# Preliminary Infrastructure Development for Altair Sortie Operations

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**NASA's Exploration Systems Architecture Study (ESAS) report envisions humans returning to the Moon in the 2020 timeframe. However, many factors still need to be addressed in depth. They include site selection, materials, and design of inhabitable and survivable infrastructure elements. One of the most important issues dealing with a manned return mission to the Moon is lunar dust. Dust suppression is a critical issue with regard to Altair operations as well as surface vehicles in the proximity of the habitat. Dust and debris thrown up by vehicles can also degrade exposed payloads such as telescope elements and photovoltaic arrays. This paper explores several architectural concepts relating to developing essential preliminary infrastructure for humans on the lunar surface during the first several missions. Concepts discussed include certain selection criteria aspects for lunar habitat location as well as a variety of architectural elements, which can ameliorate the effects of lunar dust during Altair operations and routine surface vehicle movement around the primary lunar settlement. Specifically, these elements include a microwave sintered landing zone around a hard, paved and topped landing pad for repeated service use, inflatable structures for blast aprons, a light rail system with pallet, winch and gantry support for lander and payload transport from landing pad to hangar or habitat location, a hard, topped dust-free platform on which to erect the habitat and allied structures, and a built-up access road from the habitat area to the hangar and the landing pad. An emergency exit route from habitat to a standby escape vehicle is also depicted as well as a dust monitoring system and a dust cleaning rover attachment is suggested as well.**

## I. Introduction

THE USC ASTE 527 team project of Fall 2008 "Return to the Moon: Looking Glass 204" explored a variety of concepts for NASA's plan to return people, first on one week surface stays, extending them to 14 days and eventually up to six months.

The USC team was tasked specifically to go beyond NASA's Mars Forward technology development program to propose on two more fronts, namely to commission a variety of permanent assets that are useful not only to the scientists but also for the public and to look at how this specific project might be employed to inspire a new generation of explorers.

This project is envisioned to happen between 2020 and 2040. Assuming two or three Altair missions every year, we expect between 50-60 Altair derived landers to be serviced around the lunar globe, with at least 50 of them in the vicinity of a south polar lunar settlement. They include both crew sortie and cargo missions. The other 10 landers would primarily be cargo landers with specialized payloads to be commissioned in remote locations of the lunar globe. Substantial international participation is foreseen in all aspects including Earth to Moon transportation, landers and payloads. It is in this context that the preliminary infrastructure development concepts proposed in this paper are portrayed.

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## II. Lunar Settlement in Polar Region

While satellites are still gathering crucial data, there is some consensus building within the space community which suggests that polar regions might offer a better initial location for manned lunar operations. The South Polar Region is shown in figure 1. [1]

The Malapert mountain range, the Malapert crater and environs have been discussed in recent literature as potential regions of interest to locate a lunar settlement[2]. The Shackleton crater and environs, almost directly at the South Pole has also been targeted as a site of interest[1]. The distance to the Schrodinger crater is also shown in figure 1, primarily because it is an ideal location to setup sensitive radio telescopes. This far-side location of the Moon would effectively block any interference from radio-noise generated on Earth. Eventually, an advanced far-side settlement would also better simulate conditions on a planetary base without the Earth-disc in view for the crew.

Pending more specific data from missions in progress including the Lunar Reconnaissance Orbiter/Lunar Crater Observation and Sensing Satellite (LRO/LCROSS), these two locations were adopted as the sites of interest for the Fall 2008 USC project.

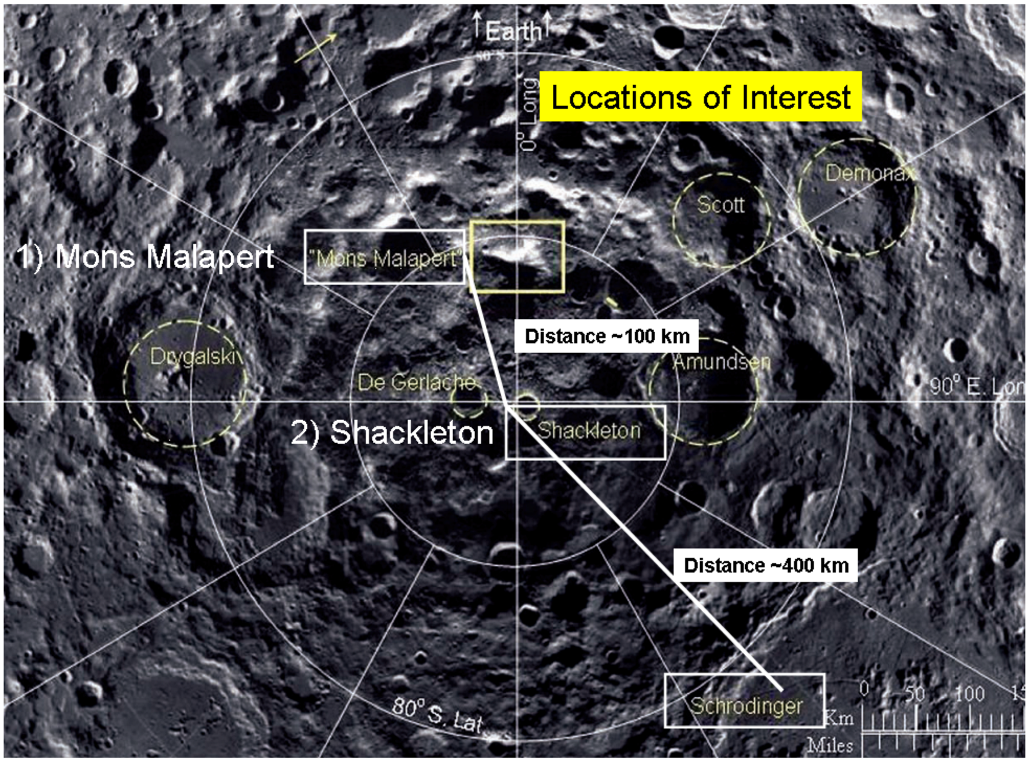



**Figure 1: Image of Lunar Map of the South Pole[3, 4].** *Lunar map shows regions of interest for the lunar colony; Mons Malapert and Shackleton, and their distances between each location. The distance to the Schrodinger crater is shown as it is a good location for situating certain observatories away from Earth noise using robots and crew in extra-vehicular activities (EVA).*

## III. Preliminary Infrastructure (PI) Elements

Generally, besides offering ample opportunity for exploration and technology development, a site must provide a safe zone for crew to operate in. It must present a viable route for logistics support and emergency abort operations and rescue missions. The polar regions of the Moon also offer longer periods of solar illumination[2, 5], allowing the quick and straightforward deployment of photovoltaic power plants for near-continuous electricity generation. If water and volatiles are confirmed there, this will be a boon to the settlement by providing liquids and gases to replenish power, consumption and other losses.

Sulfur has been proposed as a binder for lunar concrete[6]. Water could also make a good binding agent, allowing straightforward regolith stabilization and dust suppression, through sublimation-deposition process, in permanently shadowed lunar development.

For Altair operations, the following site attributes and systems are considered essential:

A. Topography suitable for direct line-of-sight visual acquisition of landing zone for Altair pilot, preferably both during lunar day as well as lunar night, aided by Earth shine.
B. Dust suppression employed around approach and ascent zone.
C. A well lit, sturdy and dust free landing pad.
D. A simple and easy to deploy system for transporting Altair lander and payload from landing pad to hangar and habitat.
E. A safe and reliable means to transfer crew and cargo to and from habitat.
F. A similar way to conduct lift-off operations.
G. A quick and reliable exit to abort or rescue crew in the event of an emergency.
H. Allied structures to support these activities.
I. Other Systems for PI depicted in Looking Glass 204 Project

Figure 2 depicts the main preliminary infrastructure design of the proposed lunar colony.

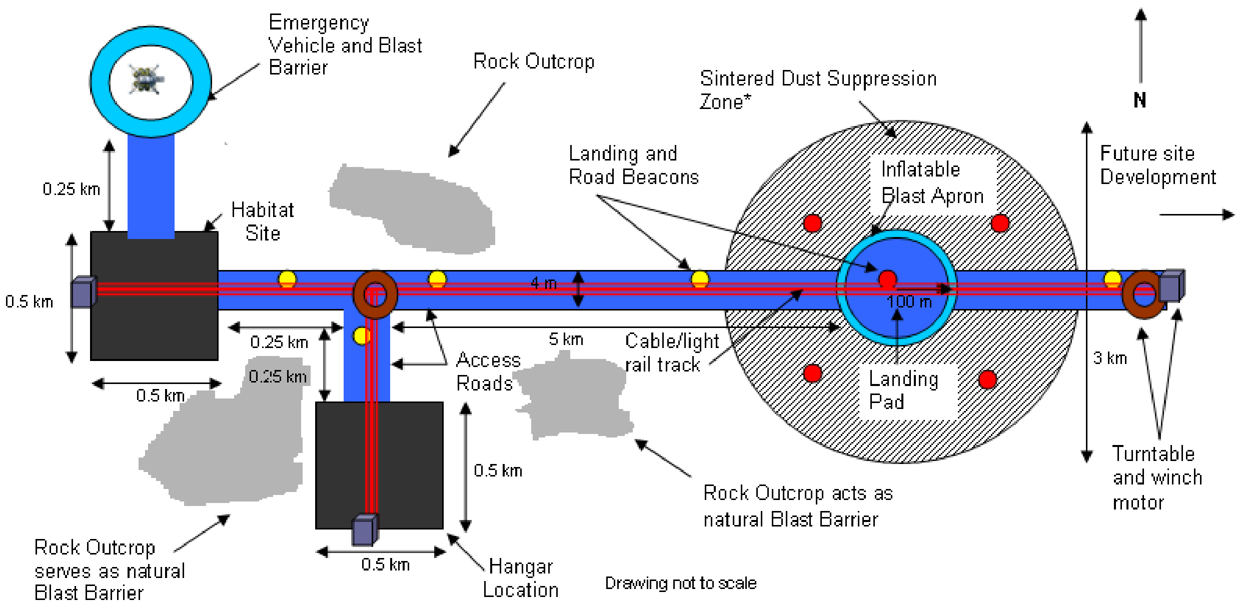



**Figure 2: Preliminary Infrastructure (PI) design.** *Design and dimensions of lunar base, top view (drawing not to scale), which includes the emergency escape vehicle, the cable/winch system for moving equipment easily out of the landing pad area as well as shows the various regolith rock outcrop show depending on location. *Note the landing pad and dust suppression zone is on top of an elevated surface.*

## A. Direct Visual Acquisition of Landing Zone and Pad - Earth Shine

The shallow insulation angles in the polar regions tend to present a dimly lit lunar surface with stark relief and stretched shadows. However, since Malapert range faces the Earth, a carefully selected landing site in this region would also be illuminated by the Earth disc for most of the lunar night[2]. Earthlight would allow for visual acquisition of landing zone for Altair pilots. Even though the Altair lander would be assisted by instrumental landing aids, the ability for the pilot to take the controls at any time during descent and touchdown is considered essential. Earth shine would also allow for enhanced lunar surface operations, alleviating thermal loads on operational systems across the board.

## B. Dust Suppression

As the Altair lander descends towards the landing pad, the main engines and reaction control system (RCS) will kick up a large amount of lunar dust[7] as shown in the images of figure 3. To minimize this effect caused by Altair descent engines, it is proposed to deploy the landing pad atop a natural hill or mound with a slope of between 1:12 to 1:20. To further prevent this dust scattering, the regolith surface around in an area about 3 km in diameter surrounding the landing pad, called the landing zone, will be stabilized.

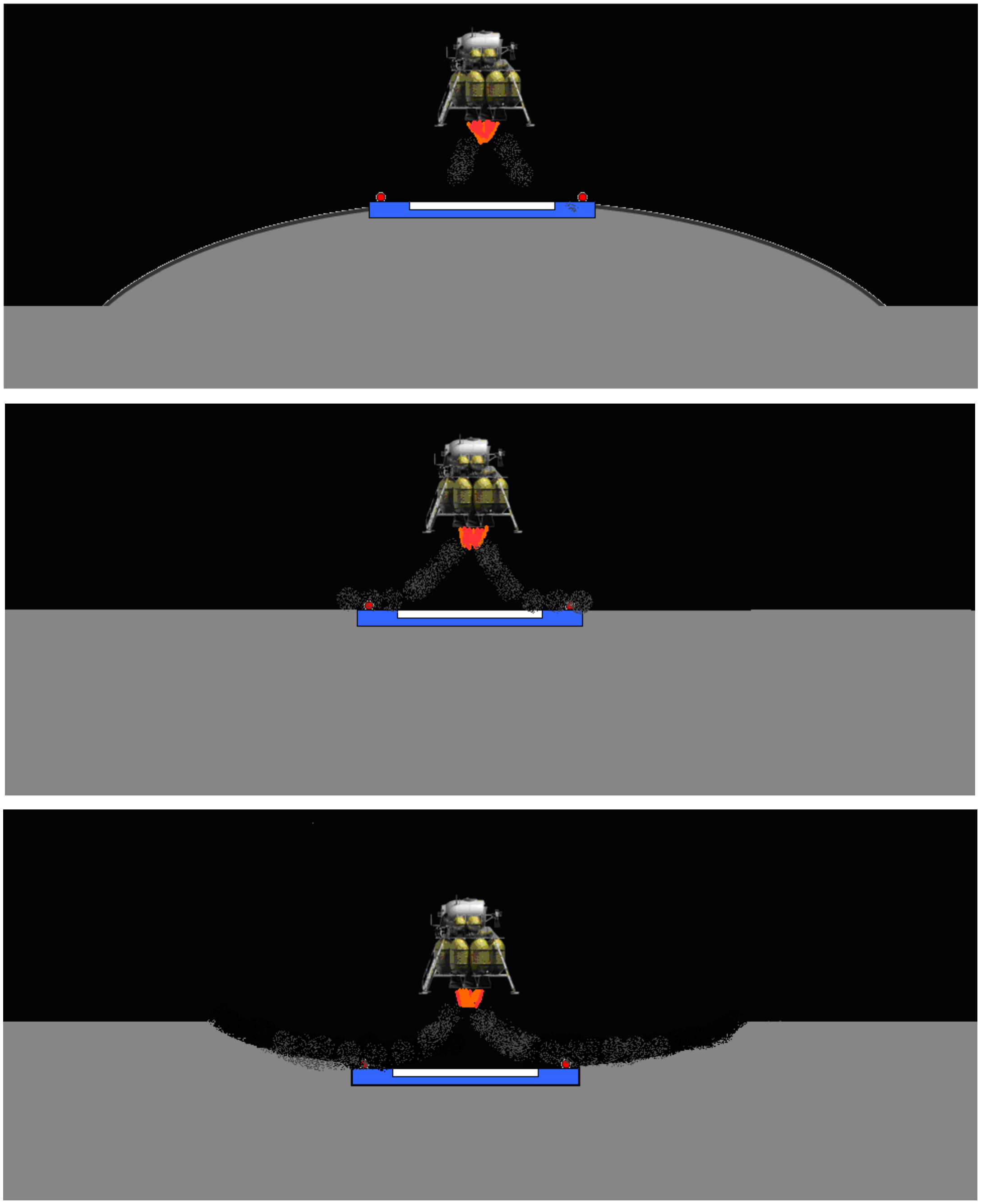


**Figure 3: Effects of lunar dust disturbance and Altair thruster ejecta on various landing terrain.** *Top images depicts landing on an elevated surface. Middle image depicts landing on a level/flat terrain. Bottom image depicts landing on a concave, crater surface. Detailed studies are needed to verify that an elevated pad on the lunar surface would show diminished dust disturbance than the other two alternatives depicted.*

### C. Landing Pad

The reusable landing pad should be easy to identify within the landing zone for the Altair pilot. It will have a resilient surface for repeated operations as well as all the supporting elements to assist in quickly moving the lander and payload in and out of this zone of activity. Inflatable aprons to contain or curtail lander ejecta are suggested.

By locating the habitat directly east from the landing pad and a possible expansion of the settlement located due west, the two-stage descent module of the Altair could approach and touch-down from the south and the ascent stage module could lift-off to the north when the astronauts depart the settlement, as seen in figure 4. This setup could help prevent or reduce lunar dust or propellant ejecta from landing on the lunar roads, and more importantly, the habitat location.

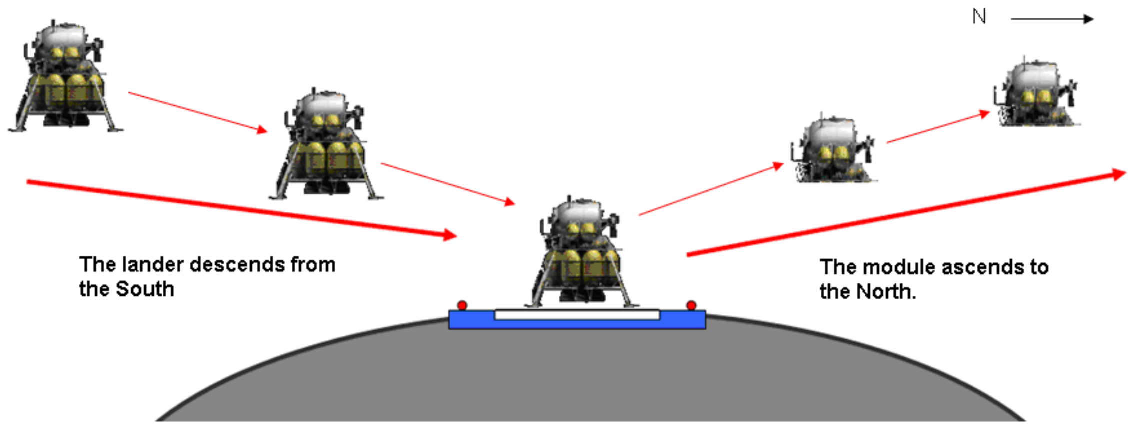



**Figure 4: Altair Lunar Lander[8] Ascent and Descent on Landing Pad.** *Image shows the approach and lift-off operations of the Altair lunar lander descent stack at touchdown (left) and ascent stage during lift-off (right).*

### D. Lander Payload and Cargo Handling

Once landed, an Altair cargo vehicle stack would be completely moved, cargo and descent stage intact, to the hangar, using a pallet on wheels and gantry crane assembly, preferably on a light rail track, powered by a winch system, in two stages. The first stage would operate between the landing pad and the hangar. The second stage would move payload from hangar to habitat as needed. This way, the landing pad and access is kept clear for the next Altair lander. In an alternate concept, if wheels are available on Altair stack, the lander may be winched away from the landing pad to the hangar, eliminating the need for the pallet system.

### E. Crew Transfer

Altair crew may be transferred from landing pad to habitat either by the winch and pallet system or using a rover traversing on the lunar access road. Rovers would also be used off-road to leave the colony and traverse the lunar surface and conduct various EVAs. Depending on the length of tour of duty, the Altair stack may stay on the landing pad intact with the ascent stage or may be moved to the hangar.

### F. Altair crew lift off

At end of tour-of-duty, the crew is transported back to the landing pad from the habitat by a rover. If additional cargo is involved, the pallet and winch system may also be employed. After crew departure, the expended descent stage launch platform will be removed by the pallet and winch system and taken to a hangar storage area, where it is salvaged for other uses including structures and tools.

### G. Mission Abort: Crew Rescue or Emergency

Crew safety is the top, overriding priority in all manned missions. In the event of an abort, caused by an unforeseen event or life threatening situation, a reliable procedure must be in place for rapid crew evacuation. Therefore it is proposed to have a standby Altair emergency vehicle, at a location close to the habitat as shown in figure 2, primed and always ready, if the need arises, to quickly retrieve the crew and inject them into a direct, homeward-bound trajectory. For this reason, a lunar ambulance is proposed to be emplaced and operational in advance of crew arrival at the settlement.

### H. Lunar Settlement Support Infrastructure

Though walkers, hoppers and other exotic means of mobility have been suggested, wheeled vehicles on tracks and hard topped, stabilized regolith roads are considered the prime crew transportation systems for an initial operational base. Pallets on wheels as one shown in figure 6, powered by winches are considered good candidates for moving cargo from landing pad to hangar and habitat locations. The gentle slope from landing pad to these other locations would help to decrease the winch forces needed for tugging the Altair lander stack and payload to hangar.

A wheeled Altair lander concept may also be practical if the wheels could be lined up on the rails or if the access road design can accommodate this method of transfer. Figure 5 depicts an example as a wheeled vehicle attached to a cable/winch system moves cargo from the landing pad to the hangar location.

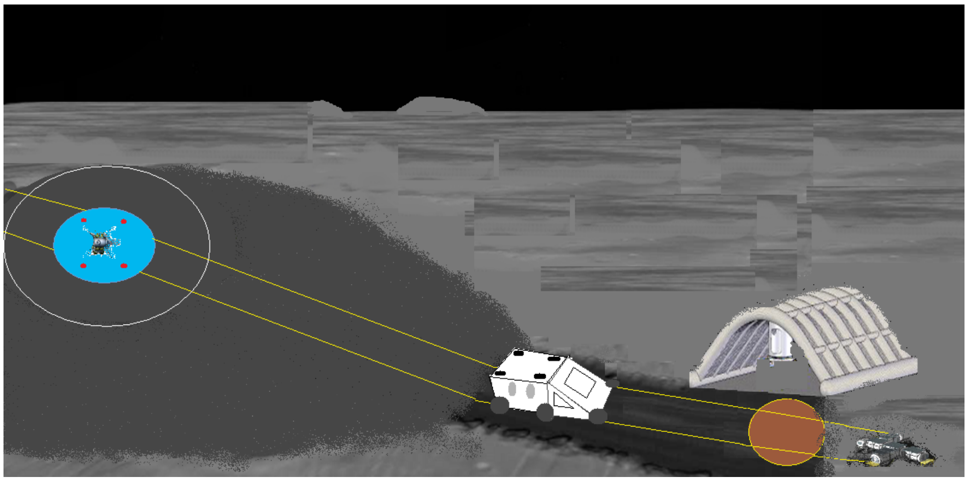


**Figure 5: Winch and Cable System[9]**. Winch and *Cable system moves large items from the landing pad location to the hangar storage location.*

## I. Other Tools/Systems for Preliminary Infrastructure (PI) - depicted in the USC Looking Glass 204 Project

Since excavation, grading and leveling are an integral part of PI, it is essential to have equipment for this purpose, transported to the site, at the earliest opportunity. Literature on lunar terrain development show various vehicles and systems, some of them variations of established and evolved technologies used very effectively on Earth[9].

In the USC Looking Glass project, under the section dealing with surface transportation concepts, the Service Car is depicted with a variety of tools including front loader, backhoe, rake, percussion drill and leveling blade for these PI tasks. A light crane, preferably mobile, is also considered essential for PI tasks[22].

In the In Situ Resource Utilization (ISRU) section of the Looking Glass Project, a crucial system for PI is the regolith crusher and sorter/grader which ingests large rocks that are quarried by the Service Car through a hopper feeder and crushes them into a range of grades of regolith to be used for the different layers of stabilized road construction[22].

In the Looking Glass Project, the Lunar Real-Time Teleoperations concept was presented as a strategy to circumvent the latency limitations associated with operating telerobotic equipment from Earth. Such a strategy would also allow the Altair lander crew to supervise robots much more effectively while minimizing risky EVA during build-up. A variation of the LunaRTT concept is the Cabin for Teleoperations that has been proposed in earlier literature (C-TOPS) [12, 22].

**Figure 6: Example Lander Vehicle[10].** *Lander with passive, unpowered wheels on NASA-JPL Athlete chassis avoids need for Pallet System or active steering, and may be towed by winch system to hangar.*

Since the Moon is a much smaller sphere than planet Earth[2], (~3476 km in diameter at the equator compared to 12,756 km for Earth), horizon distances are very close and Altair crew, even though arriving from altitude, will have limited time to react to maneuvers during approach and landing. So, systems are needed for reliable and safe guidance to landing pad.

As the vehicle approaches the lunar surface, the powerful plume of exhaust gases from the reaction engines, coupled with RCS thrusters, will raise a large quantity of small rocks, dust and ejecta, setting them off in dangerous trajectories at supersonic velocities[11]. This phenomenon, if not curtailed at the origin, can have devastating effects on high value assets, including habitat elements, crew in EVA, and exposed science payloads and observatories. The hover and touchdown maneuver can also cause similar damage over a long range.

Once landed, vehicles used for movement of payload and crew to and from the landing area to the habitat will also add to dust disturbance and effects, which, when compounded over several sorties, can adversely affect critical systems, impairing reliability and performance, all over the vicinity of the settlement[12], like the lunar colony example depicted in figure 7.

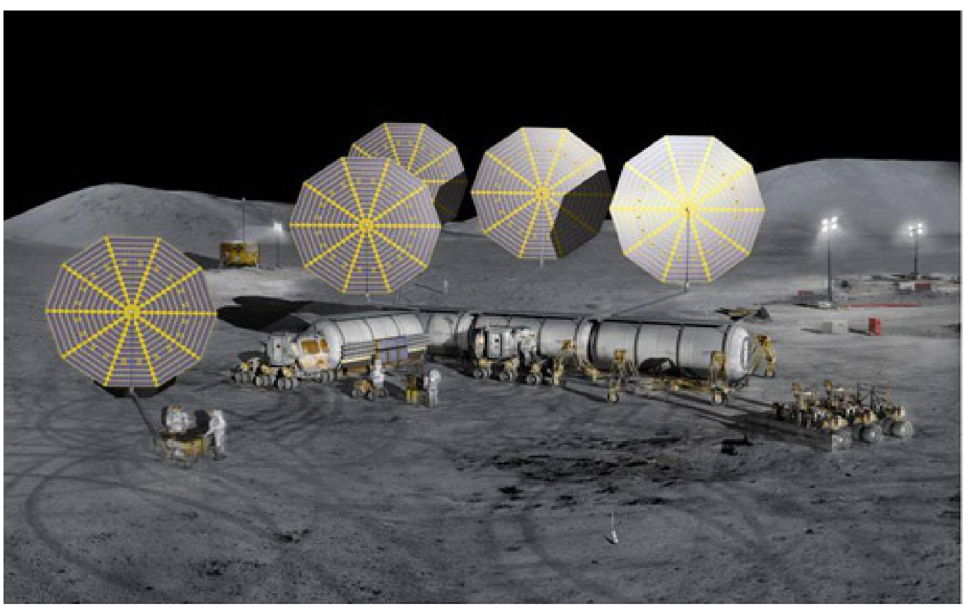


**Figure 7: Image of example Lunar Colony[8].** *Without regolith stabilization, dust would hamper operations in the vicinity of the settlement. Therefore dust-free platforms are essential, upon which modules can be assembled, before settlement can be certified for habitation, and routine activities commence.*

Concepts and notional imagery routinely depict wheeled vehicles racing around habitats and science payloads, while lunar base buildup is in progress, see figure 7. However, in reality, systems and vehicles operations need to be carefully evaluated as dust and debris transport in vacuum and low gravity conditions can seriously hamper lunar activity, as observed in the Apollo missions[7, 23]. See figure 8.

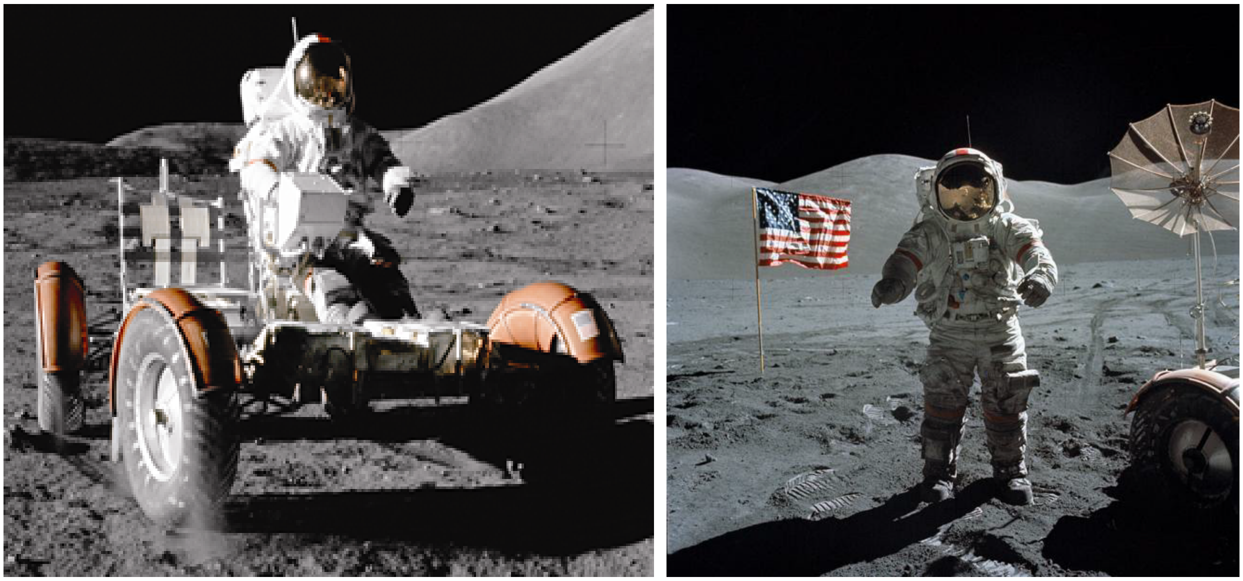


**Figure 8: Images of NASA Apollo missions.** Shows *the kick-up of lunar dust on and around the vehicle and the possible effects vehicles and crew may have to face around a lunar settlement (left)* ‡*. EVA suits are caked with dust very quickly and will affect nominal system performance. Contamination from backtracking dust into habitat is a major concern to be addressed. Eugene Cernan, Apollo 17-last J series mission, poses for camera (right)* §.

## IV. Critical Dust Suppression Systems

The lunar surface is mainly classified as the newly formed, dark colored, magma plains called "Mares" (because they looked like seas to early astronomers) and the light colored "Mons"(mountains) or lunar highlands that are much older, more heavily cratered, and present a very rugged terrain[5].

The topography of the Polar Regions mainly presents the latter terrain. Apollo missions landed mostly in the smooth mares, primarily for vehicle safety during descent approach and lift-off, but Apollo 16 sampled material from the highlands. Apollo 17 drill sampled down to 3 m. Lunar regolith is constantly bombarded by meteorites in a natural tilling process called "gardening," and presents a loose, top layer of fine, talc-like material[2].

Apollo missions indicate that is should be possible to work the lunar surface regolith (excavate and grade) easily to a depth of 0.5-1.0 m, which may be sufficient for digging the light-rail trenches, building the landing pad, the habitat and hangar platforms as well as the access roads.

In this study, we point to the following systems which are considered crucial for keeping lunar dust and debris in check. The preliminary infrastructure design shown in figure 2 takes into account many of the following systems dealing with lunar dust suppression.

A. Landing zone dust suppression system – using microwave sintering technology
B. Vectra surfaced Sturdy Landing Pad to service up to 100 Altair missions (landings and liftoffs)
C. Inflatable Blast Protection Aprons
D. Built-up and topped service roads between Landing Pad, Habitat and Hangars
E. A light rail system with pallet and winch operating between Landing Pad to Hangar and Habitat in two stages.
F. A dust-free platform for Habitat and associated structures
G. A dust cleaning vehicle to keep up and maintain structures

‡ "Where Dust Rules: Contamination and Coatings Engineering Branch to Build Dust Chamber," 11th, May, 2007, http://technology.gsfc.nasa.gov/Chamber.htm
§ Kipp, T., "Astronomy Picture of the Day," NASA, 17th Dec. 2005, http://apod.nasa.gov/apod/ap051217.html

H. A Dust Alarm and Monitoring System which detects dust disturbance caused both by natural agents (meteoritic impacts, micrometeoroid showers, anomalous solar events) as well as vehicles.
I. Hangar and Storage Location
J. Use of natural terrain as an asset to enhance safety

**A. Landing Zone Dust Suppression System**

Regolith stabilization methods include, firstly, selecting a region and site that has little dust. As experienced in some of the Apollo missions, some sites were naturally less dust laden[3]. If such sites exist in the selected rugged highlands of the South Polar region, then it might help reduce the need for extensive regolith stabilization in the landing zone.

Secondly, it may be possible to coat the area with a to-be-determined (TBD) material. However, the volume of material needed and the process involved need further study once hard data become available. As indicated earlier, if water is available and the landing zone is located in permanently shadowed region, surrounding a well-lit landing pad atop a hill or mound, perhaps water might be used as a binding agent to stabilize the shaded landing zone.

Third, microwave sintering of regolith is considered a viable approach for dust suppression, especially when such a surface is not subjected to appreciable point loads as caused by dragging the Altair lander and its payloads over it. It is possible to imagine a robotic microwave sintering unit atop a solar powered rover that slowly stabilizes ~10 $km^2$ of lunar surface surrounding the landing pad. The sintered regolith zone will be very large, circular, with a diameter of ~3 km. This lunar surface stabilized dust-coat will be created through an apparatus that will consist of a radio-frequency (RF) laser that will penetrate the lunar regolith dust and melt the top layer surface into a uniform, bonded structure that will be solid enough to prevent a lunar dust plume from being created when the Altair arrives and lifts-off from the landing pad[13-15]. This lunar dust-coat will help prevent the dust plume that would otherwise have been created during Altair landing or lift-off, from reaching the habitat. This laser apparatus will be attached to a robotic mini-rover that will continuously sinter the lunar dust over time either autonomously or tele-robotically, with crew supervision as needed.

The reason why this sintering process is such a slow process is because of the time it takes to sinter, the lunar environment, as well as the area of regolith that needs to be sintered. The mini-rover will traverse around the diameter of 3 km several times over just to completely sinter one section of the zone into a stabilized lunar dust coat. After the first section is completely sintered, the rover has to traverse inward in a concentric, circular, spiraling path, sintering closer and closer to the center of the circle, up to where the landing pad is located. This is done so that the rover does not roll over the sintered regolith. Since this sintered surface is brittle, any direct forces applied to it might cause it to fracture. Therefore, the adopted procedure avoids the rover accidentally fracturing the sintered surface.

**B. Vectra surfaced Sturdy Landing Pad - to service up to 100 Altair missions (landings and liftoffs)**

At the outset, at least three options are possible to designing a sturdy, road-like surface on the Moon[12]. Ranging from the low to the high energy expenditure options they are:

In the first option, naturally occurring, raised, flat rock outcrop of the required 100 m diameter, needed to service the Altair vehicle. If such an opportune site exists, then with minimal dust and regolith debris clearing, it may be possible to convert it into a landing pad by clearing the gardened, top regolith material and exposing the solid, monolithic surface for landing pad[12]. See figure 10a.

One method to clear the gardened, monolithic rock outcrop, during this phase of build-up when there is a paucity of equipment and infrastructure, might be for the Altair lander to conduct an extended TBD period hover maneuver over the site, which would effectively blow away all loose rock and dust over such site, exposing bedrock. Once the site has been cleared this way, after minimal "cut, scrape and clear" preparation, a resilient top may be rolled out and pinned in place. Of course, the penalty is the added fuel required on a loaded Altair lander, and trade-off's need to be studied. The effects of the LOX/LH2 cryogenic RL10A-4 engine cluster superheated $H_2O$ exhaust[16], impinging the lunar surface might create a stabilized ice surface by itself, and depending on ambient lunar surface temperature, could be used to stabilize the terrain, even if temporarily.

In the second option, since there is no appreciable lunar atmosphere to deal with, if the surface is hard and compacted, with minimal improvements, it may be possible to roll out and pin down a lightweight, tough, impermeable, dust resistant membrane (TBD) over a smoothly leveled and compacted surface. This might be a quick way to deploy a landing pad[12]. Helipads, aircraft carrier decks and runway tarmacs may offer clues on how to deploy such a surface. See figure 10b.

In the third and the fully built-up option, a naturally occurring round hill or elevated mound, as known to exist in the equatorial regions visited by Apollo missions, if found in the polar region of interest, is selected around the chosen site[12]. An extensive layer by layer road surface is built up, resembling roads on Earth, a tested and sturdy technology evolved from the Roman era. See figure 10c.

Since 60 landings were assumed at the outset, it became clear that a highly serviceable landing pad and support systems are necessary. The design requirement assumes 100 Altair touchdowns on the landing pad.

The primary mission of the first crew assisted by robots on site is the landing pad and access road construction. The construction of this landing pad will need to take into account the space environment, regolith ranging from microscopic lunar dust particles to large rocks as well as extreme temperatures. The materials that will be used to create these landing pads could be Vectra fabric, carbon fiber and/or Kevlar[11]. It may be shown that one or more of these materials can be very useful in the lunar environment as well as be able to handle high velocity impacts, which is needed to service accidental or unintentional rough landings.

The landing pad dimensions will have a diameter of 100 m and will take into account the size of the Altair lunar lander which is estimated to have a footprint of 14.9 m in diameter[16]. The Altair lunar lander, see figure 9, powered by RL-10A-4 main engines which lands with 83 kN thrust, and the ascent stage which lifts off with 24 kN, and with several thrusters firing monopropellant at a force of 445 N each[17], can create lunar dust ejecta that will shoot out from every direction creating a dust plume that will spread around the landing pad area, including into the lander itself[11]. The landing pad is located several kilometers away from the main habitat for this reason. It is meant to protect the equipment, rovers and other structures from being adversely affected by energetic particles of lunar rock, dust and ejecta.

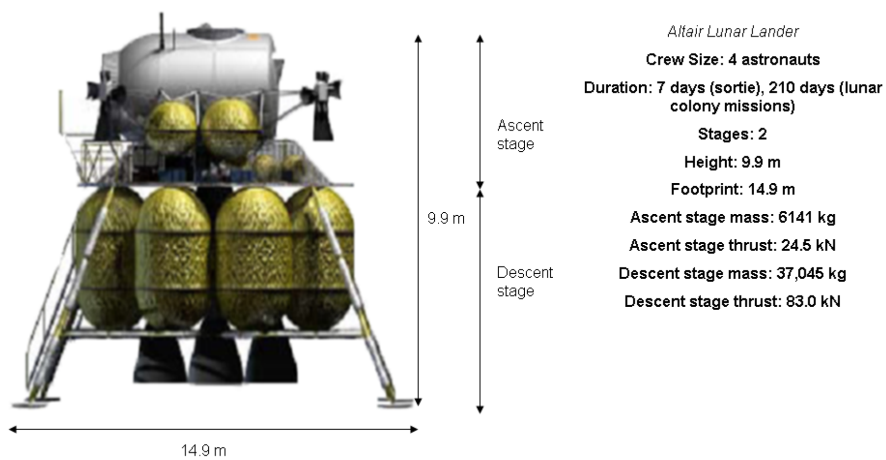



**Figure 9: Reference Altair Lunar Lander specifications[16].** *Image and specs shows the notional full stack (payload crew module, ascent / descent stage tankage, RL-10 engine cluster) Altair Lunar Lander's dimensions.*

The second factor that has to be taken into account when developing the landing pad is the lunar weight of the actual Altair vehicle relative to the landing structure as well as the topography and subsurface conditions of the lunar hill or mound that the landing pad is going to be constructed on. The lander can touchdown with a maximum impact loading of up to 35 mT when fully loaded with equipment and other cargo[17], therefore the composite surface created for this lunar landing pad must handle at least 50 mT, accounting for a rough landing with safety factor.

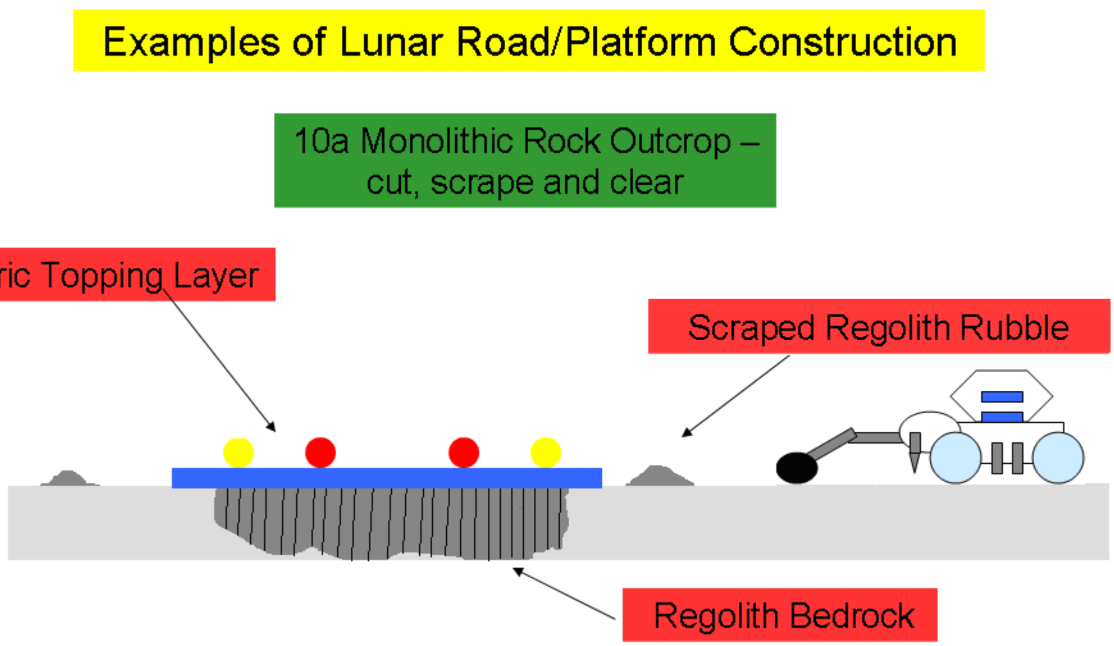
The Department of Defense and the International Civil Aviation Organization are examples of agencies that continually monitor, evaluate and innovate for crew and passenger safety on runways and heliports, and could offer insight into design, operations and maintenance of lunar landing pads[18].

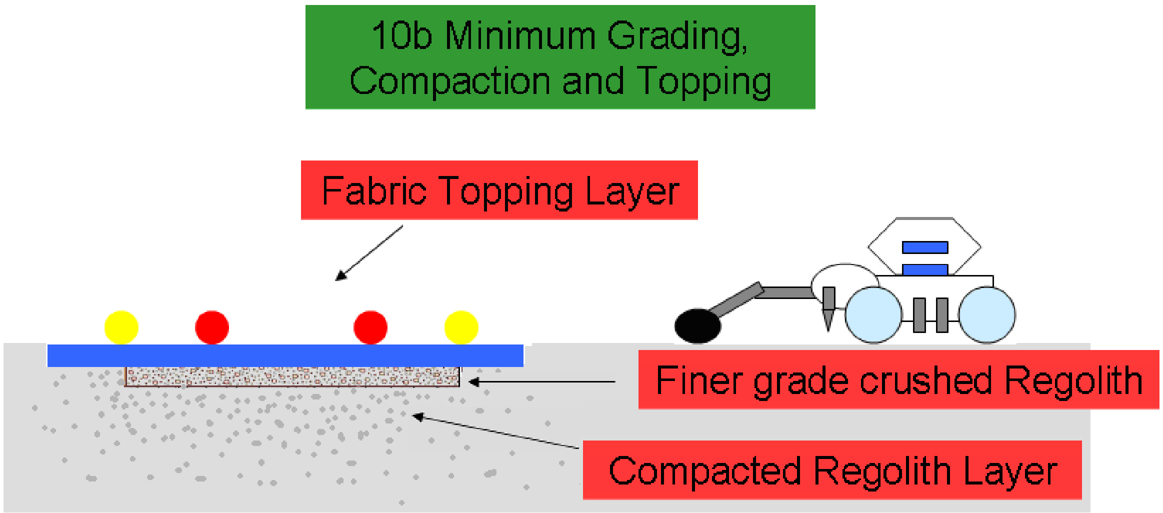
### C. Inflatable Blast Protection Aprons

The blast barrier/apron will consist of an inflatable membrane with woven fabric exterior to impede ejecta particles and dust[19]. This blast apron will directly surround the landing pad and will be installed in several sections, with one or two sections being mobile for access in and out of the landing pad. These sections will be large enough so that all cargo, materials and equipment can easily pass through. The blast apron will be anchored to the ground as well as to each other by pins, hooks and anchors. Cold gas monopropellants would be used to inflate the blast apron to a height of 3 m. Also, lunar regolith ballast can be added to provide it with an additional layer of stability as well as natural protection from lunar dust. This layer of lunar regolith, added to the inside of the blast apron, can be separated or partitioned off from the area of the monopropellant.

**D. Built up and Hard topped Service Roads between Landing Pad, Habitat and Hangars**

The first step in built-up road construction design (based on figure 10c) would be to excavate and grade the lunar surface, specifically the area that will include the landing pads, roads and habitat/storage platform areas. Astronauts will conduct several EVAs, using ISRU techniques to clear regolith and survey the area in which the flat, road-like surfaces are to be constructed upon[9]. While the excavation and grading/leveling is taking place, several loads of regolith are crushed in a mechanical crusher that will create the aggregate and the various sizes of crushed regolith that will be used to grade the road-like surfaces. After the excavation and surface leveling is complete, a layer of compacted regolith will be spread around the leveled surface, creating the first of several layers of regolith. Next, a layer of crushed regolith, lunar rock that has been removed from the surface and crushed into a usable form will be added on top of the compacted regolith. The third stage would be to add a type of regolith aggregate that is very coarse. This stage would add strength as well as reinforcement to the road-like surfaces. Directly after this stage, a finer grade of regolith aggregate would be added onto the previous layers[20]. The final stage would be to roll out the Vectra fabric topping layer on the surface of the regolith layers. This fabric laid on top will be anchored onto the layer with screws. After anchoring the main surface layer of the road-like surfaces, landing beacons will be installed and markers applied throughout the road-like surfaces as aid for visual navigation. Figure 10a-c shows the various layers used in the construction of the lunar roads as well as compares the monolithic outcrop and minimum grading options.





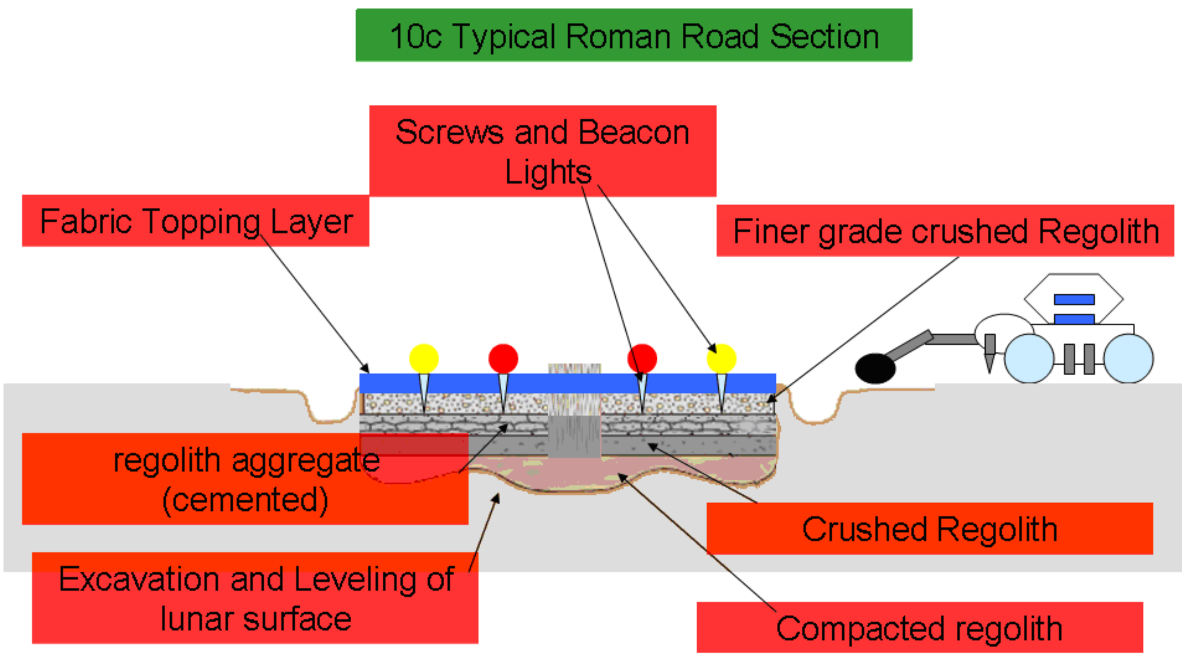




**Figure 10: Construction examples of Lunar Road-Like surfaces:** *Three examples are shown. First method is to use the cut, scrape and clear technique on the exposed regolith bedrock (10a). Second method is to use compacting, minimal grading and topping (10b). The third, extensive method is to detail the different layers of construction of road-like surfaces using grades of regolith via ISRU*** *(10c). A similar strategy is used to build up the habitat and hangar platforms on which lunar structures for habitats and storage are to be erected.*

### E. A light rail system with pallet and winch operating between landing pad and hangar and habitat

A light rail system is considered an effective, safe and energy-efficient way to transport the Altair lander stack, complete with payload, from the landing pad to the hangar and habitat. This system coupled with a stationary winch, one each at the hanger and the habitat-end of the rail track, allows all the power and traction systems to be located at

** Encyclopedia Britannica, Copyright 1999, http://www.britannica.com/EBchecked/topic-art/507905/19287/Ancient-Roman-road-shown-in-cross-section the settlement, while being able to move large masses between the pad, hangar and habitat zones. This system, in two stages, simplifies the need for distributed power and other massive components which are otherwise needed on the Altair lander. A light gantry crane located either on the pallet or at turntables at the pad, hangar and habitat completes the payload handling system. An added advantage is that since the pallet is held in place by the winch cables and it operates on tracks, the heavy Altair stack can travel much faster and perhaps more reliably than a comparable rover with more degrees of freedom of movement.

**F. A Dust-free Platform for Habitat and associated structures**

The access road terminates at one end at the landing pad, and at the other, a large deployed or built-up dust-free platform on which to erect the settlement modules. As mentioned earlier, without such a platform, the settlement will be hampered by dust from vehicles and crew operating in the vicinity, and will quickly become unserviceable.

The habitat platform is the location where the crew living quarters are and where a temporary setup of mobile rovers will be converted into a livable habitat for the astronauts. It is where they will sleep, eat, and conduct experiments. The area that it encompasses should be able to handle not only the living quarters, but equipment as well, including satellite antennae, multiple rover vehicles, tool and service sheds, and other equipment needed to develop the settlement on the Moon. Therefore, necessary expansion hooks and scars are built into platform periphery to facilitate incremental expansion.

The habitat platform will be constructed in virtually the same manner as that of the lunar landing pads and lunar access roads. The lunar habitat area is an extension of the lunar roads and opens up in a similar fashion to that of a common parking lot. The habitat components will be transported from the Altair and will traverse down the mound through the several kilometers of road into the completed habitat platform.

In the case of a deployed platform, the surface is leveled, graded and then a TBD fabric is rolled and screwed into place as in the landing pad system. If a built-up platform is deemed necessary, depending on estimated traffic patterns and usage, the same grade-by-grade, layer-by-layer method is used to raise up the platform, and finally topped with TBD dust impermeable fabric.

**G. A Dust and Particulate Cleaning System - to keep up and maintain structures**

A dust cleaning system will be used to help remove lunar dust off the habitat platform as well as access roads on a regular maintenance routine. The system might be mounted on an unpressurised or robotic rover such as the Chariot and is used as needed to keep lunar dust at bay. Since fine lunar dust is electrostatically charged and electromagnetic[2], this system might use those properties to remove it by collecting it in a retainer for later disposal.

**H. A Dust Monitoring and Alarm System**

Since lunar dust can quickly impair lunar settlement activity, it is essential to keep track of dust and its movement around the surroundings. A system which continually detects dust disturbance caused both by natural agents (micrometeoroid showers) as well as vehicles and crew in EVA and informs the crew is proposed.

Dust detection, monitoring and control is a well established technology here on Earth, with applications ranging from clean rooms in electronic chip manufacture, biotechnology and surgical theaters to smog control and pollen monitoring and other particulate detection and distribution in the atmosphere. Space qualified equipment for atmospheric studies are also available. Employing the physics of back scatter or other principles, highly sensitive instruments should be able locate, identify and alert crew about lunar dust movement and potential contamination hazards well in advance, so necessary action may be taken to neutralize the threat.

Lunar dust phenomena are not fully understood. The processes which generate them include natural meteorite impacts, micrometeoritic showers and effects caused by charged solar particle events as well as those that might be artificially caused by lunar buildup activity.

A dust alarm system would be created and implemented that will warn astronauts of incoming particles of debris that is a threat to the settlement. This detection system will consist of scanning laser sensors around the periphery of the settlement and they will electronically transmit and relay information back to the habitat computers or other mobile information systems that the astronauts use so that they can either prepare and take precautionary steps in order to mitigate lunar dust or assign the dust cleaning vehicles to clean up the lunar dust.

**I. Hangar and Storage Location**

The proposed hangar storage location will be directly adjacent to the main access road. The purpose of this location is to store any used items that would otherwise be discarded. This “Moon Junkyard” primarily would store the descent module of the Altair lunar lander as well as other expended items that could later be salvaged to build other structures or tools in the future. Furthermore, this area could well be expanded from its current design of 0.25

km$^2$ if the storage area is filled to capacity or needs to be partitioned off to separate descent stages of the lunar lander with that of other decommissioned materials. This storage location will be useful into the future because all the used materials collected over time can be used in place of bringing additional materials from Earth, and thus saving time and money, and over time, it would help to make the lunar settlement more self-sufficient.

**J. Use of natural topography and terrain assets to enhance safety**

The rugged polar highlands offer both a challenge for Altair pilot operations and well as opportunity for lunar settlement designers. While flight trajectories may require pilots to deal with some visual acquisition and navigation difficulties, instruments would allow them to lock-on to target to be guided safely to the landing pad employing instrumental landing system aids.

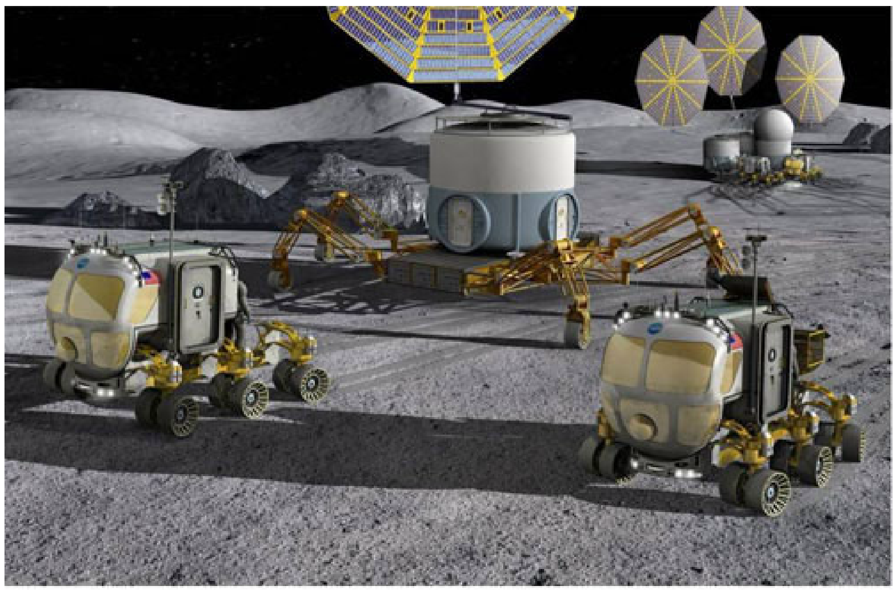


**Figure 11: Image of Lunar Rovers in Rugged Polar Terrain[9].** *Craters, large rock outcrops (as seen in this image) and other natural terrain features could be used to enhance safety by providing naturally stable thermal environments, shelter from solar storms and particle events, serve as blast barriers and be an effective micrometeorite shield for a variety of exposed payloads as well as habitat facilities.*

The natural rock outcrops such as those depicted in figure 11, if "designed in" with care, may provide large areas with less dust disturbances as well as act as natural blast barriers for situating hangars and habitat infrastructure. Suitably sized craters may also be surveyed for natural landing pad aprons, fuel caching depots and storage areas. Natural terrain contours and landmarks could be employed to effectively reduce distances between Altair lander operations and permanent habitat location. Therefore, high fidelity terrain topography and subsurface data are essential before detailed lunar base site planning and architectural layouts can be initiated. Both orbital and surface precursor missions are expected to provide this crucial information.

## V. Further Studies

Periodic meteoritic impacts, constant micrometeoroid bombardments, and solar particle events may all play a significant role in lunar dust levitation and transport. Lunar dust transport mechanisms including electrostatic and electromagnetic processes need to be investigated in more depth before permanent assets are deployed.

The reference Altair lander has a 14.9 m landed footprint. Winch theory and allied applications like cable cars, escalator and conveyor systems as well as specialized aeronautical applications such a glider launch support are well established. If towing by winch to destination is the adopted strategy, then the laying of light rails and the width of access roads need more definition. Stationary winches will require solid anchor supports and need to be studied.

New concepts to reduce footprint after Altair lander touchdown may offer an alternative venue to investigate. Variations of the NASA/JPL Athlete chassis may offer some solutions and needs to be looked into[21].

The grading and hard-topping procedure depicted is a reference case based on road and platforms built and serviced on Earth. More hard data on lunar polar surface stability and subsurface conditions including cold trap phenomena and permafrost effects (if volatiles exist at those depths), soil mechanics parameters such as compaction, soil bearing strength, are all necessary for developing detailed designs.

The effects of the Altair Lander LOX/LH2 cryogenic RL10A-4 engine cluster's superheated $H_2O$ exhaust, impinging the lunar surface vacuum[24,26,30], posing extreme temperature gradients (123$^o$C sunlit to -233$^o$C shade), might create a stabilized ice surface by itself, and depending on ambient lunar surface temperature, could be used to stabilize the terrain, even if temporarily. This effect may have important advantages, or might pose added exhaust ejecta threat,[25, 27] especially relating to lander dust and ejecta mitigation, and needs detailed investigation.

Since the operations depicted in PI are sequentially chained and complex, with tolerance bottlenecks in activities and their schedules, studies and end-to-end high fidelity simulations, using a variety of systems are essential, to fully appreciate the merits and limitations of alternate strategies and equipment proposed here.

## VI. Conclusion

Candidate preliminary system architecture concepts to tackle, curtail, suppress, moderate and eliminate lunar surface dust during settlement buildup are presented in this paper.

The permanent lunar settlement's preliminary infrastructure includes the construction and commissioning of several elements including a serviceable landing pad for repeated Altair sortie operations, a sturdy system of access roads and light rails for transporting the lander, crew and cargo from the landing pad to the habitat and hangars, and a dust-free platform on which to erect the settlement for routine vehicular access, logistics and crew activities.

Since lunar dust has extreme cohesive properties and adheres to and fouls up anything that it comes in contact with, as evidenced during the Apollo missions[27,29], dust suppression technologies are of critical importance. Precaution and care in the design and deployment of infrastructure is deemed essential, for successful settlement operations in this aggressively abrasive, and clingy, dust-laden environment.

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Participants coordinated various concepts to weave the team project together. The entire collaborated work was presented to a panel of industry experts who lectured, reviewed and provided feedback. Thanks are due to the ASTE 527 class for providing constructive criticism and for debating concepts throughout the semester as well as the panel of faculty, agency and industry experts who provided valuable feedback on this study. Also thanks are due to Prof. Thangavelu for his enthusiastic and creative guidance, and to all the guest lecturers who presented various topics of their expertise relating to manned space systems, human factors, nanotechnology, architecture, as well as systems architecture.

Slides of Fall 2008 Looking Glass 204 team project including the PI presentation are found at:
http://astronautics.usc.edu/concepts-studio/lookingglass.htm

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