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The Nomad Explorer Assembly Assist Vehicle : An Architecture For Rapid Global Extraterrestrial Base Infrastructure Establishment

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ABSTRACT

Traditional concepts on lunar bases describe scenarios where components of the bases are landed on the lunar surface, one at a time, and then put together to form a complete stationary lunar habitat. Recently, some concepts have described the advantages of operating a mobile or "roving" lunar base. Such a base vastly improves the exploration range from a primary lunar base. Roving bases would also allow the crew to first deploy, test, operationally certify, and then regularly maintain, service and evolve long life-cycle facilities like observatories or other science payload platforms that are operated far apart from each other across the extraterrestrial surface. The Nomad Explorer is such a mobile lunar base. This paper describes the architectural program of the Nomad Explorer, its advantages over a stationary lunar base and some of the embedded system concepts which help the roving base to speedily establish a global extraterrestrial infrastructure. A number of modular autonomous logistics landers will carry deployable or erectable payloads, service and logistically resupply the Nomad Explorer at regular intercepts along the traverse. Starting with the deployment of science experiments and telecommunication networks, and the manned emplacement of a variety of remote outposts using a unique EVA Bell system that enhances manned EVA, the Nomad Explorer architecture suggests the capability for a rapid global development of the extraterrestrial body. The Moon and Mars are candidates for this "mission oriented" strategy. The lunar case is emphasized in this paper.

2. NOMENCLATURE

AMCL- Autonomous Modular Common Lander
DIPS - Dynamic Isotope Power System
ETO - Earth to Orbit
EVA - Extra Vehicular Activity
ECLSS- Environmental Control and Life Support System
GNC - Guidance, Navigation and Control

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LOI - Lunar Orbit Insertion
MOSAP- Mobile Surface Applications Traverse Vehicle
POS - Point Of Start
RFC - Regenerative Fuel Cell
RMS - Remote Manipulator System
TLI - Translunar Injection
VLTV - Very Long Range Traverse Vehicle

3. INTRODUCTION

Permanent lunar base establishment will entail detailed terrain exploration, sampling and analyses. Current studies expect all the site analyses to be performed robotically. Though unmanned precursors and remote sensing satellites would provide valuable information on possible sites for lunar base location, in order to "live off the land", as President Bush directed, detailed manned exploration and formal site analyses of selected candidate sites will be required. Since site selection is a critical task, initial manned missions will have to "site-hop" before settling on the prime candidate site or sites. Global mobility then becomes imperative in the initial manned mission. Following this initial activity, long duration facilities like optical / ultraviolet interferometry observatories emplaced on the extraterrestrial surface will require regular on-site manned supervision for maintenance, refurbishment, and for steady evolutionary enhancement of capability. As these science and observatory platforms would be spread out over rather large stretches of extraterrestrial surfaces, again global mobility would greatly enhance such activity. And finally, these remote autonomous science outposts, observatories, technology testbeds and pilot manufacturing plants would have to be in constant communication with the Earth. As most of these facilities are stationary, extraterrestrial fiber optic networks linking them all together offers promise. Again, the mobile rover strategy would make it viable to lay fiber optic cables across the extraterrestrial surface, interlinking all of these outposts and providing simple, reliable yet very high quality telecommunication with the Earth.

Examining the program requirements which have already been developed by NASA(1), it might be possible to design a single manned mission assisted by an autonomous logistics lander system that would conduct all the required tasks as well as establish a global infrastructure of remote science outposts, observatories, technology testbeds for long duration missions and pilot indigenous materials manufacturing plants, and all of the necessary telecommunication networks to support such activity, all of which activities could be simultaneously manifested in a combined manned/unmanned mission architecture.

4. DEVELOPMENT OF THE NOMAD EXPLORER STRATEGY

Starting from the need to establish, service and progressively evolve a series of highly versatile observatories for deep space, planetary, solar and Earth observation, The Nomad Explorer mission is tailored expressly to meet this highly specific objective in a rapid, timely and economic manner. Immediate high quality return on investment is an aim of this mission.

NASA exploration studies indicate the need for manned rovers to assist in the development of extraterrestrial bases. Three classes of rovers have been identified and studied. Point design concepts have also been proposed in all three categories(1). Studies include the short range rover for around-the-base activity with a range of 50-100km, the long range vehicle with an operating range of 1000km and finally, the very long range traverse vehicle(VLTV) capable of covering 3000-10,000km on a single traverse. The mobile surface application traverse vehicle(MOSAP) is a vehicle that NASA has proposed for this purpose(2). Capable of all the exploratory functions and normal EVA that is carried out from a conventional stationary base, the VLTV, by virtue of its long range and enhanced manned crew systems capability, is in essence, a "roving lunar base"(3). Unlike a stationary base, from which detailed manned terrain exploration is limited by the range of the rovers, this mobile concept for a primary exploration-oriented base offers unlimited range for exploratory traverses(Fig.1). It is an extension of the program requirements of this very long range traverse vehicle that leads to the possibility of the Nomad Explorer strategy for lunar base/observatory establishment.

The Nomad Explorer Strategy is a synthesis of two major system architectures. They are :

4.1. The Nomad Explorer Vehicle

The Nomad Explorer vehicle is derived from the MOSAP vehicle developed by NASA. Several other studies done by NASA contractors on long range rovers are also available. Very long range traverses are possible using this vehicle. The architecture of this vehicle is adaptable to both manned or autonomous unmanned operations. The configuration studied in this paper portrays a manned Nomad Explorer vehicle. See Schematic in Fig.2.

4.2. The Autonomous Modular Common Lander System

The Autonomous Modular Common Lander(AMCL) is a common vehicle that can deliver both crew or cargo depending on the modular configuration employed. Logistics, consumables, and erectable/deployable science outpost components that are launched from Earth are delivered to the lunar surface using the AMCL system. The concept is derived from the lunar lander(3) and the Common Lander Study(4) which NASA has developed. The AMCL is outfitted with modular payload on the Earth, landed autonomously on the lunar/Mars surface, intercepted by the Nomad Explorer and the payload unloaded and deployed or transferred to the roving vehicle. The modular capability allows the lander to be sized for any mission, ranging from 5MT to 25MT depending on the requirements during the traverse of the Nomad Explorer vehicle.(fig.2)

The Nomad Explorer strategy is aimed at establishing a global scientific and telecommunication network, even during the initial "trail blazing" permanent base selection run. The Nomad Explorer, besides being a VLTV, is also conceived as a manned EVA and assembly assist vehicle.

Exploratory activity like soil sampling, soil mechanics, locating natural formations that enable habitation like lava tubes(5) is followed by the deployment of science outposts and habitation facilities during the course of the same mission. This vehicle, during the course of its very long traverse, will intercept autonomously landed payloads("modular common lander" payloads ?) along the traverse route, assemble the payloads or deploy them, check them out at the site, certify them for operations, doing all of these functions using the crew of the vehicle. During the later stages of the extraterrestrial base evolution, the strategy could be used for maintenance, repair activity and evolutionary enhancement of these remotely based highly sensitive scientific experiments like optical interferometry observatories(6) /pilot plants for manufacturing lunar indigenous materials and components (7) /telecommunications relay platforms etc.

4.3. The Nomad Explorer Global Extraterrestrial Basing Strategy is as follows:

1. Precursory high resolution mapping of the entire lunar/Mars surface using polar orbiting satellites.
2. Analysis of terrain information, followed by determination of alternate likely candidate sites for lunar/Mars base location. Alternate rover traverse routes established with the aim of maximizing scientific returns(8) along the route while conducting detailed terrain surveys for locating alternate sites for a permanent base. A lunar polar traverse might be considered to explore trapped volatiles.(9)
3. One or more Nomad Explorer VLTVs launched from ETO, coupled with lunar lander tankage in LEO, and landed on the lunar surface at the predetermined point of start of traverse.
4. Lunar lander with crew accompany Nomad Explorer to the point of start(POS) of traverse.
5. Crew transfer to Nomad Explorer and begin traverse. First telecommunication Earth link established at POS.
6. Modular autonomous landers deliver modular payload along traverse route. Alternate base sites surveyed. Crew intercept payload, retrieve consumables/logistics modules, prepare and carry out assembly and deployment of science experiments and telecommunication relay stations, using manned EVA enabling systems which are part of the Nomad Explorer vehicle architecture.
7. Nomad Explorer completes traverse. Establish global fiber-optic telecommunication network. Install scientific outposts. Conduct detailed geologic surveys and prospecting. Determine location for a permanent lunar settlement*.
***8.** If more than one Nomad Explorer is landed, parallel activity would further speed up the base site selection and global infrastructure development. If required, the teams could assist each other by congregating at a particular site of interest, for exploration,

for need of added manpower, or for establishing a permanent manned lunar base at a most suitable location.

9. At end of traverse, moth ball Nomad Explorer into energy conserving "hibernation mode" or set up vehicle for remote traverse operations. Permanent base site established.

10. Crew transfer to Earth return vehicle that has been autonomously landed at end of traverse. Crew depart for Earth. Mission complete. Permanent base establishment activities commence.

11. Nomad Explorer crew return to vehicle on future missions and proceed on traverses at prescribed intervals to repair, maintain or evolve remote outpost elements.

The Nomad Explorer Strategy for lunar basing is depicted in Fig.3

5. THE NOMAD EXPLORER VEHICLE SYSTEMS ARCHITECTURE

The Nomad Explorer is a VLTV with an essentially unlimited operating range which depends entirely on the number of logistic resupply missions that are flown to it during the course of the mission. Assisted by the AMCL system, the Nomad Explorer carries only enough consumables, logistics and spares required by it between regular intercepts of the AMCL; much like the optimum pitstops and refueling operations carried out in automobile racing. A 10,000KM traverse could be used as an example to demonstrate the proposed capability of the Nomad Explorer. Duration of traverse could be six months to a year with the possibility of a complete crew changeout during the middle of the mission. Two regenerative fuel cell(RFC) power plants with a total peak output in the range of 50kW are required for powering the drive train and all of the manned and unmanned systems. Advanced photovoltaic arrays would assist the rover systems during the lunar day cycle. Mission architecture dictated a crew of four for optimum performance and the manned systems and life support are provided for four crew. A simple exploded schematic in fig.4 shows the basic systems of the manned Nomad Explorer.

The main features of the Nomad Explorer are as follows:

5.1. Habitation

The pressurized volume of the vehicle is about 300cum.
This volume contains long term accommodation facilities for four crew, work and conferencing areas, a command and control center and ample storage space. Besides a galley, hygiene and waste management facilities, the long term accommodations include a health maintenance facility and a recreation space.

5.2. Environmental Control Life Support System(ECLSS)

The ECLSS will handle the needs of four crew. Cryogenic nitrogen, Oxygen, Hydrogen and water are available from RFC operations. Though complete closure of the ECLSS is not envisaged, it may be possible to operate with a 90% efficiency(1).

Space station Freedom will provide the basis for the Nomad Explorer ECLSS.(10,11,12,13)

5.3. The EVA Bell

The EVA Bell for enhancing manned EVA is a prominent feature of the vehicle and is described later in detail. The invention allows the astronaut crew to perform EVA in a more comfortable manner by providing a shirtsleeve environment around the payload to be assembled and deployed during the earlier mission or, serviced, repaired or enhanced during later extraterrestrial base evolutionary activity.(Fig.6)

5.4. The Utility Belt

An utility belt is strapped around the perimeter of the vehicle. This belt has modular racks which carry "plug on" modules for logistics, consumables and waste management that are replenished by replacement modules arriving on autonomous landers which the vehicle intercepts from time to time along the traverse. The belt also carries tools and accessories for EVA. Two small unpressurized rovers for "around-the-base" traverses are also part of the EVA accessories. These rovers have a range of about 100km and are powered by fuel cells and advanced photovoltaics.

5.5. The Remote Manipulator System

Two remote manipulator systems that are capable of assisting manned EVA, loading and unloading cargo, and providing anchoring or scaffolding support during assembly/deployment operations, run along two tracks on the top and bottom through the entire length of the utility belt. High resolution cameras mounted on this track as well as in other strategic points provide video support during the traverse as well as during assembly operations.

5.6. Traction System

Traction could be provided using several options. The Nomad Explorer configuration in fig.5 depicts independently powered and steerable large variable diameter wheels which are unfurled and deployed after landing. Fig.7 schematic shows a telescopic traction system that is capable of adjusting the height of the Nomad Explorer chassis for enhancing traverse as well as assembly operations.

5.7. Radiation Protection

Radiation protection is provided by skillful placement of system hardware on the vehicle so that they provide sufficient mass for protection. Tankage might be employed to enhance radiation protection(14). Regolith bags could be packed and laid in areas that require additional protection during solar particle events which might occur during the traverse.

5.8. Guidance, Navigation and Control System

Guidance, navigation and control(GNC) of the vehicle is achieved through appropriate systems. Visual feedback could be direct or augmented by video support. Real-time telecommunication is possible through a 3m Earth pointing antenna and a chain of surface-based relays or low orbiting satellites that could be employed for contact when line of sight communications is not possible. Electronically steered planar array antennas could be employed to maintain contact with low orbiting satellites or stationary extraterrestrial relay stations while the rover is in motion, even over rugged terrain. Fiber optics/free space laser communication and related technologies could enhance Nomad Explorer operations.

5.9. Power System

Advanced Regenerative Fuel Cell(RFC) technology, advanced photovoltaics, as well as nuclear technology are suggested for the Nomad Explorer power system. The nuclear power option using the Dynamic Isotope Power System(DIPS) needs further study(1). Shielding requirements need to be considered for nuclear power systems. A set of RFC batteries could power the Nomad Explorer between AMCL intercepts. At each intercept of the AMCL, these RFCs could be recharged. In addition, advanced photovoltaic arrays could be employed to provide support to the RFCs. In generating about 50 kW of power,(25kW for drive train and 25kW for the manned systems including the ECLSS), the heat rejection system would have to handle about 16kW. High efficiency heat rejection systems are required. Dust contamination of radiator surfaces will require study and appropriate design. Recent developments in "power beaming", a technique whereby a microwave/laser beam from an external source is used to transmit power to the vehicle during traverse operations could substantially improve the performance of the Nomad Explorer by reducing the payload associated with power generation and storage equipment. (15,16,17,18)

5.10. Mass and Payload Configuration

All these systems are designed to fit within a HLLV(Energiya or revived Saturn V-B technology) payload shroud that is 30m tall and 10m in diameter. The payload mass at launch is about 35MT+propulsion, tankage and structure for TLI, LOI and lunar landing. This mass is above the NASA lunar lander capability of 25MT. Though this Nomad Explorer study suggests that larger landers are required for the mission, it would be possible to scale down the vehicle and still preserve the mission architectural strategy for a smaller vehicle. The unmanned version of the Nomad Explorer is such a small vehicle. Substantially smaller(5-7MT), the robotic Nomad Explorer would employ the same mission strategy. However, reliability and the capability to handle contingencies require demonstration. A possible manned Nomad Explorer configuration is depicted in fig.5.

In the next section, the paper will discuss certain special features of the Nomad Explorer vehicle which were developed to enhance mission capabilities.

6. THE PROBLEM WITH CONVENTIONAL EXTRA VEHICULAR ACTIVITY

Conventional EVA is a most time consuming, hard and inefficient yet essential part of human activities in space or on the extraterrestrial surface. Complex and lengthy preparatory procedures are part of EVA. Present studies aimed at establishing extraterrestrial bases will require substantial EVA during buildup operations. Long hours of continuous EVA are expected during the early development phase of these projects. It is well known that present day designs for space suits are simply inadequate for these operations(19). When inflated to the optimum operating pressure of about 8psi, the suit becomes very stiff and quite difficult to flex at the required joints.The astronaut then has to work against this suit pressure stiffness as well as the forces which are required of the task to be performed. Loss of dexterity is the result and almost every component in a payload package to be assembled or deployed has to be designed to adapt to the limitations imposed by this loss of dexterity(Fig.6). In past EVA missions, astronauts and cosmonauts have complained about the difficulty of working in the EVA suit. Lunar dust is notorious for degrading astronaut as well as vehicle performance(20,21). Compounded by the fact that future missions are expected to be more complex and substantially longer in duration, it is imperative that alternate methods for conducting EVA be studied. Hard suits, where the fabric is substituted for a metallic shell with articulation mechanisms at the essential joints have been studied but they have their limitations too. Compact modules with appropriate life support and remote manipulator systems(the so called "man-in-a-can" concepts)have also been suggested as an alternate means for enhancing long duration EVA. Fully robotic systems have yet to prove their ability to handle contingencies, and until then, manned EVA will continue to play the leading role in assembly operations in space and on the extraterrestrial surface. It is also possible that hybrid concepts employing both robotic and manned systems may prove to be more effective, using a mutual support strategy, during extravehicular buildup activity.

7. RATIONALE FOR AN ALTERNATIVE MANNED EVA SYSTEM

The EVA Bell concept proposed in this paper is a concept for enhancing manned EVA operations on the extraterrestrial surface. The rationale for this concept are as follows:

1. Conventional EVA is an extremely inefficient way of utilizing astronaut capabilities. EVA time is expensive and must be used more efficiently.
2. Conventional EVA requires that components to be assembled/deployed be designed to respond to the limitations of the EVA suited astronauts. Such a strategy limits efficient design and operation and therefore should not be a design driver.
3. Extraterrestrial base development will surely involve much more complex and arduous EVA tasks that will heavily tax the physical and mental capabilities of the best astronauts. Though the conventional EVA suits may be ample for some of the envisaged activity, alternate concepts for EVA are required to handle different and diverse EVA scenarios, which are a natural implication of the plethora of necessary EVA tasks required that will eventually lead to a final establishment and operation of the base.
4. "Back to stay" missions entail long duration missions, and most importantly, long life cycle facilities. These facilities will require servicing, repair activity as well as associated evolutionary enhancement and modification procedures. EVA must be simplified in order to help the crew repeat these functions with ease.

5. Dust contamination from the extraterrestrial surface has and will continue to pose a serious threat to successful assembly and maintenance operations(20,21). EVA concepts are needed that will effectively combat this problem during assembly/repair operations.
6. It may not be possible to tackle all EVA scenarios using the same strategy.(i.e. use of only the conventional EVA suit). Therefore, at the planning stage, it is prudent to have as many alternate concepts for manned EVA as possible, so that tasks may be designed for efficient execution.
7. Many payloads to be deployed and maintained remotely on an early lunar base could be designed to be quite small in their physical dimensions.(e.g. remote data relay stations, small science experimental platforms, photovoltaic arrays, optical interferometery array components).
8. It should be possible to provide an EVA environment for the assembly/repair/maintenance crew which is less taxing and more comfortable. Concepts are required which would enable the astronaut crew to perform more precise and delicate tasks on the site without the strain imposed by EVA suit constraints.
9. A rapid and highly flexible global extraterrestrial telecommunication/scientific experimental station network infrastructure establishment may be possible if a manned and robotic hybrid architecture is adopted during the primary phase of buildup activities.

It is on the basis of these premises that the Nomad Explorer architecture for rapid lunar/Mars global infrastructure development and the EVA Bell concept for enhancing manned EVA is developed.

8. THE EVA BELL SYSTEM ARCHITECTURE

In its simplest manifest, the idea is to separate the astronaut from the suit and try to provide as close to a shirtsleeve environment as possible during EVA. In order to accomplish this, we will provide a pressurized shack, referred to as the "Bell"(programatically similar in many ways to the diving bell used underwater), at the place where the EVA is to performed.(Fig.6) Obviously then, this Bell becomes an integral part of the Nomad Explorer !

Though only one configuration of the EVA Bell is addressed in this paper, several other ways exist in which to provide this protective enclosure around the payload and the astronauts during assembly activities. They are being studied at the institute.

The Bell works in the following manner:

1.The Nomad Explorer drives to the EVA/Assembly site. The payload to be deployed could have been landed at the site separately,(Common lander concept ?)or carried in the vehicle.
2. The surface is approximately leveled by the RMS on the vehicle. A surface seal fabric is unrolled on the smoothed out terrain. (This fabric could be part of each common lander payload.)

3. The payload/experiment to be assembled/deployed is then unloaded on top of the prepared surface seal fabric.
4. The Nomad Explorer then aligns itself with the prepared surface seal and gently lowers the Bell so that the complete payload is covered by it with space around the payload to spare. The volume inside the Bell is about 150cum.
5. The Bell is lowered till it uniformly contacts the surface seal fabric all around the payload. The Bell is then secured to the surface seal fabric in such a way as to produce a nominal pressure seal between the inside of the Bell and the extraterrestrial surface. Studies are under way that examine several ways of establishing this pressure seal.
6. The Bell is then pressurized.(8psi nominal.)
7. After assuring that the seal is operational and that the nominal leakage rates are not exceeded, an airlock into the Bell allows the astronaut crew to access it from inside the Nomad Explorer.
8. The assembly/deployment activity is performed by the crew wearing minimal EVA garments.(An emergency pressure suit?). After test and checkout of the experiment/setup or system(eg.optical IF, VLBI components, relay stations, remote monitoring equipment), the crew get back into the vehicle.
9. The Bell is depressurized, retracted and the Nomad Explorer is on its way to the next assembly assist /experiment setup/maintenance/repair site.
10. In the case of a repair or regular facility maintenance mission, the same procedures listed above are employed except that the mission will be simpler because the surface seal fabric is already in place from the primary mission. It would be much easier now to deploy the EVA Bell over the facility and complete the mission.

This sequence of operations is illustrated in Fig. 7.

9. CHALLENGES POSED BY THE EVA BELL SYSTEM

1. How do we mitigate counter pressure ? At 8psi, a 4 x 6m Bell footprint would produce a total uplift of nearly 300,000 lbs. !!. However, we have a substantial surface contact perimeter of 20m to devise an anchoring mechanism. External as well as internal anchoring mechanisms for the EVA Bell are being explored.
1. How do we make sure of the seal ? We will require a 100% reliability on the seal mechanism if a shirtsleeve environment is the goal.
3. How large a Bell can we practically build and operate? It has to be compatible with payloads that we intend to assemble and deploy, of course!.
4. The surface seal fabric will have to be left in place after the assembly activity.
5. The payload cannot contact the surface during the assembly operation.

10. ADVANTAGES OF THE EVA BELL SYSTEM

1. Shirtsleeve environment for assembly/deployment activity. No prebreathing or associated EVA preparations are required.
2. The fully enclosed EVA Bell system provides a completely dust contamination-free environment during assembly and checkout of sensitive experimental equipment.

3. Lacking post landing serviceability, conventional missions carrying sensitive scientific equipment need to be designed to accommodate the shock of lunar lander impact. This translates directly as additional mass or design for shock absorption. Alignment, and recalibration of equipment could pose a problem. The EVA Bell strategy provides a way to circumvent this problem.
4. If the 8psi pressure is too much to handle, then the crew could still work inside of the Bell wearing a pressure suit just enough to combat the differential pressure between the Bell and the suit. For e.g. if the Bell can withstand up to 4psi, then the crew needs roughly another 4psi inside the suit. Such a decrease in suit pressure will make the suit less stiff during operation and enable more comfortable EVA. This method of operation is also very safe in the event of a Bell pressure seal failure. New, more maneuverable and comfortable pressure suits could be designed to use with the Bell.
5. All of the multilayer insulation used in the conventional EVA garment for radiation and micrometeoritic protection are eliminated from the suit which then retains only the pressure garment.

11. ADVANTAGES OF THE NOMAD EXPLORER STRATEGY

1. The Nomad Explorer strategy completely eliminates the need for conventional buildup equipment and infrastructure. All the heavy machinery and associated equipment, roads, launch and landing pad facilities associated with previous studies are not required during the initial stages of development.
2. Nomad Explorer technology is mature and does not require heavy investment to realize. NASA has studied long range vehicles like MOSAP in enough detail to be able to build and test Nomad Explorer prototypes.
3. Prototypes based on existing vehicles used for special terrestrial purposes(like the MX Missile transporter and other advanced recreational vehicles) could also be modified and studied in order to design and build the Nomad Explorer economically.
4. The Autonomous Modular Common Lander(AMCL) is not a new concept. NASA has been working on several lunar landers including the "common lander" and Artemis using existing RL-10B or equivalent engine technology. Modular clustering of engines and tankage need more study in order to realize the AMCL concept. Innovative ways of landing bulk payload that is not so sensitive to higher than average terminal impact velocities(5-10m/s) need further study(22).
5. If the AMCL system is employed to land modular payload containing experiments, logistics and consumables at various locations along a predetermined traverse route, then the Nomad Explorer could assemble and deploy the payload at regular intercepts along the path. Such a strategy will provide unlimited range for the Nomad Explorer.
6. The autonomous common lander approach would bring to the Nomad Explorer architecture a powerful design flexibility. During the course of the traverse, if unforeseen events require different logistics, science or consumable payloads, the landers could be outfitted and flown to intercept the Nomad Explorer with the required mission specific hardware at short notice.
7. During the course of the Nomad Explorer global traverse, if a globally accessible fiber-optic cable could be laid by the vehicle along the traverse, then it may be possible

to eliminate the need for the deployment and maintenance in orbit of a constellation of telecommunication satellites.

8. This flexible open-ended mission architecture can be tailored as the mission proceeds. The if-then philosophy is best suited for exploration oriented missions and can be used to alter the traverse to best suit the exploration and extraterrestrial base site selection as well as the science mission goals.

9. The EVA Bell on the Nomad Explorer will provide a less stressful environment for astronaut crew on long duration EVA missions. The crew will have more freedom to alter traverse routes on the basis of their own exploration results, making the mission more exciting and eventful for both astronaut crew as well as mission control.

10. This ultra-dynamic strategy will also hold the fascination of the public because of the continuously changing terrain vistas, the regular rendezvous with the AMCL system, the number of mission goals which are rapidly met, and the spontaneous nature of the tasks that may have to be performed by the crew during this mission.

11. In this way a speedy global infrastructure may be established on the lunar/Mars surface.

12. The strategy offers tremendous potential for international collaboration. The use of the Energiya HLLV for Nomad Explorer deployment is a possible example.

13. The Nomad Explorer Strategy is a clear and precise "mission oriented" project. The mission objective is the rapid deployment of a highly versatile series of observatories on the moon for deep space, planetary, solar and Earth Observation that are evolved progressively during subsequent missions.

14. A very high quality cislunar telecommunication network is an essential part of the Nomad Explorer architecture. Fiber optics and free space lasers are employed in a round-the-clock communication network architecture which maximizes scientific return and promotes 24 hour use of the facilities by the international community.

12. TECHNOLOGY FOR THE NOMAD EXPLORER STRATEGY

The Nomad Explorer vehicle and the Autonomous Modular Common Lander System employ state-of-the-art and mature technologies. NASA has been working on similar concepts and sufficient data exists within the U.S. which could be used to build and test prototypes.

The Nomad Explorer vehicle requires a heavy lift launch vehicle(HLLV). HLLVs are required in order to minimize otherwise costly and risky on-orbit assembly and rendezvous procedures for which the infrastructure is not in place yet(23,24). Reviving the Saturn V-B and incorporating new modifications to the twenty year old technology could result in a work horse launcher that NASA needs and that is essential for any permanent manned presence on the moon or Mars(29).The Russian Energiya is a typical example of an operational HLLV that could provide primary deployment support for the Nomad Explorer operations(25).

Communications technology has come a long way since Apollo. Fiber-optics and free-space laser communication systems can provide dependable and very high bit rate communications for the Nomad Explorer strategy. Furthermore, if the Nomad Explorer is used to lay a fiber-optic network as the traverse proceeds, eventually it might be possible to have a global extraterrestrial communication system that would eliminate the need for a constellation of satellites in unstable orbits(in the lunar case) and poor life times. Optical line-of-sight free-space laser communications without atmospheric disturbances and associated attenuation is possible on the lunar surface. Laying such extraterrestrial fiber optic cable/free-space links require serious study. Preliminary studies indicate that fiber optics is a feasible option for the moon.(26)

13. THE NOMAD EXPLORER BUDGET

Project Apollo cost $100 billion in 1990 dollars(27,28). Much of the technology base had to be built up from scratch. Though much of the hardware and infrastructure associated with the project is no longer with us, much wealth in hardware and experience from the project remains dormant within NASA and the space industry. In addition, NASA and the space industry have already done much study on long range rovers and landers. MOLAB and MOSAP are some of the long range rovers which have been studied in depth. Several designs have also been developed by NASA for lunar landers. Artemis, lunar lander and the Common Lander some of the NASA studies under way. The Nomad Explorer strategy will rejuvenate NASA and the manned spaceflight hardware builders of the world by tapping into research that is already underway. Using Apollo as the gauge for the Nomad Explorer, it should be possible to return to the moon using the Nomad Explorer and the Autonomous Modular Common Lander for about the same price tag.

14. CONCLUSIONS

The Nomad Explorer Strategy for Extraterrestrial Base Evolution is an alternate strategy for global extraterrestrial infrastructure establishment. Capable of all the functions normally conducted from a stationary base, a mobile base like the Nomad Explorer, when coupled with an autonomous payload/logistics lander system like the AMCL system, has unlimited exploration range as well as a highly tailorable mission plan. Maximum flexibility is the chief attribute of this "open architecture". The "if-then" capability allows the mission to be tailored as it proceeds while maintaining close contact with mission control. Autonomous modular common landers carry mission specific hardware as dictated by the crew.

The Nomad Explorer mission objective is highly defined : To establish, service and progressively evolve a highly versatile series of observatories for deep space, planetary, solar and Earth Observation. Immediate and high quality return on investment is envisaged.

The EVA Bell, a new system concept for enhancing manned EVA in the Nomad Explorer vehicle will help to assist assembly and deployment of science experiments and pilot projects while the vehicle traverses from site to site, examining them in detail for establishing a permanent manned base.

An extraterrestrial fiber-optic/free-space global telecommunication infrastructure may be laid during the course of the exploratory traverse which will eventually eliminate the need for expensive operation and maintenance of a constellation of telecommunication satellites which would otherwise be required as complex extraterrestrial projects evolve. Rapid extraterrestrial development that will hold the interest and excitement of the public as the mission proceeds from site to site is the consequence of using such a mobile strategy. The various systems constituting this architecture require further study and analyses.

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16. REFERENCES

1. NASA(1989). Exploration Studies Technical Report TM 4170, Volume III: Planetary Surface Systems. NASA Office of Exploration. b. NASA(1988)Exploration Studies Technical Report TM 4075, NASA Office of Exploration, FY 1988. Volumes 1 & 2. c. Eagle Engineering(1988). Lunar Reports. NASA contract NAS9-17878. Eagle Engineering Inc., Webster, Texas. d.3. Landis, G.A.(1989). Solar Power for the Lunar Night. NASA TM102127. 9th Biennial SSI Princeton Conference on Space. e.Thangavelu, M.(1991). The Very Long Range Traverse Vehicle: Option for Primary Lunar Base Establishment. Space Systems Division, Rockwell International,Downey, CA. f. Landis, G.A.(1989). A Proposal for a Sun Following Moon Base. Journal of the British Interplanetary Society.

2. Alred, John.(1989).Lunar Outpost. Systems Definition Branch, Advanced Programs Office, NASA Johnson Space Center.

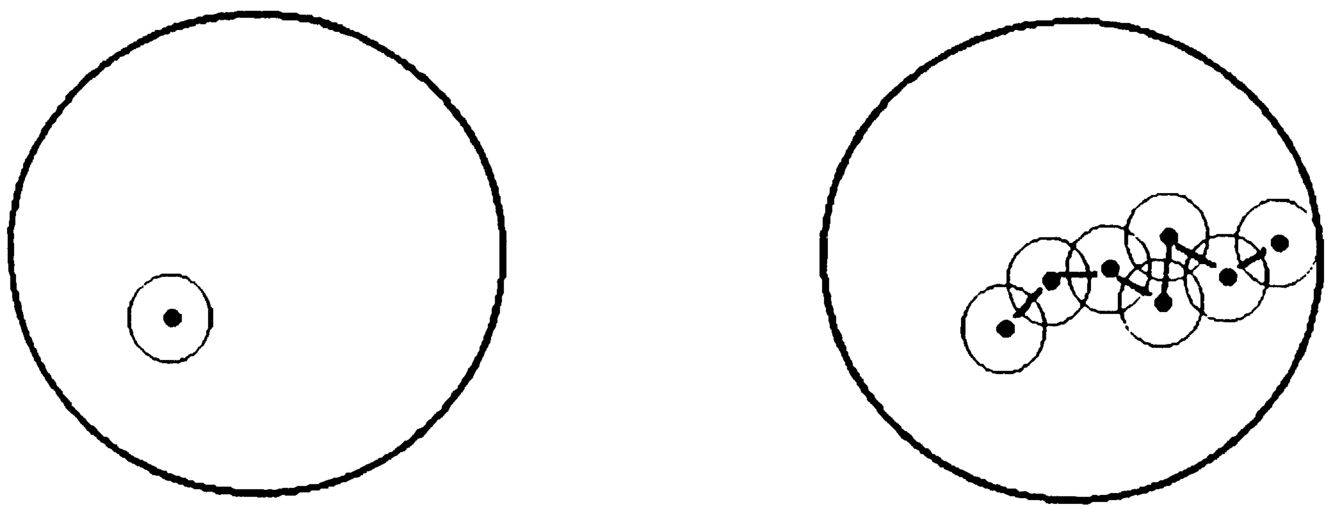
3. Cohen, Aaron, et al.(1989). Report of the 90 Day Study on Human Exploration of the Moon and Mars. NASA Johnson Space Center, Houston, Texas. b. National Research Council.(1990). Human Exploration of Space. A Review of NASA's 90 Day Study and Alternatives. National Academy Press, Washington D.C.

4. Common Lander Study (1991). NASA JSC. NASA Office of Exploration.

5. Horz, Fredrich.(1985) Lava Tubes: Potential Shelters for Habitats. Lunar Bases and Space Activities in the 21st Century. Ed. Mendell W.W. Lunar and Planetary Institute, Houston.

6. Burke, F.B.(1985). Astronomical Interferometry on the Moon. Lunar Bases and Space Activities in the 21st century. Ed. Mendell W.W. Lunar and Planetary Institute.
7. Haskin, L.A.,(1985) Toward a Spartan Scenario for Use of Lunar Materials. Lunar Bases and Space Activities in the 21st century. Ed. Mendell W.W. Lunar and Planetary Institute.
8. Cintala, M.J., Spudis, P.D., Hawke, B.R.(1985) Advanced Geologic Exploration Supported by a Lunar Base: A Traverse Across The Imbrium-Procellarum Region of the Moon. Lunar Bases and Space Activities in the 21st century. Ed. Mendell W.W. Lunar and Planetary Institute.
9. Burke,J.D.(1985) Merits of A Lunar Polar Base Location. Lunar Bases and Space Activities in the 21st century.
Ed. Mendell W.W. Lunar and Planetary Institute.
10. Humphries, R.(1991). Life Support and Internal Thermal Control System Design for Space Station Freedom. NASA MSFC, Huntsville, USA. 4th European Symposium on Space Environmental Control Systems. ESA SP-324
11. Rummel, J.D., Averner, M.(1991) Regenerative Life Support: The Initial CELSS Reference Configuration. Life Sciences Division, NASA Hq. Regenerative Life Support Systems and Processes. Society of Automotive Engineers. SP-873, paper#911420.
12. Schwartzkopf, S.H., Brown, M.F.(1991) Evolutionary Development of A Lunar CELSS. Regenerative Life Support Systems and Processes. Society of Automotive Engineers. SP-873, paper# 911422.
13. Hypes, W.D. and Hall, J.B.(1988). ECLS Systems for a Lunar Base- A Baseline and some Alternate Concepts. SAE 881058. 18th Intersociety Conf. on Environmental Systems, San Francisco, CA.
14. Griffin,B. & Appleby, M.(1991). The Pressurized Lunar Rover. Radiation Analysis using the Boeing Radiation Exposure Model(BREM). Advanced Civil Space Systems Division, Boeing Co.
15. Stone, C.(1991). ALPS: Advanced Lunar Power System. Space Systems Division, Rockwell International,Downey Ca.
16.E.P. Coomes, J.E. Dagle, J.A. Wise(1992). Design Study of A Laser Beam Powered Lunar Exploration Vehicle. Pacific Northwest Laboratory. IAF-92-0742.
17. Brown, W.C.(1969) "Experiments involving a Microwave Beam to Power and Position a Helicopter", IEEE Transactions, Aerospace Electronics Systems., Vol.AES-5
18. Glaser, P.E.(1974) Feasibility Study of A Satellite Power Station, NASA CR-2357.
19.Kuznetz, L.H.(1990). Space Suits and Life Support Systems for the Exploration of Mars. NASA Ames R.C.
20.Wise,Todd(1991). Dust Contamination Control. IDEEA Conference,Houston, Texas.
21.Glaser,Peter(1991). Dust Contamination and Control. IDEEA Conference, Houston, Texas.

22.Thangavelu, M.(1991). The Multicellular Airbag Landing System. A concept for landing extraterrestrial payloads. Space Systems Division,Rockwell International, Downey,CA.
23. Stafford, T.P.(1991). America at the Threshold: Report of the Synthesis Group on America's Space Exploration Initiative. Washington,DC.
24. Augustine, N.(1991) Report of the Commission for the Future of the Space Program.
25. Gobanov, B.I.(1989). Energia - A New Versatile Rocket Space Transportation System, IAF-89-202.
26. Lutes, G.F(1991). Communicating On The Moon Via Fiber Optics. Lunar Fiber Optic Link Study. NASA JPL. California Institute of Technology. NAS7-918.
27.Crawley, Ed(1988). Aerospace Systems Analysis and Costing. Lecture to the International Space University at MIT, Boston
28.Sellers, W.O. and Keaton, P.W.(1985). The Budgetary Feasibility of a Lunar Base. Lunar Bases and Space Activities in the 21st Century. Ed. Mendell W.W. Lunar and Planetary Institute, Houston.
29. Frieling, T.J(1993). Return To The Moon To Stay : Logistical Considerations For SEI Lunar Missions Using Earth Orbit Rendezvous. Bainbridge College, Georgia.

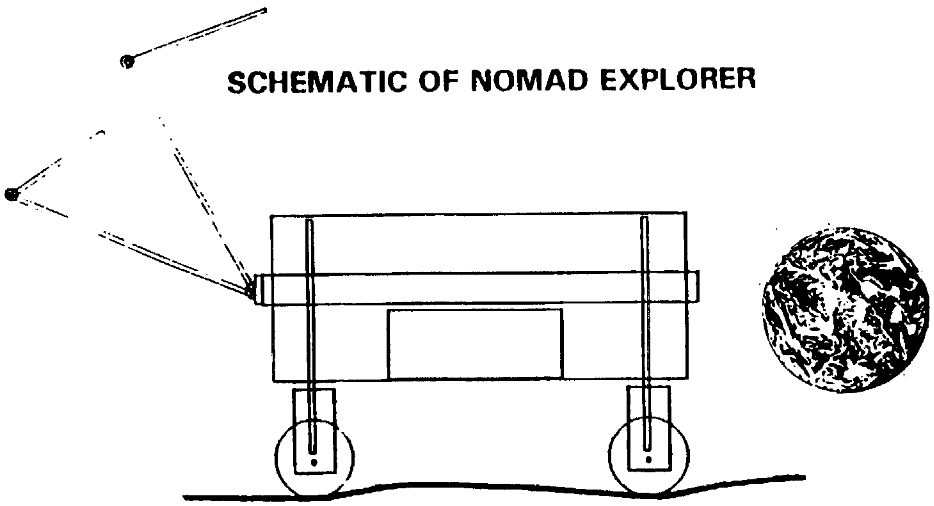


STATIONARY EXTRATERRESTRIAL BASE
• LIMITED EXPLORATION RANGE

MOBILE EXTRATERRESTRIAL BASE
• UNLIMITED EXPLORATION RANGE

Fig. 1

SCHEMATIC OF NOMAD EXPLORER



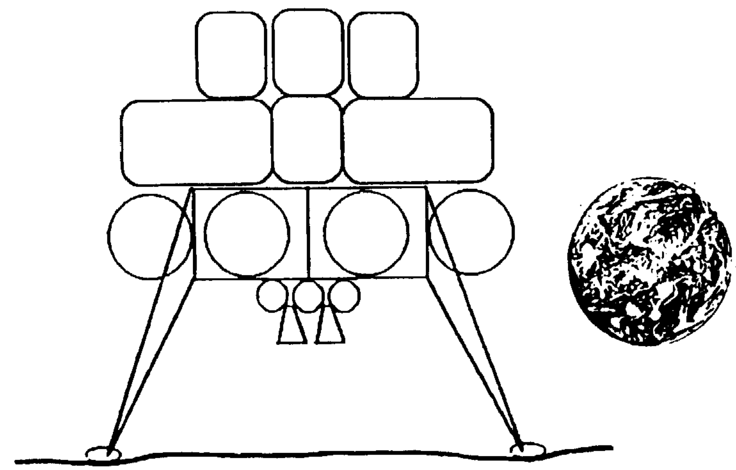
SALIENT FEATURES

1. VERY LONG RANGE TRAVERSE VEHICLE
2. CREW OF THREE, SIX MONTHS, 10,000 KM.
3. MANNED ASSEMBLY ASSIST VEHICLE.
4. BELL ATTACHMENT FOR ENHANCING MANNED EVA.
5. NUCLEAR POWER.
6. LOGISTICALLY RESUPPLIED BY MODULAR REPLACEABLE UNITS DELIVERED BY THE AUTONOMOUS LANDER.

MISSION

1. "SITE-HOP" TO LOCATE BEST SITE FOR PERMANENTLY MANNED LUNAR BASE.
2. DURING TRAVERSE, ESTABLISH SCIENCE OUTPOSTS ALONG THE WAY, DEPLOY EXPERIMENTS, AND ESTABLISH EXTRATERRESTRIAL GLOBAL TELECOMMUNICATION INFRASTRUCTURE USING FIBER OPTICS AND LASER TECHNOLOGY.

SCHEMATIC OF AUTONOMOUS MODULAR COMMON LANDER



SALIENT FEATURES

1. AUTONOMOUS LANDING CAPABILITY
2. MODULAR STRUCTURAL/PROPULSION DESIGN
3. COMMON CARRIER FOR NOMAD EXPLORER CREW TRANSPORT, LOGISTICS, ERECTABLE OR DEPLOYABLE SCIENCE PAYLOADS
4. PAYLOAD CAPABILITY - 5,10,15,20,25 MT DEPENDING ON MODULAR CONFIGURATION

MISSION

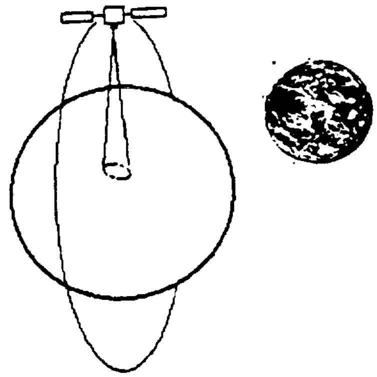
1. PROVIDE CREW TRANSPORT, LOGISTICS SUPPORT FOR THE NOMAD EXPLORER
2. CARRY SCIENCE/OTHER PAYLOADS TO BE DEPLOYED/ERECTED BY CREW OF NOMAD EXPLORER.

Fig.2

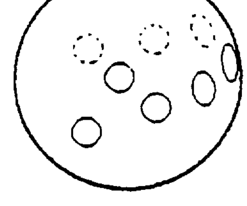
AAA-VISIONEERING M. THANGAVELU

THE NOMAD EXPLORER MISSION PLAN

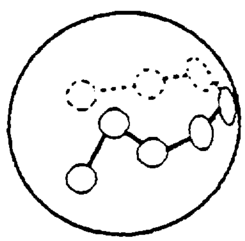
Fig.3



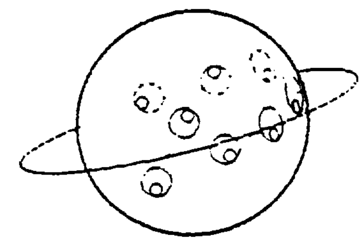
1. HIGH RESOLUTION IMAGING OF EXTRATERRESTRIAL SURFACE. DETAILED GLOBAL MAPS PREPARED.



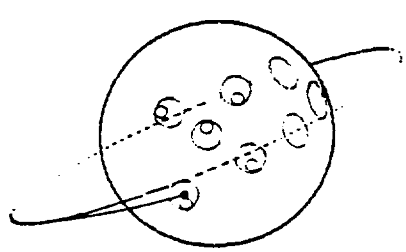
2. SEVERAL CANDIDATE BASE SITES IDENTIFIED. BOTH ON LUNAR NEAR SIDE AND FAR SIDE.



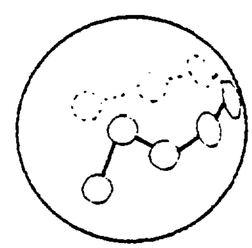
3. ALTERNATE NOMAD EXPLORER TRAVERSE ROUTES EXAMINED. FINAL TRAVERSE ROUTE IDENTIFIED.



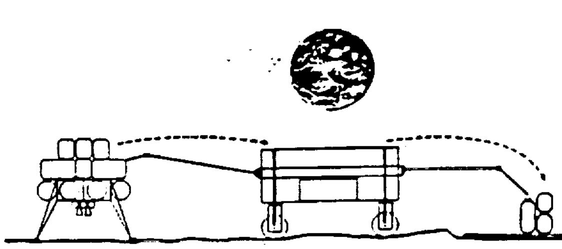
4. AUTONOMOUS LANDER(AMCL) DELIVERS LOGISTICS TO CANDIDATE SITES.



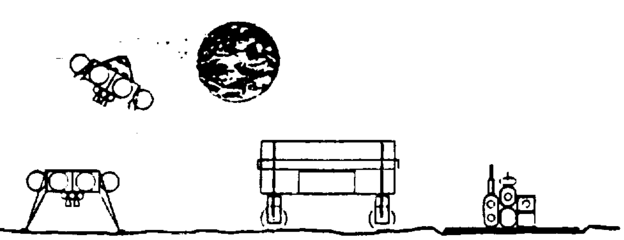
5. NOMAD EXPLORER LANDED AT POINT OF START OF TRAVERSE. ALL SYSTEMS CHECKED OUT FROM EARTH. CREW LANDS NEXT TO VEHICLE IN AMCL CONFIGURED FOR CREW TRANSPORT. TRANSFERS TO NOMAD EXPLORER.



6. DETAILED MANNED EXPLORATION OF NATURAL TERRAIN FORMATIONS(LAVA TUBES, RILLES ETC.) SOIL MECHANICS AND OTHER "HANDS-ON" EXPERIMENTS CONDUCTED. TELECOMMUNICATION LINK DEPLOYED AS MISSION PROCEEDS.



7. AS MISSION PROCCEDS, NOMAD EXPLORER REGULARLY RENDEZVOUS WITH AMCLs CARRYING SITE SPECIFIC PAYLOADS OF SCIENCE EXPERIMENTS AND RELATED HARDWARE. NOMAD EXPLORER INTERCEPTS AMCLs, ASSEMBLES AND DEPLOYS SCIENCE PACKAGES. LOGISTICS REPLENISHED. IF MISSION DURATION EXCEEDS SAFE STAY TIMES, SECOND FULL CREW REPLACEMENT ARRIVES DURING MIDDLE OF MISSION AND THE FIRST FULL CREW RETURN TO EARTH IN AMCL.



8. NOMAD EXPLORER COMPLETES TRAVERSE. VEHICLE SWITCHED TO "HIBERNATION MODE" TILL NEXT MISSION. CREW RETURN TO EARTH IN AMCL THAT IS READY AND WAITING AT END OF TRAVERSE.

THE NOMAD EXPLORER
SCHEMATIC OF SYSTEMS

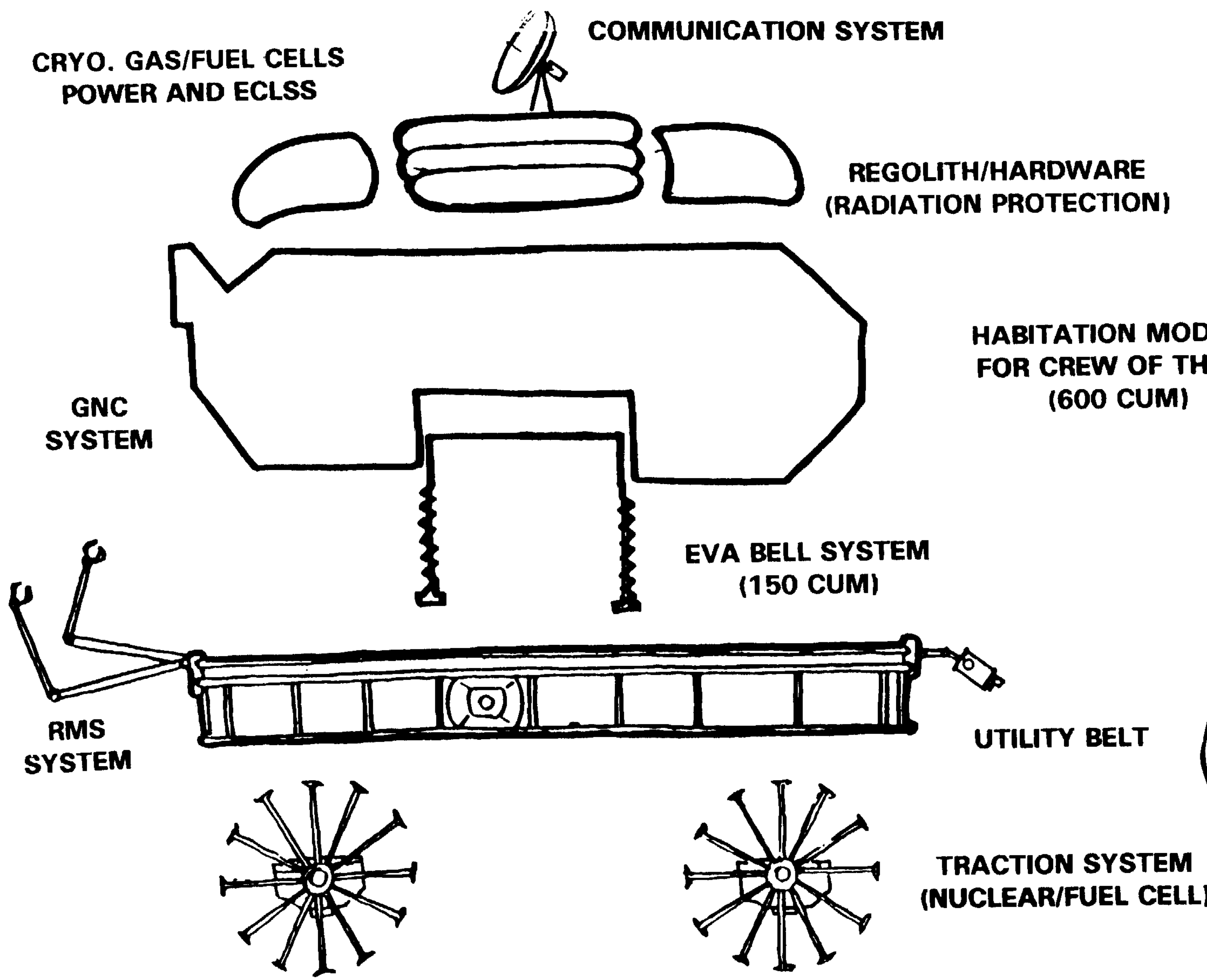


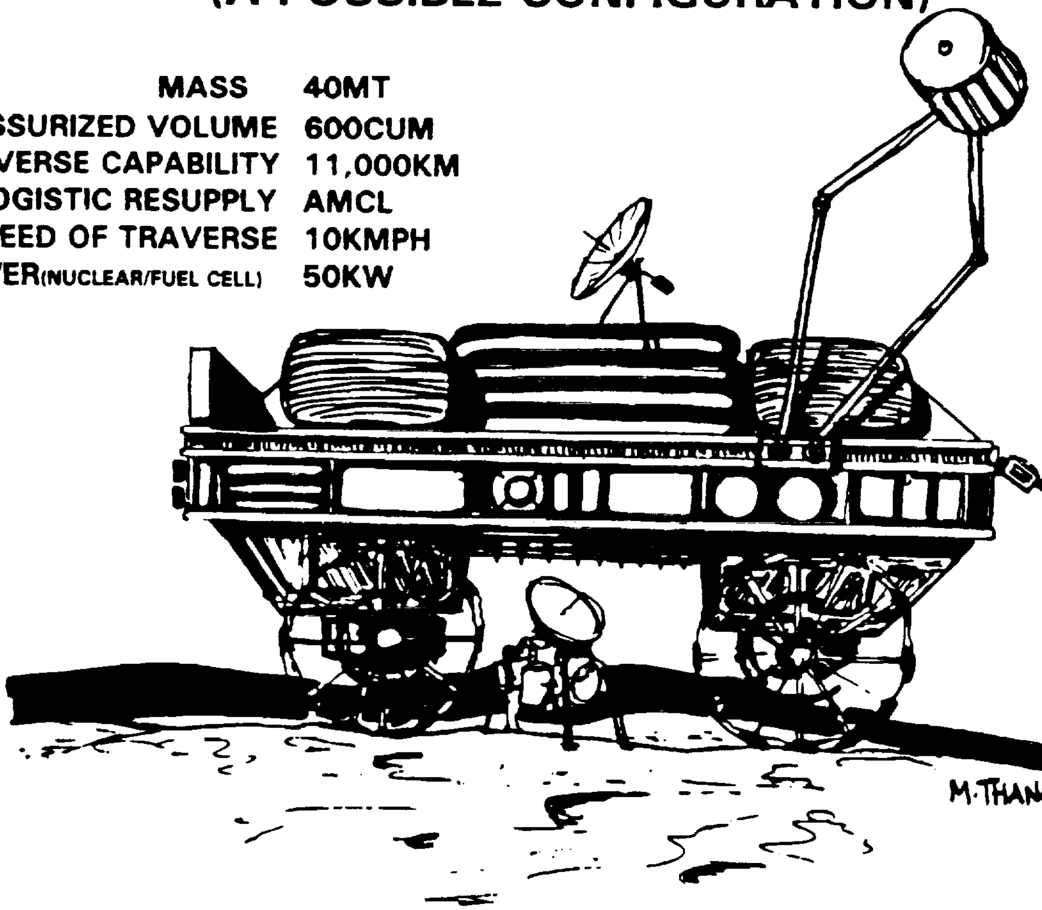
Fig.4

THE NOMAD EXPLORER

(A POSSIBLE CONFIGURATION)

Fig.5

MASS	40MT
PRESSURIZED VOLUME	600CUM
TRAVERSE CAPABILITY	11,000KM
LOGISTIC RESUPPLY	AMCL
SPEED OF TRAVERSE	10KMPH
POWER(NUCLEAR/FUEL CELL)	50KW



LONGITUDINAL SECTION

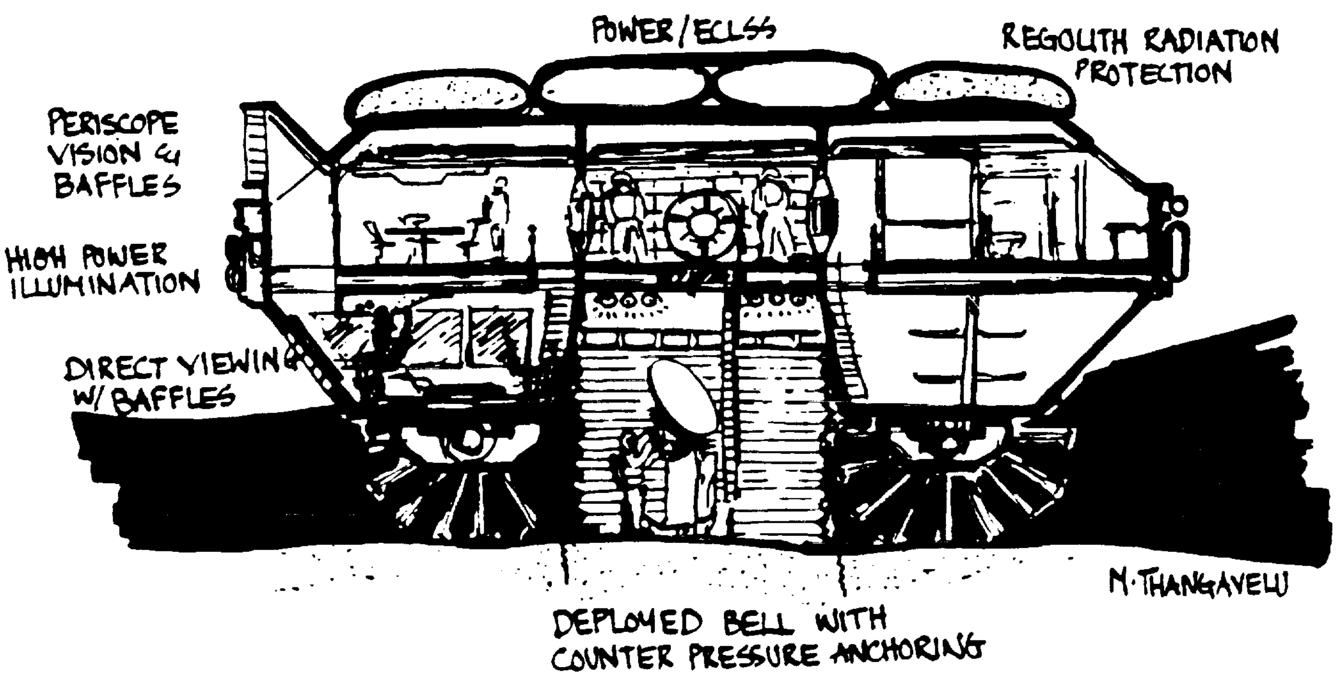
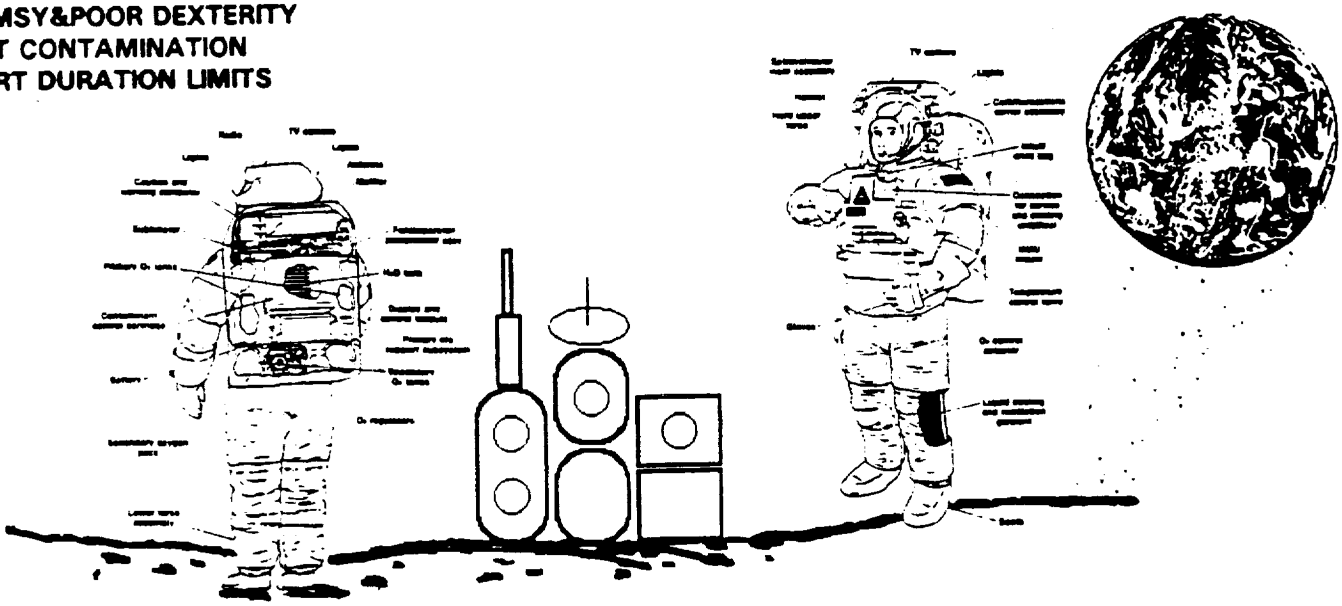


Fig.6

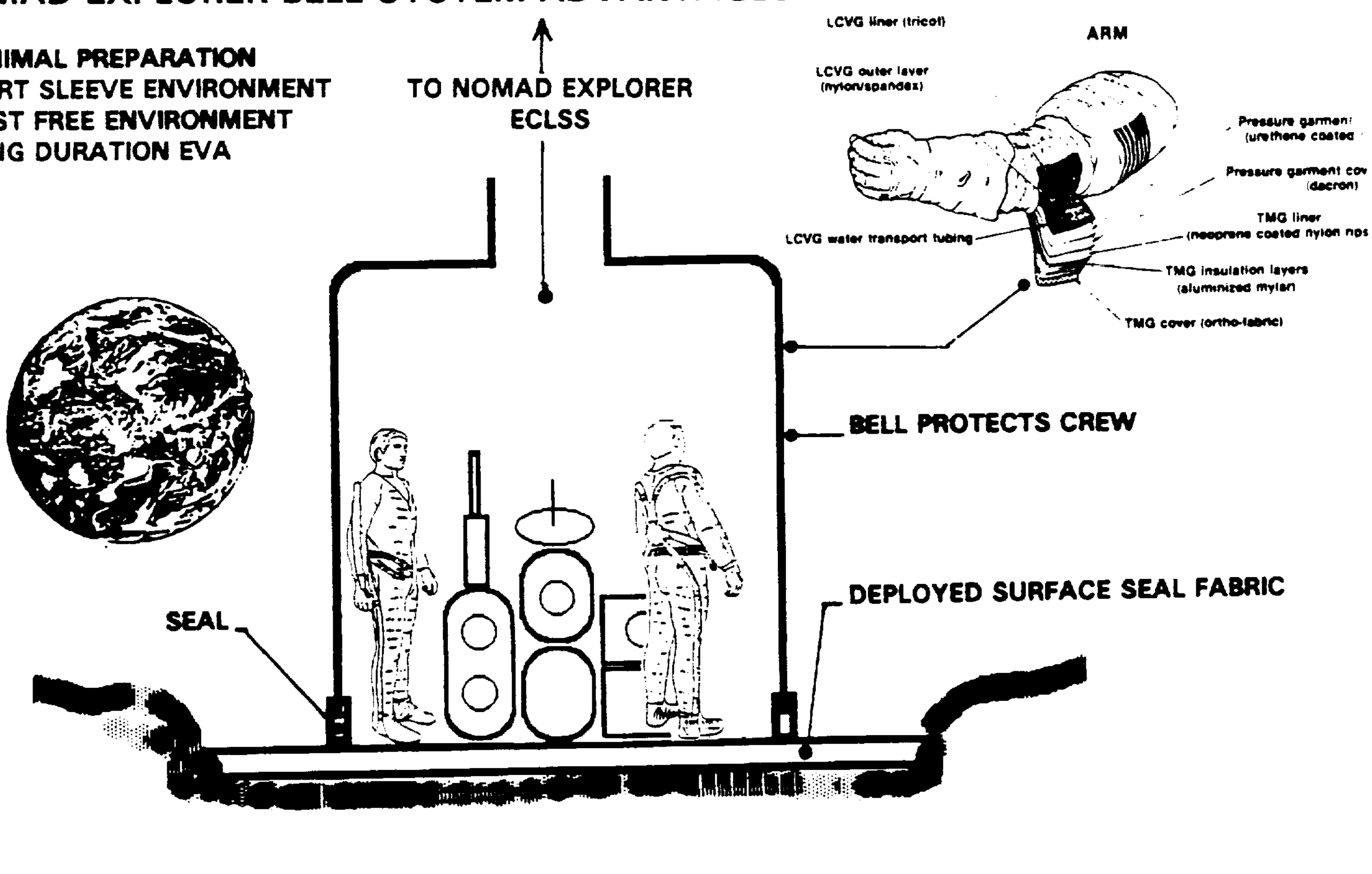
CONVENTIONAL EVA PROBLEMS

- COMPLEX, LENGTHY PREPARATION
- ASTRONAUT FATIGUE
- CLUMSY&POOR DEXTERITY
- DUST CONTAMINATION
- SHORT DURATION LIMITS



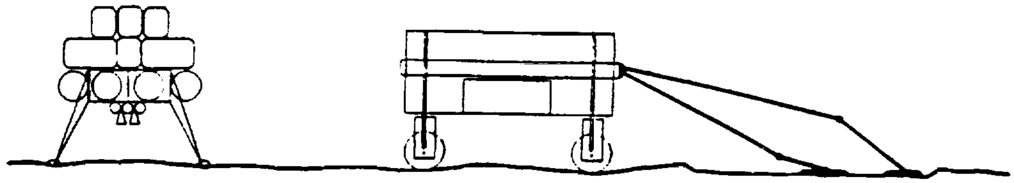
NOMAD EXPLORER BELL SYSTEM ADVANTAGES

- MINIMAL PREPARATION
- SHIRT SLEEVE ENVIRONMENT
- DUST FREE ENVIRONMENT
- LONG DURATION EVA

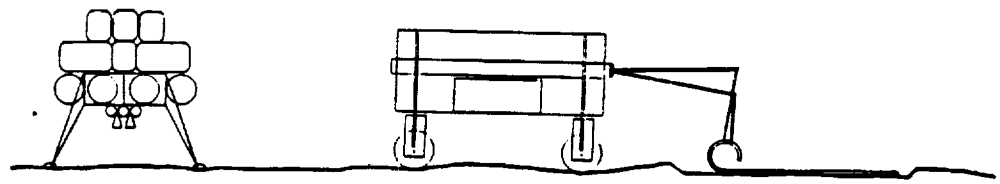


NOMAD EXPLORER PAYLOAD ASSEMBLY ASSIST SEQUENCE

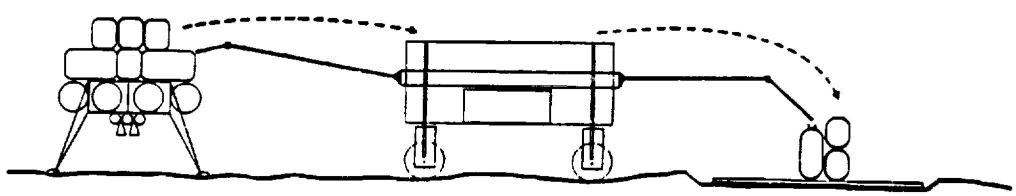
Fig.7



1. NOMAD EXPLORER INTERCEPTS AND PARKS CLOSE TO AUTONOMOUS MODULAR COMMON LANDER(AMCL) WHICH CARRIES LOGISTICS AND SITE SPECIFIC SCIENCE PAYLOADS. MODULAR LOGISTICS RETRIEVED. SUPPLIES REPLENISHED. DEPLETED LOGISTICS MODULES/WASTE DISCARDED.
2. NOMAD EXPLORER PREPARES TERRAIN FOR PAYLOAD ASSEMBLY/DEPLOYMENT.



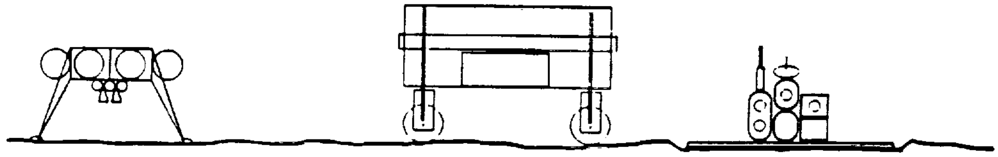
3. NOMAD EXPLORER LAYS SURFACE SEAL FABRIC OVER PREPARED TERRAIN. THIS FABRIC WILL HELP TO CONTAIN THE PRESSURE INSIDE THE DEPLOYED EVA BELL.



4. NOMAD EXPLORER UNLOADS PAYLOAD FROM AMCL OVER THE SURFACE SEAL FABRIC AT THE PAYLOAD ASSEMBLY SITE.

5. NOMAD EXPLORER IS ELEVATED. SLOWLY MOVES TO PREPARED SITE AND ALIGNS EVA BELL OVER THE PAYLOAD AND THE SURFACE SEAL FABRIC.

6. NOMAD EXPLORER DEPLOYS EVA BELL WHICH PROVIDES CREW A SHIRT-SLEEVE ENVIRONMENT FOR MANNED EVA. CREW ASSEMBLE, CHECK OUT, CERTIFY PAYLOAD INSIDE DUST FREE, THERMAL, MICROMETEORITIC, AND RADIATION PROTECTED AND PRESSURIZED EVA BELL.



7. ASSEMBLY COMPLETE. EVA BELL RETRACTED. NOMAD EXPLORER MOVES AWAY FROM PAYLOAD ASSEMBLY. PAYLOAD IS OPERATIONAL. PROCEEDS TO NEXT SITE.