Spacecraft and Mission Design for the SP-100 Flight Experiment

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The design and performance of a spacecraft employing arcjet nuclear electric propulsion, suitable for use in a space reactor power system (SRPS) flight experiment, are outlined. The vehicle design is based on a 92 kW_e ammonia arcjet system operating at an I_{sp} of 1050 s and an efficiency of 45%. The arcjet/gimbal system, power processing unit, and propellant feed system are described. A 100 kW_e SRPS is assumed and the spacecraft mass is baselined at 5250 kg, excluding the propellant, propellant feed system, and integrated chemical boost engine. A radiation/arcjet efflux diagnostics package is included in the performance analysis. Three mission scenarios are described that are capable of demonstrating the full capability of the SRPS. The missions considered include power system deployment to possible surveillance platform orbits and a spacecraft storage mission to an orbit of three times geosynchronous (GEO), with return to GEO corresponding to ΔV between 7400–7900 m/s.

Nomenclature

GEO	= geosynchronous orbit; 0 deg inclination, 35,860 km alt
I_{sp}	= specific impulse, *s*
kg	= kilograms
kW_e	= kilowatts of electrical power
m	= meters
$M_{f/s}$	= mass of propellant feed system
M_p	= propellant mass
NH_3	= ammonia
s	= seconds
SP-100	= space power at 100 kW_e
ΔV	= velocity increment

Introduction

EXPLORATION and intensive study of the planets of our solar system will require high-power, electrically-propelled spacecraft.[1-5] In addition, high-power, lightweight propulsion systems will be needed to transfer high-mass payloads from low earth orbit to their operational orbits.[6-10] Nuclear electric propulsion (NEP) systems using space reactor power systems (SRPS) and electric propulsion modules are being studied as options to satisfy these mission needs. Numerous mission studies have been conducted in which NEP was identified as either mission enabling or as the optimum propulsion choice.[1-11] Several studies were also conducted in which the integration of power and electric propulsion subsystems into an NEP spacecraft were considered.[1,7,10,12-14]

The future availability of viable NEP systems requires the simultaneous development of SRPS and electric propulsion systems. The projected needs of the Strategic Defense Initiative (SDI) indicate unprecedented power level requirements (hundreds of kilowatts to hundreds of megawatts) and an order of magnitude increase in power density. A program in space power and power conversion has been initiated for the development of the critical technologies required to meet these power needs.[15] The four program elements are: requirements and assessment, multimegawatt prime power, pulse power conditioning, and baseload power. The last, baseload power, consists of SP-100 and alternative nonnuclear technologies. The nuclear technology assessment phase of the SP-100 program has been completed with selection of a space reactor power source concept that includes a fast-spectrum, liquid-metal cooled reactor coupled with an out-of-core thermoelectric conversion system.[16] The primary objective of phase II, which has been initiated, is the 1991 ground test of a 100 kW_e SRPS based on the selected system concept.

The SP-100 flight experiment, a flight demonstration of a 100-kW_e class SRPS, has been proposed as an adjunct to the SP-100 program, using an electric propulsion module as an active load.[17] The primary purpose of this proposed flight test is the demonstration of space-based nuclear power system operation. The SP-100 flight experiment also will demonstrate nuclear electric propulsion for orbit raising and maneuvering.

The test goal is to operate the SP-100 SRPS for its seven year, full-power life. An active power system load is required for up to six months to verify power system compatibility with a payload and satisfy potential users of this compatibility.[15,17] No alternative to electric propulsion has been identified for the active load, which meets the flight experiment constraints as currently defined. These constraints include a low developmental risk and cost, wide performance throttlability, and scalability to future SDI power levels well beyond the 100-kW_e range being considered for the flight demonstration. This mission will provide a unique opportunity to examine the control scenarios required for NEP orbit transfer, to examine the maneuvering of an orbiting spacecraft to enhance operations and survivability, and to examine a representative transfer similar to that required for the SDI. Arcjet electric propulsion has been selected as the baseline electric propulsion system for the SP-100 flight experiment.[17]

This paper outlines a baseline arcjet NEP spacecraft design for use in the SP-100 flight experiment. Detailed descriptions of the arcjet/gimbal platforms, power processing units (PPU), propellant flow subsystem, and diagnostic packages are included. Expected propulsion system performance is provided

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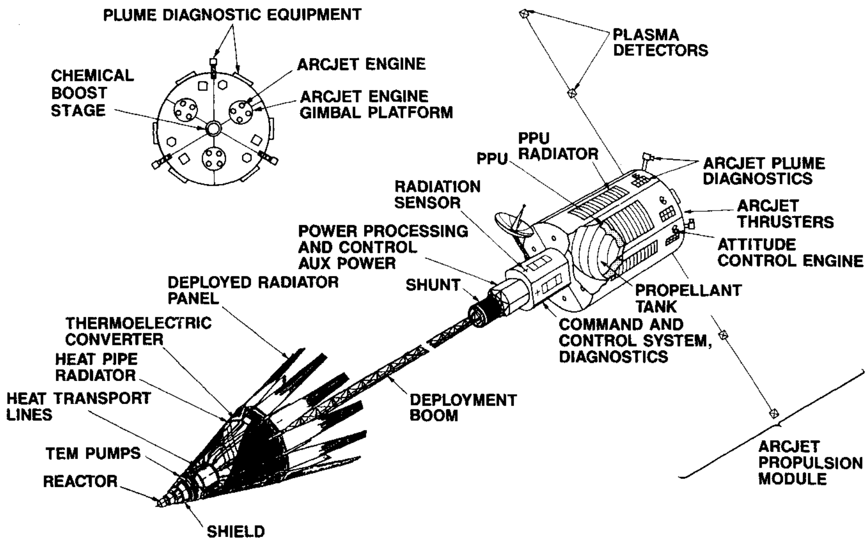

Fig. 1 Proposed spacecraft configuration for the SRPS flight experiment.

Table 1 Space reactor power system performance specifications[16]

Parameter	Specification
Power level	100 kW_e
Primary voltage	200 V_{dc}
Specific mass	30 kg/kW_e
Secondary power	300 W
Secondary voltage	28 V_{dc}
Continuous load following	0.1 kW_e/ms
Thermal flux at user interface	0.14 W/cm^2
10 year radiation fluence	$< 10^{13}$ $neutrons/cm^2$
at user interface	$< 5 \times 10^5$ rads

Table 2 Projected mass summary for the 100 kW_e arcjet SRPS flight experiment spacecraft

Subsystem	Mass, kg
SRPS	3000
Spacecraft bus	1000
SRPS/thruster system diagnostics	500
Arcjet module	250
Propellant feed system	Depends on propellant load[a]
Miscellaneous	500
Integrated chemical stage	2555

[a]See Propellant Flow Subsystem section.

for two different arcjet technology levels, with launches from the Kennedy Space Center (KSC) using the Shuttle transportation system (STS). The missions considered include power system deployment to possible SDI platform orbits and a spacecraft storage mission to an orbit of three times geosynchronous (3 × GEO) with return to GEO. This paper builds on two previous papers and is aimed at better defining the SP-100 flight experiment NEP opportunity.[10,18]

SP-100 Flight Experiment Spacecraft Configuration

A proposed spacecraft configuration for the SP-100 flight experiment is shown in Fig. 1. This system is composed of a 100-kW_e SP-100 SRPS, spacecraft bus, an arcjet propulsion module, an integrated bipropellant chemical transfer stage, and a SRPS radiation/arcjet plume diagnostics package. A 100-kW_e power level was chosen, since it is the recommended power for the SRPS flight demonstration.[10,15,17] This spacecraft concept uses an end thrust design, through the spacecraft centerline, so that the deployment boom is in compression during thrusting. The SRPS will be considered in this paper only to the extent of general performance specifications and major SRPS/payload interactions. The SP-100 SRPS parameters germane to this study are listed in Table 1.

The arcjet propulsion module comprises: three sets of four engines, with each set of engines on a single gimballed platform, a PPU system, the propellant feed system, a radiation/thruster efflux diagnostics package, and associated structure. During arcjet system operation, one engine from each platform operates to provide thrust. After 1500 h of operation, these three engines are turned off and another three (one per platform) are turned on. This process repeats after the next 1500 h of operation to accumulate a total operating time of 4500 h. At that time the arcjet mission has been completed. A fourth set of three engines is provided as backup. There are two dedicated PPU's per gimballed platform, with one serving as a spare. Separate propellant feed lines provide ammonia to each platform. Three thrusters can be operated at maximum power, using 92 kW_e of power when accounting for the 98% efficiency of the PPU system.

The thruster module is enclosed within a 4.5-m outside-diameter, 6-m-long cylinder with the propellant tank located on the end nearest the SRPS. The three sets of arcjet engines and gimbals are located on the end of the cylinder opposite the SRPS. The PPU system is located within the cylindrical enclosure between the propellant tank and engine modules with its six radiators facing space on the outer surface of the cylindrical enclosure. The combined thrust of this system is 7.8 N when three engines are operating at full power. The command, data handling, and telecommunications functions are part of the spacecraft bus. A mass summary of the spacecraft components is provided in Table 2.

A block diagram of the arcjet SP-100 flight experiment vehicle is shown in Fig. 2. It includes all of the primary system components for converting SRPS power into thrust. The arcjet PPU is used to start and run the arcjet. The propellant system runs parallel to the power train and consists of the tankage, valves, lines, and so forth, required to provide a constant propellant flow rate to each operating engine. The command, data handling, and telecommunications subsystems receive and process ground commands and control overall system operation. The diagnostics package provides the ability to both monitor the reactor radiation included environment and measure the particulate and field emissions from the arcjet thrusters in the vicinity of the electric propulsion module. Thermal control allows for the rejection of waste heat from the arcjet and PPU's, while the structural members tie all of the subsystems together.

Concerns that should be addressed during the SP-100 flight experiment design phase, with respect to arcjet system, include: flight diagnostics, NEP demonstration scenarios, ground vacuum test facility availability (with regard to high-power, high-temperature and high-mass-flow systems) and safety concerns, particularly at integration and launch.

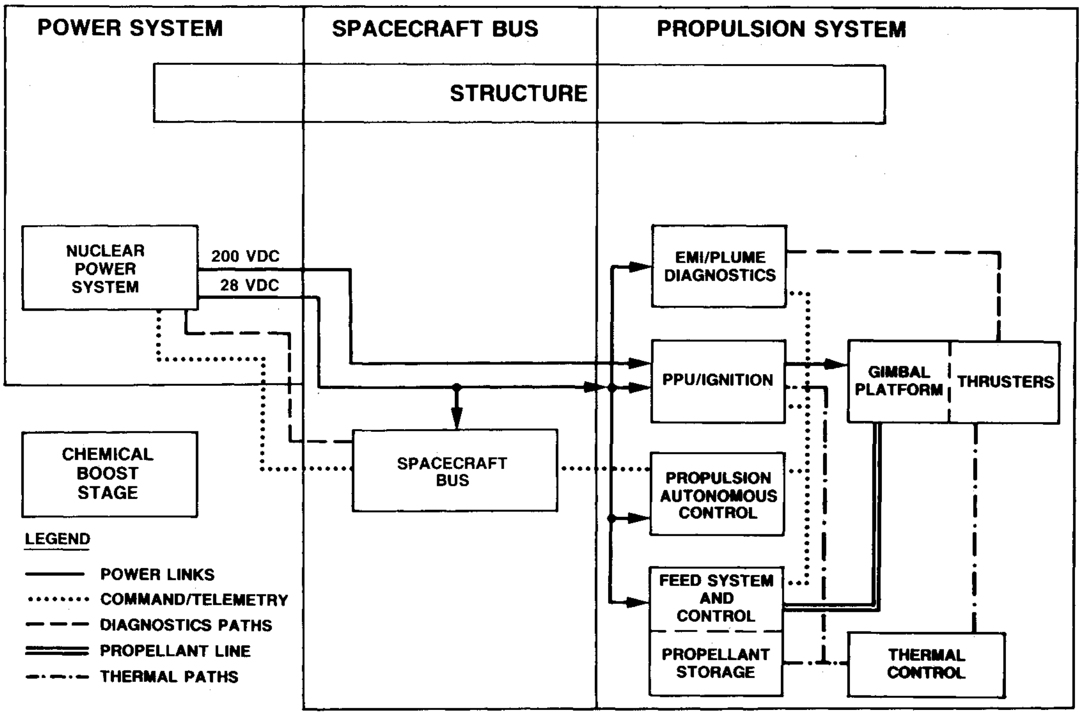

Fig. 2 Arcjet NEP system block diagram for the SRPS flight experiment.

Technology concerns are primarily the issues of adequate arcjet durability and lifetime. Continual component life testing should be conducted to demonstrate reliability.

System Components

Detailed descriptions of the engine/gimbal platforms, PPU, propellant system, and diagnostics package are presented next.

Arcjet Engine/Gimbal Platform

The arcjet technology level assumed for the SP-100 flight experiment spacecraft, as defined in this study, is given in Table 3. A schematic of a proposed engine/gimbal platform configuration is shown in Fig. 3. Each engine/gimbal platform consists of four 30-kW$_e$ arcjet engines, a heat shield/platform, a high-power, high-current switch, and a gimbal mechanism, including a set of flexible high-current power leads and propellant lines. Three platforms are used and are located on the aft end of the spacecraft, with one engine per platform operating at a time. The high-power, high-current switch is used to select which arcjet engine will be operated on that platform. As engines reach the end of their useful life, a new engine can be switched into operation. Some development of mechanical high-power rotary switches has taken place.[19] However with the gains made recently in high-power electronics, such a switching mechanism should be possible using high-power transistors, diodes, etc., and contain no moving parts. The use of a power switch mechanism can be avoided if each engine has a dedicated PPU and the associated mass penalty can be excepted. A propellant distribution manifold runs parallel to the power switch and distributes propellant to the desired engine. The platform itself is the primary structural member and serves as a heat shield to protect the main spacecraft structure from the radiated arcjet heat.

Arcjet Power Processing Unit

There will be two PPU's associated with each engine gimbal platform. One PPU will serve as a spare. Each PPU consists of a pulsed, low-power, high-voltage "start" supply in parallel with a high-power, low-voltage "run" power supply.

Table 3 Projected arcjet thruster operating characteristics

Parameter	Value
Propellant	NH_3
Engine input power	30 kW$_e$
Specific impulse	1050 s
Engine efficiency	0.45
Arc voltage	120 V
Arc current	250 A
Mass flow rate	0.25 g/s
Thrust	2.6 N
Engine mass	7 kg
Lifetime	1500 h

The run power supply is based on a "buck" regulator design that is efficient, reliable, and compact.[20] The PPU specific mass goal is 0.2 kg/kW at an efficiency of 98%. The PPU's are self-radiating, with each rejecting 0.61 kW of power while maintaining the component base plate at 300 K. The high power and elevated temperature electronic components could be mounted directly to the PPU baseplate, which might be a honeycomb panel heat pipe/radiator. This type of lightweight radiator has been investigated and shows promise for use as a low-temperature radiator.[21,22]

During engine startup, the "start" supply sends rapid high-voltage pulses to the thruster, causing a voltage breakdown through the propellant gas, heating the cathode. Once the cathode tip reaches thermionic emission temperatures, the run power supply takes over and is ramped up to full power in several tens of seconds. This technique allows the arcjet to be started rapidly in a nondestructive manner. The run supply provides approximately 250 A at 120 V, steady-state, at full power following arcjet startup. Other design considerations include hardening the PPU/ignition system to the SP-100 radiation environment and compatibility of the PPU/ignition system with the SP-100 thermal environment.

Propellant Flow Subsystem

The propellant flow system includes the propellant storage tank and a feed system to supply propellant to the thrusters.

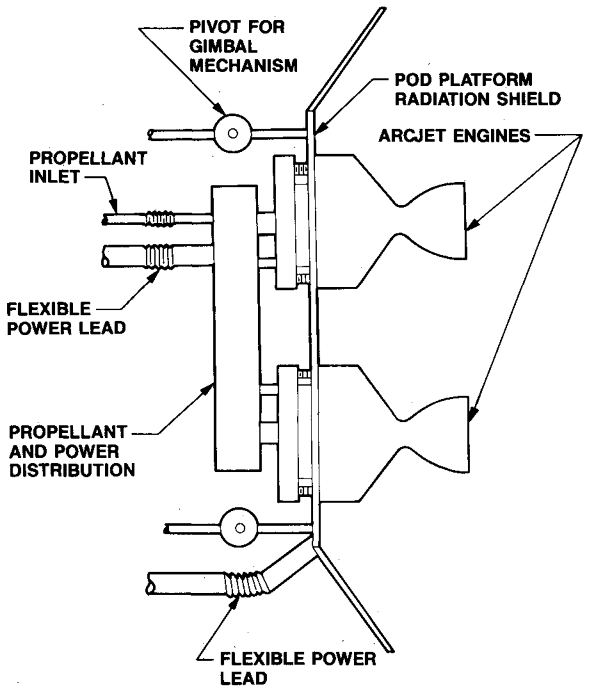

Fig. 3 Schematic of an arcjet engine/gimbal platform configuration.

Ammonia propellant storage and feed systems are a mature technology that have been flown several times.[23-26] A schematic of the proposed ammonia propellant flow system is shown in Fig. 4. Ammonia is stored in a spherical titanium tank at about 150 psia. Titanium was chosen for the tank material because of its low mass and chemical compatibility with ammonia. At 150 psia, ammonia boils at 298 K, implying that a minimum of propellant thermal control is required. An electric heater system provides heat to vaporize the ammonia and maintain the 150-psia tank pressure. Multilayer insulation is used to minimize the number of heating cycles required to maintain ammonia vapor in the propellant tank. At these storage conditions, the maximum ammonia propellant load possible is 18,278 kg, using a 4 m internal diameter tank. A 10% ullage is assumed. The tank is loaded with the proper mission-dependent propellant mass prior to launch. A space-based propellant refill capability is assumed should future testing or other needs require restart of the arcjet NEP system.

The feed system consists of the propellant lines, valves, transducers, filters, regulators, flow controllers, structure, etc., required to provide the proper propellant flow rate to the arcjet thrusters. Vacuum operable flow controllers are required to throttle the engines and optimize their operation as functions of efficiency and specific impulse. Development of this type of flow controller is ongoing.[27] If the mission design does not require throttling with respect to efficiency and specific impulse, then a single flow rate can be provided by a regulator/orifice assembly. The total tankage and feed system mass, $M_{f/s}$ consists of a fixed component independent of propellant load and a variable component dependent on the propellant load M_p, and is given by

$$M_{f/s} = 100.0\ \text{kg} + 0.20 M_p \tag{1}$$

This equation includes a 10% contingency on all components. This system provides a constant mass flow of 0.25 g/s of ammonia to each operating arcjet thruster for the full mission duration. The propellant requirement for six months of arcjet operation is 11,700 kg.

Diagnostics Package

A diagnostics package is carried on the SP-100 flight experiment to monitor the SRPS induced radiation environment at

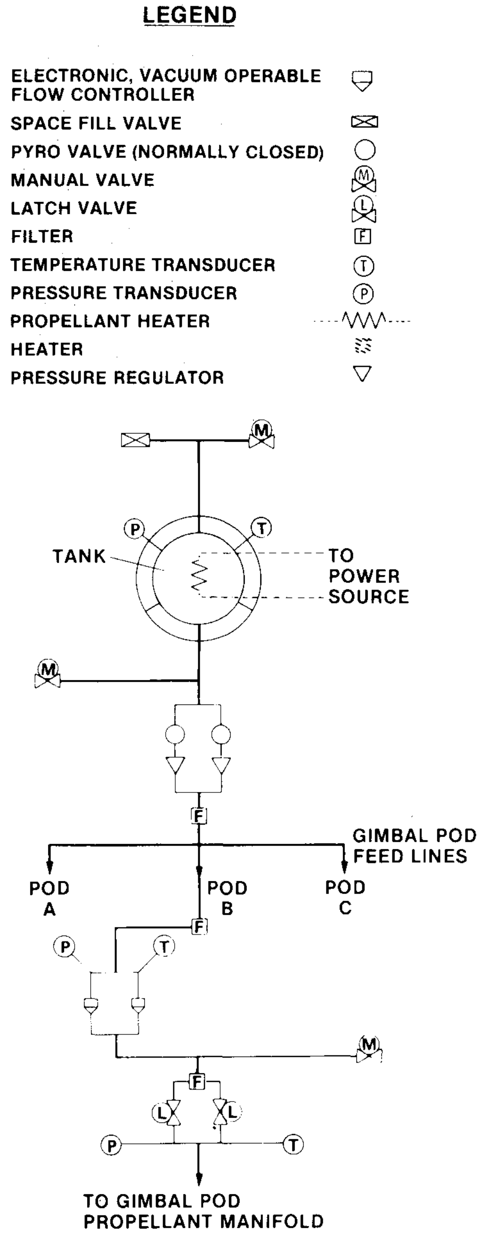

Fig. 4 Ammonia (NH_3) feed-system schematic.

and beyond the user interface and to examine the arcjet propulsion system particulate and field emissions. Such a diagnostics package would enable future users of both the SP-100 SRPS and arcjet engines to better assess the potential impacts of these systems on their payloads.

Arcjet efflux can be of some concern since a small portion of the exhaust plume will extend back behind the thruster nozzle exit plane, because of gas dynamic expansion, and impinge on the arcjet module and SRPS. Particulate contamination is expected to be minimal, since the gas is rarified and the volatile contaminant density is very low.[28] The primary particulate contaminants are expected to be hydrogen, nitrogen, tungsten, boron, and thorium. Of these, the metals and boron pose the greatest potential hazard, since they will condense on most any surface they contact. However, it should be noted that for a six-month mission, the maximum expected tungsten loss from all engines totals less than 30 g, based on erosion data from previous arcjet tests.[29-32] All of this material would have to be focused on one location to cause a significant problem.

The electromagnetic interference (EMI) characteristics of arcjet thrusters are not well known, but the engines are expected to be "noisy," since they produce a plasma. Considering that the onboard spacecraft power is almost two orders-of-magnitude greater than present-day spacecraft, indicates that EMI guidelines will need extensive revision. Thermal radiation from arcjet thrusters also can be severe, since up to 10% of the engine input power can be radiated away by the nozzle alone.[33,34] Heat shields will be required to reduce radiative heating of the upstream spacecraft components.

Finally, the SRPS will be emitting neutrons and gamma rays, the levels of which will have to be evaluated. As a result of these spacecraft self-contamination issues, a diagnostics package is included as part of the add-on equipment. A list of possible diagnostic instrumentation is given in Table 4.

Arcjet NEP Performance

The following analysis is based on the well-known orbital mechanics equations for electric propulsion transfers[35] and the previously mentioned propellant feed, power processing, and arcjet subsystem characterizations. Launches from KSC using the STS launch vehicle are assessed for three proposed flight experiment scenarios. A vehicle mass summary was given in Table 2. The mass goal of a 100-kW SRPS is given as 3000 kg.[16] The propulsion system is assumed to have a mass of 250 kg, excluding propellant, tankage, and the feed system. The spacecraft bus, which includes the primary command and control and communications equipment, is assumed to have a mass of 1000 kg. The mass assumed for the diagnostics equipment is 500 kg. An additional 500 kg has been set aside for miscellaneous spacecraft systems. The integrated bipropellant chemical engine has a mass of 2555 kg and is used to place the spacecraft in a 925 km nuclear safe circular orbit.

Arcjet Propulsion System Parameters

The arcjet system technology levels assumed for this study are presented in Table 5. Two system technology levels were examined to determine SRPS flight experiment performance. The baseline system parameters are derived from recent performance testing of an arcjet engine at the Jet Propulsion Laboratory.[36,37] During the course of arcjet performance evaluation, values of specific impulse as high as 958 s (high power) and thruster efficiencies up to 52% (low power) were noted.[37] The engine thrust ranged up to 2.65 N at an ammonia flow rate of 0.35 g/s. Engine performance was examined at flow rates between 0.175–0.35 g/s and input power levels ranging from 10.0–29.0 kW_e. The values in Table 5 represent an extrapolation of the performance data up to a 30-kW_e power level and should provide an effective lower bound for arcjet performance.

The advanced arcjet technology performance projections in Table 5 represent expected arcjet performance as a result of continued research and development activities. During the 1960's, ammonia arcjet testing demonstrated 30-kW_e power level operation at specific impulses of 978 and 1012 s at 38.0 and 38.6% efficiency, respectively.[38,39] During a recent duration test, an arcjet engine operated at a specific impulse of 967 s and an efficiency of 37% when extrapolated to 30 kW.[29,40,41] Based on these data, the major technology upgrade is the proposed increase in the thruster efficiency. Such a performance improvement could be facilitated by using a bell-shaped nozzle, which has shown potential nozzle efficiency improvements of up to 20%.[36,37,42] In addition, regenerative cooling will help recover some of the conduction power loss through the cathode. Such cooling also preheats the propellant gas, enabling a small increase in overall engine efficiency. The outer anode surface will be deposited with a high-temperature, high-emissivity coating to improve its radiative cooling properties, which reduces the nozzle temperature and should improve the thruster durability.[43]

Constraints and Assumptions

Because of safety concerns, the SRPS cannot be operated until the spacecraft has reached a 925-km (500 n.mi.) nuclear safe orbit. An integrated chemical stage will be employed to boost the NEP flight demonstration spacecraft to 925 km from STS orbit, which is assumed to be 280 km (150 n.mi.) at an inclination of 28.5 deg for this study. It is also assumed that the upper launch mass limit for STS is 22,700 kg; 4100 kg of airborne support equipment (ASE) is needed; and a single, dedicated shuttle launch from KSC is required for the flight experiment. The integrated bipropellant chemical motor will not perform any part of required plane changes. The chemical system ($I_{sp} = 280$ s) that could be used to make this orbital altitude change, corresponding to a ΔV of 349 m/s, weighs 2555 kg. The initial spacecraft mass delivered to the 280 km circular orbit is 18,600 kg.

Mission Scenarios and Results

Three missions were examined that could be used to demonstrate SRPS operation. The first two missions involved power system deployment to possible SDI platform orbits of 3000 or 10,000 km. An advantage of these orbits is that they contain a minimum of man-made orbital debris, reducing the chance of a collision.[44] The third mission involved a spacecraft storage demonstration to an orbit of 3×GEO with a return to GEO.

3000 km Orbit

A 3000 km circular orbit, with a final inclination between 55 and 85 deg, has been identified as a potential SDI platform orbit.[45] As a result, this orbital altitude was chosen as a destination for this study so that the mission would have to address the control scenarios required to perform a low-altitude, high-inclination change low-thrust mission. The orbital analysis was done so that the entire available propellant load was con-

Table 4 Possible diagnostic instrumentation

Space nuclear power system	Arcjet NEP system
Neutron detectors	Quartz crystal microbalances
Gamma ray detectors	Solar cell witness plates
Temperature monitors	Faraday probes
Infrared radiation sensors	Langmuir probes
Mass spectrometer	Antennas
	Video camera
	Mass spectrometers

Table 5 Arcjet performance characteristics assumed for this study

Parameter	Value	
Technology level	Baseline	Advanced
Propellant	NH_3	NH_3
Input power per thruster, kW_e	30	30
Thruster efficiency	0.37	0.45
PPU efficiency	0.98	0.99
Specific impulse, s	967	1050
System specific mass per engine,[a] kg/kW_e	1.81	1.26
Thrust per engine, N	2.35	2.6

[a]Excludes SRPS, propellant, tankage, and feed system.

Table 6 Arcjet engine throttling values

Engine	Power, kW_e	Efficiency, %	Specific impulse, s
Baseline	10	51	650
	20	41	822
	30	37	985
Advanced	10	62	715
	20	51	887
	30	45	1050

sumed to reach the highest inclination possible for each of the arcjet technology levels described in Table 5. A SP-100 flight experiment vehicle using the baseline arcjet system would enable the power system to be delivered to a 67 deg final inclination in 154 days at an orbital altitude of 3000 km. This corresponds to a mission ΔV of 7137 m/s. If the vehicle were based on the advanced arcjet technology, it would be capable of achieving a mission ΔV of 7856 m/s corresponding to a 3000 km, 72-deg final orbit. The trip time is 149 days in this case.

10,000 km Orbit

A 10,000 km circular orbit was chosen as the target altitude for an arcjet NEP throttling demonstration and was compared to a nonthrottled case. Again, the analysis was done so that the entire available propellant load was consumed to reach the greatest orbital inclination possible for each of the arcjet technology levels described in Table 5. In the nonthrottled case, the baseline arcjet technology provided a total ΔV capability of 7158 m/s, corresponding to a 10,000 km, 71.5-deg final orbit with a 155-day trip time. The advanced arcjet technology would enable a nonthrottled total ΔV of 7794 m/s, corresponding to a final orbit of 10,000 km at 76.5 deg with a trip time of 148 days.

The throttled arcjet engine values are given in Table 6. The baseline values come from performance test results discussed earlier,[33,34] whereas the advanced arcjet values are projected based on theory and the previously mentioned test results. The orbital analysis was not trajectory optimized to achieve the maximum inclination possible when throttling the arcjet engines. The calculations were conducted as follows: with the three arcjets operating at 30 kW_e each, the flight experiment spacecraft was raised from a 925-km, 28.5-deg orbit to a 6500-km, 28.5-deg orbit, corresponding to a ΔV of 1827 m/s. From this orbit, the vehicle was moved to a 10,000 km, 38.5 deg, a ΔV of 1567 m/s, with three arcjets operating at 10 kW_e each. The next leg was accomplished using three arcjets operating at 20 kW_e each and resulted in a final orbit of 10,000 km, at 48.5 deg for an additional ΔV of 1325 m/s. The final leg was completed with three arcjets operating at full power until all the available propellant was consumed. This resulted in a final orbit of 10,000 km, at 66 deg for the baseline arcjet system and a 10,000-km, 71-deg orbit for the advanced arcjet system, corresponding to ΔV for the final legs of 2184 and 2762 m/s, respectively. These results are summarized in Table 7. Throttling of the engines provides a demonstration of the SRPS load following capability in splitting power between the user and power system shunt and demonstrates the flexibility of both the arcjet NEP system and the SP-100 SRPS.

Spacecraft Storage Mission

The final mission considered involved demonstrating low-thrust control scenarios to a moderate inclination change, high orbit. A spacecraft storage mission from a 28.5-deg, 925-km orbit to 3×GEO with a return to GEO fits this description. The first leg of the trip had a final orbital inclination of 0 deg at an altitude of 107,580 km for a ΔV of 6211 m/s. The spacecraft then returned to GEO, requiring an additional ΔV of 1204 m/s. The baseline arcjet system reached 3×GEO in 140 days; however, this technology level would not permit a return to GEO, since an additional 275 kg of ammonia propellant would be required. The advanced arcjet propulsion system was able to propel the spacecraft to 3×GEO in 126 days and then return to GEO in 13 days.

Conclusions

The design and performance characteristics of an arcjet NEP spacecraft suitable for conducting the SP-100 flight experiment have been presented. The simplicity of arcjet thrusters and their relatively advanced state of development allow them to meet the SP-100 flight experiment constraint of low-developmental risk. In addition, arcjets can be scaled with power into the 100's of kilowatts regime and beyond, making them compatible with future SDI power levels. As a result, arcjets are particularly well-suited for the SRPS flight experiment.

A proposed flight experiment vehicle has been outlined and consists of a 100 kW_e SRPS, a radiation/arcjet efflux diagnostics package, and an arcjet propulsion module with an integrated chemical kick stage, in an end-thrust configuration. The propulsion system module consists of three 30-kW_e ammonia arcjets operating at a specific impulse of 1050 s and an efficiency of 45%. A total system thrust of 7.8 N is generated, with three engines operating at full power. The baseline vehicle mass is 5250 kg, excluding the propellant, feed system, and chemical stage.

Orbital analysis was conducted to evaluate the SRPS flight experiment vehicle performance. A single dedicated STS launch was assumed from KSC. A number of candidate missions were proposed with no attempt to recommend one over another. The intent was, rather, to present options, any one of which might be representative of future mission deployment requirements. The analysis showed that this vehicle is capable of mission ΔV's of 7400–7900 m/s. A propulsion system throttling demonstration would verify the SRPS load following capabilities.

Three specific missions were examined and included power system deployment to possible surveillance platform orbits and a spacecraft storage mission. Analysis has shown that the vehicle could reach a 3000-km, 72-deg inclination final orbit in 149 days for a mission ΔV of 7856 m/s. A 10,000-km, 76.5-deg final orbit could be achieved in 148 days for a mission ΔV of 7984 m/s. A spacecraft storage mission with power system deployment to 3×GEO and return to GEO was also examined. The up leg required 126 days and a ΔV of 6211 m/s, whereas return to GEO required 13 days and a ΔV of 1204 m/s.

Table 7 Summary of arcjet throttling orbital analysis

System	Engine power, kW_e	Initial altitude, km	Final altitude, km	Initial inclination, deg	Final inclination, deg	Trip time, days	Delta V, m/s
Baseline	30	925	10,000	28.5	71.5	155	7158
	30	925	6,500	28.5	28.5	45	1827
	10	6,500	10,000	28.5	38.5	44	1567
	20	10,000	10,000	38.5	48.5	20	1325
	30	10,000	10,000	48.5	66.0	23	2184
Totals			10,000		66.0	132	6903
Advanced	30	925	10,000	28.5	76.5	148	7794
	30	925	6,500	28.5	28.5	40	1827
	10	6,500	10,000	28.5	38.5	42	1567
	20	10,000	10,000	38.5	48.5	19	1325
	30	10,000	10,000	48.5	71.0	25	2762
Totals			10,000		71.0	126	7481

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