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Future Military Spacecraft Power Systems

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ABSTRACT

During the past several years, a number of military space mission studies have concluded with interesting new information on the future needs and directions of military spacecraft power systems. In all cases, the trend to higher power level, for continuous as well as pulsed requirements, is clear. Although precise dates are impossible to define at this time, military spacecraft of the next twenty years will require steady state electrical power in the range of 10 to 100 kilowatts with pulsing capabilities in the megawatt region. As such, the major thrust of the DOD space power technology program focuses on the development of military power systems which will extend capabilities to the upper end of these ranges while maintaining technology applicability to the current lower level power requirements. Because of assumed delivery and orbital transfer limitations, the weight and volume of these high power systems must be kept as low as possible without sacrificing the reliability and lifetime of the power systems. These constraints necessitate the early application of very advanced solar/array battery systems and possibly nuclear reactor power supplies. As usual, the survivability of the power systems to natural and imposed radiation environments remains a concern for military systems. In addition to the above, the need for spacecraft system autonomy is being emphasized and programs to enhance the fault-tolerance and energy management of future military power systems are being initiated.

INTRODUCTION

Power system technology for future military spacecraft applications faces several development challenges, some evolutionary and some revolutionary. The Department of Defense is developing and planning spacecraft missions from low earth orbit to geosynchronous and higher orbits. The power systems for these spacecraft must be hardened and/or survivable to a variety of potential threats (nuclear, laser, electromagnetic, conventional weapons). Future military space operations may require autonomous operation from space, hence the power systems must become autonomous (self monitoring and self correcting). Performance (weight and volume, degradation, and life) of the power system remains a key system design issue, because of STS/IUS and continuing payload weight constraints to non LEO.[1,2,3] Scale up to the 100kw regime represents a new and important technology challenge.

EVOLUTIONARY NEEDS

Military spacecraft missions in the communications, navigation, and meterological areas will demand evolutionary power technology improvements. The power requirements for these areas are forcasted to grow moderately from the current 1-2kw regime to the 5-15kw by the 1990's due to evolutionary mission changes. Combined frequency communication systems and the need for smaller, more diversified ground communication facilities will cause growth in communication satellite power requirements. In space data processing and enhanced communication crosslinking will require increased spacecraft "housekeeping" power. Figure 1 shows a historical, current, and near future trend for some operational and experimental evolutionary spacecraft missions of interest.

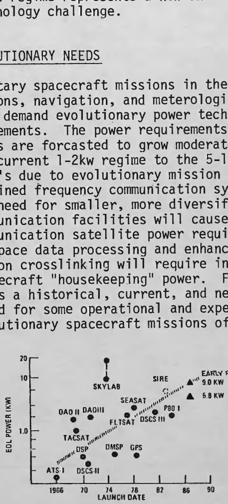

FIGURE 1 EVOLUTIONARY SPACE POWER SYSTEMS REQUIRE

The system impact of power system weight has been pointed out in recent Air Force and Navy studies concerning experimental or near term space based radar missions, which will require 5-15kw[1,4]. Due to spacecraft weight limitations, battery undersizing has been considered, allowing only partial operation during satellite eclipse periods. Weight limitations, hence, power system performance, in half synchronous and higher orbits are equally critical. In most cases, more power could be used for the missions if available at a modest system weight penalty. Typically 20-30% of current spacecraft payload weight is allotted to the power system.

For these evolutionary systems, life and power system reliability design goals and requirements are increasing to minimize replacement costs and system life cycle costs. LEO and GEO life requirements of greater than 5 and 10 years respectively are becoming common[1,2].

REVOLUTIONARY NEEDS

While the growth in traditional military space missions is predicted to increase power requirements to 5-15kw by the mid 80's, a more ambitious set of mission categories is being considered by Air Force planners which place revolutionary design requirements on the power system[2]. These include surveillance, defense, special communication, propulsion, and other concepts aimed at operations in the post 1990 period.

Space surveillance systems involve both IR and radar techniques [1,4,5] Primary emphasis has been placed on developing electro-optical surveillance technologies with more recent emphasis in developing technology to support space based radar systems. Electro-optical system power requirements will increase from present levels as systems evolve which must detect and tract cold bodies. This leads to focal planes requiring active coolers. Unless the performance of active coolers increases, prime power approaching 100kWe will be required for such systems. Space-based radar concepts may require from 10kWe to as much as 400kWe[2]. These requirements will vary as a function of the altitude, coverage, radar cross section of the targets, and tracking requirements.

Long range DOD requirements in the communication field exist for high power, space-based laser communication satellite. A laser communication satellite would incorporate the use of electric discharge laser devices as a transmission link to communicate with submarines while still submerged. An operational device may require as much as 100kWe of prime power. This requirement may be lowered as the efficiency of the laser increases.

An important potential military role in space is the defense of unmanned and manned space systems. The military will be tasked to protect both civilian and military systems in space. This role will likely include both quick response space rescue and defensive missions against hostile action. Defense methods will include passive hardening to potential nuclear, laser, conventional weapons, jamming, and perhaps laser or other weapons.

With the requirements of inherently larger and heavier space systems, a need for increased payload to high orbits is apparent. These space system concepts would utilize high specific impulse, low thrust, electric propulsion devices. High electric power sources in the range of 100-400kWe will be required. Air Force studies have identified that 200-1000kWe would enable the use of magnetoplasmadynamic (MPD) electric thrusters generating several lbs of thrust each. These devices would enable the orbital transfer to geosynchronous orbit of payloads in excess of 60,000 lbs in an economical fashion. Although transfer time will be longer when compared to chemical propulsion devices, at this high a payload weight, the life cycle cost heavily favors electric propulsion regardless of shorter transfer time advantage of alternative propulsion systems.

Other advanced space-based systems would also require high power. A space-based device that would neutralize radar coverage could meet megawatts of prime power. The full range of power required is dependent on mission requirements.

The escalation of power requirements from the 1kw to 100kw regime and beyond introduce some difficult power system development decisions. A reasonable resource mix for near term and far term technology development support must be established. An experience base and precedence for operating larger and larger space power system must also be established. The use of nuclear reactor power systems for high power missions will occur only if major resource commitments are devoted to their development. These resources cannot be obtained by diverting solar power technology resources without impacing evolutionary systems needs. The options for future development, resultant capabilities, and suggested time oriented development objectives are presented in the following sections.

Power Trends. Figure 2 shows the projected high and low power system level trends projected for the twenty years.

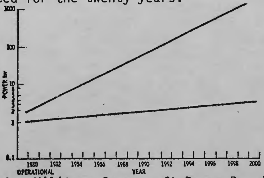

Fig 2. Military Spacecraft Power Requirements Projections, 1980-2000

Life Goals. Although some spacecraft systems are limited to 3-5 years life in low earth orbit (LEO) due to battery cycle life and/or Van Allen belt radiation degradation of solar arrays, no significant trend towards longer LEO life requirements can be identified. LEO missions tend to be limited by technical observance of the payload function (e.g., surveillance). In the future, on-orbit maintenance appears to offer favorable cost benefits for low earth orbits. By contract, synchronous orbit (e.g., communications) life goals of 10-15 years are paced primarily by investment cost amortization considerations.

Performance. Present LEO solar orbit power systems are relatively heavy (2-3 w/lb) due primarily to the energy storage (battery) weight. Typically 40% of the overall power system weight is attributed to the battery while the remaining weight percentages are divided approximately equally between the solar array and the power distribution and control subsystems. For geosynchronous orbit applications, the battery, solar array, and power distribution and control subsystem weight percentages are approximately equal. Battery weight is reduced substantially for geosynchronous applications since battery cycle life-depth or discharge limitations are relaxed. Attainable solar power system energy density for present geosynchronous applications are in the range of 6-7 w/lb. Solar power system per copy cost is in the range of 1-2 million dollars per kilowatt.

The current solar power systems may be designed to meet JCS Nuclear Survivability Design Criteria within relatively modest (∿10%) weight and cost hardening penalties. Hardening penalties to envisioned laser threats appear to be much higher (≥50%). Efforts are presently underway within the Air Force to address laser hardening of the power system.

Present nuclear power systems applications with DOD are limited to a few experimental applications. Radiosotope Thermoelectric generators are relatively heavy (0.5 - 1 watt/lb) and expensive, although their reliability is more than competitive with solar power systems. Isotope dynamic power systems (e.g., Organic Rankine, Brayton cycles) are presently under development by the DOE as alternatives to solar power systems, but their relatively heavy weight (2.5 - 3 watts/lb), high cost and lack of demonstrated long life make them relatively unattractive to systems planners. Nuclear reactor power subsystem offer significant performance advantages over solar at higher power levels. Advanced reactor power systems in the 100 kilowatt range could provide energy densities of 50 w/lb or more, as compared to 25 w/lb for solar power, depending on the specific design concept and energy conversion scheme. Presently, DOE and NASA are pursuing only limited component technology development programs; major resource investments are required beyond the modest levels presently being invested if reactor power systems are prototyped, flight qualified and become operational. The thrust of the high power missions for the 1980-2000 period may give impetus to enhance development. The nuclear reactor power system projected energy density, inherent compactness and probably ruggedness make it an ideal candidate for high power military applications requiring maneuverability, survivability and long life.

Figure 3 shows the present (1980) and projected (2000) space power morphology. Today's capabilities include low power silicon photovoltaic-nickel cadmium battery solar power systems and isotope thermoelectric system. By 2000, solar power systems for military applications will improve to 25-30 w/lb for geosynchronous applications, and 10-15 w/lb for low earth orbit missions. Performance in excess of 50 w/lb is anticipated from advanced reactor-static conversion systems by 2000.

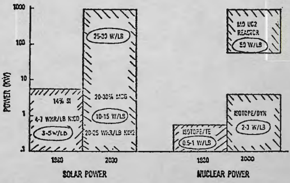

Fig. 3 Current and Projected Spacecraft Power Systems Regimes of Applicability

Figure 4 shows the anticipated performance improvement trends for solar power system obtainable via technology transition from present photovoltaic and battery types to more advanced devices. Major reductions in solar array weight will be realized through cell efficiency improvements via silicon to gallium arsenide to multi-bandgap cells transitions. Energy storage weight reductions will be placed by transition from nickel-cadmium to nickel-hydrogen to high energy density molten salt battery technology.

Figure 5 illustrates anticipated performance vs. power level trends for reactor-static conversion systems, extrapolated from data reported in reference 8. The technology for heat pipe cooled reactor thermoelectric systems could be system ready by early 1990's if development and qualification resources are invested in the 1980's. Higher temperature, higher performance reactor thermionic systems based on the same heat pipe cooled core to converter concept could be developed by 2000.

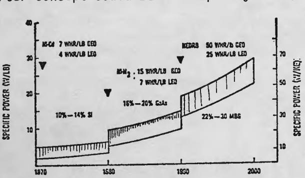

Fig. 4 Solar Power System Technology Evolution

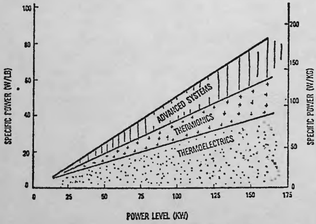

Fig. 5 Nuclear Reactor Power Systems Performance vs. Power Projections

Survivability. Military spacecraft power systems must be survivable to several natural and manmade threats. Present solar power systems are degraded by natural radiation over the mission life. Synchronous orbit degradation for long life missions can be as high as 30%. Some long duration missions at 5000-6000nm are completely infeasible due to life limiting solar cell degradation by trapped radiation or by radiation enhancement threats caused by potential nuclear weapons detonation in the belts. Solar array charging and subsequent high voltage breakdown by natural or manmade causes are also a design issue.

Hardness to nuclear weapons has successfully been demonstrated for solar power systems for threat criteria defined by the Joint Chiefs of Staff (JCS). Only modest weight and cost penalties (10%) are imposed on the power system. Laser threat hardening is presently being addressed for solar power systems and the hardening penalties may exceed 50% under some engagement scenarios. Details to harden power systems to laser threats are classified, but several generic approaches are being considered from component, subsystem, system and system operation and deployment strategy standpoints. Desirable technology capabilities may include solar arrays capable of maneuvering, retracting or orienting against the threat. Other design alternatives such as concentrating photovoltaic systems may offer hardness advantages (and perhaps cost advantages) over conventional hardened planar arrays.

Another survivability issue coupled to life and reliability is autonomy; that is, the ability of the spacecraft to function independent from ground command if necessary. From a power system standpoint, this requires fault diagnosis and correction, attack sensing and defense response, and self management under load switching and power control operations.

Availability and Cost. For the envisioned mission scenario, the need for high power (25-100kw) spacecraft power systems by the early to mid-1990's is projected by a number of military mission planners. This high power mission tends to be revolutionary (first employment) missions. However, growth versions of continuing traditional military space missions also underwrite the need for survivable spacecraft high power technology. Lower and medium power (1-25kw) requirements will continue and the military power technologist must address both in future development activities.

The performance incentives desired for future power systems will likely increase the costs of power systems over the present $1-2 million dollar per kilowatt range, irrespective of inflation considerations. Major investments in technology development for high power systems (on the order of hundreds of millions of dollars) will be required by virtue of their scale. Tens of millions of dollars will be invested in supporting device technology efforts to meet efficiency, hardness, and life objectives. The rule of thumb used today in allocating 10% of the system cost to the power system may be passe when considering the scale and performance requirements envisioned for these advanced missions. It should remain as a design reminder, however. The DOD is constrained to accomplish its national defense goals under a myraid of politico-economic constraints. The point to be made is that the least expensive way to accomplish the mission objectives within the life cycle cost design philosophy is chosen by DOD planners. In the space power arena, solar power systems have been chosen, in the main, over competing nuclear power systems for the relatively low power missions of the 1960's and 1970's primarily because of cost. This same driven selection methodology will likely continue. Higher cost, mission enhancing alternatives are difficult to "sell" if basic mission objectives are met with a lower cost approach; i.e., mission functions are often set by total cost rather than total capability.

Outline for an Integrated Development Approach

Scope. The military mission planners and spacecraft designers have established a set of needs for future spacecraft power systems which significantly challenge the power system community. The needs included much improved performance (i.e. 40-80% weight reductions), multithreat survivability, and tenfold growth in available power. Subcutaneous needs include much improved power processing and thermal management techniques, reduced degradation, and enhanced on-orbit maneuverability.

A new category of short duration "refuelable" power system (100kw, 1-7 day) may be employed to conduct space operations and support missions. This technology will involve development of an advanced H_2O_2 fuel cell, high energy density primary battery or turbine generator auxiliary power unit.

Technology Options. The solar power technology base available from basic and applied research includes a number of maturing photovoltaic concepts (GaAs, multi-bandgap, composite cells, array concepts [lightweight concentrators, integral array-radiators, graphite-alumina structures] and energy storage concepts [Ni-H_2, molten electrolyte batteries, flywheels, inductive storage]).

The nuclear technology base available includes the DOE heat pipe cooled Mo-O_2 fueled thermoelectric reactor concept and improved heat source and converter variants of that design.[7] Radioisotope power systems will likely find special purpose, but limited application for future missions.

Parallel Development, Solar and Nuclear. It is clear that both solar and nuclear power systems will be required to meet future missions needs. Solar power will continue to be the workhorse power system for the numerically superior, evolutionary requirements of 1-25kw. Ultimate solar power energy densities of 25 w/lb appear achievable within the next 20 years; nuclear reactor power systems promise energy densities in the range of 50 w/lb or greater in the higher power range of interest (50-100kw). High power solar power systems will likely find civilian near earth applications in the range of 100-250kw; military requirements in this range will probably employ nuclear reactor power systems due to survivability and maneuverability demands of this mission. Although much uncertainty remains in future missions and attainable power system performance characteristics, it is clear that the development path for both high power solar and nuclear reactor systems is both long and expensive. Significant resources must be expended during the eighties to assure availability of these power sources in the nineties.

SUMMARY AND CONCLUSIONS:

Space power systems will play a vital role in realizing the goals of future generation space vehicles. Planners will be concerned with the following issues in arriving at a power system technology decision; reliability, survivability, volume, life cycle cost, availablity, system weight and other performance factors which impact system "risk".

Space systems will be tasked to perform autonomous operation. Signal processing will be performed onboard rather than on the ground. Survivability constraints will be harsh as new and evolving threats to spacecraft security arise.

Current military space power systems are generating about 2kWe prime power. Next generation space systems will require 5-15kWe prime power. The lower power regime will be those required by weather, communication, and navigation satellites. The higher power regime are requirements for various space surveillance systems. Near term electro-optical surveillance systems may need as much as 8kWe prime power, while space based radars will require at least 10kWe.

Without long lead technology programs to advance the scale of space power systems, key mission areas and operations in space may not be realized. New opportunities which hold potential revolutionary changes in military capabilities in space will be forfeited. In light of future high value of military systems, advanced power systems should be developed to support both the evolutionary and revolutionary mission needs of the late 1980's and 1990's.

Currently, power system technology readiness is being limited by available development funding. To meet the performance, scale-up, and technology ready-mission commitment dates described here, significant increases in development resources are required.

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