Planetary Surface Transportation and Site Development

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This paper presents considerations and concepts for planning surface mobility systems and site development scenarios for the Moon and Mars. Reference concepts for multipurpose rovers, means to land them, and an operational site development implementation sequence are also illustrated.

Surface mobility and operations under reduced gravity planetary conditions pose special challenges. Among these, an ability for the prime mover or rover to develop necessary surface traction to pull or push massive habitat modules or other large elements is especially problematic. The surface mobility systems must also be sufficiently versatile and robust to accomplish diverse scientific and site development tasks, potentially including services as drilling rigs, crew and cargo transport carriers, cranes and mobile power line development vehicles. Design proposals illustrate how such needs and functions can be accomplished.

I. Introduction

Any surface transportation and base deployment strategy must optimize all systems and operations for diverse and difficult conditions (Figures 1 and 2):

- Environmental Influences :
  - Systems should be designed to accommodate rough/ hilly terrain features at all candidate sites without requiring a large inventory of equipment.
  - Extremely cold temperatures will degrade battery power efficiency/ life, and long lunar nights will exacerbate this condition.
  - Reduced gravity will limit wheel traction, and dust will cause friction and degrade mechanical functions.

Figure 1. SICSA Reference Module Concept.

- Operational Influences:
  - Large parts and accessories will be difficult to change out/ repair under EVA conditions.
  - Systems must be versatile to meet diverse and changing evolutionary mission requirements.
  - Offloading of modules/ cargo from carriers must be made as simple and safe as possible.
  - Launch and delivery of all devices to the site should apply a universal transportation strategy.

Figure 2. SICSA Base Reference Concept.

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II. Rover Manifesting for Launch and Deployment

Rover planning must consider launch manifesting influences on surface landing and deployment (Figure 3):

- Scheme A assumes a horizontal bologna-slice payload orientation :
  - If the payload carrier lands in a vertical orientation, landing loads will act on wheels/ shelves, and means must be provided to lower the stacks.
  - If the payload carrier lands horizontally, loads will act on a platform end, and rovers must tip down.
- Scheme B assumes a vertical manifest (platforms aligned with the launch axis) :
  - If the carrier lands in the original launch orientation, loads will act upon a platform end and rovers must tip down for offloading.
  - If the carrier lands horizontally, impact loads will act through wheels and the rovers must download from the stacks.

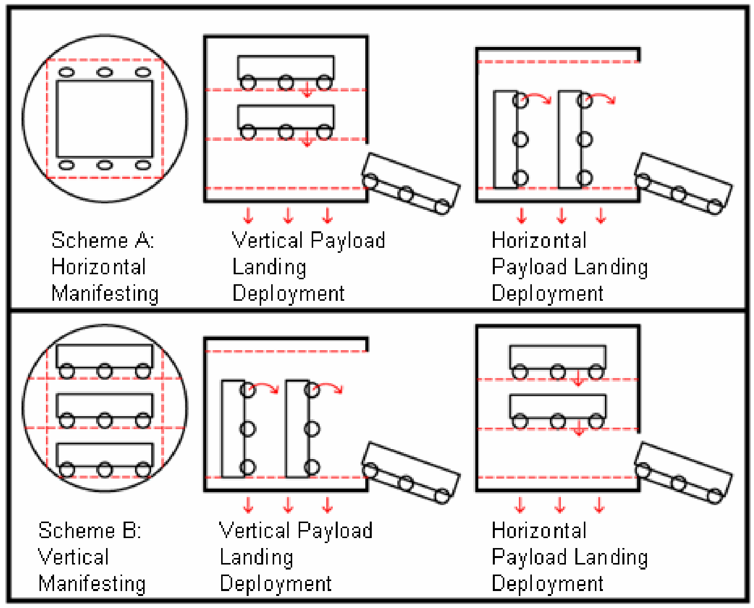


Figure 3. Manifesting and Landing/ Deployment.

III. Energy Storage, Maneuverability and Traction

Rover design must consider energy and cargo storage capacity for long traverses, maneuverability on rough/ hilly surfaces, and ability to achieve adequate traction (Figure 4):

- Platform geometry must be correlated with launch manifesting and influences upon available platform area/ volume for energy storage and payloads:
  - Given that batteries and other payloads are most likely to be rectilinear, a square shape (Scheme A) might be most ideal.

- Individual unit and fleet maneuverability might utilize variable power applied to fixed wheels or steerable wheels (possibly individually powered and controlled) :
  - Steerable wheels may offer maneuvering advantages for some fleet applications.

- Traction will be determined by vehicle loaded mass, contact surfaces and wheel/ track design :
  - More wheels may often provide more contact surface and contact occurrences.

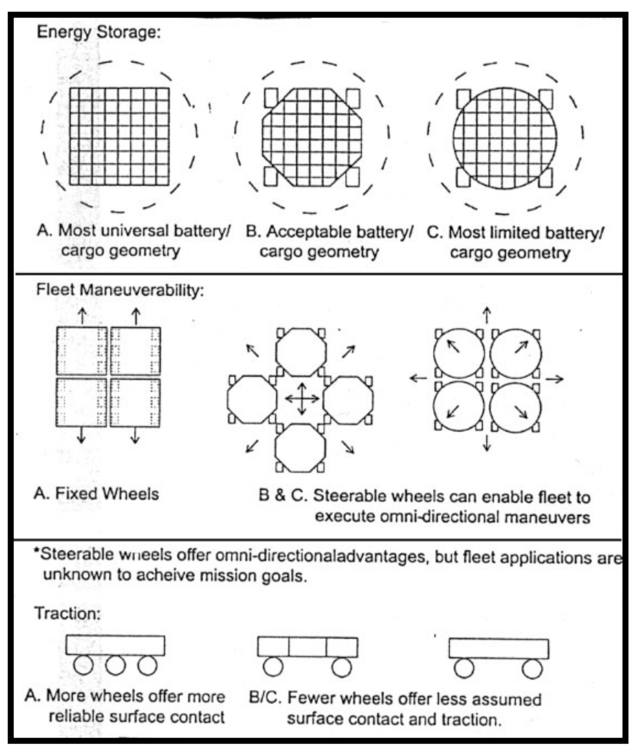


Figure 4. Platform and Wheel Options.

IV. Payload Transfers and Positioning

SICSA considered 4 different element approaches for moving and positioning large items such as modules and logistics carriers (Figure 5):

- Option A – Tow Winches with Lock-down :
  - Multiple rovers might be outfitted with power winches that pull wheeled cargo items after the rovers "lock-down" with anchoring devices, eliminating a need for wheel traction.
- Option B – Rovers with Cargo Carriers :
  - Payloads would be placed on one or more rover beds to optimize traction, but large items would need offloading means, potentially requiring cranes or other massive equipment.
- Option C – Rovers Attached to Landing/Support Structures:
  - Payloads would be supported by individual rover platforms at each corner with real-time operational coordination and maneuvering, an approach which can be perilous on uneven surfaces.
- Option D – Ganged Towing Rovers:
  - This approach would depend upon total rover mass and wheel contact to develop sufficient traction, potentially requiring many units.

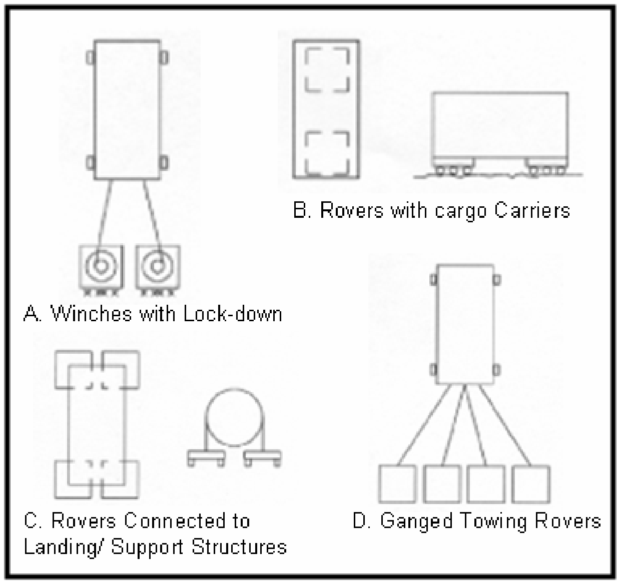


Figure 5. Design and Operational Approaches.

V. The Tow Winch Approach

The tow winch scheme was selected as a reference design approach to enable a pair of relatively small rovers to move and position modules and other large elements under low-gravity conditions that greatly reduce wheel traction (Figure 6):

- Winch spindle cables are attached to the wheeled module through automated or crew-assisted interfaces.

- The two rovers advance forward along a pathway that avoids large rocks and other surface barriers, and then anchor themselves in place.

- Winches are used to pull and align the module along the pathway, and the procedure is repeated.

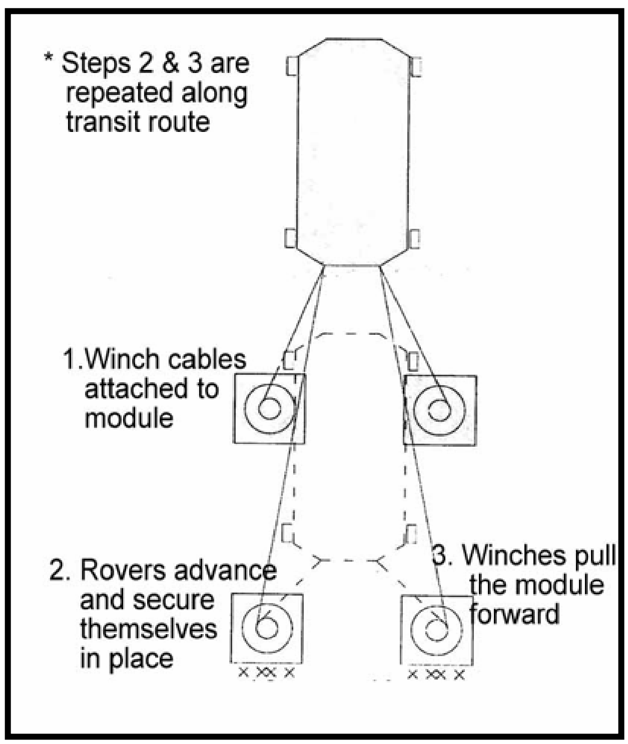


Figure 6. Winch Towing Approach.

The tow winch approach offers a variety of important advantages (Figure 7):

- Minimization of rover size and numbers :
  - The lockdown feature makes the system much less dependant upon rover mass for pulling traction than other wheeled or track alternatives, reducing rover transport launch, transfer and landing costs.
  - Smaller, lighter rovers will be more power efficient, enabling longer traverses with larger payloads.
  - More rover units can be delivered within a given transportation payload budget, enabling functional versatility and redundancy.
- Optimization of Capabilities :
  - The rover winches can be used to deploy electrical cables between the base and a nuclear power source located a safe distance away.
  - A standard rover platform can be outfitted with cranes, drilling rigs and other useful equipment.

Figure 7. Surface Module Relocation.

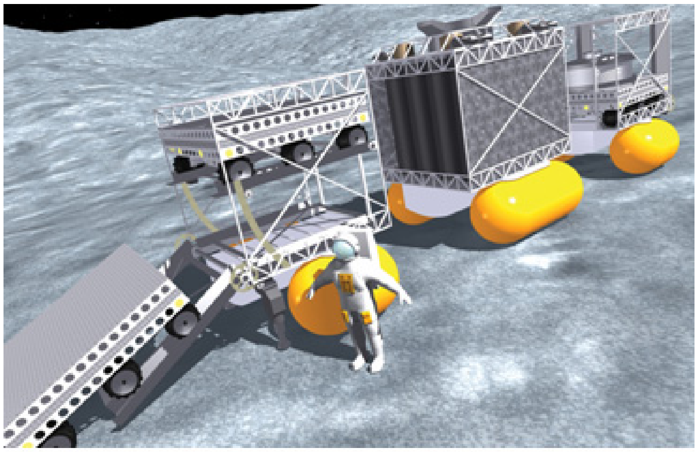
VI. Multipurpose Rover Platform

SICSA has conceptualized a multipurpose rover platform that can be adapted for a variety of functions using augmentation devices (Figures 8-14):

- All applications sue a common wheeled platform system that incorporates battery power and automation/ telerobotic control systems.

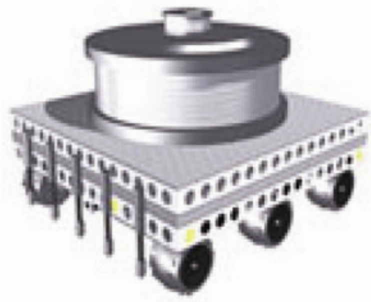
- In most cases, the functional augmentation devices are installed on the platforms prior to launch/ landing, and are too large to be change out on the surface by EVA crews.

- Multiple units can be launched together within a 12 ft. diameter rocket shroud.



SICSA has investigated ways to deliver rovers and other large logistics payloads to lunar/Mars surfaces in support of human missions.

Figure 8. Logistics Carrier with Rovers.

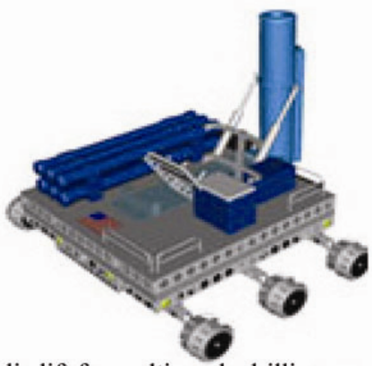


- Spool carries power cable from RTG to module
- Winch for moving modules
- Extendable rods anchor the rovers for pulling

Figure 9. Spool/ Winch.

- Flexible cargo area adapts to modular containers of varying size
- Removable guard rails secure payloads
- Automatically controlled

Figure 10. Cargo Carrier.



- Hydraulic lift for multi-angle drilling
- Revolving chamber with chuck bits extract core samples
- Storage tubes provide assorted bits and core samples

Figure 11. Mobile Drilling Rig.

- Life-support system located within each seat
- Versatile storage areas with perimeter guards
- Manual, teleoperated or automated control

Figure 12. Crew Transport.

- Automatically controlled
- Can provide power for rover fleet or backup power for habitats
- Maintenance tools and air supply stowage in chassis

Figure 13. Mobile Power System.

- 360 degree range of movement for boom
- Box-truss for lightweight telescoping structure
- Retractable outriggers for stability

Figure 14. Crane.

VII. Initial Base Development Scenario

A scenario for establishing initial planetary base operating capabilities is outlined in four general stages that follow (Figures 15-17):

Stage 1 : A pressure system is landed and deployed:

1. An unpressurized logistics carrier lands and delivers a RTG power source, 2 rovers with winches, and a crew rover.

1A. Rovers are automatically deployed and the 2nd winch rover in a 2-rover train dispenses a power until the spool is depleted at a power interface junction.

1B. The winch rovers reverse order, and the full spool winch dispenses remaining cable to the destination site.

1C. The spent winch rovers park at the destination site with power connections to the RTG.

1D. The crew rover automatically proceeds to the power interface junction, parks and recharges.

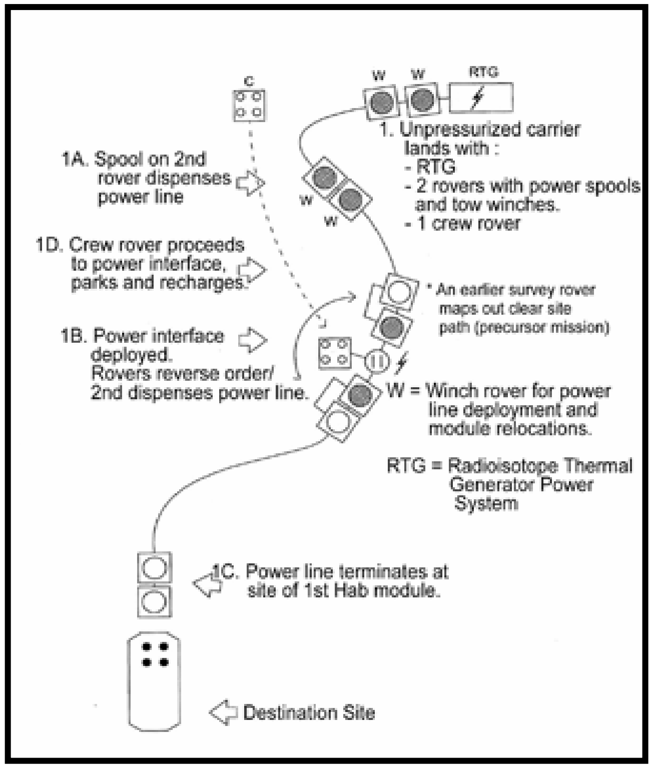


Figure 15. Stage 1: Power is Established.

Stage 2 : The first module is landed at the site.
-The module parks unmanned at the end of the power line leading from the RTG.

Stage 3 : The first 4-person crew arrives at a different landing site at a safe distance from the module.

3A. The crew rover leaves the power interface charging station and automatically tracks to the crew landing site.

3B. The crew departs on the rover and proceeds to the module site to connect the power cable and set up/ check out operational capabilities.

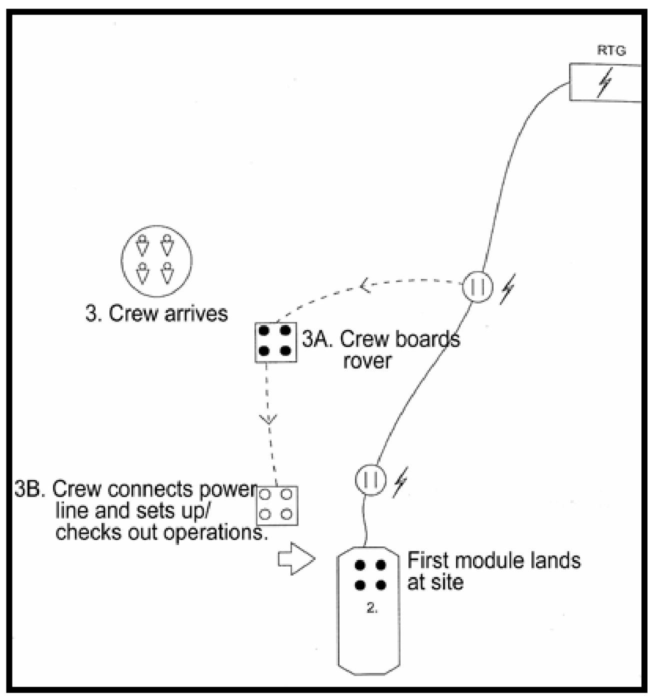


Figure 16. Stages 2 & 3:1st Module Set-up/employment.

Stage 4 : A second hab module which also carries logistics supplies lands at a new site.

4A. All rovers recharge at the site of the first module.

4B. The rovers with tow winches proceed to the power interface and recharge.

4C. Two of the crew members depart on the crew rover to the 2nd module.

4D. The tow winch rovers are automatically dispatched to rendezvous with the crew at the 2nd module and winch cables are attached to the module.

4E. The winch rovers tow the 2nd module to the site of the 1st module, and the crew onboard their rover control operations.

4F. The full crew participates in positioning the 2nd module into a berthing alignment with the 1st, check out interfaces, and complete operational readiness procedures.

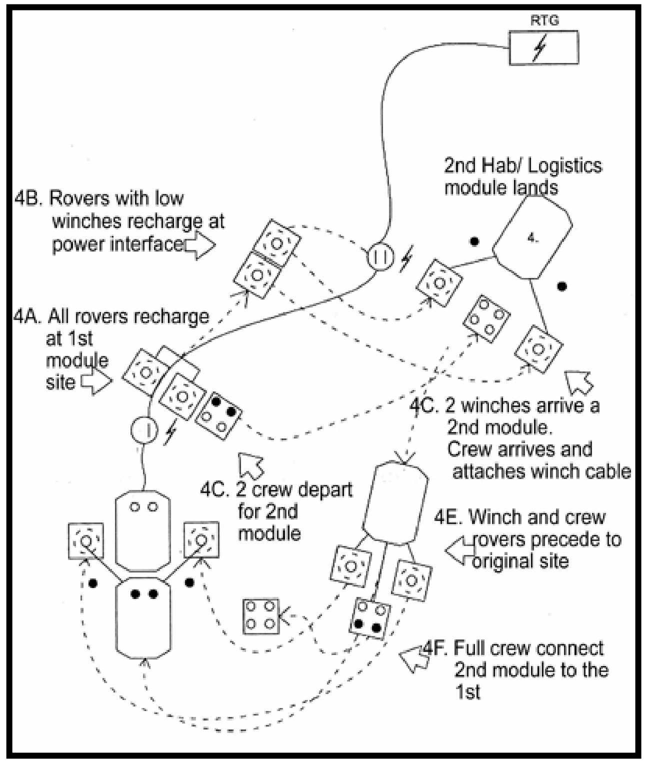


Figure 17. Stage 4: Operational Status.

VIII. Radiation Shielding Considerations

A variety of lunar habitat shielding concepts have been proposed to take advantage of natural geologic features and surface materials for radiation protection:

- Putting modules in underground lava tubes.
- Tunneling into crater walls.
- Covering facilities with 50 centimeters or more of lunar soil (regolith). (Figure 18)

Each of these proposed approaches present significant problems:

- Use of lava tubes will severely limit site selection and development options.
- Tunneling or material transfer to cover modules will require large, automated equipment, and it will be difficult or impossible to connect other modules later.

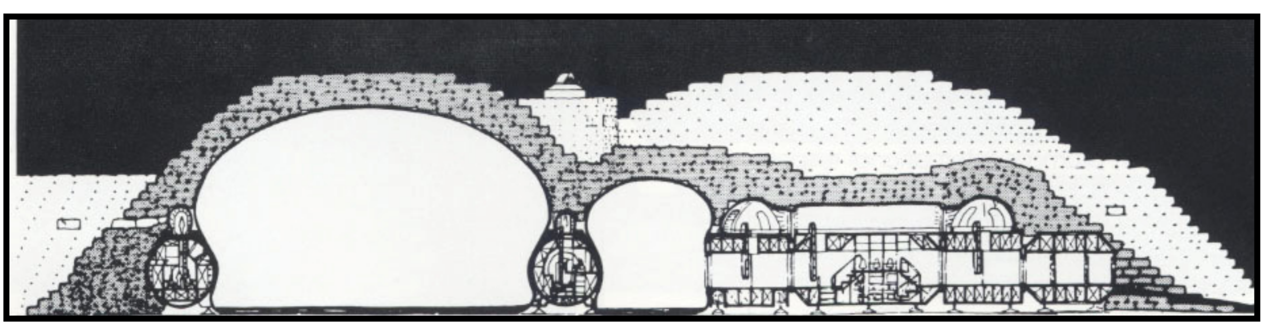


Figure 18. Early SICSA Concept Using Bagged Regoltih for Radiation Shielding.

As shown in Figure 19, use of regolith radiation shielding is not recommended for lunar/ Mars surface habitat applications:

- The amount of material that would have to be excavated, moved and emplaced exceeds capabilities of equipment that would be practical to launch, transfer and land.
- After a module is covered, it would be unimaginably difficult to connect another for evolutionary growth.
- Very long EVA tunnels would be required to enable access/ egress at points beyond regolith slope angles.
- Flexible tunnels and other inflatable structures would be collapsed by loads in the event of temporary pressure losses.
- Outside viewing would be prevented due to material obstruction.

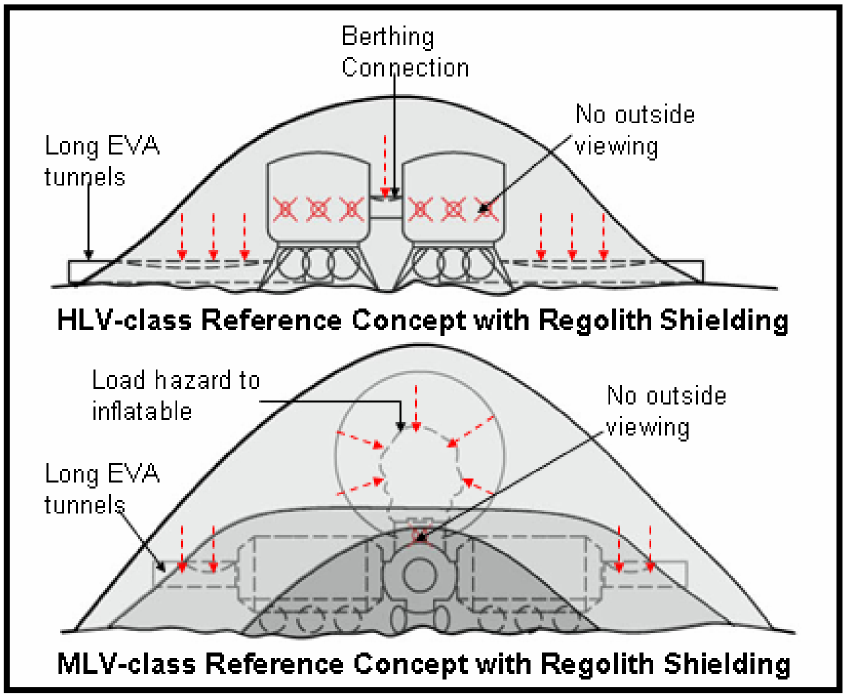


Figure 19. Regolith Shielding Problems.

References

The assumptions, concepts and conclusions presented in this paper are based upon numerous design studies conducted by the Sasakawa International Center for Space Architecture (SICSA). Related and supportive reports can be accessed on SICSA's website: www.sicsa.uh.edu. All reports are available free of charge to interested parties.