5105-134

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Parabolic Dish Systems Development

DOE/JPL-1060-70
Distribution Category UC-62b

Solar Parabolic Dish Technology Annual Evaluation Report

Fiscal Year 1983

April 15, 1984

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
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The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy and is part of the Solar Thermal Program to develop low-cost solar thermal and electric power plants.

ABSTRACT

This report summarizes the activities of the JPL Solar Thermal Power Systems Parabolic Dish Project for FY 1983. Included are discussions on designs of module development including their concentrator, receiver, and power conversion subsystems together with a separate discussion of concentrator development. Analyses and test results, along with progress on field tests, Small Community Experiment system development, and tests at the Parabolic Dish Test Site are also included.

ACKNOWLEDGMENT

This report was published by the Jet Propulsion Laboratory through NASA Task Order RE-152, Amendment 327 and was sponsored by the U.S. Department of Energy (DOE) under Interagency Agreement DE-AM04-80AL13137 with the DOE Albuquerque Operations Office.

GLOSSARY

ACRONYMS AND INITIALISMS

AGT	Advanced Gas Turbine
B-N	Barber-Nichols
DOE	U.S. Department of Energy
DTM	Development Test Model
ESOR	Experimental Solar-Only Receiver
FACC	Ford Aerospace and Communications Corporation
GE	General Electric Company
GRI	Gas Research Institute
GTEC	Garrett Turbine Engine Company
JPL	Jet Propulsion Laboratory
LeRC	Lewis Research Center
NASA	National Aeronautics and Space Administration
ORC	Organic Rankine Cycle
PCA	Power Conversion Assembly
PDC-1	Parabolic Dish Concentrator No. 1
PDC-2	Parabolic Dish Concentrator No. 2
PDTS	Parabolic Dish Test Site
PMA	Permanent Magnet Alternator
PON	Program Opportunity Notice
S/A	Sanders Associates
SABC	Subatmospheric Brayton Cycle
SAGT	Solarized Advanced Gas Turbine
SCE	Southern California Edison Company
SCSE-1	Small Community Solar Experiment No. 1
SCSE-2	Small Community Solar Experiment No. 2
SNLA	Sandia National Laboratories at Albuquerque
TAP	Turbine-Alternator-Pump
TBC	Test Bed Concentrator
USAB	United Stirling of Sweden

UNITS

C	centrigrade	hp	horsepower
F	Fahrenheit	MW	megawatt
W/m^2	watts per square meter	cm	centimeter
%	percent	rev/min	revolutions per minute
m	meter	h	hour
ft	foot	m^2	square meter
M	million	ft^2	square foot
kWt	kilowatt thermal	$/kW	dollars per kilowatt
kWe	kilowatt electric		
MPa	megapascals		
psi	pounds per square inch		
Hz	Hertz		
mi/h	miles per hour		
mm	millimeter		
in.	inch		

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Figures

SECTION I

EXECUTIVE SUMMARY

A. INTRODUCTION

Solar parabolic dish technology is being developed for the U.S. Department of Energy (DOE) by the Jet Propulsion Laboratory (JPL) under an Interagency Agreement with the National Aeronautics and Space Administration (NASA). The status of this work is described in this report in terms of module and concentrator development. The concentrators, or parabolic dishes, reflect the sun's rays into a very small aperture at the dish focal point. A power conversion assembly (PCA) consisting of an integral receiver, engine, and alternator are mounted at the focal point converting the sun's heat entering the receiver into mechanical energy operating an alternator to produce electricity. A concentrator or dish with power conversion assembly and controls is called a module. Testing is accomplished at the Parabolic Dish Test Site (PDTS) to verify the performance of the module prior to deploying the dish systems in field experiments in user environments.

Parabolic dish systems uniquely combine a modular configuration with the ability to develop high temperatures. Dishes can be used to generate electricity or to produce thermal power; alternatively, dishes can be used for cogeneration purposes. Various fluids can be operated at temperatures between 315°C (600°F) and 1650°C (3000°F), providing maximum efficiencies for heat engines. Because dishes are modular, a single dish can be used autonomously in remote applications, or a field of dishes can be deployed with their outputs electrically connected. Power can be added incrementally, as required, and individual dishes serviced without disturbing other units in the field. Modularity also offers manufacturing, installation, and control advantages because a large number of identical units are deployed.

B. MODULE DEVELOPMENT

Three modules are being developed -- each based on a different engine cycle.

Design of the Vanguard dish-electric module using a Stirling-cycle power conversion assembly (PCA) was completed by a team led by Advanco Corporation under a Cooperative Agreement with the DOE Albuquerque Operations Office. By the end of the year, all 320 fusion glass/foam glass reflective facets for the 11-m-diameter concentrator (Figure 1, p. 6) had been fabricated and tested. The 16 steel racks for the facets and the support structural parts were also fabricated. The United Stirling (USAB) Model 4-95 solar Mark II engine for the Vanguard module was designed, fabricated, and tested at Malmo, Sweden; its design was based on tests of USAB Model 4-95 Mark I engines during FY 1982 and FY 1983 at the JPL Parabolic Dish Test Site (PDTS). Similarly, a new experimental solar only receiver (ESOR IV) design was readied for the Vanguard module on the basis of tests of ESOR II and III receivers. The Vanguard module will be installed and tested in Rancho Mirage, California, during FY 1984.

Ford Aerospace and Communications Corporation (FACC) is the system contractor for the organic Rankine-cycle (ORC) module. As a result of cost limitations and minimum output power requirements specified by DOE for the Small Community Solar Experiment No. 1 (see below), FACC replaced the concentrator designed by the General Electric Company (Parabolic Dish Concentrator No. 1 or PDC-1) for the ORC module with the concentrator (PDC-2) under development by Acurex Corporation. (See Figure 3, p. 10.) PDC-2 will provide 96 kW thermal power to the ORC engine. Design of PDC-2 was completed, and packages to secure bids to fabricate the components and subsystems were being assembled at the end of the year.[1]

During the fiscal year, the primary effort by FACC's subcontractor, Barber-Nichols, on the ORC power conversion assembly was solving the problem of bearing wear and electrical arcing in the turbine-alternator-pump (TAP) unit. Optical proximity probes were used to measure movement of the turbine shaft while the TAP was operated. Test results led to changes in the design of the bearings. Also, electrically insulated bearing carriers and a grounding strap were added. Subsequent test runs showed no detectable bearing wear in twenty hours of engine operation at various speeds and loads.

In early FY 1983, DOE and JPL approved the recommendation by Sanders Associates that the first Brayton module consist of a Garrett AiResearch subatmospheric Brayton-cycle (SABC) engine (with 7 kWe output), a Sanders ceramic matrix receiver adapted to the engine, and a concentrator from LaJet Energy Company. (See Figure 7, p. 17.) Early engine tests indicated higher than expected compressor and leakage losses, which necessitated redesign of the compressor and seals and rework of the engine. A receiver was assembled after successfully passing a detailed design review. The membrane facet of the LaJet concentrator performed satisfactorily in optical tests at JPL, and the concentrator for the development test model was prepared for shipment to Sanders.

Feasibility tests of the solarized metal advanced gased turbine (AGT) from the Garrett Turbine Engine Company at the PDTS was postponed to FY 1984 pending resolution of developmental problems with the automotive AGT-101 engine. A ceramic version of this engine is planned for use in an advanced Brayton module.

C. CONCENTRATOR DEVELOPMENT

Testing of PDC-1 in the fall of 1982 showed an unexpectedly large image at the focal plane. Subsequent optical tests utilizing new techniques demonstrated that the panels were distorted by excessive tension. Reinstallation of the panels brought PDC-1 performance to expected levels.

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[1] Rankine module development activities, including those to build the 12.2-m PDC-2, were suspended in early FY 1984 when DOE and FACC were unable to finalize contractual arrangements for carrying out the Small Community Solar Experiment No. 1. DOE has decided to resolicit bids for the experiment; the PON was released in December 1983.

The development of more cost-effective parabolic dish concentrators for the evolving higher efficiency power conversion assemblies was started for DOE by the preparation of a draft Program Opportunity Notice for an "Innovative Point Focus Solar Concentrator."

D. SYSTEM EXPERIMENTS

Small Community Solar Experiment No. 1 (to be located in Osage City, Kansas, as a result of a DOE decision made in FY 1982) was to consist of four ORC modules resulting in a 100-kWe plant. Ford Aerospace and Communications Corporation was the system contractor, and Acurex Corporation was to carry out the plant detail design and manage the construction activities in addition to supplying the PDC-2 concentrators. Phase III, which would complete the module development and include the construction of the plant, had been initiated by a letter contract between DOE and FACC in August 1983. (See footnote on page 2.)

Also during FY 1983, effort was initiated on Small Community Solar Experiment No. 2. A draft statement of work and a systems requirements document were prepared for DOE.

E. MANAGEMENT CHANGE

Late in the fiscal year, JPL informed DOE of its desire to phase out of the dish-electric project during FY 1984. At DOE's direction, planning was initiated to transfer the project to Sandia National Laboratories at Albuquerque.

SECTION II

MODULE DEVELOPMENT

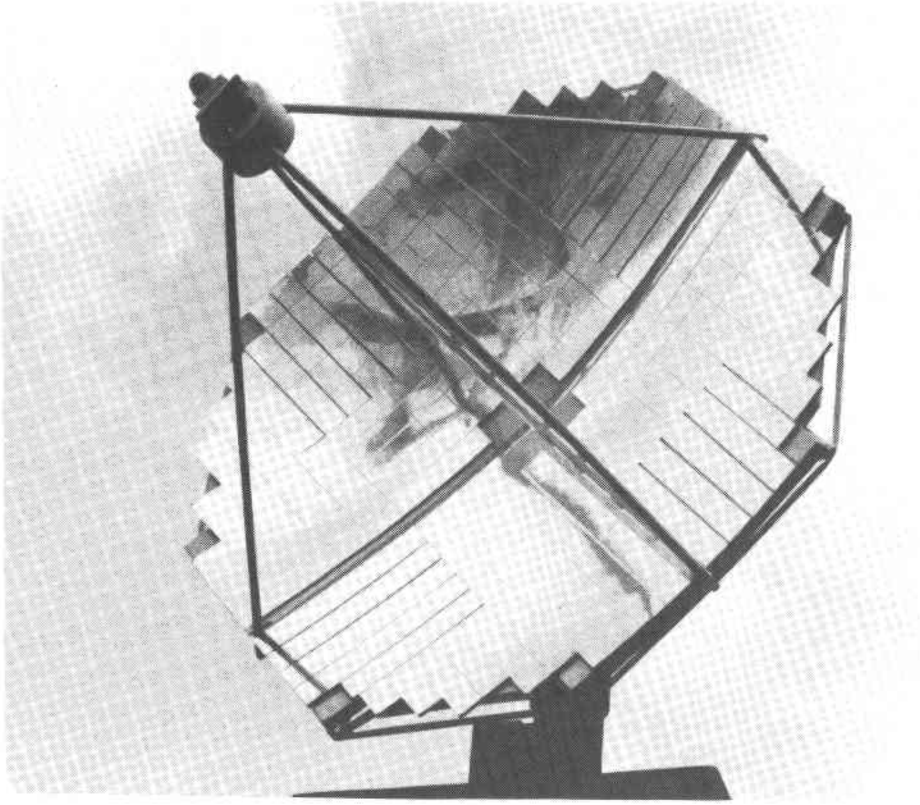
A. STIRLING-CYCLE TECHNOLOGY

Solar parabolic dish-Stirling module development has been pursued by the U. S. Department of Energy through Government laboratories and industrial participants since FY 1978. This type of module consists of a solar collector coupled to a Stirling-engine-powered electrical generator. The module has been designed to convert solar power to electrical power in parallel with other identical units coupled to an electrical utility power grid or remote user of electricity.

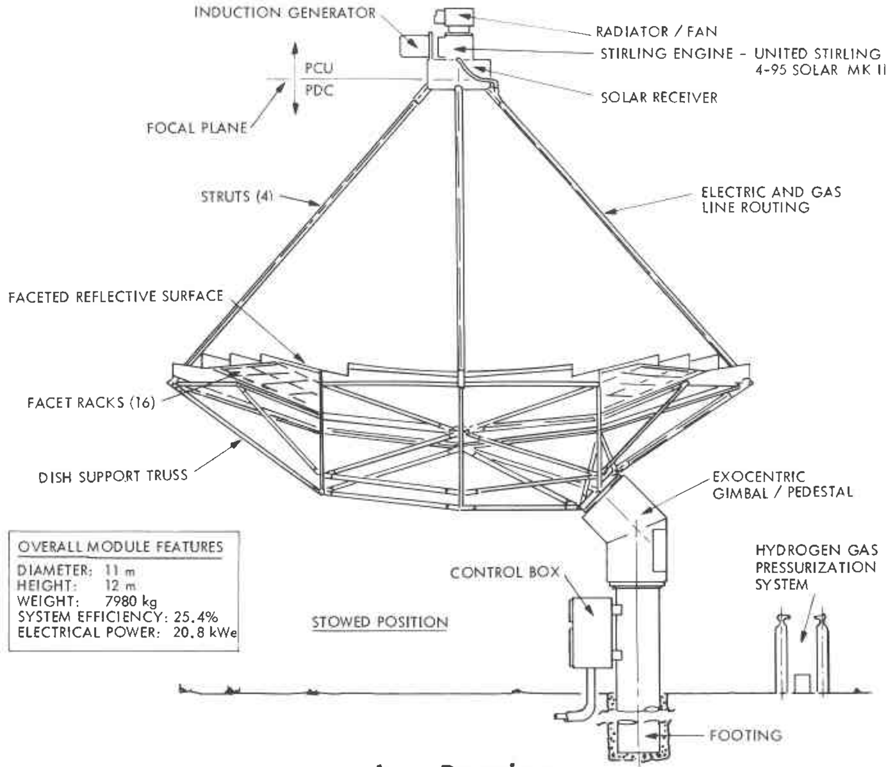
At the end of FY 1983, the Stirling module was being assembled as a commercial prototype by the Advanco Corporation at the Southern California Edison Company's Santa Rosa Substation located in the city of Rancho Mirage, California. The participants are planning to construct an electricity generating plant at Barstow, California, consisting of 1500 commercial units in the 1985-1986 time frame if tests of the commercial prototype (named Vanguard) prove the equipment to be effective and reliable, and if economic and related factors are favorable.

In order to prepare for the Vanguard module assembly, Advanco Corporation worked with their subcontractors to design, fabricate, assemble, and test the many components and subsystems over the past year. A sketch of the module is shown in Figure 1b. At its facility, Advanco designed, fabricated, and tested the 320 fusion glass/foam glass reflective facets, and the 16 steel racks for the reflective panels for the 11-m-diameter concentrator. A photograph of a rack being tested is given in Figure 2a. Rockwell International Energy Systems Group designed and fabricated the panel support structure, which carries the panel weight, as well as earthquake and wind loads, into the integrated drive support. An engine/generator quadripod support structure attaches to the integrated box-type drive support. The azimuth drive and elevation drive motors are housed in an exocentric-gimbal mechanism connecting the drive support structure with the hollow-steel tube footing.

The United Stirling (USAB) Model 4-95 solar Mark II engine used with the Vanguard differs from the previous Mark I engine in several significant ways that reduce production cost by 30%, increase lifetime of some components by a factor of 2, yet keep the overall performance close to 30%. Engine changes included the following: (1) The engine drive shaft was replaced by a direct gear-driven generator shaft; (2) the engine heater head and receiver cavity were improved; (3) the regenerator and cooler were optimized, and the engine block was modified; and (4) the cylinder and piston dome were lengthened to reduce heat losses and increase piston ring life, and working fluid controls were modified.

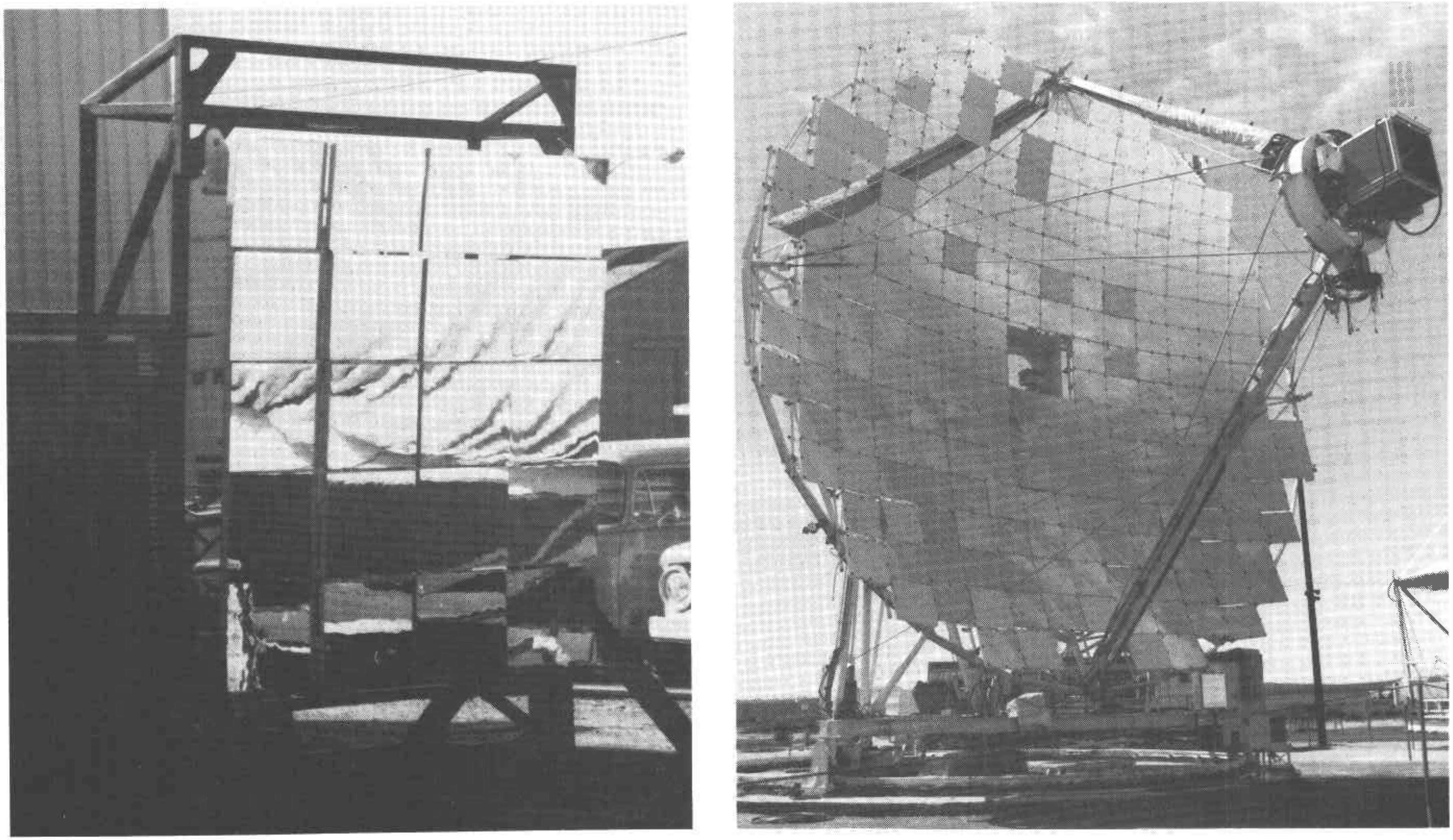


a. Model



b. Drawing

Figure 1. Vanguard Dish-Stirling Module



a. Facet Rack Under Test

b. Closed-Coupled Radiator Under Test

Figure 2. Facet Rack and Radiator System of the Vanguard Module

USAB and JPL tested two USAB Model 4-95 engines on the test bed concentrators at the Parabolic Dish Test Site, Edwards AFB, California, during the past year. Improvements in the reliability and performance of the USAB Model 4-95 solar engine result from knowledge gained in these tests, as well as from the DOE/NASA-sponsored automotive Stirling engine tests at USAB and Mechanical Technology, Inc., and the laboratory tests by USAB in Malmo, Sweden. The joint USAB/JPL solar tests of the two Model 4-95 engines provided an actual environment for functional, performance, and endurance measurements. Results from these tests are being used to improve the hardware and software and to estimate the commercial value.

During the past year, a newly designed experimental solar only receiver (ESOR) with single tubes, increased diameter, and outer tube "hair pin" curvature, was built and tested. The new design (named ESOR III) demonstrated a performance only slightly better than an earlier model (ESOR IIA); however, ESOR III has a high ratio between power output and engine working gas pressure because the tube length has been optimized in comparison to the outer receiver diameter. The improvement results in a relatively lower operating pressure for the same output power. The highest module output can now be obtained within the 20 MPa maximum pressure limit. The most common test setup has 80% of the concentrator facets uncovered and uses helium as the engine working gas in order not to exceed the maximum working gas pressure. Helium is readily available at the test site and is relatively safe.

The test bed concentrator was realigned to concentrate all insolation on the receiver tubes rather than some on the ceramic cavity walls and center plug. The solar flux is distributed on the annular receiver tubes in a doughnut shape with a maximum flux of 80 W/cm^2. The cavity aperture receives a maximum flux of 800 W/cm^2 with all insolation within a 20-cm-diameter circle. Realignment of the concentrator facets resulted in an increase of 10 to 15% in electrical output power.

Tests without an optical cavity around the heater head resulted in an additional heat loss of 8 kWt -- about twice the loss with a cavity. Also, tests with a cavity aperture quartz window reduced the power output by up to 1 kWe at full load. There were no problems with the survival of the aperture window. Quantitative measurements of performance in winds indicate an output power loss of up to 1 kWe at full load with a 13 meter/second average wind speed.

One of the Stirling 4-95 engines tested has a complete cooling water radiator system installed directly on the engine. The radiator system consists of four radiator matrices built up in a box-like form with a radial air fan in the center (Figure 2b). A water pump consumes 200 W of electrical power. The cooling design criterion of 20°C temperature difference between the air and water at full load and full fan power of 1250 W was more than achieved. Partial fan power of 790 W resulted in a 23°C temperature difference at full load (22.4 kWe output with helium).

During testing, many different sequences were run to evaluate control system parameters. The microcomputer allows automatic, remote operation and requires setting many values of parameters in the logic for standard operation, failure limits, and shutdown.

Testing during FY 1983 included over 500 engine hours on two test bed concentrators. No problems with piston rings or gas seals were noted. A piston rod failed due to material fatigue at its weakest point. Faulty start-up sequences, combined with fuse failure, resulted in the accidental burn-out of two receivers. Operating with hydrogen, the output from the electric generator was 24.8 kWe, and the solar-to-electric generator efficiency was 29.5%. The efficiency dropped to 28.4% when prototype pump and fan power were subtracted.

B. ORGANIC RANKINE-CYCLE TECHNOLOGY

The organic Rankine module consists of a parabolic dish, a cavity receiver, an organic Rankine-cycle (ORC) engine with an integral permanent magnet alternator, and associated controls and electric power conversion equipment.

The ORC power conversion assembly (PCA) development was initiated in December 1979 with a contract to Ford Aerospace and Communications Corporation (FACC) for development of a receiver and electric power conversion equipment and system controls. FACC selected the Barber-Nichols Engineering Company to develop the engine, which uses toluene as the working fluid. This contract was expanded in 1982 to include the fabrication, assembly, and test of a parabolic dish concentrator (PDC-1) designed by the General Electric Company (GE). During FY 1983, the majority of the activity in the ORC area centered around three subsystems: the concentrator, the power conversion subsystem, and the control subsystem.[2]

1. Concentrator

Although the original plan envisioned the use of the GE-designed PDC-1 for the ORC power module, that concentrator will be replaced by the larger, more efficient PDC-2 (Figure 3) from Acurex Corporation. This change came about as a result of cost limitations and strict minimum output power requirements specified by DOE for the Small Community Solar Experiment No. 1, which is to be built at Osage City, Kansas. To meet these requirements, the dish must be able to provide more than 96 kW thermal power to the receiver of the ORC engine. Like PDC-1, it is a single reflection, point-focusing, two-axis tracking solar concentrator. Its diameter is 12.2 m, and it uses thin back-silvered glass bonded to cellular foam glass gores, which have been machined into paraboloidal shape. Figure 4 shows how the individual segment is related to the full paraboloid and what provisions have been made for adjusting the alignment of individual panels.

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[2] Rankine module development activities, including those to build the 12.2-m PDC-2, were suspended in early FY 1984 when DOE and FACC were unable to finalize contractual arrangements for carrying out the Small Community Solar Experiment No. 1. DOE has decided to resolicit bids for the experiment; the PON was released in December 1983.

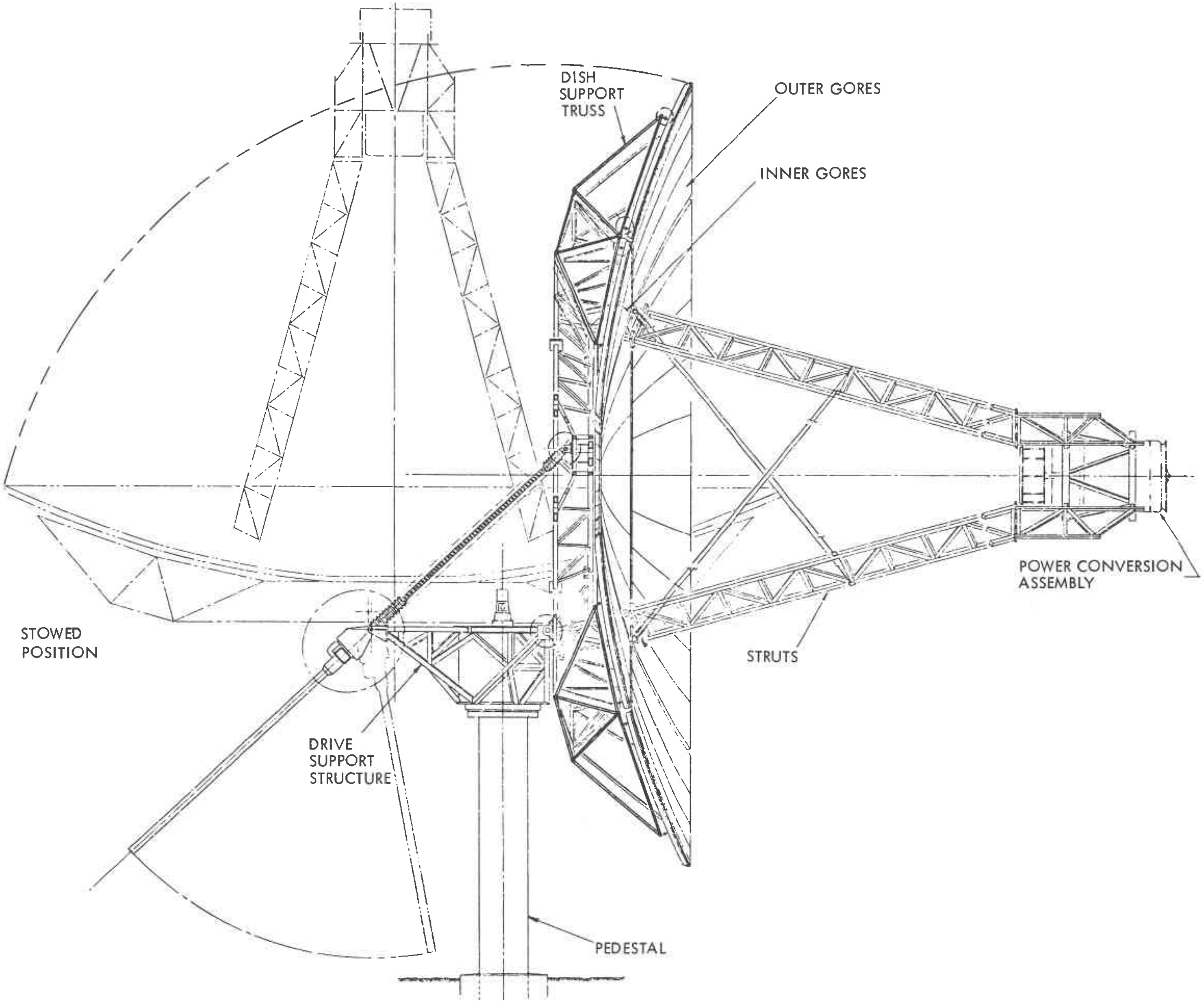
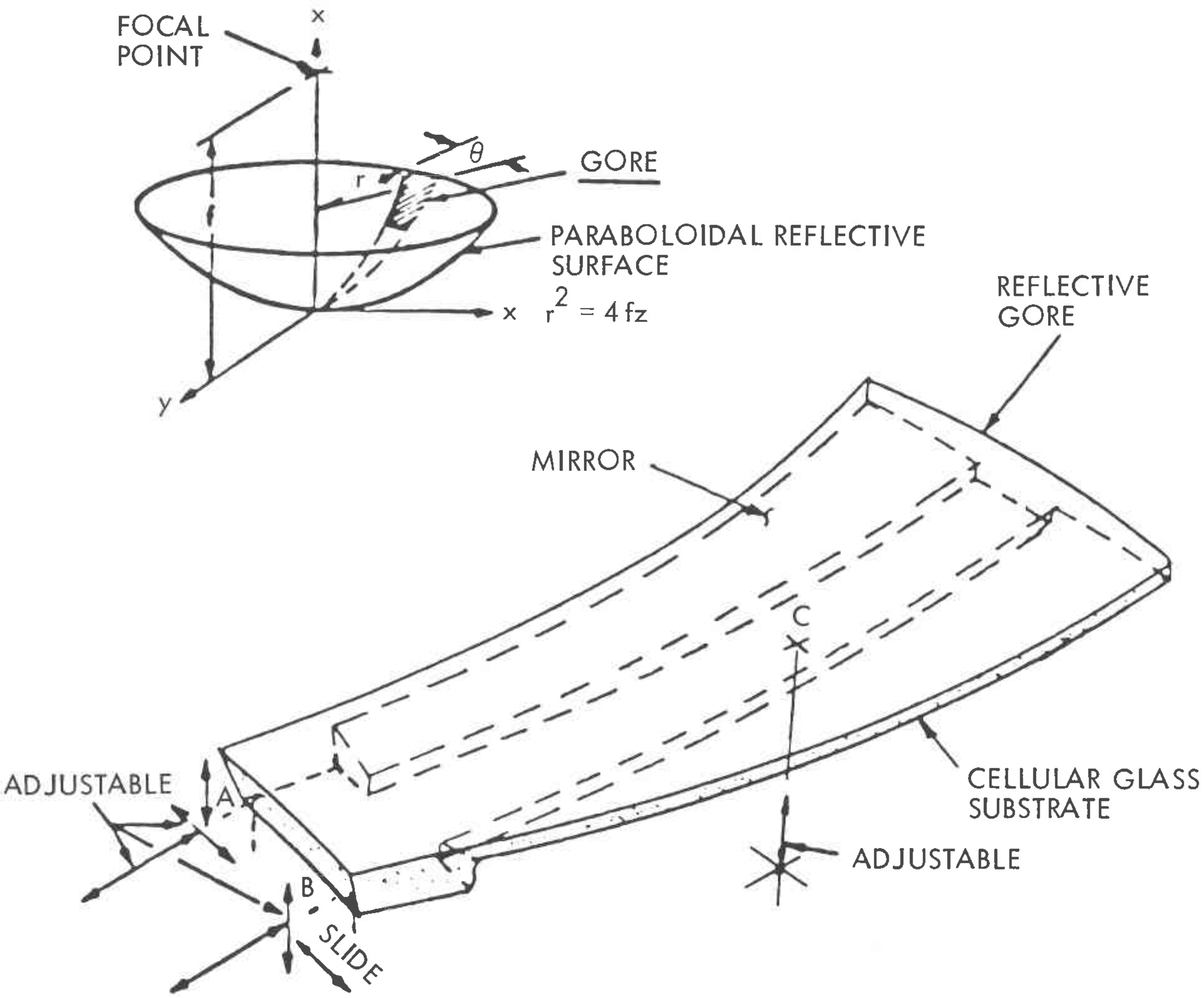


Figure 3. Drawing of Parabolic Dish Concentrator No. 2



SUPPORT BOUNDARY CONDITIONS @ SUPPORTS A, B, C

- 6 DEGREES OF FREEDOM RESTRAINED (WITH 4 OF THESE DEGREES OF FREEDOM ADJUSTABLE)
- 1 SLIDING DEGREE OF FREEDOM SLIDING ALONG RING
- ALL ROTATIONS WILL BE UNRESTRAINED

Figure 4. Characteristics of PDC-2 Mirror Segment

A detailed design review of PDC-2 was successfully completed and packages are being assembled for the purpose of securing bids to fabricate the components and subsystems. Meanwhile, a facility is being put together by Acurex for the purpose of shaping the cellular glass panels and for bonding the reflective glass sheets to them. Optical and environmental tests are being developed to ensure that the optical performance of the concentrator is consistent with the stringent performance requirements.

2. Power Conversion Subsystem

Since the completion of "on sun" tests, which were performed in March 1982 with the engine mounted on the test bed concentrator, primary effort has been directed toward solving the problems of turbine-alternator-pump (TAP) bearing wear and electrical arcing revealed by those tests. Basic changes were made in the bearing design, and elegant techniques were employed to measure and analyze the dynamic performance of the TAP assembly. In order to operate and measure the performance at the high rotational speeds (60,000 rev/min), it was necessary to design and build a high-speed test apparatus that had the required torque and speed to drive the unit and at the same time permit measurement of the various experimental parameters and dynamic behavior. Figure 5 shows the test apparatus with the TAP assembly in place.

Optical proximity probes were used to measure the excursion of the turbine shaft at various rotational speeds. These measurements suggested that the original bearings were susceptible to the phenomenon known as sub-synchronous whirl -- an unstable dynamic condition that can result in severe bearing wear. By replacing the original bearings with five-pad, fully flooded, tilting pad bearings, the whirl problem was eliminated.

Subsequent visual and energy dispersive x-ray examinations revealed evidence of parasitic high current leakage paths across the hydrodynamic film gap. These paths were then eliminated by insulating the bearings with bearing mounts made of insulating material instead of metal.

Mounting the new bearing in the electrically insulated carrier eliminated all detectable bearing wear. Subsequent test runs showed no detectable wear in over twenty hours of engine operation at various speeds and loads.

3. Control Subsystem

Work continued and is continuing in two control subsystem areas: plant control and concentrator control. Previous developmental work in the plant control area was reviewed and continued toward a definitive operating strategy and its implementation. Interfaces with the individual module control microprocessors are now well defined. The ongoing task, which was initiated in FY 1983, is to structure a plant control system that will permit

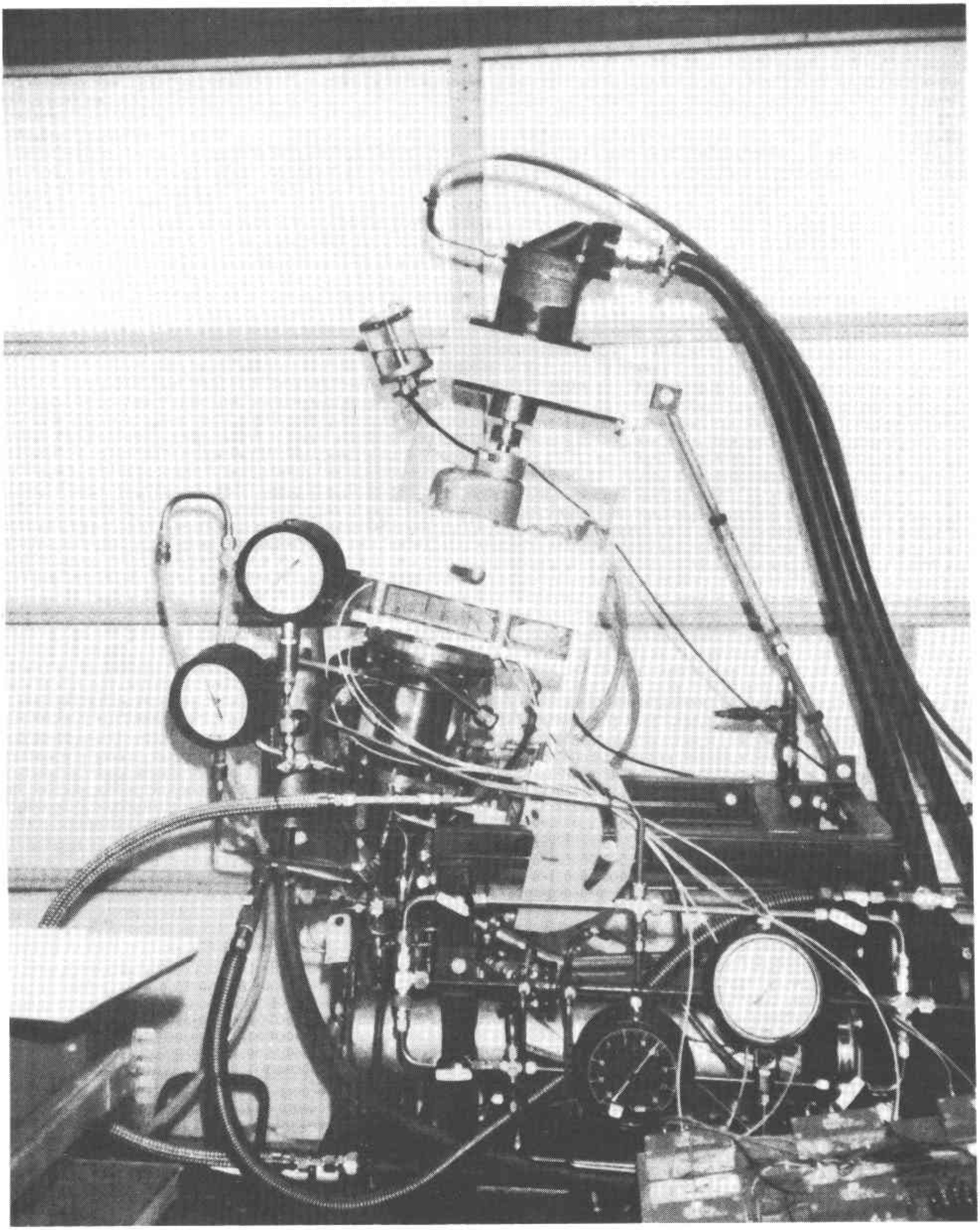


Figure 5. ORC Test Apparatus with TAP Assembly in Place

manually controlled start-up for initial test operations with step-by-step activation of automatic features leading ultimately to fully autonomous plant operation.

In the concentrator control area, operation of a stand-alone control subsystem for the PDC-1 concentrator was demonstrated. For this case, a separate microprocessor was used at the module, and automatic control was done through a remotely located small computer. The current task for the PDC-2 unit was also initiated in FY 1983. This task is to transfer the demonstrated digital logic to the PCA control microprocessors, thereby eliminating all the stand-alone units (microprocessor, digital communication link, and remote small computer). The central logic is being reviewed and extended as required to provide for safe, autonomous plant operation.

C. BRAYTON-CYCLE TECHNOLOGY

In FY 1982 Sanders Associates initated work on a contract to design and integrate a Brayton-cycle parabolic dish module. An early activity was a trade study of various engine/concentrator configurations. As a result of this study, Sanders recommended both a near-term and an advanced module. The near-term module would use the 7-kWe AiResearch subatmospheric Brayton-cycle (SABC) engine and an industry-developed small concentrator for a module to be completed in FY 1984. The advanced module would use a solarized modification of the ceramic advanced gas turbine (being developed by the Garrett Turbine Engine Company for automotive application) for a module in FY 1986. The Sanders recommendation, approved by JPL and DOE, provided the basis for Brayton activities in FY 1983.

1. Near-Term Module Preliminary Design

The first activity in FY 1983 was the system preliminary design for the near-term module with a preliminary design review held at Sanders in January 1983. The module system consists of the following subsystems:

(1) AiResearch SABC engine modified for solar application with a new permanent magnet alternator (PMA)

(2) Sanders ceramic matrix receiver modified for SABC flow and pressure and LaJet concentrator aperture

(3) LaJet Energy Company standard LEC 460 concentrator modified for engine/receiver interface

(4) Controls and transport using Sanders standard microprocessor parts and a solid-state, single-phase inverter from Abacus or Helionex

The module is designed to provide automated operation in fossil-fuel, hybrid, or solar-only modes with primary emphasis on hybrid operation. Peak power output is approximately 7 kWe at rated conditions with about 10% parasitic losses.

The project plan is to first obtain prototype subsystems for individual developmental testing, then combine subsystems in a development test model (DTM). Design modifications based on these test results will be presented in a critical design review prior to completion of module subsystems and module system assembly.

2. Subatmospheric Brayton-Cycle Engine

The SABC engine has been developed by the AiResearch Manufacturing Company for application as a gas-fired commercial heat pump with funding from the Gas Research Institute (GRI). The air turbine engine operates with a turbine inlet temperature of 871°C (1600°F) and a subatmospheric turbine outlet pressure to provide a design shaft power of 8 kWe at a speed of about 75,000 rev/min. The engine uses all foil bearings and is fully recuperated. It operates closed cycle, except for makeup combustion air, and has a sink heat exchanger. Several thousand hours of development testing has been accumulated on the engine with no mechanical problems.

The current Mark IIIA version of the SABC engine has higher than expected compressor and leakage losses and only provides about 6 kWe of output at an efficiency below 20%. The compressor and seals have been redesigned, fabricated, and tested as components. The improved Mark IIIB engine is expected to provide about 8 kWe of shaft output at an efficiency of at least 25%. Engines that have undergone preliminary tests at heat pump manufacturer facilities are being reworked to the improved Mark IIIB configuration. A sketch of the solarized power conversion assembly is shown in Figure 6.

3. Receiver

Previously, Sanders had successfully solar tested their high-temperature, ceramic matrix receiver at temperatures exceeding 1204°C (2200°F). The receiver for the near-term Brayton module incorporates modifications based on these tests and on the smaller mass, lower density flow of the SABC engine. The receiver has an outside diameter of 31 in. and an inside insulation diameter of 19 in. The quartz window aperture is 10 in. to match the characteristics of the LaJet 460 concentrator.

A detailed design review of the prototype receiver was held and all open areas resolved. Components for the receivers have been fabricated, and one receiver has been assembled and is being instrumented for ground testing.

4. Concentrator

The LaJet Energy Company has developed, with their own funds, a concentrator using circular membrane facets as shown in Figure 7. Each facet is 5 ft in diameter with the membrane shape controlled by a low vacuum and a mechanical stop. Facets are attached to the frame at a determinate three points and are easily installed, aligned, or replaced. The concentrator utilizes a polar mount with diurnal and declination drives. Alignment is accomplished with stepper motors on each drive that are controlled by a microprocessor ephemeris and sun sensor correction.

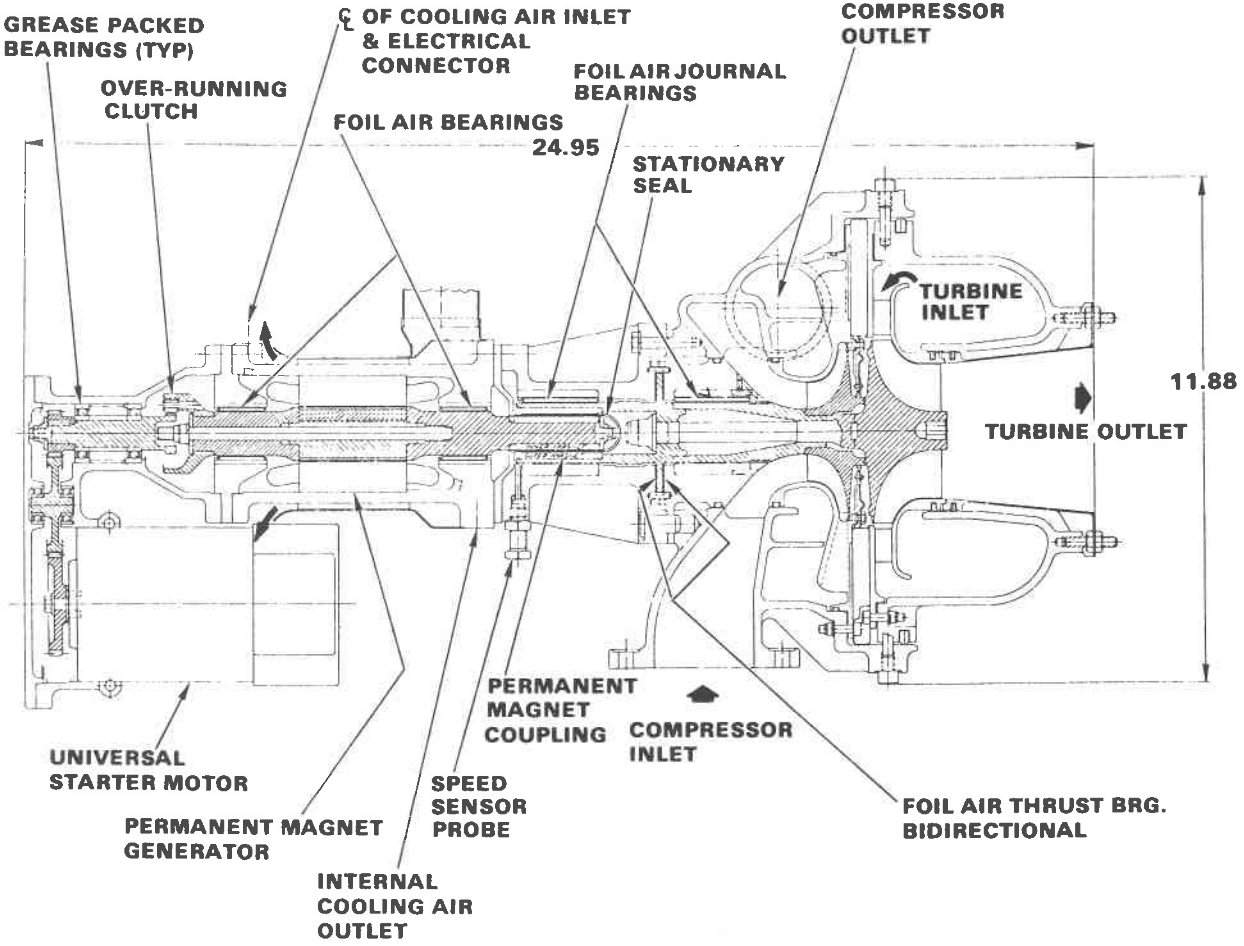


Figure 6. Drawing of Subatmospheric Brayton Power Conversion Assembly

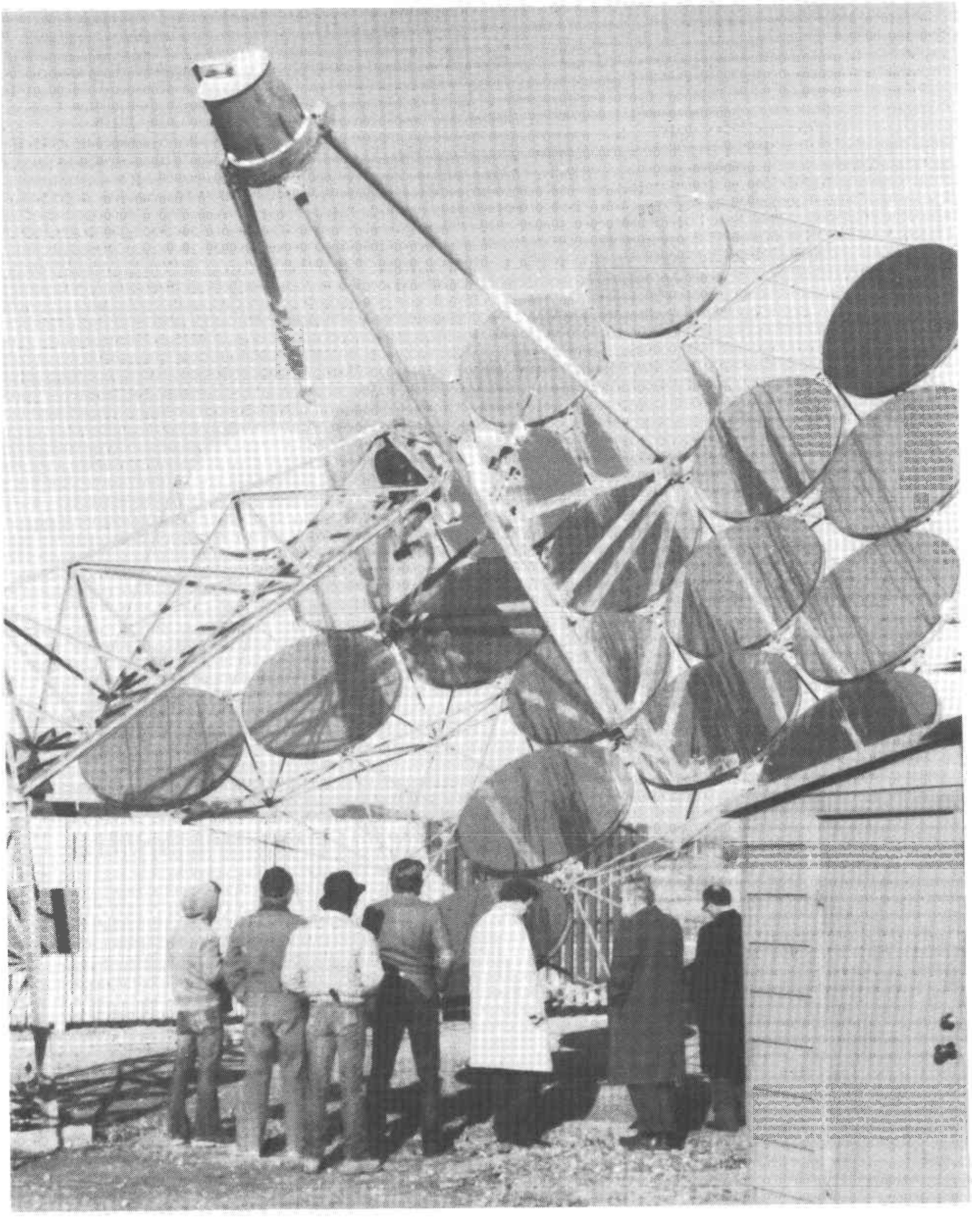


Figure 7. LaJet Membrane Concentrator

Facet optical testing conducted at JPL included on- and off-axis autofocus and solar source tests. Analysis of the test results indicates that the energy from an LEC 460 concentrator should fall within a 9-in. aperture.

The baseline 24-facet concentrator (LEC 460) for developmental testing has been checked out at Abilene, Texas, preparatory to shipment to Sanders.

5. Advanced Brayton Module

In preparation for the high-temperature ceramic advanced gas turbine (AGT) engine, Garrett has been testing a metal AGT at 870°C (1600°F) turbine inlet temperature. AGT modifications to resolve high-speed dynamics and leak problems are expected to be tested early in FY 1984, at which time the feasibility test efforts will continue.

The metal engine is designed to provide about 20 kWe at an efficiency of about 30%. The ceramic engine is expected to provide up to 50 kWe for solar application at an efficiency of about 40% for a turbine inlet temperature of 1150 to 1370°C (2100 to 2500°F). Ceramic parts have been built and tested as components, with engine testing due next year. A solarized modification of this metal engine (SAGT-1A) has been integrated with the Sanders receiver for limited solar and fuel feasibility testing on a test bed concentrator. This testing has been delayed pending resolution of developmental problems of the AGT.

SECTION III

CONCENTRATOR DEVELOPMENT

Testing of the Parabolic Dish Concentrator-1 (PDC-1) began early in the fall of 1982. When the reflecting panels were installed the first time, the focal plane image was found to be unexpectedly large. Because the optical panels had shown good imaging characteristics during earlier tests, it appeared that the source of the problem must be the concentrator structure or the method of panel installation. To determine the source of the problem, an optical technique was developed which viewed a target of colored patterns mounted at the focal plane (Figure 8) from a distance of 600 to 900 m (2000 to 3000 ft) through a small telescope. Pictures could also be taken through this telescope (Figure 9). The observed color of each part of the reflecting panels indicated the area on the target that would be illuminated by a distant point source reflected from the panels. These diagnostic pictures indicated that the panels were distorted by excessive tension. When this tension was removed by reinstalling the panels, the image quality was greatly improved -- approximately reaching analytical predictions. This technique also indicated that the basic concentrator structure was very rigid, showing no significant deformation by gravity. In addition, the technique demonstrated that the concentrator was less temperature sensitive after the panels were reinstalled. Final characterization was initiated in the spring of 1983. Initial work with the cold water calorimeter did confirm that the full power of the dish, approximately 75 kWt, could be focused through a 25.4-cm (10-in.)-diameter aperture. Additional calorimeter measurements are in progress, as time and resources permit, to confirm experiment locations on the optical axis. Flux mapping is in the planning stage.

The development of parabolic dish concentrators for the evolving higher efficiency power conversion assemblies was started for DOE by the preparation of a Program Opportunity Notice for an "innovative point focus solar concentrator." The prime objective of the PON is to design, fabricate, and test an innovative concentrator that has significantly lower life-cycle costs than current designs when produced in large quantities. All documentation for the PON was essentially complete by June 1983. Sandia National Laboratories at Albuquerque (SNLA) will take over as monitor in FY 1984 with technical support from JPL.

The objectives of Phase I of the effort are to complete the preliminary design of an innovative concentrator, develop and fabricate two full-sized optical panels (or a representative surface area) of the design, and generate the detail design documentation necessary for fabrication in Phase II. Phase II, if given DOE approval to proceed, includes the fabrication, erection, and evaluation testing of a prototype unit. The innovative concentrator is to be used with the evolving high-efficiency power conversion assemblies expected to be available in the 1985-1988 time frame while still meeting the project's long-term mass-production cost targets of 105-160$/kWt (FY 1981 dollars/kilowatt of thermal energy through the receiver aperture) in quantities of 10,000/year. It is the intent to award two cooperative agreement contracts, both of which will be completed through Phase II. The contractors will be expected to make a financial contribution to the effort. The two contractors probably will be selected so that the innovative concentrators being designed will represent different generic approaches or configurations.

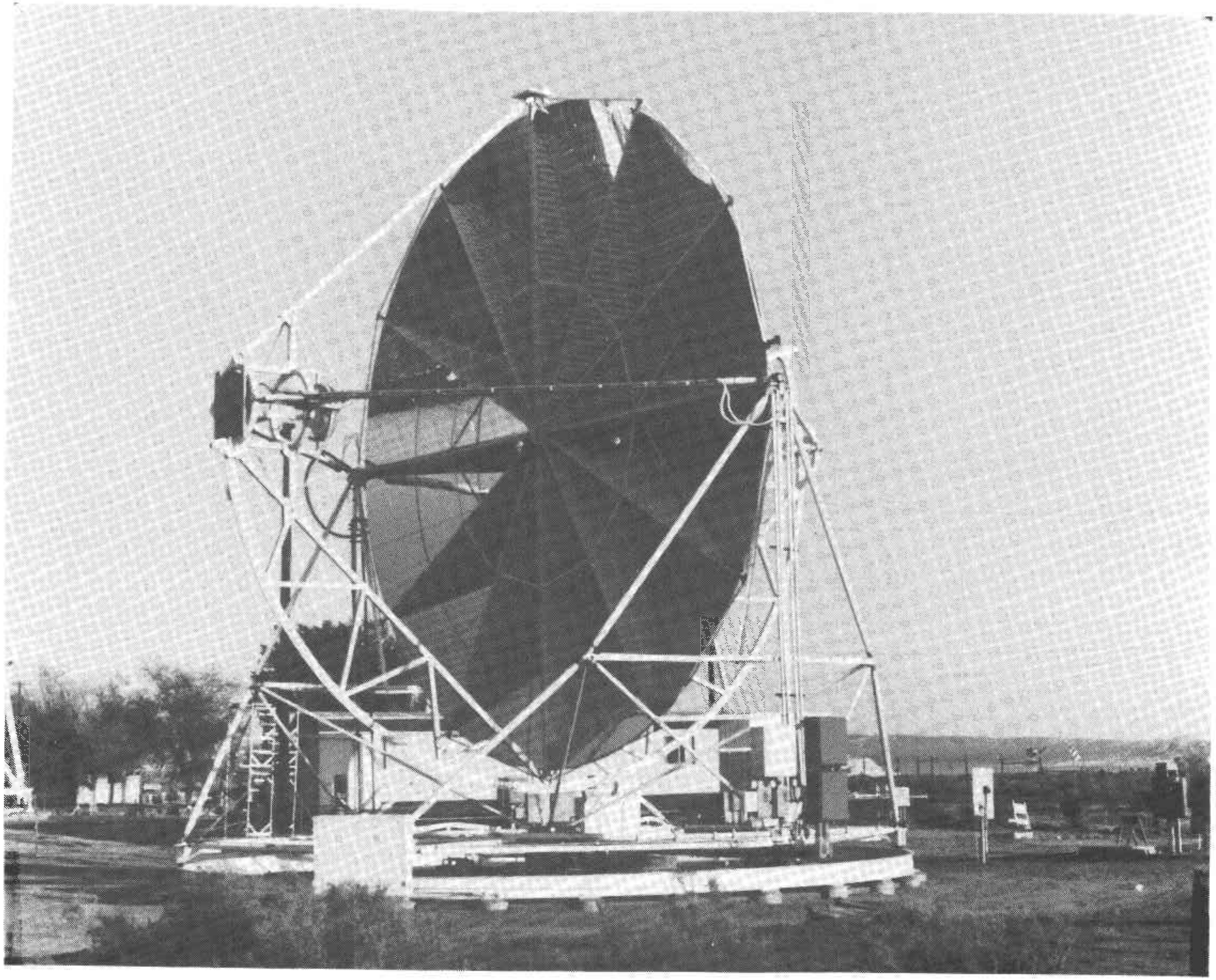


Figure 8. PDC-1 Assembled Concentrator at the PDTS. (The colored targets were mounted in the focal plane (left) and a flood light for nighttime photographs is mounted near the vertex.)

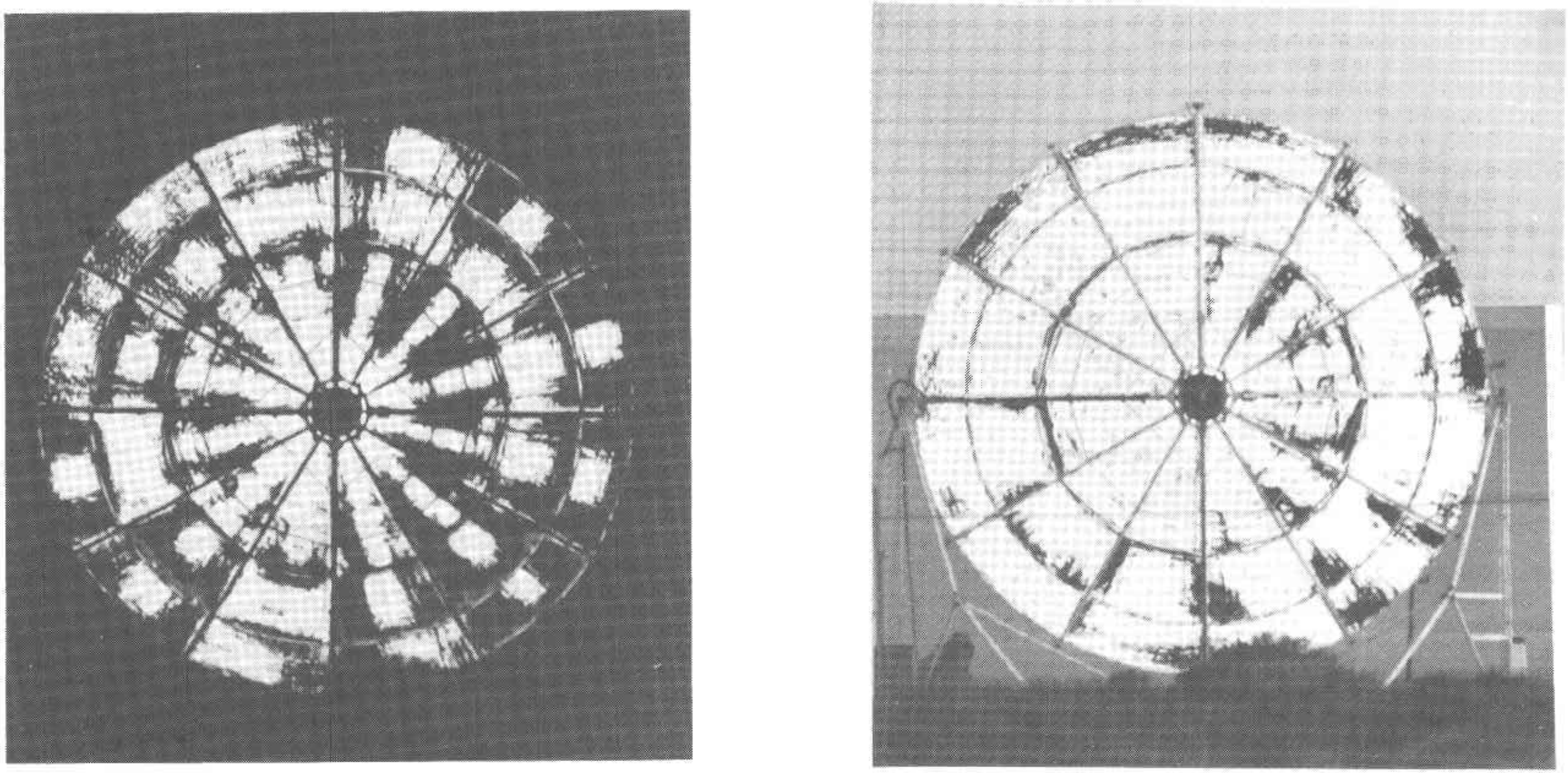


Figure 9. Diagnostic Photographs of PDC-1. (The left image is at an ambient temperature of 1.67°C (35°F) and the right image at 18.3°C (65°F). The white areas indicate regions of the reflecting panels forming an image smaller than 15 cm (6 in.) in diameter. The dark areas indicate panel areas forming images up to 38 cm (15 in.) in diameter from the colored parts of the focal plane target.)

SECTION IV

SYSTEMS EXPERIMENTS

A. SMALL COMMUNITY SOLAR EXPERIMENT NO. 1

The Small Community Solar Experiment No. 1 (SCSE-1) will be located at Osage City, Kansas, as a result of a DOE procurement awarded in FY 1982. SCSE-1 centers around a four-module 100-kWe plant, which will be operated in the user environment for a period of at least one year by the experiment system contractor, Ford Aerospace and Communications Corporation (FACC). (See footnote, page 9.) Acurex Corporation, under subcontract to FACC, will carry out the plant detail design, manage the construction activities, and prepare the site for construction. These activities are in addition to their role as supplier of the PDC-2 concentrators.

The module upon which the plant is based is being developed by FACC under the ORC development program. In addition to the four power modules, the plant will consist of: (1) a building to house the control equipment, electrical power equipment, and office space, (2) a maintenance area, (3) a toluene storage area, (4) miscellaneous plant support facilities, and (5) electrical cable to carry power and control signals between site components.

The proposed plant layout is shown schematically in Figure 10. The dish layout has been selected to give minimum shading over the reflective portion of the dishes at any attitude of the sun when considered over a complete year.

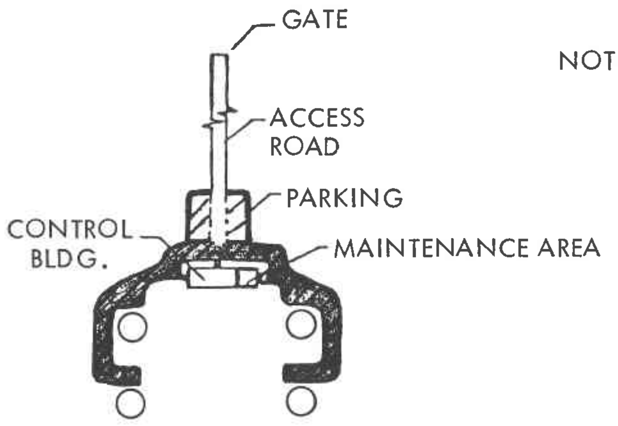
Figure 11 shows a simplified schematic of the SCSE-1 hardware with only one power module illustrated. Solar energy is concentrated into the PCA receiver where the engine working fluid, toluene, is heated to provide vapor that drives the engine turbine. The turbine is directly coupled to the electrical alternator, which generates high-frequency (300-Hz) power. This power is converted by the rectifier to dc, combined with the output of the other modules, and converted to grid-compatible ac power by the inverter. Automatic control of the complete four-module plant is provided by a master power control computer and four microcomputers, one for each concentrator. Each concentrator can then automatically track the sun.

The construction phase (Phase III) of SCSE-1 was initiated by a letter contract between DOE and FACC in August 1983.

B. SMALL COMMUNITY SOLAR EXPERIMENT NO. 2

The JPL effort on SCSE-2 in FY 1983 involved limited support to the DOE procurement activity. Early in the fiscal year, a draft statement of work and a systems requirements document were prepared and transmitted to DOE for review. The presumptions in the draft statement of work were the following:

(1) A multi-module experimental power plant with a net rating of 100 kWe or greater



NOTE: CONCENTRATOR LOCATIONS NOT TO SCALE

-SITE LAYOUT SHOWING ROADS & PARKING-

-CONCENTRATOR LAYOUT-

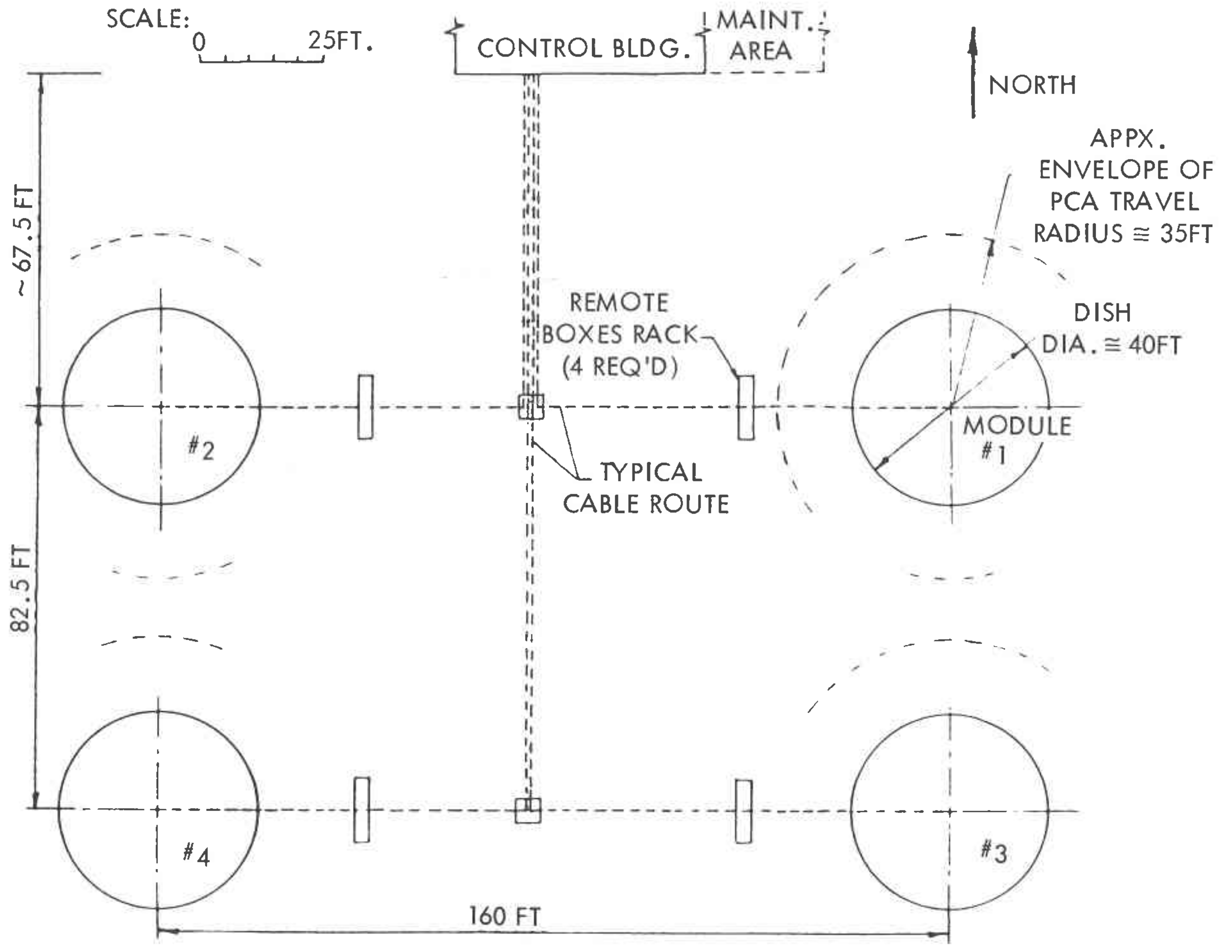


Figure 10. Plant Layout Proposed for SCSE-1

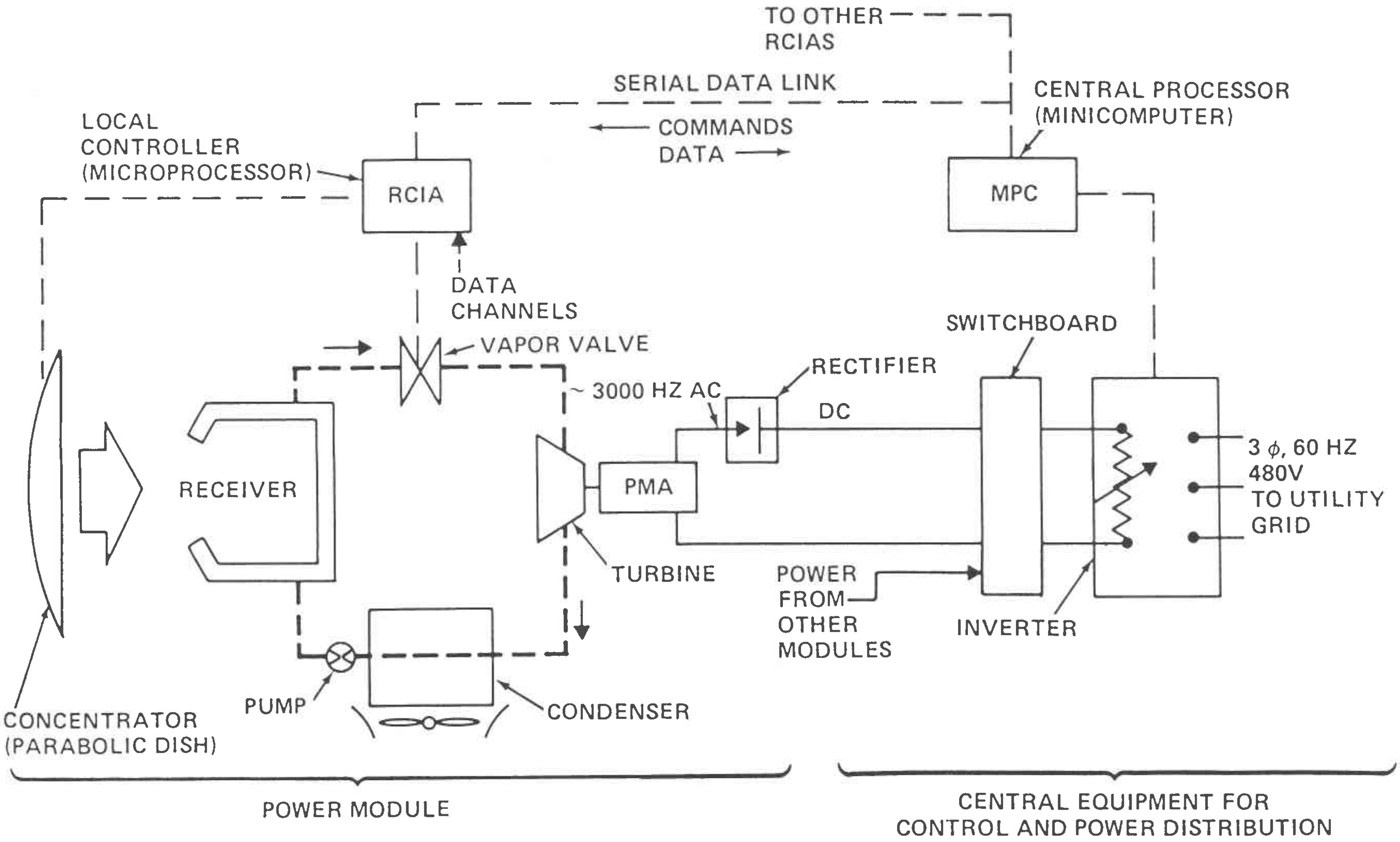


Figure 11. Simplified Schematic of SCSE-1 Hardware

(2) Located at Molokai, Hawaii, or at such other site the Government may designate

(3) A separate site participation contract similar to SCSE-1, not a part of the system procurement

(4) A modular parabolic dish system with distributed electric generation

(5) Use of a heat engine technology not used in SCSE-1 (e.g., Brayton or Stirling)

(6) Fixed price contract with preference for cost-sharing proposals

(7) No funds for subsystem development

(8) Requires evidence of existing subsystems with minor modifications allowed for the proposed module system

The work statement was structured in the following three phases with an acceptable review required for continuation to the next phase:

(1) Module subsystem and system verification

(2) Experimental plant construction

(3) Experimental plant operation

It is expected that DOE will complete the SCSE-2 definition and start procurement action early in FY 1984.

SECTION V

PARABOLIC DISH TEST SITE

The JPL Parabolic Dish Test Site (PDTS) at Edwards Test Station (a JPL facility located on Edwards Air Force Base, California) is shown in Figure 12. The principal features of the PDTS are two identical 11-m-diameter test bed concentrators (TBCs) and a single dish, 12 m in diameter, designated Parabolic Dish Concentrator No. 1 (PDC-1). The TBCs were used throughout the year to test two Stirling engines with various heater-head combinations. The TBCs were also used for materials testing and gamma ray astronomy testing as well as terminal concentrator testing. Rework of PDC-1 was completed and characterization was initiated.

FY 1983 activities at the PDTS are detailed below:

(1) Completed a series of tests on TBC-1 of various materials that could be used to withstand a walk-off of the beam of concentrated sunlight at the focal plane. The materials tested were each subjected to an exposure of concentrated sunlight at a flux density of about 7000 kW/m^2 for 15 minutes. Types of materials tested under simulated walk-off conditions included graphite, silicon carbide, silica, various silicates, alumina, zirconia, aluminum, copper, steel, and polytetrafluoroethylene. Of these, the only material that neither cracked nor melted was grade G-90 graphite, a premium grade. Grade CS graphite, a lower-cost commercial grade, cracked halfway across, but did not fall apart. With proper design, this grade should perform satisfactorily as a receiver aperture plate.

(2) Conducted testing on materials to be used for receiver aperture plates that must withstand conditions other than walk-off such as solar acquisition and deacquisition and solar spillage. Grade CS graphite was tested for up to 2000 cycles simulating one-second periods of acquisition at the same flux density as the walk-off test. Loss during 2000 cycles at moderate to high winds was about 5 mm in thickness or 3% of the sample mass; this appears to be tolerable. At spillage levels of up to 2%, the lip temperature of grade CS graphite was 150 to 300°C (300 to 570°F), low enough to provide adequate lifetime of this material with respect to oxidation.

(3) Completed several tests to detect high-energy gamma radiation emitted from various celestial objects. Dr. Richard Lamb, Professor of Physics at Iowa State University was the Principal Experimenter. Both TBCs were used during these nighttime tests, which were termed highly successful by Dr. Lamb in detecting high energy gamma radiation using the Cerenkov effect.

(4) Completed testing of a terminal concentrator or secondary reflector which was used to increase energy collection in the aperture plane of TBC-1. The trumpet-shaped mirrored collectors

Figure 12. Parabolic Dish Test Site. (PDC-1 is on the left; the two TBCs are on the right.)

demonstrated that a significant increase in energy collection, as high as 33%, was possible through the aperture of a solar receiver. This successful test was carried out in collaboration with the developers, Professor Roland Winston and Dr. Joseph O'Gallagher of the University of Chicago's Enrico Fermi Institute.

(5) Completed the rework of PDC-1. This was followed by optical tests and characterization using the cold-water cavity calorimeter. The PDC-1 thermal output through a 20.5-in. aperture on the calorimeter was measured at 76 kWt.

(6) Tested three different heater-head combinations on the Stirling engine: Experimental solar-only receiver (ESOR)-2A, ESOR-2B, and ESOR-3. These were tested at various times on both TBCs and were also tested with and without a quartz window to assess the effect of a window on Stirling engine performance.

(7) Tested the Stirling engine with a focal-plane-mounted cooling system on TBC-1 (as opposed to the cooling system for the Stirling engine on TBC-2, which is mounted on the concentrator structure near the ground). Mounting the cooling system at the focal plane results in a reduction in parasitic power for the pump and fan of 3 to 4 kWe.

(8) Demonstrated dual operation of the USAB Model 4-95 engines on TBC-1 and TBC-2. This gives parallel, multi-module operation and provides quality assurance and reliability with both engines operating. The combined electrical output from the two engine-alternators was fed into the Southern California Edison grid at the PDTS.

(9) Developed a TBC rapid alignment method with the aid of T. B. Elfe of the Georgia Institute of Technology Research Institute. Instead of aligning the mirrors one at a time (with all other mirrors covered), mirror alignment was accomplished by uncovering all mirrors and aligning all mirror images at once on a target placed about 30 in. in front of or behind the principal focus. The remote light, used as the point source, was located 1650 ft from the concentrator.

SECTION VI

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