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14. ABSTRACT

Space solar power generation systems have a significant impact on Electric Propulsion (EP) technology development. Recent advances in solar cell, deployment, and concentrator hardware have led to significant decreases in component mass, reducing system specific power. Combined with maneuvering requirements for Air Force and DoD missions of interest, propulsive requirements emerge that provide direction for technology investments. Projections for near- to mid-term propulsion capabilities are presented indicating the need for thrusters capable of processing larger amounts of power (100 – 200 kW), operating at relatively moderate specific impulse (2000 – 5000 s) and high efficiency (> 60%), and having low mass (< 1 kg/kW). Two technology areas are identified and discussed in the context of the above thruster constraints. Concentric channel Hall thrusters are an extension of a mature technology, offering operation over expanded power levels and lower specific mass at SOTA efficiencies. Field Reverse Configuration (FRC) thrusters are a specific type of Compact Toroid (CT) that have the potential to operate up to MW power levels, at specific masses even lower than concentric channel Hall thrusters, and on a wider range of propellants. However, FRCs are currently less mature than the Hall thruster variants. Comparisons of candidate technologies are evaluated with VASIMR, a well publicized high power EP device currently under development.

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Air Force Research Laboratory High Power Electric Propulsion Technology Development

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Abstract— Space solar power generation systems have a significant impact on Electric Propulsion (EP) technology development.[1,2,3] Recent advances in solar cell, deployment, and concentrator hardware have led to significant reductions in component mass, thereby decreasing power generation system specific mass. Combined with maneuvering requirements for Air Force and DoD missions of interest, propulsive requirements emerge that provide direction for technology investments.

Projections for near- to mid-term propulsion capabilities are presented indicating the need for thrusters capable of processing larger amounts of power (100 – 200 kW), operating at relatively moderate specific impulse (2000 – 6000 seconds) and high efficiency (> 60%), and having low propulsion system mass (< 1 kg/kW). Two technology areas are identified and discussed in the context of the above thruster constraints. Concentric channel Hall thrusters are an extension of a mature technology, offering operation over expanded power levels and lower propulsion system specific mass at state-of-the-art (SOTA) efficiencies. Field Reverse Configuration (FRC) thrusters are a specific type of pulsed inductive accelerator that have the potential to operate up to MW power levels, at propulsion system specific masses even lower than concentric channel Hall thrusters, and on a wider range of propellants. However, FRCs are currently less mature than the Hall thruster variants. Comparisons of candidate technologies are evaluated with VASIMR, a well publicized high power EP device currently under development.

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1. INTRODUCTION

The United States Air Force is the primary government organization conducting research and development of technology to address current and future national space propulsion needs. The Air Force supports space propulsion through three organizations: Air Force Research Laboratory (AFRL), Air Force Office of Scientific Research (AFOSR), and the AFOSR European Office of Aerospace Research and Development (EOARD). Within AFRL, the Spacecraft Branch (RZSS) at Edwards AFB has primary responsibility for research and development of in-space propulsion technology for the Department of Defense (DoD). AFRL conducts research across the breadth of technical maturity, from investigations into fundamental physics, to engineering development, to flight hardware. This includes both advanced chemical propulsion and electric propulsion.

Because of the vast array of spacecraft sizes and potential maneuvers, space propulsive requirements cover an extremely wide range of thrust, specific impulse, and propellant throughput. Secondary considerations, such as spacecraft power, mass and volume constraints, also impact the choice of propulsion. Technology development is driven by propulsive requirements that, first and foremost, fall out of the specific orbital elements comprising a given mission: total orbital maneuver velocity increment (ΔV), maximum allowable orbital maneuver time (Δt), and deliverable spacecraft mass (m_{dry}). The critical parameters for a given propulsion device are the available thrust (T) to power (P) ratio, specific impulse (I_{sp}), and efficiency (η). The relationships between these mission and thruster variables are shown explicitly in Eq. (1) and Eq. (2):

$$\eta = \left(\frac{g}{2}\right)\left(\frac{T}{P}\right)I_{sp} \tag{1}$$

$$\Delta t = \left(\frac{m_{dry}}{P}\right)\frac{\left(gI_{sp}\right)^2}{2\eta}\left(\exp\left[\frac{\Delta V}{gI_{sp}}\right]-1\right) \tag{2}$$

where g is earth gravitational constant. From these equations, it is clear that there is a large trade space of mission elements and corresponding propulsive

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requirements. Although not addressed explicitly in the above equations, the on-board power system has a significant impact on mission planning and propulsion parameters, both in terms of the total power available as well as the specific mass of the propulsion system. This trade-space can be significantly reduced by considering missions of relevance and identifying those with the greatest potential payoff to Air Force and DoD interests. Increased payload to orbit and expanded on-orbit maneuvering are two areas of high payoff and, and when combined with projected advances in space power generation, point to high power electric propulsion as a prime area for future technology development.

2. SPACE POWER AS A PROPULSION SYSTEM TECHNOLOGY DRIVER

Significant improvements in both delivered payload and orbit transfer time are achievable using advanced propulsion systems. Advances in solar power generation systems are increasing the total amount of available on-board power as well as decreasing the power generation system specific mass, α_{PG}, both of which impact propulsion technology development. As an example of the impact of increased power, the spacecraft mass that can be delivered to geostationary earth orbit (GEO) using SOTA EP is shown in Figure 1, assuming a starting wet mass of 5000-kg. Results are shown for maneuvers starting at low earth orbit (LEO) and geosynchronous transfer orbit (GTO). For the transfer from LEO to GEO (400-km circular starting orbit), the use of EP more than doubles the delivered payload compared to using a chemical bipropellant upper stage. For the GTO case, the payload improvement spans the range of roughly 30%-60%, depending on the time allotted for the transfer. As revealed by the "60-kW" curves in Figure 1, the availability of advanced power systems dramatically reduces total trip times for EP-based orbit transfers.

The specific mass of the power generation system also has a significant impact on delivered payload and propulsion requirements. From Eq. (1), increasing I_{sp} at the expense of T/P increases delivered payload by reducing the propellant mass required to perform a given maneuver. However, increasing I_{sp} comes at a cost in terms of increased power generation system mass. There is a point where the increase in power generation system mass exceeds the reduction in propellant mass. Thus there is an optimum I_{sp} defined such that deliverable payload is maximized (or minimizes required propellant) within the constraints imposed by ΔV, α_{PG}, and Δt. As an example, consider a LEO-GEO orbital transfer maneuver requiring a total ΔV of 5.8 km/s and assuming thrusters with an efficiency of 60%. Although lower specific impulse electric propulsion systems (< 2000 seconds) typically operate with reduced efficiency, the assumption of 60% will not alter the trends derived from this analysis. Figure 2 illustrates the maximum delivered dry mass fraction to GEO, and corresponding optimum I_{sp} as a function of spacecraft specific power. Although ΔV and Δt impact the optimum I_{sp} and vary widely for different missions, this analysis provides an effective bound on future mission scenarios. A LEO-GEO orbit transfer represents an upper bound on ΔV for Air Force near-term to mid-term missions with 30 days providing an effective lower bound on trip times. Spacecraft specific power of 500 W/kg is considered an optimistic estimate for satellites using solar power generation in the mid- to far-term. This provides a range of thruster operating parameters and a well defined direction for propulsion technology development.

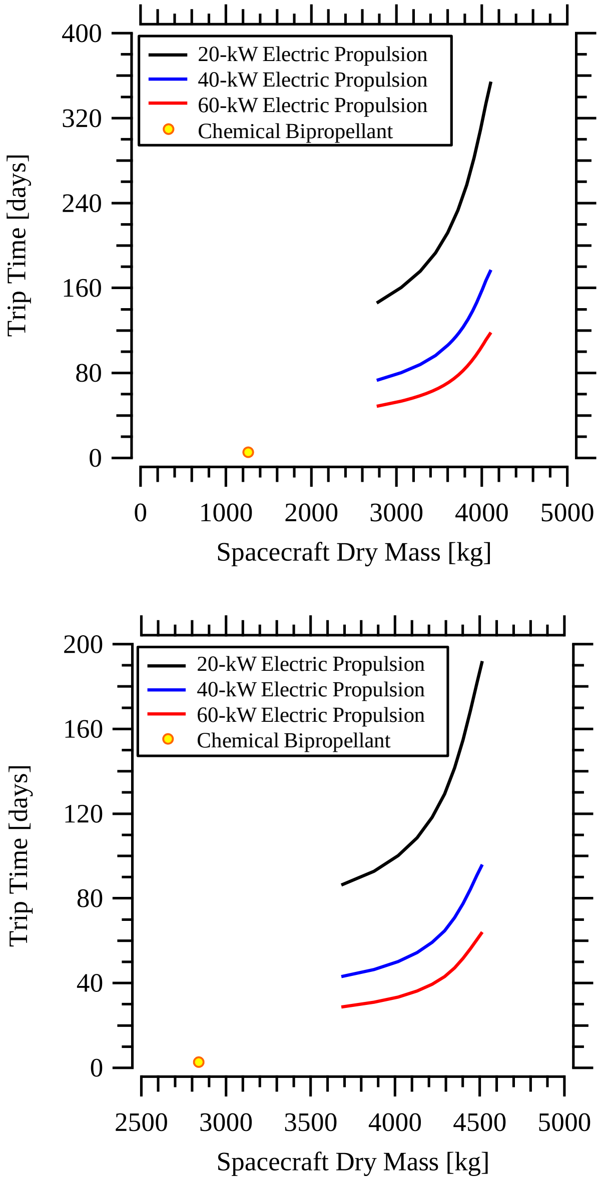

Figure 1 - Trip time required to complete an orbit transfer from LEO (top, ΔV=5.8 km/s) and GTO (bottom, ΔV=3.0 km/s) to GEO as a function of the spacecraft dry mass for various spacecraft power levels. In all cases, the starting spacecraft wet mass was taken to be 5000-kg.

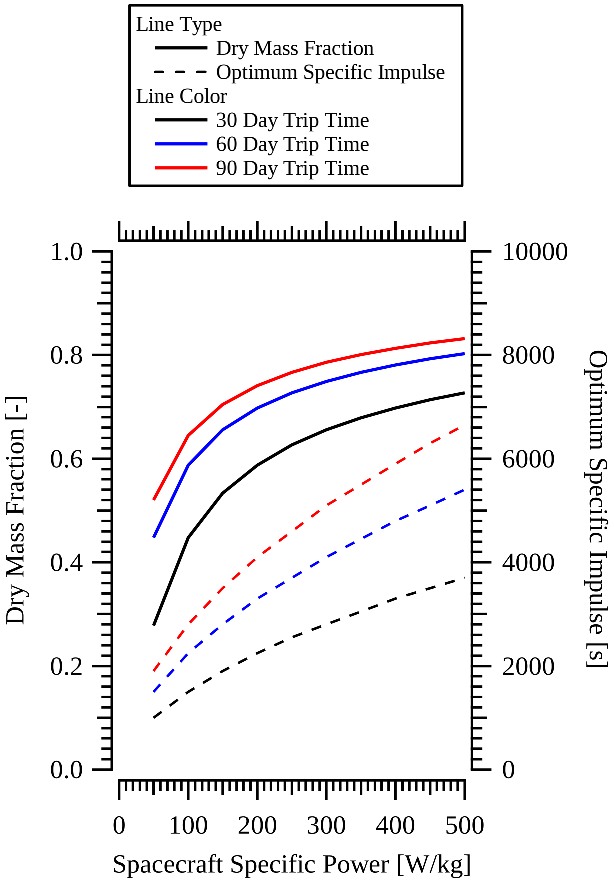

Figure 2 - Delivered dry mass fraction and corresponding optimum specific impulse as a function of spacecraft specific power for electric propulsion orbit transfer trip times of 30, 60, and 90 days. For all cases, 60% thruster efficiency is assumed and ΔV = 5.8 km/s (LEO-GEO low thrust trajectory).

Based on the analyses presented above, near-term and mid-term propulsive capabilities emerge, providing a basis for technology development efforts that are summarized below:

1. Spacecraft size and specific mass indicate the need for propulsion technology capable of taking advantage of increased available on-board power (100 kW – 200 kW).
2. For the foreseeable future, propulsion devices should operate over a relatively moderate specific impulse range (2000 s – 6000 s).
3. Propulsion systems should meet or exceed total efficiency of current technology ($\eta > 60\%$).
4. Low mass propulsion systems (< 1 kg/kW) are preferred based on mass trends of the power generation system.

3. HIGH POWER ELECTRIC PROPULSION RESEARCH AND DEVELOPMENT

The DARPA Fast Access Spacecraft Testbed (FAST) program has significantly progressed state-of-the-art high-power generation systems, with goals of achieving 50-80 kW of on-board power at specific power levels greater than 130 W/kg (approximately 8 kg/kW specific mass) [1]. As advancements in spacecraft power systems increase on-board power availability and decrease specific mass, the variation in optimal thruster specific impulse and power operating regime necessitates development of electric propulsion technologies for evolving mission needs. While contemporary Hall effect thruster (HET) designs are attractive for current and near-term Air Force missions, developments in power generation system capability increases the optimal specific impulse range of interest beyond the levels of current Hall thruster technology. In addition, the Hall thruster propulsion system mass, including power processing, becomes non-trivial compared to the power generation system mass. Minimizing the propulsion system mass and size becomes more advantageous as the power generation system specific mass and on-board power improves to and surpasses the level of DARPA FAST goals. Several evolving propulsion concepts may enable a viable high-power plasma propulsion device suitable for mid-term power levels from 20-kW to 200-kW. These concepts range from propulsion designs based on established Hall thruster system technology to basic research on advanced concepts in the laboratory demonstration phase.

Concentric Channel Hall Thrusters

State-of-the-art Hall thrusters are single channel devices for which mass scales nearly linearly with input power. As on-board power increases and power generation system specific mass decreases, traditional Hall thrusters become very massive. This issue may be mitigated by nesting multiple discharge channels in a concentric design to reduce the thruster specific mass, and has been investigated by several groups in the past decade [2,3]. Advantages of the concentric channel laboratory model design are derived from the shared magnetic circuit and significant reductions in thruster footprint, as illustrated in Figure 3. Preliminary studies based on existing engineering model and laboratory model HET designs indicate this approach may reduce the thruster specific mass to less than 1 kg/kW. The improvements associated with nesting multiple channels increases with discharge power, and the concept will be compared to other high-power propulsion alternatives in Section 4.

AFRL is currently supporting development of concentric channel Hall thruster technology by ElectroDynamic Applications (EDA) and the Plasmadynamics and Electric Propulsion Laboratory (PEPL) at the University of Michigan. The dual channel Hall thruster shown in Figure

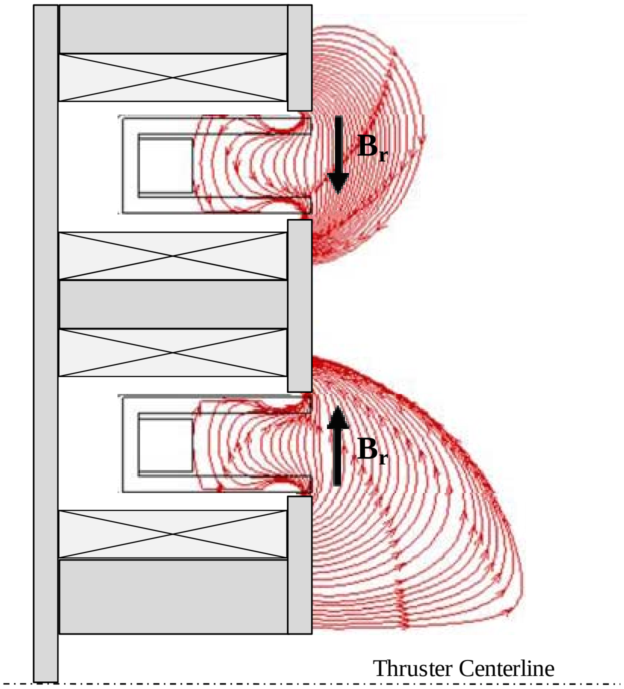

Figure 3 – Diagram of the concentric channel Hall thruster concept with two nested channels and a typical magnetic field topography. The net radial magnetic fields of the inner and outer channels are in opposite directions due to the shared magnetic circuit.

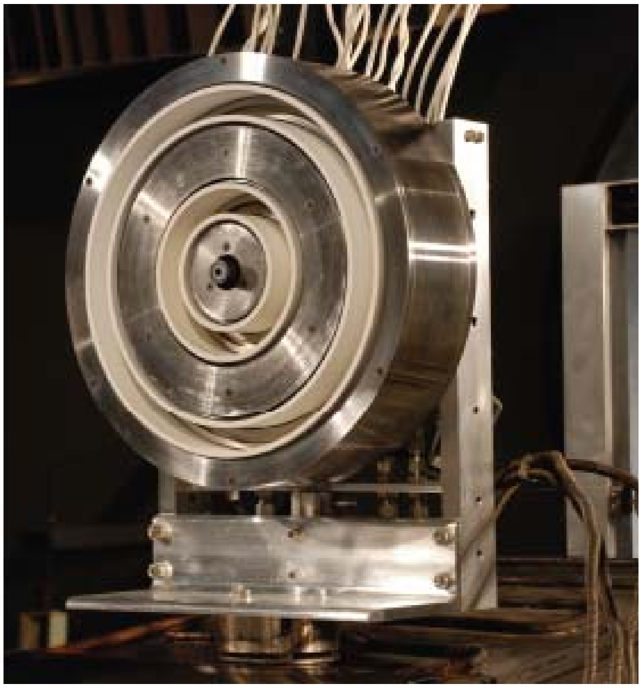

Figure 4 - Photograph of the concentric channel Hall thruster with centrally mounted cathode at the Plasmadynamics and Electric Propulsion Laboratory. (image courtesy of PEPL)

4 was developed based on past AFRL and PEPL design experience to maintain high performance at constant 6-kW power over a range of low to high specific impulse. The concentric channel Hall thruster features two nested discharge channels of identical width and length, with an identical anode cross-section and an internally mounted cathode. Past studies of low voltage HET characteristics have shown the *T/P* typically optimizes at a low discharge current density for a given anode potential. The inner channel may be used for high I_{sp} and low *T/P* operation (high current density), the outer channel is used for moderate I_{sp} operation (moderate current density), and both channels are used for low I_{sp} and high *T/P* operation (low current density). This expands the constant power, high performance operational envelope of current Hall thruster technology and minimizes thruster mass and volume for a given power level.

Preliminary studies are underway at PEPL with the two channel design shown firing in Figure 5. The thruster performance and plume will be characterized for several operating configurations and power levels. The thruster characteristics with dissimilar channel operation may result in improved coupling or expanded range of high performance. These results may lead to further investigation of the discharge coupling between channels and with the centrally mounted cathode. Past investigations of Hall thruster cluster operation have demonstrated high

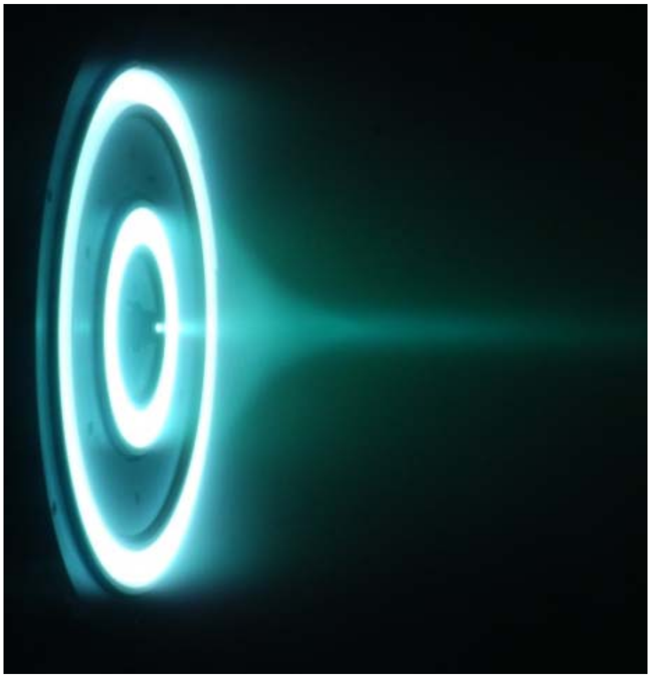

Figure 5 – Photograph of the concentric channel Hall thruster firing the Plasmadynamics and Electric Propulsion Laboratory. Combined power to the inner and outer channels is 6-kW. (image courtesy of PEPL)

performance operation with multiple cathodes or in a single-shared cathode configuration [4]. However, the local plasma properties may be affected in certain cathode configurations. The applied magnetic field topography in Figure 3 illustrates the opposite direction of the radial magnetic field components due to the shared magnetic circuit between the channels. This generates counter-rotating Hall currents in the inner and outer channel. It is unknown what instabilities and interactions may arise between the channels, including the breathing mode oscillations and rotating spoke instabilities that develop during high *T/P* operation.

Pulsed Inductive Acceleration Concepts

A primary advantage of high-power electromagnetic propulsion concepts over electrostatic thruster technology is that the electric fields are not used for direct acceleration of ionized particles. As a result, this class of electric propulsion is not space-charge limited and may operate at higher power and higher thrust densities compared to electrostatic propulsion. Inductive plasma accelerator concepts generate plasma through magnetic induction and accelerate through the Lorentz force. This minimizes plasma-wall interactions and eliminates the need for an electrode. These characteristics provide an important advantage over magnetoplasmadynamic thruster (MPDT) designs, where electrode erosion and lifetime are significant technical challenges.

Past research at AFRL has studied the formation and translation of plasmoids by field reversed configuration (FRC) technology [5,6,7,8,9]. While FRC devices originated in the fusion research community, the technology has transitioned to the electric propulsion community in several forms, including: plasmoid formation studies in the XOCOT program [5], plasmoid translation studies of an annular field reverse configuration (AFRC) device [8], the Plasmoid Thruster Experiment (PTX) [10], and the Electrodeless Lorentz Force (ELF) thruster [11]. A diagram of the AFRC configuration is shown in Figure 6. One advantage of the FRC generated plasmoid over other pulsed inductive plasma accelerator concepts, such as the pulsed inductive thruster (PIT) [12] or the faraday accelerator with radio-frequency assisted discharge (FARAD) [13,14], is the enhanced electromagnetic coupling between the thruster generated fields and the plasma. This increased coupling in FRCs results in less required input energy per pulse and increases the timescales for ionization and acceleration processes. The plasmoid is uncoupled from the external magnetic field, which eliminates issues associated with magnetic detachment. Thus, coupling in FRC devices is expected to increase the thrust density, increase efficiency, and minimize the thruster footprint.

Experimental investigations of pre-ionization techniques and plasmoid formation on the XOCOT at AFRL demonstrated low-voltage AFRC formation viable for spacecraft power systems (500-V to 1-kV) with energy levels on the order of 250-J to 450-J per pulse [5]. The discharge parameter space was evaluated over a range of voltages, discharge timing, capacitor charging, propellants, and pre-ionization techniques. Studies of FRC formation and compression in the XOCOT device is shown for a single pulse in Figure 7. These results focused efforts for enhanced discharge characteristics, including: high neutral fill densities, coil voltages greater than 500-V, and better pre-ionization uniformity. Xenon and argon propellants were studied due to the reduced ionization energy and heavier masses than hydrogen or deuterium, which make them more suitable for high-power space propulsion.

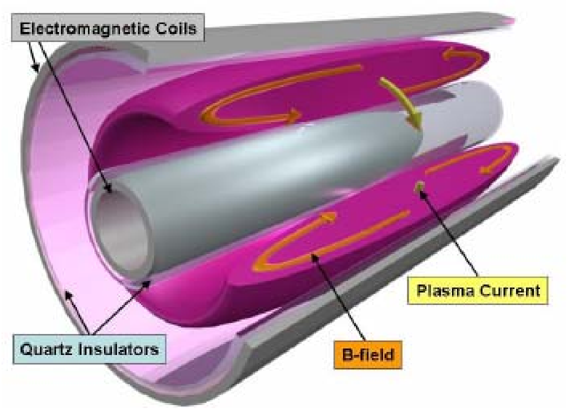

Figure 6 – Diagram of the annular field reversed configuration concept, illustrating the plasmoid and direction of the internal magnetic field.

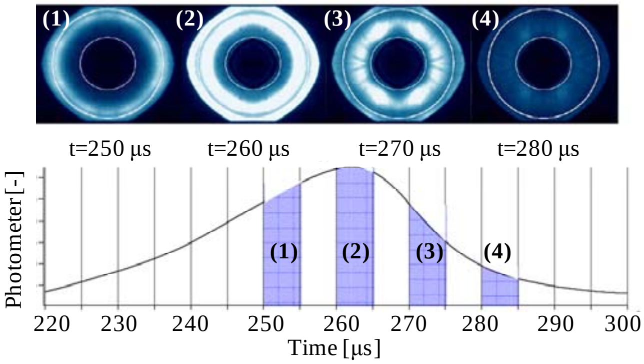

Figure 7 – DICAM photographs (top-down) of a single pulse during a 500-V XOCOT discharge over a 5 µs integration time (shutter speed). Photometer data shows the 5 µs integration period with respect to the pulse, and details the FRC formation and compression regimes, (1) initial formation and reversal, (2) radial compression and heating, (3) radial compression and rotational instability, and (4) instability related to radial expansion [7].

The AFRC device constructed for investigation of translation physics at AFRL is shown in Figure 8.

Figure 8 – Photograph of the annular field reverse configuration translation experiment at AFRL.

Preliminary translation studies of AFRC plasmoids at AFRL proved inconclusive [8], and indicated the JxB Lorentz force was insufficient to accelerate a coherent plasmoid [15]. AFRC translation research was continued in collaboration with the Ion Space Propulsion (ISP) Laboratory of the Michigan Technological University (MTU). This effort involved development of an analytical-numerical model of plasmoid acceleration to predict translational behavior and physics [9]. The model used a genetic algorithm and gradient-based numerical optimization to aid in the design of a new AFRC coil geometry and circuit properties. Fabrication is currently underway at AFRL, and probe-based translation studies will evaluate the time-resolved, spatial variation in ion density of translating FRC plasmoids. These translation experiments are expected to benefit a wide range of FRC propulsion concepts, and may lead to development of a laboratory model AFRC thruster for performance evaluation.

Although AFRL has focused primarily on AFRC technology, the 50-kW ELF thruster developed by MSNW is a promising FRC alternative. MSNW is a leader in FRC propulsion, and has advanced the ELF device shown in Figure 9 from the concept demonstration phase to a laboratory thruster design. The ELF utilizes a rotating magnetic field (RMF) to generate a large azimuthal current in the device. The diagram in Figure 10 illustrates the plasmoid formation and subsequent acceleration by the JxB Lorentz force term produced through a large axial magnetic field gradient [11]. Generation of the azimuthal current with an RF-discharge is expected to produce significant benefits, including reduced power system complexity and requirements. One advantage of introducing energy through the steady, transverse rotating magnetic field as opposed to a pulsed coil is the efficient conversion process of electrical energy to translational energy of the plasmoid. The strong coupling of the ELF concept is compared to the PTX and PIT in Figure 11. The decline in the Lorentz force (normalized to peak) with downstream distance from the initial maximum illustrates the difference in how the applied fields deposit energy and increase plasma momentum in the ELF. Prototype versions of the ELF device have demonstrated FRC formation, acceleration, and ejection.

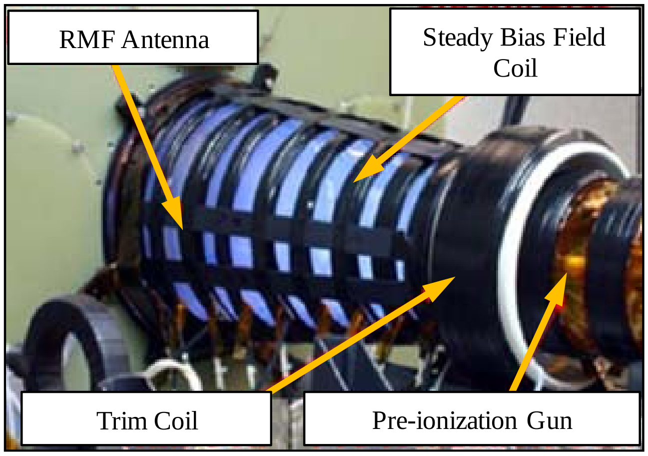

Figure 9 – Photograph of the ELF device, showing the RMF antenna and steady field bias coils [11].

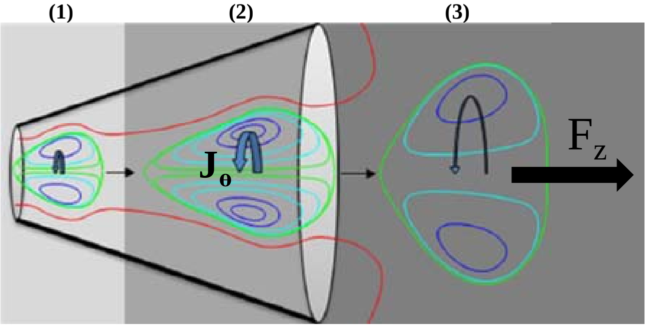

Figure 10 – Diagram of FRC plasmoid formation, acceleration, and detachment in the ELF thruster. Regions show the (1) high density plasmoid formation, (2) FRC growth and $J_\theta xB_r$ acceleration, and (3) plasmoid expansion and ejection [11].

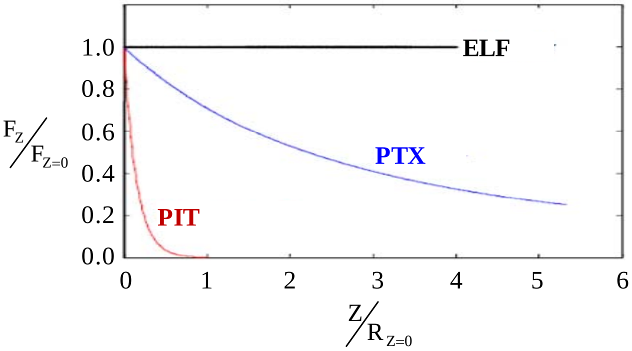

Figure 11 – Decline in the Lorentz force in the ELF compared to the PTX and PIT. Force (F_z) is normalized to the peak value ($F_{z=0}$) and downstream distance (z) is normalized to the device radius ($R_{z=0}$) at the peak Lorentz force. Note the length of the ELF device is approximately 4 radii [11].

Further development and experimental study of a laboratory thruster performance, plume characterization, and lifetime evaluation are required to establish the ELF thruster as a viable high-power alternative for Air Force missions.

4. COMPARISON OF HIGH POWER PROPULSION SYSTEM ALTERNATIVES

Performance and system specifications of the high-power propulsion alternatives discussed in the previous sections are evaluated in Table 1. The concentric channel Hall thruster is scaled to a 200-kW device with three nested channels, operating with 12-kW, 48-kW, and 140-kW on the inner, central, and outer discharge channels, respectively [16]. For comparison, the 200-kW concentric channel HET is compared to a cluster of three the single channel NASA-457M Hall thrusters operating at approximately 67-kW each. Performance and mass of the NASA-457M thruster cluster is determined using the individual thruster performance and mass characteristics [17]. It is important to note the 200-kW concentric channel thruster performance and mass are conservative estimates based on existing engineering model monolithic thrusters and the laboratory model concentric thruster developed at PEPL. The 200-kW power processing system mass is scaled from the analysis of HET power processing unit (PPU) attributes by Spores et al. [18], which was based on a common system power bus for multiple Hall thrusters. In the study, a 200-kW PPU was estimated at approximately 0.9 kg/kW for a high-power Hall thruster propulsion system.

The ELF device was scaled to 200-kW by MSNW [19]. This thruster is designed to operate from 10-kW to 200-kW, however, the technology scales to power-levels in the megawatt range. The high performance includes conservative estimates of frozen flow losses, discharge circuit losses, and an additional factor to account for unknown loss mechanisms such as radiation, excitation, and divergence. Values are based on measured ion velocity and the exit plasma temperature of smaller scale channel configurations. Although the ELF propulsion system is an emerging technology requiring systematic characterization and optimization to evaluate the operational performance envelope, preliminary studies of the thruster impulse have been conducted with a highly sensitive ballistic impulse pendulum. The ballistic pendulum was calibrated at NASA Glenn Research Center with a micro-Newton thrust stand in VF-3, and demonstrated FRC plasmoid impulse bits greater than 1 mN-s for a single 50-J pulse [11].

The Hall thruster and ELF propulsion designs are evaluated with the stated design goals for the well-publicized VASIMR VX-200, a nominal 200-kW dual thruster system currently in development by Ad Astra for the International Space Station. This concept is currently in development, and performance is estimated based on smaller scale laboratory devices [20,21]. The specific mass is estimated from a mass model suitable for estimation of a 100-kW to a megawatt-class VASIMR thruster. However, the total mass of the VASIMR propulsion system including all auxiliary hardware is unknown, and may be higher than listed in Table 1.

Table 1. Estimated performance of high-power propulsion scaled to 200-kW [16-21].

	Concentric Channel HET (3 channels)	**NASA-457M Cluster (3 thrusters)**	**ELF-375 (200-kW design goals)**	**VASIMR VX-200 (design goals)**
Input Power	200 kW	200 kW (3 devices at 67-kW)	200 kW	200 kW (2 devices at 100-kW)
Specific Impulse	1300 – 5000 s	3000 s	1500 – 5000 s	5000 s
Thrust	5 – 14 N (25 – 70 mN/kW)	8.4 N (42 mN/kW)	7 – 18 N (35 – 95 mN/kW)	5 N (25 mN/kW)
Mass Flow Rate	100 – 1100 mg/s (Xe)	280 mg/s (Xe)	140 - 1200 mg/s (Xe)	130 mg/s (Ar)
Efficiency	45% – 64%	63%	65% – 85%	60%
Specific Mass	0.5 kg/kW (thruster) 1.4 kg/kW (thruster, PPU)	1.3 kg/kW (thruster[4]) 2.2 kg/kW (thruster, PPU)	0.25 kg/kW (thruster) 0.7 kg/kW (thruster, PPU)	1.5 kg/kW (thruster[5])
Major Thruster Dimensions	0.65-m diameter 0.10-m length	0.55-m by 1.6-m 0.15-m length	0.38-m diameter 0.5 meter length	1.5-meter diameter 3.0 meter length

[4] Specific mass of the NASA-457M is based on the 50-kW design point for an 80-kg thruster mass. This will be decreased if the individual thruster operating power of 67-kW is used.

[5] Scaled from a MW-level device

Estimation of specific mass and performance of the Hall thruster designs have the lowest uncertainty, since they are based on existing hardware of a mature technology. The ELF and VASIMR propulsion concepts have the largest uncertainty, as they are in the technology development stage. It is also important to note the VASIMR will operate over a wider range of specific impulse than indicated by the design goals. However, it is expected the design goal is a representative assessment of the VASIMR technology for the limited scope of this qualitative review based on expected performance.

The comparison in Table 1 reveals the 200-kW concentric channel Hall thruster would have a lower specific mass, volume, and footprint than the cluster of three NASA-457M Hall thrusters. In this case, the cluster of Hall thrusters is expected to have a footprint approximately 250% larger than the 200-kW concentric channel thruster. The performance is expected to be similar. The concentric channel thruster also shows advantages over the VASIMR VX-200 design goals and estimated performance. These include a lower specific mass, smaller thruster footprint, and expanded capability for low specific impulse operation at high efficiency. This low I_{sp} operation enables higher T/P for time-sensitive maneuvers. Primary advantage also include flight heritage, demonstrated high performance over a range of operation, and extensive investigations of Hall thruster loss mechanisms and life-limiting processes. It is noteworthy that a cluster of existing NASA Hall thrusters meets the performance capability of VASIMR, and may have similar a propulsion system specific mass when all auxiliary hardware is accounted for. This analysis indicates existing Hall thruster technology may be suitable and competitive for mid-term power levels. However, additional trade-studies are warranted that compare these propulsion systems with other emerging high-power propulsion concepts.

The ELF thruster offers the possibility of very low propulsion system specific mass with a large performance envelope at high efficiency. Benefits of the ELF thruster include the electrodeless design and the magnetic isolation of the plasmoid, which minimizes thermal contact and chemical wall interactions and thereby increases thruster lifetime. This propulsion concept also has the added benefit of operation with a wide variety of propellants, including argon, krypton, air, and possibly emerging green propellant alternatives. In contrast to other pulsed inductive concepts and FRC designs that utilize inductively driven currents, the RF driven azimuthal current in the ELF has less demanding power electronics requirements that can be satisfied with existing commercial solid state technology. Extensive investigations of the ELF thruster performance and plasma properties are scheduled for 2010.

5. SUMMARY

Improvements in next generation space solar power systems are reducing the power generation system specific mass and increasing the level of total on-board power. Combined with envisioned mission requirements, this has had a profound effect on the direction of AFRL technology development. Current research is focused on propulsion devices capable of processing large amounts of power, at moderate specific impulse and high efficiency, with particular attention paid to concepts capable of operation at minimal specific mass. Both concentric channel Hall thrusters and FRC-based propulsion have the potential to meet future Air Force needs and compare favorably against other well-publicized concepts, such as VASIMR. Future efforts will be geared toward maturing the identified concepts to validate system parameters and evaluate performance in a representative environment.

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