DEVELOPING A SPACE STATION-BASED DEMONSTRATION FOR THE VASIMR PLASMA ROCKET

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INTRODUCTION

The Advanced Space Propulsion Laboratory at the Johnson Space Center is dedicated to the development of an advanced form of propulsion known as the Variable Specific Impulse Magneto-Plasma Rocket (VASIMR). The VASIMR is being developed to enable fast human and robotic missions throughout the solar system[1]. In the VASIMR, radio-frequency waves are used to ionize a propellant, such as hydrogen or other gases, forming plasma. The heated plasma then expands through a magnetic nozzle, generating thrust. A primary feature of the VASIMR system is the ability to vary the thrust and specific impulse at constant power, which allows for optimization of interplanetary trajectories. The VASIMR is being developed to operate at specific impulse levels ranging from 3,000 to 30,000 seconds. The system can be scaled to operate with electrical power levels ranging from tens of kilowatts to hundreds of megawatts, using solar power or nuclear power as appropriate for the mission. The VASIMR concept offers performance improvements over existing propulsion systems which are dramatic yet achievable within a decade and represents a bridge between current technology and fusion-powered systems of the future.

In the development of the VASIMR technology, a series of ground-based experiments and space demonstrations are envisioned[2]. A ground-based experiment of a low-power VASIMR concept is currently underway at the Advanced Space Propulsion Laboratory. This ongoing research is supporting the development of a ground test unit to demonstrate the operation of an integrated thruster in a vacuum chamber at a power level of 25-50 kilowatts. Following the ground demonstration, the next proposed step is to build and fly a similarly sized VASIMR engine as an external payload on the International Space Station. This experiment will provide an opportunity to demonstrate the performance of the rocket in space and measure the induced environment. The experiment will also utilize the space station for its intended purpose as a laboratory with vacuum conditions that cannot be matched by any laboratory on Earth.

This paper will describe the proposed space demonstration and the supporting technology development activities. A preliminary design of the space station experiment has been completed. The device would be delivered to orbit in the Space Shuttle payload bay. It would be mounted on a standard payload attachment structure. The experiment would receive one to three kilowatts of power from the station. About 600 watts would be used for cryogenic cooling and control devices. Additional power would be stored in a set of batteries. The batteries are designed to provide 24 kilowatts of power for up to ten minutes when fully charged. The VASIMR experiment would be operated for short periods when the batteries can provide power to the amplifiers that feed radio-frequency power to the thruster assembly.

Following development of a ground-based demonstration, the flight testing on the International Space Station will be an early step leading to more powerful and capable propulsion systems that will be demonstrated on free-flying spacecraft in near-Earth space and eventually on missions to the planets.

The initial VASIMR experiment on the Space Station could also demonstrate the wider application of the Space Station as a facility for the testing and certification of many forms of advanced electric propulsion and power systems. A concept for a generic electric propulsion test facility for the International Space Station is shown in Figure 1. Because of the unlimited vacuum conditions in space and the lack of chamber walls more realistic testing can be performed including long-duration lifetime testing and studies of the engine exhaust at great distances. These features will be especially valuable as more powerful electric propulsion systems are developed. A space facility may enable some propulsion testing that is not possible in any facility on Earth. And although it may seem to violate the conventional wisdom today, in the future, some aspects of testing in space may become less expensive than testing in ground facilities.

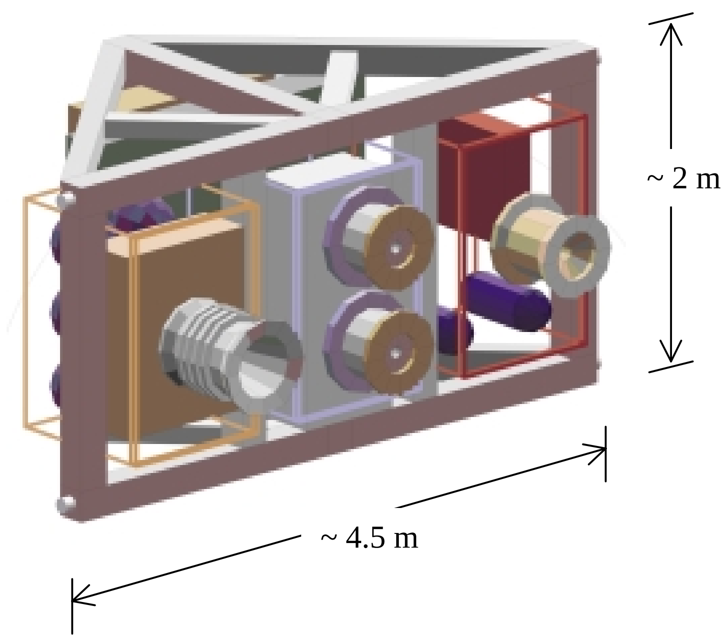


Figure 1: Concept for an International Space Station Electric Propulsion Test Facility

Objectives of Flight Experiment

The objectives of the experiment are to operate the VASIMR system in space and to collect data on its performance and its induced environment. The minimum success criteria are to operate the thruster at ten kilowatts for up to ten minutes and to operate the thruster at its full power of 24 kilowatts for at least ten seconds. The extended goal for this experiment is to operate the thruster for a ten-minute cycle at least once per day in a program lasting three to four months. The experiment is designed for at least 200 operation cycles at full power of 24 kilowatts for 10 minutes.

Preliminary Design of ISS Flight Experiment

A preliminary design of the proposed VASIMR flight experiment is illustrated in Figure 2. The VASIMR flight experiment would be delivered to orbit in the Space Shuttle payload bay. It would be mounted on a standard payload attachment structure. After removal from the payload bay by the shuttle robotic arm, it would be handed to the space station robotic arm that would place it at an external payload attach site on the station truss. A mating device for power and data connections exists at the payload sites shown in Figure 3.

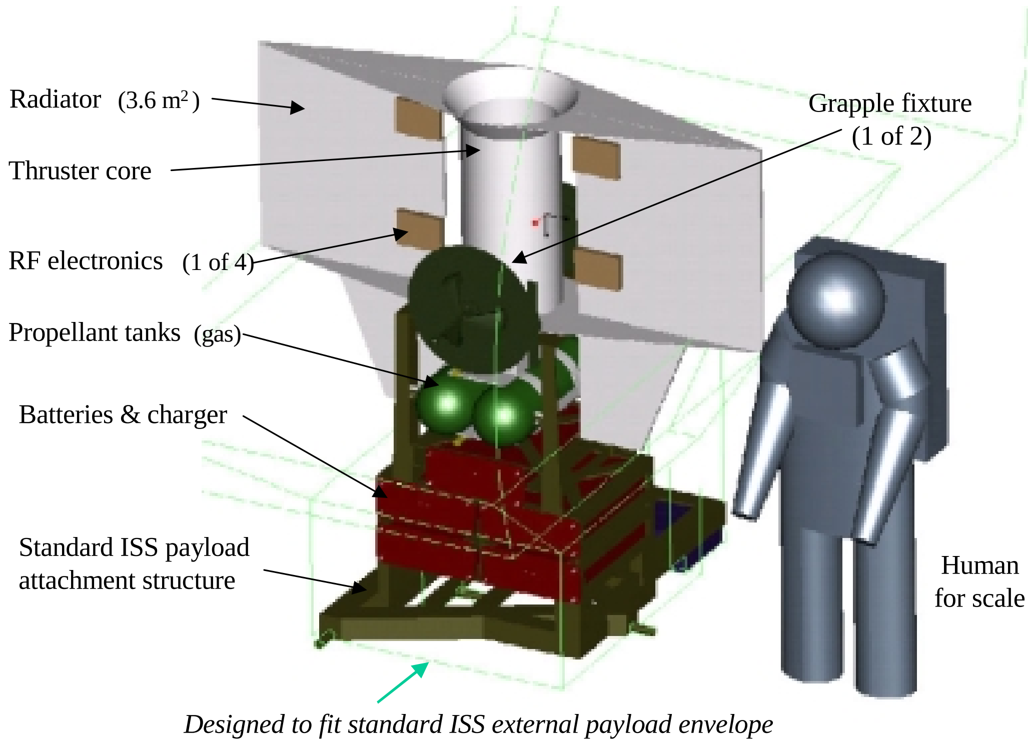


Figure 2: Preliminary design of VASIMR Experiment for the International Space Station

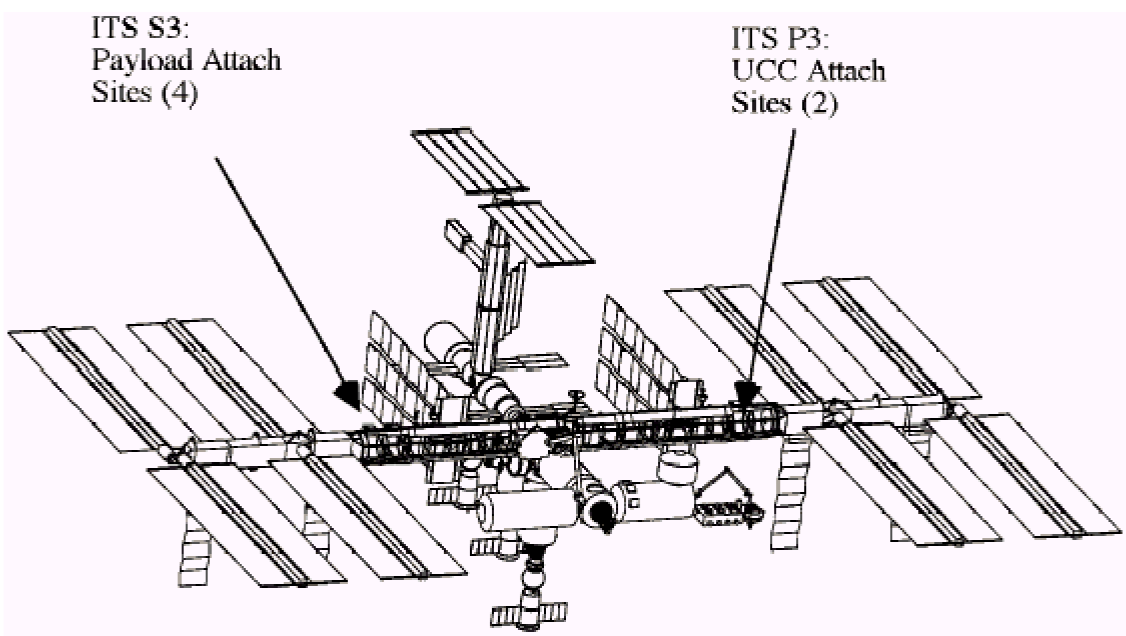


Figure 3: Payload Attachment Sites on the International Space Station

Thruster Assembly

The thruster assembly is composed of an inner tube in which the neutral propellant is injected and ionized and a larger tube, which supports the radio frequency antennas, which ionize the gas and heat the plasma. Electromagnet coils surrounding these tubes provide the magnetic field to constrain the flow of the plasma and form the magnetic nozzle. High temperature superconducting magnets will be used. At full power of 24 kilowatts, the thruster will be able to generate a thrust of 0.35 N at a low specific impulse of 6,000 seconds and a thrust of 0.25 N at a higher specific impulse of 10,000 seconds. I will be possible to vary the thrust and specific impulse over that range and to operate at lower power levels if desired. A more detailed explanation of the thruster is provided in the references.

Propellant Supply

The experiment will carry two dedicated propellant tanks which each have the capacity to store all the propellant needed for an experimental program lasting several months. With two propellant tanks, the opportunity exists to perform experiments with more than one type of propellant. Deuterium is the primary choice for propellant but helium and hydrogen are also of interest and could be included. All the propellant is stored and used in gaseous form at ambient temperature. Each cylindrical tank has a length of 78 cm. and a diameter of 25 cm. Propellant will be stored at an initial pressure of 3600 psi. The duration of thruster operation possible with the capacity of both tanks is provided in Table 1.

Table 1: Duration with Two Propellant Tanks

Propellant	**5 mg/sec**	**2 mg/sec**
Hydrogen	52 hours	132 hours
Deuterium	106 hours	264 hours
Helium	108 hours	270 hours

Power Supply

The experiment would receive one to three kilowatts of power from the Space Station. About 600 watts would be used for cryogenic cooling and control devices. Additional power would be stored in a set of batteries. The battery system is composed of nickel-cadmium cells arranged in four modules. Each module can provide 1.92 kilowatt-hours of power, has dimensions of 64 cm. by 41 cm. by 17 cm. and a mass of 75 kg. The total mass of four battery modules, two charging units and cabling is 540 kg.

The batteries are designed to provide 24 kilowatts of power for up to ten minutes when fully charged. The VASIMR experiment would be operated for short periods when the batteries can provide power to the amplifiers that feed radio-frequency power to the thruster assembly.

Thermal Control

Thermal control is the most significant engineering challenge in the design of the flight version of the rocket. The superconducting electromagnets will need to be maintained at cryogenic temperatures in order to operate properly. The magnet is in close proximity to the plasma so a combination of compact insulation and passive and active heat transport techniques will be employed. Parts of the thruster core and radiator surfaces are made of highly conductive material. Heat from the thruster core is passively conducted to the radiators. Integral phase-change material made of wax absorbs excess heat during thruster operation and dissipates the heat during the long periods when the thruster is not operating. The use of this heat sink material allows for smaller radiator surfaces. Heat pipes are employed in high temperature areas such as the antennas to transport heat efficiently to the radiator surfaces. The amplifier electronics are mounted on the radiator surfaces for direct heat dissipation.

Command and Control

The experiment will be designed to allow for operation and data collection either from onboard the Space Station or from the ground. Commands and data will pass through one of two Universal Mini-Controllers mounted on the experiment to the Space Station data management system. The Universal Mini-Controller is a compact, generic control system being developed at the Johnson Space Center for a variety of applications. There will be a variety of diagnostic instruments installed on the experiment to monitor its performance and the environment surrounding the thruster. A diagram of the command and control system is provided in Figure 4.

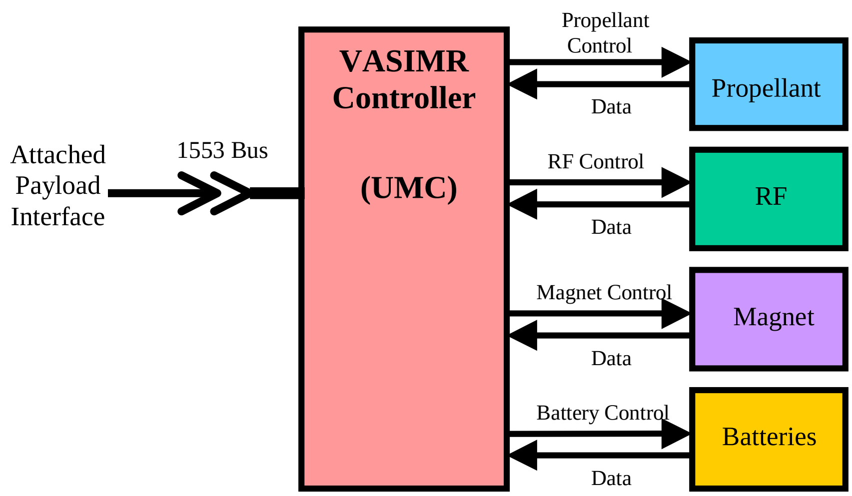


Figure 4: Command and Control System Schematic for the VASIMR Experiment

Mass Properties

The mass of each major system and total mass are shown in Figure5. As indicated in the graph, the power storage system represents the largest portion of the overall mass.

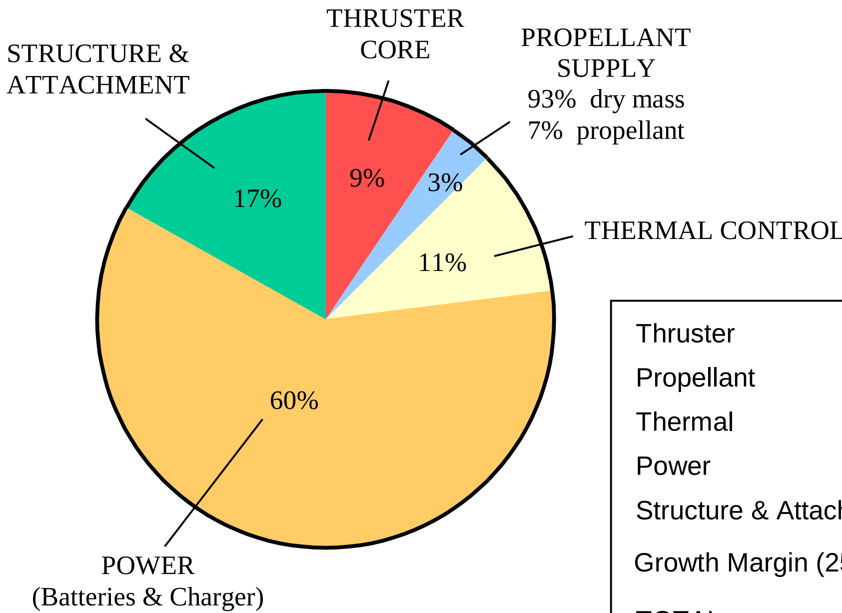
Servicing

The experiment will be designed for delivery, deployment, and operation with no extra-vehicular activity requirements. However, provisions will be included to capitalize on the presence of humans in case repairs or servicing is required. The batteries, propellant tanks, and electronic components will be designed for on-orbit removal and replacement, if necessary.

Component Development and Status

Thruster Core: Extensive experimentation is underway at the Advanced Space Propulsion Laboratory to characterize and refine the design of the basic VASIMR thruster. Detailed temperature measurements are being taken to help define the thermal loads. An integrated thruster prototype will be built and tested prior to deployment of the space flight experiment.

High-Temperature Superconducting Magnet: A prototype of a flight-like superconducting magnet has been fabricated and is currently undergoing testing. This magnet has been cooled to the superconducting range and operated.



Thruster	84	
Propellant	30	
Thermal	95	
Power	540	
Structure & Attachment	153	
Growth Margin (25%)	226	
<u>TOTAL</u>	<u>1128</u>	kg

Figure 5: Mass of VASIMR Experiment on the ISS

Propellant Supply: The propellant tanks proposed for this demonstration are existing tanks that were developed for the Space Shuttle Manned Maneuvering Unit program. A number of surplus flight-certified tanks are in storage at the Johnson Space Center and would be available for use.

Power System: The nickel-cadmium batteries and the battery charging unit proposed for this demonstration are based on a mature design developed for the X-38 flight vehicle program at the Johnson Space Center. There is also a possibility of using slightly less mature lithium battery technology that would result in greatly reduced size and mass for the system.

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References

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