Performance Potential of Gas-Core and Fusion Rockets: A Mission Applications Survey

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Theme

THIS paper reports an evaluation of the performance potential of five nuclear rocket engines for four mission classes. These engines are the regeneratively cooled gas-core nuclear rocket, the light-bulb gas-core nuclear rocket, the space-radiator-cooled gas-core nuclear rocket, the fusion rocket, and an advanced solid-core nuclear rocket which is included for comparison. The missions considered are Earth-to-orbit launch, near-Earth space missions, close interplanetary missions, and distant interplanetary missions.

Contents

Included in the study are 1) an advanced solid-core nuclear rocket (SCNR), 930 sec I_{sp}, thrust-to-engine mass ratio (F/M) of 100 N/kg; 2) regeneratively cooled gas-core nuclear rockets (REGEN.GCNR), 1000–2000 sec I_{sp}, F/M of 14–25 N/kg; 3) light bulb gas-core nuclear rockets (LBGCNR), 1700 to 2650 sec I_{sp}, F/M of 10–20 N/kg; 4) space-radiator-cooled gas-core nuclear rockets (SRGCNR), 2600 to 6500 sec I_{sp}, F/M of 1–3 N/kg; and 5) fusion rockets (FUSION), up to 200,000 sec I_{sp}, power-to-engine mass ratio (P/M, or $1/\alpha$) of 1 kW/kg.

The first mission considered is the Earth-to-orbit launch. For this mission, the high specific impulse and the thrust-to-mass ratio of 10–20 N/kg of the LBGCNR make it more attractive than the other candidates. A relatively minor weight growth, however, would greatly degrade its performance. Moreover, it is debatable whether any nuclear rocket would be allowed to operate within Earth's atmosphere.

Several near-Earth space missions are studied next. In the Lunar Ferry mission, the reusable nuclear rocket stage, which is initially in a parking orbit about Earth, follows a minimum energy transfer trajectory to deliver various amounts of payload into a lunar orbit. The vehicle then returns with a 50,000-kg payload (crew, command module, etc.) to Earth and into the original parking orbit. The performance of four of the nuclear rocket concepts is shown in Fig. 1, with the SRGCNR showing significantly lower initial mass in Earth orbit (IMEO) than the other three.

The second near-Earth mission studied is the "slingshot," essentially an advanced version of the "space tug." The vehicle is initially in an Earth parking orbit, then boosts out of orbit to a given hyperbolic excess velocity V_∞ and separates, with a 500,000-kg payload continuing along the initial path. The nuclear rocket then retrofires, returning to low Earth orbit where an additional impulse places the vehicle with a 50,000-kg payload back into a circular parking orbit. The same four engines are studied with results shown in Fig. 2; the SRGCNR again shows the best performance.

Manned round trips to Mars are studied next. For "fast" missions, the vehicle is assumed to start in a 600-km circular Earth parking orbit, proceed to Mars, enter a 0.9 eccentricity parking orbit with periapsis at 1.1 planet radii, and then return to Earth with a 50,000-kg payload (command module, crew, etc.) plus a re-entry vehicle; no mass is jettisoned at Mars. The re-entry vehicle employs atmospheric braking with no limit on entry velocity (actual velocities turn out to be between 2 and 3 times the circular velocity in Earth orbit). This is called a "courier" mission for which, as shown in Fig. 3, the three gas-core nuclear rockets are reasonable candidates. Mission durations between 60 and 200 days are considered, with the SRGCNR accomplishing the 80-day trip for a surprisingly low IMEO of 1 million kg.

Conventional trips to Mars are of longer duration. These "Science/Exploration" missions start in low Earth orbit and proceed to a 0.9 eccentricity parking orbit at Mars, where they remain for 40 days. A payload of 150,000 kg is left which might have been used for landing, building an orbiting

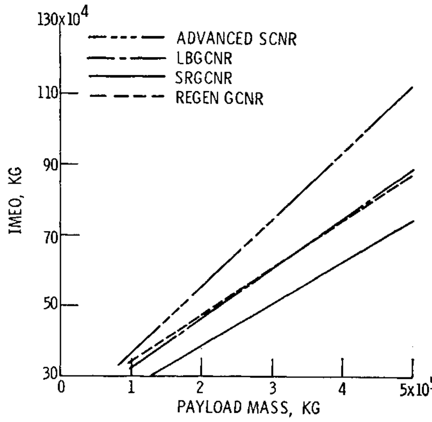

Fig. 1 Effect of payload mass on lunar ferry mission.

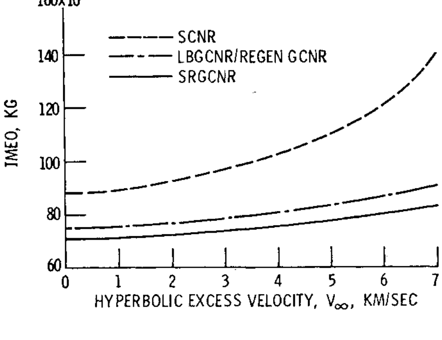

Fig. 2 Slingshot mission to various hyperbolic excess velocities.

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Index categories: Manned Lunar and Interplanetary Systems; Spacecraft Mission Studies and Economics; Nuclear Propulsion.

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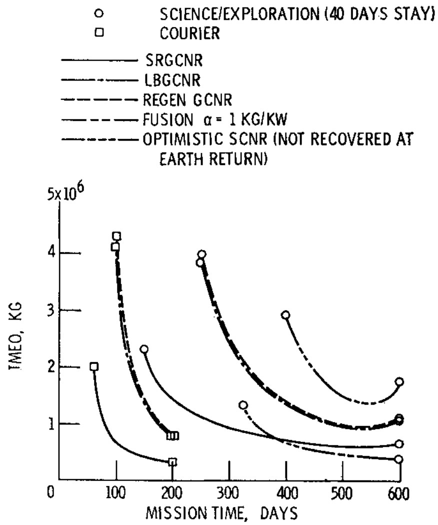

Fig. 3 Effect of Mars round-trip mission time, for various nuclear rocket engines.

observatory, etc. The vehicle then returns to Earth with a payload of 100,000 kg.

The results of the study are also shown in Fig. 3. Even with an easier mission profile (atmospheric entry at Earth return), the SCNR still requires the highest IMEO. The LBGCNR and REGEN.GCNR again yield almost identical results, the 500-day mission requiring about 1 million kg IMEO. The mission can be reduced to 1 yr by increasing IMEO to about 1.6 million kg.

The SRGCNR appears to offer significant savings in terms of IMEO or trip time, requiring only 60% as much IMEO as the LBGCNR at 500 days, or only 55% as much trip time for a 1 million kg IMEO. The fusion rocket appears promising at long trip times, where it excels the other engines.

The last class of missions studied is trips to the major planets Jupiter, Saturn, and Uranus. Feasible trips for relatively high-thrust rockets occur only at discrete intervals of 12–14 months. Thus, for all but the fusion rocket, missions exist only at the specific data points shown in Fig. 4; these have been connected with straight lines to identify the rocket type and indicate trends. Two mission modes are again considered: Courier (no payload to planet, 50,000 kg back to

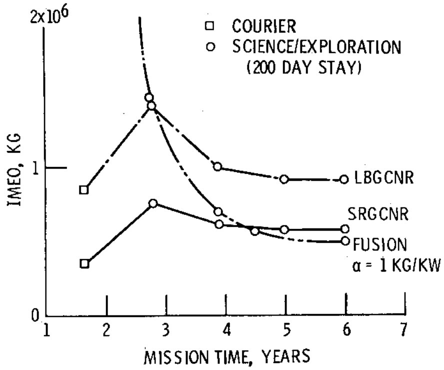

Fig. 4 Effect of Jupiter round-trip mission time.

Earth and atmospheric re-entry) and Science/Exploration (150,000 kg to planet, 100,000 kg to Earth, 200-day stay time in 0.9 eccentricity parking orbit with periapsis at 1.1 planet radii, and recovery into low Earth orbit).

The Courier mode requires 1.67 yr to Jupiter and an IMEO of 350,000 kg for the SRGCNR and 840,000 kg for the LBGCNR. The fusion rocket, shown by the long-short-short dashed curve, gives continuous performance but cannot perform the 1.67-yr trip.

The next opportunity for high-thrust rockets occurs at 2.8 yr. The IMEO increases over that at 1.67 yr as a result of switching from Courier to Science/Exploration-type trips. At this trip time, fusion and LBGCNR IMEO's are at about 1.4 million kg while the SRGCNR requires 750,000 kg or about 54% as much.

In conclusion, all of the advanced concepts examined promise appreciably better performance than the solid-core engine. Selection of a preferred concept must await continued work to establish feasiblity and better define engine performance and cost characteristics.

Among the five nuclear rockets studied here, the space-radiator-cooled gas-core rocket appears to always require the least IMEO for the missions studied if excessive trip times are ruled out. Based on this engine, a significant class of fast Mars missions has been suggested where a 1 million kg IMEO vehicle can accomplish a manned round trip in as little as 80 days. Ecological restrictions may make the light-bulb gas-core nuclear rocket a more logical choice for the near-Earth missions since it does not emit radioactive wastes.