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Omnium-G Parabolic Dish Optical Efficiency — A Comparison of Two Independent Measurement Techniques

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OMNIUM-G PARABOLIC DISH OPTICAL EFFICIENCY--A COMPARISON OF TWO INDEPENDENT MEASUREMENT TECHNIQUES

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OCTOBER 1980

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PREFACE

The cooperation of Jack Patzold and John Roschke of the Jet Propulsion Laboratory (JPL) in making the calorimetric measurements has been greatly appreciated. We would also like to acknowledge the assistance of the SERI Measurement, Design, and Support Branch. The technical review by John Zimmerman of Sandia Laboratories is also appreciated. This report documents work completed in December 1979.

Mark Bohn, Leader
ACRES R&D and Data Analysis Task

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SECTION 1.0

INTRODUCTION

Optical and thermal testing of the Omnium-G parabolic dish collector has been underway at both SERI and JPL (Jet Propulsion Laboratory, Pasadena, Calif.) for the past year. The original intention of testing the same piece of equipment at two laboratories was to allow an objective comparison of two independent methods used to measure optical and thermal performance of the dish.

Results of preliminary measurements of optical efficiency performed at SERI were given in Bohn (1979). Although JPL has not released or published any of its results, close contact with its effort indicates that there are some differences in the results of the two laboratories. The measurement of primary interest is that of the solar flux focused by the concentrator into a 10-cm diameter aperture at the focal plane, which is significant because it is the aperture size employed on the original Omnium-G receiver. Results such as given in Bohn (1979) have led Omnium-G to increase the receiver aperture to 20 cm, but for consistency the 10-cm aperture has been retained for testing purposes at both JPL and SERI.

The purpose of this report is to present results of measurements made on the SERI concentrator using the JPL measurement technique and to compare that with results obtained at SERI by an independent technique.

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SECTION 2.0

TEST PROCEDURE AND RESULTS

The JPL measurement technique utilizes a cold-water calorimeter placed at the focal plane of the concentrator (Fig. 2-1). The calorimeter is a flat copper plate, approximately 38-cm square, with cooling water channels on the back of the plate. Flat black paint (3M Nextel) is used on the side of the plate exposed to the flux to increase solar absorptance to 0.97. Measurements made with the JPL calorimeter in this report do not take into account the 3% reflectance of optical energy by the Nextel paint. For comparing the calorimeter data with results that would be expected for the Omnium-G receiver, it should be noted that Bohn (1980) has shown that the optical reflectance of the Omnium-G cavity is 0.5%. A series of asbestos/cement plates with machined circular holes of various diameters are used to adjust the active area of the calorimeter. These aperture plates are fixed in a frame at the concentrator focal plane, with the calorimeter 10 cm behind the plate.

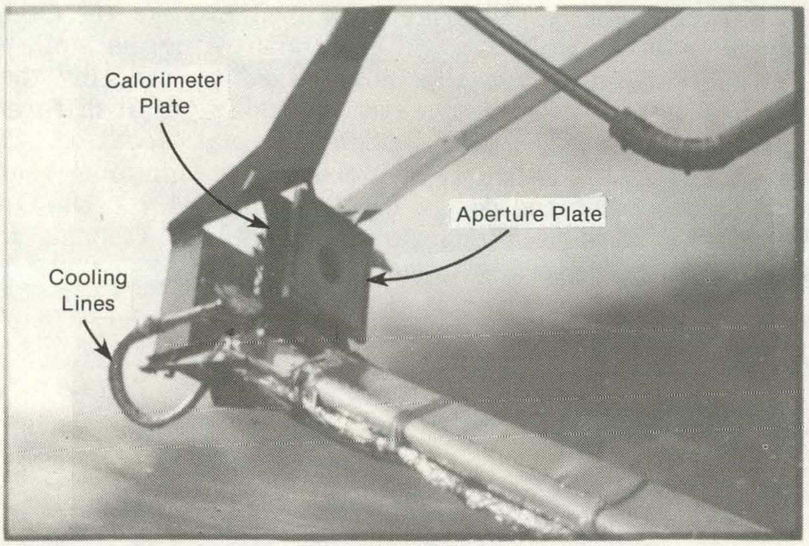

Figure 2-1. The JPL Calorimeter

An Eppley Normal Incidence Pyrheliometer (NIP) was used to scale all power measurements to a beam insolation of 1000 W/m^2. A 10-junction thermopile is used to measure the temperature rise of the water pumped through the calorimeter. The calorimeter average temperature was kept to within 5° C of ambient temperature with a nominal water flow rate of 1 m^3/h giving a thermal loss of 0.1% of the solar energy input to the plate. Flow rate was measured with a Brooks rotameter Model 1110. Pyrheliometer output, ambient temperature, calorimeter plate temperature, and thermopile output were recorded at 20-second intervals on a Fluke 2240B data logger. Accuracy of the rotameter is ±1% full scale. Thermopile error is estimated to be ±0.1° C, with the typical temperature rise across the calorimeter being greater than 5° C. The Reynolds number at the thermopile probes was 16,000. The NIP introduced ±0.5% error into the measurement. Total measurement error is estimated to be ±4%.

The Omnium-G reflectors are cleaned with a soap solution and rinsed with water before measurements are taken. This practice minimizes the effect of dirt on collector performance.

A significant source of error was discovered during testing and was corrected before the measurements presented in this report were made. It was found that the aperture plates could reach temperatures of 400° C within 15 minutes of exposure, a typical time required for one measurement. At this temperature, the aperture plate radiates significant energy. Since the calorimeter is located close to the aperture plate (view factor approximately 1) and since the Nextel paint has an infrared absorptance of 0.90, a large fraction of the energy radiated from the aperture plate is absorbed by the calorimeter. To determine the magnitude of the error, a 5-cm thick, white ceramic blanket insulation was used to cover the exposed face of the aperture plate. The aperture itself was not affected. Testing this way, the aperture temperature plate did not exceed 60° C, and measured power at the calorimeter was reduced by 1 kW. Thus the calorimeter was exposed only to the solar flux passing through the aperture.

After the first series of experiments were run with various aperture sizes (see lower curve, Fig. 2-3), the concentrator was optically aligned by a technique that appears to have several advantages over previous methods used to align the Omnium-G concentrator. The technique may be useful for other concentrators as well. First, the correct focal length for the parabolic dish was determined by utilizing the JPL calorimeter without any aperture plates. The calorimeter was operated at different focal lengths to generate thermal output as a function of calorimeter plate location. Figure 2-2 gives the results. The optimum focal length corresponding to the minimum beam waist was found to be about 5-cm shorter than the design focal length of 4 m. The Omnium-G Company has indicated that their petals curl somewhat upon curing (tending to reduce the focal length slightly), which is consistent with our result.

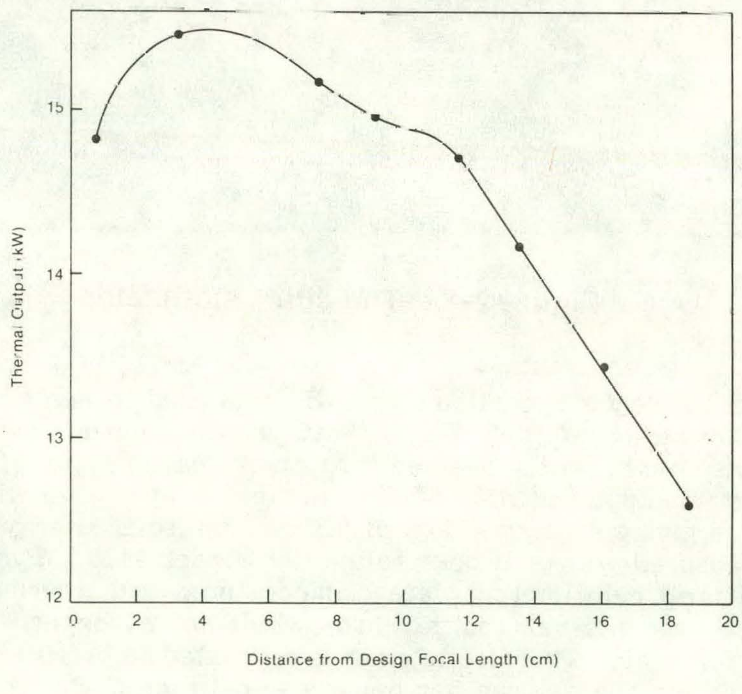

Figure 2-2. Determination of New Focal Length — Focus Locus Test

After the new focal length was determined, an innovative approach to petal alignment was performed. We call this technique the Reverse Reflection Method. A fluorescent orange disc, 10 cm in diameter, is placed at the focal plane. An observer standing on a hill 2.5 km away views the dish through a telescope. After the dish is aligned to the telescope, the observer instructs an assistant to adjust each petal until it appears to have the maximum amount of area illuminated with orange color. This method is repeated for all 18 petals.

One of the most difficult aspects of the Reverse Reflection Method is the initial alignment of the dish to the telescope. The best approach seems to be a trial-and-error method whereby the observer instructs a technician via a walkie-talkie to move the dish vertically and azimuthally until all the petals are maximally illuminated with color.

The major advantage of the Reverse Reflection Method is that it can be performed without removing the thermal receiver. Therefore, the petals are focused when the receiver support arms are loaded. Also, specific areas of misalignment on each petal can be identified, and poorly manufactured petals can be replaced. Another advantage of this method is that it can be done during day or night. Finally, a telephotograph of the dish image can serve as a hard copy of petal alignment as well as providing a means through densitometry to measure the amount of petal area that is extremely misaligned.

The JPL calorimeter test was performed again after the Reverse Reflection Method. The thermal output was improved significantly, as shown by Fig. 2-3. Qualitatively, the calorimeter plate could not be placed at the focal plane without burning the black Nextel paint, even with maximum cooling flow through the calorimeter. The burn mark on the calorimeter was 10 cm in diameter.

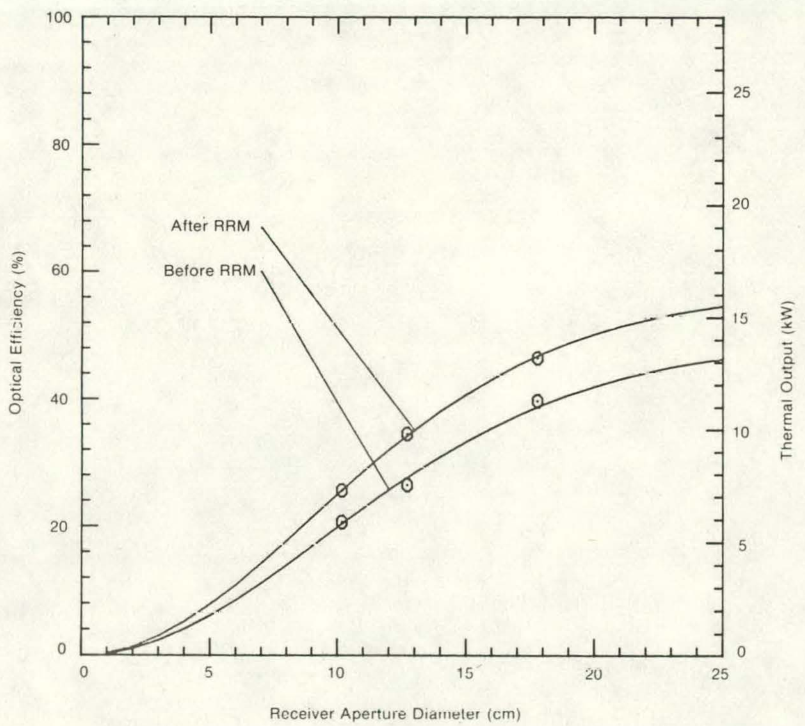

Figure 2-3. Thermal Performance Measured with the JPL Calorimeter

The values for thermal outputs in Fig. 2-3 are scaled to an insolation of 1000 W/m^2, as previously mentioned. The optical efficiencies are based on the gross aperture area of the parabolic dish and are simply the ratio of the power absorbed by the cooling water to the power incident on the collector aperture (28.27 m^2). The two curve fits through the data points in Fig. 2-3 were determined theoretically with the methodology of A. Rabl (Bendt et al. 1980). Essentially, the curve fits are a convolution of the geometric angular acceptance function for a parabolic dish and a Gaussian distribution that accounts for all beam spreading, e.g., mirror nonspecularity, contour or slope error, tracking error, misalignment of receiver/petals, and the finite size of the sun. A SERI report (now in preparation) will give the details of how to measure the optical quality of a parabolic dish.

Figure 2-3 shows that the optical efficiency for a 10-cm receiver aperture was 21% and was improved to about 25% using the Reverse Reflection Method for dish optical alignment. Using a 20-cm receiver aperture, the optical efficiency increased from 40% to 47%.

SECTION 3.0

COMPARISON WITH EARLY SERI RESULTS

The first measurements of Omnium-G optical efficiency were made at SERI in March 1979. The technique used at that time involved focusing the dish until the aluminum thermal mass in the Omnium-G receiver was completely molten. Measurements of the time required to melt the thermal mass, and of the time required for freezing the mass after defocusing, allow for the determination of the energy focused into the receiver aperture. Details of the technique are given in Bohn (1979).

Results from that experiment indicate that approximately 10.7 kW were focused into the 10-cm receiver aperture for 1 kW/m^2 insolation. Because initial JPL measurements (summer 1979) indicated half that amount of focused energy, efforts were begun to bring the JPL calorimeter to SERI. By using the JPL measurement techique on the SERI dish, it was felt that the discrepancy, if any, could be found.

The results shown in this report indicate agreement with the JPL results. After correcting the error induced by aperture plate radiation, the SERI dish focuses approximately 5.8 kW into the 10-cm aperture. Note that petal realignment brings this number up to 7.2 kW for the SERI dish.

After completing the series of experiments, it was felt that it would be appropriate to repeat the early SERI experiment using the molten aluminum technique as described in Bohn (1979). Repetition of the experiment was the only way to determine the reliability of the 10.7 kW measured in March. The data from the JPL calorimeter supplied a reliable comparison for the molten aluminum technique.

The molten aluminum experiment was repeated in mid-December, and the results indicated 7.2 ± 0.4 kW for the energy focused into the 10-cm receiver aperture at 1 kW/m^2 insolation. Since this agrees favorably with the 7.4 kW (7.2 kW corrected for the 3% optical reflectance of the Nextel paint) measured with the JPL calorimeter, it can be assumed that the molten aluminum technique is reliable and, moreover, that the 10.7 kW measured in March was a true indication of the optical performance of the Omnium-G dish at that time.

Based on our several measurements of the optical performance, it appears (Table 3-1) that the dish degraded by 46% between March and October 1979. Thirty percent of this loss was recovered by an optical alignment in November. As of December 1979, the Omnium-G is focusing 7.2 kW into the 10-cm receiver aperture at 1 kW/m^2 insolation. The source of the 3.5 kW loss that could not be recovered by petal realignment is not known at this time but is being investigated.

Table 3-1. MEASUREMENTS OF OMNIUM-G OPTICAL PERFORMANCE AT SERI (1979)

Date	Technique	$Q_{1\,kW}$[a]	Comments
March	Molten Aluminum	10.7	
October	JPL Calorimeter	5.8	Test run with insulated aperture plate
November	JPL Calorimeter	7.2	After petal realignment
December	Molten Aluminum	7.2	

[a]$Q_{1\,kW}$ is the energy focused into a 10-cm receiver aperture for 1 kW/m^2 beam insolation.

Reflector cleanliness was approximately the same for all four tests.

SECTION 4.0

CONCLUSIONS

Omnium-G optical performance measured at SERI with the JPL calorimeter essentially agrees with performance measured at JPL with the same technique. It was found that reradiation by the asbestos aperture plates could cause the measured power absorbed by the calorimeter to be approximately 1 kW higher than the correct value. An optical alignment technique was devised that significantly improved optical performance of the SERI north dish. Preliminary optical performance data taken at SERI in March 1979 was shown to be valid, indicating that the dish degraded by nearly 50% between March and October 1979. Almost half of this loss was recovered by the optical alignment technique.

SECTION 5.0

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report describes measurements made at SERI of the optical efficiency of the Omnium-G parabolic dish concentrator. Two independent techniques were used: the cold-water calorimeter method and the heat of fusion method. Results from both techniques agree quite well and indicate that the optical efficiency for a 10-cm receiver aperture is 25%. Optical efficiency measured in early 1979 was 37%, and in mid 1979 it had degraded to 21%. An optical alignment procedure is described that resulted in the increase in optical efficiency from 21% to the current value of 25%.

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