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Second Generation Heliostat Evaluation Summary Report

Heliostat Development Division

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.

Printed January 1982

Sandia National Laboratories
energy report

2900-QQB(3-80)

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

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SECOND GENERATION HELIOSTAT EVALUATION SUMMARY REPORT

Heliostat Development 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 five heliostat designs. Four of the heliostats are viable designs with unique approaches to the same generic design. The designs have varying amounts of risk and additional development required and minor design changes can benefit all of the designs. Detailed cost estimates indicate that the heliostat cost goal can be met at low production rates. The evaluation pertains to the heliostats only and does not rate the contractors (ARCO, Boeing, Martin Marietta, McDonnell Douglas, and Westinghouse). A condensed version of this report is available in the Executive Summary (SAND81-8033).

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ACKNOWLEDGMENTS

Sandia National Laboratories thanks the Users Panel and the evaluation Review Committee members, as well as their respective companies, for many helpful suggestions and participation in the Second Generation Heliostat Evaluation.

Users Panel

A. Akhil - Public Service of New Mexico
D. L. Barnes - Arizona Public Service
J. E. Bigger - Electric Power Research Institute
T. Guckes - Exxon
P. Joy - Exxon
R. McCleary - U. S. Gypsum
J. N. Reeves - Southern California Edison
C. P. Winarski - Southern California Edison
K. Ross - Southern California Edison

Review Committee

B. P. Gupta - Solar Energy Research Institute
L. M. Murphy - Solar Energy Research Institute
V. Truscello - Jet Propulsion Laboratory
B. Carley - Jet Propulsion Laboratory
S. D. Elliott - Department of Energy
K. Rose - Department of Energy
C. Grosskreutz - Black & Veatch (Solar Thermal Review Committee)

SECOND GENERATION HELIOSTAT EVALUATION-SUMMARY REPORT

1.0 Summary of Evaluation Process

Sandia National Laboratories Livermore funded five contractors to develop Second Generation Heliostats.

- ARCO Power Systems (ARCO) (formerly Northrup Inc.)
- Boeing Engineering & Construction (BEC)
- Martin Marietta Corporation (MMC)
- McDonnell Douglas Astronautics Company (MDAC)
- Westinghouse Electric Corporation

The development supports the Department of Energy Solar Central Receiver Development Program. Each contractor's effort was evaluated by a Sandia evaluation panel which was assisted by a panel of potential users and a Review Committee. The following organizations were involved:

- Sandia National Laboratories Livermore
- Sandia National Laboratories Albuquerque
- U. S. Department of Energy
- Solar Energy Research Institute
- Electric Power Research Institute
- Jet Propulsion Laboratory
- Public Service Company of New Mexico
- Arizona Public Service
- Southern California Edison
- Exxon
- U. S. Gypsum
- Black & Veatch

The results of the evaluation process do not rate or rank the designs and a Sandia preferred composite design is not proposed. The evaluation provides information as follows:

- Design Summaries
- Mass-Production and Installation Highlights
- Analysis Results
    - Structural
    - Performance
    - Heliostat Price Estimates
    - Busbar Energy-Cost Estimates

- Testing Results
    - Operational Modes
    - Performance
    - Wind Loading
    - Heliostat Life-cycling
    - Mirror Module Survival and Life Expectancy
- Design Strengths, Concerns, and Potential Solutions
- User Concerns
- Comparisons with Requirements
- Readiness for Near-term Application
- Further Research and Development Requirements
- Published Reports on Testing and Analysis
- Public Presentation of Evaluation Results

2.0 Conclusions and Recommendations

The five Second Generation Heliostats have been thoroughly evaluated. Each of the contractors completed a detailed mass production design for their heliostat, prepared a conceptual design for production of 50,000 heliostats per year, and estimated the price of installed heliostats in a 50 MW electrical power plant. With the exception of Westinghouse, two prototype heliostats were built and tested by each contractor and also tested side by side at the Central Receiver Test Facility (CRTF) in Albuquerque, N.M. Independent analysis and testing were performed by Sandia to characterize the designs for proper operational modes, performance, survival under environmental loads, and wear and degradation under real-time and accelerated life-cycle tests.

The results of the evaluation show that with low risk design changes the four tested Second Generation Heliostats are viable designs. The Westinghouse heliostat evaluation could not be completed because prototype hardware was not fabricated and tested. The other four designs each have unique approaches to the same generic design with varying amounts of risk and additional development required. The inherent design weaknesses of previous designs have all been eliminated by one or more of the new approaches in the current designs. However, some relatively minor design changes or proven alternative approaches can benefit all the designs.

Heliostat controls development was not emphasized during the Second Generation Heliostat Program; therefore, additional controls development is required for ARCO and Boeing. Additional development and/or design verification for component lifetimes is needed for all mirror modules and drive mechanisms. The reliance on adhesives and sealants is the major mirror module concern. Boeing's mirror module developed silver corrosion and cracks during testing and Martin Marietta's mirror module had a core/skin bond failure under simulated wind loading and cracks and bond failures have occurred at the CRTF. Both mirror module designs have unacceptable lifetimes. Inherent design problems with the drive mechanisms were identified for the ARCO and MMC drives. The ARCO stepper motor speed/torque characteristics are inadequate and the feasibility of MMC's stow lock feature has not been demonstrated. The Boeing and MDAC drive require design changes to improve lifetime as wear was observed after life cycle testing.

The contractors' installed heliostat cost estimates indicate that the DOE cost goal can be met at relatively low production rates with the normal expected learning after a few years of production. The cost of energy from a central receiver power plant continues to be attractive.

3.0 Introduction

3.1 Heliostat Development Programs

The Second Generation Heliostat Development Program is the second major heliostat development cycle in the Department of Energy's (DOE) Solar Thermal Central Receiver Program. During the first development cycle 222 heliostats were built for the Central Receiver Test Facility (CRTF) in Albuquerque and a design was developed and selected for the Pilot Plant near Barstow, California. The Pilot Plant heliostat design concept was selected in 1977. Preproduction prototypes for the Pilot Plant were competitively developed by Martin Marietta Corporation and McDonnell Douglas Astronautics Company. Martin Marietta's design won the competition, and 1818 of their heliostats are being used in the Pilot Plant.

The second heliostat 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. Rather than continue these contracts into Phase 2, DOE decided to initiate the recently completed Second Generation Heliostat contracts. Sandia placed the contracts in July 1979.

Technical management and evaluation of the Second Generation Heliostat contracts was performed by Sandia. Heliostat testing was performed at the CRTF. An overview of these activities is presented in the following two sections.

3.2 Second Generation Heliostat Program

The Second Generation Heliostat development contracts are summarized below.

Second Generation Heliostat Contractors	Contract Dates Start	Complete	Contract Costs
ARCO Power Systems (formerly Northrup Inc.)	July 79	Feb 81	$1.0M
Boeing Engineering and Construction	July 79	Feb 81	$1.7M
Martin Marietta Corp.	July 79	Apr 81	$1.4M*
McDonnell Douglas Astronautics	July 79	Feb 81	$1.5M*
Westinghouse	July 79	Sept 80	$1.7M

*Actual contracts included additional costs for "New Ideas" developments that were incorporated with these contracts to reduce costs.

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

- Establishing a heliostat design(s) with associated manufacturing, assembly, installation, and maintenance approaches that, in quantity production, would yield low capital and operating costs over an assumed 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.
- Testing and evaluating of prototype heliostats side by side and evaluating production plans and cost estimates.

All the program objectives have been met for all contractors except Westinghouse since Westinghouse was not able to build prototype heliostats within the funding limits; therefore, only limited information is available for the Westinghouse design.

3.3 Evaluation Program Overview

Sandia evaluated the Second Generation Heliostat designs through testing, design analysis, analysis of contractor production methods and cost estimates, and cost projections of busbar energy costs for a power plant. Heliostat testing was performed at the CRTF to verify operational modes, to determine performance capabilities, and to verify the 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.

The objectives of the evaluation and test program were to:

- Compare design features
- Identify design strengths and weaknesses
- Estimate reliability and lifetimes of key components
- Determine performance capabilities
- Identify user concerns
- Estimate central receiver energy cost
- Identify further development requirements
- Disseminate information

Sandia was assisted in the evaluation by a Review Committee and advisors consisting of representatives from other solar programs and potential users as shown below.

<u>User's Panel</u>

- Public Service Company of New Mexico
- Arizona Public Service
- Southern California Edison
- Exxon
- U. S. Gypsum

<u>Review Committee</u>

- Department of Energy
- Electric Power Research Institute
- Solar Energy Research Institute
- Sandia's Solar Energy Projects Department
- Sandia's CRTF Division
- Sandia's Solar Central Receiver Department
- Jet Propulsion Laboratory Solar Program
- Black and Veatch

Information from the evaluation program is being disseminated in the form of published contractor and Sandia reports and a public seminar. The contractor reports which have been published are listed in Section 10 of this report.

4.0 Design Summaries

A complete description of the Second Generation Heliostat designs, production plans, installation methods, and cost estimates can be found in the reports listed in Section 10.

4.1 Heliostat Design Highlights

ARCO Power Systems--Photographs of the front and back of the ARCO heliostat are shown in Figure 4.1-1 and the key features of the design are shown in Figures 4.1-2 and 4.1-3. The unique features of the design are the steel pipe for the foundation and pedestal and the silicone grease used to hold the two half-facet size mirrors to the sandwich-construction all-steel mirror support assembly. The grease also protects against silver corrosion and eliminates stresses in the glass due to differences in thermal expansion coefficients. The steel pipe foundation can be grouted into an augered hole or vibrated into the ground with a vibratory hammer; however, rocks will preclude vibratory hammer installation at some sites.

Boeing Engineering and Construction--Photographs of the front and back of the Boeing heliostat are shown in Figure 4.1-4 and the key features are shown in Figures 4.1-5 and 4.1-6. The unique features of the design are the glass cellular-glass glass mirror module sandwich and the unlubricated polymer nut on the elevation drive screw. The all-glass mirror module precludes defocusing and eliminates stresses in the glass due to thermal expansion coefficient differences. The polymer nut allows the linear actuator screw to operate without lubrication.

Martin Marietta Corporation--Photographs of the front and back of the Martin Marietta heliostat are shown in Figure 4.1-7 and the key features are shown in Figures 4.1-8 and 4.1-9. The unique features of the design are the locking mechanism "Stow-Lock" on the elevation drive and the polyisobutylene (PIB) used to hold the mirrors to the steel-paper honeycomb-steel mirror support sandwich assembly. The stow-lock feature carries high wind loads that would normally be carried by the elevation drive gears; thus the elevation gear strengths can be smaller. The PIB that holds the two half-facet size mirrors to the mirror support assembly acts as a non-rigid adhesive to preclude thermally induced stress in the glass. Mirror degradation protection is also provided by the PIB.

McDonnell Douglas Astronautics--Photographs of the front and back of the McDonnell Douglas heliostat are shown in Figure 4.1-10 and the key features are shown in Figures 4.1-11 and 4.1-12. The unique features of the design are the laminated mirrors, and environmentally sealed linear actuator, and a slip-joint pedestal/foundation interface. The mirrors are made of two pieces of glass that are laminated together like automobile windshields with an edge seal as added protection against mirror corrosion. The slip-joint pedestal/foundation makes it easy to change the foundation size or shape for different soil conditions and minimizes field installation time. The small amount of concrete above the ground simplifies the foundation installation by minimizing the forms and concrete curing problems when ambient temperatures are hot or cold.

Westinghouse Electric Corporation--A trimetric drawing of the Westinghouse heliostat is shown in Figure 4.1-13 and the key features are shown in Figures 4.1-13 and 4.1-14. The unique features of the design are the first

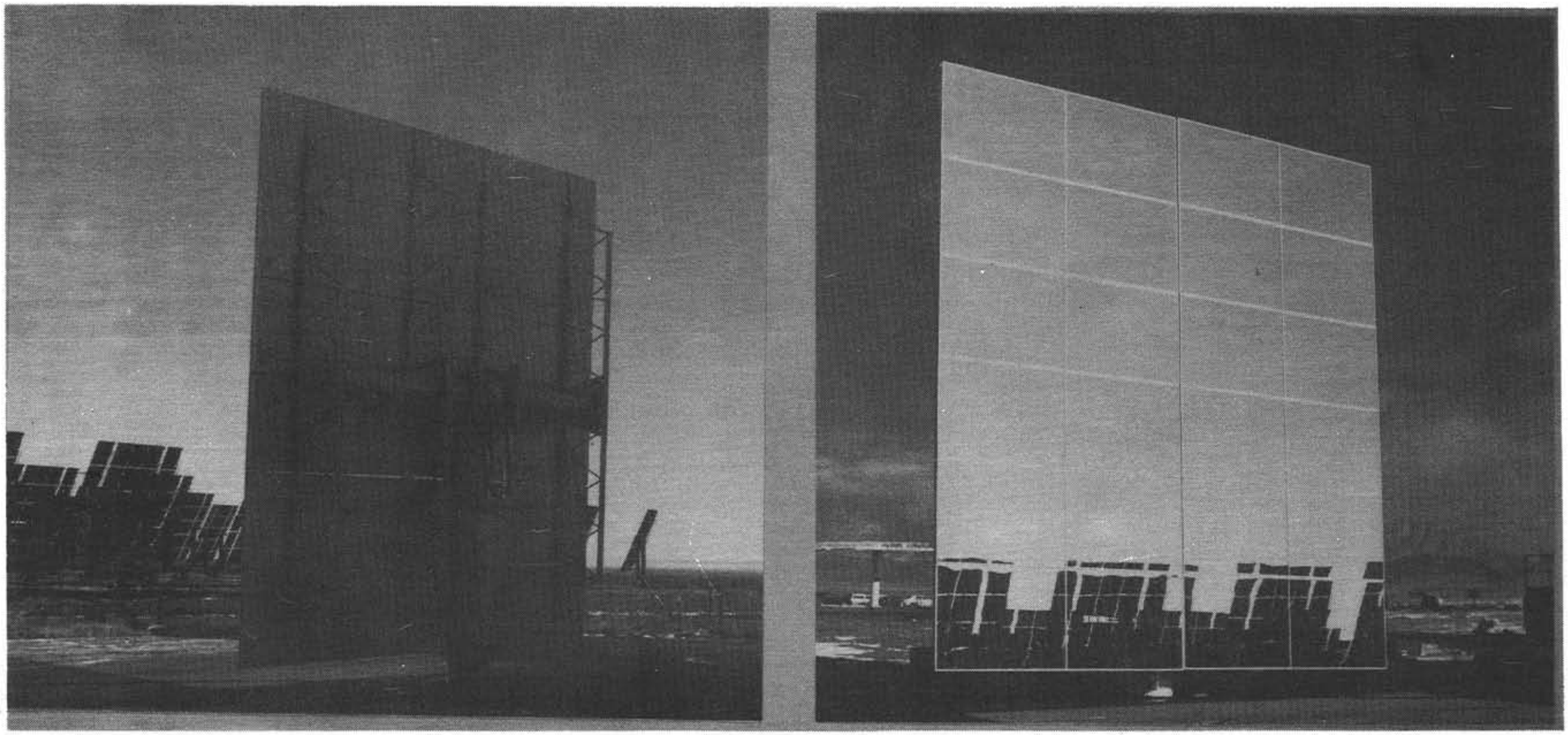


Figure 4.1-1. ARCO Second Generation Heliostat

MIRROR MODULE

Mirror held to all-steel sandwich with silicone grease and edge cap

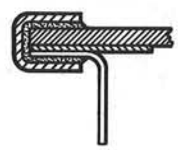
2.4 mm float glass mirror 1.22 x 1.83 m (2 each)

Metal edge cap

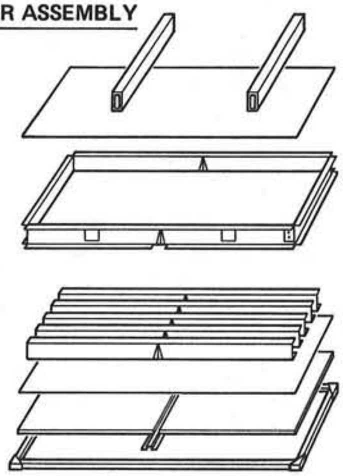
Sandwich bonded with acrylic adhesive

Offset 3-point mount

EDGE SEAL



MIRROR ASSEMBLY



MIRROR AREA	52.76 m^2	568 ft^2
WEIGHTS	**kg/m^2**	**lb/ft^2**
Heliostat*	42.9	8.79
Mirror modules	20.1	4.21
Drives	10.6	2.17
Structure	11.8	2.41
Pedestal	3.9	.81
Foundation	2.7	.56

*Excludes foundation/pedestal.

Figure 4.1-2. ARCO Second Generation Heliostat Mirror Features

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

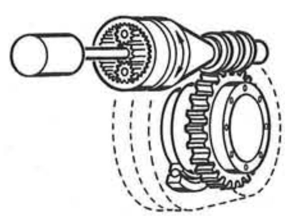
61 cm diameter

3 mm wall

3.4 m above ground

HELIOSTAT CONTROLLER IN PEDESTAL

1ϕ, 115 V AC



ELEVATION DRIVE

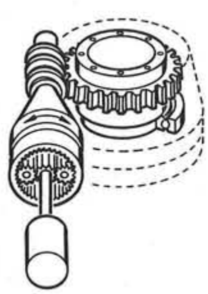
Worm/gear 40:1

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 4.1-3. ARCO Second Generation Heliostat Support Features

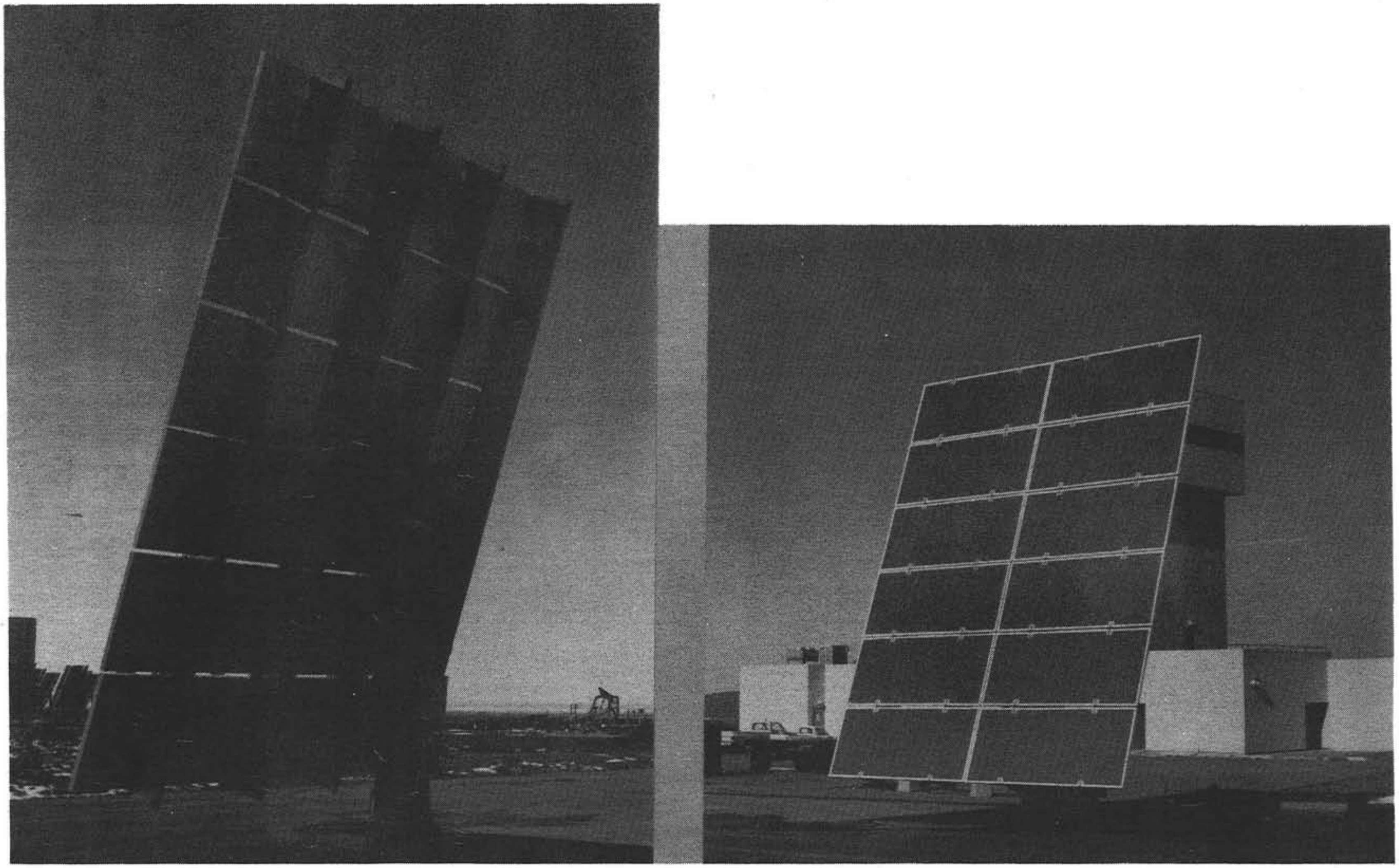
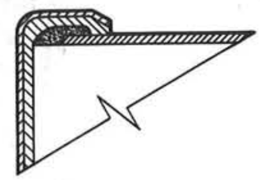


Figure 4.1-4. Boeing Second Generation Heliostat

MIRROR MODULE

Mirror—cellular glass—glass sandwich
1.5 mm fusion glass mirror
4-point edge clamp support
Epoxy adhesive
Polyisobutylene (PIB) and asphalt urethane edge seal

EDGE SEAL



MIRROR AREA	43.67 m^2	470 ft^2

WEIGHTS	kg/m^2	lb/ft^2
Heliostat*	41.4	8.45
Mirror modules	20.3	4.13
Drives	7.2	1.48
Structure	13.9	2.84
Pedestal	33.2	6.80
Foundation	42.6	8.72

*Excludes foundation/pedestal.

Figure 4.1-5. Boeing Second Generation Heliostat Mirror Features

SUPPORT STRUCTURE

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

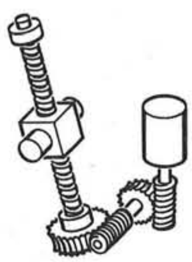
Torque tube, 40.6 cm diameter, 3 mm wall, 29.8 kg/m

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



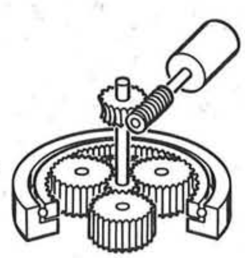
ELEVATION DRIVE

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 4.1-6. Boeing Second Generation Heliostat Support Features

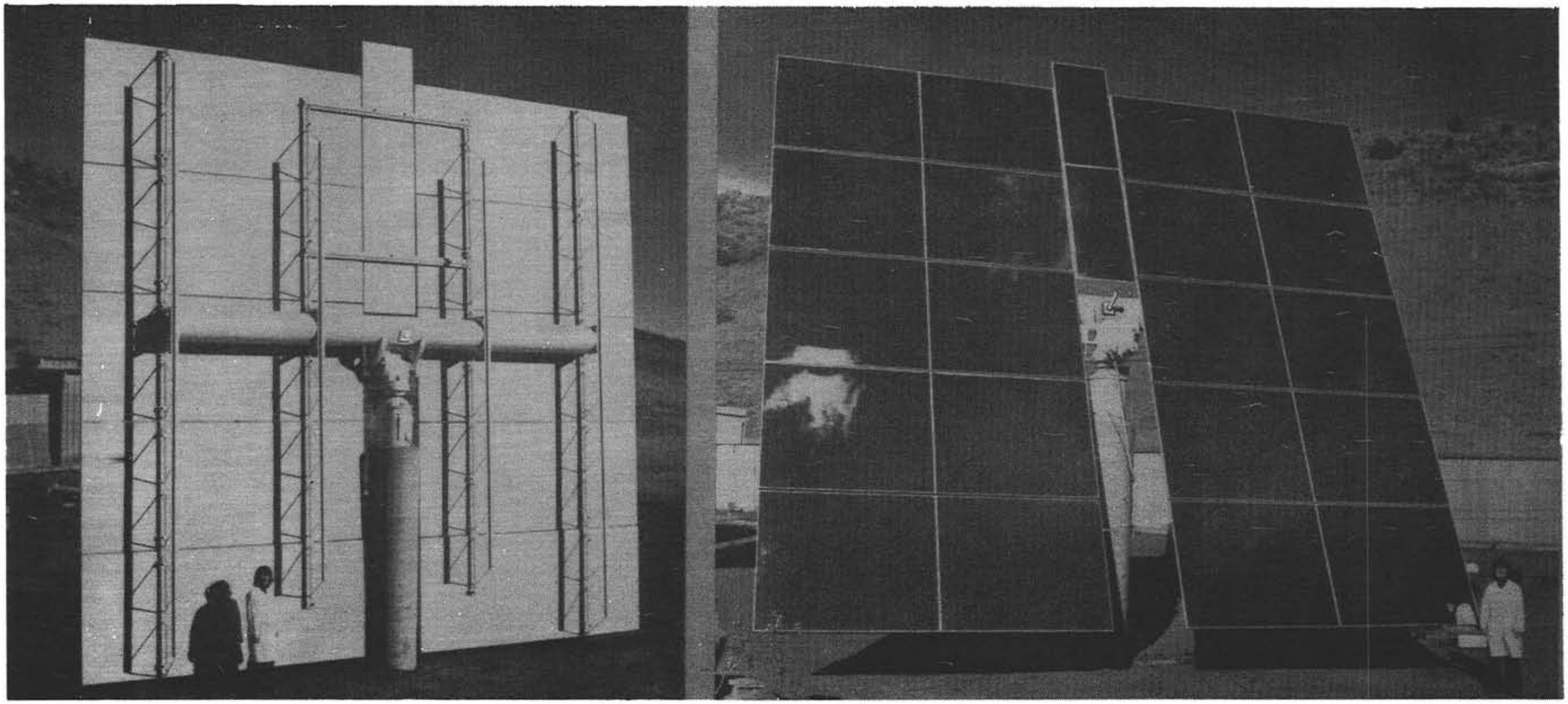


Figure 4.1-7. Martin Marietta Second Generation Heliostat

MIRROR MODULE

Mirror bonded to steel—paper honeycomb—steel sandwich with polyisobutylene (PIB)

Paper honeycomb impregnated with phenolic resin

1.5 mm fusion glass mirror

Sandwich bonded with neoprene phenolic adhesive

3-point support

PIB and RTV silicone edge seal

MIRROR AREA	57.4 m^2	618 ft^2

WEIGHTS	kg/m^2	lb/ft^2
Heliostats*	43.50	8.91
Mirror Modules	21.19	4.34
Drive	9.57	1.96
Structure	12.74	2.61
Pedestal	51.26	10.5
Foundation	54.44	11.15

*Excludes foundation/pedestal

STOW-LOCK

Elevation drive lock

Mirror down position

Wind load protection

EDGE SEAL

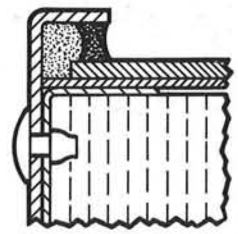


Figure 4.1-8. Martin Marietta Second Generation Heliostat Mirror Features

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

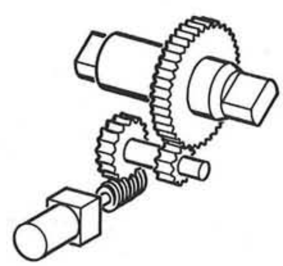
Pipe, 0.6 m long, 46 cm dia., 6 mm wall

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

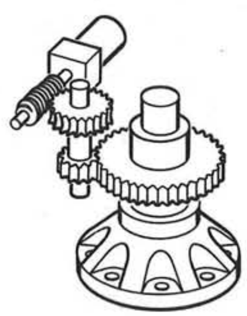
Spur gear 5.9:1

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 4.1-9. Martin Marietta Second Generation Heliostat Support Features

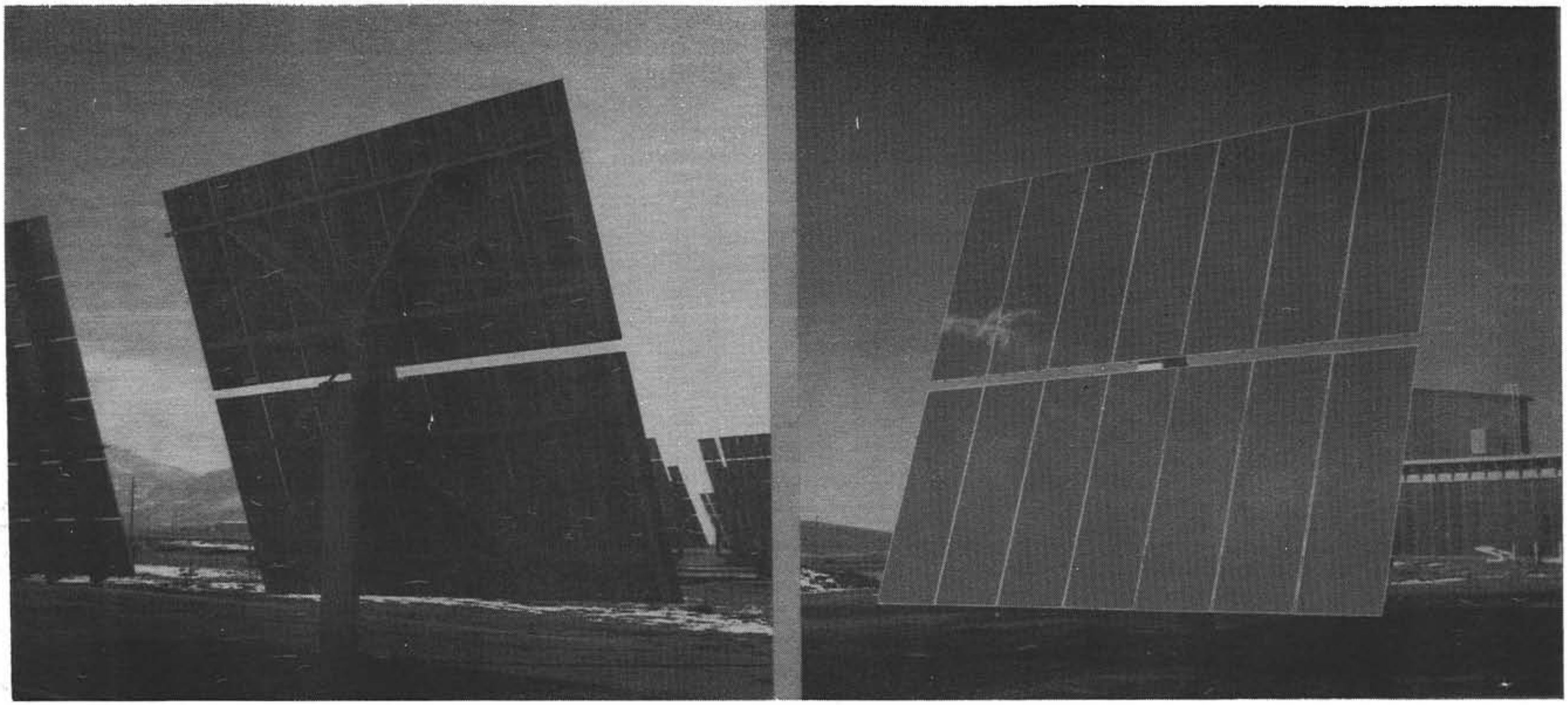


Figure 4.1-10. McDonnell Douglas Second Generation Heliostat

MIRROR MODULE

Laminated glass with steel hat-section stiffeners

1.5-mm fusion glass mirror 1.22 x 3.35 m

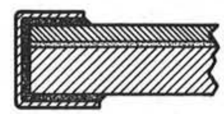
Laminate is autoclaved with polyvinylbutyrol

Stiffeners attached to steel "shim" with polyurethane adhesive. "Shims" bonded to glass with slow-curing Stabond X1894M.

Silicone edge seal

4-point support

EDGE CAP



MIRROR AREA 56.88 m^2 612 ft^2

WEIGHTS	kg/m²	lb/ft²
Heliostat*	40.67	8.33
Mirror Modules	23.34	4.78
Drives	4.4	.91
Structure	12.9	2.64
Pedestal	3.47	.71
Foundation	71.4	14.63

*Excludes foundation/pedestal.

Figure 4.1-11. McDonnell Douglas Second Generation Heliostat Mirror Features

SUPPORT STRUCTURE

Channel sections
Box beam

PEDESTAL

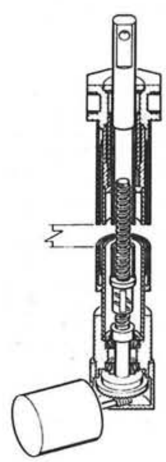
Steel pipe
3.3 m long
53 cm diameter
5 mm wall

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

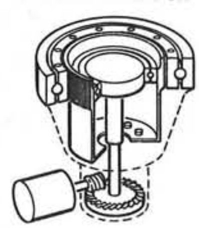


Figure 4.1-12. McDonnell Douglas Second Generation Heliostat Support Features

PEDESTAL/FOUNDATION

Wood piles (3)
Steel caps and lateral ties
6.2 m long
33 cm diameter
0.4 m above ground

ELEVATION DRIVE

± 270° rotation

Gear ratios, double worm/gear 800:1 cable/sprocket 43:1, overall 34,400:1

1/3 hp, 3ϕ, 460 V AC, 850 rpm induction motor

AZIMUTH DRIVE

Gear ratios, double worm/gear 1200:1, cable/sprocket 25:1

1/2 hp, 3ϕ, 460 V AC, 850 rpm induction motor

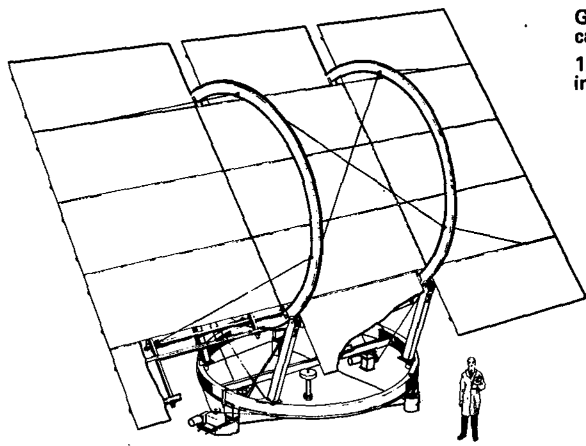


Figure 4.1-13. Westinghouse Second Generation Heliostat

MIRROR MODULES

First surface mirror or laminated glass with stainless steel hat section stiffeners

First surface mirror with TiO_2 overcoat, or 1.5 mm fusion glass mirror, or 0.6 mm Glaverbel mirror

Stiffeners bonded to glass with polyurethane adhesive

6-point support

CONTROLS

On pedestal

Absolute encoders

MIRROR AREA 76.57 m^2 824 ft^2

WEIGHTS	kg/m^2	lb/ft^2
Heliostat*	50.19	10.27
Mirror modules	20.55	4.21
Drives**	5.08	1.04
Structure	24.56	5.03
Pedestals	.49	0.1
Foundation	12.6	2.58

*Excludes foundation/pedestal.

**Excludes elevation and azimuth rings.

Figure 4.1-14. Westinghouse Second Generation Heliostat Mirror Features surface mirror, the large mirror area per heliostat, the stretched cable support structure, and the cable drives. The first surface silver mirror with a TiO_2 overcoat provides a high reflectivity while using conventional low-cost float glass. Low costs are due to the normal iron content in the glass and ease of manufacturing and handling due to its 6 mm thickness. The cable drives locate the drive components near the ground for easy maintenance. The stretched cable support structure complicates the field assembly and may complicate mirror washing. The area is large, which reduces the number of heliostat controllers, heliostat field controllers, drive mechanisms, and power and control hook-ups to make and maintain.

4.2 Production Highlights

Each contractor provided a conceptual design, labor requirements, and a cost estimate for heliostat production. A common production rate was specified at 50,000 heliostats per year. All heliostats were to be installed within a 400-mile radius of a centrally located factory in the southwestern United States. The degree of vertical integration for heliostat production was determined by the contractors. The highlights of the production planning from each contractor are shown in Table 4.2-I. Each heliostat contractor was assisted with their production planning as shown below:

TABLE 4.2-I

HIGHLIGHTS OF PRODUCTION PLANNING -- SECOND GENERATION HELIOSTATS -- 50,000 PER YEAR

Item	ARCO	Boeing	Martin Marietta	McDonnell Douglas	Westinghouse
Central Manufacturing Plant Location (Floor Space, m^2)	Albuquerque (57,600)	Phoenix (51,767)	Albuquerque (47,103)	Tucson (24,183)	Not Selected (3066)
Capital Equipment In Manufacturing Plant	$72M	$50M	$30M	$36M	$1.3 M
Degree of Vertical Integration	High	Low	Moderate	Low	Very Low

Second Generation Heliostat Contractors

ARCO	Boeing	Martin Marietta	McDonnell Douglas	Westinghouse
• Booz-Allen & Hamilton	• Ford Aerospace	• F. J. Lamb	• General Motors	None
• Bechtel	• Ford Motor Company	• Black & Veatch	• F. J. Lamb	
• Winsmith	• Winsmith	• Safeguard Power Transmission		
	• Pittsburgh Corning			

4.3 Heliostat Installation Methods

Each contractor provided a concept for heliostat site assembly and installation for a 50 MW solar thermal central receiver power plant. A site assembly building is used by all but McDonnell Douglas, which aligns mirrors and does most of the assembly at the central factory. The major features of the site activities are as follows:

Heliostat Site Activities

Item	ARCO	Boeing	Martin Marietta	McDonnell Douglas	Westinghouse
Site Assy Bldg Floor Space (m^2)	697	557	2648	372	2908
Foundation Installation	Auger & Grout	Auger & Grout	Auger, Rebar & Place Concrete	Auger, Rebar & Place Concrete	Drive Wooden Pile
Field Wiring	Power & Control Cables	Power & Control Cables	Power Cables & Fiber Optic Control Lines	Power Cables & Fiber Optic Control Lines	Power & Control Cables
Heliostat	Assemble, Align, Install, Check-out	Assemble, Align, Install, Check-out	Assemble, Align, Install, Check-out	Install on Foundation, Check-out	Assemble, Align, Install, Check-out

5.0 Testing

5.1 Testing and Analysis

The Sandia evaluation of the Second Generation Heliostat designs was supported by an integrated program of testing and analysis consisting of:

- Prototype heliostat testing at the CRTF
- Mirror module testing
- Heliostat optical performance analysis with the HELIOS computer code
- Structural analysis with the SAP4 computer code
- Field performance analysis with the DELSOL computer code

The HELIOS calculations and structural analyses are used to reduce the scope and cost of the test program by determining optical performance for a variety of field and sun positions and environmental conditions. Figure 5-1 shows the test results that are fed into both SAP4 and HELIOS. Results from SAP4 are used both directly and by HELIOS. HELIOS is ultimately used to determine whether the optical performance requirements are met.

The DELSOL field performance code was used at the beginning of the Second Generation program to determine the number of heliostats required for a 50 MWe field. Nominal performance parameters for beam pointing and beam quality were assumed. The DELSOL analysis was rerun after the conclusion of the testing program using performance parameters based on measured values.

CRTF Testing--The purpose of the testing at the CRTF was to characterize the heliostats relative to the Second Generation design specification. Operational ability, optical performance, environmental survival, and projected life expectancy were assessed.

Two prototype heliostats of the ARCO, Boeing, and McDonnell Douglas designs were installed for testing at the CRTF in November, 1980. Martin Marietta installed its two heliostats in February, 1981. The heliostats were subjected to a series of 11 tests, which are summarized in Table 5-I. The test program was scheduled to last three months. Testing of the ARCO, Boeing, and MDAC designs was mostly complete by March, 1981, and testing of the Martin Marietta heliostats began in April, along with retests of ARCO and the newly added Foundation Testing. Final testing, with the exception of the Long-Term Operation test, was completed in July, 1981.

Mirror Module Testing--Four extra mirror modules of each design were delivered: three to Sandia, Livermore and one to the CRTF for laser ray trace contour mapping and to serve as a spare for the heliostats. The mirrors were evaluated for optical performance, weatherability, and survival of wind, hail, and temperature extremes. Table 5-II summarizes the mirror module tests.

Structural Analysis--Each of the heliostat designs except Westinghouse's was structurally modeled using the SAP4 finite element computer code. The purpose of these analyses was to provide information, not readily

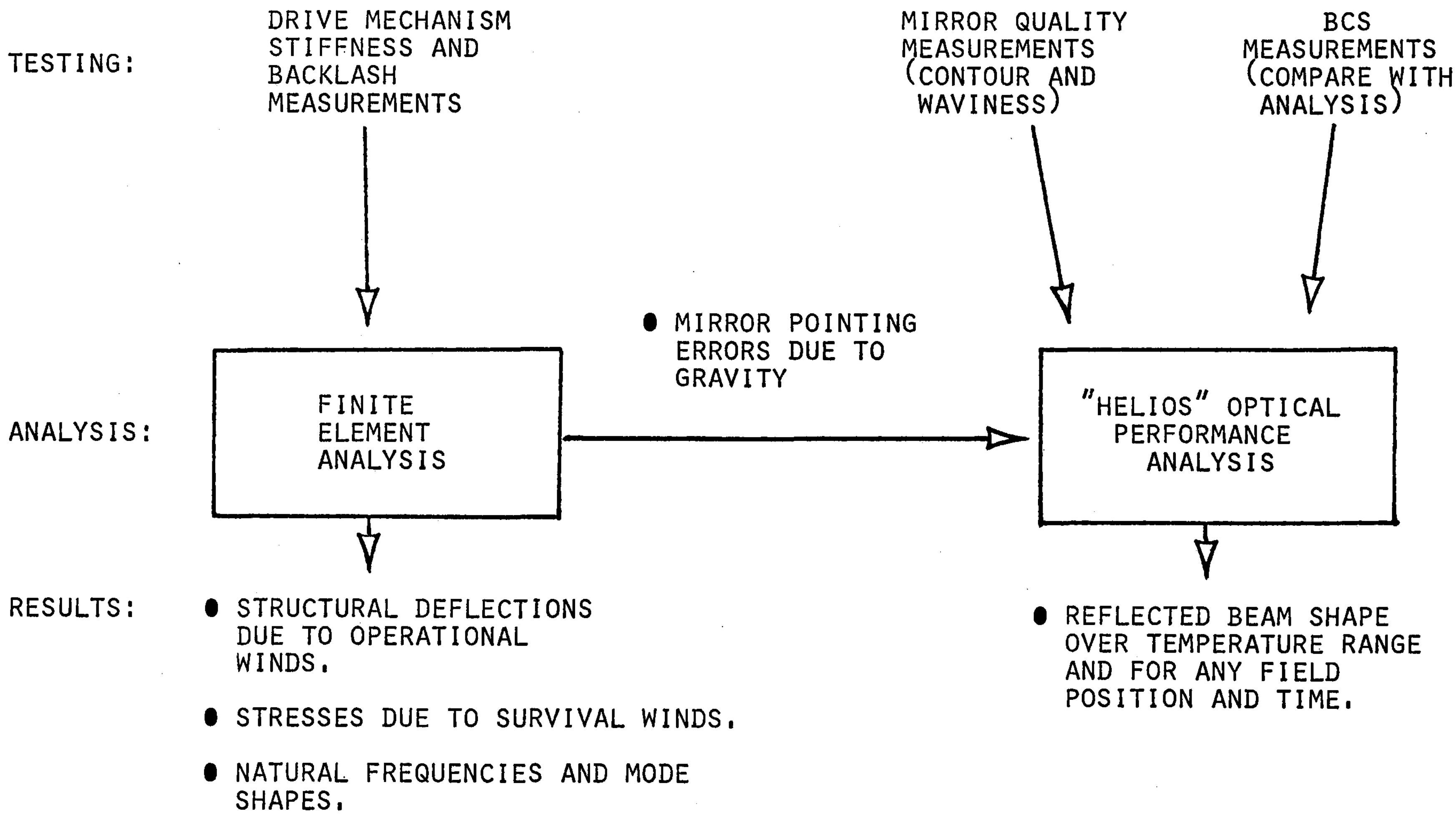


Figure 5.1. Second Generation Heliostat Analysis

TABLE 5-I

HELIOSTAT TESTING AT CRTF

Test	Purpose	Method
1. Operational Modes	• Determine that heliostat can perform required functions such as track, stow, standby, reference update, and assume a commanded position.	• Operate heliostat through required modes.
	• Determine power requirements.	• Measure power consumption during track and slew.
2. Beam Quality	• Determine compliance with beam quality specification.	• Measure reflected beam shape and determine performance parameters for HELIOS.
3. Pointing Accuracy	• Determine compliance with beam pointing accuracy specification.	• Measure beam centroid error for a full day at beginning and end of test program.
4. Heliostat Surface Accuracy	• Qualitatively assess reflective surface slope errors.	• Use "backward gazing" Heliostat Characterization System.
5. Life Cycle Testing	• Assess drive mechanism wear and control hardware problems for prolonged operation.	• Cycle heliostat continuously for six weeks, with slew to stow once each hour.
6. Pointing Accuracy with Operational Wind Loads	• Determine pointing error under steady wind loads for comparison with specification.	• Apply simulated wind loads while tracking and measure pointing error with BCS.
7. Wind Load Deflections	• Determine wind load deflections of structure, drive mechanism, pedestal, and foundation due to winds up to 50 mph.	• Apply simulated wind loads and measure deflections.
	• Assess survivability of structure and azimuth drive to 50 mph wind.	• Apply simulated wind loads and then recheck pointing accuracy.
	• Assess motor torque adequacy to drive against a 50 mph wind (both axes).	• Apply load and run motors at slew speed.
8. Survival Wind Load, Heliostat Stowed	• Assess survivability of elevation drive mechanism and to 90 mph wind.	• Apply simulated wind load and then recheck pointing accuracy.
9. Water Spray, Disassembly, and Inspection	• Assess resistance to rain and wash water of drive mechanism and control box, and examine drive for wear.	• Spray heliostat with water before tear down and inspection.
10. Long-Term Operation	• Assess long-term performance, wear, and weathering characteristics.	• Operate heliostat at CRTF for one year with periodic inspection and performance evaluation.
11. Foundation Testing	• Characterize tilt and twist of pedestal/foundation during and after high wind loads.	• Apply simulated wind loads to top of pedestal after removal of drive and reflective structure, and measure deflections.

TABLE 5-II

MIRROR MODULE TESTING

Test	Purpose	Method
1. Contour Measurement	• Determine large scale mirror contour (focal length)	• Measure mirror shape with a matrix of linear displacement gages.
2. Wind Load Glass Stress	• Assess capability to survive 90 mph wind.	• Uniformly load module with weights and measure glass stress with strain gages.
3. Thermal Stress and Contour Change	• Determine temperature-induced glass stress and contour change.	• Measure contour and glass stress at different temperatures.
4. Residual Glass Stress	• Determine residual and fabrication stresses in the glass.	• Measure with reflection polariscope.
5. Gravity Sag	• Determine contour change due to gravity.	• Load mirror module uniformly with equivalent of its own weight and measure contour.
6. Thermal Cycling	• Assess capability to survive thaw-freeze cycling and temperature extremes.	• Cycle between -20°F and 120°F 112 times.
7. Environmental Cycling	• Assess weatherability of mirror module.	• Cycle temperature between 70°F and 130°F four times per day and vary humidity between wet and dry weekly, with continuous UV radiation.
8. Hail Test	• Determine compliance with hail requirement.	• Impact mirror module with ice balls.
9. Cold Water Shock	• Assess capability to survive cold wash or rain.	• Splash water on hot mirror.
10. Reflectivity	• Determine solar-weighted reflectance.	• Measure mirror modules and mirror samples with several reflectance instruments.
11. Laser Ray Trace	• Determine effective mirror waviness.	• Measure with laser ray trace technique.

available by testing, about the performance and survivability of the designs.

The following were determined for each design:

(1) Angular deflections of each mirror facet due to gravity as a function of heliostat elevation angle. This information was used with HELIOS to assess reflected beam quality.

(2) Structural deflections of the heliostats due to operational wind loads (up to 27 mph). The overall angular deflection of the reflective surface was limited in the design specification to 3.6 mrad (root-mean-square), discounting the foundation.

(3) Critical stresses in the structure under survival wind load conditions.

(4) Natural frequencies and mode shapes from the dynamic analysis of each design.

All of the loadings and resulting deflections in (1) and through (3) above were assumed to be static. For these cases, the drive mechanisms were assumed to be rigid. Drive mechanism deflections were measured at the CRTF under simulated wind loads, and the measured deflections were combined with calculated values for the remainder of the structure to determine total deflections. The drive mechanisms were modeled as torsional springs for the dynamic analysis. The assumed spring constants were determined from measured deflection versus load curves.

The results of the structural analysis were as follows:

- Structural deflections due to gravity were found by HELIOS analysis to have only a slight impact on beam quality.
- All of the designs were found to be within the 3.6 mrad deflection requirement in a 27 mph wind.
- Stresses in the major structural components were found to be acceptable for each design.
- Natural frequencies were found to be above the frequencies which could be driven in a major vortex-shedding mode.

In summary, the structural analysis showed that all of the heliostats are well designed in terms of stiffness and strength.

5.2 Compliance with Requirements

The heliostat design specifications can be broken up into four categories: operational modes, optical performance, survival, and 30-year life. These requirements are briefly summarized in Table 5-III. The test program identified specific weaknesses in each heliostat design. The key findings

TABLE 5-III

HELIOSTAT DESIGN REQUIREMENTS

Operational Modes:	• Normal modes (track, standby, wire walk, stow) • Track to 35 mph wind • Slew in 50 mph wind • Resolve singularity in 15 minutes • Reposition in 15 minutes • Emergency defocus in 3 minutes • Electrical transients (3 - cycle dropout)
Optical Performance:	• Beam pointing (1.5 mrad RMS maximum, reflected beam error for each axis) • Beam quality (theoretical beam shape plus 1.4 mrad fringe, 32°F - 122°F) • Wind load deflection (3.6 mrad RMS maximum reflective surface deflection in 27 mph wind, discounting foundation) • Foundation deflection (0.45 mrad maximum set after survival wind, 1.5 mrad maximum twist or tilt in 27 mph wind)
Survival:	• 90 mph wind, heliostat stowed • 50 mph wind, heliostat in any orientation • Temperature, -20° to 122°F • Hail, 3/4" at 65 ft/sec, any orientation 1" at 75 ft/sec, heliostat stowed • Cold water shock
30-year Life:	• Life of all components must be cost-effective for 30 years • Mirrors and drive mechanism are critical components.

are summarized in Table 5-IV, along with potential solutions to the problems. In conclusion, all four built-and-tested designs can meet the requirements with certain low-risk changes.

ARCO's main problems were the drive motors and the foundation. The motors need to be replaced with larger units having greater torque and slew-rate capability. The vibration-installed foundation was an unsuitable concept for the soil at the CRTF although the concept did work in Dallas and at the CRTF until rocks were encountered. Augering and Grouting the ARCO foundation pipe in place is an acceptable solution or one of the other foundation designs can be easily adapted to the ARCO heliostat.

Boeing's mirror module was judged to be unacceptable. Silver corrosion five was found on mirrors at the CRTF. Two mirrors cracked with no apparent external impact, indicating high thermal and/or fabrication stresses. Finally, the integrity of the foamed glass core strength as well as protection of the mirror silver depends on the edge seal. Disassembly of one of the mirror modules revealed that a considerable amount of water had gotten through the edge seal, resulting in silver deterioration and debonding of the front and back sheets of glass from the core. It is recommended that Boeing use a low-risk mirror module design such as one employing laminated glass. The Boeing pedestal/foundation was also unsuitable for the rocky soil conditions at the CRTF. As with ARCO, there are other foundation concepts (including grouting in place) which could be adapted to this heliostat design.

The major problems with the Martin Marietta design were the mirror module and the stow lock concept. When loaded to a 90 mph wind condition the mirror module failed by debonding between the paper honeycomb and the back sheet. MMC reports that the bond was poor because the adhesive "skinned over" before the parts were mated. At the CRTF, cracks have appeared on three different mirrors. Brown-stained water ran out of the modules at the CRTF when the heliostat was moved from a stow position. Inspection showed waterlogged, soggy, debonded honeycomb cores. It is recommended that MMC use a low-risk concept, such as laminated glass, for near-term applications.

The MMC stow lock has not been demonstrated to be feasible for production. Extremely tight tolerance controls and a fail-safe feature to prevent accidental damage are needed for the present design to work. Problems were encountered with the locking devices on both heliostats at the CRTF. Further development is needed before this design will work reliably. Otherwise, the drive must be redesigned to take survival wind loads without the stow lock.

The McDonnell Douglas heliostat had no major deficiencies. The elevation drive mechanism showed some wear after the life-cycling, as did the drives of all of the other designs but MMC's. Some design modifications and further testing have been performed by MDAC to assure a long life for the drive.

Overall, the problems which have been identified can be solved with some redesign. They represent the typical kind of development problems which can be cleaned up in the course of the design evolution of heliostats.

TABLE 5-IV

SUMMARY OF KEY TEST RESULTS

Contractor	Deviation from Spec.	Potential Solution
ARCO	• Inadequate drive speed and torque • Marginal tracking accuracy • Marginal beam quality • Foundation loose in ground	• Change motors • Improve control system software • Mirror module production tooling may correct curvature • Different foundation design required for some sites
BOEING	• Low mirror module life expectancy • Foundation loose in ground • Wear on elevation drive jack worm gear • Pointing error after 90 mph wind load	• Use alternate mirror module design • Different foundation design required for some sites • Winsmith has developed an improved lubricant and has performed verification testing
MARTIN MARIETTA	• Low mirror module life expectancy	• Further testing and analysis required • Use alternative mirror module design
	• Inadequate motor torque for track and slew from non-production motors • Feasibility of stow lock device not demonstrated on prototype or for production • Pointing error after 90 mph wind load	• Install and test production motors • Redesign stow lock, or redesign drive to delete stow lock • Further testing and analysis required
MCDONNELL DOUGLAS	• None identified	

6.0 Cost Estimates

The user costs (prices) for installed heliostats were estimated by the Second Generation Heliostat contractors and independently evaluated by Sandia. The contractors were given common set of cost estimating guidelines. They also provided operations and maintenance cost estimates for a 50 MWe heliostat field.

6.1 Users Costs for Installed Heliostats

The guidelines that were provided to the contractors are summarized below.

Summary of Cost Estimating Guidelines

- Cost and price in April 1980 dollars for installed heliostats in a 50 MWe plant vs. cumulative production of 520,000 heliostats
- First production heliostat, June 1, 1984 -- 20,000 units in first year
- 50,000 heliostats per year starting June 1, 1985
- One manufacturing facility -- 2 shifts
- Factory located in southwestern United States
- Heliostats installed at solar plants evenly distributed within 400-mile radius of factory
- Contractor determines
  - Make or buy items
  - Depreciation schedules
  - Profit

Indirect cost
Labor hours and rates
Material, factory, and shipping costs
Operations and maintenance costs for one 50 MWe field

- Sandia determines busbar energy cost for each type heliostat

6.2 User Costs for Installed Heliostats

Sandia has reviewed the contractor-provided cost estimates and adjusted them for omitted items and errors. The effect of making the contractors' estimates for identical items the same has also been investigated. The price for the Martin Marietta Pilot Plant heliostat has also been estimated for a production rate of 50,000 per year. A summary of the various cost estimates follows.

Contractors Estimates - Installed Heliostat Prices
1st Year, $\$/m^2$ (April 1980)

	ARCO	BEC	MMC	MDAC	Barstow*
Reflective Assembly	33	47	35	34	63
Drive Assembly	45	41	35	28	51
Controls	14	16**	16	14	24
Support Structure	15	22	11	15	17
Foundation/Pedestal	11	21	12	20	18
Total Installed Price***	118	147	109	111	173

*Battelle Pacific Northwest estimate for a production rate of 50,000 heliostats per year.
**Price estimated by Sandia; no estimate provided by BEC.
***Assembly/installation cost center apportioned to the above accounts.

The effect on the price of each design for a uniform shipping cost scenario and equal glass and mirror costs as well as identical costs for controls is shown below.

Effect of Uniform Estimates on Second Generation Heliostat
Prices in $\$/m^2$ During First Year of Production

	ARCO	BEC	MMC	MDAC
Contractors Cost	118.00	147.00	109.00	111.00
Uniform Shipping Assumptions	+.10	+3.00	0	+1.60
Uniform Glass/Mirror Costs	+.25	+.89	-3.30	+1.18
Uniform Controls Costs ($600.00)	-1.90	0	-5.20	0
Total Price	116.45	150.89	100.50	113.78

The change in heliostat prices versus production rate from a factory which nominally produces 50,000 heliostats per year is shown below.

Change In Heliostat Prices Versus Production Rate

Annual Production Rate (Heliostat/yr)	ARCO	BEC	MMC	MDAC
25,000	+4%	+4%	+12%	+14%
50,000	Nominal	Nominal	Nominal	Nominal
67,000	-1%	-1%	-3%	-3%

6.3 Operations and Maintenance Costs

Operations and Maintenance (O & M) costs for a 50 MWe heliostat field were estimated by the contractors. Component failure rates and repair times were used to make maintenance estimates. A range of annual O & M costs was obtained and reviewed by Sandia. All of the expected costs were not provided by all of the contractors; therefore, Sandia has made a nominal estimate. The O & M costs are summarized below.

Contractor Estimated Annual O & M Costs ($1000's)
(50 MWe)

	ARCO	BEC	MMC	MDAC
Operating Labor	--	79	88	--
Maintenance				
Labor	125[1]	193	150	191
Material	62	103	64	81
Washing	160[2]	363[2]	32[3]	136[3]
Power	247	23	--	--
Total	594	761	334	408
Initial Spares			31	8

1. Includes $110,000 oil changes and painting.
2. Six washes/year.
3. Twelve washes/year.

Operating and Maintenance
Nominal Annual Costs (Sandia Estimate)
(50 MWe)

Operator	$ 75,000	1/3 operator, 3 shifts/day
Maintenance		
Labor	200,000	1 foreman, 2 techs x 2 shifts
Material	100,000	
Washing	150,000	12 washes, $2/wash
Power	120,000	1 x 10^6 kWhr x $.12/kWhr
	$645,000	

6.4 Energy Costs

Levelized energy costs have been calculated by Sandia for a 50 MW electric solar plant (37% capacity factor) and for an equal size plant for industrial process heat. The energy costs for each of the Second Generation Heliostat designs were calculated using the appropriate economic scenario and heliostat performance characteristics. The results are summarized below.

Economic Assumptions

	Electric Power	Thermal Power
Inflation Rate (%)	8	8
Levelizing Period (yr.)	30	20
Interest During Construction (%)	10	5
Fixed Charge Rate (%)	15.9	22.9

Levelized Energy Costs (1980 $'s)

	ARCO	BEC	MMC	MDAC
Heliostat Parameters:				
Reflective Area, m^2	52.75	44.00	57.40	56.85
Reflectivity, average, %	89	92	92	92
Pointing Error, mrad				
Azimuth	.75	0.5	0.5	0.2
Elevation	0.6	0.5	0.4	0.2
Mirror Surface Error, mrad	1.8	1.0	1.1	1.2
Installed Price, $/$m^2$	118.00	147.00	109.00	111.00
O & M, $/$m^2$	1.50	2.70	1.20	1.90

Field Characteristics:				
Land Area, Km^2	1.61	1.61	1.60	1.51
Average Density	.22	.21	.20	.22
Number of Heliostats	6584	7489	5685	5713
Optical Efficiency, yearly Ave.	.61	.63	.64	.65
Energy Cost:				
Busbar Energy, mills/Kw-hr.	107	121	99	103
Thermal Energy, $/MBTU				
Base of Tower[1,2]	12.34	14.42	11.13	11.75
Input to Receiver[3] (solar fuel cost)	5.39	6.83	4.90	5.00

1. Receiver and piping losses, 22.4% annually
2. Includes levelized O & M costs
3. Does not include any O & M costs

Levelized Energy Cost Breakdown--
50 MW_e, mills/kWhr (1980 $'s)

	ARCO	BEC	MMC	MDAC
Capital	88	96	82	83
Heliostat O&M	10	16	8	11
Balance-of-Plant O&M	9	9	9	9
Total	107	121	99	103

7.0 User Concerns

Potential heliostat users assisted Sandia with the Second Generation Heliostat Evaluation. The following representatives from industry and electric utilities reviewed the designs and the results of testing and analysis.

Second Generation Heliostat Evaluation Users Panel

Abbas Akhil - Public Service of New Mexico
Darryl Barnes - Arizona Public Service
John Bigger - Electric Power Research Institute
Charles Grosskreutz - Black & Veatch
Terry Guckes - Exxon
Patrick Joy - Exxon
Ray McCleary - U. S. Gypsum
Joe Reeves - Southern California Edison
Carman Winarski - Southern California Edison

Comments received from the Users Panel regarding the Second Generation Heliostat Program as well as heliostats in general are summarized below.

Heliostat User Concerns and Comments

Second Generation Heliostat Program

Major Emphasis

- Cost Estimates
- Program Goals
- Performance

Minor Emphasis

- Operability
- Maintainability
- Reliability

Ownership Considerations

- Equipment Quality and Reliability
- Logistics Support
- Human Factors
- Capital Costs
- Operations and Maintenance Costs
- Safety
- Insurance

User Concerns

- Lack of documentation to develop realistic operating requirements
  - Washing
  - Dust build-up
  - Effects of agricultural, animal and industrial chemicals
  - Long-term mirror life and reflectivity
  - Site selection criteria

- Lack of documentation on effects of component/subsystem failures
  - Dangers to workers
  - Reliability of emergency defocusing from receiver
  - Effect of one heliostat off-tracking
  - Power outages
  - Warranty plans (entire system, heliostats, and components)

- Lack of documentation to develop realistic maintenance requirements
  - Skill levels
  - Man-hours
  - Scheduled vs unscheduled
  - Times between maintenance
  - Plant design impact (extra heliostats)
  - Spare parts, inventory, availability, and replacement frequency
  - Failure modes and effects analysis
  - Reliability indices (these are currently based on component reliability; operating reliability is needed)

User Recommendations

- Heliostat suppliers, in partnership with utilities, industries, and other agencies, should install a few heliostats in the field at various sites
- Sandia, in support of this effort should collect, evaluate, and publish the operation, maintenance, and reliability data.
- For this new technology, information should be provided to the insurance industry for insurance codes and the following insurance:
  - Liability
  - Fire
  - Pressure Vessel
  - Business Interruption
  - Construction

8.0 Design Comparisons

The Second Generation Heliostat Evaluation has resulted in an assessment of the heliostat characteristics, performance capabilities, structural adequacy, production feasibility, installed costs and projected energy cost from a solar plant. The designs have not been ranked and a Sandia preferred composite design is not proposed. Further development requirements have been identified as have areas of risk for near-term applications. Published evaluation reports and a public presentation have provided the public and potential heliostat users with the following information to compare and evaluate the designs.

Results of Evaluation Process

- Design summaries
- Mass-production and installation highlights
- Analytical Results
  - Structural
  - Performance
  - Heliostat price estimates
  - Busbar energy costs
- Testing Results
  - Operational modes
  - Performance
  - Wind loading
  - Heliostat life-cycling
  - Mirror module thermal cycle
  - Comparisons with requirements
  - Design strengths, concerns, and potential solutions
  - Areas of risk for near-term applications
  - Further development requirements

In addition, the Second Generation Heliostat design characteristics can be compared with previous designs. This comparison, along with cost information, shows that there have been significant improvements in the designs and that four of the designs can be competitive. Some additional development is required for each design and there are varying degrees of risk.

8.1 Strengths, Design Concerns, and Potential Solutions

The Second Generation Heliostat strengths, design concerns, and potential solutions for the concerns are summarized below.

SECOND GENERATION HELIOSTAT EVALUATION SUMMARY

Heliostat	Strengths	Concerns	Potential Solutions
ARCO	• Low-Risk Drive • Good Mirror Module Concept • Easy Maintenance • Simple Field Assembly	• Controls require development	◦ Update design based on test experience and design and test (in progress)
		• Stepper motor speed /torque characteristics are inadequate	◦ Change to induction or DC motor (in progress)
		• Rust and deterioration of controls due to water condensation inside of pedestal	◦ Provide ventilation (controls now outside pedestal)
		• Mirror module life is difficult to demonstrate	◦ Field test at multiple sites 3-5 years ◦ Demonstrate accelerated life tests
		• Adhesives and sealants in mirror module require good quality control and acceptance tests are difficult to perform	• Adopt laminated glass for near-term applications ◦ Develop & demonstrate cost-effective test and QC methods

SECOND GENERATION HELIOSTAT EVALUATION SUMMARY (Cont'd)

Heliostat	Strengths	Concerns	Potential Solutions
Boeing	• Low risk azimuth drive • Simple, light-weight elevation drive	• Controls require development	• Update design based on test experience, design and test
		• Mirror module life is unacceptable	• Adopt alternate design (in progress) • Use laminated glass for near-term applications
Martin Marietta	• Simple field assembly • Simple mirror canting adjustment • Easy maintenance • Fiber-optics immunity to electrical noise and lightning • Operational Flexibility of inverted stow	• Stow lock requires development	• Redesign to minimize sensitivity to dimensional tolerances • Provide fail-safe locking method
		• Mirror module life is unacceptable	• Adopt alternate design (in progress) • Use laminated glass for near-term applications
McDonnell Douglas	• Low-risk laminated mirror module • Low-risk drive • Minimal field assembly • Easy maintenance	• Cannot readily detect azimuth drive oil leaks • Life of adhesive between glass and steel unknown	• Add deflector so oil exits pedestal • Field test at multiple sites 3-5 years • Demonstrate accelerated life tests

SECOND GENERATION HELIOSTAT EVALUATION SUMMARY (Cont'd)

Heliostat	Strengths	Concerns	Potential Solutions
	• Fiber- optics immunity to electrical noise and lightning		• Develop attachment using silicone adhesive or no adhesive
		• Rust due to water condensation on inside of pedestal	• Improve ventilation
Westinghouse	• Reduced field wiring, number of controllers and drive mechanisms due to large mirror area • Good conceptual design for field wiring • First surface mirror	• High risk cable drive • Difficult to wash mirrors • High costs due to: 1. High weight/unit mirror area 2. Complex site assembly and installation 3. Six point mirror attachment will complicate alignment process • Prototypes have not been built and tested	• Have not been addressed

8.2 Heliostat Comparisons

When the Second Generation Heliostat designs that were built and tested are compared to the CRTF and Pilot Plant prototype heliostats, there are several inherent design improvements that have been made as well as continuing concerns. These improvements and concerns are summarized below.

				2nd Generation			
INHERENT DESIGN IMPROVEMENTS	CRTF	MDAC PILOT PLANT	MMC PILOT PLANT	ARCO	BEC	MMC	MD
Good Silver Protection	x			x		x	x
Minimal Thermal Defocus	x			x	x	x	
Easy Maintenance			x	x		x	x
Low Weight/Unit Area		x		x	x	x	x
Well Sealed Drive			x	x	x	x	x
Fiber Optics Immunity to Electrical Noise and Lightning						x	x
DESIGN FEATURES THAT CONTINUE TO BE OF CONCERN							
Mirror Module Life Difficult to Demonstrate		x	x	x	x	x	x
Marginal Mirror Module Strength					x	x	
Difficult to Wash Mirrors			x[1]			x[1]	

Note: [1]Motors protrude beyond mirrors unless in near-horizontal position

8.3 Areas of Risk

The areas of risk for near-term applications in the Second Generation Heliostat designs are shown below along with the Martin Marietta Barstow heliostat.

SECOND GENERATION HELIOSTAT
AREAS OF RISK
NEAR-TERM APPLICATIONS

HELIOSTAT	Years Before Problems Might Occur			
	0-1	1-5	5-10	10-20
ARCO	Software (Medium to Large Fields)		Mirror Module	Pedestal
Boeing	• Mirror Module • Control Hardware and software			El Drive
Martin Marietta Barstow (Other Applications)			Mirror Module[1]	
Martin Marietta 2nd Generation	Mirror Module			
McDonnell Douglas	Fiber-optic Hardware			• Mirror Module • Pede-stal

Note: [1]Mirror module may accumulate water if dew point is frequently reached.

9.0 Further Research and Development Requirements

The remaining development required for the Second Generation Heliostats is shown below.

REMAINING SECOND GENERATION HELIOSTAT DEVELOPMENT

Item	Arco	BEC	MMC	MDAC
Foundations For Other Soils	x	x	x	x
Controls				
Heliostat Controller	x	x		
Heliostat Field Controller	x	x		
Heliostat Array Controller Software	x	x		
Optimized Beam Control Strategies	x	x	x	x
Mirror Modules		x	x	
Drive Mechanisms	x		x[2]	
Production Processes				
Mirror Modules	x	x	x	
Mirror Canting	x	x	x	x
Test Standards For Production	x	x	x	x

Notes: [1]Replace stepper motor
[2]Stow Lock Fail-safe Feature and Feasibility In Production

Other areas requiring on-going development are summarized below.

<u>On-Going Heliostat Development Requirements</u>

- System Requirements for Controls
- Mirror Modules
  - Accelerated and real-time test methods
  - First-surface mirror
  - Design without adhesives or seals
  - Inspection methods

Canting tools
Glass handling equipment
Methods for estimating dirt accumulation rates
Fast-cure adhesives

- Drive Mechanisms
  Accelerated life-cycle test methods
  Lower-cost designs

- Field Wiring Design
  Incorporating systems considerations
  Lower-cost concepts

- Heliostat Mirror Washing
  Methods
  Equipment

- Field Reflectometer

- Safe Beam-Control Methods

- Heliostat Optical Quality Measurement Methods

- Refined Costing and Pricing Guidelines

- Standard Test Methods

- Improved Collector Subsystem Performance Codes

Research is required to support further heliostat development and to improve the designers' understanding of degradation mechanisms. Areas for further research are:

- Silver Degradation Mechanisms

- Glass Solarization

- Glass Weathering

- Adhesive Degradation Mechanisms

- Sealant Degradation Mechanisms

- Lubrication Improvements

- Corrosion Resistant Coatings for Steel

10.0 Second Generation Heliostat Reports

The contractor reports for the Second Generation Heliostat Program are shown below and copies are available from:

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

ARCO Power Systems Reports

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

2. "Second Generation Heliostat Development for Solar Central Receiver Systems, Final Report," Northrup, Inc., March 1981, SAND81-8178.

   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

Boeing Engineering and Construction

"Final Report, Second Generation Heliostat Development for Solar Central Receivers", Boeing Engineering and Construction, March 31, 1981, SAND81-8175.

   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

Martin Marietta Corporation

1. "Second Generation Heliostat Development," Martin Marietta Corporation, September 1980, SAND79-8192/I and SAND79-8192/II.

   Volume I -- Detailed Design Report
   Volume II -- Appendices

2. "Second Generation Heliostat Development," Martin Marietta Corporation, April 1981, SAND81-8176.

   Volume I -- Final Report
   Volume II -- Appendices

McDonnell Douglas Astronautics Company

1. "Second Generation Heliostat Detailed Design Report," McDonnell Douglas Astronautics Co., August 1980, SAND78-8192.

2. "Second Generation Heliostat Program, Executive Summary," McDonnell Douglas Astronautics Co., April 1981, SAND81-8177.

3. "Final Report -- Second Generation Heliostat with High Volume Manufacturing Facility Defined by General Motors," McDonnell Douglas Astronautics Co., April 1981, SAND81-8177.

Volume I -- Final Report
Volume II -- Definition of a Heliostat Manufacturing Facility

Westinghouse Electric Corporation

"Design Report, Westinghouse Second Generation Heliostat," Westinghouse Electric Corp., June 1980, SAND79-8193/I and SAND79-8193/2.

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

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