INTERESTS IN ELECTRIC PROPULSION

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ABSTRACT

The United States Air Force (USAF) realizes that a wide range of orbit transfer and maintenance missions can be greatly improved in terms of deliverable payloads and on-orbit life times through the use of electric propulsion technologies. The trend toward more massive payloads and increasing on-board power availability make electric propulsion competitive with chemical systems. For this reason, the Air Force Astronautics Laboratory (AFAL) has been charged with the responsibility of representing the Air Force's interests in electric propulsion.

The AFAL is currently concentrating on developing 30 kilowatt class arcjets and conducting research on magnetoplasmadynamic (MPD) thrusters. The AFAL's first electric propulsion priority is a space test of a 30 kilowatt class low impedance ammonia arcjet. Toward this end, in FY89 AFAL will begin funding the design phase of an advanced technology development program to develop an arcjet system for a space test sometime between 1992 and 1994. In parallel with this effort, the AFAL is also developing a high-impedance arcjet which shows potential for both higher efficiencies and longer life times. The USAF is continuing its research on the MPD thruster both through contractual efforts and in the AFAL's Electric Propulsion Laboratory (EPL). In addition, the AFAL is working with the Air Force Office of Scientific Research (AFOSR) to develop new diagnostics for plasma research.

The AFAL's goals in electric propulsion will be widening in the near future. As the sole representative for the Air Force in this field, we cannot limit ourselves to looking at just a few electric propulsion technologies. Where arcjets and MPD thrusters received most of AFAL's interest in the past, the future will find us looking at ion engines, Hall-type thrusters, and support system technologies. In this manner, the AFAL will be able to offer a wide range of electric propulsion technologies to best meet the varied mission requirements of the United States Air Force.

1.0 INTRODUCTION

The USAF has long appreciated the benefits to be realized through the application of electric propulsion in supporting missions in space. To insure the development of this technology in those areas identified as essential, the Electric Propulsion Section at the AFAL was created. The charter for this section is to direct, through contracts and in-house research, activities which would carry the best electric propulsion options, from basic research through development and eventual space testing.

Current emphasis at the AFAL's Electric Propulsion Laboratory is on high power electric propulsion. High power in this case being defined as any device requiring an input power of 10 kilowatts or greater. The reason for this is that the greatest payoffs in terms of increasing net payload or on-station lifetime can be achieved by using electric propulsion to accomplish orbit transfer. It also enables orbit transfers of very massive payloads which are beyond the capability of currently available launch systems.

The devices dominating the USAF's investment in electric propulsion at this time are arcjets and MPD thrusters. The AFAL recognizes the advanced state of development of low power ion engines and is closely monitoring the progress of these devices as they grow into the high power regime. A new device to the AFAL is the Pulsed Electrothermal Engine (PETE), which we plan to support in FY89. Also of interest to the AFAL are the related technologies of power systems and materials research. This paper presents information on how the USAF, through the AFAL, views each of these topics and how the AFAL is supporting them.

2.0 ARCJETS

The first and most important priority of the AFAL's Electric Propulsion Section is the demonstration of the low impedance 30 kWe ammonia arcjet in space. This vital demonstration will verify arcjet operation in space and serve to open the door for other arcjet and/or plasma thrusters. The planned program will develop a self-contained arcjet propulsion system. This will include the thruster, propellant feed system, power source, structure, and diagnostic package. The space test will be of short duration that will provide verification of performance measurements made in laboratory vacuum chambers and provide meaningful insight into environmental issues that may be associated with using high power arcjet thrusters. The diagnostic system will measure thrust, thruster voltage and current, EMI and plume deposition as a function of radius, and thermal radiation on the supporting structure. The on-board power system shall consist of the power source which will provide 26-kWe to the thruster for some period of time and the power conditioning unit. In FY89, AFAL intends to begin this program to build and flight qualify this self contained unit that will then be flown as an experiment. The present schedule has an anticipated launch date between 1992 and 1994.

In the past the AFAL has funded basic research and development on the arcjets themselves and power conditioning units. We are currently funding a new contract to examine life limiting failure modes in arcjets. The thruster configuration to be used in this program has incorporated regenerative cooling to decrease the amount of heat radiated to the back of the thruster. This cooling method was developed at JPL and will complete in FY89.

The AFAL views the low impedance ammonia arcjet as an essential first step for establishing the use of electric propulsion for orbit transfer. We see this device as potentially operating at, or slightly above, 900 seconds specific impulse (Isp) at a nominal input power of 30 kilowatts, with efficiencies of 40 to 45 percent. It provides thrust levels high enough to enable orbit transfers faster than higher specific impulse devices, such as ion thrusters, while still retaining much of the benefit realized by using electric propulsion over chemical systems. The nominal power level for a single thruster is available using current technology, yet small groupings of arcjets can make use of more than 100 kilowatts when this power level becomes available. While higher performance has been achieved using hydrogen, the AFAL is concentrating on ammonia as the primary propellant because it greatly simplifies handling and storage. For these reasons we believe the ammonia arcjet is destined to become one of the major engines in the progress of electric propulsion into the realm of primary space propulsion.

3.0 MAGNETOPLASMADYNAMIC THRUSTERS

The AFAL believes the self field MPD thruster, when fully developed, will become the primary propulsion work horse for future orbit transfer. This device provides high thrust density, mechanical simplicity, specific impulse ranging from 1800 to 2500 seconds, and potentially 50 percent or better efficiency. This collection of capabilities makes possible the optimization of delivered payload/trip time payoffs for orbit tranfer missions. The primary technological barriers to be overcome before this thruster is ready for mission applications are thruster lifetimes and the development of lightweight power sources in the multikilowatt to megawatt power regime. The AFAL has supported MPD research through both contracts and in-house research. Our contracts have provided for basic research into the physics of MPD operation, modeling, mission studies, general thruster configuration development, and steady state operations. In-house efforts at the AFAL have concentrated on developing an extensive map of MPD performance as a function of electrode configuration and scaled size. The current objective is to determine a configuration which exhibits magnetically dominated operation at power levels low enough to be accessible in the foreseeable future. In addition to the existing in-house program, a joint program between the AFAL and AFOSR has been established to develop new diagnostic techniques for use in furthering electric propulsion technologies. The AFAL is also funding the University of Stuttgart to conduct research and development on steady-state MPD operation. In addition to self field thruster research, the AFAL has planned an effort in FY92 to begin examining a variety of applied field thrusters.

4.0 PULSED ELECTROTHERMAL ENGINES

A new device that has been incorporated into the AFAL plan is the Pulsed Electrothermal Engine (PETE). This engine possesses many unique and exciting attributes which could make it a dominant factor in applications of electric propulsion. The configuration of the PETE that interests the AFAL is a capillary-fed, water fueled arcjet. Early indications are that this device may achieve greater than 60 percent efficiency using water for fuel at specific impulses in the 1500 to 2000 second range. This would make it ideal for the majority of orbit transfer missions. While this is a pulsed device, the capillary fuel supply system eliminates the requirement for a long life, high speed valve to control the propellant flow. Capacitor lifetime is a problem which will require addressing, but this is greatly mitigated by the advantages of using water as the propellant. The advantages in storability, handling, and safety realized by using water are very attractive to potential users. The truly unique aspect of this thruster is that it operates at pressures greater than 100 atmospheres. This reduces the mean free path to the point where collision rates are high enough to significantly reduce the frozen flow losses which plague plasma propulsion devices.

In FY89 the AFAL plans to conduct a feasibility study on this device. This study involves testing a radiation-cooled version of the thruster under vacuum, on a thrust stand for one million pulses at 100 pulses per second, at a power level of 2 to 5 kilowatts. Thrust, specific impulse, and efficiency will be determined. At the end of the test the thruster will be examined to determine the locations of greatest erosion. If this feasibility study successfully demonstrates the levels of performance indicated by preliminary studies, the AFAL plans to proceed into an aggressive research and development program on this device to optimize its performance, extend its lifetime, and increase the power level to the 30 kWe realm.

5.0 ION ENGINES

The AFAL has no current plans to fund research on ion engines. However, the excellent work being conducted on low power engines by the National Aeronautics and Space Administration's Lewis Laboratory (NASA Lewis), the Jet Propulsion Laboratory (JPL) in Pasadena, CA, private industry, and others in recent years has drawn our attention. The outstanding successes in reducing the parts count for a thruster system, and increasing the beam power demonstrate Xenon-ion engines are rapidly developing into a strong competitor for primary orbit transfer propulsion. While their high specific impulses of 2800 to 4400 seconds are past the optimal point for most orbit transfers, their high efficiencies of 65 to 75 percent keep them competitive for these missions. For the present, the AFAL only plans to monitor ion engine progress. The possibility does exist that at some future date the AFAL may consider funding research and development on these engines.

6.0 RELATED TECHNOLOGIES

Research on electric propulsion devices will be of little value if parallel efforts are not carried out in those technologies needed to support electric propulsion. One area of particular importance to all thrusters is research into improved electrode materials. An advance in cathode material technology, for example, would benefit all thrusters from arcjets to ion engines. Toward this end, the Electric Propulsion Section plans to incorporate an allowance for research into this critical field into its next five year funding plan. Another area of paramount concern is the development of increased power in space. Toward this end the AFAL has created a Space Power Section which is dedicated to advancing the prospects of high power in space.

7.0 SUMMARY

The AFAL has been conducting research and development of a wide range of electric propulsion devices, and will continue to do so. For the present, emphasis is concentrated on preparing for a space test of an ammonia arcjet. The AFAL will continue to support research into MPD thrusters. Additional support may be provided for potentially valuable thrusters such as the Pulsed Electrothermal Engine and applied field electromagnetic thrusters. The future will also see an increase in cooperative efforts between the AFAL and such organizations as NASA Lewis and JPL. Through our mutual efforts, electric propulsion is certain to become a reality and establish itself as a dominant element in the military and industrial use of space.

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