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NASA Technical Memorandum 106876

Overview of the Solar Dynamic Ground Test Demonstration Program at the NASA Lewis Research Center

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March 1995

(NASA-TM-106876) OVERVIEW OF THE SOLAR DYNAMIC GROUND TEST DEMONSTRATION PROGRAM AT THE NASA LEWIS RESEARCH CENTER (NASA. Lewis Research Center) 9 p

N95-23450

Unclas

G3/20 0042144

National Aeronautics and
Space Administration

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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. Data from the SD GTD program will be provided to the joint U.S. and Russian team which is currently designing a 2 kW SD flight demonstration power system. This SD technology has the potential as a future power source for the International Space Station. This paper reviews the goals and status of the SD GTD program. A description of the SD GTD system includes key design features of the system, subsystems and components.

INTRODUCTION

The NASA Office of Aeronautics and Space Technology initiated the 2 kW_e Solar Dynamic (SD) Space Power Ground Test Demonstration (GTD) Program which is managed by NASA Lewis Research Center (LeRC)[1,2,3]. The primary goal of this program is to conduct testing of flight prototypical components as part of a complete SD system in 1995. The SD space power system includes thermal energy storage in an environment simulating a representative low earth orbit (LEO).

In January 1994, the International Space Station Program Office initiated the joint U.S./Russian Solar Dynamic Flight Demonstration program which is also managed by the NASA Lewis Research Center. The primary goal of this program is to demonstrate the capabilities of the Solar Dynamic power system during orbital space flight on board the Russian Orbital Space Station (OSS) MIR. This flight demonstration is a stage in the development of the SD system for the International Space Station (ISS) Alpha [4].

A block diagram of a SD system is shown in Fig. 1. The solar dynamic power system collects the suns rays onto a solar collector which in turn focus the light into a chamber known as the receiver. This results in heating of the receiver which in turn heats a fluid, helium-xenon, that powers a turboalternator/compressor resulting in the production of electrical energy. The solar receiver is also designed to transfer energy to the fluid during the sun phase, and to store energy for operation during the shade phase. The fluid is then cooled by the radiator that rejects waste heat to space.

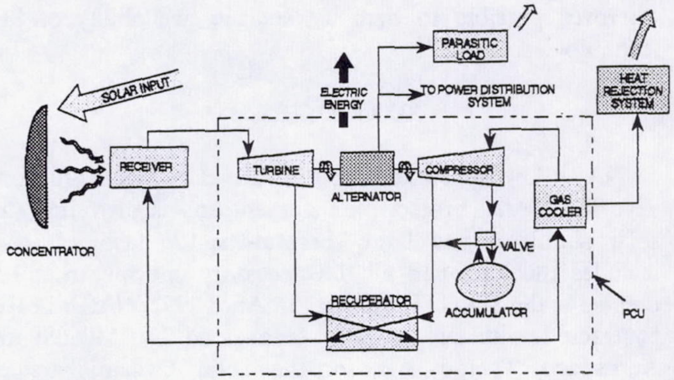

Fig. 1 - Block Diagram of a SD System

NASA programs during the past 30 years have developed SD component technologies which are now 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[5]. 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 start-up and shutdown transients, 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. The Tank 6 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 (about 200 K) provided by the space environment, and an electric load simulator (ELS) capable of dissipating up to 4 kW of electrical power. Flight typical components are used in the SD system wherever possible to demonstrate the availability of SD technologies.

SD GTD TEAM

NASA Lewis Research Center, Cleveland, OH is responsible for overall project management and is providing the solar simulator and large thermal-vacuum facility. This includes the 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, Tempe, AZ, for the Solar Dynamic system capable of producing up to 2 kW_e. The aerospace contractor team includes: Harris Corporation, Melbourne, FL for the offset solar concentrator; AlliedSignal Aerospace, Torrance, CA, for the solar heat receiver (with thermal energy storage) and gas cooler; AlliedSignal FS, Tempe, AZ, for the power conversion system; Loral Vought Systems, Dallas, TX for the radiator; and Rockwell International Company, Rocketdyne Division, Canoga Park, CA, for system integration and test support. Solar Kinetics Incorporated (SKI), Dallas, TX is supplying the reflective facets for the concentrator while Aerospace Design & Development (ADD), Niwot, CO is supplying the multilayer insulation (MLI) for the heat receiver and power conversion subsystem.

The SD GTD system is currently being installed in the NASA vacuum facility with expected completion in 1994. An overview of the activities during the first and second years are provided by Shaltens[1,2]. Development activities which included the manufacturing processes for the facets by SKI and the Thermal Energy Storage (TES) canisters by AlliedSignal and refurbishment of the TAC and recuperator were completed during the second year. Fabrication and acceptance testing by the contractors of all the major subsystems: the solar concentrator structure, the reflective facets, the radiator systems, the power conversion unit (PCU) and the data acquisition and control system (DACS) were completed and delivered ahead of schedule. System verification tests are expected to be complete by late 1994 by the AlliedSignal team. Installation of the SD components started in the spring of 1994 at LeRC with "turnkey" of the SD system moved forward to late 1994/early 1995. The NASA/industry team will begin integrated testing of the SD system in early 1995[6]. The SD GTD Program is ahead of schedule and within budget for completion in 1995.

SOLAR SIMULATOR

A recently developed optics (controlled magnification) system which provides the basis for the advanced solar simulator (SS) design consists of nine 30 kW Xenon lamps which will provide a flux distribution of +/- 10 per cent with a subtense angle of about 1.0 degree for testing solar dynamic systems[7]. A cross section of the solar simulator is shown in Fig. 2. Key components in the optical system are the Xenon arc lamp, the reflective collector, the lens and the turning mirror. The apparent "sun" is 0.305 m diameter which at 17.2 m subtends about one degree. This SS provides an apparent "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 4.79 m diameter and 17.2 m from the apparent "sun" . A water cooled shutter is provided to simulate various orbits. The advanced SS system design 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. NASA completed the CDR for the advanced solar simulator, as planned, in September 1993 and started fabrication of the support structure along with the critical optical components. Fabrication, assembly, installation and checkout of the SS integrated with Tank 6 by NASA LeRC personnel is scheduled to be complete by September 1994. A detailed description of the solar simulator and results from early testing of a subscale optics system are discussed by Jefferies(7).

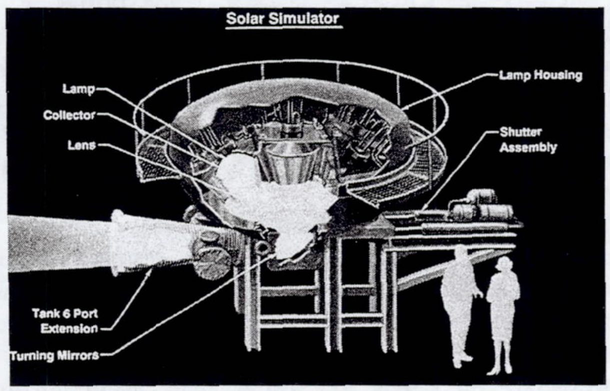

Fig. 2 - Cross-section of Solar Simulator at CDR

SOLAR DYNAMIC SYSTEM

The SD system 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 rejection system, 5) the appropriate controls and power conditioning and 6) all the necessary auxiliaries required to make up the complete system. The SD system with energy storage is estimated to produce about 2 kW of electric power and has an 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. 3 illustrates the modular design of the SD components as it is configured in Tank 6. The modular design of the SD system offers the potential for NASA to evaluate advanced subsystems and components at a later date. Further, development, verification and qualification tests are being planned to support the joint U.S./Russian flight demonstration project.

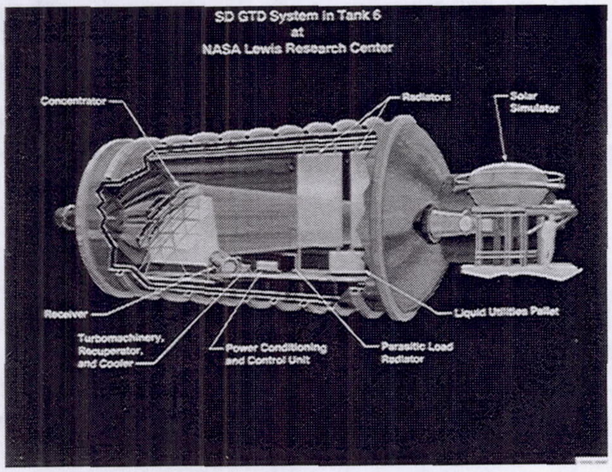

Fig. 3 - SD GTD System Installed in Tank 6

Performance analysis (maximum insolation orbit) of the SD system, shown in Fig. 4, shows the relationship of the energy stored in the solar receiver, the TAC's turbine inlet temperature (TIT) and compressor inlet temperature (CIT), with the resultant electrical output over two orbits. Integrated system testing will be conducted over its full operational range to meet the objective of evaluation and validation of previously developed analytical models, by both the aerospace contractors and government [6].

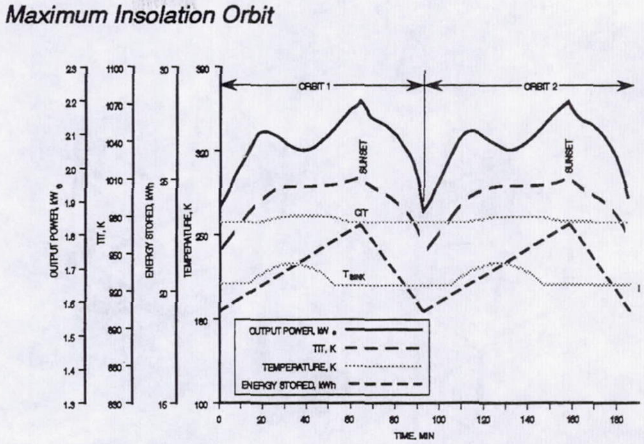

Fig. 4 - Orbital Performance of the SD GTD System

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 completed offset concentrator structure, shown in Fig 5, consists of 7 hexagonal panels with 6 reflective facets per panel. The concentrator is 4.75 m wide by 4.55 m tall and supported on a leaning tripod support structure which attaches to the NASA buildup and assembly platform. The concentrator's surface consists of 42 aluminum honeycomb facets developed by SKI [8]. There are two different facet curvatures, spherical radii of 5.08 m and 6.25 m, used in different regions of the concentrator. Facet reflectivity exceeds 85 per cent and the mass is about 2.5 kg/m^2. Manufacturing development for the facets was completed by SKI in early 1994. The facets will be installed in hexagonal panels made of graphite reinforced box beams interconnected by latches. Both the box beams and the latches are oversized because they are existing hardware that is being reutilized from a previous NASA program. A detailed description of the offset concentrator design is provided by Bahnman [9]. Harris is providing special test equipment for facet alignment and flux distribution in Tank 6 which is described by Campbell [10].

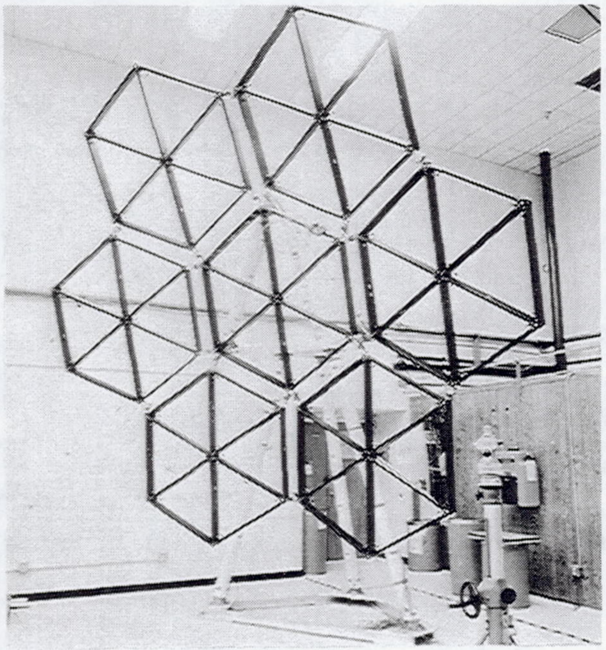

Fig. 5 - Completed Concentrator on Tripod Support Structure

A full-sized reflective facet, as shown in Fig. 6, was exposed to a thermal vacuum environment at LeRC to examine the durability of the as-produced facet to vacuum thermal cycling. Performance of the facet was evaluated measuring total and specular reflectivity, and the radius of curvature, before and after three thermal cycles between -50 and 207°F. The facet was heated by an array of quartz halogen lamps and was allowed to cool to a gaseous nitrogen cooled cold wall. Essentially no change was observed on total or specular reflectivity or the radius of curvature after the three thermal cycles.

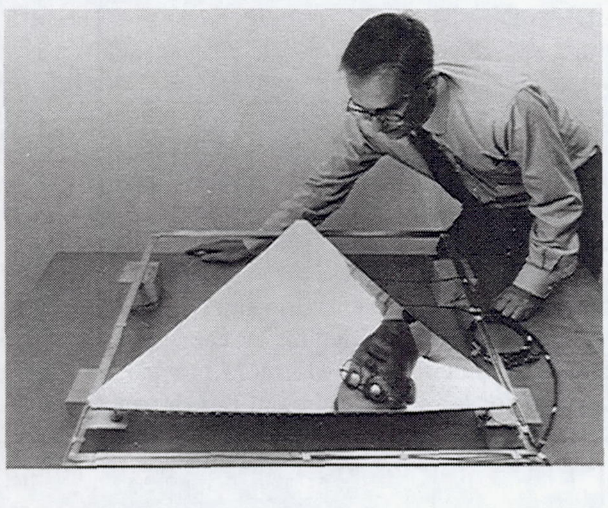

Fig. 6 - Completed Aluminum Honeycomb Facet

RECEIVER SUBSYSTEM

The solar receiver, shown in Fig. 7, is used to both transfer the solar energy to the cycle working fluid and to store solar energy for system operation during eclipse. The receiver design is essentially a scale model from the 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 and testing of the canisters has been completed by AlliedSignal ASE [11]. The TES consists of the Haynes 188 canister, or hollow doughnut, filled with LiF-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. A complete description of the receiver design is provided by Strumph [12,13].

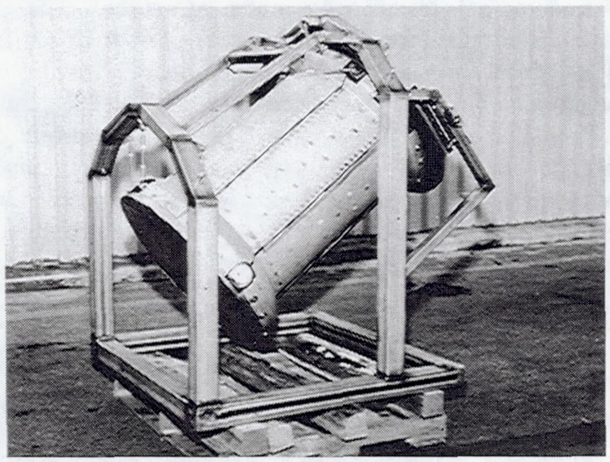

Fig. 7 - Completed Solar Heat Receiver

Surface modifications to improve thermal emittance characteristics of the Haynes 188 canisters is required to radiate heat away from local hot spots, improving heat distribution which result in improved service life. LeRC and AlliedSignal specialists evaluated 14 different types of surface modification techniques for emittance and vacuum heat treatment durability enhancements. An 0.025 mm thick alumina based coating was selected due to a very high emittance (0.85 after 2695 hrs with 32 thermal cycles) for the receiver canisters. A detailed review of the coating evaluation and selection is provided by de Groh[14].

POWER CONVERSION UNIT (PCU) SUBSYSTEM

The Power Conversion Unit (PCU) subsystem includes the Closed Brayton Cycle (CBC) Conversion unit which consists of the turboalternator/compressor (TAC), gas coolers, recuperator, ducting and support structure. The PCU subsystem was used for Hot Loop Testing at AlliedSignal, and is shown in Fig. 8. The TAC, known as the mini BRU, consists of a single stage radial flow compressor and turbine with a brushless four pole Rice Alternator. Foil gas bearings are used to provide long life operation. The alternator, bearings and shaft are cooled by the compressor discharge flow. Gas cooling of the alternator has resulted in favorable mass and reduced complexity benefits. However, this feature places an upper limit on compressor discharge temperature in order to maintain acceptable winding temperatures [15]. The TAC will produce electric power up to a maximum of 2.2 kW while operating at 52 000 rpm. The CBC unit uses a helium-xenon gas mixture with a molecular weight of 83.8 as the working fluid. The compressed working fluid is preheated in a recuperator by 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.

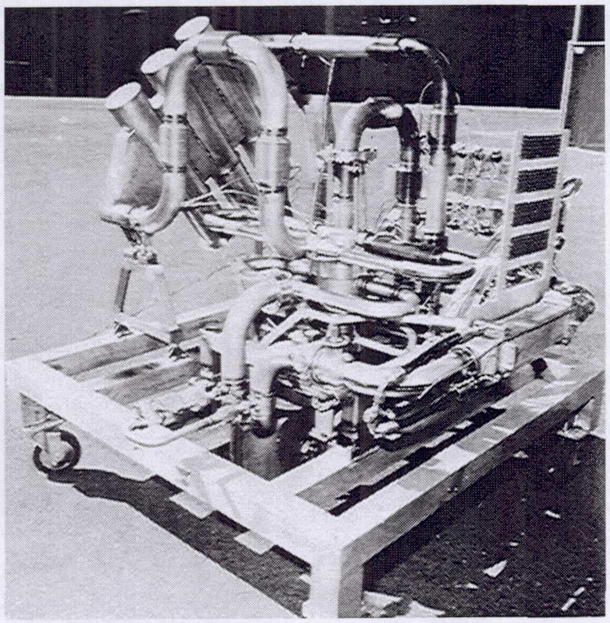

Fig. 8 - Photo of Power Conversion Unit with Electric Heater at AlliedSignal

WASTE HEAT SUBSYSTEM

The completed waste heat rejection system, shown in Fig. 9, consists of two (2) identical radiator panels plumbed in series and a Liquid Utilities Pallet (LUP) in a closed pumped liquid loop design. The LUP contains the pump(s), accumulator and sensors for the *n*-heptane coolant fluid. Each bonded aluminum honeycomb panel is about 1.83 m by 3.66 m with a radiating area of 12.96 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. Each panel is coated with chemglaze A276, a white epoxy paint. The waste heat system is integrated into the CBC loop by means of two gas-to-liquid heat exchangers, or gas coolers.

A detailed description of the analysis, design, fabrication and testing of the waste heat subsystem are described by Fleming [16,17,18]. Acceptance testing of the waste heat subsystem was completed at the NASA-LeRC facilities with Loral Vought, LeRC and AlliedSignal personnel. Testing included operation at nominal pressure and flow in the thermal vacuum environment of Tank 6.

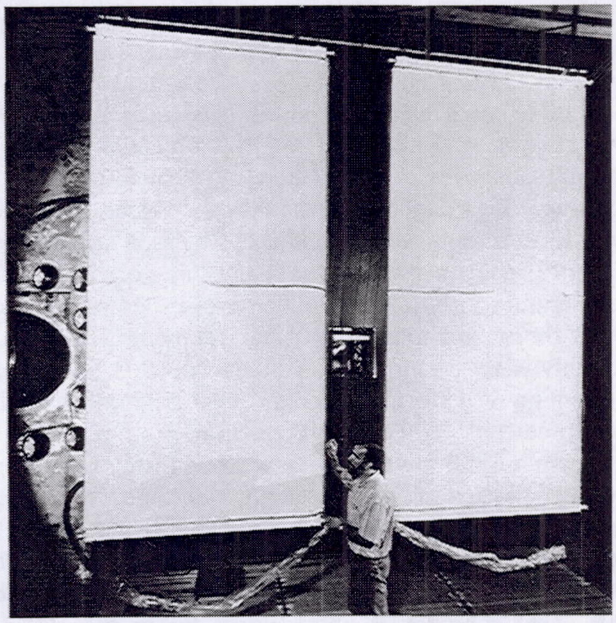

Fig. 9 - Completed Waste Heat Removal System Installed in the LeRC Tank 6

POWER CONDITIONING & CONTROL SUBSYSTEM

The Power Conditioning and Control Unit (PCCU) contains the power electronics, will be located in the thermal vacuum environment of Tank 6 as part of the integrated SD system. The start inverter power supply (SIPS) is a commercially available, variable, controllable 3 phase power supply which provides the ability to operate the TAC alternator 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 of Tank 6. 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.

HOT LOOP TESTING

The Hot Loop Test integrates the PCU, PCCU, DACS and ELS with the gas heater (electric) to simulate the receiver and a facility waste heat removal system (LN_2 cooled ethylene-glycol bath). The acceptance testing has successfully demonstrated TAC starting (motoring and automatic) using He-Xe as the working fluid. Steady state operation has achieved a power level over 2.0 kW while operating at over 1860 R (1400°F). Operation of the Hot Loop Test shown in Fig. 10, shows typical data from a cold start-up. Fig. 10 shows gradually increasing temperature with increasing power (as indicated by increasing current). Fig. 10 also shows the relationship of heater inlet temperature with turbine and compressor temperature data. Both thrust and journal bearings temperatures and rotor stability were shown to be within acceptable limits. Early evaluation of performance data show operation of the PCU is as predicted. While simulation of on-orbit operation such as heating, is not part of the Hot Loop testing, the trend of gradually increasing power output, with time, after reaching self-sustaining speed, brought about by the gradually increasing temperatures throughout the system has been demonstrated. The start-up characteristics, from a "cold" (ambient) condition, demonstrated during the Hot Loop Test, have qualitatively duplicated predicted start transients by Mock [19]. The PCU has been shipped to NASA for final integration with the heat receiver for installation with the balance of the major subsystems in the LeRC thermal-vacuum facility.

SD FLIGHT DEMONSTRATION PROGRAM

The joint U.S./Russian program combines the solar dynamic technology expertise of Russian and the United States. Fig. 11 shows the design of the flight SD power system which integrates both U.S. and Russia hardware for OSS MIR. The Russian Space Agency has contracted with NPO-Energia for a deployable solar concentrator, the radiator including the thermal control system and a pointing/and tracking system for the SD unit. NASA has contracted with AlliedSignal for the solar heat receiver, the power conversion unit with power electronics/controls and the integration structure. The Russian hardware is sized for 10 kW, while the U.S. hardware will use existing designs and hardware experience from the 2 kW SD GTD program. The targeted Shuttle launch date to OSS MIR is June 1997 for installation on the Krystall module. On orbit operation is planned for up to one year after launch. If successful, a SD power system will be considered for use on the ISS Alpha[4].

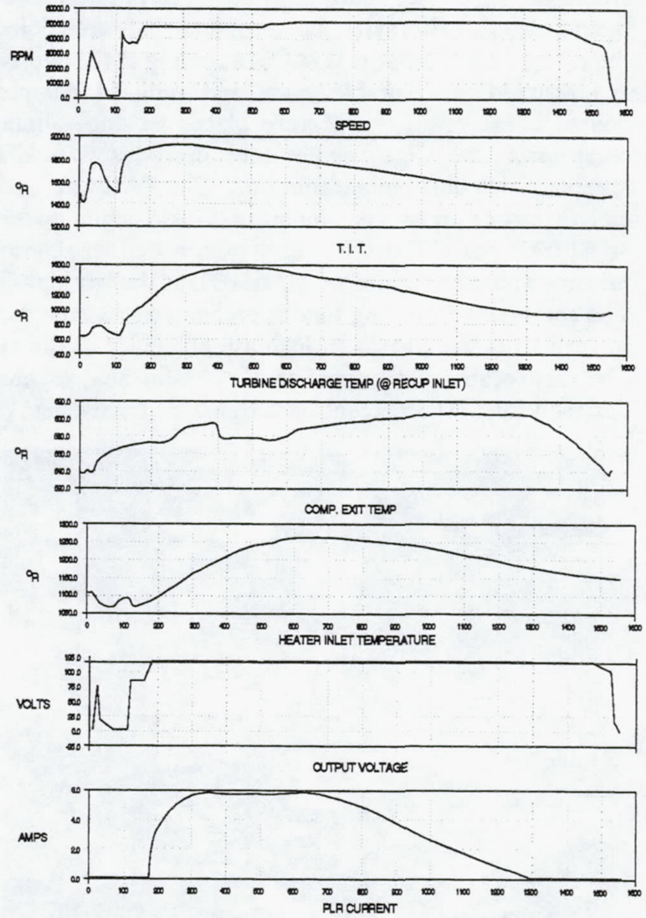

Fig. 10 - Hot Loop Test Data Showing Ambient Start-up

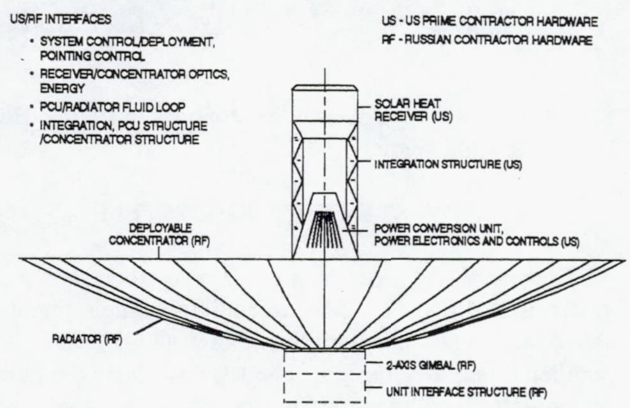

Fig. 11 - Cross-section of the Flight SD System

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 for Space. Studies have shown that solar dynamic power with thermal energy storage can provide significant savings in life cycle costs and launch mass when compared with conventional photovoltaic power systems with battery storage for providing continuous electric power in near-Earth orbits. Applications include potential growth for ISS Alpha, communication and earth observing satellites, and electric propulsion[4,20,21]. An aerospace government/industry team is working together to show that we can do it "cheaper, better, faster" to successfully demonstrate solar dynamic power for space. The SD GTD program is ahead of schedule and within budget for completion in 1995.

ACKNOWLEDGEMENT

I would like to thank Mr. Henry Yee for his assistance in the preparation and review of this paper.

REFERENCES

[1] Shaltens, R. K. and Boyle, R. V., Update of the 2 kW Solar Dynamic Ground Test Demonstration Program, NASA TM 106730, Proc. 29th IECEC, **1994**.

[2] Shaltens, R. K. and Boyle, R. V., Overview of the Solar Dynamic Ground Test Demonstration Program, NASA TM 106296, Proc. 28th IECEC; **1993**.

[3] Calogeras, J. E., et al., The Ground Testing of a 2kW, Solar Dynamic Space Power System, Proc. 27th IECEC; **1992**.

[4] Huckins, E. and Ahlf, P., Space Station Power Requirements and Issues, Proc. 29 IECEC, **1994**.

[5] Jefferies, K. S., Ed., Solar Dynamic Power System Development for Space Station Freedom, RP1310, May **1993**.

[6] Mason, L. S., et al., Solar Dynamic Ground Test Demonstration System Test Plans, ASME; **1994**.

[7] Jefferies, K. S., Solar Simulator for Solar Dynamic Space Power System Testing, NASA TM 106393, ASME; **1994**.

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

[9] Bahnman, D. W. and Jensen, P. A., Design of a Solar Concentrator for the Solar Dynamic Ground Test Demonstration Program, ASME; **1994**.

[10] Campbell, J. S. and Jensen, P. A., Design, Analysis and Test of a Solar Concentrator for Space Applications, ASME; **1994**.

[11] Strumph, H. J., et al., Fabrication and Testing of the Solar Dynamic Ground Test Demonstration Heat Receiver, Proc. 29th IECEC., **1994**.

[12] Strumph, H. J., et al., Thermal and Structural Analysis of the Heat Receiver for the Solar Dynamic Ground Test Demonstrator, ASME; **1994**.

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

[14] de Groh, K. K., et al., Performance and Durability of High Emittance Heat Receiver Surfaces for Solar Dynamic Power Systems, ASME; **1994**.

[15] Amundsen, P. C., et al., BIPS Turboalternator-Compressor Characteristics and Application to the NASA Solar Dynamic Ground Demonstration Program, Proc. 27th IECEC; **1992**.

[16] Fleming, M. L., et al., Solar Dynamic Ground Test Demonstration Radiator Design and Test, Proc. 29th IECEC; **1994**.

[17] Fleming, M. L. and Flores, R. R., Solar Dynamic Radiator Design Development, ASME; **1994**.

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

[19] Mock, E. A., Solar Dynamic Ground Test Demonstrator System Orbital and Startup Control Methods, ASME, **1994**.

[20] Brown, M., et al., Solar Dynamic Power System Deployment Structures and Pointing Controls Systems Study, Naval Research Lab. Naval Center for Space Technology, Washington D.C.; **1992**.

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

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1995

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Overview of the Solar Dynamic Ground Test Demonstration Program at the NASA Lewis Research Center

5. FUNDING NUMBERS
WU–233–03–0B

6. AUTHOR(S)
Richard K. Shaltens

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E–9501

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM–106876

11. SUPPLEMENTARY NOTES
Responsible person, Richard K. Shaltens, organization code 5490, (216) 433–6138.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 20

This publication is available from the NASA Center for Aerospace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

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14. SUBJECT TERMS
Solar dynamic power; Space power; System demo; Brayton cycle

15. NUMBER OF PAGES
09

16. PRICE CODE
A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	