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THE EXTENDED MISSION ROVER (EMR)

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Abstract

A key component in ensuring America's status as a leader in the global community is its active pursuit of space exploration. On the twentieth anniversary of Apollo 11, President George Bush challenged the nation to place a man on the moon permanently and to conduct human exploration of Mars in the 21st century. The students of the FAMU/FSU College of Engineering hope to make a significant contribution to this challenge, America's Space Exploration Initiative (SEI), with their participation in the NASA/USRA Advanced Design Program. The project selected by the 1991/1992 Aerospace Design group is the design of an Extended Mission Rover (EMR) for use on the lunar surface. This vehicle will serve as a mobile base to provide future astronauts with a "shirt-sleeve" living and working environment. Some of the proposed missions are planetary surface exploration, construction and maintenance, hardware setup, and *in situ* resource experimentation. This vehicle will be put into use in the 2010-2030 time frame.

Project Management and Organization

The 1991/1992 Senior Aerospace Design class was organized in a matrix managment fashion with all students involved in the progect assigned to a design group and a management group. This provided the students with a true feeling for how projects are organized in the industrial sector. The class consisted of seven mechanical engineering students and nine electrical engineering students. Due to the diverse makeup of the class, students were often involved in interdisciplinary tasks.

Mission Statement and Requirements

The purpose of an EMR is to provide transportation, shelter, and working quarters for a crew of four on long duration lunar surface missions. The preliminary mission requirements as defined by the Mission Requirements Working Group which researched existing technologies and forecasts of available future technologies include:

- Mission Distance: 1000 km round-trip
- Mission Duration: 28 Earth days (1 lunar day)
- Maximum Crew Size: 4
- Maintain self-sufficient environment to support crew and cargo (oxygen, food, water, climate)
- Maintain interior environment during egress
- Provide shielding from environmental elements
- Collect/analyze/store data
- Possess robotic data sample/data collection capability
- Transport various experimental apparatus
- Travel over rough terrain (45° head-on, 20° traverse)
- Possess path-clearing abilities
- Provide internal navigation support
- Possess communication capability with base and Earth
- Possess unmanned capability
- Provide redundant systems
- Be easy to maintain

By keeping the expected traverse distance under 3000 km for a time period of approximately one month, the size of the fuel cell tankage was small enough to keep from interfering with the accomplishment of the mission objectives.

The multi-purpose nature of the vehicle design makes it flexible enough for use in many applications such as firsthand observation and assessment of the terrain within a 500-km radius of the base. Lengthy analysis and assessment of mineral deposits could be conducted from the vehicle, as well as setup of sensitive hardware such as space radio telescopes at a great enough distance from the permanent lander base to prevent interference from vibrations caused by the lander's engines.

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System Design and Integration

The design of the EMR was based upon the forecast of future technologies consistent with those included within available references. Rather than trying to carry out detailed calculations on the transportation system, the approach was to ensure that the mass and size of the EMR did not exceed the limitations predicted by the available references. Figure 1 shows a side view of the vehicle.

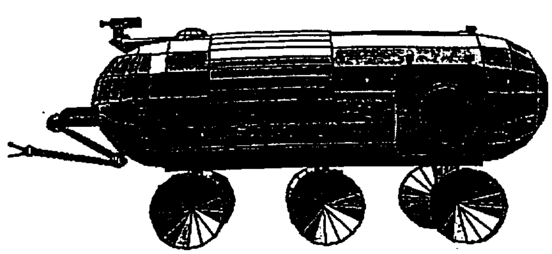

Fig. 1 Side view of vehicle

From the report released by Boeing Defense and Space Group, Advanced Civil Space Systems, in Huntsville, Alabama, a launch vehicle and lander system was found that would easily accommodate the EMR. The estimated payload delivered to the lunar surface was 45 mt based on the concept of delivering a fully integrated habitat to the lunar surface. This would fit into Boeing's LTV tandem stage expendable mode using the Direct, Lunar Orbit Rendezvous (LOR) high-thrust profile. The launch vehicle proposed by Boeing was in the range of 100-400 mt with a payload shroud of 10 m x 30 m. The preferred method of carrying the cargo is to hang it on the underside of the lander to make it easy to unload on the lunar surface. If the payload is to be underslung on the lander, some deployment or assembly of the EMR may be needed on orbit if the launch vehicle is less than 10 m in diameter.

Suspension

The rough terrain of the lunar surface represents great difficulties for the locomotion system of a ground-based vehicle. Mobility requirements for a lunar-based vehicle are very diverse. Mission requirements vary greatly, and the environment of locomotion may be literally anywhere on the moon. To meet these diverse needs, all practical mobility concepts, including tracked vehicles, walkers, and wheels, were examined.

Wheels will be the preferred mobility option for many missions. Wheels are mechanically efficient, can be designed into lightweight systems, and can be built with excellent reliability. A disadvantage in terrestrial all-terrain applications is their small footprint, but the reduced gravity field of the moon does not require a large ground contact area.

The EMR will use six cone-shaped carbon graphite wheels, each with a diameter of 72 inches and a thickness of 0.5 inches. Tread width is 20 inches for maximum traction to help prevent slippage on the lunar surface. Minimum ground clearance for the wheel is estimated to be 36 inches. Overall weight for six cone wheels is approximately 624 kg.

To accomplish the vehicle mission, the suspension system must meet the following requirements:

1. Ensure height mobility under lunar surface conditions of rough terrain, loosely cohesive soil with low bearing strengths, and a coefficient of resistance of motion (f) of 0.6.

2. Overcome elevations of up to 25°.

3. Ensure reliable motion on the lunar surface despite obstacles such as groups of rocks, scarps, and counterscarps, fissures and craters.

4. Ensure a highly reliable operation of all systems without need for repair within the required service life.

5. Be within a definite geometric size with a minimum weight in keeping with the requirements of the space rocket capacity.

The final design for the primary and secondary suspension system is shown in Figure 2.

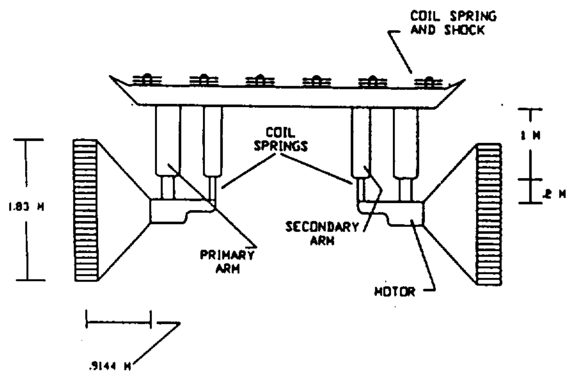

Fig. 2 Primary and secondary suspension

Radiation Shielding

The problem of providing sufficient radiation shielding for the crew of the EMR was approached from a very conservative point of view. It has been suggested that a spacecraft with shielding equivalent to 5 gm/cm^2 of aluminum would suffice for a manned Mars mission. This would seemingly be a sufficient amount of shielding for a lunar mission. However, this amount was deemed low and through an interative research and mass trade-off process, a figure of 10 gm/cm^2 shielding was agreed upon for normal radiation protection.

Since a high inensity radiation storm could prove lethal to crewmembers in the EMR, it is assumed that by the time this vehicle is deployed on the moon, an early warning system to detect radiation storms and solar flares will have been developed.

Airlock

An airlock that allows the crew and equipment to enter or exit the vehicle without depressurizing the whole craft is necessary in order to satisfy mission requirements. A conventional airlock design will be used.

Vehicle Shell

The internal shell will be made of 2219 aluminum alloy. Aluminum is a proven material for lining pressurized vessels because of its weight-to-strength ratio (0.5) and its manufacturing capability. It is easily maintained, and is suited for welding and forming. The internal framing will be welded together.

Avionics

The primary purpose of the avionics system is to integrate successfully a comprehensive set of general aviation electrical and electronic functions into a complex system architecture. It should meet the users' needs by improving the safety and dependability of the vehicle system operations without increasing the requirements for astronaut training/experience by overexploiting advanced technology in computers, displays, and overall system design. The overall purpose will be to design a system at an affordable price. The system will be comprised of Avionics Vehicle Control, Robotic Arms/Video, Navigation, Communications, and Data Transfer/Acquisition to provide critical information, improved functional capability, and shared electronic displays without losing important considerations about overall system cost, reliability, producibility, and overall maintainability of the entire avionics system. The mass of the total avionics system is about 100 kg $\pm$ 5 kg; the volume of the avionics system is 4.5 m^3, including the avionics display of 0.5 m^3, communication system of 1 m^3, and workstation of 3 m^3. The total power requirement of the avionics system is approximately 600 watts.

Workstation

The concept of a modular, reconfigurable, expandable, general purpose, human-engineered workstation is envisioned for use by scientists, technologists, design and system engineers, and space and ground operators. The workstation encompasses concepts of machine independence, modularity, standardized interfaces, expert system technology, and human machine interaction techniques.

Input and Output Devices

The primary input device of the workstation is the keyboard, which will either be attached or remote so that astronauts can enter data directly in memory without coming near the workstation. Other devices such as a touch-sensitive screen, optical character reader, and a light pen will also be available for input. There will also be a digital mouse or track ball to enhance the workstation's capabilties.

Communication

Since communication between the base and the EMR is a top priority and the vehicle has a range of about 1000 km, a system of lunar orbiting satellites and a tower antenna at the base or on the vehicle are suggested. Figure 3 illustrates the case when the rover is on the far side of the moon and two satellites are required for communication with the base.

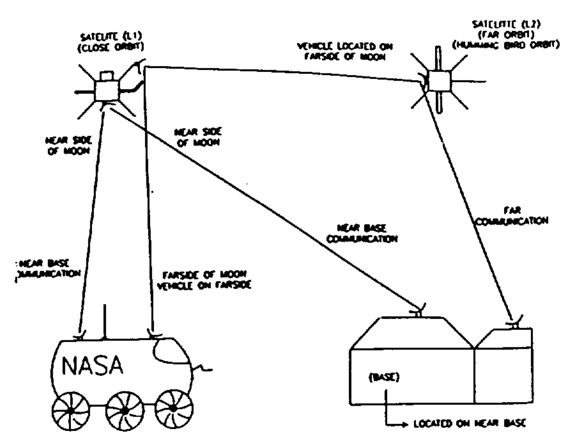

Fig. 3 Communication network

Link Performances and Antenna Types

Link performance analysis deals with sizing communication system power and antennas so that the received signals are strong enough that the data can be extracted from the signal. Of the many types of antennas avilable, the dish reflector possesses a major advantage because it concentrates signal energy on the receiver, thus improving the signal-to-noise ratio.

Navigation

Navigation on the moon is difficult because there is no coordinate system equivalent to the Earth's North and South poles. The navigation system is divided into the following main displays:

- Attitude Indicator -- provides indications of vehicle's pitch and roll. This instrument indicates pitch upslope (u) and downslope (d) within a range of ± 25 °. The damper on the side of the indicator can be used to damp out oscillations.
- Heading Indicator - displays the vehicle heading with respect to lunar north.
- Bearing Indicator - shows the bearing to the base.
- Distance Indicator -- reports distance traveled by the vehicle in increments of 1 km.
- Sun Shadow Device - determines the vehicle's position with respect to the sun. This heading can be compared with the gyro heading at regular intervals as a check against gyro drift.
- Speed Indicator - shows the vehicle velocity from 0 to 20 km/hr, and is driven by odometer pulses from the right rear wheels.
- Gyro Torquing Switch - adjusts the navigation gyro to correct the heading indication during navigation update.

Heads-Up Display

A helmet-mounted visual display system will provide an astronaut with a broad range of visual information for experiments and critical information about human aspects, the robotic arm, and the pathfinder. In addition, the display offers a nearly unlimited field of vision.

Robotic Arm

The design of the robotic arm will incorporate key issues of compactness, versatility, reliability, accuracy, and weight. The arm can be used on both the lunar vehicle and lunar base for a variety of functions. The lunar vehicle will have connections for the robotic arm on the lower center front and on the rear of the vehicle.

Electronically-Scanned Laser Pathfinder

The electronic laser scanner will use a laser diode array(s) and charge-coupled cameras (CCD) to sweep across its field of view to measure the distance of objects from 0.5 to 20 m away. No mechanical moving parts will be necessary. The scanner device will guide the EMR around large to medium-scale obstacles.

Moving Map Display Processor for Finding LC Path

A VLSI (Very Large Scale Integrated) circuit design will implement a processor to find the lowest-cost map path by associating a traversal cost at each pixel node and calculating at each node the total cost of a path from a unique originator node to that node. This design concept will be very important due to the mission requirement of capability for a 1000-km round-trip.

Thermal/Fluid

Environmental Requirements

The environment that will be experienced on the lunar surface poses many problems to the engineer. Because of the closed nature of the life support system on the EMR, the ability to revitalize the atmosphere becomes a major factor in maintaining the health of the astronauts. Several important conditions are temperature, pressure, humidity, composition, and purity. The biological needs of the astronauts must be quantified and the effects of certain conditions evaluated to ascertain their hazard levels.

Waste Removal and Storage

Storage will consist of a cylindrical tank of thin stainless steel sheet with an insulation jacket to reduce heat dissipation. The waste will be treated chemically with active enzymes which break down the bacteria growth and reduce odors. The urinal system will be sealed when not in use to reduce accumulation of odors in the latrine. A forced air system will complement the toilet to ensure proper flow direction of waste material. The chemical treatment system will be controlled by a flow meter which can sense additions to the tank. The chemical treatment will consist of sulfuric acid 10 (a triple salt monopersulfate compound) which will disinfect, control pH to between 2.0 and 2.5, and fix free ammonia and ammoniated compounds.

Water Supply

The water will be stored in cylindrical tanks to minimize space requirements. Storage will be external to allow for modularity and maintenance. A pump will provide usable pressure for tasks such as showering, waste removal, and galley feedwater. The estimated power consumption is 391 W at a flow of 0.456 m^3/hr. See Figure 4 for details.

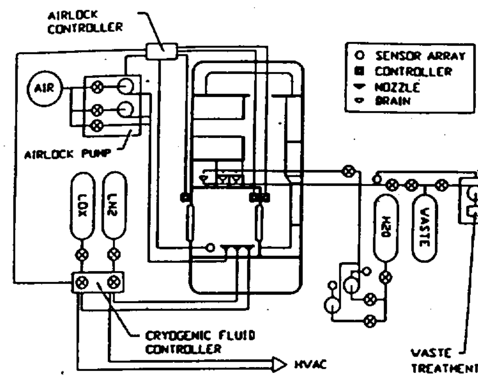

Fig. 4 Water supply and waste removal schematic

Cryogenic Storage

The atmosphere in the vehicle will be composed of a mixture of 80% nitrogen and 20% oxygen, which is very close to the 78.084% nitrogen, 20.9476% oxygen plus traces of other gases for normal atmospheric breathable air. Nitrogen and oxygen will be stored in two separate cryogenic cylindrical tanks located outside the vehicle and mixed accordingly. Concerns for safety in the cryogenic fluid storage vessels are addressed in the design of: 1) the inner vessel pressure relief valve, 2) the inner shell burst-disk assembly, and 3) the annular space burst-disk assembly.

Leak Containment

Because of the high vacuum that characterizes the lunar environment, maintenance of a suitable atmosphere in the vehicle is imperative. A pressure of approximately 12 psi, close to the sea level pressure of 14.7 psi on Earth, has been chosen for optimum crew health and performance. The inside living quarters cabin shell will be surrounded by another shell to provide a deterrent to leak propagation.

Airlock Management

The airlock is the only outlet from the vehicle. It is also the last protection the astronauts have from any physiological problems that could result from the pressure decrease that ocurs during EVA. A compressor will be used to depressurize the airlock. A second compressor will be carried in the vehicle for redundancy. The compressors will require no more than 15 kW of power during airlock pumpdown. The first stage of depressurization will require 7.2 kW, and the second stage requires 14.9 kW of power.

Fire Suppression

The hazard of fire aboard the vehicle is compounded by the closed loop system and the restrictions it places on the emergency equipment. Though there are many ways to combat a fire, all use basically the same principle, which is the removal of oxygen from the flame. On the EMR, fire suppression will consist of removing all the air and replacing all available oxygen with inert materials (CO^2, Halon, dry chemical). This will be complemented through the use of CO^2 in the cabin areas and Halon 1301 in the electrical compartments.

Power Generation

Radioisotope Generators

To meet critical power requirements, a dynamic isotope power system (DIPS) has been selected. The isotope used in the system is Pu^{238}, one of a group of reactor-produced fuels including Cm^{242} and Cm^{244}. Reactor-produced fuels can be divided into two classes: those that absorb one neutron and those that absorb more than one neutron. In the first class, a stable isotope captures one neutron and thus becomes radioactive. In the second class, a stable isotope (one with a long half-life) absorbs more than one neutron until it ends up as the desired radioisotope. Pu^{238} is characteristic of the second class of fuels.

Fuel Capsules

Metallic fuel capsules that hold long-lived alpha emitters must contain a vent for the helium gas generated by the radioactive decay of the nuclear fuel unless adequate space is provided within the system for the venting to occur. These vents can be either selective or nonselective. Selective vents pass helium, but retain any larger gas molecules and solid particulates from the fuel. Nonselective vents also retain solid particulates from the fuel, but pass helium and other gaseous effluents, including uncondensed fuel, impurity vapors, and possibly other fuel decay products such as radon.

Overall Design

The overall design of the DIPS power system consists of five major components: (1) an isotope heat source, (2) a compressor, (3) a thermal radiator, (4) a turbine, and (5) a generator. The components have been integrated so that the complete system follows a closed Brayton cycle configuration. Based on this configuration, heat addition and rejection occur at constant pressure, while expansion and compression are assumed to occur at constant entropy. To simplify the design of the power system, it was organized so that both the compressor and the turbine make use of the same shaft.

Radiator Design

The design of the radiator for the lunar rover will follow a configuration of a series of tubes through which the coolant will flow. The mass flow rate of the coolant (helium) was found to be 0.0904 kg/s and the specific heat, C_p, was determined to be a constant value of 5.193 KJ/Kmol·K.

Future Considerations

If increased power requirements are necesary, dynamic power conversion units can be coupled with radioisotope heat sources. That results in the extension of the power generation range beyond that practically obtainable with other systems such as telluride TE converter systems. Lower unit costs are obtained through higher power conversion efficiencies. A bar chart of the power requirements can be seen in Figure 5.

Backup Power

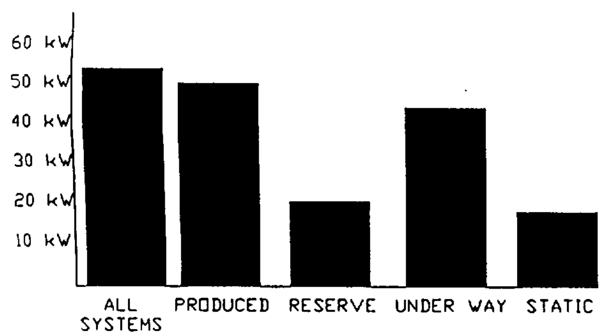

Fig. 5 Power requirements for lunar rover

The maximum power required for the EMR while traversing a 20° slope is 43.4 kW_e. The maximum power requirement for static operation, which includes experimentation, is 18.6 kW_e. The maximum power required if all systems are working simultaneously and at maximum operating conditions is 53.9 kW_e.

Propulsion System

The propulsion system for the EMR consists of electric motors designed to meet the following requirements: variable torque, variable speed, light in weight, high efficiency, and high torque for obstacle clearance combined with optimum speed to maximize the vehicle's exploration range.

Motor

The brushless DC motor contains the following main components: (1) motor, (2) sensing system, (3) electronic commutator, and (4) control. The brushless motor consists of a rotor on which permanent magnets are mounted. These magnets are always arranged in pole pairs. The winding is placed in an external, slotted stator.

Power Control Methods

A varying supply voltage to the commutation system will provide power control. The six switching transistors will control commutation at the proper angular intervals, and the series-connected power transistors will handle velocity and current control of the brushless motor. This can be accomplished by pulse-width or pulse-frequency modulation.

Tachometers

Tachometers are often necessary in high-performance servo applications in which they provide velocity feedback for speed control purposes or servo system stability. For this system an Electro-Carft brushless DC tachometer will be used. The tachometer is based on a permanent magnet motor and a multi-coil stator structure, which is commutated by an MSI circuit.

Summary

An Extended Mission Rover to provide transportation, shelter, and working quarters for a crew of four on long-duration lunar surface missions has been designed by students from the Departments of Mechanical and Electrical Engineering at the FAMU/FSU College of Engineering. The vehicle will serve as a mobile base to provide future astronauts with a "shirt-sleeve" living and working environment. The mult-purpose nature of the vehicle design makes it flexible enough for use in many applications on the lunar surface.