AIAA 81-0676R

Free Radical Propulsion Concept

C.E. Hawkins*
Northern Kentucky University, Highland Heights, Kentucky
and
S. Nakanishi†
NASA Lewis Research Center, Cleveland, Ohio

Abstract

A NEW propulsion concept which may have particular usefulness for transfer of loads from low Earth orbit (LEO) to geosynchronous Earth orbit (GEO) is presented. Electrical energy in the form of microwaves is used to heat a propellant gas, thus providing thrust. An outline of the concept and experimental results in support of it are presented.

Contents

A variety of possible future space missions involve the transfer of substantial masses from LEO to GEO.[1] A crucial factor in propulsion systems designed to meet this need is the ratio of total mass required in LEO to payload mass in GEO, due to the fact that Earth-to-orbit cost is a major fraction of total cost.

Systems presently considered for such missions include chemical systems and electrostatic ion propulsion systems. Figure 1 presents payload mass ratio as a function of specific impulse for these systems. Chemical systems provide short trip times at the expense of mass ratios of 3 or greater. Electrostatic ion propulsion systems can achieve mass ratios of 1.25-2.5, but require trip times of 50 days or longer. There is an intermediate range of specific impulse not accessible to present systems which would allow moderate trip times while maintaining mass ratios similar to those of electrostatic systems. The free radical propulsion concept presented here may prove capable of operating in that regime.

The concept is illustrated schematically in Fig. 2. Electric power from solar panels is used to operate a microwave generator, and microwave energy is coupled to a propellant gas by means of a resonant cavity. The gas is ionized partially by the microwave fields, and inelastic collisions of gas molecules with the resultant electrons serve to dissociate the gas. The gas is allowed to recombine downstream, with the recombination energy heating the gas. The hot gas is expanded through a nozzle to produce thrust. Molecular hydrogen, with a theoretical specific impulse of 2100 s (100% conversion), is the most attractive propellant. Sample calculations on a hydrogen thruster for a thrust of 1 N and a specific impulse of 1500 s yield the following results: mass flow rate, 6.8×10^{-5} kg/s; minimum input power, 7.3 kW; minimum flow area (nozzle throat), 4×10^{-2} to 4×10^{-4} m^2 for pressures of 13.3 to 1330 N/m^2, respectively; and thrust densities of the order of 100 N/m^2. Attractive features of the free radical propulsion concept in comparison to electrostatic ion propulsion or similar systems are increased thrust, thrust density, and thrust-to-power ratio.

Presented as Paper 81-0676 at the AIAA/JSASS/DGLR 15th International Electric Propulsion Conference, Las Vegas, Nev., April 21-23, 1981; submitted July 30, 1981; Synoptic received Feb. 25, 1982. Full paper available from AIAA Library. 555 West 57th Street, New York, N.Y. 10019. Price: Microfiche, $4.00; hard copy, $8.00. **Remittance must accompany order.**

*Associate Professor of Physics.
†Aerospace Research Engineer, Space Propulsion Division.

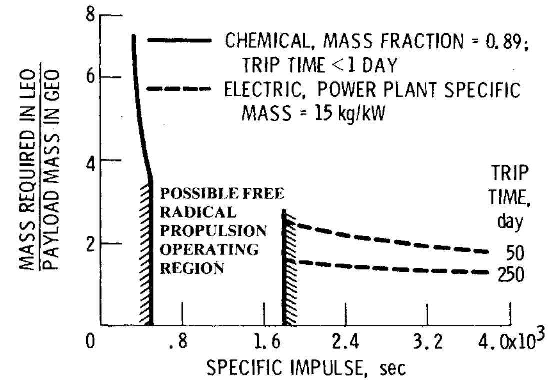

Fig. 1 Mass ratio of various LEO to GEO propulsion systems.

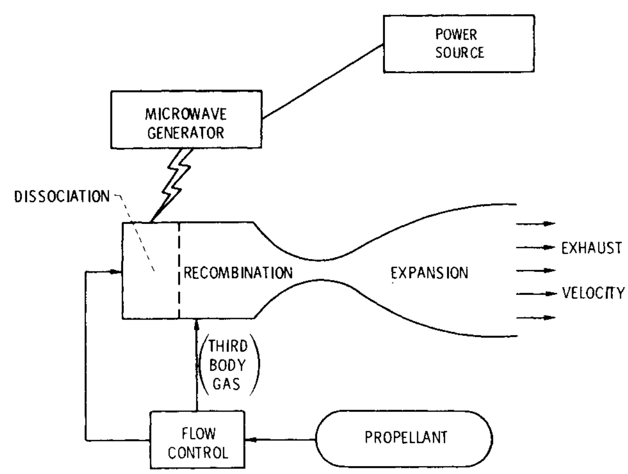

Fig. 2 Free radical propulsion concept.

Experimental Results

A variety of experiments have demonstrated that molecular gases can be dissociated by microwave systems.[2,3] A series of experiments has been undertaken at NASA Lewis Research Center to verify the earlier work and to assess the feasibility of the concept. A discharge was produced in a quartz flow tube inserted concentrically into a cylindrical microwave cavity. The quartz tube was a converging-diverging venturi type to simulate a thruster nozzle and to facilitate temperature measurements. Provision was made for monitoring gas pressure and flow rate, incident and reflected microwave power, and optical radiation in the discharge and efflux regions.

A major experimental problem is adequate means of temperature determination in the expected range of several hundred to several thousand Kelvin. Two methods were used to estimate gas temperatures. In the first, a gas-dynamic technique, the pressure of the gas upstream of the venturi was monitored at a constant gas flow rate with the discharge off and with discharge on. Analysis of the flow equations shows

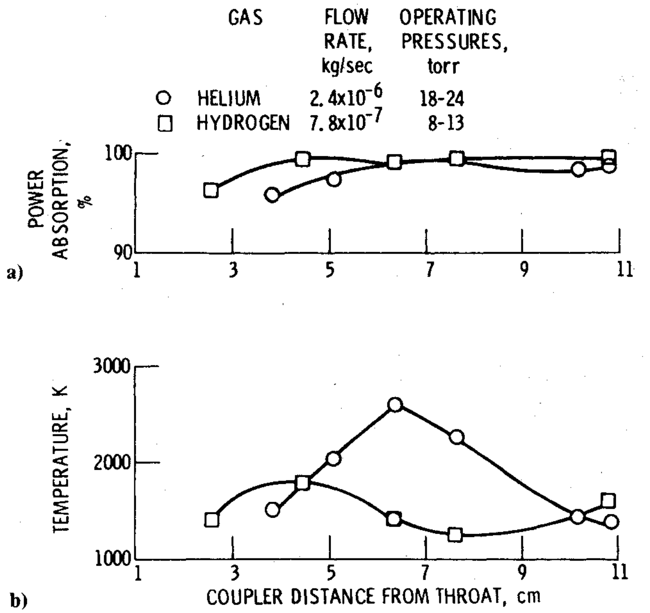

Fig. 3 Effects of coupler position on helium and hydrogen discharges, frequency, 2450 MHz; incident power, 300 W; a) power absorption and b) inferred gas temperatures.

that $T_{on}/T_{off} = (P_{on}/P_{off})^2$, where T_{on}, P_{on}, T_{off}, and P_{off} are the temperature and pressure with the microwave power on and off, respectively. T_{off} was taken to be the ambient temperature. The second method used was to measure the relative intensities of a band of rotational lines in the spectrum of the gas. The temperature was then determined from the slope of a semilogarithmic plot of intensity vs rotational quantum number. The results obtained by the two methods are not identical, but appear to agree to within the present experimental uncertainties of 10-15%.

Figure 3 shows temperature and percent absorption of input power in hydrogen and helium gases. These data are plotted as functions of the relative positions of the flow tube throat and the cavity input probe, to illustrate the effects of geometry on the system. Power absorption of 97% or greater and temperatures of 1500-2500 K have regularly been obtained with this system.

Figure 4 shows gas temperature as a function of input power for hydrogen, helium, and nitrogen at a variety of pressures. In all cases relatively high temperatures were achieved, with substantial increases as the input power was increased. Calculated values of specific impulse for hydrogen in the temperature and flow rate ranges obtained are about 900 s.

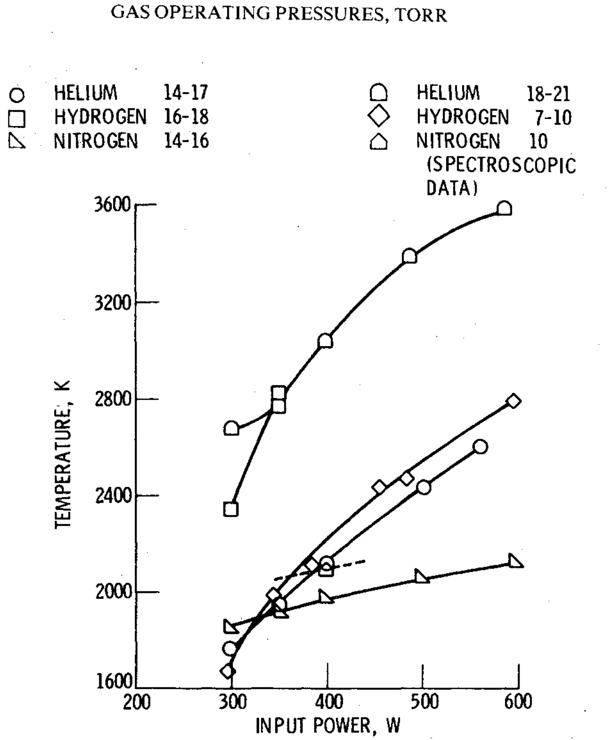

Fig. 4 Inferred gas temperatures of various gases in a microwave discharge.

Conclusion

A free radical propulsion concept is described. If successful, the concept will make available a high specific impulse propulsion system at thrust densities not currently obtainable with ion propulsion. Preliminary experiments tend to support the concept, giving gas temperatures of 1500-3500 K under a variety of combinations of pressure and input power. Further work to assess the validity of the concept, including absolute thrust measurement, is currently under way.

References

[1] Byers, D.C., "Upper Stages Utilizing Electric Propulsion," NASA TM-81412, 1980.

[2] Shaw, T.M., "Dissociation of Hydrogen in a Microwave Discharge," *Journal of Chemical Physics*, Vol. 30, May 1959, pp. 1366-1367.

[3] McCarthy, R.L., "Chemical Synthesis from Free Radicals Produced in Microwave Fields," *Journal of Chemical Physics*, Vol. 22, Aug. 1954, pp. 1360-1365.