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MARSX : MARS IN 10 YEARS[*]

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I. INTRODUCTION: MARS DIRECT AND ITS OFFSPRING.

"Better is the enemy of good enough"
- old Russian proverb

Mars Direct by Robert Zubrin (1) was a watershed event in the exploration of space and most probably, in human history. It demonstrated that the very things that make Mars desirable – its atmosphere and near terrestrial surface conditions – allow a Human Mars Mission (HMM) to be mounted to at much lower cost and Mass In Low-earth-orbit (MIL) than previously conceived. Prior concepts for a Mars mission were based on the experience of the Apollo missions and assumed that Mars was a Moon–like planet, bare of resources. However, the Mars Direct concept of using the richness of Mars resources themselves to assist in the mission has given rise to many other ideas, all focused on the goal of reducing the cost of a HMM further. It is the purpose of this article to briefly summarize a new proposed architecture for a HMM, that builds on the foundation of Mars Direct with several new concepts to hasten the day of the first human footsteps on Mars.

Cost, not technology, has been the major barrier to a HMM since the days of the Apollo missions, when human space flight between major space bodies was demonstrated repeatedly. Therefore, any mission architecture that reduces cost without sacrificing crew safety can hasten the day of a human landing on Mars. In this study, the key concepts of Mars Direct, the technological legacy of the Apollo effort, and the advance of key electric propulsion technologies are used to attempt to lower mission costs to $20 billion and the time of development of an HMM effort to ten years.

Controllable factors which can impact Mars mission cost can be traced to four principal areas:

1. MIL- the Mass In Low Earth Orbit (LEO), consisting mostly of fuel, that must be emplaced in LEO in order to ultimately emplace human team on Mars and return them safely. This mass can cost 20 million per metric ton (MT).

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2. Research and development costs for new technologies, engines, and vehicles – the tendency of HMM planners to reinvent capabilities and vehicles.

3. Controversy – the launching of such a mission without strong public support being fostered beforehand or incorporating mission elements that provoke strong opposition.

4. Boondoggle – the tendency for large projects to become larger and more costly as they are seen as a source of congressional largess rather than as a goal-oriented program.

How does one build on Mars Direct to lower cost further and minimize the above listed factors? 1. Use Mars resources optimally with Mars nuclear site power, as proposed in Mars Direct. 2. Use the Shuttle and ISS (international Space Station) as LEO infrastructure. 3. Use an MOR (Mars Orbit Rendezvous) mission architecture to minimize mass required on the Mars surface. 4. Keep crew size at three. 5. Avoid nuclear propulsion for the initial Mars mission unless broad public support is evident for it. The provoking of controversy always ends up raising costs. Often this occurs by forcing the mission to become a boondoggle to shore up congressional support in the face of determined opposition. 6. Use aero-capture and aero-brake on planetfall to lower propellant needs. 7. Make the program a ten year program like Apollo. Crash programs actually save money by forcing people to make decisions. 8. Make the HMM joint with the Russians and other ISS partners to take advantage of cheap Russian LEO access and long duration flight experience. 9. Minimize R&D by using legacy technologies from Apollo wherever possible. This seems counter-intuitive at first, but rather than being anti-new technology, this approach seeks to channel R&D into focused areas such as propulsion. This will minimize costs; the goal is to get to Mars at low cost rather than funding R&D for R&D's sake. 10. Use new technologies – electric propulsion with large solar arrays rather than nuclear to lower mass in LEO. Nuclear power would require substantial R&D, and bring with it the controversy that accompanies nuclear propulsion in LEO. The key technology for this mission is the MET (Microwave Electro-Thermal) thruster using water propellant with 800 seconds I_{sp}. Such a system, using 500 kW of solar electric power generation, will be able to use 80 tonnes of water to boost 30 tonnes of payload to Mars on a Hohmann-like transfer orbit.

II. MARS X: MARS IN TEN YEARS

Mars X basic architecture is to use water fueled MET (Microwave Electro-thermal) thrusters for interplanetary transfer to lower LEO by high I_{sp} and use of water fuel to lower fuel costs. We use a Hohmann-like transfer orbit. In this the Solar Aqueous MET (SAMET) propulsion functions much like a chemical burn. We assemble vehicles in LEO at the ISS, boost water propellant into orbit, and accumulate it using the Progress re-supply vehicle. We use aero-capture and aero-braking at Mars and Earth. We build on Mars Direct by making LOX-kerosene on Mars using a nuclear powered chemical plant. This would involve man-rating a "pony" version of the Atlas 5 for the Mars ascent vehicle – an earlier Atlas lifted John Glenn into orbit, and a similar rocket will be able to lift three persons into Mars orbit from its surface. We will use an Apollo-derived command-service module for a three-person Crew Transfer Vehicle (CTV).

Vehicle	**Payload**	**Fuel mass**	**Type of propulsion**	**Role**
SL-4 Progress	4 MT	N/A	LO_2-Kerosene	Boosts cargo and fuel to ISS
Space shuttle	30 MT	N/A	LO_2-H_2/solid fuel	Boosts crew and cargo to ISS
MOTV(Mars orbital TransferVehicle)-Pioneer	30 MT 4 MT H_2	80 MT H_2O	SAMET (Solar Aqueous MET)	Boosts MLV Pioneer (uncrewed precursor) to Mars
MLV (Mars Landing Vehicle)-Pioneer	28 MT	Makes 100 MT LO_2 –RP1	Aero-brake	Lands and makes fuel sets up habitat and MAV
MOTV(Mars Orbital Transfer Vehicle)-Command			Aero-brake	Takes crew to Mars Orbit and back again
CTV (Apollo Command-Service Module derived vehicle)			Nitrogen tetroxide Un-symmetrical Dimethyl-hydrazine	Apollo Command-Service Module derived vehicle. Takes crew from ISS to join MOTV in high orbit
MDV (Mars Decent Vehicle)	4 MT		aerobrake	Apollo Command-Service Module derived vehicle. Takes crew to Mars surface
MAV(Mars Ascent vehicle	10 MT		LOX –RP1	Atlas 5 (pony version) with Apollo Command Module as payload) Brings crew and return fuel water back to Mars orbit

Vehicles and Appropriate Masses

Leo Operations: Assembly Of Vehicles And Mission Elements In Leo At Iss

The HMM will consist of two parts using the same MIPS (Mars Interplanetary Propulsion Stage) (Figure 1) with SAMET propulsion as a booster from LEO and later from LMO (Low Mars Orbit). The first portion will be the MPV (Mars Pioneer Vehicle) and the second will be the MCV (Mars Command Vehicle) carrying crew and supplies. The MPL (Mars Pioneer Lander) will contain the Mars in-situ fuel plant (MIFP), the MCH (Mars Crew Habitat), the Mars Ascent Vehicle (MAV) and a diesel (and oxygen) powered robot tractor for deployment of the nuclear reactor on site.

Some have complained that the ISS station orbit is too highly inclined to allow efficient mass accumulation from Kennedy. This is an important objection, since even with SAMET electric propulsion most of the mass for a Mars mission is dedicated to propulsion. However, the ISS orbit is perfect for an international mission anchored on a US partnership with the Russians. Such a mission can be supplied from Baikonur where most of mass and bulk – water propellant in this case – will be lifted using heavy and inexpensive Russian boosters and delivered using modified versions of the Progress resupply vehicle. The shuttle, due to its high reliability, will be reserved for both high value cargo and crew deliveries.

The mission preparation will begin with the delivery into ISS orbit of a large, empty propellant tank, of approximately 100 cubic meters capacity (2 m diameter, 8 m long). This will be parked at the station and modified in place as a mission fuel tank. A special docking port on the station will allow dedicated Progress re-supply vehicles to bring up water and off load it into pipes connected to the mission tank. Offloads of water from shuttle mission will also be used. Assuming 8 MT of water brought up per month two years will allow the accumulation of the approximately 80 MT of water required.

The MOTV (Mars Orbit Transfer Vehicle), the SAMET booster, is boosted into orbit in pieces and assembled by astronauts at the station. It will consist of six large space station solar panels mounted around a central hub that contains power conditioning units and approximately 20 MET thruster modules (Figure 1). This will occur concurrently with the accumulation of water fuel. The MET thruster uses a vortex stabilized electrode-less microwave discharge to heat gases – in this case water vapor – to very high temperatures at high thermal efficiency.

Mars fuel plant and Mars ascent vehicle (Atlas + Apollo capsule) are sent up. The Apollo command module will be used because it is already a proven, man-rated design. Computers and other gear will obviously be updated. A pony version (shortened fuel tanks) of the Atlas V will be used as the MAV (Mars Ascent Vehicle since it can be accommodated in the Shuttle bay. The vehicle will have approximately the same performance as the Atlas that lifted John Glenn into orbit, except that in the thin atmosphere and weaker gravity of Mars, it will lift a three person Apollo derived capsule from Mars surface into low Mars orbit (LMO). The vehicle will be assembled and tested in LEO and then readied for its departure to Mars.

It is assumed that a precursor mission has already landed on Mars and has demonstrated in-situ Mars fuel production and the launch of the MAV (Mars Ascent Vehicle) mission under Mars conditions as well as precision Mars landing. Such a full-up test would be considered essential for safety and minimizes risks for the HMM by pre-positioning supplies. The MAV carries ten MT of water into Mars orbit as a test payload that serves as an emergency fuel return package for the HMM. The full success of such mission would be considered essential to this HMM. This precursor mission also establishes a Mars habitat supply dump for the HMM and is landed as close to the desired HMM landing site as possible.

Mars Orbit Injection –Pioneer Mission

The Mars Pioneer Vehicle MPV will undock from the ISS and begin a three month long burn with 20 MET thrusters consuming 500kW of power. Burns will be intermittent until sufficient orbital altitude is achieved to minimize the earth's shadow. The first two months will be spiraling out to escape velocity. Because of gravity losses, 6 km/s will required to achieve escape velocity. The Mars transfer orbit injection burn will begin when escape velocity has been achieved. This burn will occur continuously for one month to achieve the required 3 km a second for a Hohmann-like transfer orbit to Mars. Ten months of free flight will follow until the MPV and its propulsion section reaches Mars. It will aero-brake at Mars to assume LMO (Low Mars Orbit).

In a realistic scenario, this craft will be the second or even third such MPV vehicle launched to Mars, with the initial ones serving to perform a full-up test of all systems on Mars surface – especially the crucial launch of the MAV into Mars orbit, a non-trivial task. Such a precursor mission would not only increase crew safety but could also establish the beginning of the Mars base for the human landing, and also emplace vital return fuel, water, in orbit around Mars to serve as emergency return fuel for any late abort of the human landing.

LMO (Low Mars Orbit) Operations

Once in LMO, the MPL will detach and descend to the surface of Mars. At the designated landing site the Mars tractor will prepare a bed in a crater and deploy the nuclear reactor to it as in Mars Direct. It will also deploy the Mars crew habitat some distance from it in a similar prepared bed. The main landing body will serve as the launch pad of the MAV.

Mars In-Situ Fuel Production

The Mars in-situ fuel plant will use electric power from the nuclear plant to make liquid oxygen and kerosene for the MAV. It will use 5 tonnes of hydrogen to make approximately 100 tonnes of LOX-RP-1 and water propellants. It will do this by making use of stabilized plasma discharges to make a mixture of hydrogen and Martian atmosphere into "syn-gas" (synthesis gas), a mixture of CO , H_2 and H_2O that is the starting point for the Fischer-Tropp process to create kerosene. The Fischer –Tropp process has been employed by governments with abundant coal and water who are cut off from petroleum. It was employed successfully in large scale plants by the Germans during WWII to make diesel fuel when they were cut off from petroleum.

Kerosene in refined state is RP-1, the fuel for many existing rockets, and diesel oil for the tractor is easily produced by the same process. This will also be used to fuel the Mars tractor, together with oxygen, for constructing the Mars base and other tasks. The advantage of making RP-1 on Mars is that this allows production of propellant of comparable I_{sp} to methane (I_{sp} of LOX-RP-1 = 360 seconds, versus I_{sp} for LOX –Methane = 370 seconds) but at twice the mass efficiency of hydrogen (1 MT H_2 yields 40 MT of propellant for LOX-RP-1 versus 20 MT for LOX-Methane). The use of RP-1 also allows the ready adaptation of an Atlas 5 or similar rocket designs for use on Mars and means that no new engine needs to be designed for a MAV, thus saving much R&D cost. The manufacture of RP-1 on Mars will also hasten the expanded settlement of Mars, since it is easier to store than methane in the thermal environment near human habitats and will allow the use of a broad range of legacy rocket and diesel technology. What we need is Detroit Diesel power on Mars.

Kerosene is a “paraffin,” or straight line hydrocarbon of approximate formula $C_{12}H_{14,}$ that can be made by the Fischer-Tropp process. It is created with other hydrocarbons of greater or lesser molecular weight, so the product vapor stream from the Fisher-Tropp catalyst beds will have to be distilled to yield kerosene of the required purity. The light and heavy hydrocarbons can either be stored for other uses or simply burned and re-supplied to the syn-gas generator to be sent through the catalytic bed again. The manufacture of kerosene from Martian atmosphere by the Fischer-Tropp process has already been demonstrated under an SBIR program by TDA research in Colorado in 1998 (Peter Geberstein, private communication).

Landing Site Selection

The Mars landing site should be strategically located for a Mars base of human operations, and will be the eventual capitol of the Mars Republic. Primary in its consideration should be that it is near water, and secondarily it must be centrally located on Mars near many points of interest in the planet’s exploration.

The shoreline of what appears to have been a Paleo-ocean on Mars, named the Malacandrian Ocean (2), runs around the northern hemisphere of Mars at the zero kilometer elevation line, and may contain a fossil water table. The coincidence of this paleo-shoreline with other areas of scientific interest may make an ideal region for a landing site.

The end of the Mariner Canyon is considered an area rich in scientific targets, and the landing site should be near it. This may rule out other sites better suited to robotic exploration. Gusev crater, for example, is apparently water rich and but is far from the Mariner Canyon terminus. A site close to the Viking I and Mars Pathfinder site would probably be better, and near the Canyon terminus at Chryse Planum. Such a site would be near zero longitude, close to the equator to provide good sunlight for base auxiliary power, and near the zero kilometer elevation (possible paleo-ocean shore) line. Exploration of even the mouth of the Mariner Valley will be the great prize of any scientific expedition because its exposed strata and debris talus from past floods will reveal much of Mars geological history.

Launch Of The Mars Exploration Team

The Mars CV vehicle undocks from the ISS where it has been assembled and tested and is launched to Mars. It spirals out as it gains speed. The Mars crew joins the vehicle after passage through Van Allen belt using the Apollo Command-Service module for crew transfer. The commit to Mars transfer orbit injection is given, and the Mars transfer orbit injection burn is initiated. We, our own human flesh and blood, are off to Mars.

Once the Mars transfer burn is completed, we will stow the solar arrays and spin the vehicle for gravity. Spin induced gravity in small vehicles, requiring spin rates of perhaps once a second, have been criticized due to the Coriolis forces this will induce on the crew in addition to simulated gravity. However, as has been pointed by Dr.Claes-Gustaf Nordquist, M.D.(Private Communication), the human body and nervous system is very adaptable and the crew will quickly develop “sea” legs to adjust to this rotating environment. Such a prediction could be easily tested in LEO with a special space station module or even part of the Mars mission crew quarters. Following Doctor Nordquist’s prescription, crew quarters should be toroidal and stretched around the ship to minimize spin for .4 g, and sectioned into small rooms to minimize rapid movement. These provisions will minimize Coriolis effects, aiding adaptation. We will also endeavor to keep crew busy during ten months by turning part of their water tank into living quarters.

We use aero-capture – aero-brake at Mars and assume a desired orbit. Mars decent for the three person Apollo capsule is accomplished by heat shield, parachute and landing rockets. The robot tractor comes out to pick up the crew and their capsule for transport to the habitat. The capsule will be added to the habitat to enlarge it. The tractor will be used to expand and construct new living quarters by entrenching and covering constructed tubular sections.

Mars surface activities will consist of enlarging the habitat with partially buried structures, and exploring for and exploiting water resources. Both of these activities will be the beginning of the Mars colony. Harvested water can be used directly on later missions for propellant and hydrogen production. It is believed at this time that Mars water use on initial missions is probably not advisable unless those resources are very well characterized. Finally, the crew must to prepare for departure, and board the MAV rocket by a rope ladder.

MLO final operations

Mars orbit will not only lift the crew from Mars but also bring up 10 MT of water for a departure burn to get out of Mars gravity well. The trade-off involved is the desirability of lowering the amount of time spent spiraling out from Mars gravity as well as the desirability of minimizing the amount of mass lifted from the Mars surface with the crew. In one limit, the crew and large mass of water go up to MLO and rendezvous with the MITV for the trip home. The water is used to reach Mars escape and Earth orbit transfer injection. In the other limit, the MITV stays in high Mars orbit and the MAV lifts the crew and a small amount of water to fuel the return home. This requires a larger launch from Mars surface, however, which is more difficult and certainly more dangerous. For the initial mission, then, we will go for MOR in MLO to minimize MAV launch mass. It is also possible that the initial return trip water will be lifted up into Mars orbit by a previous Mars precursor mission to demonstrate Mars fuel production and launch from its surface.

Once MOR is achieved the MITV spirals out of MLO; this will take approximately two months. Then, the Earth transfer orbit burn is then initiated. This mission plan is time consuming, but it is simple, and for an initial mission simplicity is desirable. The ten month cruise to Earth is then done. There will then be an aero-capture at Earth and a stay on the ISS for debrief and quarantine.

III SUMMARY

Mars X builds on the genius of Mars Direct and applies many other tricks, including using R&D strategically, to reduce costs. It must be remembered that R&D is expensive, and so it must not be used to reinvent capabilities that have already been demonstrated.

Accordingly, Mars X relies primarily on vehicles that either exist or once did. Even the MAV is simply a modified version of the Atlas V. The only truly new vehicle is the SAMET-propelled MTOIV, which consists of a ring-shaped, space station-derived crew habitat, a propulsion unit consisting of modular solar panels derived from the space station, and a cluster of twenty MET modules which have low technical risk and use present day technologies. Thus technical risk and R&D is concentrated on the crew habitat on Mars, which should be made as similar to the crew habitat of the ship as possible and in the MAV and its in-situ fuel plant, which by themselves are straightforward applications of presently understood technologies. The small nuclear reactor, necessary for the whole enterprise, is similar to demonstrated small nuclear power plants used by the US army in the Cold War for portable arctic bases. Given the low technical risk of this enterprise, it appears reasonable that it could be done in ten years for $20 billion.

Mars X is flexible; the rapid development and public acceptance of space nuclear power can be incorporated in the architecture to speed Mars X. It is suggested that a nuclear-electric propulsion fly-by mission to Pluto, since it would be robotic and one-way, would help build public confidence in such propulsion technology.

The use of electric propulsion produces dramatic reduction of mass in LEO. The use of water fuel reduces launch costs by allowing many small cheap launches to bring up fuel and accumulating it. The use of kerosene at Mars for MAV fuel allows utilization of legacy systems for Mars ascent vehicles. Cost can be reduced in a ten year program to under $20 billion and allow a rapidly mounted mission.

REFERENCES

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FIGURES

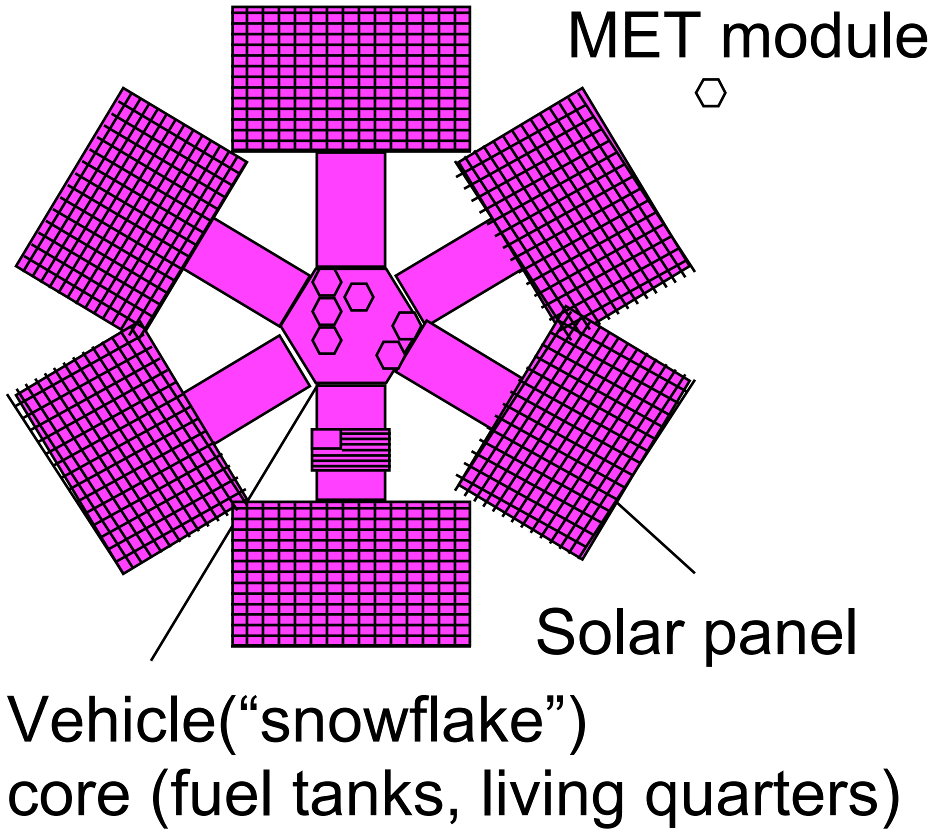

Figure 1. SAMET interplanetary propulsion stage. Solar panels can be derived from those used on the ISS and are much longer than shown here.

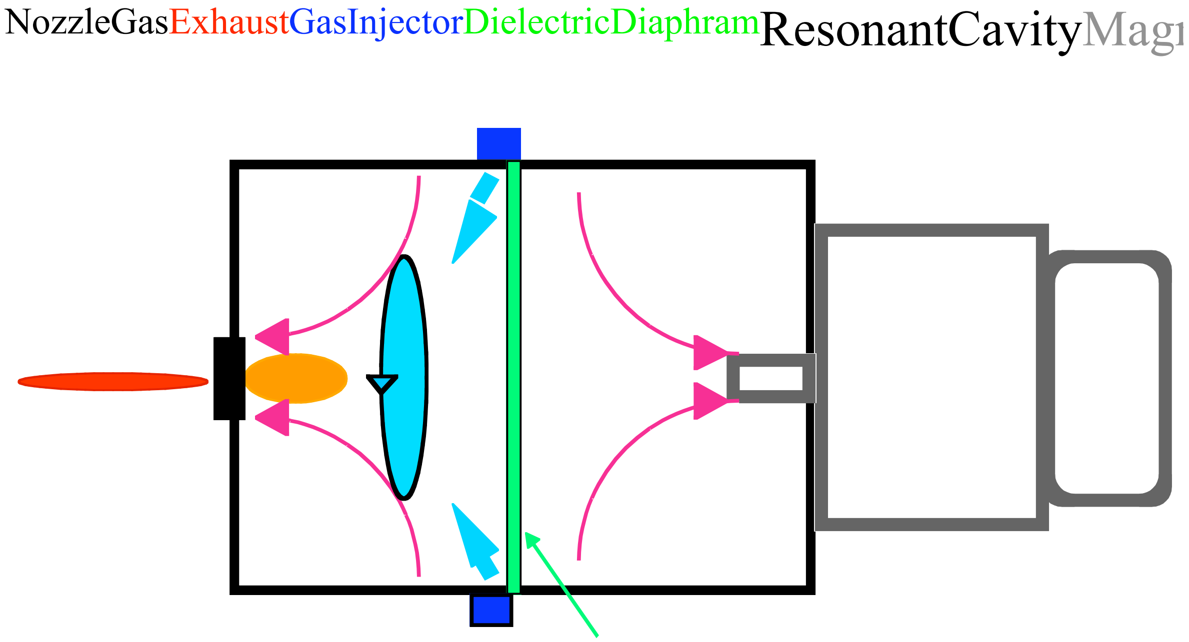

Figure 2. MET thruster diagram.

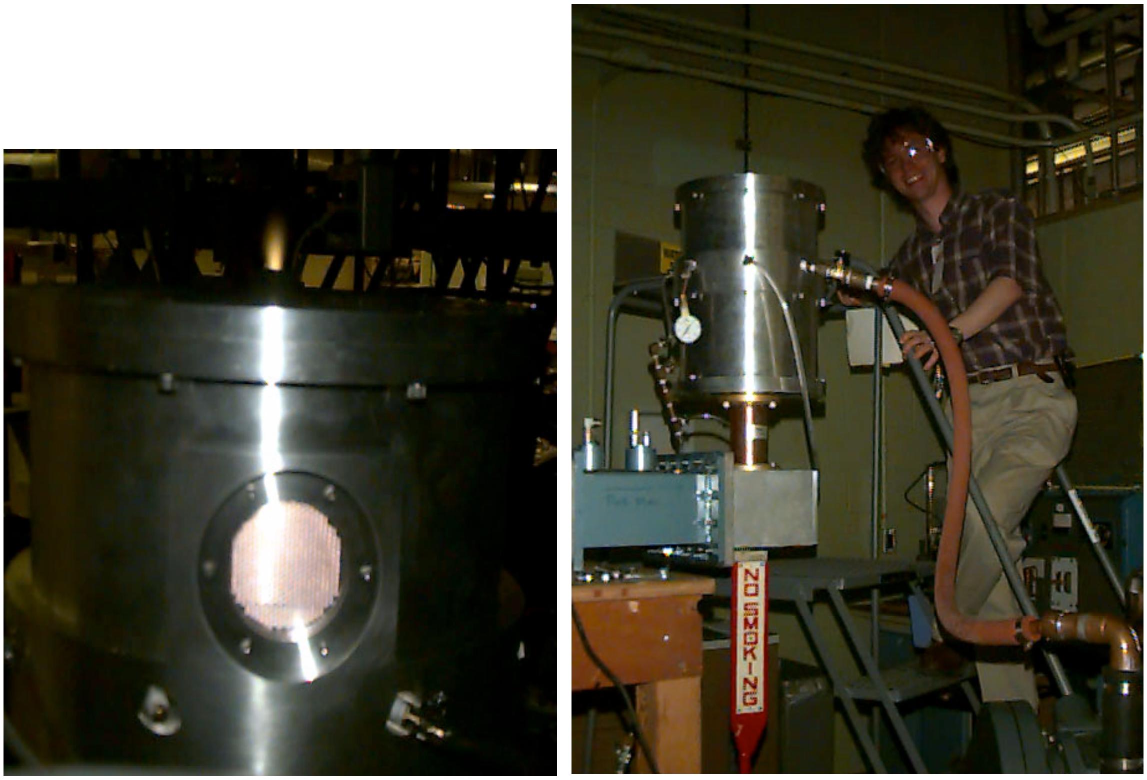

Figure 3. The 50kW, 915MHz MET thruster being run using air propellant. Second image shows its size relative to human being.