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NUCLEAR ROCKET USING INDIGENOUS MARTIAN FUEL
NIMF

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The concept that I am going to be talking about has the endearing name of NIMF. It's a little bit different than the other concepts that have been and will be presented at this meeting because the NIMF is not primarily a space transportation technology. It has an impact on space transportation requirements, but fundamentally the NIMF is a different way altogether of making use of nuclear thermal rocketry through enhanced capability for Mars missions and other kinds of planetary missions.

As everyone here knows, in the 1960's we had the NERVA and ROVER programs, and they developed hydrogen-fueled NTR engines (Figure 1). They were hydrogen fueled in order to have the maximum specific impulse, and the reason why you wanted maximum specific impulse was to lower the mass of the manned Mars missions by increasing the efficiency of space transportation.

There have been innumerable trade studies done of NTR propulsion that show benefits on the order of a factor of 2 for reducing the initial mass in LEO of the manned Mars mission.

But there is a different potential capability of NTR engines. Rather than attempt to exploit them for their potential performance, let's attempt to exploit them for the potential versatility inherent in the concept. What I mean by that is that there is the possibility of designing NTR engines that can use propellants other than hydrogen, in particular propellants that are volatiles indigenous to an extraterrestrial body. If you can do that, you can have tremendous enhancement of the mission capability because you can endow the mission with global mobility at the target planet.

In particular, in talking about Mars, it's quite clear what the optimum indigenous propellant is. The Mars atmosphere is 95 percent carbon dioxide (Figure 2).

You've got a vehicle that comes in and lands on Mars with just enough propellant to set it down, perhaps after a parachute assisted landing (Figure 3). Now it's sitting on the surface of Mars with no propellant in its tank. Then, run a pump and acquire Martian CO_2.

With the temperatures that exist on Mars, CO_2 can be liquefied without refrigeration. It can be liquefied simply by putting it under about 100 psi pressure. So you run a pump, you fill a tank with liquid CO_2, and then, when you want to fly, you just run it through the NTR, heat it to a high temperature-vapor, and shoot it out the rocket nozzle and away you go.

And the performance, while modest by rocketry standards, is good enough to get you back up to orbit, or, what is far more important, to be able to hop from one point on the surface of Mars to any other point on the surface of the planet in a single hop, at which point you can land again and refuel. So you have unlimited global mobility. It means a manned Mars mission can visit ten sites instead of one. So we are talking about an order of magnitude increase in the exploratory capability of a Mars mission by exploiting this potential.

Figure 4 shows a concept of what a NIMF vehicle might look like. You have the astronauts on the control deck, and an additional habitation deck. The pumps are actually much smaller than shown. You only need about 25 kilowatts of pumping power to do the job, which is like a 30 horsepower pump.

Here's the tank of propellant and the NTR engine with a shadow shield above it. A coaxial tank wrapped around the reactor provides supplementary shielding when we are on the surface. So when the reactor is being fired, the crew is up here and they are protected by the shadow shield, by the enormous mass of propellant in the main tank, by miscellaneous equipment, and by a second shield, which is positioned right under them.

The second shield protects them against possible reflected radiation that comes during landing, which is the most critical point of the mission from the shielding point of view. There is more that could be said about vehicle design.

If we are talking about alternative propellants, Figure 5 may be of interest because we always talk hydrogen. These are ideal Isp's. The figure shows infinite expansion ratio Isp's with no nozzle losses included. If you were to include that stuff and had an expansion ratio of say 100, you would be talking about 93 percent of these numbers as realistic performance numbers. So, if we talk about 2800 K, we are talking about 265 seconds Isp with CO_2. Now, with water we are up in the mid 300's, with methane in the high 500's. But water is only available on Mars in the form of ice or permafrost, and so it's much more difficult to access. Methane would require chemical synthesis which makes it still more difficult to access. So, CO_2 is the one that's important.

We can acquire it with simple pump compression (Figure 6). The energy cost of acquiring the CO_2 is very low because it's a simple physical acquisition process. It's on the order of 80 kilowatt hours per ton. That is about 2 orders of magnitude less than the energy cost required to manufacture a propellant; for example, by electrolyzing water and liquefying it or dissociating CO_2 into CO and O-2 and liquefying them.

Since we can use the volatile in its raw form, and the energy comes from the reactor, we have a device that can make its own fuel. The energy costs are so low that the propellant acquisition system can travel with the vehicle, which is not true for a system that would have to synthesize chemical fuel. As I say, the performance is in the mid to high 200's, but that is good enough to attain highly energetic orbits around Mars.

But there is a sticking point. The CO_2, when elevated to high temperatures, becomes an oxidizing medium. It would not be compatible with the fuel elements that were developed for the NERVA program. So, if we are to utilize CO_2 in a nuclear thermal engine, we have to master a new engine chemistry for oxidizing media.

You have a number of options for the propellant acquisition system (Figure 7). You could use a dual use reactor which would allow you high power levels, perhaps a hundred kilowatts. This would allow for rapid refueling. With a hundred kilowatts we could fuel this thing to fly up to its maximum orbit in just 12 days. But you have an issue with the shielding of a critical reactor on the Martian surface for an extended period of time.

We could use solar arrays. They would be set up by the astronauts with a couple of days work on the surface. That could be done. That will work. It's more massive than the other alternatives, but you could do it.

The one that I like the best and which I selected in the NIMF design study that we did (for NASA Headquarters) at Martin was a dynamic isotope power source. It's less than half the mass of a solar array, producing the same amount of power on the Martian surface. We don't have the problem with a critical reactor on the surface. But all three options are viable.

The key issues that define the feasibility of the concept, include the need for a high thrust-to-weight engine (Figure 8). The use of CO_2 as your propellant helps. It degrades your specific impulse, but it increases the thrust for the same energy density of the reactor, so we are talking about triple the thrust of hydrogen at the same power level.

In order to get high thrust, I think we need a high pressure engine, though numbers greater than 800 psi no longer scare people in the NTR communities, so that's not that big a deal.

For high heat transfer area, this would mean that concepts such as particle or pebble bed, where you maximize the heating area of the fuel elements, are most promising for the NIMF. Also, obviously, a small reactor eases the shielding problem, and if the NIMF is going to be used as a manned vehicle, that would also help a lot.

We require fuel materials or coatings that can withstand corrosion by hot CO_2. With a hydrogen NTR, you want 2500-2800 K because you are in direct competition with chemical aerobrake. Unless you have those rather high temperatures, you can't demonstrate a performance advantage of significance.

With the NIMF, that's not the case. There is nothing in competition with it. There is no other enabling technology for global mobility on Mars. If it works at any level of performance, it does the job.

The high temperature 2800 K is desirable because it would enable you to go from the surface of Mars to extremely energetic, highly elliptical orbits around Mars. But frankly, a suborbital vehicle that could hop around the planet, which would require fuel temperatures on the order of 1200 or 1400 K, would represent a tremendous increase in our capability on Mars.

So the most promising appears to be mixed thoria/urania oxide fuel pellets coated by zirc oxide, which might reach the 2800 K temperature. Beryllium oxide was used in the Pluto program. It's a lower temperature material, maybe 2400 K. If we are under 1900 K or so we could talk about urania/carbide fuel elements coated by silicon carbide, which after all resists oxidation in air on space shuttle tiles at that kind of temperature, and air is a more serious oxidizer than CO_2.

The data in Figure 9 was compiled by people at NASA Lewis working on resistojets. As you can see, the zirc oxide was good up to 2700 K in oxygen. So that really might get us close to where we want to be.

There needs to be a serious program of engine chemistry to determine the optimum materials and test them, and this can be done at fairly modest cost, near-term, in electric furnaces.

Figure 10 shows what the propellant temperature does. As you can see, if you are interested say in attaining low Mars orbit, and if the vehicle can have a mass ratio up to 8, which is reasonable because CO_2 is a high density propellant, even 2000 K does it.

If you want to attain a highly energetic elliptical orbit, you better have 2600 K. And if you want to do a direct trans-Earth injection from the Martian surface, you better be over 2800 K. So depending upon what you want to do, the temperature requirement that you have to be able to attain is determined.

The ballistic NIMF is probably the more promising one (Figure 11). It's lighter and can do more, and you can see that this was designed at 2800 K and it could attain the highly elliptical Mars orbit. But even as low as 2000 it was still getting to low Mars orbit. That's consistent with what I mentioned before.

Sometimes in the past people have proposed using a carbon monoxide/oxygen bipropellant hopper as the basis for Mars global mobility.

Since Mars atmosphere is CO_2, people have proposed making bipropellant out of it. The problem is that the energy requirements for propellent productions are 100 times greater than for the NIMF (Figure 12). What that means is that the carbon monoxide hopper (CMH) has to have a fixed base. Therefore, to explore a particular site, it has to do twice the Delta V as the NIMF because it has to hop there, land there, and then hop back to the base. Additionally, the Isp is almost the same on the CMH as on the NIMF.

You can get the mass ratio up a little more because the thing is lighter, but fundamentally the doubling of the Delta V is the dominating factor here. You can see that CMH loses it at around the 1300 kilometers range, whereas the NIMF can just hop up to orbit and come down anywhere on the planet. So the NIMF has global mobility and a chemical hopper simply does not have global mobility. That's all there is to it.

The NIMF can also be used to deliver cargo (Figure 13). With 10 tons we can still make it back up to orbit, but with 40 tons we could hop 4000 kilometers, which is roughly the distance from the Martian pole to the equator.

So if you had a base at the equator where there is more solar energy and warmth and so forth, but no water, you could send the NIMF up to the pole, scoop up 40 tons of water from the polar cap, and hop back to the base with it. Also obviously you could hop around the planet depositing science payloads in various places and setting up a global science network.

It can take 40 tons 4000 kilometers, or it could take 100 tons 1000 kilometers. If we have a base on Mars, there will always be some raw material which isn't situated right where you are and it would really be useful to have this capability to move payloads around the planet.

Now, I did not analyze the NIMF using the same mission plan that was used as the standard mission for the other concepts at this conference. The reason for that is twofold. First of all, the NIMF completely changes what the payloads are that you would send to Mars, so you are changing the manifest: the comparison goes out the window.

The other thing is that I think that the mission plan that was chosen for this conference doesn't have any merit because it spends 400 days in transit and only 30 days at Mars. That's a very inefficient way to try to explore Mars.

Figure 14 shows a variety of propulsion options: Chemical propulsion, chemical with an Aerobrake, NTR, NTR with an Aerobrake, carbon monoxide hopper and NIMF.

As an example, say NTR all propulsive, on the first mission where the NIMF or the CMH have to both be transported to Mars, the mission masses are not too different. But on the second mission, CMH & NIMF halve the mass in LEO.

Even if you were to average this over a five mission sequence, they would be roughly a factor of 2 lower in LEO than the conventional approach. The CMH and the NIMF are about the same mass-wise. However, the CMH can only visit one site whereas the NIMF has global mobility.

Figure 15 shows the figure of merit I use for a manned Mars mission. Figure 16 shows that the NIMF mission has about a factor of 30 greater figure of merit than the conventional lander, and a factor of 10 greater than the CMH.

If we assume all NTR, all propulsive for the space transfer, and you want to conduct a program of Mars exploration incorporating landing at 50 discrete locations on the surface of Mars, Figure 17 shows the total mass of the NTR mission with and without the NIMF. The total mass with a conventional lander is 11700 tonnes, using the NIMF reduces this to 640 tonnes. Using the NIMF shows a factor of 20 benefit. This is much greater than would be afforded by any advanced space transportation propulsion technology.

Figure 18 depicts a manned Mars mission being launched using a NIMF and one launch of a heavy lift launch vehicle.

One early possible application of the NIMF would be unmanned as a Mars Rover sample return mission (MRSR). The Centaur throws the NIMF to Mars where it lands on Mars, it hops around, visits ten sites. The unmanned NIMF collects samples from ten sites, then ascends to orbit. It then shoots the samples back in one of these sample return vehicles (Figure 19). Now, we may discover that site Numbers 3 and 8 were the interesting ones. So, we send the NIMF back there and get a second consignment of samples and fire them back.

The comparison between this and a conventional MRSR mission is quite profound. We are able to do it in one launch instead of several. We return 220 kilograms of samples instead of five, 22 times more sample payload. They come from at least ten sites instead of one, and there are two sample shipments allowing some degree of feedback in the mission, instead of none.

It's possible to extend the NIMF concept to other destinations in the solar system (Figure 20). There is water ice on the moons of Jupiter, Saturn, and Uranus. There is methane on Titan, and we could actually envision performing sample return missions from these bodies using this sort of approach, though there would be some technological change.

Envision an unmanned sample return mission to Titan. It would use methane as propellant. It uses on NTR to kick itself out to Titan where it aerocaptures. Once it's going slow in Titan's atmosphere, it unfolds wings.

Titan has four times the atmospheric density of the Earth and 1/7th the gravity, so it's the aviation paradise of the solar system. A vehicle with wings can remain airborne flying at a speed of 25 miles an hour in Titan's atmosphere.

When it's all done doing its low-level aerial reconnaisance of Titan, which is necessary because Titan is clouded over, you tank up with methane from Titan's atmosphere. Then you either do a big Delta V and go back to Earth, or you could actually fly from Titan to any one of Saturn's other moons (except for Mimas), land, collect some samples, go back to Titan and refuel, and then jet back to Earth. So it opens up the capability for some rather spectacular unmanned outer planetary missions.

In conclusion, the NIMF technology offers extremely high leverage in increasing the cost effectiveness of missions to Mars and the outer solar system (Figures 21).

It reduces the IMLEO of a given Mars mission (if we figure it as part of the sequence of even three or four missions) by about a factor of 2, regardless of the propulsion technology, simply because you are reducing the payload manifest. It enables a manned Mars mission in a single HLV launch.

It increases the number of sites visited per mission by a factor of 10 or more, and that is really what counts. That's the big leverage. It enables global transport on Mars. It increases the science return of a Mars Rover sample return by an order of magnitude, and extensions of the technology could enable sample return missions to the outer solar system.

Therefore, I maintain that the NIMF offers greater leverage for Mars exploration than any other advanced propulsion concept.

The NIMF is not a trivial technology challenge. I would say this concept is at technology level 2; we have to demonstrate new engine chemistry. However, there are no fancy physics here. It's the same kind of thing we did with the NERVA or other NTR concepts except we're doing it in a different context. It's just a solid core reactor with a different propellant.

What we recommend is this: The immediate focus should be a NERVA derivative or other solid core hydrogen fueled NTR system (Figure 22). The number two priority should be the development of a CO_2 NIMF because, even though the chemistry is different, the people, the test facilities, a lot of the computer codes and so forth that are used in the hydrogen NTR program could be shifted over later to the NIMF.

Once the NERVA clears the test facilities, we could put the NIMF in there. So I see it as an evolutionary program. I would say that the NTR development evolving towards NIMF can enable a much more capable and cost effective program.

A VOICE: Have you received any feedback, that, by operating a nuclear propulsion system in the atmosphere of Mars, you may be disturbing the ground which you are striving to gather and study by neutron activation?

MR. ZUBRIN: Oh, well, you would collect the samples from an adequate distance from the landing site.

A VOICE: You could be a kilometer away and still have a significant aggravation.

MR. ZUBRIN: Oh, I don't think so. The activated materials will be very easy to identify as such since we are quite clear that these things don't exist in neutron-activated short half-life form on the surface of Mars.

A VOICE: I think you have a potential problem here that the science folks will really have a problem with.

MR. ZUBRIN: Well, actually our strongest support has been from the science house in NASA.

A VOICE: Those are mission planners, those aren't the guys that get the samples back.

MR. ZUBRIN: The samples can be collected from sufficient distance from the landing site.

MR. ZUBRIN: Let me just take one more question.

A VOICE: What's the probability in your mind that this ability to hop around will be a mission requirement, either initially or second or third mission?

MR. ZUBRIN: Well, I don't know if it will be a mission requirement for the manned mission, but it's extremely desirable from the point of view of being able to carry out effective science.

Initially, we may have a small unmanned NIMF which acts as an auxiliary for the manned crew. They can send this thing hopping around the planet, which also gets you around a number of shielding problems on the vehicle so it can fetch and bring, collect samples.

That might be an initial way to implement it; prove the technology in an unmanned mode. But in terms of whether JSC all of a sudden will come out and say that is a requirement, I couldn't predict that.

BIBLIOGRAPHY

Robert Zubrin
Martian Propellants

1. Zubrin, Robert. "Nuclear Rockets Utilizing Indigenous Martian Propellants." AIAA 89-2768, 25th AIAA/ASME Joint Propulsion Conference, Monterey, CA, July 1989.

2. Zubrin, Robert. "Mission to Mars and the Moons of Jupiter and Saturn Utilizing Nuclear Thermal Rockets with Indigenous Propellants." AIAA 90-0002. 28th Aerospace Science Meeting. Reno, NA. January 1990.

3. Zubrin, Robert. "The Engineering of a Nuclear Thermal Landing and Assent Vehicle Utilizing Indigenous Martian Propellants." 26th AIAA/ASME Joint Propulsion Conference. AIAA 90-1995. Orlando, FL. July 1990.

4. Zubrin, Robert and R. Decher. "Potential Performance of a Nuclear Thermal Rocket Engine Utilizing Martian CO2 as a Propellants." 27th AIAA/ASME Joint Propulsion Conference. Sacramento, CA. June 1991.

Introduction

In the 1960s, Nuclear Thermal Rocket (NTR) engines were developed and ground tested capable of yielding Isp of up to 900 s at thrusts up to 250 klb.

Numerous trade studies have shown that such traditional hydrogen fueled NTR can reduce the IMLEO of Lunar missions by 35% and Mars missions by 50 to 65%.

The same personnel and facilities used to revive the hydrogen NTR can also be used to develop NTR engines capable of using indigenous Martian volatiles as propellant.

By putting this capability of the NTR to work in a Mars Descent/Ascent Vehicle, the NIMF (Nuclear rocket using Indigenous Martian Fuel) can greatly reduce the initial mass in LEO of a manned Mars mission, while giving the expedition unlimited planetwide mobility.

Figure 1

The Martian Atmosphere

Carbon Dioxide	95.00 %
Nitrogen	2.70 %
Argon	1.60 %
Water	0.30 %
Oxygen	0.13 %
Carbon Monoxide	0.07 %

Figure 2

Nuclear Rocket Utilizing Indigenous Martian Fuel (NIMF)

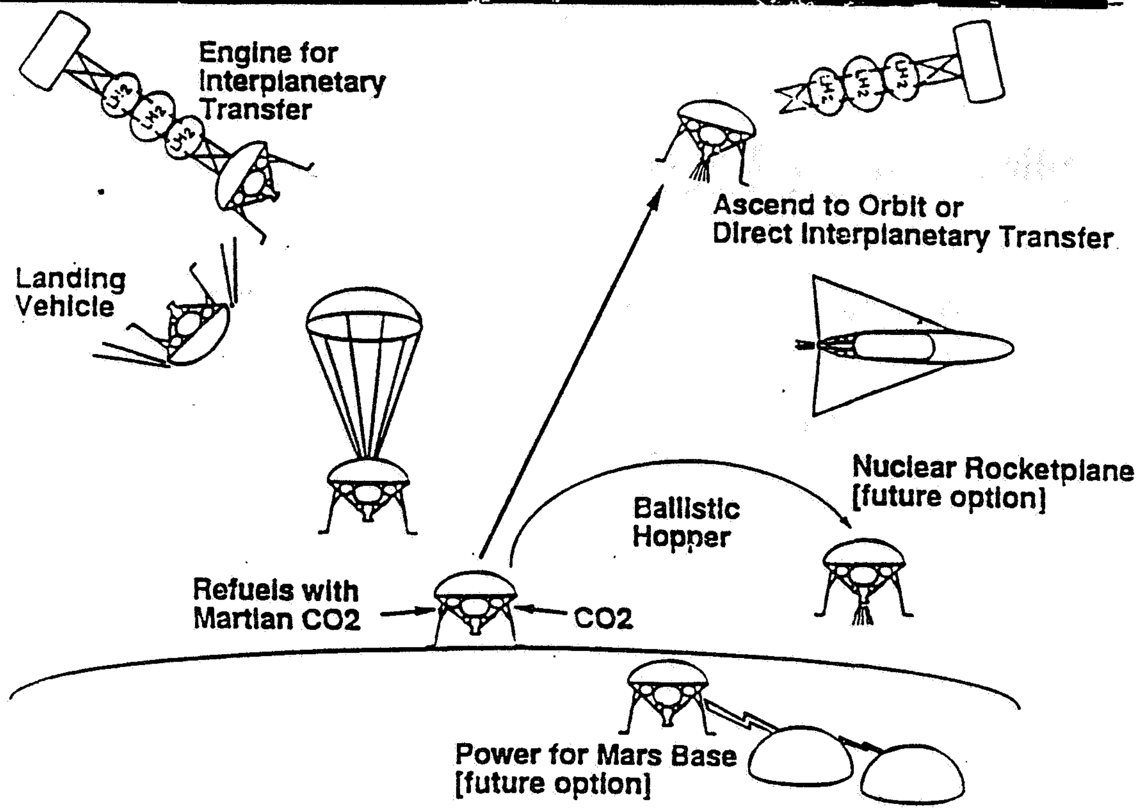

Figure 3

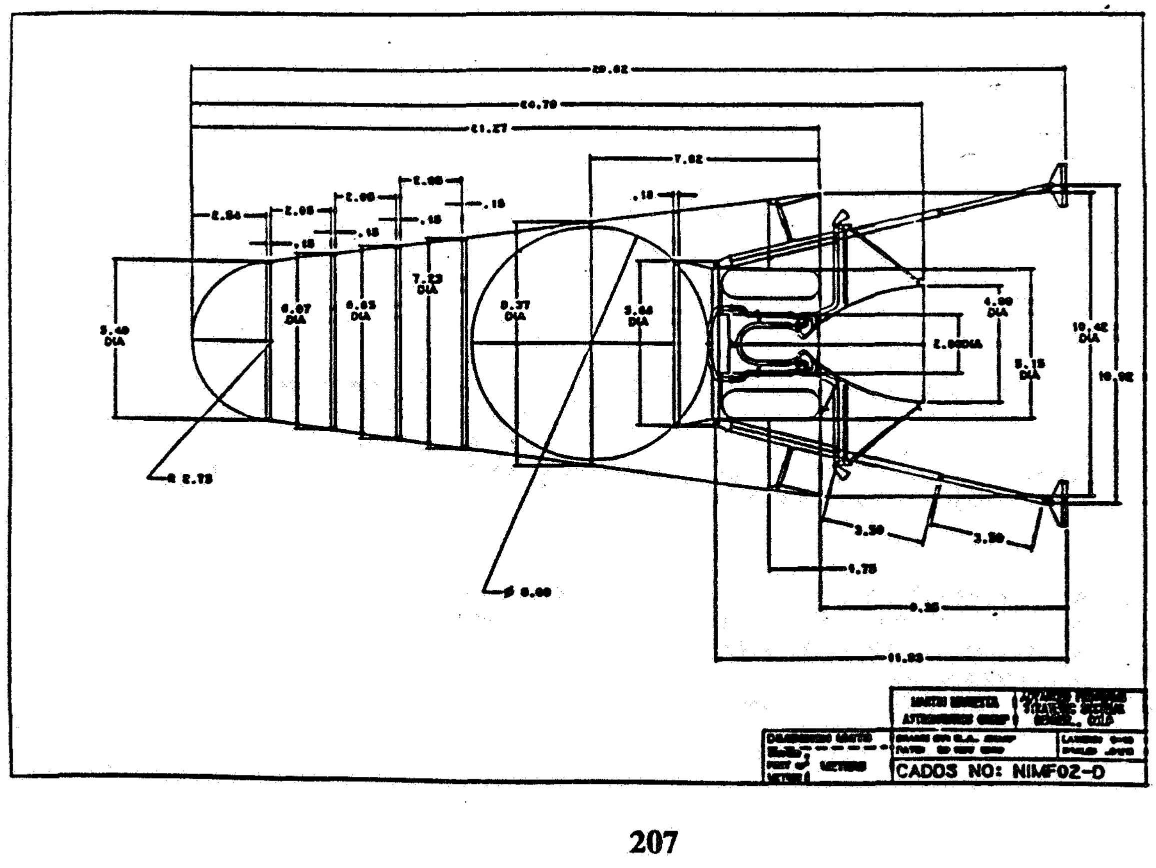

Figure 4

Ideal Specific Impulse of Martian Propellants

Temperature	CO2	Water	Methane	CO or N2	Argon
1400 K	162	222	460	162	110
2800 K	283	370	606	253	165
3000 K	310	393	625	264	172
3200 K	337	418	644	274	178
3500 K	381	458	671	289	187

Figure 5

NIMF Propellants

Carbon Dioxide

- Most readily available propellant on Mars. Can be aquired by simple pump compression at an energy cost of 84 kW-hrs per metric ton.
- Storable liquid at 233 K under 147 psi pressure, Density is 1.16 that of water.
- Modest performer. Isp ≈ 280 sec. Sufficient for ascents to high orbits.
- Requires the development of oxide fuel elements.

Water

- Aquisition requires the melting of ice or permafrost. Reactor heated CO2 or steam can be used to do this.
- Propellant tanks must be insulated or heated to avoid freezing under martian conditions.
- Good performer. Isp ≈ 350 sec. Sufficient for direct ascent to Trans-Earth Injection.
- Widely available on moons of outer planets, and possibly on Phobos and several asteroids as well.
- Requires the development of oxide fuel elements.

Methane

- Aquisition requires melting of ice or permafrost, and using reactor heat to crack CO2 and drive synthesis.
- Mild cryogen. Liquid at 135 K under 74 psi. Density is 0.46 that of water.
- Excellent performer. Isp ≈ 560 sec. Sufficient for direct ascent to high energy Trans-Earth Injection orbits.
- Available on Titan and Triton.
- Can use conventional NERVA carbide fuel elements. Coking may be a concern.

Figure 6

Propellant Acquisition System Options

(1) Dual Use Reactor.
- 100 kWe possible.
- Allows flight to max orbit in 12 days refueling.
- Shielding of critical reactor on surface an issue.

(2) Solar Arrays
- 25 kWe average (round the clock) power requires 3500 m^2 array.
- Such an array would mass 8.8 tonnes and take 3 astronauts 2 days to set up.
- Solar option appears feasible but unattractive.

(3) Dynamic Isotope Power Source (DIPS)
- 30 kWe DIPS would mass 4 tonnes.
- Allows fueling for flight to maximum orbit in 50 days.
- No major operational issues.
- Selected.

Figure 7

Key Issues Defining NIMF Feasibility

- Requires high thrust to weight NTR engines

•• Use of CO_2 propellant helps. Provides triple the thrust of hydrogen NTR at the same power level.

•• High pressure (> 800 psi) engines appear desirable to increase the power density.

•• High heat transfer area concepts such as the particle or pebble bed appear most promising.

- Requires fuel materials or coatings that can withstand corrosion by hot (> 2200 K CO_2).

•• Prime options for high temperature operation include coatings of either ThO_2, ZrO_2, or BeO around UO_2/ThO_2 fuel pellets. Operation with UO_2/ThO_2 fuel pellets coated by ZrO_2 as high as 2800 K may be feasible.

•• Experience base exists for high temperature BeO (Pluto program). May enable operation as high as 2400 K.

•• Possible alternatives for lower temperature (< 1900 K) operation include UC_2 fuel coated with either SIC or NbC. Would enable use of NERVA/ROVER fuel technology in suborbital hopping vehicle.

Figure 8

MATERIAL	REACTIONS	EVAPORATION RATE (gms./cm^2 sec) temperature	mass loss
Hafnium Carbide	1000°C Nb,Ta,W,N_2,H_2 1700°C O_2,(air) 2000°C Mo	2500°C 2700°C	1×10^{-6} 8×10^{-6}
Zirconia Carbide	1000°C Nb, N_2,H_2 <1200°C O_2(air) 2000°C Mo	2500°C 2700°C	2×10^{-8}(calculated) 3×10^{-6}(calculated)
Tantalum Carbide	1000°C Nb,H_2,W	2700°C 2900°C	1×10^{-6} 6×10^{-6}
Titanium Carbide	1000°C Nb, N_2 1200°C CO_2 2000°C Mo 2400°C H_2 <2000°C O_2(air)	2200°C 2300°C	3×10^{-5} 1×10^{-4}
Niobium Carbide	1600°C W, H_2 1800°C Nb,Ta,Mo	2500°C 2700°C	7×10^{-7} 7×10^{-6}
Zirconia Oxide	1900°C NH_3,C 2400°C H_2,O_2(air)	2000°C 2400°C	2×10^{-7} 2×10^{-5}
Thoria Oxide	2600°C O_2,(air)	2000°C 2400°C	2×10^{-6} 3×10^{-4}
Magnesia Oxide	?°C CO, H_2O	similar to zirconia	

Figure 9

NIMF Performance as a Function of Propellant Temperature

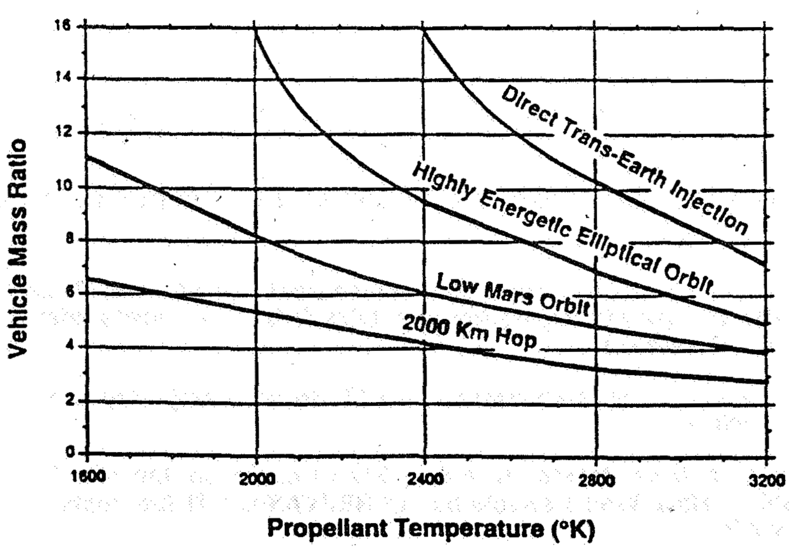

Figure 10

Performance of CO_2 Propelled NIMF

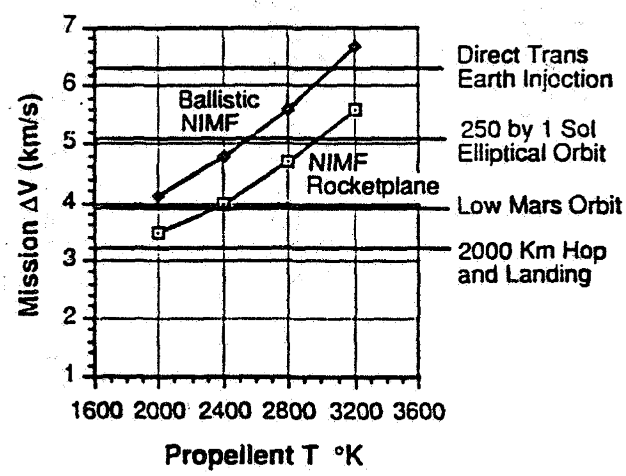

Figure 11

NIMF and CMH Mass Ratio vs Hop Range

Comparison of Mobility of Ballistic NIMF
and Carbon Monoxide Hopper (CMH)

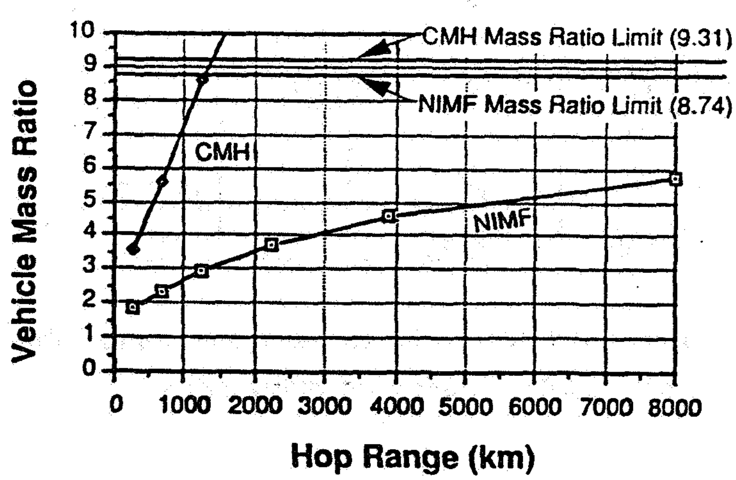

Figure 12

Cargo Capability of the Ballistic NIMF

Cargo(tonnes)	Mass Ratio	Delta-V(Km/s)	Range(km)
10	7.03	5.047	Orbital
20	6.04	4.65	8500
30	5.23	4.28	6000
40	4.61	3.96	3920
50	4.13	3.67	3000
60	3.73	3.41	2280
70	3.41	3.17	1800
80	3.13	2.96	1450
90	2.90	2.75	1220
100	2.70	2.57	1000

We thus see that the ballistic NIMF can transport cargos of up to 40 tonnes over distances of 4000 km, and cargos of up to 100 tonnes over distances of 1000 km across the Martian surface.

The NIMF requires no propellant producing infrastructure at either end of the route to accomplish the cargo transport. To achieve a comparable performance, a chemical vehicle would require propellant producing base facilities at both ends of the route.

Figure 13

ETO Masses of Manned Mars Missions (tonnes)

Propulsion	CMD/AV	CMH	NIMF
	1st/2nd	1st/2nd	1st/2nd
cryo	616/591	546/399	551/363
cryo/AB(E)	431/406	360/214	365/178
cryo/AB(EM)	355/330	297/174	301/142
NTR	258/228	220/124	223/104
NTR/AB(E)	226/201	188/ 93	184/ 74

The NIMF and CMH ETO masses are comparable, but the NIMF can visit 10 times as many sites.

Figure 14

Merit Factor for Manned Mars Missions--

$$m = (n)(t)(p)$$

m = dimensionless merit factor. Should be made as high as possible.

t = time efficiency = (time on Mars)/(time in transit)

p = (dry payload on Mars)/(ETO mass)

n = number of discrete landing sites visited by drymass payload.

Figure 15

Merit Factor "m" for All Manned Mars Mission Options

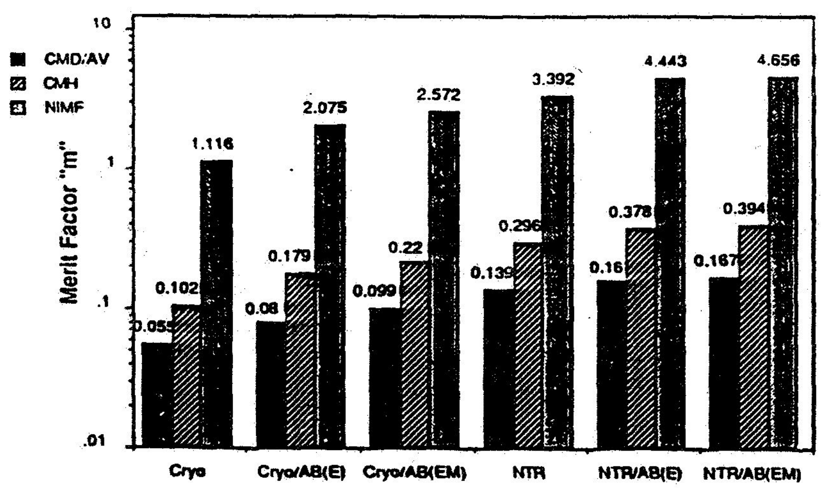

Figure 16

ETO Mass Required for Manned Mars Landings at 50 Sites

Conventional Lander	11700 tonnes
NIMF	640 tonnes

- Assumes NTR all propulsive for space transfer.

Why 50 landings? Mars is a big place. Assuming the use of ground exploration vehicles with a 1000 km one way range, 50 widely separated landings will only provide one-time access to 27% of the martian surface.

The use of the NIMF thus reduces the ETO mass required to support a program of Mars exploration by a factor of 20.

This is much greater leverage than that afforded by any advanced space transportation propulsion technology. Even a hypothetical perfect (i.e. infinite T/W, infinite Isp) space transportation engine using a conventional lander would still be outclassed by an NTR/NIMF combination by a factor of 5.

Figure 17

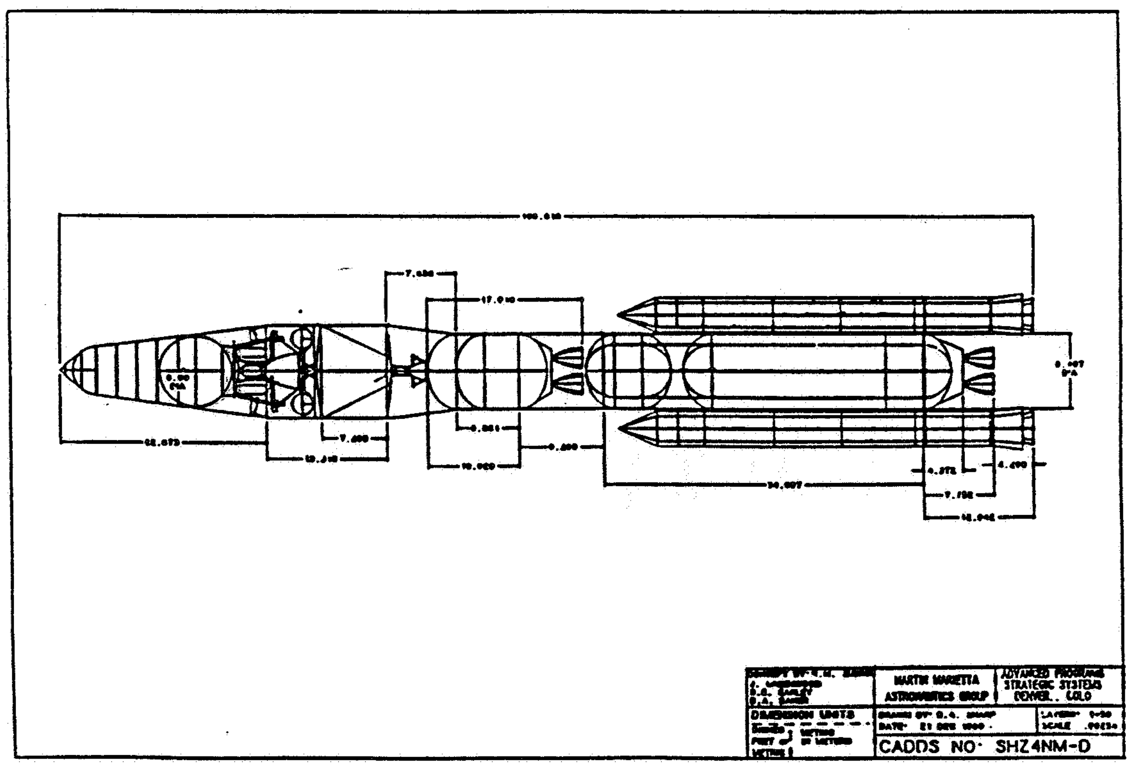

Figure 18

Mars Rover Sample Return Utilizing a NIMF

Mission Parameters

NIMF mass	5.30 tonnes	
SRVs (2)	0.56 tonnes	
Science payload	1.00 tonnes	
Cryogenic stage	14.40 tonnes	Isp= 460 s
Sample returned	0.22 tonnes	

Launch Vehicle	Titan IV
Number of Sites Visited	10
Number of Sample Shipments	2

(allows redirection by scientists after the first SRV returns)

The NIMF MRSR mission returns 45 times as much samples from 10 times as many sites as a conventional MRSR mission.

Figure 19

Exotic Missions Made Possible By NIMF Propulsion

In addition to its primary purpose as facilitating technology for manned and large scale unmanned Mars missions, the NIMF engine can also enable a number of exotic missions. Some of these exotic missions include:

- Multiple sample missions from all the moons of the major planets. Ice is available on several of the moons of Jupiter, Saturn, and Uranus; methane is available on Titan and Triton. A methane fueled NIMF could use Titan as a base for repeated sorties to each of Saturn's moons. Water fueled NIMFs could use the ice worlds as bases.
- Prospecting the asteroid belt with water fueled NIMFs. Ice is available on Ceres and several Trojan asteroids.
- Venus surface sample return carried out by a winged automated NIMF using CO2 propellant.
- Atmospheric sample return from Saturn, Uranus, or Neptune carried out by a winged NIMF using hydrogen propellant and airborne aquisition.
- Comet core sample return, using the comet ice itself for return propellant. Possible mission to the Oort Cloud, using comets as bases.
- Shuttle service between the Earth's Moon and Phobos, using lunar SO2 and Phobos water as propellants.

Figure 20

Conclusions

• NIMF technology offers extremely high leverage in increasing the cost-effectiveness of missions to Mars and the outer solar system.

•• Reduces the IMLEO of a given Mars mission by a factor of 2.
•• Enables a Manned Mars mission in a single HLLV launch.
•• Increase the number of sites visited per mission by a factor of 10.
•• Enables global mobility on Mars.
•• Creates the capability for global transport of cargo (essential for settlement)
•• Increases the science return of MRSR by an order of magnitude.
•• Enables sample return missions to the outer solar system.

The NIMF offers greater leverage for Mars exploration than *any* other advanced propulsion concept.

• NIMF technology poses a development challenge more formidable than the revival of NERVA, but less than that of the exotic NTR propulsion concepts.

•• New engine chemistry must be mastered.
•• But no "fancy physics" is required.

Figure 21

We therefore Recommend:

• That the immediate focus for advanced propulsion development be an updated hydrogen driven NERVA derivative;

• That the development of a CO_2 propelled NIMF be made the number 2 program priority.

• Thus, as the NERVA derivative moves through various phases of its maturity, the capabilities associated with earlier phases of its development be rescheduled to support the development of the NIMF. Such capabilities include:

•• Preliminary design, engineering, and test personnel.
•• Thermal hydraulics, shielding, and neutronics codes.
•• Test facilities.

• NTR development evolving towards NIMF technology will thus enable a much more capable and cost effective Space Exploration Initiative.

Figure 22