LAUNCH OPTIONS FOR MARS NETWORK MISSIONS USING SMALL SPACECRAFT

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The currently-planned Mars Global Network Mission calls for a Delta II launch to deploy spacecraft that will place small stations on the surface of the planet. This study of small launch vehicles revealed that the Taurus is more cost efficient than large launch vehicles such as the Delta II and Titan IV. The Taurus can launch 1092 lb into a Mars transfer orbit at a cost of $13,740/lb while the Delta 7925 can place 2350 lb into the transfer orbit at $17,450/lb. Small vehicles such as the Scout G-1 and Pegasus can place less than 300 lb into the transfer orbit, inadequate payload for a Mars mission. A growth version of the Scout II can place 422 lb into the transfer orbit, but at the relatively high cost of $35,550/lb. The small vehicles were assumed to have launched the Mars spacecraft into a 150 nm circular orbit with low inclination; the spacecraft were assumed to have bipropellant hydrazine propulsion for orbit transfer.

INTRODUCTION

Studies by the Solar System Exploration Committee (Ref. 1), National Research Council (Ref. 2), and European Space Agency have identified network missions as a next step in the exploration of the planet Mars. Such missions would involve the emplacement of several penetrators and surface stations for seismic, meteorological, and composition investigations. Most of the proposed instruments are small, do not take much power, and do not generate large amounts of data. The requirement for many stations makes small spacecraft an attractive alternative for Mars network missions.

An earlier NASA concept for the Mars Global Network Mission required two Titan IV launches, each with an orbiter and six landers (Ref. 4). NASA recently reduced the size of the spacecraft so the missions could be launched on the smaller Delta II (Ref 5). Other studies have indicated that even smaller spacecraft might be feasible (Ref. 6), so an examination of the Mars capabilities of small launch vehicles is of interest.

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LARGE LAUNCH VEHICLES

The interplanetary capabilities of the Delta II and Titan IV are listed in Table 1. Approximate costs of the Delta and Titan are quoted from Reference 7; the higher Titan costs were used since an interplanetary mission would use the more expensive Centaur upper stage. The heliocentric departure velocity (v_∞) for a Hohmann transfer from Earth to Mars is 2.94 km/sec (Ref. 8). The launch energy C3 is the heliocentric departure velocity squared, for this case 8.64 km^2/sec^2.

Table 1. Large Launch Vehicle Mars Trajectory Performance

Vehicle	Weight to Mars (lb)	Cost ($M)	Cost /Weight ($/lb)
Delta 7925	2350	41	17,450
Titan IV	14,000	218	15,570

The three-stage Delta 7925 can lift 2350 lb into an Earth escape trajectory with sufficient energy to reach Mars (Ref. 9). The Titan IV is the largest expendable vehicle in the U.S. inventory; with a Centaur upper stage, a Titan IV can send 14,000 lb to Mars (Ref. 10). A measure of cost efficiency is the launcher cost per unit weight in the Mars transfer orbit in $/lb. The Titan IV is slightly more cost efficient than the Delta II and can launch almost six times the payload.

INTERPLANETARY TRAJECTORIES

While small launch vehicles could fly direct ascent trajectories for interplanetary transfer orbits, data for such trajectories is not available. An alternative is for the small launch vehicle to deliver a spacecraft with escape propulsion into a low Earth parking orbit. A circular orbit of 150 nm altitude was chosen as the reference orbit since is high enough to allow adequate orbit lifetime in case there is a problem with the spacecraft. No dedicated upper stages are available for use with these small launchers, thus the Mars spacecraft will have to use integral propulsion. Solid rocket motors are capable but less flexible than liquid propellant. A current trend in commercial communications satellites such as Intelsat VI is to use integral bipropellant hydrazine propulsion subsystems for orbital maneuvers (Ref. 11). Such subsystems have specific impulse of approximately 300 seconds and offer increased flexibility in design since the fuel can be located in many small tanks.

Assumptions made for calculating the interplanetary trajectories were that the orbits of Earth and Mars are coplanar and circular, launches from Earth take place when Mars is in the optimum position, and the spacecraft escape when the plane of the parking orbit is coplanar with the plane of the ecliptic. The 150 nm (278 km) reference orbit has a radius of 6656 km (using the mean radius of the Earth of 6378 km). The Δv required to achieve a heliocentric departure velocity of v_∞ is given by Reference 12 and is

$$\Delta v = \sqrt{v_\infty^2 + \frac{2\mu}{r_0}} - \sqrt{\frac{\mu}{r_0}}$$

For a v_∞ of 2.94 km/sec from the reference orbit, a Δv of 3.59 km/sec is required. The ratio of fuel weight to initial weight is given by Reference 13 and is

$$\frac{m_{fuel}}{m_{initial}} = (1 - e^{-\Delta v / I_{sp} g_0})$$

Using the Δv given above and specific impulse of 300 seconds for bipropellant hydrazine, the ratio is 0.705. This means that 70.5% of the weight carried by the launcher is for fuel to achieve the Mars transfer orbit, leaving 29.5% for the spacecraft that travels to Mars.

SMALL LAUNCH VEHICLES

The small launch vehicles studied include the Scout, Scout II, Pegasus, and Taurus. Launchers that can only be used from the Western Test Range such as the Atlas E and Titan II, were not considered since easterly launches provide much better performance. Some firms developing small launchers are having financial difficulties, so only current vehicles (Scout and Pegasus), vehicles for which contracts are in place (Taurus), and derivatives of existing vehicles (Scout II) were considered.

Table 2 is a summary of the five vehicles analyzed. Launch weight is the number of pounds that the launch vehicle places into the 150 nm reference orbit. Mars weight is the weight injected into the transfer orbit to Mars and is equal to 29.5% of the launch weight. Cost estimates are from Reference 14. A range of $10-12M was listed for the Scout G-1; the higher value was used. A growth version of a follow-on Scout was considered to cost the same as the follow-on since no other cost information was available. The launcher cost divided by the Mars weight is the measure of cost efficiency used for comparison with the large launch vehicles.

Table 2. Small Launch Vehicle Trajectory Performance

Vehicle	Launch Wt. (lb)	Mars Wt. (lb)	Cost ($M)	Cost/Mars Wt. ($/lb)
Scout G-1	550	162	12	74,070
Scout II	1120	330	15	45,450
Scout II Growth	1430	422	15	35,550
Pegasus	910	268	6.3	23,510
Taurus	3700	1092	15	13,740

The LTV Scout has been in use for over 30 years (Ref. 15). The Scout G-1 is the current version and has the smallest capacity of the five vehicles analyzed. LTV has teamed with SNIA in Italy to develop the Scout II, a derivative of the Scout that uses two solid rocket boosters. A possible growth version of the Scout uses four solid rocket boosters for higher performance. All launches were assumed to take place from the San Marco platform off the coast of Kenya to take advantage of its position close to the equator.

The Orbital Sciences Corporation/Hercules Aerospace Company Pegasus is an air-launched vehicle that can deliver payloads to 0° inclination (Ref. 16). The OSC Taurus is ground-launched vehicle that can be deployed to the Eastern Test Range (Ref. 17).

RESULTS

The Scout G-1 and Pegasus launchers probably cannot deliver sufficient payload to a Mars transfer orbit to meet the requirements of the Mars Global Network Mission. The Scout II, especially the growth version, may be able to provide adequate payload with 422 lb into the transfer orbit, but is not as cost efficient as the large vehicles. The Taurus injects over 1000 lb of payload into the transfer orbit and is suprisingly competitive with the large launch vehicles in cost per weight. In fact, the Taurus is more cost efficient than both the Delta II and Titan IV and has lower total cost that could make the mission more affordable.

CONCLUSIONS

The Taurus launch vehicle should be a candidate for the Mars Global Network Mission. Taurus is more cost efficient for the mission than the Delta II specified in current plans and has lower total cost.

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