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Mobile Lunar and Planetary Bases

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ABSTRACT

This paper presents a review of design concepts over three decades for developing mobile lunar and planetary bases. The idea of the mobile base addresses several key challenges for extraterrestrial surface bases. These challenges include moving the landed assets a safe distance away from the landing zone; deploying and assembling the base remotely by automation and robotics; moving the base from one location of scientific or technical interest to another; and providing sufficient redundancy, reliability and safety for crew roving expeditions. The objective of the mobile base is to make the best use of the landed resources by moving them to where they will be most useful to support the crew, carry out exploration and conduct research.

This review covers a range of surface mobility concepts that address the mobility issue in a variety of ways. These concepts include the Rockwell Lunar Sortie Vehicle (1971), Cintala's Lunar Traverse caravan, 1984, First Lunar Outpost (1992), Frassanito's Lunar Rover Base (1993), Thangavelu's Nomad Explorer (1993), Kozlov and Shevchenko's Mobile Lunar Base (1995), and the most recent evolution, John Mankins' "Habot" (2000-present). The review compares the several mobile base approaches, then focuses on the Habot approach as the most germane to current and future exploration plans.

INTRODUCTION: MOBILE BASE RATIONALE

The mobile lunar base presents several key advantages over conventional static base notions. These advantages concern landing zone safety, the requirement to move modules over the lunar surface, and the ability to stage mobile reconnaissance with effective systemic redundancy. All of these concerns lead to the consideration of a mobile walking habitat module and base design. The key issues that the design of a mobile base must resolve include automated assembly and deployment, the configuration and methods for connecting modules, and mission duration. The principal advantage of the stationary base is that it affords the build-up of infrastructure and resources in one location, which can lead to economies of scale and of agglomeration, without added the transportation costs of making it all mobile.

Landing Zone

The landing zone (LZ) poses the problem that once a habitat lands on the moon, it is not possible to land another vehicle within several kilometers because of safety concerns from ejecta in a normal landing and in case of an explosive failure on impact. Therefore, if the lunar mission intends to create a well-established approach range and LZ, it is necessary to move the landed habitats and payloads well away from the LZ, much in the manner that aircraft taxi off the runway after landing at an airport. So what is the best way to move the module? FIGURE 1 from the First Lunar Outpost (FLO) Study, 1992, illustrates this problem. A pressurized module has landed on a "dumb" lander. The crew must bring a crane and flatbed rover to the LZ to off-load from the now inert and soon to be abandoned lander. Thus three major pieces of hardware are required because of the lander's immobility. Also, this offloading and transport operation appears to require direct crew EVA operation. There are many precedents from earth such as tractor-trailers or self-propelled vehicles that move on wheels or treads. However, given the fact that the lander will require articulated legs to absorb the compression of the landing impact and stabilize the lander, it will be a relatively simple task to give the legs walking capability, to move the module away from the LZ.

Exploration Mobility Approaches

A further advantage of the mobile lunar base concerns exploration traverses of the lunar surface. The conventional model of exploration is that a crew of two or more astronauts travel in a pressurized or unpressurized rover to a remote site, perform an EVA, collect some rock, soil and regolith samples, and then return to the base. An unpressurized rover is limited to a traverse measured in hours. If the rover is pressurized, then the crew can make a longer traverse, under some scenarios lasting days (sols) or weeks.

Reliability, Redundancy and Availability

The problem with this conventional rover scenario is one of reliability and redundancy. If the rover should experience a failure that prevents its return to base or that otherwise compromises safety or is life-threatening, how will other astronauts at the lunar base rescue them?

The usual answer is to have a second rover that can perform the rescue. But what if it runs into a problem too – the same or a different problem? Well, that means a third rover. Following this chain of reasoning, fairly soon, most or all of the landed mass resources of the lunar mission becomes devoted to ensuring the safety of a pressurized traverse mission.

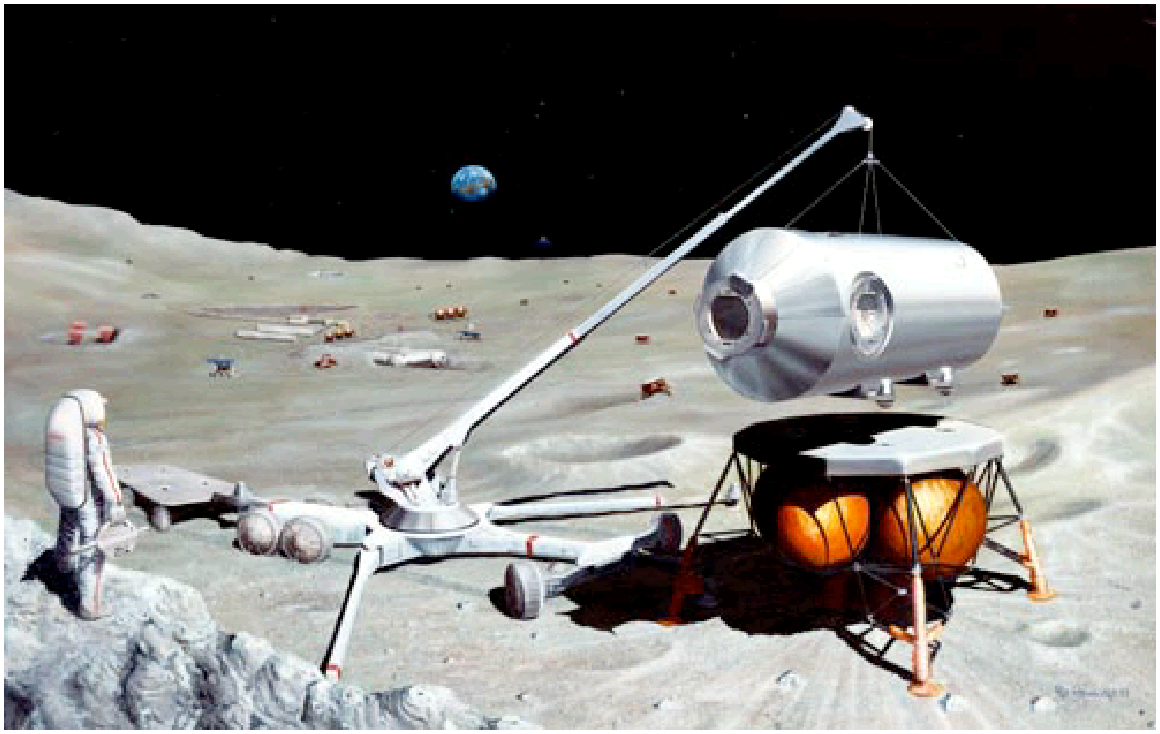

FIGURE 1. 1992, THE PROBLEM, illustrated. This image is from a joint study McDonnell Douglas in the U.S. and Shimizu Corporation of Japan. This design evolved from NASA's proposed Artemis lander and the First Lunar Outpost (FLO)

So, why not make the entire base mobile, so that all the resources, *reliability* and *redundancy* of the lunar mission move with the exploration crew? This approach means that the laboratory facility will travel with the explorers, affording them the capability to conduct complex and sophisticated scientific assays and analyses on site, without a need to return to the base. Once the lunar exploration concept transcends the convention of a rover as a delivery truck for rocks, vast new potentialities open up. The Mobile Lunar base allows the explorers to bring the base to the sites of scientific interest to make the most complete investigation, without the severe constraints and limitations to traverses and EVA sortie time. A further advantage of the Mobile Base system is *availability*. With the versatility of the Mobile Base approach, it is possible to land new mobile modules with new equipment, supplies or logistical support in the path of the moving ensemble. These new units could then join the "wagon train" to continue on the journey, or simply provide a cache of supplies for the crew to pick up along the way.

LITERATURE REVIEW

Although there have been a great many concepts proposed to build stationary lunar and planetary bases, and perhaps even more concepts for pressurized planetary surface mobility systems, (Arno, 1999; Cohen, 2000, Mendell, 1985), there are relatively few concepts that combine both notions. This combination is the peculiar domain of the mobile lunar base. The issues include the landing zone, robotic habitat deployment and verification, and surface mobility. The literature review identifies two basic approaches to the mobile base: the train concept and the independent unit cluster concept.

Tractor Train Concepts

The earliest approaches to mobile bases incorporated one or more tractor units to pull the coupled train across the lunar landscape. Typically, these "engines" would be pressurized to serve as a crew accommodation and as a separable rover. The two principal concepts of this type are North American (1971) and Cintala, Spudis and others, (1985).

North American Lunar Sortie Vehicle, 1971
As the Apollo Program achieved its historic success, NASA commissioned North American, the contractor for the Apollo Command and Service Modules, to develop an advanced lunar base development strategy. One component of this project was the Lunar Sortie Vehicle (LSV), modeled on the design analogy of a railroad train without the rails. The LSV consisted of three pressurized units and several unpressurized utility or equipment trailers for energy, research and construction. One unpressurized trailer, the Mobile Power Unit (MPU) would carry a very large radiothermal generator (RTG) that used plutonium or other isotopes to generate 3.5 kW of power. In FIGURE 2, presumably the MPU appears in the middle of the "train," showing a cavalier disregard for radiation safety of the crew. The pressurized units were of two types: a six wheeled Prime Mover Vehicle (PMV) that served the locomotive function and a four wheeled habitat "trailer" that surprisingly lacked a snappy acronym. A single PMV could support two crew members on a 2 sol traverse. With the full complement of "railway carriages" that included a second PMV locomotive bringing up the rear and the MPU, the goal was for the complete train to be capable of a 90 sol traverse across the lunar surface.

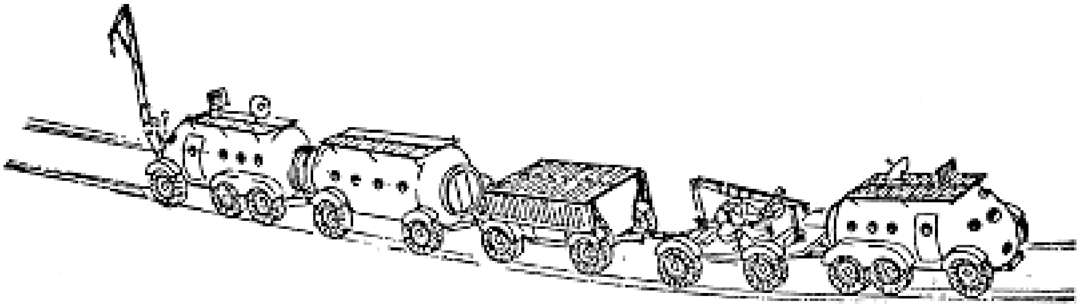

FIGURE 2, "Lunar Sortie Vehicle," North American Rockwell.

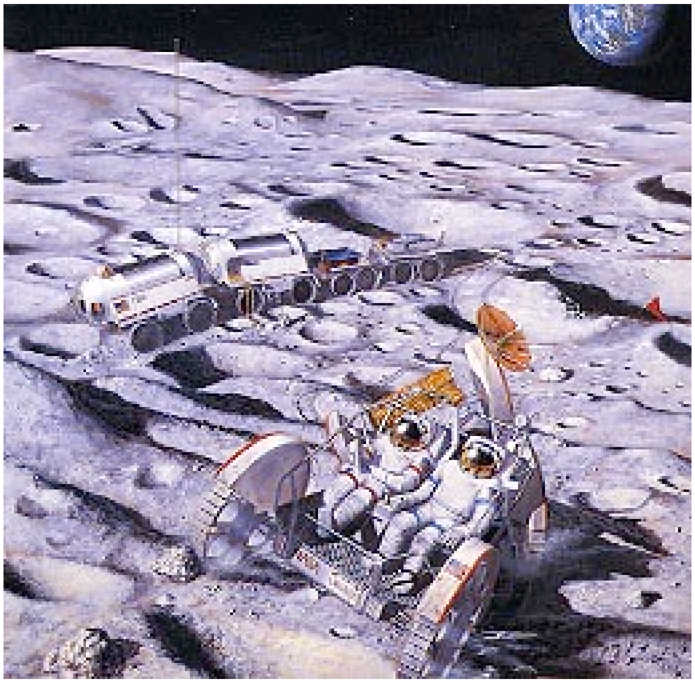

FIGURE 3. Geological Traverse Vehicle, 1984.

Cintala Geological Traverse Vehicle, 1985
Cintala, Spudis and Hawke (1985) describe a proposed 4000 km lunar surface traverse one way or 2000 km round trip by a crew of up to six geologists plus two technicians in a pressurized Geological Traverse Vehicle (GTV). Although the authors do not give a timeline, this expedition would surely take months to complete. The GTV carries two smaller, unpressurized rovers that the explorers would drive on short side trips. The GTV includes space suits for all crewmembers, but it is not clear if it incorporates an EVA airlock or uses the Apollo LM method of depressurizing the vehicle when crew members go EVA. Subsequently, Cintala and colleagues went on to catalog the geological exploration tools that would be required for a more modest pressurized rover, with a 500 km range of operations (Nash, et al, 1989).

Mega-Mobile Base Concepts

The essence of the Mega-Mobile concept is a very large base assembly on wheels or tracks that moves as a single complete and integrated base. This section reviews two such concepts, Madhu Thangavelu's Nomad Rover and Kozlov and Shevchenko's Mobile Lunar Base.

Thangavelu's Nomad Explorer, 1992.

Madhu Thangavelu presented the argument that there are two crucial problems to solve for a successful lunar base: dust and spacesuits, notably the barriers necessary to keep out the dust. Thangavelu asserts that it should be possible to solve both these problems by combining two existing technologies: the wheel and the diving bell. In his approach the crewmembers would stay inside a mega-rover as much as is feasible, with the capability of supporting a crew of six over thousands of kilometers of exploration. The Nomad pulls a power trailer, very much in the tradition of the SLV and the GTV, and in this respect, it represents a transitional phase from tractor train to mega-mobile base. Mass estimates for the Nomad runs to 45 mTon range, exclusive of descent and landing system, so it will weigh approximately twice as much as the total Apollo lunar stack of the Command Module Service Module and Lunar Module (22.5 mTons). This great mass in a single landed payload implies a single launch vehicle with a capacity at least twice that of the Saturn V rocket. Unfazed by any possible impracticality in this scheme, Thangavelu gives it an acronymizable name Very Long Traverse Vehicle (VLTV), and proposes the dimensions as 16m long, 4.5m wide and 10m high. Assuming a bottom clearance of the pressurized volume of 1m, these dimensions give a potential pressurized volume of about 650 m3. With all the mechanical and mobility systems required, the projected mass of 45 mTon is probably a low estimate. An artist's rendering of the Nomad appears in FIGURE 4. The "diving bell" style airlock appears in the cutaway view of the lower level\, between the two wheels

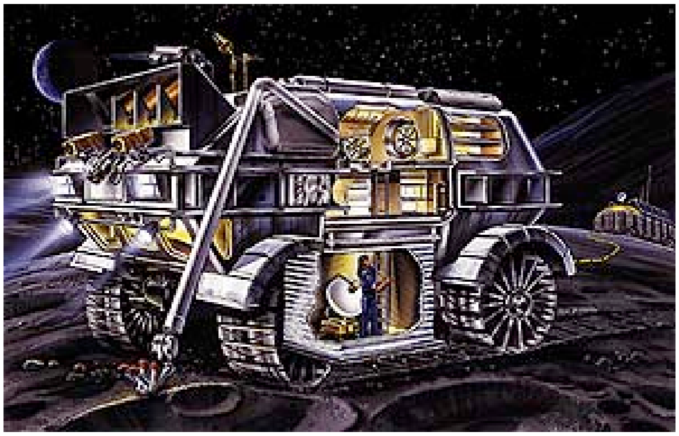

FIGURE 4. Thangavelu's Nomad Explorer VLTV. Courtesy of Madhu Thangavelu.

Kozlov and Shevchenko's Mobile Lunar Base Project, 1995

Despite the failure of the Soviet human lunar program in the 1960s, the Russians have continued to conceive and plan for crewed landings on the moon (Van den Abeelen, 1999). Perhaps the most riveting concept is the Mobile Lunar Base presented by Kozlov and Shevchenko (1995). FIGURE 5 shows two stages in the assembly and deployment of this concept. The drawing on the left shows three pressurized modules clustered together on a very large (approx. 9m wide) truncated-triangular chassis, transported on three double tank-treads. The drawing on the right shows a protective shield added above the pressurized modules, except for the cupola above the left rear module. The pressurized modules are two stories high with two floor levels.

Kozlov and Schevchenko envisioned this design as requiring nine landings on the moon to construct, with the crew of six arriving in two groups of three, on the 7th and 8th landings. The assembly sequence would rely almost exclusively upon a large and powerful manipulator arm, but the authors do not describe much about the automation or robotic systems that presumably would be necessary to make this arm perform. Once they arrive, the crew would take an active role in setting up and operating scientific equipment.

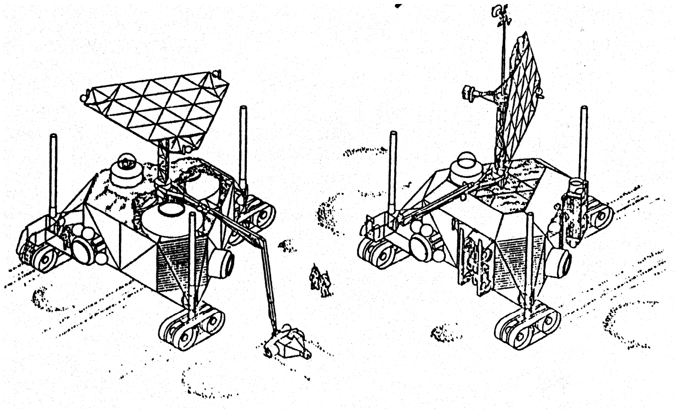

FIGURE 5. Kozlov & Shevchenko's Mobile Lunar Base, Reproduced by Permission of the British Interplanetary Society. Published originally in the *JBIS,* 1995, p. 53.

"Wagon Train" Concepts

The "Wagon Train" was an American pioneering technique in which a group of ox-drawn Conestoga wagons traveled together in line. When they stopped for the night, they would "circle the wagons" to form a temporary base cluster.

Frassanito's Lunar Rover complex, 1993

The industrial designer John Frassanito provided many of the design images for the NASA Mars Design Reference Mission (Hoffman, Kaplan, (1997, July), and the studies that lead up to it (Weaver, Duke, 1993). One offshoot of these studies was a concept for a lunar base formed by a group of several independent lunar rovers. In this concept, the rovers would travel together as individual units "wagon train" style. At a likely site they would join together to form a temporary base. FIGURE 6 illustrates this concept. There is a central "core module" with two lateral docking ports on either side. At the end showing in the picture is an EVA airlock exiting to a deployable platform and stair. The driver's position is presumably at the distal end of the core module, although perhaps it could be towed. The two modules docked on each side of the core would "back into" the docking ports. The driver's station appears on the right as a large gold coated lens. While the pressurized modules are docked together, they afford a continuous atmosphere among the three vehicles. While the rovers are docked, the crew would employ the small unpressurized rover on the left for local mobility.

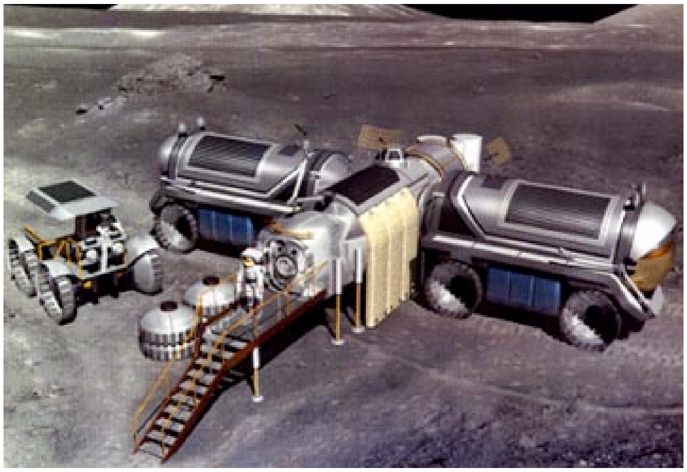

FIGURE 6 Frassanito's Lunar Rover base complex, 1993. Courtesy of NASA-Johnson Space Center.

Mankins' Habot

John Mankins introduced the Habot concept (Habitat Robot) in 2000 as a radical departure from traditional lunar base studies. The strongest attribute of the Habot is its "small is beautiful" emphasis upon feasibility compared to conventional "bigger is better" approaches as typified by the 90 Day Study (1989), and other mega-concepts. The Habot modules land on six articulated legs, and then takes double advantage of the legs by using them to walk away robotically from the landing zone. The pressure vessels are hexagonal insofar as they require three cross-axes separated equally at 60° of arc. They cluster together automatically to form a temporary base. The possible module size ranges from about 3 to 5m diameter. The crew arrive and depart the surface of the moon in a separate Descent/Ascent vehicle that may share some hardware commonality with the Habot units, but is optimized for transporting the crew through cis-lunar space, landing and taking off from the lunar surface. With self-ambulating lunar base modules, it would be feasible to have each module separate itself from its retro-rocket thruster unit, and walk five to ten km away from the LZ to a pre-selected site. These walking modules can operate in an autonomous or teleoperated mode to navigate the lunar surface. At the site of the base, the walking modules can combine together, make pressure port connections among themselves, to create a multi-module pressurized lunar base. FIGURE 7 presents an artist's rendering of the Habot concept, showing both a Habot cluster base, and habot rovers moving about the lunar surface, driven by astronauts. A peculiar power source appears in the form of the cylinders mounted atop each Habot, which mount photovoltaic cells to provide power during the 14 sol lunar day.

DISCUSSION

This review presents perspectives on several types of mobile lunar and planetary base concepts. These concepts fell into three broad categories of the "tractor train" (North American; Cintala et al); the "mobile mega-base" (Thangavelu; Kozlov and Shevchenko); and the "wagon train" of individual units that move separately but cluster together to "circle the wagons" (Frassanito; Mankins). Of these three approaches, the "wagon train" appears to offer most promising advantages for a number of reasons, while the other two categories bring advantages and disadvantages that much more closely cancel each other out. The Tractor-Train concept offers very limited independent mobility of the units, and it would appear that removing one tractor unit from the train might disable its movement, while certainly reducing the reliability and redundancy. The main draw-backs of the mega concept are both size in and of itself (an enormous mass to travel over unknown terrain and ground conditions) and the fact that it requires extensive assembly and integration before it can function. Also, the mega-mobile approach is vulnerable to all the threats of a "one of a kind" single unit system in terms of reliability and redundancy.

Among the two wagon train concepts, the Habot presents the most advantages. It allows considerable flexibility in the independent movement of each of the pressurized modules. It affords the opportunity to allow reconfiguration of the module cluster. In the Mankins' Habot concept, there is an additional integration of robotic and human capabilities that offers the promise of uniting the strengths of each capability, in such a way as to compensate for their weaknesses. The remainder of this article focuses on the Habot concept as the most highly evolved and most promising of the mobile base concepts.

KEY HABOT PARAMETERS

The fundamental idea is that the Habot is a combination of a human habitat and a robot. The Habot lands autonomously on the Moon on a set of articulated legs. The Habot then uses those legs or wheels mounted on the legs to move itself away from the designated landing zone so that more Habots can land. Once enough Habots arrive to form the lunar base, they cluster together at a site of scientific or technical interest, and make the vital connections for pressurized access.

Robotic Habitat Deployment and Verification

The basic issue that the Habot -- more than any of the previous concepts -- addresses is how to best use the cost and effort of very expensive crew time on the lunar or planetary surface. Gordon Woodcock of Boeing led a notable study on the use of lunar surface robotics that took into consideration what were the best uses for humans and for robots (Woodcock et al, 1990). Race, Criswell and Rummel pose the question this way: “Can a habitat be deployed or built robotically on the surface and its operational readiness be fully verified prior to sending humans there? (2003, p. 7). Once enough Habots arrive to form the lunar base, they cluster together at a site of scientific or technical interest, and make the vital connections for pressurized access, communications, data, life support, etc. Once the Habots have completed joining together to form the lunar base, it becomes possible for the first lunar expedition crew to arrive. After the crew completes their mission at that particular site, they return to the Earth, in a separate, dedicated vehicle. In the following weeks or months, the Habots separate from one another, and move across the lunar surface to a new location of scientific interest, and a second crew arrives. It is also possible for the crew to travel with the Habots. The crewmembers will also use individual Habot units as pressurized rovers to explore the lunar environment. In FIGURE 7, the articulated legs carry manipulator devices that can pick up rocks. A hexagonal cluster appears in the middle ground at the right.

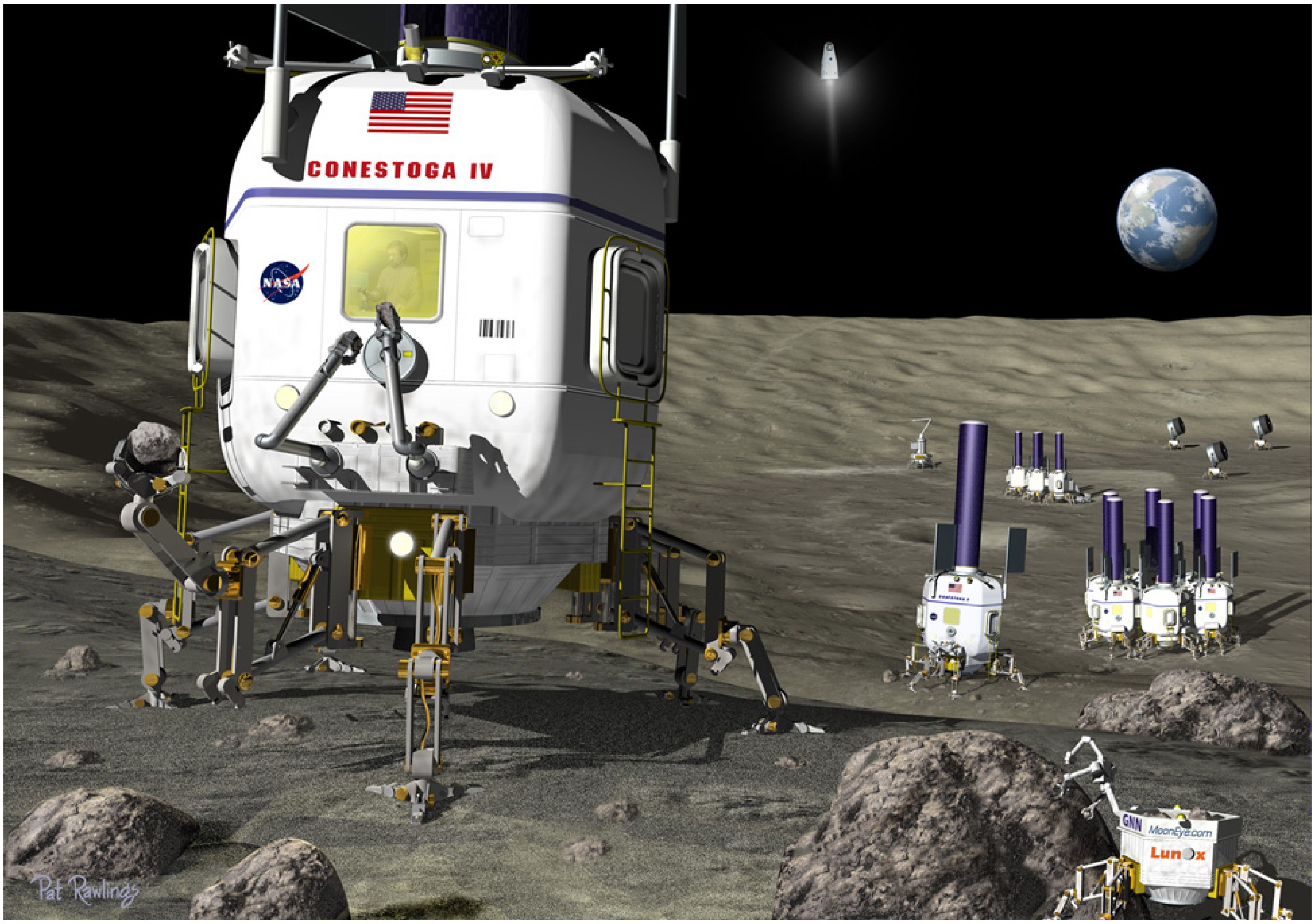

FIGURE 7. Pat Rawlings’ rendering of the “Habot” Mobile Lunar Base concept, courtesy of John Mankins, NASA HQ, and Neville Marzwell, Jet Propulsion Laboratory.

Not to be outdone in the acronym competition, John Mankins created the title “Human and Robotic Modular Infrastructures/sYstems,” (HARMONY) In his “notional concept, the Habot mission baseline would be 100 sols with the capability of supporting six crew members for that duration. However, the analysis for this section takes a different approach. Within the baseline 100 days, the nominal Habot mission would for a crew of four astronauts to spend two complete lunar day/ night cycles – 56 sols – on the lunar surface, with a planned 8 sol margin for a total planned mission duration range of 64 sols. The 36 additional sols would constitute a reserve capacity. In Mankins’ construct, the Habot infrastructure should serve a baseline of 10 crews rotating through the Habot base, each time in a different location on the lunar surface, for a total of 1000 sols of occupancy, which approaches the overall time necessary for a human Mars mission. This baseline implies a total productive occupancy of 560 sols with a total planned margin of 80 sols. Total reserve would be 360 sols. Of course, in the event that the crew had a problem lifting off from the Moon, it would be possible to resupply them from the Earth, almost anywhere on the moon.

This initial phase of the Habot study is considering crew sizes from 4 up to 8 crew members for the purpose of assessing the relationship between crew size and productivity. These crewmembers would occupy and utilize several Habot modules. The lesson of the International Space Station is quite dramatic: with three crew members on board, they spend almost all their time just maintaining and operating the station, with very little time – minutes per day, really – to perform science. The Habot Project includes a detailed study of crew time for this range of crew sizes to analyze the affects of the skill mix and required “overhead” activities upon prospective crew productivity.

Mission Activities

During the lunar day, the crew will conduct the exploration portion of the mission. During the lunar day, the habot units will make maximum utility of their walking capability. Thus the habot units will move separately across the lunar terrain, meeting and docking as necessary for various crew operations and procedures. As the lunar day approaches its end, the habots will cluster together and dock, creating a continuous pressurized habitable environment. During the lunar night, the crew will “hunker down” in this united lunar base. They will conduct scientific work in the laboratory unit and prepare scientific and technical publications.

Exclusion

The main point is that the Habot is not intended to serve as a crewed spacecraft in LEO, in cislunar space or in lunar orbit. It is intended for crew use only on the lunar surface. The crew will travel to the moon in a separate vehicle that is optimized to serve as a crew descent/ascent and Earth Return vehicle. This vehicle or set of vehicles could derive from the Apollo architecture, but make common use of the Habot six-legged lander for the lunar descent stage. This crewed lunar transportation vehicle is not part of the Habot study.

Mission Profile

The Habot Mission profile incorporates several key features that support the goals of the “Early Human Return to the Moon” initiative. This profile encompasses strategies for launch, transportation to the moon, landing, the mass budget, energy system, mobility system, and the Habot Module types.

Launch Opportunities

The Habot mission will be able to launch to the moon, land and deploy at almost any time in the lunar cycle. The preferred landing opportunity is the beginning of the Lunar day, as with the Apollo program. In the lunar dawn, the lunar environment is making a thermal transition from the profound cold of the lunar night and starting to warm up into a briefly benign temperature range, before heating up to in the full lunar day.

Cis-lunar Transportation

The Habot launches to Low Earth Orbit on a conventional launcher in the size range of the Delta 4, Atlas V or Ariane V. The trans-lunar injection stage launches on a second vehicle, then rendezvous with the Habot in LEO. The first, Habot launch package includes its own lunar descent and landing stage.

Landing

After Trans-lunar injection (TLI), the Habot stack goes into lunar orbit. The TLI vehicle (TLIV) separates from the Habot, which begins descent under its own power, and lands on six articulated legs. After landing, it squats close to the surface, detaches and drops the descent engine unit. Then, it stands up and walks away from the landing zone.

Preliminary Mass Budget

John Mankins’ original concept for the Habot aimed for a mass budget per unit of 3 to 5 mTons. This mass limit would be very convenient for launch by existing conventional expendable rockets. However, as a preliminary analysis the 5 mTon mass budget per unit is extremely tight for a nominal 100 sol mission by the crew of 4. A more realistic Habot mass budget baseline may be closer to 10 mT (10,000kg), separate from the descent engine unit. TABLE 1 presents a preliminary mass budget for this Habot unit, working with the range of masses that Mankins envisions. These bounding values appear in the top line for the pressurized habitat and its contents, including outfitting. However, these mass values are simply too small to provide the complete system for one Habot with a crew of 4 over 100 days. The lines below the pressurized habitat indicate the additional elements that would be needed.

This analysis leads away from the traditional approach to the mass and capacity question: How many crew members can this habot support and sustain on the lunar mission? Because of the modularity of the Habot system it leads to a different formulation of the question: How many Habots will be necessary to support the required crew? The next question is: What is the optimal distribution of equipment, supplies and mass among these several Habot units? The answer to this second question will demand a very detailed exercise in design optimization.

TABLE 1. Preliminary Habot Mass Budget.

Component	**Min Mass in mTon**	**Max Mass in mTon**
<u>Pressurized Habitat:</u> Pressure Vessel Structure Life Support & Thermal Control Habitability Accommodations Operational Systems	3.0	5.0
Exterior Protection Radiation Shielding Thermal Protection Micrometeoroid Protection	2.0	2.8
Mobility System Habot "Unibody" consisting of Base frame, 6 legs, motors and mechanisms.	.8	1.2
Energy Systems Solar Cells, batteries, SSP/"Nukebot" microwave Antenna Possible RTGs	.5	1.0
Margin	1.0	0
Limits (not totals)	7.3	10.0

Energy System

The energy system incorporates several elements. A cylindrical tower atop the module carries photo-voltaic cells to provide constant "lifeline" power during the lunar day. Atop this tower sits a parabolic dish antenna to receive beamed microwave or laser power. The primary source of this power will be a space solar power satellite at the lunar L1 or L2 point or both, which would provide power in the 100 to 300 kW range. A leading alternative to the solar power satellite would be a nuclear reactor mounted on a Habot chassis (Cataldo). FIGURE 8 shows Robert Cataldo's mobile Lunar Reactor concept, following and powering a pressurized rover. This "Nukebot" would follow the Habots from a distance of several kilometers away, and beam power by microwave to the same antenna that would serve for solar satellite power. A possible back-up option for "lifeline" power would be to install a radiothermal generator unit at the top of the tower, with a neutron-absorbing radiation shield below. Safe disposal of spent nuclear fuel will be required to make this concept viable.

Mobility System

Although the intial artist's concept in FIGURE 5 for the Habot presents the walking "Conestoga" idea, this Habot study is not presupposing any specific mobility system. Only after analyzing all of the necessary functions and components of the Habot habitat and base configurations, will it be reasonable to develop requirements for the mobility system.

Never-the-less, since the Habot is closely associated with the walking model, it is appropriate to describe the candidate walking aspect. The Habot will have a very modest walking speed. There is no advantage in designing it to move "fast" if that translates into a huge energy burden that will be used for only short periods of time. The baseline is a maximum of 2 km/hr with a crew driver over smooth, level terrain. On rough terrain, the speed will be reduced to whatever is safe, perhaps as slow as .5 km/hr on slopes or rough terrain. The baseline speed without a crew on board is .5 km/hr.

All Habots will land uncrewed. They will walk about 10km away from the LZ to a base deployment site. There, the habots will dock together and await the arrival of the crew. When the crew land in the descent/ascent vehicle, they travel on the same walking system to the base deployment site. There, the crew transfer via a docking tunnel in a shirtsleeve environment to the united base. As a contingency, the descent/ascent vehicle will carry EVA suits the crew can use to make the transfer. Additional contingencies if the descent/ascent vehicle is unable to walk, a Habot from the base will come to the LZ and pick up the crew. The final fall-back is that the crew can walk the 10 km EVA to the base.

FIGURE 8. Robert Cataldo's concept for an "follower" nuclear reactor rover. Courtesy of Robert Cataldo, NASA-Glenn Research Center.

Habot Module Types

In his 2000 and 2001 articles, John Mankins proposes six Habot modules that form the Modular Integrated Lunar Outpost "MILO" cluster. These modules would all derive from the same basic pressure vessel, platform and chassis, comprising the complete living and working environment:

- Airlock and Stowage, including the NASA "Robonaut" anthropomorphic master-slave tele- robot and EVA suit Stowage and maintenance.
- Command and Communications Center.
- Ward Room (back-up Command and Communications Center).
- Crew "Cabin" (Sleeping Quarters).
- Laboratory# 1, Life Sciences.
- Laboratory # 2, Physical Sciences (Cupola and Observatory).

The allocation of functions to this concept is somewhat reminiscent of the early stages of the Space Station, when NASA was proposing two US habitability modules and two US lab modules, plus an airolock. DIAGRAMS 1 and 2 illustrate two candidate configurations for the Habot base cluster. DIAGRAM 1 shows the relatively open-ended configuration that Mankins presented in the original 2000 paper on the Habot. DIAGRAM 2 presents the closed-loop ("benzene ring") configuration that appears in the artist's rendering shown in FIGURE 5. The module labels in DIAGRAM 1 correspond to the designations in the original concept. The labels in DIAGRAM 2 show an interpretation of those modules into the ring configuration. In both diagrams, a detached Habot Rover unit appears in proximity to the airlock / docking module.

CONCLUSION

This article reviewed a number of mobile base concepts, and found that the Habot offers the greatest promise of a versatile, safe and reliable approach. The Habot concept marks a significant evolution beyond the earlier mobile base concepts. Its most significant development is the reliance upon automation and robotics assembly to move the mobile units across the lunar terrain and then to assemble them and verify the readiness of the base for the arrival of the crew. A major challenge emerges as allocation of resources and distribution of capabilities among the Habot modules. The architecture for combining the Habots into the base cluster will play a substantive role in facilitating the use of resources and application of capabilities of all types.

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DEFINITIONS

EVA Extravehicular Activity

FLO First Lunar Outpost

GTV Geologicqal Traverse Vehicle

Habot "Habitat Robot"

HARMONY Human and Robotic Modular Infrastructures/sYstems

IAF International Astronautical Federation

JBIS Journal of the British Interplanetary Society

kW Kilowatt

L1, L2, Earth-Moon libration points

LEO Low Earth Orbit

LM Apollo Lunar Module, originally designated the Lunar Excursion Module

LSV Lunar Sortie Vehicle

LZ Landing Zone

MILO Modular Integrated Lunar Outpost cluster

MPU Mobile Power Unit

mTon Metric Ton, 1,000 kilograms

NASA National Aeronautics and Space Administration

PMV Prime Mover Vehicle

Robonaut An anthropometric, master-slave telerobot developed at NASA Johnson Space Center

RTG Radio-thermal generator

Sol One solar Earth day – 24 hours

TLI, TLIV Trans-lunar Injection (Vehicle)

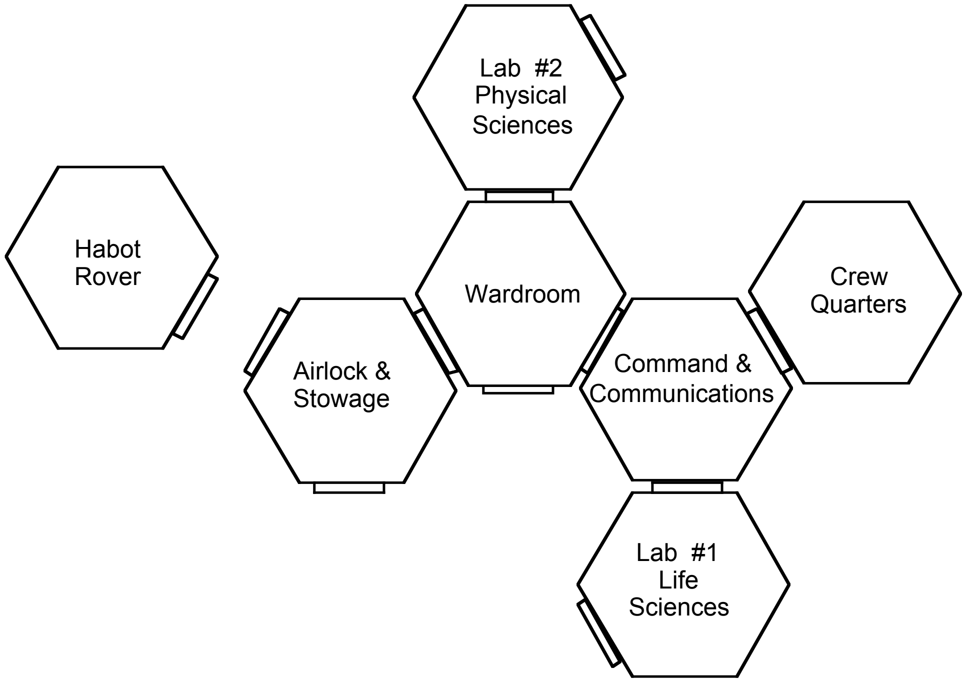

DIAGRAM 1. 2000 Habot "HARMONY" Concept Configuration

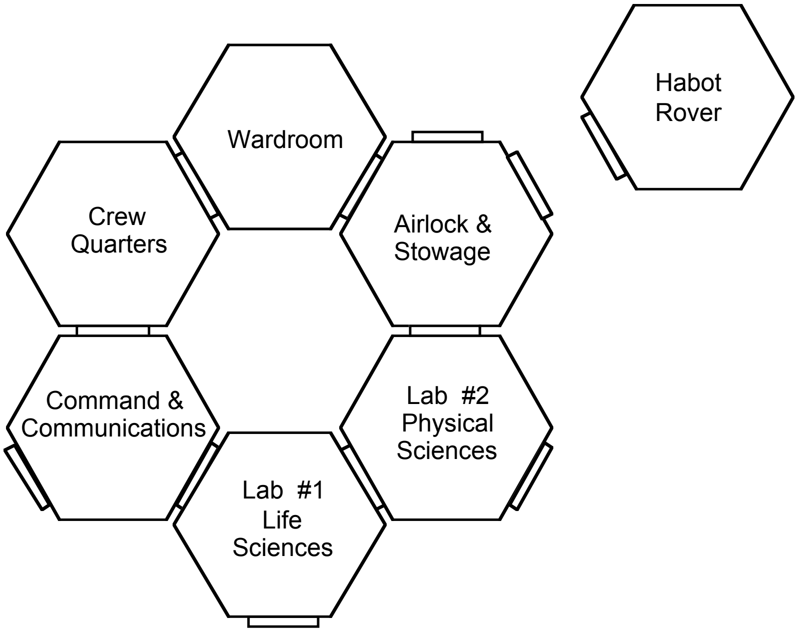

DIAGRAM 2. 2001 Habot "Conestoga" Concept Configuration