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by John C. Evvard
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Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at Conference on Non-Chemical Propulsion sponsored by the American Institute of Aeronautics and Astronautics and Catholic University of America
Washington, D. C., January 12, 1967

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The decision to develop an advanced propulsion system for flight use must depend upon at least three factors:

1. The advanced system must be technically feasible.

2. The advanced system must have combinations of actual or feasible useful missions which will justify or serve as a rationalization for the development costs.

3. The advanced system must be more promising for its intended uses than competitive or available systems.

Each of these requirements must be satisfied. Clearly, the most common space propulsion system to be competitively replaced is the chemical rocket. The chemical rocket itself replaced the airbreathing ramjet vehicle (Fig. 1) because it could perform more simply a 5,000 mile mission carrying the same payload and with about the same accuracy as the Navaho. The heavy Navaho required a big chemical rocket booster to achieve cruising speed and as pictured in Figure 1, the Navaho and its booster were actually taller and more complicated than the Atlas. If you eliminate the Navaho structural weight, a somewhat enlarged booster, the Atlas, will do the same job.

The chemical rocket is a tough competitor to beat. For one thing, the development and the launching complex have largely already been paid for. Any new system that would compete with the chemical rocket must then represent an additional drain from the taxpayer's pocketbook that might not be required if the chemical rocket itself is utilized. The sophistication, the reliability, and the flight worthiness experienced by the chemical rocket lend confidence to the planner that his mission will succeed. Any competitive new system must establish this confidence. Furthermore, as is illustrated on Figure 2, the chemical rocket might be considered for missions that were once beyond its capability. For example, the Earth-orbital weight required for a seven-man Mars stopover round trip in 1980 can be reduced by a factor of 9 by using elliptic rather than circular parking orbits, by using atmospheric rather than propulsive braking at Mars, and by utilizing a Venus flyby on the outbound leg.

Clearly, the nuclear rocket can do each of these mission profiles better. But the question must be asked as to whether the margin of superiority for the nuclear rocket is sufficient to justify the intensive man-rated nuclear-rocket development program that would be required for the first manned Mars landing. My guess is that the availability of man-rated chemical rockets will weigh heavy in this decision.

Nevertheless, sizeable funds have already been spent on nuclear heat transfer rockets with some relatively successful demonstrations. I think we can safely assume that nuclear rockets will some day be man-rated for interplanetary flights. We are clearly going to need the increased performance capabilities that nuclear rockets offer.

Gas core nuclear rockets cannot presently command this confidence, and funding for gas core rockets must be kept within research support levels. There are several possible difficulties; (1) If the gas core reactor is heavy - of order 250,000 to 500,000 lbs. - then several million pounds of equipment in Earth orbit including fuel would be required before gas cores would break even with conventional nuclear rockets. The increased reactor weight would have to be compensated by the savings in fuel; (2) If the gas core reactor, through ingenious design, could have a weight comparable to conventional nuclear rockets - say of order 100,000 pounds - there is still a difficulty. The gas core reactor deposits fissioning products in the exhaust stream. Preliminary calculations suggest that the radiation from the exhaust plume may be of serious concern - of order 25 rem/hr at the crew compartment.

In spite of these difficulties, the performance improvements of the gaseous core over conventional nuclear rockets would be well worth seeking if the nation planned many manned interplanetary spaceflights per year. Such a possibility would exist if either Mars or Venus could be colonized. Without colonization, the manned flight frequency might be of order one or two per year or less. Correspondingly, the need to develop a gas core rocket under such circumstances would greatly diminish. We should therefore consider the probability of planetary colonization.

Mars has a surface atmospheric pressure less than 10 millibars with very little water or oxygen content. Its surface has been and is being bombarded by meteoroids and asteroids. During intense solar flares, a Martian dweller would have to take cover or accept a strong radiation dose. The erosion processes associated with wind and water are essentially minimal on Mars so there would likely be little top soil. The environment for colonization is quite hostile, resembling the Moon except its location is further from both the Earth and the Sun. Manned expeditions to Mars in this century will not likely be motivated by desire for colonization.

To my way of thinking, Venus is much more interesting but colonization might also be unfeasible due to high surface temperatures, unsuitable atmospheric composition, or other reasons. One therefore concludes that the contemplated manned planetary missions will not require heavy gas core reactors. If gas cores can be built light enough to replace nuclear heat transfer rockets - fine. Otherwise, they will not likely leave the research phase.

These arguments do not apply to electric propulsion. Electric propulsion is unique in several respects. (1) Light-weight electric powerplants will surely be needed for near-Earth satellite activities. Hence the decision for development is largely a matter of timing. (2) Electric propulsion might provide a capability beyond what other systems can do. If flight to the edge of the solar system were contemplated, electric propulsion would surely be the leading contender. (3) Most space flights require on-board power systems so electric propulsion can serve a dual function. (4) Hybrid systems using electric propulsion show distinct payload advantage over other systems. I will illustrate this latter point with figures 3 and 4.

On Figure 3, the payload mass fraction is plotted against electric propulsion system specific weight. The lower horizontal line represents the all nuclear case. The solid line is all electric propulsion for this Mars round trip. There is a sizeable gain in payload mass fraction for the combined nuclear and electric hybrid, suggesting also that perhaps relatively heavier specific powerplant weights can be tolerated.

Figure 4 shows the useful payload that can be achieved with a chemical rocket - electric propulsion hybrid system on a solar probe mission. About 2300 pounds of payload can be carried to .1AU (astronomical unit) from the Sun. For this study, a powerplant specific weight of 100 lbs/kw was assumed and orbit was achieved by means of a Saturn IB rocket. Because of the limited lifting capability of the Saturn IB, both the all-chemical and the all-nuclear systems have negative payload capability.

The value of 100 lb/kw might be achieved with solar cells. The Boeing studies suggest that an oriented solar panel can be built weighing no more than 50 lb/kw. This leaves a margin of 50 lbs/kw for the power conditioning and thrustor equipment. This figure is only one of many illustrating the use of solar-powered electric propulsion for space science missions.

In this discussion, I have purposely said very little about the nuclear heat transfer rocket. I suggest that we hear from Carl Schwenk at this time who will express his views on this important system.

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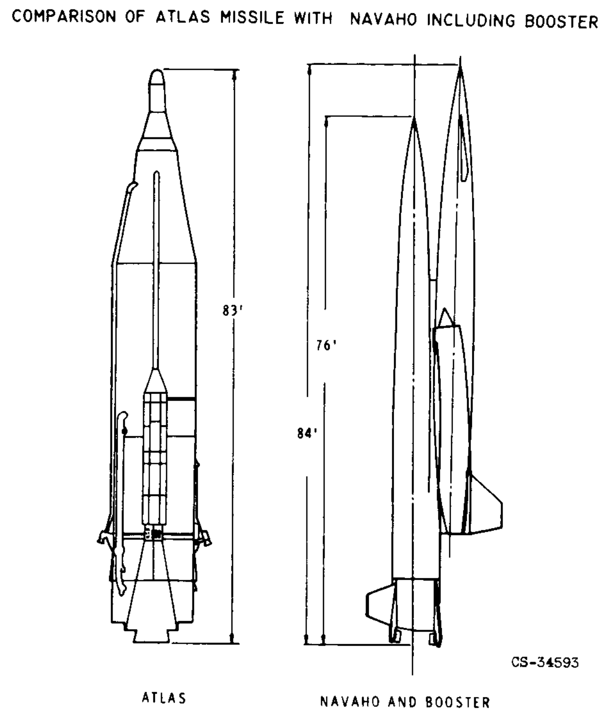

Figure 1.

SEVEN-MAN MARS STOPOVER ROUND TRIPS IN 1980

MISSION PROFILE	TRAJECTORY	TOTAL TRIP TIME, DAYS	ATMO-SPHERIC ENTRY VELOCITY AT EARTH RETURN, FT/SEC	MARS PARKING ORBIT	VELOCITY FOR SPACESHIP AT MARS	SPACE VEHICLE PROPULSION: CHEMICAL (I = 460 SEC)	SPACE VEHICLE PROPULSION: NUCLEAR (I = 840 SEC)
						RELATIVE WEIGHT IN EARTH ORBIT	
A	CONVENTIONAL[a]	500	37,000	LOW CIRCULAR	PROPULSIVE DECELERATION TO ORBITAL SPEED	1.00	0.34
B	CONVENTIONAL[b]	500	52,000	LOW CIRCULAR		0.40	0.16
C	CONVENTIONAL[b]	500	52,000	ELLIPTIC		0.22	0.11
D	CONVENTIONAL[b]	430	52,000	ELLIPTIC	37,000 FT/SEC ATMOSPHERIC ENTRY SPEED	0.18	0.10
E	VENUS FLYBY[b] ON OUTBOUND LEG	550	37,000	ELLIPTIC		0.11	0.07

[a]SOLID INERT SPACE RADIATION SHIELDING USED.

[b]ON-BOARD PROPELLANTS FOR SPACE RADIATION SHIELDING USED.

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Figure 2.

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EFFECT OF COMBINED ROCKET ON ALLOWED POWERPLANT SPECIFIC WEIGHT

MARS ROUND TRIP; APPROACH SPEED AT EARTH, 37,000 FT/SEC

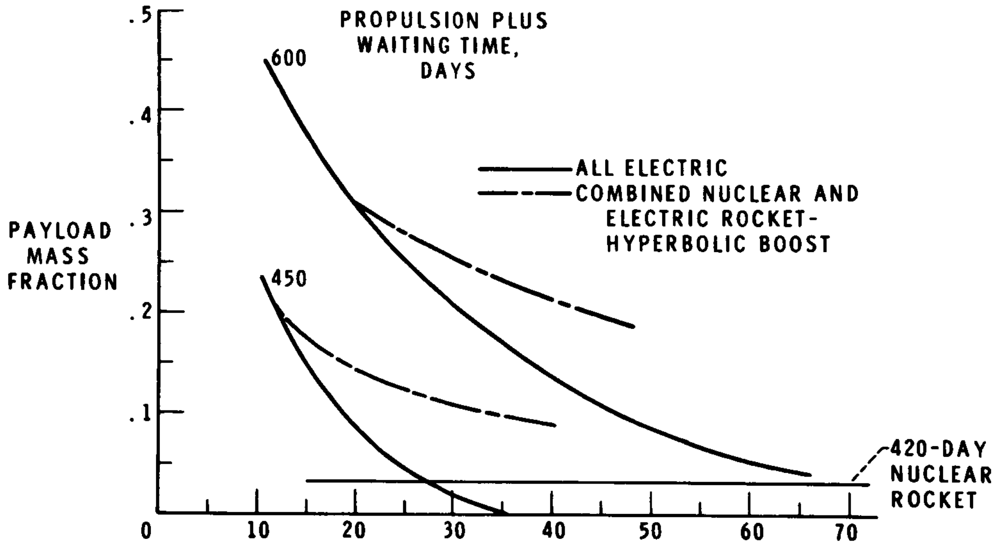

Figure 3.

SYSTEM PERFORMANCE FOR 0.1 AU SOLAR PROBE MISSION

SATURN IB BOOSTER α = 100 LB/KW

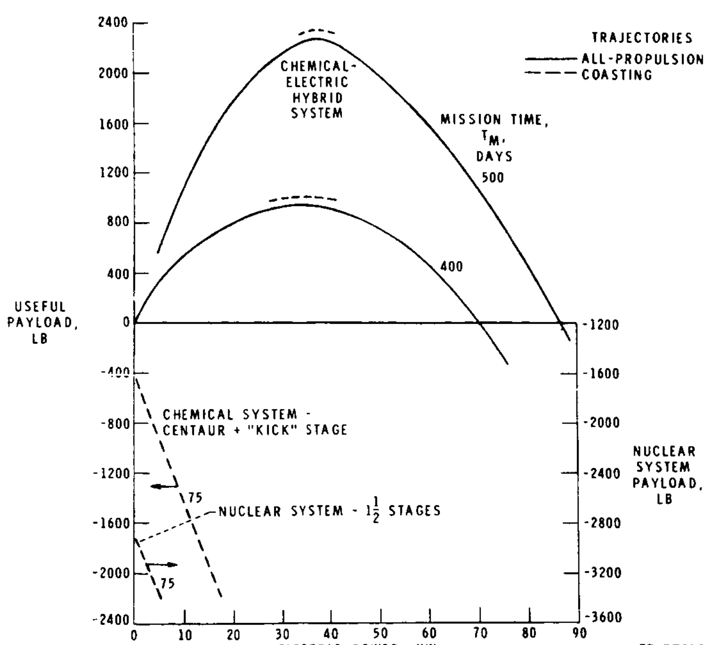

Figure 4.