N94- 25704

Table 2 PARAS mass summary

Observatory Modules	15,500 kg
Bus Module	710 kg
Propulsion System	4,280 kg
Total mass	20,490 kg

Table 3 PARAS main characteristics

Antenna type	Phased array
Nominal diameter	150 m
Observing wavelength (tentative selection)	1.35 cm, 18 cm
Mapping time	A few hrs to 48 hrs
Orbit	Geosynchronous
Propulsion/station keeping	16 monopropellant thrusters 16 hydrazine arcjets
Power systems: Observatory	GaAs/Ge arrays and NaS battery
Central bus	GaAs/Ge arrays and NiH_2 battery
Arcjets	RTG and NaS battery
Operational lifetime	10 years
Total mass	20,500 kg

Table 4 Expected Astronomical Performance

Linear resolution:	
at 1.35 cm	30 microarsec which corresponds to 4 light days at the galaxy M87
at 18 cm	0.1 milliarcsec
Sensitivity:	if 24-hr observation, a dynamic range map of 100 to 1 may be achieved
	at 1.35 cm for 25-50 sec
	at 18 cm for 5-10mJy sources

PRESSURIZED LUNAR ROVER (PLR)

PLR I: Kenneth Creel, Jeffrey Frampton, David Honaker, Kerry McClure, Mazyar Zeinali

PLR II: Manoj Bhardwaj, Vatsal Bulsara, David Kokan, Shaun Shariff, Eric Svarverud, Richard Wirz

Abstract

The objective of this project was to design a manned pressurized lunar rover (PLR) for long-range transportation and for exploration of the lunar surface. The vehicle must be capable of operating on a 14-day mission, traveling within a radius of 500 km during a lunar day or within a 50-km radius during a lunar night. The vehicle must accommodate a nominal crew of four, support two 28-hour EVA's, and in case of emergency, support a crew of six when near the lunar base. A nominal speed of 10 km/hr and capability of towing a trailer with a mass of 2 mt are required. Two preliminary designs have been developed by two independent student teams.

The PLR I design proposes a 7-m-long cylindrical main vehicle and a trailer which houses the power and heat rejection systems. The main vehicle carries the astronauts, life support systems, navigation and communication systems, lighting, robotic arms, tools, and equipment for exploratory experiments. The rover uses a simple mobility system with six wheels on the main vehicle and two on the trailer. The nonpressurized trailer contains a modular radioisotope thermoelectric generator (RTG) supplying 6.5 kW continuous power. A secondary energy storage for short-term peak power needs is provided by a bank of lithium-sulfur dioxide batteries. The life support system is partly a regenerative system with air and hygiene water being recycled. A layer of water inside the composite shell surrounds the command center allowing the center to be used as a safe haven during solar flares. The PLR I has a total mass of 6197 kg. It has a top speed of 18 km/hr and is capable of towing 3 metric tons (in addition to the RTG trailer).

The PLR II configuration consists of 2 4-m-diameter, cylindrical hulls which are passively connected by a flexible passageway, resulting in the overall vehicle length of 11 m. The vehicle is driven by eight independently suspended wheels. The dual-cylinder concept allows

articulated as well as double Ackermann steering. The primary power of 8 kW is supplied by a dynamic isotope system using a closed Brayton cycle with a xenon-hydrogen mixture as the working fluid. A sodium-sulfur battery serves as the secondary power source. Excess heat produced by the primary power system and other rover systems is rejected by radiators located on the top of the rear cylinder. The total mass of the PLR II is 7015 kg.

Pressurized Lunar Rover I

Configuration

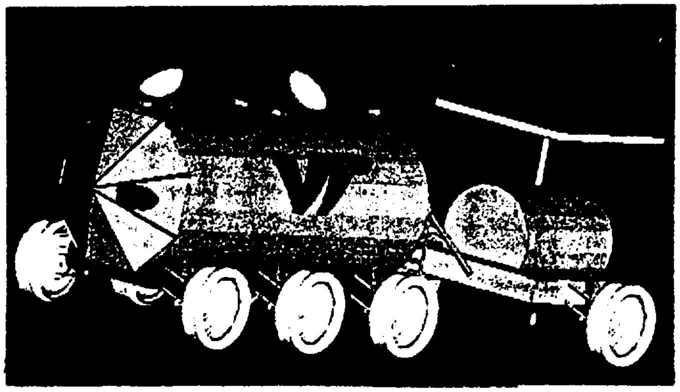


Fig. 9 View of PLR I

Simplicity and low total weight have been the driving principles behind the design of PLR I. The overall configuration consists of a 7-m-long, 3-m-diameter cylindrical main vehicle and a two-wheeled trailer (Figure 9). The cylinder of the main body is capped by eight-section, faceted, semi-hemispherical ends. The trailer contains the RTG power source and is not pressurized. The shell of the main body is constructed of a layered carbon fiber/foam/Kevlar sandwich structure. Included in the shell is a layer of water for radiation protection. The layer of water extends from the front of the rover over the crew compartment and creates a safe haven for the crew during a solar flare-up. The carbon fiber provides the majority of the strength and stiffness and the Kevlar provides protection from micrometeoroids. The Kevlar is covered with a gold foil and multi-layer insulation (MLI) to reduce radiation degradation and heat transfer through the wall. A thin thermoplastic layer seals the fiber and provides additional strength.

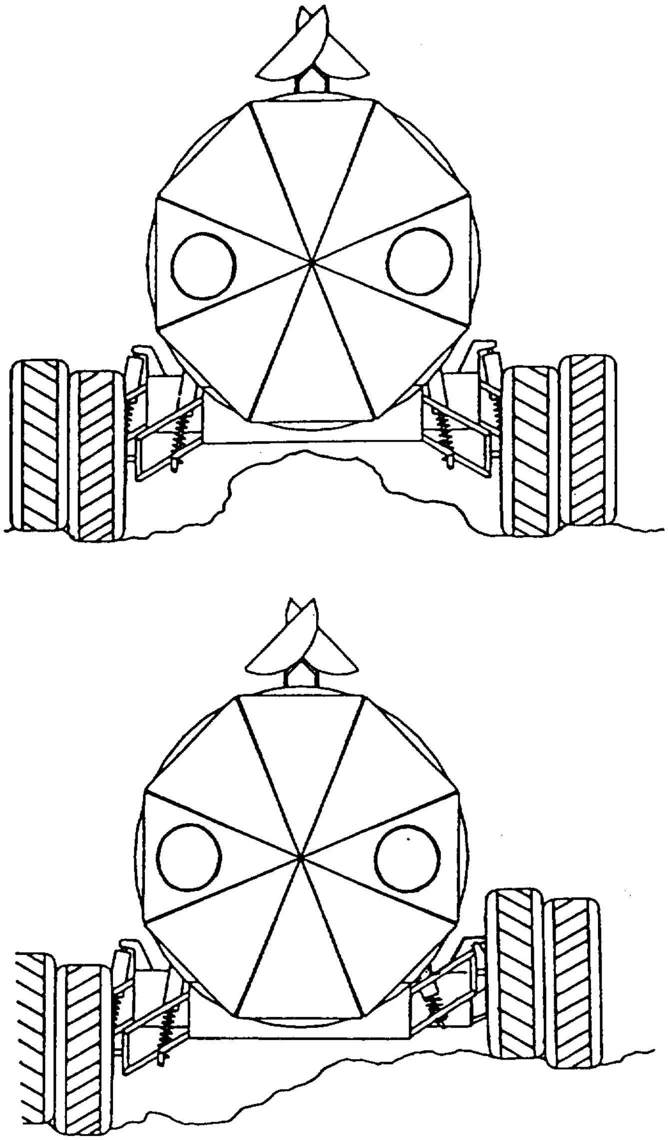


Fig. 10 Front view of main body

Mobility

A double A-arm suspension provides a ground clearance of more than 0.85 m, reliability, stability, and total independence of the wheels. The A-arms are connected to the main body with simple pivot joints that allow for up-and-down motion only (Figure 10). They are also connected to the kingpin by the same kind of joints. The A-arm shape allows for the placement of the shock inside the arms. The chosen design provides effective performance with minimal mechanical complexity, thus minimizing the chance of suspension failure. Six wheels are chosen on the basis of load and mobility considerations. Tires made of a composite flexible plastic matrix are proposed. They have a 1.5-m-diameter and a width of 0.5 m and would experience a sinkage of approximately 5 cm in the soft lunar soil. The high performance/high torque brushless motors (Inland RBE-6202-B50) are mounted with harmonic drive units inside each of the wheels. The rover is steered by electrically varying the speeds of the wheels on either side of the rover. Each wheel supplies a torque of 521 Nm to turn the rover within its own length with zero forward velocity. The tire's rounded cross-sectional shape should minimize friction during a turn. To slow or stop the rover, the motors are used as generators charging the batteries.

Interior Layout

A few interior layouts of the rover are shown in Figure 11. The command center is located in the front two meters. The command center is also used as a safe haven in case of a solar flare warning. The exterior shell is shielded with a layer of water and the interior is separated by an aluminum divider. When there is no danger, the aluminum divider is kept open to create more space. Immediately behind the command center is the lab area on the right and the first pair of bunks on the left. This area is also two meters in length. The next section contains the galley on the right and storage on the left. The bathroom is adjacent to the galley. An airlock and the remaining two bunks are located in the rearmost portion of the rover. When not in use, the two upper bunks can be folded down to create two couches for the crew to relax or eat on.

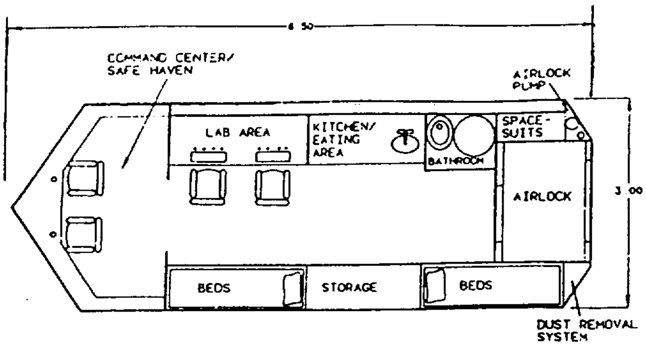
Power System

The power system supplies power to four major areas:

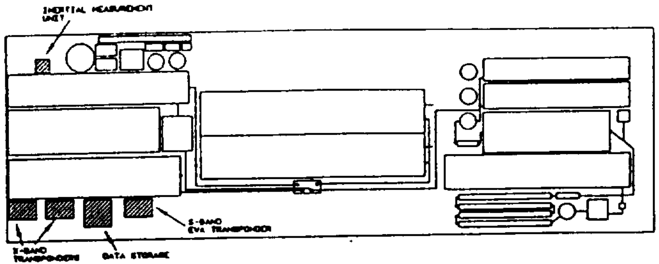
Life Support	1.5 kW
Drive System	4.5 kW ave./8 kW max
Communications/ Controls/ Lights	1.0 kW
Battery Charging	0.1 - 0.2 kW

Average and peak power requirements have been established at 6.5 kW and 9.5 kW, respectively. These values have been derived by examining power profiles for typical short duration missions (such as a 1-day soil

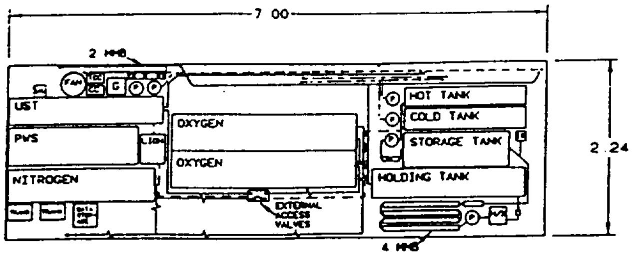
Main interior layout



Underfloor electronic layout



Floor layout



Ceiling computer layout

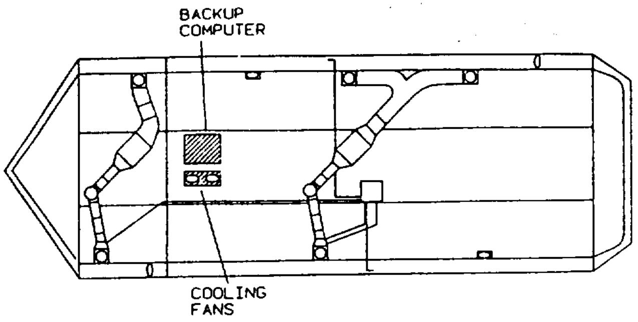


Fig. 11 Interior layouts

sample mission) and long duration missions (e.g., 12-day optical interferometer mission). A trade study of photovoltaic, dynamic isotope and radioisotope thermoelectric generator (RTG) power systems has resulted in selection of the modular silicon-germanium RTG as the superior candidate. The RTG provides the needed redundancy and survivability without a need for multiple space parts. With the modular RTG, the total power is supplied by several modules. If a single module fails, the rover continues to be operational and returns to the lunar base using the remaining power.

The RTG will be liquid cooled. A 9 m^2 radiator is positioned on a boom on top of the RTG housing and is connected to the RTG via a thermal joint which allows the radiator to be steered. A critical design factor with the RTG is crew safety. This factor, in addition to versatility, led to the use of the RTG in tow. The trailer (Figure 12) houses the RTG and its required thermal controls. The RTG's external deployment requires less radiation shielding. The latter consists of multi-layer foil which, in combination with the main rover's foil shielding, provides adequate radiation protection for the crew members. The RTG's external positioning adds a significant versatility. For example, the RTG power can be used to charge lunar base batteries when the rover is not in operation. Also, docking to the lunar base will be facilitated with the trailer unhooked.

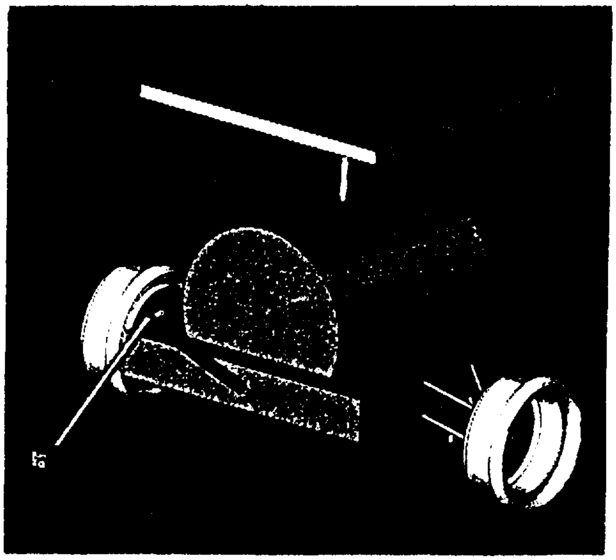


Fig. 12 View of the trailer

Secondary power and peak power are provided by a bank of batteries that are continuously charged by the RTG. A small array placed on the PLR thermal control radiator shield charges the batteries if the RTG is detached. The lithium-sulfur-dioxide-type battery is chosen because of its high energy density and degree of discharge. There are ten separate stacks, each containing 10 cells in series that supply 6 kW-hrs. The batteries are placed under the crew beds in the PLR's midsection.

Life Support System

The Life Support System (LSS) breaks into five modules:

- Air Revitalization Module (ARM)
- Water Management Module (WMM)
- Food Provision Module (FPM)
- Waste Disposal Module (WDM)
- Crew Health Module (CHM)

The Air Revitalization Module (ARM) maintains the cabin atmosphere at a temperature of 295 K, relative humidity of 50%, pressure of 1 atm and composition of 79% N_2/21% O_2. To maintain temperature, the ARM removes excess heat due to crew metabolism, electronics, solar radiation, lunar radiation, and lunar-reflected solar radiation. Thirty layers of multi-layer insulation (MLI) reflect solar radiation and greatly reduce conductive heat transfer. The maximum excess heat load is 2540 W. Eleven fans circulate air throughout the PLR and provide a uniform temperature distribution. Two condensing heat exchangers extract excess heat and humidity. A 3.272 m^2 radiator, which is augmented by a thermal heat pump that utilizes a Rankine-Rankine cycle, rejects the excess heat. The excess humidity is sent to the Water Management Module (WMM).

To maintain atmospheric pressure and composition, the ARM monitors cabin pressure and composition with pressure taps and a mass spectrometer. Control software in the LSS control computer uses the measurements to decide if, and how much, nitrogen and oxygen should be released into the cabin from storage tanks. The ARM also removes contaminants: lithium hydroxide sorption beds remove carbon dioxide; platinum catalysts remove carbon monoxide; charcoal and activated charcoal sorption beds remove odors and other contaminants.

The Food Provision Module (FPM) provides food and drink, which are supplied by the lunar base. It is assumed that the supplied food is dehydrated, canned, and/or storable at ambient conditions. An energy-efficient microwave prepares food.

The Water Management Module (WMM) provides potable water for drinking, cooking, EVA, cleaning, and hygiene purposes. The design calls for a recycling system consisting of a potable water supply and a water recycling system. The potable water supply consists of a storage tank containing 0.3 m^3 of water for drinking, food preparation, and EVA purposes. The water recycling system utilizes heat, a series of four multi-media sorption beds (1-in radius, 40-in long), an alcohol catalyst, and iodine to purify waste water. The flow rate through the beds is 79 cc/min, which gives a contact time of 26 minutes. Due to media usage rate, one multi-media bed exhausts its media every 140 hours of processing, roughly 10 days in operation.

The Waste Disposal Module (WDM) disposes of waste materials in a sanitary method that ensures crew health and stores wastes in such a manner that facilitates recycling at the lunar base. Dry wastes, such as trash, are disposed of by a hand cranked compactor. Human wastes are collected and stored by a design that combines the earth toilet's simplicity and the space station toilet's ease of recycling and water savings. A personalized cup collects urine and a water-iodine mixture carries the urine to the urine storage tanks. Collection bags collect feces and vomitus.

For crew morale and fitness, the design calls for, among others, an exercise bike that recharges some of the batteries during operation. For crew health, the design focus is on radiation shielding. The shielding protects the crew from RTG radiation, nominal solar radiation, micrometeors, and solar flare events.

Table 1 LSS mass and power summary

Mass	765 kg (empty)	1,490 kg (stocked)
Power	1378 W (average)	2,330 W (peak)

The mass total does not include the shielding.

Electronic Systems

The electronic systems include communication, navigation, and computer systems.

The communication system provides direct voice, video, and data communication with Earth, person-to-person communication, and EVA short-range communication. For Earth-Moon communication, the system takes advantage of lunar relay satellites assumed to be orbiting the Moon. The system uses X-band (8400-8500 MHz), which has low power requirements yet provides a high data transmission rate of 20 Mbps, low quality television images, and overall good performance with proven technology. In addition, the system has the capability to communicate directly to Earth should a satellite fail. The on-board transponders allow simultaneous transmission and reception through two 0.9 m antennas. To communicate with crew doing EVA work, the PLR uses S-band and an omnidirectional 0.1 m whip antenna.

The navigation system directs the PLR through the lunar terrain and accurately determines its location on the Moon. The system uses a strapdown inertial measurement unit, consisting of three laser gyroscopes and three accelerometers, to measure the rotation and acceleration in all three dimensions. In addition, two star mappers mounted on the PLR exterior periodically correct the position. Four cameras mounted on the rover provide information on the local terrain. The rover also uses a laser rangefinder assembly to determine the distance to objects and, with the computer, generates a rough topological map.

The PLR computer is crucial for monitoring and controlling vehicle systems. The primary computer is installed in the command center. The PLR has a secondary computer capable of maintaining the basic needs of the rover. A bank of display screens shows camera, computer, and navigation system outputs.

The main characteristics for PLR I are presented in Table 6.

Table 6 PLR I main characteristics

Nominal speed	10 km/hr
Maximum speed	18 km/hr
Maximum incline	35 deg.
Minimum turn radius	7 m
Ground clearance	0.85 m
Range:	
at 10 km/hr	1680 km radius
at 18 km/hr	3192 km radius
Towing Capacity (6 km/hr, 30 deg. max)	4.2 metric tons
Nominal power	6.5 kW
Maximum power	9.5 kW
Total mass	6,197 kg

Pressurized Lunar Rover II

Configuration

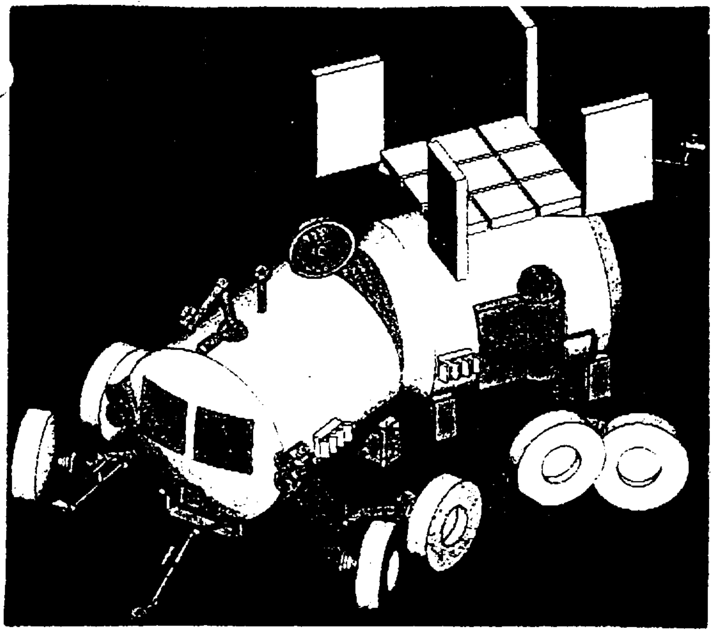


Fig. 13 View of PLR II

The PLR II configuration consists of 2 4 m-diameter, cylindrical hulls passively connected by a flexible pasageway, resulting in the overall vehicle length of 11 m (Figure 13). The rover's shell is made of two graphite/epoxy laminates separated by a NOMEX honeycomb core. A multi-layer insulation and an aluminum bumper shield provide thermal barrier and micrometeoroid protection (Figure 14).

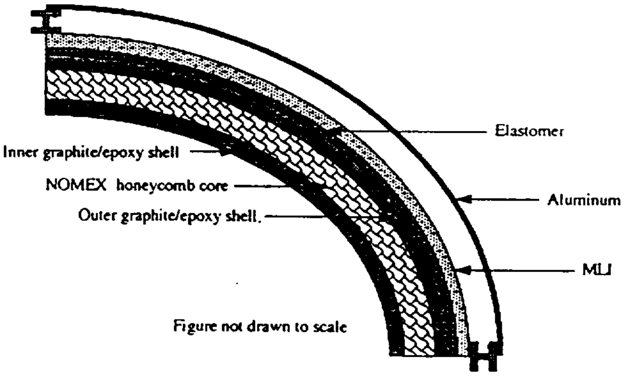


Fig. 14 Pressure hull cross section

Mobility

The cylindrical hulls are supported by aluminum saddles which are connected by an articulation joint (Figure 15). The joint controls yaw and allows for free pitch and roll between the two hulls. The articulated turning of the rover is controlled by a motor attached to the yaw axis. An unusual "pinned wheel" concept is chosen for improved mobility. Each side of each hull is supported by two wheels which are connected at their centers by a hollow cylindrical bar pinned at its midpoint (Figure 16). The bar is attached at the pin through a passive suspension system to the saddle. The bar ends are bent away from the hull making Ackermann steering possible. This configuration should allow a large degree of vertical motion by the wheels while still maintaining constant ground contact (Figure 17). The independent suspension consists of a double transverse wishbone suspension using two telescopic shock absorber-dampers balanced by springs.

A dual steering system, combining double Ackermann and articulated frame steering, has been chosen. As the steering wheel is turned, an electronic control system

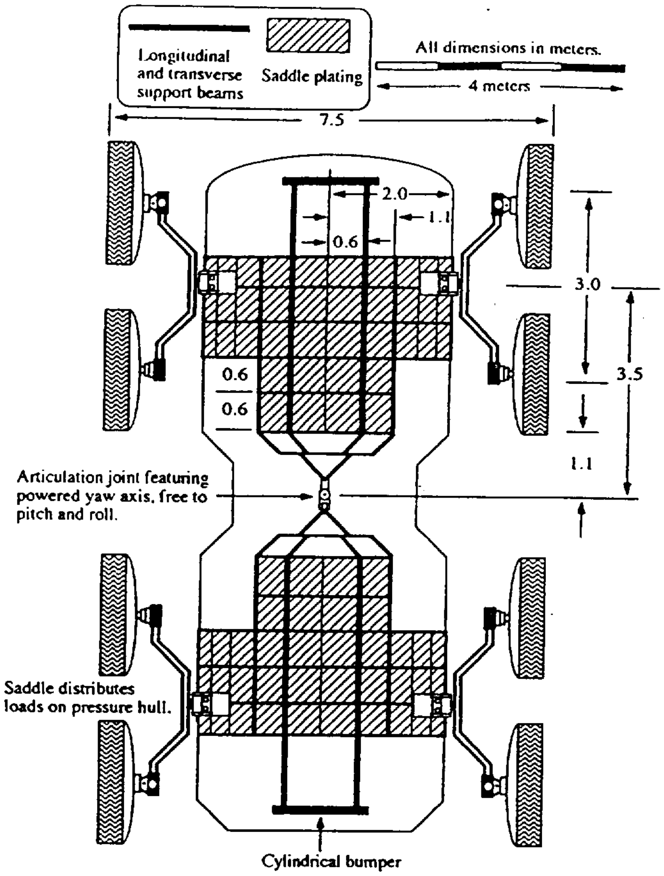


Fig. 15 Vehicle substructure

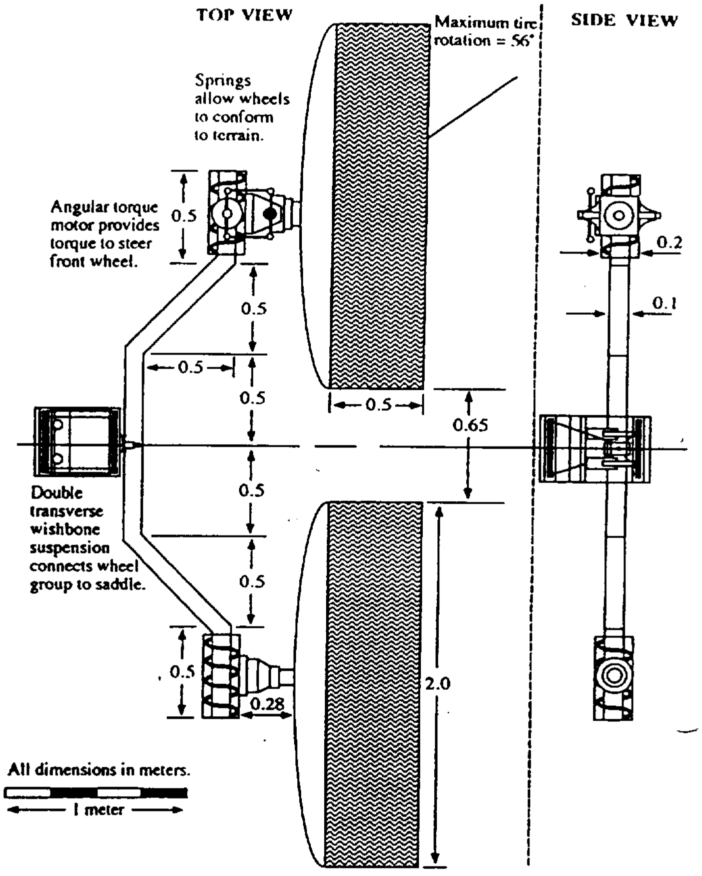


Fig. 16 Wheel group

turns the front and rear wheel pairs (using motors mounted at the bar ends) and the articulation joint to produce the geometry for an ideal, neutral steer turn. This geometry produces a minimum turn radius of 9.4 m. However, after the articulated frame has been turned through its full angle, the ideal geometry may be sacrificed by turning the wheels further. This leads to a slight oversteer condition which will allow a tighter turn. In an emergency, the driver has the option of utilizing skid steering, since the wheels are already individually powered.

The wheel/tire assembly consists of the wheel well containing the drive motor as well as the wheel, tire, and required gearing and support (Figure 18). The drive motor rotates a 0.45 m radius rigid cylindrical frame that is rigidly connected to the back of the wheel. Slightly elastic rings fill the area between the frame and the tire. These rings support the tire to enhance traction. The drive motors and articulation motor will have equal pull capabilities. High performance DC brushless motors with variable speed drive, rated at 600 Nm and 1.5 kW, will be mounted inside the hubs of the wheels. Smaller motors will be used for wheel turning.

Power System

To determine power requirements, a few possible lunar missions were analyzed and their power profiles were estimated. These missions included a 14-day lunar survey, a four-day transport mission and a two-day search and rescue mission. It was established that a continuous power of 8 kW is needed; the peak power required if all

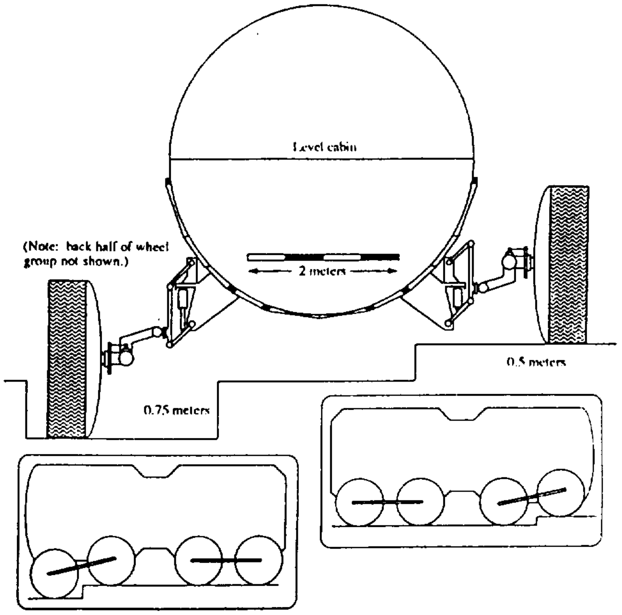


Fig. 17 Maximum suspension displacements

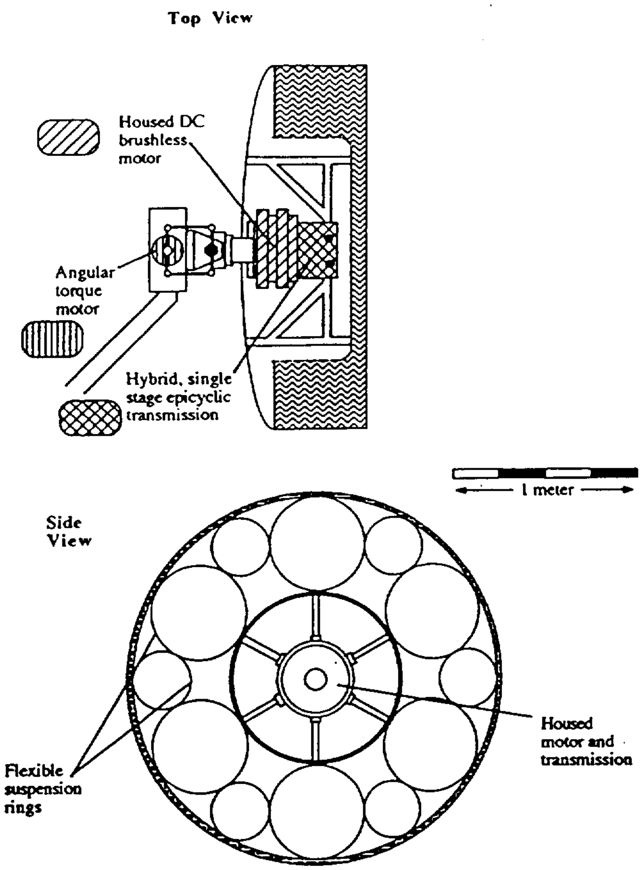


Fig. 18 Wheel assembly

eight wheels have to be driven at once would be 12 kW. The power system will consist of a 8 kW primary source and a 4kW storage capacity. A dynamic isotope power system (DIPS) using a closed Brayton cycle (CBC) has been chosen as the primary energy source. Eight plutonium 238 powered heat source units (HSU) will heat a xenon-hydrogen mixture used as a working fluid in the turboalternator compressor assembly generating electrical energy. The radiator of the CBC system has an area of $15 m^2$. To protect the crew from the radiation given off by the HSU, a shield made of tantallum alloy will partially encase the HSU.

For secondary energy storage a sodium-sulfur battery, sized for 4 kWhr capacity has been selected.

Thermal Control

Passive, semi-passive, and active thermal control techniques will be used to control the temperature inside the rover. The most critical part of the interior thermal design is the rejection of approximately 25 kW waste heat produced by the power system which is located in the rear module under the floor. The power system is carefully insulated with MLI, and 20 heat pipes serve to transport the heat to the 15 m^2 space radiator on top of the rover. A climate control system will cool the interior during a lunar day and heat the interior (using waste heat from the power system) during a lunar night. The crew life support is provided by a partially closed environmental control system that reclaims air and water.

Electronic Systems

The communications system allows for communication with the lunar base, with an option for direct communication with Earth via a lunar satellite link. The rover is fitted with a parabolic reflector dish for S-band transmission, and an omnidirectional antenna for local EVA communication.

The PLR II guidance, navigation and control subsystem consists of an inertial guidance system, an orbiting lunar satellite, and an obstacle avoidance system. In addition, the rover is equipped with a number of external fixtures including lights, telerobotic arms, cameras, manlocks, a docking fixture, and a scientific airlock.

Table 7 PLR II Main Characteristics

Nominal velocity	10 km/hr
Maximum velocity	14.7 km/hr
Maximum gradient	26.5 deg.
Wheel diameter	2 m
Climbable step height	0.53 m
Minimum turn radius	
Neutral steer	8.6 m
Oversteer	6.6 m
Range	2000 km
Continuous power	8 kW
Maximum power	12 kW
Total mass	7015 kg