SANDIA REPORT SAND82-8036 • Unlimited Release • UC-62d
Printed November 1983

Wind Load and Life-Cycle Testing of Second Generation Heliostats

W. S. Rorke, Jr.

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America
Available from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A08
Microfiche copy: A01

SAND82-8036
Unlimited Release
Printed November 1983

UC-62d

WIND LOAD AND LIFE-CYCLE TESTING OF SECOND GENERATION HELIOSTATS

William S. Rorke, Jr.
Systems Evaluation Division
Sandia National Laboratories, Livermore

ABSTRACT

As technical manager of the Second Generation Heliostat development contracts for the Department of Energy, Sandia National Laboratories has evaluated four heliostat designs. The evaluation of the heliostats included the life-cycling and simulated wind load testing of prototype heliostats and foundations. All of the heliostats had minor problems during this testing; as a result, specific design improvements were identified for each drive mechanism and for two of the four foundations.

ACKNOWLEDGMENTS

Many people contributed to the effort documented in this report. While it is impractical to list all of these people, I would like to thank specifically the staff of the Central Receiver Test Facility, especially David King, Bernard Ellis, and Chauncey Matthews, who performed much of the testing described in this report. They were assisted by Howard Nunes, Harold Thomas, and William Putnam for the structural and load tests. None of this work would have been possible without the cooperation and assistance of the heliostat contractors. Expertise on the drive mechanisms was provided by Frank McGrogan of the Aerospace Corporation.

CONTENTS

ILLUSTRATIONS

TABLES

WIND LOAD AND LIFE-CYCLE TESTING OF SECOND GENERATION HELIOSTATS

Executive Summary

As technical manager of the Department of Energy's Second Generation Heliostat development contracts, Sandia National Laboratories has evaluated heliostats designed by ARCO Energy Systems (formerly Northrup, Inc.), Boeing Engineering and Construction (BEC), Martin Marietta Corporation (MMC), and McDonnell Douglas Astronautics Company (MDAC). This evaluation included testing prototype heliostats of each design. The results of the wind load and life-cycle testing are described in this report, along with Sandia's recommendations concerning the suitability of each of the designs. Other portions of the evaluation are reported in additional publications. Reports written by each of the contractors describing in detail their heliostat design, development testing, and analyses, as well as their manufacturing plans and cost estimates for producing 50,000 heliostats per year, have also been published. A list of the relevant publications is provided in the reference section.

The testing showed that all of the heliostat designs had minor problems. However, none of these problems is inherent to any of the designs. Each has a readily implemented solution. The ARCO and MMC heliostats had difficulties with insufficient motor torque, which can be easily corrected with different motors. The ARCO and BEC foundation designs were not compatible with the soil conditions at the test site; but since foundation designs vary for a given heliostat design installed at different locations, excessive foundation deflections during this testing were not viewed as a serious problem. Even so, this difficulty highlighted the need for careful attention to foundation designs for each proposed installation site. The MMC stow-lock, which was not tested using production tolerances under actual operating conditions with dynamic wind loads, remains unproven. All of the contractors, with the exception of BEC, had assembly problems, particularly with improperly torqued bolts.

Introduction

The Second Generation Heliostat Development Program is the second major heliostat development cycle in the Department of Energy (DOE) Solar Thermal Central Receiver Program. During the first development cycle 222 heliostats were built for the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico. Also, a design was developed and over 1800 heliostats were installed at the central receiver pilot plant near Barstow, California.

The second development cycle started in 1978 with the DOE Prototype Heliostat Phase 1 contracts. These paper study contracts developed heliostat conceptual designs and mass-production cost estimates. At the conclusion of these contracts, it was decided to initiate the Second Generation Heliostat Development Program. Sandia National Laboratories (SNL) placed these contracts in July 1979.

Technical management and evaluation of the Second Generation Heliostat contracts were performed by Sandia at their Livermore facility (SNLL). Heliostat testing was performed at the CRTF. Mirror module testing was accomplished at Livermore.

The objectives of the Second Generation Heliostat Development Program were to support the solar central receiver research, development, and demonstration effort by:

- Establishing heliostat designs and associated manufacturing, assembly, installation, and maintenance plans that, in quantity production, would yield low capital and operating costs over a designed 30-year lifetime.
- Stimulating broader industry participation in the DOE solar energy program.
- Obtaining design data, manufacturing plans, and projected production costs for release to the solar community.
- Performing side-by-side testing and evaluation of prototype heliostats and evaluating production plans and cost estimates.

The Second Generation Heliostat development contracts are summarized in Table I.

The program objectives have been met for all the contractors except Westinghouse, which was not able to build prototype heliostats within the funding limits. Therefore, this report does not include any test results for the Westinghouse design.

Each contractor except Westinghouse delivered two prototype heliostats and four spare mirror modules to Sandia for testing. Photographs of the ARCO, Boeing (BEC), Martin Marietta (MMC), and McDonnell Douglas (MDAC) heliostat designs are shown in Figs. 1 and 2. Detailed design reports and

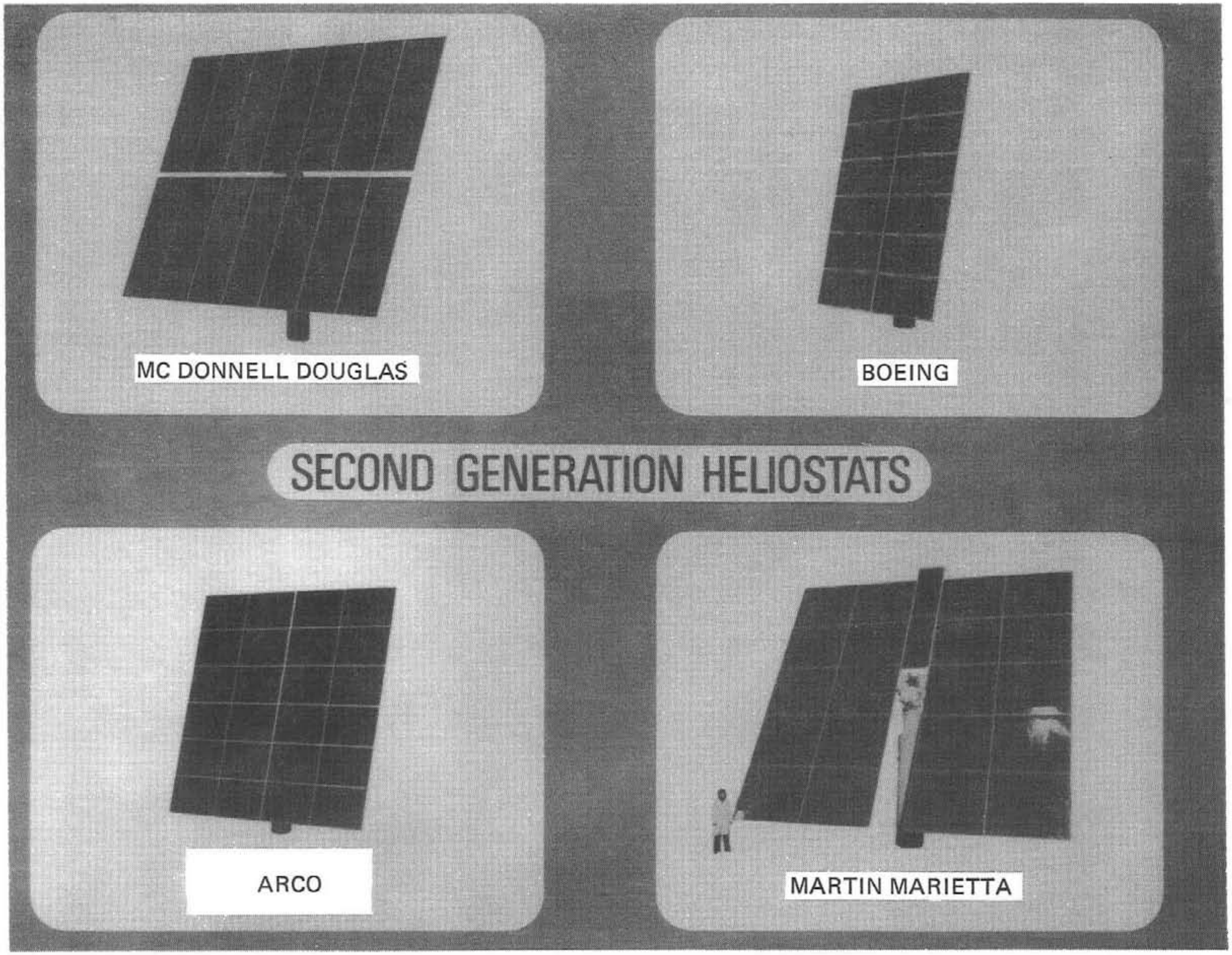


Figure 1. Second Generation Heliostats--Front View

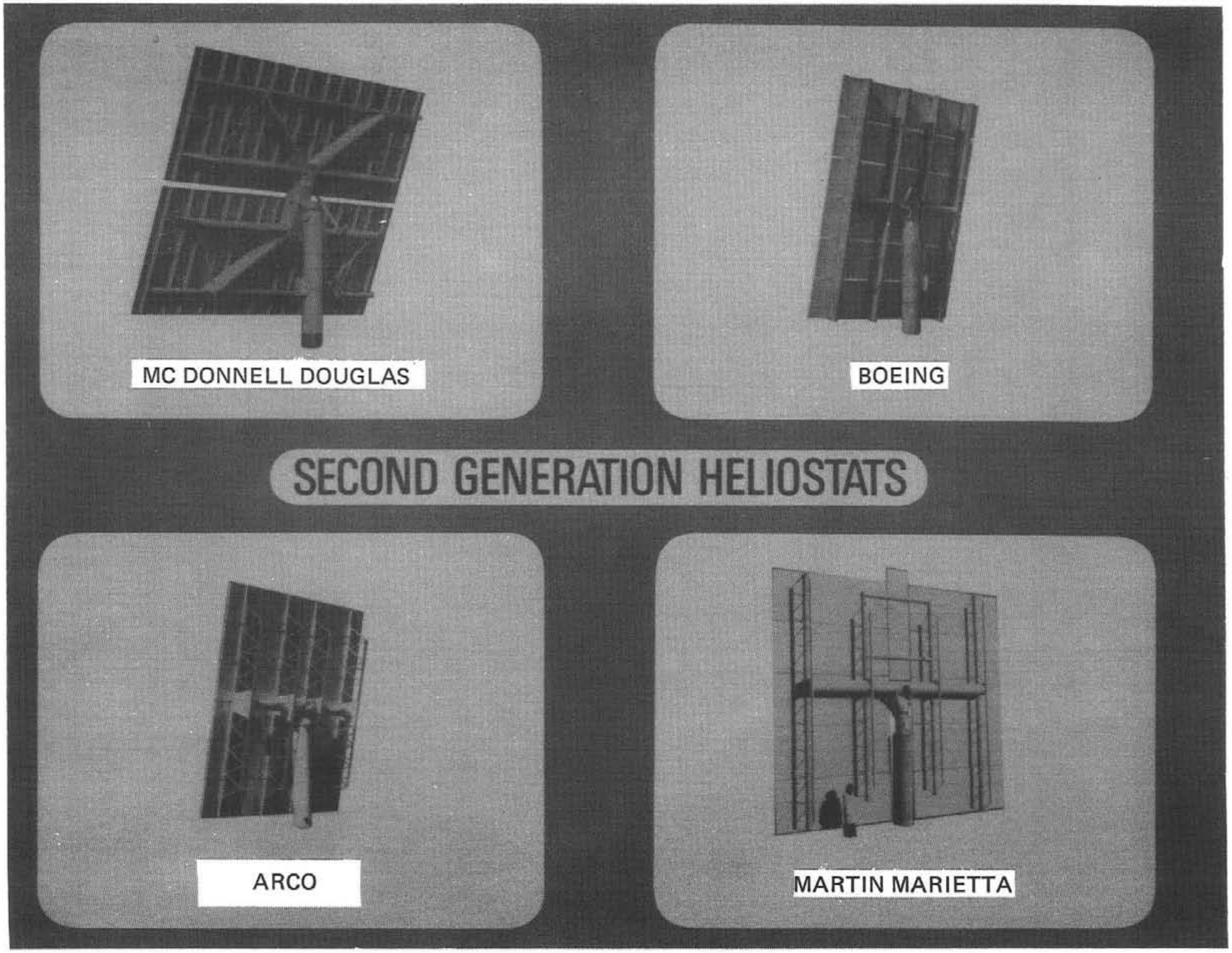


Figure 2. Second Generation Heliostats--Rear View

TABLE I

SECOND GENERATION HELIOSTAT CONTRACTS

Second Generation Heliostat Contractors	Contract Dates Start	Complete	Contract Costs
ARCO Power Sytems (Formerly Northrup, Inc.)	July 79	February 81	$1.0M
Boeing Engineering and Construction	July 79	February 81	$1.7M
Martin Marietta	July 79	April 81	$1.4M
McDonnell Douglas Astronautics	July 79	February 81	$1.5M
Westinghouse	July 79	September 80	$1.7M

final reports containing costs, manufacturing, installation, and maintenance data were also delivered. Westinghouse delivered only a detailed design report.

The testing reported in this document pertains to the heliostat foundations, drive mechanisms, and support structures. Sandia testing of mirror modules, tracking errors, beam quality, and structural analysis are reported in Refs. 1, 2 and 3. A summary of the entire evaluation is reported in Refs. 4 and 5. The contractors' reports (Refs. 7-14) contain much more information on each design than is included in this test report and should be referred to for further details.

Second Generation Heliostat Evaluation

Sandia evaluated the Second Generation Heliostat designs. The evaluation involved testing, design analysis, analysis of contractor production methods and cost estimates, and cost projections of busbar energy costs for a power plant. Heliostats were tested at the CRTF to evaluate performance and to verify their ability to survive environmental requirements. Two prototype heliostats from each contractor were tested. Similar performance and environmental testing of individual mirror modules was also performed in the laboratory at SNLL.

The objectives of the evaluation and test program were to:

- Compare design features
- Identify design strengths and weaknesses

- Estimate central receiver energy costs
- Identify further development requirements
- Disseminate information

Sandia was assisted in the evaluation by a Users Panel and a Review Committee. Advisors for these groups consisted of representatives from other solar programs and potential users, as shown in Table II.

TABLE II

MEMBERS OF USERS PANEL AND REVIEW COMMITTEE

Users Panel	Review Committee
Public Service Company of New Mexico	Department of Energy
Arizona Public Service	Electric Power Research Institute
Southern California Edison	Solar Energy Research Institute
Exxon	Solar Energy Projects Department, SNLA
U. S. Gypsum	CRTF Division, SNLA
	Solar Programs Department, SNLL
	Jet Propulsion Laboratory Solar Program

Design Requirements

The design requirements for the Second Generation Heliostats are given in Appendix A (Sandia Specification A10772-D, "Collector Subsystem Requirements"). Deviations from this specification were acceptable, with sufficient justification, in order to improve performance and/or reduce cost. The requirements can be divided into four major areas: operational modes, optical performance, environmental survival, and 30-year life.

All of these areas impose requirements on the drive mechanism, heliostat structure, and/or foundation. The following sections list the key design requirements, as given in the specification, for the heliostats that were tested.

Operational Modes--

- Elevation and azimuth drives shall not drift from last commanded positions (back-drive) due to environmental loading.
- Drive systems must be capable of positioning a heliostat to stowage from any operational orientation within 15 minutes while maintaining beam safety.*
- A maximum wind of 22 m/s (50 mph) from any direction may occur, resulting from unusually rapid wind rise rates, such as severe thunderstorm gust fronts. Using the simplest operating scenario, this implies that the heliostat must be capable of driving both axes simultaneously against such a wind impinging at the worst angle of attack.

Optical Performance--

- Reflective surface static deflections (excluding gravity effects) in a 12 m/s (27 mph) wind and worst case conditions shall be limited to 5.1 mrad, of which no more than 1.5 mrad shall be due to foundation deflections and 3.6 mrad to deflection of the remainder of the heliostat. The foundation/heliostat interface is defined by a horizontal plane approximately 150 mm (6 in.) above grade.

Survival--

- The allowable permanent deflection of the foundation, resulting from a 22 m/s (50 mph) wind load, shall not exceed 0.45 mrad.
- The heliostat shall maintain structural integrity in a non-operational state in a 22 m/s (50 mph) wind in any orientation. It should be noted that operational constraints require that the heliostat be able to drive both axes in such a wind.
- When stowed, the heliostat shall survive a 40 m/s (90 mph) wind, including gusts, impinging at a 10° angle of attack.

Lifetime--

- The collectors shall be designed to require a minimum of routine field maintenance. All parts shall be protected from corrosion and the drive systems shall be environmentally sealed. Design and material selection are to be based on a 30-year plant life.

---

*Beam safety requires protection of personnel and property within and outside the plant facility, including air space, from hazardous intensities of reflected solar radiation.

Design Descriptions

The following sections provide a brief overview of each design. Additional information on the designs is provided in the reports given in the list of references.

Drive Mechanisms--Two of the Second Generation Heliostat drive mechanisms (ARCO and MMC) use enclosed gear drives for the entire drive, while the other two (BEC and MDAC) use jack-type mechanisms for their elevation drives. Both MMC and MDAC designs evolved from their Pilot Plant prototype designs. The other two designs (ARCO and BEC) were built by Winsmith.

The ARCO, BEC, and MDAC designs calculate heliostat position by counting rotations of the drive input shafts after a starting reference position is established. The MMC drive measures heliostat (drive output) position directly.

a) ARCO (Fig. 3): The ARCO design uses separate, enclosed, two-stage gearboxes for elevation and azimuth drives. These two drives are very similar, having virtually identical gear trains. Motion is provided by a stepper motor that drives a differential planetary gear drive. The output stage is a worm gear which cannot be backdriven.

b) BEC (Fig. 4): The Boeing elevation drive is unique among these designs in that it uses an exposed stainless steel screw running in a polymer (Delrin - AF), self-lubricating nut. The screw is driven by a double worm gear reducer. The azimuth is, in essence, a reversal of the ARCO drive, utilizing a worm gear input and a differential planetary gear output stage. The planetary gears cannot be backdriven.

c) MMC (Fig. 5): The azimuth and elevation gear sets, which are enclosed in a common case, are similar to each other. Both use gear motors for initial speed reduction. Power is then transmitted through a worm and gear to a spur gear output stage. The MMC position indicator is unique among the four Second Generation designs, calculating heliostat position by measuring the position of the output of the drive with an absolute encoder.

d) MDAC (Fig. 6): McDonnell Douglas uses an enclosed ball-bearing screw-jack for elevation. Azimuth motion is provided by a harmonic drive. Both drives use Helicon spiral bevel gears for first-stage speed reduction.

Structure/Foundation--The heliostat support structures can be seen in Fig. 2. Three of the designs (ARCO, BEC, and MMC) use similar layouts: four vertical beams or trusses connect to a horizontal, circular cross-section torque tube. The ARCO torque tube is a split design with each half bolted to the outside of the elevation drive. Both BEC and MMC utilize single-piece torque tubes. The MDAC design is different, employing horizontal mirror support beams with substantial cross-bracing. The middle beams are

SUPPORT STRUCTURE

Trusses, 75 cm deep, 10 kg/m,

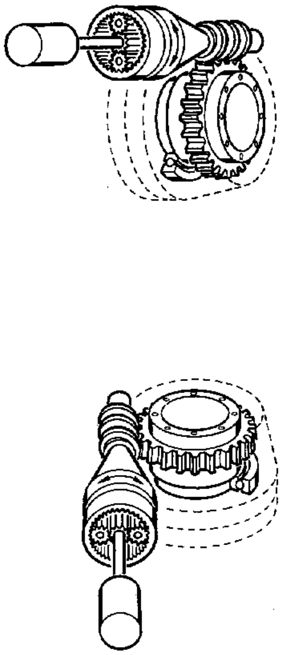
Torque tube, 32.4 cm dia.,
6.4 mm wall, 49 kg/m,

FOUNDATION/PEDESTAL

Steel pipe
Grouted in place
6.5 m long
61 cm diameter
3 mm wall
3.4 m above ground

HELIOSTAT CONTROLLER IN PEDESTAL

1ϕ, 115 V AC



ELEVATION DRIVE

Worm/gear 40:1
Planetary 450:1 and 18,018:1
Stepper motor
Sealed casting
12.7 ℓ Mobil 626 oil

AZIMUTH DRIVE

Worm/gear 40:1
Planetary 450:1 and 18,018:1
Stepper motor
Sealed casting with expansion chamber
12.7 ℓ Mobil 626 oil

Figure 3. ARCO Heliostat Drive and Structural Features

SUPPORT STRUCTURE

Z-beams, 48 cm deep, 11 kg/m,

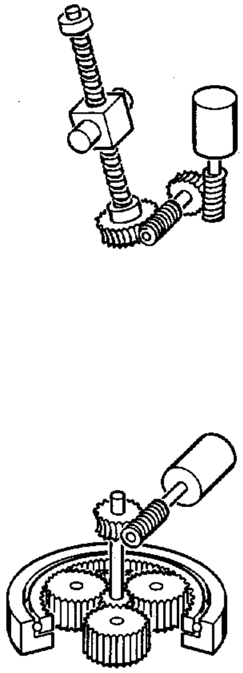
Torque tube, 40.6 cm diameter,
3 mm wall, 29.8 kg/m

FOUNDATION/PEDESTAL

Prestressed concrete grouted in place
8 m long
60 cm diameter
10 cm wall
4.5 m below ground

HELIOSTAT CONTROLLER

3ϕ, 208 V AC



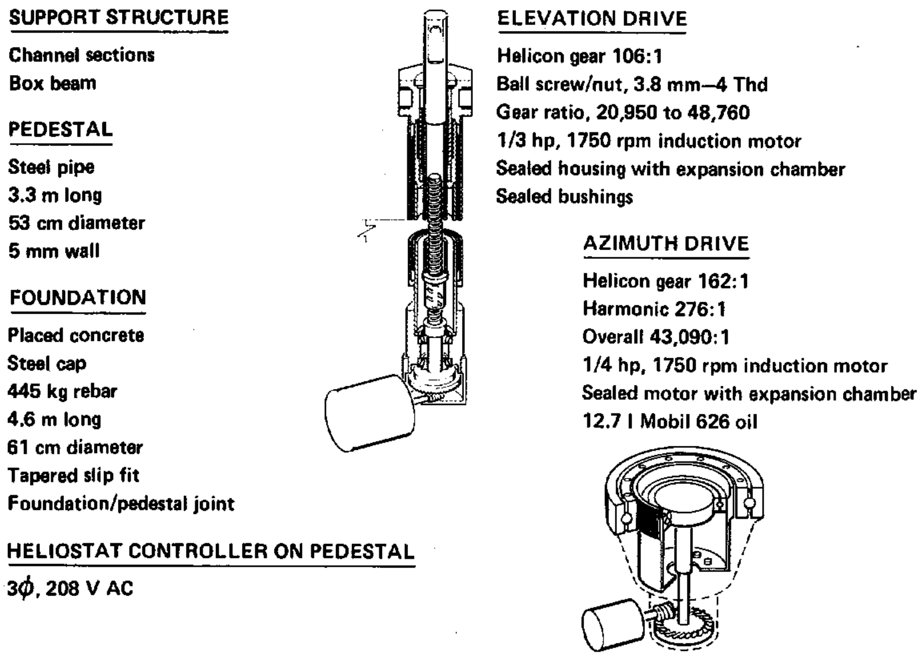
ELEVATION DRIVE

Gear ratios: worm/gear 24:1, worm/gear 10:1, screw/plastic nut (3.81 cm dia.—ACME), overall 102,200:1
Sealed gear box
Open screw/nut
1/3 hp, 1750 rpm induction motor

AZIMUTH DRIVE

Gear ratios: worm/gear 71:1, planetary 739:1, overall 52,500:1
1/6 hp, 1750 rpm induction motor, Mobil 626 oil

Figure 4. BEC Heliostat Drive and Structural Features



SUPPORT STRUCTURE

Channel sections
Box beam

PEDESTAL

Steel pipe
3.3 m long
53 cm diameter
5 mm wall

FOUNDATION

Placed concrete
Steel cap
445 kg rebar
4.6 m long
61 cm diameter
Tapered slip fit
Foundation/pedestal joint

HELIOSTAT CONTROLLER ON PEDESTAL

3ϕ, 208 V AC

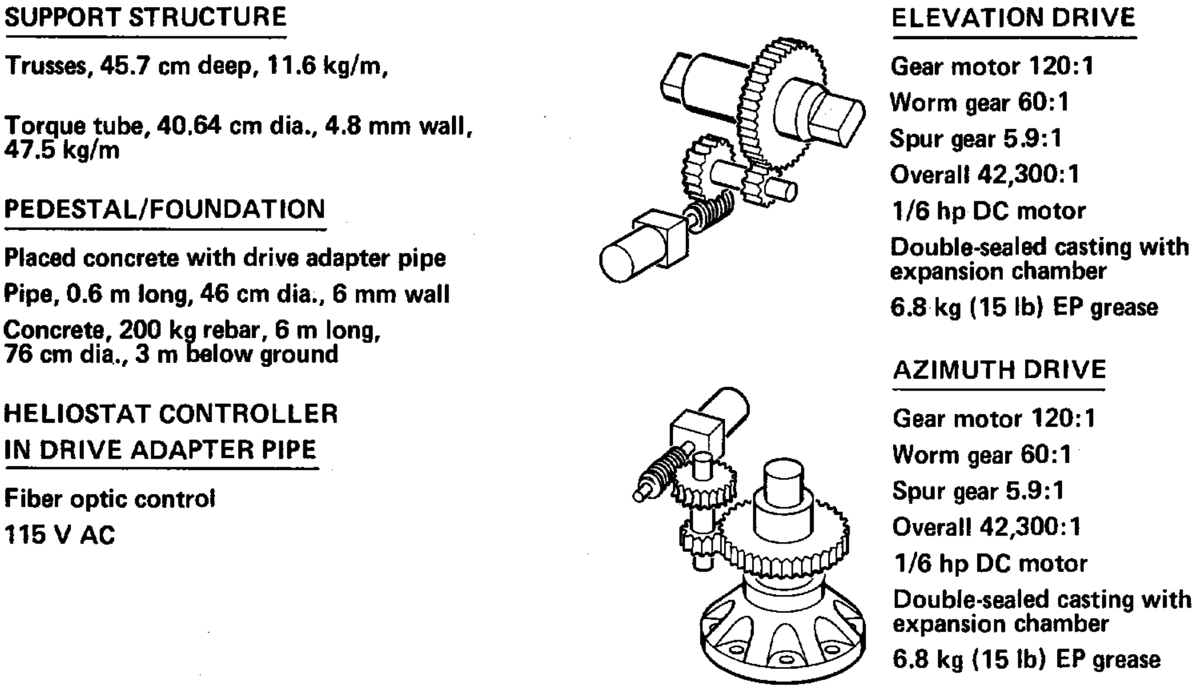
ELEVATION DRIVE

Helicon gear 106:1
Ball screw/nut, 3.8 mm–4 Thd
Gear ratio, 20,950 to 48,760
1/3 hp, 1750 rpm induction motor
Sealed housing with expansion chamber
Sealed bushings

AZIMUTH DRIVE

Helicon gear 162:1
Harmonic 276:1
Overall 43,090:1
1/4 hp, 1750 rpm induction motor
Sealed motor with expansion chamber
12.7 l Mobil 626 oil

Figure 5. MMC Heliostat Drive and Structural Features



SUPPORT STRUCTURE

Trusses, 45.7 cm deep, 11.6 kg/m,

Torque tube, 40.64 cm dia., 4.8 mm wall, 47.5 kg/m

PEDESTAL/FOUNDATION

Placed concrete with drive adapter pipe
Pipe, 0.6 m long, 46 cm dia., 6 mm wall
Concrete, 200 kg rebar, 6 m long, 76 cm dia., 3 m below ground

HELIOSTAT CONTROLLER IN DRIVE ADAPTER PIPE

Fiber optic control
115 V AC

ELEVATION DRIVE

Gear motor 120:1
Worm gear 60:1
Spur gear 5.9:1
Overall 42,300:1
1/6 hp DC motor
Double-sealed casting with expansion chamber
6.8 kg (15 lb) EP grease

AZIMUTH DRIVE

Gear motor 120:1
Worm gear 60:1
Spur gear 5.9:1
Overall 42,300:1
1/6 hp DC motor
Double-sealed casting with expansion chamber
6.8 kg (15 lb) EP grease

Figure 6. MDAC Heliostat Drive and Structural Features

joined to the ends of a box section main beam, which also acts as the torque arm for the elevation drive.

Even though they were all designed for the same soil conditions and minimum installed cost, the four foundation designs are different. ARCO uses a vibratory-hammered hollow steel pipe. BEC has a pretensioned cast-concrete piling which is driven by conventional pile driving techniques. Both MMC and MDAC use cast-in-place concrete foundations. The MMC foundation extends approximately 10 ft above ground and is capped with a short steel tube which houses the controller and acts as a base for the drive mechanism. The MDAC foundation extends about 3 ft above ground and has a slight taper. A hollow steel tube pedestal is hydraulically forced down over the tapered foundation with the friction of the taper joint holding the pedestal in place.

Simulated Wind Load Test Program

The overall purpose of the Second Generation Heliostat test program was to characterize the designs relative to the design requirments. The specific objectives of the simulated Wind Load Test Program were:

- Measure heliostat tracking accuracy while exposing the heliostats to structural loads equivalent to operational wind loads.
- Quantify drive mechanism backlash, compliance, and hysteresis.
- Verify the capability of the heliostat to drive against structural loads equivalent to a 22 m/s (50 mph) wind load.
- Confirm the ability of the heliostat structure to survive loads equivalent to survival winds of 22 m/s (50 mph) in any orientation and of 40 m/s (90 mph) when stowed.

Test Plan Summary

The Second Generation Heliostat Test Plan is found in Appendix B. The simulated wind load tests are Tests 6, 7, and 8 in Section A of the Test Plan. Wind loads were calculated according to the method given in Appendix C. A summary of these tests is shown in Table III.

All of the tests were performed at the CRTF. A layout of the CRTF showing heliostat locations is shown in Figure 7. The tracking accuracy tests were performed on the heliostats at the 1050 ft target distance (prototype-1 heliostats). These heliostats underwent detailed pointing and beam quality measurements to characterize them before load testing, and after testing entered a one-year period of operation to assess long-term stability.

TABLE III

SIMULATED WIND LOAD TEST SUMMARY

Test	Purpose	Method
Pointing Accuracy	Measure tracking accuracy of heliostat under operational wind loads.	Apply simulated wind loads to heliostat while tracking. Measure pointing error using BCS.
Wind Load Deflections	Determine backlash, compliance, and hysteresis of drive.	Measure angular deflections of several heliostat locations before, during, and after applying loads.
Drive Torque	Verify ability of heliostat to start, drive against, and survive a 50 mph wind at worst angle of attack.	Start and drive heliostat against applied load.
Survival Wind	Confirm ability of heliostat structure and drive to survive 50 mph wind in azimuth, 90 mph wind in elevation and cross-elevation, and measure residual deflections (set) after experiencing such loads.	Apply survival wind loads to elevation and cross-elevation axes of stowed heliostat. Measure angular deflections at several heliostat locations.

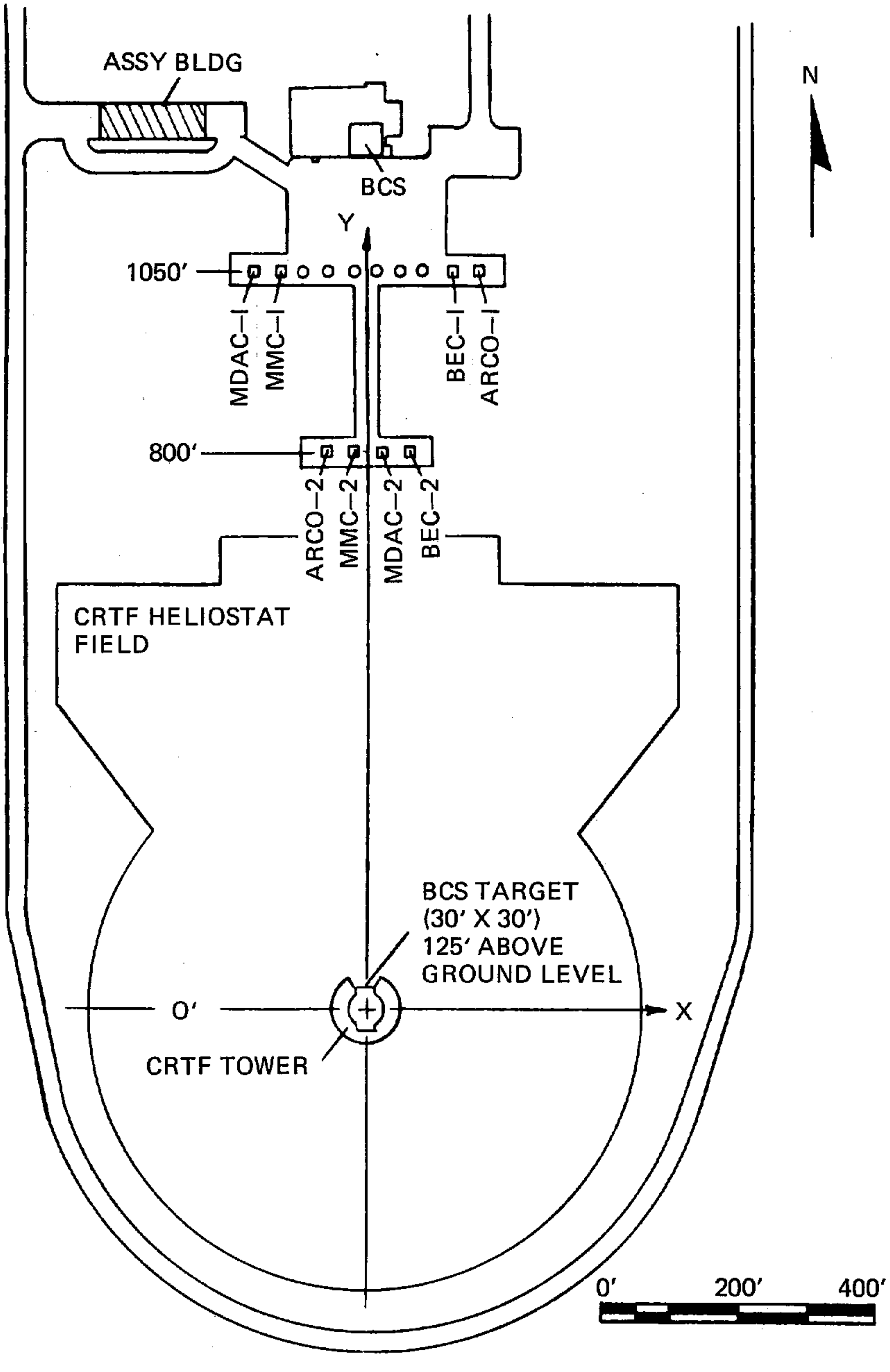


Figure 7. Second Generation Heliostat Locations at the CRTF

The survival wind loads and drive torque tests were performed on the 800 ft slant range heliostats (prototype-2 heliostats) which were life-cycled, disassembled, and inspected. This change from the test plan allowed close inspection of drive internals to check for any possible damage resulting from the high survival test loads and cycling.

Hardware

Two prototype heliostats of each of the Second Generation Heliostat designs were delivered to the CRTF for testing. ARCO, BEC, and MDAC delivered their hardware in October and November of 1980. The contractors installed their own units with the assistance of Sandia personnel. After preliminary testing and checkout by the contractors, the heliostats were turned over for the test program, which commenced December 1, 1980. The MMC heliostats were delivered in March 1981. As a result, the testing of the MMC prototypes was approximately three months behind that of the others.

Both ARCO and BEC encountered soils much harder than anticipated when they attempted to install their foundations at the CRTF and had their foundations stopped short of their design depth. One of the ARCO steel pipes had to be shortened by approximately 3 ft after being bent twice from hitting rocks. These foundations were subsequently installed after drilling pilot holes to reduce driving loads.

Early operation and testing of the MDAC-2 heliostat caused severe oil leakage and revealed very low load capacity of the azimuth drive. Disassembly showed that the bolts holding the drive together were loose. All testing, including survival loads and inspection, was performed on MDAC-1. After being returned to the factory, the MDAC-2 azimuth drive was modified to increase its load capacity and subsequently underwent extensive life-cycle and load testing at MDAC which verified its compliance with all specifications. Details of this testing are contained in Ref. 15.

Tracking accuracy testing of ARCO-1 showed the drive mechanisms to have low drive torque capacity. Disassembly showed unnecessarily tight tolerances in the first-stage planetary gear box and improper tooth shapes on the gears, resulting in interference and binding. The ARCO-1 drive was retested after shimming with thicker gaskets to allow greater internal clearance. ARCO-2 was not readjusted.

Martin Marietta could not deliver the motors they had chosen for their production design because of the high costs that would be incurred for a special order manufacturing run of only a few motors. Instead, the prototype heliostats used motors which were readily available but which lacked sufficient torque to track in 27 mph winds. The MMC control system utilizes a high voltage to drive the motors at slew speed and lowers the voltage (thus lowering motor torque) for track speed. The MMC heliostat required that the high slew voltage be applied to the prototype's motors in order to develop sufficient torque to track against the higher operating wind loads.

Test Results

The specific load tests conducted on each heliostat design are reported in this section in detail. Each test section contains the purpose of the test, the detailed test description, the specific results of each test, and the conclusions drawn from these results. Loads and test procedures are described in Appendix B.

Pointing Accuracy--

a) Purpose--This test allowed direct measurement of the pointing accuracy of a heliostat that was tracking the sun under controlled load conditions. No dynamic loading was attempted and no assessment can be made of heliostat performance under dynamic wind load conditions.

b) Description--Tracking measurements were made for each heliostat at low (<8 mph) wind conditions over an entire day before any loading. Testing was performed by having each heliostat individually track the BCS target on the CRTF tower. The image centroid was calculated by the BCS and averaged over a few minutes to take into account such information as heliostat position updates. A photo of the MDAC-2 heliostat tracking the BCS target is shown in Figure 8. This data provided a baseline against which to compare heliostat accuracy while the heliostat was loaded. Details are reported in Ref. 2.

This type of load testing was performed on each prototype-1 heliostat. Simulated wind loads were fed into the heliostat structure at the quarter chord points. Loads were calculated according to the method described in Appendix C. Low loads could be applied at a single point. Higher loads were distributed among four points along each quarter chord.

Loads were generated by hanging weights over a sheave, which allowed the heliostat to track under constant load. Azimuth loads were applied in clockwise and counterclockwise directions, and elevation loads wereapplied to deflect the reflected beam down (wind loads tend to drive a tracking heliostat in that direction). Between load conditions, data were taken at a no-load position. Beam quality was monitored during the test to assure that no excessive distortion of the image resulted from point loading of the structure.

c) Results--Results of the pointing accuracy test are plotted in Fig. 9. Also included on the plots are the specification and results for a Barstow production heliostat.

The ARCO-1 heliostat could not drive in azimuth against loads greater than a simulated 20 mph wind because of improper gear tooth tip profile, rubbing of the planetary carrier face on the cover of the planetary drive, and insufficient motor torque. Motor torque had been previously increased by lowering the stepping rate. This slowing of the motors resulted in heliostat slew rates of approximately 1.3 mrad/s, which did not meet the specification of a minimum of 1.7 mrad/s, and still did not provide adequate torque to track in a 27 mph wind. After the ARCO-1 drive failed the initial test, the ARCO-2 drive was successfully tested at 35 mph. The ARCO-1

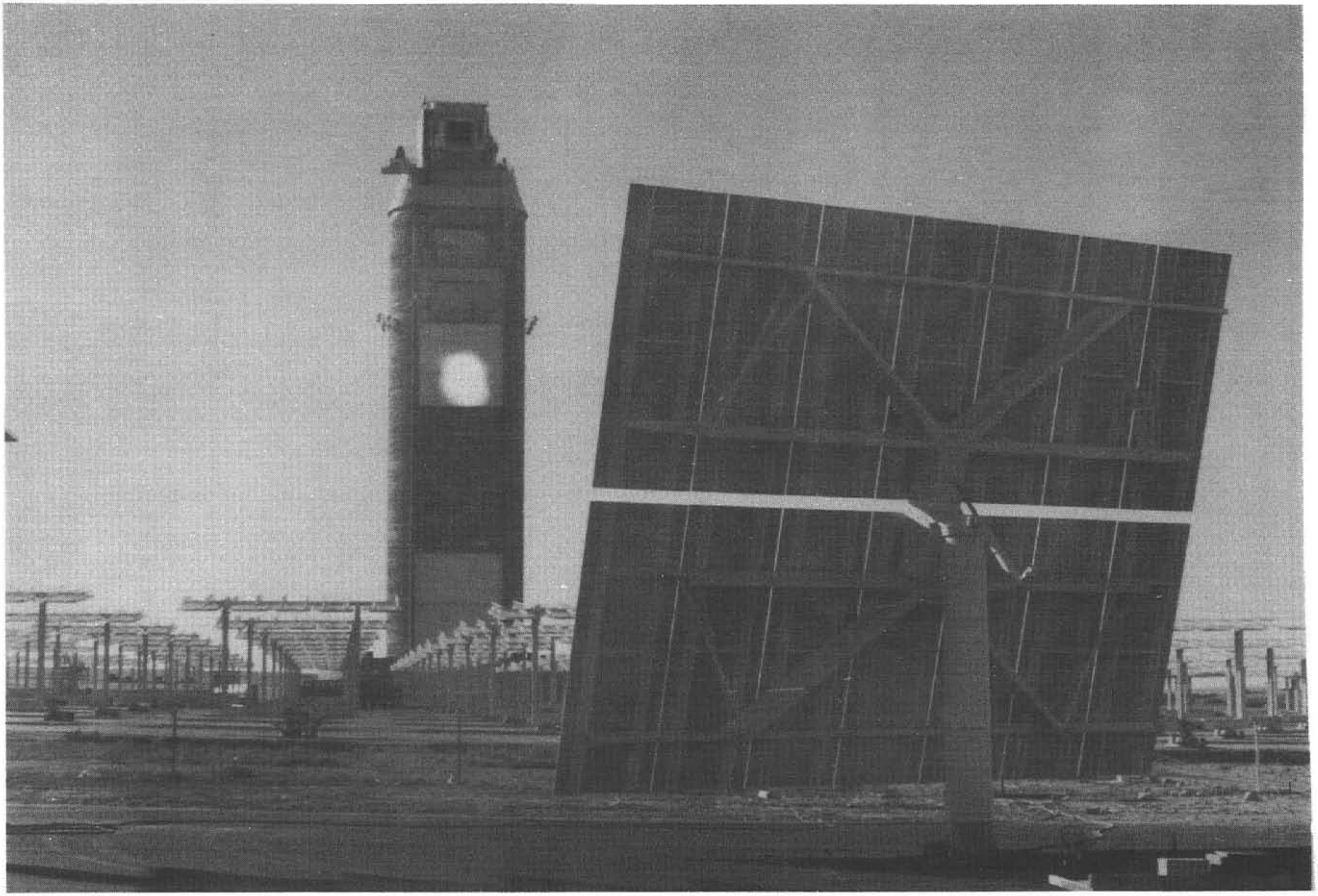


Figure 8. MDAC-2 Heliostat Tracking the BCS Target at the CRTF

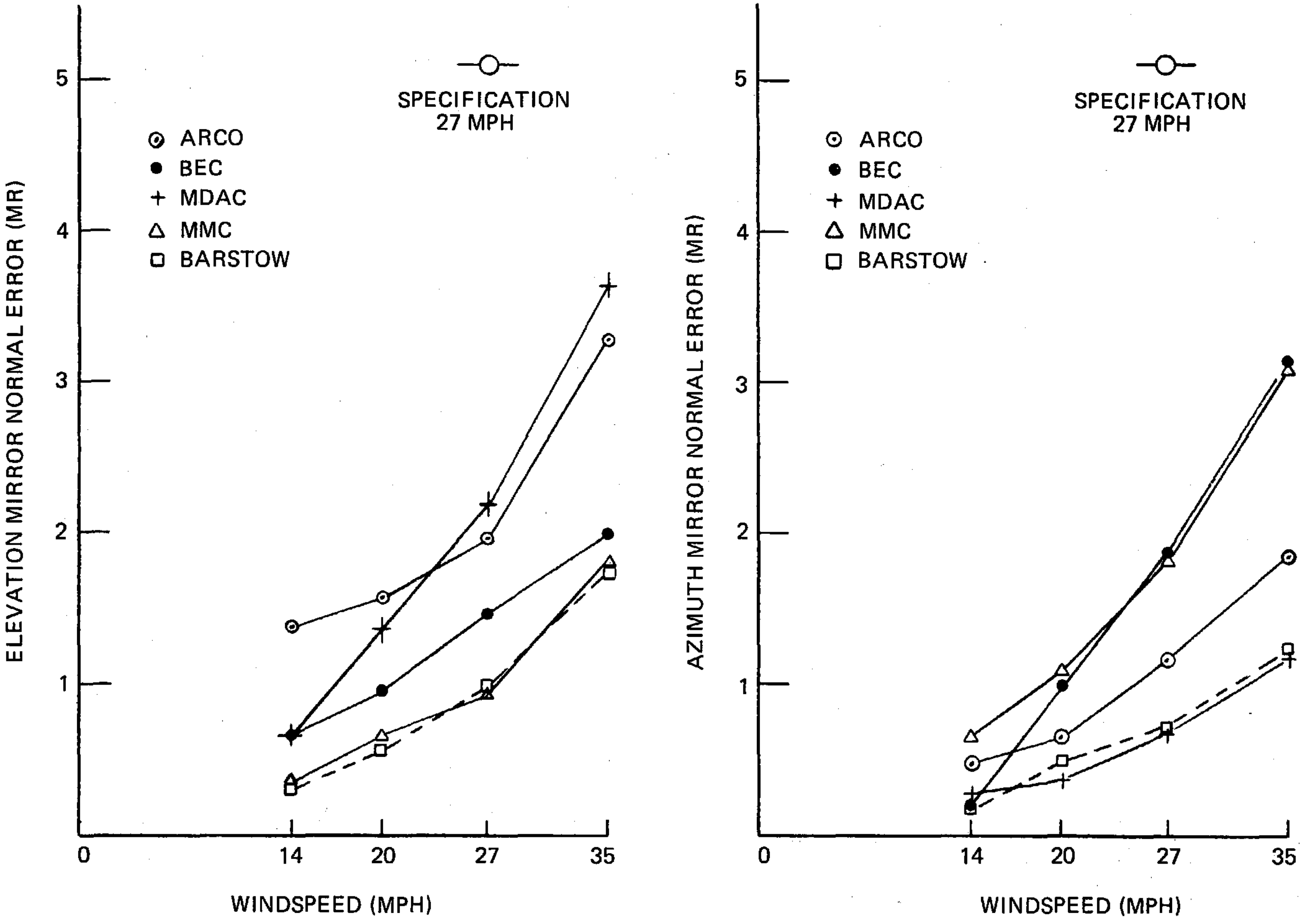


Figure 9. Tracking Error Under Simulated Wind Load

azimuth planetary drive was opened and inspected. Figure 10 shows the planetary carrier with wear on the carrier face. Wear was also detected on the tips of the gear teeth from insufficient tip relief. This caused a high-frequency torque load on the stepper and severely limited the drive torque capacity. The drive was then reassembled, with the planetary cover gasket thickness changed from 0.008 in. to 0.060 in. to eliminate rubbing of the carrier face on the cover. That drive was subsequently driven against a 50 mph load and produced the tracking results shown in Fig. 9, although it still had an insufficient slew rate. The ARCO-2 drive was not readjusted.

The MMC heliostat is designed to tolerate more backlash than the other designs and uses position sensors on the drive output to keep tracking errors within the specified limits. When the controller updates time and position, which would typically happen every few seconds in an operating plant, the sensors report any deflection of the drive ouput from the commanded position. The control system then attempts to drive the heliostat in the direction to remove the errors. The controller applies a high voltage to the motors whenever the heliostat position is more than a few milliradians away from its commanded position. As the error decreases and the heliostat approaches its commanded position, the controller drops the motor voltage to a lower level, decreasing the available motor torque.

The motors delivered on the MMC prototype heliostats lacked sufficient torque at low tracking voltage to compensate for tracking errors. Wind loads of 27 mph caused deflections in excess of the specification. Controller updates caused the system to slew at high voltage to reduce the error. However, when the controller dropped the voltage to the motors, the heliostat stalled. Only continuous application of high voltage to the prototype motors enabled the heliostat to update correctly. The results reported for MMC are those obtained after the position updates and using high slew voltage to obtain sufficient tracking torque.

Neither BEC nor MDAC had problems with this test.

d) Conclusions--All of the heliostats are capable of achieving tracking errors, under wind loads, less than half of the allowable. The BEC and MDAC heliostats, as delivered, are well within limits.

Both ARCO and MMC require different motors to meet the specification. The ARCO stepper motor allows needlessly precise control of the input to the drive (due to the small steps it can make) at the expense of inherently insufficient torque. ARCO has stated they are no longer using stepper motors on their drives, but their new system has not been tested by Sandia. MMC has stated that the motors delivered on the prototype heliostats are not representative of production hardware. Their production hardware has not been tested by Sandia. Proper motor sizing by ARCO and MMC to meet the tracking specification should not be a problem.

The large backlash in the MMC drive raises a question about its dynamic performance, which was not quantified in testing. At certain angles of attack, the dynamic interaction of the heliostat and wind can cause sudden load reversals resulting in "bouncing" of the heliostat and its reflected beam. These loads can cause the MMC heliostat to deflect more than is indicated by these steady-state measurements. The performance of this

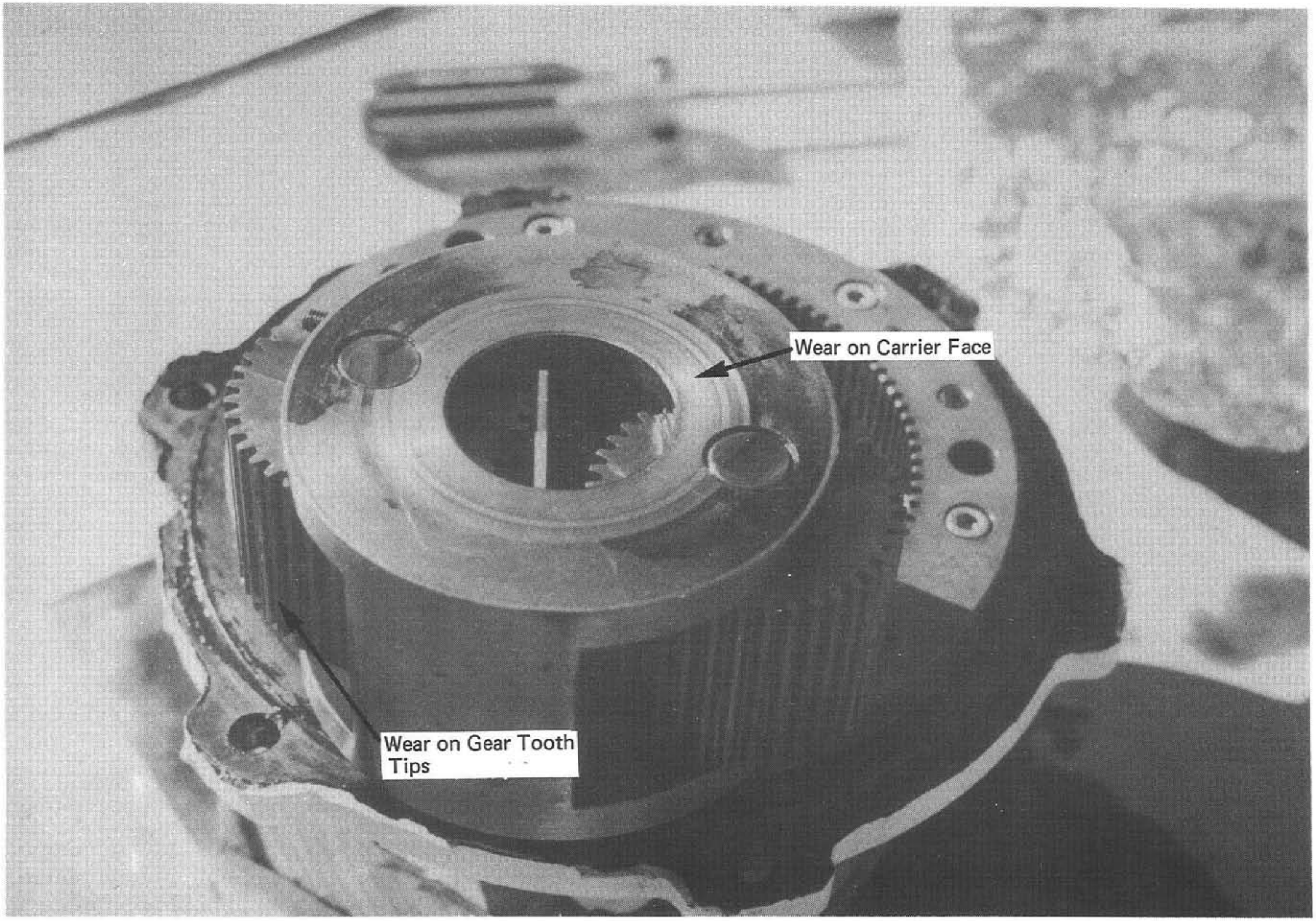


Figure 10. ARCO Planetary Carrier

heliostat under dynamic conditions, averaged over time, would not be as good as the steady-state results reported. Dynamic loads will cause variation in the heliostat aim point, which will have the same effect, averaged over time, as a heliostat with lower beam quality, i.e., produce a larger image size with a lowered peak intensity.

Wind Load Deflections--

a) Purpose--This test was designed to measure the backlash, compliance, and hysteresis of heliostat drives and structures at loads equivalent to windspeeds up to 35 mph. These results were subsequently fed into a finite element structural analysis to determine natural frequencies and modes of vibration and overall heliostat deflections (Ref. 3).

b) Description--These tests were run on the prototype-1 heliostats. Lasers were attached to the heliostat pedestal top and bottom and to the outputs of the azimuth and elevation drives (Figs. 11 and 12) and were aimed at a target grid approximately 150 ft away from the heliostat. This system provided approximately 0.1 mrad resolution. The four lasers allowed the deflection of each major heliostat component to be determined. The laser at the pedestal bottom indicated foundation deflection. (This laser was replaced by an inclinometer during elevation tests for increased sensitivity.) The difference between pedestal top and bottom lasers gave that component of the deflection that was due to the pedestal itself. Since all of the azimuth drives were mounted to the top of the pedestal, subtracting the deflection at the pedestal top from the deflection of the azimuth output laser produced azimuth drive deflection results. Elevation drive deflections were determined from the difference between elevation output and azimuth output (all elevation drives were mounted on the azimuth output). The elevation drive output laser measured the deflection of the torque tube or main beam of the heliostat. Actual deflection of the mirror module support structure outboard of this point is small due to wind load and was not measured in these tests. Calculation of these deflections outboard of the main beam/torque tube is reported in Ref. 3.

The heliostat was loaded in the positive and negative directions alternately with increasing loads. Deflections were measured before, during, and after each loading. Azimuth drives on the prototype-1 heliostats were tested at only the worst orientation (20° angle of attack, heliostat vertical). Elevation drives on the prototype-1 heliostats were tested at four positions--0°, 30°, 60°, and 90°--to encompass the changing kinematics of the jack mechanisms and loads which resulted from gravity at the various orientations. At each orientation, the heliostats were tested at loads corresponding to 14, 20, 27, and 35 mph winds at a 20° angle of attack. The prototype-2 heliostats were checked at only one elevation position (horizontal) and at one azimuth orientation at a single load level (27 mph, 20° angle of attack). Loads were calculated according to the method given in Appendix C.

c) Results--The results are summarized in Table IV. The results presented for the prototype-2 heliostats were obtained at a single 27 mph equivalent wind loading at the start of the survival wind load testing. Plots indicating the deflections at the various locations on the prototype-1

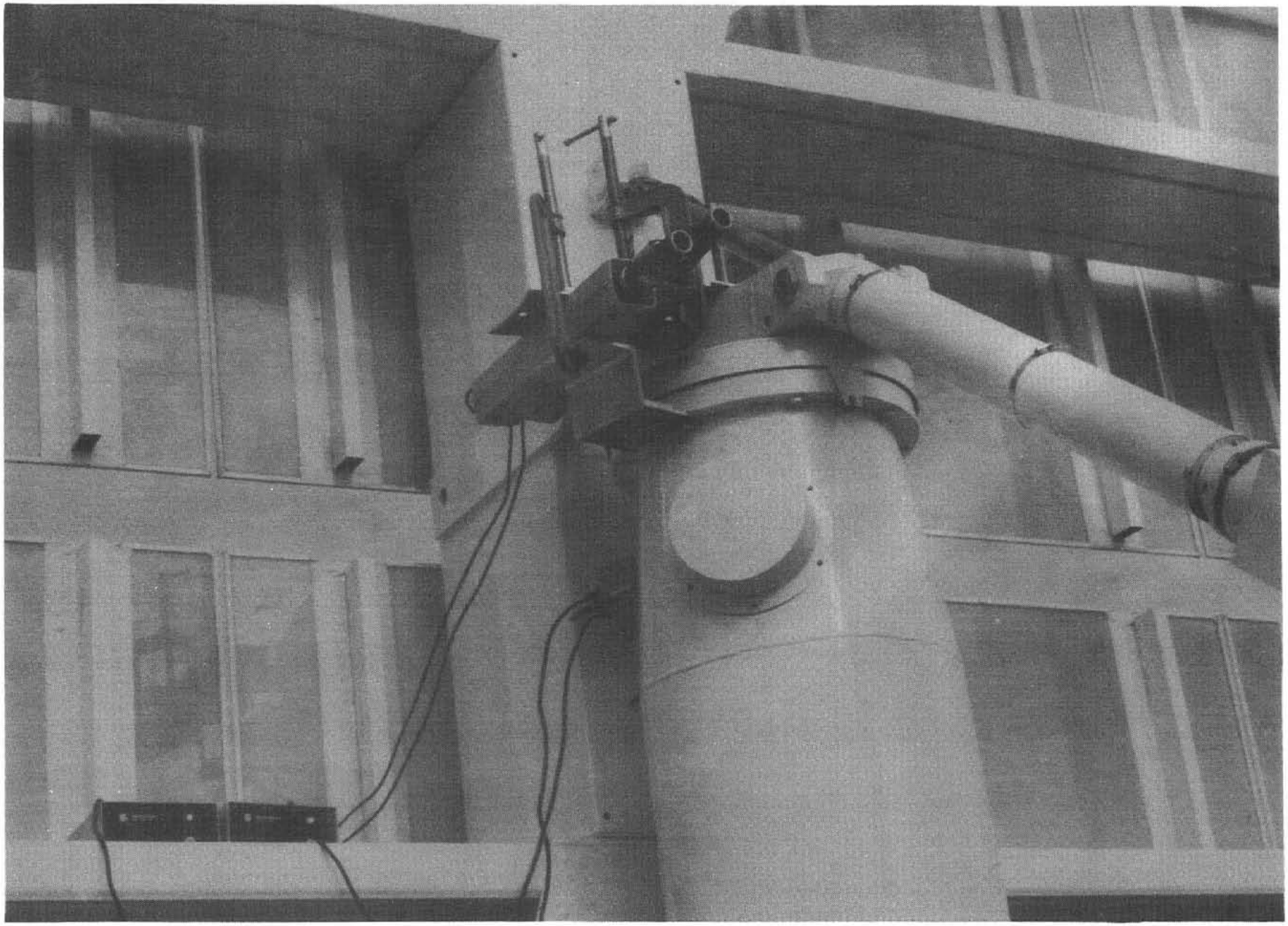


Figure 11. Pedestal Top and Azimuth Output Lasers on MDAC Heliostat

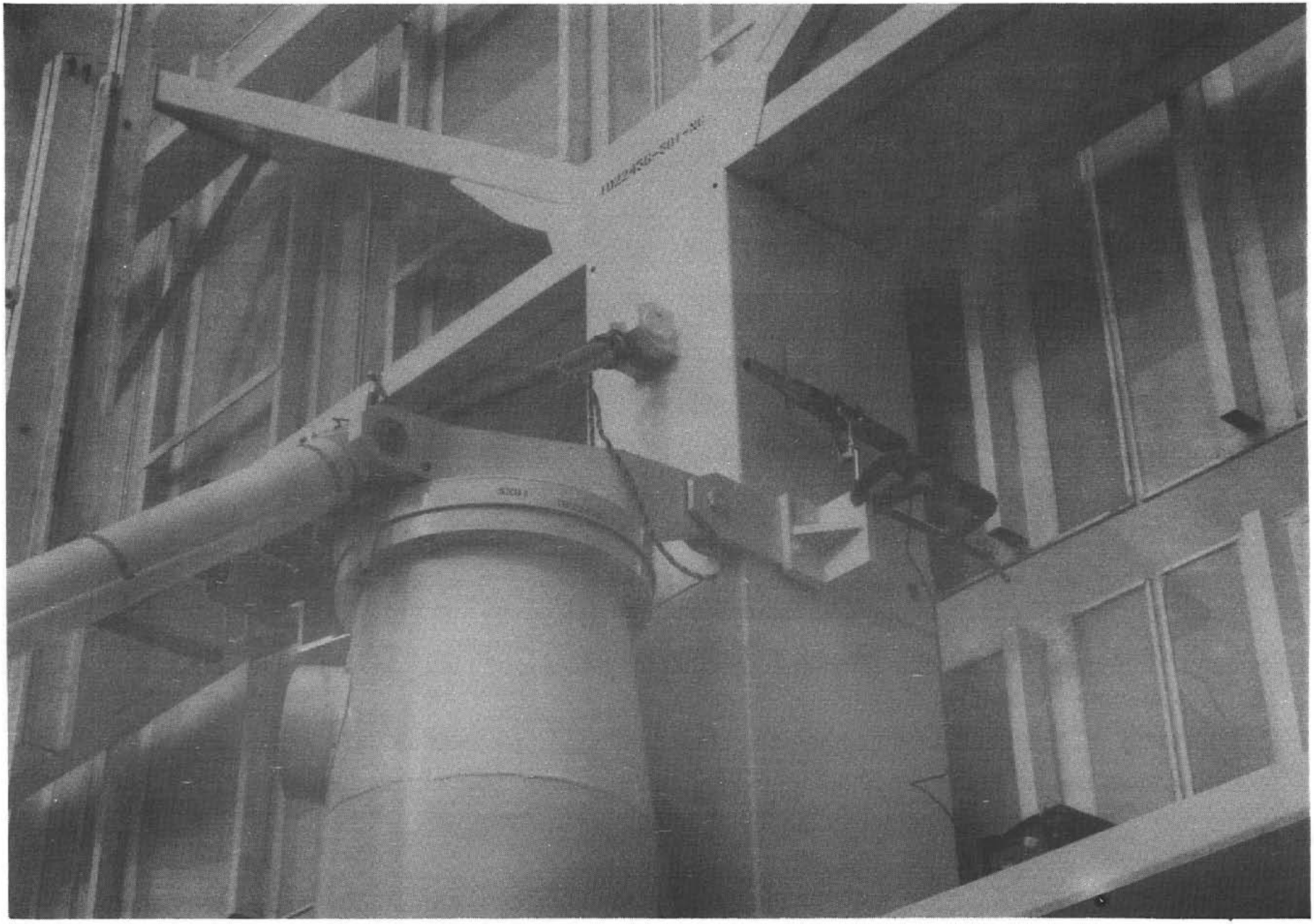


Figure 12. Elevation Output Laser on MDAC Heliostat

TABLE IV

MAXIMUM DEFLECTIONS AT TORQUE TUBE (MRAD)*
FOR SIMULATED 27 MPH WINDLOAD

Heliostat	ARCO		BOEING		MMC		MDAC	
Load Axis	#1	#2	#1	#2	#1	#2	#1	#2
AZIMUTH	±1.9	±1.2	±1.6	±1.6	±2.2	±2.7	±1.9	±1.2
ELEVATION	2.0	1.7	1.0	0.6	3.2	1.1	1.5	1.0

*Azimuth: ±(peak to peak)/2
Elevation: horizontal, rotation toward vertical

heliostats are shown in Figures 13-16.* The MMC heliostat was tested with its control system active. Initial deflections of this heliostat were greater than those shown, but they were subsequently reduced to the values listed when the controller performed its regular update of the heliostat position. A sample of the deflection without the active control system is shown in Figure 15.

d) Conclusions--All of the Second Generation Heliostats meet the specification for allowable deflection under wind load. The following observations were also made:

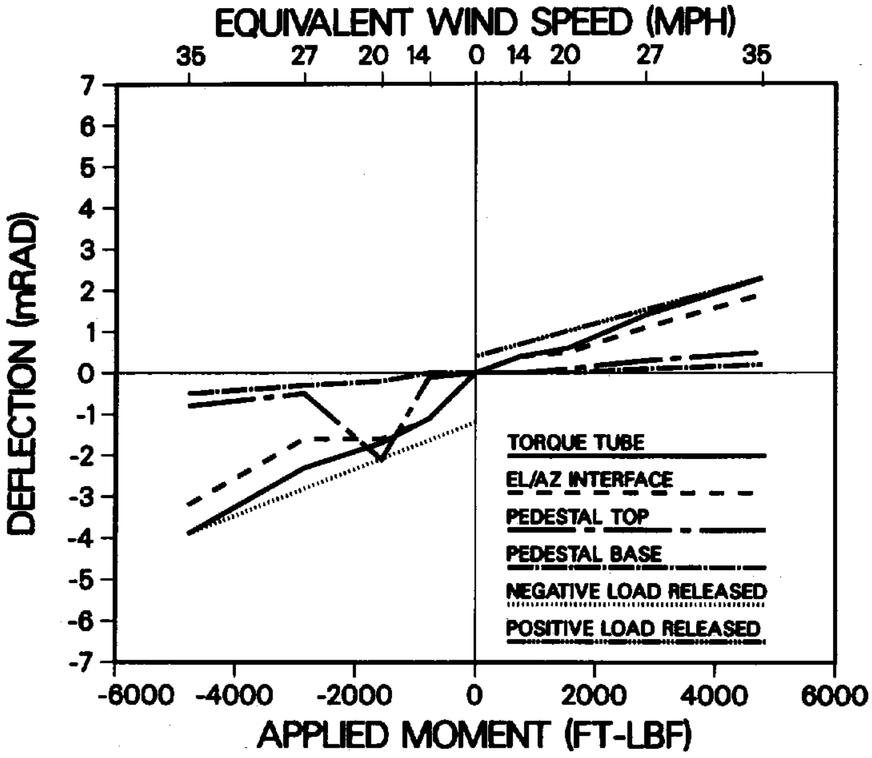
- The jack-type elevation drives on the BEC and MDAC designs appear to be stiffer than the gear box designs of ARCO and MMC.
- The BEC azimuth drive exhibits virtually no deflections when subjected to overturning elevation loads.

Drive Torque--

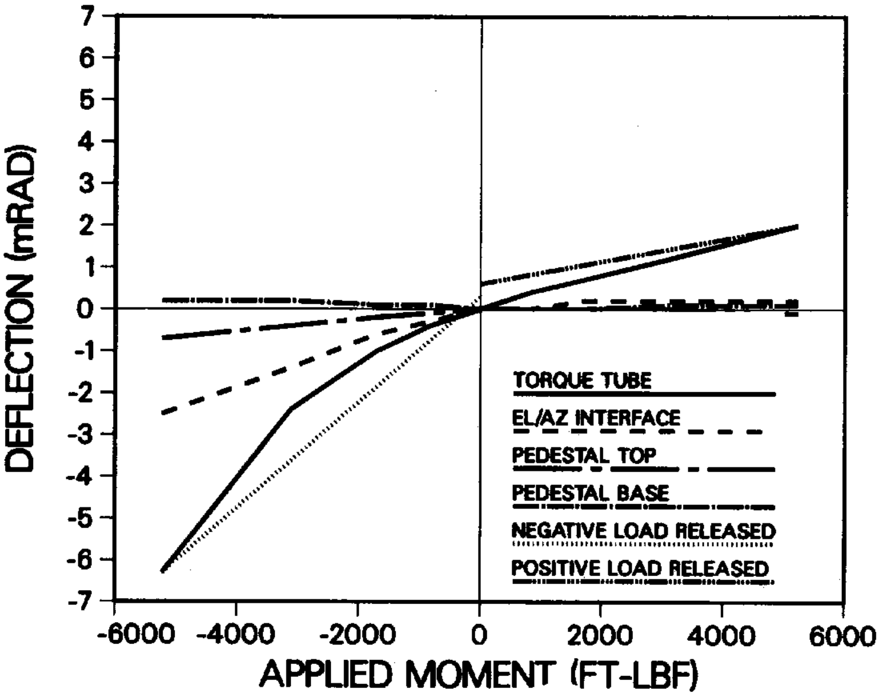
a) Purpose--This test verified the ability of the heliostats to start, drive against, and survive a 50 mph wind impinging on them at the worst angles of attack in elevation and azimuth.

---

*The large dip in the Pedestal Top curve on the ARCO azimuth plot (Fig. 13) is attributed to measurement error and should be discounted.

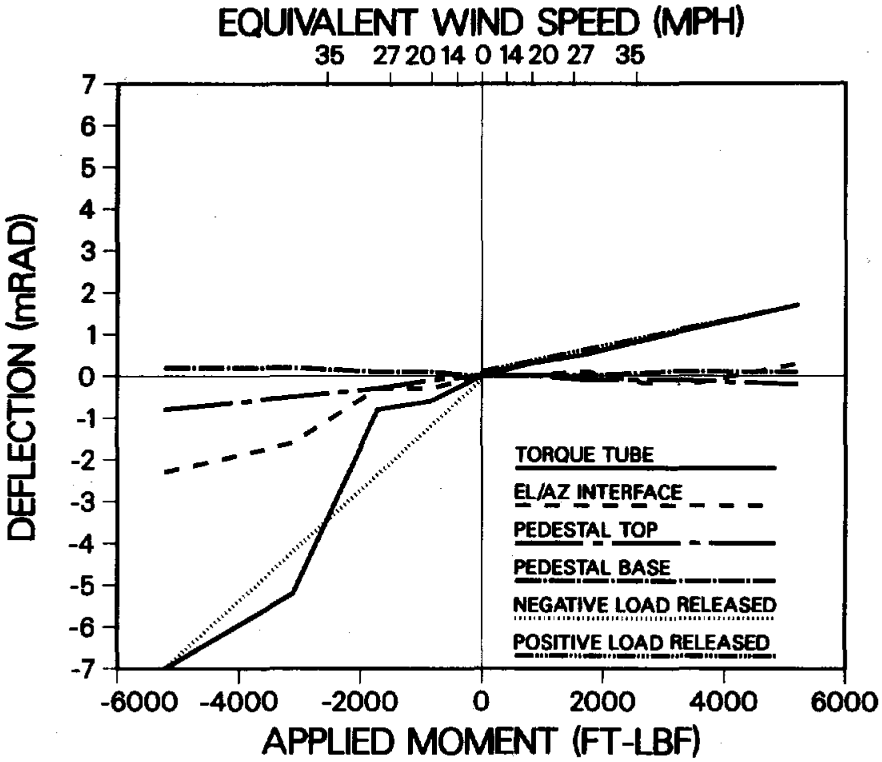


(13a) Azimuth

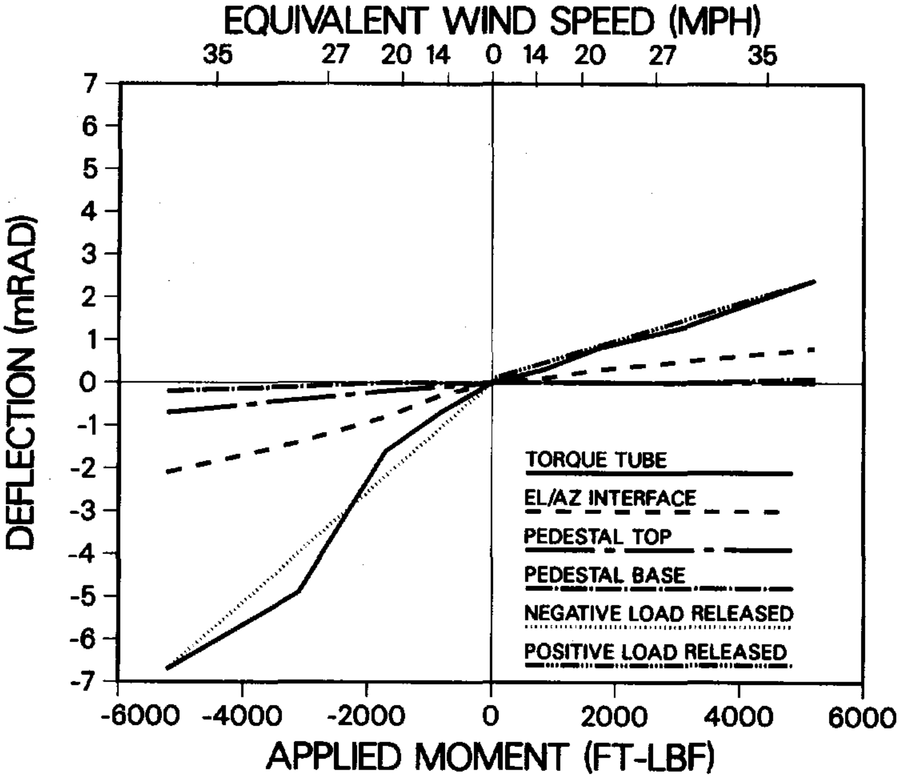


(13b) Elevation (Vertical)

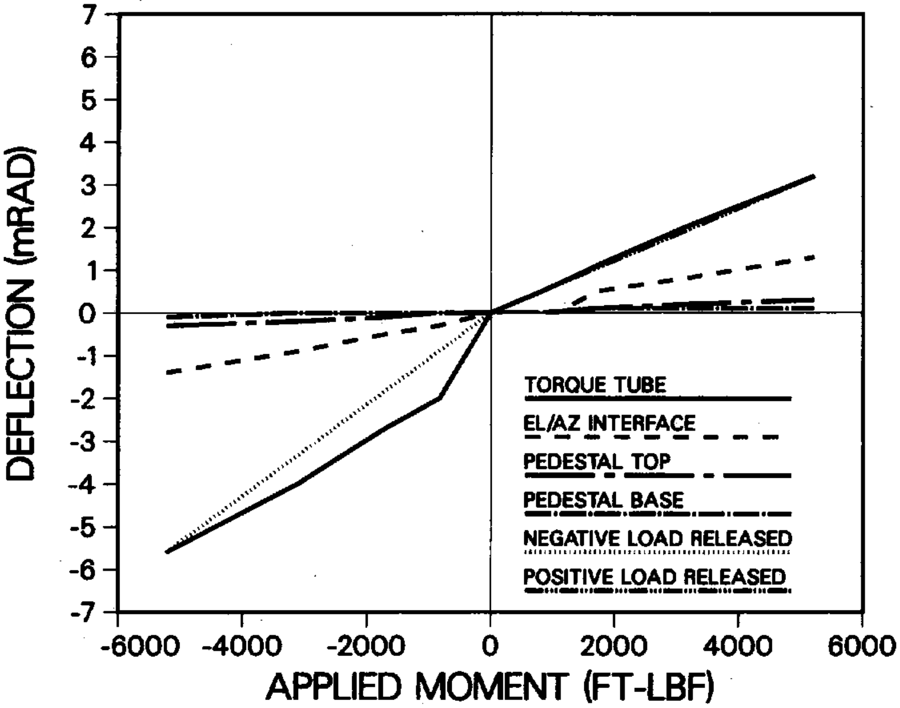
Figure 13. ARCO Simulated Wind Load Deflections



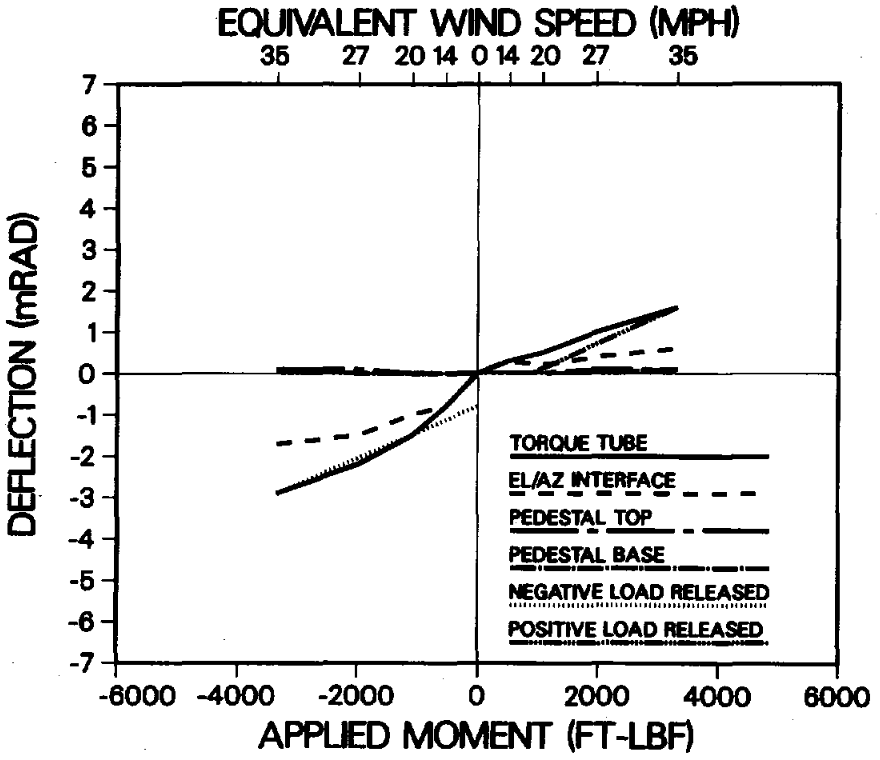
(13c) Elevation (60° from Horizontal)



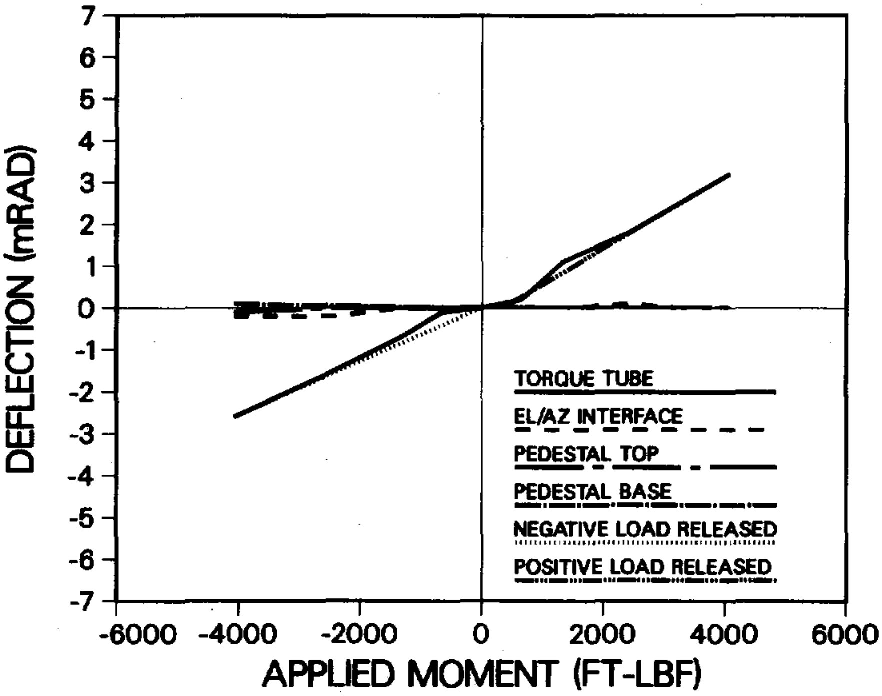
(13d) Elevation (30° from Horizontal)



(13e) Elevation (Horizontal)

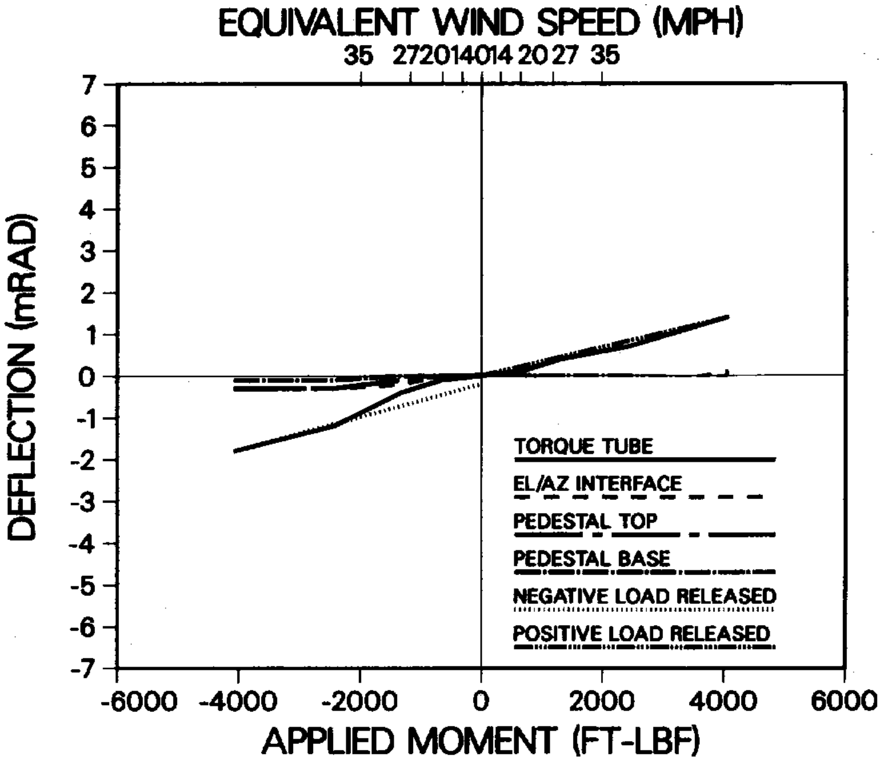


(14a) Azimuth

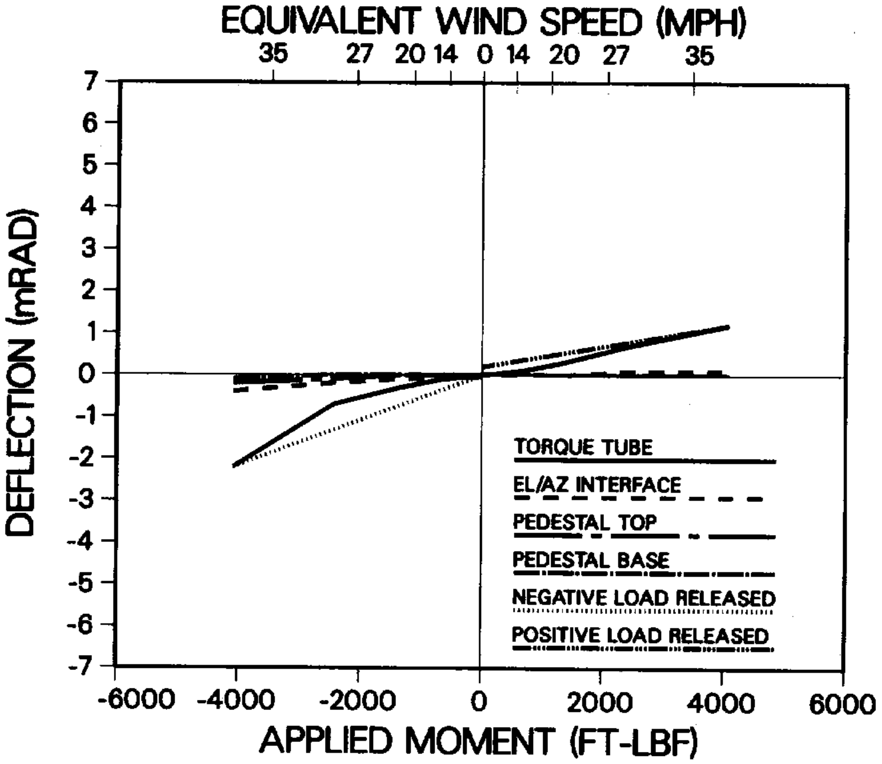


(14b) Elevation (Vertical)

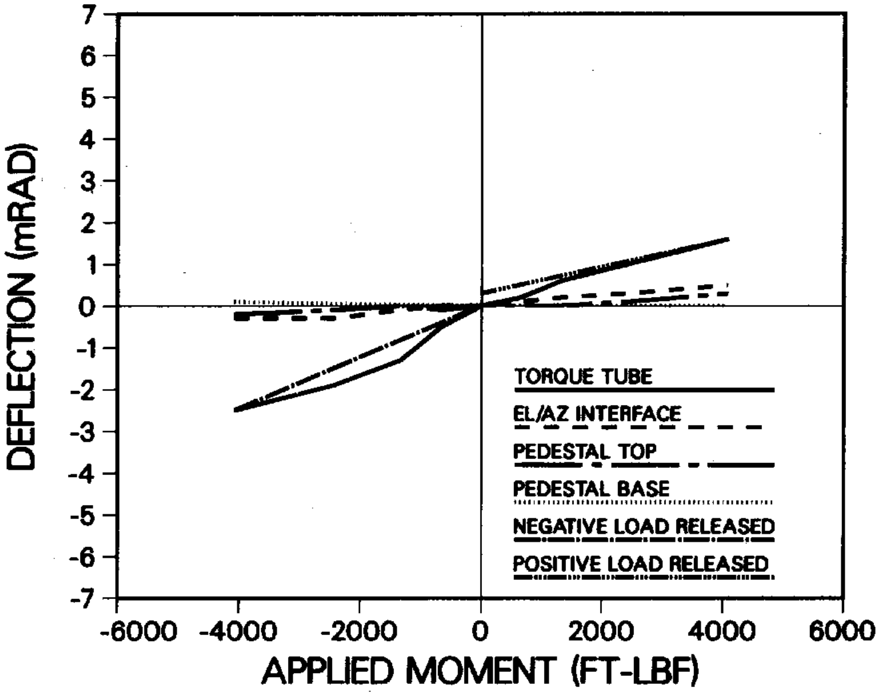
Figure 14. BEC Simulated Wind Load Deflections



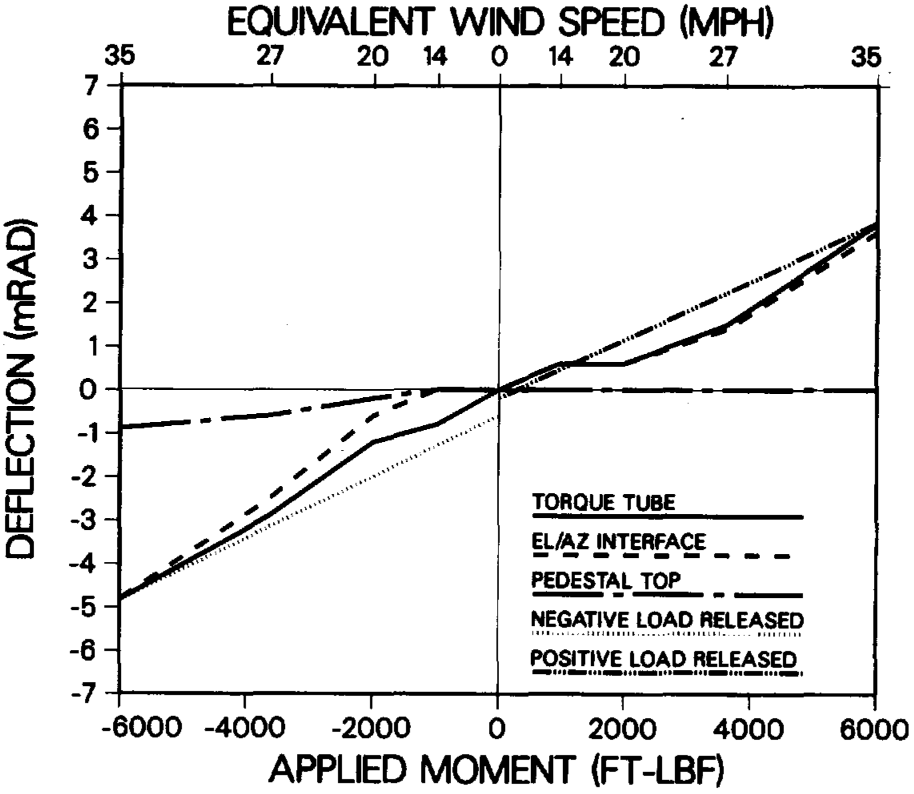
(14c) Elevation (60° from Horizontal)



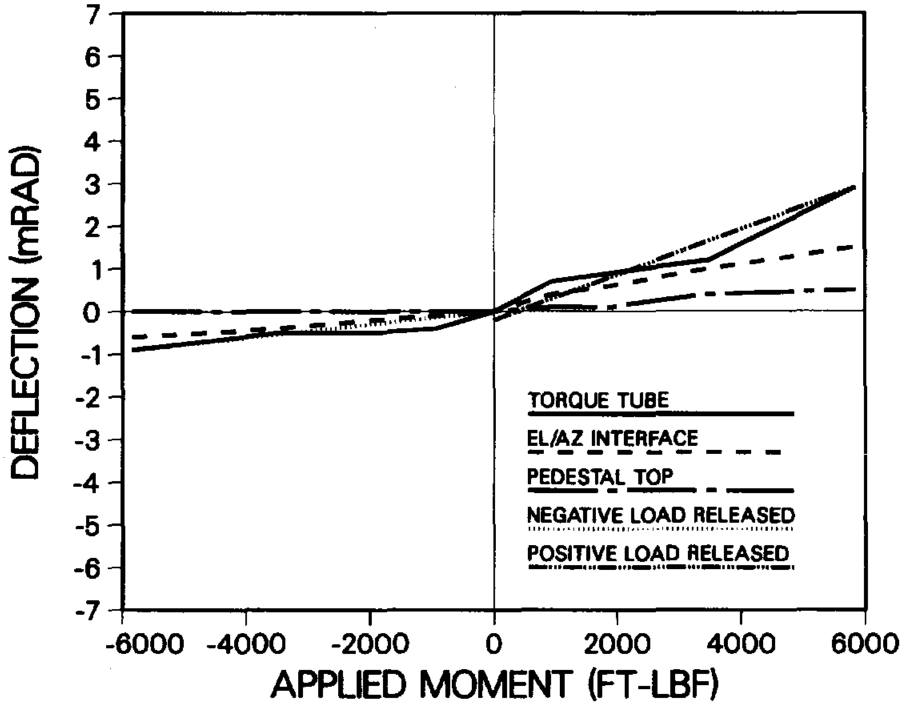
(14d) Elevation (30° from Horizontal)



(14e) Elevation (Horizontal)

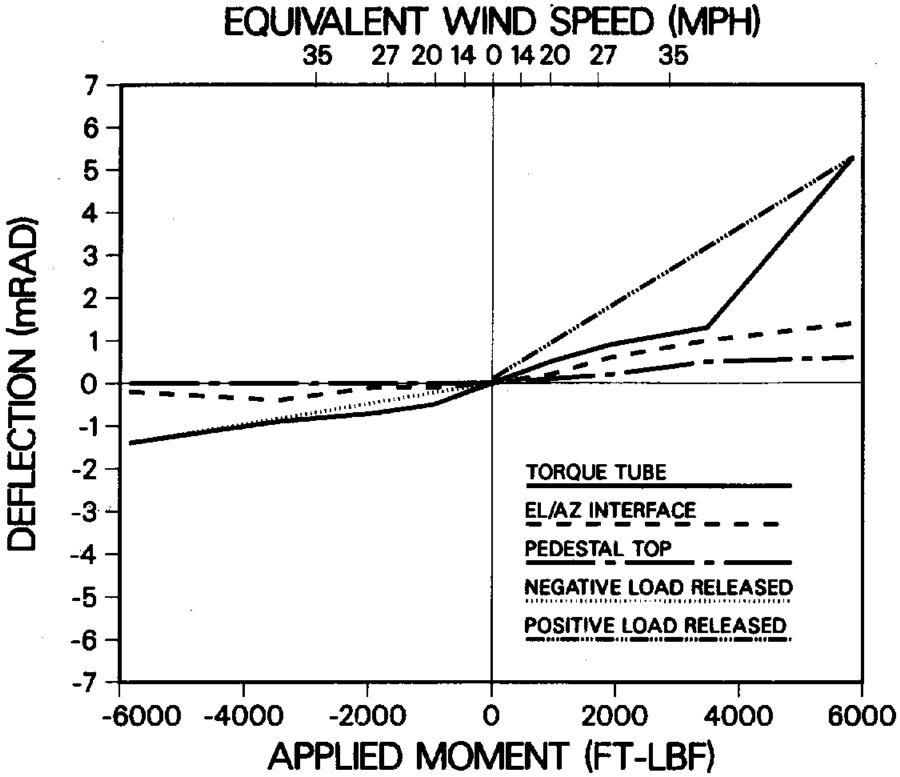


(15a) Azimuth (Active Controller)

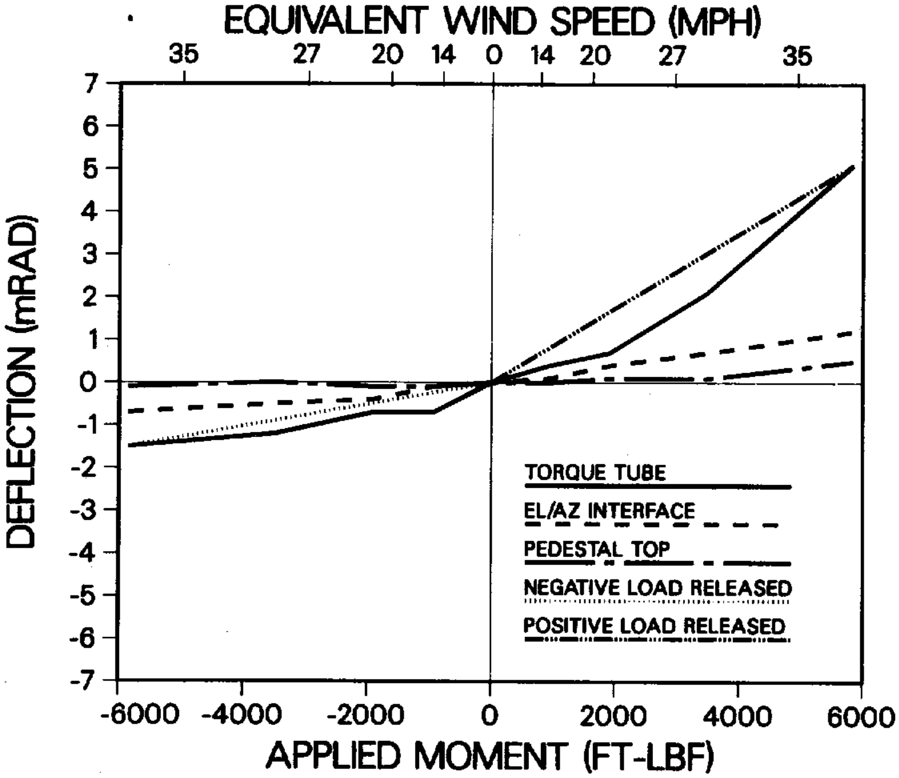


(15b) Elevation (Vertical; Active Controller)

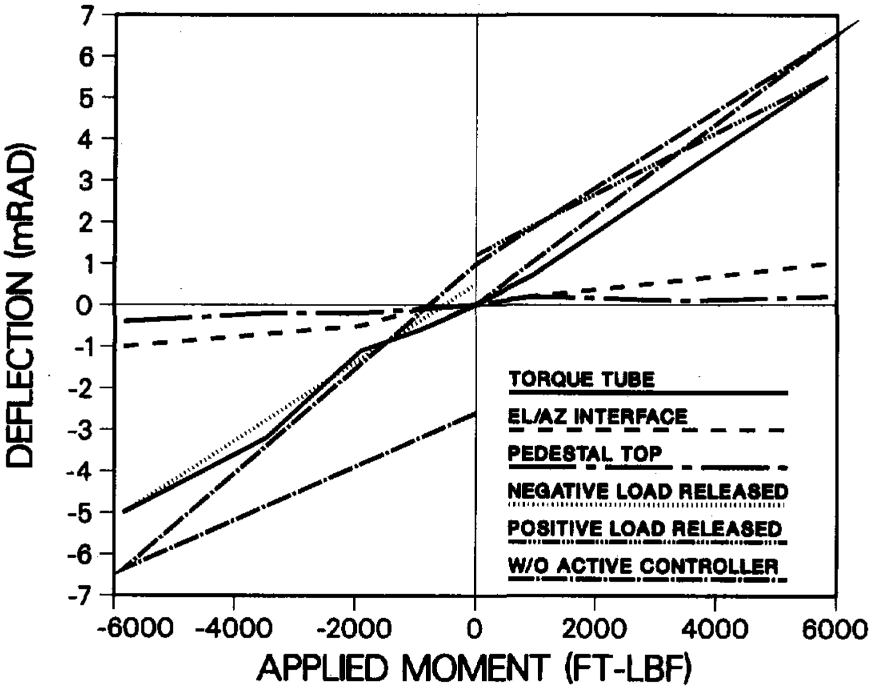
Figure 15. MMC Simulated Wind Load Deflections



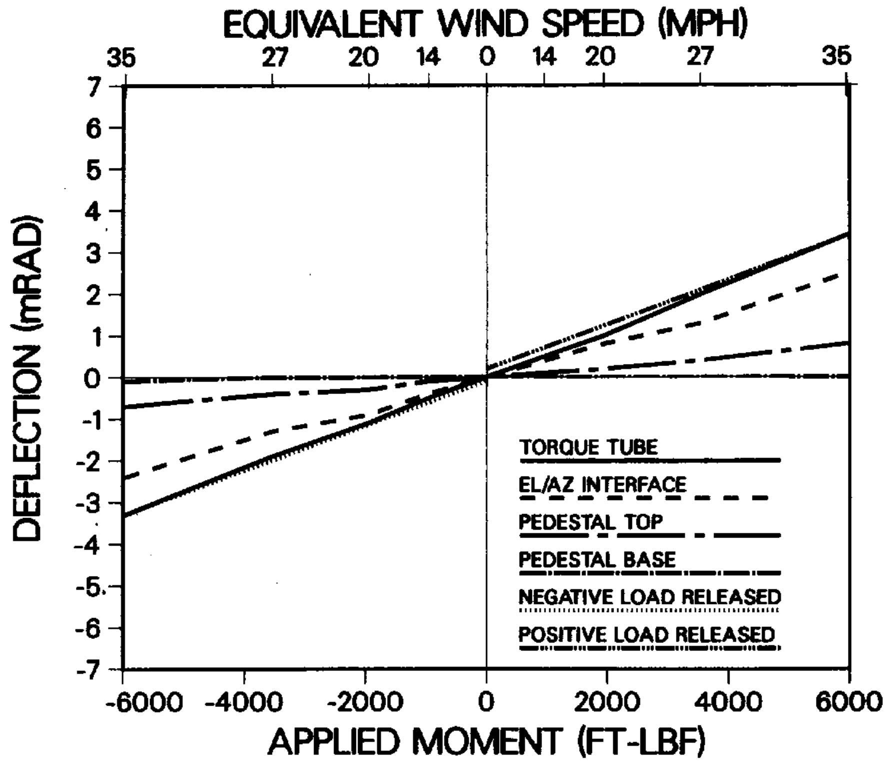
(15c) Elevation (60° Horizontal; Active Controller)



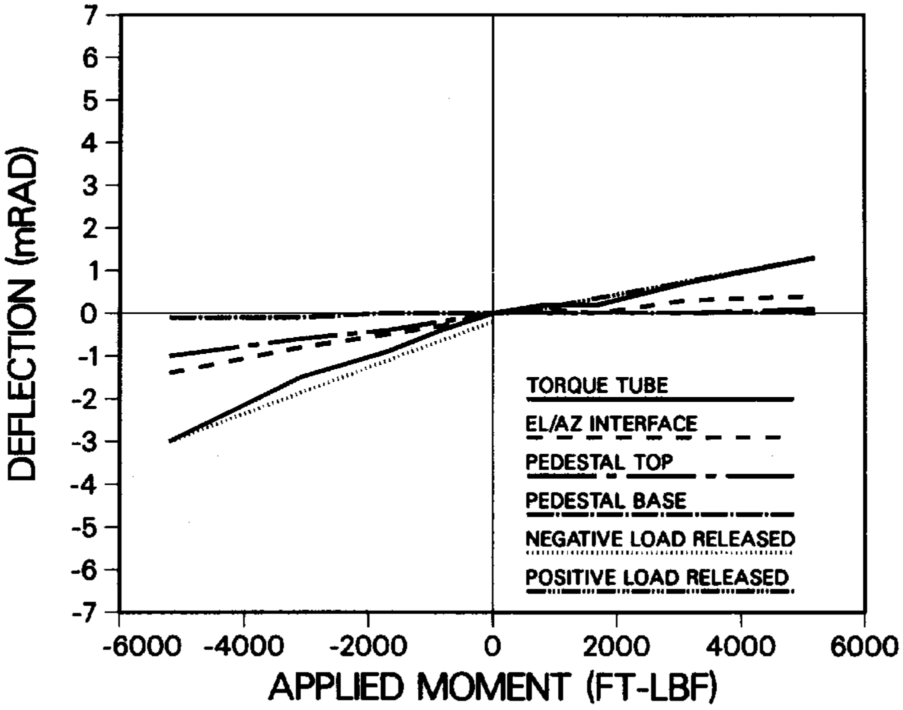
(15d) Elevation (30° from Horizontal; Active Controller)



(15e) Elevation (Horizontal; Active Controller)

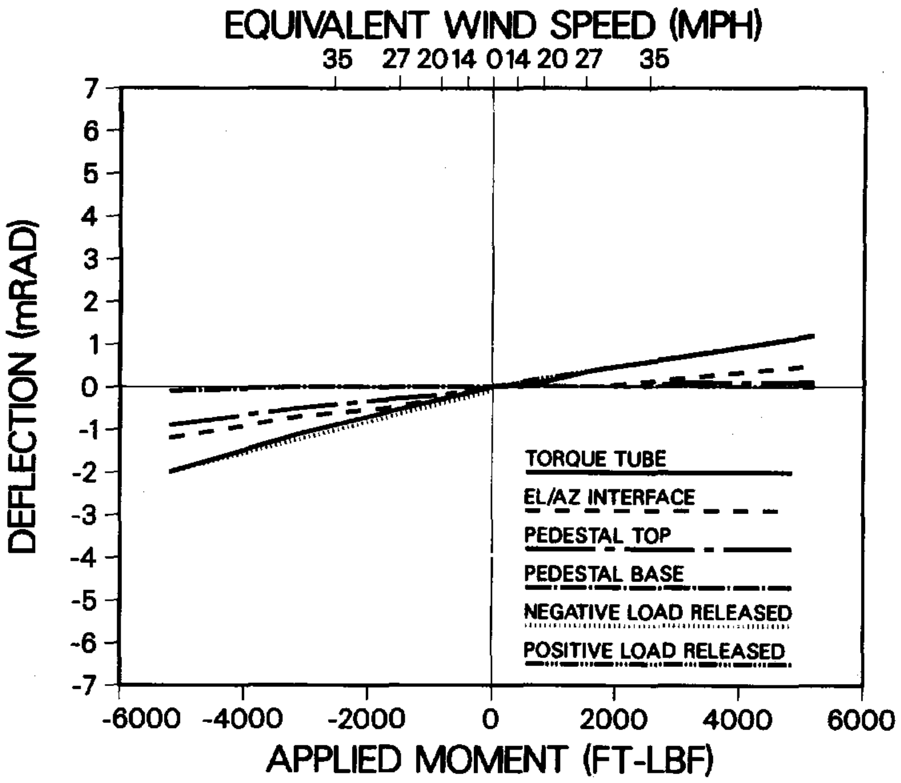


(16a) Azimuth

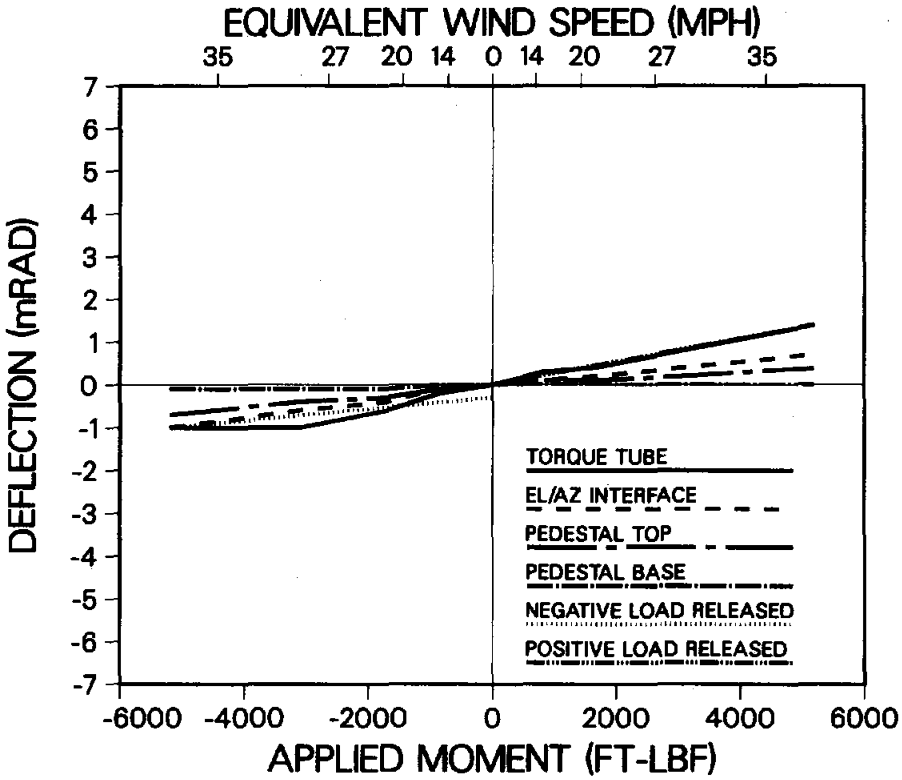


(16b) Elevation (Vertical)

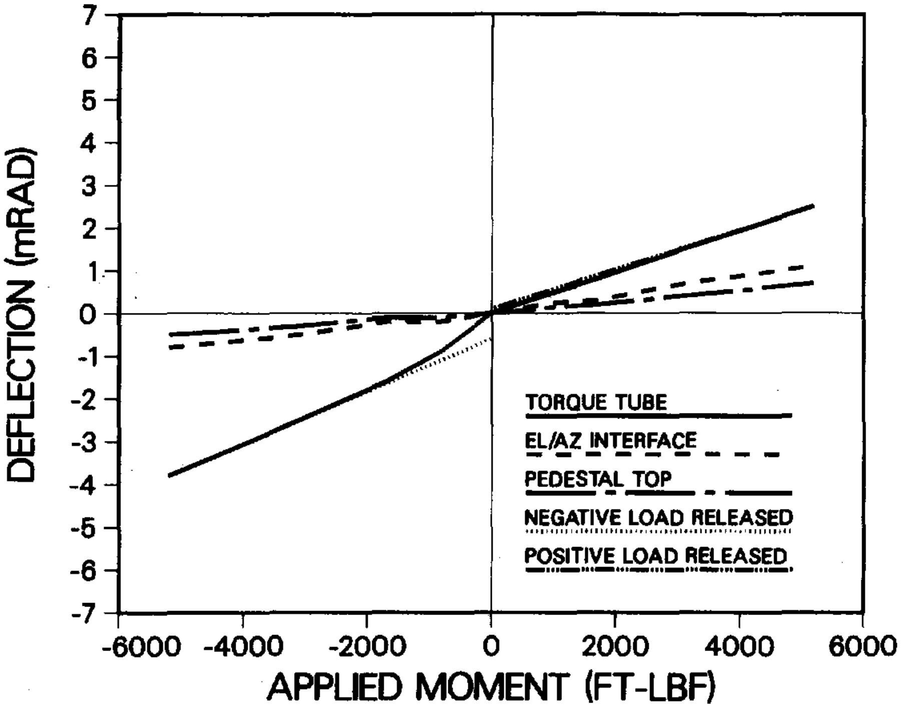
Figure 16. MDAC Simulated Wind Load Deflections



(16c) Elevation (60° from Horizontal)



(16d) Elevation (30° from Horizontal)



(16e) Elevation (Horizontal)

b) Description--Each of the prototype-2 heliostats was tested in elevation and in azimuth. This change from the prototype-1 heliostat specified in the test plan allowed the drive internals to be inspected for possible damage when the drives were disassembled at the end of life-cycling. The elevation tests were run from 30° to 10° from the horizontal to incorporate the drive kinematics at the worst angle of attack. Loads were applied through the test fixturing used in the other tests. A 35 mph equivalent load was applied, and the heliostat was commanded to slew against the load. The load was increased up to 50 mph equivalent load as the heliostat continued to slew through the approximately 20° of travel. The heliostat was then stopped and restarted against the 50 mph load. Test loads are given in Appendix B. The test loads were calculated by the method given in Appendix C.

c) Results--A summary of the test results is shown in Table V. The BEC and MMC heliostats had no problems driving either axis against the specified loads.

Prior to the application of any simulated wind load testing, the MDAC-2 heliostat was observed to ratchet at low loads (the motor would turn without moving the heliostat). The drive was subsequently determined to have been improperly assembled (the azimuth drive bolts were not tightened) with slight damage resulting from use. The azimuth drive was disassembled, inspected, and returned to MDAC for refurbishment. The MDAC-1 azimuth drive was tested and found to be capable of starting against a 35 mph load but would ratchet at approximately 41 mph. The wave generator in the harmonic drive was modified on the MDAC-2 drive to increase the torque capacity. This drive underwent extensive load and life-cycle testing at MDAC and was determined to be capable of starting and driving against the specified 50 mph wind load. The MDAC elevation drive performed well at all test conditions.

The tracking tests which were performed on the prototype-1 heliostats previous to these torque tests indicated that the ARCO drive had marginal torque capacity. During the tracking tests, the ARCO-2 azimuth drive was found to be capable of driving against a 35 mph load. After adjustments during the tracking tests, the ARCO-1 azimuth drive successfully started and drove against a 50 mph load. The motor torque testing of the ARCO-2 heliostat stalled the azimuth drive at a load equivalent to 40 mph. Both elevation drives started and drove against loads equivalent to a 50 mph wind.

d) Conclusions--The BEC, MMC, and MDAC drive mechanisms are all capable of starting and driving their respective heliostats against a 50 mph wind at the worst angle of attack. The ARCO drive mechanisms can easily meet the specification with proper gear shape and higher torque motors. The ARCO stepper motors could easily be replaced with conventional AC- or DC-type motors, similar to those used by other contractors.

Survival Wind--

a) Purpose--This test was conducted to confirm the ability of the heliostat structures and drives to survive the specified wind loads (50 mph

TABLE V

MOTOR TORQUE TEST RESULTS AND MEASURED CURRENT DRAW

	ARCO		BOEING		MMC		MDAC		BARSTOW	
	El	Az	El	Az	El	Az	El	Az	El	Az
Drive against 35 mph wind	Yes[1] 1.9A	Yes 1.9A	Yes 1.2A	Yes 1.0A	Yes	Yes	Yes 1.3A	Yes 1.2A	Yes 0.9A	Yes 1.6A
Drive against 50 mph wind	Yes 2.8A	No	Yes 1.7A	Yes 1.2A	Yes	Yes	Yes 1.3A	Yes[2] 1.4A	Yes 1.1A	Yes 2.9A
Start against 50 mph wind	No	No	Yes	Yes	Yes	Yes	Yes	Yes[2]	Yes	Yes

Specification: Start 35 mph, any orientation
Survive gust front (~50)
Maintain beam safety

1 - Required readjustment
2 - Retest of modified Az drive

in azimuth, 90 mph in elevation and cross-elevation*) and to quantify their residual deflections after experiencing such loads.

b) Description--This test was performed on each prototype-2 heliostat. This change from the test plan allowed close inspection of the drive internals when the drives were disassembled following life-cycling.

The azimuth survival load test procedure is described in Appendix A under "Wind Load Deflection Test." Each heliostat was tested in a vertical position. Since the heliostat had already withstood 50 mph loads as part of the motor torque testing, this test measured deflections of the structure and drive during and after loading.

The elevation and cross-elevation tests were performed with the heliostat in its horizontal stow position. The ARCO, BEC, and MDAC heliostats were tested faceup. The BEC test setup is shown in Fig. 17. The MMC heliostat was tested facedown, with its stow-lock engaged. Four mirrors had to be removed from this heliostat to allow access to the load fixturing which was mounted on the back of the heliostat, as shown in Fig. 18.

The heliostats were loaded using the method described in the Tracking Accuracy and Wind Load Deflection sections of this report. Lasers were attached to the heliostat as previously described. Loads were generated by hydraulic actuators and were measured by load cells installed in-line between the actuator and the load fixturing.

Laser deflections were recorded at no-load, positive load, no-load, negative load, and no-load conditions. The test was repeated three times at each load level to check for repeatability.

c) Results--The residual deflections resulting from each test are summarized in Fig. 19. The MDAC heliostat had no problems with these tests. Both the ARCO and BEC heliostats had their pedestals twist in the ground during the azimuth load testing. Also, the ARCO elevation drive rotated slightly on top of the azimuth drive during the azimuth test. The bolts were subsequently torqued to a higher load (the original torque of 80 ft-lb was increased to 200 ft-lb), and no further slipping occurred. The MMC heliostat also had its drive slip on top of the adapter section of the pedestal. Investigation disclosed that the mounting bolts had not been torqued to their design values. Tightening of the bolts to the specified torque eliminated the problem.

---

*The cross-elevation axis is orthogonal to the elevation and azimuth axes.

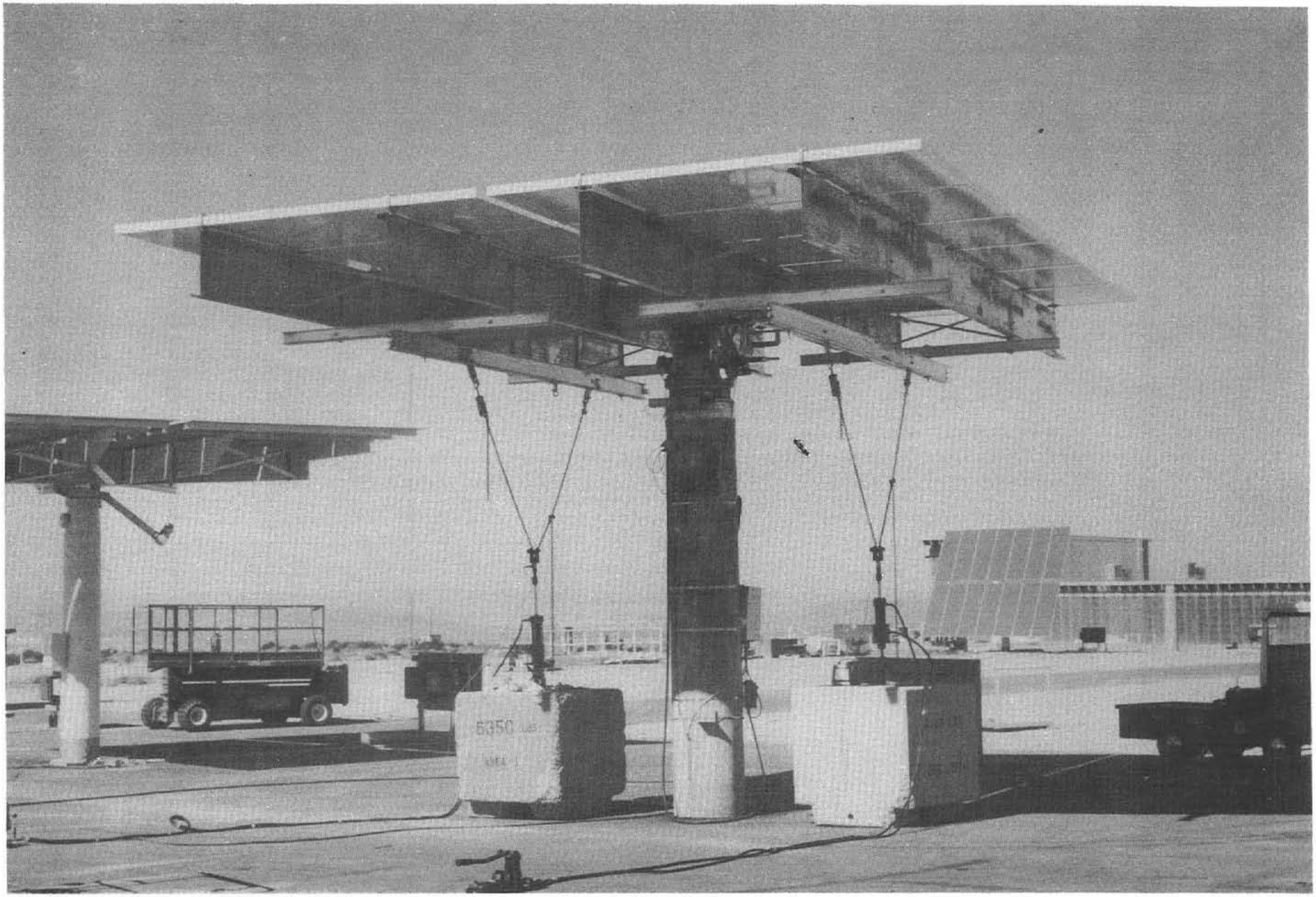


Figure 17. BEC-2 Heliostat Undergoing Cross-Elevation Survival Wind Load Test

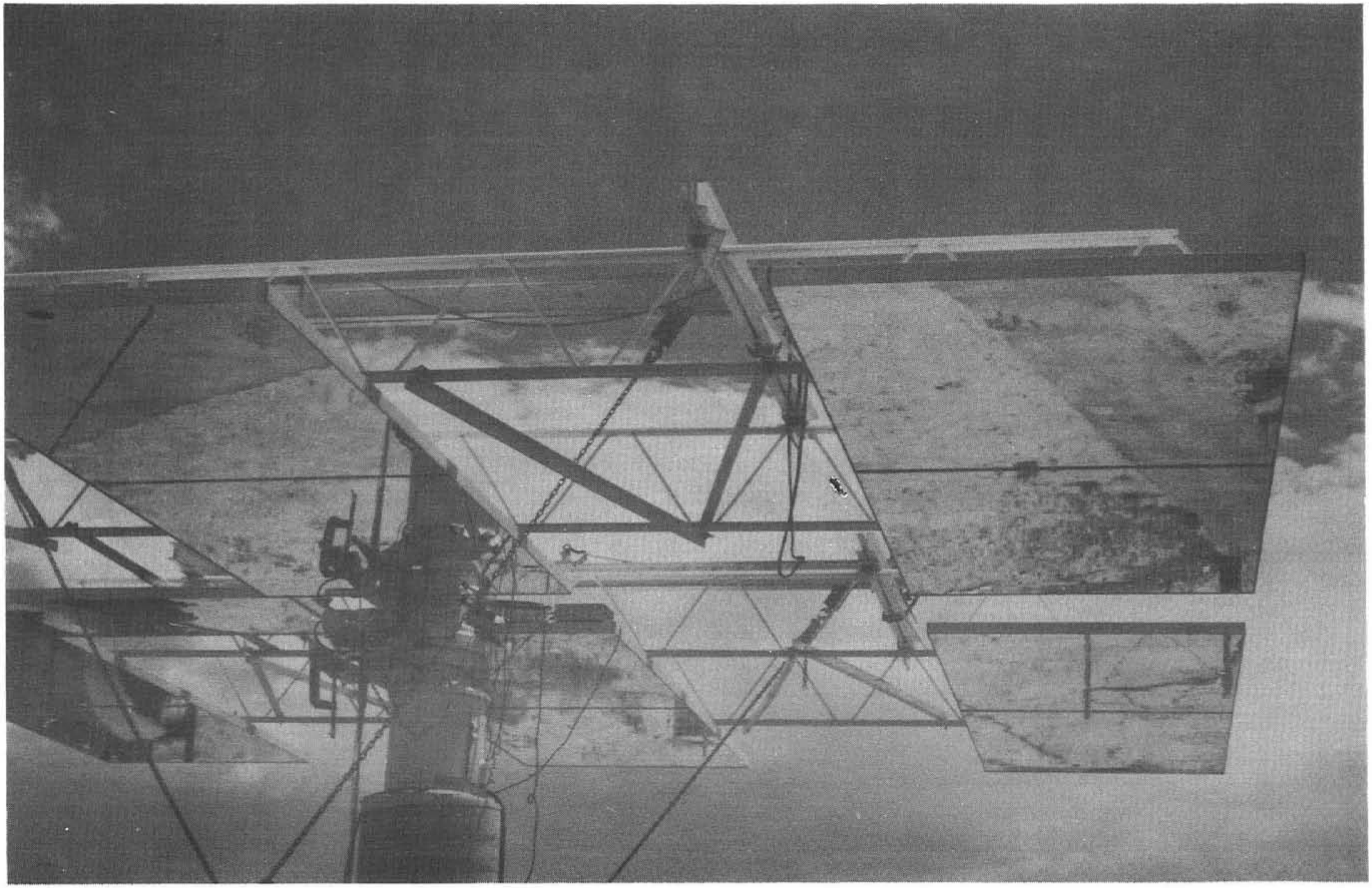


Figure 18. MMC Load Attachment for Cross-Elevation Survivial Wind Load Test

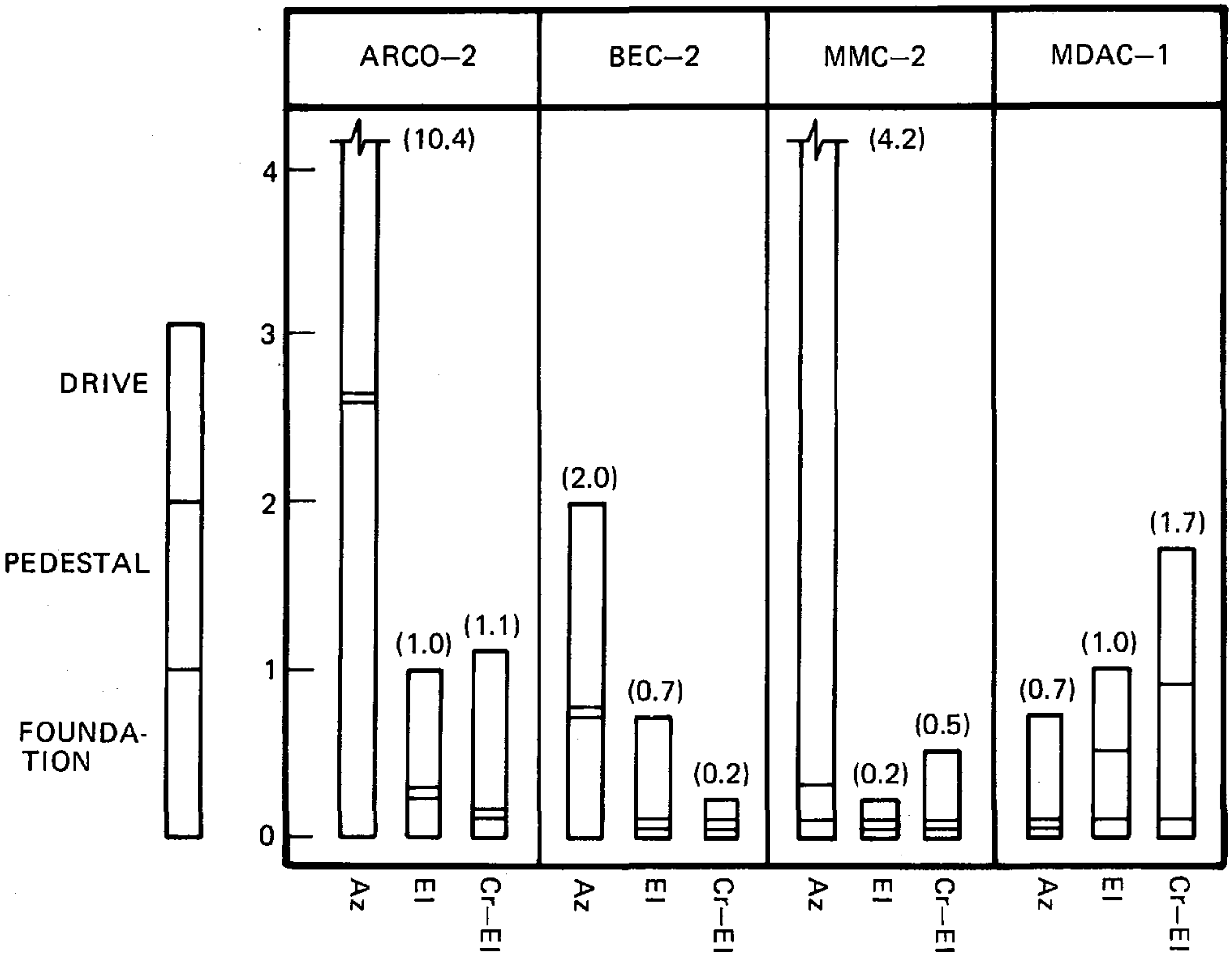


Figure 19. Maximum Residual Deflections After 100% Survival Load

Because of backlash and hysteresis in all of the prototype heliostats, the residual set measured immediately after a test may not accurately portray the effect of the loading on the heliostat's tracking accuracy. The test may set the heliostat drive over to one side of the backlash, or may cause a set that can be removed by operating the heliostat in a normal tracking mode. Tracking accuracy was measured on these heliostats before and after these survival tests. The RMS tracking errors, averaged over an entire day, are shown in Table VI. The posttestnumbers were measured after all of the survival tests, including the 10% overload tests, were run. Due to the loose drive and pedestal on ARCO-2, the posttest tracking accuracy was run on ARCO-1 after it was loaded to 100% survival loads.

TABLE VI

TRACKING ACCURACY BEFORE AND AFTER SURVIVAL WIND LOAD TEST

Reflected Beam Angle Error (mrad, RMS)

	Pretest		Posttest	
	Horizontal	Vertical	Horizontal	Vertical
ARCO-1	1.5	1.9	2.0	2.1
BEC-2	1.4	1.2	1.2	2.1
MMC-2	0.8	1.3	0.6*	2.9
MDAC-1	0.4	0.4	0.5	0.4

---

*Heliostat was re-biased after its drive slipped during azimuth testing.

The tracking errors in Table VI are different from the deflections presented in Fig. 19. The values in Fig. 19 are the heliostat azimuth and elevation deflections, while Table VI presents the horizontal and vertical angle errors of the reflected beam. A given error in azimuth (or elevation) can produce combined horizontal and vertical angle errors. The relationship between heliostat azimuth/elevation deflections and horizontal/vertical deflections of the reflected beam depends on the orientation of the heliostat relative to the sun and the target.

d) Conclusions--The MDAC heliostat is capable of withstanding loads equivalent to the wind loads in the specification with no degradation of performance. The ARCO, BEC, and MMC heliostats are structurally sound and capable of surviving the loads but require refinement to obtain satisfactory production designs.

Care needs to be taken in the design and installation of foundations like these having smooth circular cross-sections. These designs offer marginal torsional break-away strength, especially when installed in a drilled hole. Grouting and/or fins may be required to eliminate large residual deflections of the foundation after high azimuth loads.

Care also needs to be taken in the design and assembly of heliostat joints which are exposed to torsional loads. Joints subject to these loads should have some type of positive fixturing to prevent rotational slippage. Quality control cannot be relied upon to ensure proper performance. Knowing the close scrutiny to which the heliostats would be subjected, the contractors each delivered heliostats which were undoubtedly assembled with the greatest of care; yet, both ARCO and MMC heliostats experienced slipping. This type of joint slipping has been seen before in the heliostat program, notably in the elevation/torque tube joints on the MMC/Barstow heliostat.

The MDAC heliostat exhibited no change in its excellent tracking accuracy as a result of the survival wind loads. The ARCO, BEC, and MMC heliostats may require reaiming after a survival wind. However, these tests were worst-case loads--heliostats experiencing free-stream winds (such as that which occurs at the edge of a field) at the worst angle of attack. Therefore, the tracking accuracy for fields of heliostats should not be expected to degrade as much.

There is one conclusion which is not evident from the test results. Survival of the MMC heliostat in high winds depends on the stow-lock which, while structurally adequate, remains unproven under operating conditions. Since the testing program, MMC has modified their stow-lock, increasing the lock's internal tolerances to facilitate lock engagement under dynamic wind loads. MMC has presented data and analysis to Sandia supporting this refined stow-lock, but the device has not been tested by Sandia.

Life-cycling Test Program

The objectives of the Life-cycling Test Program were:

- Estimate design lifetimes with emphasis on drive mechanism components
- Assess the field maintenance requirements
- Check the environmental sealing of the drives
- Determine if any damage resulted from the simulated Wind Load Test Program

Test Plan Summary

The life-cycling tests are Tests 5 and 9 in Section A of the Test Plan (Appendix B). Long-Term Operation (Test 10, Section A), which involves one year of operation, commenced at the end of the wind load and life-cycle testing and is not covered in this report.

These tests were performed at the CRTF on each prototype-2 heliostat, except for the MDAC-1 heliostat.* These heliostats were continuously cycled 24 hours a day through a one-hour duration stow-slew-track-slew-stow sequence. This cycle was interrupted when high winds occurred, when individual heliostats were tested or when components or control systems failed. The heliostats were exposed to rain, snow, sleet, hail, and dust storms. After accumulating approximately 700 cycles (equivalent to two years of operation), each heliostat was hosed down with water to simulate a heavy rain and then immediately disassembled and inspected.

Hardware

After each contractor turned over the heliostats for testing, the heliostats were inspected. All of the heliostats were generally in excellent condition. The following items deserve specific mention:

- The exposed plastic nut on the elevation drive jack-screw of the BEC-2 heliostat was removed before any load testing or life-cycling and measured to obtain a baseline to determine any subsequent wear.
- Both MDAC heliostats had accumulated approximately 2000 cycles in testing at MDAC prior to their installation at the CRTF.

---

*Early in the test program, the MDAC-2 heliostat was found to have an improperly assembled drive mechanism. The heliostat was disassembled, the azimuth drive modified, and the reassembled heliostat subjected to extensive load and life-cycle testing at MDAC. This testing is reported in Ref. 15.

- Due to funding limitations, control system development was not funded under these contracts. The control systems which were delivered were capable of operating the heliostats and performing life-cycle testing. In general, the control systems performed very well. Failures of the control systems during testing are not reported here, since the systems were nonrepresentative of production hardware. Production control systems need to be designed (incorporating installation-specific requirements), built, and extensively tested to obtain a high level of confidence in their performance.

Test Results

One of each of the contractors' heliostats was successfully cycled through more than 700 operating cycles, equivalent to two years of operation, without a failure. The disassembly and inspection, which were performed at the CRTF with the assistance of each contractor, revealed nearly all of the drive mechanism components to be essentially like new. Magnetic flux inspection of all critical drive components revealed no cracks or other damage.

The ARCO drive mechanism showed light scuff marks on the large worm gears, probably as a result of the survival wind load testing. This should not be considered a problem, since the polishing action of worm gear drives will tend to remove these marks with use.

The BEC drive showed severe wear on one of the reduction worm gears on the elevation jack. Investigation by Winsmith, the drive manufacturer, revealed that the lubricant had thickened and channeled, resulting in a lack of lubrication on the gear. Winsmith has since performed a lubricant study and successfully developed and tested a lubricant which eliminates the problem (Ref. 17). The exposed Delrin-AF nut on the jack-screw performed remarkably well, showing no measurable wear. The bolts holding the elevation drive motor had loosened.

In the BEC azimuth drive, burrs along the oil grooves in the washers under the planet carrier had begun to mill into the carrier, and the planet carrier thrust face had begun to mill into the housing (burrs around the planet bearing holes acted as cutting edges). This action could be reduced or eliminated with minor design changes, such as using a softer material for the washers and changing the carrier thrust face so it would not intersect the planet bearing holes.

The MMC drive mechanism showed no wear, but the breather diaphragm was rusted and had allowed water to enter the drive lubricant. The lubricant was about 3 in. below the design level, which resulted in no apparent damage. The inspection also revealed that the main azimuth shaft, which supports the drive mechanism, had been reworked before delivery to aid in the fit between the shaft and a bearing assembly. This custom fit may have produced results which were nonrepresentative of production hardware.

The MDAC ballscrew jack showed severe pitting and spalling in the areas of high load. This drive had almost 3000 operating cycles on it from testing at MDAC and the CRTF. The jack may have lasted through the 10,000 cycles it would experience over 30 years, but MDAC was directed to redesign the ballscrew. MDAC and their suppliers, Duff-Norton and Saginaw, redesigned the jack to use a larger diameter screw and reduce loads. MDAC has cycled the new design under load over 30,000 times without failure. Testing is reported in Ref. 15.

Other than these few problems, which are not unexpected in prototypes, the heliostats were in excellent condition. Many of the drive components such as gears and bearings were virtually indistinguishable from new, showing the original machining marks.

Conclusions

All of these heliostat structures and drive mechanisms have demonstrated the equivalent of two years of operation without significant wear or component failure and have expected lifetimes in excess of 30 years. Control systems, which are predicted to constitute a large portion of collector field maintenance requirements, have not been tested. Production hardware and software need to be designed and tested to obtain high confidence in their satisfactory performance and lifetime.

Foundation Test Program

The Foundation Test Program measured the deflections of heliostat foundations and pedestals resulting from loads in excess of those induced by survival winds. Testing of the heliostats and foundations as described under the Simulated Wind Load Test Program revealed that the ARCO and BEC foundations developed insufficient torsional breakaway strength. The overturning moments developed by the survival wind loads were well below the foundations' ultimate strengths, with correspondingly small deflections. In order to obtain more accurate load/deflection data, a test program was instituted to measure these deflections at higher loads. The results of this test program were used as inputs to a foundation modeling study that was sponsored jointly by the Electric Power Research Institute (EPRI) and SNLL (Ref. 18). A detailed investigation of the CRTF soil properties was conducted by GAI Associates, Inc., as part of this test program. The results are presented in Appendix D.

Test Plan Summary

Both bending and combined bending/torsion tests were performed on the prototype-2 heliostat foundation/pedestals. The bending tests were performed by applying a horizontal load at the pedestal top as shown in Fig. 20. The combined bending/torsion test required that the load be applied to a horizontal torque arm bolted to the pedestal top as shown in Fig. 21. Loads were increased in steps up to a maximum of 200% of the 50 mph wind

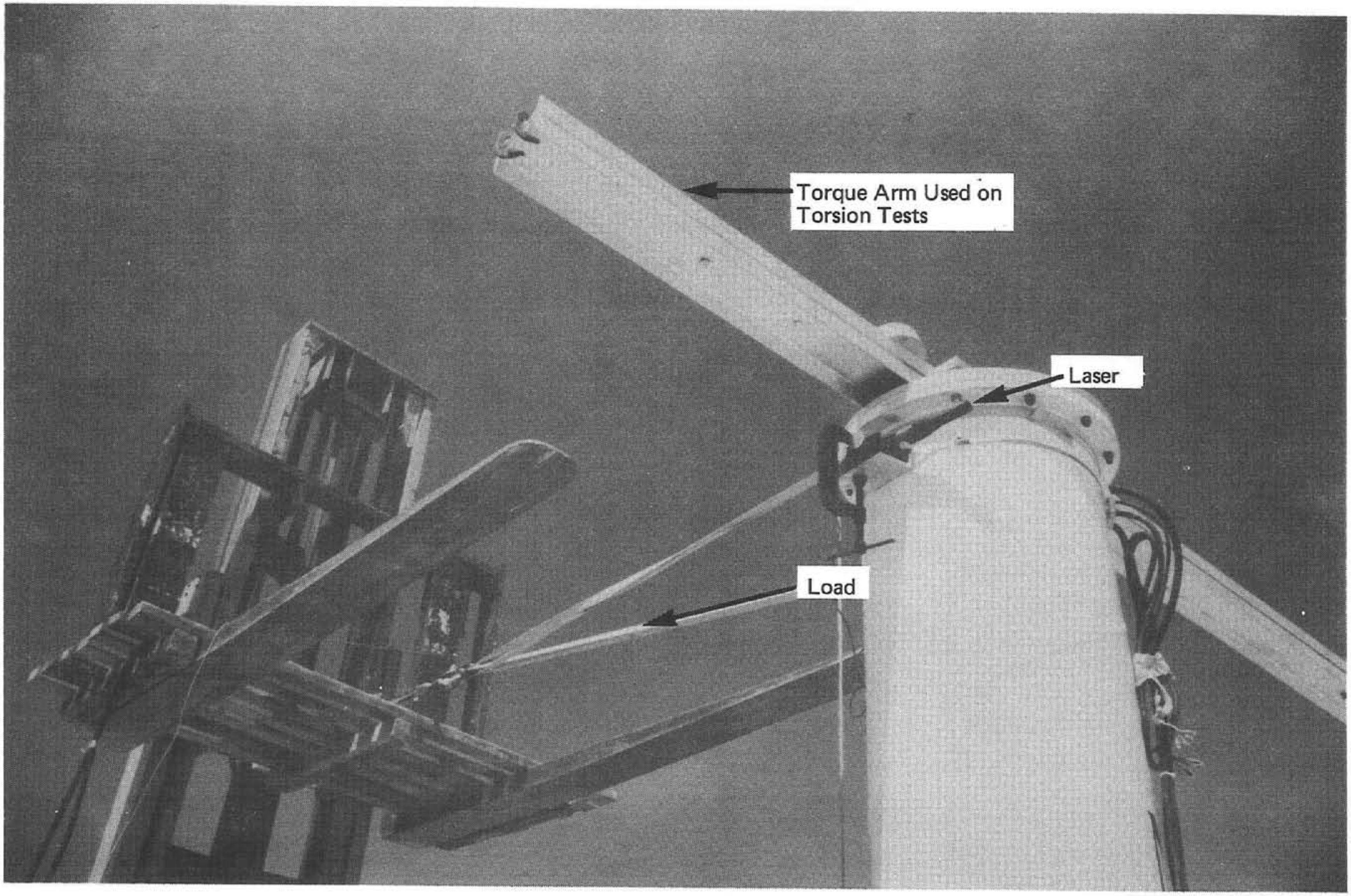


Figure 20. ARCO Pedestal Undergoing Bending Test

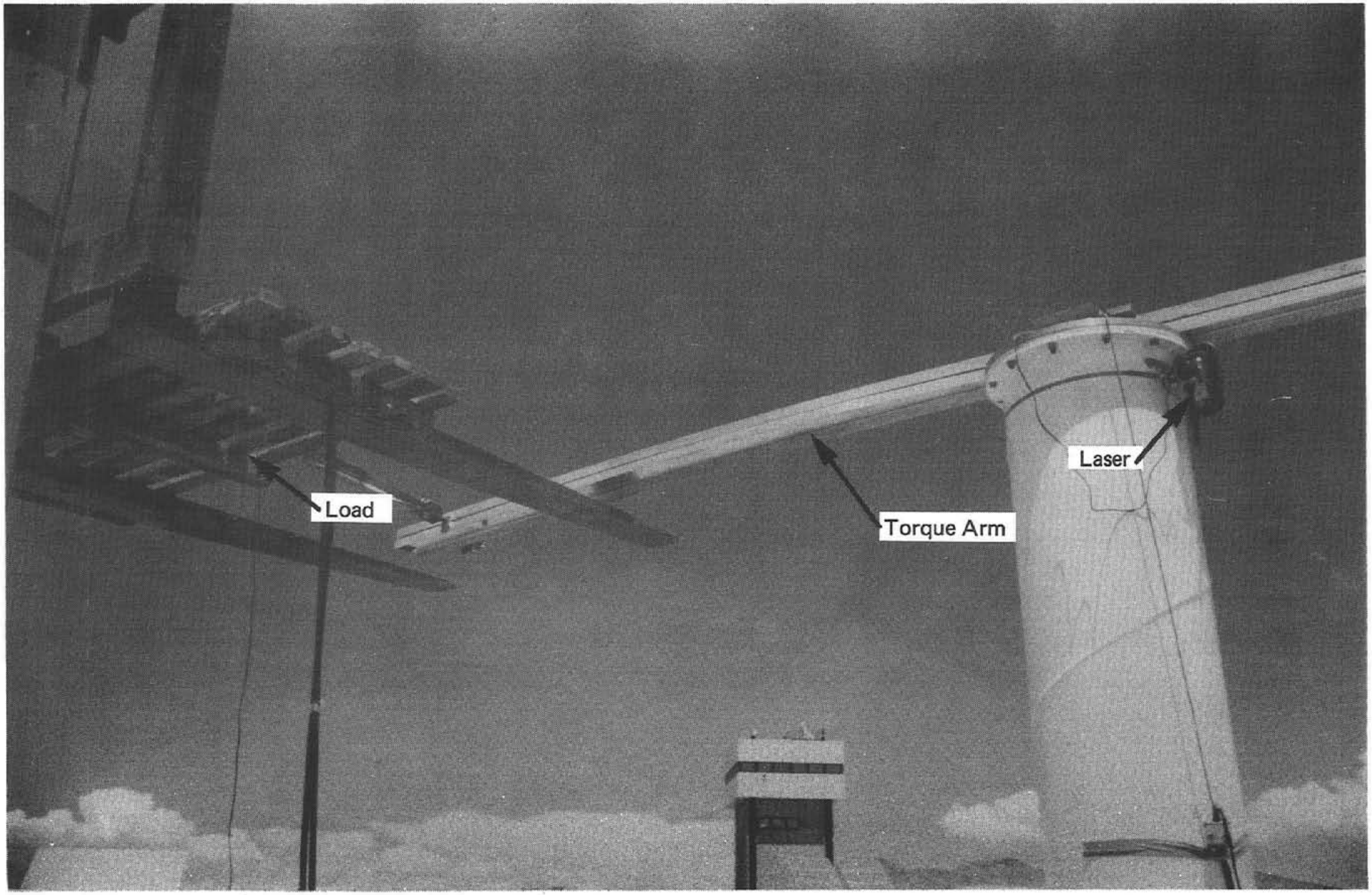


Figure 21. ARCO Pedestal Undergoing Bending/Torsion Test

load. Loads were released to zero before progressing to the next higher load. Deflections of the pedestal and foundation were measured at each load step and at zero load before applying the next higher load.

Hardware

The testing was performed on the prototype-2 heliostat foundation/pedestals following the disassembly of the heliostats at the conclusion of the life-cycle testing (see Appendix B, Section A, Test 11). In both the bending and combined bending/torison tests, loads were generated by a hydraulic actuator and were measured by an in-line load cell. Lasers were mounted to the pedestal at its top and base, and angular deflections were calculated from the deflection of the laser beams on a target approximately 150 ft away. The laser at the pedestal base was replaced by an inclinometer for increased resolution in the bending tests.

Test Results

A summary of the foundation/pedestal test results is given in Tables VII and VIII. Plots of the results of the testing are shown in Figs. 22-29. The foundation and pedestal deflections need to be added together to determine actual deflection at the top of the pedestal. All of the residual deflections measured at the intermediate zero load levels have been omitted from the figures for clarity, except for the final residual set which was measured at the end of the test series.

The ARCO-2 torsion test was halted after the deflections at 150% of the rated 50 mph wind load exceeded the measurement capability of the CRTF test equipment. The residual set after the 150% test was nearly 3.5 mrad. This twisting was expected, especially after twisting had been discovered during the motor torque testing.

The BEC foundation also exhibited significant twisting in the ground under torsional loads.

Conclusions

Both the ARCO and BEC foundations require increased torsional yield strength which could be provided by fins or grouting.

The lateral load capacities of all of these designs exceed the design requirements by at least a factor of two. These designs would meet the specification for heliostats twice as large or for 70 mph winds at the worst angle of attack. However, each contractor has stated that foundation design is site-specific. Soil conditions may affect size, and weather and available facilities may affect the type of foundation (e.g., precast or poured-in-place). Substantial savings may result from testing foundations installed at the actual site before full-scale installation commences.

TABLE VII

FOUNDATION TEST RESULTS
PERMANENT SET (MRAD) AFTER 50 MPH WIND LOAD

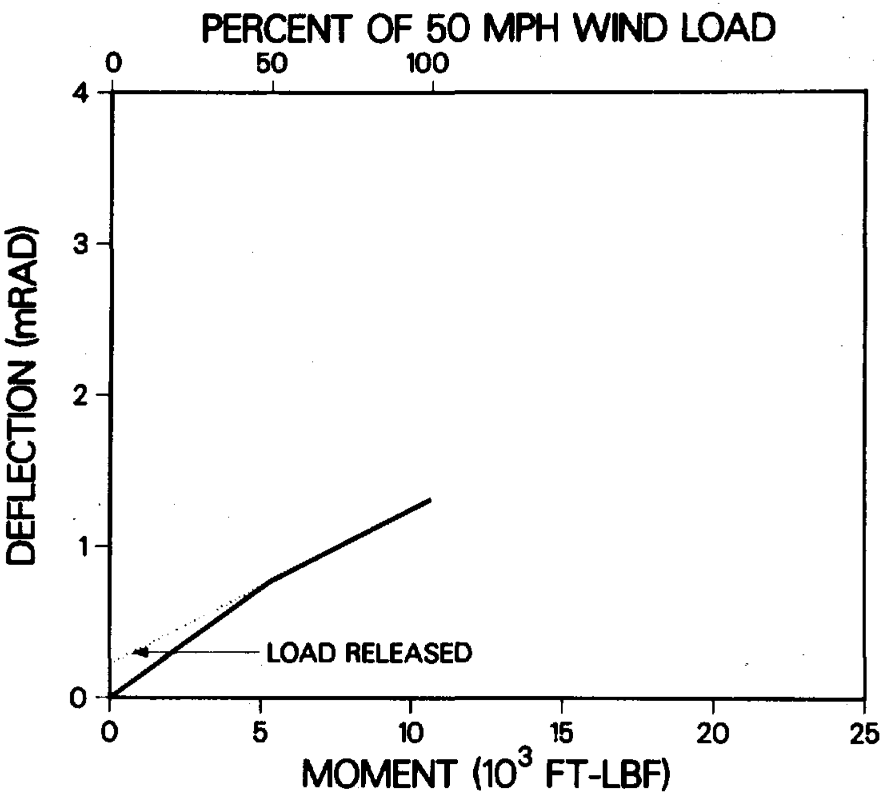
	Bending	Torsion
ARCO-2	0.0	2.1
BEC-2	0.0	0.4
MMC-2	0.0	0.0
MDAC-2	0.0	0.0

Specification: 0.45 mrad (maximum allowable)

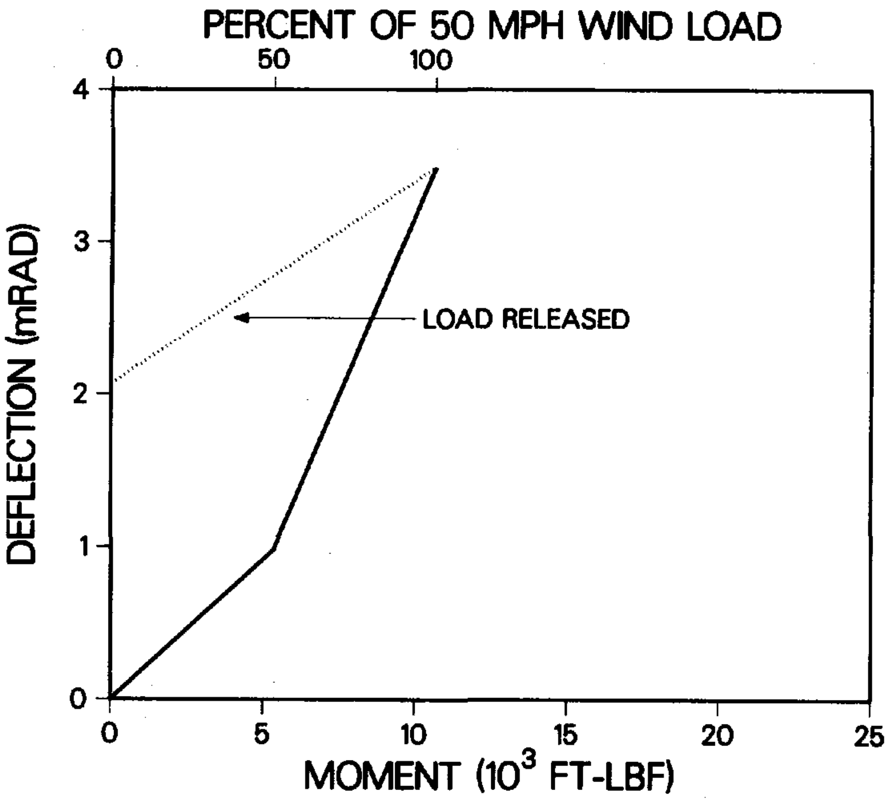
TABLE VIII

FOUNDATION TEST RESULTS
PERMANENT SET (MRAD) AFTER 200% OF 50 MPH WIND LOAD

	Bending	Torsion
ARCO-2	0.1	3.5
BEC-2	0.1	2.3
MMC-2	0.4 (0.0 @ 175%)	0.0
MDAC-2	0.7 (.1 @ 175%)	0.0

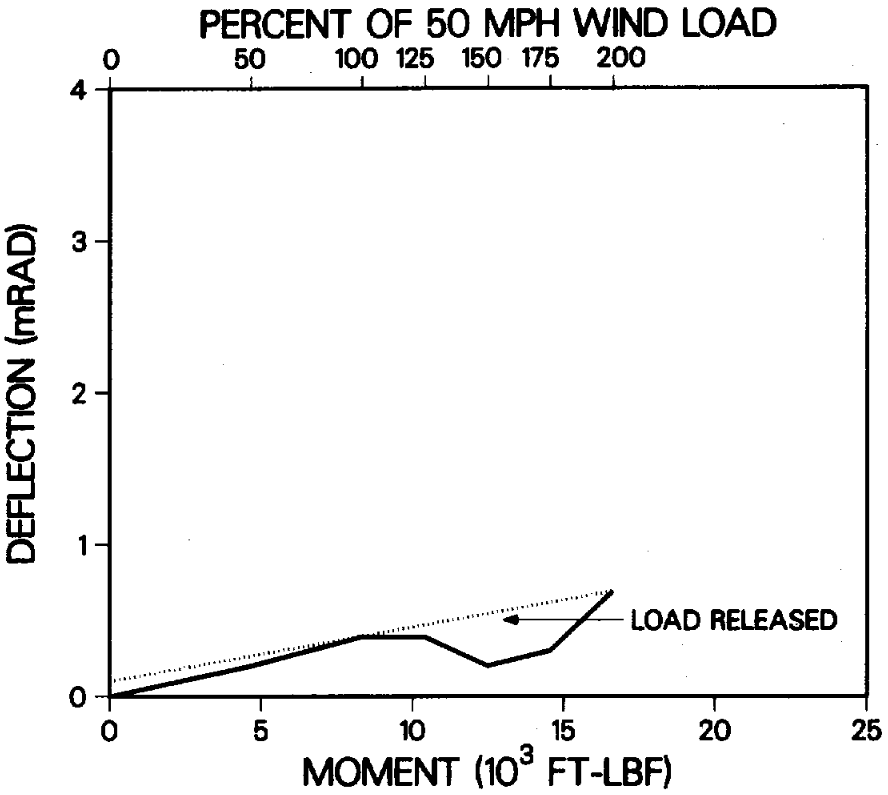


(22a) Pedestal

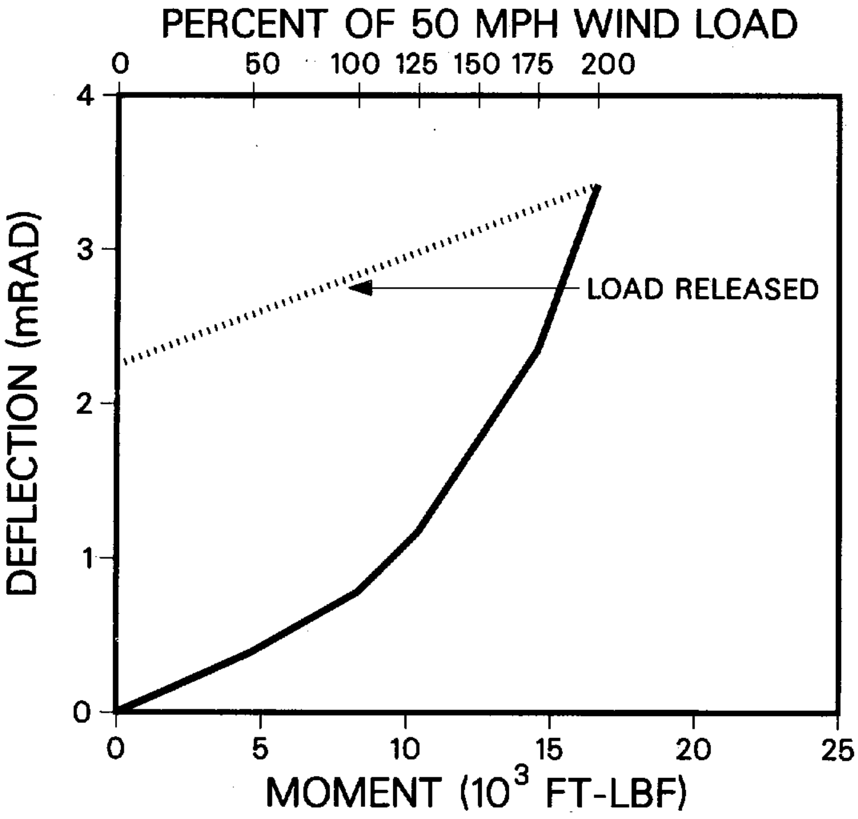


(22b) Foundation

Figure 22. ARCO Torsional Deflections

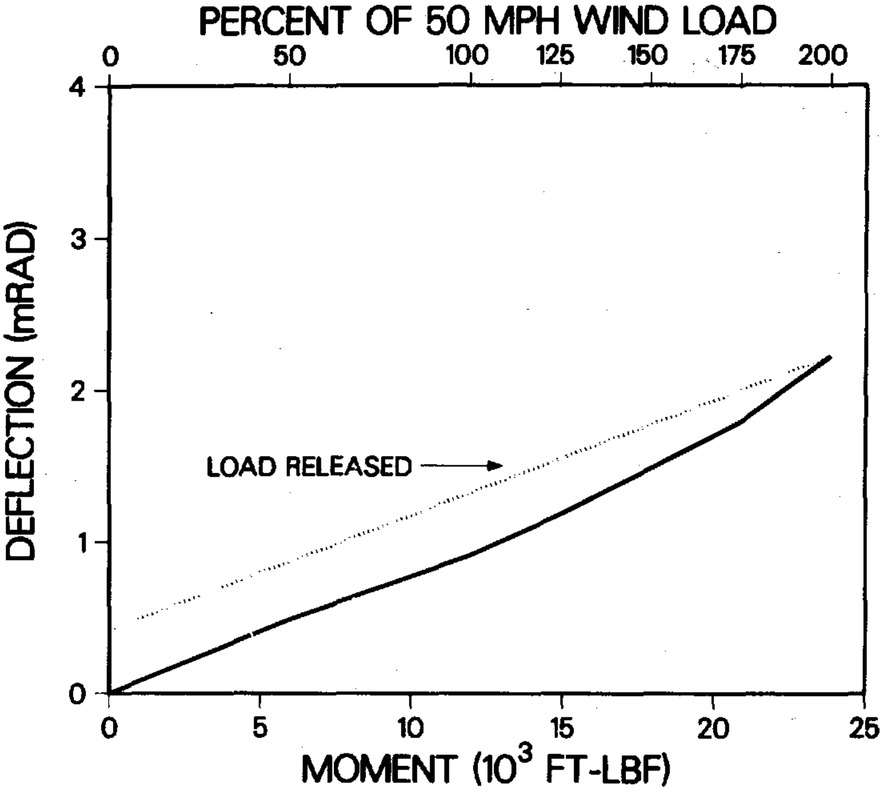


(23a) Pedestal

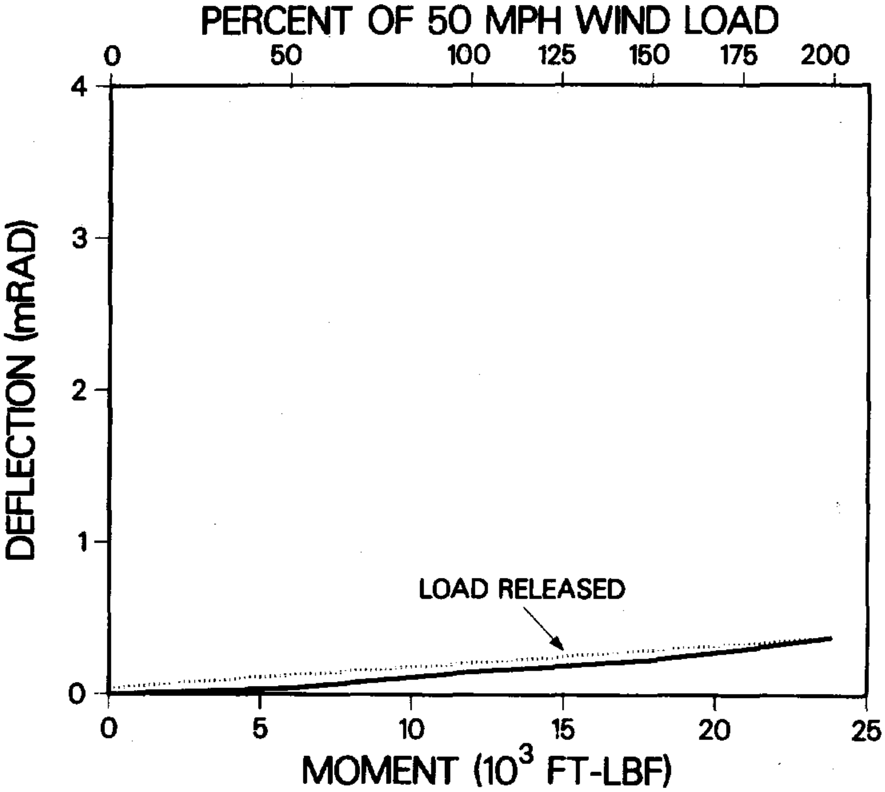


(23b) Foundation

Figure 23. BEC Torsional Deflections

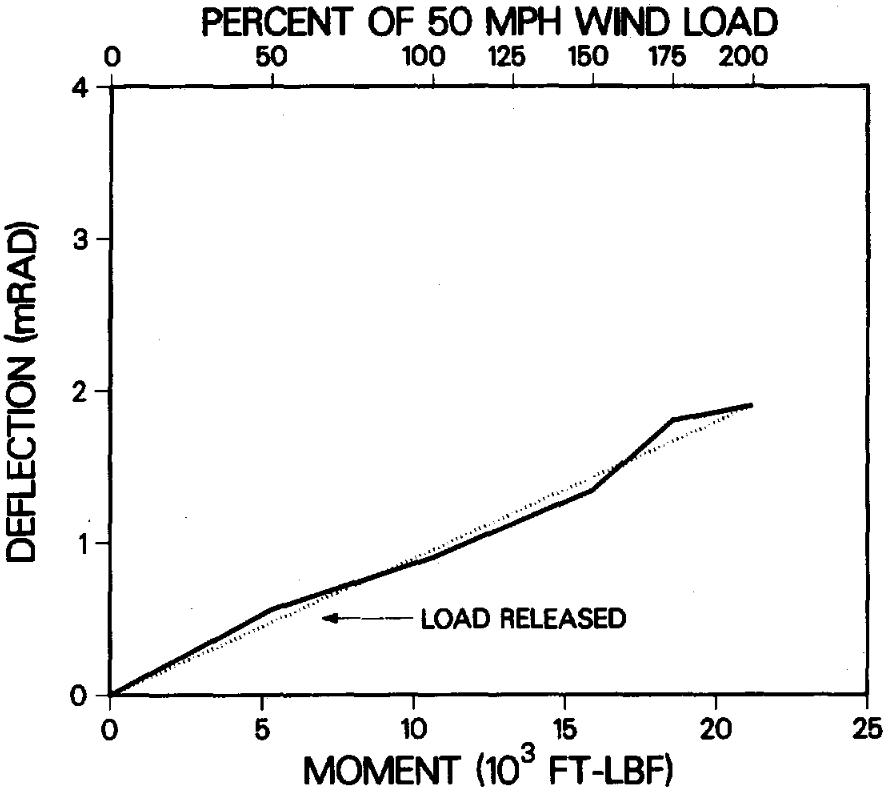


(24a) Pedestal

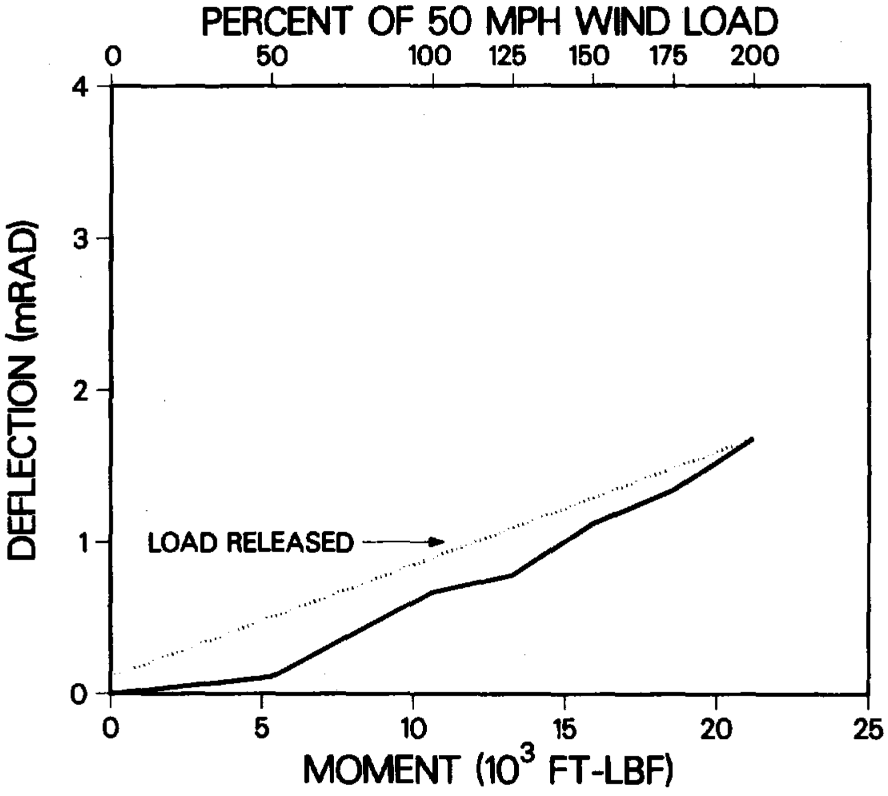


(24b) Foundation

Figure 24. MMC Torsional Deflections

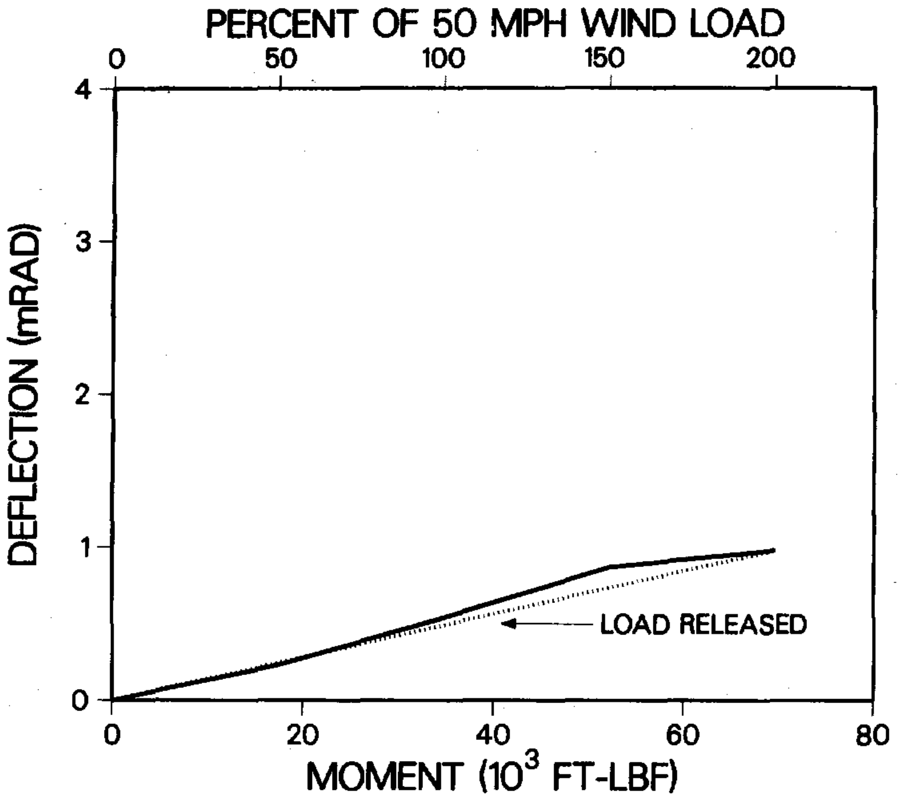


(25a) Pedestal

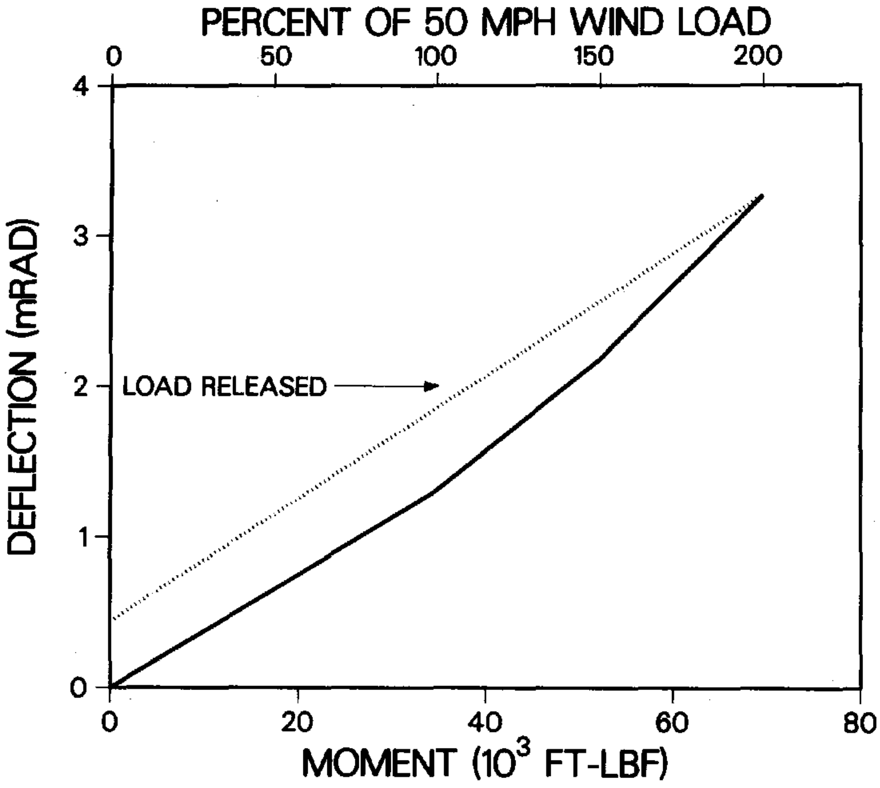


(25b) Foundation

Figure 25. MDAC Torsional Deflections

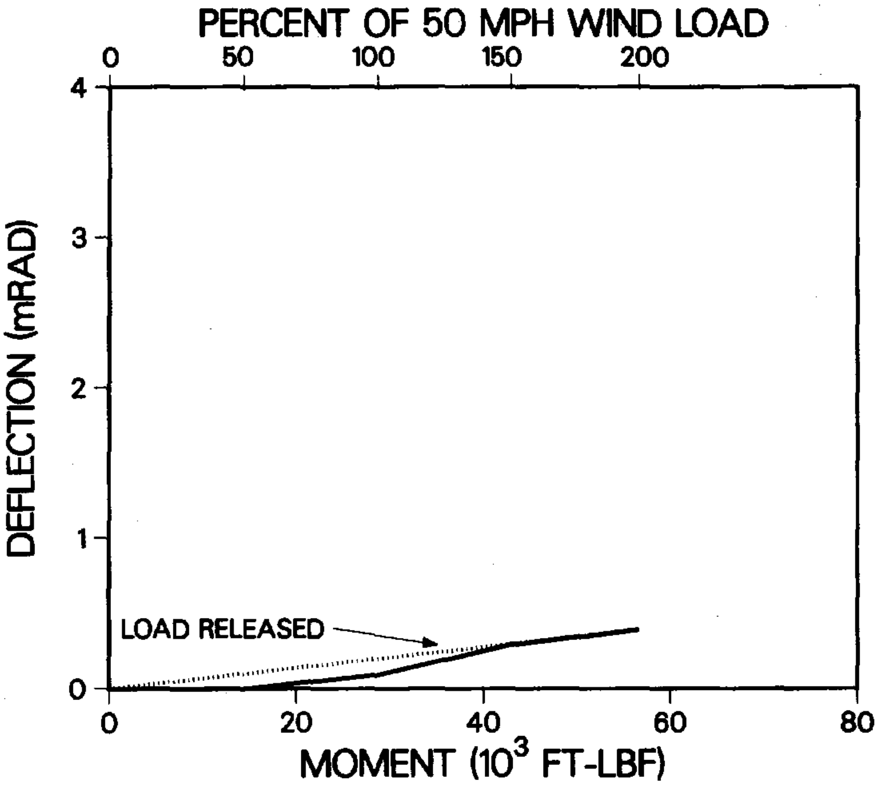


(26a) Pedestal

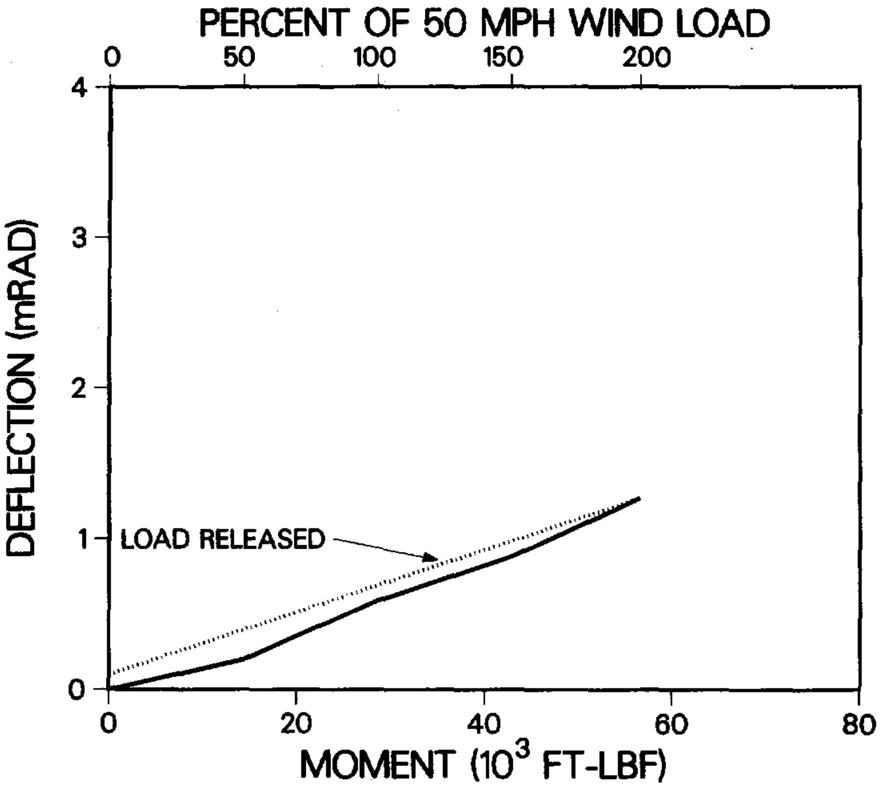


(26b) Foundation

Figure 26. ARCO Bending Deflections

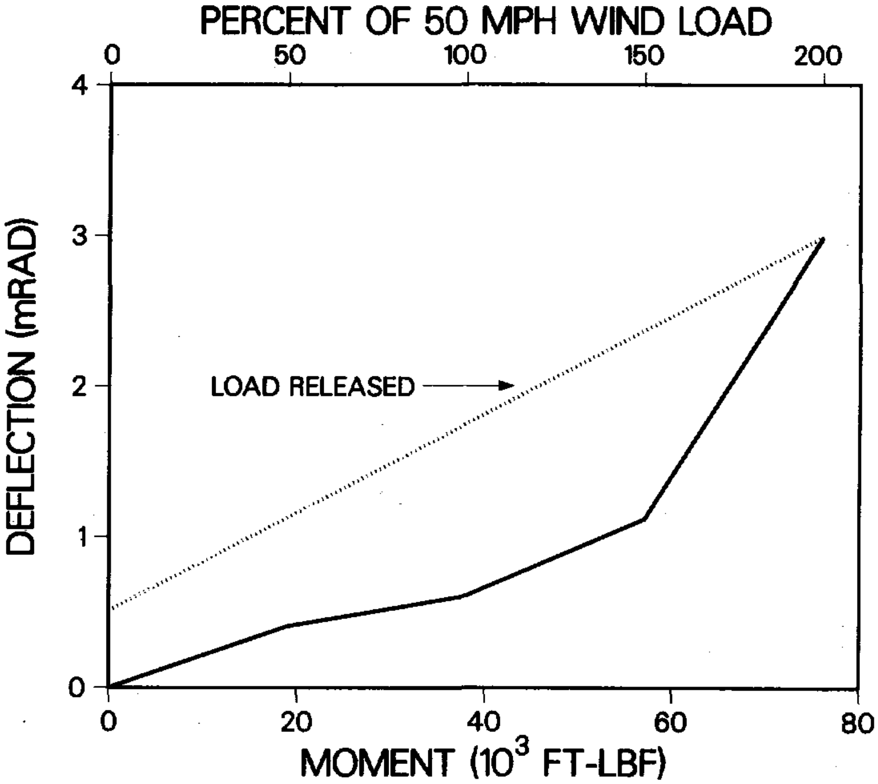


(27a) Pedestal

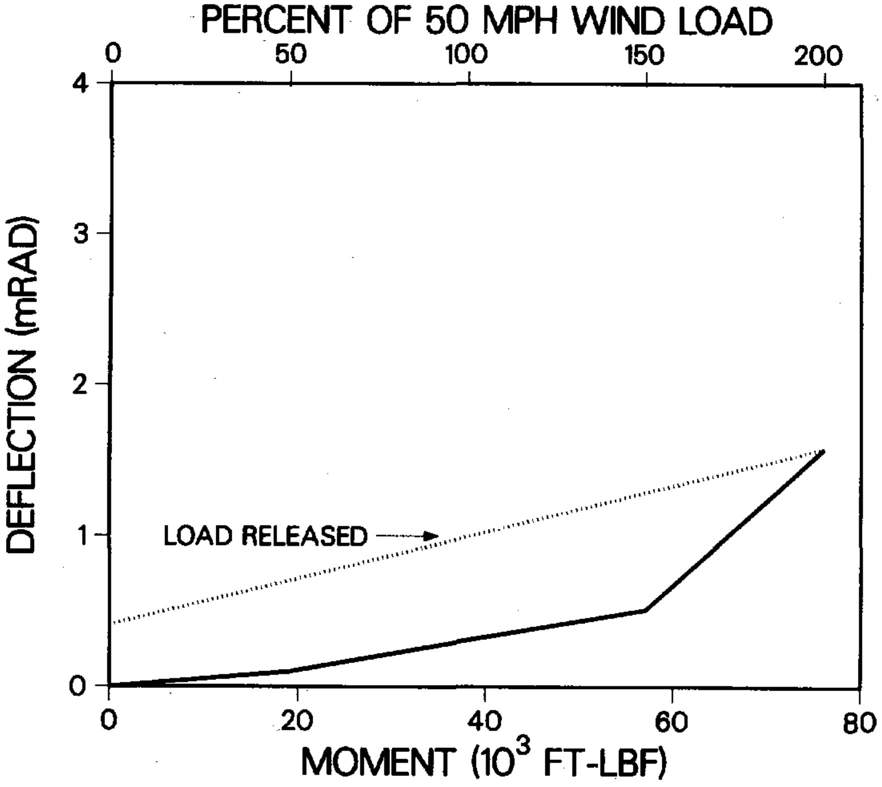


(27b) Foundation

Figure 27. BEC Bending Deflections

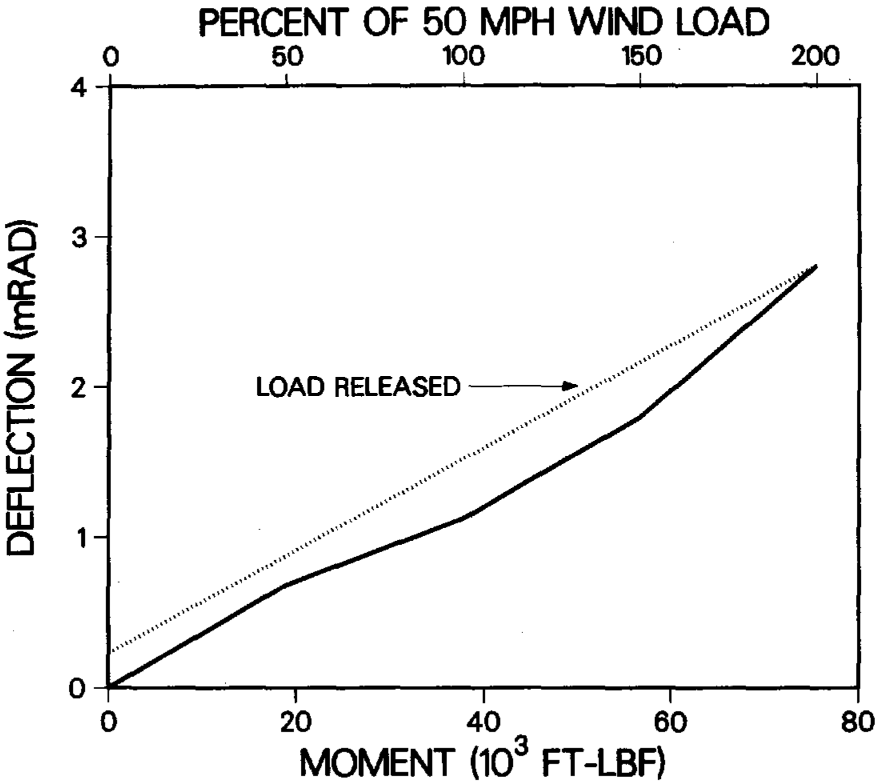


(28a) Pedestal

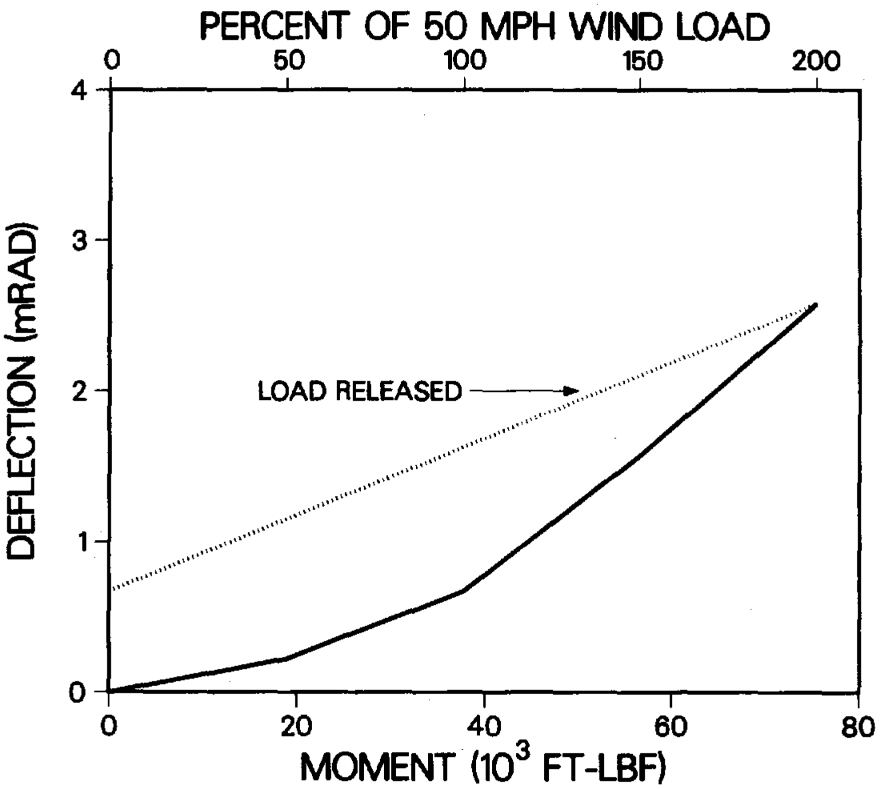


(28b) Foundation

Figure 28. MMC Bending Deflections



(29a) Pedestal



(29b) Foundation

Figure 29. MDAC Bending Deflections

Conclusions and Recommendations

The DOE Second Generation Heliostat Development Program produced four new heliostat designs which meet the structural and wind load requirements of the specification issued by Sandia National Laboratories. Sandia's conclusions and recommendations, based on testing, observations, and past experience, are as follows:

ARCO Power Systems

The stepper motors used on the ARCO prototype heliostats do not develop sufficient torque for meeting the design requirements. Stepper motors were originally selected by ARCO because of their fine resolution and precise positioning capability. Subsequent experience, however, showed that such resolution was not required for the high reduction ratio gearboxes. A simple design change to more conventional AC or DC motors would allow the ARCO heliostat to meet all of the drive speed and load requirements. (ARCO has, in fact, now modified its heliostat design and is manufacturing the design with DC motors. This modification has not been tested by Sandia.)

The hollow steel tube pedestal foundation, which was to be installed at the CRTF using a vibratory hammer, encountered installation difficulties because of rocks in the soil. Furthermore, it twisted in the ground during testing. Since foundation designs are site-specific, the type and size of the foundation and the procedures used for installation should be defined and tested for each heliostat field. A variety of foundation designs and installation procedures exist which can be easily and economically adapted to each design. This process will enable the heliostat to meet all foundation requirements. The difficulties encountered with ARCO's two foundations at the CRTF are not considered to compromise the ability of the overall heliostat design to meet the specifications.

Some problems arose during testing which are attributable to insufficient care during manufacturing and assembly. The improper tolerances and tooth profiles in the planetary gearboxes, and the inadequately torqued drive bolts which were found in these prototypes, are not inherent design flaws but emphasize the necessity for a high level of quality assurance and control. Even MMC and MDAC, with their previous experience in testing prototype and production heliostats, had assembly problems (notably loose bolts) which required correction. The necessity of adequate quality assurance and control, and the desirability of designs which minimize the potential for production and assembly errors, cannot be overemphasized.

Boeing Engineering and Construction

The BEC heliostats were the only design which did not suffer from assembly errors. However, they have many areas which can be improved to minimize assembly difficulties in high-volume production. The limit switches and encoders have not been well integrated into the drive design. The prototypes could be redesigned to eliminate many of the screwed or bolted connections such as the limit switches, covers, mirror mounts, and screwed or bolted connections such as the limit switches, covers, mirror mounts, and stiffeners. This would improve the manufacturability and quality of the product and reduce field maintenance.

The exposed polymer nut used in the elevation drive performed very well and showed virtually no wear after the testing, which included operating the drive through cycles that simulated two years of use. Sandia's confidence in the performance and lifetime of this novel design has greatly increased as a result of this testing.

The BEC foundation experienced installation problems similar to those of ARCO. The conclusions and recommendations concerning the ARCO foundations apply here as well.

Martin Marietta Corporation

The unique MMC stow-lock mechanism remains unproven under actual operating conditions. While the concept of removing high wind loads from the gear teeth appears very attractive, the performance of this specific mechanism under dynamic wind loads with production tolerances has not been tested. More detailed analysis and testing are required to verify the capabilities of the MMC stow-lock.

The MMC heliostats were tested using nonrepresentative motors. Simple load tests should be performed using production motors.

The comments directed at ARCO and BEC concerning proper quality assurance and quality control also apply to MMC.

McDonnell Douglas Astronautics Company

At the conclusion of testing, the MDAC design successfully completed all testing. However, improper assembly required one prototype to be dismantled early in the test program. The recommendations made to the other contractors regarding quality assurance and quality control can be repeated for MDAC.

APPENDIX A--COLLECTOR SUBSYSTEM REQUIREMENTS

FSCM NO. 14214
C.MAVIS,8451,x3031
C.LUNDBOM.8273
AS

A10772

COLLECTOR SUBSYSTEM REQUIREMENTS

Page	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Issue	D	C	C	C	C	C	C	C	C	D	C	C	C	C	C	C	C	C	C	C

Page	21	22	23	24	25
Issue	A	C	C	C	C

Design Agency Control Number	Issue	Release/Change No.	Date
	A		4-27-78
	B		10-12-78
	C		10-10-79
	D		12-11-79

TABLE OF CONTENTS

Table of Contents continued

1. GENERAL

1.1 Scope This specification establishes the performance, design, fabrication, construction, operation, maintenance and test requirements for a Central Receiver Collector Subsystem.

2. DOCUMENTS

The equipment, material, design, installation and checkout procedures, and construction of the Collector Subsystem shall comply with all Federal, State, Local, and user standards, regulations, codes, laws, and ordinances which are currently applicable for siting in TBD and to the using utility, the TBD Company. These shall include, but are not to be limited to, the documents itemized below. If there is an overlap in or conflict between the requirements of these documents and the applicable Federal, State, County, or Municipal codes, laws or ordinances, Sandia Laboratories will resolve the issue.

The following documents are in effect on the date of contract award and form a part of this specification to the extent specified herein. Conflict between the documents referenced herein and the contents of this specification are to be resolved by Sandia Laboratories.

2.1 Standards

MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-1472	Human Engineering Design Criteria
ANSI CI-1975	American National Standards Institute
ANSI A58.1-1972	Building Code Requirements for Minimum Design Loads in Buildings and other Structures

National Electrical Manufacturer's Association (NEMA) Standards

Manual of Steel Construction, 8th Edition, 1974, American Institute of Steel Construction

Uniform Building Code - 1976 Edition, Vol I by International Conference of Building Officials

National Electrical Code, NFPA 70-1975

Soil & Foundation Investigation Report, 5MW STTF,Sandia Labs

2.2 Other Publications.

"Wind Forces on Structures", ASCE Paper No. 3269, Transactions, American Society of Civil Engineers, Vol 126, Part II, 1961

Environmental Conditions (see Appendix 1)

3. REQUIREMENTS

3.1 Collector Subsystem Definition The Collector Subsystem is composed of an array of heliostats and supporting power and control elements which interact with the master control. The heliostat array reflects solar radiation onto the elevated absorber (boiler/superheater) of the receiver system in a manner which satisfies receiver incident heat flux requirements. Deviations from this specification are acceptable, with sufficient justification, to improve performance and/or reduce cost. Performance shall be on an annual energy basis and costs include initial capital costs as well as operations and maintenance costs.

The Collector Subsystem components are:

a. Heliostats

1. Mirror modules

   Reflector
   Mirror Support

2. Structural support including foundation and protective enclosure if applicable

3. Drive units

4. Control sensors

5. Pedestal and mounting interface

6. Heliostat cabling

   Power
   Signal

b. Heliostat Controllers

1. Controller

2. AC/DC power supplies

3. AC motor control electronics

3.1 continued

c. Heliostat Array Controller (HAC)

1. Master control interface including electronics
2. Main and backup computers
3. Time base
4. Beam characterization system interface including electronics
5. Software

d. Heliostat Field Controllers (HFC)

1. Controller
2. AC/DC power supplies
3. Heliostat Controller interface including electronics
4. Heliostat array controller interface including electronics
5. Software

e. Support Equipment and Procedures

1. Alignment
2. Washing
3. Operation and Maintenance
4. Installation and Removal

3.1.1 Collector System Diagram Figure 1 represents one possible heliostat configuration. Figure 2 shows a possible collector field control configuration and interfaces and Figure 3 shows a block diagram of the control system and interfaces. Other heliostat configurations and field control systems are not precluded by this specification. Other configurations and control systems are encouraged if the total collector field annual cost/performance is improved

3.1.2 Interfaces

3.1.2.1 Collector/Physical Site The physical arrangement, outer boundaries of the array of heliostats, the foundations, and field power and control wiring shall be supplied as part of the collector subsystem.

3.1.2.2 Collector/Receiver Subsystem The Collector Subsystem shall concentrate the redirected energy onto the receiver. The receiver is a vertical cylinder approximately 12.0 m (39.4 ft) in diameter and 12 m (39.4 ft) high and the center is 140 m (459 ft) above ground level.

3.1.2.3 Collector/Plant Power Uninterruptible plant power is to be supplied to the heliostat array controller, heliostat field controllers, and each heliostat junction box.

3.1.2.4 Heliostat Array Controller (HAC)/Master Control System (MCS). HAC shall be configured such that the MCS can automatically achieve intergrated control of, and alarm the Collector Subsystem. The overall interface signals for plant operation are as follows:

Control Commands
Operational Data Requests
Operational/Alarm Data Outputs

3.1.2.5 Heliostat Array Controller (HAC)/Data Acquisition System (DAS). The DAS will perform the data collection function for evaluation of the plant system. The evaluation interface signals for the plant are as follows:

Evaluation Data Requests
Evaluation Data Outputs

Each of these sets of signals in 3.1.2.4 and 3.1.2.5 is further designated as either continuous (i.e., automatically generated at regular preprogrammed intervals) or on-demand by an operator (i.e., issued upon request or over selectable intervals). Error checking shall be employed in all message transfers.

3.1.2.6 Heliostat Array Controller (HAC)/ Beam Characterization System (BCS). The HAC shall provide heliostat data, control, and positioning required for beam characterization. The HAC initiates beam characterization by directing a heliostat to focus on the BCS target. The BCS will be commanded to execute data acquisition and return beam centroid location to the HAC. Additional measurements will be made as needed to resolve all tracking error terms. In cases of large errors, the HAC will be requested by the BCS to adjust the heliostat alignment to bring the heliostat on target.

3.2 Specifications

3.2.1 Performance In order to attain overall plant field performance such that 95% of the redirected energy will impinge on the receiver with an incident angle of less than 60°, the following requirements have been established for designing and evaluating individual heliostats.

a. Maximum beam pointing error (tracking accuracy) shall be limited to 1.5 mrad standard deviation for each gimbal axis under the following conditions:

- Wind - none
- Temperature - 0° to 50°C (32° to 122°F)
- Gravity Effects - at all elevation and azimuth angles that could occur in a heliostat field
- Azimuth Angles - at all angles except during gimbal lock
- Sun Location - at least .26 rad above horizon, any time of year
- Heliostat Location - any position in the field

Pointing error is defined as the difference between the aim point and measured beam centroid for all of the above conditions for any tracking aim point (on target or at standby).

b. Beam quality shall be such that a minimum of 90% of the reflected energy at target slant range shall fall within the area defined by the theoretical beam shape plus a 1.4 mrad fringe width. Heliostat beam quality shall be met throughout 60 days without realignment. Beam quality requirements are applicable under the following conditions.

- Wind - none
- Temperature - 0° to 50°C (32° to 122°F)
- Gravity Effects - at all elevation and azimuth angles that could occur in a heliostat field
- Sun Location - at least .26 rad above horizon, any time of year
- Heliostat location - any position in the field and any slant range.

3.2.1b continued

- Operating Mode - tracking on plant receiver
- Facet Alignment - as planned for the plant
- Theoretical Beam Shape - the theoretical beam contour, determined by HELIOS, is the isoflux contour that contains 90% of the total power. This isoflux contour will be increased by 1.4 mrad fringe. The HELIOS computer code is available through Sandia.

c. Overall structural support shall limit reflective surface static deflections to an effective 1.7 mrad standard deviation for a field of heliostats in a 12 m/s (27 mph) wind.
Wind deflections of the foundation, pedestal, drive mechanism, torque tube, and mirror support members shall be included, but not the slope errors due to gravity and temperature effects. Wind deflection limits apply to the mirror normal (not reflected beam) for each axis fixed in the reflector plane. Both beam quality and beam pointing are affected.

To assure that the net slope errors of a field of heliostats is less than 1.7 mrad, the rms value of the slope errors taken over the entire reflective surface of an individual heliostat, computed under the worst conditions of wind and heliostat orientation (but excluding foundation deflection), shall be limited to 3.6 mrad for a single heliostat. This limit represents a 3-sigma value for the field derived by subtracting foundation deflection (see 3.2.1.d) from the total surface slope error (1.7 - .5 = 1.2 mrad standard deviation x 3 = 3.6 mrad 3-sigma). The conditions under which this requirement applies are:

- Wind, including gusts - 12 m/s (27 mph) at 10 m (33 ft) elevation
- Temperature 0° to 50°C (32° to 122°F)
- Heliostat Location - any position in the field at any time of the year
- Gravity Effects - not included
- Mirror Module Waviness - none
- Facet Alignment Error - none

3.2.1 continued

d. The allowable tilt and/or torsional rotation of a heliostat foundation shall not exceed ± 1.5 mrads total angular deflection per axis, when the heliostat is subjected to a 12 m/s (27 mph) operational wind load. This total deflection shall, in addition to elastic response, include the amount of plastic or permanent deflection, including any wobble (looseness) resulting from a prior 22 m/s (50 mph) wind experience. The allowable plastic or permanent deflection of the foundation resulting from a 22 m/s (50 mph) wind load shall not exceed ± 0.45 mrads.

Both deflection allowances are 3-sigma limits expressed for a single heliostat/foundation field position, and are computed under the worst condition of wind and heliostat orientation. For a full field of heliostat foundations, the effective limits will result in a standard deviation or 1/3 of the deflection allowances specified for a single foundation.

The deflections specified are applicable at the foundation-to-heliostat interface located on a plane parallel to and approximately 50.8 mm (2 inches) above the pier concrete surface, which is represented by the underside of the heliostat pedestal mounting flange. If there is no foundation-to-heliostat interface as described above, an imaginary interface shall be defined by a horizontal plane that is approximately 150 mm (5.91 inches) above ground.

Trade-offs among the above requirements relative to to a proposed heliostat configuration must be coordinated with and approved by Sandia.

Standard deviation as used in these requirements shall be determined from a sample of at least 20 data points from each individual heliostat tested.

3.2.2 Operation Operational control requirements are as follows:

a. The Collector Subsystem shall function as appropriate for all steady-state modes of plant operation. This shall include the capability of controlling the number of heliostats in tracking mode so as to vary the redirected flux to the receiver between zero and the maximum achievable level with step changes no larger than ten percent of the total collector field output.

3.2.2 continued

b. Drive systems must be capable of positioning a heliostat to stowage, cleaning, or maintenance orientation from any operational orientation within 15 minutes.

c. Elevation and azimuth drives shall not drift from last commanded positions due to environmental loading.

d. Drive systems must be capable of resolving south field control singularity (i.e., "over-the-shoulder" limits or gimbal lock) within 15 minutes.

e. Drive system shall provide for cost effective stowage of the reflective surface to minimize reflected beam safety hazards and dust or dirt build-up on the mirrors. Heliostat orientation shall be available to master control at all times. Calculated gimbal angles are acceptable, orientation sensors are not required.

f. Heliostat control shall be by computer. Control functions shall be accomplished as follows:

Heliostat Array Controller (HAC) shall:

Initiate operational mode commands to HFC
Address commands to HFC groups or individual HC
Respond to MCS commands and requests
Interface with beam characterization system
Provide time base

Heliostat Field Controller (HFC) shall:

Determine individual heliostat azimuth and elevation position requirements
Transmit position requirements to HC
Transmit status and data to HAC
Initiate safe stowage command upon loss of HAC communication
Control groups of HCs

Heliostat Controller (HC) shall:

Control drive motors
Provide heliostat axis position data to DAS

3.2.3 Safety Operational safety requirements are as follows:

a. The Collector Subsystem shall be capable of emergency defocusing upon command to reduce peak incident radiation on the receiver to less than 3% of initial value within 120 seconds.

3.2.3 continued

b. Heat fluxes on tower and normally unirradiated portions of the Receiver Subsystem are limited to (25) kW/m^2 (7880 BTU/FT^2 hr).

c. Beam control strategy and equipment will protect personnel and property within and outside the plant facility including air space.

3.2.4 Maintainability The collectors will be designed so they require a minimum of routine field maintenance, with the exception of periodic washing.

The Collector Subsystem shall be designed to report any subsystem malfunctions at the HAC console and provide fault isolation information on critical components. Critical components are those components that, because of failure risk, downtime, or effect on overall plant performance, materially affect the system availability, or the system safety with respect to the reflected beam in the surrounding air space or on the ground.

3.2.5 Physical Characteristics The Collector Subsystem detailed design shall be based on the following basic configuration:

a. Reflective surface of most cost effective area and reflectivity.

b. Local override of heliostat controller and ability to stow without use of heliostat drive motors.

c. Environmentally sealed drive systems.

d. Corrosion protection of all parts.

3.2.6 Environmental Design Conditions "Environmental Conditions" (Appendix 1) describes representative site conditions to be encountered and survived by the Collector Subsystem. The Collector Subsystem must maintain structural integrity in any applicable combination of the environments.

3.2.6.1 Wind Loading The natural wind environment specified produces a vibratory response both from the oscillatory nature of the gusts and from periodic vortex shedding. The Collector Subsystem shall be designed to withstand, and/or operate when subjected to, the loads produced by this vibration. The actual loads must be computed taking into account structural configuration and dynamic characteristics, and the velocities of the winds.

3.2.6.1 continued.

In computing the angle between the wind direction and the plane of the heliostat reflective surface, the wind shall be assumed to deviate by up to, plus or minus 10° from the horizontal.

3.2.6.2 Operational Limits The Collector Subsystem must meet performance requirements for the following conditions unless the component is located in a controlled environment (building).

Environment	Level
Wind, including gusts	12 m/s maximum (27 mph)
Temperature	0 to 50°C (32 to 122°F)
Gravity	All elevation angles

To achieve morning operational position or evening stow position, the heliostat will be required to function with ambient temperatures down to -9°C (16°F) and component temperatures that are colder or hotter than ambient temperatures due to thermal lag and/or absorption of direct insolation.

3.2.6.3 Stowage Initiation The heliostats will continue to track the target with wind speeds up to 16 m/s (35 mph),but with degraded performance allowed, above which stowage action will be initiated as a result of an externally provided signal. The heliostat must maintain structural integrity in a non-operational state in a 22 m/s (50 mph) wind in any orientation.

3.2.6.4 Hail The heliostat, in any orientation, must survive 19 mm (0.75 inch) diameter, 0.9 specific gravity, hail impacting at 20 m/s (65 ft/s). The temperature of simulated hail shall be -6.7°C (20°F) for all tests.

Heliostat may be in stowed position to survive hail conditions cited in Appendix 1, Environmental Conditions.

3.2.6.5 Lightning The Collector Subsystem shall have lightning protection consistent with the following guidelines:

Direct Hit	Total destruction of a single heliostat and its controller subjected to a direct lightning strike is acceptable.

Adjacent Strike	Damage to a heliostat adjacent to a direct lightning strike should be minimized within appropriate cost-risk limits.
Controller	The HACs, HFSs, and HCs adjacent to a direct lightning strike must be protected.

For design purposes, the maximum current in a lightning strike shall be limited to 200,000 amperes.

3.2.7 Transportability Collector Subsystem components or assemblies shall be designed for transportability by highway handling equipment within applicable Federal and State regulations.

3.3 Design and Construction Commercial design and construction standards shall be employed. Where applicable, the Uniform Building Code (1976 edition) and the American Institute of Steel Construction's Manual of Steel Construction (8th edition) shall be used. ANSI A58.1 1972 and ASCE paper No. 3269, Wind Forces on Structures (ASCE Transactions, Vol 126, Part II, 1961) shall be used during design when determining loading due to winds. For electrical components, the National Electrical Code (ANSI C1), the National Electrical Manufacturer's Association (NEMA) and MIL-STD-454 standards for electronic equipment shall be used.

Design and material selection is to be based on a 30-year plant life.

3.3.1 Materials, Processes, and Parts To the maximum extent possible, standard materials and processes, and off-the-shelf components shall be used. Wherever possible, commercial specifications shall be employed. All non-commercially available parts shall be defined and documented in deliverable documents.

3.3.2 Electrical Transients The HAC is expected to tolerate power transients which are commercially acceptable to the HAC purchased equipment suppliers.

The heliostat field controller (HFC) and heliostat controllers (HC) shall operate through the following power transient conditions:

a. Increasing Transient - one cycle of the fundamental frequency at 1.7 PU voltage followed by an expoental decay back to the original voltage in 5 cycles.

3.3.2 continued

b. Decreasing Transients - A voltage dropout (zero volts) for 3 cycle maximum of the fundamental frequency.

3.3.3 Electromagnetic Radiation The Collector Subsystem control wiring shall be designed to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference.

3.3.4 Flammability In a high temperature, low humidity environment of a typical desert, the heliostat field shall not be vulnerable to extensive fire damage.

Given that a fire exists in any part of the heliostat field, the fire should not damage any heliostats, that are not directly adjacent to the fire, due to burning of a heliostat or any heliostat wiring. If a heliostat or any part of a heliostat burns, for any reason, the heliostat fire should not spread to other parts of the field due to blowing winds, component explosions, or any other means.

3.3.5 Nameplates and Product Marking All major elements and assemblies shall be labeled with a permanent nameplate listing, as a minimum: manufacturer, part number, serial number, and date of manufacture.

3.3.6 Workmanship The level of workmanship shall conform to practices defined in the codes, standards, and specifications applicable to the plant site and the using utility. Where specific skill levels or certifications are required, current certification status shall be maintained with evidence of the status available for examination. All work shall be finished in a manner that presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a uniform appearance.

3.3.7 Interchangeability Items with a common function shall have a common part number and be interchangeable. Components with similar appearance, but different functions, shall incorporate protection against inadvertent erroneous installation. Heliostats do not need to be interchangeable within the array; however, the number of non-interchanceable types shall be limited to the most economic choice.

3.3.8 Safety The Collector Subsystem shall be designed to minimize safety hazards to operating and service personnel, the public, and equipment. Electrical components shall be insulated and grounded. All components with elevated temperatures shall be insulated against contact

3.3.8 continued

with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements, and safety override controls/interlocks shall be provided for servicing.

3.3.9 Human Engineering The Collector Subsystem shall be designed to facilitate manual operation, adjustment, and maintenance as needed and provide the optimum allocation of functions between personnel and automatic control. The Collector Subsystem design shall provide electrical and electronic packaging which ensures rapid repair and replacement, placarding of hazardous work areas, and equipment for item removal and handling. MIL-STD-1472, Human Engineering Design Criteria, shall be used as a guide in designing equipment.

3.4 Documentation

3.4.1 Characteristics and Performance Equipment functions, normal operating characteristics, limiting conditions, test data, and performance curves shall be provided for inclusion in overall plant design description.

3.4.2 Instructions Instructions shall cover assembly, installation, alignment, adjustment, checking, lubrication, maintenance, and operation of the Collector Subsystem. All instructions shall include reference to applicable system engineering data and guides to troubleshooting instruments and controls. All phases of Collector Subsystem operation shall be addressed, including start-up, normal and synthetic tracking operation, on-line and off-line maintenance, shut down, contingency operation, and emergency operations.

3.4.3 Construction Engineering assembly and installation drawings shall be provided to show the equipment construction, including assembly and disassembly procedures. Engineering data, wiring diagrams, and parts lists shall be provided.

3.4.4 Format. Plant documentation (drawing, specifications, instructions, etc.) shall be compatible with Southern California Edison Format. (Format to be provided by Sandia.)

4. QUALITY ASSURANCE PROVISIONS

Contractor's efforts and products shall be governed by an approved quality assurance plan.

4.1 General Requirements Quality assurance activities shall be conducted in accordance with a plan to be prepared by the contractor and approved by Sandia.

4.2 Responsibility The Contractor shall participate in all quality assurance activities. These activities may be witnessed by Sandia or its representatives or the witnessing may be wavied. In either case, substantive evidence of hardware compliance with all requirements is required.

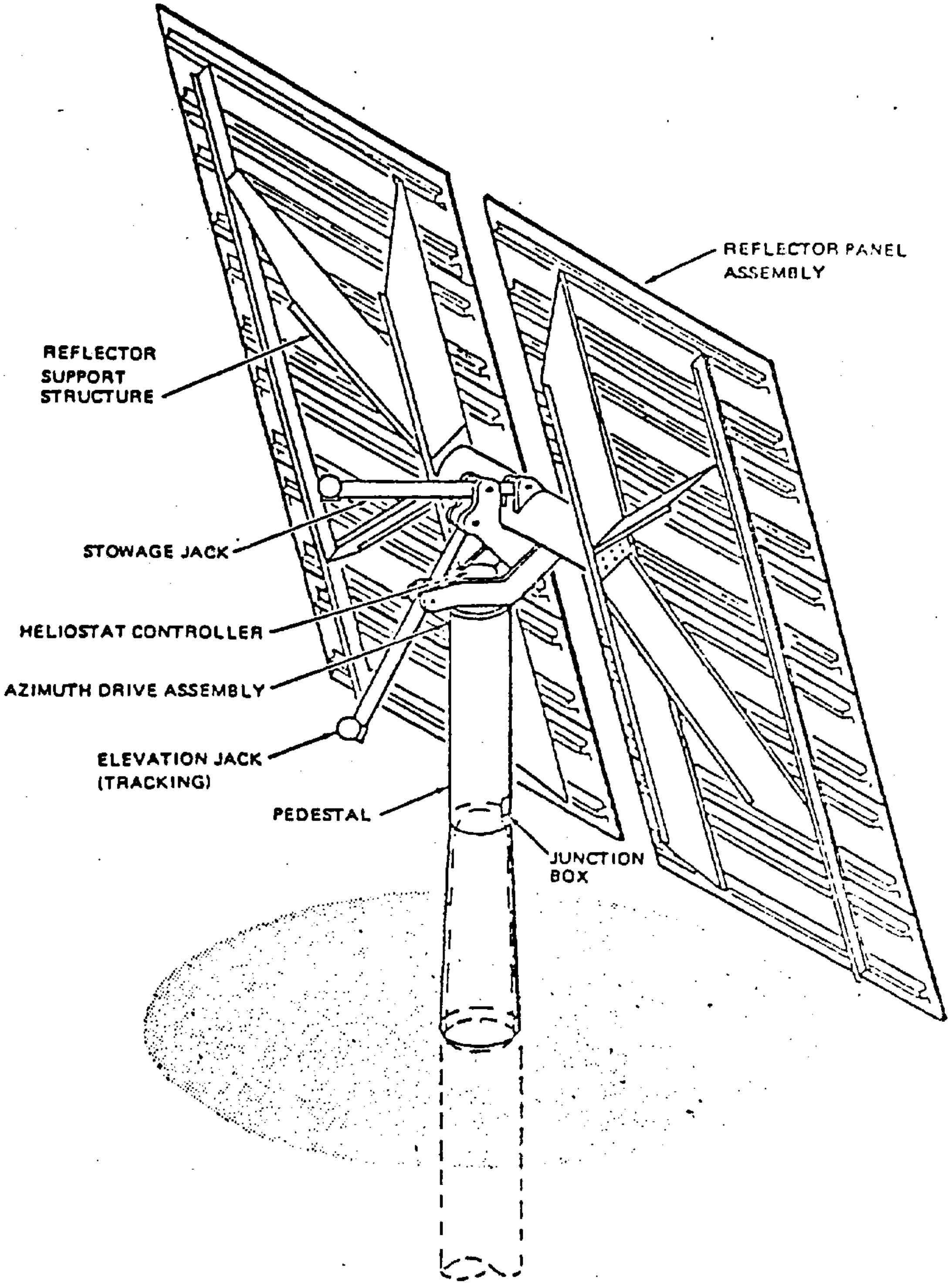


Figure I. Heliostat Configuration

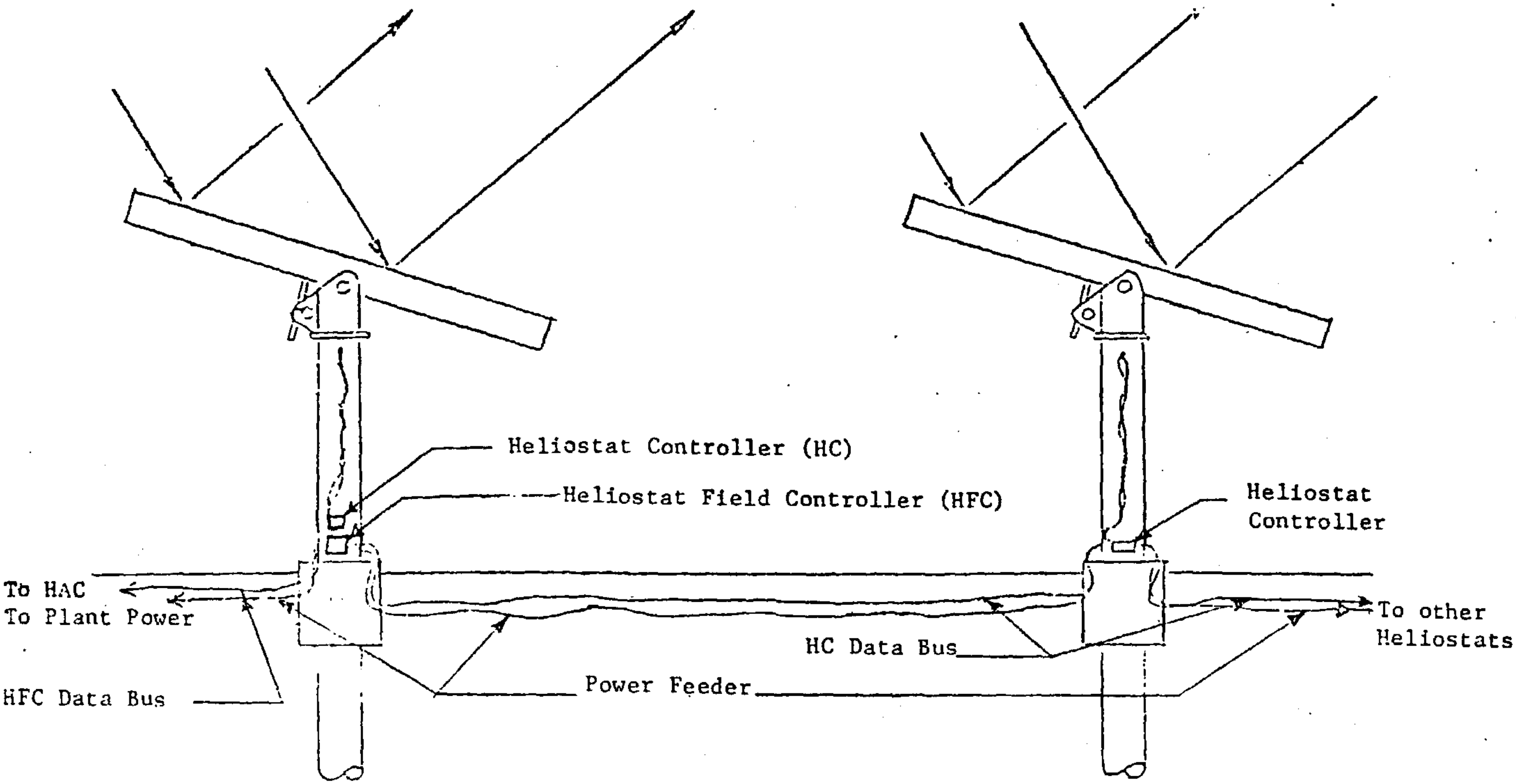


Figure 2. Heliostat Field Control Configuration

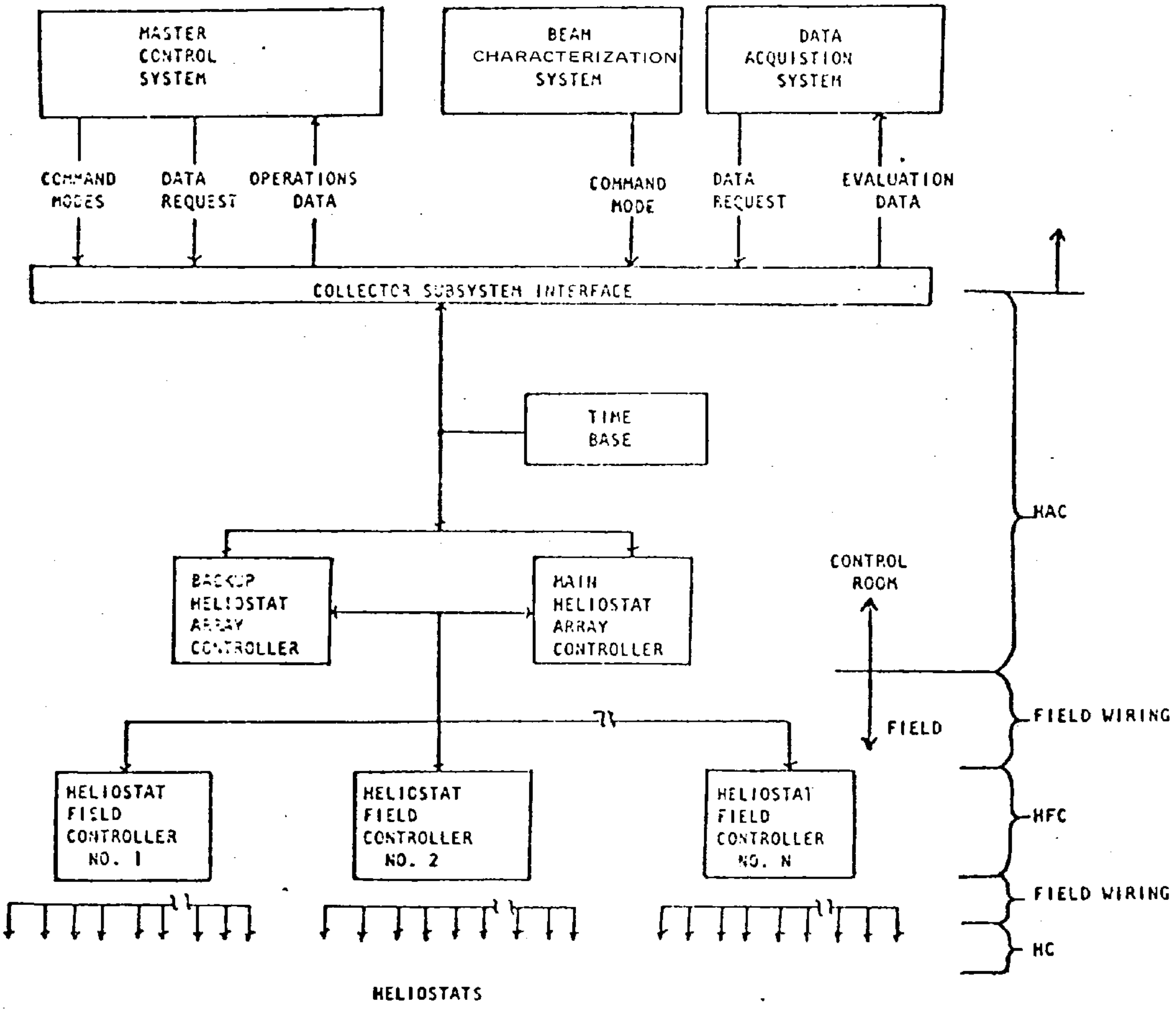


FIGURE 3 - PILOT PLANT COLLECTOR SUBSYSTEM CONTROL AND INTERFACE

APPENDIX 1 - ENVIRONMENTAL CONDITIONS

1. GENERAL

1.1 Scope This document lists representative environmental conditions for a Solar Central Receiver Plant.

2. DOCUMENTS

The following documents for a part of this specification to the extent stated herein.

MIL-STD-810B	Environmental Test Methods

Uniform Building Code - 1976 Edition, Volume 1 by International Conference of Building Officials

3. ENVIRONMENTS

Environmental conditions include winds and gusts, temperature extremes, rain, sleet, hail, snow, earthquake and soil conditions as follows:

3.1 Wind The wind speed specifications during daylight hours at a reference height of 10m (30 ft) shall be:

3.1.1 Speed Frequency

Speed, m/s	(mph)	Frequency, Percent
0-2	(0-4.5)	29
2-4	(4.9-9.0)	21
4-6	(9.0-13.5)	19
6-8	(13.5-18.0)	14
8-10	(18.0-22.5)	8
10-12	(22.5-27.0)	5
12-14	(27.0-31.5)	3
14-	(31.5-)	Less than 1

For the calculation of wind speed at other elevations, assume the following model:

$$V_H = V_1 (H/H_1)^c$$

Where: V_H = wind velocity at height H
V_1 = reference wind velocity
H_1 = reference height (assume 10 m (30 ft)
$c = 0.15$

3.1.2 Wind Rise Rate Under normal conditions, the maximum wind rise rate is 0.01 m/s^2 (0.02 mph/s). A maximum wind of 22 m/s (50 mph) from any direction may occur resulting from unusual rapid wind rise rates, such as severe thunderstorm gust fronts.

3.1.3 Survival Wind A maximum wind speed, including gusts, of 40 m/s (90 mph).

3.1.4 Dust Devils Dust devils with wind speeds up to 17 m/s (38 mph).

3.1.5 Sandstorm Environment Sandstorm limits within tests per MIL-STD-810B, Method 510.

3.2 Temperature Ambient air temperatures range from -30 to +50°C (-22 to +122°F).

3.3 Precipitation

3.3.1 Rain Average annual: 750 mm (30 in) maximum 24-hour rate: 75 mm (3 in).

3.3.2 Ice Freezing rain and ice deposits in a layer up to 50 mm (2 in) thick.

3.3.3 Hail

Diameter	25 mm (1 in)
Specific Gravity	0.9
Terminal Velocity	23 m/s (75 ft/s)
Temperature	-6.7°C(20°F)

3.3.4 Snow Maximum 24-hour rate: 0.3m (1 ft); maximum loading: 250 Pa (5 lbs/ft^2).

3.4 Insolation

3.4.1 Maximum Flux Direct normal nominal insolation of 1100 watts/square metre maximum at the plant site.

3.4.2 Rate of Change The maximum rate of change of incident flux shall be assumed as that which would result from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the plant site at a velocity of 20 m/s (45 mph).

3.5 Earthquake Seismic zone 3 (Uniform Bldg Code)

3.6 Soil Properties The soil properties to be used for heliostat foundation design are extractions from the soil analyses report of the Albuquerque Solar Facility (Soil and Foundation Investigation Report, 5MW STTF, Sandia Labs) and are as follows:

3.6.1 Description

- Rolling terrain sloping gently toward the west
- No free ground water was encountered and soil moisture is very low

As indicated by the exploratory borings, the subsoils and rock underlying the site can be generalized into a 3-strata profile as follows:

Stratum No. 1 This stratum consists predominantly of silty sands with varying amounts of gravel interbedded with lesser amounts of sandy silts and relatively clean sands which extend to depths of about 30 feet below existing grade. These soils are generally low in plasticity to nonplastic. This deposit is stratified and contains layers which are weakly to moderately cemented, the amount of cementation generally increasing with depth. The soils are generally moderately firm to firm near the surface becoming very firm to hard with depth. However, erratically distributed softer or looser zones were noted at several of the borings to depths of up to approximately 8 feet.

Stratum No. 2 Silty sands and gravels were encountered underlying the surface stratum and extended to depths of about 45 feet below existing grade. These soils were generally moderately to strongly cemented and very firm to hard throughout their extent. Auger drilling into this deposit was very difficult. The hollow stem auger refused within this stratum in some instances.

Stratum No. 3 Conglomerate was encountered at depths of about 45 feet and extended to the full depth of the borings. This rock consists of very strongly cemented sand and gravel with occasional cobbles and is generally moderately hard to hard. However, occasional thin softer layers containing considerable clay are present. Auger drilling to any extent into this formation was not possible and tricone rollercone bits and NX diamond coring equipment were used to penetrate this deposit. Although thin layers are present which are soft geologically, the entire unit is very hard and an excellent foundation material from an engineering standpoint.

3.6.1 continued

The change between Stratum No. 2 and 3 appears to be a transitional zone without a well defined contact.

In the transitional zone, the materials generally become more cemented with increased depth. However, the materials are highly stratified throughout with softer zones or lenses present in all intervals.

3.6.2 Seismic Refraction Survey Data Seismic refraction surveys consisting of approximately 3600 lineal feet oriented along two orthogonal surface traverses were conducted on the site. The surveys were performed using a partakle analog refraction seismograph consisting of SIE RS-44, 12 channel, dry recording system, and low frequency (4.5 Hz) MARK L-1 vertical and horizontal geophones. The values of compression wave velocity (V_p), Poisson's ratio, and elastic modulus (E) determined from the seismic surveys are summarized in Table 1.

TABLE 1 - SEISMIC REFRACTION SURVEY DATA

Depth Intervals, m (ft)			V_p		Poisson's	E	
From	To		$\frac{m}{sec}$	$\frac{(ft)}{sec}$	Ratio's	$\frac{kg}{(cm^2)}$	(psi)
0	0.5-0.9	(1.5-3)	274-366	900-1200	0.33	935- 1,603	13,300- 22,800
0.5-0.9 (1.5-3)	2.4-3.7	(8-12)	488-610	1600-2000	0.33	3,129- 4,254	44,500- 60,500
2.4-3.7 (8-12)	7.6-10.7	(25-35)	793-914	2600-3000	0.20- 0.30	10,968- 12,093	156,000- 172,000
7.6-10.7(25-35)	18.29	(60)	-	-	0.42	12,937- 38,810	184,000- 552,000
18.29 (60)	-	-	-	-	0.42	72,417- 137,803	1,030,000- 1,960,000

The values of E are based on shear strains of about 10^{-4} percent

3.6.3 Penetration and Moisture Content Data The data in Table 2 * are average values as determined from boring logs B5, B6, B8, B9, B18, and B19.

TABLE 2 - PENETRATION AND MOISTURE CONTENT

Depth		Blows per Foot (140 pounds 30 inches free fall drop hammer)	Moisture Content % of dry weight	Unified Soil Classifications**
m	(ft)			
0-1.5	(0-5)	30	5.6	SM and ML
1-5.3	(5-10)	21	4.3	SM and ML
3-4.5	(10-15)	24	3.3	SM
4.5-6.1	(15-20)	66	4.5	SM
6.1-7.6	(20-25)	75	2.6	SM and SP
7.6-9.1	(25-30)	62	4.0	SM and SP
9.1-10.7	(30-35)	50	4.0	SM
10.7-12.2	(35-40)	50	4.0	SM

* A detailed description of testing, test equipment, and boring logs is available upon requests from Sandia Laboratories. (Reference: Soil and Foundation Investigation Report, 5MW STTF, Sandia Laboratories)

** See "The Unified Soil Classification System" Corp of Engineers, US Army Technical memorandum No. 3-357 (Revised April 1960) or ASTM Designation D2487-66T

3.6.4 Summary of Direct Shear Tests

Boring No. B11 at 5.94 m (19.5 Ft)
C = 0
ϕ = 36.5°

Test No.	Normal Stress kg/m^2	(lb/ft^2)	Shearing Stress kg/m^2	(lb/ft^2)
1	4880	(1000)	3220	(660)
2	9765	(2000)	6440	(1320)
3	14650	(3000)	11720	(2400)

Boring No. B8 at 0.76 m (2.5 ft)
C = 684 kg/m^2 (140 lb/ft^2)
ϕ = 39°

Test No.	Normal Stress kg/m^2	(lb/ft^2)	Shearing Stress kg/m^2	(lb/ft^2)
1	2200	(450)	2440	(500)
2	7810	(1600)	6350	(1300)
3	12450	(2550)	10990	(2250)

APPENDIX B--SECOND GENERATION HELIOSTAT TEST PLAN

SECOND GENERATION HELIOSTAT

TEST PLAN

November 3, 1980

Approved by: P. J. Eicker

P. J. Eicker
Heliostat Development Division

TABLE OF CONTENTS

Introduction — Page

Section A - Heliostat Testing at CRTF

Section B - Mirror Module Tests

SECOND GENERATION HELIOSTAT TEST PLAN

Introduction

1. Scope

This Second Generation Heliostat Test Plan represents the document referenced in Task 3.E of the Second Generation Heliostat Development contracts between Sandia National Laboratories, Livermore, and five contractors. Those contractors and their contract numbers are: Martin Marietta Corporation (83-2729B), Boeing Engineering and Construction (83-2729C), Westinghouse Electric Corporation (83-2729D)*, Northrup Inc. (83-2729E), and McDonnell Douglas Astronautics Company (83-0024A).

2. Purpose

The purpose of this test program is to characterize the Second Generation Heliostat designs relative to the design specifications, A10772, Issue D. The results of this testing will be available for use to evaluate the heliostat designs by potential heliostat users at the conclusion of the Second Generation Heliostat program.

3. Test Summary

The test program is divided into two sections. Section A consists of the testing of two complete heliostats of each design at the Central Receiver Test Facility (CRTF) at Sandia National Laboratories, Albuquerque (SNLA). Section B consists of the testing of individual mirror modules. Compliance with both operational/performance and survival requirements will be assessed. The tests are summarized as follows:

Section A - Heliostats at CRTF

Test	Purpose
1) Operational Modes (Heliostats 1 and 2)	Determine whether heliostats can perform such required functions as tracking, stowing and assuming a commanded orientation.
2) Beam Quality (Heliostats 1 and 2)	Characterize reflected beam shape in as-delivered canting condition.
3) Beam Centroid Pointing Accuracy (Heliostats 1 and 2)	Measure beam centroid pointing error with BCS while tracking the sun.
4) Heliostat Surface Accuracy (Heliostats 1 and 2)	Characterize mirror module contour and canting accuracy with "backward gazing" Heliostat Characterization System

---

*Westinghouse exhausted its contract funds before completing any hardware. Therefore, testing of the Westinghouse heliostat is not possible and test loads for this design are not included in this test plan.

Test	Purpose
5) Life Cycle Testing (Heliostat 2)	Cycle one heliostat during all working hours for the remainder of the test period to assess wear on drive mechanisms. Cycle will simulate typical heliostat usage but at an accelerated rate. Repeat Tests 2 and 3 at completion of cycling.
6) Beam Centroid Pointing Accuracy with Operational Wind Loads (Heliostat 1)	Measure beam centroid pointing error with the BCS while heliostat is tracking the sun and while simulated wind loads are applied to the heliostat structure.
7) Wind Load Deflections (Heliostat 1)	a) Measure structural and drive mechanism deflections due to wind loads up to 50 mph while heliostat is not tracking.
	b) Measure foundation deflections due to wind loads up to 50 mph.
	c) Assess "survivability" of azimuth drive in maximum wind load conditions.
	d) Assess motor torque adequacy to start and drive against a 50 mph wind load.
8) Survival Wind Load with Heliostat Stowed (Heliostat 1)	a) Assess ability of stowed heliostat to survive 90 mph wind without damage or performance degradation.
	b) Measure permanent foundation deflection after load removal.
9) Water Spray, Disassembly and Inspection (Heliostat 2)	Spray life-cycle heliostat with water to stimulate rain and wash environment and disassemble and inspect for water penetration and evidence of wear from the life cycle testing.
10) Long Term Operation (Heliostat 1)	Run heliostat for one year in normal operating mode at the CRTF.

Section B - Mirror Modules

1) Contour Measurement	Measure large-scale mirror contour (curvature).
2) Wind Load Glass Stress	Measure stress in glass due to wind loads.
3) Thermal Stress and Contour Change	Measure glass stress and change in mirror contour due to temperature change.
4) Residual Glass Stress	Measure combined residual and fabrication-induced stresses in mirror.

5) Gravity Sag	Measure change in large-scale mirror contour due to gravity sag.
6) Thermal Cycling	Assess survivability to temperature cycling between -20 and 120°F.
7) Environmental Cycling	Assess survivability to accelerated aging test consisting of alternating high and low humidity, UV radiation, and temperature cycling.
8) Hail Test	Assess survivability to hail.
9) Cold Water Shock	Assess survivability to cold water wash or rain on a hot day.
10) Reflectivity	Measure specular reflectivity.
11) Laser Ray Trace	Measure mirror contour and local waviness.

The overall test plan outlined in this document represents a minimum baseline plan to verify heliostat compliance to design specifications. Sandia reserves the right to alter the existing tests or include additional testing as judged necessary prior to or during the test period.

4. Hardware and Test Locations

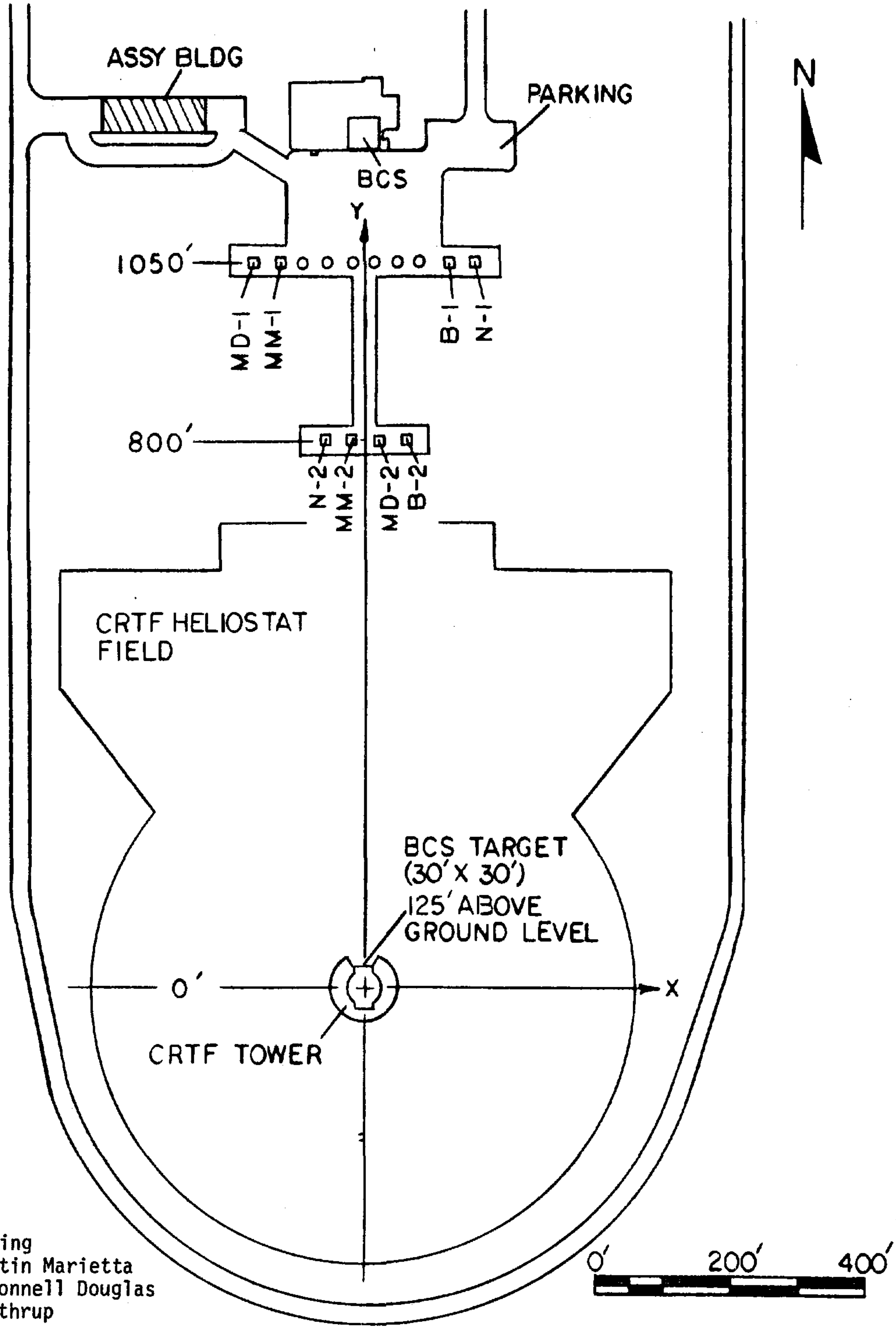
All of the heliostat tests in Section A will be performed at the CRTF in Albuquerque. Two complete heliostats of each design are required by the test plan. Heliostat foundation locations are shown in Fig. 1. Heliostat 1 of each design will be located 1,050 feet from the tower, while Heliostat 2 will be located 800 feet from the tower.

The majority of the mirror module tests in Section B will be performed at SNLL. However, due to the location of certain test equipment and experienced personnel, the Reflectivity (Test 10) and Laser Ray Trace (Test 11) tests will be done at SNLA. Three mirror modules of each design are required for Tests 1-9 at SNLL and one unit is needed for Tests 10 and 11 at SNLA, for a total of four mirror modules of each design. Also required are extra mirror samples for reflectivity measurements and scrap glass samples needed for strain gage temperature compensation. These last two items have been requested from the contractors.

5. Schedule

The schedule for this test program is shown in Fig. 2 (Section A) and Fig. 3 (Section B). The testing is scheduled to begin on December 1, 1980, and to be mostly completed by the first week in March, 1981. Testing of the heliostats and mirror modules will continue as necessary to evaluate the designs fully. However, the only formally scheduled testing in this plan past the end date is the continued running of heliostats at the CRTF (Section A, Test 10) and the long term environmental cycling of the mirror modules (Section B, Test 7).

A separate test schedule for Martin Marietta will commence in March, 1981.



B	- Boeing
MM	- Martin Marietta
MD	- McDonnell Douglas
N	- Northrup

Fig. 1 - Second Generation Heliostat Locations at CRTF

Fig 2

① = Heliostat at 1050'
② = Heliostat at 800'

SECOND GENERATION HELIOSTAT
TEST SCHEDULE - SECTION A

2 Week Christmas Break (between 12/15/80 and 1/5/81)

Week Beginning:

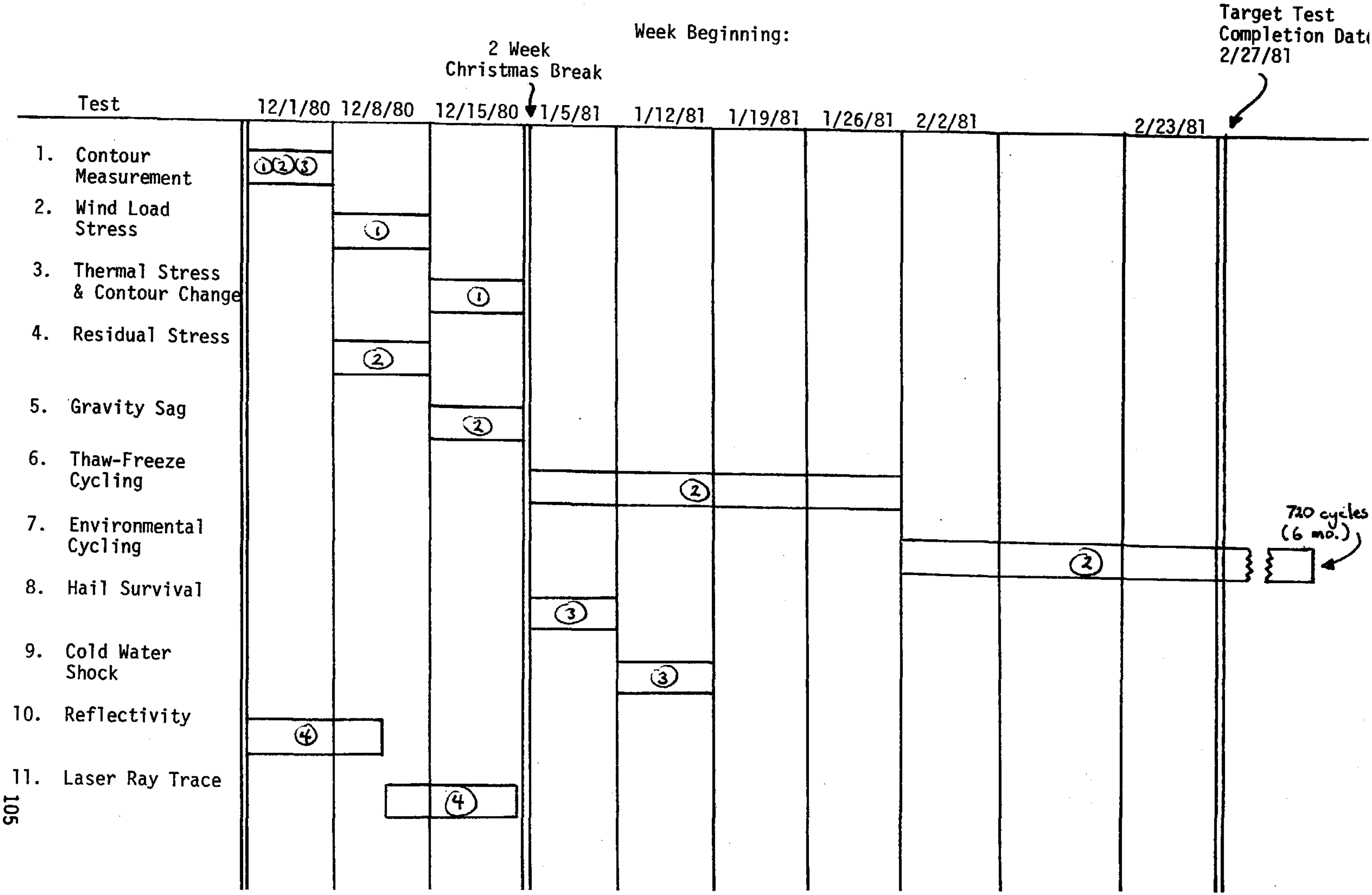
Target Test Completion Date 3/6/81

Test	12/1/80	12/8/80	12/15/80	1/5/81	1/12/81	1/19/81	1/26/81	2/2/81	2/9/81	2/16/81	2/23/81	3/2/81
1. Operational Modes	① ②											
2. Beam Quality		①	②								②	①
3. Beam Pointing		①	②								②	①
4. Heliostat Surface Accuracy				① ②								
5. Life Cycling					②	②	②	②	②	②		
6. Operational Wind Loads					①	①						
7. Wind Load Deflections							①	①	①			
8. Survival Wind Loads										①	①	
9. Water Spray, Disassembly, & Inspection												②
10. Long Term Operation	(Test begins at completion of Test 8 and continues for one year)											

①②③ = mirror modules at SLL
④ = mirror module at SLA
ⓘ = mirror module with strain gages

Fig. 3

SECOND GENERATION HELIOSTAT
TEST SCHEDULE - SECTION B



6. Supporting Tests and Analysis

Since it is impossible to test the heliostats for specification compliance under all possible operating or survival conditions, two separate computer analyses will be used to support this test program. First, the heliostat optical performance code HELIOS will be used to determine heliostat beam quality under temperature and orientation conditions different from those tested. BCS beam quality measurements will confirm the HELIOS model under known conditions. Second, a finite element structural analysis will be performed for each design which will determine (1) mirror facet alignment errors due to gravity sag at different elevation angles, (2) structural deflections due to operational wind loads, (3) maximum stresses due to survival wind loads, and, (4) natural dynamic frequencies and mode shapes which may be excited by earthquakes or vortex shedding of the wind.

It is also planned to perform design-specific accelerated aging tests on selected materials such as sealants and adhesives found in the mirror modules. These tests and materials will be defined at a later date.

7. Responsible Personnel

Division 8451 at SNLL has overall responsibility for proper scheduling, implementation, data reduction, and documentation of the tests outlined in this test plan. Any changes in the tests, schedule, or responsible personnel must receive the express prior approval of Division 8451.

To implement the test plan, responsibilities have been broken down into the categories "Test Engineer" and "Technical Advisor." The Test Engineer shall see that the tests are properly scheduled and that the appropriate personnel, test hardware, and test equipment are coordinated and at the test site at the proper time. The Technical Advisors shall help write the test requirements, review and approve any detailed test plans written by test organizations, observe the test, resolve all technical questions concerning the test implementation and/or results, reduce the data, and see that the test results are documented. Individuals who are Test Engineers and Technical Advisors are listed in Table 1.

TABLE 1

SECOND GENERATION HELIOSTAT TEST PLAN

RESPONSIBLE PERSONNEL AND ORGANIZATIONS

Section A Tests	Test Engineer	Technical Advisor
1. Control System Operational Modes	D. L. King (4713)	D. N. Tanner (8451)
2. Beam Quality	D. L. King (4713)	C. L. Mavis (8451) D. L. King (4713)
3. Beam Pointing	D. L. King (4713)	C. L. Mavis (8451) D. L. King (4713)
4. Heliostat Surface Accuracy	D. L. King (4713)	T. D. Brumleve (8451)
5. Life Cycle Tests	D. L. King (4713)	C. J. Pignolet (8451)
6. Pointing Accuracy with Operational Wind Loads	D. L. King (4713)	W. S. Rorke, Jr. (8451) D. L. King (4713)
7. Wind Load Deflections	D. L. King (4713)	W. S. Rorke, Jr. (8451)
8. Survival Wind Loads	D. L. King (4713)	W. S. Rorke, Jr. (8451)
9. Water Spray, Disassembly, and Inspection	D. L. King (4713)	C. J. Pignolet (8451)
10. Long Term Operation	D. L. King (4713)	H. F. Norris, Jr. (8451)
Section B Tests		
1. Contour Measurement	V. P. Burolla (8424)	W. R. Delameter (8451)
2. Wind Load Stress	V. P. Burolla (8424)	W. R. Delameter (8451)
3. Thermal Stress and Contour Change	V. P. Burolla (8424)	W. R. Delameter (8451)
4. Residual Stress	V. P. Burolla (8424)	W. R. Delameter (8451)
5. Gravity Sag	V. P. Burolla (8424)	W. R. Delameter (8451)
6. Thaw-Freeze Cycling	V. P. Burolla (8424)	W. R. Delameter (8451)
7. Environmental Cycling	V. P. Burolla (8424)	W. R. Delameter (8451) V. P. Burolla (8424)
8. Hail Survival	V. P. Burolla (8424)	W. R. Delameter (8451)
9. Cold Water Shock	V. P. Burolla (8424)	W. R. Delameter (8451)
10. Reflectivity	J. E. Bear (1535)	W. R. Delameter (8451)
11. Laser Ray Trace	J. E. Bear (1535)	W. R. Delameter (8451)

SECOND GENERATION HELIOSTAT TEST PLAN

SECTION A - HELIOSTAT TESTING AT CRTF

General Observations

The following general observations will be made and recorded during the test period by the Test Engineer for the Section A tests:

a) A log will be kept for each heliostat at the CRTF for the purpose of recording required maintenance or repairs, problems encountered, and any other unusual or interesting events pertaining to the operation or testing of the heliostat. Failure modes and reasons for failure will be determined and entered into the log.

b) Liberal photo-documentation will be made of all tests and of any unusual or interesting events of a visual nature which occur during the test period.

c) The following environmental information will be recorded in the log at the CRTF during the test period:
   - i. Daily high and low temperatures.
   - ii. Wind speed and direction when in excess of 30 mph.
   - iii. Precipitation.
   - iv. Relative humidity with special attention to dew formation.
   - v. Occurrence of blowing sand.
   - vi. Any other unusual weather phenomena.

d) Videotape or movie documentation of heliostat dynamic response to winds exceeding 30 mph will be made.

e) Videotape or movie documentation of the heliostat beam on the BCS target during winds exceeding 15 mph will be made.

f) Steady state heliostat component temperatures will be measured on a warm, sunny day with the heliostats operating and also with the heliostats stowed (sun on back). Of particular interest are the following:
   - i. Mirror module temperatures, front and back.
   - ii. Temperature gradients in pedestal.
   - iii. Motor temperatures.
   - iv. Temperature gradients in structural members.
   - v. Temperatures of control box and selected electrical components.

   Temperature measurements are to be made when the heliostats are newly installed and again at a later date when dirt build-up and surface oxidation or corrosion have occurred.

Test 1 - Control System Operational Modes

1.1 Objective: To verify that the heliostat is capable of performing the operational modes required for this test program, and to determine the additional control capabilities of each design.

1.2 Prerequisites: Closely inspect the heliostats with particular attention given to the mirror modules, the drive mechanism exteriors, the control electronics boxes, and the pedestal interiors.

1.3 Description: The following tests are to be performed on both heliostats of each design:

1.3.1 Standard Modes: The heliostat shall be operated through the tests shown in Table 2.

1.3.2 Special Modes: The heliostat shall be operated through the tests shown in Table 3.

1.3.3 Power Measurements: Heliostat electrical input power will be measured with a watt meter and a watt-hour meter for the following conditions:

a) Stow to standby
b) Standby to track
c) Track to standby
d) Standby to stow
e) Tracking for a 10 hour day starting from stow and returning to stow.

1.3.4 Control/Drive Repeatability: A laser will be mounted on the heliostat and the heliostat will be cycled 10 times from the stow position to a fixed gimbal angle position with the laser beam incident on a ground-mounted target. Tests will be run from both vertical stow and mirror face-up or face-down, whichever is appropriate (MMC is the only design with face-down stow). The fixed gimbal angle position used will be determined during the test setup.

1.3.5 Reference Update: This test shall immediately follow the completion of 1.3.4. With the heliostat in the stow position, the power shall be turned off for a sufficient period of time so that heliostat initialization is required (time greater than 100 milliseconds). The heliostat shall then be initialized to a position which is in error 10 to 20 milliradians from the actual position in both azimuth and elevation. The heliostat shall then be subjected to its reference update procedure and the Control/Drive Repeatability test (1.3.4) is repeated.

1.4 Data: Data from these tests shall be identified with date, time, test identification and run number. Commands, alarms, and any other pertinent data will be recorded.

1.4.1 Heliostat Data: Heliostat data will either be recorded on a hard copy printer or manually recorded during or immediately following the test. Data of interest includes:

a) Heliostat status.
b) Heliostat actual azimuth and elevation gimbal axis position.
c) Time for actual position (day, hour, minute, second).
d) Log of operational mode commands issued during the test and the time the command is issued.
e) Alarms or error messages.

1.4.2 Beam Centroid Data: Beam centroid location will be measured with the Beam Characterization System (BCS) for the tests indicated in Table 2.

1.4.3 Observations: An observer will be present near the heliostat to detect by motor sound or reflected beam movement any indication of control instability or "hunting".

1.4.4 Control/Drive Repeatability: The results of the repeatability testing will be evaluated in terms of the deviation of the heliostat azimuth and elevation angles as measured on the ground-mounted target. Standard deviations of the azimuth and elevation angular errors about the mean aimpoint will be determined. This data provides an assessment of heliostat pointing repeatability.

1.4.5 Reference Update: The results of the reference update test will be evaluated in the same manner as the Control/Drive Repeatability test (2.4.2). The mean aimpoint after the reference update will be compared with the mean aimpoint determined by the previous testing. The standard deviation of the aimpoint data from before and after the reference update will also be compared. Significant differences in either the mean aimpoint or the standard deviation of the aimpoint data will be noted.

TABLE 2

STANDARD MODES

Test Number	Heliostat #1	Heliostat #2	Data*	Remarks
1	Stow to Standby**	Stow	Position	
2	Standby to Target**	Stow	Position Beam Centroid	Correlate beam centroid position with commanded position.
3	Target	Stow to Standby	Position	
4	Target	Standby to Target	Position	
5	Target to Standby	Target	Position Beam Centroid	Correlate beam centroid position with commanded position.
6	Standby to Stow	Target	Position	
7	Stow	Target to Standby	Position	
8	Stow	Standby to Stow	Position	
9	Standby to Target	Standby to Target	Position	
10	Standby to Target	Standby to Target	Position	

---

*Data received is described in Para. 1.4

**Standby position and target position are SB and A1 defined in Figure 4 for all tests in this table. Tracking these points is required.

TABLE 3

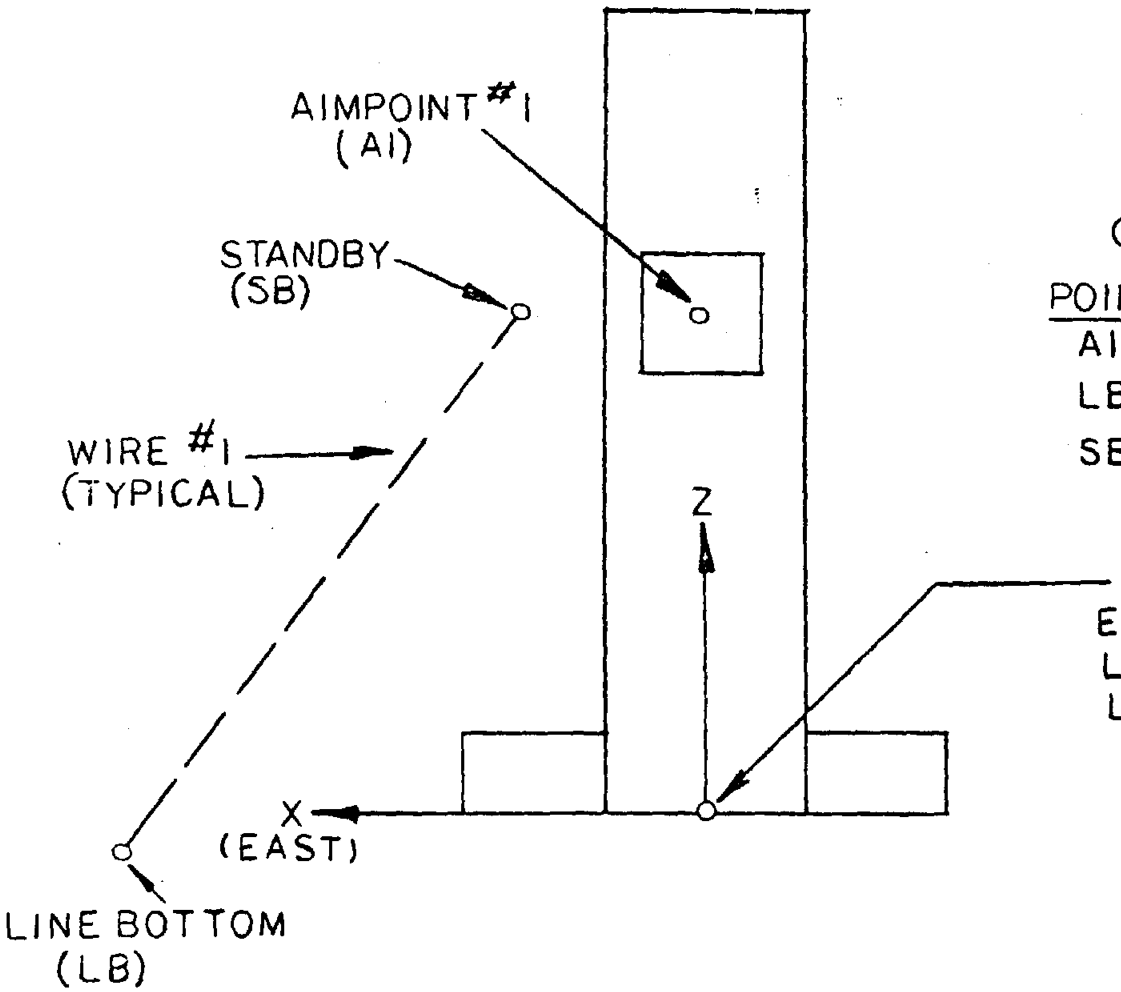
SPECIAL MODES

Test Number	Azimuth* Position	Elevation* Position	Data	Remarks
1	-90°	90°	-	Initial conditions
2	-180°	90°	Position	Azimuth slew rate
3	-180°	0°	Position	Elevation slew rate
4	0°	90°	-	
5	-90°	0°	Position	Combined azimuth and elevation slew rate
6	0°	+45°	-	
7	-**	+45°	Position	
8	+**	+45°	Position	
9	0°	+45°	-	
10	0°	+**	Position	
11	0°	-**	Position	
12	0°	+45°	Position	

---

*Azimuth position is based on contractor defined reference. Elevation position 0° is mirror face up, +90° is mirror vertical.

**Heliostat should move to the limit of travel in the specified direction.



COORDINATES (METERS)

POINT	X	Y	Z
A1	0.057	9.768	37.578
LB	60.00	0.00	-2.00
SB	25.00	0.00	37.59

TOWER ORIGIN
ELEV: 5585.500 FT
LAT: 34° 57′ 44.033″
LONG: 106° 30′ 32.512″

FIGURE 4

BCS AIMPOINT & STANDBY COORDINATES

TEST 2 - BEAM QUALITY

2.1 Objective: The test objective is to characterize the reflected beam shape (energy flux distribution). This will be used along with theoretical beam shapes calculated with an optical performance computer code (HELIOS) for each heliostat to determine compliance with the beam quality performance specification. Beam quality will be measured with the mirror facets in the as-delivered canted condition.

2.2 Prerequisites: Prior to this test, the heliostat facets should be canted by the contractor. Facet curvature versus ambient temperature must be available prior to the HELIOS analysis (See Tests 1 and 3, Section B). Measured sunshape must also be obtained prior to or during the test. Wind speeds below 8 mph are required for this test. The heliostats will be positioned at or near the operating orientation for at least 60 minutes before measurements are made to allow the mirror modules to come to thermal equilibrium.

2.3 Description: The BCS will be used to obtain measured beam quality data. BCS measurements will be taken for both heliostats of each design at several sun positions (times of day). Also, BCS measurements will be made on at least three different individual mirror facets, with the remaining facets covered, on Heliostat 2.

2.4 Data: The BCS measured beam data obtained during this test will be compared to theoretical beam data obtained from the computer code HELIOS. BCS data in conjunction with the HELIOS analysis will determine compliance with the beam quality performance specification over the required temperature range (0°C to 50°C) and operating geometries. Any heliostat that will not meet the specifications over the full temperature range will be characterized for the useful temperature range. Temperature and wind speed and direction will be recorded with each BCS measurement.

TEST 3 - BEAM POINTING

3.1 Objective: The objective of this test is to provide beam pointing accuracy data for all heliostats in terms of the deviation of the beam power centroid location from the desired aimpoint on the BCS target. Compliance with the beam pointing performance specification will be assessed. Inclinometers will be used to measure any errors associated with the pedestal/foundation.

3.2 Prerequisites: Prior to the test, the facets should be canted by the contractor and the encoder bias setting (if any) should be checked. Metal brackets will be permanently attached to the top and bottom of the pedestal such that inclinometers can be temporarily used to measure any transient or permanent displacements of the pedestal and/or foundation. Wind speeds below 8 mph are required for this test.

3.3 Description: This test will be accomplished using the CRTF Beam Characterization System (BCS). Aimpoint A1 (Fig. 4) on the BCS target will utilized. The test will be repeated for both heliostats of each design. Test duration for each heliostat will be at least six hours. The basic procedure to be used during the beam centroid pointing test for each heliostat is as follows:

3.3.1 On request from the BCS operator the heliostat operator will bring the heliostat beam to line bottom (LB), to standby (SB), and then to aimpoint A1 as indicated in Fig. 4.

3.3.2 Data from several contractors' heliostats may be taken during the same day-long interval. This will require that all heliostats be held at standby (SB) and then on request from the BCS operator moved onto the target aimpoint A1. Each heliostat will be cycled to A1 at approximately 30 minute intervals and will remain at A1 for approximately 3 minutes prior to returning to standby. During this 3 minute period, 30 sets of data will be recorded and the rms and average beam centroid error will be determined from these data. The rms beam centroid error for the entire day will also be determined.

3.3.3 Pedestal tilt data will be initially taken prior to any beam pointing data. Data will be recorded at 8:00 AM, 10:00 AM, 12:00 AM, 2:00 PM, and 4:00 PM. The heliostat will be tracking on target or at standby during this test. A second set of pedestal tilt data will be taken approximately three months after the initial measurements.

3.4 Data: The data obtained from this test will provide a statistical measure of the beam centroid pointing accuracy of the test heliostats. Azimuth and elevation components of the pointing error will be determined. Temperature and wind speed and direction will be recorded with each BCS measurement.

TEST 4 - HELIOSTAT SURFACE ACCURACY

4.1 Objective: The test objective is to check the contour and canting accuracy of the heliostat mirrors and to diagnose the nature of any surface distortion, misfocusing, or canting problems.

4.2 Prerequisites: Same as for Test 2 except that facet curvature vs. temperature is not required.

4.3 Description: The HCS will be used to evaluate the surface accuracy of both heliostats of each design. The heliostats will be aimed and canted as in Test 2. The test sequence is as follows:

4.3.1 Perform necessary HCS calibration functions including the setting of the VP-8 color bands using a direct or previously stored sun image.

4.3.2 Aim heliostat at HCS camera.

4.3.3 Observe heliostat image on HCS color monitor and check for any obvious problems in focus, canting, or module distortion.

4.3.4 Record heliostat image on video tape and voice-annotate relevant test conditions.

4.3.5 Repeat at 30 minute intervals. Test may be run in conjunction with Test 3.

4.4 Data: Color-coded heliostat images will be recorded on color video tape and retained for comparison with other heliostat designs and for future reference. An image will be recorded for about 15 seconds at each of the selected measurement times throughout at least one complete day. Images will be calibrated and colors assigned such that each color represents a known deviation of the mirror normal from perfect. Heliostat identification, times, test conditions and other pertinent information will be voice annotated on the video tape. Any special tests or conditions, such as response to wind gusts, will also be recorded.

TEST 5 - LIFE CYCLE TESTS

5.1 Objective: To obtain "limited" life-cycle data on the motors and mechanical components. The "limitation" arises from the fact that we can only operate at the ambient environmental conditions at CRTF during the three months of testing, and then only during the available times between the other scheduled test events.

5.2 Prerequisites: Initial beam pointing and beam quality measurements per Tests 2 and 3 will be taken before the life-cycle testing.

5.3 Description: The basic concept for this limited life-cycle test is to initially measure the beam pointing and quality characteristics of a given heliostat, then subject it to as much operational cycling as possible within the three month test period, and finally remeasure beam pointing and quality characteristics as a means of detecting performance degradation. After completion of the final water spray in Test 9 the drive mechanism will be disassembled and inspected for evidence of abnormal wear or foreign material.

Heliostat 2 of each design will be operated for six weeks in an automatic life-cycle mode defined by the following requirements:

a.) Each cycle shall consist of moving the heliostat from a stowed position to a tracking position, follow a simulated track, and then return to stow.

b.) Each cycle shall be of approximately one hour duration. The unstow and stow motions at slew rate will require about 15 minutes total of each cycle. Twenty-four one-hour cycles per day results in about 1000 cycles in six weeks which corresponds to roughly three years of operation.

c.) The simulated tracking of each cycle (about 45 minutes/cycle) shall result in about 30 degrees of both azimuth and elevation travel. A complete day need not be simulated by this part of the cycle.

Emergency Shutdown - If the wind rises above 35 mph, the heliostats will stop cycling and will be stowed to preclude damage resulting from wind loads. Also, if the temperature drops below 16°F, or if there is hail, ice formation, or snow, the heliostats will be stowed. In the early part of the life cycle testing, the stow command will be initiated by heliostat test operators who will be present on a 24 hour-a-day basis for just this purpose. In later stages of the testing, the heliostats will be controlled by a central CRTF computer which will receive input from wind and temperature monitoring devices and will automatically command the heliostats to stow when conditions require it. The heliostats will be either manually or automatically returned to cycling when wind and temperature conditions permit. The time and date of shutdown and return to cycling will be noted in the log.

5.4 Data: Time of operation, number of cycles, wear and abnormal indications, washing and maintenance required, and any other pertinent observations will be documented. The results of before and after beam pointing and beam quality measurements will also be compared.

TEST 6 - POINTING ACCURACY WITH OPERATIONAL WIND LOADS

6.1 Objective: This test is to assess the pointing error of the heliostats due to simulated operational wind loads. The results are to be compared to the performance specification.

6.2 Prerequisites: Fixturing must be attached to the heliostat to allow the application of simulated wind loads while the heliostat is in a solar track mode. Tests 2 and 3 should be completed prior to this test. Wind speeds less than 8 mph are required for this test.

6.3 Description:

6.3.1 The test shall be performed on Heliostat 1 from each contractor.

6.3.2 Beam centroid data is to be obtained with the BCS for each heliostat while tracking and subjected to applied moments given in Table 4 corresponding to maximum wind loads associated with wind speeds of 8, 20, 27 and 35 mph. The change in beam position due to load application will be measured. Azimuth and elevation moments are to be applied separately with BCS measurements taken for each load condition. Azimuth moments will be applied in both clockwise and counterclockwise directions. Elevation moments will be applied only in the direction to move the reflected beam down.

TABLE 4

Wind Load Moments (ft-lbf)

Windspeed (mph)	Axis	Boeing	MDAC	MMC	Northrup
8	AZ	174	311	318	250
	EL	213	272	305	272
20	AZ	1087	1947	1986	1563
	EL	1331	1698	1909	1705
27	AZ	1981	3548	3620	2848
	EL	2426	3094	3478	3108
35	AZ	3329	5962	6083	4786
	EL	4077	5199	5845	5223

6.3.3 The simulated wind loads are to be applied in the following sequence:

a) No load, 8 mph wind load, no load, 8 mph wind load (in reverse direction for azimuth).
b) No load, 20 mph wind load, no load, 20 mph wind load (in reverse direction for azimuth).
c) No load, 27 mph wind load, no load, 27 mph wind load (in reverse direction for azimuth).
d) No load, 35 mph wind load, no load, 35 mph wind load (in reverse direction for azimuth).

6.4 Data: The BCS shall be used to determine heliostat beam centroid pointing error at each applied load level compared to the tracking position when not loaded. The beam centroid data will be reduced to back out the deflections of the heliostat reflective surface. Time of day, date, ambient air temperature, and pedestal/foundation twist and/or tilt shall also be recorded.

TEST 7 - WIND LOAD DEFLECTIONS

7.1 Objective: The purpose of this test is to determine the structural and drive mechanism deflections of a non-tracking heliostat while subjected to simulated wind loads up to 50 mph. In addition, this test will assess the ability of the azimuth and elevation motors to start and/or drive against a 50 mph wind, and the motor power requirements under such loads, and assess the ability of the azimuth drive to survive a 50 mph wind plus a 10% overload.

7.2 Prerequisites: Wind speeds less than 8 mph are required for this test. Tests 2, 3 and 6 should be completed prior to this test. Fixturing should be attached to each heliostat to allow the application of simulated wind loads. Instrumentation should be installed to measure deflections of the foundation, pedestal, drive mechanism, and support structure.

7.3 Description:

7.3.1 The test shall be performed on Heliostat 1 from each contractor.

7.3.2 Deflection data is to be obtained for each heliostat before, during, and after being subjected to the applied moments given in Table 5 corresponding to wind speeds of 8, 27, 35 and 50 mph impinging at a 20° angle of attack. The heliostats are to be tested at four elevation angles for the elevation drive test: 0°, 30°, 60° and 90° from horizontal. Only one position is required for the azimuth drive test, where the mirrors shall be vertical. Moments will be applied in both directions.

TABLE 5

Wind Load Moments (ft-lbf)

Windspeed mph	Axis	Boeing	MDAC	MMC	Northrup
8	AZ	174	311	318	250
	EL	213	272	305	272
20	AZ	1087	1947	1986	1563
	EL	1331	1698	1909	1705
27	AZ	1981	3548	3620	2848
	EL	2426	3094	3478	3108
35	AZ	3329	5962	6083	4786
	EL	4077	5199	5845	5223
50	AZ	6794	12168	12414	9768
	EL	8320	10611	11929	10659
10% Overload	AZ	7473	13385	13655	10745

7.3.3 Simulated wind loads will be applied to the elevation drive at orientations of 0°, 30°, 60°, and 90° and to the azimuth drive at a single position. The following is the loading sequence:

No load, 8 mph wind load, no load, reverse 8 mph wind load.
No load, 20 mph wind load, no load, reverse 20 mph wind load.
No load, 27 mph wind load, no load, reverse 27 mph wind load.
No load, 35 mph wind load, no load, reverse 35 mph wind load.

Deflections will be measured and recorded at each load level.

7.3.4 Simulated wind loads associated with winds up to 50 mph will be applied in both positive and reverse directions to the elevation drive with the mirrors face-up and to the azimuth drive with the mirrors vertical. Loads and deflections will be recorded at 20% intervals of the maximum load while the load is applied in the following sequence:

No load
50 mph wind load
No load
Reverse 50 mph wind load
No load

7.3.5 Simulated wind loads associated with a 10% overload of a 50 mph wind will be applied to the azimuth drive only with the mirrors vertical. Loads and deflections will be recorded for the following loading sequence:

No load
10% overload
No Load
Reverse 10% overload
No load

Of particular interest is the presence of any residual deflection after the removal of the loads.

7.3.6 Determine drive motor torque capabilities by loading the heliostat to 35 mph equivalent wind load indicated in Table 6.

For azimuth, begin driving against the load and increase load up to 50 mph equivalent. Continue driving for a total travel of 20°.

For elevation, position heliostat 30° from horizontal (inverting designs should be 30° from fully inverted). Begin driving toward horizontal against load, increasing load to 50 mph equivalent. Continue driving until heliostat is 10° from horizontal.

For both azimuth and elevation, stop motors and start motor against a simulated 50 mph wind load.

TABLE 6

Wind Load Moments (ft-lbf)

Axis	Windspeed (mph)	Boeing	MDAC	MMC	Northrup
AZ	35	3329	5962	6083	4786
	50	6794	12168	12414	9768
EL	35	4077	5199	5845	5223
	50	8320	10611	11929	10659

7.4 Data:

7.4.1 Wind load deflection data shall include:

Heliostat position
Pedestal tilt and rotation
Drive tilt and rotation
Foundation tilt and rotation

7.4.2 Motor torque adequacy data shall include:

Heliostat position vs. time
Applied load vs. time
Motor power draw vs. time
Ambient air temperature
Motor temperature

TEST 8 - SURVIVAL WIND LOAD - HELIOSTAT STOWED

8.1 Objectives: This test is to determine whether the heliostats in a "stowed" position can survive the loads induced by a 90 mph wind at a 10° angle of attack without damage or increased pointing error, and without backdriving the elevation drive mechanism. One heliostat of each design will be tested to a load equivalent to a 90 mph wind load, reduced appropriately to account for the specified wind profile. Subsequently the same heliostats will be tested to a 10% overload to assess design margin.

8.2 Prerequisites: Tests 2, 3, 6, and 7 should be completed prior to this test.

8.3 Description: Heliostat 1 from each contractor will be loaded in a manner to simulate a 90 mph wind at a 10° angle of attack. The loads will be applied vertically downward at the quarter point of the reflective surface with the heliostat in a horizontally stowed position. It will be determined if loading one side of the heliostat is potentially more detrimental than loading the opposite side, and the more detrimental loading configuration will be employed. Load levels listed in Table 7 equivalent to 80%, 90%, 100%, and 110% of the maximum 90 mph wind load will be applied about the elevation axis and the cross-elevation axis. At each load level, the load will be applied and then removed several times. Laser and inclinometer data will be recorded to determine whether permanent deflections have been induced, either in the foundation or in the heliostat structure or drive mechanism. Deflections will also be monitored during the load application in an attempt to observe early signs of failure so that excessive damage to the heliostat can be avoided.

TABLE 7

Wind Load Moments (ft-lbf)

Percent of Maximum 90 mph Wind Load	Axis	Boeing	MDAC	MMC (Inverted)	Northrup
80%	El	15911	19358	21457	19477
	Cross El	13054	24434	22734	19159
90%	El	17900	21777	24139	21911
	Cross El	14685	27488	25575	21554
100%	El	19889	24197	26821	24346
	Cross El	16317	30542	28417	23949
110%	El	21878	26617	29503	26781
	Cross El	17949	33596	31259	26344

The loads will be applied by means of a steel cable appropriately attached to the heliostat and anchored to the ground with a hydraulic actuator and a load cell in series. The cable will be attached to the heliostat in such a manner as to spread the applied load over the mirror support structure and avoid concentrated loading. Dental cement or an equivalent brittle substance will be applied to joints prior to loading to detect slippage.

This test will be repeated with diagnostic instrumentation if warranted by data from the initial testing.

8.4 Data: Heliostat and foundation deflections measured with appropriately mounted lasers and/or inclinometers will be recorded at each of the load levels representing 80%, 90%, 100%, and 110% of the 90 mph wind load. Residual deflections after removal of each load will also be recorded.

TEST 9 - WATER SPRAY, DISASSEMBLY, AND INSPECTION

9.1 Objective: To determine whether water spray, simulating a wash and/or driving rain environment, penetrates any sensitive heliostat components; to observe any abnormal wear which may have resulted from the prior Life Cycle Testing; and to measure the weights of the drive mechanisms and reflective structure of each heliostat.

9.2 Prerequisites: The heliostat to be tested will have completed Test 5, Life Cycle Testing. Electrical power to the heliostats may be removed during spraying to preclude any safety hazard.

9.3 Description: This test simulates a wash and/or driving rain environment, and will be performed on heliostats during the final week of Life Cycle Testing. Water spray will be applied every working day for the week prior to disassembly and inspection. The heliostat should be as warm as possible under ambient weather conditions when the water spray is applied. Since the principal objectives of this water spray test do not include mirror module evaluation, it will not be necessary to deliberately spray the mirror assemblies, but rather to concentrate spraying effort onto and around the gimbal drive boxes, and exposed cable harnesses. Inadvertent spraying of the mirror modules is of no consequence.

Standard hose/nozzle equipment can be used to apply the spray from approximately 10 feet away. The spray dimensions, nozzle pressure, etc. are not critical as long as the water is not applied in a solid stream. The spray should be as representative as possible of a wind-driven rain. Apply spray as uniformly as possible around the heliostat center for a total elapsed time of 8 to 10 minutes.

The test units will be returned to the cycling mode after each spray and for approximately 15 minutes after the final spraying to confirm normal operation.

Following the final spray test and the 15 minutes of operation, the heliostat is to be disassembled and inspected for evidence of water penetration and wear in the presence of Sandia personnel. Particular attention will be given to the inspection of electronic components for evidence of dirt, water, or other foreign and potentially troublesome material, and to the inspection of the drive mechanism components for evidence of water, dirt, and/or unusual wear. Oil and/or grease samples will be saved for chemical evaluation.

During or after disassembly, the drive mechanism and the reflective structure will be weighed.

9.4 Data: Liberal photo-documentation and written observations of the inspection will be made. Any unusual wear or foreign material discovered during the inspection will be further evaluated by the appropriate experts as deemed necessary by designated Sandia personnel. Weights will be recorded.

TEST 10 - LONG TERM OPERATION

10.1 Objective: The purpose of this test is to determine whether any operational, wear, or weathering problems develop during long term operation of the heliostat.

10.2 Prerequisites: Test 1-4 and 6-8 should be completed prior to this test.

10.3 Description: Heliostat 1 will be operated daily during working hours initially using the contractor's controller and using the Sandia controller when available for a period of at least one year. The heliostat will track the sun and reflect a beam to a specified point (probably the standby point) during daylight hours and will be stowed as specified by the contractor at night. Beam pointing, beam quality and heliostat surface accuracy will be checked at least every three months per Tests 2, 3 and 4.

Each heliostat will be washed and maintained during the test period as required. Reflectivity shall be measured once a week and before and after washing at 30 points on one representative mirror facet of each heliostat at the CRTF.

10.4 Data: For each heliostat a log will be kept to record required maintenance, washing, problems encountered, and total time of operation. Data from periodic repetition of Tests 2, 3 and 4 will be recorded. Photographs will be taken of any visible degradation observed during the test period. Reflectivity data shall be recorded.

TEST 11 -- FOUNDATION TESTING

11.1 Objectives: The purpose of this test is to characterize the angular deflections of the heliostat pedestal/foundations under high loading conditions. The heliostats have already been qualified in previous testing for compliance to the performance specification. Therefore, this test is designed to gain additional information about these foundations by overloading them by a significant factor and possibly to the point of permanent set or slippage in the ground. This test will be performed on the pedestal/foundation of Heliostat 2 (closest to the tower) of each design after the drive mechanisms and reflective units have been removed for shipment to Livermore. After this test, the pedestal/foundations will be removed from the CRTF site.

11.2 Prerequisites: Prior to this test, Test 9 must be completed on Heliostat 2 and the drive mechanism and reflective structure removed. Fixturing is to be attached to the top of the pedestal so that a twisting moment may be applied with a 10 ft. moment arm, as illustrated in Figure 11-1. Two lasers are to be mounted on the pedestal to monitor angular deflections. One laser is mounted near the top of the pedestal, and a second is mounted as close to the ground as practical. The lasers are to be aimed at a ground-level target located at a distance of about 200 ft. in the direction 90° to the moment arm fixturing.

11.3 Description: Two tests will be performed -- first a bending test, followed by a combination bending/twisting test.

11.3.1 Bending Test -- In this test, loads are to be applied to the top of each pedestal such that there is bending of the pedestal, but no twist. Loads are applied in the following sequence:

	Applied Load (lb)			
Fraction of 50 mph Wind Bending Moment	Boeing	MMC	MDAC	Northrup
50%	1243	1631	1595	1492
	0	0	0	0
100%	2486	3263	3190	2983
	0	0	0	0
150%	3729	4894	4786	4475
	0	0	0	0
200%	4972	6526	6381	5966
	0	0	0	0

Laser data measuring pedestal deflections are to be recorded at each load and no-load condition.

11.3.2 Twist/Bend Test -- In this test, loads are to be applied to the top of each pedestal through a 10-ft. moment arm such that there is twisting as well as bending of the pedestal. Loads are to be applied in the following sequence:

Fraction of 50 mph Wind Twisting Moment	Applied Load (lb) on 10' Moment Arm			
	Boeing	MMC	MDAC	Northrup
50%	416	596	531	533
	0	0	0	0
100%	832	1193	1061	1066
	0	0	0	0
125%	1040	1491	1326	1333
	0	0	0	0
150%	1248	1790	1592	1599
	0	0	0	0
175%	1456	2088	1857	1866
	0	0	0	0
200%	1664	2386	2122	2132

Laser data measuring pedestal angular deflections are to be recorded at each load and no-load condition.

11.4 Data: Laser beam deflection data will be reduced to indicate tilt and twist of the pedestal, measured in mrad. Pedestal twist at the top and bottom will be plotted against the applied twisting moment (twisting moment = applied force x 10 ft.). Pedestal tilt at the top and bottom will be plotted against the applied bending moment in the pedestal at ground level (bending moment = applied force x pedestal height above ground level).

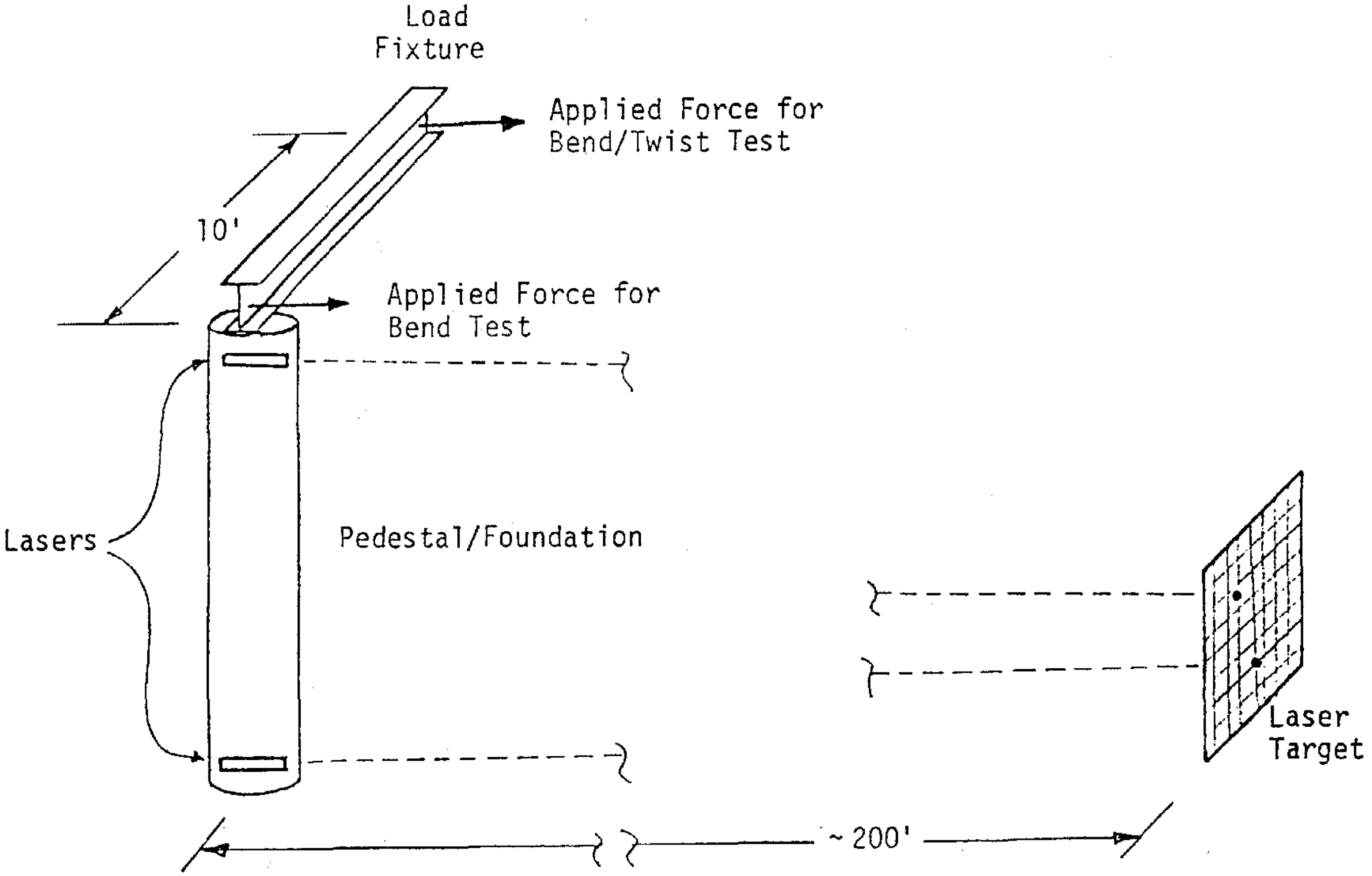


Figure 11-1 Test Set-up for Foundation Testing

SECOND GENERATION HELIOSTAT TEST PLAN

SECTION B - MIRROR MODULE TESTS

General Observations

The following general observations will be made during the test period by the Test Engineers for the Section B tests.

a) A log will be kept for the purpose of recording test completion dates, environmental cycles completed, problems encountered, and any other unusual or interesting event or observation pertaining to the mirror modules.

b) Liberal photo-documentation will be made of all tests and of any unusual or interesting visual observation.

c) Each of the mirror modules delivered to and tested at Livermore will be photographed before and after testing with a large grid (approximately 4" x 4" mesh) reflected in the mirror. If possible, each of these mirrors will also be characterized by the Heliostat Characterization System (backward gazing) at SNLL before and after testing.

d) The mirror module weight of each design will be measured.

e) Destructively evaluate one mirror module of each design at the completion of testing if appropriate.

TEST 1 - CONTOUR MEASUREMENT

1.1 Objective: To measure the large-scale mirror contour (curvature).

1.2 Prerequisites: Mirror modules should be held at a constant ambient temperature between 65°F and 80°F for at least six hours prior to the test to assure constant temperature throughout the module. Front and back surface temperatures of the module should be measured to determine whether temperature gradients exist. The mirror should be suitably supported as directed by Division 8451 personnel to simulate the heliostat-mounted support condition for the particular module design being tested.

1.3 Description: Mirror contour measurements will be made with a TBD instrument. Contour measurements will be made on each of the three mirror modules of each design delivered to SNLL at the time of delivery and as required by the other tests in this section.

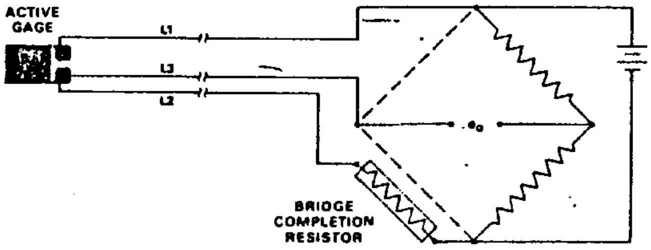
1.4 Data: Contour measurements, ambient temperatures, and temperatures of the front and back surfaces of each mirror module will be recorded. When the mirror module is loaded (e.g., with sandbags), the loading condition will be recorded.

TEST 2 - WIND LOAD GLASS STRESS

2.1 Objective: To determine the stress in the glass due to simulated wind loads. Also, to assess the adequacy of the mirror module attachment hardware.

2.2 Prerequisites: One mirror module from each contractor shall have biaxial SR-4 strain gages mounted on the front glass surface of the mirror in locations to be specified for each design.

A biaxial gage will be mounted on a small stress-free piece of glass which is subjected to the same temperatures as the mirror module so that apparent strains due to temperature change can be determined. The glass shall be taken from mirror samples supplied by each contractor. To minimize errors, strain gages from the same lot will be used, all gage wire leads will be the same length, and three-wire leads as shown below will be employed for each gage to compensate for temperature-induced resistance changes in the lead wires.



Three-Wire Lead for Strain Gage

It is very important that these precautions be taken due to the low levels of strain which are being measured.

2.3 Description: The mirror module to be tested will be placed mirror-face down, appropriately supported by the attachment hardware. The strain gages shall be nulled. The mirror module is then loaded uniformly to 20 psf with sandbags to simulate a 90 mph wind. The strains are read immediately and again after one hour. The strain gages are again nulled and test is repeated. The load is then left on the mirror module overnight. The ambient temperature shall be recorded at the time of each set of strain readings. One mirror module from each contractor is to be tested.

2.4 Data: Strain data for each mirror module design will be recorded. Any observed failure in the mirror module or attachment hardware will be documented.

TEST 3 - THERMAL STRESS AND CONTOUR CHANGE

3.1 Objective: To determine the change in mirror contour and stress in the glass with temperature change.

3.2 Prerequisites: One mirror module from each contractor will have strain gages mounted on it as described in Test No. 2. All strain reading precautions described there apply to this test.

3.3 Description: One mirror module from each contractor, instrumented with strain gages, will be placed face-up in an environmental chamber. The test sequence is as follows:

a. Hold temperature at 70°F for at least six hours.
b. Measure and record contour and mirror module temperatures (front and back surfaces) and null strain gages.
c. Raise temperature to 120°F and hold for at least 2 hours.
d. Measure contour, strains, and mirror temperatures.
e. Lower temperature to 70°F and hold for at least 2 hours.
f. Repeat d.
g. Lower temperature to 20°F and hold for at least 2 hours.
h. Repeat d.
i. Raise temperature to 70°F and hold for at least 2 hours.
j. Repeat d.
k. Repeat c, d, e, and f.
l. Lower temperature to -20°F and hold for at least 2 hours.
m. Record strains.
n. Raise temperature to 70°F and hold for at least 2 hours.
o. Repeat d.

3.4 Data: The information to be recorded consists of contour data, strain gage readings, and temperature measurements of the front and back surfaces of each mirror module.

TEST 4 - RESIDUAL GLASS STRESS

4.1 Objective: To measure the combined residual and fabrication-induced stresses along the edges of the glass.

4.2 Prerequisites: Clean glass. Hold mirror module at a constant ambient temperature between 65 and 80°F for at least six hours prior to the measurements.

4.3 Description: A reflection polariscope will be used to measure stress along the edges of the mirrors (as close to the edge as possible) at 6-inch intervals. The ambient temperature at the time of the measurements is to be recorded. One mirror module from each contractor will be tested.

4.4 Data: Stress measurements at 6-inch intervals along the edge of the glass will be recorded. Mirror glass temperature will also be recorded.

TEST 5 - GRAVITY SAG

5.1 Objective: Measure the change in the large-scale mirror contour due to different orientations of the mirror module to gravity.

5.2 Prerequisites: Hold the mirror module at a constant ambient temperature for at least six hours to assure that no changing thermal gradients affect the contour measurements. Appropriately support the mirror module to simulate the heliostat-mounted support condition with the mirror plane horizontal.

5.3 Description: Measure the mirror contour as specified in Test 1 (Contour Measurement) of this section. Then, without moving the mirror module, uniformly load the mirror module surface with sandbags or equivalent with a total mass equaling the weight of the mirror module. Repeat the contour measurement. One mirror module of each design will be tested.

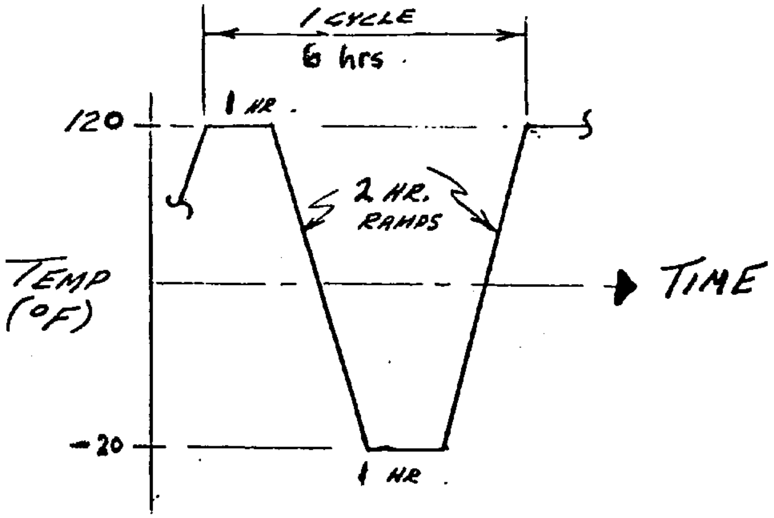
5.4 Data: The contour measurements taken with the mirror module both unloaded and loaded are recorded along with the ambient temperature and the front and back surface temperatures of the mirror module. The difference between the loaded contour and the unloaded contour is the contour change due to gravity sag.

TEST 6 - THERMAL CYCLING

6.1 Objective: To demonstrate structural and functional integrity of the mirror module. Specifically, to determine if any damage or change in mirror curvature results from thermal cycling between the temperature extremes.

6.2 Prerequisites: Measure contour (Test 1)

6.3 Description: One mirror module of each design will be temperature cycled for 28 days (112 cycles) between -20°F and 120°F (with uncontrolled humidity) as shown below:



TEMPERATURE CYCLE

Before and after cycling the mirror modules are to be closely inspected and the mirror contours are to be measured per Test 1 at a room temperature between 65 and 75°F. Mirror modules are to be held at a constant ambient temperature for at least six (6) hours before the contour measurements are made, and this temperature is to be recorded with the contour data.

If temperatures significantly higher than ambient are measured on a mirror module design under actual outdoor conditions, modules of that design may be tested to a temperature higher than 120°F.

6.4 Data: Visually observe at least once a week and record any damage to the mirrors due to cycling, and measure mirror contours before and after the test.

TEST 7 - ENVIRONMENTAL CYCLING

7.1 Objective: To demonstrate mirror integrity of the different mirror module designs when subjected to a quasi-accelerated aging test consisting of alternating high and low humidity, ultra-violet radiation, and temperature cycling. Potential survivability of these mirror module designs over the expected 30-year lifetime will be evaluated.

7.2 Prerequisites: This test is to immediately follow Test 6 in the environmental chamber.

7.3 Description: One mirror module of each design is to be temperature/humidity cycled for 180 days in accordance with the plan as shown. The significant aspects of the test plan are as follows:

7.3.1 TEMPERATURE CYCLING - The temperature will be cycled between 70°F and 130°F the entire period. The higher than specified temperatures will provide faster aging acceleration, as well as "thermal pumping" for the high humidity exposures. (Temperatures in excess of 130°F might have atypical effects on the sealant materials used. However, if temperatures significantly higher than ambient are measured on a mirror module design under actual outdoor conditions, modules of that design may be tested to a temperature higher than 130°F). Once a week, at the end of the "wet" cycle, the temperature will be lowered to -20°F.

7.3.2 RELATIVE HUMIDITY - The R. H. cycle will provide a very wet period (4 days) and a very dry period (3 days) alternating throughout the duration of the test. This cycle promotes degradation of sealants due to photolytic oxidation (wet period) and sealant bake out (drying and cracking). During the wet cycle, R.H. will be controlled to not less than 94% at 130°F, and not greater than 30% R.H. at 70°F for the dry cycle.

7.3.3 WETNESS - will be provided during the R.H. cycle by condensation or water spray.

7.3.4 ULTRA-VIOLET LIGHT - A source of UV light similar in spectra to solar UV at Air Mass 1 will shine continuously on portions of the module edge seals. (UV intensities greater than this may also give atypical results.)

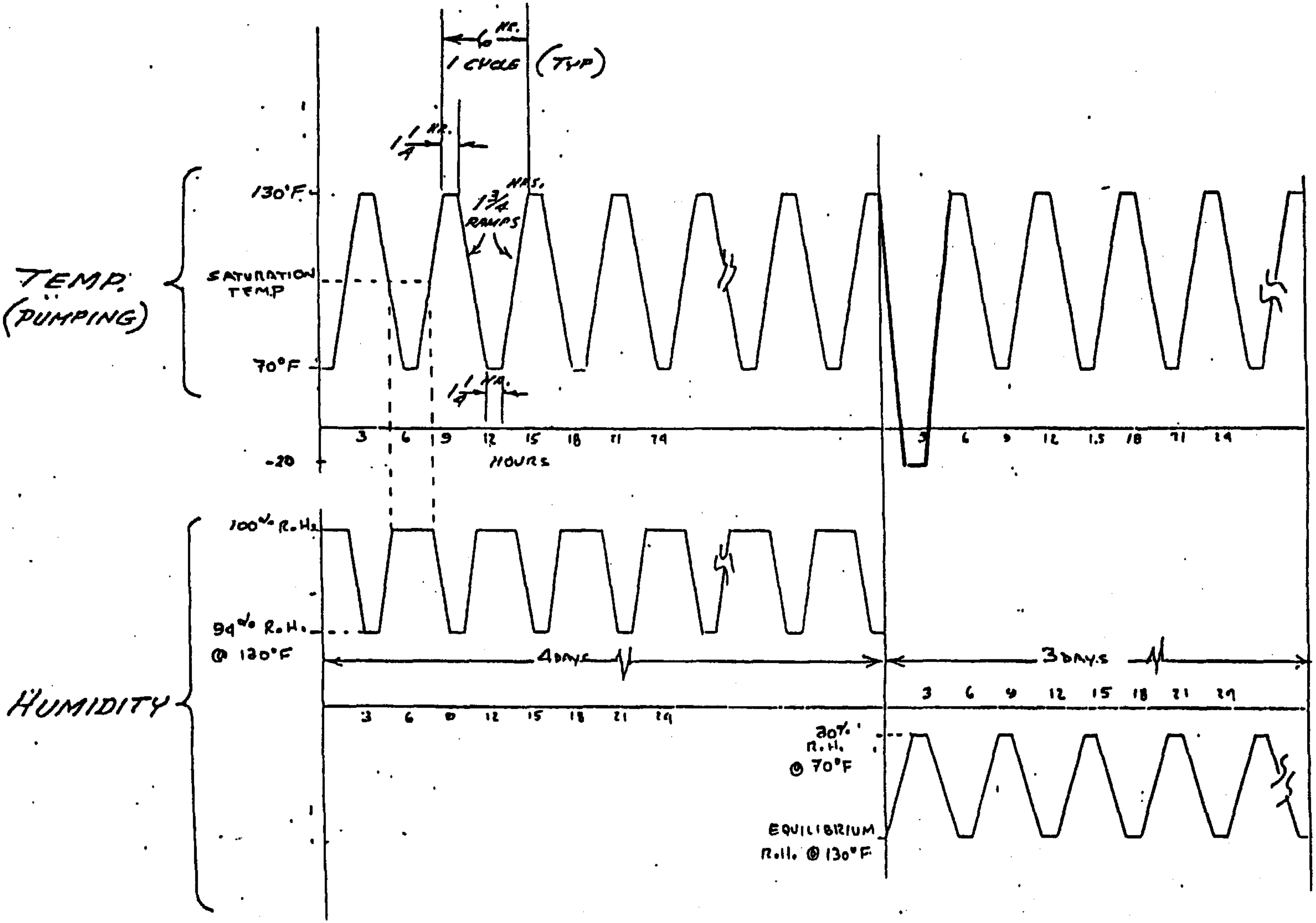
Every 30 days, the mirror modules are to be visually inspected. After 180 days of cycling, their contours are to be measured again per Test 1 after holding at least 6 hours at a constant temperature between 65 and 75°F. Further cycling, mirror module disassembly, or other disposition of this mirror module will be recommended by Division 8451 at the conclusion of this test.

7.4 Data: The humidity and temperature within the environmental chamber are to be continually recorded.

7.4 Data - Cont.

Measured contour data taken after completion of the cycling are to be recorded, along with the temperature at which contour measurements were taken.

Observations made during visual inspections are to be documented, noting particularly any signs of mirror deterioration.



TEMPERATURE AND R.H. CYCLES
FOR ACCELERATED AGING TESTS

TEST 8 - HAIL TEST

8.1 Objective: To determine whether the mirror module can meet the hail impact requirements.

8.2 Prerequisites: None

8.3 Description: One mirror module from each contractor will be subjected to 3/4-inch hail impacted at 65 ft/sec and/or 1-inch hail impacted at 75 ft/sec. Contractors without the feature of face-down stow (MDAC, BEC, and Northrup) will be required to survive the 1-inch hail on the mirror and the back of the module. The MMC design is stowed face down and is therefore required to survive 3/4-inch hail on the mirror. At least twenty simulated hailstones will be propelled at and perpendicular to the mirror glass, with the shots concentrated at locations most likely to break the glass. Any visible flaws in the glass should be tested. Twenty of the 1-inch ice balls will then be propelled at the backside of all modules at similar locations. Temperature of the ice balls should be between 20 to 25^{o}F during testing.

8.4 Data: Visually inspect both sides of the mirror module for hail-induced damage. If damage is evident the number of failures and locations shall be recorded, along with photo documentation of damaged areas. Impact locations should be recorded.

TEST 9 - COLD WATER SHOCK

9.1 Objective: To determine whether glass fractures will occur when a hot mirror module is subjected to cold water shock due to washing or rainfall.

9.2 Prerequisites: Completion of Tests 1 and 8.

9.3 Description: The mirror modules are to be visually inspected for prior crack damage and then placed in an environment chamber at 120°F for at least six hours. The modules are then removed and sprayed with 60 ± 5°F water within five minutes of removal. The facets shall then be inspected for crack damage. One mirror module from each contractor will be tested.

9.4 Data: Visually inspect for crack damage. If damage is evident, the number of failures and locations shall be recorded, along with photo documentation of damaged areas.

TEST 10 - REFLECTIVITY

10.1 Objective: To measure the specular reflectivity of the mirrors for a solar-weighted wavelength spectrum.

10.2 Prerequisites: Clean glass.

10.3 Description: Currently no portable reflectometer exists that will determine the solar-weighted specular reflectance properties of solar mirror materials. The detailed specular reflectance properties will be measured on small samples (approximately 6" x 6") using laboratory equipment: (1) Beckman DK-2 hemispherical reflectometer and (2) bi-directional reflectometer for cone angles from 1 mrad to 15 mrad at 500 nm. These results will be correlated with several portable reflectometers: (1) Gier Dunkle Solar Reflectometer Model MS-251; (2) portable bi-directional reflectometer developed by Sandia; and (3) portable absolute specular reflectometer developed by Beckman Instruments. The number of measurements taken will be sufficient to obtain an uncertainty in the average reflectance values of better than 1% with a 90% confidence level.

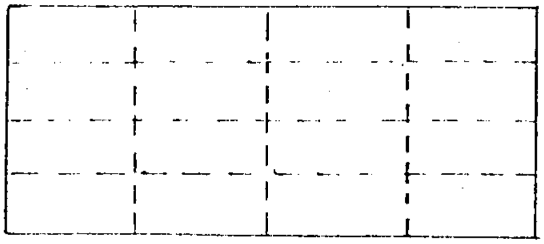
10.4 Data: Record reflectance data from the portable instruments for all mirror modules. Calculate average, standard deviations and confidence levels for all measurements. From all measuring, infer solar-weighted specular reflectance for cone angles from 1 mrad to 15 mrad.

TEST 11 - LASER RAY TRACE

11.1 Objective: To measure the effective mirror waviness which impacts on overall beam quality.

11.2 Prerequisites: Mirrors should be cleaned before the test and held at a constant ambient temperature between 65° to 75°F for six hours prior to the test.

11.3 Description: Mirror slope error measurements will be made with a reflected laser ray-trace set up. Six ray-trace sweeps will be made on each mirror, three parallel to the long edge of the mirror, and three parallel to the short edge of the mirror, as illustrated.



The mirror will be placed mirror-face up on a flat table while measurements are made. The mirrors are to be at uniform ambient temperature which must be recorded at the time of measurement for each mirror. One mirror module from each contractor will be measured. If there are apparent visual differences between the tested mirror and the mirrors mounted on the CRTF test heliostat of each design, then mirrors from the heliostat may be removed and characterized by laser ray trace also.

11.4 Data: Record mirror slope errors along three lines parallel to the long edge of the mirrors and along three lines parallel to the short edge of the mirrors. The reduced data should include plots of each sweep, the slope of a best-fit straight line passing through the data for each sweep (this gives the curvature of the mirror), and the rms value of the slope when the curvature has been subtracted from the data. Mirror temperature shall also be recorded.

APPENDIX C--CALCULATION OF HELIOSTAT WIND LOADS

The equation for moment on a flat plate about its center due to an aerodynamic load is:

$$M = \frac{1}{2} \rho L V^2 A C_m$$

where (for a heliostat):

ρ - air density
V - wind velocity
L - length of reflective area
A - area
C_D - drag coefficient
C_L - lift coefficient
C_{cp} - center of pressure coefficient
C_m - moment coefficient

The air density was chosen to be 0.081 lbm/ft^3 corresponding to approximately 32°F, 14.7 psia.

Wind velocity was calculated according to the equation in A10772 Collector Subsystem Requirements:

$$V = (V_o)(h/30 \text{ ft})^{.15}$$

where:

V_o - free stream velocity in ft/sec
h - height of center of pressure above ground (ft)

The moment coefficient (C_m) was calculated from data presented in ASCE Paper No. 3269, "Wind Forces on Structures." A plot of this data is shown in Fig. C-1.

The moment coefficient (C_m) was calculated based on the wind load force diagram in Fig. C-2.

$$\text{Moment} = \frac{1}{2} \rho V^2 A L C_m$$

$$\text{Drag} = \frac{1}{2} \rho V^2 A C_D$$

$$\text{Lift} = \frac{1}{2} \rho V^2 A C_L$$

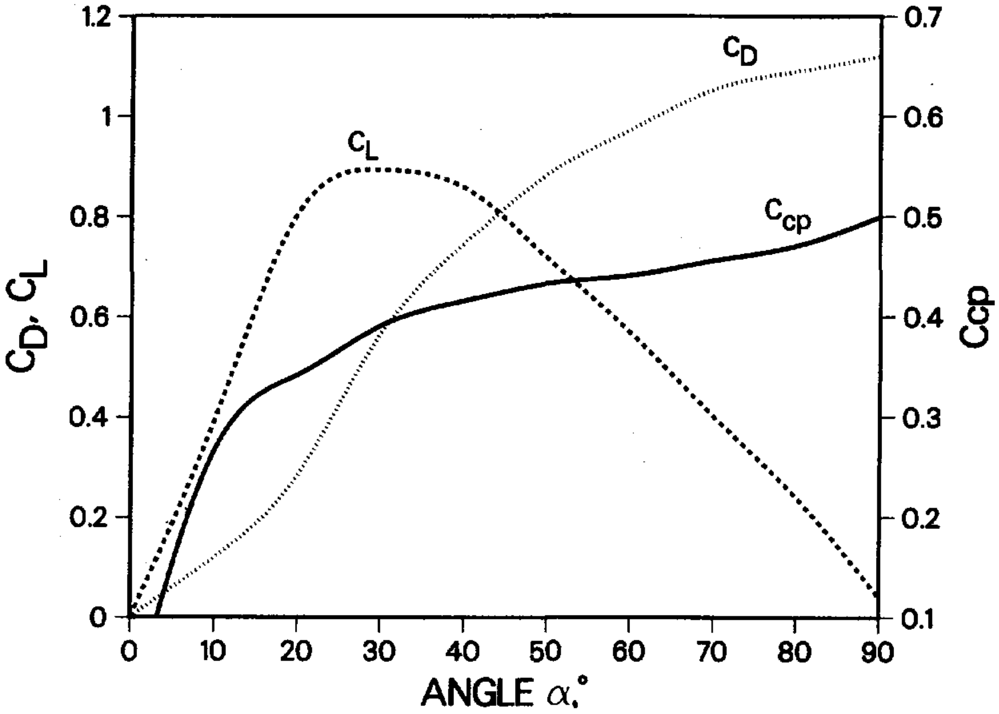


Figure C-1. Aerodynamic Coefficients

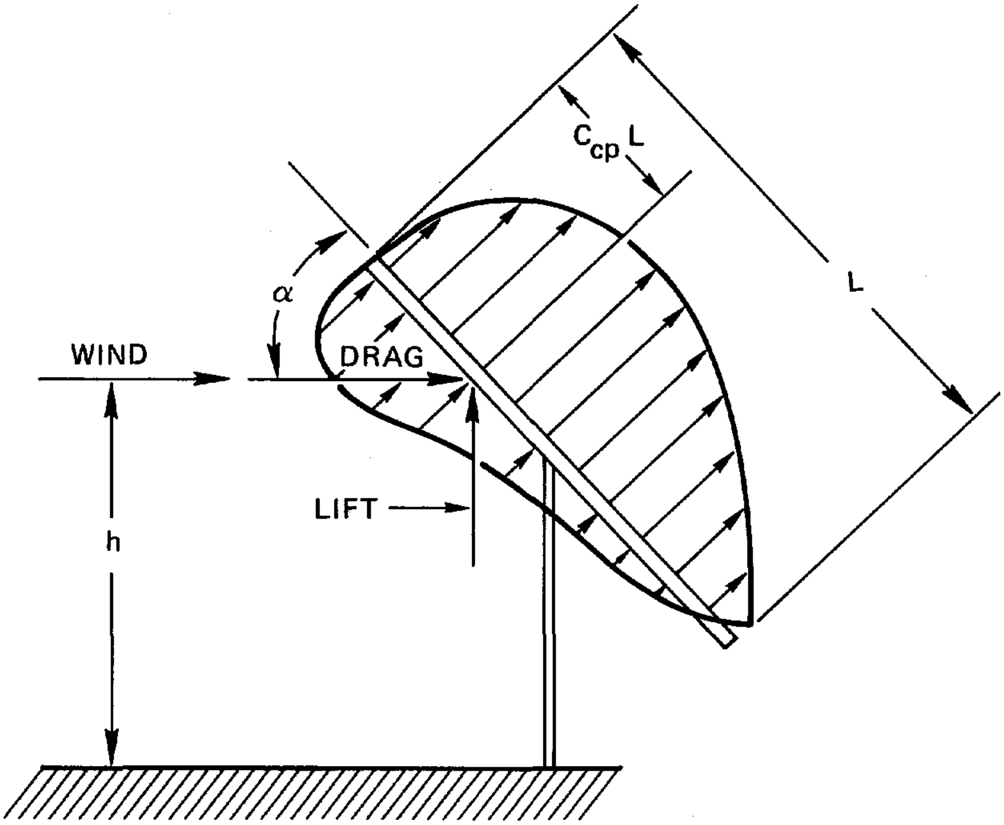


Figure C-2. Wind Load Force Diagram

$$\text{Moment} = \text{Drag} \times L \sin\alpha \left(\frac{1}{2} - C_{cp}\right)$$

$$+ \text{Lift} \times L \cos\alpha \left(\frac{1}{2} - C_{cp}\right)$$

$$\frac{1}{2}\rho V^2 ALC_m = \frac{1}{2}\rho V^2 AL \left(\frac{1}{2} - C_{cp}\right)\left(C_D \sin\alpha + C_L \cos\alpha\right)$$

$$C_m = \left(\frac{1}{2} - C_{cp}\right)\left(C_D \sin\alpha + C_L \cos\alpha\right)$$

Some results of this equation are given in Table C-I.

The physical dimensions for each contractor's heliostat are given in Table C-II. It should be noted that the area of the small slots between adjacent mirror modules was included in the total heliostat area in these calculations. Table C-III gives the calculated test loads for the heliostats.

The operating windloads were calculated for the heliostat oriented at a 20° angle to the wind, which produces the highest moments. Tests at other orientations, such as the 60° elevation tests, were run at these same loads (not the same equivalent windspeed); therefore, the test conditions at these other orientations are higher than the heliostat would experience at the tested angle of attack and stated windspeed.

The survival wind loads in elevation and cross-elevation were calculated for the wind impinging at a 10° angle of attack as required in A10772.

TABLE C-I

AERODYNAMIC COEFFICIENTS

	C_{cp}	C_L	C_D	C_m
0	0	0	0	0
10	0.267	0.394	0.119	0.095
20	0.342	0.806	0.284	0.135
30	0.391	0.893	0.567	0.115
40	0.416	0.857	0.746	0.084
50	0.433	0.716	0.884	0.076
60	0.441	0.567	0.973	0.066
70	0.456	0.400	1.054	0.050
80	0.471	0.239	1.090	0.032
90	0.500	0.040	1.120	0

TABLE C-II

SECOND GENERATION HELIOSTAT DIMENSIONS

	ARCO	BEC	MMC	MDAC
Area (ft^2)	591	493	643	640
Elevation				
L(ft)	24.5	24.5	25.2	22.5
h(ft)				
stow	15.0	14.0	12.2	15.0
20°	17.0	16.1	15.4	16.7
Azimuth				
L(ft)	24.1	20.1	26.7	28.4
h(ft)	13.3	13.3	12.7	12.4

TABLE C-III

EQUIVALENT WIND LOAD MOMENTS

Windspeed (mph)		ARCO El	ARCO Az	BEC El	BEC Az	MMC El	MMC Az	MDAC El	MDAC Az
14		833	766	652	533	934	974	832	954
20		1705	1563	1331	1087	1909	1986	1698	1947
27		3108	2848	2426	1981	3478	3620	3094	3548
35		5223	4786	4077	3329	5845	6083	5199	5962
50	80%	-	7814	-	5435	-	9931	-	9734
	90%	-	8791	-	6115	-	11173	-	10951
	100%	10659	9768	8320	6794	11929	12414	10611	12168
	110%	-	10745	-	7474	-	13655	-	13385
			Cross El		Cross El		Cross El		Cross El
90	80%	19477	19159	15911	10354	21457	22734	19358	24434
	90%	21911	21554	17900	14685	24139	25575	21777	27488
	100%	24346	23949	19889	16317	26821	28417	24197	30542
	110%	26781	26344	21878	17949	29503	31259	26617	33596

APPENDIX D--SUBSURFACE SOIL CONDITIONS AT THE CRTF

SUBSURFACE INVESTIGATION AT SANDIA'S CENTRAL RECEIVER TEST FACILITY

INTRODUCTION

This section describes the subsurface investigation at Sandia's Central Receiver Test Facility (CRTF), Albuquerque, New Mexico. This investigation was conducted in order to determine the subsurface stratigraphy and to develop strength and stiffness parameters for the soils in the vicinity of the prototype heliostats (see Figure P-1). These data were used to make refined predictions of the lateral load-deflection behavior of the heliostat foundations.

SUBSURFACE INVESTIGATION

On March 25, 26, and 27, 1981, two borings were drilled by Sergent, Hauskins, and Beckwith of Albuquerque, New Mexico, under continuous monitoring by Mr. P. E. Glogowski of GAI. Referring to Figure P-1, one of the borings was located approximately 45 feet (14 m) north of Arco Heliostat No. 2, while one of the borings was located approximately 50 feet (15 m) southwest of McDonnell Douglas Heliostat No. 1. In addition, a nearby foundation excavation for the proposed instrument calibration facility was examined. Detailed field classification sheets for Borings TB-1 and TB-2, and for the excavation noted above are presented in Figures P-2, P-3 and P-4, respectively.

The drilling program consisted of disturbed sampling, standard penetration testing, and pressuremeter testing. In addition, soil samples from the borings and a bulk sample from the foundation excavation were returned to GAI's laboratory for further evaluation.

The borings were advanced and cleaned using hollow stem augers and a tri-cone roller bit and synthetic drilling mud. Standard Penetration Tests were conducted at intervals ranging from three to five feet (0.9 to 1.5 m).

Referring to the detailed field classification sheets presented in Figures P-2, P-3, and P-4, subsurface conditions at the site consist of four to five feet (1.2

to 1.5 m) of medium dense to dense silty sand and gravel, underlain by medium dense to very dense sand and gravel. The water table at the site is apparently in excess of 18 feet (5.5 m) below ground surface (maximum boring depth). Referring to Figure P-4, the excavation for the instrument calibration facility revealed an approximately four-foot (1.2 m) thick cemented sand and gravel layer near the ground surface. In general, the soil at the site can be said to be angular and well graded, with random layers of boulders in excess of 6 inches (152 mm).

A three-inch (76 mm) O.D., NX-size pressuremeter probe was used at the CRTF site. A tri-cone roller bit and revert drilling mud were used to prepare pressuremeter test sections. Pressuremeter data are presented in Table P-1.

LABORATORY TESTING

Undisturbed samples of the soils at the CRTF could not be obtained because of the presence of gravels in the soil. However, as noted above, a bag sample was returned to GAI's laboratory for testing. This sample was considered to be representative of the dominant soil at the site (sand and gravel). Referring to Table P-2, relative density limits (ASTM D 2049-69) were developed for this sample. Direct shear tests were then conducted on samples remolded at relative densities of 22.8, 50.0 and 100 percent. As can be seen in Table P-2, the effective angle of internal friction varied from 40.5 degrees to 50.0 degrees, while the apparent effective cohesion varied from zero to 1050 psf (49 kPa). The considerable strength of this soil can be attributed to the angularity of the soil particles and to the well-graded nature of the soil.

Table P-1

Sandia's Central Receiver Test Facility
Pressuremeter Test Data

Boring	Test Number	Pressuremeter Test Depth (ft)	Modulus of Deformation (ksi)	Soil Type*
TB1	1	3.0	2.0	Silty Sand and Gravel
TB1	2	8.8	2.0	Gravel
TB1	3	13.0	6.9	Sand and Gravel
TB2	4	2.5	5.7	Silty Sand and Gravel
TB2	5	6.0	0.7	Sand and Gravel
TB2	6	9.5	1.3	Sand and Gravel
TB2	7	13.0	5.4	Sand and Gravel
TB2	8	16.5	5.3	Sand and Gravel

---

*Field Classification

Note: 1 ft = 0.3048 m
1 ksi = 6.895 MPa
1 ksf = 47.83 kPa

Table P-2

Sandia's Central Receiver Test Facility
Summmary of Laboratory Tests
Bag Sample from the Instrument Calibration Facility Excavation

						Direct Shear** Test Results	
Sample Identification	Moisture Content	Minimum* Density (pcf)	Maximum* Density (pcf)	Remolded Density (pcf)	Relative Density (percent)	Effective Angle of Internal Friction, $\bar{\phi}$ (Degrees)	Effective Cohesion, (psf)
Remolded Sample No. 1	Air Dry	96.0	126.0	101.5	22.8	40.5	0.0
Remolded Sample No. 2	Air Dry	96.0	126.0	109.0	50.0	50.0	180.0
Remolded Sample No. 3	Air Dry	96.0	126.0	126.0	100.0	50.0	1050.0

---

* Determined by ASTM Standard D 2049-69.

** Determined by ASTM Standard D 3080-72(79).

Notes: The bag sample (sand and gravel) was divided on a U.S. Standard No. 4 Sieve. The material passing this sie was used to determine relative density limits and to prepare the remolded test specimens for the direct shea tests.

1 pcf = 1.609 kg/m^3
1 psf = 47.38 Pa

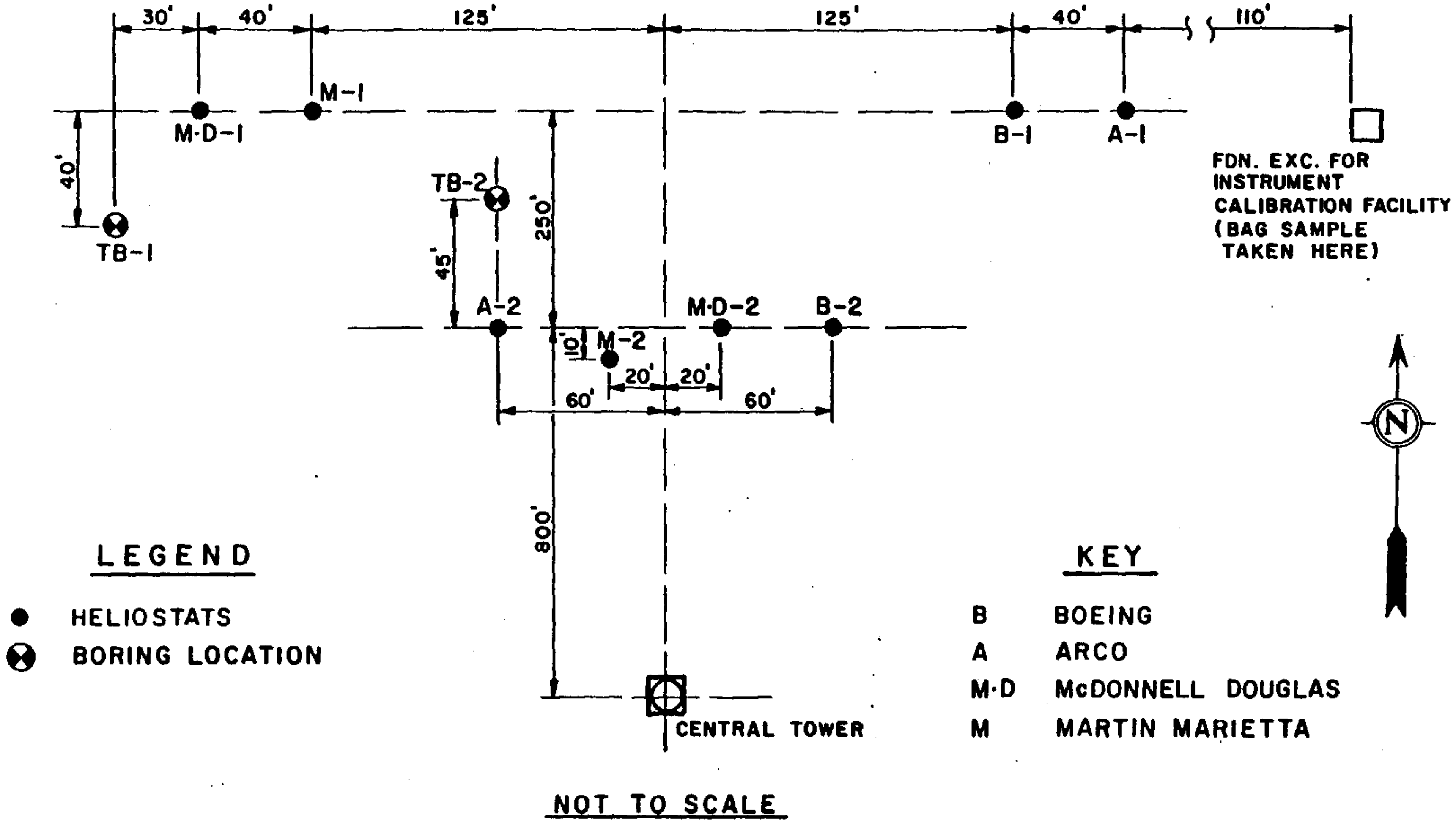


FIGURE P-1 PLAN AND LOCATION OF TEST BORINGS AND HELIOSTATS, SANDIA'S CENTRAL RECEIVER TEST FACILITY

PROJECT SANDIA'S CRTF PROJECT NO. 76-527-610
ELEVATION 99.8 *GWL 0 HRS DRY BORING NO. TB-1
HRS
DATE 3-25-81 FIELD ENGINEER P. E. Glogowski PAGE NO. 1 OF 2

DEPTH FEET	BLOWS PER SIX INCHES OR CORE RECOVERY/RUN	SAMPLE NO., TYPE & RECOVERY OR % ROCK RECOVERY	CASING BLOWS	DESCRIPTION				USCS OR ROCK BROKENNESS	REMARKS* PERTINENT TO PRESSUREMETER TESTING
				LAYER BOUNDARIES	SOIL DENSITY-CONSISTENCY OR ROCK HARDNESS	COLOR	MATERIAL CLASSIFICATION		
1	2	3	4	5	6	7	8	9	10
	4				MED DENSE	BRN	SILTY SAND-TRACE OF GRAVEL		
	8	S-1							
1.5	7			1.5			(ROCK FRAGMENTS)		
					MED DENSE	TAN	SILTY SAND AND GRAVEL		
		ST-1							
									PROBE CT.@ 3.0'
3.5									
4.0									
	9			4.5					
	22	S-2			MED DENSE	BRN TO	SAND AND GRAVEL		
5.5	20				TO DENSE	TAN			
				6.0					
					MED DENSE		GRAVEL		
				8.0					
					DENSE TO	GRAY	SAND (MED COARSE) AND GRAVEL		
					VERY DENSE	TAN			8.75' CENTER OF
									PROBE
10.5									
	29								
	29	S-3							
12.0	50								
									13.0' CENTER OF
									PROBE

REMARKS:** REVERT MUD, TRI-CONE BIT AND HOLLOW STEM AUGERS USED TO ADVANCE HOLE

PROJECT NO. 76-527-610
BORING NO. TB-1

* POCKET PENETROMETER READINGS
** METHOD OF ADVANCING AND CLEANING BORING
* USE DATUM-BASE OF McDONNELL DOUGLAS HELIOSTAT NO. 1 AS 100.0'

Figure P-2a. Sandia's CRTF
Detailed Field Classification Sheet, Boring TB-1

PROJECT SANDIA'S CRTF PROJECT NO. 76-527-610
ELEVATION 99.8 GWL 0 HRS DRY BORING NO. TB-1
HRS
DATE 3-25-81 FIELD ENGINEER P. E. Glogowski PAGE NO. 2 OF 2

DEPTH FEET	BLOWS PER SIX INCHES OR CORE RECOVERY/RUN	SAMPLE NO., TYPE & RECOVERY OR % ROCK RECOVERY	CASING BLOWS	DESCRIPTION				USCS OR ROCK BROKENNESS	REMARKS*
				LAYER BOUNDARIES	SOIL DENSITY-CONSISTENCY OR ROCK HARDNESS	COLOR	MATERIAL CLASSIFICATION		
1	2	3	4	5	6	7	8	9	10
14.5			14.	5	VERY DENSE	GRAY TAN	SAND (COARSE TO MED) AND GRAVEL		
	9		15.	0	MED DENSE	BRN	FINE SAND		
	25	S-4			DENSE TO	TAN	SAND (COARSE) AND GRAVEL		
16.0	27				VERY DENSE	GRAY			
					↓	↓	↓		
					MED DENSE TO DENSE	TAN GRAY	SAND (COARSE TO MED) AND GRAVEL		
17.3									
	9								
	18	S-5							
18.8	21				↓	↓	↓		
							BOTTOM OF BORING		

REMARKS** REVERT MUD, TRI-CONE BIT AND HOLLOW STEM AUGERS USED TO ADVANCE HOLE

PROJECT NO. 76-527-610

BORING NO. TB-1

* POCKET PENETROMETER READINGS
** METHOD OF ADVANCING AND CLEANING BORING

Figure P-2b. Sandia's CRTF
Detailed Field Classification Sheet, Boring TB-1

PROJECT SANDIA'S CRTF PROJECT NO. 76-527-610
ELEVATION 100.4 * GWL 0 HRS DRY BORING NO. TB-2
HRS
DATE 3-26-81 FIELD ENGINEER P. E. Glogowski PAGE NO. 1 OF 2

DEPTH FEET	BLOWS PER SIX INCHES OR CORE RECOVERY/RUN	SAMPLE NO., TYPE & RECOVERY OR % ROCK RECOVERY	CASING BLOWS	DESCRIPTION				USCS OR ROCK BROKENNESS	REMARKS*
				LAYER BOUNDARIES	SOIL DENSITY-CONSISTENCY OR ROCK HARDNESS	COLOR	MATERIAL CLASSIFICATION		
1	2	3	4	5	6	7	8	9	10
	7			0.5	DENSE	BRN	SILTY SAND - TRACE OF GRAVEL		
	10	S-1			DENSE TO	TAN	SILTY SAND AND GRAVEL		
1.5	24				VERY DENSE				
				2.0					
					MED DENSE	TAN	FINE TO COARSE SAND, SOME GRAVEL		CENTER PROBE AT
									2.5'
3.5									
	6								
	8	S-2		4.5					
5.0	13				DENSE	BRN TO TAN	FINE TO COARSE SAND AND GRAVEL		
									CENTER PROBE AT
									6.0'
7.0									
	8								
	15	S-3			DENSE	TAN	SAND (COARSE TO MED) AND GRAVEL		
8.5	17								
									CENTER PROBE AT
									9.5'
10.5									
	12			11.0					
	25	S-4			VERY DENSE	TAN	SAND (COARSE TO MED) AND GRAVEL		
12.0	28								
									CENTER PROBE AT
									13.0'

REMARKS** REVERT MUD; TRI-CONE ROLLER BIT AND HOLLOW STEM AUGERS USED TO ADVANCE HOLES

PROJECT NO. 76-527-610
BORING NO. TB-2

* POCKET PENETROMETER READINGS

** METHOD OF ADVANCING AND CLEANING BORING

* USE DATUM-BASE OF NORTHRUP #2 AT 100.0'

Figure P-3a. Sandia's CRTF
Detailed Field Classification Sheet, Boring TB-2

PROJECT SANDIA'S CRTF PROJECT NO. 76-527-610
ELEVATION 100.4 GWL 0 HRS DRY BORING NO. TB-2
HRS
DATE 3-26-81 FIELD ENGINEER P. E. Glogowski PAGE NO. 2 OF 2

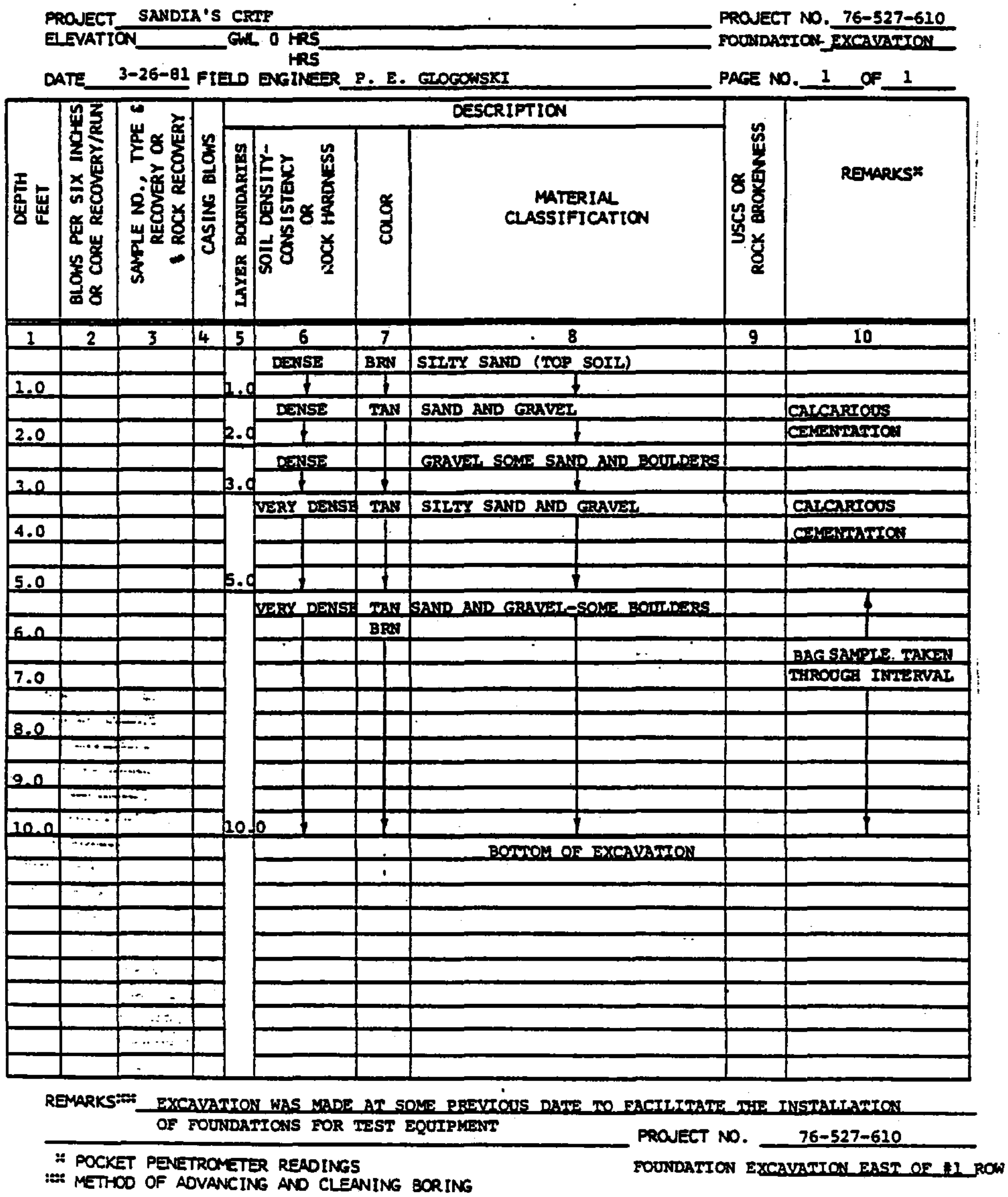
DEPTH FEET	BLOWS PER SIX INCHES OR CORE RECOVERY/RUN	SAMPLE NO., TYPE & RECOVERY OR % ROCK RECOVERY	CASING BLOWS	DESCRIPTION				USCS OR ROCK BROKENNESS	REMARKS*
				LAYER BOUNDARIES	SOIL DENSITY-CONSISTENCY OR ROCK HARDNESS	COLOR	MATERIAL CLASSIFICATION		
1 14.0	2	3	4	5	6	7	8	9	10
	27				VERY DENSE	TAN	SAND (COARSE TO MED) AND GRAVEL		
	47	S-5							
15.5	37								
									PROBE CENTER AT
									16.5'
17.5									
							BOTTOM OF BORING		

REMARKS** REVERT MUD; TRI-CONE ROLLER BIT AND HOLLOW STEM AUGERS USED TO ADVANCE HOLES.

PROJECT NO. 76-527-610
BORING NO. TB-2

* POCKET PENETROMETER READINGS
** METHOD OF ADVANCING AND CLEANING BORING

Figure P-3b. Sandia's CRTF
Detailed Field Classification Sheet, Boring TB-2



PROJECT SANDIA'S CRTF PROJECT NO. 76-527-610
ELEVATION ______ GWL 0 HRS FOUNDATION EXCAVATION
HRS
DATE 3-26-81 FIELD ENGINEER P. E. GLOGOWSKI PAGE NO. 1 OF 1

				DESCRIPTION					
DEPTH FEET	BLOWS PER SIX INCHES OR CORE RECOVERY/RUN	SAMPLE NO., TYPE & RECOVERY OR % ROCK RECOVERY	CASING BLOWS	LAYER BOUNDARIES	SOIL DENSITY-CONSISTENCY OR ROCK HARDNESS	COLOR	MATERIAL CLASSIFICATION	USCS OR ROCK BROKENNESS	REMARKS*
1	2	3	4	5	6	7	8	9	10
					DENSE	BRN	SILTY SAND (TOP SOIL)		
1.0				1.0	↓	↓	↓		
					DENSE	TAN	SAND AND GRAVEL		CALCARIOUS
2.0				2.0	↓		↓		CEMENTATION
					DENSE		GRAVEL SOME SAND AND BOULDERS		
3.0				3.0	↓	↓	↓		
					VERY DENSE	TAN	SILTY SAND AND GRAVEL		CALCARIOUS
4.0									CEMENTATION
5.0				5.0	↓	↓	↓		
					VERY DENSE	TAN	SAND AND GRAVEL-SOME BOULDERS		↑
6.0						BRN			
									BAG SAMPLE TAKEN
7.0									THROUGH INTERVAL
8.0									
9.0									
10.0				10.0	↓	↓	↓		↓
							BOTTOM OF EXCAVATION		

REMARKS** EXCAVATION WAS MADE AT SOME PREVIOUS DATE TO FACILITATE THE INSTALLATION OF FOUNDATIONS FOR TEST EQUIPMENT

PROJECT NO. 76-527-610
FOUNDATION EXCAVATION EAST OF #1 ROW

* POCKET PENETROMETER READINGS
** METHOD OF ADVANCING AND CLEANING BORING

Figure P-4. Sandia's CRTF
Detailed Field Classification Sheet, Foundation Excavation

REFERENCES

1. V. P. Burolla and W. R. Delameter, "Testing and Evaluation of Second Generation Heliostat Mirror Modules," Sandia National Laboratories, SAND81-8263, 1982.

2. D. L. King, "Beam Quality and Tracking Accuracy Evaluation of Second Generation and Barstow Production Heliostats," Sandia National Laboratories, SAND82-0181.

3. V. D. Dunder, "Structural Analysis of Second Generation Heliostats," Sandia National Laboratories, SAND81-8023, 1981.

4. "Second Generation Heliostat Evaluation, Executive Summary," Sandia National Laboratories, SAND81-8033, 1982.

5. "Second Generation Heliostat Evaluation, Summary Report," Sandia National Laboratories, SAND81-8034, 1982.

6. H. F. Norris, Jr., and S. S. White, "Manufacturing and Cost Analyses of Heliostats Based on the Second Generation Heliostat Development Study," Sandia National Laboratories, SAND82-8007, 1982.

7. Northrup, Inc., "Second Generation Heliostat Development for Solar Central Receiver Systems, Detailed Design Report, Volume I, Technical Discussion, and Volume II, Appendices," Sandia National Laboratories, SAND79-8194, 1980.

8. Northrup, Inc., "Second Generation Heliostat Development for Solar Central Receiver Systems, Final Report," Sandia National Laboratories, SAND81-8178, 1981.

   Volume I - Introduction, Summary, Heliostat Description
   Volume II - Manufacturing, Transportation, Field Assembly, Installation, Maintenance, Cost Estimates
   Volume III - Bill of Material, Drawings, Trade Studies, System Studies
   Volume IV - Control Software, Test Results, Manufacturing, Pile Installation, Pile Coatings

9. Boeing Engineering and Construction, "Final Report, Second Generation Heliostat Development for Solar Central Receivers," Sandia National Laboratories, SAND81-8175, 1981.

   Volume I - Detailed Design Report
   Volume I - Appendices I - Detailed Design Report
   Volume I - Appendices II - Detailed Design Report
   Volume II - Production Planning and Cost Estimates
   Volume III - Appendices I, J

10. Martin Marietta Corporation, "Second Generation Heliostat Development," Sandia National Laboratories, SAND79-8192, 1980.

   Volume I - Detailed Design Report
   Volume II - Appendices

11. Martin Marietta Corporation, "Second Generation Heliostat Development," Sandia National Laboratories, SAND81-8176, 1981.

12. McDonnell Douglas Astronautics Company, "Second Generation Heliostat Detailed Design Report," Sandia National Laboratories, SAND78-8192, 1980.

13. McDonnell Douglas Astronautics Company, "Second Generation Heliostat Program, Executive Summary," Sandia National Laboratories, SAND81-8177, 1981.

14. McDonnell Douglas Astronautics Company, "Final Report--Second Generation Heliostat with High Volume Manufacturing Facility Defined by General Motors," Sandia National Laboratories, SAND81-8177, 1981.

15. McDonnell Douglas Astronautics Company, "Final Report--Second Generation Heliostat with High Volume Manufacturing Facility Defined by General Motors," Sandia National Laboratories, SAND81-8187, Addendum to SAND81-8177, 1981. Test Report - Life Cycle and Operational Torque Capability of the Second Generation Azimuth Drive.

16. Westinghouse Electric Corporation, "Design Report, Westinghouse Second Generation Heliostat," Sandia National Laboratories, SAND79-8193, 1980.

   Volume I - Design Engineering
   Volume II - Manufacturing, Installation, Transportation, and Cost Estimates

17. R. Zajac, "Lubricant Study for a Special Elevation Drive for Ford Aerospace and Communications," Winsmith, unpublished report.

18. GAI Consultants, Inc., "Laterally Loaded Drilled Pier Research," Electric Power Research Institute, EL-2197, 1982.

   Volume I - Design Methodology
   Volume II - Research Documentation

19. American Society of Civil Engineers, "Wind Forces on Structures," Paper 3269, 1972.

UNLIMITED RELEASE

INITIAL DISTRIBUTION

U.S. Department of Energy
James Forrestal Building
1000 Independence Avenue, SW
Washington, DC 20585
Attn: C. Carwile
K. T. Cherian
F. Morse
M. Sheve

U. S. Department of Energy
1333 Broadway
Oakland, CA 94612
Attn: R. W. Hughey
For: K. A. Rose

U.S. Department of Energy
Solar One Field Office
P. O. Box 366
Daggett, CA 92327
Attn: S. D. Elliott

University of Houston
Energy Laboratory
4800 Calhoun
Houston, TX 77004
Attn: A. F. Hildebrandt

AMFAC
700 Bishop Street
Honolulu, HI 96801
Attn: G. St. John

ARCO Power Systems
7061 S. University
Suite 300
Littleton, CA 80122
Attn: J. Anderson
F. A. Blake

ARCO
911 Wilshire Boulevard
Los Angeles, CA 90017
Attn: J. H. Caldwell, Jr.

Arizona Public Service Company
P.O. Box 21666, Sta. 5629
Phoenix, AZ 85036
Attn: D. L. Barnes
E. Weber

Arthur D. Little, Inc.
One Maritime Plaza
San Francisco, CA 94111
Attn: John F. Butterfield

Battelle/Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99532
Attn: K. Drumheller

Bechtel National, Inc.
P.O. Box 3965
San Francisco, CA 94119
Attn: E. Lam
G. W. Braun
For: J. B. Darnell
R. L. Lessley

Black & Veatch
P.O. Box 8405
Kansas City, MO 64114
Attn: C. Grosskreutz
For: J. E. Harder
J. Kintigh
S. Levy

Boeing Engineering and Construction
P.O. Box 3707
Seattle, WA 98002
Attn: R. L. Campbell
R. B. Gillette

California Energy Commission
1111 Howe Avenue
Sacramento, CA 95825
Attn: A. Jenkins
M. Ringer

Chevron Oil Field Research Company
P.O. Box 446
La Habra, CA 90631
Attn: W. Peake
For: S. Griston
J. Ploeg
W. Stiles

Chevron Research Company
576 Standard Avenue
Richmond, CA 94804
Attn: L. Fraas
J. P. Jarrell

Corning Glass Works
Advanced Products, Bldg. 8-5
Corning, NY 14830
Attn: A. F. Shoemaker

El Paso Electric Company
P.O. Box 982
El Paso, TX 77960
Attn: J. D. Brown
M. L. Bonem

Exxon Enterprises
Solar Thermal Systems
P.O. Box 592
Florham Park, NJ 07932
Attn: P. Joy
For: D. Nelson

General Electric
1 River Road
Schenectady, NY 12345
Attn: J. Garate
For: R. N. Griffin

General Motors
GM Technical CenterDetroit, MI 48090
Attn: J. F. Britt

Houston Lighting and Power
P.O. Box 1700
Houston, TX 77001
Attn: J. Ridgway

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
Attn: A. T. Marriott
For: W. J. Carley
V. W. Gray
T. O. Thostesen

Kaiser Engineers
P.O. Box 23210
Oakland, CA 94623
Attn: F. L. Harris

Los Angeles Water and Power Department
111 North Hope Street
Los Angeles, CA 90051
Attn: R. F. Balingit
W. Engels
J. Kluger
T. Miller
B. M. Tuller

Martin Marietta
P.O. Box 179
Denver, CO 80201
Attn: P. R. Brown
    A. E. Hawkins
    L. P. Oldham
    W. L. DeRocher, Jr.

McDonnell Douglas
5301 Bolsa Avenue
Huntington Beach, CA 92647
Attn: C. R. Easton
    B. K. Knowles
    D. A. Steinmeyer
    L. Weinstein

Modern Alloys, Inc.
11172 Western Avenue
Stanton, CA 90680
Attn: E. Davis

Muller Associates, Inc
600 Maryland Avenue SW
Suite 430
Washington, DC 20024
Attn: J. Singleton

Polydyne, Inc. & Associates
1230 Sharon Park Drive, Suite 61
Menlo Park, CA 94025
Attn: P. B. Bos

Public Service Company of New Mexico
P.O. Box 2267
Albuquerque, NM 87103
Attn: A. Akhil

Rockwell International
Energy Systems Group
8900 DeSoto Avenue
Canoga Park, CA 91304
Attn: A. Ullman

Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401
Attn: L. W. Murphy
    J. Thorton
    B. L. Butler

Southern California Edison
P.O. Box 800
Rosemead, CA 92807
Attn: J. Reeves
M. J. Skowronski
P. Skvarna
C. Winarski

Southwestern Public Service Company
P.O. Box 1261
Amarillo, TX 79170
Attn: M. D. Freeman
A. Higgins

Standard Oil of California
555 Market Street
San Francisco, CA 94105
Attn: S. Kleespies

U.S. Gypsum
101 S. Wacker Drive
Chicago, IL 60606
Attn: Ray McCleary

Washington Water & Power
E 1411 Mission Street
Spokane, WA 99216
Attn: A. Meyers

West Texas Utilities Company
P.O. Box 841
Abilene, TX 79604
Attn: C. A. Bissett
For: R. Stanaland

Westinghouse
P.O. Box 10864
Pittsburgh, PA 15236
Attn: R. W. Devlin
W. G. Parker

Winsmith
172 Eaton
Springville, NY 14141
Attn: W. H. Heller

C. S. Selvage
DFVLR
Operating Agent for IEA/SSPS
P.O. Box 649
Almeria, Spain

P. J. Eicker, 0301
R. G. Kepler, 1810; Attn: L. A. Harrah, 1811
J. G. Curro, 1813
F. P. Gerstle, 1814
J. N. Sweet, 1824; Attn: R. B. Pettit, 1824
E. P. Roth, 1824
E. H. Beckner, 6000
V. L. Dugan, 6200
D. G. Schueler, 6220; Attn: J. F. Banas, 6221
J. A. Leonard, 6227
J. V. Otts, 6222
R. S. Claassen, 8000; Attn: D. M. Olson, 8100
A. N. Blackwell, 8200
D. L. Hartley, 8300
V. D. Revelli, 8122
R. J. Gallagher, 8124
M. John, 8125
C. S. Hoyle, 8129
W. S. Rorke, Jr., 8131
S. S. White, 8162
R. L. Rinne, 8220; Attn: J. Vitko, 8228
L. Brandt, 8228
F. R. Hansen, 8228
R. W. Rohde, 8310; Attn: L. A. West, 8315
W. R. Even, Jr., 8315
L. Gutierrez, 8400; Attn: R. A. Baroody, 8410
A. G. Schuknecht, 8420
H. Hanser, 8440
J. Barham, 8460
J. Wright, 8450
H. F. Norris, Jr., 8452
A. C. Skinrood, 8452
D. N. Tanner, 8452
T. B. Brumleve, 8453
W. R. Delameter, 8453
C. L. Mavis, 8453
W. G. Wilson, 8453 (10)
J. B. Woodard, 8454
Publications Division 8265, for TIC (27)
Publications Division 8265/Technical Library Processes Division, 3141
Technical Library Process Division, 3141 (3)
M. A. Pound, 8424, for Central Technical Files (3)