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THE SURVIVABLE POWER (SUPER) SUBSYSTEM DEMONSTRATION PROGRAM

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ABSTRACT

This paper presents an overview of the Survivable Power (SUPER) Subsystem Demonstration program. The program is discussed in terms of rationale and needs for increased survivability and power levels for satellite solar power subsystems, the technical approaches being investigated on both the component and subsystem levels, and the specific requirements and programmatics. A summary of current progress achieved in the program is presented.

1. INTRODUCTION

SUPER is a development program which will provide and demonstrate survivable power technology for near-term military satellite programs. Satellite survivability to military threats is becoming increasingly important to many diverse DoD missions. One of the most vulnerable parts of any satellite is the power subsystem. SUPER represents a solution to this vulnerability by integrating many recently developed component concepts into a full power subsystem. The SUPER program will result in a optimized solar power subsystem demonstrated by thorough ground testing and a space flight demonstration. The program is funded by the Strategic Defense Initiative Office and is being managed by the Wright Research and Development Center at Wright-Patterson AFB, Ohio.

1.1 Background

Until recently satellite survivability to military threats was not an important issue because anti-satellite weapon technology was immature. Currently many types of anti-satellite weapons are available or are being developed. These include lasers, nuclear warheads, high velocity projectiles, and microwaves. This anti-satellite technology becomes a very important and dangerous threat when considering the growing importance of our satellite force to military missions. Satellites now provide key links in surveillance, early warning, communications, navigation, and meteorology to the Air Force, Army, and Navy.

Because of these military threats, satellites currently being designed for SDI and the Air Force require much higher survivability levels than previous or current satellites. In the electrical power area, many component technologies are being developed to meet the survivability requirements related to photovoltaic, nuclear, and solar dynamic power systems. However, no subsystem-level demonstrations based on advanced component technologies have taken place to build the required confidence in the overall power subsystem's ability to generate power and be survivable to the wide range of threats.

Since photovoltaic subsystems are the most advanced of the survivable technologies being developed, each of the SUPER approaches is being designed around a photovoltaic concept. To enhance technology transition and to insure that survivability is considered for all power subsystem components, SUPER is being developed at the subsystem level. Thus, everything that is required to provide a "wall plug" to a satellite is part of SUPER, including solar arrays, batteries, power conditioning and control, thermal management, array pointing and tracking mechanisms, array deployment mechanisms, and associated structures.

1.2 Program Rationale

Presently Air Force and SDI satellites have two categories from which to choose power subsystems. The first option is to employ existing components. This choice gives the designers a high level of confidence in the components since there is a database resulting from qualification and operational performance of similar hardware. However, this approach does not provide the level of threat survivability required of military satellites. The other current option is to build the subsystem with components from technology programs which have developed hardware to survive the threat environment. The potential shortfall of this selection is the increased risk of baselining components which have not been space qualified or tested, thus presenting a low level of confidence in their operational capabilities.

SUPER bridges both the technology and confidence gaps between these two categories by designing, building, qualifying, and space-flight testing a power subsystem which has been proven to withstand the full suite of hostile threats.

1.3 Objective

The essential objective of SUPER is to develop a power subsystem which is survivable to the full range of military threats and is practical enough to allow numerous satellite programs to use the technology. Practicality primarily addresses cost and weight, but it also encompasses issues such as reliability and design flexibility. In most areas, the SUPER requirement is to be competitive with existing "off-the-shelf" technology. For example, the power density of the subsystems being developed is in the 3 to 6 watts-per-kilogram range while most current subsystems are in the 3 to 4 watts-per-kilogram range when all the same pieces are included.

1.4 Approach

The approach to SUPER is driven both by technologies and by programmatics. The two are not inseparable due to the fast-paced development needed to meet technology freeze dates and program schedules for the various satellite System Program Offices considering using SUPER technology for their power subsystems. Below, an overview of the programmatics is given and then the technologies of interest are addressed by giving a synopsis of the applicable requirements.

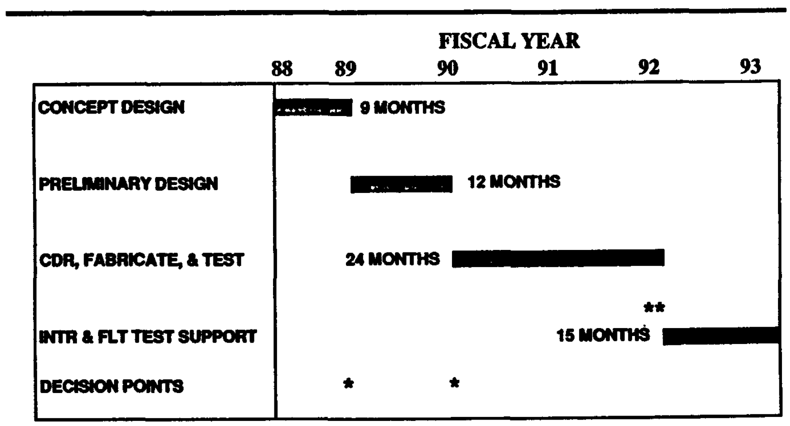
1.5 Competitive Strategy

The SUPER program implements a competitive strategy in order to develop the best design option and to reduce the risk inherent in producing a fully tested flight-qualified subsystem in three-and-one-half years. Four nine-month-duration Phase One contracts were awarded. Phase One gives the competitors the opportunity to fully develop their concepts. At the end of Phase One (May 1989) the Government held a Concept Design Review and decided which of the four concepts would be continued into Phase Two. These contractors develop specific designs for the flight experiment and in one year (April 1990) a Preliminary Design Review is held to choose which of the contractors will continue on to Phase Three. The final remaining contractor builds and tests the qualification subsystem for ground testing and the flight demonstration subsystem. This contractor delivers the flight subsystem to the flight vehicle integrating contractor and supports this integration and the flight test in Phase Four.

2. PROGRAM SCHEDULE

The program schedule is shown in Figure 1. Phase One, Concept Design, ended in May 1989 with the downselect from four contractors. The Preliminary Design phase, Phase Two, is twelve months in duration and ends in May 1990 with the selection of one design. The largest portion of the program is the twenty-four month Phase Three wherein the hardware is fabricated, tested, and delivered to the spacecraft integrator. Phase Four lasts 15 months and is a support effort for the integration and flight test.

SUPER PROGRAM OVERVIEW



** SUPPORTS INTEGRATION AND FLIGHT TEST CONTRACTOR

FIGURE 1

2.1 Phase One

Phase One was the concept design phase. Here the four competitors produced the baseline design for the flight experiment plus four point designs: a two kilowatt nominal power, five year lifetime, five-hundred kilometer orbital altitude Mission A; a fifteen kilowatt nominal power, seven year lifetime, two-thousand kilometer orbital altitude Mission B; a forty kilowatt nominal power, seven year lifetime, ten-thousand-four-hundred kilometer orbital altitude Mission C; and a six kilowatt nominal power, ten year lifetime, thirty-five-thousand-eight-hundred kilometer orbital altitude Mission D.

Included in the Phase One work were component trades and analyses, survivability assessment and optimization, and definition of components critical to the design in light of the short time necessary for development.

Four contracts were signed for SUPER in August 1988. The prime contractors are Boeing Aerospace in Kent, WA; Lockheed Missiles and Space Company in Sunnyvale, CA; Martin-Marietta Space Systems Company in Denver, CO; and TRW Space and Technology Group in Redondo Beach, CA.

2.2 Phase Two

Phase Two is the preliminary design phase. Here the contractors will design specifically for the flight test. Specific design requirements are being set, hardware prototypes will be built and tested for study, the development of items identified as critical components will take place, and a failure modes and effects analysis will be performed. In addition, cost proposals for Phases Three and Four will be prepared and submitted (these last two SUPER phases were bid on a not-to-exceed basis in the original proposals).

2.3 Phase Three

Phase Three is the critical design, fabrication, and qualification phase. The final selected contractor will build on the results of the first two phases to develop critical design specifications for the qualification and flight hardware. Test requirements will be developed for functional tests, qualification tests, and acceptance tests. Survivability testing of key components and major subsystem elements will be carried out. Manufacturing drawings for the qualification and flight hardware will be developed and the two sets of hardware will be built and tested. The contractor will also support interface meetings with the flight vehicle integrator.

2.4 Phase Four

Phase Four is the integration and flight test support phase. This phase requires the SUPER contractor to support the flight vehicle integration, and give range, countdown, on-orbit, and flight data analysis support.

3. REQUIREMENTS

Paragraph five of the Statement of Work outlines the requirements for SUPER. This section contains both hard requirements and some design philosophies which are to be incorporated. A summary of the requirements follows.

Military satellite missions are planned in a wide range of orbits from low Earth orbit to geosynchronous Earth orbit and beyond. Mission point design orbits were discussed earlier. The power subsystem is to be survivable to the natural environments associated with the various orbits as well as to the hostile military threats. The SUPER designs are required to achieve survivability to a range of military threats including those produced by lasers, nuclear weapons effects, high power microwaves, pellets and projectiles, and are also required to withstand the mechanical loads induced by spacecraft maneuver levels. Some threat values are given as a range indicating a minimum requirement at the low end and a goal for the power subsystem at the high end. For these cases the contractors will assess the effect on the subsystem parameters of designing to meet the goal and, based on this assessment, determine the optimum design approach.

Baseload power levels of two to forty kilowatts are expected for military satellites in the near future. The SUPER subsystems will be designed to be modular, such that maximum interchangeable use of common components can be accomplished, for power subsystems operating over this range of power levels. The power subsystem weight is required to scale at least linearly with power such that when the power level is increased by some factor, the size and weight of the power subsystem will be increased by no more than that same factor. Based on normal operating conditions at end of life, the subsystem will deliver a minimum of two watts per kilogram with a goal of five watts per kilogram. The mass includes all components associated with the SUPER subsystem.

The electrical power conditioning and distribution system is to be designed such that the subsystem performance is optimized. Both AC and DC distribution systems are to be considered and various voltage levels will be investigated. Power subsystem autonomy is to be maximized such that ground station command and control is minimized. The subsystem will be designed to accept and respond to ground and/or vehicle commands required for proper operation and safety. A predetermined salvageable power capability is to be a feature of SUPER. Such a capability would allow time-shared/limited/degraded operations during most failure modes affecting the power subsystem. The power subsystem includes fault tolerance as a basic design philosophy. Fault diagnostics for check-out through on-orbit operations is a requirement.

Instrumentation will be provided for the measurement of parameters essential for command and control, health monitoring, and built-in test of the power subsystem and its components. This information will be accessible via a telemetry link. Sensors and their interfacing electronics are to be configured so that transducer and circuit failures can be distinguished from actual out of normal range measurements.

The power subsystem design is to be flexible to allow for use on a wide range of potential satellites with a view towards compactness, ease of access, and repair. The design will also accommodate launch on a wide variety of expendable booster systems, such as the Titan and Atlas families of launch vehicles, as well as the Space Shuttle.

The expected worst case transportation and ground handling, storage and standby, and launch environments are outlined. The launch environment covers acceleration, random vibration, mechanical shock, pyrotechnic shock, and acoustic noise specifications.

The SUPER flight test subsystem will have a minimum life in orbit of six months. The subsystem design must be demonstrated by analysis to have a minimum operational life of at least five years in LEO, seven years in MEO, and ten years in GEO. The expected temperature and pressure ranges for the orbital environments are specified. The contractors are required to use MIL-STD-1543A to determine component reliabilities and the reliability of each component is to be maximized within the scope of the SUPER program.

SUPER is being designed for simple integration into a range of satellites. All mechanical, thermal, electrical, and telemetry interfaces will facilitate use of the power subsystem on a wide range of potential satellites. The contractor will provide mating electrical connectors and cables between SUPER and the flight test vehicle. The power subsystem will provide power for all internal power subsystem loads. SUPER is being designed to accept ground power to charge its energy store through the vehicle electrical umbilical. The power subsystem will be capable of dissipating its own internally-generated waste heat.

SUPER is an SDI program and requires the use of SI units throughout the course of the design and development. However, previously qualified components may use the original units be they English or SI.

The producibility of the power subsystem and its components is to be maximized. A production rate of components which allows a monthly power subsystem production rate of twenty kilowatts (i.e. ten two-kilowatt subsystems or four five-kilowatt subsystems) is desired for the eventual production configuration. The cost of producing flight qualified hardware is to be minimized.

4. COMPONENT INTEGRATION

Many Air Force, SDI, and NASA programs in recent years have developed component technologies which are being considered in the SUPER program. The solar energy conversion concepts include both concentrating and hardened planar photovoltaics. Nickel-hydrogen battery technology is perceived as being sufficiently mature to incorporate it in the SUPER subsystem. Carbon-carbon structures are being evaluated for possible use. Various equipment shielding approaches are under investigation to mitigate damage from orbital debris and kinetic threats. Power conditioning, control, and distribution architectures and components which optimize performance and survivability are being implemented. Waste heat management components under consideration include innovative survivable radiator designs and a number of heat pipe configurations.

5. PHASE ONE RESULTS

In April 1989 the Government team of approximately thirty-five scientists and engineers evaluated each of the four Phase One contractor's designs in order to implement the required downselect. The team was divided into specialty groups which examined the following subsystem elements: photovoltaics, energy storage, power management and distribution, thermal management, survivability, mass properties, program management, and subsystems integration. Each group graded the contractor designs in the respective specialty and submitted final scores which were then used to make the downselect decision.

The resulting Phase Two contractors are TRW and Martin Marietta. Since this program phase is still competitive, great detail on their individual conceptual designs can not be given here. However, a summary of the major design attributes is allowable and follows.

The TRW design uses a derivative of the Survivable Concentrating Photovoltaic Array (SCOPA) concept for solar energy conversion. The SCOPA element is a miniature Cassegrain mirror system which concentrates incident sunlight by a factor of roughly 100 onto a gallium-arsenide photovoltaic cell. Nickel-hydrogen cells are employed for energy storage. The chosen power distribution architecture is a d.c. battery-regulated bus for lower power satellites and a higher voltage d.c. battery-regulated bus for higher power levels. The thermal management system employs fixed conductance and variable conductance heat pipes to transport heat to the survivable radiators.

The Martin Marietta design also uses concentrating photovoltaics for solar energy conversion. In this concept the solar array design work is done by the subcontractor, General Dynamics, which has developed the Survivable Low Aperture Trough Solar (SLATS) concentrator array. This concentrator uses parabolic cylindrical mirrors to concentrate incident solar flux onto gallium-arsenide photovoltaic cells with a concentration ratio of approximately twenty. Nickel-hydrogen cells are used for energy storage. An unregulated power distribution bus was chosen for this concept, operating at array voltage. The thermal management system employs a new heat pipe design to acquire waste heat and transport it to survivable radiators.

6. CONCLUSION

The SUPER program is demonstrating the practicality of survivable satellite power technology for near term programs. The program builds confidence in previously developed survivable components through thorough testing and space-flight demonstration. The program has been coordinated extensively with the military space programs and the military space community in general. SUPER has shown the feasibility of practical and survivable power technology and will continue, through detailed design followed by extensive ground and space testing, to verify this capability.