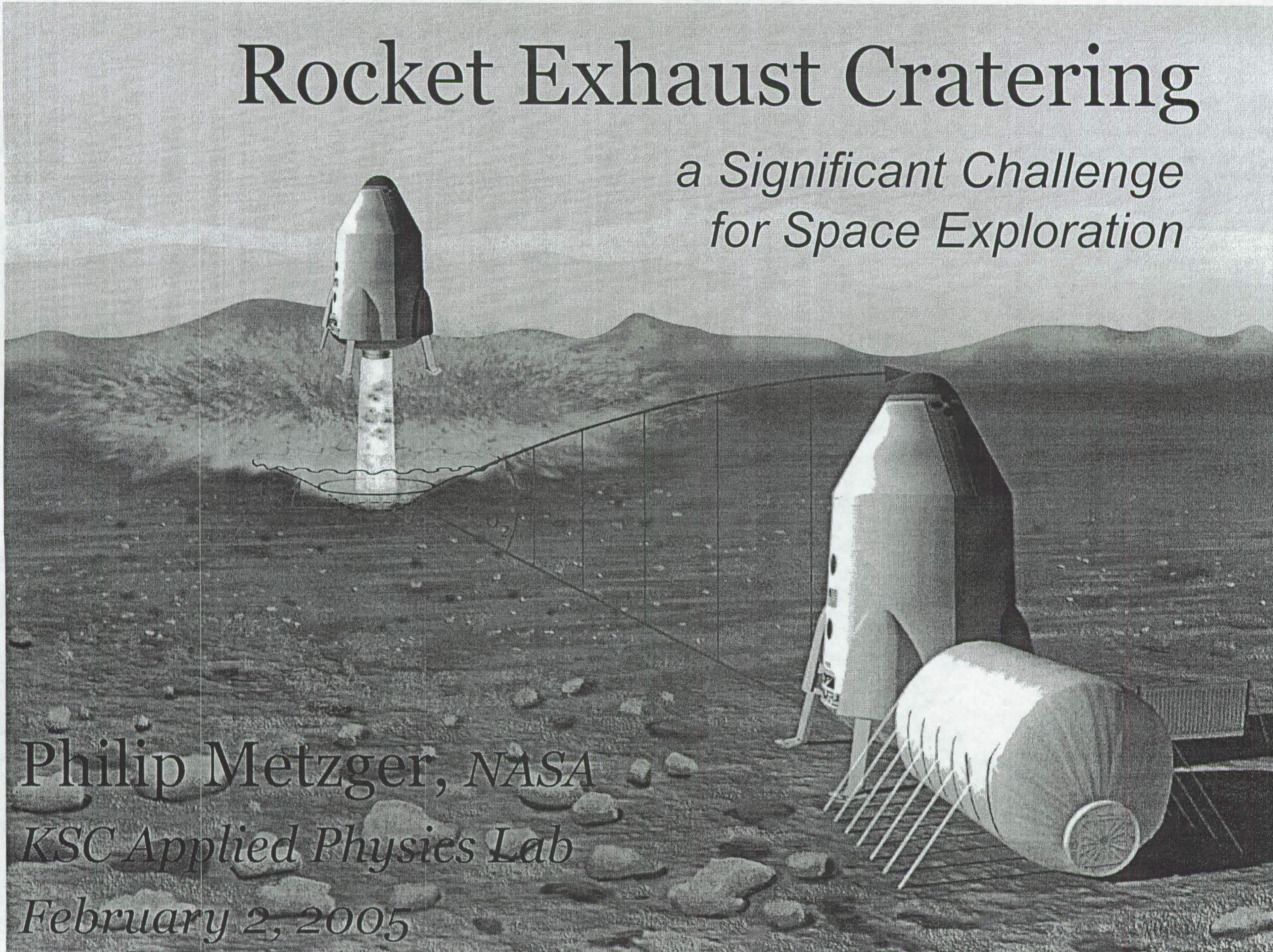
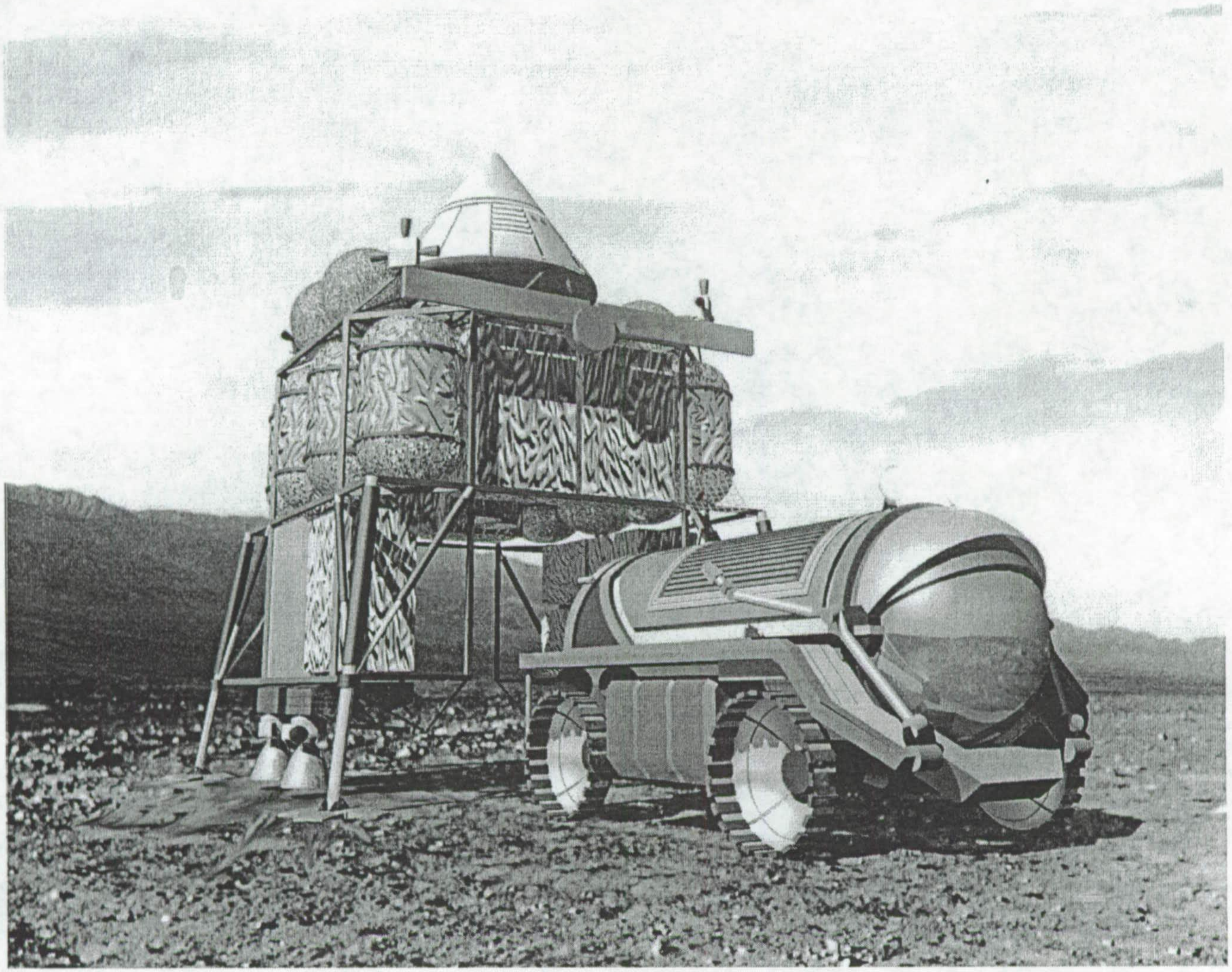

Rocket Exhaust Cratering
a Significant Challenge
for Space Exploration
Philip Metzger, NASA
KSC Applied Physics Lab
February 2, 2005

Background

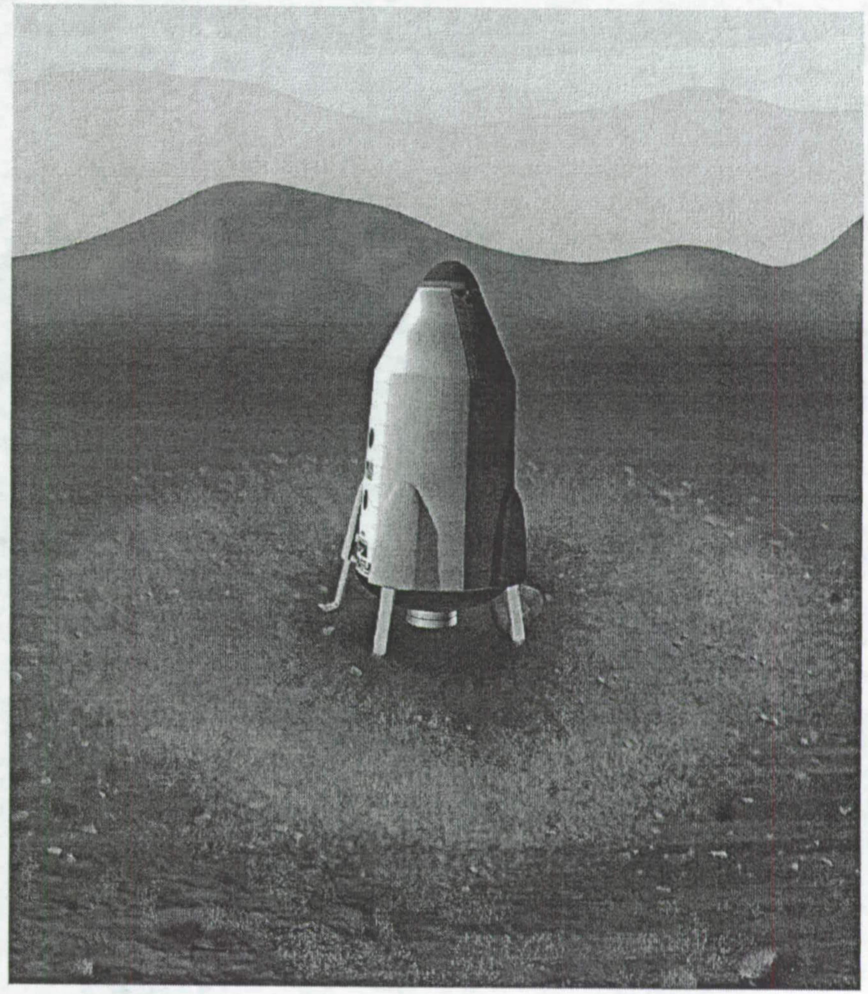
- During the Apollo and Viking programs, NASA needed to know how the rocket exhaust would affect the soil on the Moon and Mars.
- A number of studies were done during the 50’s through 70’s, but little or no work has been done since then.
- Existing models are crude and significant theoretical questions still exist

Landing spacecraft must not damage themselves

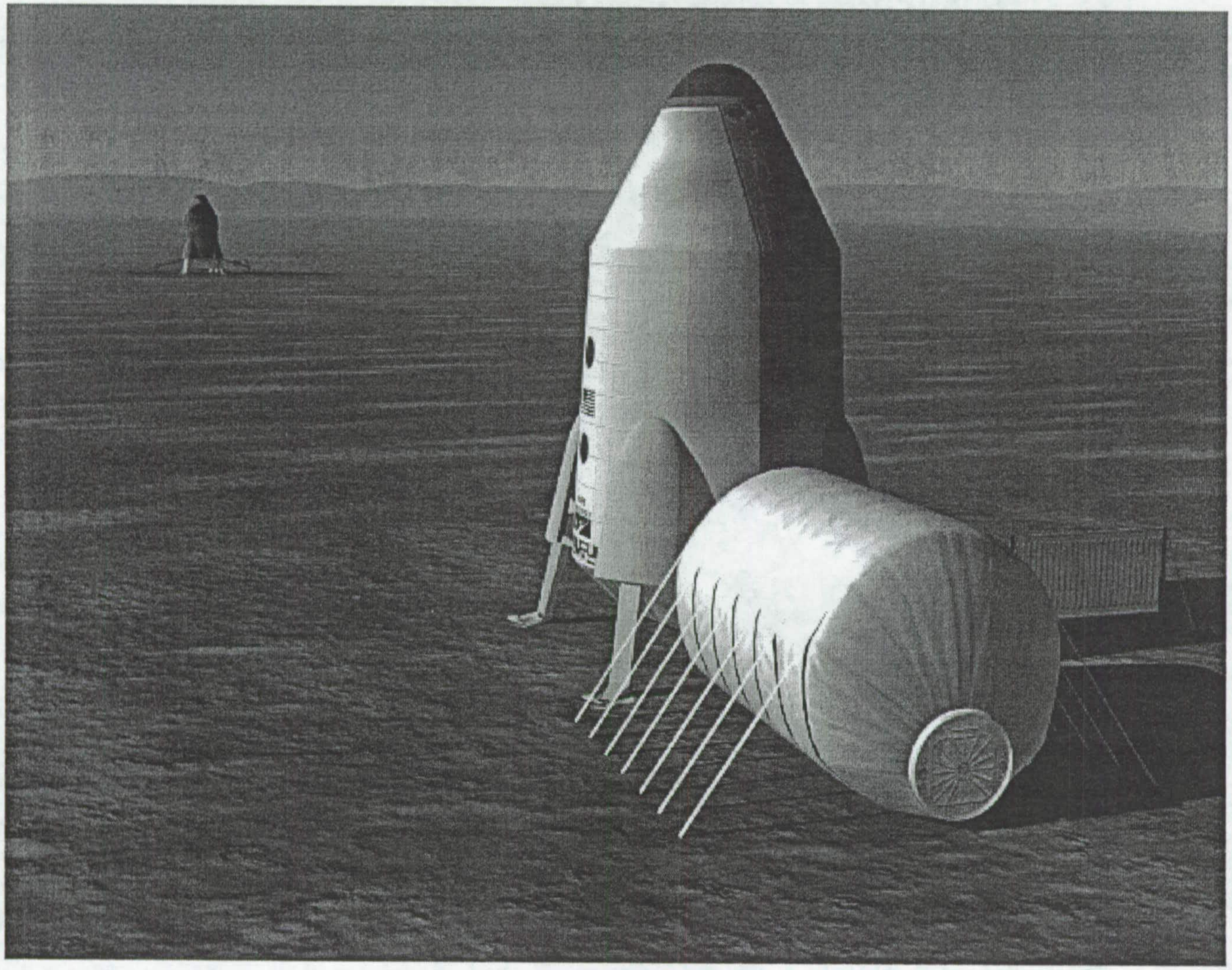


Concerns

- Impact damage from debris strikes
- Momentum transfer during landing
- Landing visibility
- Jamming or spoofing sensors
- Contamination of critical systems
- Debris blanket on spacecraft
- Stability of landed spacecraft

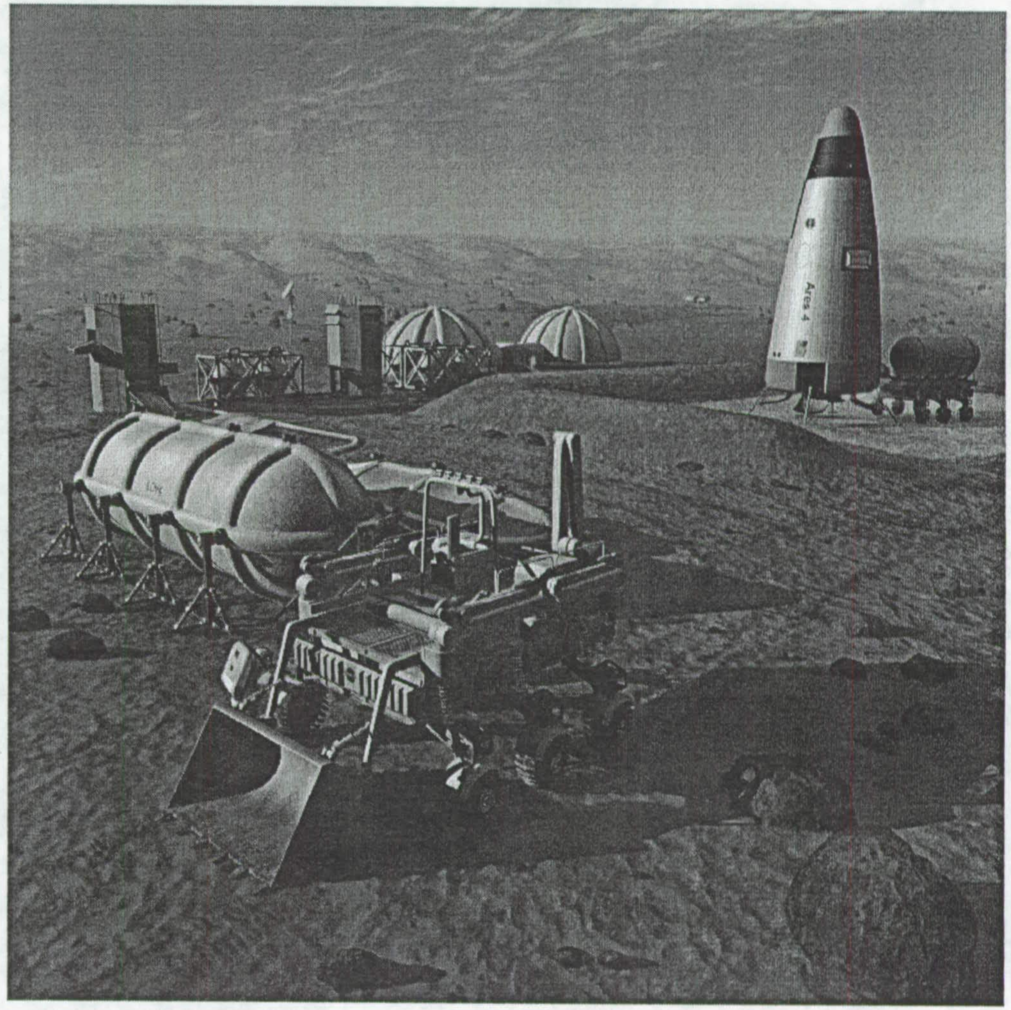


Co-Landed spacecraft must not damage each other

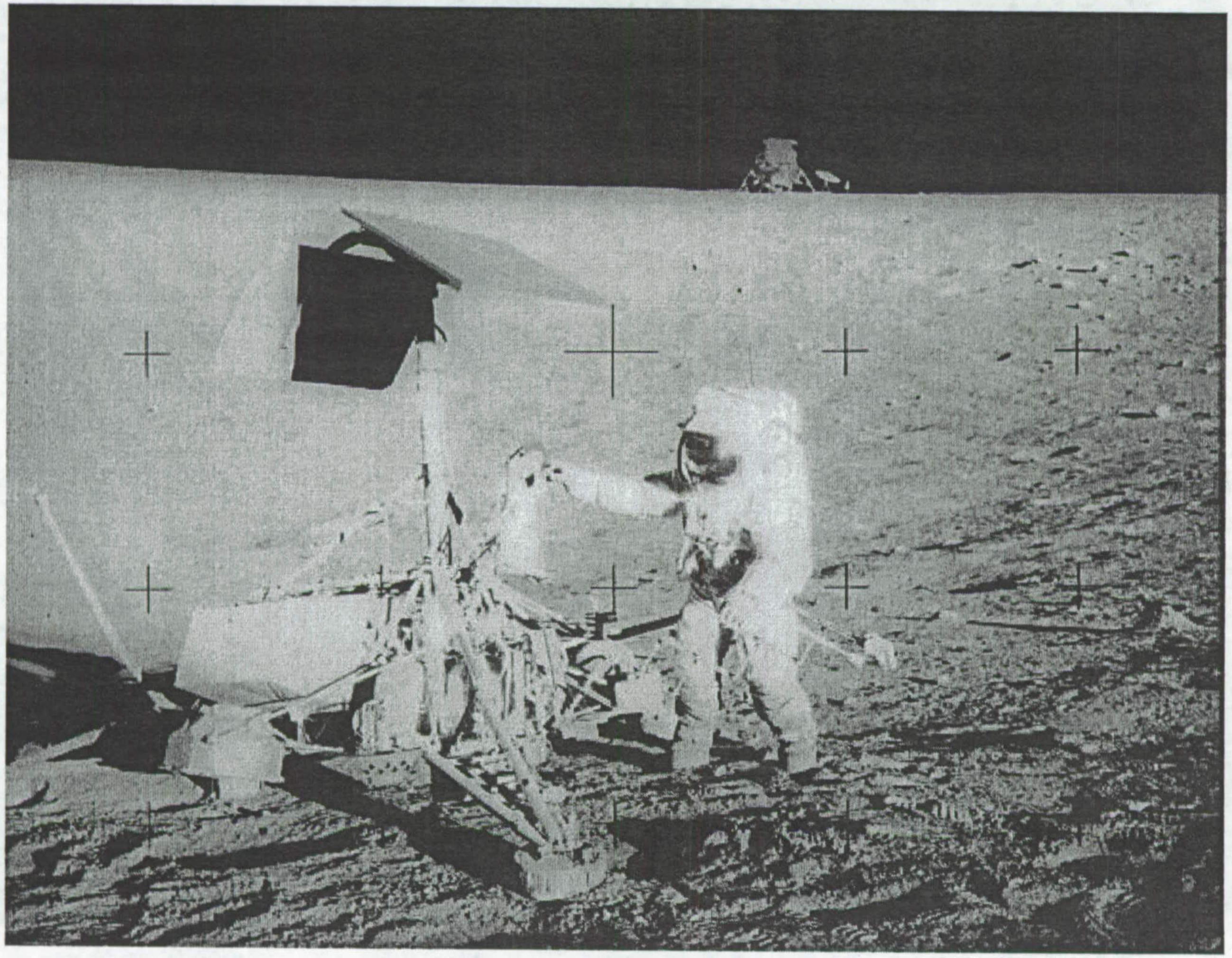


Concerns

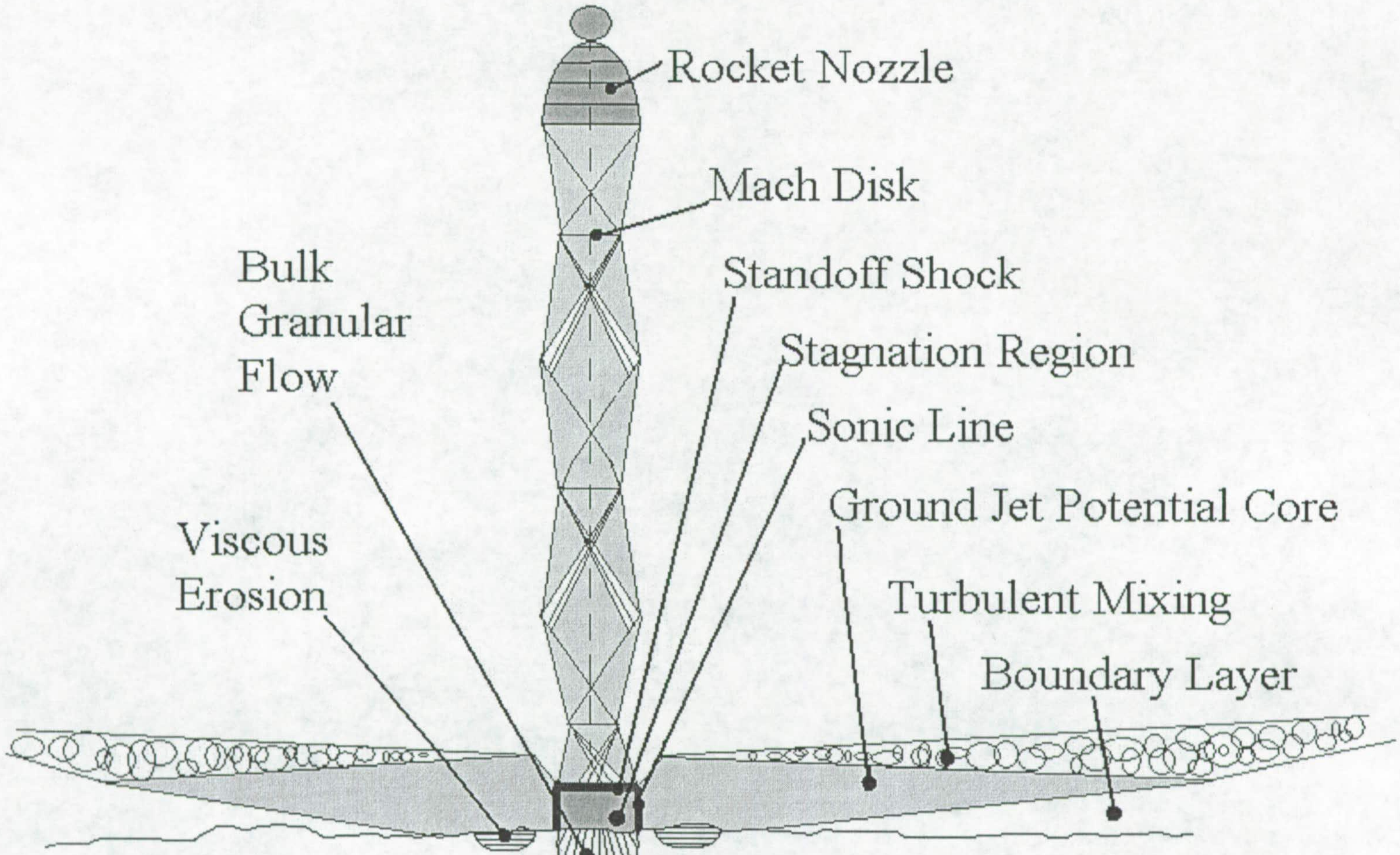
- Too close:
  - Damage
  - Contamination
  - Excessive blast hardening required
- Too far apart:
  - Excessive umbilical lengths & mass
  - Excessive travel between sites

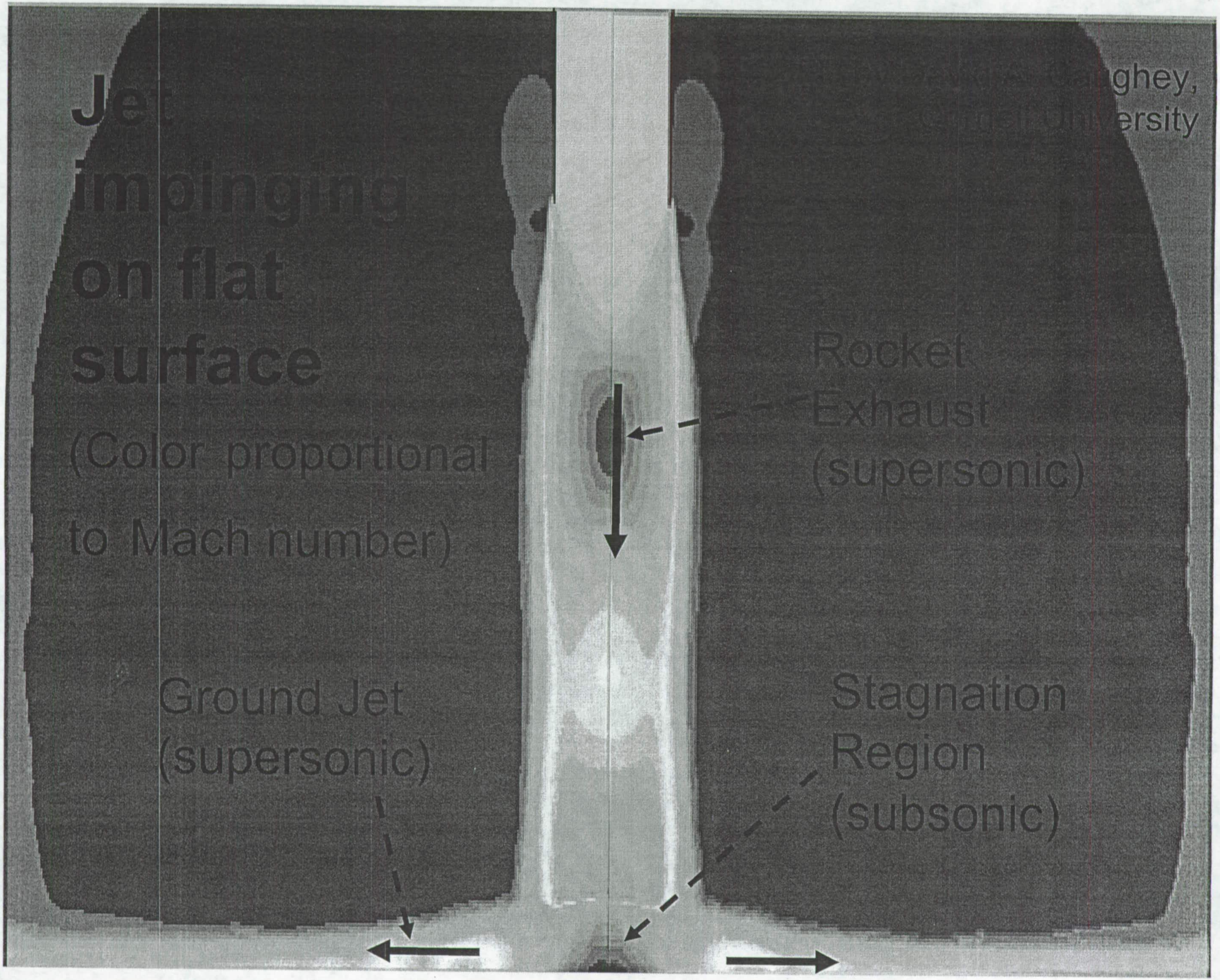


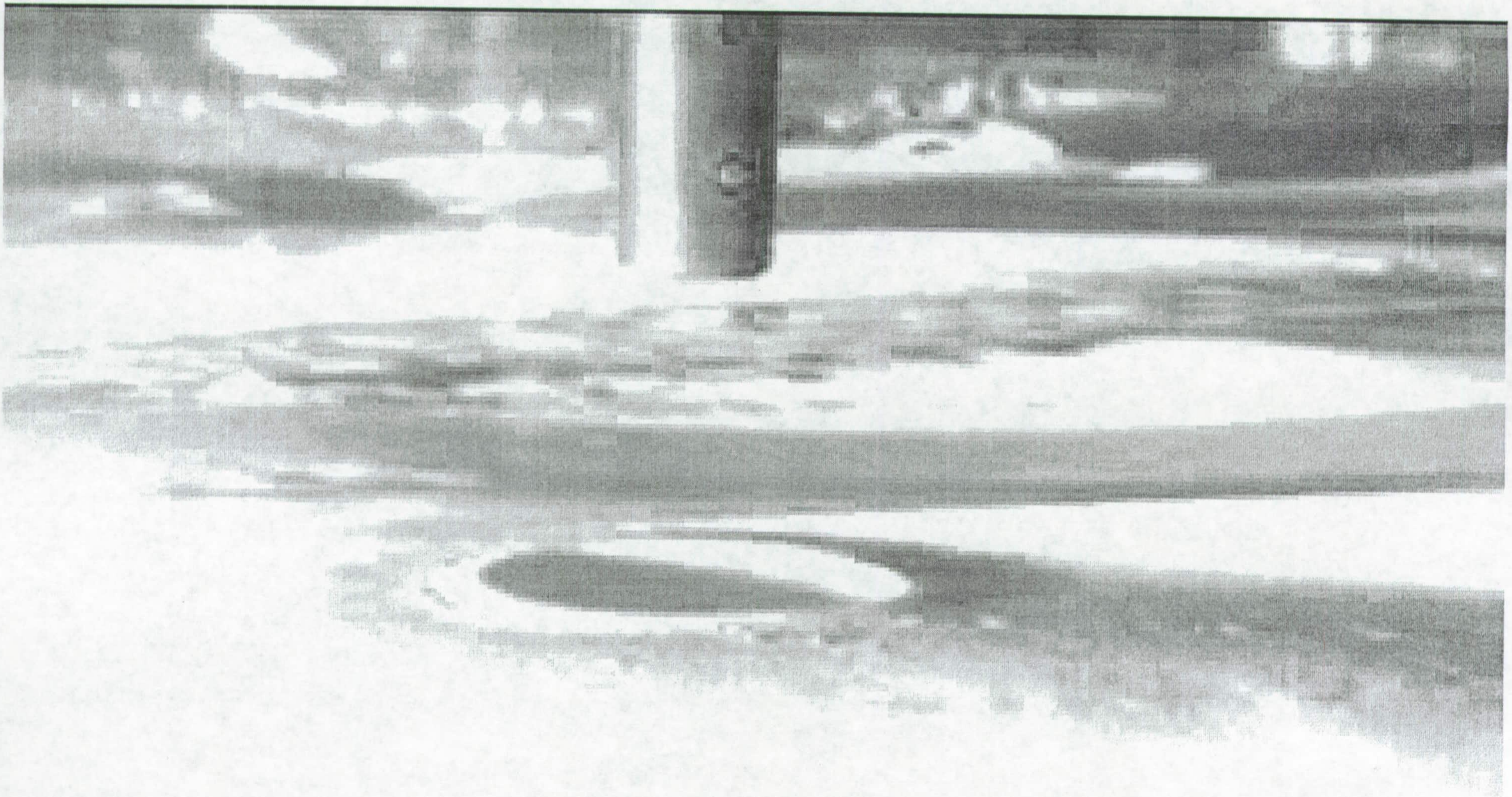
Apollo 12 / Surveyor 3 Damage



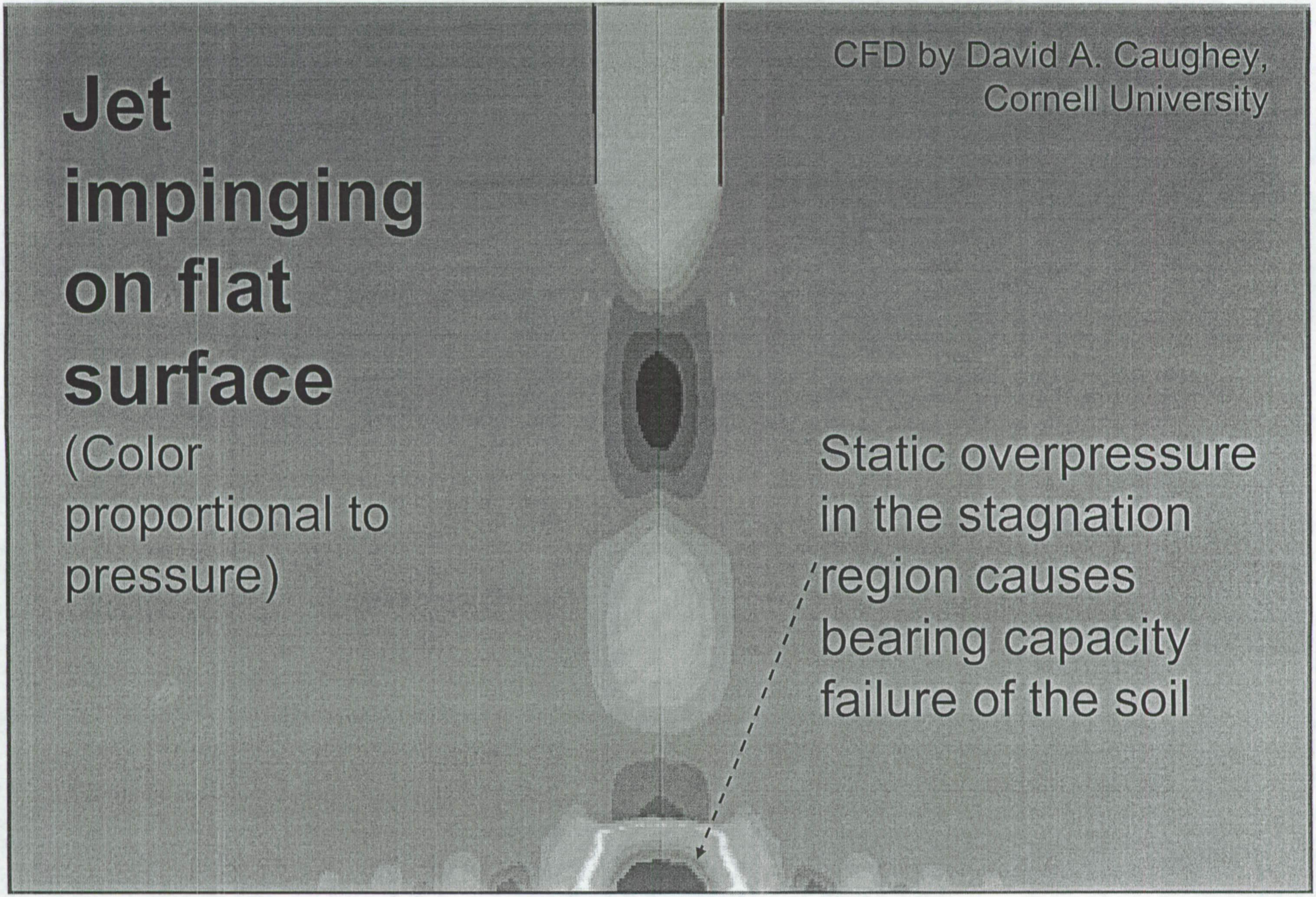
Plume / Regolith Interactions

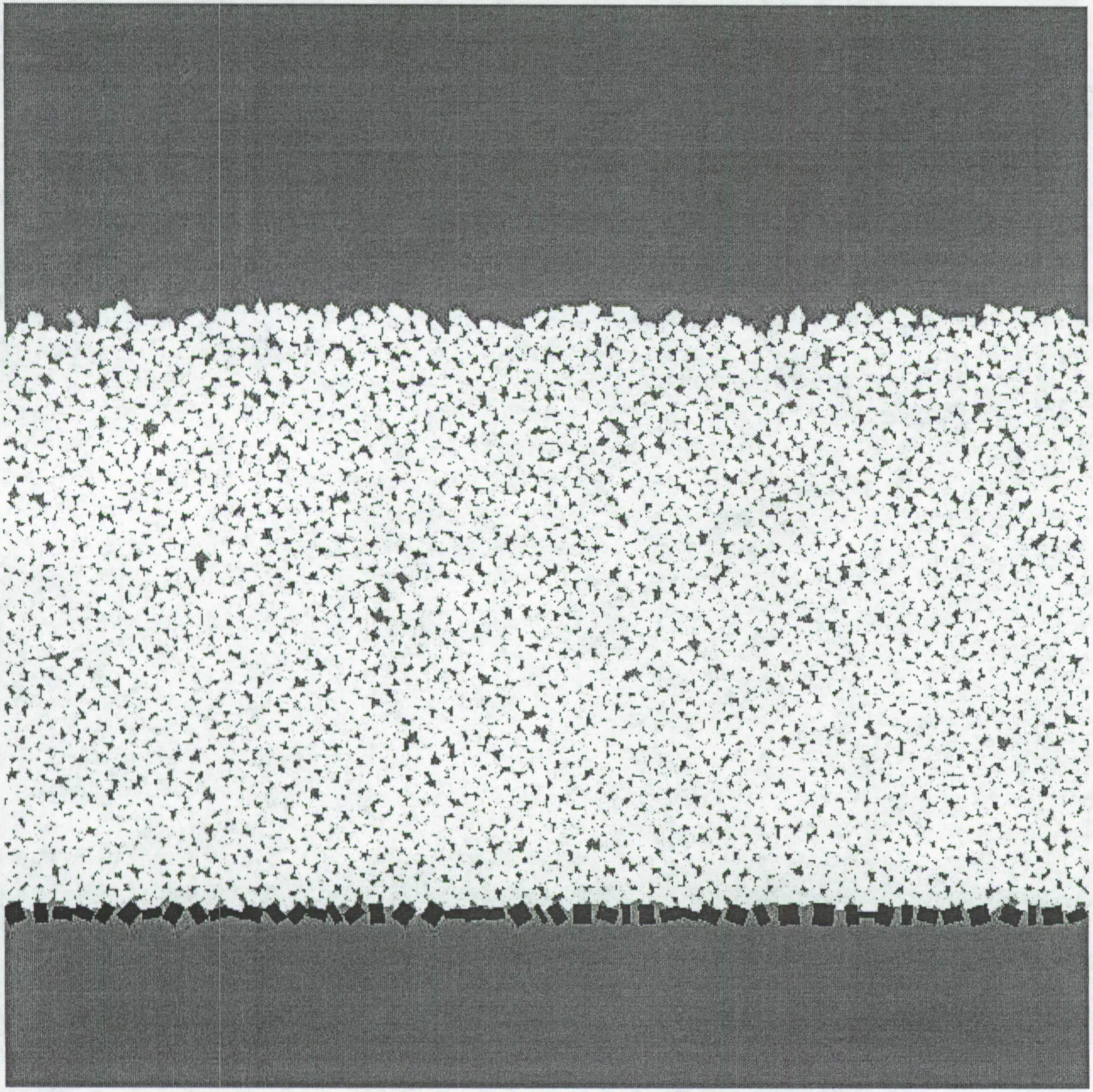



Jet impinging on flat surface
(Color proportional to Mach number)
Rocket Exhaust (supersonic)
Ground Jet (supersonic)
Stagnation Region (subsonic)

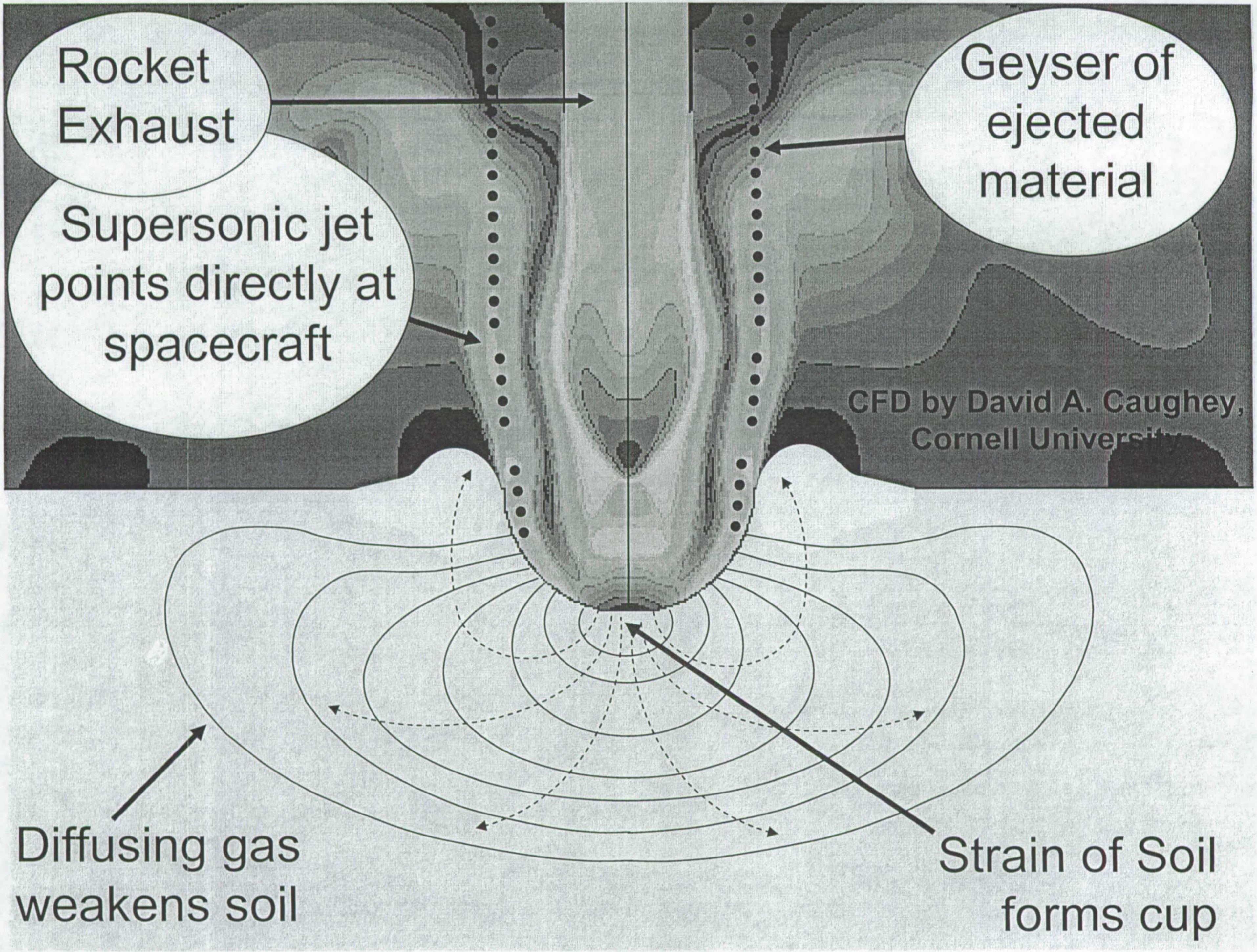


Credit: Robert B. Haehnel, U.S. Army Cold Regions Lab


CFD by David A. Caughey,
Cornell University
Jet impinging on flat surface
(Color proportional to pressure)
Static overpressure in the stagnation region causes bearing capacity failure of the soil

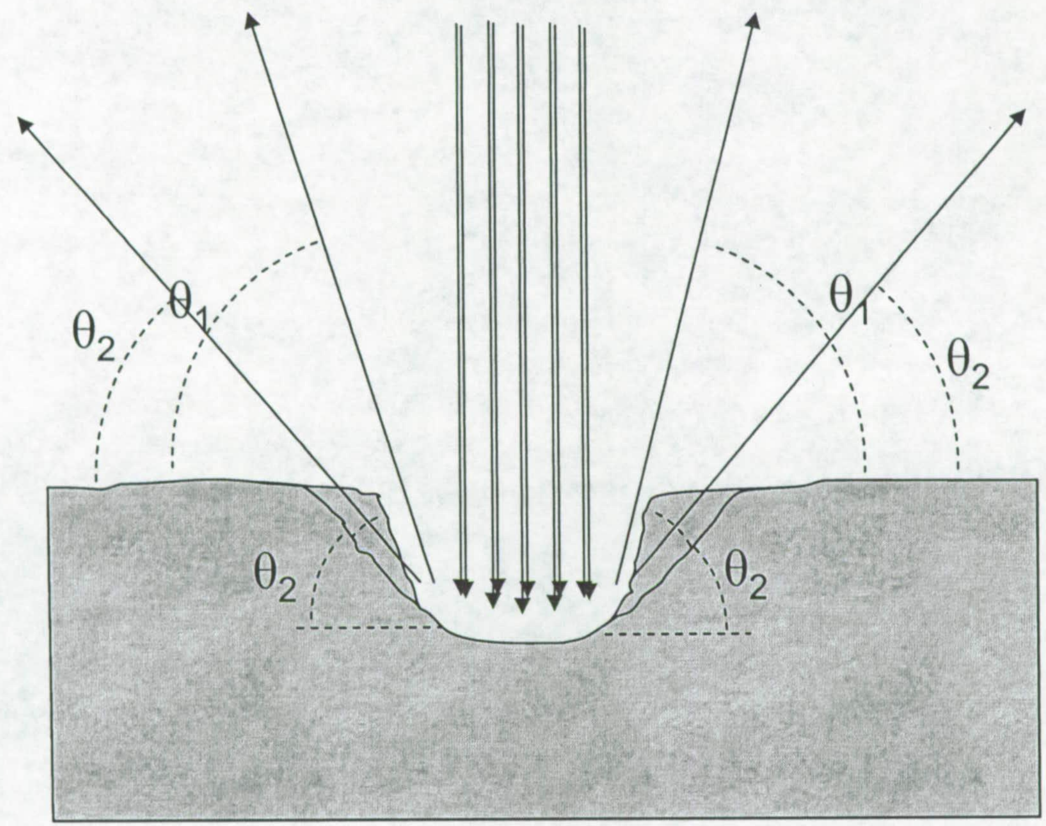


Credit:
Mark A. Hopkins,
U.S. Army Cold
Regions Lab


Rocket Exhaust
Geyser of ejected material
Supersonic jet points directly at spacecraft
CFD by David A. Caughey, Cornell University
Diffusing gas weakens soil
Strain of Soil forms cup

The shape of the evolving crater

determines the shape of the evolving blast field



Cratering Flow Regimes

- Viscous Erosion (VE)
  - Mild scouring of annular region
- Gas diffusion into the pores
  - Beneath the jet's stagnation region
- Annular blowout
  - due to pressure gradient beyond stagnation region
- Bearing Capacity Failure (BCF) after 200 msec
  - Gas diffusion weakens the shear strength of the soil
  - Plastic deformation of the soil forms a cup
- Violent blowout
- Heavy but less violent VE after 500 msec
- Central core eruption after engine cutoff

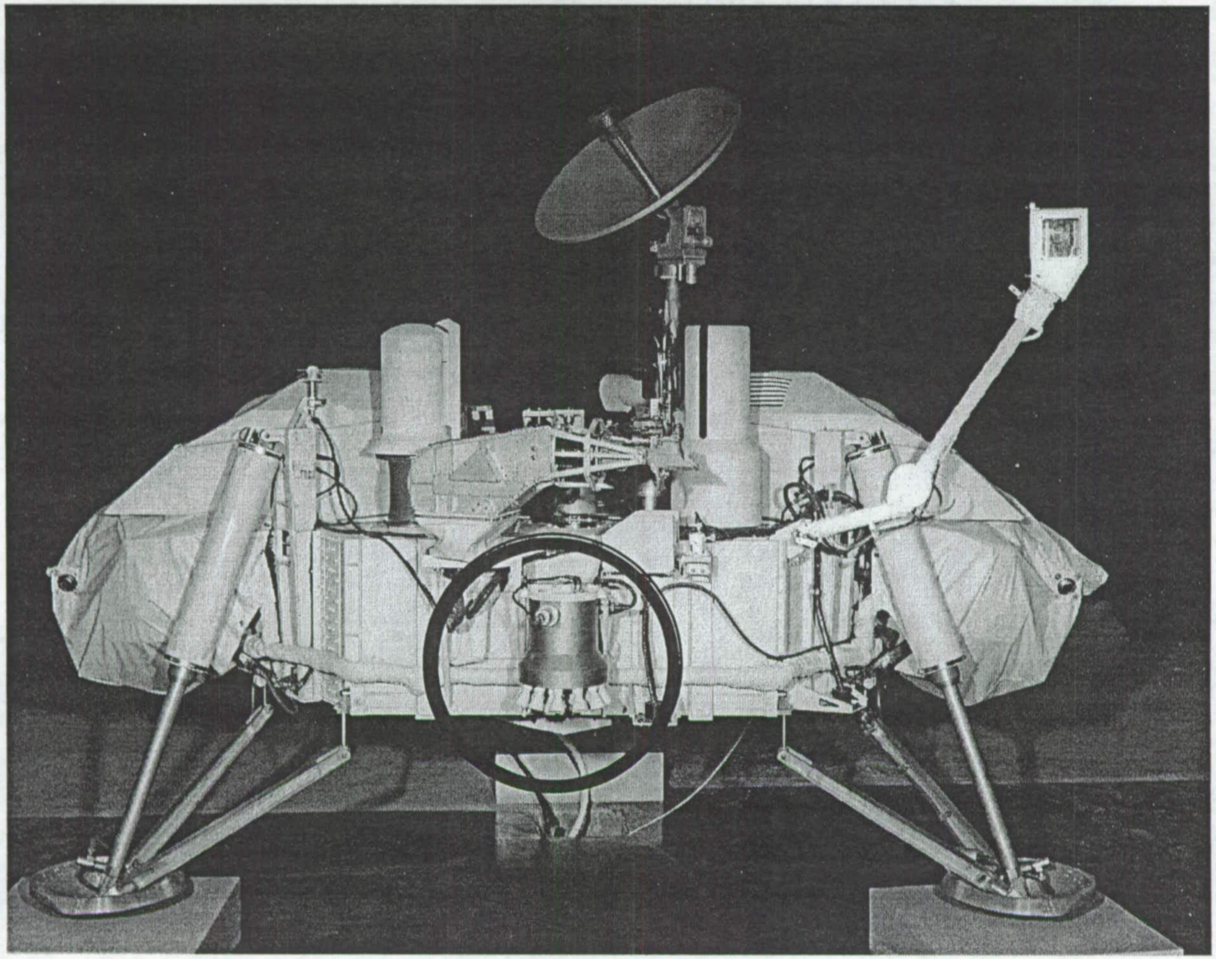
Complications on Mars

- Presence of water and CO_2 ices in the regolith
  - Unknown mechanical properties due to cementation of the grains
  - Unknown porosity
  - Unknown sublimation rates
  - Unknown effects due to spike in pore pressure
- Much larger spacecraft
  - Cannot avoid BCF
- Mission Architecture
  - Co-landed spacecraft

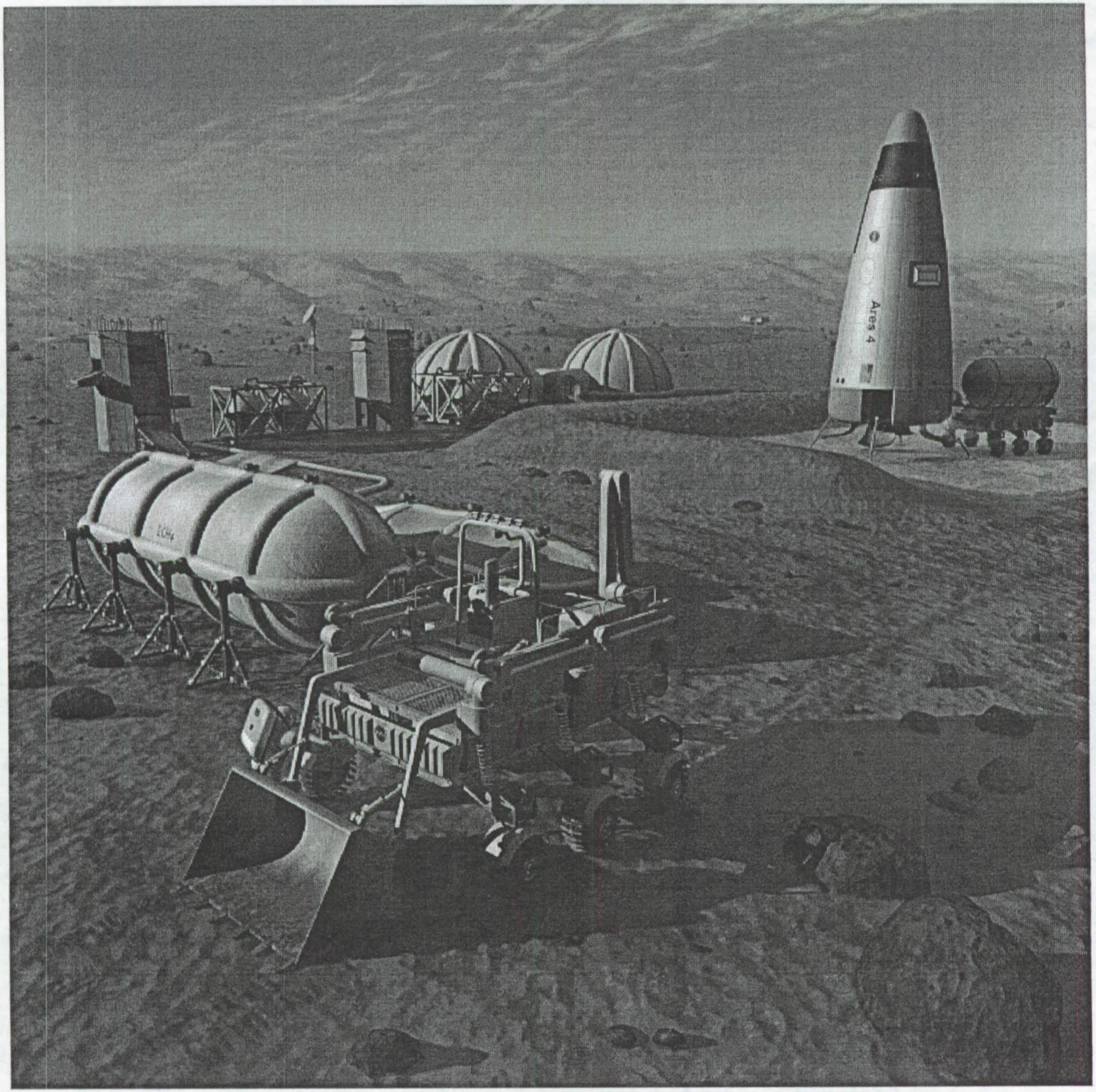
Systems of Systems Implications

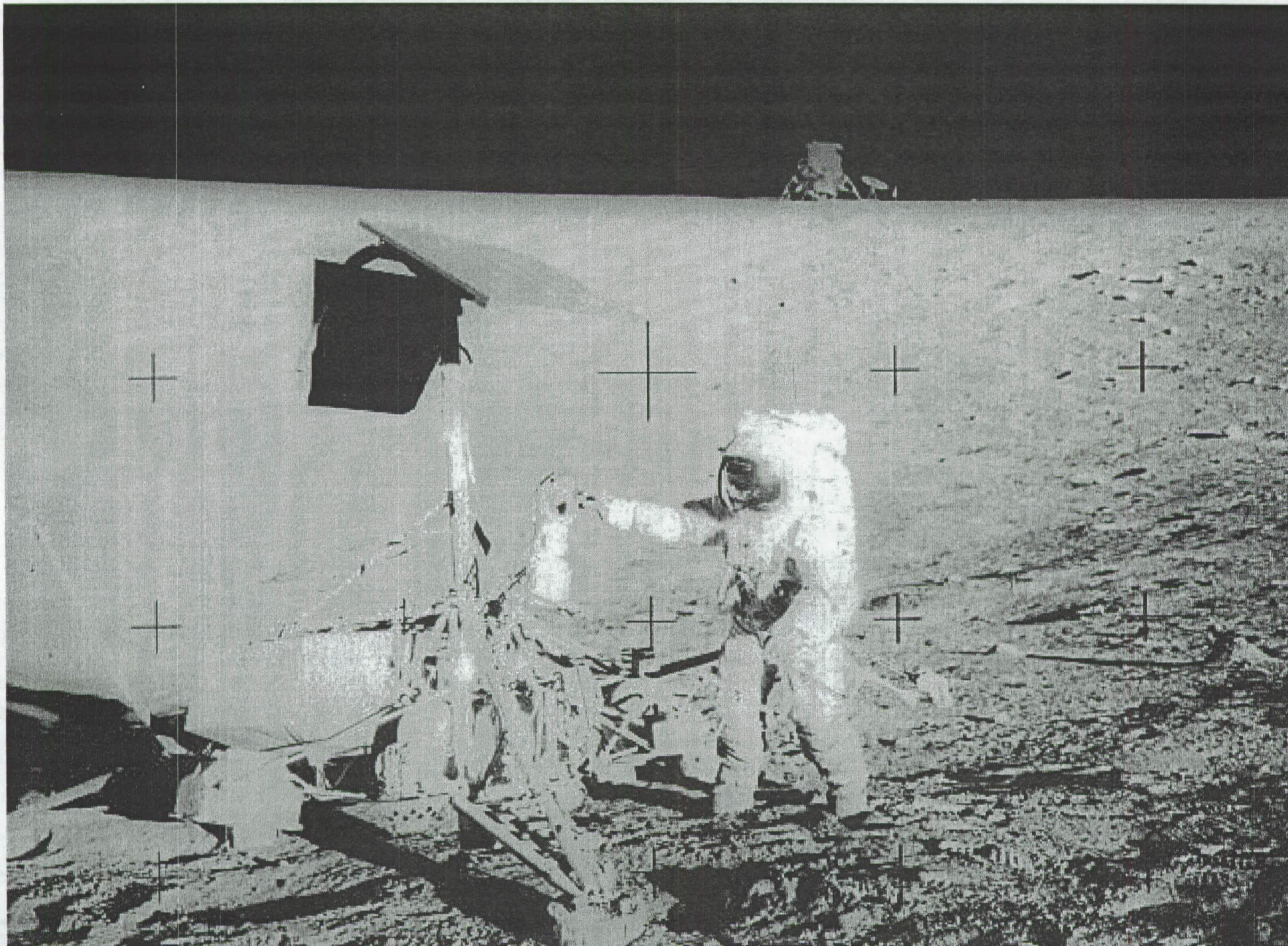
- Scale of blast determines scale of mission
  - Number crewmembers affects life support mass affects propulsion requirements
  - You can't take more people than you can safely land
- Controlling blast will constrain basic design of propulsion system
  - E.g., late redesign in Viking program
- Design of propulsion system affects multiple spacecraft systems
- Blast field shape constrains surface operations

Viking Lander Re-designed



This solution will not work for human-tended missions!


Ares 4



Testing vs. Modeling + Testing

- Q: Why is granular materials modeling needed to help solve this problem?
- A: You can't test rocket engines in a vacuum chamber
  - Not without the big bucks, anyway!
  - Maintain atmosphere during engine firing
  - Variety of seasonal and terrain conditions
- A practical program needs Modeling + Testing!

Modeling vs. Research + Modeling

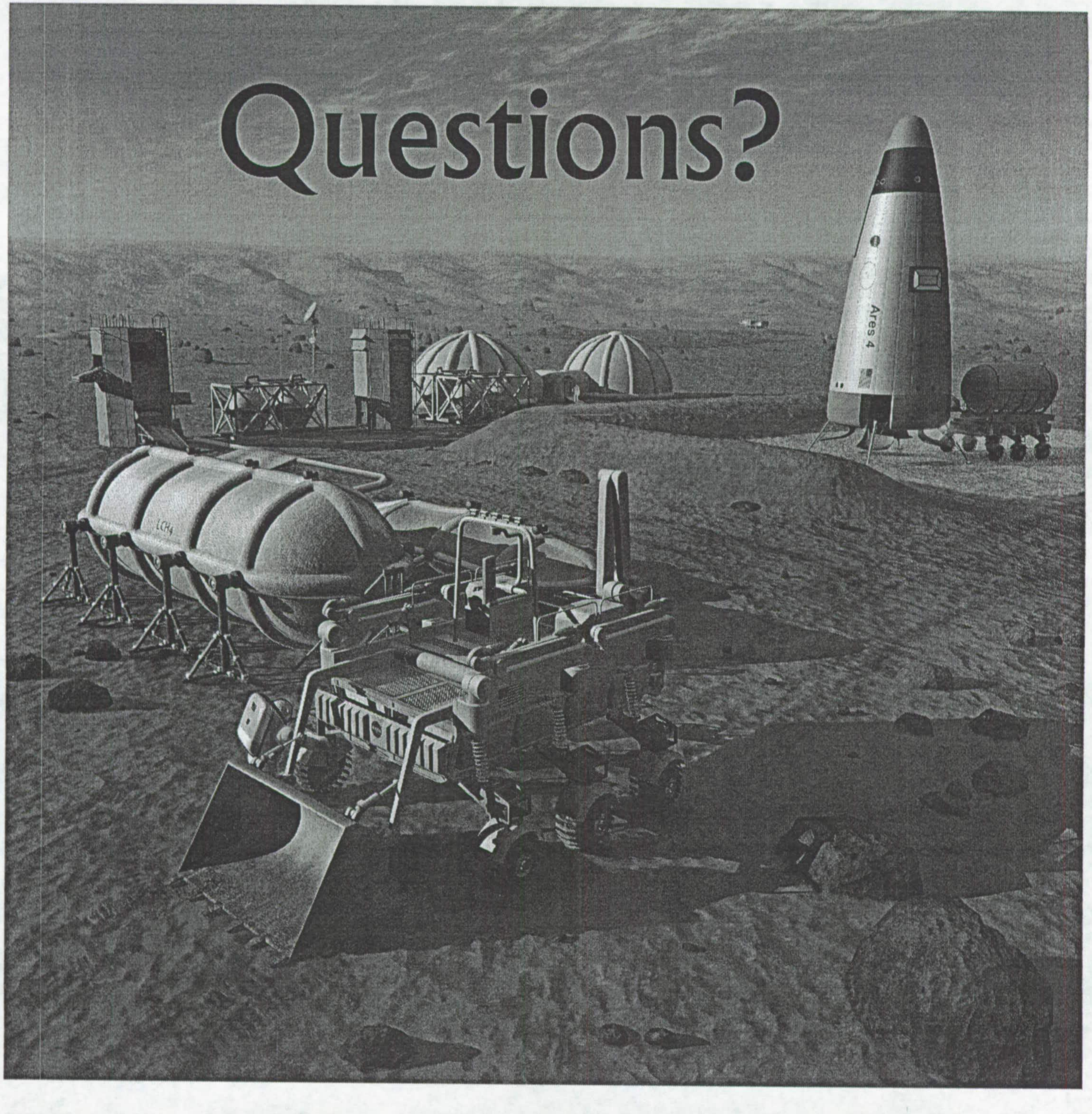
- Why not just do the modeling later, when the actual engines are going to be designed?
  - Who needs research?
- Scaling versus computational power
- Grain/gas interactions are complex
  - Viscous scouring of surface
  - Armoring due to grains left behind
- Cratering processes are complex
- The Moon and Mars are complex

Proposed Action

- Significant research is required
  - Perhaps 10 years solid effort
- Fundamentals of basic cratering process
- Develop models
- Validate models with terrestrial, lunar and planetary opportunities
- Robotic mission characterize Martian regolith to relevant depth of cratering effects
- Validate landing system with full-scale but unmanned precursor
  - Instrumentation in-place on surface to document

Can this research be postponed?

- Basic decisions must be made early in the program
- NOW is the time
- Avoid costly re-designs late in the design cycle
  - E.g., Viking propulsion
  - Limited re-designs may not be possible with large, human-scaled missions
- Long lead time to get adequate predictive capability
  - Solve idealized problem first
  - Add regolith fidelity next
  - Validate realistic propulsion designs later
  - Design spacecraft last


Questions?
Ares 4
LCH4