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THE EFFECT OF MARS SURFACE AND PHOBOS PROPELLANT PRODUCTION ON EARTH LAUNCH MASS

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ABSTRACT

Fuel and oxidizer produced on the surface of Mars and on the Martian moon Phobos can reduce the cumulative mass of fuel and oxidizer which must be launched to low Earth orbit for Mars exploration missions.

A scenario in which ten conjunction class trajectory missions over a twenty year period land a surface base and propellant production facilities on the Martian surface and on Phobos was examined. Production of oxygen on Phobos provides the greatest benefit. If all the propellant for Mars operations and Earth return is produced at Phobos and on Mars, a 30% reduction in cumulative LEO mass can be achieved at the end of the 20 year period.

INTRODUCTION

Manned missions to Mars utilizing cryogenic oxygen/hydrogen or oxygen/propane engines can benefit from the production of propellants on one of Mars' moons (Phobos or Deimos) or on the surface of Mars, to provide propellant for the return trip. Cases where either oxidizer or oxidizer and fuel are produced on Phobos (or Deimos) and or Mars are presented here. The mission concept utilized is a conjunction class mission, described in Reference 2, utilizing a 500 km, 24 hr elliptical parking orbit with a 500 km periapsis at Earth and Mars. A small Mars-orbit transfer vehicle Mars-OTV is utilized between the elliptical Mars orbit and low circular Mars orbit, Phobos or Deimos. Table 1 gives delta V requirements for various legs of the trip. A conjunction class opportunity is available on approximately 2-year centers (each round trip requires three years). As requirement for conjunction class missions do not vary much from opportunity to opportunity, a generic set of delta Vs was used here. A base building scenario requiring 10 missions over a 20 year period was examined.

Table 2 describes mission components and delivery capabilities. Each mission delivers 44.7 MT of payload which remains on Mars. In ten

TABLE 1

DELTA V's AND PROPULSION CHARACTERISTICS

		ISP	PROP.	MASS FRACT.
Trans Mars Injection (TMI) (departing from 500 km circular Earth orbit)	- 3.808 km/sec	468	LO_2/H_2	.925
Mars Orbit Insertion (MOI) (into 500 x 32,963 km, 24 hour ellipse)	- 1.666 km/sec	370	LO_2/H_2	.85
Trans Earth Injection (TEI) (departing from 24 hour ellipse)	- 1.490 km/sec	370	LO_2/prop	.94
Earth Orbit Insertion (EOI) (into 500 x 71,00 km, 24 hour ellipse)	- .967 km/sec	370	LO_2/prop	.89
Mars 24 hour, 30 deg. inclination ellipse to Deimos, one way	- .900 km/sec	460	LO_2/LH_2	.68
Mars 24 hour, 30 deg. inclination ellipse to Deimos, one way	- .750 km/sec	460	LO_2/LH_2	.68
Deorbit from 24 hr Mars ellipse	- .100 km/sec	360.5	LO_2/MMH	
Landing on Mars surface	- 1.000 km/sec	360.5	LO_2/MMH	
Ascent from Mars surface to 500 km	- 4.500 km/sec	360.5	LO_2/MMH	

TABLE 2

SPACECRAFT WEIGHTS AND PROPULSION AND DELIVERY CHARACTERISTICS

Each Baseline Mission Consists of:

One Mission Module (or round trip crew compartment) -	53 M. tons
Three expendable landers -	62 M. tons each
Two manned landers carry ascent stages and -	9.1 M. tons cargo (each)
One unmanned lander for cargo (descent stage only) -	26.5 M. tons cargo
One (loaded with 21 metric tons of propellant) expendable Mars OTV -	31.00 M. tons
Each Baseline mission delivered cargo -	44.7 M. tons

Lander Characteristics:

Manned Lander ascent inert -	3.8 M. tons
Manned Lander total ascent propellant (oxygen/propane) -	13.6 M. tons
Manned Lander total ascent oxygen -	8.4 M. tons
Manned and Cargo Landers total descent propellant (oxygen/propane) -	20.7 M. tons
Manned and Cargo Landers descent oxygen -	12.8 M. tons

missions, approximately 447 MT could be delivered to Mars, which could emplace a base with the characteristics shown in Table 3.

DEVELOPMENT SCENARIOS

In order to assess the effect of producing propellant at Mars the following scenario were assumed.

Baseline Reference

No Mars propellant was assumed. All fuel and oxygen were brought from Earth. One mission was flown every conjunction opportunity (every 2 years) for 20 years. Each mission carried one manned mission module (MM) plus 3 expendable landers to Mars orbit. The three landers are alike and all weigh the same. Two of the landers carry manned ascent stages plus consumables to the surface. The third lands unmanned carrying 26 tons of Base elements for the permanent Martian Base. The MM is returned to low Earth orbit at the end of the mission.

Each mission also carries a fueled Mars orbital transfer vehicle (Mars-OTV) which allows exploration of the Martian moons, Mars orbital mapping, and in-orbit rescue, etc. Throwaway propulsive stages were sized for each mission. Table 3 shows the base masses landed on Mars surface. The masses are the same as for a lunar base previously developed (Ref 3).

In-Situ Propellant Production (ISPP) Scenarios

Scenarios were investigated in which oxygen-only and oxygen-plus-fuel were produced by delivery of production plants to Phobos and Mars. The Mars surface base buildup progresses at the same pace for all the scenarios. The ISPP scenarios thus require increased mass during the early missions to deliver the propellant production plants.

Missions 1 and 2 would deliver the Phobos O_2 or O_2 and fuel plants in addition to the normal mission cargo. The Phobos O_2 plant is estimated at 50 metric tons. These missions would also have to carry a total of 12 extra tons of Mars-OTV fuel (above baseline missions) to transport the plant to Phobos. A Phobos plant which could produce both oxygen and fuel is estimated at 75 tons plus 18 tons extra Mars-OTV fuel. These weights are carried in addition to the reference mission weights. Mission 3 and subsequent missions are then refueled from this plant.

TABLE 3

MARTIAN BASE ELEMENTS (DERIVED FROM LUNAR BASE ELEMENTS)

0	Habitats - 5 X 17.5 M. tons each (13 or 26 M. ton units)	- 87.5 M. tons
0	Power units - 3 X 17.5 M. tons each	- 52 M. tons
0	Earthmover/Crane - 1 at 26 M. tons	- 26 M. tons
0	Surface O2, pilot and production plants = 3 X 17.5 M. tons each	- 52 M. tons
0	Pressurized mobility unit 3 X 17.5 M. tons	- 35 M. tons
0	Geo/Chem lab - 2 X 17.5 M. tons	- 35 M. tons
0	Workshops - 2 X 17.5 M. tons	- 35 M. tons
0	Ceramics & metalurgy plants 2 X 17.5 M. tons each	- 35 M. tons
0	Misc. mobility - 2 X 17.5 M. tons	- 35 M. tons
0	Total	- 392.5 M. tons

Figure 1 shows a low-g Phobos propellant production plant concept and an Mars-OTV delivering propellant.

The Mars surface O_2 production plant weighs 16 metric tons, to be delivered on the third mission. Another O_2 plant is already in place, landed on the first two missions as part of the base. The surface O_2 and fuel plant combined would weigh 56 metric tons. This combination would be landed on mission 3 and 4. These plants would be landed in the place of the normally scheduled base elements. The replaced cargo would be brought down on later missions after propellant production has started.

MISSION DESCRIPTION

The reference mission at departure from Earth consists of the MMM, 3 Mars landers, 1 Mars-OTV, two LO2/propane propulsive stages for return from Mars and two LO2/LH2 propulsive stages for transport for Mars.

The first LOX/LH2 stage performs the Trans Mars Injection (TMI) burn and is then discarded. When Mars is reached several hundred days later, the second LO2/LH2 stage is used for Mars Orbit Insertion (MOI) placing the stack into a 24 hour elliptical (500 kmx 3 3,000 km) parking orbit around Mars at an inclination of around 30%. The landers are separated and aerobrake to low circular parking orbits to await proper alignment and phasing for precision landing at the base site. Meanwhile, the MOTV is used to visit and explore the Martian moons and for detailed Mars in-orbit mapping at the end of the mission (1.5 years later) the ascent stages bring the crew back up to the MMM. They are then discarded. The MOI stage is discarded and the first LO2/propane stage performs the trans-Earth injection burn (TEI). This stage is then discarded. The original Mars parking orbit was selected so that natural precession will have so placed the orbit so that this TEI departure burns at periapsis.

When Earth is reached all that remains is the MM plus the final LO2/propane stage which provides Earth orbit insertion (EOI) into a 24 hour (500 km x 71,000 km) ellipse.

If oxygen alone is produced on Phobos the scenario is the same except that the Earth return stages (LO2/prop.) and the landers leave Earth with empty oxygen tanks. After Mars orbit is reached, the MOTV flys to Phobos and brings back oxygen to fill these tanks before continuing the mission. If oxygen and fuel (most probably Hydrogen) are both available at Phobos, the LO2/prop stages are not carried at all and

Figure 1

Phobos Propellant Plant

the landers propellant tanks are carried empty. At MOI the MOTV flys to Phobos and returns with fuel for the landers and also refuels the stage which was used for Mars orbit Insertion. This stage is no longer discarded but instead is used to return the MMM to Earth (both TEI and EOI burns).

GROUNDRULES

1. Conjunction missions are used throughout.
2. All interplanetary maneuvers are propulsive. No aerobraking capability is assumed except for the landers.
3. Earth departure is from 500 km circular LEO.
4. Mars parking orbit is a 500 x 33,000 km 24 hr. ellipse.
5. This Mars parking ellipse can be positioned at Mars insertion so that natural precession effects will align the orbit properly for departure to Earth.
6. The spacecraft returns to a 24 hour ellipse at Earth.
7. Transport of fuel, mining plants, etc. in Mars orbit will be provided by the Mars-OTV.
8. LO2/LH2 propellants were used for transport to Mars and LO2/propane were used for return because of the difficulty of storing LH2 for long periods in Mars orbit. When propellant was produced at Mars the appropriate tanks were simply carried empty from Earth and filled at Mars. It was assumed that the stages could be altered to burn whatever fuel was available at Mars, ie., the ascent stages would be altered to burn LO2/LH2 if H2 is available on the Martian surface.
9. Propellant produced on the surface of Mars is only used for fueling the ascent stages.

RESULTS

Figure 2 shows the case where all stages are loaded with fuel and oxidizer at Phobos or Mars wherever they arrive empty. The scenario requires more mass in LEO in the early years than the baseline which assumes no Phobos or Mars propellant production, as these early missions must transport the machinery or propellant to Mars. After the second mission, cumulative gains in performance are realized. Extrapolating the results beyond the 20 year period of Figure 1 gives the results of Table 4. The longer the program, the greater the benefit of producing

TABLE 4

Years Since Program Start	Percent Reduction in Cumulative LEO Mass at the given year	
	O2 and Fuel Production	O2 Only
20	31	23
40	42	32
60	46	35
80	48	36

propellant at Mars. Improvement in performance (weight required in LEO) from 23% to nearby 50% in a very long program are possible.

Figure 3 shows the cumulative weight reduction versus year for the best case, with propellants provided to all stages, and for a case with propellants provided to all stages except the lander descent stage. Landers may not initially be designed for propellant loading in space. The payback for designing in this feature is shown.

Figure 4 shows the cumulative weight reduction if only oxygen is produced for all stages except the lander descent stages. Phobos oxygen for the lander descent stages results in a savings of 7% more over a twenty year period than with LEO delivered descent stage oxygen.

Figure 5 shows the effect of only producing oxygen on Mars and for producing oxygen and fuel on Mars Oxygen production alone results in a 5.5% savings over a twenty year period and oxygen and fuel saves 7.5% of the no-ISPP total LEO mass. Figure 5 shows no initial gain in LEO mass because early optional cargo mass is just replaced with plant mass, and the initial cargo is then brought down later, after propellant production has started.

Figure 6 shows the effect of oxygen, and oxygen and fuel production on Phobos. The (Mars-STS) lander ascent and descent stages, are loaded with propellant at Phobos. Phobos propellant production alone produces a 25% savings over a twenty year period.

Figure 6 shows the effect of using Phobos produced oxygen and fuel in the Mars-STS and descent stages and using them only in the Mars-STS. Figure 5 shows a roughly 15% gain at the end of twenty years, if the descent stages are loaded with propellant at Phobos.

Fig. 2

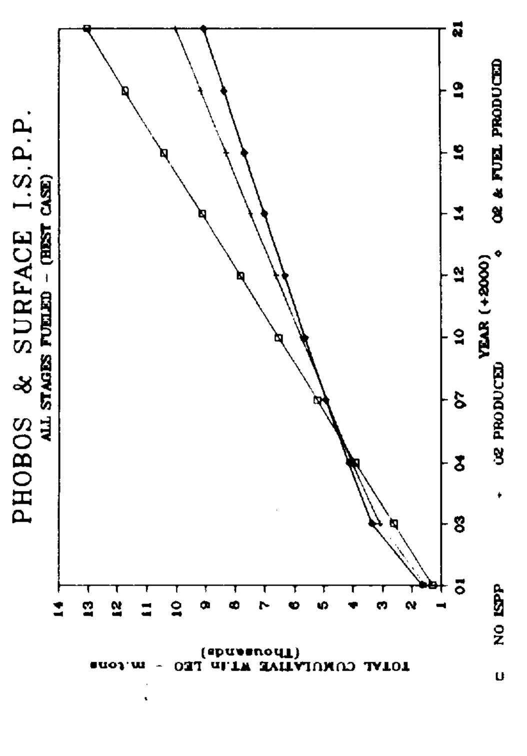


Fig. 3

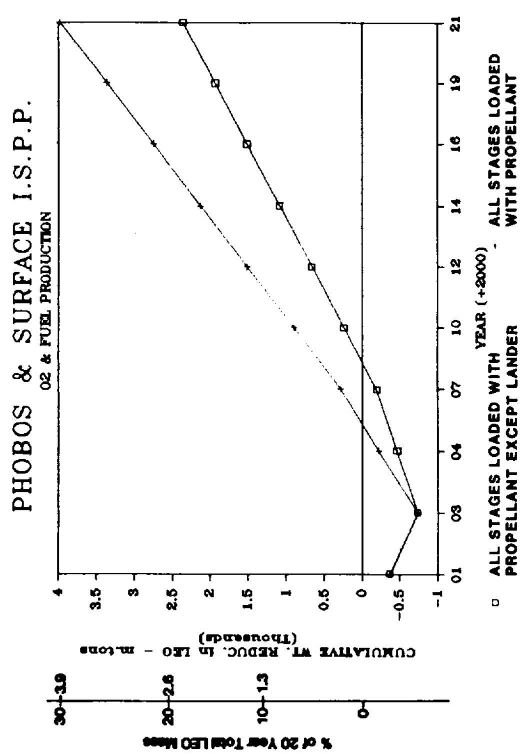


Fig. 4

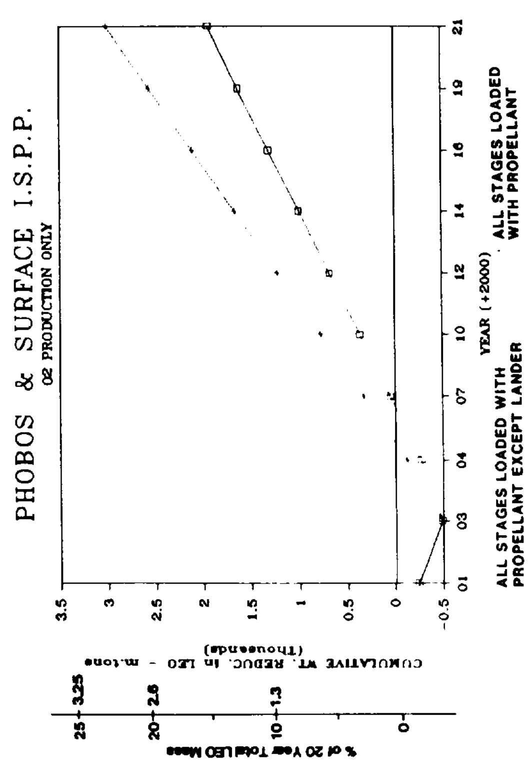


Fig. 5

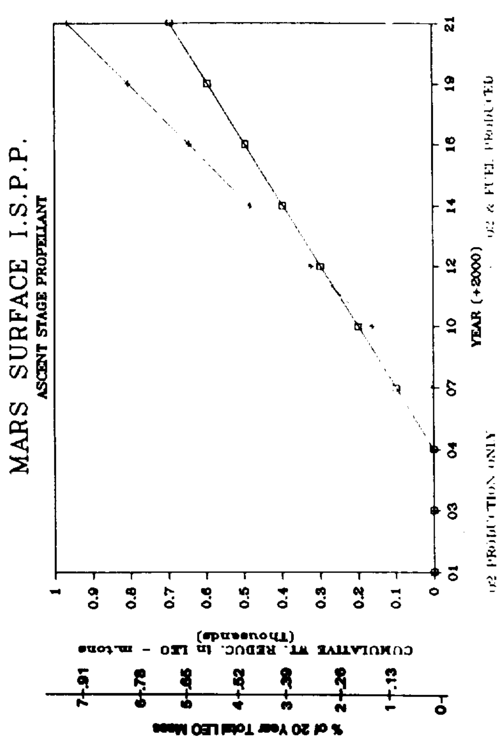
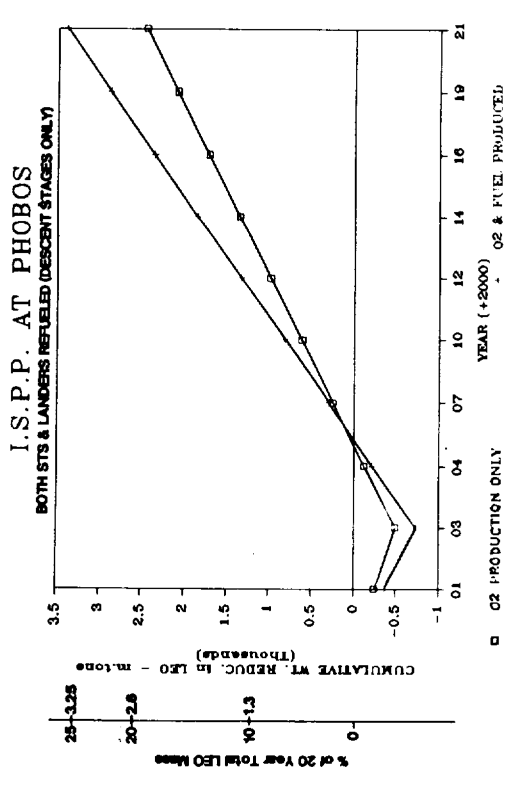


Fig. 6



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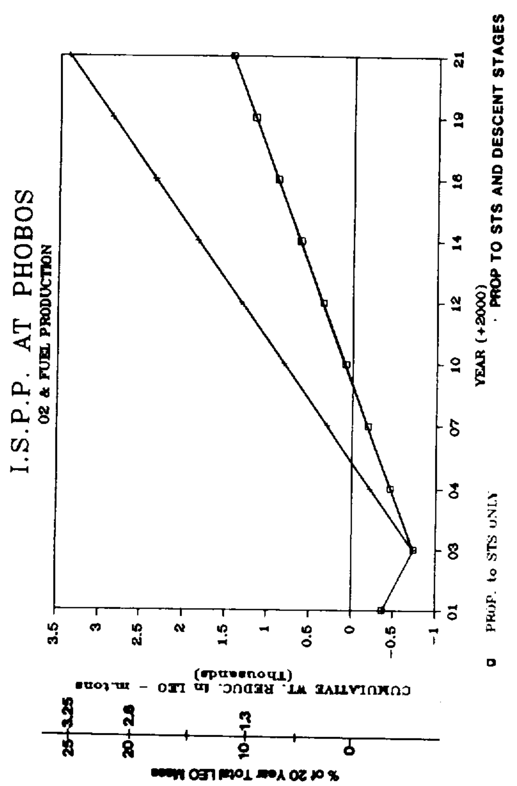

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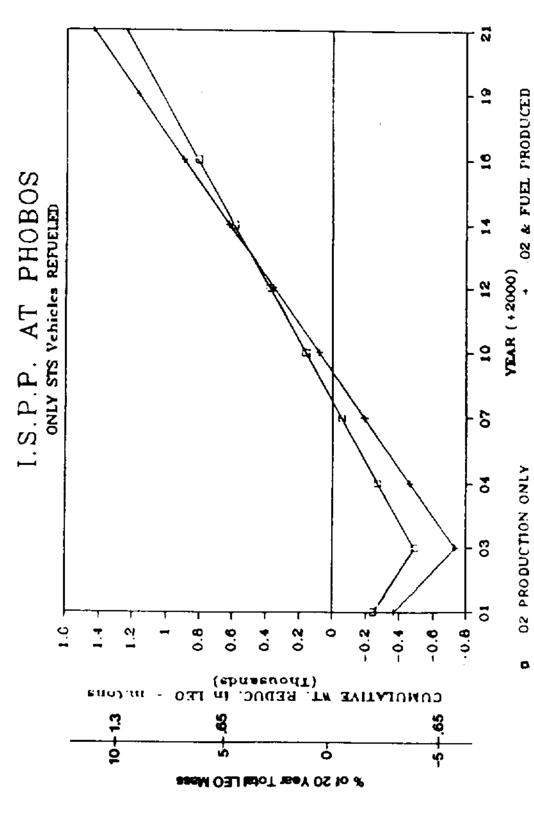

Fig. 9

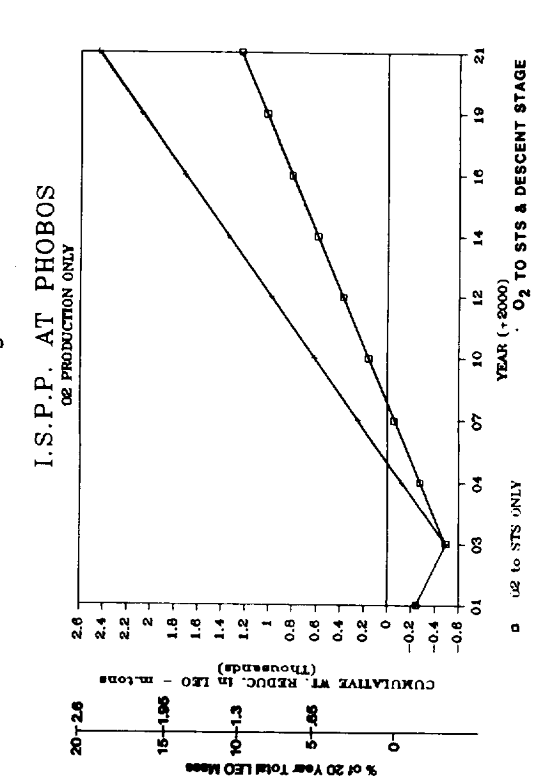

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Figure 7 compares the effect of producing all propellant on Phobos, or oxygen only, if the Mars-STS is loaded with propellants. The benefit of producing fuel is small; almost all the gain comes from the production of oxygen.

Figure 8 shows the effect of oxygen only production for the Mars-STS only and Mars-STS and the descent stages. Loading the descent stages with oxygen results in a roughly 10% gain at the end of twenty years.

TMI PROPELLANTS FROM PHOBOS

There is one other technique that may decrease the LEO mass requirement: return propellant from Phobos or Deimos to Earth orbit to be used in the initial trans-Mars injection burn, where most of the total propellant is consumed.

Studies of lunar derived oxygen (Ref. 4) have shown it possible to return more oxygen from the lunar surface to LEO than the required hydrogen sent to LEO, even if all hydrogen must come from Earth. Ref. 5 addresses the use of lunar derived propellants for a manned Mars program. The economics of such an operation are still being studied. The mass payback ratio (propellants returned from the Moon over propellants sent from the Earth) ranges from just over one if all hydrogen must be transported from Earth to as high as 20, if hydrogen can be produced on the Moon. This mass payback ratio is sensitive to aerobrake mass and boiloff and very sensitive to whether lunar hydrogen can be used.

It requires less delta V to get from LEO to Phobos and return than that required for a round trip from LEO to the lunar surface (Table 5).

Thus, there is a performance advantage to using propellants from Phobos delivered to LEO. However, Phobos propellant production for Earth return will almost certainly require 1,000 days round trip for the transportation return, and the large problems of large scale low-g mining may be significant. Thus, the technology and economics are not clear and the concept requires more study.

CONCLUSION

In a long term exploration of Mars with frequent repeated missions, propellant production at Phobos and on the Mars surface offer sufficient performance gains to warrant further study.

TABLE 5

(both cases use Earth aerobraking, all delta Vs in km/sec)

LEO-Mars Orbit-LEO			LEO-Lunar Surface-LEO		
TMI	-	3.7	TLI	-	3.3
MOI	-	1.1 (without aerobraking)	LOI	-	1.0
	-	.1 (with aerobraking)			
To Phobos Orbit	-	.8	Lunar Descent	-	2.1
From Phobos Orbit	-	.8	Lunar Ascent	-	1.9
TEI	-	.9	TEI	-	1.0
EOI	-	.2	EOI	-	.1
TOTAL	-	7.5 (without aerobraking)	TOTAL	-	9.4
	-	6.5 (with aerobraking)			

Most of the gain is realized by simply having a Phobos oxygen plant and in-orbit refueling. This has the advantages of not requiring a single permanent Mars surface base. Each mission could land at a different spot for wide-spread exploration and still realize the gain from a Phobos plant.

REFERENCES

1. Davis, Hubert P., Lunar Oxygen Impact upon STS Effectiveness, Eagle Engineering, Inc., Houston, Texas, Eagle Report No. 83-63, May 1983.
2. Davis, Hubert P., A Manned Mars Spacecraft Configuration with Artificial G, Eagle Engineering Inc., Houston, Texas, NASA JSC Contract # NAS9-17317, presented at the MSFC Mars Workshop, June 10-14, 1985, Huntsville, Alabama.
3. Babb, Gur R. and Stump, William R., Mars Vicinity Trades and Options, Eagle Engineering Inc., Houston, Texas, NASA JSC contract # NAS9-17317, presented at the MSFC Mars Workshop, June 10-14, 1985, Huntsville, Alabama.

4. Lunar Surface Return Report - In-house JSC study presented March 1984, contact Barney B. Roberts (NASA JSC).

5. Babb, Gus R. and Stump, William R., Departure from Lunar Orbit and L2 Using Lunar Produced Propellants, Eagle Engineering Inc., Houston, Texas, NASA JSC Contract # NAS9-17317, presented at the MSFC Mars Workshop, June 10-14, 1985, Huntsville, Alabama.