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LONG RANGE INHABITED SURFACE TRANSPORTATION SYSTEM POWER SOURCE FOR THE EXPLORATION OF MARS (MANNED MARS MISSION)

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ABSTRACT

A hydrogen-oxygen fuel cell system is identified as a viable power source for a long range inhabited surface transportation system for the exploration of Mars. Power system weights and power requirements are determined as a function of vehicle weight. For vehicles weighing from 2700 to 7300 kg in LEO, the total power system weight ranges from 1140 to 1860 kg, with the reactants and energy conversion hardware (fuel cells, reactant storage, and radiator) weighing 430 to 555 kg and 610 to 1110 kg, respectively. Vehicle power requirements range from 45 kw for a 2700 kg vehicle to 110 kw for a 7300 kg vehicle. Power system specific weights and power profiles for housekeeping and the operation of scientific equipment such as coring drills and power tools are also specified.

INTRODUCTION

The extensive and sustained exploration of Mars, once a manned base has been established, will require an inhabited transportation system to explore the planet. This vehicle will require a power system capable of being recharged at the base in order to carry out continuing missions. A hydrogen-oxygen fuel cell may be a candidate for such a power system. The oxygen storage tanks may be integrated with the life support system, with significant weight savings. The waste heat from the hydrogen-oxygen fuel cell may also be used for internal environmental control of the vehicle.

The vehicle weights reported in this study are based on the following mission profile: velocity 10km/hr, range 100 km, duration 5 days, occupancy 5 persons, and slope climbing capacity of 30 degrees uphill for 50 km. Exact vehicle weights will be determined when an actual mission is defined.

POWER SYSTEM DESIGN

In order to define a power system and determine appropriate weights, both power and energy needs must first be determined.

Power and energy must be produced by the on-board system to counteract rolling resistance, carry out a slope climbing function, and operate internal and external equipment required for the mission. The rolling resistance of the Long Range Inhabited Surface Transportation Vehicle (LRIST) is determined for a 32 inch diameter Lunar Rover-type wheel in loose sand (reference 1,2) for the Mars surface gravity environment. The energy budget, which determines the reactant requirements and tank sizes, consists of the reactants needed to overcome the rolling resistance, the increase in potential energy due to slope climbing, and the operation of internal and external functions. A 25% reactant reserve is added for contingency reasons.

The vehicle power requirements are determined by the rates of energy expenditure to meet the rolling resistance and the slope climbing requirements, in addition to the internal power requirements while the vehicle is underway. A 50% power reserve is added to the fuel cell to accommodate a reactant trailer, which may be used to extend either mission range or duration by an additional 100 km / 5 days if desired. An outline of the power requirements and mission requirements is given in Tables 1 and 2.

Seven categories of weights are considered. They are the power dependent hardware, energy dependent hardware, waste heat rejection, radiator, reactants (not trailer), power management and distribution system (PMAD), and electric drive motors. Hydrogen-oxygen fuel cells representing year 2000 technology are used to determine power system hardware weights, including the energy dependent hardware such as Kevlar filament-wound pressure vessels. Table 3 gives the fuel cell and related power system parameters. Figure 1 is a schematic of the fuel cell/electrolyzer system.

TABLE 1

LONG RANGE INHABITED SURFACE TRANSPORTATION SYSTEM
POWER SOURCE FOR THE EXPLORATION OF MARS

Operational Power Requirement

Externally Mounted Corning Drill	10 kw - 3 hrs/day
External Power Tools	2 kw - 4 hrs/day
Housekeeping - Internal Power	5 kw - continuous
Power Reserve	50% (kw)
Energy Reserve	25% (kw-hrs)

Extended Range/Duration

Excess reserve power is provided in order that a "reactant trailor" could be towed to extend the range/duration by another 100 km / 5 days. If desired.

TABLE 2

LONG RANGE INHABITED SURFACE TRANSPORTATION SYSTEM
POWER SOURCE FOR THE EXPLORATION OF MARS

Mission Profile

Range	100 km
Speed	10 km/hr
Duration	5 days
Terrain	

30^0 for 50 km at 10 km/hr (rolling resistance = 0.32 - loose sand)

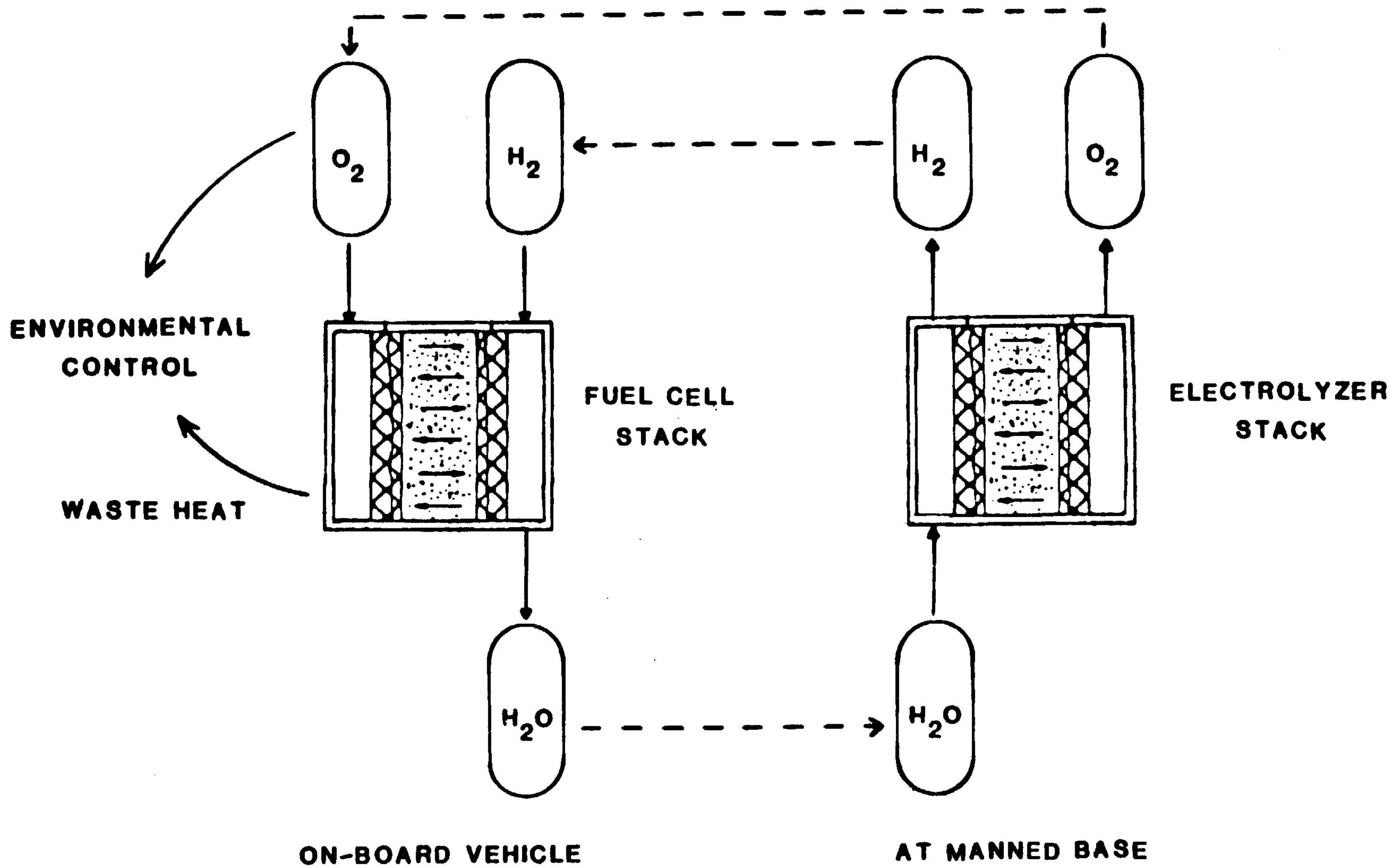

FIGURE 1. - SCHEMATIC OF LRIST HYDROGEN-OXYGEN FUEL CELL SYSTEM.

TABLE 3

LONG RANGE INHABITED SURFACE TRANSPORTATION SYSTEM
POWER SOURCE FOR THE EXPLORATION OF MARS

<u>Power System Specific Weights</u>

H_2-O_2 Fuel Cell	
Power Dependent Hardware (Cells)	2 kg/kw
Energy Dependent Hardware (Tanks)	0.3 kg/kw-hr
Reactants	0.36 kg/kw-hr
Efficiency (Discharge)	75%
Radiator	5 kg/kw
Power Management and Distribution	$\frac{5.31}{P_{KW_e}^{0.25}}$
Electric Motors	1 kg/kw

The operation of this system is outlined in the section describing the mission logistics.

RESULTS

The on-board power system weights are shown in Figure 2. Power requirements, reactant requirements, and energy conversion hardware weights are given as a function of LRIST vehicle weight. The energy conversion hardware consists of the fuel cells, reactant storage tanks, and radiator. The total power system weight, which includes the weight of the power management and distribution system and electric drive motors, as well as the energy conversion hardware and reactant weights, is also represented as a function of total vehicle weight.

The fraction of the total vehicle weight that can be attributed to the power system is given in Figure 3. As the figure shows, the power system represents a smaller percentage of the LRIST vehicle weight as the weight of the vehicle increases.

MISSION LOGISTICS

The LRIST reactant tanks are fully charged at the Mars base prior to the mission. As the mission proceeds, hydrogen and oxygen are combined in the fuel cell to produce electricity and water. The water is stored in a tank for reuse in recharging the vehicle reactant tanks upon return to the base. The life support system may be integrated with the oxygen reactant tanks to provide breathing oxygen and cabin make-up gas. This type of life support/fuel cell integration would give some benefit by reducing the overall vehicle system weight. Upon returning from the mission, the water is electrolyzed at the electrolysis facility (Figure 1) on the base. After electrolysis, the hydrogen and oxygen are pumped into the respective reactant tanks either on the LRIST or the support trailer. The concept shown here would require an additional support system mass delivered to the Mars surface to electrolyze the water and recharge the vehicle reactant tanks. The design of the support system was not considered for this report.

CONCLUSION

This study shows the viability of a hydrogen-oxygen fuel cell power system for a long range inhabited Mars surface transportation vehicle. To provide additional benefits, the power system can be integrated with the life support system to provide breathing oxygen for the crew and

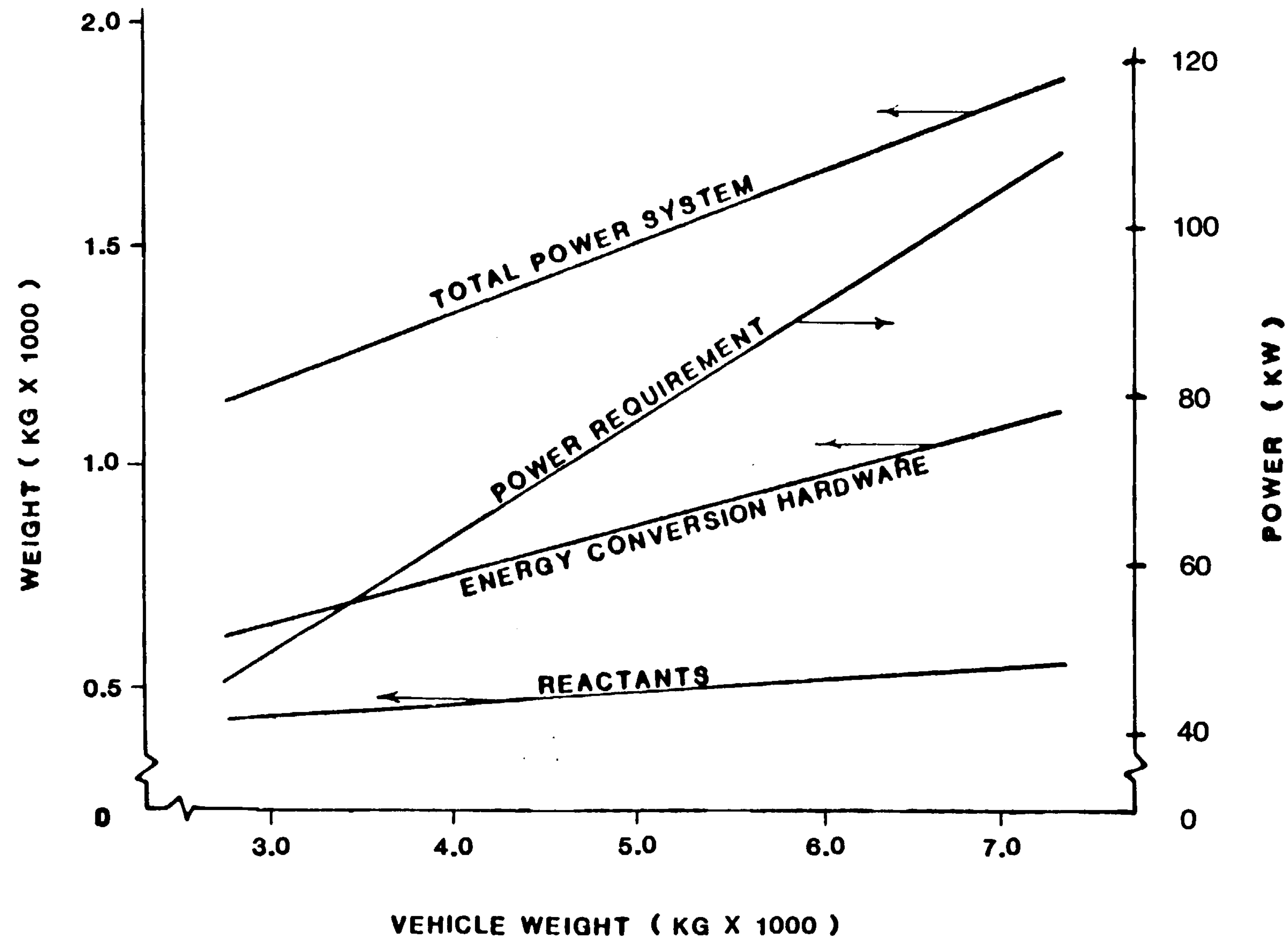

FIGURE 2. - LRIST POWER SYSTEM WEIGHT EFFICIENCY

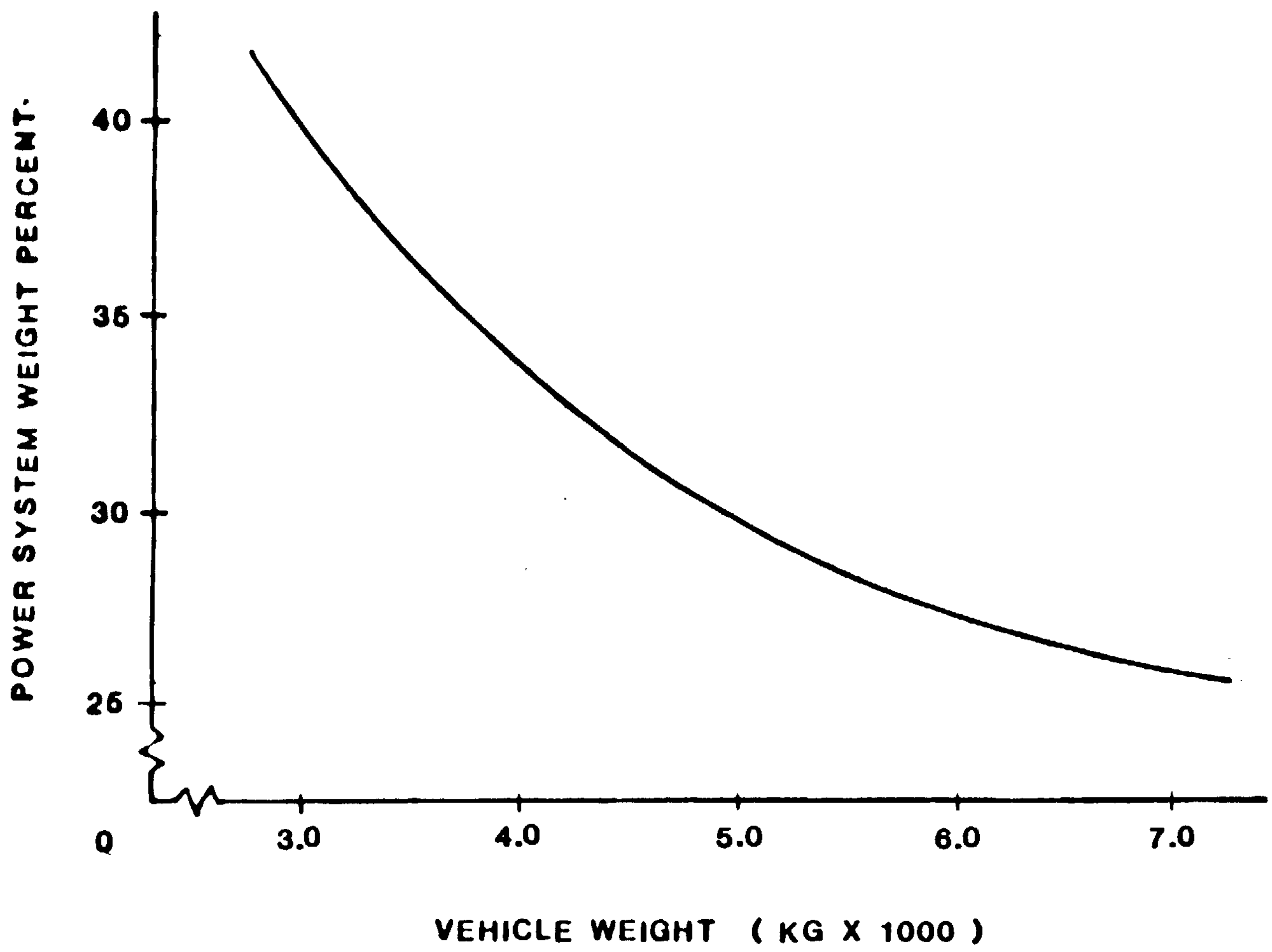

FIGURE 3. - POWER SYSTEM WEIGHT PERCENT AS A FUNCTION OF TOTAL VEHICLE WEIGHT

thermal environment control using the fuel cell waste heat . As Figure 3 shows, the fuel cell power system comprises 41% of the vehicle weight for a light (2700 kg) vehicle, but drops to 25% for a heavier (7300 kg) vehicle.

The mission profile and other parameters used in this study are indicative of those that would result from an actual mission design process. The actual vehicle design weight will depend upon the final mission definition.

REFERENCES

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