NASA's First Nuclear-Thermal Mars Expedition Study (1960)

- By David S. F. Portree
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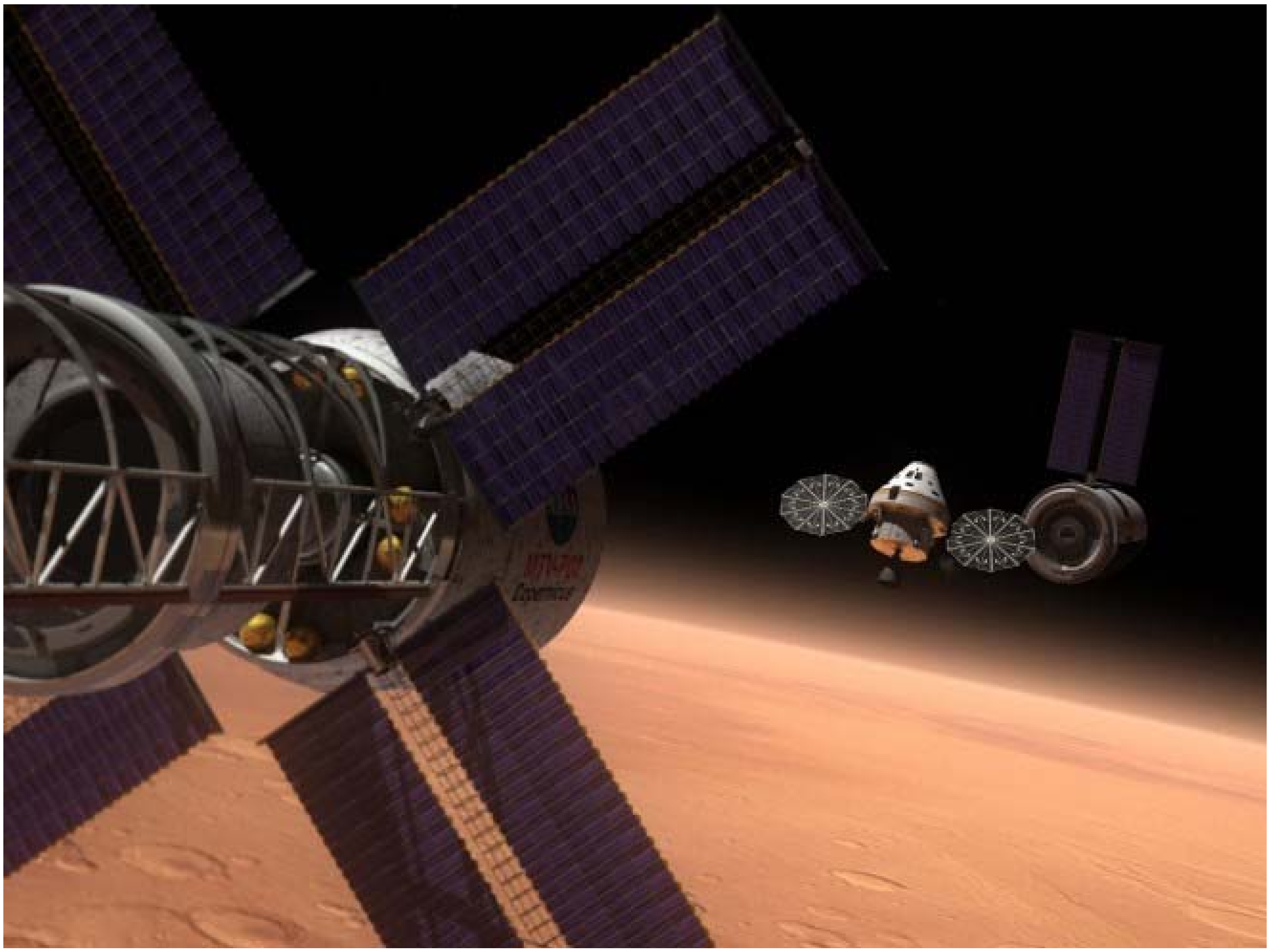
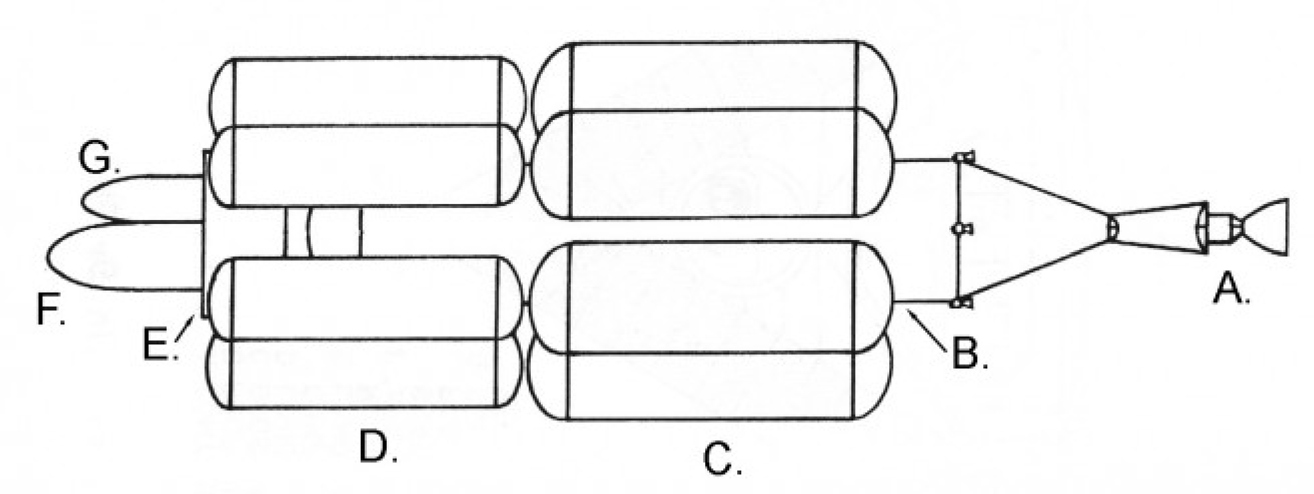


Scene from NASA's most recent nuclear-thermal propulsion piloted Mars mission plan (2007). Image: NASA

As early as November 1957 – the same month the Soviet Union launched the dog Laika into Earth orbit on board Earth's second artificial satellite, the 508-kilogram Sputnik 2 – about 20 engineers at Lewis Research Center, a National Advisory Committee on Aeronautics laboratory in Cleveland, Ohio, commenced research into nuclear-thermal, chemical, and electric (ion) rocket propulsion for interplanetary flight and other applications. When NASA opened its doors on 1 October 1958, Lewis became a NASA center. In April 1959, the Lewis researchers testified to Congress about their work and solicited funding for a focused Mars expedition study. Congress agreed to support the study – the first piloted nuclear-propulsion Mars expedition study ever performed by a U.S. government agency, and one of the first detailed Mars expedition studies ever.

For their analysis, which formally concluded in October 1960, the Lewis researchers assumed a Mars mission profile that would, by the end of 1960s, come to be seen as wholly conventional. In a January 1961 paper that summed up their study, they wrote that the mission would begin with the Mars spacecraft in orbit about the Earth. The seven-man spacecraft would either be launched from Earth's surface as a single unit by an enormous rocket or launched in parts by smaller rockets and assembled in orbit. Following checkout, a high-thrust nuclear-thermal rocket engine would launch the spacecraft from Earth orbit onto a transfer trajectory to Mars.



General layout of NASA Lewis Research Center's piloted Mars spacecraft. A. nuclear-thermal rocket engine; B. central propellant tank; C. aft propellant tank cluster; D. forward propellant tank cluster; E. crew compartment; F. Mars Landing Vehicle; G. Earth Landing Vehicle. Image: NASA

Upon arrival at Mars, the nuclear-thermal rocket engine would decelerate the spacecraft so that the planet's gravity could capture it into orbit. While the crew waited for the launch window for the flight back to Earth to open, astronauts would descend to Mars's ochre surface in a Mars Landing Vehicle using chemical propulsion. After a period of surface exploration, they would lift off and rendezvous with the orbiting spacecraft, which would then use its nuclear-thermal rocket to accelerate onto an Earth-return trajectory. Upon reaching Earth, an Earth Landing Vehicle would separate and decelerate in the atmosphere to return the crew to the Earth's surface. The abandoned Mars spacecraft and its nuclear-thermal rocket would, meanwhile, swing past Earth and enter a safe disposal orbit about the Sun.

The Lewis researchers focused on how three interrelated factors affect spacecraft mass at Earth-orbit departure. These factors were: mission duration; aerobraking; and acceptable levels of crew radiation exposure.

As might be expected, fast Mars trips using a nuclear-thermal rocket would generally require more propellant (liquid hydrogen, in the Lewis team's plan) than slow trips, while the crew would require more supplies (mainly air, water, and food) for slow trips than for fast trips. The LeRC researchers opted for a 420-day round trip with a 40-day "wait period" at Mars. For analysis purposes they targeted a 1971 launch, but they cautioned that this was "not meant to imply that actual trips [were] contemplated for this period." They assumed departure from a 300-mile-high Earth orbit.

They found that the optimum launch date would be 19 May 1971, when Earth-to-Mars transfer would require a total propulsive velocity change (delta V, in spaceflight parlance) of 12.29 miles per second if the nuclear-thermal rocket engine performed all acceleration and deceleration. Delta V would be supplied by heating propellant in a nuclear reactor and expelling it from a rocket nozzle; thus, the greater the delta V, the more propellant would be needed. For comparison, a 300-day mission would need a delta V of 16.5 miles per second and a 950-day mission would need only 7.7 miles per second.

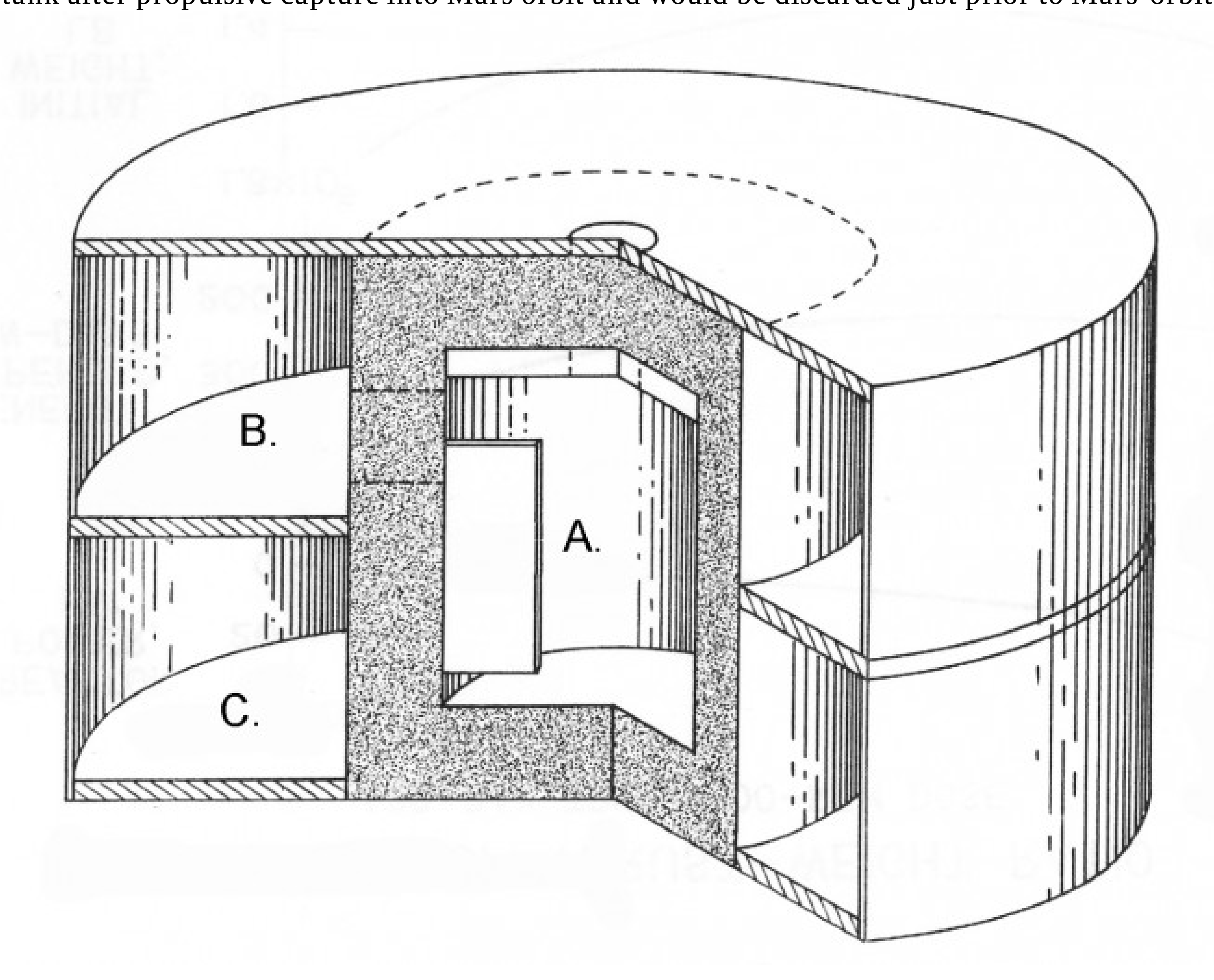
The authors determined that aerobraking, or using atmospheric drag at Earth and/or Mars to slow the spacecraft, showed great promise for reducing required delta V (and thus required propellant mass). In theory, if the spacecraft employed aerobraking to enter Mars orbit and again to slow down and land on Earth, the nuclear-thermal rocket might need to supply only half as much delta V as would be necessary if the expedition used only rocket propulsion.

This assumed, however, that the aerobraking heat shield that would be required to protect the spacecraft from atmospheric entry heating would have no mass. In practice, aerobraking at Mars was made problematic by the need to aerobrake the liquid hydrogen propellant required for the flight from Mars back to Earth. Liquid hydrogen, the Lewis researchers noted, is "tenuous" – that is, of low density – so large tanks would be needed to contain the required quantities. A heat shield large enough to protect the tanks would thus be massive, reducing aerobraking mass savings at Mars from 25% to only 3%.

Because of this, the Lewis researchers opted for Earth aerobraking only. Their 15-ton, 22-foot-wide lifting-body Earth Landing Vehicle would include a heat shield that would ablate – that is, char and erode, carrying away atmosphere-entry heat. (Vostok, Mercury, Voskhod, Gemini, and Apollo spacecraft used ablative heatshields; Soyuz and Shenzhou spacecraft still use them today.) The heat shield would lose less than 10% of its mass during aerobraking and the seven-person expedition crew would experience up to eight Earth gravities of deceleration. The authors found that the Earth Landing Vehicle heat shield would have only one-sixth the mass of the propellant needed for propulsive braking at Earth.

In considering the effects of radiation on Mars spacecraft mass, the Lewis team cautioned that "knowledge of radiation hazards is still not completely satisfactory." They assumed the existence of the following ionizing radiation sources: Van Allen Belts at Earth and Mars (in reality, Mars lacks radiation belts), cosmic rays, solar flares, and the spacecraft's own nuclear-thermal rocket engine.

Hydrogen propellant would propel the 222-foot-long Lewis Mars ship, but also would serve as radiation shielding. When the nuclear-thermal rocket engine began to operate in Earth orbit, it would draw hydrogen from a tank complex comprising two six-tank clusters arrayed around a long central tank. Liquid hydrogen would flow from the central tank into the engine. The tank clusters would refill the central tank as it emptied to ensure that a large mass of liquid hydrogen would stand between the nuclear-thermal rocket engine and the crew compartment at the front of the spacecraft. After Earth-orbit departure, the empty tanks in the aft cluster would top off the central tank, then be jettisoned. The forward cluster tanks would refill the central tank after propulsive capture into Mars orbit and would be discarded just prior to Mars-orbit departure.



Cutaway showing general layout of NASA Lewis Research Center's piloted Mars spacecraft crew compartment. A. vault shielded against radiation (doubles as crew sleeping quarters); B. living quarters deck; C. storage deck. Image: NASA

The crew compartment – a lightly shielded two-deck drum with a total volume of 4200 cubic feet and 50 square feet of floor space per crewmember ("between that provided for chief petty officers and commissioned officers on submarines," the Lewis team explained) – would contain a heavily shielded cylindrical "vault" with a volume of 615 cubic feet at its center. Minus the vault, the 15-foot-high, 29-foot-diameter crew compartment would have a mass of only 15 tons. The seven crewmembers would retreat into the vault during Van Allen Belt passages, nuclear-thermal rocket engine operation, and large solar flares. They would also sleep in the vault to minimize their cosmic ray exposure. The Lewis researchers suggested that the 15 tons of supplies needed for the 420-day Mars expedition should be packed around the vault to serve as extra shielding.

Not surprisingly, the total mass of the "carbon shielding" required for the vault would depend on the allowed crew radiation exposure. If major solar flares could be avoided and a total radiation dose of 100 Roentgen Equivalent Man (REM) were permissible, then 23.5 tons of shielding would suffice. If, on the other hand, one major flare was assumed and 100 REM remained the dose limit, then the mass of the shielding required around the vault would jump to 82 tons. If 50 REM were the limit and one major flare was assumed, then shielding mass would become "enormous" – 140 tons. "These data," the Lewis team reported, underscored "the importance of determining more precisely the nature and virulence of the radiation in space."

The Lewis researchers determined that, based on their assumptions, "short trips [would be] as, or more, economical, in terms of weight, than long-duration [Mars] missions," even if they would generally require more propellant, because long trips would require more shielding to keep the crew within the radiation dose limit. They estimated that a 420-day round trip with a maximum allowable total radiation dose of 100 REM would yield a total Mars spacecraft mass of 675 tons at Earth-orbit launch in the 1971 Earth-Mars transfer opportunity.

Reference:

"A Study of Manned Nuclear-Rocket Missions to Mars," IAS Paper No. 61-49, S. C. Himmel, J. F. Dugan, R. W. Luidens, and R. J. Weber; paper presented at the 29th Annual Meeting of the Institute of Aerospace Sciences in New York City, 23-25 January 1961.

I research and write about the history of space exploration and space technology with an emphasis on missions and programs planned but not flown (that is, the vast majority of them). Views expressed are my own.

Read more by David S. F. Portree

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