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Overview of the Solar Dynamic Ground Test Demonstration Program

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Overview of the Solar Dynamic Ground Test Demonstration Program

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Abstract

The Solar Dynamic (SD) Ground Test Demonstration (GTD) program demonstrates the availability of SD technologies in a simulated space environment at the NASA Lewis Research Center (LeRC) vacuum facility. An aerospace industry/government team is working together to design, fabricate, build and test a complete SD system. This paper reviews the goals and status of the SD GTD program. A description of the SD system includes key design features of the system, subsystems and components as reported at the Critical Design Review (CDR).

Introduction

The 2 kW_e Solar Dynamic (SD) Space Power Ground Test Demonstration (GTD) Program was initiated by the NASA Office of Aeronautics and Space Technology and is managed by NASA Lewis Research Center (LeRC) (Calogeras, 1992; Amundsen, 1992; Harper 1991). The primary goal of this program is to conduct a ground-based test of a solar dynamic space power system which includes energy storage in an environment simulating a representative low earth orbit (LEO).

SD technologies have been developed by NASA programs during the past 30 years and are available for near-Earth orbit applications. However, several technical challenges were identified during the Space Station *Freedom* (SSF) program which can be resolved in a ground-based test. These key issues are:

Flux tailoring - integration of the concentrator and receiver such that adequate solar flux is transferred into the cycle without excessive flux deposition in any one area of the receiver,

Control methodology - investigate methods of varying turboalternator compressor (TAC) speed and system management to maintain optimum system operation (energy management) as a result of long time period changes in insolation.

Transient mode performance - evaluation of startup and shutdown transients, load following capabilities, and multiple orbit operations, including radiator thermal lag effects,

Concentrator facet fabrication and manufacturing techniques,

Thermal energy storage (TES) canister fabrication and manufacturing techniques, and

Scalability to the 20 to 25 kW_e range.

The SD GTD program will demonstrate a complete SD system in a thermal-vacuum environment, i.e. the large space environmental facility, known as Tank 6, at NASA LeRC (Fig. 1). The Tank 6 vacuum facility includes a solar simulator to supply the equivalent of "one" sun, a liquid-nitrogen-cooled wall operating at 78 K to simulate the heat sink provided by the space environment, and an electric load simulator (ELS) capable of dissipating up to 4 kW of electrical power. To minimize cost, the project uses existing hardware wherever possible (TAC and recuperator from the Brayton Isotope Power System (BIPS) program of the mid-70s and a gas cooler from an Air Force program) coupled with new components based on SSF designs (a solar concentrator, heat receiver and radiator) (Jefferies, 1993). Components will be flight typical wherever possible.

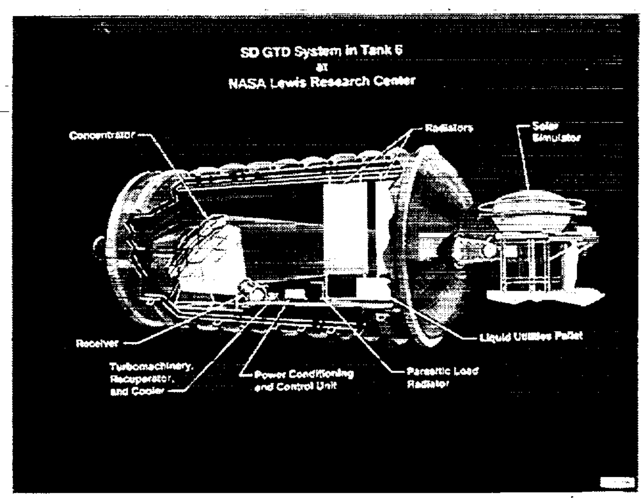

Fig. 1 - SD GTD System Installed in Tank 6

Government/Aerospace Industry Team

NASA Lewis Research Center, Cleveland, OH is responsible for overall project management and will provide the solar simulator and large vacuum facility with an electric load simulator (ELS) and all the necessary interface requirements for the SD GTD system. In April 1992, NASA LeRC contracted with an industry team lead by AlliedSignal Aerospace, Fluid Systems (FS) [formerly Garrett Fluid System Division], Tempe, AZ, for the 2 kW_e Solar Dynamic system. The aerospace contractor team includes: Harris Corporation, Melbourne, FL for the solar concentrator; AlliedSignal Aerospace Systems & Equipment (ASE) [formerly Airesearch Los Angeles Division], Torrance, CA, for the heat receiver with thermal energy storage and gas cooler; AlliedSignal FS, Tempe, AZ, for the power conversion system; LORAL Vought System [formerly LTV Aerospace and Defense Company], Dallas, TX for the radiator; and Rockwell International Company, Rockwell Division, Canoga, CA, for system integration and test support. Solar Kinetics Incorporated (SKI), Dallas, TX is supplying the facets for the concentrator to Harris Corp while Aerospace Design & Development (ADD), Niwot, CO is supplying the multilayer insulation (MLI) for the heat receiver and power conversion subsystem.

In Fig. 2, a four year schedule is shown for delivery of a complete "turnkey" SD system installed in the NASA vacuum facility. During the first year the industry team has completed the System Requirements Review (SRR), Preliminary Design Review (PDR) and Critical Design Review (CDR) of the SD system. Government furnished equipment (GFE) is currently being refurbished, while fabrication for all new component hardware is underway. NASA completed the PDR for the solar simulator in March 1993, with CDR planned for September 1993. Installation of the SD components is expected to start in the fall of 1994 with "turnkey" of the SD system planned for the spring of 1995. The NASA/industry team will begin testing in the spring of 1995.

Solar Simulator

The solar simulator design consists of nine 30 kW Xenon lamps with a recently developed optics (uniform magnification) system which will provide a subtense angle of about 1.0 degree (Pintz, 1992). A cross section of the solar simulator is shown in Fig. 3. The simulator provides an apparent 30.5 cm diameter "sun" just outside the vacuum tank that shines through a quartz window into the tank to provide the desired flux density (up to 1.8 kW/m^2) at the target area. The target area is 17.2 m from the apparent "sun" and 4.79 m diameter. A shutter is provided

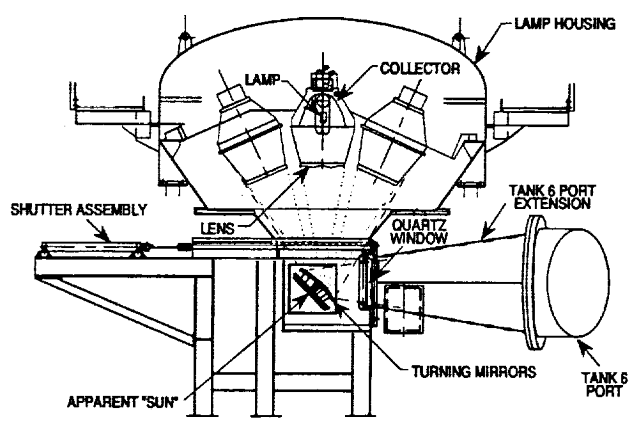

Fig. 3 - Cross-section of Solar Simulator at PDR

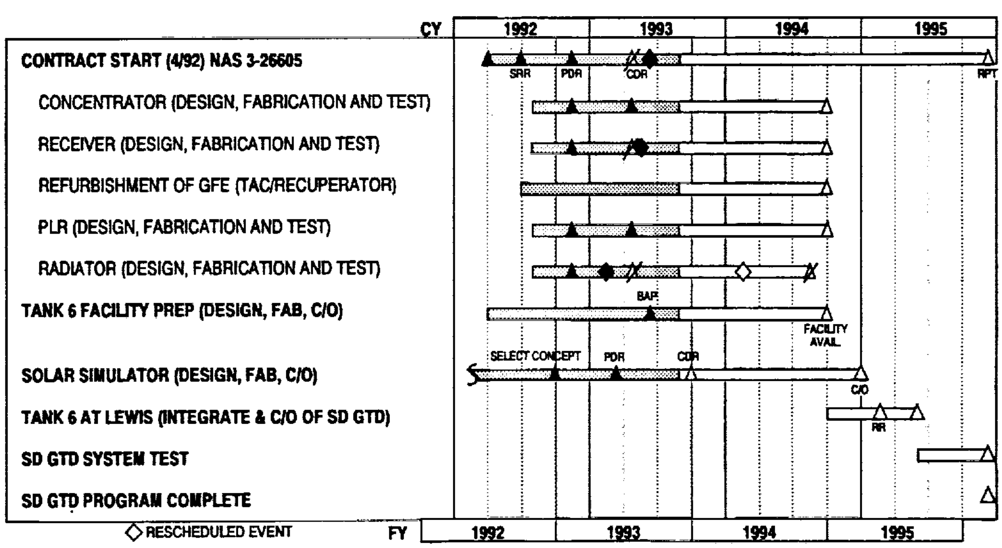

Fig. 2 - SD GTD Master Program Schedule

to simulate various orbits. The new optics system provides for a 50 percent improvement in system efficiency, which significantly reduces its size and initial cost as well as future operating and maintenance costs. Analysis, design and fabrication of the "turnkey" installation of the solar simulator by NASA LeRC personnel is scheduled to be complete by the end of calendar year 1994.

Solar Dynamic System

The SD GTD is a complete system which includes the following major subsystems and components: 1) a solar concentrator, 2) a solar receiver with thermal energy storage, 3) a power conversion system, 4) a waste heat system, 5) the appropriate controls and power conditioning and 6) all the necessary auxiliaries required to make up the complete system. The solar dynamic system with energy storage is estimated to produce about 2 kW of electric power and overall system efficiency of over 15 percent. It is noted that the system performance and life were not optimized due to the constraints of utilizing existing hardware from other government programs. The nominal design case for the GTD is the maximum insolation orbit, which represents low earth orbit (LEO) of 66 minutes of sun and 27 minutes of eclipse. The GTD system is designed for over 1000 hours of operation with up to 100 starts from a cold start condition. Fig. 1 illustrates the modular design of the system as it is configured in Tank 6. The modular design of the SD system will allow NASA to evaluate advanced subsystems and components at a later date.

System Integration

The major components of the GTD system were defined based on the requirement that their interfaces be as simple as possible and that their function be readily assignable to one or another of the performing organizations. Flight packaging was not pursued because of the desire for modularity of components and simplification of their structural interfaces.

Concentrator Subsystem

The concentrator is designed to receive the solar energy from the NASA simulator and deliver about 12.5 kW of thermal energy into the 17.8 cm receiver aperture. To accommodate the solar simulator with its apparent "sun" 17.2 m instead of 149 km away, the concentrator uses elliptical optics for the ground test rather than parabolic optics that would be required for the sun. The solar concentrator for the GTD is based on the design approach of the 25 kW_e SSF SD power system (Jefferies, 1993). The solar concentrator is about 4.57 m in diameter and consists of 7 hexagonal panels with 6 reflective facets per panel. The concentrator is supported on a leaning tripod support structure as shown in Fig. 4. The concentrator uses the aluminum honeycomb facet design and manufacturing technology developed for NASA by SKI (Schertz, 1991). Facet reflectivity will meet a minimum solar average reflectivity of 0.85 with a facet weight goal of 2.44 kg/m^2. The facets will be installed in hexagonal panels made of graphite reinforced box beams. The box beams and latches for interconnecting the panels were salvaged from the Solar Concentrator Advanced Development (SCAD) project which was conducted as part of SSF with Harris Corp (Corrigan, 1989).

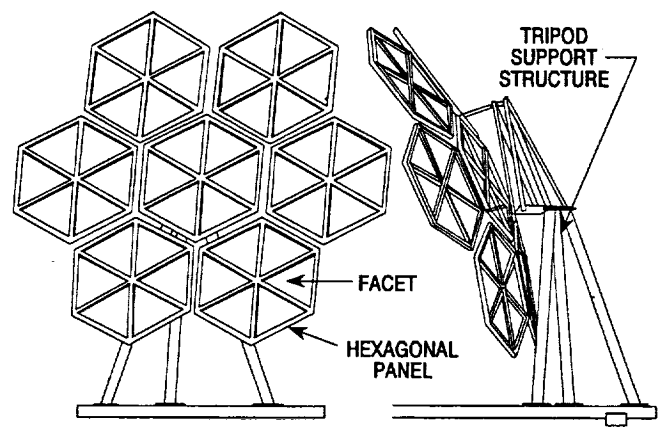

Fig 4. - Concentrator on Tripod Support Structure

Receiver Subsystem

The receiver, shown in Fig. 5, is used to both transfer the solar energy to the cycle working fluid and to store

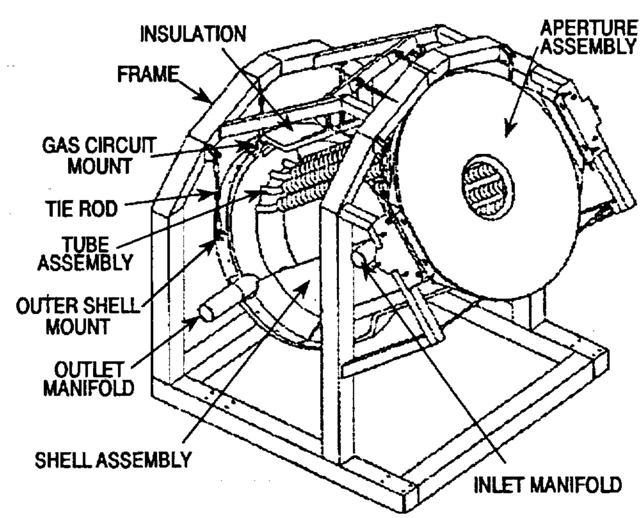

Fig. 5 - Receiver Subsystem and Support Structure

solar energy during eclipse. It is essentially a scale model of the receiver design for SSF. The receiver uses the same thermal energy storage (TES) canister (full size) as was designed, built and tested during the SSF program. Manufacturing development of the canisters has been completed by AlliedSignal ASE. (Strumph, 1993) The TES consists of the Haynes 188 canister, or hollow doughnut, filled with $LiF\text{-}CaF_2$ eutectic salt. The TES canisters will be placed in a scaled down receiver, which will have 23 tubes with 24 canisters per tube. In contrast, the full scale SSF receiver has 82 tubes with 96 canisters per tube. A manufacturing sample of the TES canisters and tube is shown in Fig. 6.

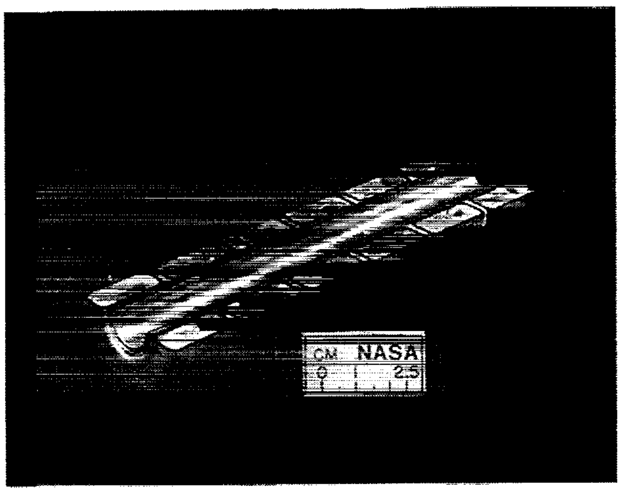

Fig. 6 - Photo of Tube and Canister Hardware

Power Conversion Unit (PCU) Subsystem

Major components of the Power Conversion Unit (PCU) subsystem are the Closed Brayton Cycle (CBC) Conversion unit including the turboalternator/compressor (TAC), recuperator, gas coolers, ducting, and support structure. The TAC, shown in Fig. 7, and the recuperator were provided as GFE from the Brayton Isotope Power Program (BIPS), which was conducted in the 1970s (Dobler, 1978). The TAC consists of a single stage radial flow compressor and turbine with a brushless four pole Rice Alternator. Foil bearings are used to provide long life operation. The TAC will operate at 52 000 rpm while producing a range of electric power from 0.35 to 2.1 kW. The CBC unit uses a helium-xenon gas mixture with a molecular weight of 83.3 as the working fluid. The compressed working fluid is preheated in a recuperator with turbine exhaust gases to increase efficiency of the cycle. The recuperator is a counterflow plate-fin heat exchanger designed for a 97.5 percent heat transfer effectiveness. (Killackey, 1978)

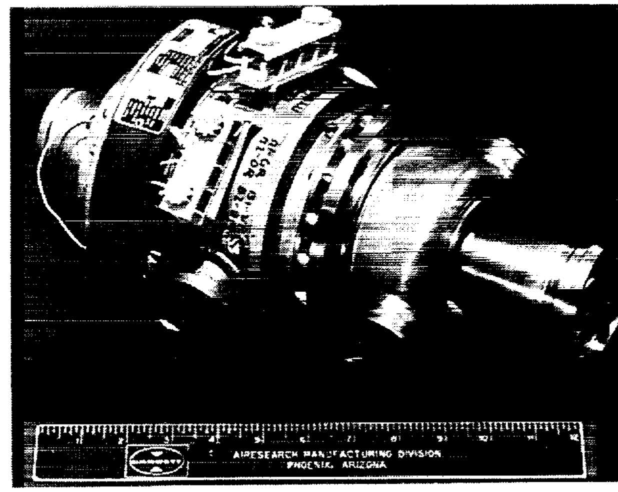

Fig. 7 - Photo of TAC from BIPS program

Waste Heat Subsystem

The waste heat removal system consists of two (2) identical radiator panels plumbed in series in a closed pumped liquid loop design. Each bonded aluminum honeycomb panel is about 1.83 m by 3.66 m with a radiating area of 6.48 m^2. Each panel has 11 active and 11 inactive flow tubes evenly spaced to simulate thermal transient response of a fully redundant flow path design. The waste heat system is integrated to the CBC loop by means of a gas-to-liquid heat exchanger, or cooler. Existing gas coolers were provided to the SD GTD program by the US Air Force, Phillips AFB. The gas coolers are counter flow plate-fin construction with vented double header bar to prevent interpass leakage. The coolant is *n*-heptane with FC75 identified as a backup coolant (Fleming, 1978).

Power Conditioning and Control Subsystem (PCCS)

Fig. 8 is a block diagram for the major components of the power conditioning and control subsystem (PCCS) which will be used for the GTD system. The PCCS performs the following functions:

Starts the TAC by operating the alternator as a 3 phase motor,

Maintains constant output voltage by varying field current to the Rice Alternator field (the magnetic flux on a Rice Alternator is created electrically),

Maintains instantaneous constant electrical output current by adding or subtracting parasitic resistive load,

Maintains constant TAC speed by changing the level of instantaneous electrical load,

Rectifies the 3 phase AC alternator output to DC,

Provides filtering of the output to minimize ripple transients, and

Provides electrical fault, overspeed and overload protection by sensing the key system parameters and initiating corrective action.

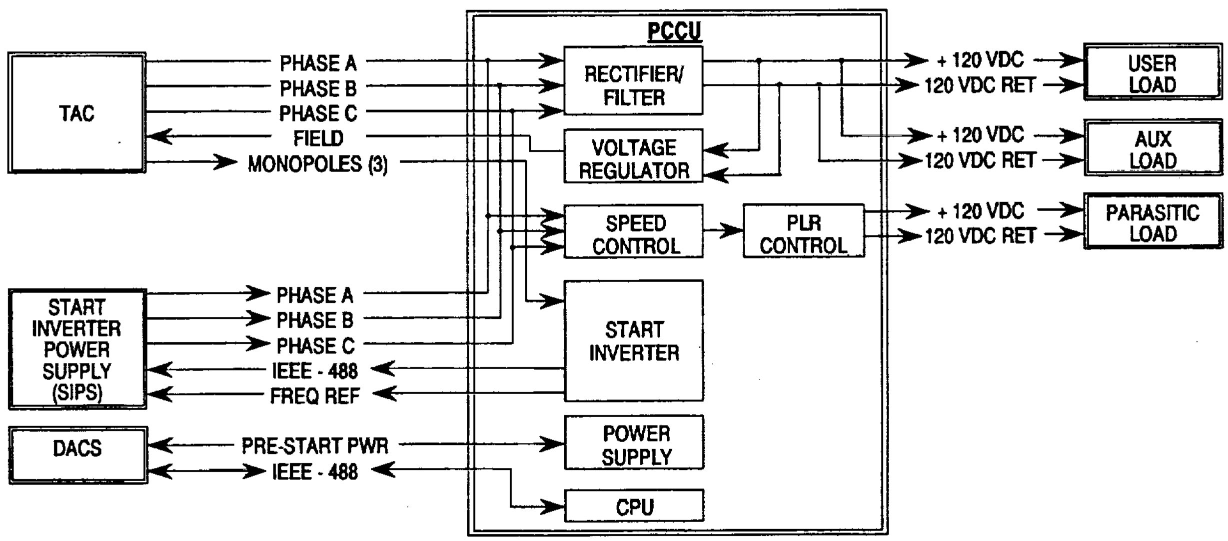

Fig. 8 - Block Diagram of PCCS and PCCU

The Power Conditioning and Control Unit (PCCU) identified in Fig. 8 contains the power electronics, and is located in the thermal vacuum environment. The start inverter power supply (SIPS) is a commercially available, variable, controllable 3 phase power supply which provides the ability to operate the TAC as both an inductive and a synchronous electric motor. Starting profiles will be investigated to ascertain, by test, the optimum starting electrical characteristics. The parasitic load radiator (PLR) is an integral part of the electric loop controls and functions as an electrical sink for excess power from the TAC which is not consumed by the user load, accessory loads, and PCCU. The PLR which is controlled by the PCCU, is also located in the thermal vacuum environment. The Data Acquisition and Control System (DACS) is special test equipment (STE) whose primary function is to record system test data. The DACS also contains the ability to communicate setpoint conditions to the PCCU to vary speed, voltage and gain setpoints. This allows for changing the control parameters during the system test without the need to physically access the PCCU within the thermal vacuum environment.

The power quality requirements of the PCCU were derived from the SSF work package 4 activities adjusted for differences in the output voltage characteristics of the existing BIPS alternator. A breadboard of the PCCU has been built and is currently under test. Preliminary data taken of the output DC voltage ripple is shown in Fig. 9 relative to SSF specification requirements.

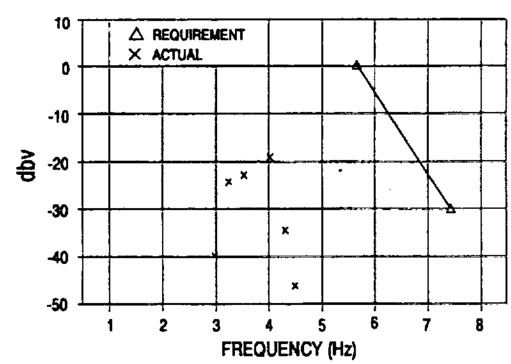

Fig. 9 - Ripple Voltage Data vs SSF Specification

Orbit Analyses

Thermodynamic analysis of system operation has been conducted to define how temperatures and output power vary during a typical low earth orbit. The receiver continuously stores energy (heats up) during the sunlit portion of the orbit; and gives up energy (cools down) during the eclipse period. When operated at constant TAC speed, the temperature and power produced by the system increase from sunrise to sunset then decrease to the original sunrise conditions. Fig. 10 shows the temperature of the hottest receiver canister as a function of orbit time. Fig. 11 shows the electrical power produced (gross kW_e at alternator output) as a function of orbit time. For purposes of analysis, the orbit is approximately 66 minutes of sun and 27 minutes of eclipse. The TES salt melt temperature is 1873 R. Examination of Fig. 10 shows that the salt within the hottest canisters becomes fully melted and superheated above the melt temperature just before sunset.

Variation in the TAC speed setpoint and system mass inventory have significant effect on the temperature conditions within the receiver. Operation of the system at lower speed or inventory results in higher receiver temperatures. Conversely increases in speed or system mass inventory result in lower receiver temperatures. Analysis has been conducted which predicts overall system and receiver operation over a wide range of speeds and mass inventories. Testing will be conducted to evaluate the analytical predictions and models.

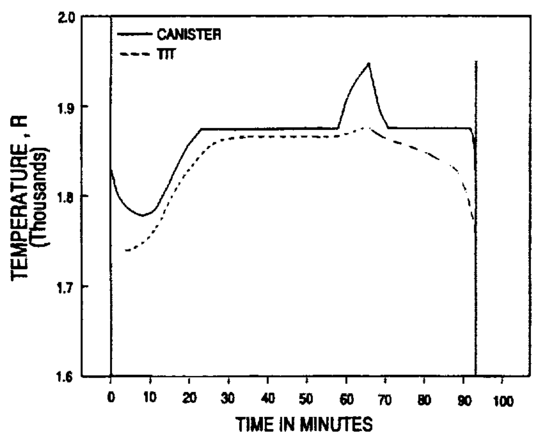

Fig. 10 - Canister Temperature vs Orbit Time

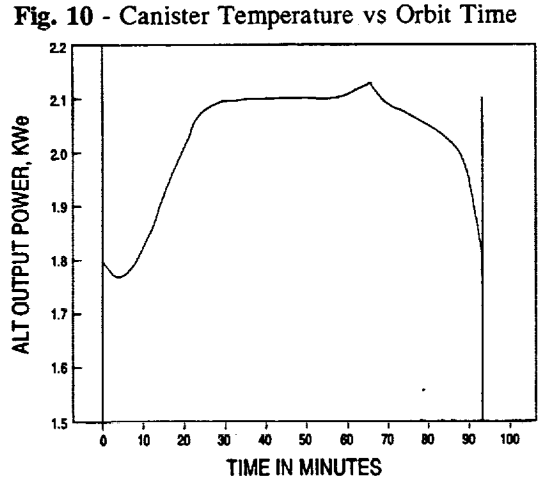

Fig. 11 - Electrical Power vs Orbit Time

Summary

The 2 kW SD GTD program provides for the demonstration of a solar dynamic power system which is of sufficient scale and fidelity to ensure confidence in the availability of solar dynamic technology. Studies have shown that solar dynamic power can provide significant savings in life cycle costs and launch mass when compared with conventional photovoltaic/battery power systems in near-Earth orbits. Applications include potential growth for SSF, communication and earth observing satellites, and electric propulsion. (Brown, 1992; Calogeras, 1991) An aerospace government/industry team is working together to show that we can do it "cheaper, better, faster" to successfully demonstrate dynamic power for space.

References

Amundsen, P.C.; et al., *BIPS Turboalternator-Compressor Characteristics and Application To The NASA Solar Dynamic Ground Demonstration Program*, Proc. 27th IECEC; **1992**.

Brown, M.; et al., *Solar Dynamic Power System Deployment Structures and Pointing Controls Systems Study*, Naval Research Lab. Naval Center for Space Technology, Wash. DC; **1992**.

Calogeras, J.C.; et al., *The Ground Testing of a 2kW$_e$ Solar Dynamic Space Power System*, Proc. 27th IECEC; **1992**.

Calogeras, J.E.; et al., *Solar Dynamic Power for Earth Orbital and Lunar Applications*, Proc. 26th IECEC; **1991**.

Corrigan, R.D.: et al., *Update Of The Solar Concentrator Advanced Development Project*, Proc. 24th IECEC; **1989**.

Dobler, F.X; et al., *Analysis, Design, Fabrication and Testing of the Mini-Brayton Rotating Unit (Mini-BRU)*, NASA CR-159441, **1978**.

Fleming, M.; et al., *Radiator Selection for Space Station Solar Dynamic Power Systems*, Proc. 22nd IECEC; **1987**.

Harper, W.B.; et al., *NASA Solar Dynamic Ground Test Demonstration (GTD) Program and Its Application to Space Nuclear Power*, Tenth Symp on Space Nuclear Power and Propulsion; January **1993**.

Jefferies, K.J., Ed.; *Solar Dynamic Power System Development for Space Station Freedom*, RP1310, July **1993**.

Killackey, J.J.; et al., *Design and Fabrication of the Mini-Brayton Recuperator (MBR)*, NASA CR-159429, **1978**.

Pintz, A.; et al., *Uniform Magnification Lamp Module Evaluation*, proposed for a NASA Solar Simulator, NASA Grant NCC3-143, AMC ER-1002; October **1992**.

Schertz, Paul; et al., *Development of an Improved Facet for Space Applications*, NASA CR-189109, **1991**.

Strumph, H.J.; et al., *Design of the Heat Receiver for the Solar Dynamic Ground Test Demonstrator Space Power System*, Proc. 28th IECEC; **1993**.

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