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RS LANDERS—LUNAR LANDER

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INTRODUCTION

The future of the U.S. space program outlined by President Bush calls for a permanently manned lunar base. A payload delivery system will be required to support the buildup and operation of that lunar base. In response to this goal, RS Landers has developed a conceptual design of a self-unloading, unmanned, reusable lunar lander. The lander will deliver a 7000-kg payload, with the same dimensions as a space station logistics module, from low lunar orbit (LLO) to any location on the surface of the Moon.

LUNAR LANDER DESIGN

The proposed design has been named "La Rotisserie" and is shown in Fig. 1. It consists of a lander, unloader, and payload. The payload and the unloader are loaded in an inverted position on top of the lander. After postlanding stabilization on the lunar surface, the entire structure will rotate 180° with respect to the legs. This rotation will take at least 30 minutes in order to minimize dynamic loads exerted on the rotation mechanisms.

When the rotation is complete, the unloader will be lowered to the surface. The unloader will then drive out between the legs and deliver the payload to its desired location. In order to avoid excessive engine plume damage, the distance between the landing location and a possible lunar base should be about 2 km. Therefore the range of the unloader was set at 5 km. Once the payload is delivered, the unloader can return to LLO with the lander, or it can remain on the surface to await the lander's return.

MAIN ENGINES

Solid-core nuclear motors were chosen for use on the lunar lander. These motors have an optimistically projected specific impulse of 1200 s and thrust-to-weight ratio of 11.3. The fuel used is liquid hydrogen. The maximum required thrust occurs during the descent phase of the mission, and it is 22,584 lbf.

It is not currently known whether a three-motor configuration or a single-motor configuration would be superior for use on the lander. For conventional motors, the three-motor configuration is recommended for situations of engine out. There are studies being done to determine the effect of clustering nuclear motors. It may be necessary to use one nuclear motor with redundant turbopumps. However, all calculations and estimations took place assuming a three-motor configuration. The internal arrangement of fuel tanks and subsystems is shown on Fig. 2.

UNLOADING MECHANISMS

The detailed design of the mechanical components of the various payload unloading mechanisms is beyond the scope of this study; however, there are a few areas that have been considered during their study. The types of electric motors, bearings, and drive train or gear reduction system have been of interest.

The motors that are most promising for the La Rotisserie concept use direct current, deliver moderate torque, medium rotation rates (around 1000 rpm), and are of a brushless design. These are the most suitable for working in the lunar environment due to their efficiency and durability.

Coated bearings are recommended for use on the lunar lander. Lubricants will prove to be ineffective in the harsh lunar environment. They will either become filled with dust, freeze up, or boil off. Possible bearing coatings include Teflon®, Nomex®, and diamond. Diamond coatings can be applied using chemical vapor deposition.

Finally, a harmonic drive system is recommended for use on the lunar lander. Harmonic drives have fewer moving parts than the conventional gear box. Therefore they are less massive and have fewer losses. Harmonic drive systems use flexible splines that wear faster than conventional gear box components; however, with the advent of advanced materials, the harmonic drive can be designed to meet the lander's requirements in the near future.

TRAJECTORIES

The lander trajectories have been designed and optimized using a computer program called Lander developed by Eagle Engineering in Houston, Texas, to simulate the ascent and descent phases of a lunar landing mission.

The landing site location of the Apollo 15 mission was chosen for the lunar lander simulation. The resulting total ΔVs were 1.839 km/s for ascent and 1.92 km/s for descent. The flight times were 50 min for ascent and 63.25 min for descent. The use of the solid core thermal nuclear propulsion system has provided more flexible parameters for trajectory optimization than conventional propulsion.

STRUCTURES AND MATERIALS

The lander structure provides connectivity and integrity to all the lander's systems. The central box of the lander structure carries all the loads generated by the subsystems. This box is a truss structure enclosed by honeycomb core panels. The truss structure is strong enough to support the loads generated by

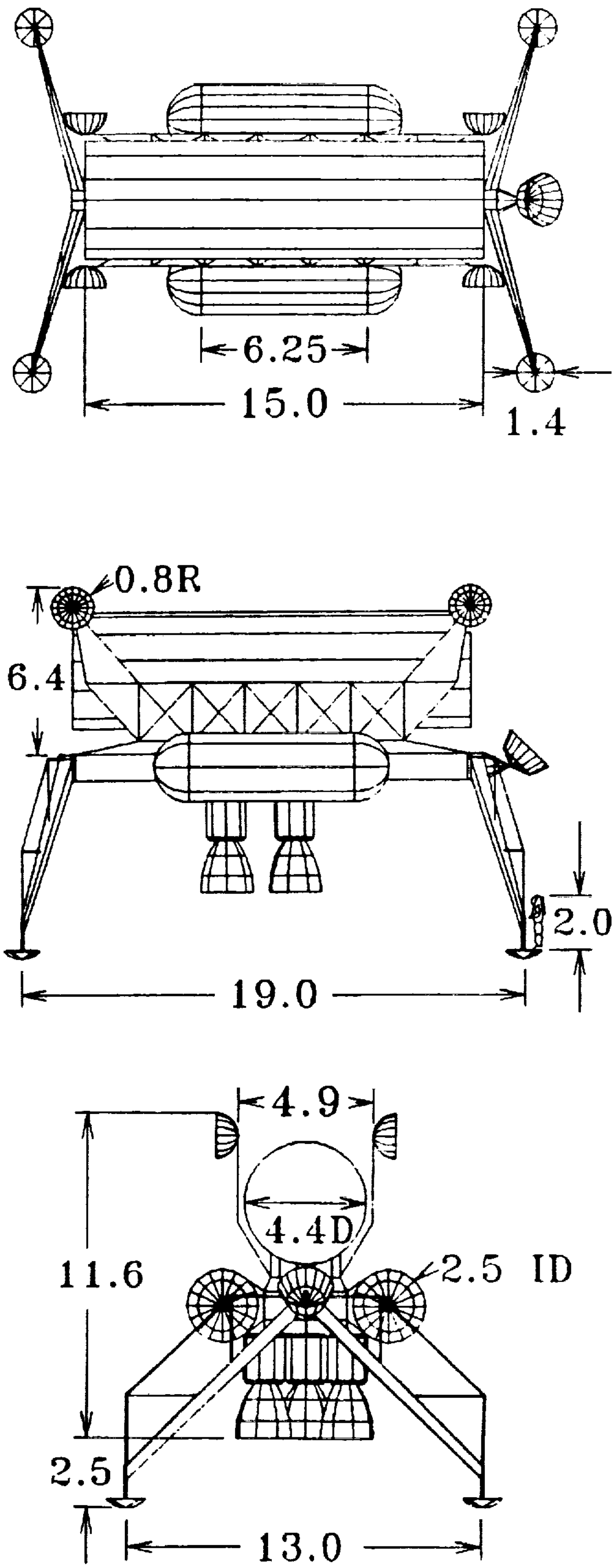

Fig. 1. The dimensions of La Rotisserie lander (meters).

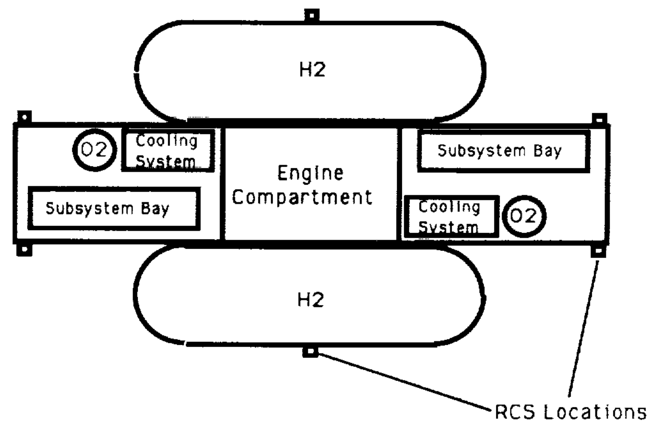

Fig. 2. The subsystem and tank arrangement in the lander.

the subsystems, and its lightweight panels protect the subsystems from solar radiation, dust, and micrometeorites.

The landing gear is composed of four struts that are lightweight planar trusses with landing pads similar to the Apollo lunar module. To enable the lander to remain level on an incline of up to 8°, a terrain adaptive system is incorporated into the landing gear.

Aluminum-lithium alloys were chosen as the main construction material for the lander. In addition to having the advantages of standard aluminum alloys, they can have a high tensile strength (over 100 ksi), along with increased weldability and a higher cryogenic strength.

GUIDANCE, NAVIGATION, AND CONTROL

The purpose of the guidance, navigation, and control (GNC) system is to determine the linear and angular position, velocity, and acceleration of the lander, to compare those data with the desired state, and to make corrections when necessary. The desired state of the lander will be provided by the predetermined trajectory analysis for each specific mission.

Three levels of sensors are used for redundancy. During optimum operating conditions, several components of each level of redundancy will be used. The primary, secondary, and emergency sensor arrays rely on a radar imaging/altimeter system, several sets of accelerometers and gyros, a transponder system, a close proximity altitude detection device, and the communications system. The communications system is only used as a sensor for emergency situations.

The onboard navigation computer will be a fault-tolerant high-performance computer. The rapid pace of computer and software development has shown that the advanced system required can be developed, and, additionally, have little mass and power consumption. The navigation computer will be responsible for monitoring the output and status of each sensor, monitoring the status of and providing input for each of the control devices, and providing an interface between the two.

The lander will use three control techniques: momentum exchange devices, small directional thrusters, and gimbaled/throttled main engines. While some redundancy exists using all three systems, the optimum operating conditions will use each technique where best suited.

The control of the unloader will be primarily automated with a remote control system as a backup. The unloader will have optical sensors that will inform the unloader's onboard computer of obstacles. The computer will then instruct the wheel motors to make the required adjustments. The unloader will be in constant communication with the lander, in case it becomes necessary to employ the back up remote control system.

COMMUNICATIONS

The communications systems provide three basic functions: telemetry, command, and tracking. The system must enable the following communication links: (1) lander to Earth; (2) lander to OTV; and (3) lander to unloader.

S-band (2.3 GHz) will be used for direct communications between the lander and Earth. The antenna on the lander will be a parabolic dish with pointing capabilities similar to that on the Apollo spacecraft. The Apollo pointing system is sufficient for the communication link with Earth.

It is recommended that a communications satellite be placed in a halo orbit on the L2 Lagrangian point. The satellite would allow transmissions to be made between the lander and Earth when the lander is on the farside of the Moon.

Communications between the OTV and the lander will be done with a VHF system. The antennas for this system will be dipoles and therefore there will not be a need for pointing. This system will be used during docking. Once the lander is docked with the OTV a data feed umbilical will be connected to the lander by means of a manipulator arm on the OTV.

The lander and unloader will communicate using a UHF system. The UHF receivers and transmitters are small, lightweight, and require little power. The UHF antennas are also small and there is no need for pointing.

POWER/THERMAL CONTROL

The energy for the power system is provided by the heat generated during engine cool-down cycles. A power conversion loop transforms the heat into electrical energy, which is then stored in rechargeable NaS batteries on the lander and the unloader. The conversion loop also serves to cool down the nuclear motors and keep the batteries at a higher operating temperature.

Two sets of batteries provide 11 kWhr of power on both the lander and the unloader. The power for the unloader allows it to carry the payload 5 km at a speed of 2.5 km/hr. In the event that the unloader remains on the surface for an extended period, two solar arrays totalling 20 sq m, mounted on the unloader, will be used. The GaAs/Ge arrays are able to recharge the batteries fully in about one solar day.

Thermal control will be accomplished using several methods. The first method will employ the use of a cryogenic refrigeration system that will be powered by the power generation loop. The second method will employ the use of 2.5″ of multilayer insulation on the propellant tanks and other areas that require thermal control. Heat exchangers on the power generation loop will also be used to keep certain areas of the lander warm.

The final method that will be used is two radiation/thermal protection umbrellas. These umbrellas will be deployed from the landing struts after the complete rotation sequence has been performed. The umbrellas will help to reduce the workload on the refrigeration system.

MASS ESTIMATES

When delivering a payload of 7000 kg, the total deorbit mass of the lander will be 21,584 kg. In addition to the payload mass, this deorbit mass includes 9780 kg of inert mass and 4804 kg of fuel. The mass of the lander is broken down in Table 1.

TABLE 1. Mass estimate for La Rotisserie.

Item	Mass (kg)
Payload	7,000
Inerts	
Structure	
(Lander)	2,290
(Unloader)	1,200
3 Engines w/Shielding	3,000
RCS	600
Fuel Tanks w/Insulation	820
Power System	700
Refrigeration System	500
Rotation Motors and Winches 300	
GN and C	150
Data Processing	40
Communication	50
Thermal Control	130
Total Inert Mass	9,780
Fuel	
Descent	2,876
Ascent	1,508
RCS	420
Total Fuel Mass	4,804
Deorbit Gross Mass	21,584