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SOLAR CENTRAL RECEIVER PROTOTYPE HELIOSTAT CDRL ITEM B.b.

Technical Progress Report - Interim

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS
CORPORATION

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MCDONNELL DOUGLAS

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CONTENTS

VOLUME I

PREFACE

This report is submitted to the Department of Energy under Contract EG-77-C-03-1605 as the Interim Technical Progress Report, CDRL Item B.b.

Section 1

INTRODUCTION AND SUMMARY

This interim progress report presents the current status of the MDAC effort on the DOE Prototype Heliostat Program. Progress is reported in each of the eight specific areas required for the final report by the contract with DOE. A summary of status in each of these areas is presented in Table 1-1 showing the area, status, and references to the portions of the report which discuss each of these areas. A further elaboration of status is given in Section 1.3.

1.1 PROGRAM OBJECTIVES

The objectives of this program are to establish a heliostat design with the associated manufacturing, assembly, installation and maintenance approaches that will:

1) Yield a significant reduction of capital and operating costs,
2) Meet performance specifications for large collector subsystems, and
3) Can be produced and deployed throughout the southwestern United States.

In addition, Phase II cost plans and schedules to develop, fabricate, and operate the heliostat defined in Phase I are to be developed. The areas of R&D which are promising, but outside of scope of the Phase I activities, are to be defined.

MDAC's study objective is to begin with a third generation heliostat which resulted from the DOE Phase I Pilot Plant Program (Reference 1) and reduce the anticipated cost of this heliostat to meet or exceed the DOE goal of $\$72/m^2R$ (cost per unit area normalized to reflectivity).

The initial baseline design has previously been subjected to extensive tests at both the component and subassembly level as well as the subsystem level. The heliostat design was shown through these tests and additional analyses to

Table 1-1

PROTOTYPE HELIOSTAT PROGRAM STATUS

REPORTING REQUIREMENT	STATUS
Collector Preliminary Design	Completed
Process Conceptual Designs	
• Manufacturing	Completed for 25,000 heliostats per year
• Installation and Checkout	Completed
• Operations and Maintenance	Completed
Bench Model and Components Tests	Completed
Cost Analyses	
• Capital Costs	Completed for 25,000 heliostats per year
• Life Cycle Costs	Completed for 25,000 heliostats per year
• Performance[a]	Completed
Preliminary Test Plan for Phase II[b]	Outline Completed
Scope and Schedule - Phase II[b]	In Progress
Drawings and Process Flow Charts	Completed
Trade Study Results	Completed

[a] Cost Performance Ratios to be Computed by Sandia Laboratories

[b] To be Presented Under Separate Cover per Request by Sandia Laboratories

meet the requirements of DOE Specification 001. The changes recommended by MDAC to reduce cost must not jeopardize this ability to meet DOE Specification 001.

Hence, the specific objectives of the MDAC Prototype Heliostat Program are to revise and refine the preliminary design heliostat resulting from the Phase I Pilot Plant Study to:

1) Accommodate high volume production methods.
2) Reduce the installed cost to less than $\$72/m^2R$.
3) Maintain conformance with DOE Specification 001.
4) Provide for deployment in large power plants throughout the southwestern United States.
5) Define manufacturing, installation and checkout, and operations and maintenance plans for this heliostat.
6) Describe the impact of production rates of 25,000, 250,000, and 2,500,000 heliostats per year, as well as define the cost of a one-time production run of 2,500 heliostats.
7) Estimate the capital cost of the production facilities required to produce at the levels of (6) above.
8) Estimate the annual operating costs, including cleaning, operation, and maintenance.
9) Provide performance estimates for the heliostat operating in the plant environments as described in Specification 001.

1.2 PROJECT APPROACH

The MDAC approach to the Prototype Heliostat is to perform a baseline perturbation, design-to-cost analysis of the collector, as illustrated by the study flow net of Figure 1.2-1.

Beginning with an initial baseline, trade studies are conducted in all project elements. Promising candidates requiring some test verification are subjected to minimum tests to ensure feasibility. Cost analyses are used to identify

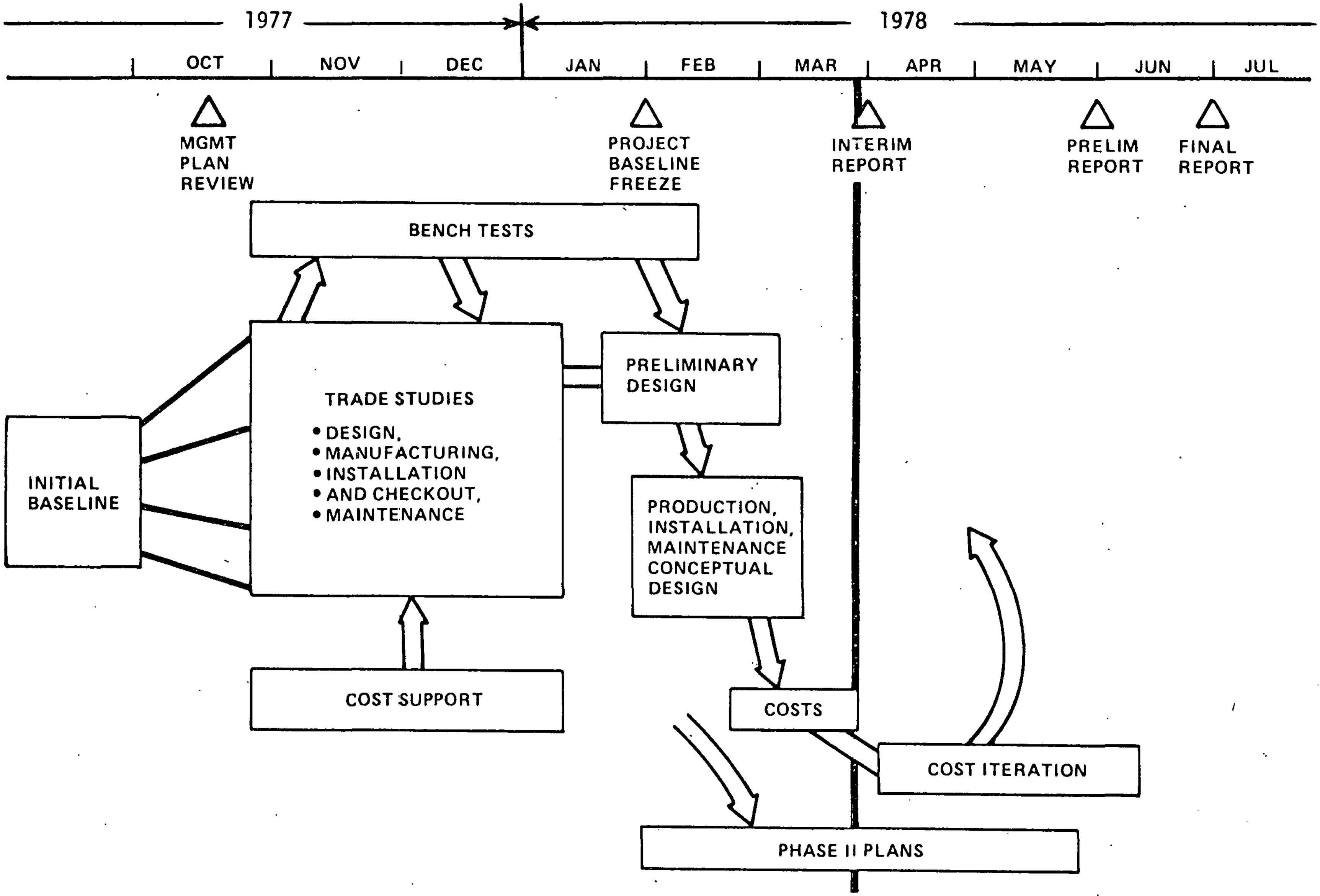

Figure 1.2-1 Study Flow Net

the areas which are most promising for cost reduction, establish and monitor progress toward cost goals, and resolve trade studies. The baseline design which results from the trade studies is then defined to the preliminary design level. Plans for manufacturing, installation and checkout, and operations and maintenance are developed. Cost estimates of the preliminary design are developed and used to feed back into the design and plans, if key cost reduction issues are still apparent. Finally, plans for Phase II testing are developed to demonstrate performance and compliance with the specifications.

The starting point is the collector subsystem definition which resulted from the DOE Phase I Pilot Plant Study (Reference 1). The heliostat is illustrated in Figure 1.2-2 and may be summarily described as follows:

Mirror Module - The mirror module is a bonded sandwich consisting of a second surface, 3 mm (1/8"), low-iron float glass mirror front face, a Styrofoam core of 57 mm (2-1/4") thickness, and a thin galvanized steel backface. The dimensions are 1.08 m (42-1/2") by 2.9 m (114").

Support Structure - The support structure consists of a tubular main beam and two pairs of channel section cross beams. Each mirror module is bolted to the cross beams with shallow cups to spread the load. Six mirror modules are used on each side to comprise a reflector unit of about 37 m^2 (400 ft^2).

Drive Unit - The azimuth drive unit employs a 240 VAC, three-phase induction motor driving an integral gear head. The gear motor drives a worm gear, which in turn drives the harmonic drive output stage.

The elevation drive employs two machine screw linear actuators. The actuators are separated by a drag link to provide for the 180 degree rotation necessary to stow the reflector unit face down. Both actuators are operated by 240 VAC, three-phase gear motors.

Pedestal/Foundation - A tubular steel pedestal is attached to the drive unit on the upper end and to the foundation on the lower end by bolted flanges. The foundation may be either a precast spread footing or a drilled pier. The anchor bolts are wired to the reinforcement in either case.

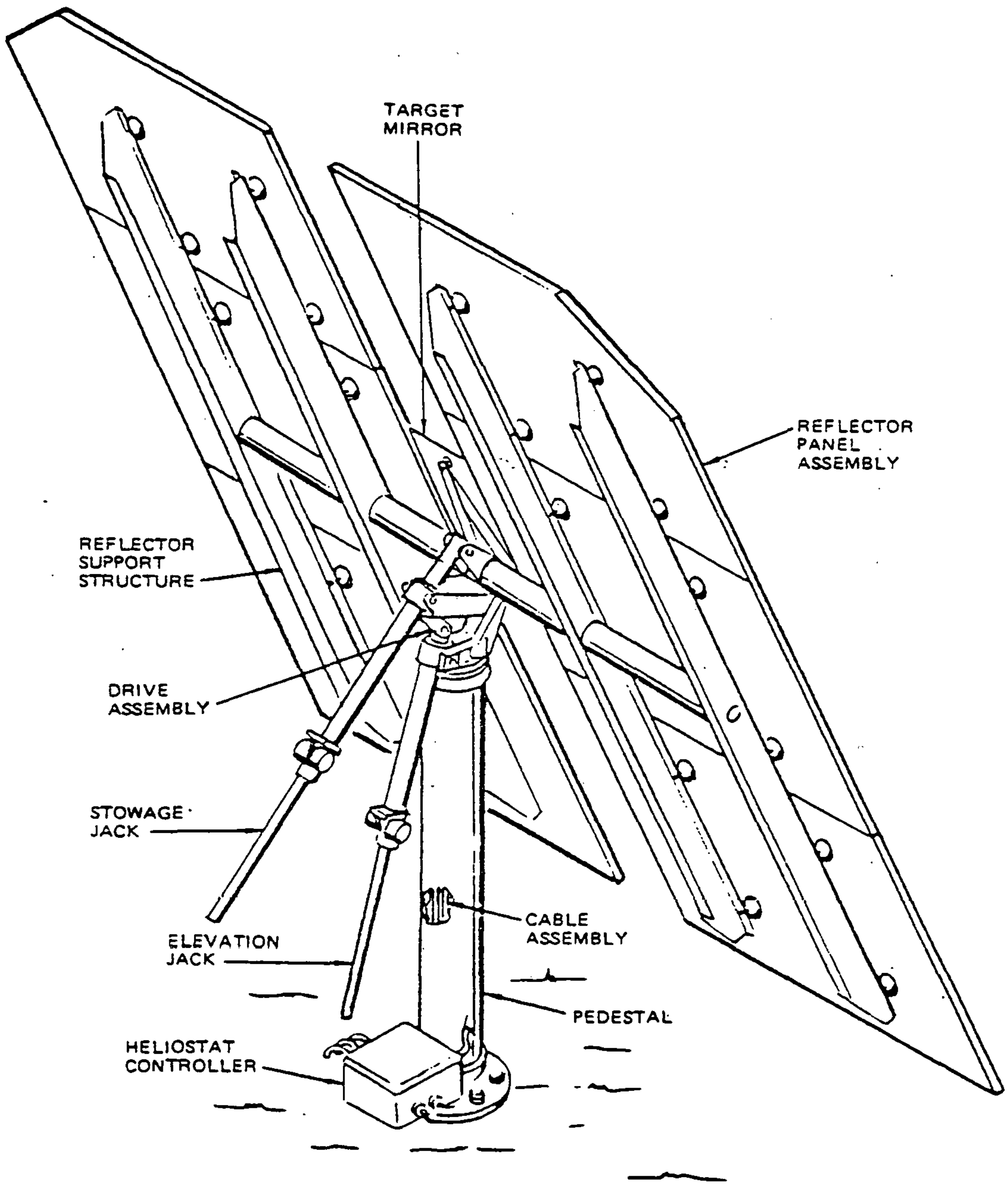

Figure 1.2-2 Heliostat Assembly - Initial Baseline Design

Controls - The heliostat employs open loop control (i.e. no beam sensor) with motor revolution counters for tracking and four-bit absolute encoders on both gimbal axes for periodic update/restart capability.

A heliostat controller located on each heliostat retains the motor revolution counts and generates error signals from data transmitted by field controllers. The motor controller section of the heliostat controller then executes the required motor revolutions indicated by the error signal.

Field controllers are located to service approximately 24 heliostats. The field controllers serve as a data interface with the master controller and calculate time, ephemeris, and gimbal axis position data to transmit to the heliostat controller.

The field electronics (Figure 1.2-3) includes primary feeders of high voltage power and high data rate communication to the field transformers and field controllers, respectively. Both hookups are serial. Branching networks from the transformers connect approximately 24 heliostats in a serial or daisy chain arrangement. Similarly, a serial connection is used between the field controllers and the heliostat controllers.

Cost reduction targets for the baseline perturbation are categorized according to:

1) Design trades to:
   - Reduce materials quantities
   - Substitute less expensive materials
   - Eliminate or improve difficult manufacturing or assembly processes
   - Decrease parts counts
   - Eliminate assembly operations
   - Simplify or eliminate site and field operations
   - Utilize emerging technology

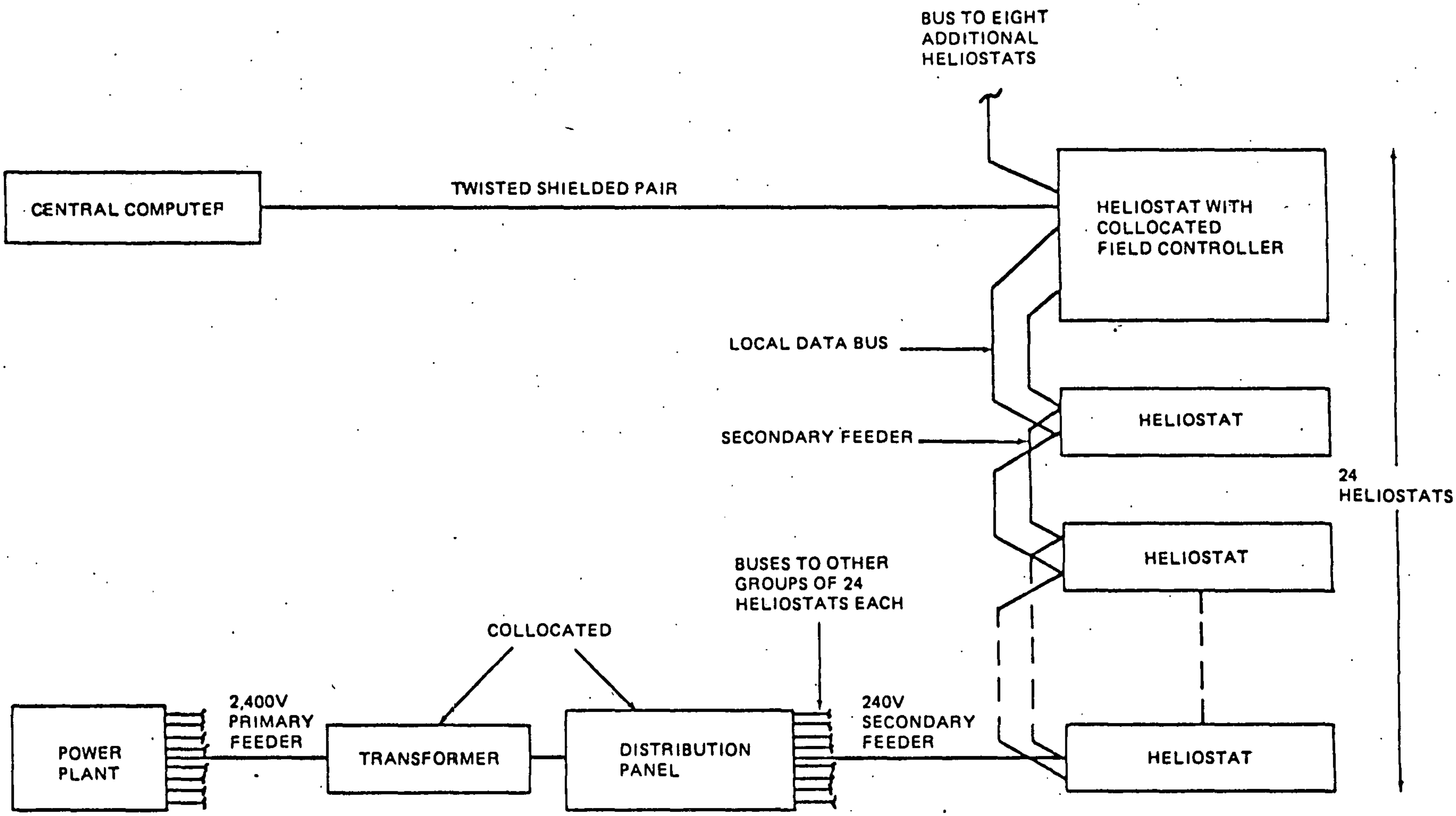

Figure 1.2-3 Branch-Collector Field Network

2) Manufacturing trades to:

- Reduce fabrication costs
- Decrease assembly costs
- Identify suitable alternate parts, materials, or processes for design evaluation

3) Installation and checkout trades to:

- Optimize on-site transportation
- Optimize checkout operations

4) Operations and maintenance trades to:

- Optimize cleaning costs
- Select optimum repair levels.

MDAC proposed a specific set of trade studies, as depicted in Table 1.2-1. The trade studies are grouped according to the specific project element designated as lead on the trade studies. Table 1.2-1 also indicates the participation of other project elements in performing the trade study.

In addition to the specifically defined trade studies, all parts and components of the heliostat were re-examined by all of the project elements with specific attention to factors such as material type, component interfaces, and required processes. These re-examinations lead to changes ranging from minor to major in almost all heliostat parts.

MDAC sought assistance from industry in making the above trades and selections. Subcontracts were let to Arthur D. Little and Stearns-Roger. Arthur D. Little gave advise on our production plans and reviewed the design from a production standpoint. Stearns-Roger developed foundation designs and installation procedures and field wiring installation procedures. Additional design, cost, and production data were provided by:

- Pittsburg Plate Glass on glass production and handling
- Duff-Norton on linear actuator design

Table 1.2-1

PROJECT TRADE STUDY SUMMARY

Lead Project Element	Trade Title	Maximum Expected Cost Reduction ($\$/ft^2$)	Project Elements Participating: Design	Cost	Manufacturing	Installation and Checkout	Maintenance	Specification Verification
Design	D-1 Optimum Heliostat Size	0.54	X	X	X	X	X	X
	D-2 Low Cost Reflector	0.32	X	X	X	X		X
	D-3 Drive Optimization	0.22	X	X	X			
	D-4 Control Optimization	0.15	X			X	X	
	D-5 Reflector Attachment	0.12	X		X	X		
	D-6 Reflector, Structure Optimization	0.09	X		X			
Manufacturing	M-1 Integral Pedestal/Foundation	0.35	X	X	X	X		
	M-2 Drive Housing Materials Reduction	0.14	X		X			
	M-3 Mirror Line Integration	0.10		X	X			
	M-4 Float Glass Line Integration	0.05		X	X			
	M-5 Foam Core Finishing	0.05			X			
	M-6 Foam Extrusion Integration	0.05		X	X			
	M-7 Adhesive Application	0.03	X		X			
	M-8 Site Factory Requirement	Unknown		X	X			
Installation	I-1 Optimum On-Site Transportation	0.08		X		X		
	I-2 Collector Checkout	0.08		X		X		
Maintenance	0-1 Reflector Cleaning	0.7¢/ft^2/year	X				X	
	0-2 Optimum Repair Levels	0.7¢/ft^2/year					X	

- United Shoe Machinery Corporation on harmonic drive design
- Spiroid Division on ITW on helicon gear sets
- Lincoln Foundries on large ductile iron castings
- Dow Chemical on Styrofoam products
- U.S. Steel on commercial steel stock
- Summer & Maca on chemical deposition mirroring
- Donnelly Mirror on vapor deposition mirroring
- 3M Company on adhesives
- Dow Corning on fusion glass properties and production
- McGill Manufacturing on bearings
- Kaydon Bearing Division of Keene on bearings
- Kelly Pipe for tubular steel products
- Peat Manufacturing Company for cast gears

1.3 STATUS SUMMARY

The project status may be described in terms of the various task and activities shown on the schedule of Figure 1.3-1.

Task 1.1 - Program Management is on schedule. This task includes preparation of monthly status reports, briefings, internal program control documents, and manpower and budgetary control.

Task 1.2 - Systems Engineering includes four activities. Each activity is proceeding on schedule, and the status of each is given below:

1) Baseline Management includes establishing, maintaining and freezing the project baseline. These activities are complete for the 25,000 heliostat per year production rate and the 2,500 heliostat production rate. Minor modifications to the project baseline will be considered for the higher production rates.

2) Specification Definition includes performance optimizations suggested by DOE Specification 001 as well as lower level specifications which directly support Specification 001. This activity is completed.

3) Specification Verification is used to ensure that the design, production, and installation activities result in a collector subsystem which will perform

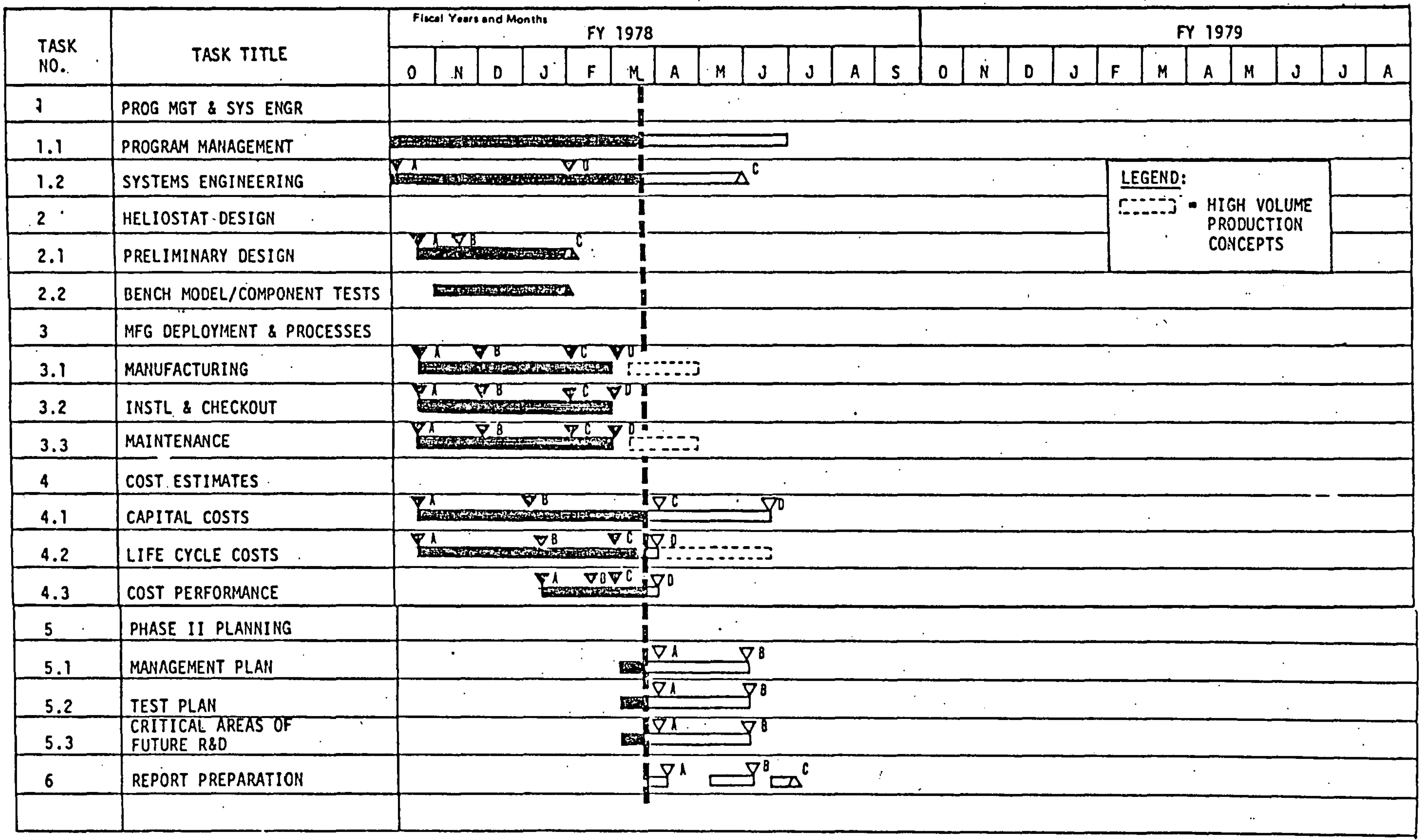

Figure 1.3-1 Prototype Heliostat Project Schedule

in conformance to specifications. This activity is also completed.

4) Establishment and Monitoring of Cost Goals is used to ensure that the design goal of $\$72/m^2R$ is met. This activity is continuing through the development of the higher volume production scenarios.

Task 2.1 - Preliminary Design is divided into two major subtasks: design trade studies and preliminary design. Both subtasks are completed.

Task 2.2 - Bench Model and Component Tests include tests to verify the durability and producibility of the alternate mirror modules. The tests include:

1) Salt spray tests to indicate durability
2) Hail impact tests to verify hail survivability
3) Thermal cycle tests to ensure acceptably low thermal stresses and no thermal fatigue problems
4) Production tests to indicate an acceptable production technique.

The salt spray, hail impact, and thermal cycling tests are complete. Data from the thermal cycling tests are still being evaluated. Preliminary evaluation indicates no problems. Production tests have been completed for small scale panels.

Task 3.1 - Manufacturing Processes includes identifying the processes, equipment, facilities, and manpower necessary to produce the heliostats and other collector equipment. This task is complete for the 25,000 heliostat per year and 2,500 heliostat rates. Activities are continuing for the larger production volumes.

Task 3.2 - Installation and Checkout Processes includes receipt of collector assemblies, on-site transportation, installation, alignment and checkout. Equipment, facilities and manpower are to be identified. This task is complete for all production rates, as on-site activities are largely independent of total production rate.

Task 3.3 - Maintenance and Operation includes analysis of maintenance actions required, including equipment, spares, and manpower; identification of repair levels on failed parts and spares requirements; scheduled maintenance of both the collector and support equipment; and operations requirements, especially cleaning processes, equipment and manpower. This activity is complete for the lower production volumes and may be perturbed for the higher production volumes.

Task 4.1 - Heliostat Capital Costs includes all of the costs necessary to procure, fabricate, assemble, install, align, and check out the collector field. This activity is nearing completion for the lower production volumes and will be continued for the higher production volumes.

Task 4.2 - Heliostat Life Cycle Costs includes the estimation of the annual cost of operations and maintenance to perform those activities identified in Task 3.3. This task is nearing completion for the lower production rates and will be continued for the higher production rates, incorporating any significant changes resulting from the Task 2.3 studies.

Task 4.3 - Cost Performance Ratio provides the performance data necessary to formulate the performance portion of the cost-performance ratio. The cost-performance ratios will be calculated by Sandia. This task is completed in preliminary form, but may be refined to provide additional data.

Task 5.1 - Phase II Management Plan provides DOE a draft statement of work and program plan for the Phase II activities. This task has been begun, with preliminary estimates of costs and schedules nearing completion.

Task 5.2 - Phase II Test Plan provides DOE with a draft test plan for the Phase II activities. This task is in progress with a preliminary test plan prepared.

Task 5.3 - Critical Areas for Future R&D provides DOE with concepts for further cost reduction which have arisen during the course of the Phase I study which show promise but are outside the scope of the Phase I study. While this task is continuing, some concepts are contained in Volume II of this report.

Task 6 - Report Preparation provides this interim progress report and the final report. This task is proceeding on schedule.

1.4 COLLECTOR DESCRIPTION SUMMARY

The collector subsystem is made up of three assemblies. The heliostat assembly includes the reflective unit, the drive unit which orients the reflective unit, the foundation which supports the heliostat, and the heliostat electronics which controls the drive unit.

Other assemblies are the collector controller which is collocated with and interfaces with the system master control, and field electronics consisting of primary and secondary power and data feeders, field transformers, distribution panels, and data distribution interfaces.

Table 1.4-1 shows a subsystem hardware tree down to the component level and indicates the correspondence to collector cost breakdown structure numbers.

1.4.1 Heliostat

The collector preliminary design is described in Section 2, including trade study and test results.

The heliostat is illustrated in Figure 1.4-1. The heliostat is divided into four subassemblies, based on the physical pieces of hardware delivered to the field. These subassemblies are the reflector panel (one half of the reflective unit), the drive unit (including the pedestal), the foundation, and the heliostat electronics (including controllers and control sensors).

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Table 1.4-1

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PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	CORRESPONDING CBS NUMBER
• Collector - (Field of Heliostats)				4400
	• Heliostat - (Includes Controller)			-
		• Reflector Panel - (Two Panels Make Reflective Unit)		4410
			• Mirror Module	4411
			• Support Structure	4412
		• Drive Unit		4420
			• Azimuth Drive	4421 & 4423
			• Elevation Drive	4422
			• Pedestal	4412
		• Foundation		4440
		• Heliostat Electronics		4430
			• Heliostat Controller	4433
			• Motor	4423
			• Pedestal Junction Box	4425

Table 1.4-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	CORRESPONDING CBS NUMBER
	• Collector Controller			4430
		• Console		
			• Key Board	
			• Cathode Ray Tube	
			• Control Panel	
		• CPU		
		• Storage		
		• Field Interface		
		• MCS Interface		
			• Mode	
		• Time Pickup		
	• Field Electronics			-
		• Power Distribution		4425
			• Power Distribution Module	4425
		• Data Distribution		4425 & 4433
			• Data Distribution Interface	4432

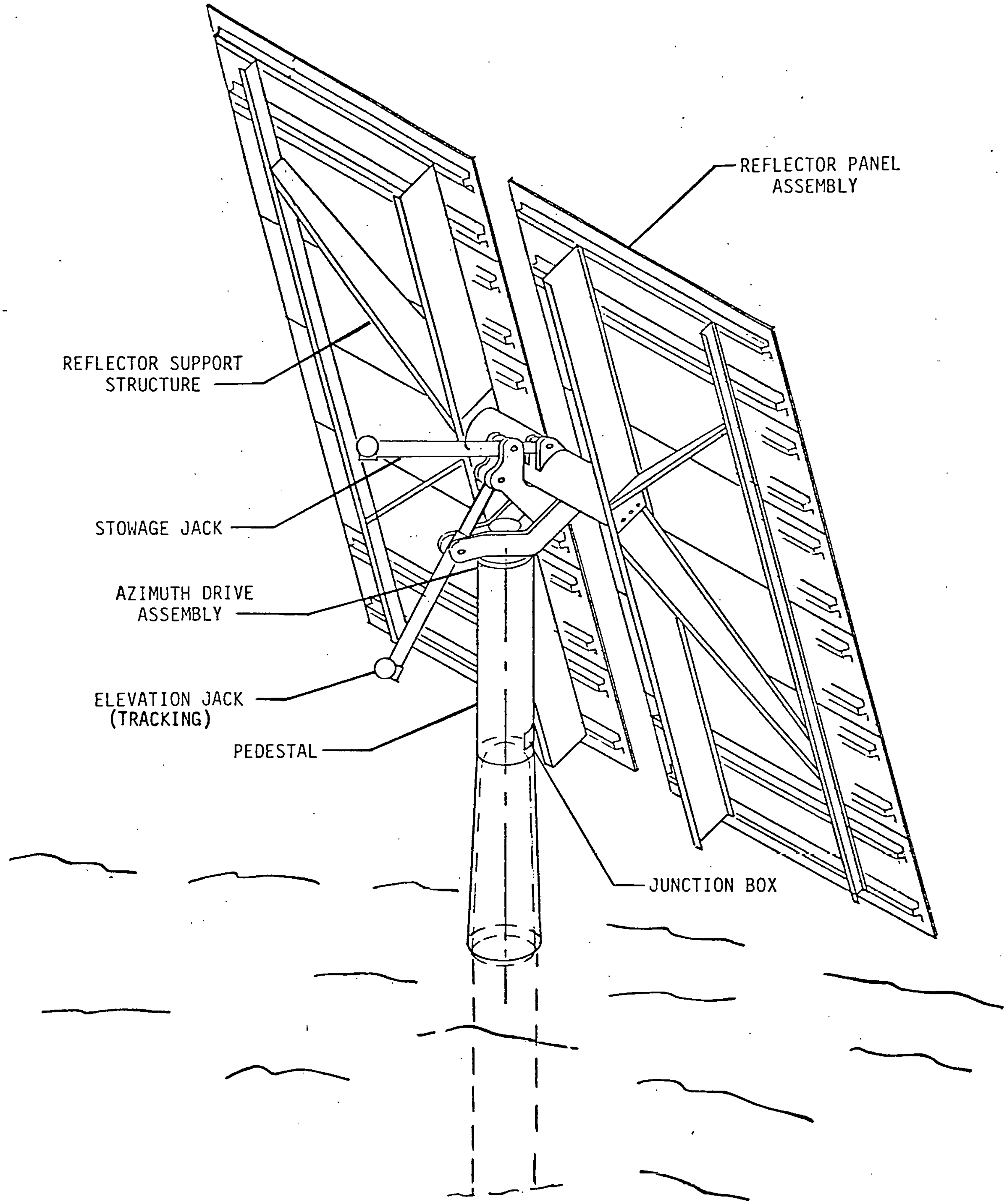


Figure 1.4-1 Primary Baseline Heliostat

Reflector - Each reflector panel is comprised of six mirror modules and a support frame. The mirror modules are 1.22 m (48") by 3.35 m (132") and made of a 1.5 mm (0.060") second surface mirror laminated to a 4.8 mm (0.1875") glass back lite. The clean reflectivity is estimated to be 0.92 at 0.05% iron and 0.945 at 0.01%.

The mirror modules are bonded to stringers which are, in turn, riveted to the cross beams. The outer cross beam is supported by two diagonal beams. All beams and stringers are made by continuous roll forming from coiled sheet stock.

Drive Unit - The drive unit is comprised of a rotary azimuth drive, a double jack elevation drive, and a pedestal. The azimuth drive motor is a three-phase, 480 VAC. A 162:1 helicon input reducer provides the first stage reduction. The output is through a 242:1 harmonic drive reducer.

The elevation jacks utilize a similar, but smaller, motor, driving a helicon gear affixed to the nut of a ball screw. The two jacks are connected by a drag link. One jack provides tracking motion while the other provides the additional motion required for stowage. The main beam is a 16" diameter tube with the final linkage of the elevation drive flange ends on the main beam providing an interface onto which the reflector panels are bolted. The tube has brackets which attach to a hinge line on one side and the tracking actuator on the opposite side.

The pedestal is a 24" diameter tube with a slight flare on the lower end which matches the tapered top of the foundation and provides a friction joint to the foundation. The top of the pedestal is closed by a dome which bolts to the circular spline of the harmonic drive.

The drive unit is delivered to the field with the heliostat electronics installed.

Heliostat Electronics - The heliostat controller is located in a housing on the top of the drive unit. The controller receives and transmits commands from the heliostat array controller and responds to requests for data. A micro-processor calculates the motor revolutions required to maintain tracking and activates the motor controllers. The motor controllers switch the motor on and off to produce the required motion. The motor revolutions sensors detect motor revolution and direction, and the controller maintains a count of the accumulated revolutions.

The field wiring terminates at a junction box located on the pedestal. A "tee" junction provides the power to operate the heliostat. Data are routed to the heliostat controller, decoded and relayed to the next heliostat in the link if not addressed to the receiving heliostat. Acknowledgment of receipt of a message and status are also transmitted.

Foundation - The foundation is a drilled pier, 24" in diameter. The pier extends about 4' above grade and 20' below. A tapered steel shell establishes the mounting surface to the pedestal and serves as a form for the protruding end of the pier.

1.4.2 Field Electronics

The field electronics is a general term for the loops which distribute power and data to the heliostats. Those loops are illustrated in Figure 1.4-2.

The central feature of the field electronics diagram is a field distribution center. This distribution center is really a collocation of the field transformer and the data distribution interface. Its power handling function is to step down voltages and dispatch power to several "daisy chains" of heliostats; i.e., heliostats connected by a single cable which tap power off that cable. The data distribution function is to decode high baud rate messages, and address them to the correct heliostat in the correct chain.

The transformer interfaces with the Electric Power Generation Subsystem and receives 4160 V, three-phase power. The primary feeders link up to three transformers in a daisy chain.

The data distribution interface links into the master control through the heliostat array controller. Data are transmitted from the heliostat array controller concerning heliostat operating modes, time synchronization, and

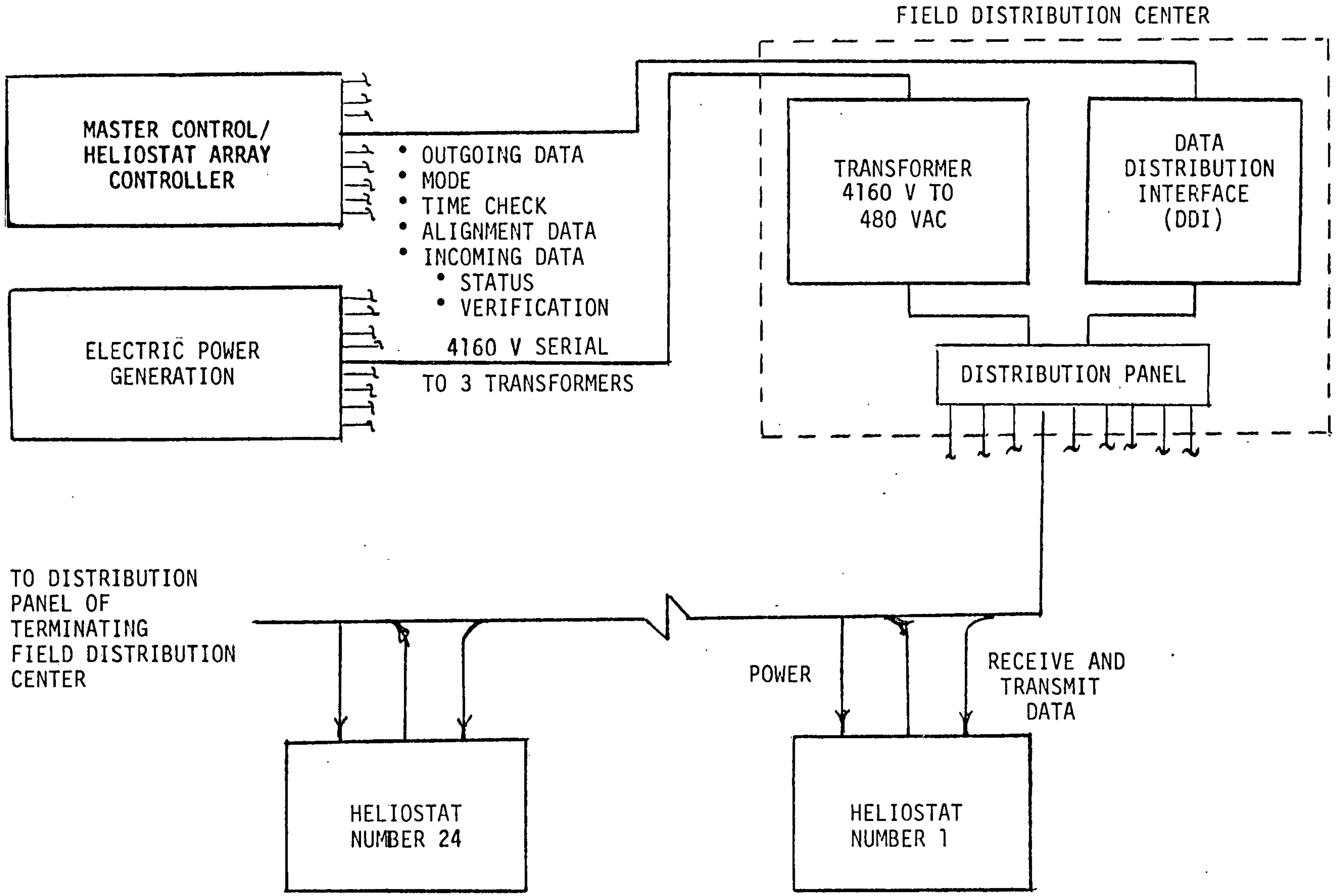


Figure 1.4-2 Collector Field Electronics

alignment/checkout parameters from the collector checkout sensors. Data received include heliostat status and verification of messages received. Again, serial connection of three data distribution interfaces is used.

All data communication is by fiber optics. The rationale are lower cost (expected in the 1985 time period) and freedom from EMI.

The data distribution interface receives data from the heliostat array controller via either of two redundant lines and logic networks. The redundancy provided should prevent loss of control of more than a few heliostats at a time. The logic network decodes the data and addresses it to the correct secondary data feeder and the intended heliostat.

Power and data are carried in the same cable from the distribution panel to the chain of heliostats. Each cable is terminated at another field distribution center. Hence, power may be fed either way on a cable if the cable fails open as in a break. A short circuit in a cable will, of course, trip the breaker in the distribution panel and cause the loss of power to all heliostats in the chain.

The control signals carried by the secondary feeder are all processed by the first heliostat in the chain. Those signals which are addressed to other heliostats are simply repeated, hence routed to the next heliostat. Signals addressed to the Nth heliostat are received by that heliostat and an acknowledgment signal is transmitted. The acknowledgment signal, which may include requested data on heliostat status, is relayed to the field distribution center at the end of the chain. From the center, data are relayed directly to the heliostat array controller.

Each heliostat has the capability to continue to operate autonomously in the event of a loss of data signals. If no transmission of data are received in a specified length of time, the heliostat will continue to track, but will transmit an alarm which indicates a loss of the data link.

1.4.3 Collector Production Summary Description

The collector production concept is described in Section 3. The heliostat is produced in the factory in three physical parts to be delivered to the field. As stated in Section 1.4.1, the drive unit and heliostat electronics subassemblies are mated in the factory. The drive/control unit is given a 100 percent functional inspection in an automated checkout facility and shipped to the field ready for installation. The other two physical parts are the reflector panels. These panels are also completely assembled in the factory. The panels are also subjected to an optical inspection by automated equipment prior to shipment.

Those parts which are delivered to the field are made in an assembly factory. Nominally, one assembly factory produces 25,000 heliostats per year. The heliostats are designed to be deployed in the proximity of the assembly facility; e.g., within a radius of 50 miles. However, there is no restriction preventing delivery to final installation sites at greater distances other than transportation costs.

To meet the higher volume production rates, the assembly factory is simply replicated at different locations and the sources of parts and materials which are fed to the assembly facility are expanded to service the greater volume. Other changes may be made to optimize the production and handling. For example, the assembly factory may be separated to drive/control factories and reflector panel factories with different capacities to optimize transportation and factory siting. The form of the received materials and parts may be altered to centralize some of the fabrication operation.

The flow diagram in Figure 1.4-3 shows the production steps for the reflector panels. The flow chart shows the actual assembly procedure without addressing the questions of where the glass, beams, and attach fittings are made. These decisions may vary with production volume.

The front lite is thin, 1.22 mm (0.060") glass. Fusion glass is tentatively specified, but other glasses may be equally adequate. The glass is cleaned, sansitized, and mirrored. Adhesive is applied in lieu of backing paint. The back lites

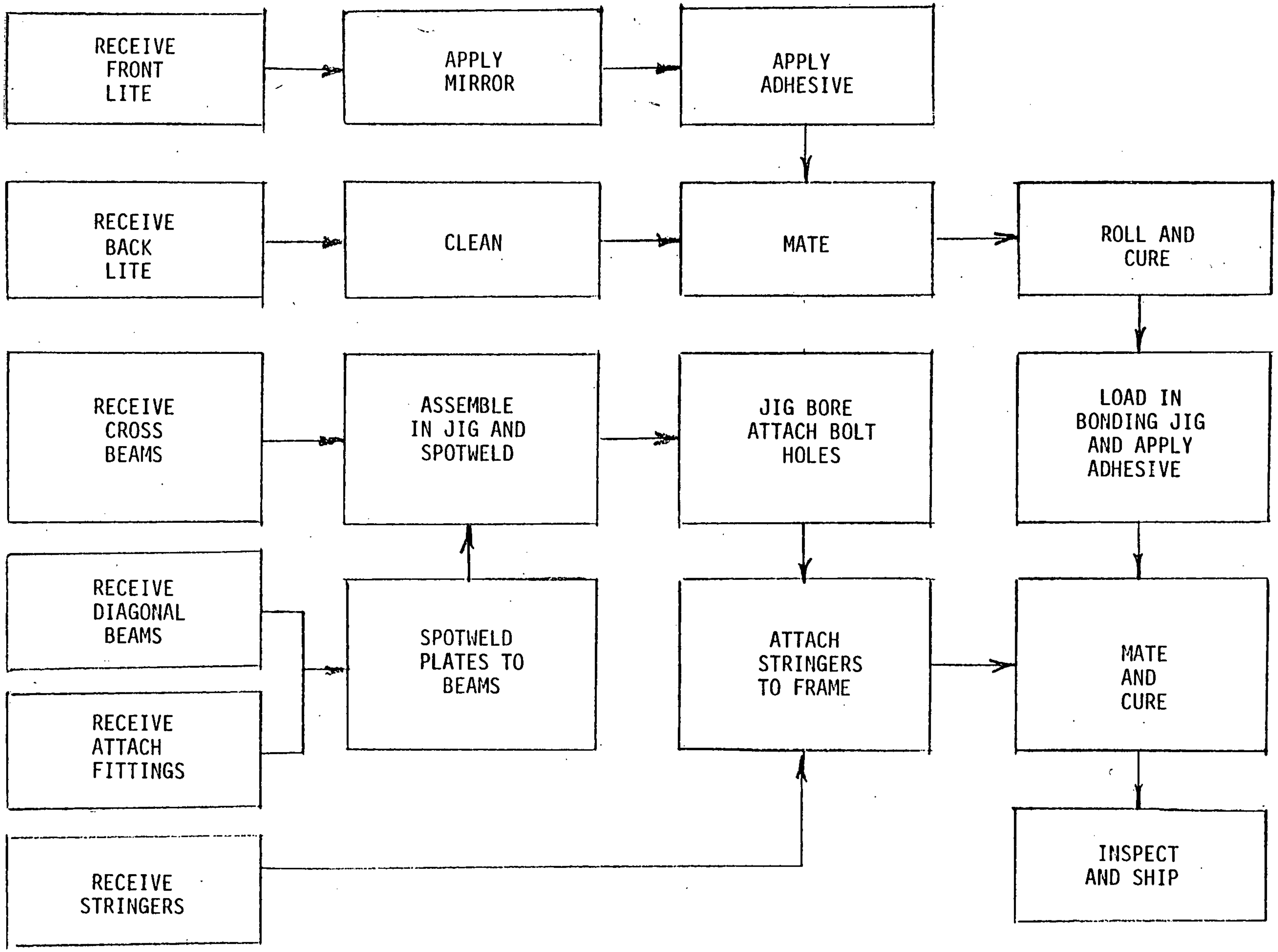


Figure 1.4-3 Panel Assembly Procedure

are 0.1875" commercial grade float glass. This glass is cleaned and dried and mated with the front lite. The assembly is rolled to insure good adhesion and cured on a conveyor belt.

The frame is assembled from its component parts by automatic spot welding in a jig. The holes for the attach bolts are jig bored. The stringers may be either riveted or spot welded.

The mirror modules are loaded into a bonding fixture at the appropriate cant angle and curvature. Adhesive is extruded onto the back surface of the mirror module and the frame is positioned such that the mirror surfaces are correctly aligned with the bolted interface to the drive unit.

After curing, the assembled panel is inspected by automatic optics analyzing a reflected test pattern. The panel is then loaded onto a reusable shipping fixture.

The azimuth drive unit assembly is illustrated in Figure 1.4-4. As can be seen, there are many steps to the assembly of the azimuth drive. However, most of these steps are in-line installation of parts or subcomponents whose assembly can be completed off-line and stock piled. Hence, the process is amenable to a very simple assembly line such as an overhead conveyor or monorail.

The completion of the drive unit assembly is illustrated in Figure 1.4-5. Again, the simple assembly line approach appears to be suitable.

At the completion of the assembly, the drive/control assembly is loaded into a computer operated fixture and given a complete functional checkout. In addition, key characteristics of the assembly can be automatically measured to provide data on the production process.

After inspection, the drive unit/control assembly is loaded onto a shipping fixture ready for delivery to the field.

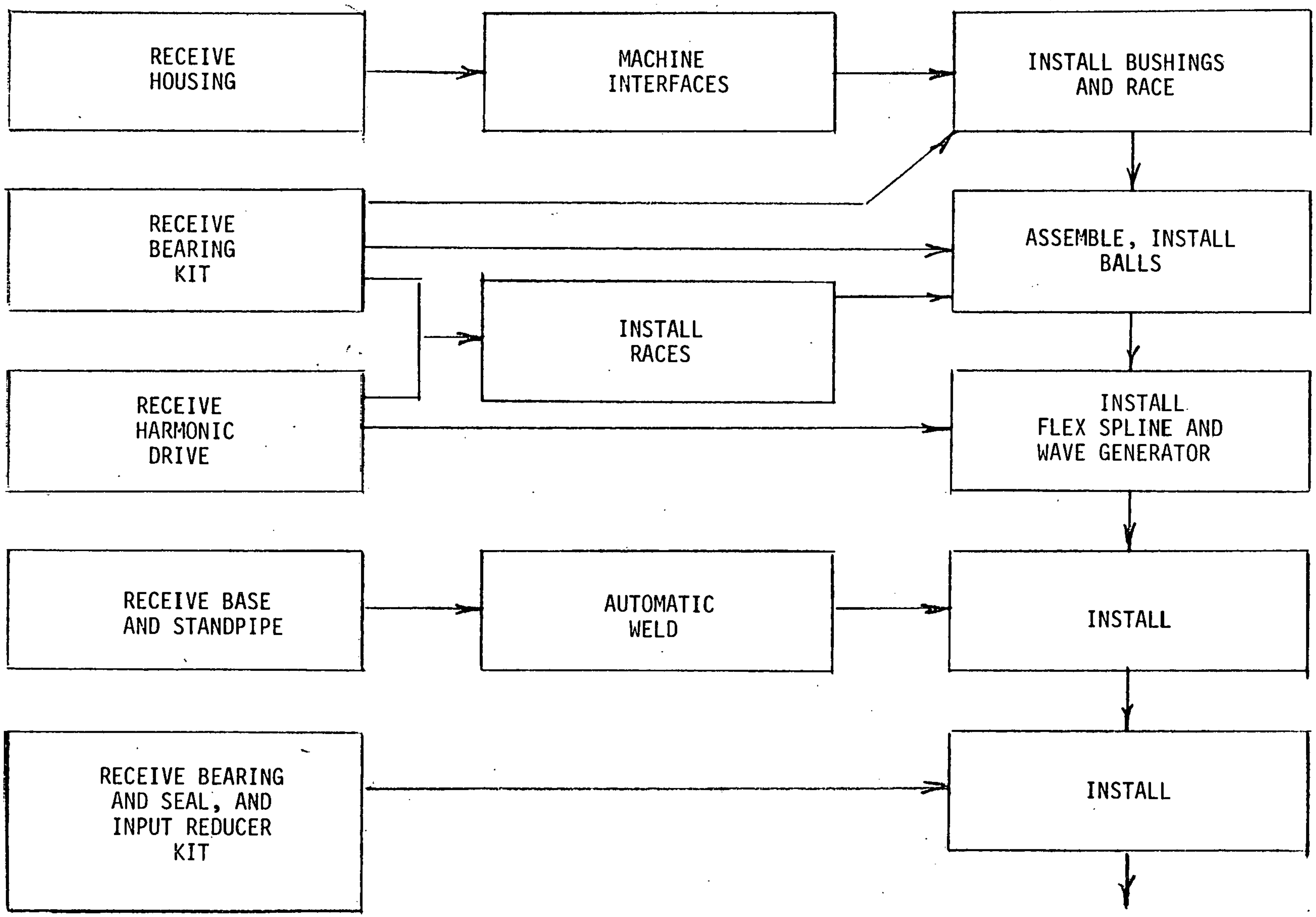


Figure 1.4-4 Azimuth Drive Assembly

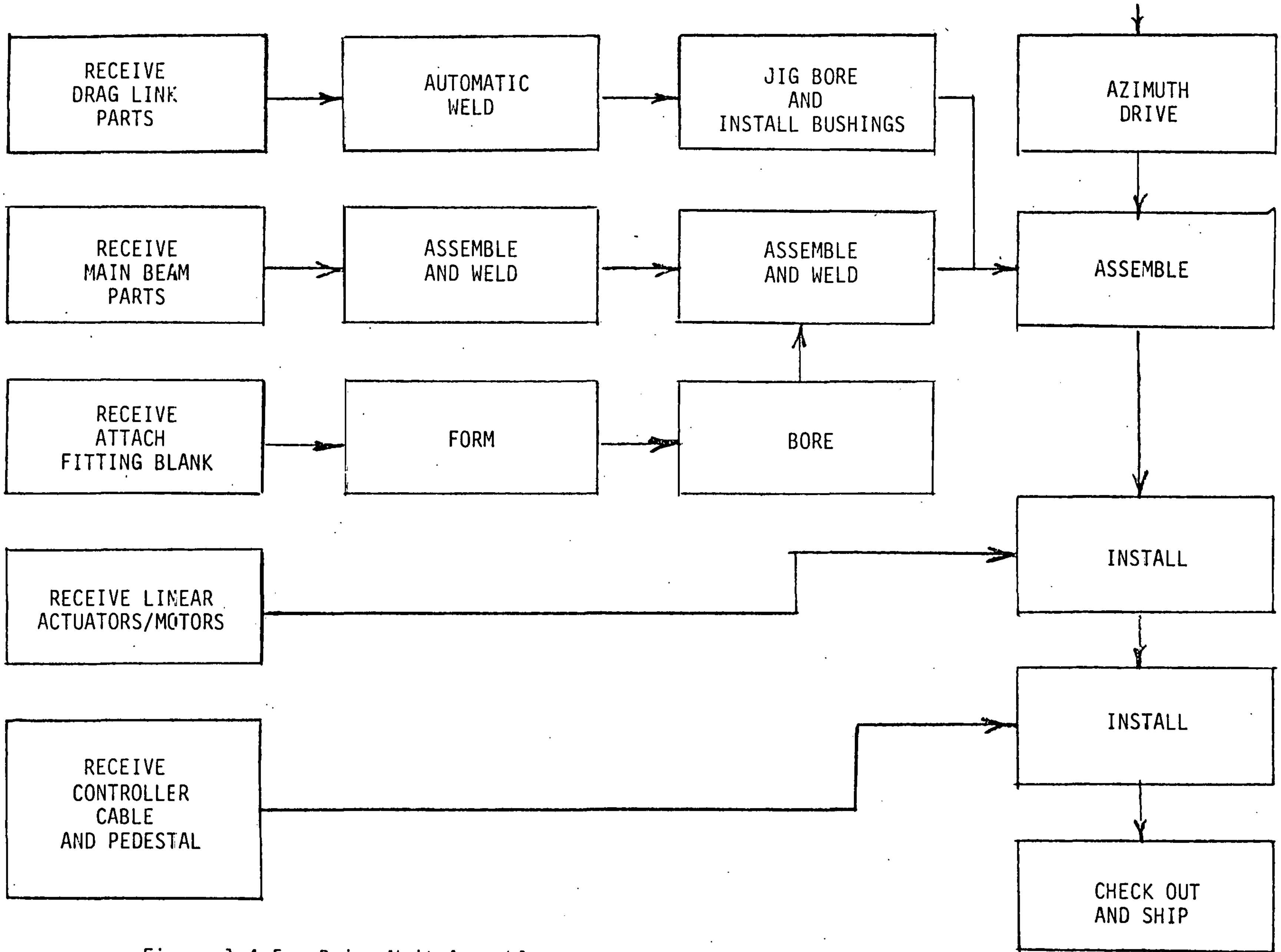


Figure 1.4-5 Drive Unit Assembly

1.4.4 Installation and Checkout Summary

The collector installation and checkout concepts are described in Section 4. The installation process flow is shown in Figure 1.4-6. Site preparation includes rough grading and surveying. The foundation hole is drilled, the rebar installed, and the foundation is poured. A thin sheet metal cone serves as a form for the mating surface to the pedestal.

The pedestal is held vertical and oriented south by the installation vehicle. After mating to the foundation, the drive is loaded and vibrated to insure adequate seating.

The secondary feeder cable is brought to the field with the ends terminated and rolled on spools. The cable is plowed into the ground and the terminations left above ground. Each cable requires bolting on three lugs, terminating one optic fiber and making electrical contact with the ground at each end. A weatherproof cover seals the junction box.

The reflector panels are installed, and the heliostat is stowed until the time for alignment and checkout.

To align, the heliostat is centered on a passive target. The motor counters are set and the heliostat is removed to standby. After the elapse of at least two hours, the heliostat is returned to target and recentered. Vertically and non-orthognality errors are computed and added to the data base. An additional return to track at a later time verifies the alignment and tracking.

1.4.5 Operations and Maintenance Summary

The collector operations and maintenance concepts are described in Section 5. Operations and maintenance includes the specific areas of reflector cleaning, routine inspection, scheduled maintenance, repair of failed heliostats and field electronics, spares inventory, repair/replacement of failed parts, and maintenance of the support equipment.

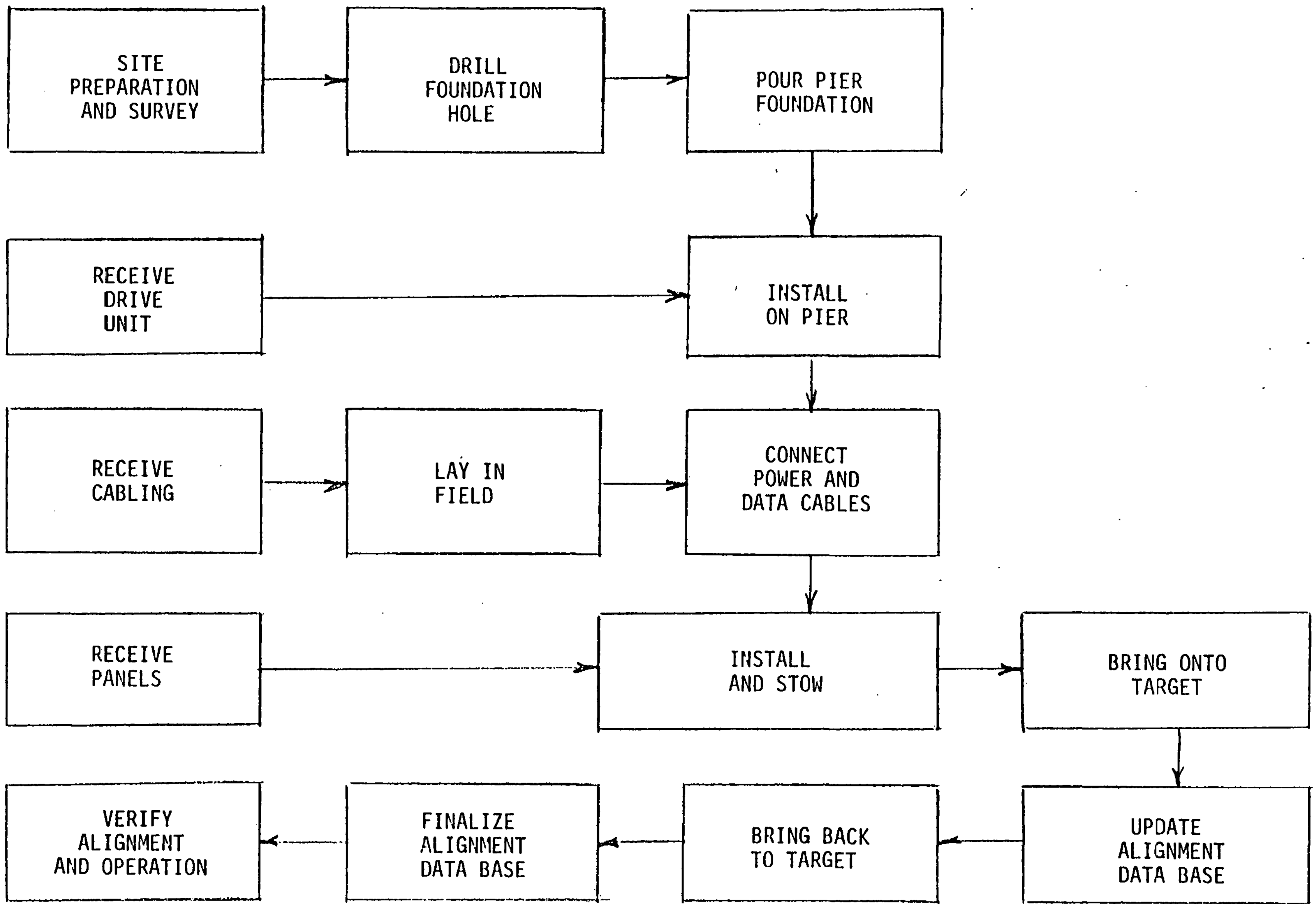


Figure 1.4-6 Installation and Checkout Processes

Reflector Cleaning - Methods for reflector cleaning were compared, and it was concluded that a mechanized system involving a sprayed or washing solution followed by a final rinse with de-ionized water would be the lowest cost. The trade did not consider the efficacy of the methods and should be revised when data on the "as cleaned" reflectivity become available.

Routine Inspection - Inspection of the collector by maintenance personnel will be conducted on approximately one year intervals. The inspectors will look for such things as lubricant leaks, corrosion, and mirror module damage.

Scheduled Maintenance - There will be no scheduled maintenance on the collector equipment in the field. However, the collector controller computer and peripherals will require scheduled maintenance on a weekly interval.

Repair of Failed Equipment - The heliostats and field electronics will be repaired by substitution of Line Replaceable Units (LRU's) from the spares inventory. Typical LRU's are mirror modules, motors, linear actuators, azimuth drive rivets, controller cards, transformers, etc. Almost all repair operations to the LRU's will be performed in the maintenance shop at the field. Few, if any, repair operations will be centralized. The location of the repair operations will vary only slightly with the production volume.

Spares Inventories - LRU spares are stocked at the field to a level which provides for a high confidence of having the spare part when needed. Additional spares are counted for LRU's which are to be repaired to account for the time elapsed between failure and return to inventory.

Repair/Replace LRU's - The decision of whether to repair or replace failed LRU's is based on economics for the individual LRU. These decisions are affected by production volume. The derived costs should be conservative, as they do not account for the salvage value of the LRU.

Maintenance of Support Equipment - The **equipment** used for maintenance must, itself, be maintained. Actions include repair and routine maintenance of the equipment and scheduled maintenance actions such as proof of testing of hoisting slings, etc.

1.5 REPORT OUTLINE

This interim progress report presents the MDAC effort concluded up to the end of March, 1978. As indicated in Section 1.3, the primary efforts to be continued are in the higher volume production scenarios of 250,000 and 1 to 2.5 million heliostats per year.

This report is presented in two volumes. Volume 1 presents the collector design, including trade study and test results, and the manufacturing, installation and checkout, and operations and maintenance concepts. Section 6, also in Volume 1, contains a discussion of specification verification and optimization.

Volume 2 contains the performance analyses in Section 7; the critical R&D areas identified in Section 8; and cost analysis in Section 9.

Section 2

COLLECTOR PRELIMINARY DESIGN

The central pedestal supported elevation/azimuth heliostat design has been used as the basic generic concept for this study because the experience gained with this design over a five-year evolutionary period has consistently shown this concept to be the most efficient and cost effective. Three specific designs have been fabricated and tested under previous programs with a variety of alternatives and variations (Reference 1 and 2). This background is directly applicable to the verification of the modified design resulting from this series of cost optimization and tradeoff studies. In addition, the depth of experience in this basic design provides a detailed point of departure for the evaluation of potential cost reduction design changes within the constraints of the performance and design requirements.

The collector preliminary design begins with a discussion of the initial baseline design. The trade study results are discussed and the rationale for each selection given. Supporting bench scale test results are presented. The final baseline design is then discussed in detail and the more important improvements summarized.

2.1 INITIAL BASELINE DESIGN

In the following sections, the requirements are summarized, the initial baseline described, and the promising areas for design improvement stressed.

2.1.1 Summary of Requirements

The heliostat design is based on the performance and design requirements of RFP EG-77-R-03-1468, Specification 001. In general, these requirements are similar to those used in the Central Receiver Solar Thermal Power System, Phase I effort. The environmental exceptions are minor and include a lower maximum temperature, higher average rainfall, and additional specifications, such as maximum 24 hour rainfall rate, and a hailstone specific gravity callout. The environmental conditions are summarized in Tables 2.1.1-1 and 2.1.1-2.

Environmental, design, and performance requirements of the specification have been used throughout the design effort and in general, the initial and final baseline designs meet all of the requirements of Specification 001.

It is emphasized that the collector is able to continue to operate throughout the survival temperature range and up to the stowage initiation windspeed. The operational range is the range of conditions throughout which all performance specifications are to be met.

2.1.2 Initial Baseline Heliostat Design Description

The design for the baseline heliostat assembly is illustrated in Figure 2.1.2-1. It consists of twelve mirror modules mounted on a support structure which connects with a drive unit for elevation and azimuth pointing and is located on top of a pedestal. The design is similar, in most respects, to that reported in Reference 1. Notable exceptions include:

1. A change back to a Harmonic drive output stage for the azimuth axis, chosen because the lower backlash and high stiffness are more consistent with open loop requirements.
2. The use of two linear actuators in elevation, one actuator for tracking and the second to invert.
3. Open loop control employing motor shaft incremental encoder revolution counters and absolute encoders on the gimbal axes.
4. Reflector panels approximately 43 inches wide and singly curved for improved focusing.

A summary description of the initial baseline heliostat design for this study follows.

Table 2.1.1-1

OPERATIONAL ENVIRONMENTAL CONDITIONS

Environment	Requirement	
Gravity	1 g	
Ambient Air Temperature	0 to 50°C (32 to 120°F)	
Winds:		
1. Wind Speed	0 to 11.6 m/s (26 mph) includes 1.3 gust factor.	
2. Wind Speed Frequency	Speed (m/s)	Frequency (%)
	0-2	29
	2-4	21
	4-6	19
	6-8	14
	8-10	8
	10-12	5
	12-14	3
	> 14	< 1
3. Stowage Initiation Speed	16.1 m/s (36 mph)	
4. Wind Rise Rate During Stowage	0.01 m/s^2 (1.3 mph/min). Heliostat shall withstand, without catastrophic failure, a maximum wind of 22.4 m/s (50 mph) from any direction.	
5. Wind Profile	Use Power Law Velocity Profile: $V_Z = V_{10m} \left(\frac{Z}{10m}\right)^{0.15}$ where: V_Z = mean wind velocity at height Z; V_{10m} = reference wind velocity at height of 10m; 0.15 = power law exponent for flat open country	

Table 2.1.1-2

SURVIVAL ENVIRONMENTAL CONDITIONS

Environment	Requirement
Gravity	1 g
Ambient Air Temperature	-30 to 50°C (-22 to 120°F)
Winds:	
1. Maximum Wind Speed Stowed	40.2 m/s (90 mph) with ± 10 deg angle of attack
2. Align Elevation Axis with Mean Wind Vector	For γ = angle from elevation axis: $\gamma = \pm 26$ deg — No Damage Any γ — No Catastrophic Failures
3. Wind Profile	Use Power Law Velocity Profile: $V_Z = V_{10m} \left(\frac{Z}{10m}\right)^{0.15}$
Earthquake	Seismic zone 3 (Uniform Building Code)
Snow/Ice	250 Pa (5 psf) snow load 50 mm (2 in.) ice load
Hail	Specific Gravity ≤ 0.9 Survive at any orientation: 20 mm (3/4 in.) at 20 m/s (65 ft/s) Survive at stowed position: 25 mm (1 in.) at 23 m/s (75 ft/s)
Rain	Average annual rainfall - 750 mm (30 in.). Maximum 24 hour rate 75 mm (3 in.)
Dust Devils	With wind speeds up to 17 m/s (40 mph)
Sand Storm	Survive tests per MIL-STD-810B, Method 510.
Lightning	Protection provided on an optimized cost/risk basis

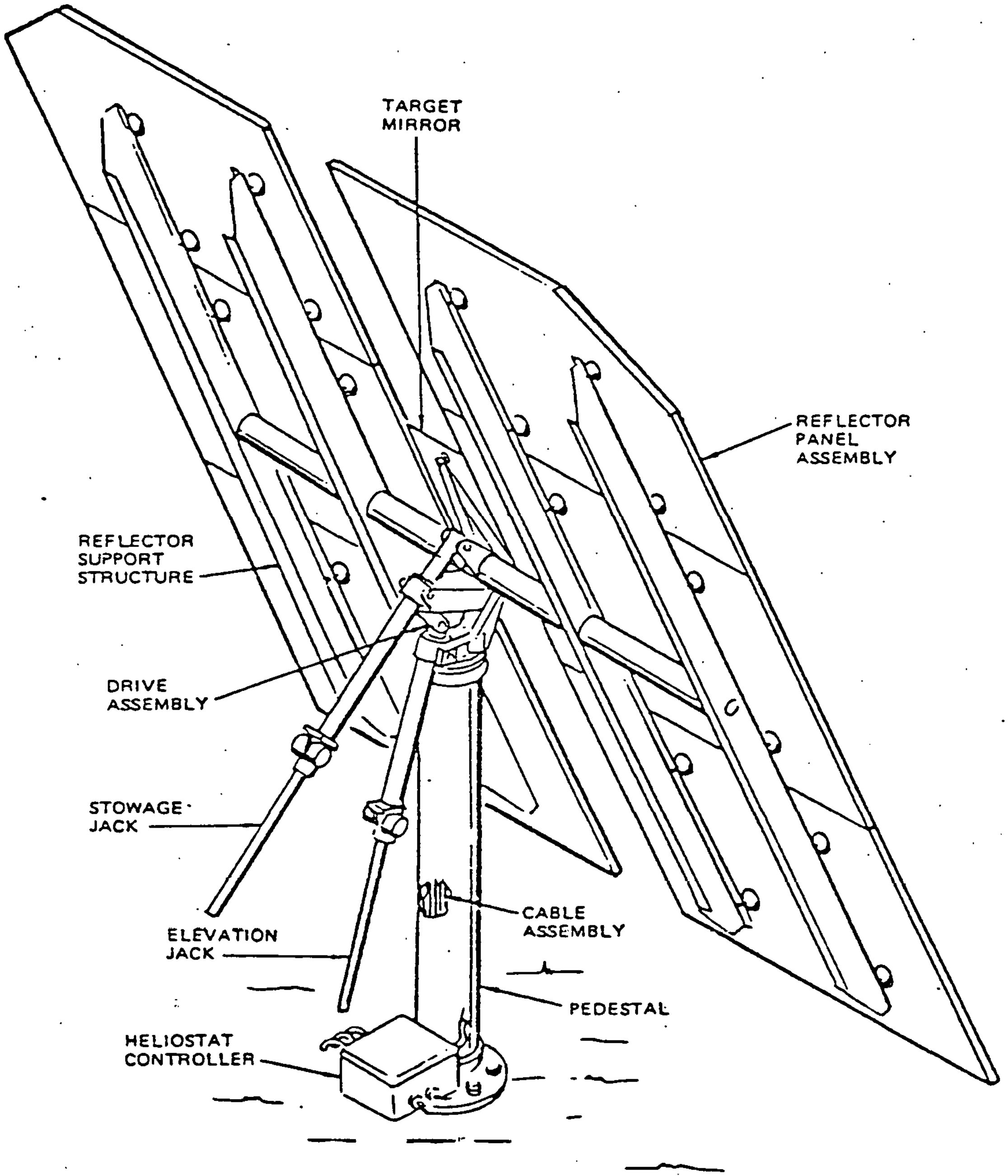


Figure 2.1.2-1 Heliostat Assembly - Initial Baseline Design

2.1.2.1 Reflective Unit

Mirror Module - The reflective unit consists of two reflector panels; each reflector panel consists of the support structure and six mirror modules. Each module is approximately 43 inches by 114.5 inches. The reflective unit is depicted in Figure 2.1.2-1. Each mirror module, Figure 2.1.2-2, is made up of a second surface silvered mirror, 3.24 mm (1/8 inch) thick of medium (0.05-0.07%) iron float adhesively bonded to a foam core, which is bonded to a thin galvanized steel back sheet. Each mirror is 42.5 inches by 114 inches, providing a total heliostat reflector area of 38 m^2 (408.3 ft^2), including a central mirror on the drive unit. The mirror and foam core will be commercial grade. Environmental protection of the panel edges is provided by a metal foil edge strip. The shallow circular steel cups bonded to the galvanized steel back sheet mount the panels to the reflector support structure. Spacers are used at two of the attach points to set the panel cant angles for focusing. Approximately half of the reflector panels will be flat, while the remaining reflector panels are singly curved to a common radius of curvature of about 2,000 feet. Each uppermost mirror module is scarfed at the outer corner.

Structural Support - The structural support consists of a main beam and four channel cross beams. As depicted in Figure 2.1.2-1 and 2.1.2-3, the four cross beams provide the structural support of the twelve mirror modules. The cross beams are spotwelded to the main beam which is bolted to the heliostat drive unit. Attachment of the main beam to the drive unit is provided by two drive attachment fittings as shown in Figures 2.1.2-3 and 2.1.2-4. Ring flanges are used to attach the cross beams to the main beam. The slot formed between each panel group provides clearance for the pedestal when the reflector is rotated to the inverted or face-down position. A central mirror is included because it is cost effective.

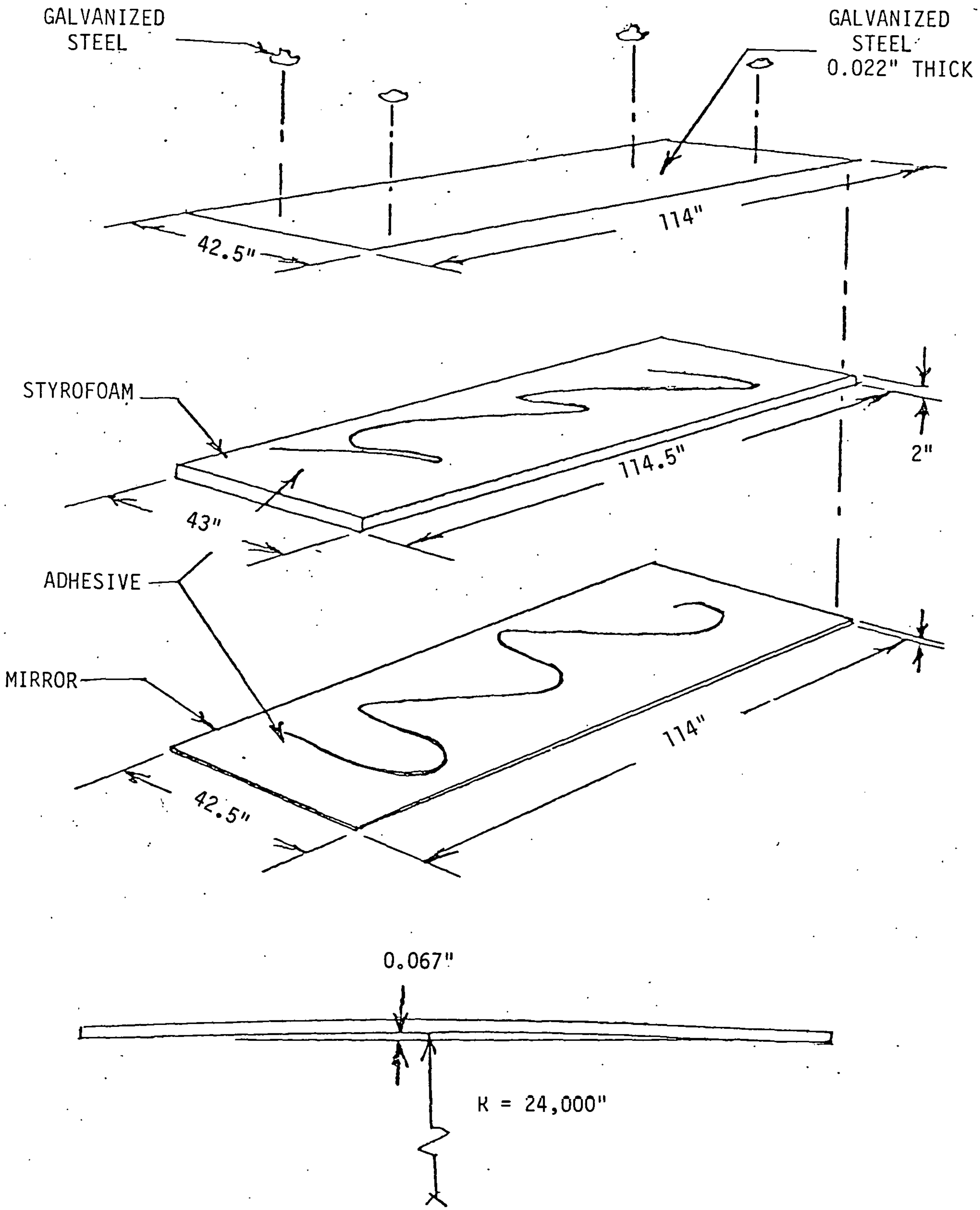


Figure 2.1.2-2 Initial Baseline Reflector Panel

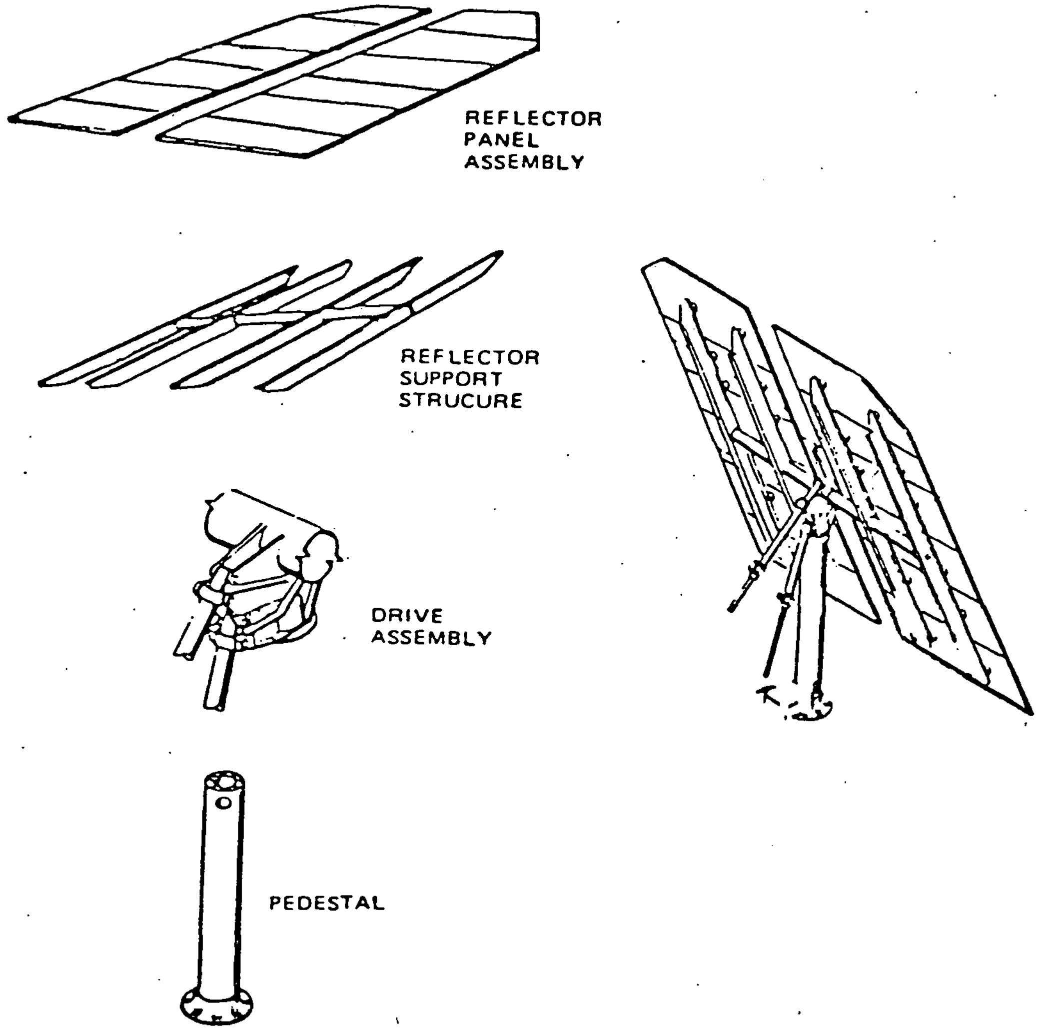


Figure 2.1.2-3 Initial Baseline Heliostat Assembly

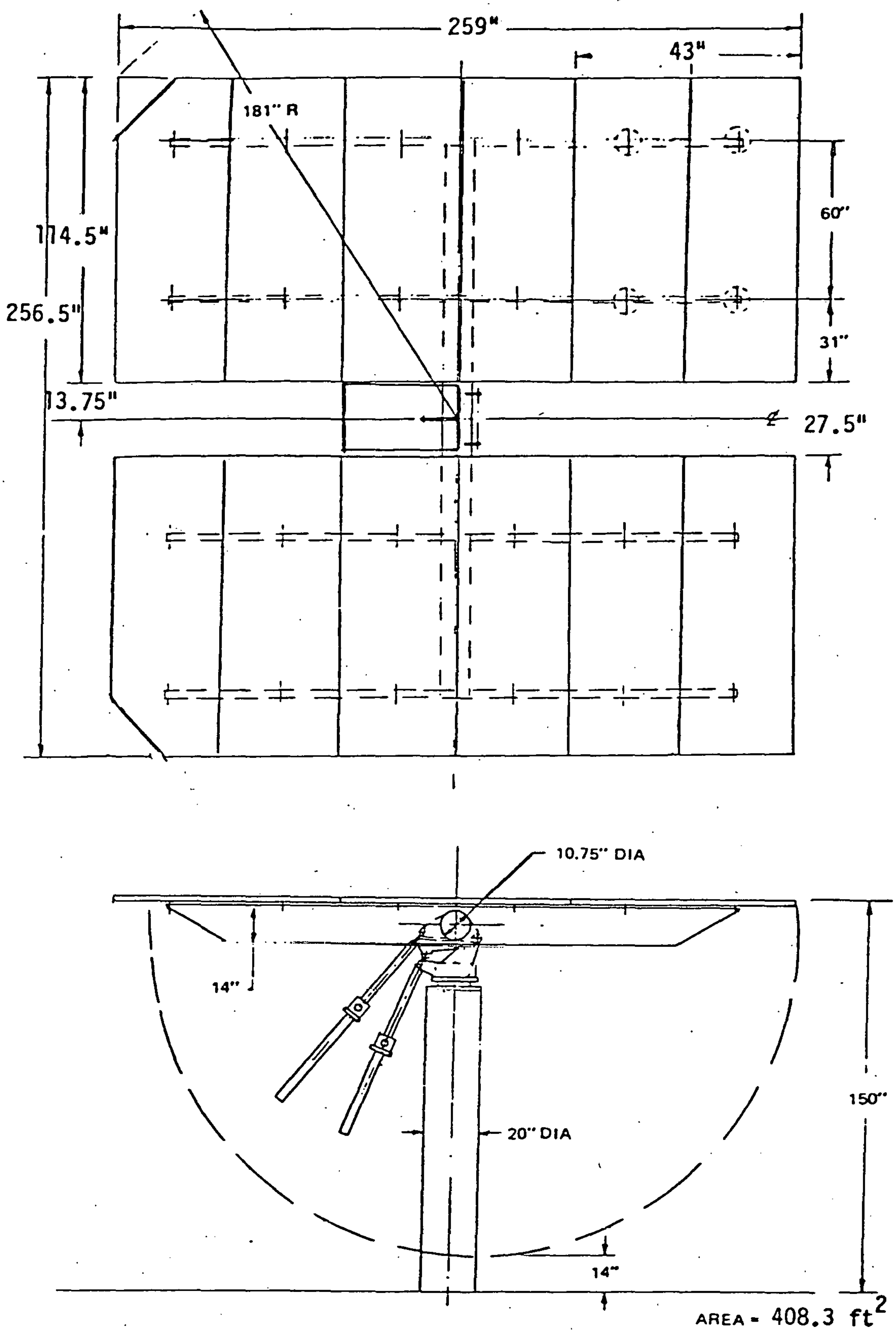


Figure 2.1.2-4 Initial Baseline Inverting Heliostat

2.1.2.2 Drive Assembly

The initial baseline drive assembly, consisting of azimuth and elevation drive units supported by the pedestal, is similar to that used for the octagonal reflector heliostat of the Phase I Pilot Plant study, Reference 1. The azimuth drive unit (Figure 2.1.2-5) includes a 240 VAC, three-phase motor with a spur gear reducer, a worm gear second stage to provide the desired anti-backdrive feature, and a 242:1 harmonic drive output stage with the attendant housing. The overall reduction ratio is about 45,000:1. The harmonic drive was selected because it provides good wear and backlash characteristics. The elevation drive unit consists of two linear actuators, one for tracking and one for inverted stowage, with a drag link connecting the two actuators, connected to the main torque tube. The actuator differs from that tested in the Phase I Subsystem Research Experiment primarily in that a housed screw is used instead of the bellows boot to give better environmental protection to the screw. The drive motors and gear heads are the same as those for the azimuth drive. Dual linear actuators were selected on the basis of high stiffness and low backlash at unit costs about equal to those of the Orbidrive units of Reference 1.

The azimuth drive housing is cast, and the drag link may be either cast or welded. Hall effect limit switches are indicated on the actuators.

The drive assembly is supported on a standard 20-inch diameter by 0.105 inch wall, welded steel pipe pedestal with a bolted flange interface, Figure 2.1.2-6.

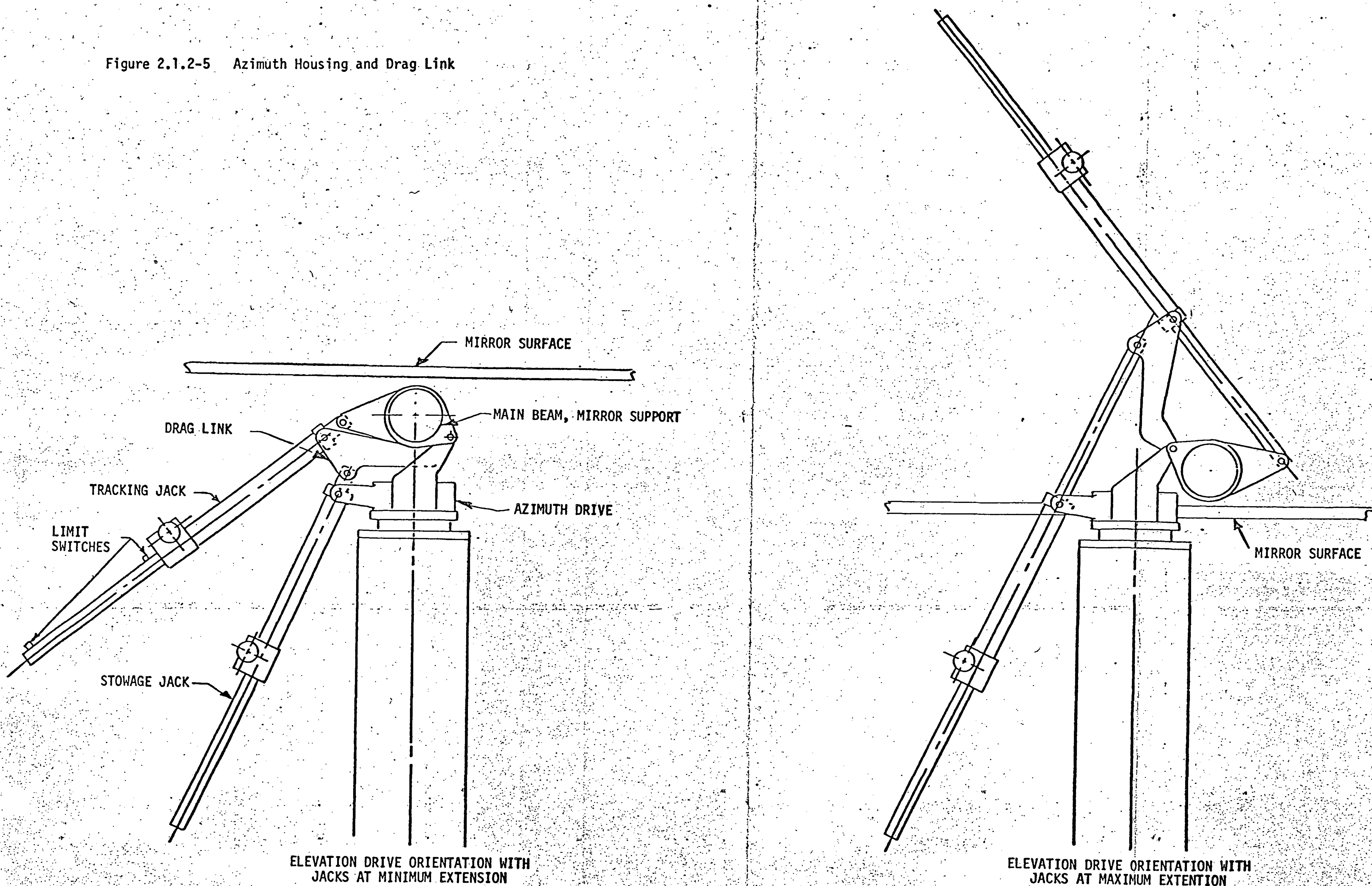
2.1.2.3 Foundation

A bolted flange interface from the pedestal to the foundation was selected to provide for removal of the drive unit for repair and complete site factory preassembly of the heliostat and controller. The foundation is a precast, reinforced concrete cone set in a drilled hole (Figure 2.1.2-6).

2.1.2.4 Heliostat Electronics Assembly

An open loop control is selected for the initial baseline. Gimbal axis absolute encoders are used to accurately locate

Figure 2.1.2-5 Azimuth Housing and Drag Link



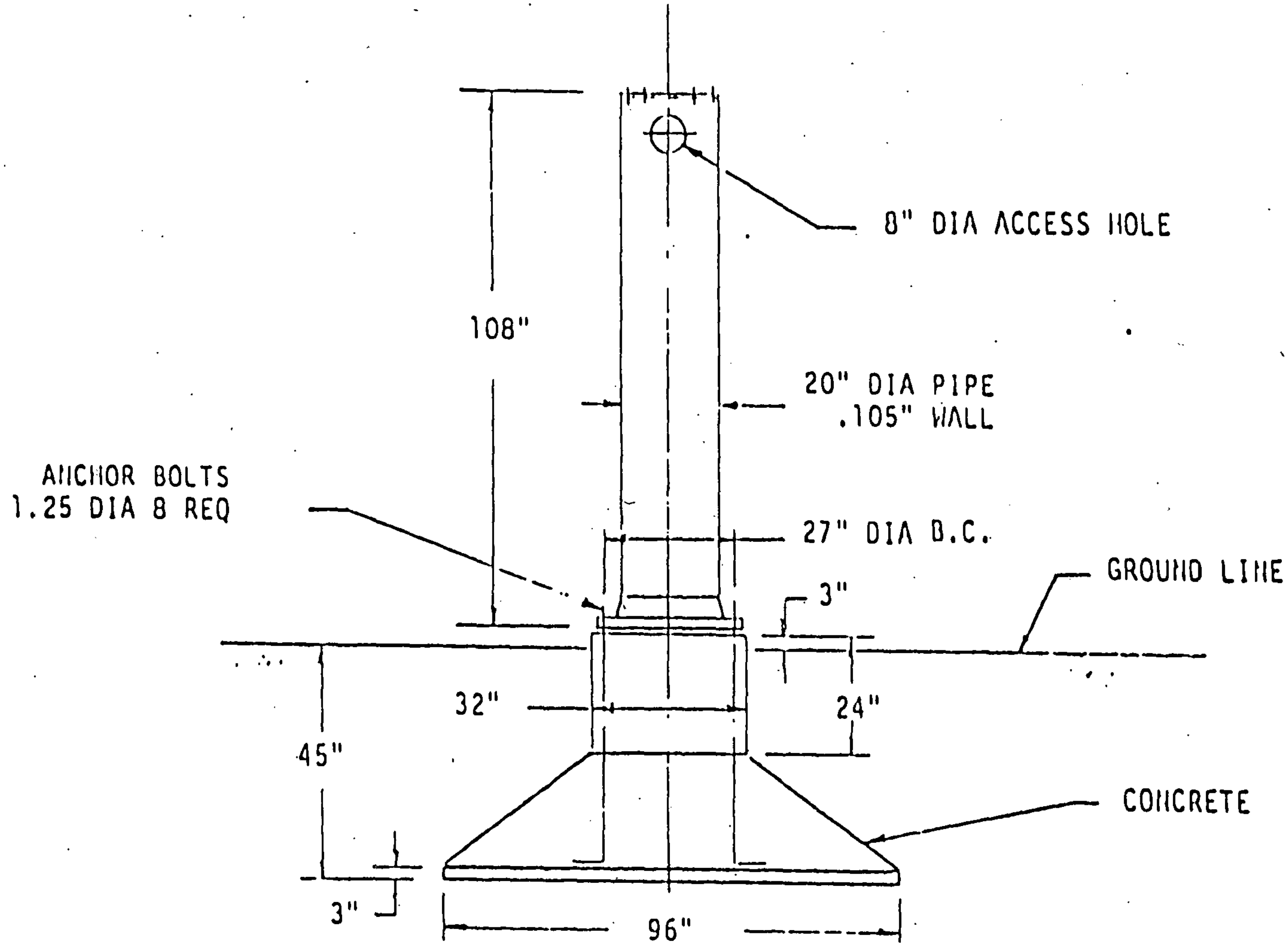


Figure 2.1.2-6 Pedestal/Foundation

reference points of gimbal axis position by the bit change in the outer ring of the encoder. A motor shaft incremental encoder is used to count motor revolutions and interpolate between bit changes on the absolute encoders. This approach provides equally accurate control of the heliostat in the tracking mode, and in the transition between stowage and normal tracking to meet both tracking and beam safety requirements.

Heliostat Controller - A heliostat controller is located on each heliostat and provides the following functions:

1. Data interface with the field controller.
2. Data interface with the controls sensors.
3. Power interface with the power distribution network.
4. Calculation of motor drive pulse requirements.
5. Power switching to the motors to produce the required number of motor revolutions.
6. Fault detection.

Wiring connecting heliostat controllers is serialized for both power and data. Data wiring between the field controllers and master control is also serialized.

A typical heliostat controller is illustrated in Figure 2.1.2-7.

Field Controller - A field controller is collocated with one out of every 24 heliostat controllers.

1. Data interface with heliostat controller and with master control
2. Coordinate transformation calculations
3. Ephemeris calculations
4. Motor turns update calculations

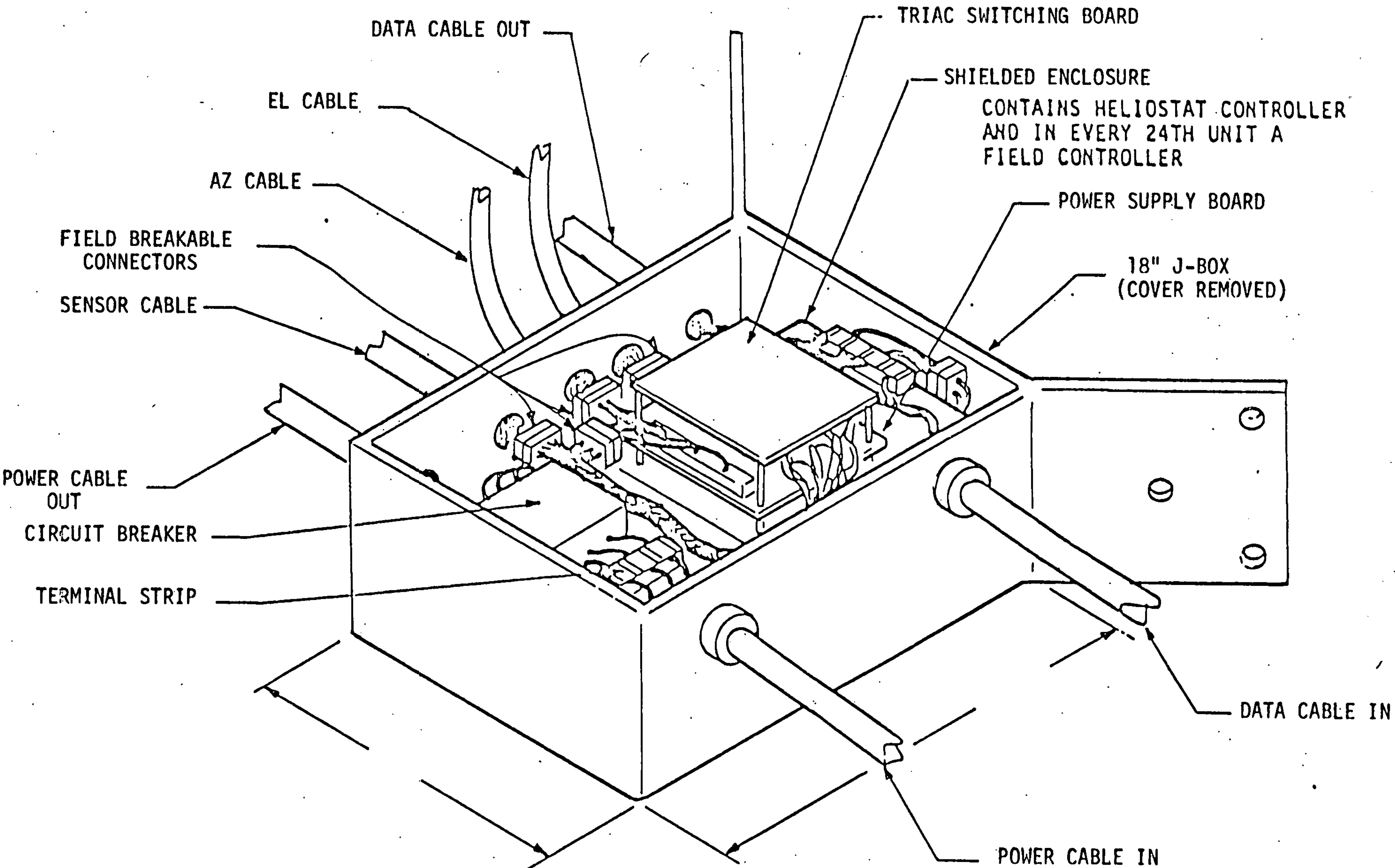


Figure 2.1.2-7 Pedestal Electric J-Box

2.2 DESIGN TRADE STUDIES

The major design trade studies undertaken to obtain substantial cost reductions are summarized in Table 2.1.2-1. These trade studies result from the baseline perturbation approach to a proven design and encompass material cost reductions, improvement of manufacturing techniques by design modifications, simplification of assembly and site operations, and use of emerging technology.

Design improvements have been incorporated which include such features as an improved reflector configuration, new actuator type, low cost, noise-free fiber optic control system data link, low cost foundation/pedestal, and a design configuration which both minimizes site assembly/installation operations and capital investment in on-site assembly facilities. Additional design effort has been conducted on manufacturing, installation/checkout, and maintenance trade studies.

The heliostat reflector area has been analyzed to maximize the area consistent with the drive unit loads capability, reconfigure the mirror modules to eliminate the scarfed corners and gaps, minimize the slot width and/or fill in the upper portion of the slot while retaining the inverted stow capability. Additionally, the potential improvements achieved by various degrees of focusing and canting were evaluated. A number of low cost mirror module configurations have been investigated to minimize raw material and production costs and/or improve the reflectivity.

The foam core sandwich design has been compared with designs having (1) mechanical attachment of the glass to the support structure, (2) bonded glass/steel sections, (3) low cost laminated mirrors, and (4) thin glass bonded to steel with protective backing material.

The drive unit initial baseline design presents a number of potential design change areas which will simplify the configuration, eliminate parts, integrate components, use new configuration elements such as helicon gears, wire race bearings, and a travelling screw nut linear actuator, and accommodate lower cost manufacturing, installation, and maintenance techniques.

Integration of the drive unit, inboard main beam, and a pedestal section into one assembly achieves a major reduction in overall cost by eliminating the on-site factory requirement, and by reducing field installation, factory checkout, and transportation costs.

Table 2.1.2-1

DESIGN TRADE STUDIES

	Trade Study	Objective
D-1	Optimum Heliostat Design	Optimize reflector area for minimum cost
D-2	Low Cost Reflector	Evaluate panel designs to reduce material and fabrication costs
D-3	Drive optimization	Integrate drive elements, reduce parts, reconfigure design
D-4	Control Optimization	Reduce cost by incorporating emerging technology in electronic components
D-5	Reflector Attachment	Reconfigure main beam to optimize on-site assembly and transportation and reduce costs
D-6	Reflector Structure Optimization	Optimize support structure for minimum weight within design constraints
D-7	Low Cost Motors	Optimize motor configuration and voltage

The heliostat electronic control design with field controllers for each 24 heliostats, heliostat controllers, absolute and incremental encoders and data wiring subject to EMI called for the application of emerging technology in electronic components to achieve significant cost reduction. Optical and Hall effect encoders were compared, non-volatile memories selected to eliminate the absolute encoder requirement, and the overall control configuration improved.

A major system cost reduction is possible with a sectioned main beam integral with the drive unit, and two reflector panels attached at the main beam. This design minimizes field assembly, eliminates the on-site factory requirement, and allows low cost common carrier transportation of the integrated drive unit/ inboard main beam and the reflector panels. In addition, factory checkout of the drive unit is facilitated, as well as high production, precision linear actuator attachment.

Support structure optimization, combined with the reflector attachment design, allows a number of cost reductions, resulting from low cost one-step bonding of the mirror modules to the support structure, optimum section thickness consistent with strength and deflection requirements, and configuring of the support structure to minimize material and attachment fittings.

Motor costs are reduced by integrating position indicators (i.e., Hall effect encoders), increasing voltage, and emplacing motor controller electronics. Other potential cost reductions have been investigated, such as use of DC motors, but have been found to be potentially cost effective with current technology only when used as part of an autonomous heliostat design which is sufficiently different from the initial baseline design to be outside the scope of this program.

Results of the seven design trade studies are presented in the following paragraphs.

2.2.1 D-1 Optimum Heliostat Size

The objective of this trade study effort was to optimize the reflector area per heliostat to reduce the cost per unit area while maintaining appropriate cost-effective power interception at the receiver. Since this effort was primarily a perturbation design study, the existing drive unit load capability was used as the primary constraint, the receiver size and field geometry was assumed fixed, and the reflector area increased to meet the drive unit load capability. The structural strength/deflection requirement was met, as presented in following sections. This approach led to a first order cost reduction of 15 percent with an insignificant difference in energy spillage at the receiver for the baseline area of 38 m^2 (408 ft^2) compared to the optimized area of 49 m^2 (528 ft^2). However, additional optimization is still feasible, depending on the actual wind loads induced for actual heliostat arrays, with a wind barrier fence surrounding the field. These considerations have not been included in the analysis, but preliminary data indicate substantial loads reductions are achievable, and therefore, the wind condition of Specification 001 may be superceded by decreased wind load criteria.

Using wind loads based on available aerodynamic coefficients, the heliostat area was increased to match the known drive unit capability. The heliostat configuration was changed in that (1) the newer mirror modules allowed smaller gaps between panels than the baseline foam core (which requires a glass/foam sealant width of 1/3 inch minimum), (2) the scarfed corner was eliminated, making all mirror modules identical, (3) the mirror width of 48 inches is a practical dimension which is easily handled and can be cut from the center section of a continuous float glass run to maximize flatness. The latter consideration is less important with the fusion glass laminated mirror module design selected in this study, but may still be a desirable feature for the float glass supporting panel.

The optical interception at the receiver was determined for a sufficient variety of conditions to verify that power loss differences between the two areas was not a constraining factor.

In order to indicate the magnitude of the effect of focusing prototype heliostats in a commercial size array, two extreme cases were run with the CONCEN programs for spring equinox, summer solstice, and winter solstice. For one case, all heliostats were flat, representing the non-focus condition. In the other case, each heliostat is focused by panel canting and single curvature for its particular slant range to the receiver. Spherical focusing was used throughout. No errors were assumed, in order to isolate the effect of focusing. The pertinent system parameters assumed were:

Tower height = 250 m

Receiver diameter = 17 m

Receiver height = 25 m

Array width = 2300 m

Total number of heliostats = 27012*

Type of array = cornfield (N-S, E-W)

Heliostat size = 7.4 m x 7.3 m

The total incident energy in the vicinity of the receiver, the total received energy (that which is intercepted by the receiver), and the percentage spillage are given in Table 2.2.1-1.

Table 2.2.1-1

ENERGY SPILLAGE ASSESSMENT

	Total Incident Energy (MWHr)	Total Received Energy (MWHr)	% Spillage
March 21			
Focused	6298.5	6298.3	.003
Unfocused	6298.5	6282.1	.26
June 21			
Focused	7561.8	7561.3	.007
Unfocused	7561.8	7546.2	.21
December 21			
Focused	4996.8	4996.7	.002
Unfocused	4996.8	4981.5	.31

*The number of heliostats used for this comparison is not representative of 100 MW commercial system, but the impact of focusing on spillage is valid.

For the unfocused cases the spillage is primarily contributed by the outer region (∿ 1.5%) and by the inner heliostats (∿ 1.1%), with those in between contributing a negligible amount.

It is to be expected that an intermediate focus condition, such as two or three fixed focus settings, would show spillage performance essentially equal to that with individual focusing. These results indicate that canting and/or focusing for the commercial array is hardly justified.

The effect of mirror module size on performance was also determined using Program CONCEN, with and without certain key errors included, for both a pilot plant and commercial array. The results indicate that there is a negligible difference in plant performance due to the increased mirror module size.

Table 2.2.1-2 compares the fractional spillage between the initial and final baseline heliostats, and shows that for a typical condition (December 21), the total power at the receiver is the same to within a small fraction of a percent for either errors included or neglected.

Table 2.2.1-2

BASELINE SYSTEM (408 FT^2 HELIOSTAT)

	Total Incident Power	Total Received Power	Fractional Spillage
No errors	37.178 MW	37.133 MW	.0012
Errors included	36.979 MW	36.225 MW	.0204

FINAL BASELINE HELIOSTAT SYSTEM (528 FT^2 HELIOSTAT)

	Total Incident Power	Total Received Power	Fractional Spillage
No errors	36.653 MW	36.645 MW	.0002
Errors included	36.528 MW	35.797 MW	.0200

System parameter values:

Receiver diameter = 6.92 m ($\lesssim$ 60° incidence on 8 m dia.)

Receiver height = 14 m

Tower height = 88 m (center of heliostat to center of receiver)

Date = December 21; hour = 1400

Atmosphere = 23 km visibility

No errors: Temp. = 70°F; Wind = 0; no gravity loading; waviness = 0

With errors: Temp. = 32°F; Wind = ≈ 26 mph; Gravity = 1 g,; waviness = 1.1 mr, 1σ

Pointing error: Horizontal = 3.4 mr; vertical = 1.7 mr, 1σ

Each heliostat focused by canting and cylindrical curvature for its location

2.2.2 D-2 - Low Cost Reflector

This section presents the data base and rationale for the selection of the reflector configuration. This selection process first began by defining potential low cost reflectors. Figure 2.2.2-1 shows the various configurations considered. Preliminary cost analyses were performed by the manufacturing element and are reported in Section 4.2. The lowest cost approaches were the low cost laminate (#2), the corrugated stiffened reflector (#3), and the hat stiffened reflector (#4). Structural stress analyses were performed on all of the candidates. Conditions include survival temperatures, survival wind, gravity, operating wind and temperature, and combined stresses. Table 2.2.2-1 summarizes the key selection criteria for the different configurations.

These three candidates were then tested in a salt spray environment and subjected to hail impact tests. Results of the salt spray tests (Section 2.3) showed all three candidates have excellent survival probability, however, the laminated edges must be sealed. A gray mirror backing paint appears adequate for the exposed second surface mirrors.

Results of the hail tests (Section 2.3) showed that:

a) The 1/8", hat section stiffened configuration is marginal to unsatisfactory for hail impact of 19 mm (.75 inch) at 20 m/sec. (65 ft/sec).

b) The 1/8", corrugated stiffened configuration would survive the 19 mm (.75 inch) at 20 m/sec (65 ft/sec), but was marginal for 25 mm (1 inch) at 23 m/sec (75 ft/sec).

c) The hat stiffened 1/8" + 1/8" low cost laminate could survive both 19 m (.25 inch) and 25 mm (1 inch) hail impacts.

Based on these results and the fact that the corrugated stiffened configuration has an operating glass stress due to temperature greater than 3.5 MPa (500 psi), the low cost laminated configuration was selected.

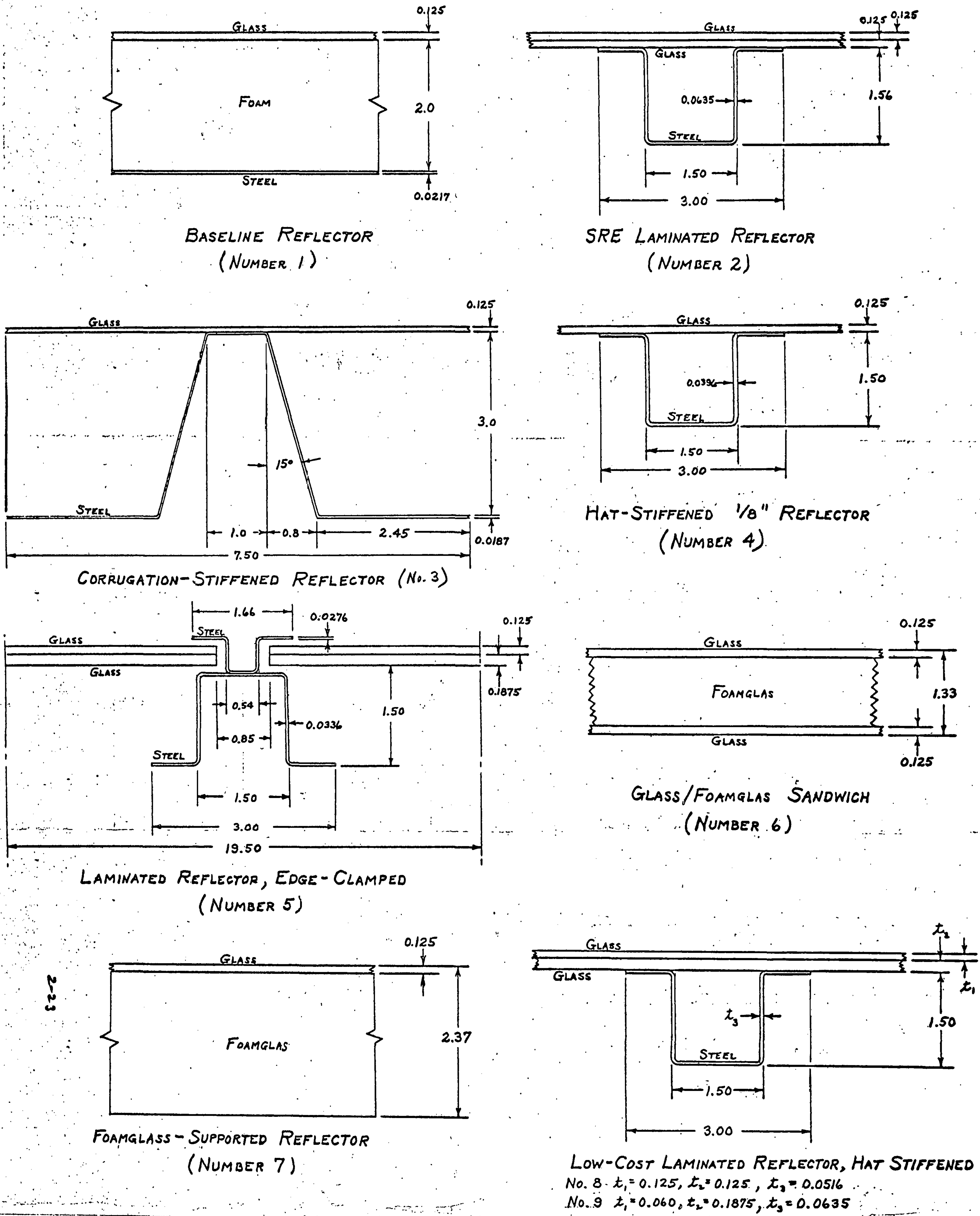


Figure 2.2.2-1 Candidate Reflector Designs

PARAMETER	REFLECTOR CONFIGURATION							
	1	2	3	4	5	6	7	8
	BASELINE SANDWICH REFLECTOR 0.125" Glass 2.0" Foam Core 26 Ga. Steel	SRE LAMINATED REFLECTOR 0.125" + 0.125" Glass 3 Hats of 16 Ga. Steel 85" Wide	CORRUGATION-STIFFENED REFLECTOR 0.125" Glass 28 Ga. Corrugation Steel	HAT-STIFFENED 1/8" REFLECTOR 0.125" Glass 4 20 Ga. Steel Hat Sections	LAMINATED REFLECTOR Edges Clamped 0.125" + 0.1875" Glass 22 Ga. Steel Hats	GLASS/FOAMGLAS SANDWICH REFLECTOR 0.125" Glass Faces 1.08" Thick Core	LOW-COST HAT-STIFF. LAMINATED REFLECTOR 0.125" + 0.125" Glass 2 18 Ga. Steel Hats	LOW-COST LAMINATED FUSION GLASS HAT-STIFF. REFLECTOR 0.060" + 0.1875" Glass 2 16 Ga. Steel Hats
WEIGHT (psf)								
Glass	1.692	3.384	1.692	1.692	4.046	3.384	3.350	3.350
Steel	0.906	0.548	1.219	0.798	0.568	-	0.517	0.637
Other	0.333	-	-	-	0.070	0.765	-	-
TOTAL	2.931	3.932	2.911	2.490	4.684	4.149	3.867	3.987
MAXIMUM SLOPE (mrad)								
Temp ($\Delta T=+50°F$)	3.821	5.579	1.816	5.505	0	0	5.743	5.751
Gravity	0.428	0.598	0.089	0.520	2.048	0.024	0.933	0.619
Wind ($^{26\ mph}_{\alpha\ =\ 30°}$)	0.390	0.384	0.077	0.527	1.104	0.015	0.609	0.519
MAXIMUM GLASS TENSILE STRESS (psi)								
Temp ($\Delta T = ^{+70°F}_{-92°F}$)	51	228	357	290	0	38	227	244
Gravity	65	84	34	75	75	8	103	99
Wind ($^{90\ mph}_{\alpha\ =\ 10°}$)	401	642	354	905	562	57	803	749
OPER. GLASS TENSILE STRESS (psi)								
Temp ($\Delta T=+50°F$)	4	163	253	207	0	27	162	174
Gravity	61	79	32	70	70	8	97	93
Wind ($^{26\ mph}_{\alpha\ =\ 30°}$)	52	54	30	76	50	5	67	63
HAIL IMPACT RESISTANCE	>1 in.	>1 in.	<3/4 in.	<3/4 in.	-	-	>1 in.	>1 in.*
RELATIVE COST	1.0	1.2	0.87	0.75	High	High	0.93	0.93

*Not tested - but inferred from hail test results of Configuration 2.

↑ SELECTED (Configuration 8)

Table 2.2.2-1

COMPARISON OF LOW-COST REFLECTORS

Analyses were then performed to optimize this configuration in terms of reducing the steel and minimizing stresses in the glass while at the same time trying to increase performance. Fusion glass with a thickness of 1.6 mm (.060 inch) was suggested as a possible candidate for the mirror. Information available showed this Corning fusion glass to be relatively flat, low in iron content and available in small quantities for evaluation tests in the near future. This effort resulted in Configuration No.8 in Table 2.2.2-1. A comparison showed that when the reflective efficiency is included in the cost estimates, the Corning fusion glass mirror is the most cost effective design.

Having selected a baseline approach of the low cost laminate, a further study was performed to determine the best approach to the mirror. Results are summarized in Table 2.2.2-2. Both the direct cost of the glass and the cost adjustment for performance (based on $72/m^2R) were considered. Low and very low iron float glass project to have a distinct effective cost benefit. However, these glasses are not presently available, the cost basis is not verified, and there is a tendency for waviness in float glass to increase with decreasing thickness. By contrast, Corning is willing to make fusion glass in low to very low iron content at the present time. The samples of fusion glass examined by MDAC in the 0.060" thickness show exceptional flatness and smoothness. Hence, a choice for fusion glass is made, pending further developments in float glass.

2.2.3 D-3 - Drive Optimization

The objective of Drive Optimization was to reduce drive unit costs by integrating parts and rearranging elements to minimize parts count, material, and labor.

In the baseline design, the azimuth drive housing is supported by a four-point contact ball bearing. The bearing races were partially contained in precision bores in the bearing retainers. The alternate designs which were considered are:

1. Use baseline bearing. Contain the outer race completely in the housing and support the inner race completely on a diameter machined on the circular spline. Eliminate precision bores in the bearing retainers.

Table 2.2.2-2

COMPARISON CHART OF VARIOUS LAMINATED GLASS CONFIGURATIONS

	CONFIGURATION	Fe CONTENT (%)	COST ($FT^2)	REFLECTIVITY + OR - FACTOR	EFFECTIVE COST ($ FT^2)	RELATIVE COST RELATIONSHIP
1.	.060 Fusion .1875 Float	.05	.32 .36	.92 (Base)	.68	1.0
2.	.060 Fusion .1875 Float	.01	.40 .36	.945 $-.20	.56	.82
3.	.085 Fusion .1875 Float	.05	.45 .36	.91 $+.08	.89	1.3
4.	.085 Fusion .1875 Float	.01	.57 .36	.94 $-.16	.77	1.1
5.	.070 Clear Float .1875 Float	.07	.17 .36	.90 $+.16	.69	1.0
6.	.070 Low Iron Float .1875 Float	.05	.19 .36	.915 $+.04	.59	.87
7.	.070 Very Low Iron Float .1875 Float	.01	.23 .36	.943 $-.18	.41	.60
8.	.085 Clear Float .1875 Float	.07	.18 .36	.89 $+.24	.78	1.1
9.	.085 Low Iron Float .1875 Float	.05	.20 .36	.91 $+.08	.64	.94
10.	.085 Very Low Iron Float .1875 Float	.01	.25 .36	.94 $-.16	.45	.66

ASSUMPTIONS:

.05% Fe content cost 10% more than .07%
.01% Fe content cost 25% more than .05%

2. Use a four-point contact ball bearing with extra thick races so that bolts passing through holes in the races can clamp the bearing in position. Eliminate the bearing retainers.

3. Use circular spline as inner race of four-point contact for ball bearing. This configuration requires retainer for bearing after race.

4. In addition to the three proposed alternates listed above, the use of a wire race bearing was evaluated.

The wire race bearing has proven to be the most cost effective of the configurations evaluated. It also integrated into the design very effectively, simplifying the assembly procedure of the azimuth drive.

Configuration 2, the thick race bearing, ranks third. It is a practical design, with previous applications in industry, but was much more expensive than Configuration 4 or Configuration 1, the wire race bearing.

Configuration 1 ranks second in the evaluation, both in terms of cost and in terms of design excellence.

Configuration 3 was not pursued to any great extent. There were technical problems which were not solved and the wire race bearing essentially does use the circular spline as the inner race of the bearing.

The baseline design was assessed to be technically unacceptable. It required an interference fit by two different parts on the same diameter of the bearing race, which created an unacceptable tolerance situation.

In the baseline design, the harmonic drive input shaft is supported by a bearing at each end. An Oldham coupling, which connects the input shaft to the wave generator, is required to compensate for misalignments.

An alternate design is to attach the drive shaft rigidly to the wave generator plug (no Oldham coupling) and support this assembly by a small bearing at one end and by the wave generator bearing at the other end. The runout of the shaft at the wave generator bearing is larger than that which would be achieved by a conventional bearing installation, but it is not excessive and can be accommodated by a very sligh t increase in backlash in the helicon gear stage. This alternate design is more cost effective than the baseline design.

In the baseline design, the azimuth drive train is made up of three stages of speed reduction; the first is the gearbox in the gear motor, the second is a worm/worm gear combination and the third is the harmonic drive.

An alternate design, which has proven to be cost effective, is to only use two stages of speed reduction and to use a motor in place of the gear motor. The first stage of the drive train is a helicon gear set and the second is the baseline harmonic drive. The reduction ratio of the helicon gears is 162:1. This value was selected to obtain a reasonable tooth size. The output helicon gear is an aluminum alloy die casting.

The baseline elevation drive consists of two identical linear actuator assemblies which work in conjunction with a drag link. Each actuator is driven by a gear motor with a gearhead reduction ratio of 25:1. The jack has a worm drive and a machine screw rod with an overall ratio of 25.4 mm (1 inch) of travel per 16 turns on the worm. It has anti-backdrive capability, an adjustable backlash feature, and is grease lubricated. Also, each unit contains two proximity switches that indicate end of travel in both directions. Kinematically both units follow the same pattern and have the same stroke (711 mm [28 in]) and torque arm for a comparable elevation angle. The effective lever arm varies according to a cosine function with a minimum length at the ends of the stroke and maximum near midstroke. As a result, the reduction ratio varies over a range from 49,750 to 35,170. All pivots (elevation axis, jack mounting trunnions, jack rod ends) incorporate self-lubricated fabric type bearings.

Two alternate elevation drives were evaluated. The first used a machine screw jack for the stowage actuator and a ball screw jack for the tracking actuator. Each jack was powered by an electric motor and had sufficient reduction in the gear drive to achieve the desired overall reduction. The high reduction ratio of the jack's gear drive made it self locking and permitted the use of the ball screw. A backlash adjustment feature is not required in either jack; the wear expected in the ball screw is negligible and the backlash in the stowage jack would be negated by preloading the jack against a mechanical stop. The jacks do not contain limit switches. Incremental encoders, integrated into each motor, will provide data to keep track of jack position. The stroke and lever arm of the jacks are equal.

The speed reduction ratio of the tracking jack varies between 50,390:1 and 35,630:1. The speed reduction ratio of the stowage jack varies between 55,140:1 and 38,990:1. The tracking jack uses a 186 W (1/4 HP) motor and the stowage jack uses a 373 W (1/2 HP) motor. Both jacks provide an integrated motor mount and the pinions of the gear sets will be mounted on the motor shaft. Both jack designs are based on the translating nut principle.

In the second alternate elevation drive configuration, the tracking actuator, which was used described above for the first alternate, is used for both tracking and stowage with a 1/4 HP motor for each jack. In all other respects, the second alternate is the same as the first.

It was concluded that the second alternate configuration was the most cost effective because of the higher efficiency and lower cost of the ball screw jack, use of a common design for both tracking and stowage, including the same motor and the negligible wear.

2.2.4 D-4 - Control Optimization

There exist several areas in the electronic hardware that are being improved to meet the advancements resulting from the emerging technology in the control field. These modifications are designed to provide both increased reliability and lower cost.

Advancements in the micro-computer field allow for the modification of the control network. The Prototype control system consists of a master control and a heliostat array controller, a data distribution interface, and a heliostat controller.

The master control and the heliostat array controller are designed to coordinate the activities of the individual heliostats and to supply the basic information to make calculations involving heliostat control. The master control and heliostat array controller are located in the central control building where they can be interfaced with printer, keyboard, and extraneous peripheral equipment.

The heliostat array controller communicates with a series of data distribution interfaces. The data distribution interfaces provide a system for distributing information to the heliostat controllers. Each of the data distribution interfaces receive control commands from the heliostat array controller and distribute them to the 300 heliostats assigned to it. The data distribution interface alleviates the task of distribution from the heliostat array controller. The data distribution interfaces are collocated throughout the field with the transformers.

No control calculations are made by the master control or the heliostat array controller. New developments in the micro-computer field make it possible for each heliostat to make appropriate calculations and carry out the necessary readjustments. These calculations take place in the heliostat controller which is located at the top of the pedestal of each heliostat. The heliostat controller receives base information from the master control and position information from encoders mounted within the motor housing. From this it is able to make the necessary movement decisions.

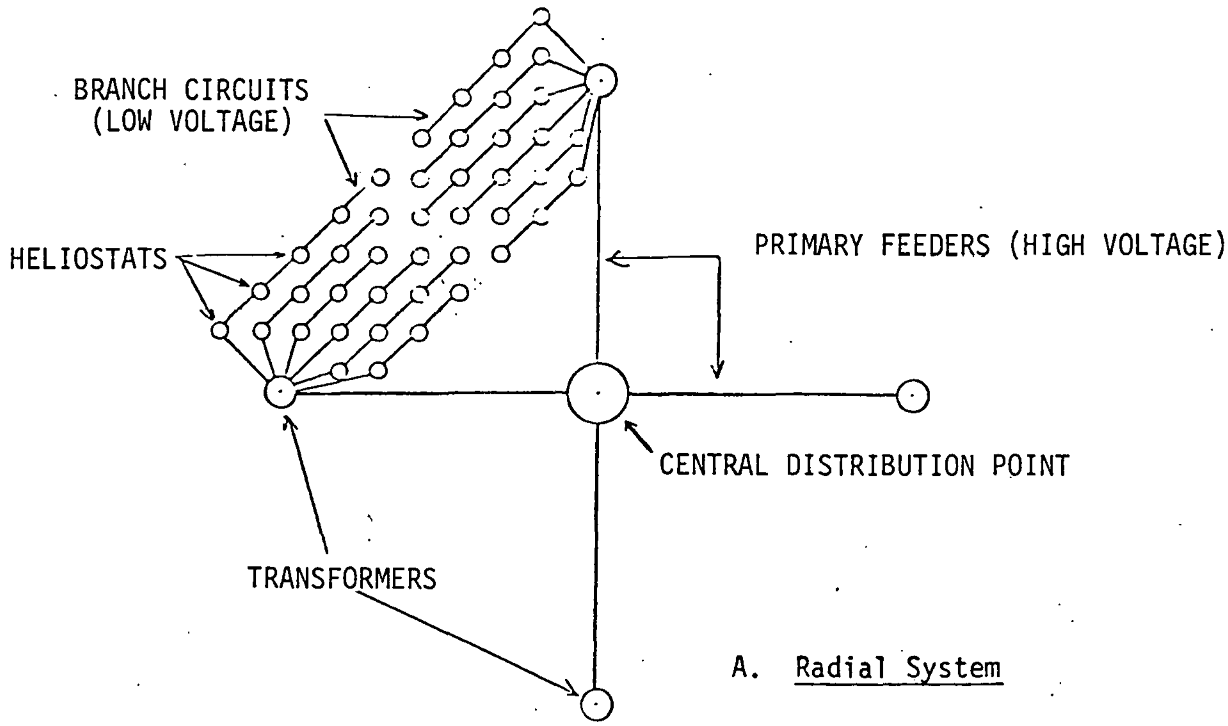
This control decreases the overall system cost and allows the removal of the field controller units which once handled calculations and command jobs in the baseline design. The micro-computers used in the heliostat controller will be capable of receiving serial information from the master control and returning serial reply information without the necessity of external circuitry. The micro-computers will contain a non-volatile RAM. This alleviates the necessity for absolute encoders for position indicators. Incremental, magnetic encoders will be designed into the motors with short data lines transmitting position information to the memory elements in the heliostat controller.

The drive interface was also revised such that the drive components would be located in the motor housing. This would alleviate the AC noise problems in the heliostat controller and reduce the wire size interfacing the controller and the motors. This concept prevents close contact between the micro-computer and the three-phase power observed in earlier designs.

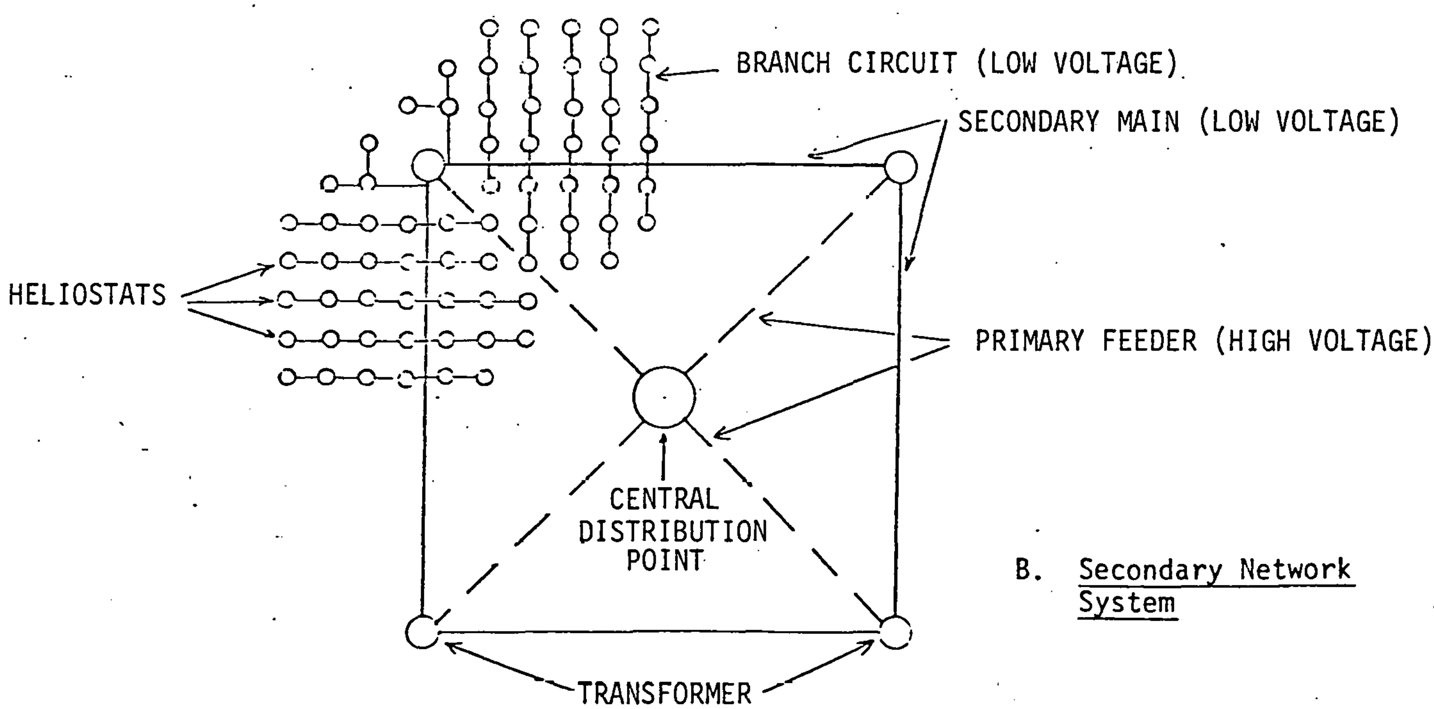
All components will operate from a 5 volt modular power supply instead of the earlier discrete multi-voltage units.

The data communication links also reflect changes resulting from new technology. The links are designed using an optical transmission medium. The unique advantage of optical transmission over electrical hardwire transmission makes its use attractive in performance and cost. Optical fiber transmission offers wider bandwidth and smaller cable cross-section than previously possible. In addition, since cables employing optical transmission neither pick up nor emit electromagnetic radiation and offer total electrical isolation, the problems of RFI, EMI, EMP, ground loops and sparking associated with electrical cables can be eliminated. In addition, fiber optics communication links eliminate the requirements for relays and line drivers and receivers in the communication lines. This also allows the data communication lines to be housed in the same cables with the power being delivered to the heliostats.

Two types of power distribution systems layouts were considered for the 100 MW Solar Power Plant: radial and secondary network (Figure 2.2.4-1). Both systems feature high voltage primary feeders to transformers located throughout the heliostat field



A. Radial System



B. Secondary Network System

Figure 2.2.4-1 Power Distribution Layouts in order to preclude the necessity for long low voltage (600 V) lines requiring large gauge cable. Distribution systems consisting solely of low voltage distribution lines were shown to be cost ineffective by the 10 MW study. Since the greater distances involved in the 100 MW plant would only aggravate this problem, low voltage distribution was not considered.

The radial distribution layout is the system proposed for the 10 MW pilot plant. It consists of high voltage primary feeder from the central power distribution point to the transformers located throughout the field. Short length, low voltage branch circuits run radially from the transformers to the heliostats. The network distribution layout consists of a grid of low voltage cable covering the field area with transformers located at the intersections of the grid. The heliostat branch circuits are then run off the grid to the heliostats.

The network distribution system is highly desirable from a reliability standpoint since the loss of a primary feeder or transformer does not cause the loss of any of the heliostats. Since each segment of the secondary mains are supplied by at least two transformers which are supplied by separate primary feeders, the loss off a transformer or primary feeder does not imply a loss of power to any section of the secondary mains. Power continues to be supplied to the secondary mains by the remaining transformers and feeders. In the radial system, however, the loss of a transformer or primary feeder causes the loss of all heliostats fed by that transformer or feeder.

The network system is not at all desirable from a cost standpoint, however The secondary mains require large gauge, high ampacity cable without reducing the requirements of the branch circuit cable. This large increase in cable requirements along with increased trenching and installation costs makes the network system more than twice as costly as an entirely radial distribution system and therefore not cost-effective even with the increased reliability. Since the transformers and primary feeders have among the lowest failure rates of any of the component in the power plant system, the cost to reliability factor of the network system is reduced even more.

It is possible, however, to partially incorporate the reliability of the network system into the radial distribution system without increasing cost. This is accomplished by making the branch circuits a continuous cable run from transformer to transformer rather than strictly radial. This permits the small gauge, low voltage branch circuit to operate as a secondary main in case of a transformer failure. This hybrid radial system (Figure 2.4.5-1 of Section 2.4.5) is not totally redundant but would provide redundancy in the form of emergency operation to approximately 90 percent of the transformers in the field. With the hybrid system, the heliostats normally supplied by a transformer which has failed are not supplied sufficiently for complete operation, as in the network distribution system, but are able to be operated into a stowage mode or other emergency procedures which increases the operating safety of the field.

The overall control system can be visualized as a marked improvement in reliability and expense as a result of these modifications, each of which complies with the technological advances in the electronics field.

2.2.5 D-5 - Reflector Attachment

The objective of this trade study was to design joints along the main beam (torque tube). Joints in the main beam allow a reduction in tube size or wall thickness in the outboard section, to reduce material requirements. Joints which divide the reflective unit in half provide a manufacturing and shipping advantage since preassembly of the reflector is allowed in a size that can be transported over highways by common carrier. Preassembly eliminates the need for an assembly facility at the field site and reduces labor costs. In the field, the panels are merely located on the ends of the drive unit main beam section and bolted in place. Normally, no field adjustment would be required. The cost savings which can result from the elimination of the site assembly facility are such that cost savings in the structure are almost incidental. The initial baseline design had a continuous one piece main beam made from 0.25 m (10 inches) diameter by 6.35 mm (.25 inch) wall pipe. Dividing the main beam at the side of the drive unit was originally considered, but since this required a large hole in the inboard cross beam, it was found more advantageous to make the joint at the inboard cross beam (see Figure 2.2.5-1).

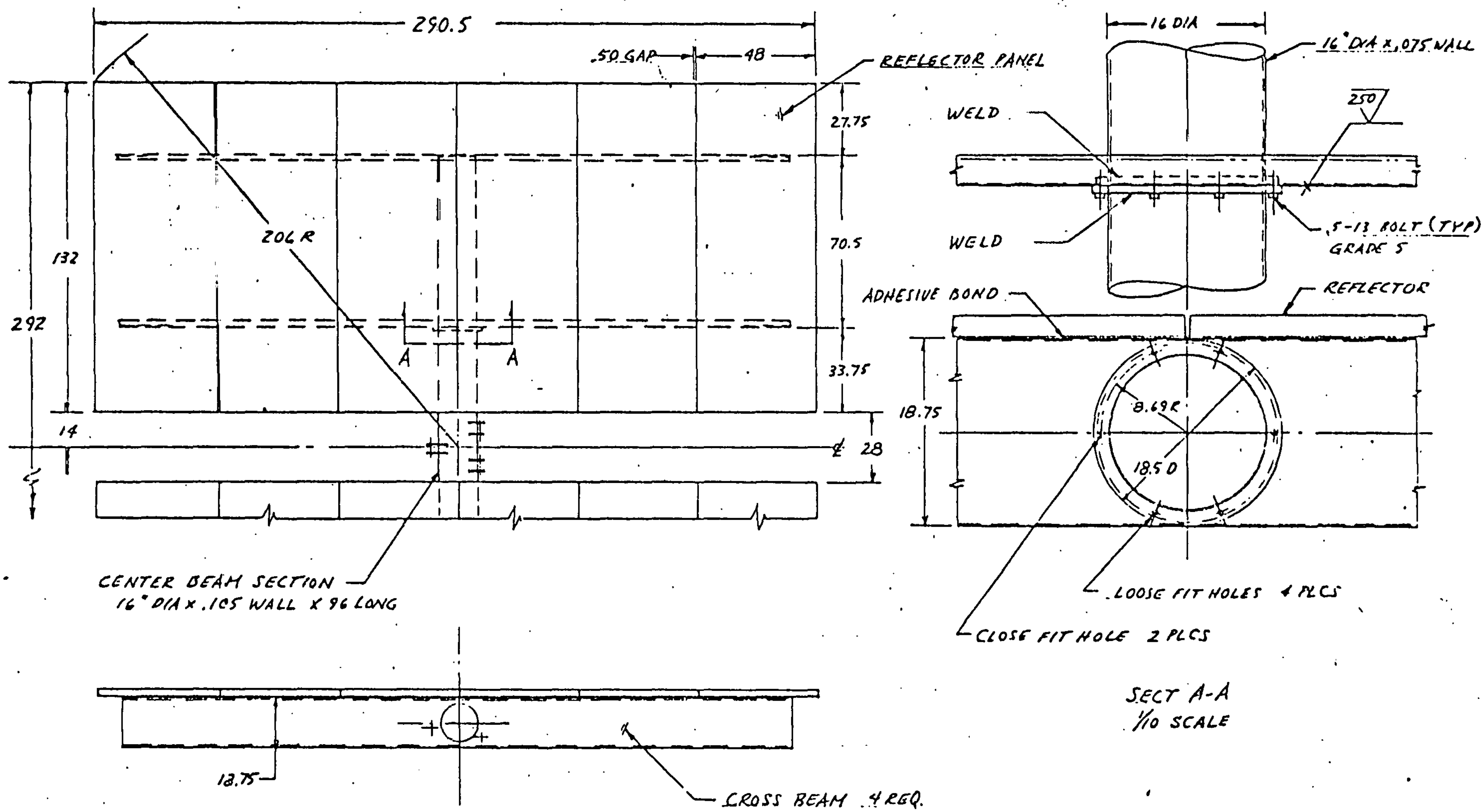


Figure 2.2.5-1 Two Segment Reflector - Three Piece Tube

This design eliminates the large hole in the cross beam to reduce manufacturing cost, and also increases the strength and stiffness of the beam. Further, with the joint at this location, the bending moment is less and the joint can be lighter.

A reduction in diameter of the outboard main beam was studied, but it was found to be better to reduce the wall thickness and leave the tube diameter the same as the center section. The constant tube diameter design is lighter and makes a simpler, more efficient joint since the loads can be carried straight through the joint.

A slightly different joint was devised for a structural arrangement which had two diagonal channel beams outboard of the joint instead of the tube, as shown in Figure 2.4.1.2-3. In this joint, the eight attach-bolts are located four above and four below the structural centerline since the bending reactions from the diagonal beams are reacted more efficiently at the deepest section of the beam.

The benefits of this task study become clear when considered together with Structure Optimization (D-6) and Site Factory (M-9).

2.2.6 D-6 - Reflector Structure Optimization

The proposed trade study was made to reduce structural materials by optimizing beam sections. The effects of varying the size of the main beam (torque tube) were investigated and it was found that larger diameter tubes having thinner walls gave lower weights for equivalent stiffness. The results are given in Table 2.2.6-1. The main beam requires a moment of inertia of at least 68.7×10^6 mm^4 (165 $inch^4$). The table shows this to be provided by a 0.40 m (16 inch) diameter tube of 2.66 mm (0.1046 inch) wall thickness. The effects of increasing the depth of the cross beams and reducing the gage thickness were also investigated. Results are shown in Table 2.2.6-2. The deeper beams have lower weights but as the gage thickness decreases, the structural stability of the beam decreases and the danger of failure by buckling or twisting increases. The cross beam selected is 0.976 m (18.75 inch) deep and 1.9 mm (.0747 inch) thickness.

Table 2.2.6-1

MAIN BEAM DESIGN COMPARISONS

Configuration	O.D. (In)	Wall Thickness (In)	Length (In)	Area (In^2)	MOI (In^4)	Bare Weight (Lb)	Galv. Weight (Lb)
PDR Baseline	10.25	0.250	206	7.854	98.2	458	469
408 Ft^2	10.25	0.250	234	7.854	98.2	520	533
	14.0	0.1046	206	4.566	110.2	266	275
Enlarged Inverted	14.0	0.1046	234	4.566	110.2	302	320
528 Ft^2	14.0	0.1196	234	5.215	125.6	345	363
	14.0	0.1345	234	5.859	140.8	388	406
	14.0	0.1495	234	6.505	156.0	431	448
	14.0	0.1644	234	7.146	171.0	473	491
	14.0	0.1875	234	8.136	194.1	539	556
Prototype Heliostat	16.0	0.1046	234	5.223	165.0	346	366
528 Ft^2	16.0	0.1345	234	6.704	211.0	444	464
Selected Design	16.0	0.1046	83'	5.223	165.0	123	130

'The selected design is terminated at the inboard crossbeams of the inflector panels.

Table 2.2.6-2

CROSS BEAM DESIGN COMPARISONS

Configuration	Depth (In)	Width (In)	Thickness (In)	Length (In)	Area (In^2)	MOI (In^4)	Bare Weight-4 Beams (Lb)	Galv. Weight-4 Beams
PDR Baseline								
408 Ft^2	14.0	2.5	.1196	240	2.39	62.0	510	526
	16.5	2.5	.0897	240	2.004	68.12	530	552
	14.0	2.5	.1196	272	2.39	62.0	735	758
Enlarged Inverted			.0747	272	1.669	56.73	500	525
528 Ft^2	16.5	2.5	.0897	272	2.004	68.12	600	625
			.1046	272	2.337	79.43	700	725
Prototype Heliostat	16.5	2.5	.1046	272	2.337	79.43	700	725
528 Ft^2			.0747	272	1.837	78.35	548	575
	18.75	2.5	.0897	272	2.206	94.08	658	685
			.1046	272	2.572	109.71	767	794
Selected Design	18.75	3.0		272	1.928	87.00	575	603

The sizes selected for the tube and channel beams as given in the description section are close to the optimum thickness to provide for minimum weight while retaining stiffening beads are included in the web to enhance the structural stability. Changes in structural geometry would be necessary to improve the stability for any further decrease in gage thickness. Such changes might take the form of additional cross members between beams to prevent beam rolling. Additional cost would be involved and such an approach is not considered economical.

Another approach for material reduction is to reconfigure the outboard section of the main beam so that it is divided into two beams which run diagonally toward the corners of the reflector, see Figure 2.4.1.2-3. With this arrangement the structural support is increased in the corner areas where the mirror deflections previously were maximum. Also, the outboard beam is supported at two points with overhang on each end so that deflection effects of the outer beam are minimized. This configuration allows the size of the outboard beam to be considerably reduced since the span lengths and bending moments are reduced. The weight saved by this configuration relative to the tubular main beam type is 426 pounds.

A trussed beam concept for reducing the cross beam material requirement is shown in Figure 2.2.6-1. A sizeable weight reduction can be achieved for the cross beams by this design, but the fabrication costs increase and mostly cancel the savings resulting from reduced material. This design therefore does not appear economical.

2.2.7 D-7 - Low Cost Motors

In the interest of designing a more efficient motor drive system alternative motors have been studied for the Prototype heliostat array. A major portion of the study involved the alternatives available in supply voltage for the three-phase drive motors. The baseline configuration was designed to operate at 240 volts. At this voltage, a starting current of 124,000 amps would be required for a 17,700 heliostat field. This imposes the problems of heavy gauge wire for the distribution network. As an alternative, a 480 volt system was studied. The motors showed a slight decrease in manufacturing cost and

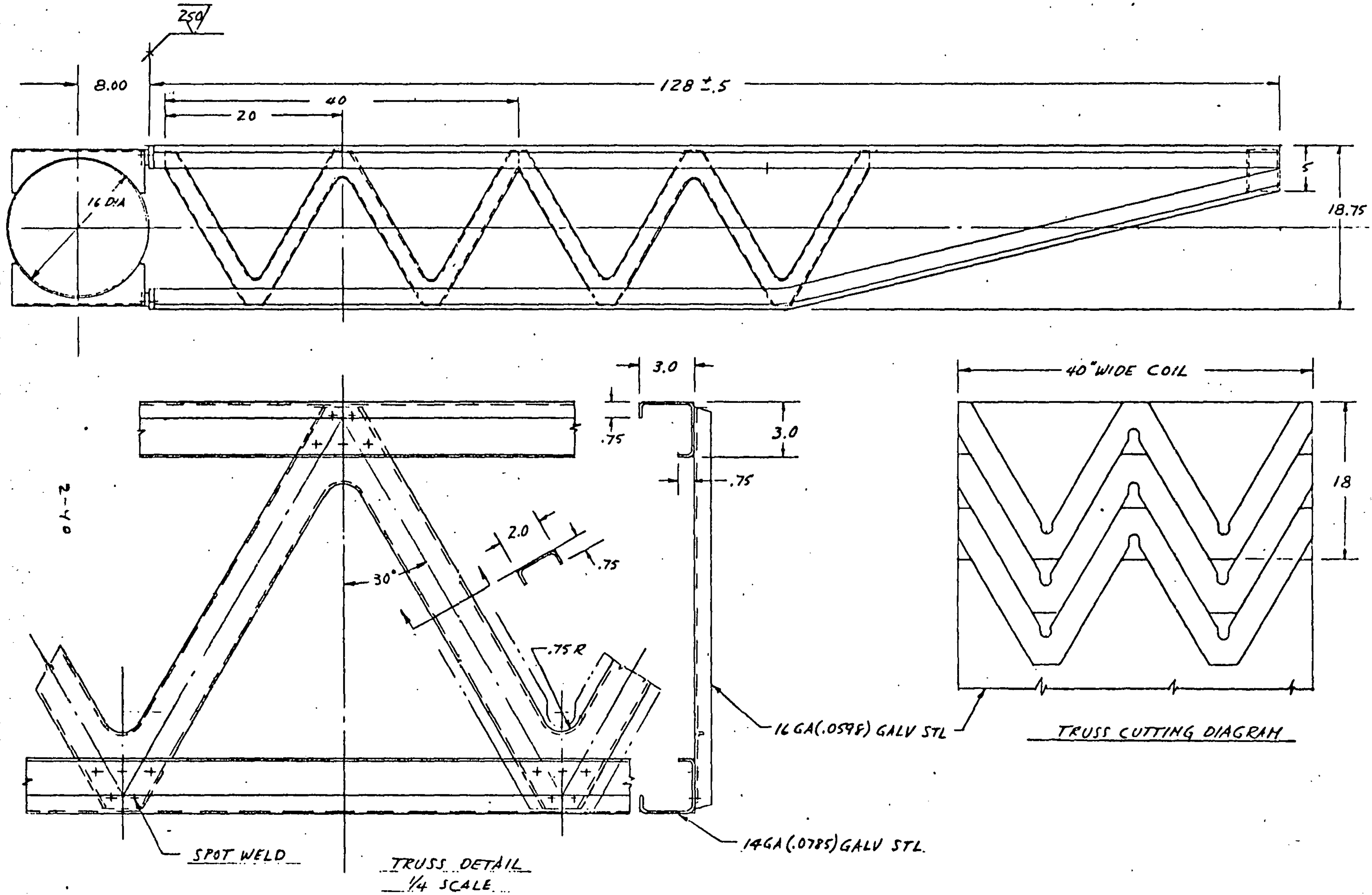


Figure 2.2.6-1 Trussed Cross Beam Design

require a smaller gauge cable for power distribution.

The asynchronous brushless motors studied also provided some promising characteristics. The DC motors proved to be high torque motors with a stall torque of 650 oz-inch, approximately twice that required for gimbal drive. The motors possessed smooth and fast acceleration and were capable of operating at very high speeds. Additional testing and study is believed necessary before the incorporation of these motors is considered.

2.3 BENCH MODEL AND COMPONENT TEST RESULTS

Two types of tests were conducted to support the trade studies and preliminary design: environmental effects tests and manufacturing techniques tests.

The environmental effects tests included:

- Salt spray test of candidate mirror module specimens to investigate accelerated, simulated weathering processes, especially of the mirror silvering and protective coatings.
- Hailstone impact tests to evaluate integrity of the mirror module designs for severe hail storms.
- Temperature cycling tests to evaluate thermal stresses and deformation of the reflector unit, including degree of permanent deformation.
- Backlighting tests to investigate the effects of heating of the back side of the mirror module on the stresses and deformations in the glass, due to differential expansion, when the reflector unit is in the inverted stow position or backlighted by adjacent heliostats.

Of the manufacturing tests, one was concerned with the actual process of bonding permanently together two panes of glass, one with a coating of copper over silver on it. Another investigation involved the fabrication of large panels of a size approaching that of the designed panel, and measuring their performance.

Flatness, image quality, residual stresses, and uniformity of bond were checked prior to and following temperature cycling tests.

The various tests are described below. Significant results and conclusions are:

1) Standard mirror backing paint provides an excellent protection of the mirror in the salt spray environment.

2) A finish paint coating may further enhance mirror survival.

3) The polyurethane adhesive selected for the low cost laminated mirror provides a good mirror protection when the coating is continuous and seals the edges.

4) The low cost laminated mirror without backing paint requires that the edges be well sealed.

5) Both the low cost laminated configuration and the corrugated support configuration showed satisfactory hail performance.

6) The stringer supported configurations showed adequate resistance to thermal cycling. Thermal stresses appeared to be high for the corrugated support mirror.

2.3.1 Test Scope

Environmental tests were conducted on 27 small coupons 12.7 cm square (5" by 5") and six specimens representative of full size panels .76 by 1.22 m (30" by 48"). Tests conducted included salt spray, hail, flatness, and temperature cycling. Tests on production methodology for laminated glass were also conducted.

Salt spray tests were performed to determine the relative durability of various mirror backings and low cost glass laminates. Coupons tested incorporated numerous types of mirror backings and edge treatments.

Hail tests were performed on three panel designs to establish survivability if exposed to a severe hail storm.

Thermal cycling tests were performed to evaluate the effects of high and low temperature on the panels. Numerous temperature and strain measurements were recorded and the resulting stresses were evaluated. Pre- and post-test flatness measurements were made to assess thermal warping induced permanent deformation.

Production methodology tests were run on glass laminates using various methods of adhesive application and pressure devices, including pressure rollers, presses and vacuum pressure.

2.3.2 Salt Spray Tests

Coupons were arranged in slotted plastic trays and positioned in the chamber at a 60° angle from the horizontal with the coated side of the mirrors facing upwards. A five percent salt solution was used.

Table 2.3.2-1 delineates the coupons tested, specifies hours tested, and rates the degradation disclosed.

Detailed descriptions of the small coupons and discussions of the results of the salt spray tests are expanded below.

A1a thru A1d - Four square 12.7 cm (5" by 5") mirrors were cut from "as delivered" 3.2 mm (1/8 inch) float glass, chemically-deposited silver, flash copper coated with Glidden gray mirror backing paint. After 262 hours of salt spray exposure, the mirrors did not show any visible degradation, so coupons A1c and A1d were placed back into the chamber. They were removed after 334 hours of exposure and some minimal edge penetration was evident as shown in Figure 2.3.2-1 for specimen A1c.

A2a thru A2d - Four square 12.7 cm (5" by 5") mirrors were cut from "as delivered" 3.2 mm (1/8 inch) ASG Lustra Sheet Binswanger mirror with Glidden white acrylic backing paint. An exposure of 209 hours caused edge penetration of 5 mm (3/16 inch) and chipping as shown in Figure 2.3.2-2.

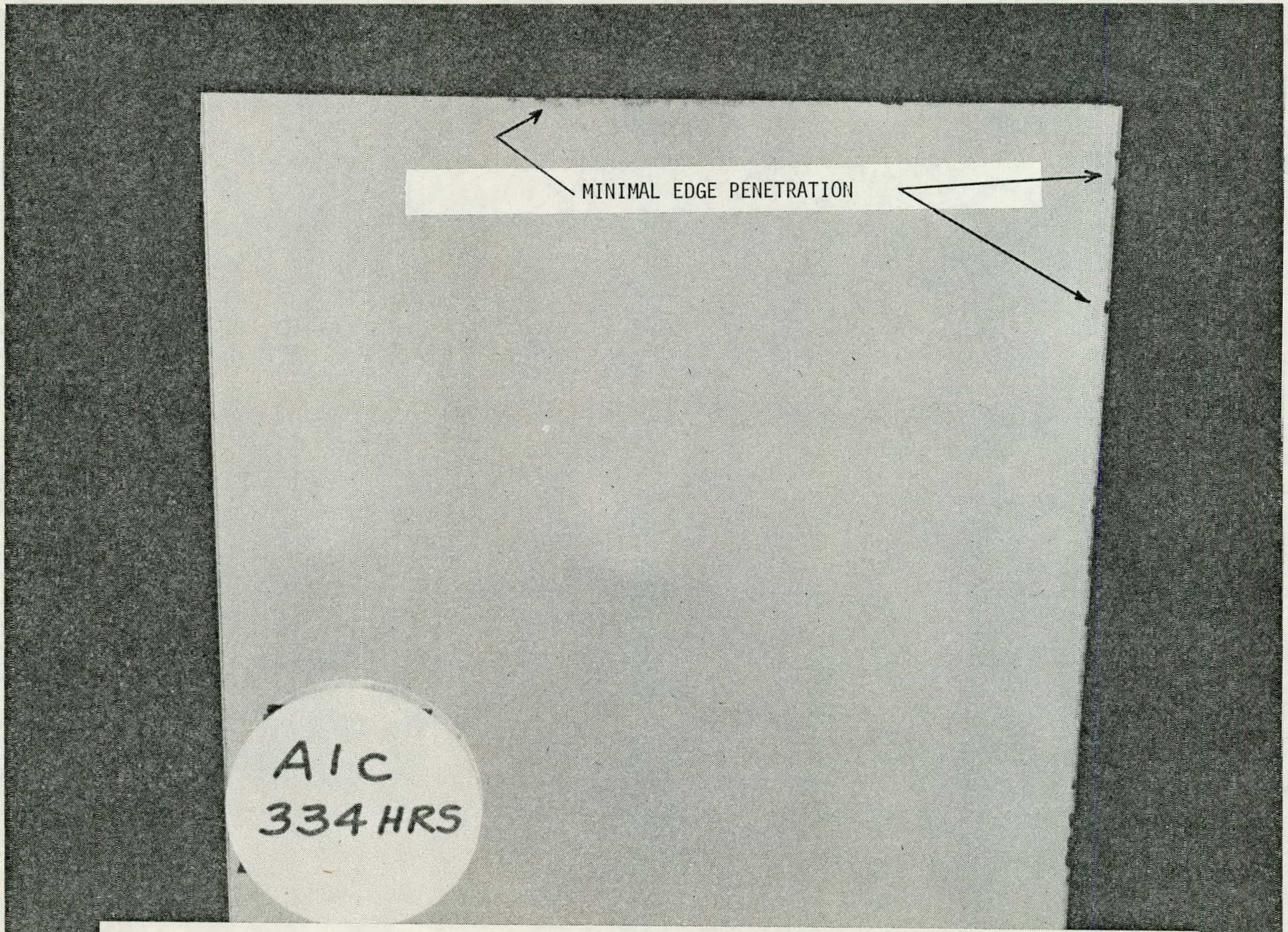


Figure 2.3.2-1 Salt Spray Coupon Alc with Glidden Gray Backing Paint

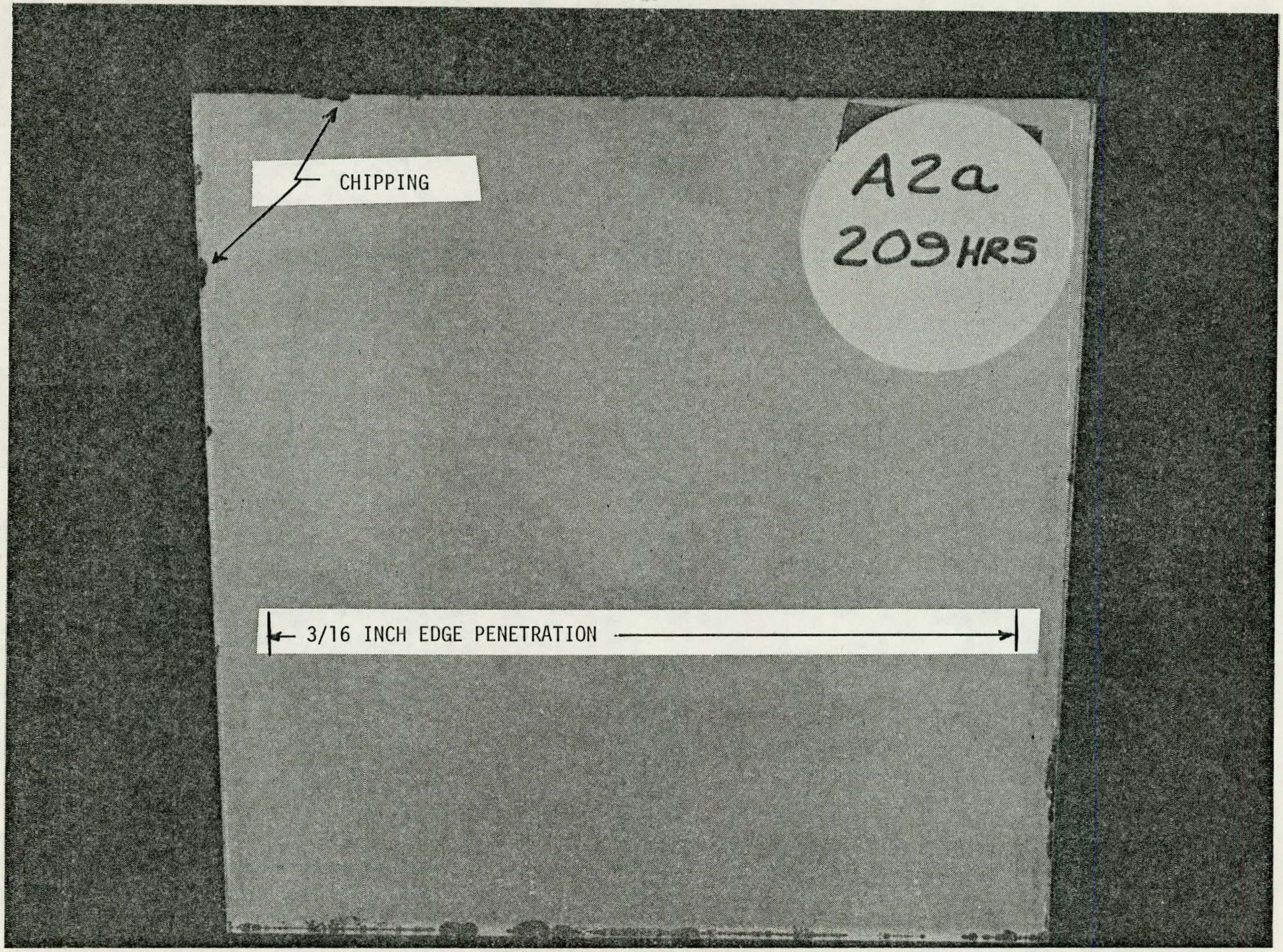


Figure 2.3.2-2 Salt Spray Coupon A2a with Glidden White Acrylic Backing Paint

Table 2.3.2-1

SALT SPRAY COUPONS - TEST RESULTS

Number	Type	Hours	Degradation
A1a	Glidden Gray Mirror Backing Paint	262	None
A1b	" " " " "	262	None
A1c	" " " " "	334	Minimal
A1d	" " " " "	334	Minimal
A2a	Glidden White Acrylic Mirror Backing Paint	209	Slight
A2b	" " " " " "	209	"
A2c	" " " " " "	209	"
A2d	" " " " " "	209	"
A3a	Glidden Gray Plus High Reflectance White Paint	257	None
A3b	" " " " " " "	257	"
A3c	" " " " " " "	257	"
A3d	" " " " " " "	257	"
A4a	Same as A3a Plus Adhesive Bonded Steel Tab	257	None
A4b	" " " " " " "	257	"
A4c	" " " " " " "	257	"
A4d	" " " " " " "	257	"
C1a	Laminated Mirror With Backing Paint and Interior Reflective Adhesive	219	None
C1b	" " " " " " " "	219	"
C1c	" " " " " " " "	219	"
C1d	" " " " " " " "	219	"
C2a	Laminated Mirror Backing Paint Removed With Interior Reflective Adhesive	219	Slight (Sealed Edge)
C2b	" " " " " " " "	219	Severe (Cut Edge)
C2c	" " " " " " " "	219	Slight (Sealed Edge)
C2d	" " " " " " " "	219	Severe (Cut Edge)
-	Non-Laminated Mirrors With Backing Paint Removed With Interior Reflective Adhesive	257	Severe

A3a thru A3d - These mirrors were identical to A1a through A1d except they were sprayed with number 6 high reflectance white paint manufactured by Triangle Paint Company. There was no degradation noted after 257 hours of exposure. These laminates would not reach as high a temperature as those with the gray paint under backlighting conditions.

A4a thru A4d - This configuration utilized the same mirror as specified for A3a with a galvanized steel tab bonded to it with 3M 3535 adhesive. The tab is shown in Figure 2.3.2-3 after 257 hours exposure. The mirror showed no deleterious effects.

C1a thru C1d - All four mirrors were the type described for A1a with Glidden gray backing paint. An adhesive (3M 3535) was applied by spatula to the mirrors and a 3.2 mm (1/8 inch) thick piece of float glass was attached to it. Coupons C1a and C1b were made with Ford glass and C1c and C1d were made with Pittsburg Plate glass. The edges of C1b and C1c were sealed. After 219 hours of exposure no degradation was noted.

C2a thru C2d - These mirrors were the same as C1a except the Glidden gray backing paint was removed and the adhesive was applied directly to the bare copper. Coupons C2a and C2b were made with Ford glass and C2c and C2d were made from Pittsburg Plate glass. C2a and C2c were made with sealed edges and C2b and C2d were cut edges. Edge sealing made considerable difference in edge degradation as shown in the photographs for coupons C2a and C2d (Figures 2.3.2-4 and 2.3.2-5). Severe degradation occurred when edges were not sealed while only slight penetration occurred with sealed edges. Close examination disclosed that minute pin holes in the sealed edge allowed seepage through the adhesive. If the adhesive were applied evenly, rather than with ridges as shown in C2d, and the edges were well sealed, this configuration would survive the salt spray environment.

Several additional mirrors were prepared by removing the backing paint and applying the adhesive directly to the bare copper, but glass was not laminated to it. Figure 2.3.2-6 shows regions of severe degradation after 257 hours of exposure, even though the edges were sealed.

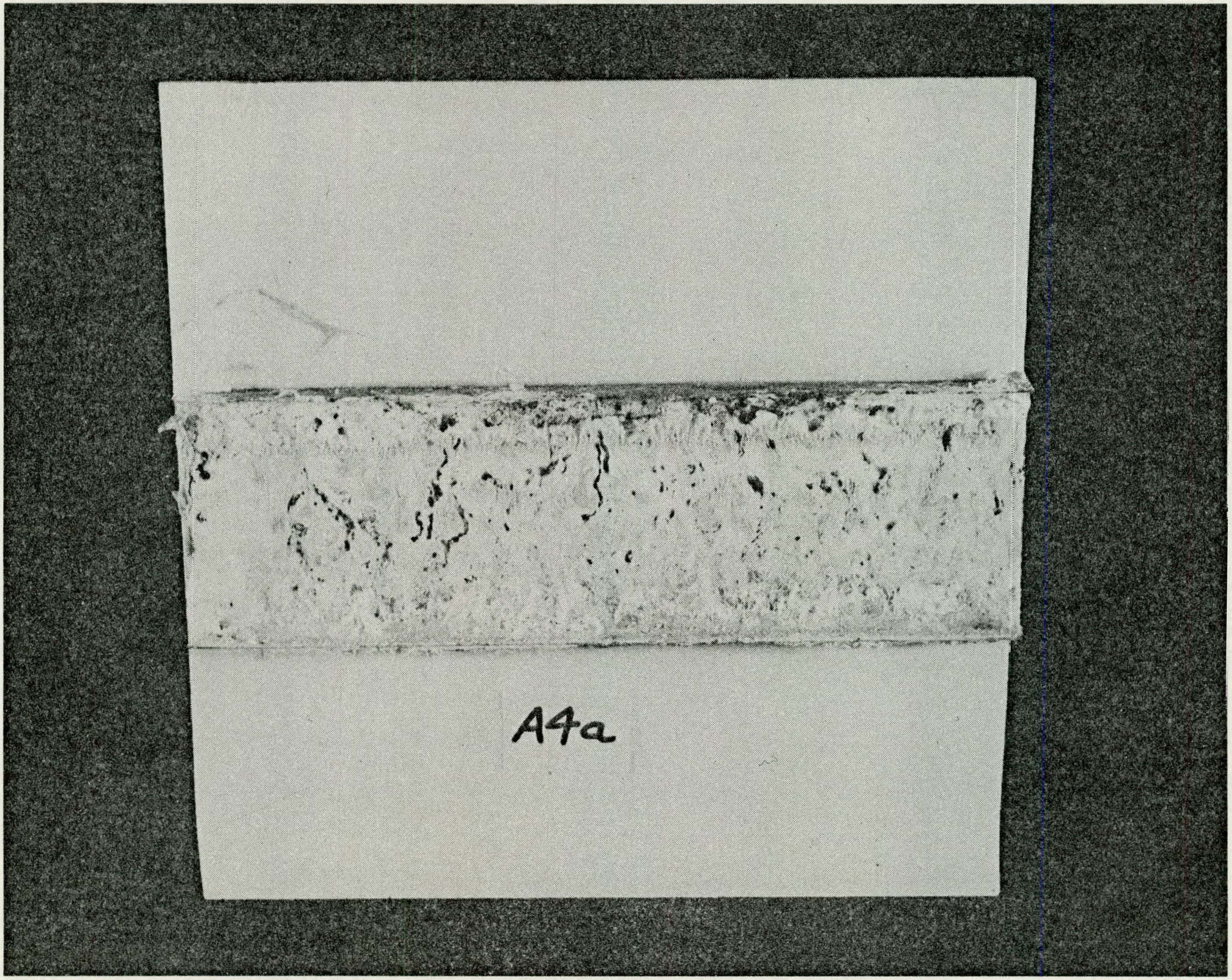


Figure A.3.2-3 Salt Spray Coupon A4a with Galvanized Steel Tab

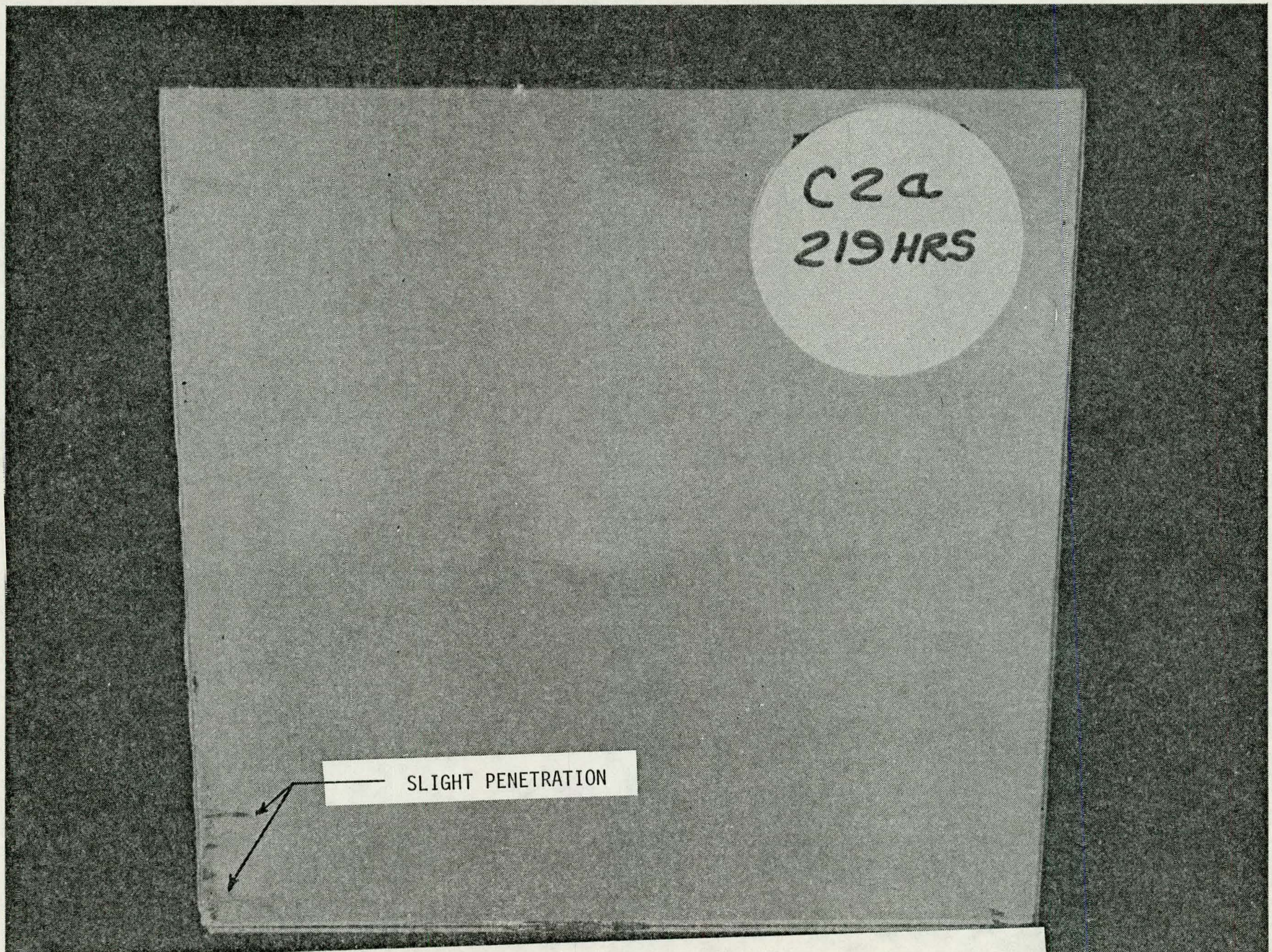


Figure 2.3.2-4 Salt Spray Coupon C2a Laminated with Sealed Edge

Figure 2.3.2.5 Salt Spray Coupon C2d Laminated with Cut Edge

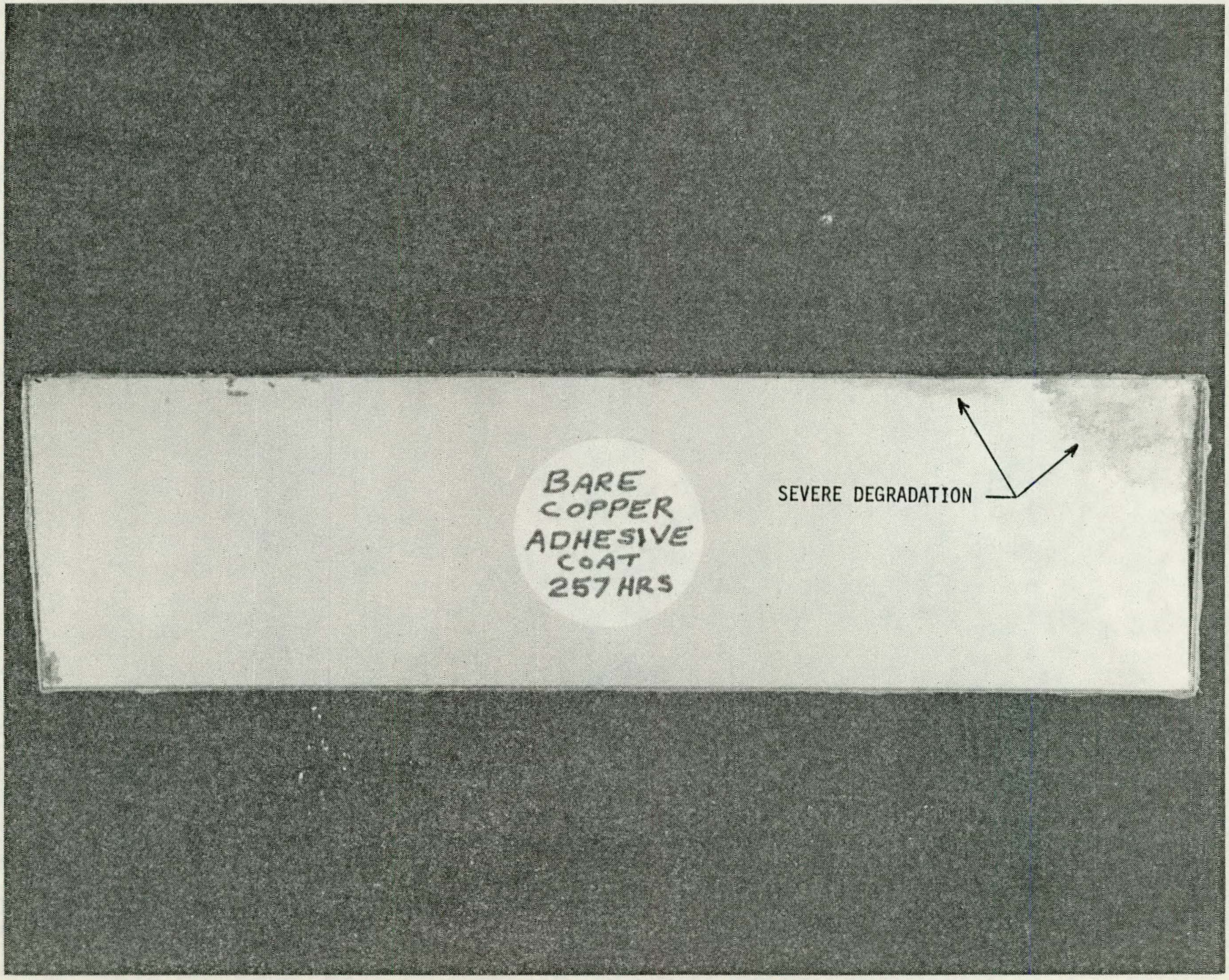


Figure 2.3.2-6 Salt Spray Coupon with Interior Reflective Adhesive

In conclusion, the mirrors covered with Glidden gray and those with Glidden gray plus high reflectance white paint survived the salt spray test far better than the other candidates. However, mirrors covered with adhesive applied directly over bare copper should not be ruled out. The adhesive seems to provide adequate protection where properly applied. Tests evaluating various application techniques of adhesive should be performed before final conclusions are drawn.

2.3.3 Hail Impact Tests

Three candidate designs were tested for hail survivability. The mirrors were impacted six times with hail stones 19 mm (0.75 inch) and 25 mm (1 inch) diameters at velocities of 20 m/s (65 ft/sec) and 23 m/s (75 ft/sec), respectively.

The simulated hail impact tests were conducted in the MDAC Experimental Stress Analysis Laboratory. A schematic diagram of the test setup is shown in Figure 2.3.3-1. A hail stone was made by freezing water to the proper diameter using a special aluminum mold. The hail stone was then loaded into the launch tube. The manual valve was opened and the reservoir was pressurized to a predetermined value. The spring driven valve was opened and the pressure was released, driving the hail stone down the launch tube to impact with the target. The launch tube had two electric eyes located a known distance apart at the target end. The electric eyes were connected to a timing device. The time for the hail stone to travel this known distance was measured and the velocity was determined.

Test results are tabulated below:

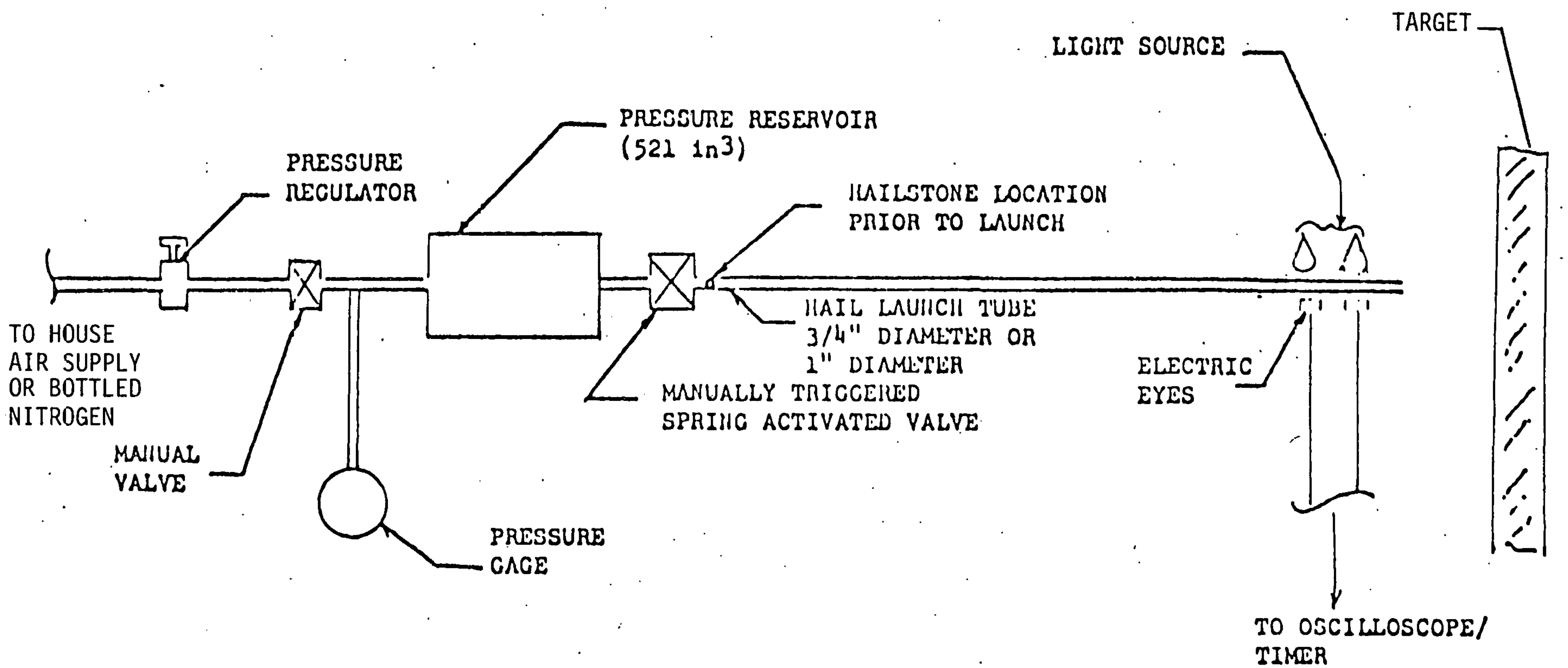


Figure 2.3.3-1 Schematic of Hail Test Setup

Panel	19 mm (3/4 inch) diameter at 20 m/s (65 ft/s)	25 mm (1 inch) diameter at 23 m/s (75 ft/s)
D1b 1/8 inch mirror supported with corrugated sections	No Damage	Failed at Corner
D2b 1/8 inch mirror supported with hat sections	Failed on Edge	Failed on Edge and Corner
E1b 1/8 inch thick mirror laminated to 1/8 inch glass	No Damage	No Damage

Descriptions of the panels tested and failure points are discussed in the following paragraphs.

<u>D1b - 3.2 mm (1/8 inch) Mirror Supported with Corrugated Sections</u> - This panel consisted of a 0.76 by 1.22 m by 3.2 mm thick (30 by 48 inch by 1/8 inch thick) float glass mirror coated with Glidden gray backing paint with a 28 gage corrugated stiffener bonded to the back side with 3M 3535 adhesive.

The panel was hit with 19 mm (3/4 inch) diameter hail stones at a velocity of 20 m/s (65 ft/sec) at four locations for a total of six shots as shown in Figure 2.3.3-2.

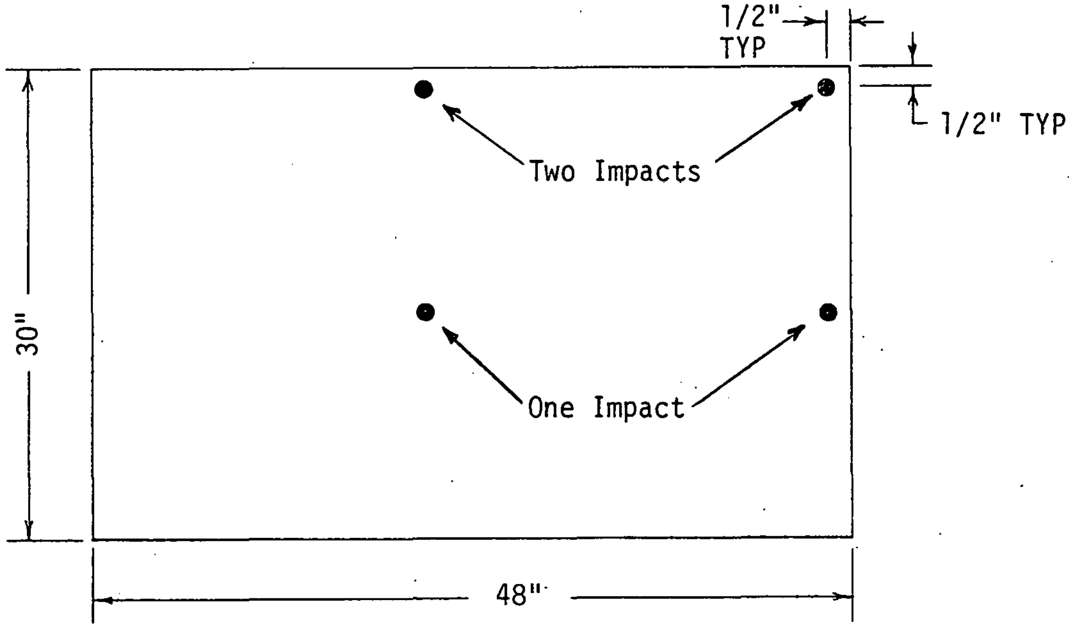


Figure 2.3.3-2 Typical Hail Impact Locations

No fractures occurred. The test was repeated with 25 mm (1 inch) diameter hail stones at a velocity of 23 m/s (75 ft/sec) and a fracture occurred in the corner after the second impact (See Figure 2.3.3-3).

D2b - 3.2 mm (1/8 inch) Mirror Supported with Four Hat Sections - This panel incorporated the same size and the type mirror as D1b. Four 20 gage hat stiffeners were bonded to the back side with 3M 3535 adhesive.

A failure in the edge of this panel resulted from the first impact with a 19 mm (3/4 inch) diameter hail stone at 20 m/s (65 ft/sec, see Photograph 2.3.3-4). It survived four other shots. The opposite side of the panel fractured when hit with a 25 mm (1 inch) diameter hail stone at 23 m/s (75 ft/sec), as did the corner.

E1b - 3.2 mm (1/8 inch) Mirror Laminated to 3.2 mm (1/8 inch) Float Glass - This panel was made from the same size and type mirror as D1b. Stiffening was accomplished by laminating a piece of 3.2 mm (1/8 inch) float glass to

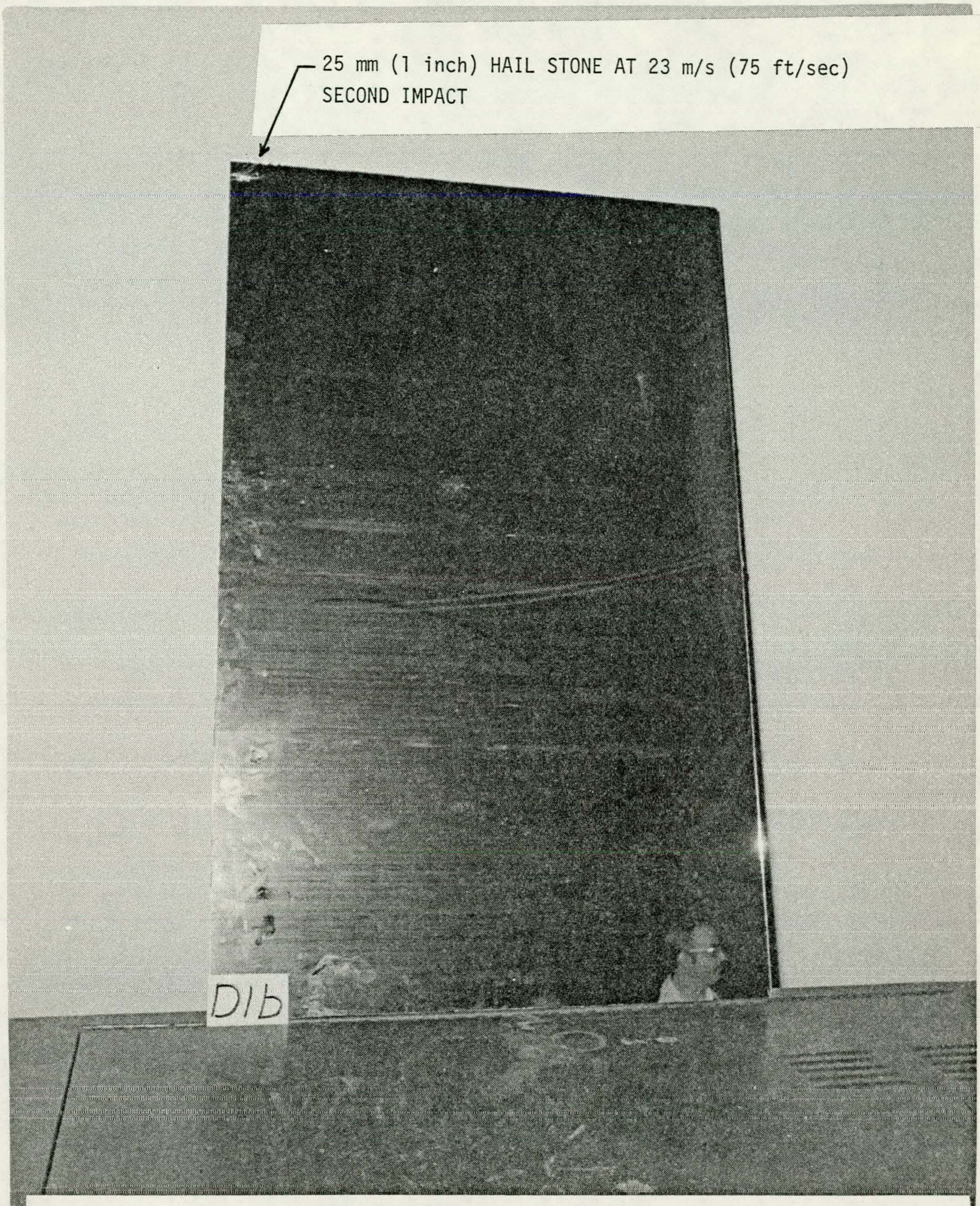


Figure 2.3.3-3 Hail Impact Test Panel D1b

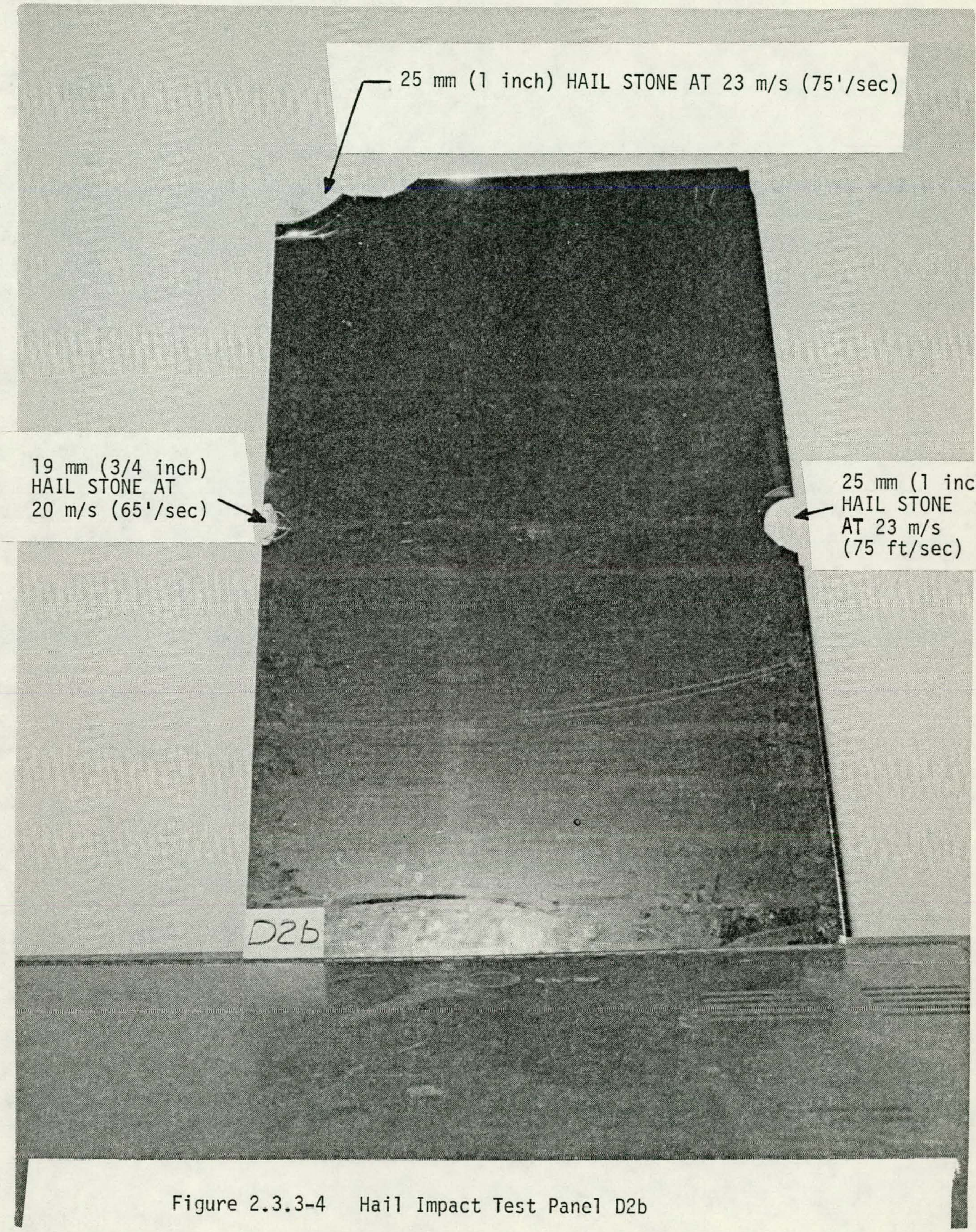


Figure 2.3.3-4 Hail Impact Test Panel D2b

the back of the mirror using 3M 3535 as an adhesive and by bonding on two 18 gage hat stiffeners. No damage was noted on this panel from any of the hail impacts.

It may be concluded that the laminated panel is the best design for hail environments since it was the only configuration that survived all impacts. However, it should be noted that the impact with the 25 mm (1 inch) diameter hail stone at 23 m/s (75 ft/sec) is a requirement for the inverted position only. All panels were tested on the front side. It has not been demonstrated that the corrugated panel would fail if impacted on the back side.

2.3.4 Thermal Cycling Tests

Three panels identical to configurations D1b, D2b, and E1b were instrumented with strain gages and thermocouples. The panels were all placed in a 1.83 by 1.83 by 1.22 m (6 ft by 6 ft by 4 ft) temperature/altitude chamber located in the Structures Laboratory.

They were subjected to a total of 72 temperature cycles at a rate of approximately four hours per cycle reaching temperature extremes of -30°C (-22°F) and +50°C (120°F).

The chamber was set to cycle automatically using an autocontroller which followed a cam profile. Typical chamber temperature profiles are shown in Figure 2.3.4-1. A Brush recorder was used to record the individual panel temperatures versus the control thermocouple temperature. These data are shown in Figure 2.3.4-2. Figure 2.3.4-3 shows the relative position of the panels in the chamber and Figure 2.3.4-4 shows the chamber controller and data acquisition system.

Four strain gages and four thermocouples were placed on the laminated panel E1a. Three strain gages and three thermocouples were placed on each of the other two panels. Strain gage and thermocouple location and number designation are presented in Figure 2.3.4-5.

Printouts show no strain in excess of 70 μ in/in (system accuracy within $\pm$ 5 μ in/in). Typical stress levels for the three panels are presented below.

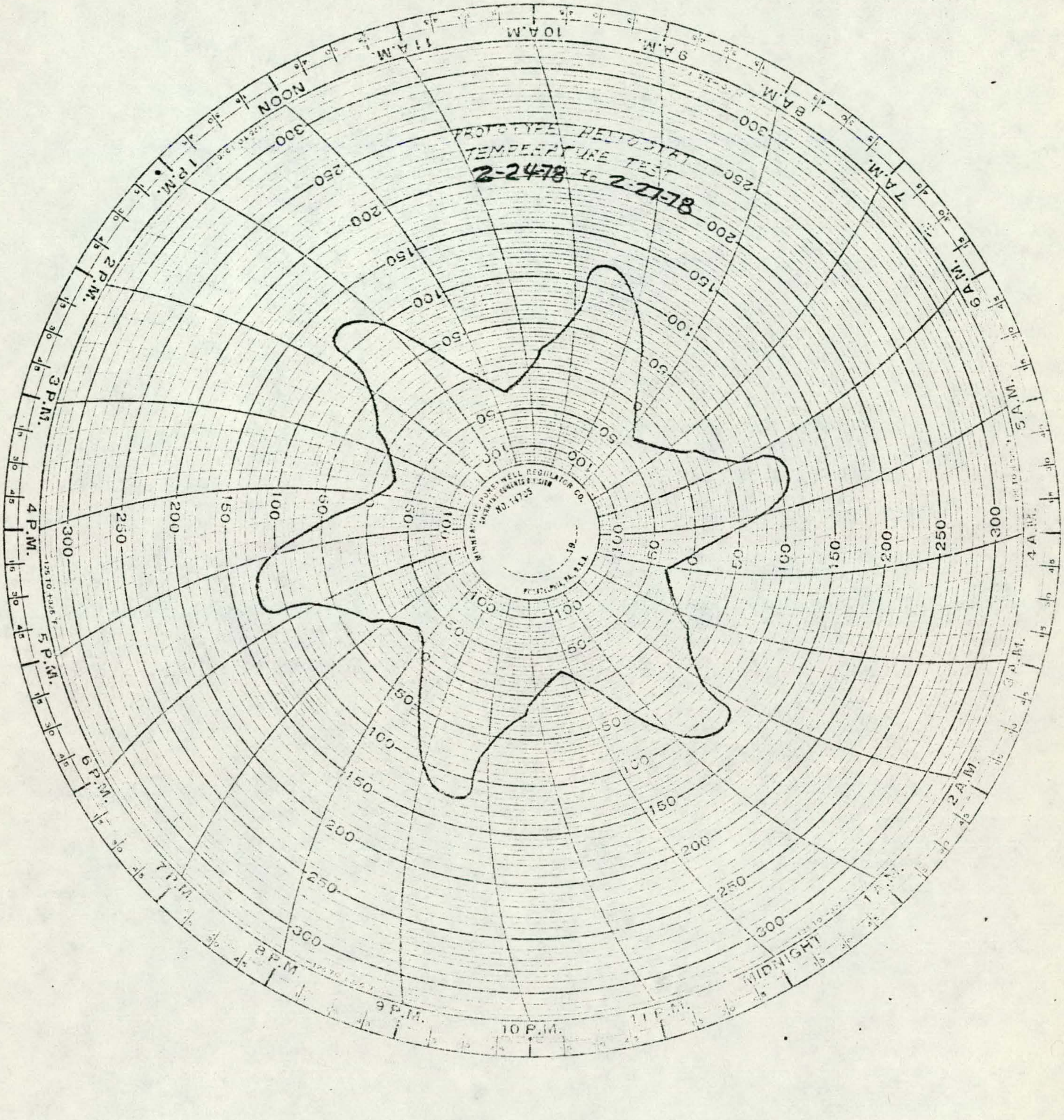


Figure 2.3.4-1 Typical Chamber Temperature Profiles

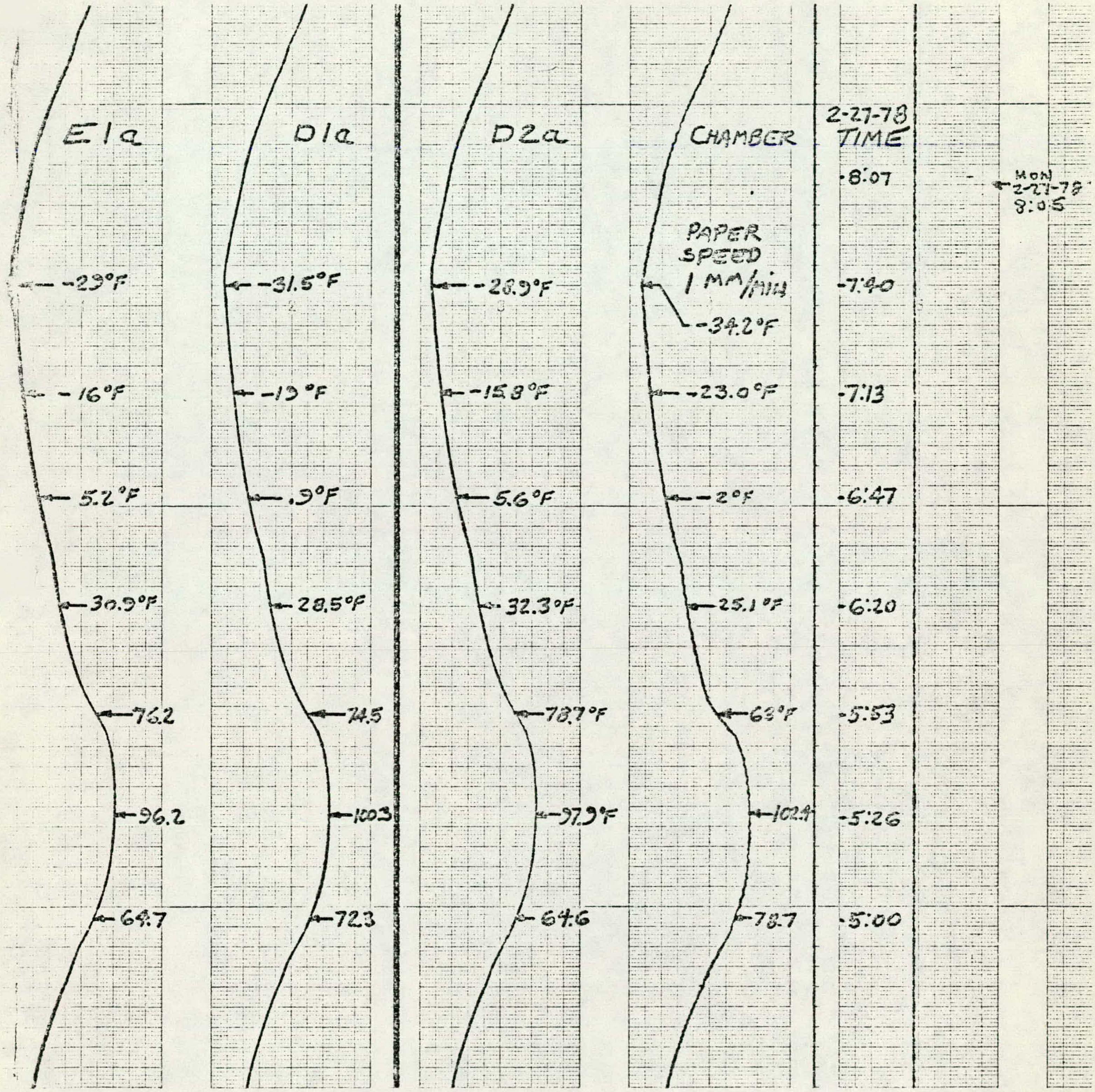


Figure 2.3.4-2 Brush Recorder Printout

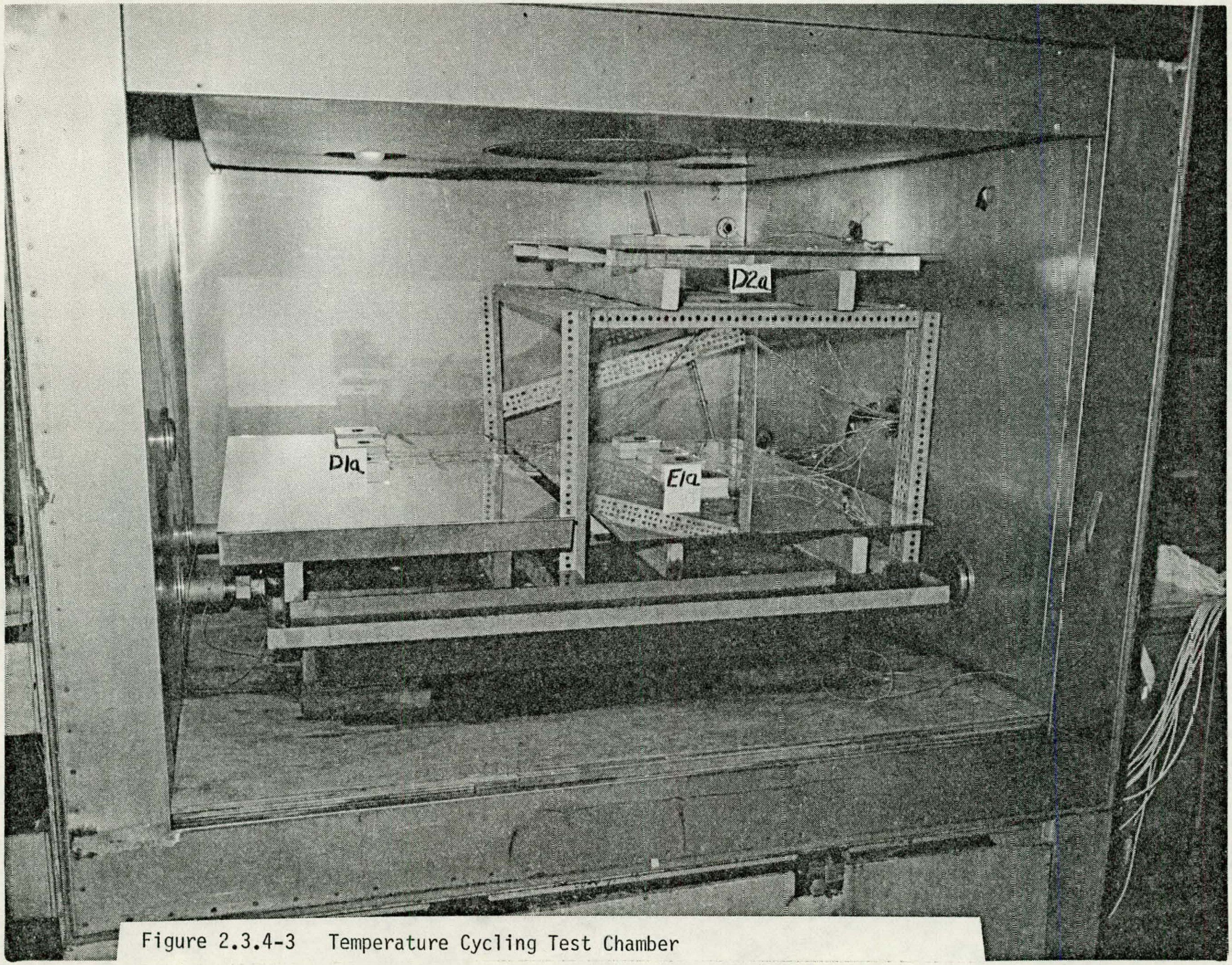


Figure 2.3.4-3 Temperature Cycling Test Chamber

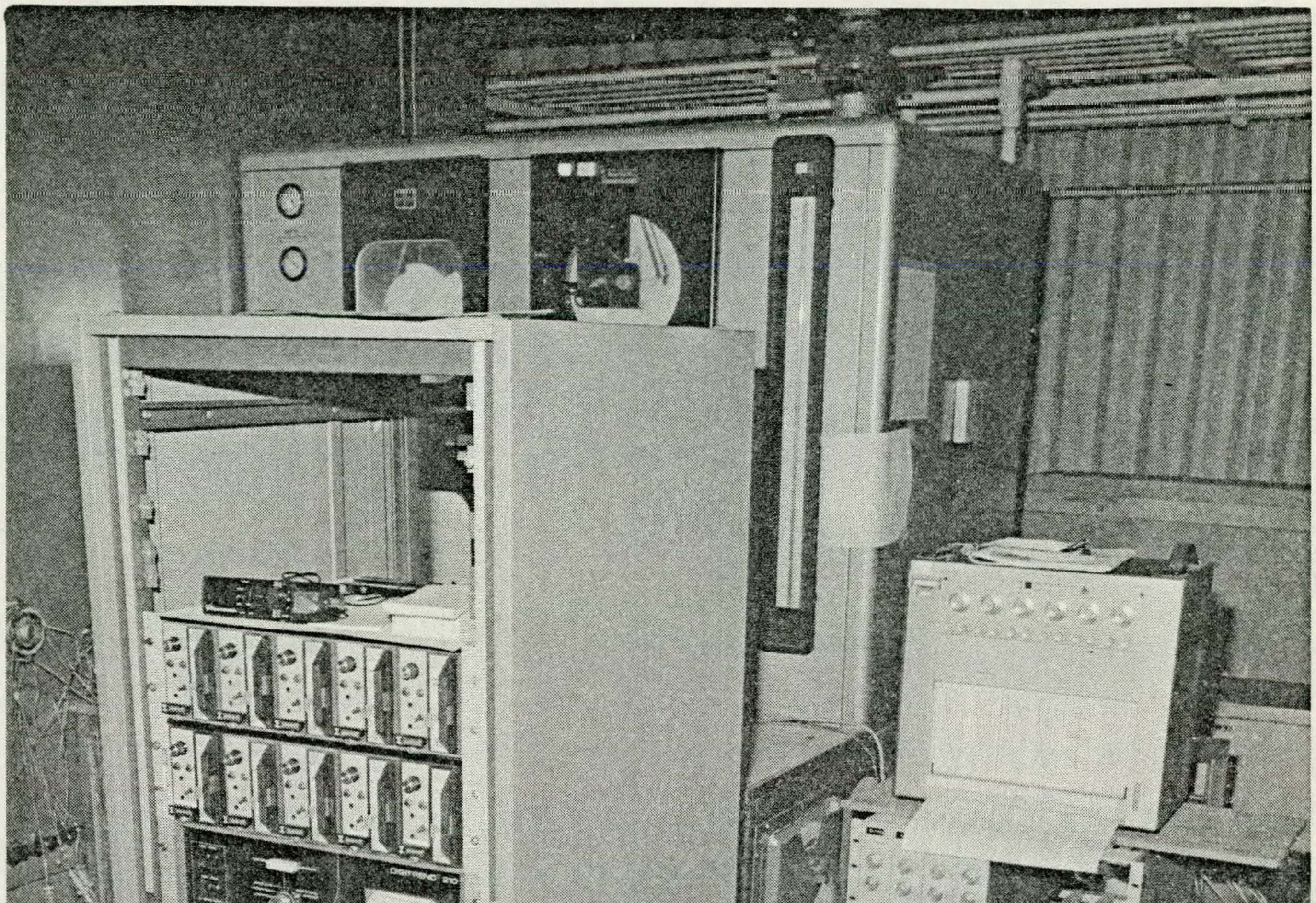


Figure 2.3.4-4 Data Acquisition System

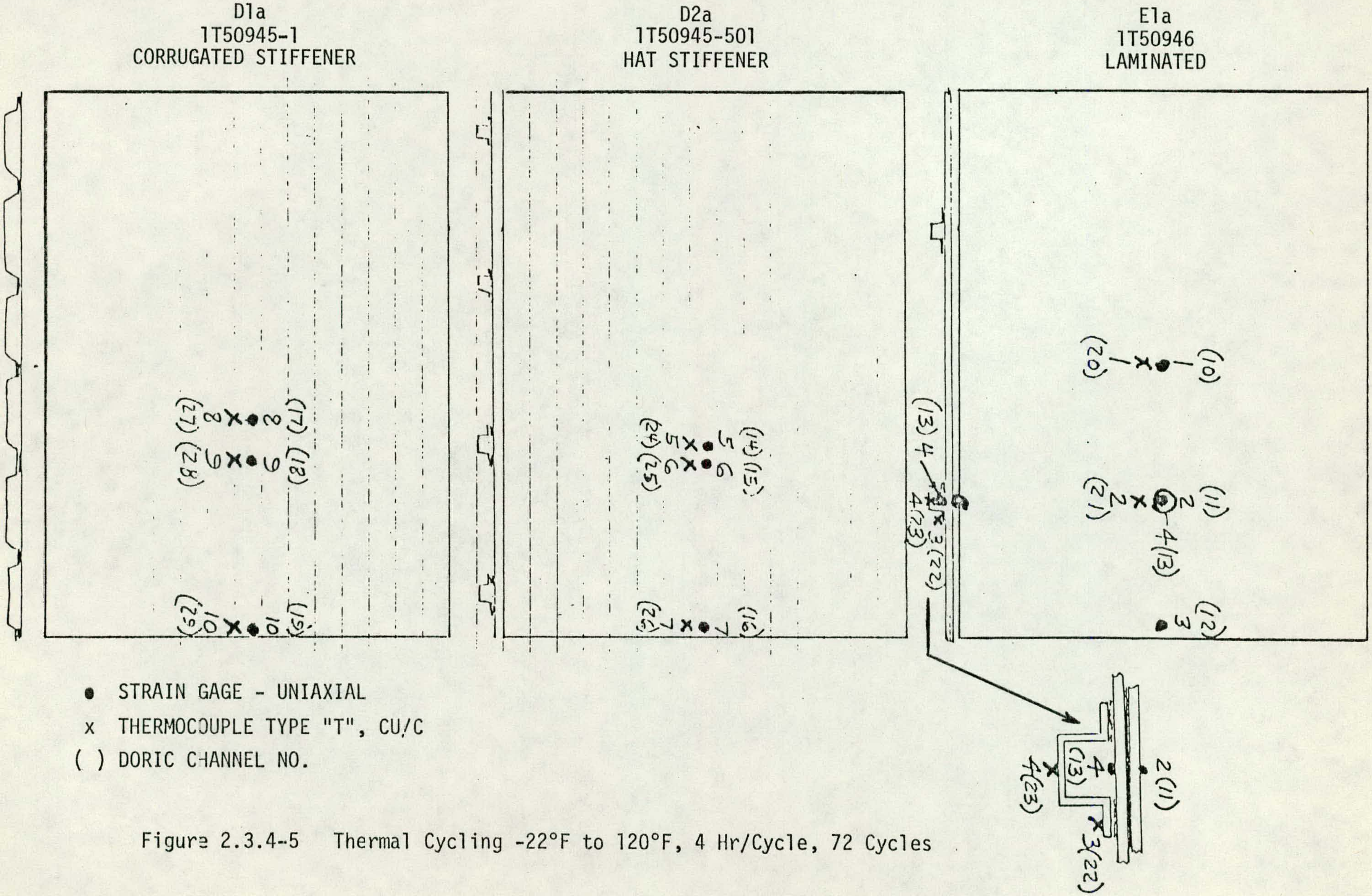


Figure 2.3.4-5 Thermal Cycling -22°F to 120°F, 4 Hr/Cycle, 72 Cycles

At the conclusion of the thermal cycling tests, during which each of the three test panels was subjected to 72 cycles of temperature change, the panels were placed on a surface table and measured for flatness. Measurements were made at 28 points, on a grid work that had been laid out on the glass surface, such that each point was 15.24 cm (6 inches) from adjacent points. The measurements were then compared with those made at the same points before the thermal cycling began. The difference was considered to be the permanent set which the panel would see after prolonged exposure in the most severe temperature environment.

The maximum change in Panel D2a, the specimen of 3.2 mm (1/8 inch) glass sheet reinforced with four hat section stiffeners of 20 gauge steel, was 0.32 mm (0.0125 inch). Panel D1a, of 3.2 mm (1/8 inch) glass sheet reinforced with 28 gauge corrugated steel, showed a maximum of 0.69 mm (0.027 inch). The laminated panel, the one selected for its low cost, had a maximum change of 1.96 mm (0.077 inch).

The results of the test indicated that the laminated glass mirror would show the greatest permanent set after prolonged exposure. However, the test was somewhat inconclusive because of the use of the surface table to measure the test points on each panel rather than supporting the panel at four points, as it is supported in the heliostat structure. It is recommended that additional permanent deformation tests be performed with a more representative support structure to more closely simulate the actual conditions.

Panel	Maximum Stress	Location	Temp
Ela Laminated	420 psi Compression	S.G.3	-30°F
Ela Laminated	360 psi Tension	S.G.3	-30°F
Ela Laminated	390 psi Compression	S.G.2	+113°F
Dla Corrugated	680 psi Compression	S.G.10	-30°F
Dla Corrugated	190 psi Tension	S.G.10	+113°F
D2a Hat	460 psi Compression	S.G.5	-29°F
D2a Hat	160 psi Tension	S.G.5	+112°F

Photographs of each of the panels with instrumentation locations are shown in Figures 2.3.4-6 through 2.3.4-8.

The strain gages used in these tests are reading down near the low end of their range. Hence, system noise and resolution lead to a significant uncertainty in the readings.

Pending further results from the tests, it is concluded that the stresses are generally of an acceptable level. The stresses are somewhat lower than predicted for the thinner mirrors and higher for the low cost laminated configurations. However, these differences are not as yet considered to be significant. The lower thermal and overall stresses in the laminated mirror are a factor in the choice of this approach.

2.3.5 Backlighting Tests

Backlighting tests have not been conducted in this phase because of the unavailability of reflector components required to simulate the preferred candidate low cost fusion glass laminate reflector. The test specimens fabricated for the thermal cycling tests are sufficiently different from the fusion glass laminate to make the application of backlighting test results from these specimens invalid for the laminate. Key differences are the mirror backing paint and glass thickness. The candidate laminate configuration consists of .060 inch fusion glass bonded to 3/16 inch float glass. The chemically deposited silver on the fusion glass would be flash coated with copper. The

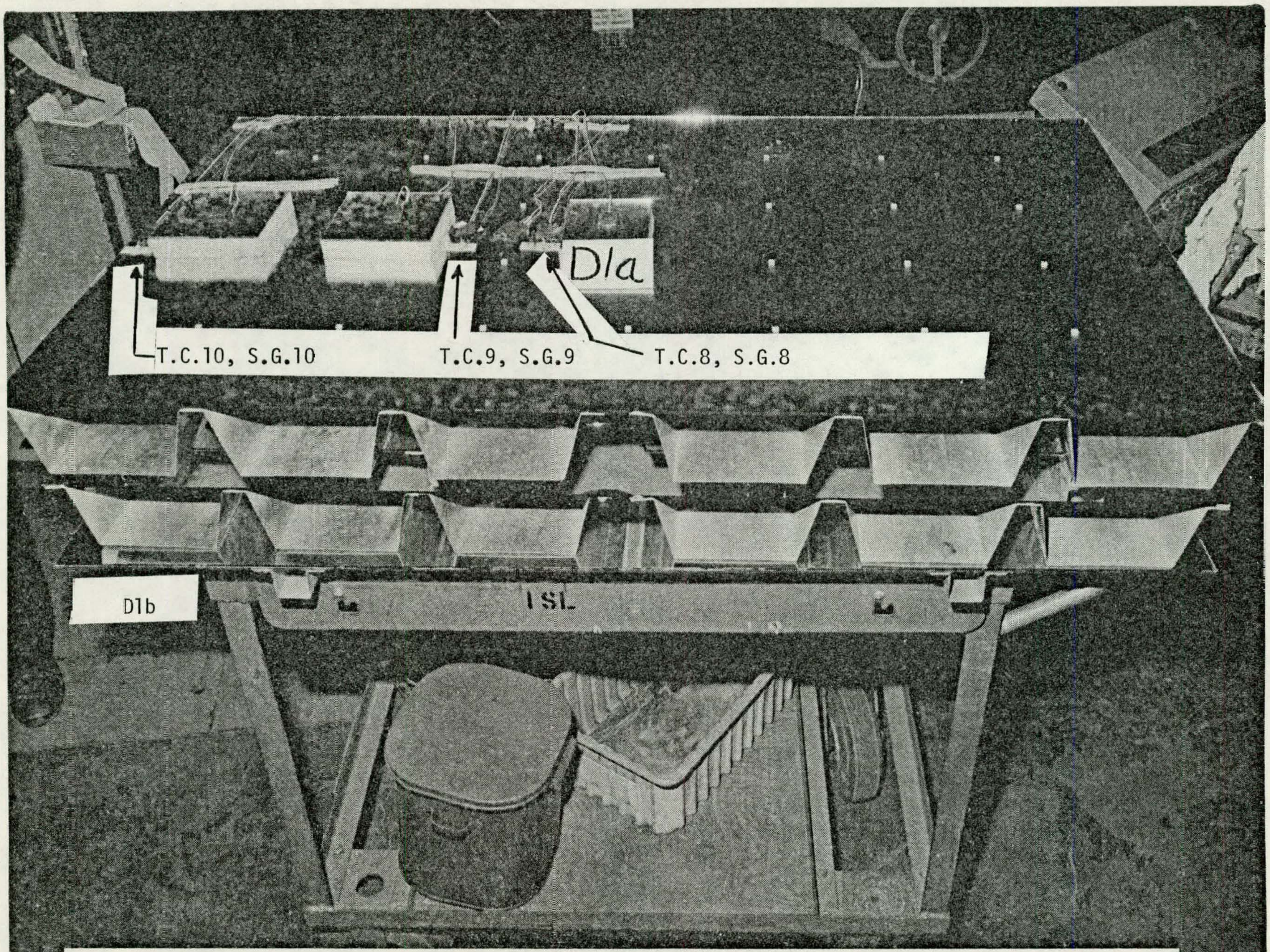


Figure 2.3.4-6 Corrugated Stiffened Panels

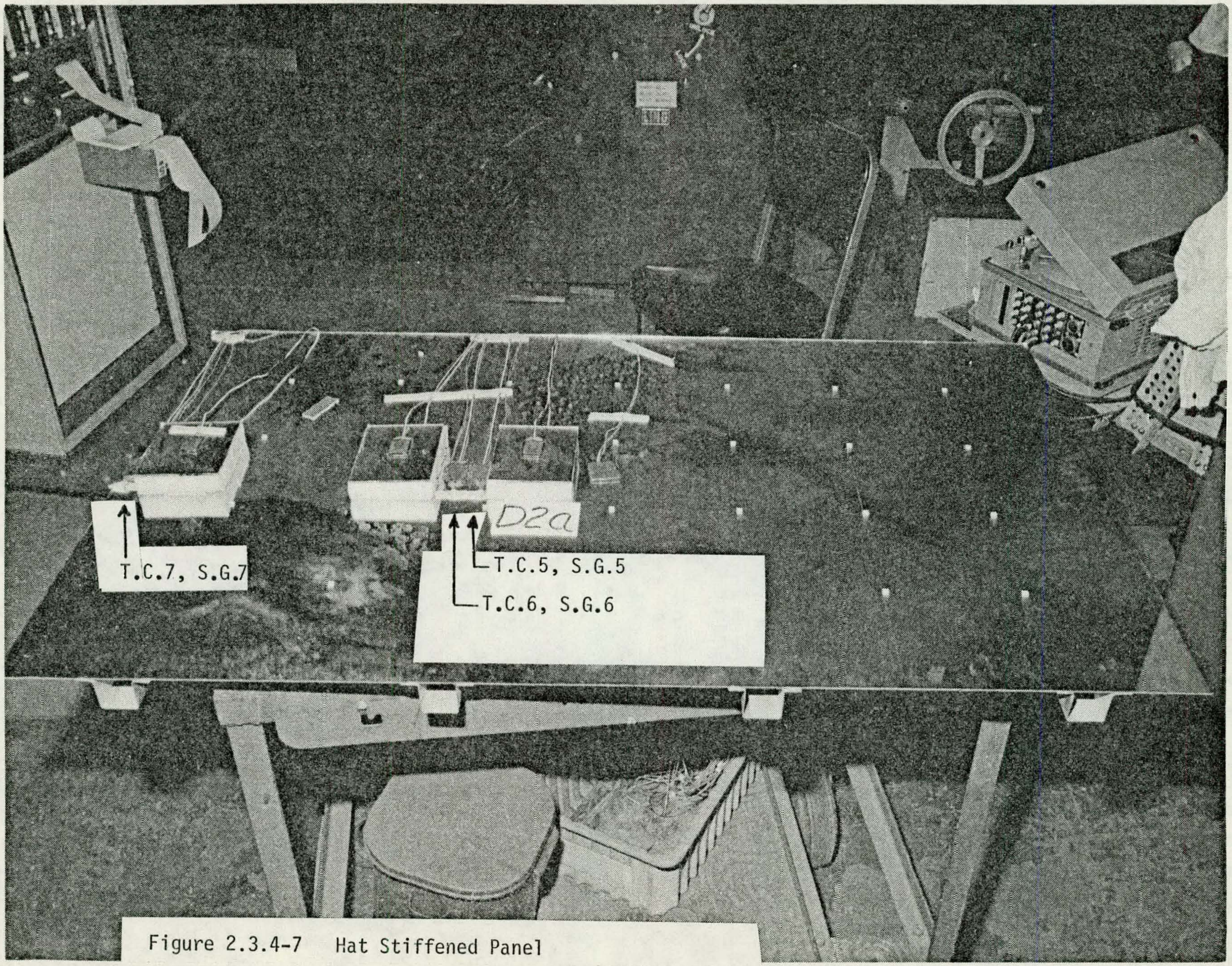


Figure 2.3.4-7 Hat Stiffened Panel

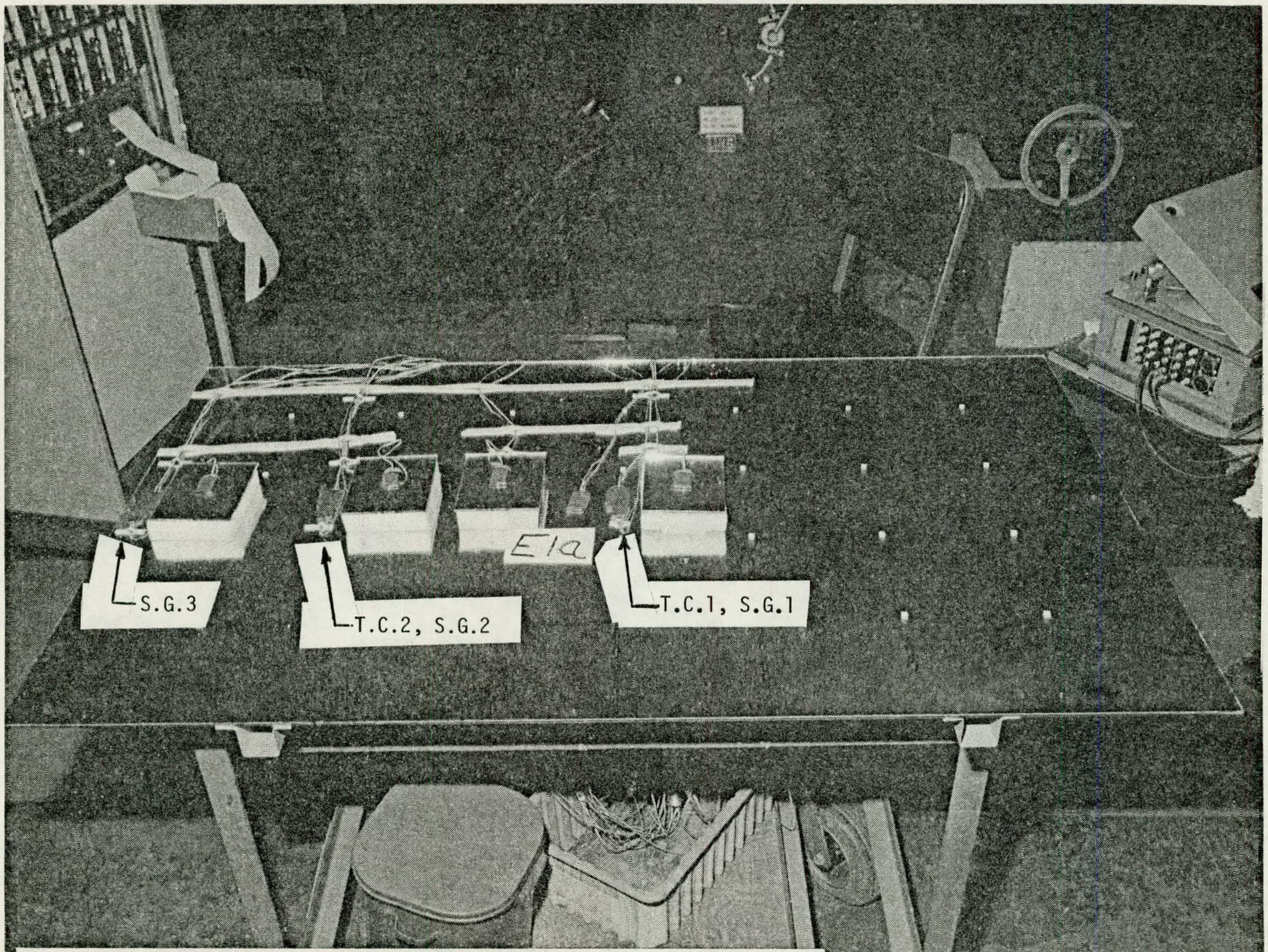


Figure 2.3.4-8 Laminated Panel

adhesive bonding is transparent, but would decrease the specular reflectivity of the copper for backlighting, to decrease light reflected from the array during inverted stow with daylight conditions. The reflectivity of the copper would decrease the maximum temperature and hence induced stresses.

Backlighting tests are recommended for near full-scale reflector panels under long-term exposure, since crack propagation in the glass is a function of time-at-stress.

2.3.6 Production Methodology Tests

Method/Facility - The MDAC adhesive lab has laminated various thicknesses of glass together using 1XA3504-2 polyurethane adhesive with different methods of pressurization. Pressure rollers, vacuum pressure and presses were used in the laminating process along with different methods of adhesive application.

Specimen Descriptions - Glass panels 1/16" thick by 48" and 3/16" thick by 9" by 48" representing the mirror module configuration, were laminated using a manual pinch roller to apply pressure to the bondline. Lap shear strength data were developed to determine rate of cure of the 1XA3504-2 adhesive.

Results and Conclusions - The 1XA-3504-2 adhesive has 40 psi shear strength within five minutes, which fits into a rapid production assembly line schedule. The pressure rollers have shown that this method is a good concept and will result in acceptable bonded-laminated mirror modules.

Bonding stringer supports with the 1XA3504-2 using a cartridge gun that dispenses and mixes at the same time allows the adhesive application to be completed within the 2-1/2 minute potlife of this material. Within 10 minutes the adhesive has attained a shear strength of 80 psi.

2.3.7 Large Panel Tests

At this time large mirrors have not been fabricated because of the need of pressure rollers 48 inches in width.

2.4 PRELIMINARY DESIGN DESCRIPTION

The heliostat configuration resulting from the trade studies is shown in Figure 2.4.1. The configuration embodies improvements over the initial baseline design in a number of key areas including the mirror module design, elevation actuator type, simplified azimuth drive, an open loop control system based on emerging technology, and a novel pedestal/foundation. A key feature of the configuration is its adaptability to low cost assembly, transportation, and installation without a site factory operation. The laminated mirror modules, each of which measures 1.22 by 3.35 meters (48 by 132 inches) are assembled in groups of six on their respective support structure assembly to produce a reflector assembly which is 3.35 by 7.38 meters (132 by 290.5 inches) in size (Figure 2.4-1). Two of these reflector assemblies are assembled to the main beam at the top of the drive unit to produce a surface of 7.38 by 7.42 meters (290.5 by 292 inches) with a slot of 0.71 meter (28 inches) width down the middle. This gives a reflecting area of 49.0 square meters (528 square feet). Each of the twelve mirrors is laminated of a mirrored pane of 1.52 mm (0.060 inch) thick fusion glass bonded to a pane of 4.76 mm (3/16 inch) thick float glass.

Each of the laminated mirror modules is stiffened with a pair of hat-section stringers which are part of the support structure assembly and are bonded to the glass when the reflector is assembled. Each of the twelve stiffeners is attached to the two cross beams which run the long distance of the reflector assembly. Two diagonal, tapered beams attach the shallow outboard cross beam to the deep inboard cross beam and to the tubular main beam. The diagonal beams tie into the outboard cross beam at two points 4.26 meters (167.9 inches) apart. The support structure of each of two reflector assemblies is bolted to a flange at each end of the main beam, which is a part of the drive unit.

The drive unit consists of an azimuth drive assembly, two linear actuator assemblies, a drag link, a main beam, and the pedestal. Maximum roation in elevation is 190 degrees, obtained with a double jack system which is motor-driven. Maximum azimuth rotation is 540 degrees, obtained with a motor-driven worm gear drive mechanism.

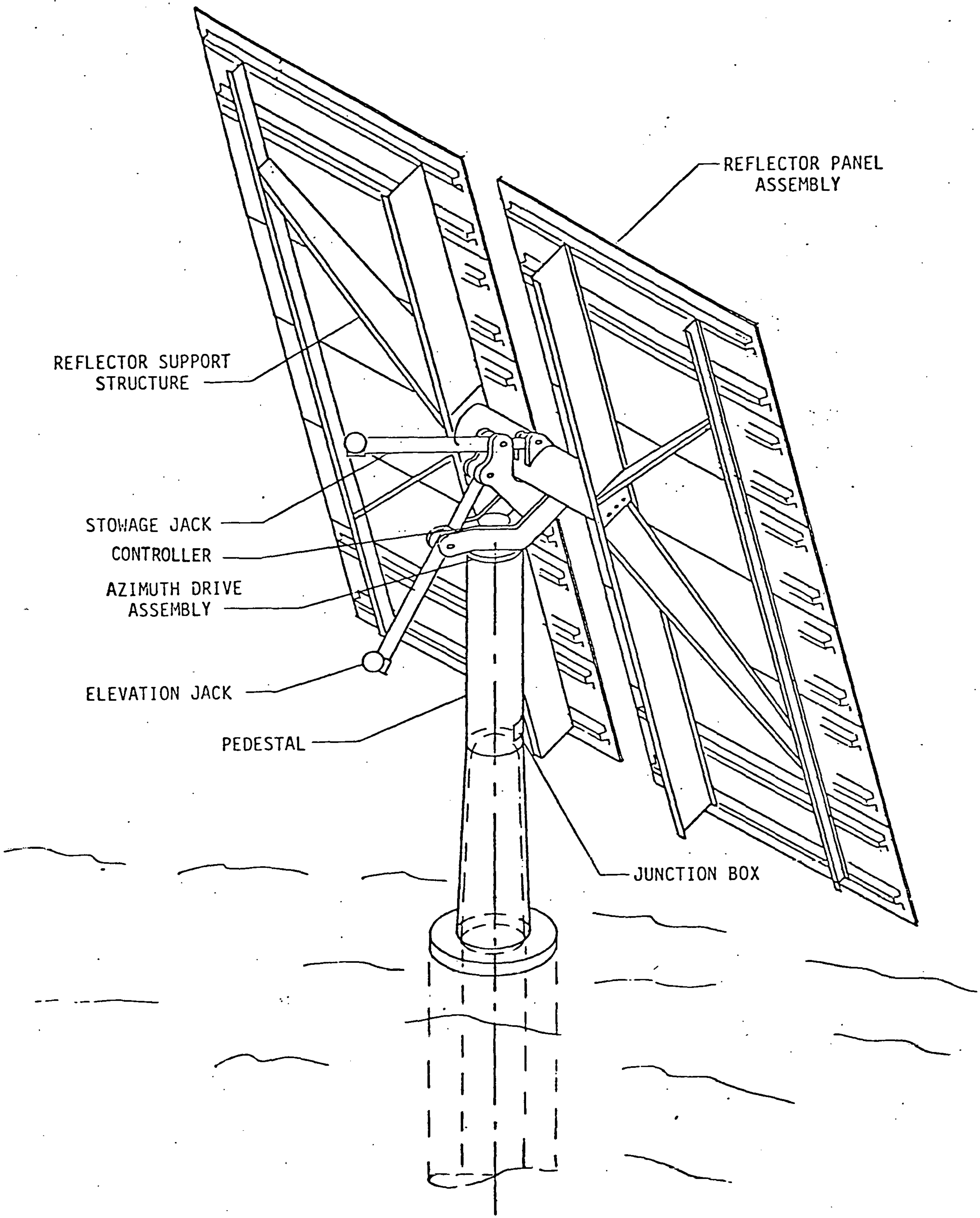


Figure 2.4-1 Heliostat Assembly

The pedestal is a vertical tube 3.18 meters (125 inches) high. At the top, the drive unit is welded to the pedestal and at the bottom the lower 1.12 meters (44 inches) is expanded to give a slight taper for a slip-joint attachment with the rigid foundation. A weight summary for the heliostat is given in Table 2.4-1.

Top Level Control/Field Wiring Description

The heliostat electronics interfaces with the secondary power and data feeders at a junction box located on the side of the pedestal. The power and data cables interface with heliostat cabling through connectors and a circuit breaker. The cabling is routed through the hollow harmonic drive shaft to the heliostat controller, located on the top of the azimuth drive unit. The heliostat controller performs all calculations necessary to operate the heliostat and execute tracking and stowage algorithms. The power cable is routed directly to the motor controllers, located on each motor. The heliostat controller switches the motors on and off to execute the required number of motor revolutions. Feedback of motor revolutions executed is provided by Hall effect sensors on the motors.

The field electronics interfaces with the system master control and the electric power generation subsystem. A schematic (Figure 2.4-2) of the data network illustrates the general flow of both networks. A heliostat array controller may be used as a separate controller, or its functions may be incorporated into the master control. The heliostat array controller commands operating modes, transmits and coordinates the reference time, and requests and receives data from the field on heliostat status.

The heliostat array controller communicates with the heliostats through a series of data distribution interfaces. The data distribution interfaces provide a radial arrangement to minimize cable runs and data rates in the cables feeding the heliostats. Data from the heliostat array controller are received and routed to one of 15 to 20 parallel data feeders, along which are located nominally 24 heliostats.

Table 2.4-1

WEIGHT OF HELIOSTAT

Reflector Assembly		1282 Kg (2827 lbs)
Mirror Module	810 Kg (1785 lbs)	
Support Structure Assembly	459 Kg (1012 lbs)	
Drive Unit Assembly		474 Kg (1045 lbs)
Center Main Beam		126 Kg (278 lbs)
Elevation Drive		105.6 Kg (232.8 lbs)
Jacks	63 Kg (139 lbs)	
Motors	9.5 Kg (21 lbs)	
Drag Link	33 Kg (73 lbs)	
Azimuth Drive		242 Kg (534 lbs)
Housing	158 Kg (348 lbs)	
Harmonic Drive Kit	51.5 Kg (113.5 lbs)	
Motor	8.6 Kg (19 lbs)	
Turret Bearing Retainer	13.3 Kg (29.3 lbs)	
Turret Bearing	3.2 Kg (7 lbs)	
Pedestal		139 Kg (306 lbs)
Foundation		5706 Kg (12,579 lbs)
Concrete	5478 Kg (12,076 lbs)	
Steel Reinforcement	194 Kg (428 lbs)	
Steel Form	34 Kg (75 lbs)	
Heliostat Controller	TBD	
Field Wiring	N/A	

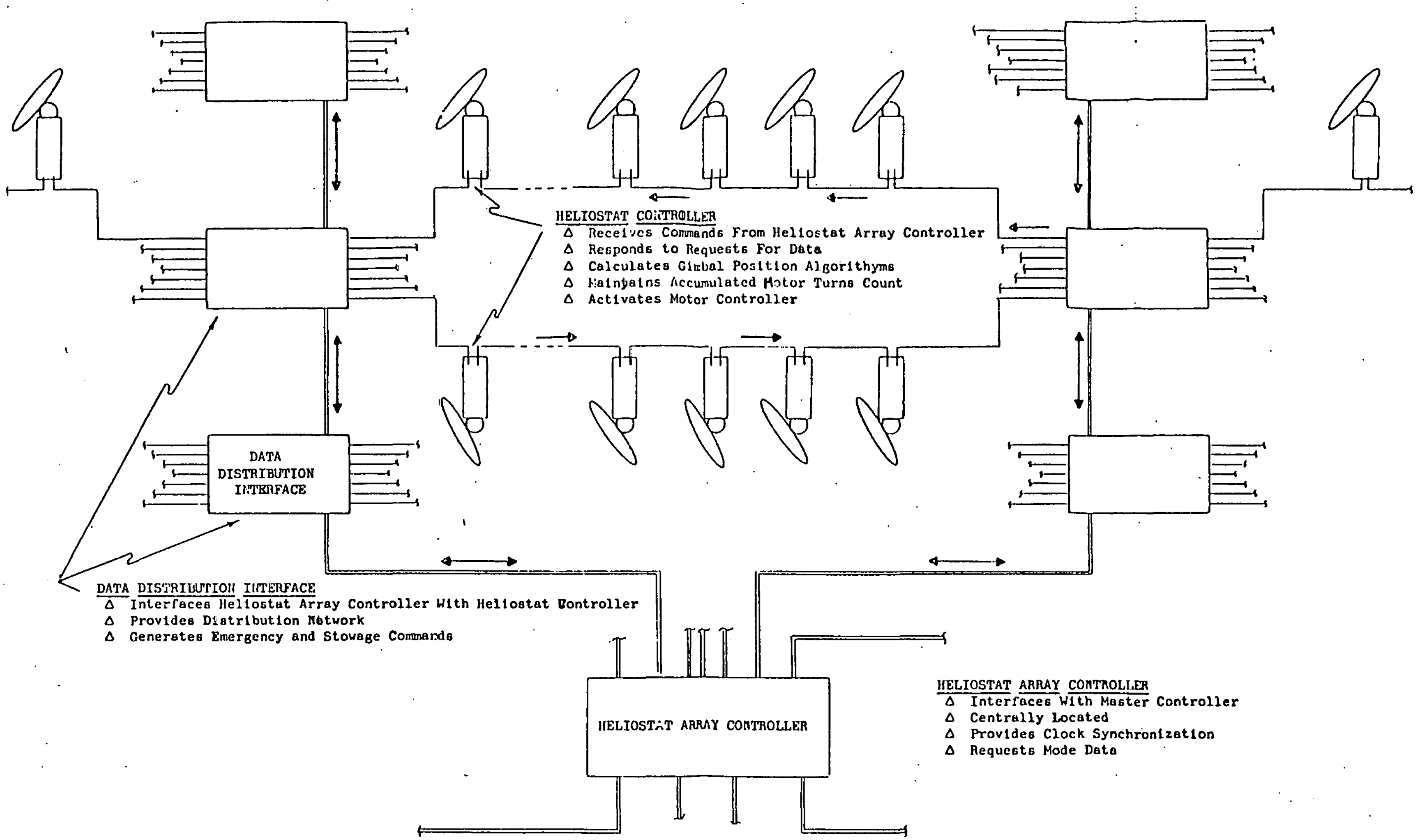


Figure 2.4-2 Data Distribution Network

All of the data links utilize fiberoptics. The fiberoptics data link provides a nearly noise-free environment, eliminates the need for line drivers/receivers, and takes advantage of major cost reductions which can be reliably projected for the near future.

The secondary data feeder connects each heliostat on the line in a series hookup. Data received by a heliostat controller are decoded and, if addressed to the heliostat,the data are retained and a message relayed onto the next heliostat,and hence to a data distribution interface at the end of the line. If the data were not addressed to the heliostat, the message is relayed to the next heliostat.

The power distribution is similar to that of the data. Power from the electric power generation subsystem is transmitted in a radial net to field transformers. Two to three transformers are located on each primary power feeder.

The transformers are collocated with the data distribution interfaces. The transformers reduce the 4160 volt primary power to the 480 volt secondary feeder voltage.

The secondary feeders connect the heliostats in a daisy chain (through wiring with power tapped off for each heliostat). The chain is connected on each end to a transformer so that a failure of a transformer does not result in complete loss of power to any heliostat.

The fiberoptics secondary feeders and the secondary power feeders are in the same cable.

The heliostats are capable of operating independent of the data network, with the exception of the commanding of operating modes and updating of the time calculations. Hence, a failure of the data network would not result in the immediate shutdown of the affected portion of the heliostat field.

Prelim Design Descr

2.4.1 Reflector Panel Design Description

In order to facilitate the shipping of large assemblies from the manufacturing facility to the installation site, the reflector has been designed that it can be built in two parts. Each identical reflector panel assembly is 7.38 by 3.35 meters (290.5 by 132 inches) in its long directions and measure 0.524 meter (20.65 inches) in maximum thickness. Two assemblies are connected together by the main beam at the installation area. This connection is made with bolts, and alignment is obtained with tapered close-tolerance holes and proper bolt placement and torquing. A detailed weight breakdown of this assembly is presented in Table 2.4.1-1.

2.4.1.1 Mirror Module - Each mirror module is made up of laminated glass as shown in Figure 2.4.1.1-1. The front sheet is a 1.52 millimeter (0.060 inch) thick pane of Corning fusion glass which is mirrored on its inner face. The mirror surface consists of chemically-deposited silver, over which copper is flash-deposited. The sheet weighs 16.2 kilograms (35.7 pounds).

The back sheet is 4.76 mm (3/16 inch) thick float glass. It weighs 50.7 kilograms (111.7 pounds). The two glass sheets are bonded together with a polyurethane adhesive (3M 1XA 3504) which weighs approximately 0.62 kilogram (1.36 pounds) per mirror module. The bonding technique must assure edge sealing.

Each mirror module is supported by two sheet steel hat-section stiffeners, which are actually part of the support structure and are bonded to the glass laminates at assembly. The difference in thermal coefficient of expansion between glass and steel creates thermal stresses and deflections in the glass and steel when the heliostat is operating at a temperature other than the assembly bonding temperature. These stresses and deflections are in addition to those due to winds and gravity which have been calculated using accepted engineering procedures. The thermal stresses and deflections (rotations) have been calculated by using a technique developed and proven at MDAC. A summary of the maximums for the design is presented in Table 2.2.2-1, Column 8. The weight of each item making up the mirror module is shown in Table 2.4.1-1.

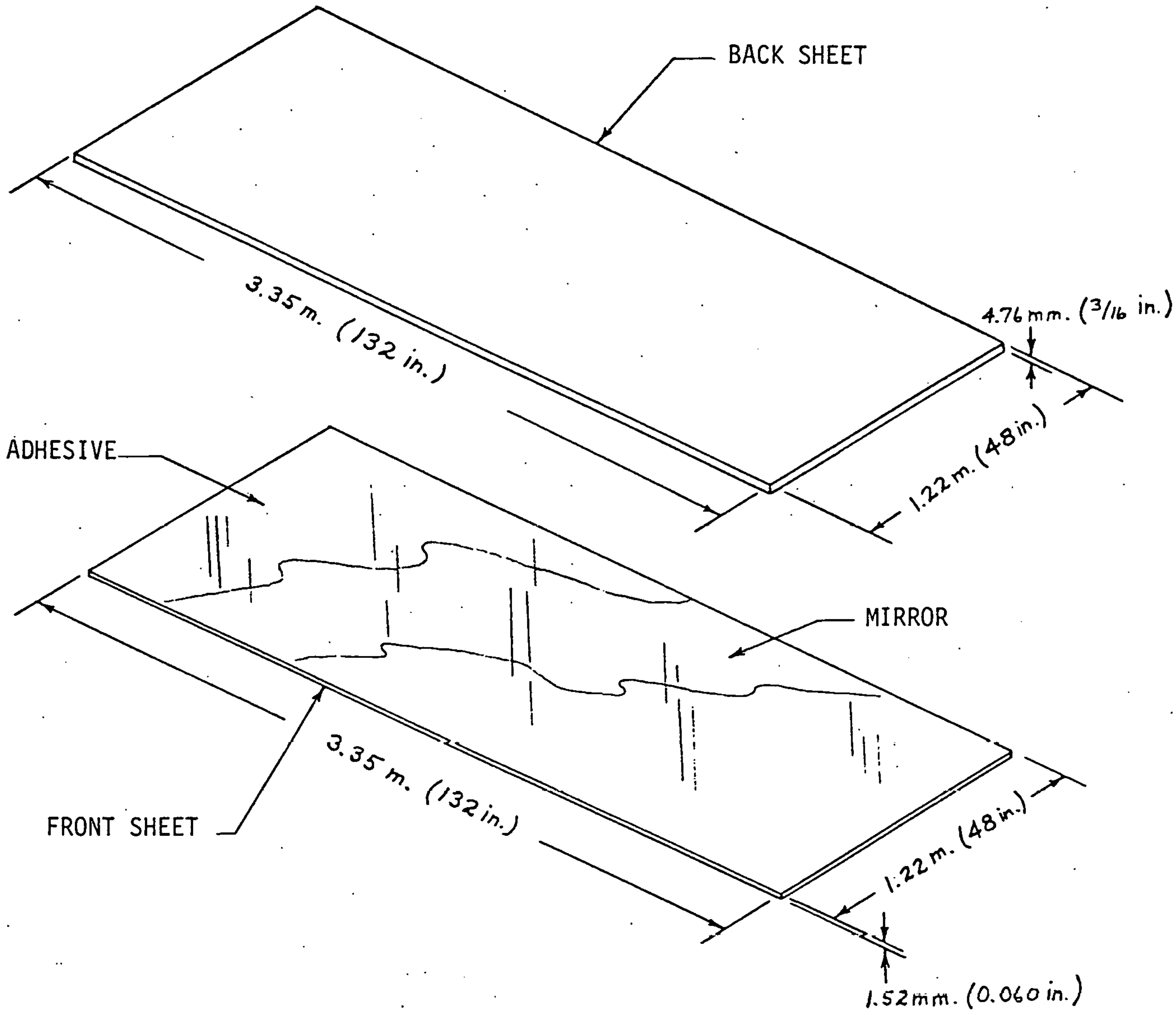


Figure 2.4.1.1-1 Mirror Module

Table 2.4.1-1

Detailed Weight Breakdown of Reflector Panel Assembly

Part Name	Size and Material (Inches)	Wt. Per Unit (Lb)	No. Per Heliostat	Total Weight (lb)
Mirror Front Sheet	0.060 x 48 x 132, Fusion Glass	35.74	12	428.82
Mirror Back Sheet	3/16 x 48 x 132, Float Glass	111.67	12	1340.06
Adhesive for Glass	t = 0.005, A = 48 x 132, 3M 1XA3504	1.36	12	16.35
TOTAL for Mirror Module				1785.23 •
Hat-Section Stringers	A = 0.352, L = 130, 16 Ga. Galv. Steel Sheet	13.76	24	330.20
Outboard Cross Beam	A = 0.517, L = 285, 18 Ga. Galv. Steel Sheet			
Inboard Cross Beam	A = 1.928, L = 285, 14 Ga. Galv. Steel Sheet	44.92	2	89.84
		163.25	2	326.50
Diagonal Beam	A = $\frac{1.864}{0.911}$, L = 110, 14 Ga. Galv. Steel Sheet	45.52	4	182.10
Joint Fitting	1/4 x 12 x 32.1, Galv. Steel Sheet	41.45	2	82.90
TOTAL for Support Structure				1011.54 •
Adhesive for Assembly	t = 0.150, A = 1.5 x 130, 3M EC3532	1.26	24	30.19 •
TOTAL for Reflector Assy				2826.96 ←

The mirror modules are assembled in groups of six, with a gap of 12.7 mm (0.50 inch) between each to produce a reflector assembly. Two reflector assemblies are subsequently joined by bolting to the center main beam, giving a reflector surface of 49.0 square meters (528 square feet). A mirror surface in the central slot area, between the two reflector assemblies, is cost effective, but is not included in the present design, pending evaluation of wind tunnel test data showing the effect of the additional mirror area on heliostat loads.

- Glass Type Selection - In order to achieve high performance at low cost, glass with a high degree of flatness and with high transmission properties over the solar spectrum is required. Because of its high absorption characteristics, iron oxide content in the glass must be kept to a minimum. For these reasons, Corning Fusion sheet glass ($<$0.05 wt.%Fe), low iron float glass ($\sim$0.05 wt.% Fe) and clear float glass ($\sim$0.08 wt.%Fe), were investigated. Corning Fusion glass was selected because of its high reflectance properties (Table 2.4.1.1-1), its adequate flatness (Table 2.4.1.1-2), and reasonable costs. Although low iron float is flatter, and the extrapolated value of reflectance efficiency after silvering at a glass thickness of 1.5 mm (0.060 inches) approaches Fusion glass, it cannot be made in that thickness. Currently, the thinnest float glass available is 2.1 mm (0.083 inches) thick which would lower the extrapolated reflectance efficiency to 92%. In addition, float glass manufacturers are reluctant to produce low iron float.

- Glass Thickness Selection - Although Corning sheet glass per pound is more expensive than float, the cost per square foot is lowered by producing the sheet as thin as possible for increased performance but still maintaining adequate hail resistance, handling capabilities, and stiffness under wind and thermal loads.

TABLE 2.4.1.1-1

TOTAL REFLECTANCE EFFICIENCY OF MIRRORS MADE FROM SELECTED GLASSES

Specimen No.	Glass Type	Reflectance Efficiency at Selected Thickness			
		1.5(0.060")	2.1(0.083")	2.4(0.043")	3.2(0.125")
	Corning Fusion Glass	95%(1)			
1	Low Fe Float	94%(2)			92%
2	Low Fe Float	94%(2)			92%
3	Low Fe Float	94%(2)			92%
120-1	Ford Clear Float	90%(2)	89%		
120-2	Ford Clear Float	91%(2)	90%		
120-3	Ford Clear Float	91%(2)	90%		
111-1	PPG Clear Float	91%(2)		88%	
111-2	PPG Clear Float	91%(2)		88%	

NOTES: (1) Paper presented at ERDA Concentrating Solar Collector Conference, Georgia Institute of Technology, Atlanta, Georgia, Sept 26-28, 1977

(2) Extrapolated data using curve in Paper presented at 1977 Annual Meeting of American Section of the International Solar Energy Society, Orlando, Florida, June 6-10, 1977.

TABLE 2.4.1.1-2

FLATNESS MEASUREMENTS OF VARIOUS GLASSES AND MIRRORS

USING SCATTEROMETER APPARATUS

GLASS TYPE	MIRROR OR GLASS	THICKNESS IN nm	RMS SLOPE ERROR IN mrad
EDMONDS λ/10 OPTICAL FLAT	GLASS		0.059
PPG CLEAR FLOAT	MIRROR	3.2 (0.125 in.)	0.074
PPG LOW IRON FLOAT	MIRROR	3.2 (0.125 in.)	0.085
PPG CLEAR FLOAT	GLASS	3.2 (0.125 in.)	0.144
FORD CLEAR FLOAT	GLASS	3.2 (0.125 in.)	0.146
PILKINGTON FLOAT NO. 3	GLASS	3.2 (0.125 in.)	0.188
FORD CLEAR FLOAT	MIRROR	3.2 (0.125 in.)	0.191
CHEM-COR SHEET (CORNING FUSION TYPE GLASS)	GLASS	1.5 (0.060 in.)	0.230
SCHOTT B270 SHEET	GLASS	3.0 (0.188 in.)	0.290
PILKINGTON FLOAT NO. 2	GLASS	3.2 (0.125 in.)	0.315
PILKINGTON FLOAT NO. 1	GLASS	3.2 (0.125 in.)	0.350
LOF SOLAR 90 SHEET	MIRROR	3.2 (0.125 in.)	0.560
LOF SOLAR 90 SHEET	GLASS	3.2 (0.125 in.)	1.300

A thickness of 1.5 mm (0.060 inches) was selected but hail, thermal cycle, and stiffness tests have to be performed to ensure design reliability. These tests are recommended for Phase II.

- Protection - Laminated mirrors traditionally have been thought of as offering the maximum protection for mirrors, i.e., glass on both sides. The recommended configuration does not use a mirror backing paint. The urethane adhesive appears to give good protection to the mirror. However, the salt spray tests showed that it is important to ensure that there is an edge seal. Where the adhesive extrudes from the mating surfaces and accumulates at the edges, it appears to provide an adequate seal. The production process must either ensure the adhesive extrusion or provide an edge seal of another form.

2.4.1.2 Support Structure - The reflector support structure must have sufficient strength to withstand combined wind and gravity loads under all operating and stowed conditions. The stiffness in bending and torsion must be sufficient to limit the angular deflections of the reflector panels attached to it to the specified maximum. The structure must resist environmental effects such as rain, snow, temperature changes, dust, humidity, and hail which occur in the field for the specified lifetime. Manufacturing and assembly costs must be low and the subassemblies of the structure must be easily transported from factory site to field location. The configuration of the structure should provide for inverting the reflector during plant shutdown periods.

The reflector support structure selected to meet these conditions is illustrated in Figure 2.4.1.2-1. Each of the laminated mirror modules is stiffened with a pair of hat-section stringers which are part of the support structure assembly and are bonded to the glass when the reflector is assembled.

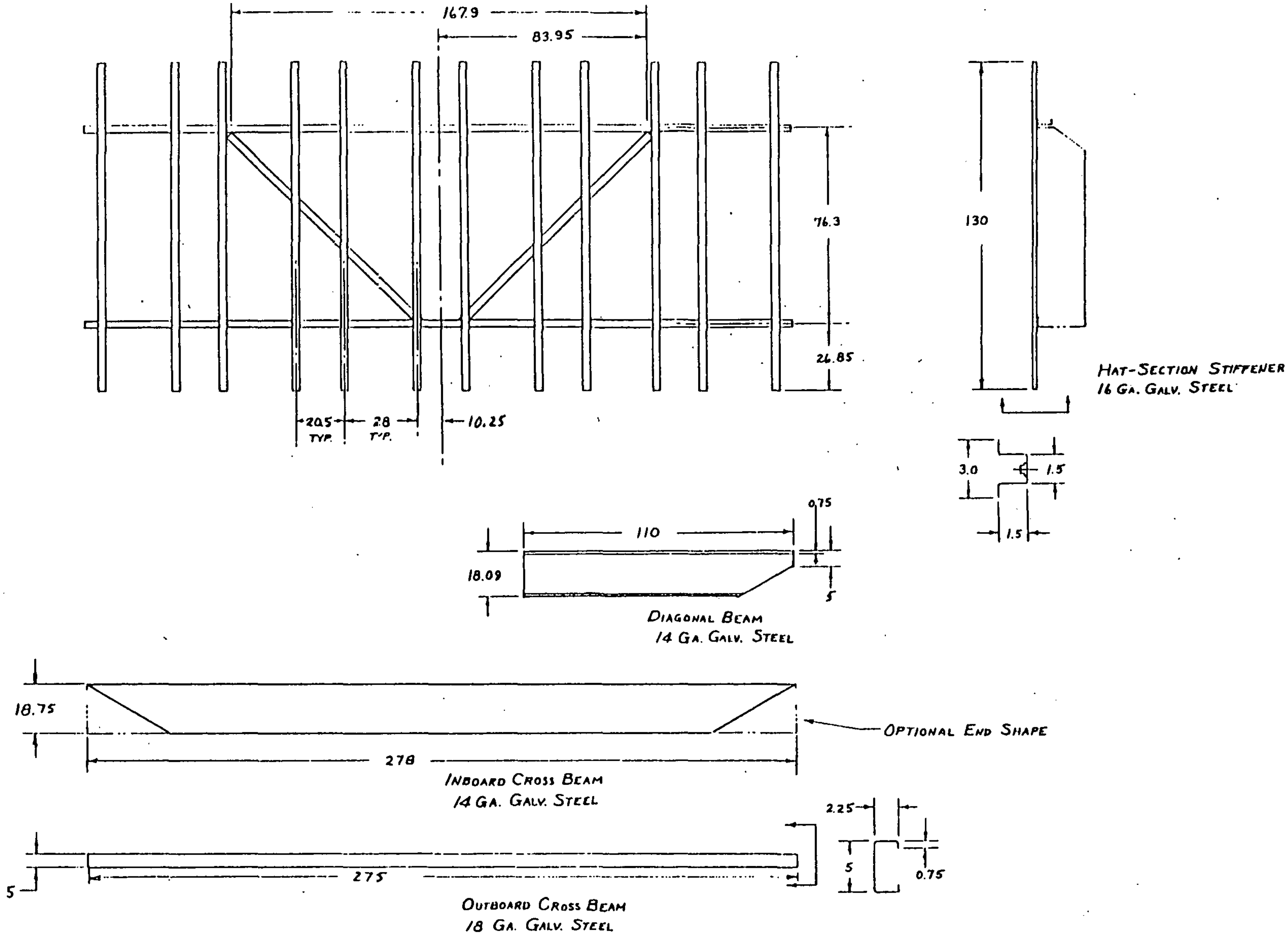


Figure 2.4.1.2-1 Reflector Support Structure Assembly

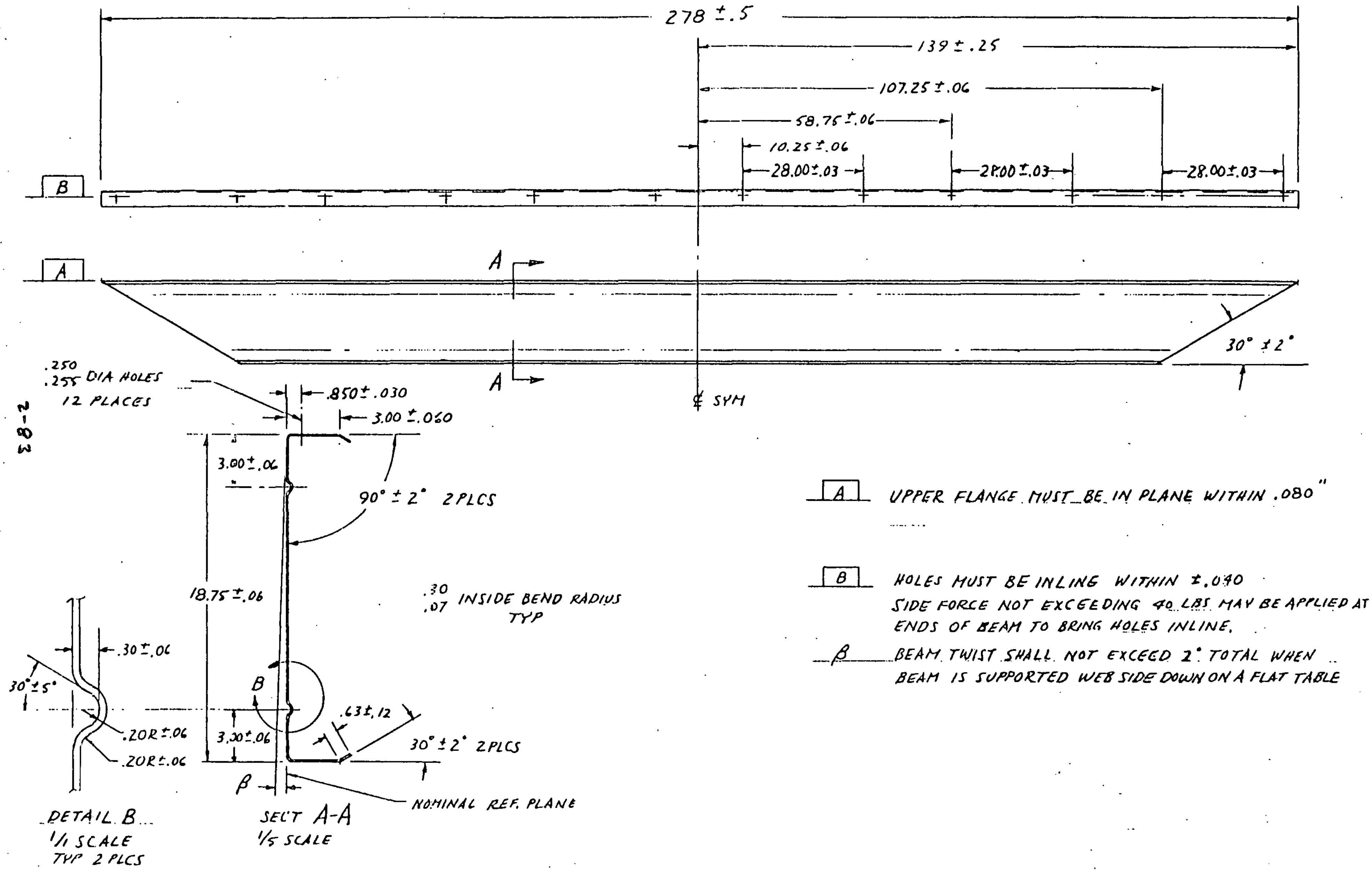


Figure 2.4.1.2-2 Cross Beam—Low Cost Heliostat

The two hat-section stiffeners measure 7.62 cm (3.0 inches) wide and 3.81 cm (1 1/2 inches) high. They are rolled from 16 gage galvanized steel sheet and are 3.30 meters (130 inches) long. The two legs are bonded to the glass back sheet along their full length. If necessary, the entire back surface of the reflector assembly may be painted white to reduce heat absorption during inverted stowage. Each stringer weighs 6.24 kilograms (13.8 pounds).

The twelve hat-section stiffeners are attached to the two cross beams which run the long distance of the reflector assembly. The deep, inboard cross beam is a rolled C-channel of 14 gage galvanized steel sheet, 0.476 meter (18 3/4 inches) deep and 7.62 cm (3.0 inches wide, with 1.59 cm (5/8 inch) wide return flanges, as shown in Figure 2.4.1.2-2. Two beads are rolled into the web of the channel to give it stability. The channel serves to transfer the airloads and dead weight loads on the mirror panels into the main beam. This beam weighs 74.1 kilograms (163.3 pounds).

The shallow outboard cross beam is a rolled channel of 18 gage galvanized steel sheet, 12.7 cm (5.0 inches) deep and 5.72 cm (2 1/4 inches) wide, with 1.91 cm (3/4 inch) wide return flanges. This cross beam is attached to the main beam by diagonal frames (beams) which tie into this cross beam at two points 4.26 meters (167.9 inches) apart. The outboard cross beam weighs 20.4 kilograms (44.9 pounds).

The diagonal outer beams, which connect the outboard cross beam into the main beam, are formed of 14 gage galvanized steel sheet. They may be constant section or tapered in depth, varying linearly from 15.24 cm (6.0 inches) deep at the outboard cross beam to 0.476 meter (18 3/4 inches) deep at the inboard cross beam, where it attaches to the tubular main beam. These diagonal beams are 6.35 cm (2.5 inches) wide with 1.91 cm (3/4 inch) return flanges.

The shear force exerted on the outboard cross beam is carried through the structure by shear in the beam webs and appropriate angle connections at the ends of the diagonal main beams, as shown in Figure 2.4.1.2-3. The angles are spot-welded to the beams and the flanges of the diagonal beams are also spot-welded to the flanges of the inboard cross beam.

The weight of each item of the support structure is given in Table 2.4.1 -1. The stress analysis of the support structure uses the airload distributions of Report MDC G6477, dated September 1976, Page 19, to calculate the airloads on the panels and support structure. Regular engineering procedures, as stated in the latest issue of the Uniform Building Code, have been used to calculate the stresses in each structural item and its allowable stresses.

The accuracy of the surface formed by the hat stiffeners will be held within 2.0 mm (.080 inch) to limit the adhesive bond thickness to a maximum of 3.0 mm (.12 inches) during assembly.

2.4.1.3 Reflector Panel Assembly - The reflector panel assembly is made by bonding six mirror modules to the steel support structure, see Figure 2.4.1.3-1. The mirror modules are supported in position on a fixture, adhesive is applied, and the support structure is positioned over the mirrors so that the hat stiffeners contact the adhesive. The polyurethane adhesive 3M EC 3532 forms a thick bond which levels out structural tolerances and cushions the glass. After the adhesive cures the assembly is ready for shipping. The overall size of the completed panel is 3.35 m (132 inches) by 7.38 m (290.5 inches). The joint to the main beam is accurately controlled so that the panel assembly is positioned within 0.5 miliradians when the bolts are tightened. Rotational position is also controlled within 0.5 miliradians by tapered holes in the frame which are indexed by conical bolts in the main beam assembly.

The completed reflector panel will be held to an angular reflection accuracy of 1.0 mrad over 90 percent of the reflector. Past experience with bonded glass/steel structures (Reference 102) show that 1.0 mrad is achievable.

The stresses and deflections in the laminated glass panel due to temperature changes have been calculated using the technique mentioned previously. This technique provides a simple method for calculating the numbers required to make comparisons between the various configurations being considered for the reflector

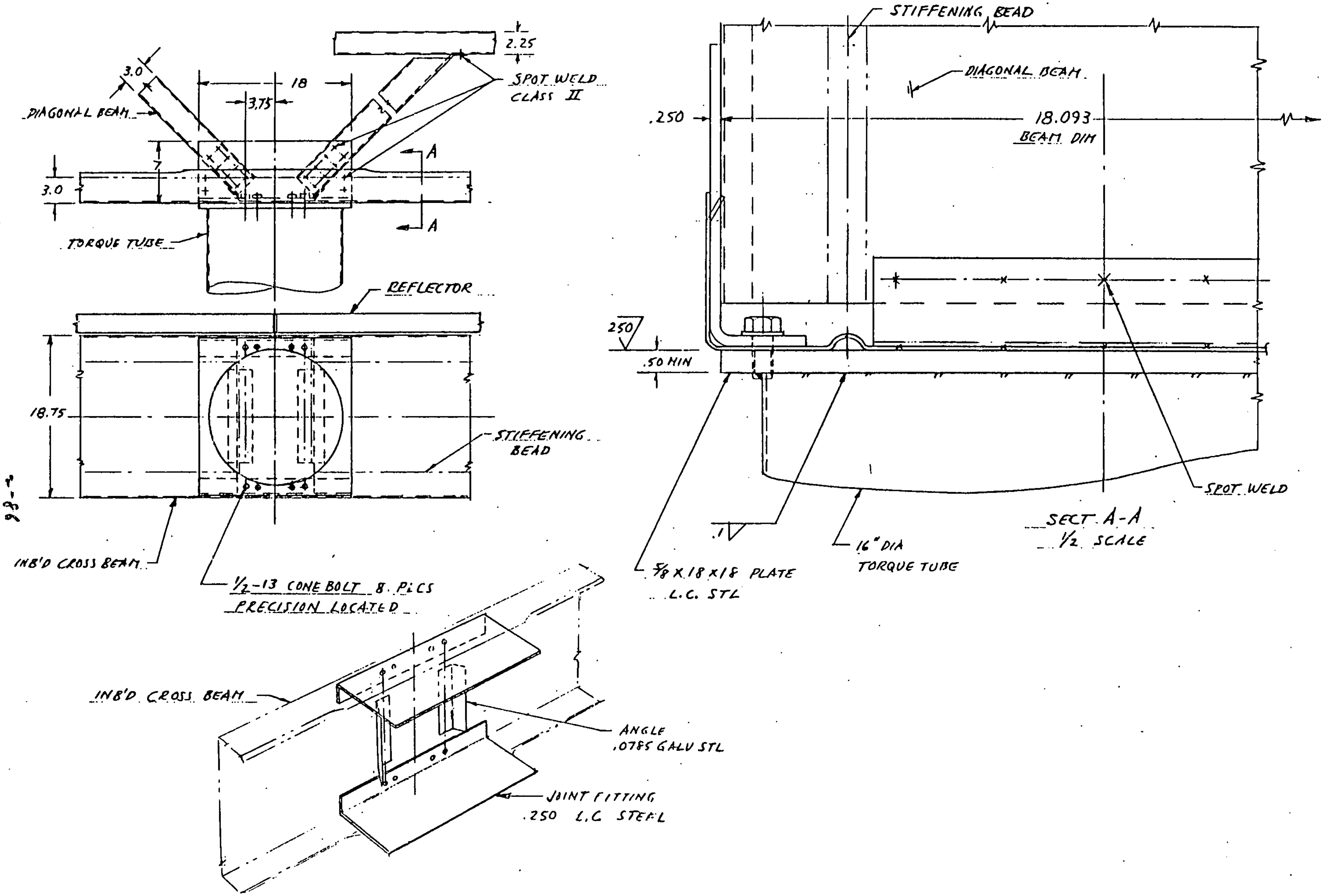


Figure 2.4.1.2-3 Reflector Panel to Torque Tube Joint

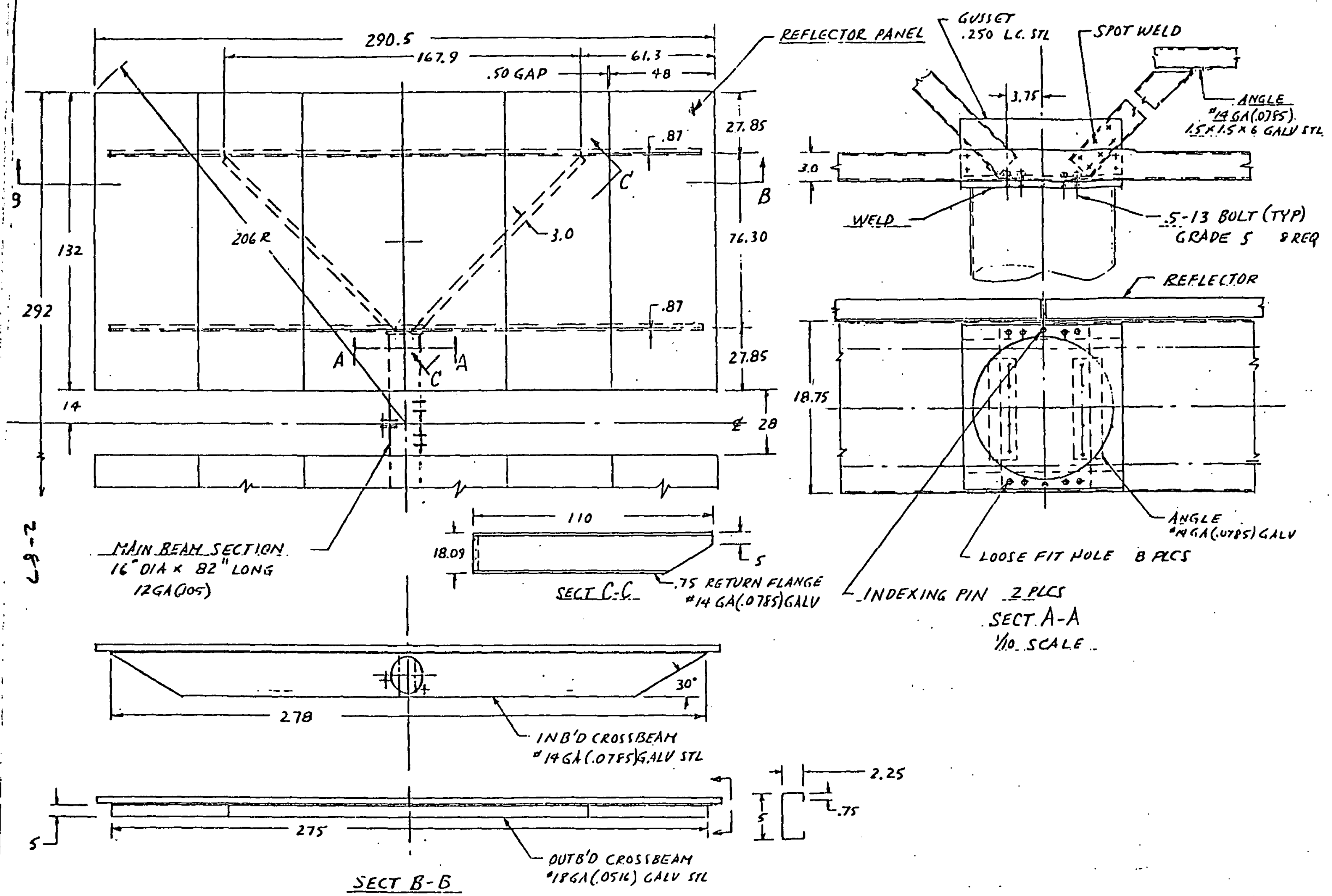


Figure 2.4.1.3-1 Tubular Center Beam—Channel Outer Beam

design. However, it ignores the effects at panel edges and corners, where the shear modulus of the adhesive has an effect on curvature and stress.

The structural analysis of the reflector panel assembly used was the NASTRAN (NASA Structural Analysis) computer program, a finite element program developed for general structural analysis of complicated structures. A mathematical model of the reflector panel assembly was formulated and physical properties assigned to each of the 502 elements and 3238 connections. Loading conditions included wind, gravity, and temperature change plus design-specified combinations of these. The printout from this program includes internal forces, stresses, deflections, and rotations for each element. In addition, plots of the deformed shape of the structure under each loading condition can be obtained. Typical plots are shown in Figure 2.4.1.3-2.

2.4.2 Drive Unit Assembly

The general function of the drive unit assembly is to rotate the heliostat mirror about an azimuth axis and an elevation axis. The drive unit will be operated for solar tracking, emergency slewing, stowage, and for maintenance activities. The major performance requirements are tabulated in Table 2.4.2-1.

The azimuth travel capacity of $\pm$ 270 degrees avoids the need for configurating the drive unit as a function of position in the field. The 180 degrees of travel about the elevation axis is required to permit inverted mirror storage. Excessive operating loads are avoided by being able to stow the mirror in less than 15 minutes in rising wind conditions. This rate capability, with respect to the South field singularity, coupled with appropriate control algorithms, will maintain the necessary beam accuracy during the azimuth turn around of the heliostat.

The calender operating life of the drive unit is 30 years. The daily activity of the drive unit will consist of moving the mirror from a stowed position to acquire the sun, tracking the sun during the day and then returning the mirror to its stowed position at the end of the day. This life will be achieved without any scheduled maintenance activity.

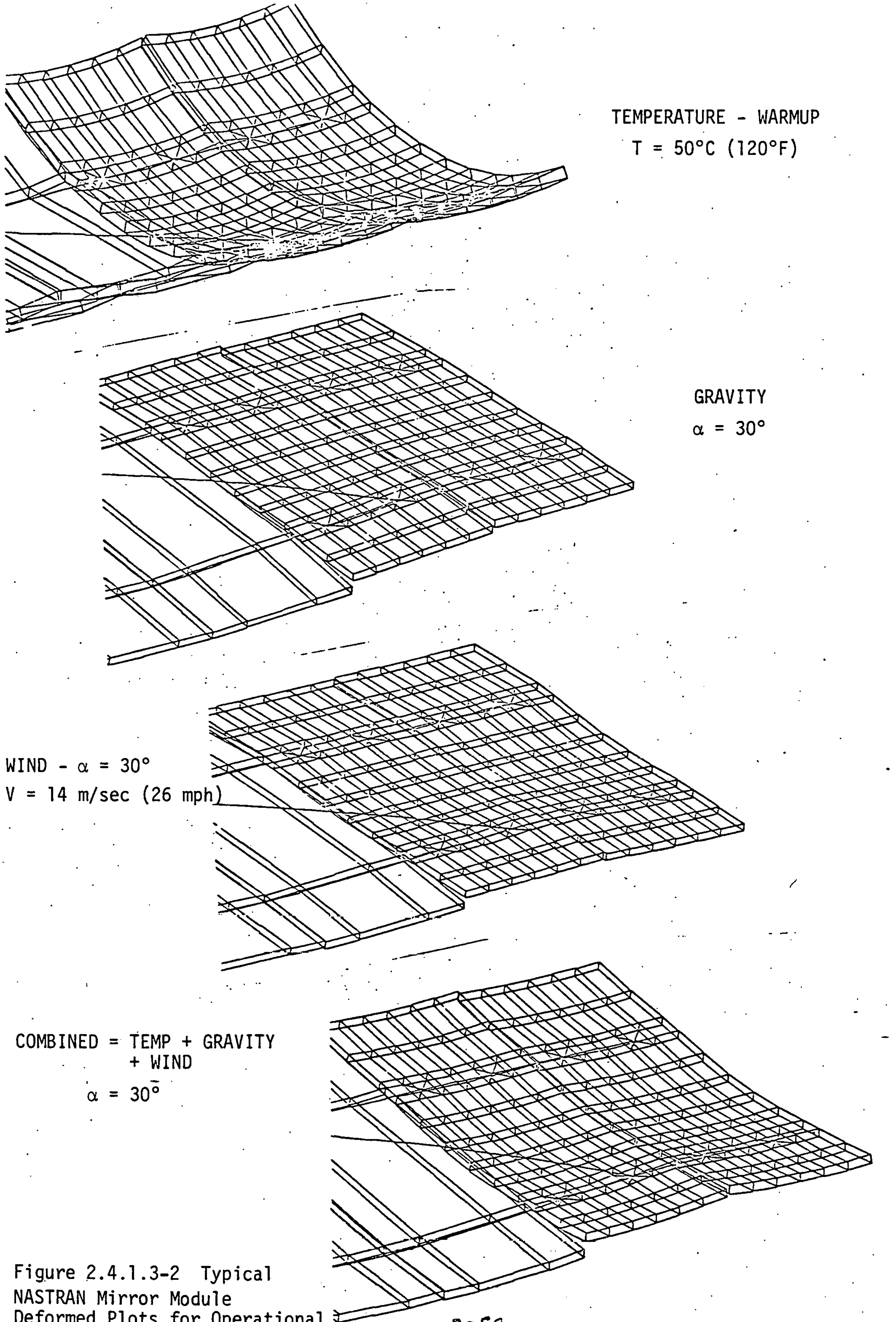


Figure 2.4.1.3-2 Typical NASTRAN Mirror Module Deformed Plots for Operational Conditions

Table 2.4.2-1

DRIVE UNIT REQUIREMENTS

Requirement	Azimuth	Elevation
• Travel	± 270°	0 to -180°
• Maximum Travel Time Under Load	180° in 15 minutes	
• Maximum Static Load	9830 N-m (87,000 in-lbs)	-32,650 N-m (-289,000 in-lbs) @ $\alpha = 0°$
• Maximum Starting Load	10,050 N-m (89,000 in-lbs)	± 13,890 N-m (± 122,900 in-lbs) @ $\alpha = -50°$
• Maximum Running Load	10,050 N-m (89,000 in-lbs)	± 26,790 N-m (± 237,100 in-lbs) @ $\alpha = -50°$
• Maximum Overturning Moment	42,140 N-m (373,000 in-lbs)	
• Backlash/Hysteresis	1 mr	1.6 mr
• Back Drive	None	None
• Calender Life	30 Years	30 Years
• Minimum Stiffners	1.13×10^6 N-m/rad (1.0×10^7 in-lb/rad)	1.516×10^6 N-m/rad (1.342×10^7 in-lb/rad)

The drive unit assembly has been designed to meet the above general requirements as well as those of Specification 001. The design is shown in Figure 2.4.2-1. The major components of the drive unit are an azimuth drive assembly, two linear actuator assemblies, a drag link, a torque tube, and the pedestal. Detailed discussions of these components are presented below.

2.4.2.1 Elevation Actuators - Two linear actuators acting in conjunction with the drag link cause the main beam assembly to rotate about the elevation axis. Each actuator must have the capacity to rotate the torque tube 90 degrees, to satisfy the requirement for a maximum travel of 180 degrees. While the two actuators are identical, one is used daily as a tracking actuator, and the other, the stowing actuator, is used occasionally, possibly 30 times a year, when inverted storage may be required. The stowing actuator is preloaded into a structural stop, when the sun is being tracked, to eliminate its backlash from the system.

The actuator performance requirements are tabulated in Table 2.4.2-2. These requirements are based on the actuators operating on a 480.4 mm (18.915 in) torque arm. The actuator, which was designed to meet the above requirements, is made up of two major components; a 186.4 watt (1/4 HP) electric motor, which is discussed in detail in Section 2.4.2.5, and a ball screw jack. The jack is a translating ball nut type, in which the ball nut is attached to the output rod of the jack (see Figure 2.4.2-1). Rotation of the jack's screw causes the nut and output rod to translate. The lead of the screw is 6.35 mm (.25 in).

All of the speed reduction between the motor and the jack's screw is accomplished in a single gear stage which is housed in the jack. The reduction ratio of the gear stage is 106:1 so that the overall speed characteristic of the actuator is .0599 mm (.00236 in) per motor shaft revolution. The actuators will stow the mirror in an inverted position in 14.3 minutes, while operating under a constant load of 58,400 N (13,100 lbs), corresponding to a 50 mph wind load.

ASSEMBLY PROCEDURES

1. CONNECT THE TORQUE TUBE ASSY AND DRAG LINK TO THE AZIMUTH DRIVE HOUSING AS SHOWN IN VIEW C C. DO NOT INSTALL DUST SEALS
2. CONNECT THE TRACKING ACTUATOR TO THE AZIMUTH DRIVE HOUSING AS SHOWN B-B.
3. POSITION THE DRAG LINK SO THAT THE ROD END OF THE TRACKING ACTUATOR IS CENTERED IN THE DRAG LINK CLEVIS
4. CONNECT THE TRACKING ACTUATOR ROD END TO THE DRAG LINK AS SHOWN IN VIEW B-B, SHIMMING ON EITHER SIDE OF ROD END TO KEEP THE TOTAL CLEARANCE TO LESS THAN .005
5. DETERMINE AND INSTALL THE SHIM REQUIRED IN VIEW C-C TO MAINTAIN THE DRAG LINK POSITION RELATIVE TO THE AZIMUTH DRIVE HOUSING WHICH WAS DETERMINE IN STEP 3, TO WITHIN .005
6. CONNECT THE STOWAGE ACTUATOR TO THE DRAG LINK AS SHOWN IN VIEW A-A
7. POSITION THE TORQUE TUBE ASSY SO THAT THE STOWAGE ACTUATOR ROD END IS CENTERED IN THE TORQUE TUBE ASSY CLEVIS.
8. CONNECT THE STOWAGE ACTUATOR ROD END TO THE TORQUE TUBE ASSY AS SHOWN IN VIEW A-A, SHIMMING ON EITHER SIDE OF THE ROD END TO KEEP THE TOTAL CLEARANCE TO LESS THAN .005
9. DETERMINE AND INSTALL THE SHIM REQUIRED IN VIEW C-C TO MAINTAIN THE TORQUE TUBE ASSY POSITION WITHIN .005 WHICH WAS DETERMINED IN STEP 7
10. COMPLETE THE ASSY AS SHOWN IN VIEW C-C.

Figure 2.4.2-1 Layout - Drive Unit Assembly

Table 2.4.2-2
ACTUATOR REQUIREMENTS

• Travel	679.5 mm (26.75 in)
• Maximum Travel Time Under Load	679.5 mm (26.75 in) in 15 min.
• Maximum Static Load	96,100 N (21,610 lbs)
• Maximum Starting Load	30,300 N (6810 lbs)
• Maximum Running Load	58,450 N (13,140 lbs)
• Backlash/Hysteresis	.261 mm (.0085 in)
• Backdrive	None
• Calender Life	30 Years
• Fatigue Life	322 cycles under 28,000 N (6300 lbs)
• Minimum Stiffness	1.313×10^7 N/m (75,000 lbs/in)

The jack incorporates an integral motor mount, so that, with the pinion mounted on the motor shaft, the jack screw is completely housed and all the joints sealed for protection of the rotating parts from the external environment. The jack is grease lubricated and no scheduled maintenance is planned during the 30 year life.

In order to meet this life requirement, a total of 10,000 cycles, as defined in Figure 2.4.2-3, must not cause the actuator backlash/hysteresis combination to increase more than 0.127 mm (0.005 in), including wear in the actuator trunnion bushings and rod end bushing.

The jack assembly does not include position sensing equipment since the control system incorporates the necessary logic to provide complete limit protection.

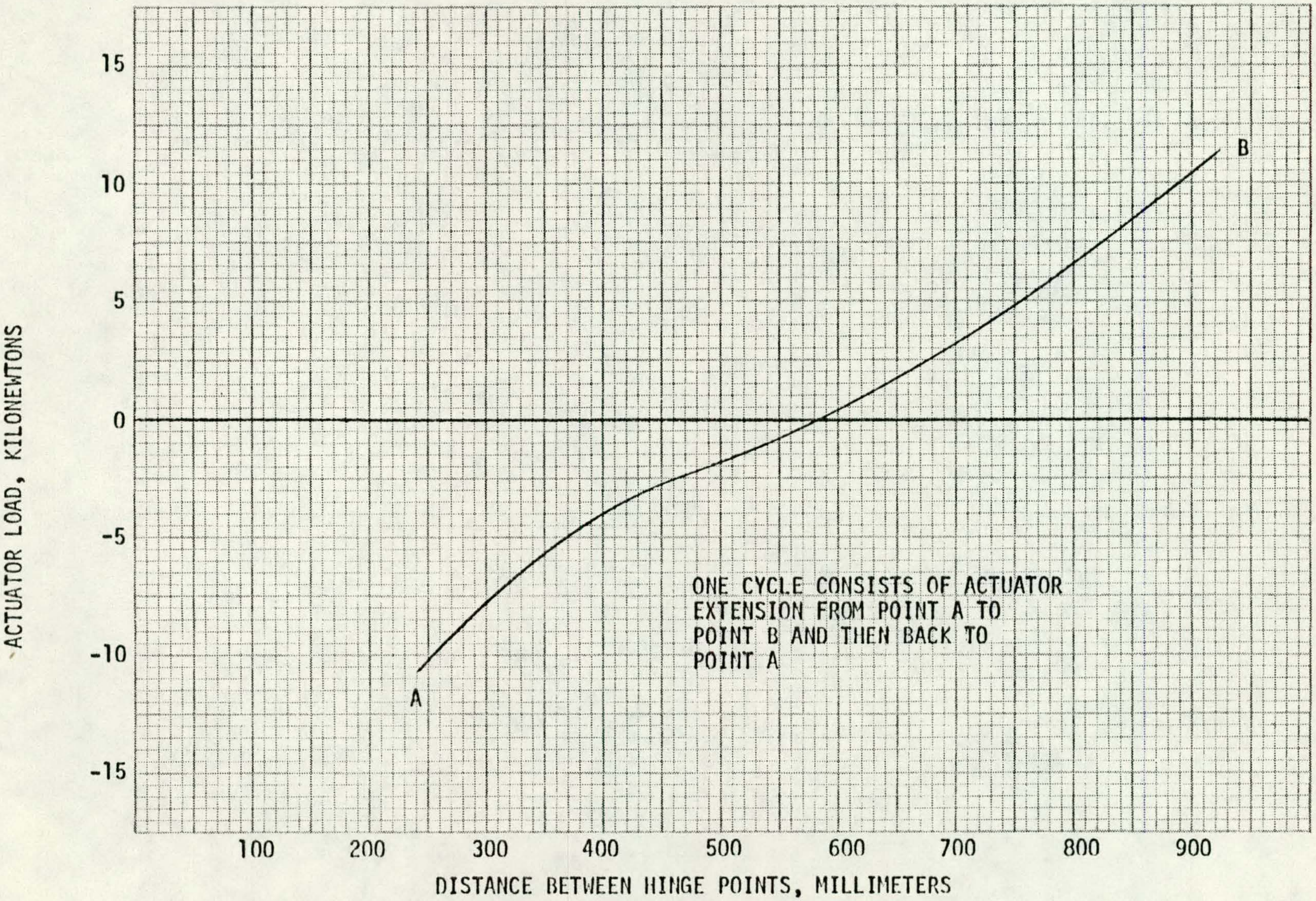


Figure 2.4.2-2 Duty Cycle for Actuator Wear Test

2.4.2.2 Azimuth Drive - The azimuth drive requirements are tabulated in Table 2.4.2-1, and the azimuth drive is pictured in Figure 2.4.2-4. The azimuth drive contains the components of the azimuth drive, provides support for the tracking actuator trunnion hinge pins and provides support for the torque tube and drag link hinge. The housing is machined from a low carbon steel weldment and is zinc plated for corrosion protection.

The azimuth drive is powered by a 480 volt, 3 phase, 249 watt (1/3 HP) induction motor. The motor is discussed in detail in Section 2.4.2.5.

The azimuth drive train is made up of two stages of speed reduction. The first stage is a helicon gear set whose speed ratio is 162:1 and the other stage is a harmonic drive, whose speed ratio is 242:1. The overall speed ratio of the drive train is 39,200:1.

The input helicon gear is mounted on or is integral with the motor shaft and the helicon output gear is mounted on the harmonic drive wave generator shaft. The helicon gear set is self-locking, so the azimuth drive cannot be backdriven.

The major elements of the harmonic drive are the wave generator, the circular spline and the flexspline. The harmonic drive input is rotation of the wave generator. The wave generator distorts the flexspline locally, so that some of the flexspline teeth engage circular spline teeth. Rotation of the points of engagement of the spline teeth cause relative motion of the flexspline to the circular spline. By attaching the circular spline to the pedestal and the flexspline to the azimuth housing, the output becomes rotation of the azimuth housing about the azimuth axis.

The harmonic drive shaft is supported by the wave generator bearing at one end and a small ball bearing at the other, so an Oldham coupling is not required as part of the wave generator.

The turret bearing, upon which the azimuth drive housing rotates, is made up of two outer wire races, two inner wire races and a set of bearing balls. One of the outer races is contained in a counterbore in the housing, and the other outer race is contained in a counterbore in the bearing retainer. The inner

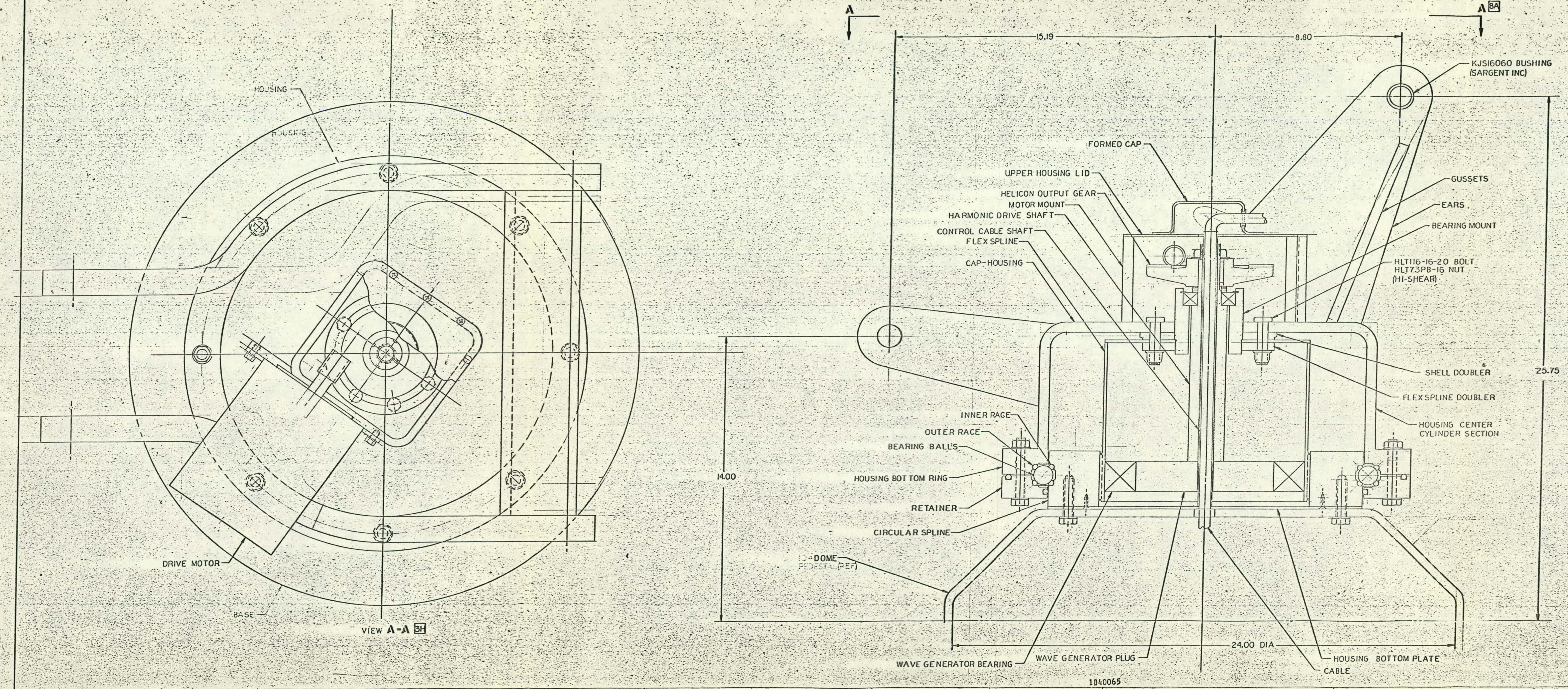


Figure 2.4.2-4 Layout - Azimuth Drive Assembly

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races are supported in grooves in the circular spline. The bearing is preloaded by tightening the retainer attach bolts.

A standpipe extends up into the hollow harmonic drive shaft. It is welded to a flat plate which covers the bottom of the circular spline. This arrangement allows the routing of the electrical cable through the harmonic drive shaft. It also allows the wave generator bearing, circular spline teeth, and flexspline teeth to be lubricated by filling the cavity created by the inner diameter of the circular spline with oil. All other moving components in the drive are grease lubricated.

Performance and life specifications require that the combination of backlash/hysteresis shall not increase more than 0.5 mrad by the application of 10,000 cycles under no load. For purposes of this requirement, a cycle consists of rotating the drive 180 degrees in one direction and then back 180 degrees to the starting point. Accelerated gear life tests for a similar design were performed (Reference 1) which indicated that the performance and life specifications would be met.

2.4.2.3 Main Beam - The central torque tube type main beam connects the two groups of six reflector panels (the reflector assembly) together and ties the reflector to the elevation hinge and the elevating jacks, at the top of the dirve unit assembly. The main beam, illustrated in Figure 2.4.2-5, carries all the airloads and dead weight loads from the reflector to the pedestal as bending, torsion and shear. It is 2.08 meters (82.0 inches) long, of circular cross-section, 0.406 meter (16 inches) in diameter (outside) formed of 12 gage steel sheet, and hot-dip galvanized after fabrication. End plates 15.9 mm (.625 inch) thick are fusion welded to each end and machined flat and parallel to provide accurate location for the reflector assemblies. Tapered holes in the reflector panels and conical bolts provide accurate angular location of the reflector panels relative to each other.

The end plates connect the main beam to each of the inboard cross beams and to each pair of diagonal beams with 12.7 mm (1/2 inch) diameter conical bolts through the web of the inboard cross beam and through the joint fitting at the end of the diagonal beams.

In the slot between the two six-panel reflector assemblies, the main beam has six lugs of steel plate welded to it. Four of these lugs, in line, serve as

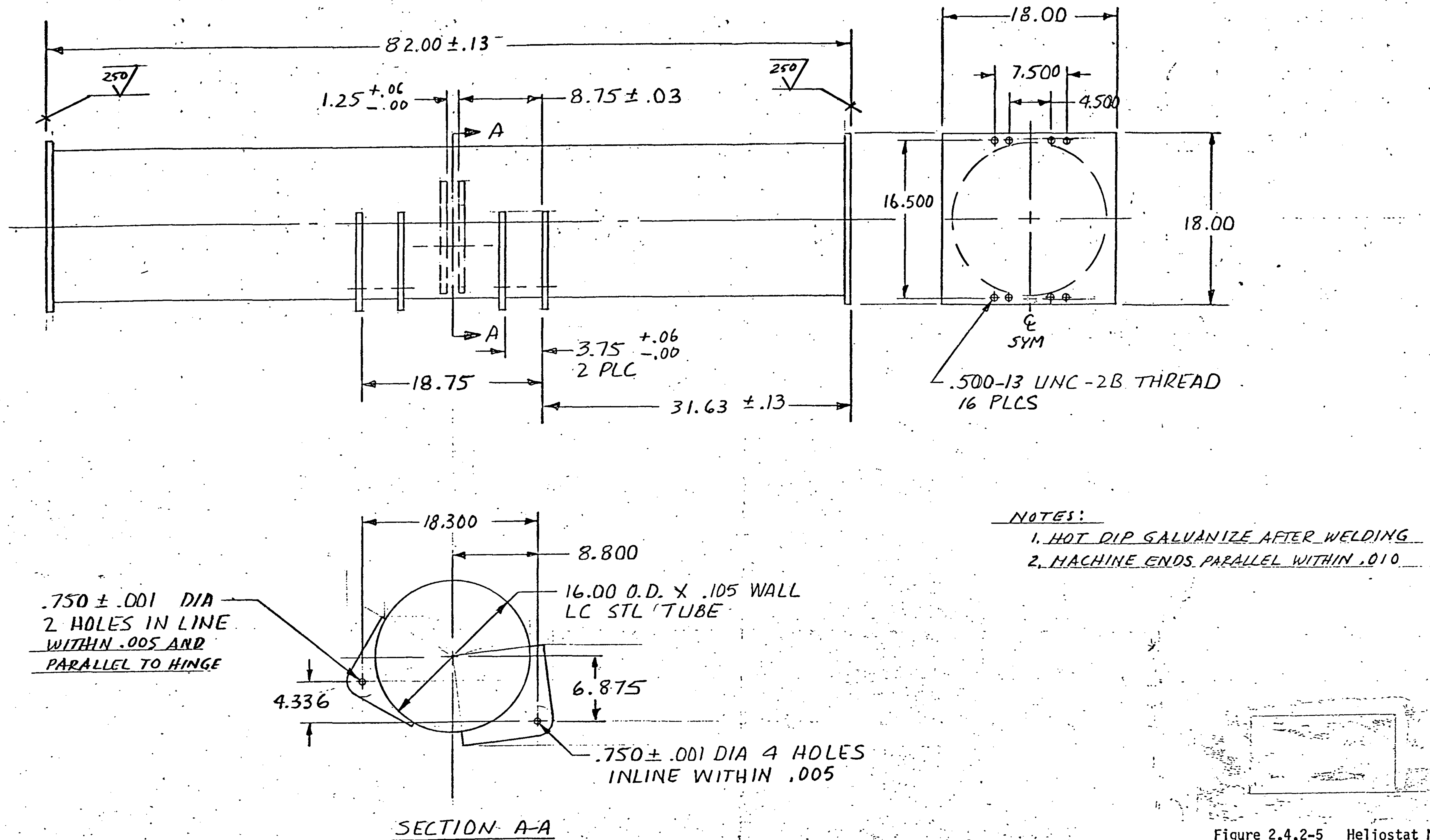


Figure 2.4.2-5 Heliostat Main Beam Assembly

the support of the elevation hinge line. They are attached to the drive housing at the top of the drive unit assembly with two bolt-type pins. The other two lugs are the mount for the stowage jack through which the elevation rotational forces are applied.

2.4.2.4 Drag Link - The function of the drag link is to connect the tracking actuator and the stowage actuator in such a way that they can provide 180 degrees of heliostat rotation about the elevation axis. The drag link consists of a finish machined, low carbon steel weldment and a pair of bushings. Although the raw stock for the weldment weighs 68 Kg (150 lbs), the finished part weighs 33 Kg (73 lbs). The design is shown in Figure 2.4.2-1.

An alternate to the design described above uses a ductile iron casting in place of the weldment. The weight of the casting would be 38.5 Kg (84.9 lbs).

2.4.2.5 Drive Motors - The motors described below provide power to the azimuth drive and the elevation actuators during tracking and slewing operations. The motors operate on 480 VAC ± 10%, 60 Hz, three-phase electrical power, and the motor windings are delta connected. The method of control is triac switching (bang-bang) of the three-phase AC line; switching durations can vary from one three-phase sinusoidal pulse to continuous three-phase sinusoid. The operation of the motors is bi-directional.

The life capability of the motors must exceed 30 years with no scheduled maintenance. The motors must be able to operate 365 days per year, where a typical daily duty cycle is 15 minutes continuous running, 7.5 hours at one three-phase sinusoidal pulse every 2 seconds, and then 15 more minutes of continuous running. The maximum duty cycle is 20 minutes continuous running, then 60 minutes off. The minimum duty cycle is one three-phase sinusoidal pulse every 10 seconds.

The motors must be totally enclosed, weatherproof, and able to operate in any attitude. The motor shaft will be supported by permanently lubricated ball bearings. Twenty-five and four tenths millimeter (1 inch) of shaft at the fan end will be provided for mounting an MDAC-installed shaft turn transducer. The output shaft will have provisions and load capacity for mounting the helicon pinions described in Sections 2.4.2.1 and 2.4.2.2.

The elevation drive motors have a torque requirement greater than 2.00 N-m (17.7 in-lb) at 0 RPM and 1.41 N-m (12.5 in-lbs) at 1500 RPM. The azimuth drive motor has a torque requirement greater than 2.85 N-m (25.2 in-lbs) at 0 RPM and 1.08 N-m (9.54 in-lbs) at 1300 RPM.

It is estimated that the elevation drive motor requirements can be met by a 42 frame motor which has NEMA C torque-speed characteristics and weighs less than 4.76 Kg (10.5 lbs). It is estimated that the azimuth drive motor requirements can be met by a 48 frame motor which has NEMA D torque-speed characteristics and weighs less than 8.62 Kg (19 lbs).

2.4.2.6 Control Sensors - Incremental encoders are mounted at the base of each of the three drive motors to provide control feedback data. The encoder is designed to provide the processor with information concerning the direction and the number of revolutions of each motor.

The incremental encoder is designed with two Hall - effect transducers. A ferrous metal vane mounted on the motor shaft produces an interrupt in each of the transducer's magnetic fields at intervals slightly out of phase depending on the direction of rotation. The sensor exhibits a level shift which latches either of two flip-flops. The latched signals are transmitted to the processor and simultaneously an interrupt signal is provided to inform the processor that one motor revolution has taken place.

The encoder sensors are environmentally sealed in durable plastic casing. Dust and dirty atmospheric conditions produce no damage or inaccuracy due to the magnetic operation of the units.

The encoder has an accuracy to within one motor revolution. This is equivalent to a deflection of 0.144 milliradian in heliostat azimuth and approximately 0.144 millradians in elevation.

2.4.2.7 Pedestal - The support for the heliostat is provided by the pedestal, which is shown in Figure 2.4.2-5. The pedestal is 3.18 meters (125 inches) high to provide clearance with the ground when the reflector is elevated at an angle. It is fabricated of 0.61 meter (24 inches) diameter spiral welded steel pipe with a wall thickness of 2.66 mm (0.1046 inch). The pedestal is hot-dip galvanized after fabrication. The lower 1.12 meter (44 inches) of the length is expanded to produce a slight taper of 11.7 mm diameter per meter of length (0.14 inch per foot) to obtain a wedged, slip-joint attachment with the foundation on installation. A recessed junction box is locaed in the pedestal 1.37 meters (4.5 feet) above its lower end. Underground electrical lines are routed externally from the ground to the box, then through the box and up the inside of the pedestal. The drive unit housing is welded to the top of the pedestal.

A draw pressed dome is fusion welded to the top of the pedestal. A bolt circle in the dome provides a bolted interface to the circular spline in the azimuth drive unit. The dome is made of 9.53 mm (.375 inch) low carbon steel.

The pedestal weighs 294 pounds without the dome. Two critical design conditions were used to calculate the maximum loads. Maximum stresses were figured from these loads using standard engineering processes. These calculated stresses were compared with allowable stresses from the Uniform Building Code to compute positive margins of safety.

2.4.3 Foundation Assembly

To properly anchor the heliostat to the ground, a rigid foundation is required. Stearns-Roger Engineering Company of Denver, Colorado designed a low-cost foundation which would meet the strength and rigidity requirements imposed by the heliostat performance. The design had to be capable of resisting an overturning moment of 7630 kilogram-meters (662,000 inch-pounds) and show a rotation not to exceed 1.3 milliradians at the ground line under a twisting moment of 1003 kilogram-meters (87,000 inch-pounds). The low-cost aspect included a novel slip-joint attachment of the pedestal.

Several types of foundations were considered in this study, and a pile-type foundation with a slip-joint pedestal attachment was recommended, as shown in

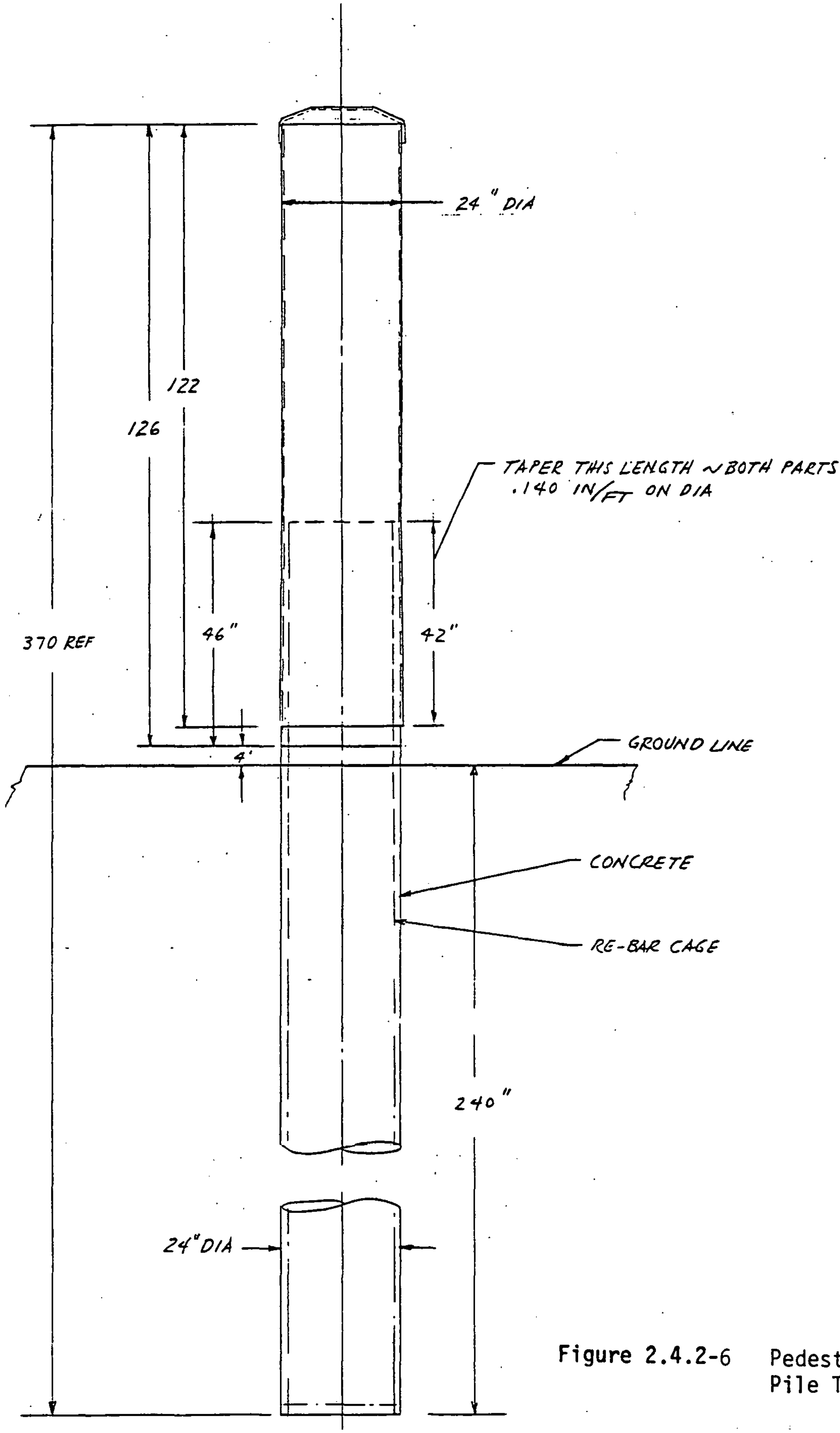


Figure 2.4.2-6 Pedestal - Pile Type I

Figure 2.4.2-6. A 0.61 meter (24 inches) diameter hole, 6.7 meters (22 feet) deep, is drilled into the ground. A prefabricated, circular rebar cage is located in that hole. This rebar cage extends 1.22 meters (4 feet) above the ground. A tapered form, of 15 gage galvanized steel sheet and 1.22 meters (4 feet) long, is slipped over the rebar extension and then the hole and form are filled with concrete. The taper on the form matches the taper at the bottom of the pedestal - 11.7 mm per meter of length (0.14 inch per foot).

The resulting foundation weighs 5706 kilograms (12,579 pounds), of which 5478 kilograms (12,076 pounds) are concrete, about three cubic yards. The tapered form weighs 34 kilograms (75 pounds), the rebar weighs 170 kilograms (374 pounds), and the guide hoops for positioning the rebar weigh 25 kilograms (54 pounds).

2.4.4 Heliostat Electronics

The heliostat electronics subassembly includes:

- Pedestal Junction/Circuit Breaker Box - located on the pedestal and interfaces with the field secondary power and data network.
- Cabling - A single cable takes power to and data to/from the heliostat controller box on the drive unit from the junction box. A second set of cables go from the controller box to the motors/sensors.
- Heliostat Controller - A microprocessor in the heliostat controller does all command calculations. The microprocessor interfaces directly with motor switching network, sensor, and communication link.
- Motors/Sensors - Incremental encoders and switching networks are mounted on the motor shaft.

The heliostat electronics receives signals from the data network and relays messages to the next heliostat in the chain. Open-loop tracking algorithms are used to determine the required heliostat position. The difference between the calculated position and actual position is used as an error signal for turning the motors on/off. The signal from the incremental encoder is used to determine the actual position by counting motor turns. The accumulated turns are stored in non-volatile electrically erasable memory (EAROM); therefore, if power should be lost, the position reference of the heliostat will not be lost.

2.4.4.1 Pedestal Junction/Circuit Breaker Box

The secondary feeder cable enters the pedestal and terminates in a junction box located on the side of the pedestal. The junction box is illustrated in Figure 2.4.4.1-1. The recessed box contains a circuit breaker which joins the incoming and outgoing cables and noninterchangeable fiber optic connectors. On the inside of the pedestal, the circuit breaker is wired directly into the cable leading to the heliostat controller.

An internal protective cover will be required to provide personnel protection from the 480 volt terminations after the wire installations are made.

The cutout will also contain a cover for environmental protection. The cover will be designed to prevent water from flowing into it and will be sufficiently tight to exclude dust and prevent the formation of significant quantities of ice. The box will have a drain hole inside the pedestal to prevent the accumulation of significant quantities of water.

It is important that proper phasing be maintained in the power distribution network. Therefore, cables will be terminated in the factory with crimp or ring terminals which will only connect in one manner (illustrated in Figure 2.4.4.1-1). Also, the fiber optic connectors will be male and female, with the male used for the incoming signal and the female for outgoing to prevent any possibility of reversing.

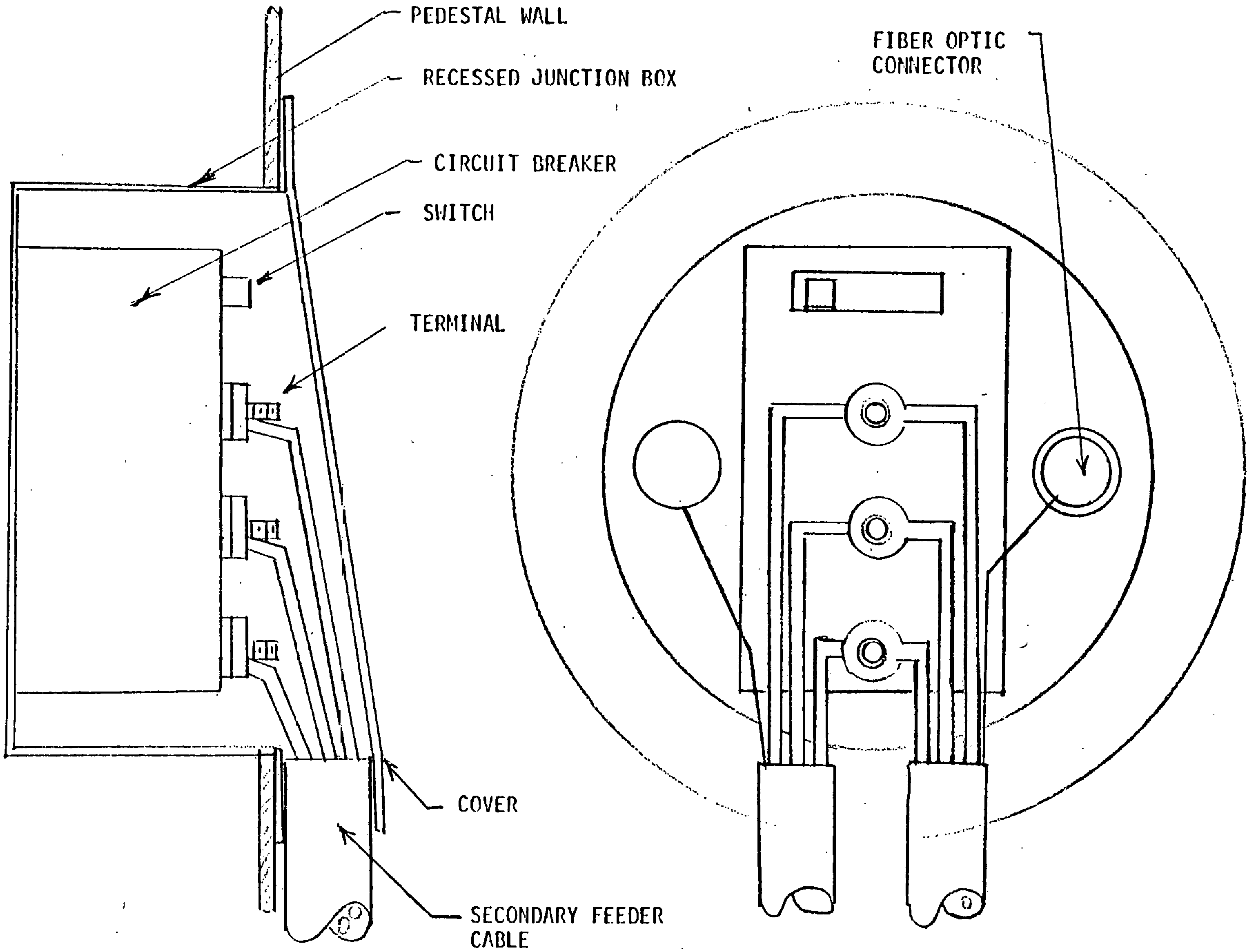


Figure 2.4.4.1-1 Pedestal Junction Box

2.4.4.2 Cabling

The heliostat pedestal wiring consists of 3 conductor, #16 AWG, 480 volt, copper wire with aluminum sheath for power distribution and twin lead optical fiber cable for data transmission. The cable runs from the junction box in the pedestal to the heliostat controller mounted on the drive unit. In order to route the cable past the gimbal axis, a hollow shaft has been designed into the center of the azimuth axis. The cable will be routed through the shaft, thus allowing for rotation and elevation of the heliostat without putting stress on the power cable. To allow for 270° rotation of the azimuth gimbal, a section of cable is left slack inside the pedestal. The cable and other components are completely wired in the factory; hence, the only field wiring required is to connect the secondary feeder to the junction box.

The connectors at the Heliostat Controller end of the cable are single fiber connectors designed to mate with terminals located on the PCB of the Heliostat Controller. The two connectors have irreversible connectors to prevent accidental misconnection.

2.4.4.3 Heliostat Controller

The Heliostat Controller is a microprocessor based unit which interfaces with the Heliostat Array Controller and the motor/sensor system.

The main functions of the Heliostat Controller are to respond to the commands from the Heliostat Array Controller, send information to the Heliostat Array Controller, calculate commands for moving the heliostat from one position to another position, and to keep track of heliostat orientation. Heliostat orientation is determined by counting the number of turns the motor makes. The processor contains a non-volatile memory (EAROM) where the motor counts are kept. Even if the power should fail, the heliostat will not lose the number of motor turns or its reference position.

It is estimated that in the 1985 time period, the required capabilities of the Heliostat Controller will easily be available in a single chip microprocessor. The current trend and demand also indicates that microprocessors will be available with electrically erasable ROM's (EAROM) within the next year or two. The microprocessor and interfaces of the Heliostat Controller are shown in Figure 2.4.4.3-1.

The communication interface consists of a differential line transceiver which receives serial data and transfers parallel data to the processor (the process is reversed for transmitting data). The address bits are decoded in the processor and, if they agree with the address of this heliostat, the message is decoded and executed.

Calculation of equations for control of the heliostats are done in the Heliostat Controller with inputs from the Heliostat Array Controller. Using a transmitted time signal, the Heliostat Controller updates its clock, calculates the sun angles, the gimbal angle required for reflecting the beam onto

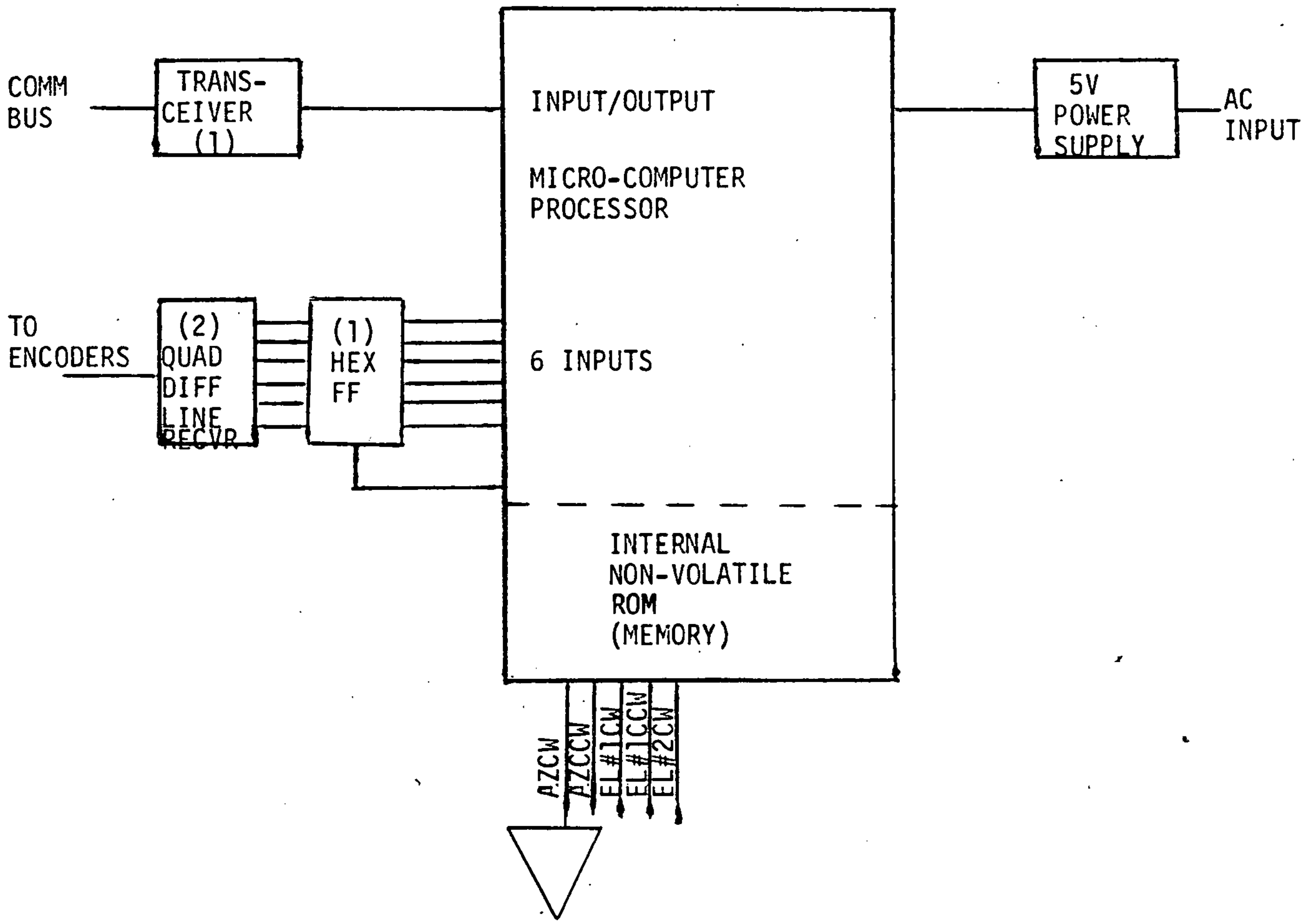


Figure 2.4.4.3-1 Heliostat Controller Microprocessor

the target, the error signal between the actual gimbal angles and the commanded gimbal angles, and the motor command for reducing the error signal.

If the operating mode should be changed from tracking on the receiver to emergency slew off the receiver, a single command is transmitted to each Data Distribution Interface which transmits the message to each heliostat assigned to it. The Heliostat Controller then commands the reflected beam to move from the receiver to an aim point near the receiver. The Heliostat Controller maintains the beam at this aim point until the operating mode is changed by the Heliostat Array Controller.

The Heliostat Controller periodically checks the communication link with the Heliostat Array Controller. If it finds that the communication link is bad, the Heliostat Controller will continue tracking.

2.4.4.4 Motors/Sensors

Besides the armature and field, the motor housing contains the motor control switching network and an incremental encoder.

The control (direction and on/off) of the 3Ø motors is accomplished by applying a positive logic signal to the appropriate input network shown in Figure 2.4.4.4-1. This signal is gated with a clock pulse to drive the optically isolated signal triac which in turn drives the motor. The motor will remain "on" until the command is removed by the processor.

The incremental encoder is a two-channel device which exhibits a logic level shift on each of the channels but shifted in phase once for each motor revolution. One channel leads the other (in phase) depending upon the direction of the motor shaft movement (CW vs. CCW). The data from the two channels are used to latch either of two flip-flops (the one latched is a function of the motor movement). The logic level shift of the encoder is generated by a Hall-effect transducer (integrated circuit package) which senses change in the magnetic field as the magnetic interruptor passes by the sensor. The latched signals are inputted to the processor and simultaneously an interrupt signal is provided to inform the processor that one revolution of motor movement has occurred.

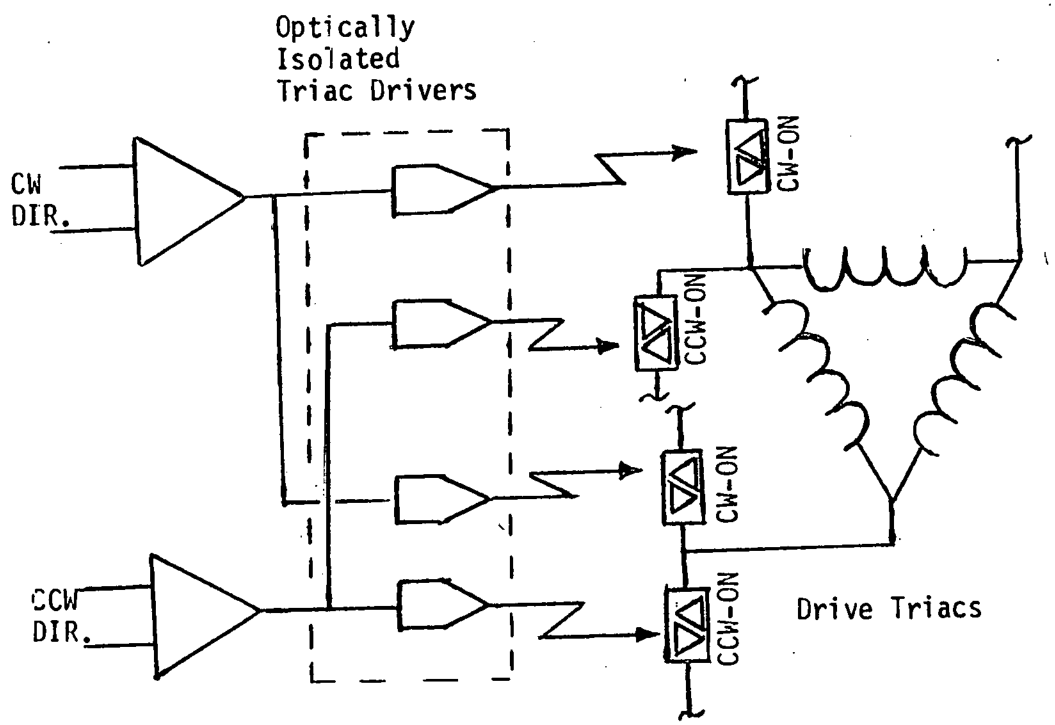


Figure 2.4.4.4-1 Motor Controller

2.4.4.5 Heliostat Electronic Assembly

The electronic components are located at five different locations on the heliostat as shown in Figure 2.4.4.5-1. The Heliostat Controller is located in an electrical J-box on the drive unit. This location was selected over a ground location in order to give added protection from the environment and ground activity, and to minimize the heliostat wire required. A junction box is located on the pedestal which contains a circuit breaker, plug connectors, and terminators for the incoming power and communication fibers. Power to a heliostat can be controlled by activating the switch on the circuit breaker. A manual control box can be plugged into this box for local control of the heliostat. Local manual control isolates this heliostat without affecting the control of any other heliostat in the field. There is a motor mounted on each drive jack and one on the azimuth drive. An incremental encoder is mounted on the motors.

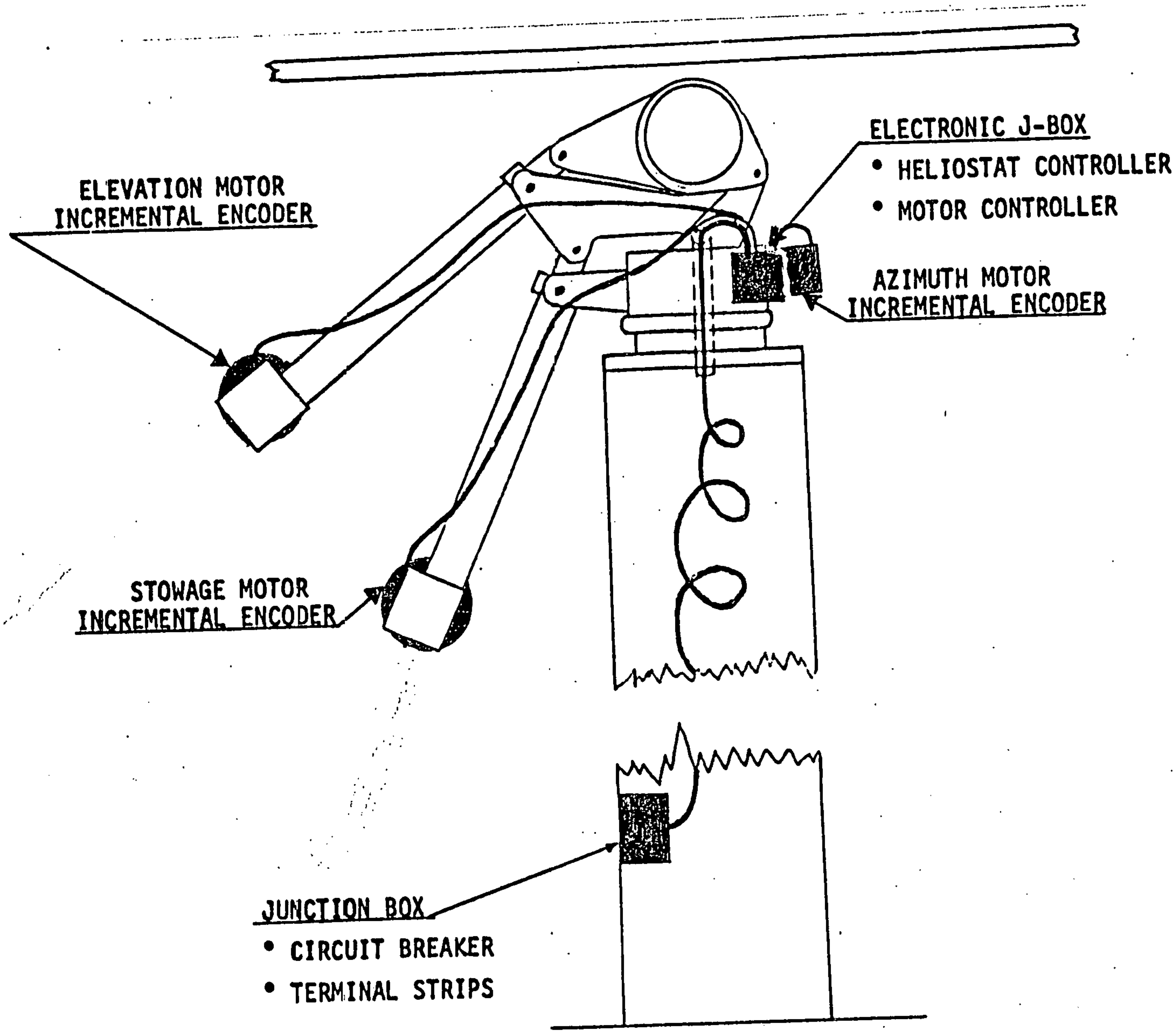


Figure 2.4.4.5-1 Heliostat Electronic Assembly

2.4.5 Field Electronics

The field electronics for the collector delivers power and control data to the heliostats and returns information on the heliostat status to the master control.

The data links interface with a heliostat array controller on the element of the master control which serve that function. A high data rate fiber optic cable links the heliostat array controller to data distribution interfaces in the field. Each data distribution interface is connected to 12 to 16 separate strings of heliostats by secondary feeders, again using fiber optics. Data from the heliostat array controller are relayed to the correct heliostat and data from the heliostats are relayed to the heliostat array controller.

The power links interface with the Electric Power Generation Subsystem. 4160 VAC 3 phase power is transmitted to field transformers by the primary power feeders. The transformers are co-located with the data distribution interfaces. The voltage is stepped down to 480 V and distributed to the secondary feeders.

Both power and data are carried in the same secondary feeder cable. The secondary feeders are terminated at both ends at data distribution interfaces and field transformers. Hence the loss of a transformer does not result in the loss of power to any heliostat.

All cables are designed for direct burial to provide adequate protection at minimum cost.

The wiring configuration proposed for the 100 MW Prototype System is designed to enhance efficiency and low cost. The system incorporates the lower cost of the radial configuration and the reliability of a network system. The field (Figure 2.4.5-1) consists of a primary distribution system originating from a central distribution point of which each feeder provides power for two or three transformers. Branch circuits between transformers provide power for the heliostats. The continuous run from transformer to transformer permits the small gauge, low voltage branch circuit to operate as a secondary main in the care of a transformer failure. This hybrid radial system is not totally redundant but will provide redundancy in the form of emergency operation to approximately 90 percent of the transformer in the field. With the hybrid system, the heliostats normally supplied by a transformer which has failed are not supplied sufficiently for normal operation, as in the network distribution system, but are able to drive into a stowage position or carry out emergency maneuvers which increase the operating safety of the field.

2.4.5.1 Primary Power

The power distribution network for the 17,700 heliostats, 100 MW solar power plant will consist of 20 primary feeders supplying 4160 volt, three-phase power from the central power distribution point to fifty-seven 225 KVA transformers in the heliostat field as shown in Figure 2.4.5.1-1. Each three conductors, #4 AWG primary will supply power to two or three transformers. Each transformer will supply 480 volt, three-phase power to 12 to 16 groups of approximately 24 heliostats through three conductors, #8AWG copper cable. The distribution system will be a hybrid radial network with branch circuit cables running circumferentially along the heliostat arcs.

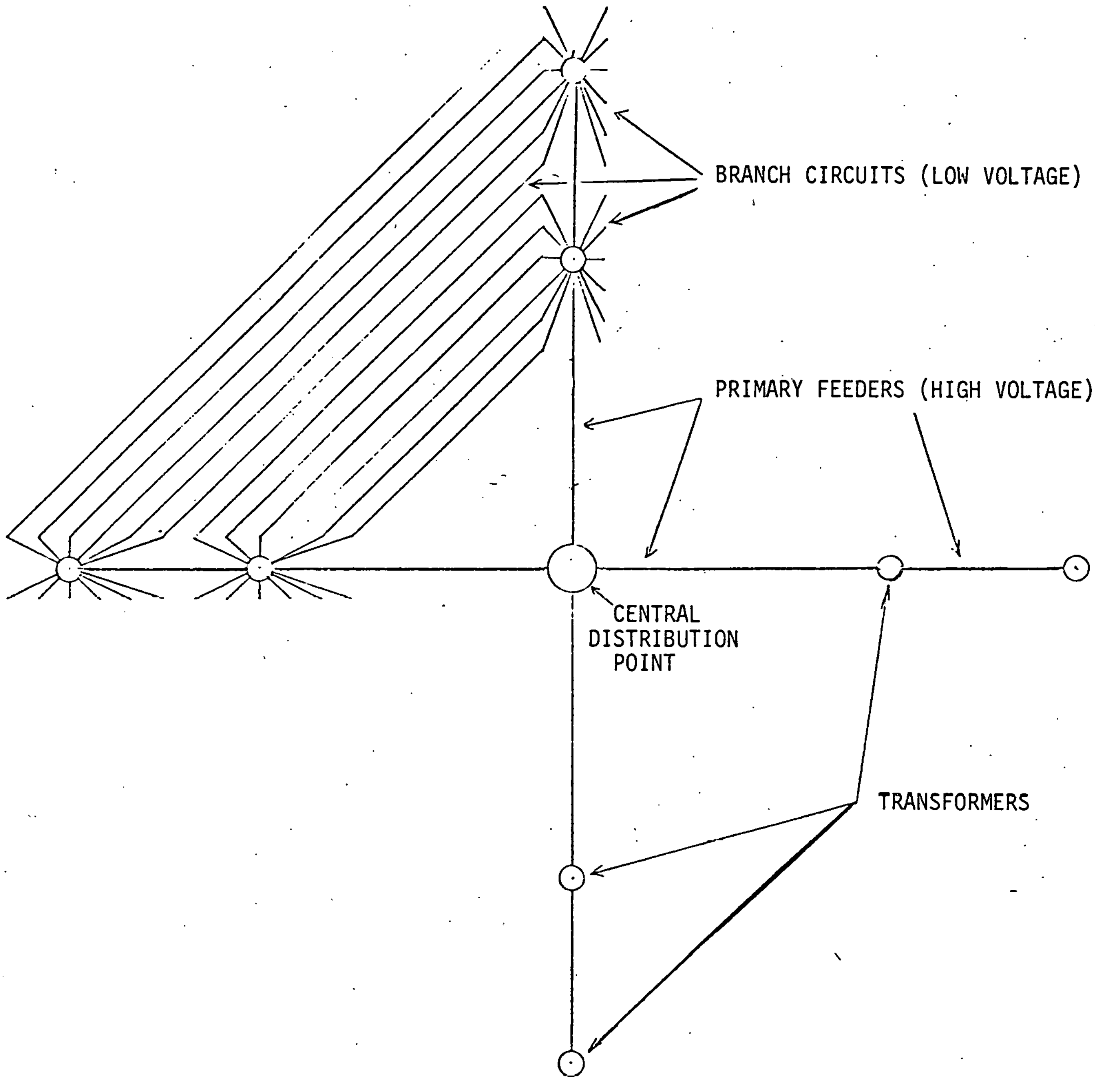


Figure 2.4.5-1 Hybrid Radial Network

2.4.5.2 Primary Data Link

The primary data link is designed using an optical transmission medium. The unique advantages of optical transmission over electrical transmission make its use attractive in performance and cost. Optical fiber transmission offers wider bandwidth and smaller cable cross-section than previously possible. In addition, since cables employing optical transmission neither pick up nor emit electron magnetic radiation and offer total electrical isolation, the problems of RFI, EMI, EMP, ground loops and sparking associated with electrical cables can be eliminated. These qualities of fiber cable allow the data transmission lines to be incorporated with existing power lines in a single cable, thus allowing for simplified routing and installation. The primary data link has, therefore, been designed coincident with the primary field wiring.

The primary data link provides the control interface between the heliostat array controller and the data distribution interface. The communication link consists of an optical transmitter unit compatible in bandwidth to the heliostat array controller, a fiber optic communication line and a photo-detector receiver for converting optical signals to their digital equivalents.

The field configuration is arranged similar to that of the primary power feeder. A primary feeder transmits information between the heliostat array controller data distribution interface and 15 to 20. At this point, information is retransmitted along primary feeders to 2 to 3 additional data distribution interfaces. Each of the data distribution interfaces communicates along 12 to 16 secondary lines to approximately 24 heliostats (Figure 2.4.5.2-1). This procedure eliminates the necessity for lengthy transmission distance between repeaters and conforms to the hybrid power distribution format.

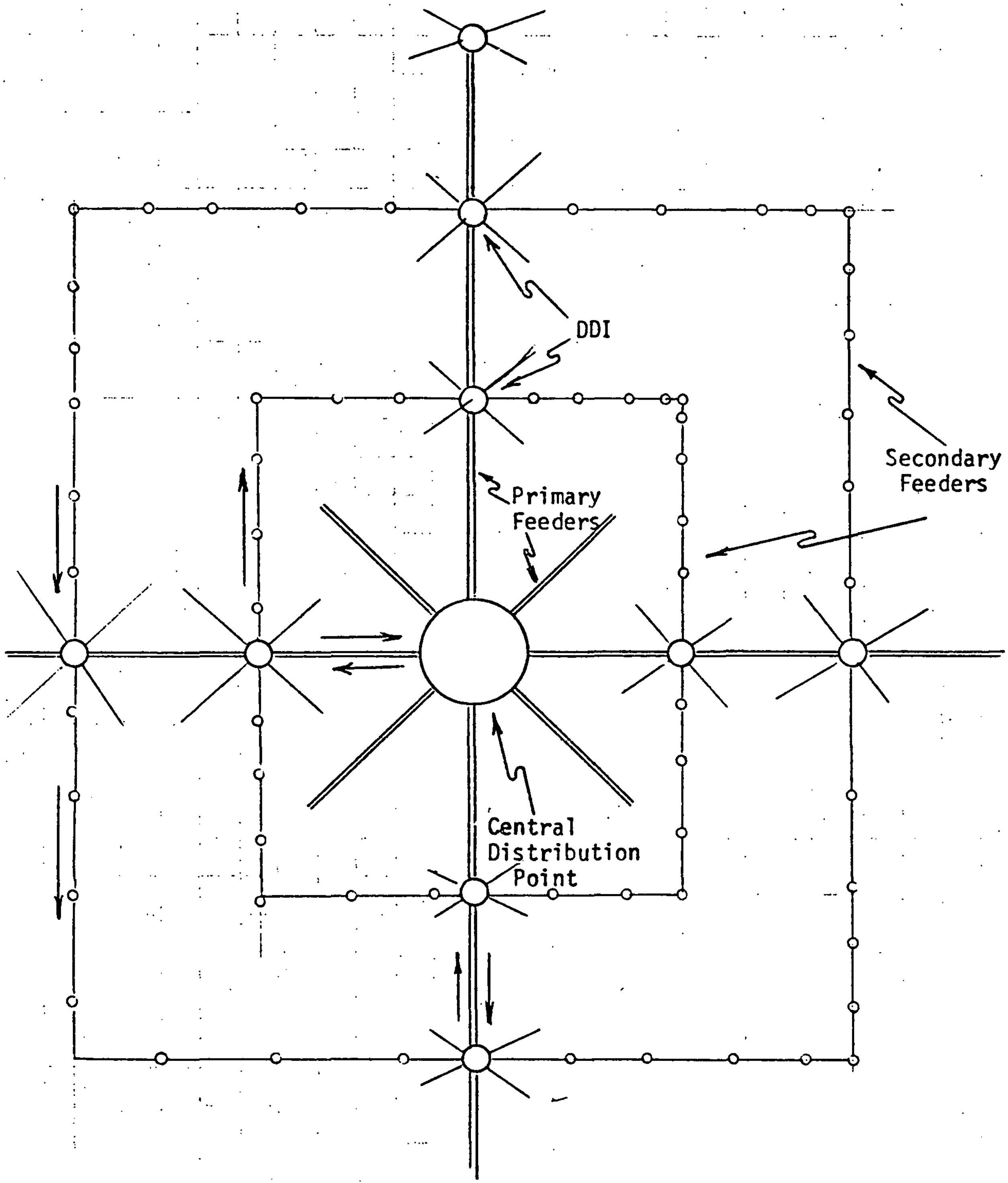


Figure 2.4.5.2-1 Primary Data Link

Data Distribution Interface

The data distribution interface will contain two identical printed wiring boards which are similar in construction to the heliostat controller boards.

The plastic box will be the same as that used to house the heliostat controller. The printed wiring boards will be installed with the components facing, thus, allowing them to nest and reduce the overall size of the box.

The manufacturing flow will be the same as the heliostat controller, but will require a different NC tape for the automatic component insertion machine.

Each data distribution interface will contain transmitter and receiver components necessary for the interface of primary and secondary communication components. All optical connectors will be mounted on the printed wiring boards to allow for automated inspection techniques.

2.4.5.3 Field Transformers and Interface

The field transformers step the 4160 volt primary power doen to 480 volts for distribution through the secondary feeders.

Each transformer is rated at 225 KVA with a 4160 V primary and a 480/270V secondary.

The secondary of the transformer connects to a main circuit breaker of 100 A capacity. A power bus from the main breaker connects to individual 40 amp circuit breakers for the secondary feeder circuits. The secondary feeder breakers are located in the power distribution panel as indicated in the sketch of Figure 2.4.5.3-1. The connectors for the secondary data feeder are also located in this panel for convenience of field hookup.

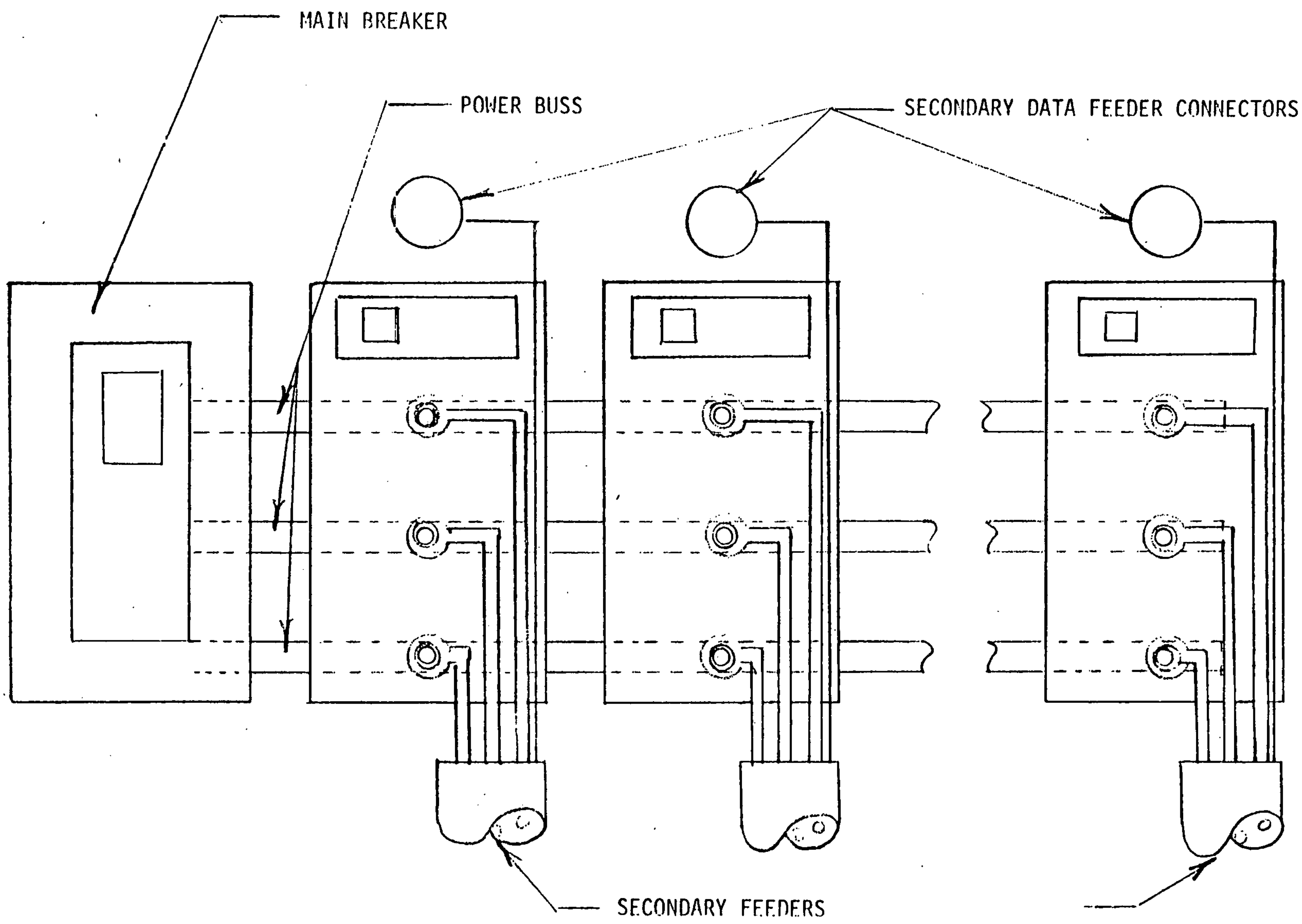


FIGURE 2.4.5.3-1 POWER/DATA DISTRIBUTION PANEL

The requirements for power transmission and cable capacity are determined by the operating voltage and current requirements of the heliostat motors. Each heliostat has three motors with a maximum of two motors operating at one time. For the initial baseline configuration, the motor were to be operated on 240 volts, 3 phase power. At this voltage the current requirements per motor were 3.5 amp starting current (4 AC cycles) and 1.4 amps running current. Thus, to start both motors on all 17,700 heliostats in the field simultaneously would require 124,000 amps at 240V or approximately 52 thousand kilovolt amps of transformers with very heavy gauge cycle to handle the large currents. It was therefore decided to size the cable network for a more realistic operating requirement.

The worst case condition for the operation of the field is the emergency slew, in which all heliostats must be moved off the receiver in 40 seconds or less. To accomplish this, all heliostats must have one motor operating and approximately 16% of the heliostats will require both motors in operation. A staggered start of the motors was chosen to reduce the danger of circuit overload; in addition, the secondary voltage was increased to 480 V to reduce the current in the secondary feeders.

At 480 V, the current requirement per heliostat would be 0.72 amps. The transformer requirement for either the 480 V or 240 V system would be 0.60 KVA per heliostat or 10620 KVA for the entire field.

The number of transformers required to supply low voltage power to the heliostats and their location in the field is closely related to the cable used in the branch circuits, due to voltage regulation and ampacity requirements. Since the major cost factor for the field network layout is the cost of the branch circuit cable and its installation, it is desirable to use the smallest gauge possible to minimize the cost of the cable. The limiting factor on the branch cable size is the voltage drop from the transformers to the heliostats on the branch circuit due to the distance between heliostats. This limits the number of heliostats supplied by a branch circuit and requires that the transformers be located as close as possible to the heliostats to minimize the voltage drop over the line. Thus, while a lesser number of larger transformers (i.e., 750 KVA) would reduce the cost of transformers alone, a greater number of smaller transformers (225 KVA) reduces the overall cost of the field layout because of a smaller gauge of cable may be used while maintaining adequate voltage regulation.

Field location of the 225 KVA transformers required for the 17,700 heliostat field is shown in Table 2.4.5.3-1. The locations were developed by determining the number of heliostats in each row (or arc) of the field layout and sectioning the heliostats in each row into groups that can be served by one transformer with adequate voltage regulation. In this manner, the number of transformers required for each group of rows is determined. The location of the transformers is then determined by calculating the number of heliostats a transformer can supply and placing the transformers in such a manner that the rows are fed by an adequate number of transformers and each transformer serves the maximum allowable number of heliostats.

Table 2.4.5.3-1

17,700 HELIOSTAT FIELD TRANSFORMER LOCATIONS

ROW[1]	TRANSFORMERS IN ROW	TOTAL ARC	LOCATION OF TRANSFORMER ALONG ARC[2]
4/5	2	360°	± 90°
12/13	3		0; ± 120°
20/21	3		0; ± 120°
28/29	4		0; ± 90°; 180°
36/37	4		0; ± 90°; 180°
44	5		0; ± 72°; ± 144°
51	5	360°	0; ± 72°; ± 144°
58	5	329°	0; ± 66.0°; ± 132°
65	5	275°	0; ± 55.2°; ± 110.4°
72	5	232°	0; ± 46.40°; ± 92.8°
79	4	192°	± 24°; ± 72°
86	4	159°	± 20°; ± 60°
92/93	4	126°	± 15.8°; ± 48.2°
98/98	4	102°	± 12.8°; ± 33.4°

(1) Rows numbered out from receiver. Row numbers X/X+1 indicates transformers located between Rows "X" and "X+1". Row numbers "X" indicates transformer located in that row of heliostats.

(2) Angles are measured from the central receiver location with North as zero.

2.4.5.4 Secondary Feeder

The secondary feeder cable is the single most costly item in the power distribution network due to the large amounts required to connect all the heliostats in the field. The only factor affecting this cost is the size of cable used, since the length required is a function of only the field size. The length of the branch circuit cables will be the total arc length of all the heliostat arcs plus a small amount for transformer to arc hookup. For the 17,700 heliostat field, the length required is approximately 290,000 meters.

Voltage regulation and ampacity requirements determine the conductor size to be used. These requirements are set by the number of heliostats on a line and the line voltage. Due to the distances between heliostats, adequate voltage regulation is the limiting factor in cable gauge selection. Voltage drop calculations, for the desired range of 20 to 25 heliostats on a secondary feeder circuit, indicate that the required wire gauge is #8AWG, 3 conductor copper for the 480 Volt, 3 phase system. The attendant reduction in wire gauge results in approximately a 50% cost savings for the secondary feeder cable with a 480 volt system compared to the 240 volt system of the initial baseline.

The secondary feeder cable also contains the fiber optic secondary data feeder cable. This cable runs from the distribution at the data distribution interface to the heliostat junction boxes. At the data distribution interface information arriving from the heliostat array controller is channeled to the appropriate secondary communication line via the data distribution interface processor. The digital information is transformed to an optical signal and routed to the first heliostat in the string. The fiber communication line is housed in the same cable with the 30 power lines. At the J-Box in the base of the pedestal a connector is provided to allow the optical fiber to be routed to the heliostat controller at the top of the pedestal. Optical information is detected by a photo transister receiver located at the heliostat controller and transformed into a digital signal compatible to the processor requirements. The information address is compared to that of the processor. If the commands are not intended for the heliostat they are re-transmitted to the next heliostat in the string.

Return information is handled via the same communication line. The information is transmitted along with the retransmitted signals to a data distribution interface at the end of the secondary data link. (See Figure 2.4.5.4-1). From there the signals are transmitted to the heliostat array controller. This configuration requires a low data rate transmitter and receives at each heliostat controller.

The repeater configuration alleviates the necessity for high quality optical fiber due to the short transmission distance. The loop configuration results in the necessity for only one way communication along a single cable.

Due to tolerance requirements, it is necessary to make fiber coupling connections in factory production. This reduces installation time and labor by requiring only mechanical snap type connections in the field.

Continuity checks should be made periodically during installation on both the fiber optics and the power cable to assure proper alignment and reproducibility of signals and phase relationships.

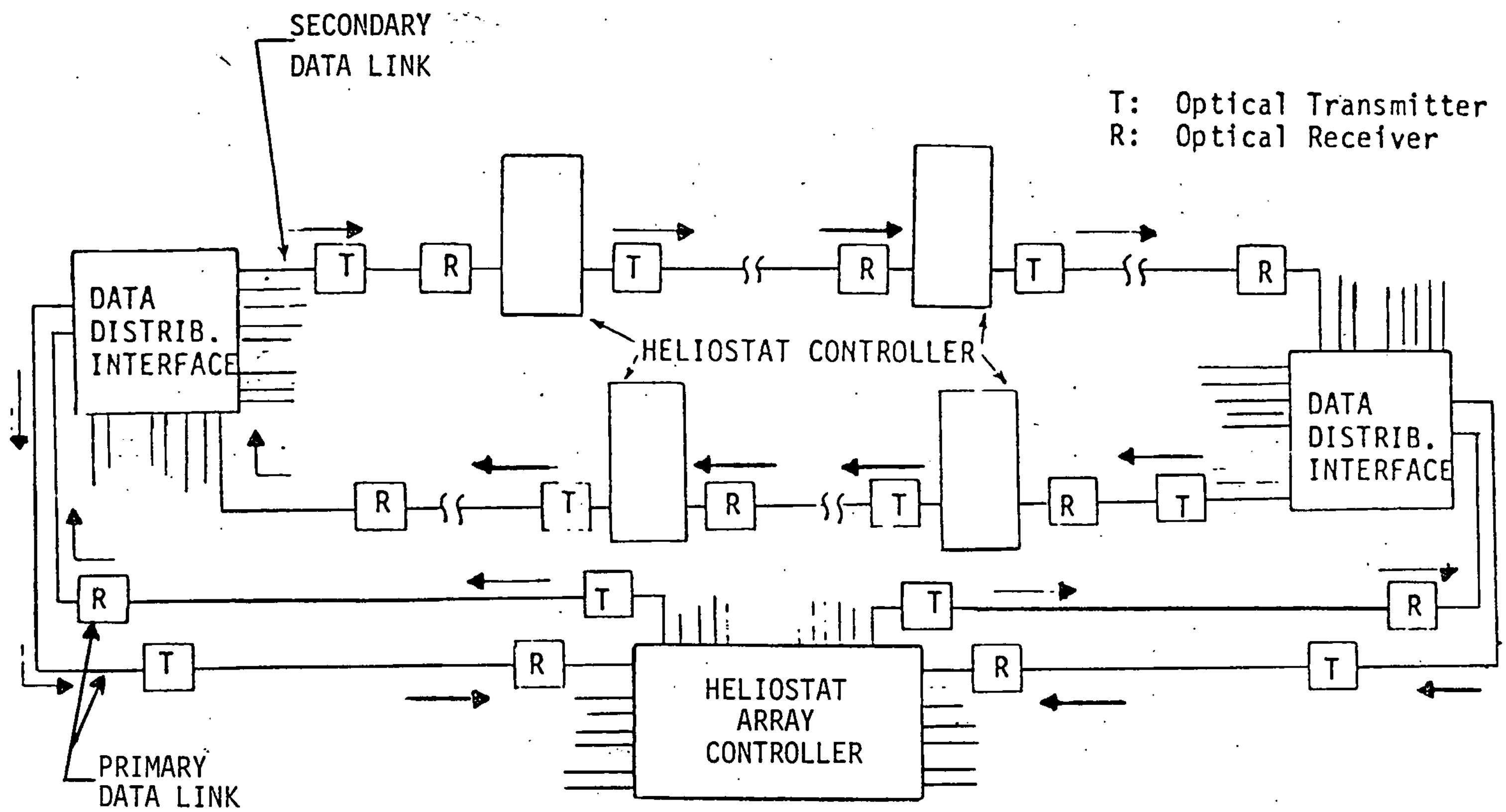


Figure 2.4.5.4-1 Primary and Secondary Data Link

2.5 DESIGN CHANGE SUMMARY

A summary of the important design changes is presented in Table 2.5-1 with the benefits associated with each change. Almost all of the design changes were initiated to achieve a cost reduction, but the method used varies from weight or part reduction to a change in material, use of emerging technology, or an improvement in the manufacturing, installation and checkout cost as a result of the design change. In some cases, the design change improves overall performance or allows use of another, more cost-effective component, even though there may be no significant cost reduction in that particular aspect of the design. In the case of the reflector design, a significant cost savings has been obtained using a laminated mirror, which adds weight of glass while decreasing the structural support weight and improving the reflectivity. A significant reduction in pedestal steel weight is achieved with the new design. In the drive unit, a welded housing is substantially heavier, yet cheaper, than the cast housing, and overall cost reductions are achieved by parts count reduction. Cost and weight improvements are achieved by use of a new type of linear actuator. In the electronics area, most of the cost savings are obtained by a series of direct, incremental improvements in the design, although manufacturing labor and installation costs are reduced also.

TABLE 2.5-1

DESIGN IMPROVEMENT SUMMARY

Design Element	Initial	Final	Cost Reduction	Weight Reduction	Parts Reduction	Material Change	Manufacturing/ Installation/ Checkout Benefit	Emerging Technology
Heliostat Size	37.55 m^2 (404 ft^2) increased to 48.33 m^2 (520 ft^2) with foam sandwich design	49.07 m^2 (528 ft^2)	X	100.3 kg (221.1 lb) (Approximate for principal design changes) 491.2 kg (1083 lbs) steel reduction	X			
Reflector								
Mirror	Foam sandwich	Laminated	X		84	X		
Glass Weight	387.3 kg (854 lbs)	778.2 kg (1716 lbs)	X	-390.9 kg (-862 lbs)				
Stiffening Weight	364.1 kg (803 lbs)	152.4 kg (336 lbs)	X	211.7 kg (467 lbs)				
Support Structure	Torque tube	Divided main Beam	X		-2	X		
Weight/Area	17.08 kg/m^2 (3.50 lbs/ft^2)	11.03 kg/m^2 (2.26 lbs/ft^2)	X	6.05 kg/m^2 (1.24 lbs/ft^2)				
Weight	461.2 kg (1017 lbs)	388.7 kg (857 lbs)		72.6 kg (160 lbs)				
Pedestal								
Type	Bolted base	Tapered base	X		2		X	

TABLE 2.5-1

DESIGN IMPROVEMENT SUMMARY

Design Element	Initial	Final	Cost Reduction	Weight Reduction	Parts Reduction	Material Change	Manufacturing/ Installation/ Checkout Benefit	Emerging Technology
Pedestal (Cont'd)								
Weight	391.8 kg (864 lbs)	113.8 kg (251 lbs)	X	278 kg (613 lbs)				
Drive Unit								
Azimuth	Gear motor 6.36 kg (14 lbs)	Motor 8.6 kg (19.16 lbs)	X	-2.44 kg (-5 lbs)	X			
	Worm gear reducer	Helicon gear reducer	X					
	Harmonic drive w/Oldham coupling	Harmonic drive w/o Oldham coupling	X		2 (major)			
	Turret bearing w/precision retainers	Wire race bearing	X	12.23 kg (26.9 lbs)	1 (Bearing retainer)			
	Pinion on separate shaft	Pinion on motor shaft	X		X			
	Separate motor mount	Integral motor mount	X		X (5 miscellaneous)			
	Cable stored by external mech.	Cable routed thru center	X	X	X			
	Cast housing	Welded housing	X	-70.45 kg (-155 lbs)				

TABLE 2.5-1

DESIGN IMPROVEMENT SUMMARY

Design Element	Initial	Final	Cost Reduction	Weight Reduction	Parts Reduction	Material Change	Manufacturing/ Installation/ Checkout Benefit	Emerging Technology
Drive Unit								
Azimuth (Cont'd)	Circular spline and base	Circular spline and base	X	5.45 kg (12 lbs)				
Elevation Linear Actuators	Translating screw 44.72 kg (98.4 lbs)	Translating nut 31.54 kg (69.4 lbs)		26.36 kg (+ 58 lbs) (total)				X
	Machine screw	Ball screw		X				
	Gear motor 6.36 kg (14 lbs)	Motor 4.77 kg (10.5 lbs)	X	3.2 kg (3.5 lbs)	X			
	Proximity limit switch	No proximity limit switch	X	X	X			
	Worm gear reducer	Helicon gear reducer						
	Pinion on separate shaft	Pinion on motor shaft	X		X			
	Separate motor mount	Integral motor mount	X		X (5 miscellan-ous)			
	Backlash adjustment	No backlash adjustment	X	X	X			
Electronics	Communication on wires	Communication using fiber optics	X			X		X

TABLE 2.5-1

DESIGN IMPROVEMENT SUMMARY

Design Element	Initial	Final	Cost Reduction	Weight Reduction	Parts Reduction	Material Change	Manufacturing/ Installation/ Checkout Benefit	Emerging Technology
Electronics (Cont'd)	Incremental and 4 bit absolute encoders	Incremental encoder/non-volatile memory	X		X		X	X
	240 VAC field wiring	480 VAC field wiring	X					
	Field controller	Data distribution interface	X		X			
	Multipart processor	Single chip processor	X		X		X	X

Section 3

MANUFACTURING, PROCESS CONCEPTUAL DESIGN

This section contains a status of the manufacturing effort. The basic manufacturing task for the prototype heliostat project is to develop manufacturing concepts for various production levels; i.e., 25,000 helio/year, 250,000 helio/year and 2,500,000 helio/year. The development of manufacturing concepts involved manufacturing specialists (i.e., Manufacturing and Industrial engineers) working with design engineers evaluating design and manufacturing alternatives. In order to objectively evaluate alternatives, cost trade-off studies were conducted. Table 3.0-1 contains a summary of the results achieved.

This section discusses the status of the cost trade-off studies. Section 3.1 describes the baseline manufacturing processes; Section 3.2 describes how the cost trade-off studies have been conducted for design and manufacturing. The results of each cost trade-off study is summarized. Supporting data for each study is also available. Section 3.3 reports on the development of the Manufacturing Plan for the 25,000 heliostats per year volume. The manufacturing plan concepts are the results of the cost trade-off studies. Key issues are discussed, such as handling .060 glass, productivity improvement, and MDAC's basic approach to achieving volume production to meet target costs. The Make/Buy approach for the 25,000 units per year level is presented. Quality Assurance control and equipment concepts are discussed. Section 3.4 reports on the Production Plant developed for the 25,000 unit per year volume level. This includes plant size, plant layout and work flow concepts. Summaries of Equipment and Manpower are provided. Section 3.5 reports on the status of packaging and transportation concepts developed for both incoming material and sub-assemblies being shipped to the site.

MDAC has received support from Arthur D. Little in the development of manufacturing approaches. Arthur D. Little has also provided considerable assistance and expertise in the production plant concepts. Pittsburg Plate Glass has supported this project in the development of the float glass integration

TABLE 3.0-1

MANUFACTURING COST TRADE STUDY RESULTS SUMMARY

Section	Proposal Ref.	Subject	Was	Is	Result
3.2.2.1	D-2	Low cost reflector	Foam sandwich panel	Laminated glass panel	o Simplified manufacturing process with fewer parts o Reduced material and labor cost
3.2.2.2	D-5	Reflector attachment	10" diameter, 206" long main beam, standard pipe, welded flanges	16" diameter, 83" long main beam, standard pipe, welded flanges	o Simplified assembly o Eliminated site factory requirement
3.2.2.3	M1	Integral Pedestal/ foundation	Precast concrete foundation steel pedestal with attach flanges	Tapered steel pipe over reinforced concrete piling	o Significant reduction in installation labor
3.2.2.4	M2	Drive housing materials reduction	Machine from castings	weldment	o Material cost savings
3.2.2.4	M2	Drive housing materials reduction	Machine from castings	Weldment	o Material cost savings

TABLE 3.0-1

MANUFACTURING COST TRADE STUDY RESULTS SUMMARY

Section	Proposal Ref.	Subject	Was	Is	Result
3.2.2.5	M3	Mirror line integration	Purchase mirrors	Integrate mirroring process with factor operations	o Uninterrupted manufacturing sequence with reflector panel assembly o Reduction in transportation handling and handling damage
3.2.2.6	M-4	Float glass line integration	Purchase glass	Purchase glass	o Not cost effective until manufacturing rate approaches 500,000 heliostats per year
3.2.2.6	New study	Fusion glass line integration	Purchase glass	Purchase glass	o Would be cost effective at a production rate of 100,000 heliostats per year
	M-5	Foam core finishing	Purchase foam	Eliminated	o Cost trade study D-2 resulted in redesign eliminating Foam Core
	M-6	Foam extrusion integration	Purchase foam	Eliminated	o Cost trade study D-2 resulted in redesign eliminating Foam Core
3.2.2.7	M-7	Adhesive application	Extruding dispenser	Spray system and extruding system	o Selected the appropriate adhesive methods for the application requirements

TABLE 3.0-1

MANUFACTURING COST TRADE STUDY RESULTS SUMMARY

Section	Proposal Ref.	Subject	Was	Is	Result
3.2.2.8	M-3	Site factory requirement	Site factory for final assembly	Eliminated	o Design changes eliminated this requirement for an assembly factory at the site
3.2.2.9	New Study	Flexspline optimization	Machine steel tube, fusion weld to cylinder	Deep draw analysis continuing	o Potential to reduce labor and material costs
3.2.2.10	New Study	Wave generator configuration	Machined bar	Powdered metallurgy net form part investigation	o Potential to reduce metal removal labor costs
3.2.2.11	New Study	Gear forming processes	Hobbing	Broaching	o Reduced manufacturing cost
3.2.2.12	New Study	Turret bearing selection	Precision ball bearings and races	Wire race ball bearing	o Reduced bearing costs o Reduced labor for machining bearing location

trade-off study, and generally in providing insight into issues such as glass handling and transportation.

It should also be noted that the Manufacturing element has worked with numerous companies and that considerable research has been expended in areas of specialized equipment and processes, to help select the approach for production. It will be apparent in reviewing this report that there is a close working relationship between the manufacturing and engineering personnel to develop a design that represents a low cost approach suitable for volume production.

3.1 INITIAL BASELINE MANUFACTURING PROCESS

The baseline manufacturing processes associated with the initial design baseline defined in Section 2.1 are described in this section. The baseline manufacturing processes and support functions are for the production of 25,000 units per year, with the 250,000 and 2,500,000 per year rates and a one time production of 2,500 units treated as a variation from this baseline. The concept in this plan is to use a centrally located fabrication/assembly plant located in Southern California, and multiple sites for assembly/final assembly plants located at the installation sites. Basis for this concept was established in the MDAC's company sponsored heliostat design/manufacturing/cost activities conducted in the Spring of 1977 with the support of the A.D. Little Company and includes the following data:

- Completed manufacturing processes
- Detailed Central Manufacturing Plant Layout
- Detail Site Plan Layout (and relocation plans)
- Factory equipment lists
- Factory moving charts
- Transportation plans
- Procurement and Quality plans

3.1.1 Plant Descriptions

The central manufacturing plant, Figure 3.1-1, consists of four fabrication/ assembly areas, as follows:

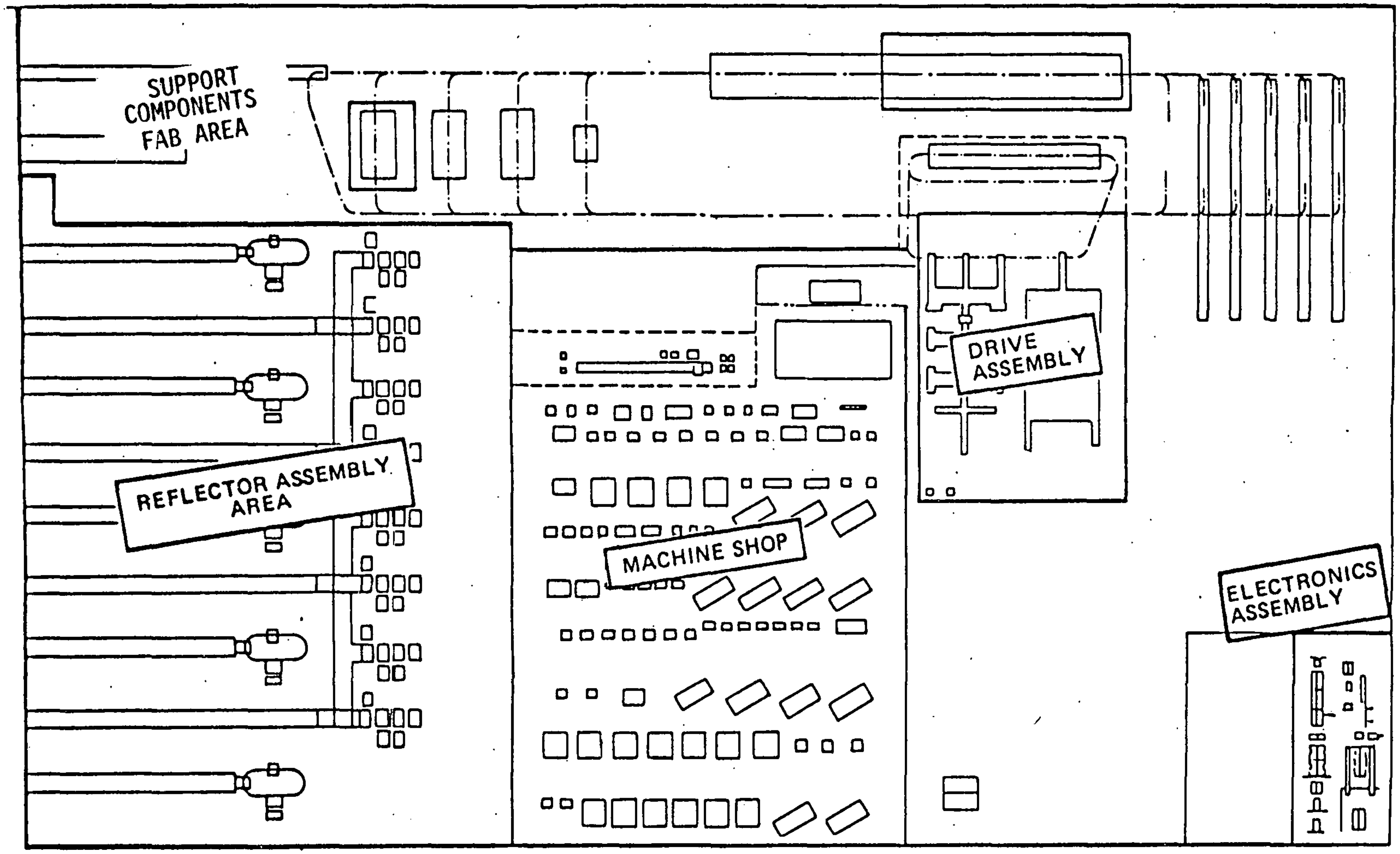


Figure 3.1-1 Central Manufacturing Plant

- Reflector surface assembly area
- Support components fab/finish area
- Machine shop/drive assembly area
- Electrical/electronics assembly area

The Site Plants, Figure 3.1-2, are located adjacent to the installation sites to reduce the final transport requirements for fully assembled heliostats and will be relocated as power plant installations are completed. Four basic assembly operations take place in the Site Plant. They include:

- Assembly of the cross beams to the torque tube.
- Assembly of the cross beams and torque tube to the reflective panels.
- Assembly of the drive units and wiring harnesses to the pedestal.
- Assembly of the reflective array and supports to the drive and pedestal.

3.1.2 Manufacturing Processes

Initial baseline manufacturing processes and assembly operations are summarized in Table 3.1-1.

3.1.3 Transportation

In order to ship manufactured items, the baseline concept of transportation is to use over-the-road trucks from the central factory and ship to the assembly sites.

Optimal loading involves the use of unitized loads prepared during packing and nesting of large parts for maximum compactness. Trucks will be loaded with a mix of items that are available at one loading dock area rather than having to be moved to a different dock to complete packing.

In summary, the heavy demand for trucking will come from large metal assemblies and from reflector sandwich loads. The metal items will be shipped on flatbed trucks. Container trucks will be required for drive assemblies and electrical controllers in cartons.

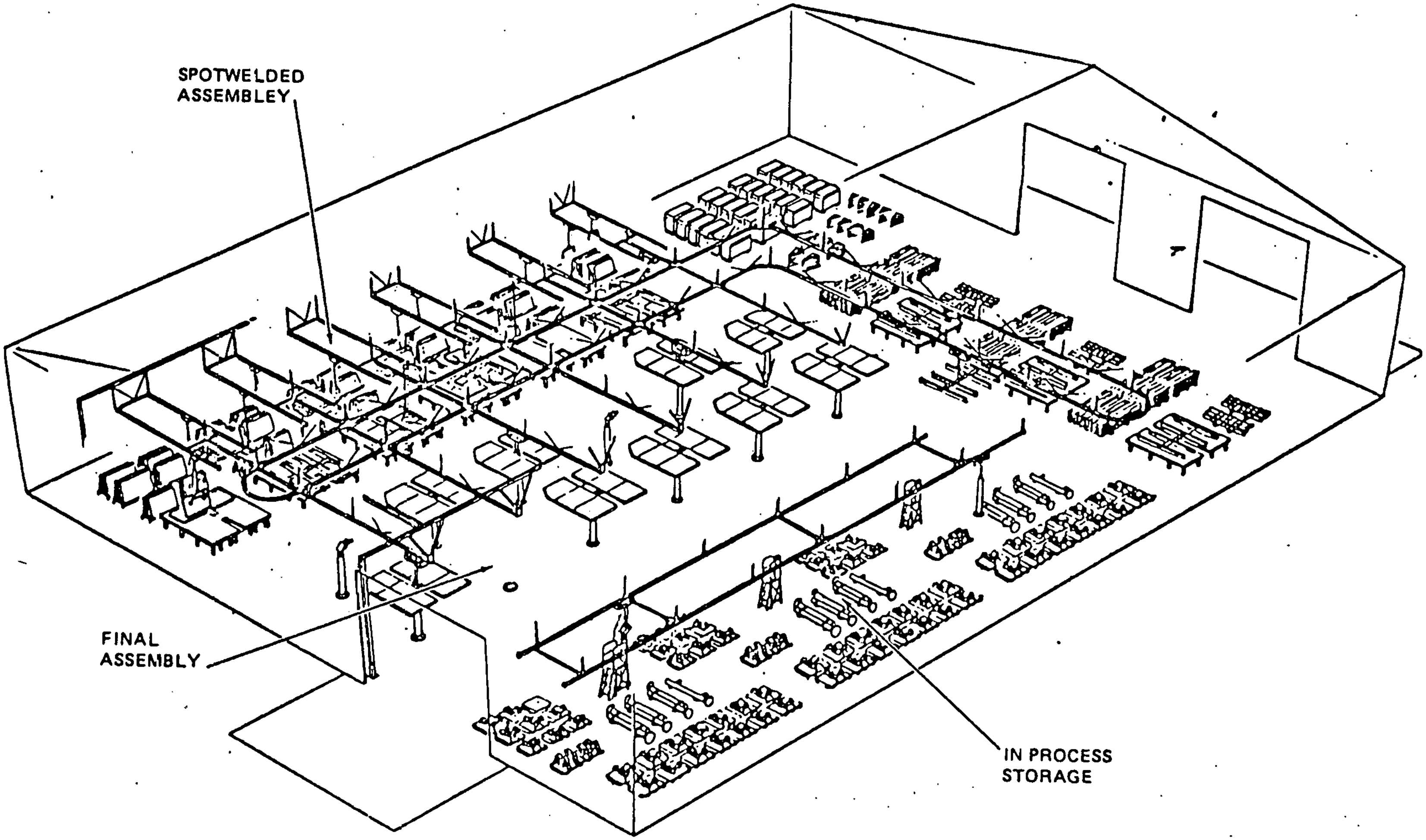
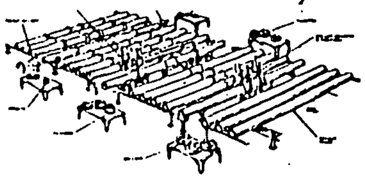
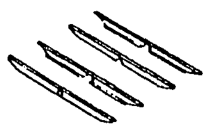


Figure 3.1-2 Site Manufacturing Plant

Table 3.1-1

SUMMARY OF BASELINE HELIOSTAT PROCESSES

Component	Method of Manufacturing	Location	Equipment
Torque Tube	• Welded 10-inch dia tubing	Buy	
Torque Tube Details (flanges, drive collars and internal donut flanges)	• Flanges - coil formed • Drive collars - machined from forgings • Donut flanges - blanked from stock	Buy	Punch press, machining fixture wheelabrator
Main Beam Assembly 	• MIG weld components (automated) • Auto wash, prime, paint and dry • Ship to Site	Factory	Auto MIG welder hot water wash, dryers, dip tank, electrostatic spray paint, wheelabrator degreaser
Cross Beam 	• Shear sheet steel to length • Center hole punched and roll formed to shape • Transfer to MIG welding station and weld 6 pads • Auto wash, prime, paint, and dry (entire process is semi-automated) • Ship to Site	Factory	Punch press, MIG welder Dip tank, dryers electrostatic paint sprayer Roll form
Support Structure Assembly	• Weld torque tube to cross beams (Semi-automated)	Site	Level layout tables, adjustable yoke, hoist monorail, welder
Mirrors	• Silvered Reflective Plating	Buy	

Buy = Purchased from Supplier Factory = Central Factory Site = Site Assembly Plant

Table 3.1-1

SUMMARY OF BASELINE HELIOSTAT PROCESSES

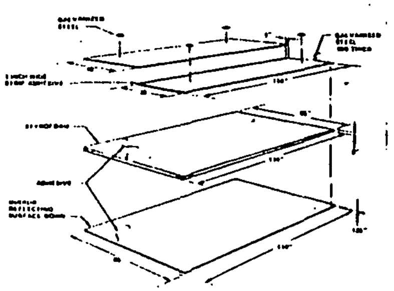
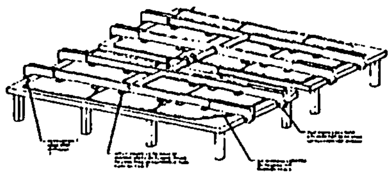
Component	Method of Manufacturing	Location	Equipment
Mirrors Processed	• Inspect edges and mirror surface for defects after arrival from vendor	Factory	Rotary table (roller equipped)
	• Automatic cleaning, drying and gluing (preparation of bonding)		Conveyors (roller, air cushion, pressure)
Styrofoam	• Both sides machined flat	Buy	
Steel Sheet Backplate 	• Unwind, straighten and shear sheets to length	Factory	
	• Notch corners (every 6th sheet)		Machining fixtures - grit blast line
	• Mask pad locations, grit blast backsheet		
	• Transfer to steel-foam laminating station Semi-automated operations		
	• Assemble mirror, styrofoam and steel sheet backplate		Press conveyor, drying tunnels
	• Package and ship to Site		
Support Structure 	• Locate and position support structure with respect to reflective surfaces	Site	Air cushioned flat panel layout table, magnetic pickup plate or vacuum plate, monorail, glue gun
	• Apply adhesive, bond and cure (semi-automated)		

Table 3.1-1

SUMMARY OF BASELINE HELIOSTAT PROCESSES

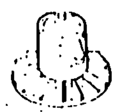
Component	Method of Manufacturing	Location	Equipment
Drive Components-Jacks for Elevation and Harmonic for Azimuth	• Major subcontracted component	Buy	
Cast Housing and Attach Fitting  	• All drive unit castings processed through wheelabrator for scale removal • Machine necessary parts and transfer to other stations accordingly • Transfer finished parts to degreaser for cleaning	Factory	NC Lathe, multi-spindle drill, radial drill wheelabrator
Drive Subsystem Assembly 	• Assemble drive unit components • Mask unit for painting • Manual spray paint (prime and finish) • Transfer through drying tunnels • Install wiring (motors, position indicator hardware, limit switch, etc) • Test and Inspect	Factory	Monorail Electrostatic manual sprayers

Table 3.1-1

SUMMARY OF BASELINE HELIOSTAT PROCESSES

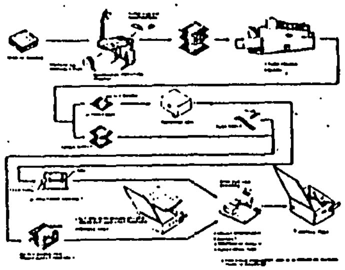
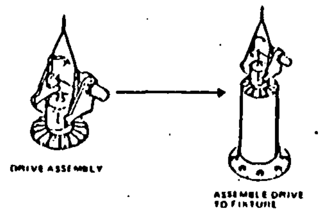
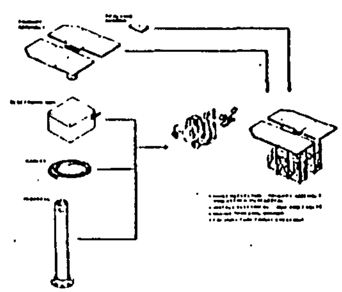
Component	Method of Manufacturing	Location	Equipment
Heliostat or Field Processor Assembly 	• Batch assembled; 1 day every 2 weeks • Manually insert components onto predrilled boards • Wave solder and dry, transfer to roller conveyor • Inspect for proper components and solder joints • Environmentally test completed P/C boards at maximum operating temperatures • Wire cutting to length, stripping, tinning and final assembly for electrical wire harnesses • Final assembly of P/C boards, terminal strips, circuit breakers and harnesses • Final Inspection (visual) and Test • Package: heliostat controller, field processor, harness	Factory	Wire cutter Wave soldering machine wire stripper tinning pots ovens miscellaneous benches, hand tools, etc.
Heliostat Pedestal 	• Machine base casting and top ring blank • Weld assembly (automated) • Auto wash, prime, paint and dry • Ship to Site	Factory	Auto MIG welder Hot water wash, Dip tank, dryers, electrostatic paint spray, machining fixtures

Table 3.1-1

SUMMARY OF BASELINE HELIOSTAT PROCESSES

Component	Method of Manufacturing	Location	Equipment
Pedestal - Drive 	• Position pedestal and drive components • Bolt aligned assembly • Spot weld cable retractor and heliostat Control Assembly • Test connections • Transfer to final assembly station	Site	Monorail, hoist spot welder roll grabbers
Final Assembly 	• Position reflective array with respect to pedestal/drive assembly • Bolt final assembly components together • Inspect and correct alignment and painted surfaces • Transport to holding position (manual, mechanical operations involved)	Site	Hoist, spray paint fork trucks

3.1.4 Quality Assurance

Baseline is for the production of 25,000 units per year and covers the assurance of quality in design and the inspection of hardware (testing, measuring, gauging and inspecting). Techniques and plans will be modified and developed for the higher production rates as degree of automation increases and quality of tooling changes.

3.2 PRODUCTION TRADE STUDY RESULTS

An important step in the development of the design and manufacturing plans has been the cost trade studies conducted for the design and manufacturing alternatives. This section reports the results for the studies completed at this point in the project. Studies will continue to be conducted as alternate approaches that offer cost advantages are identified. The studies are grouped in three categories. Design Studies (D) are studies which were identified by project design engineering (discussed in Section 2.2). This section contains a description of the manufacturing effort and relative cost ratios that were developed. Manufacturing Studies (M) deal with alternate manufacturing approaches. The third category includes completed studies identified after the project began.

3.2.1 Cost Trade Study Preparation

The approach used to conduct a cost trade study begins with the identification of technically feasible options, and the definition of these options. In the design trades, a print or sketch of alternate designs is used. In the manufacturing trade studies, a gross manufacturing approach for each concept is developed.

An initial cost evaluation is conducted prior to further definition. If it appears that an alternative is obviously not cost effective, no further effort will be expended. These decisions are jointly arrived at in reviews with the engineering and manufacturing personnel involved.

For each trade study a detailed manufacturing plan is prepared to describe the alternate. This plan includes material definition, manufacturing processes, tooling, equipment concepts and facility requirements to meet the specified production rates. In addition, common requirements and groundrules of the trade are listed, as well as characteristic differences between alternatives. The manufacturing approaches are equally optimized for the alternates to maintain a balance to the study.

The analyses compare the estimated cost to produce each of the alternates. The analyses include:

- o Recurring and non-recurring costs (or explanation of omission with an estimate of the effect of such omission(s)).

- Traeceable derivation of cost estimates in the form of references and worksheets.
- A summary of costs reflecting acceptable levels of quality.
- A consistent format to facilitate understanding, and
- Explanation or interpretation providing the reasons for unexpected differences or observed trends.

To properly assess the cost magnitude of various approaches, average manufacturing labor rates are developed, based on current national averages for each job skill involved in the study. The facilities and equipment costs for each alternative are reduced to a cost/hour rate which is then added to the basic hourly job rate. This developed rate now represents the cost for this work regardless of company or location, and provides a representative cost for the alternative. The detailed plans for the alternate chosen become the baseline manufacturing concept.

Certain cost trade studies required expertise greater than MDAC capability. For example, the M-4, Float Glass Integration cost trade study involves an understanding of float glass facilities and equipment costs. PPG has been working with MDAC manufacturing personnel and assisting in developing this trade. In a similar manner, Arthur D. Little has worked closely with manufacturing and industrial engineering to assist in the development of equipment and tooling concepts for the various plans being considered.

Other companies that provided assistance to MDAC were:

- Duff-Norton on linear actuator design
- United Shoe Machinery Corporation on harmonic drive design
- Spiroid Division of ITW on helicon gear sets
- Lincoln Foundries on large ductile iron castings
- U.S. Steel on commercial steel stock
- Summer & Maca on chemical deposition mirroring
- 3M Company on adhesives
- Dow Corning on fusion glass properties and production
- McGill Manufacturing on bearings
- Kaydon Bearing Division of Keene on bearings
- Kelly Pipe for tubular steel products

3.2.2 Cost Trade Studies Conducted

The initial baseline for these manufacturing trade studies is described in Section 3.1. The initial baseline manufacturing rate was established at 25,000 units per year. Trade studies were directed at areas of cost drivers to reduce cost and in some cases, provide improvement of the heliostat design. These studies are outlined below and reported:

Section No.	Proposal Reference	Trade Study
3.2.2.1	D-2	Low Cost Reflector
3.2.2.2	D-5	Reflector Attachment
3.2.2.3	M-1	Integral Pedestal/Foundation
3.2.2.4	M-2	Drive Housing and Drag Link Materials
3.2.2.5	M-3	Mirror Line Integration
3.2.2.6	M-4	Float Glass Line Integration
3.2.2.6	*	Fusion Glass Line Integration
	M-5	Foam Core Finishing [a]
	M-6	Foam Extrusion Integration [a]
3.2.2.7	M-7	Adhesive Application
3.2.2.8	M-8	Site Factory Requirement
3.2.2.9	*	Flexspline Optimization
3.2.2.10	*	Wave Generator Configuration
3.2.2.11	*	Gear Forming Processes
3.2.2.12	*	Turret Bearing Selection

* Indicates studies initiated during current study phase.

a - These trade studies were deleted as a result of D-2, which eliminated the foam core mirror.

3.2.2.1 D-2 Low Cost Reflector - Manufacturing supported the low cost reflector trade study by providing cost estimates for the alternate mirror module configurations. The trade study and alternates are described in Table 3.2.2-1. Significant results are:

- o Eliminated the foam core and galvanized sheet backing
- o Improved reflectivity with .060 fusion glass
- o Achieve lower manufacturing costs with fewer parts

The alternates evaluated were:

Alternate 1 - The 0.125" second surface mirror supported on a corrugated steel backing resulted in lower material costs than the baseline, but had lower optical performance than the fusion glass of Alternate 2, as discussed in Section 2.2.2.

Alternate 2 - Laminated fusion and float glass supported on stringers has a high reflectivity, therefore reducing the relative cost.

Alternate 3 - The .125" float glass bonded to stringers, while most cost effective, subsequently failed the hail impact test, as discussed in Section 2.3.3.

Alternates 4 & 5 - These alternates, using either 1" or 2.2" foamglas as the backing support for the reflective surfaces, were not cost effective due to the higher costs of the foamglas versus the other methods.

Alternate 6 - The edge clamped laminated mirror concept was not cost effective due to the quantity of details and complexity of the assembly. This concept also resulted in a 12% reduction in the reflective surface of the heliostat.

Table 3.2.2-1

LOW COST REFLECTOR (D-2)

OBJECTIVE: To evaluate mirror module panel designs in order to reduce material and subassembly costs.

CANDIDATES: Baseline - Foam core sandwich panel consisting of a .125 mirror and .022 steel back sheet bonded to Styrofoam core and (4) steel cross beam attach cups bonded to the back sheet. (Figure 3.2.2.1-1).

Alternates

1. .125 glass reflector bonded to a (2) piece corrugated steel back-up structure which is bonded to the cross beams (Figure 3.2.2.1-2).
2. Laminated .060 fusion glass and .188 float glass adhesive bonded to the reflector support structure and bolted to the cross beams (Figure 3.2.2.1-3).
3. .125 glass reflector bonded to (4) hat sections and bolted to the cross beams (Figure 3.2.2.1-4).
4. .125 glass reflector adhesive bonded to foamglas core and bonded to the cross beams (Figure 3.2.2.1-5).
5. .125 glass reflector and .125 glass backing adhesive bonded to foamglas core and bonded to the cross beams (Figure 2.3.3.1-6).
6. (60) Laminated .125 float glass reflector and .188 glass backing attached to galvanized steel supports with clamp strips and sheet metal screws (Figure 3.2.2.1-7).

In addition to the above alternates, data was prepared for comparison of costs, iron content and reflectivity of various laminated glass configurations. (See Section 2.2.2)

LOW COST REFLECTOR (D-2) Cont'd)

CONSIDERATIONS:

- o Stiffness and shape stability over the temperature range must be maintained to provide the correct panel contour (flat or single curvature).
- o Short wave length flatness must be maintained to give a satisfactory image.
- o The mirror backing paint must be protected from excessive weathering.

APPROACH: Detailed estimates of materials, fabrication and assembly costs for those parts affected by the changes.

RESULTS:

Alternate No.	Relative Cost Relationship
Baseline	1.0
1	.87
2	.93
3	.75
4	*
5	*
6	*

* Initial evaluations showed alternates were not cost effective.

Alternates 1 and 3 were rejected for the following reasons.

#1 lower optical performance than fusion glass. Reference Section 2.2.

#3 failed the hail impact test. Reference Section 2.3.

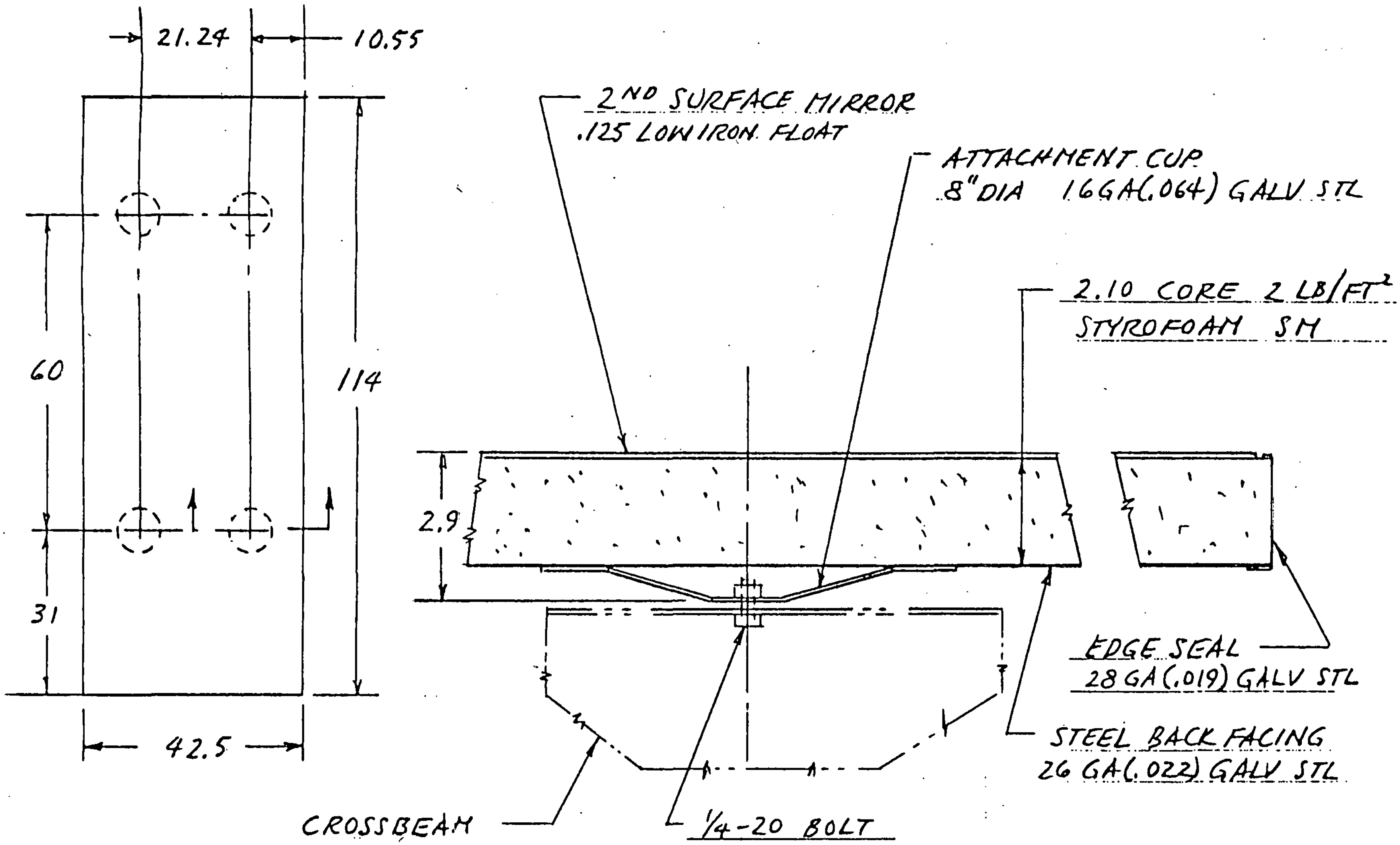


Figure 3.2.2.1-1 Baseline - Foam Core Panel

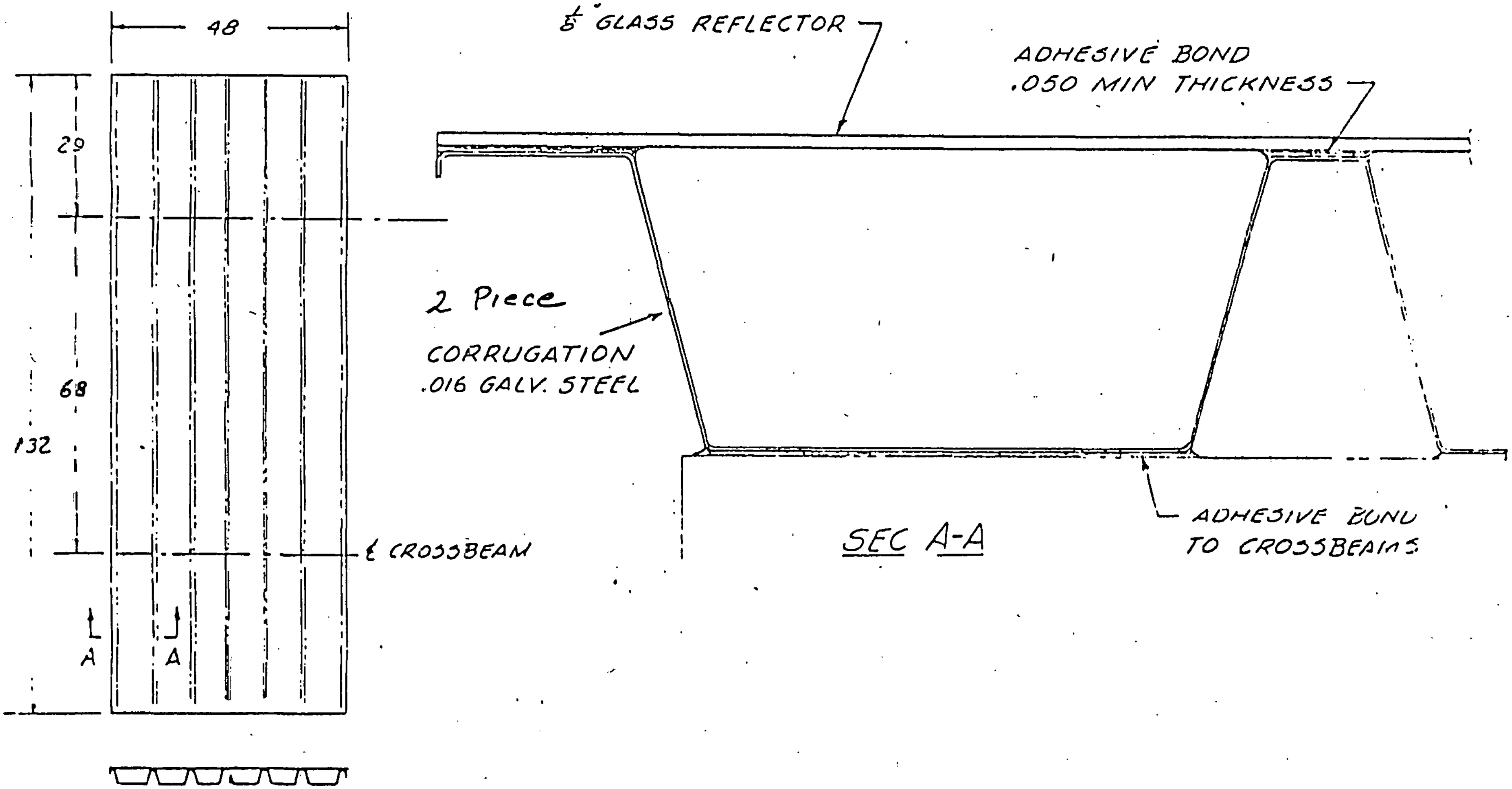


Figure 3.2.2.1-2 Alternate 1 - Corrugated Support

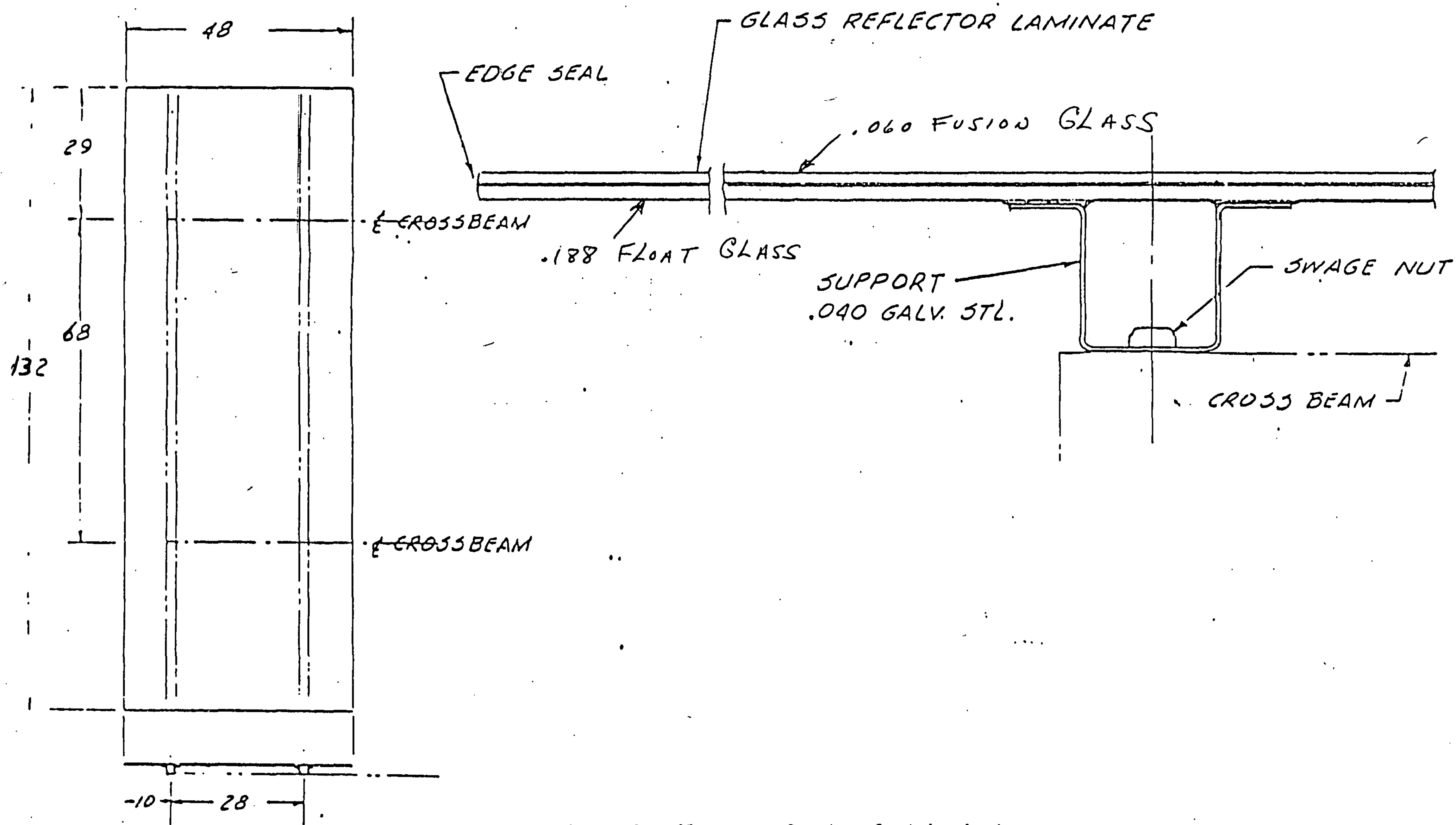


Figure 3.2.2.1-3 Alternate 2 - Low Cost Laminate

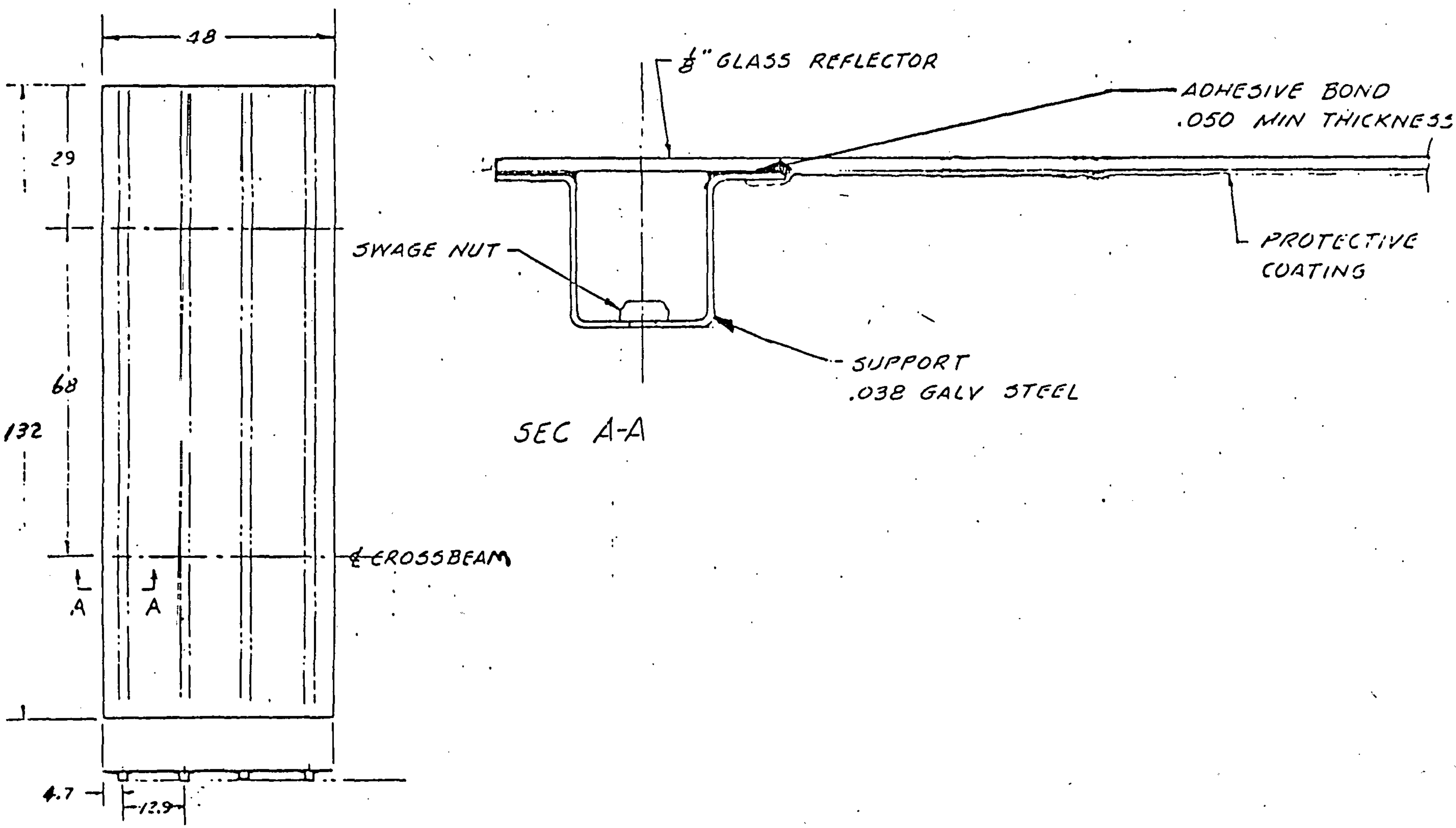


Figure 3.2.2.1-4 Alternate 3 - Stringer Support

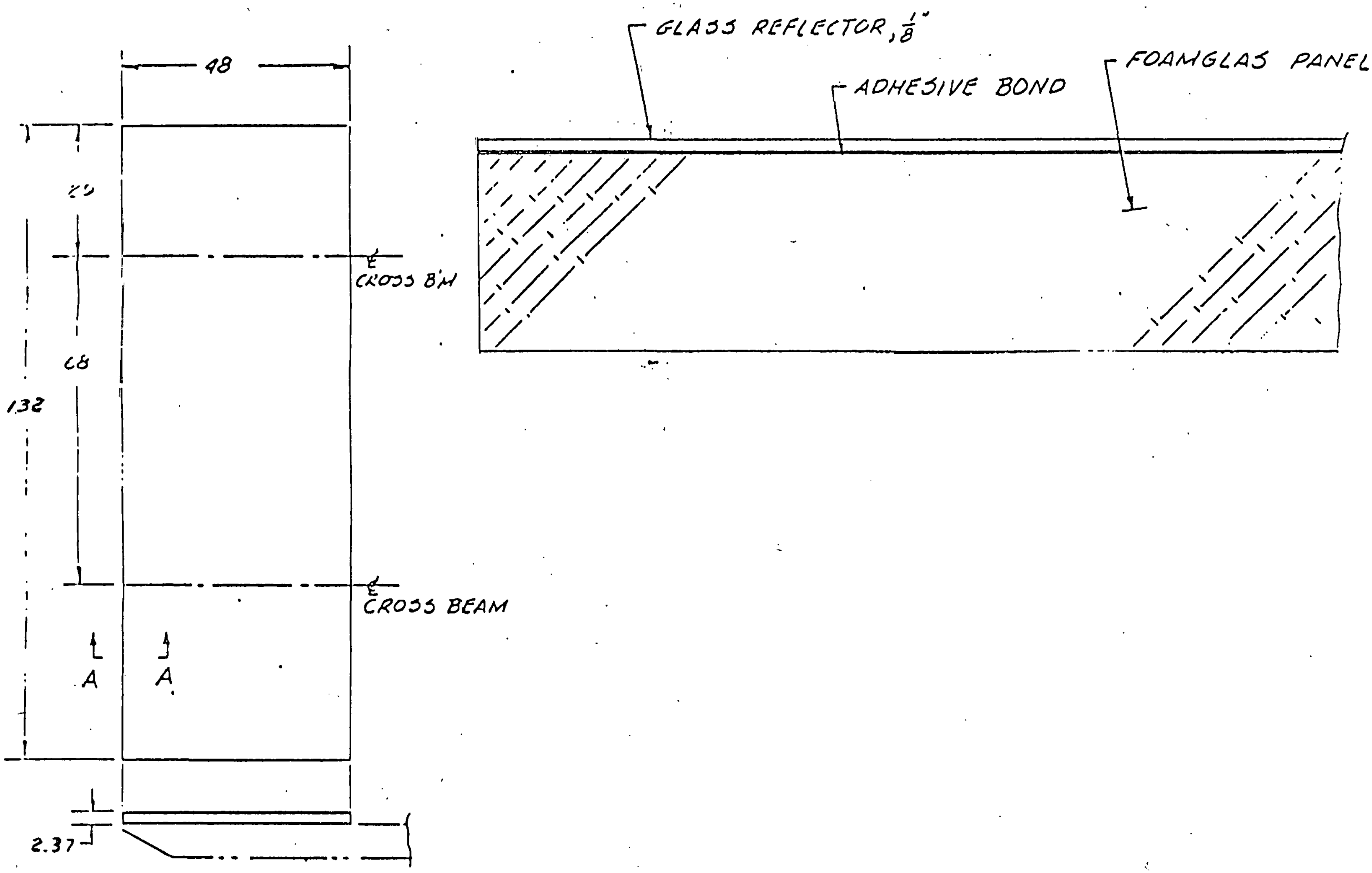


Figure 3.2.2.1-5 Alternate 4 - Foam Glass Support

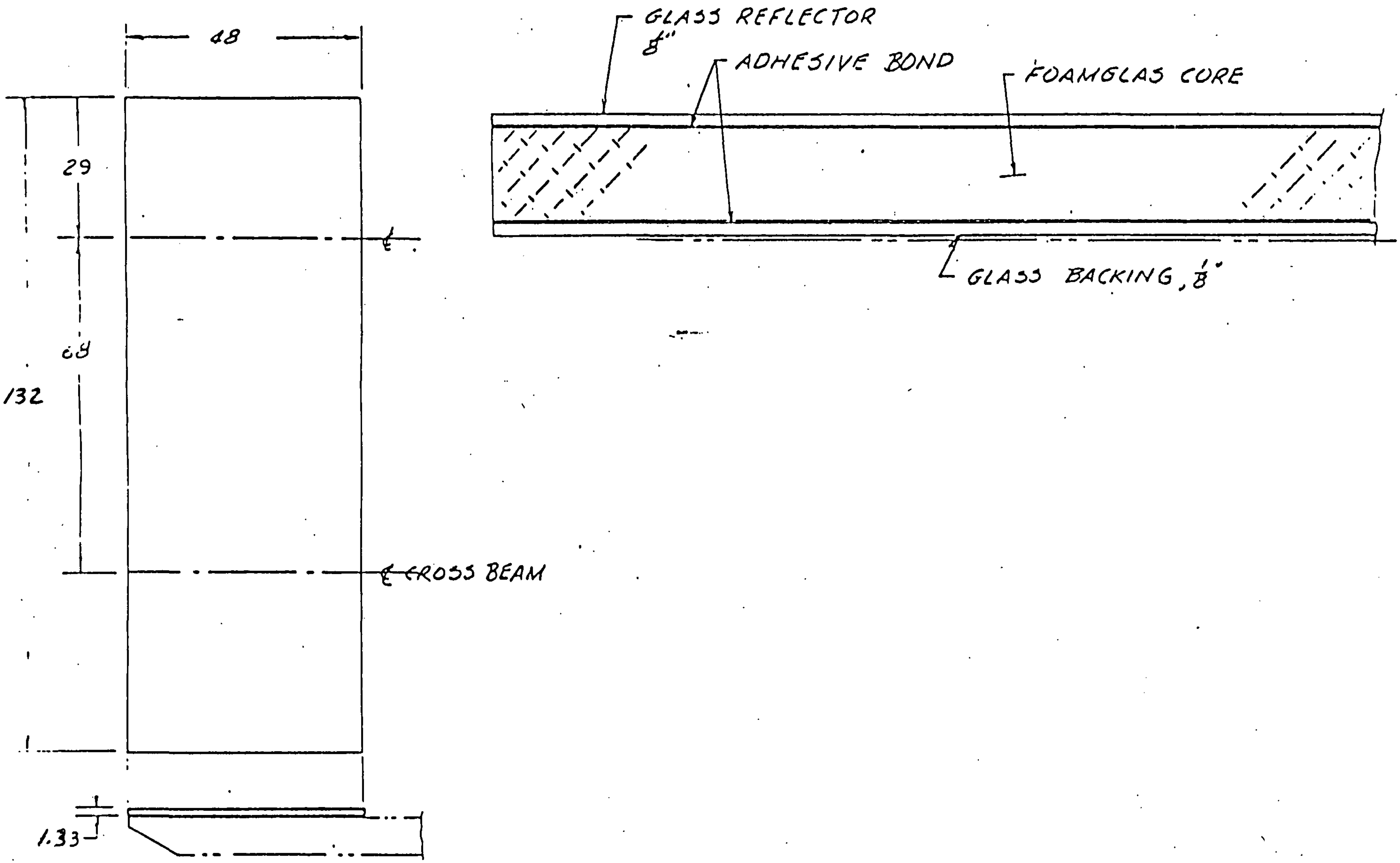


Figure 3.2.2.1-6 Alternate 5 - Foam Glass Sandwich

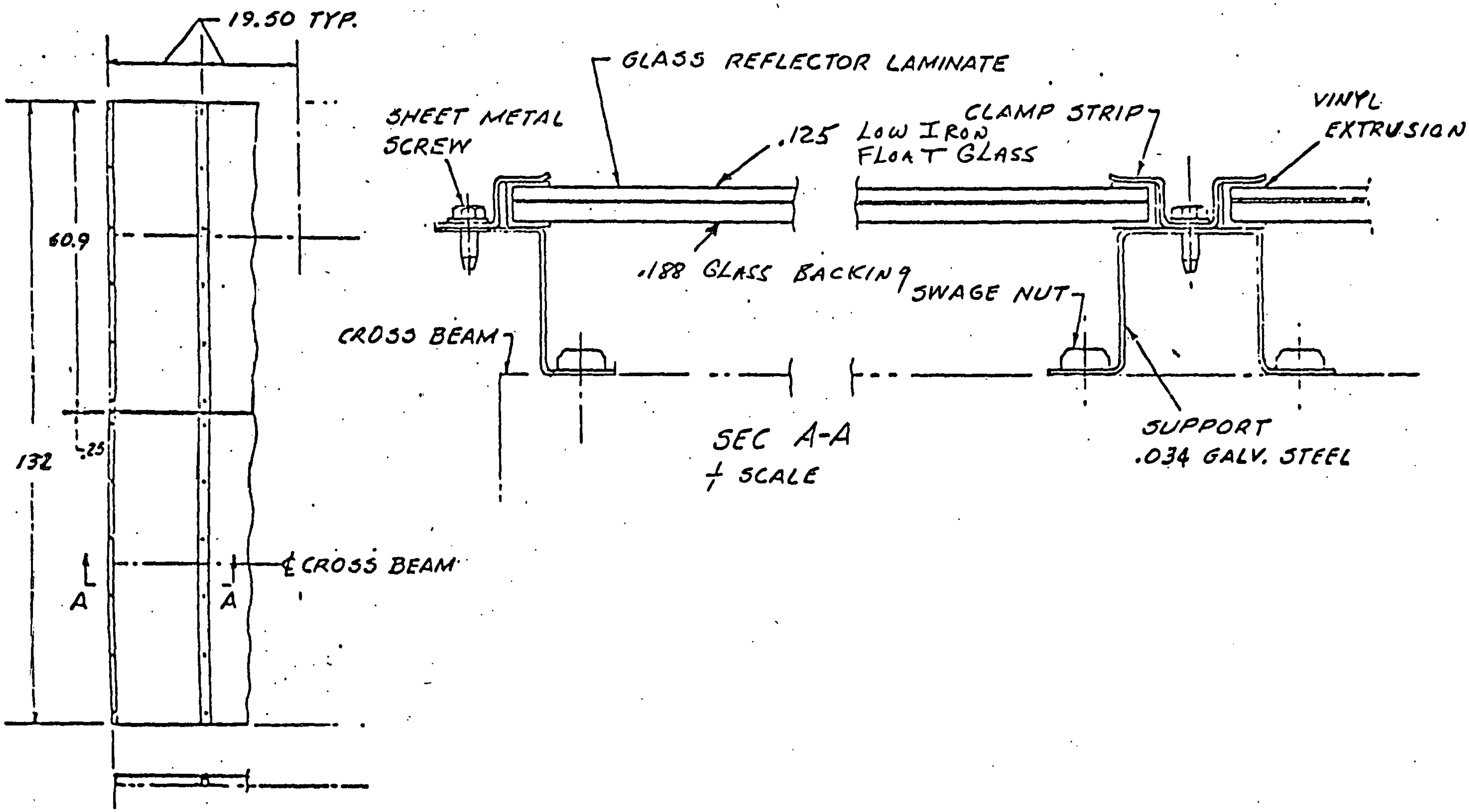


Figure 3.2.2.1-7 Alternate 6 - Laminate With Clamped Support

3.2.2.2 D-5 Reflector Attachment

The support of this trade study included review of the concepts, recommendation for improvements, and sufficient analysis of the alternates to insure the selection of the lowest cost alternate. The primary benefit of this trade study is the freedom to assemble the heliostat on the foundation in the field and delete the site assembly factory, if desired. Results are summarized in Table 3.2.2-2. Significant additional findings are:

- Reduces the length of the main beam and height of the outboard beam reduces material costs
- Increases structural strength in mirror corner areas

The alternates evaluated were:

Alternate 1 - In this design the cross beams are divided in two and are joined on installation to fittings on the main beam. One disadvantage to this concept is the quantity of detail parts required to make the necessary joint, resulting in higher assembly costs. Also, the torque tube is long and would be difficult to transport and assemble to the drive unit.

Alternate 2 - This design split the main beam into three pieces and reduced the diameter of the outboard sections. This resulted in two cross beam configurations to accommodate the rolled flanges on the 12" diameter tubes. The results were higher material costs due to the increased weight of the detail components.

Alternate 3 - Structural support between the inboard and outboard cross beams is accomplished by two diagonal beams, eliminating the requirement for a torque tube. This concept increases structural support in the corner areas where the mirror deflections were previously maximum and allows the size of the outboard cross beam to be greatly reduced.

TABLE 3.2.2-2

REFLECTOR ATTACHMENT (D-5)

OBJECTIVE: To design new joints along the main beam (torque tube) in order to reduce total material and installation costs.

CANDIDATES: Baseline - The main beam is a continuous 10 inch diameter, 1/4 inch wall standard pipe. Welded flanges attach to the drive unit. (Figure 3.2.2.2-1)

Alternates - The alternates will separate the beam. The inboard section is made integral with the drive unit.

1. (4) segment reflector, each consisting of two cross beams that are joined on installation to fittings on the main beam. (Figure 3.2.2.2-2)
2. (2) segment reflectors, each consisting of a 12" diameter torque tube and (2) cross beams. The attachment is made to a 16" diamter main beam that is attached to the drive unit. (Figure 3.2.2.2-3)
3. (2) segment reflectors, an inboard and outboard cross beam and (2) diagonal channel beams outboard of the joint instead of the tube. The structure is attached to a short 82" long main beam with (8) bolts located four above and four below the structural center line. (Figure 3.2.2.2-4)

CONSIDERATIONS:

- o Separating the main beam will be important in trade M-8, Site Factory Requirements and trade I-1, Optimum On-Site Transportation.
- o Retain adequate structural stiffness.

APPROACH: Detailed estimates of material, labor, tooling, and assembly costs.

RESULTS:

Alternate No.	Relative Cost Ratio
Baseline	1.00
1	*
2	*
3	.86

* Initial evaluation indicated these alternatives were not cost effective.

Alternate 3 costs indicated reduced material costs compared to the initial baseline design.

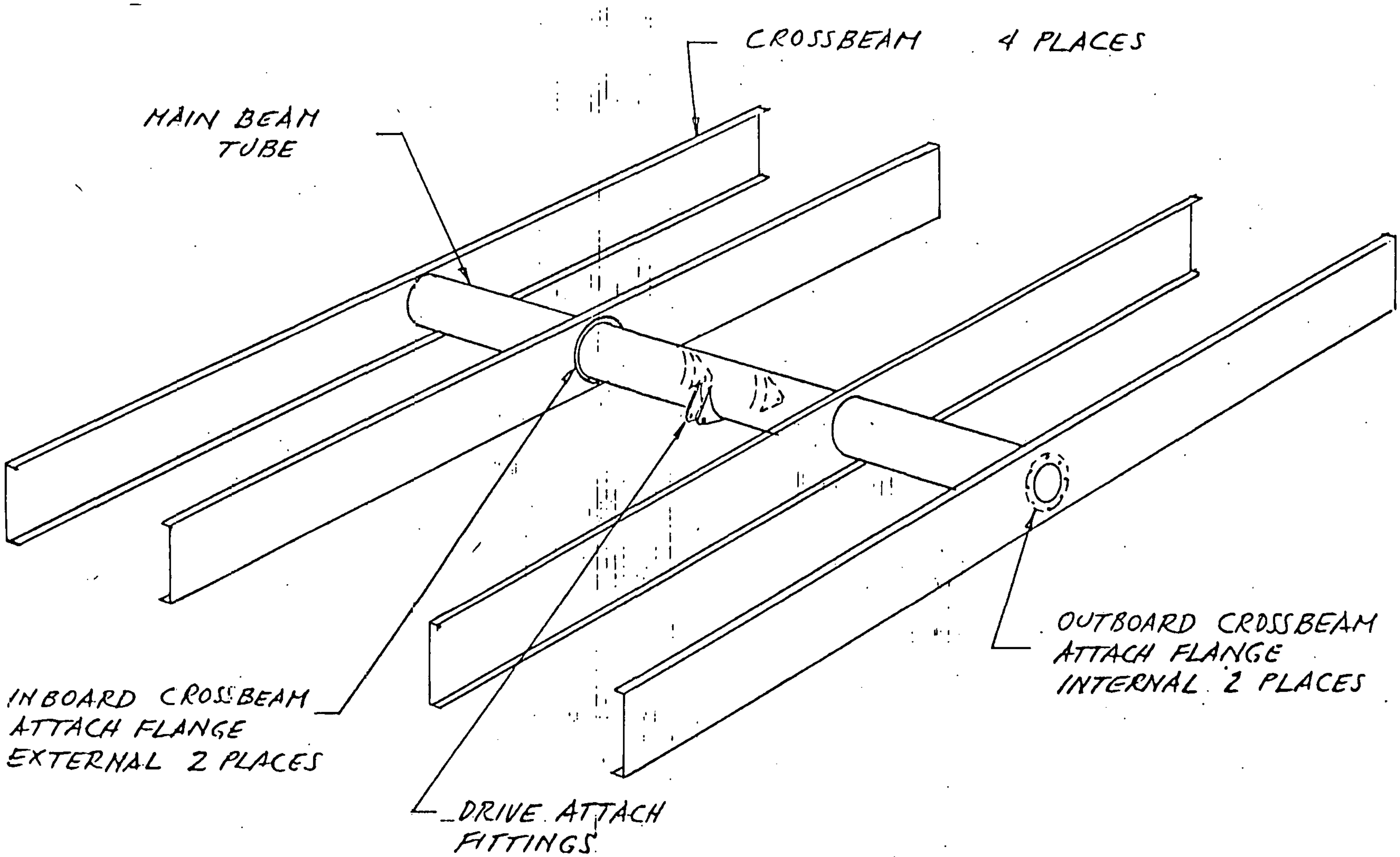


Figure 3.2.2.2-1 Baseline - Reflective Surface Supporting Structure

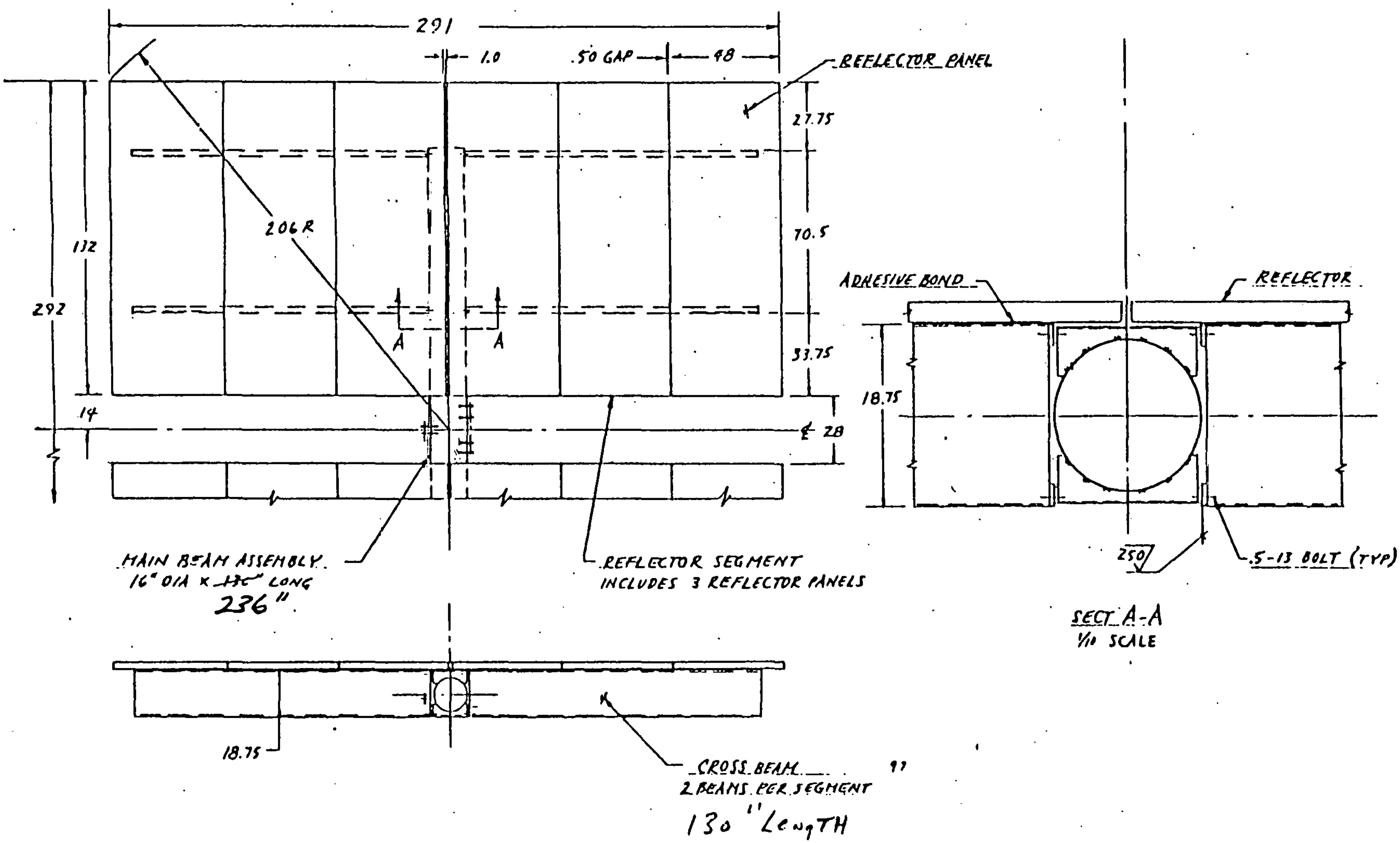


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Figure 3.2.2.2-2 Alternate 1 - Four Segment Reflector

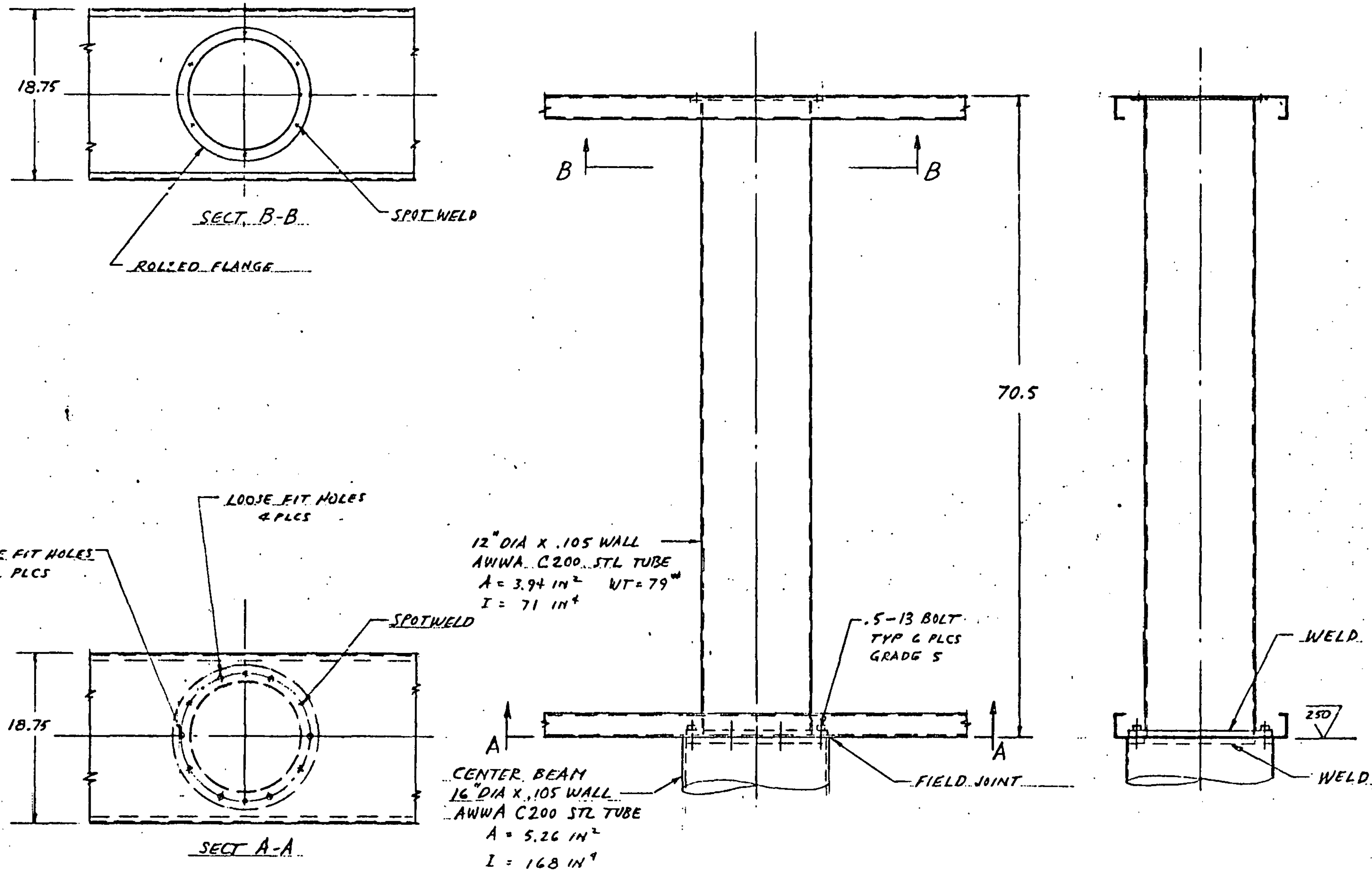

Figure 3.2.2.2-3 Alternate 2 - Two Segment - Three-Piece Tube

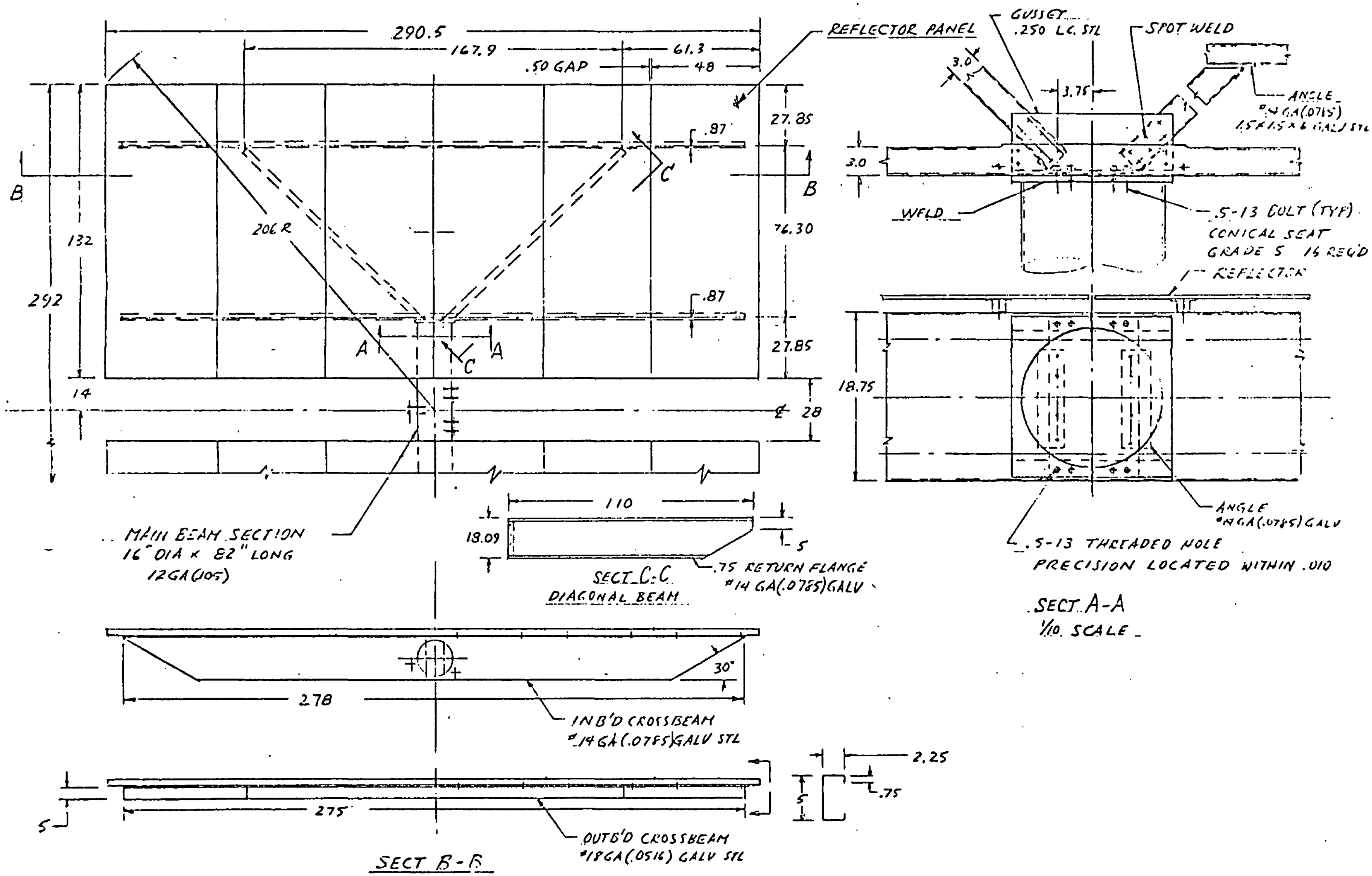

Figure 3.2.2.2-4 Alternate 3 - Two Segment - One-Piece Tube

3.2.2.3 M-1 Integral Pedestal/Foundation

This trade study was conducted to define cost reductions which might result from integrating the pedestal and foundation, see Figure 3.2.2.3-1, and improving the interface between the pedestal and the azimuth drive, see Figure 3.2.2.3-2. Stearns-Roger supported the pedestal/foundation portion of the study. Results are summarized in Table 3.2.2-3.

Pedestal and Foundation - Studies of welding the pedestal to flat or flanged metal plates were pursued. These metal plates are bolted to a concrete foundation. One alternative method was the flat plate/doubler weld assembly. This method was compared with concrete piling/tapered steel pipe assembly to the pedestal. Labor and material costs of either foundation (concrete base or piling) are approximately the same. However, total material cost of the piling approach is less than the welded assembly. This is due to the additional steel used in the welded plate and doublers. Field assembly of the piling approach entails only a slip fit of the pedestal shaft over the male stand. This represents less installation labor than the welding of plate and doubler to the pedestal shaft, bolting the plate to the foundation (with potential alignment and shimming costs).

Attachment of Pedestal and Drive Mechanism - A formed plate mounting was selected over the initial baseline design of a flat plate and ring because of lower material costs.

3.2.2.4 M-2 Drive Housing and Drag Link Materials Reduction

Housing - Castings provide blanks for both the azimuth drive housing, see Figure 3.2.2.4-1, and the drag link, see Figure 3.2.2.4-2. The blanks require only limited finish machining, hence reduce assembly costs. However, the cast blanks are substantially more expensive than an equivalent amount of plate stock. These studies were conducted to determine whether costs could be reduced by using built-up (welded) structures. Results are summarized in Tables 3.2.2-4 and 3.2.2-5. A breakout box and a cover plate attached to the top area of the housing are common to both approaches and as a result are not considered in this trade study. The current design reflects a bolt assembly of flexspline to this housing. This could change to a weldment but would have only a minor effect on total results of the study. Machining the housing is not a factor in this trade since the cost is approximately the same relative to either approach.

Baseline - Casting Type Housing - This casting would approximate the final housing configuration except for the possible addition of two torque tube support flanges and support gusset. For purposes of this trade study it was assumed that the housing can be cast complete.

Alternate Method (-2) - Welded Assembly Housing - The housing is an assembly of eight different parts. Estimates of assembly costs were based on current technology automation, i.e., it is probable that reduction in assembly costs will accrue with automation developments in areas of robotic assembly, parts positioning and simultaneous welding.

Drag Link - Final machining and cleaning operations are the same for either approach. Manufacturing costs for these operations are therefore not included in trade-off summaries and ratios.

Baseline - Machined Drag Link Casting - It is assumed that this part would be cast in the final configuration leaving only finish machining operations to be performed. Costs reflect purchase price of the casting including material, labor and die costs.

Alternate Method - Welded Drag Link Assembly - The weldment approach involves fabrication and assembly of (2) arms, (4) pads, (1) yoke and (2) ears. The (2) arms will be formed at the same time in one die on a mechanical press. The metal pads will be blanked out in a punch press. Parts are then assembled. Conveyorization and weld automation were based on technology available now and are reflected in cost estimates related to this approach.

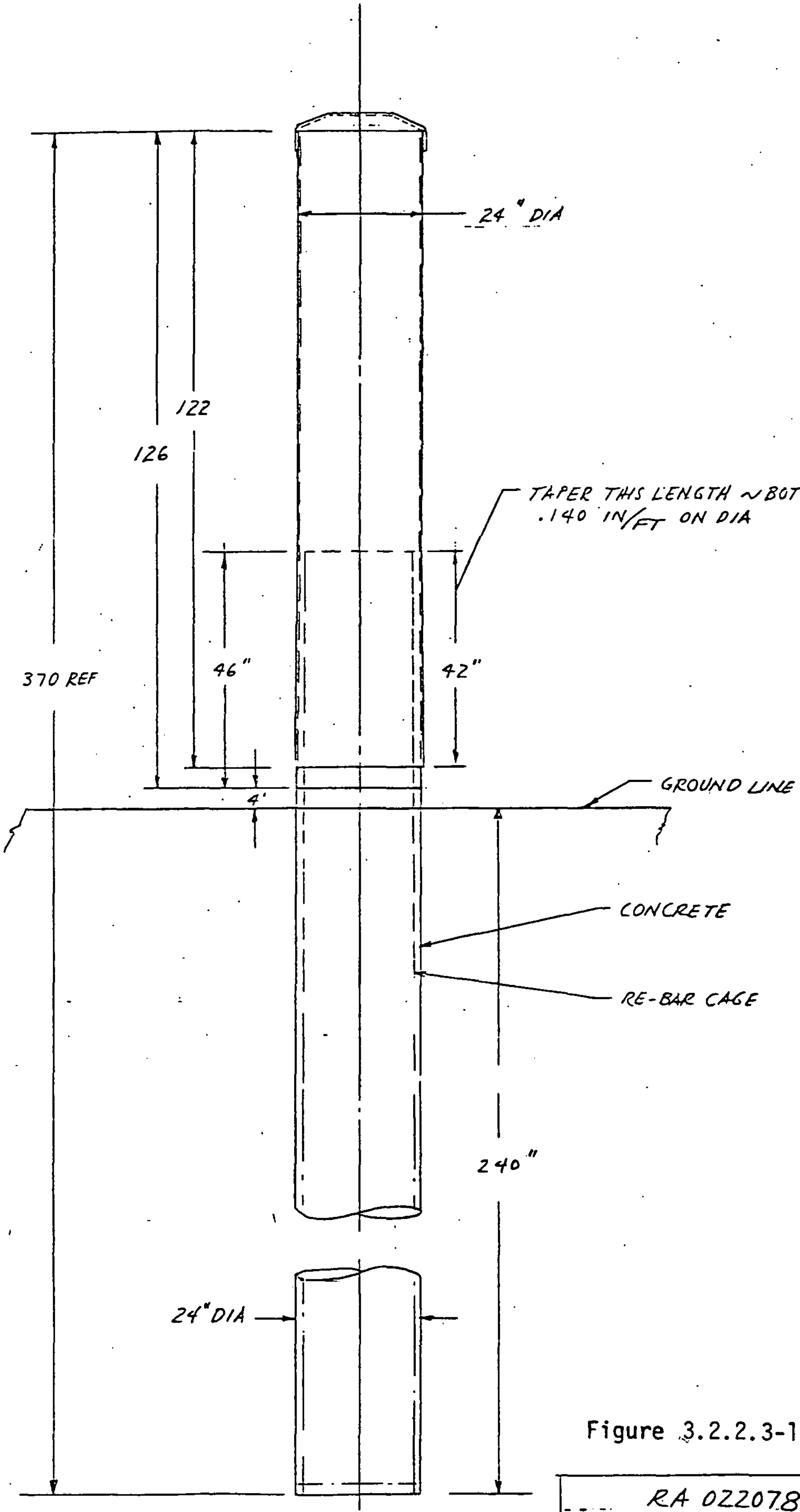

Figure 3.2.2.3-1

528 FT

RA 022078

PEDESTAL - PILE TYPE I

1/20 SCALE 2-20-78 C.R.A.

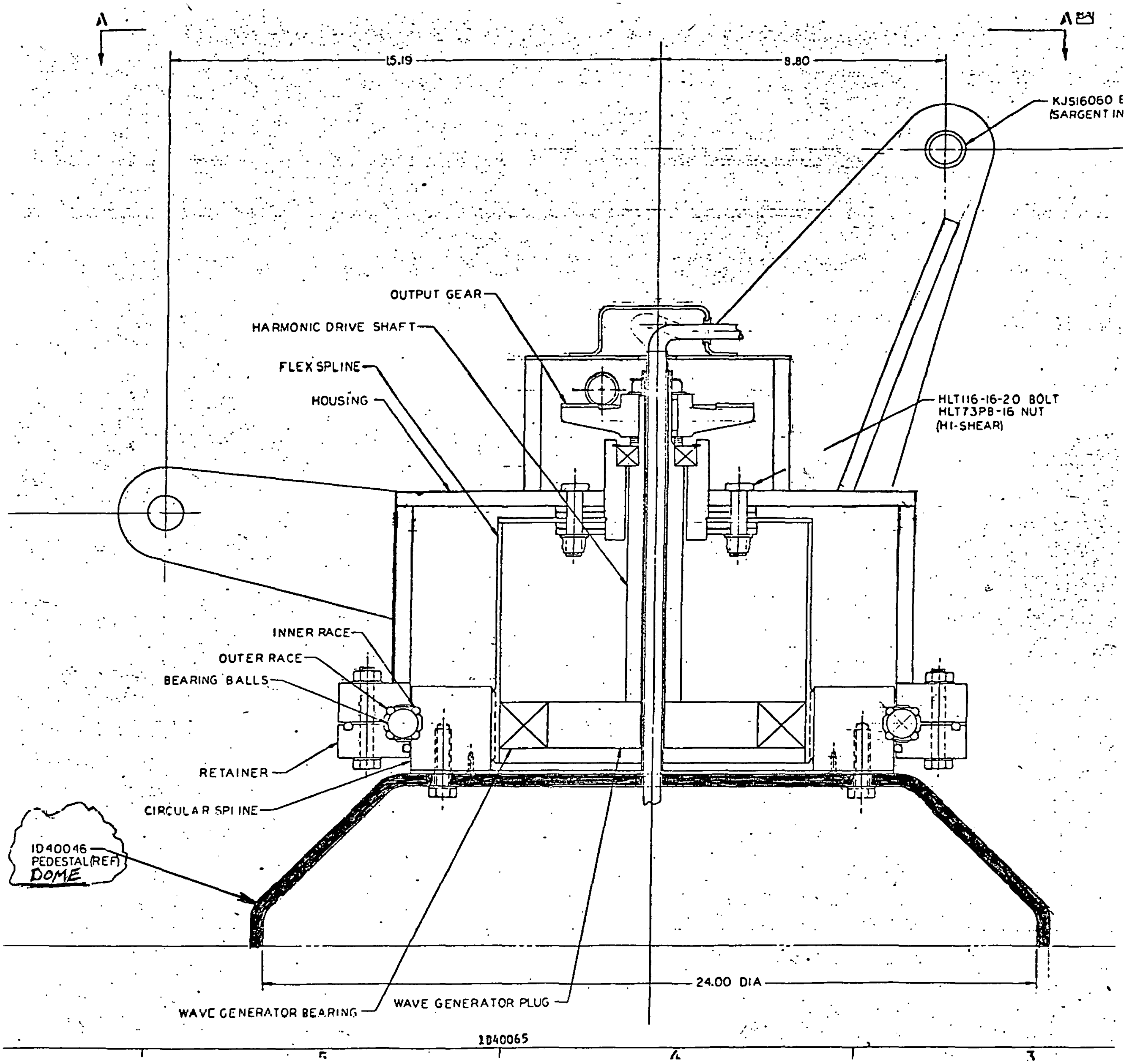

Figure 3.2.2.3-2 Dome - Pedestal/DR. Housing Attach

TABLE 3.2.2-3

INTEGRAL PEDESTAL/FOUNDATION (M-1)

OBJECTIVE:	To reduce materials and labor costs by optimizing design and fabrication of the pedestal and foundation and by simplifying the top flange attachment.
BASELINES, JULY 77:	<u>Baseline Pedestal and Foundation</u> - Precast and set a concrete foundation. Fabricate a steel pedestal with top and bottom attach flanges. Assemble pedestal to foundation. <u>Baseline Flange Attachment</u> - Fusion weld torch-cut plate stock to pedestal pipe.
ALTERNATE METHODS:	<u>Pedestal and Foundation Alternatives</u> -- Preliminary studies conducted with Stearns-Roger related to (a) Precasting the foundation with an integral fabricated steel pedestal with a top attach flange and (b) Replacing the pedestal and foundation with a piling, either cast on site or precast and driven indicated that some aspects of each approach had merit. However, further evaluation revealed two other, more cost effective designs utilizing some facets of these earlier alternatives. These alternates are (1) Extend a drilled pier foundation about 4' above grade, using a tapered, thin wall steel tube as a form, and mate to a matching flare on the base of the pedestal to form a friction joint (2) Weld the pedestal to a torch cut steel plate which in turn is stud bolted into a concrete base. <u>Attachment Alternatives</u> - Several flanged attach alternatives as well as formed and flat plate and welded rings were considered as methods of attaching the drive mechanism to the pedestal. From these alternatives, a formed plate welded to the pedestal and bolted to the drive mechanism was selected for further study. This approach was then compared with the baseline to indicate the most cost effective method.
CONSIDERATIONS:	• Cost of materials. • Fabrication, forming, machining and processing of materials. • Site preparation • Assembly (factory and site) • Manufacturing equipment and space required • Transportation

TABLE 3.2.2-3

INTEGRAL PEDESTAL/FOUNDATION (M-1)

RESULTS:

- Pedestal and Foundation - The selected approach is a tapered steel pipe over a reinforced concrete piling, extending above ground and utilized as a male base. To this base is mated a tapered (female) steel tubing pedestal.

- Pedestal/Drive Mechanism Attachment - The most cost effective method utilizes the formed steel plate mounting. Cost trades result in a cost ratio advantage over the baseline method of .41 to 1.00.

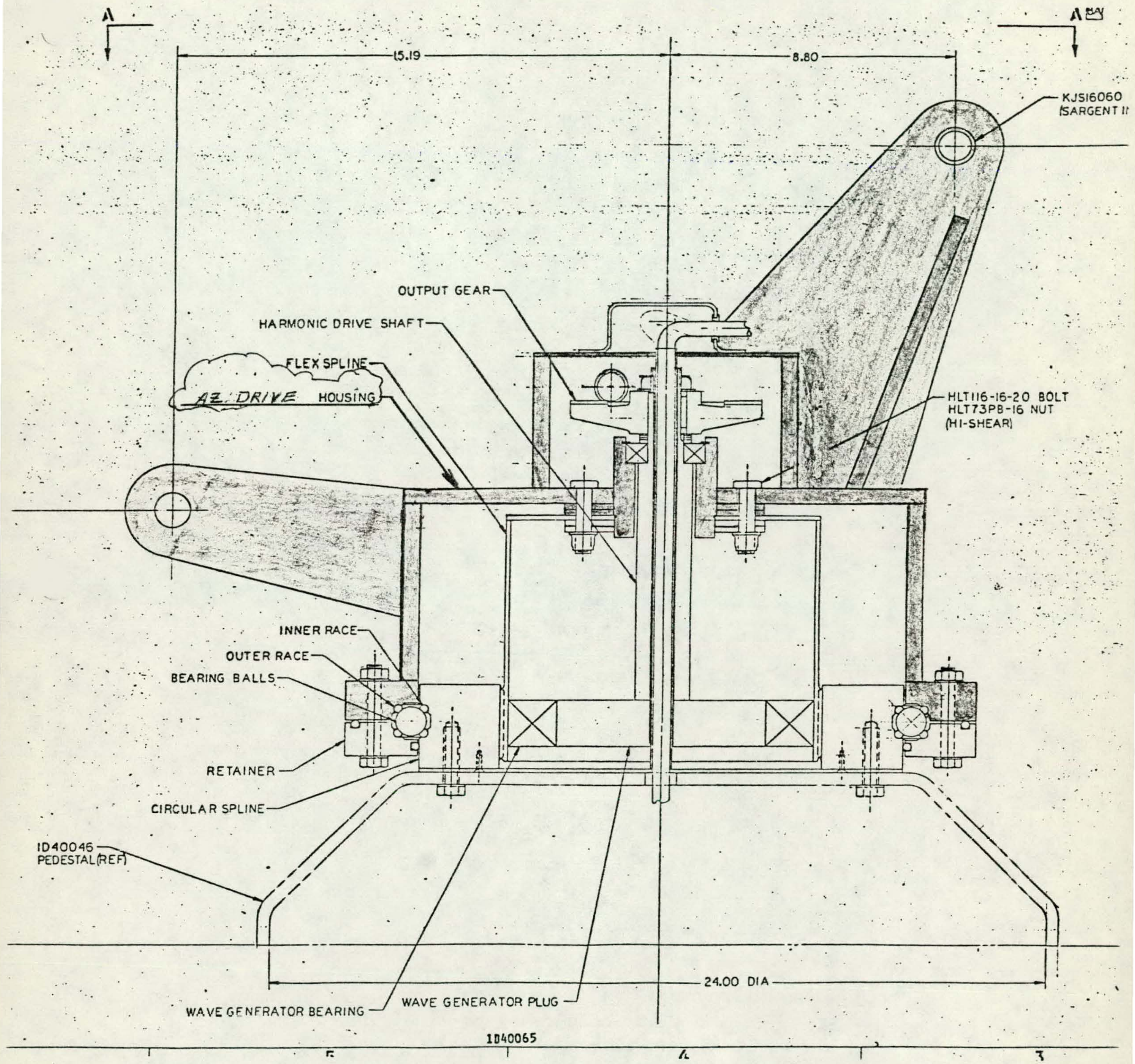

Figure 3.2.2.4-1 AZ. Drive Housing Assembly

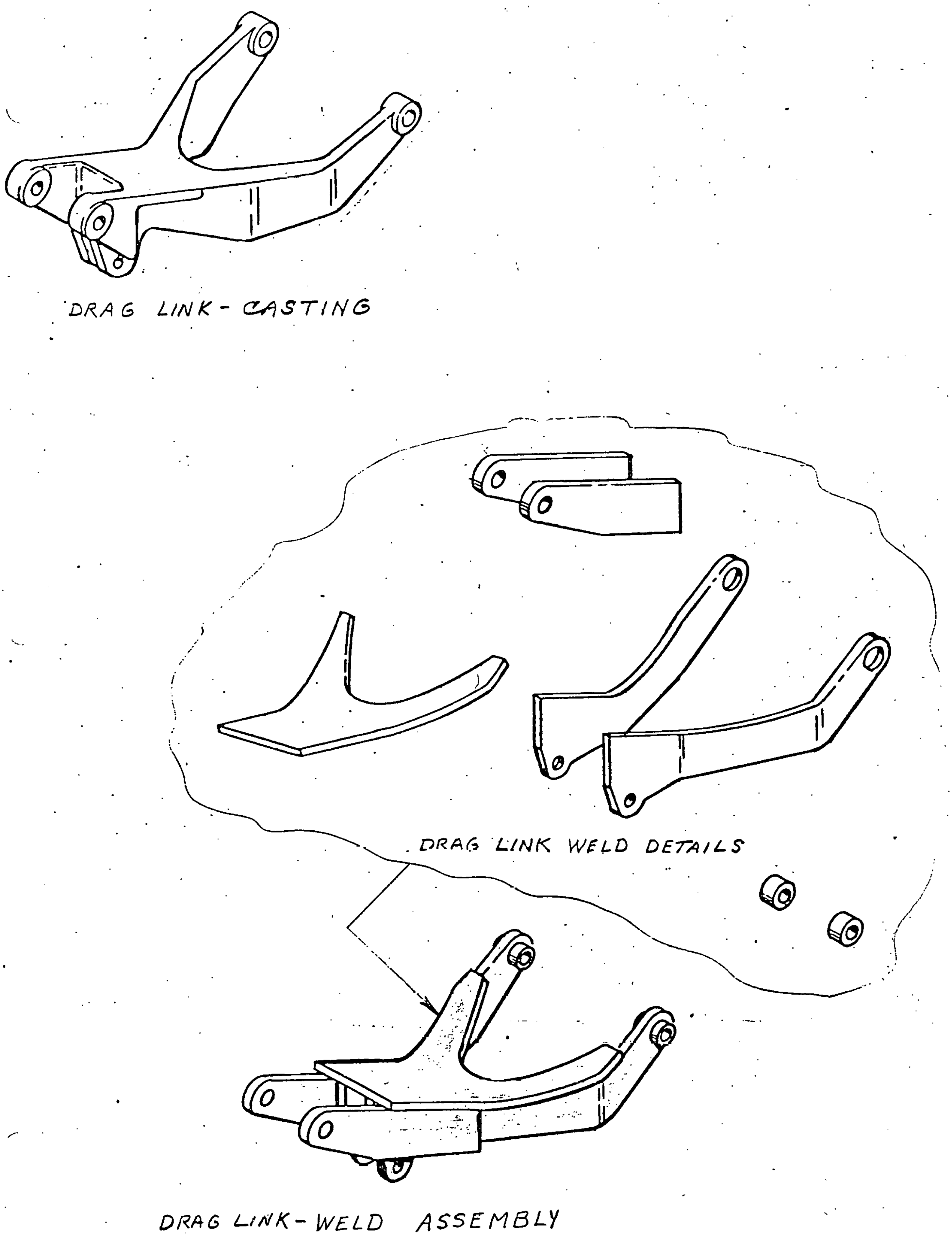

Figure 3.2.2.4-2 Drag Link Assembly

TABLE 3.2.2-4

DRIVE HOUSING MATERIALS REDUCTION (M-2)

OBJECTIVE:	To reduce materials and labor costs of the drive housing.
BASELINE:	Baseline (-1) - Machine the drive housings from castings.
CANDIDATE:	Alternate (-2) - Machine the drive housing from formed and welded assemblies.
CONSIDERATIONS:	Consideration was given to the potential limitations in supplier ability to deliver castings at the production rates.
APPROACH:	Detailed Estimates o Cost of Materials o Transportation o Manufacturing Labor o Tooling and Equipment o Facilities
RESULTS:	A number of design and manufacture approaches for the baseline housing casting were analyzed prior to finalizing trades between casting and welded assembly. Preliminary analysis also included possible forged and deep drawn approaches. Selected as the best methods were the baseline casting and a weldment concept. These were then studied for cost comparisons. On the basis of these studies, it was determined that the casting approach cost appreciably more than the weldment version. A cost ratio of 1.00 to .58 resulted in favor of a welded assembly. The cost of material, i.e., plate stock versus casting was a key factor in the study. Supplier data indicated a material cost difference of 4:1 in favor of plate stock. The welded assembly has been selected as baseline approach.

TABLE 3.2.2-5

DRAG LINK MATERIALS REDUCTION (M-2)

OBJECTIVE:	To reduce materials and labor costs of the actuator support-drag link.
CANDIDATES:	Baseline - Machine the actuator support drag links from castings. Alternate - Machine the drag links from formed and welded assemblies.
CONSIDERATIONS:	Considerations were given to the potential limitations in supplier ability to deliver castings at the production rates.
APPROACH:	Detailed Estimates o Cost of Materials o Transportation o Manufacturing Labor o Tooling and Equipment o Facilities
RESULTS:	Cost comparisons for a drag link assembly resulted in the following: Cast and Machine Assembly - 1.00 Formed and Welded Assembly - .56 The cost of materials, i.e., plate stock versus casting was a key factor in the study. Supplier data indicated a material cost difference of 4:1 in favor of plate stock. The baseline design was changed to the weldment approach.

3.2.2.5 M-3 Mirror Line Integration - Integration of the mirror line into the factory eliminates double handling of the glass, eliminates a cleaning step, eliminates the need for mirror backing paint, and allows the use of special handling equipment to minimize breakage.

The results of this trade study are summarized in Table 3.2.2-6. It appears that mirror line integration is well justified for plants of 25,000 units per year and up.

Table 3.2.2-6

MIRROR LINE INTEGRATION (M-3)

OBJECTIVE:	To determine cost savings, point in time, and rate to incorporate mirroring into the production line.
BASELINE, JULY 77:	Transport glass from glass supplier to mirror supplier. Mirror supplier will mirror, package and transport to production factory.
ALTERNATE METHOD:	Transport glass from glass supplier to production factory. Incorporate mirroring capability in the heliostat production complex. Mirror and move glass for subsequent operations.
CONSIDERATIONS:	• Place mirroring line into an uninterrupted manufacturing sequence with the reflector panel fabrication lines. • Effect on transportation, handling, handling damage, and storage between glass supplier, mirror vendor fabrication/assembly facility.
APPROACH:	• Develop transportation, handling and handling damage estimates. • Develop costs to implement mirroring capability.
RESULTS:	• Mirror line integration becomes economical at annual heliostat production rates of 25,000 units per year. • Breakeven of a mirroring plant would occur in approximately 1.5 years (See Breakeven Chart Figure 3.2.2.5-1) at 25,000 units per year production. • The mirroring process could be effectively utilized to support assembling operations.

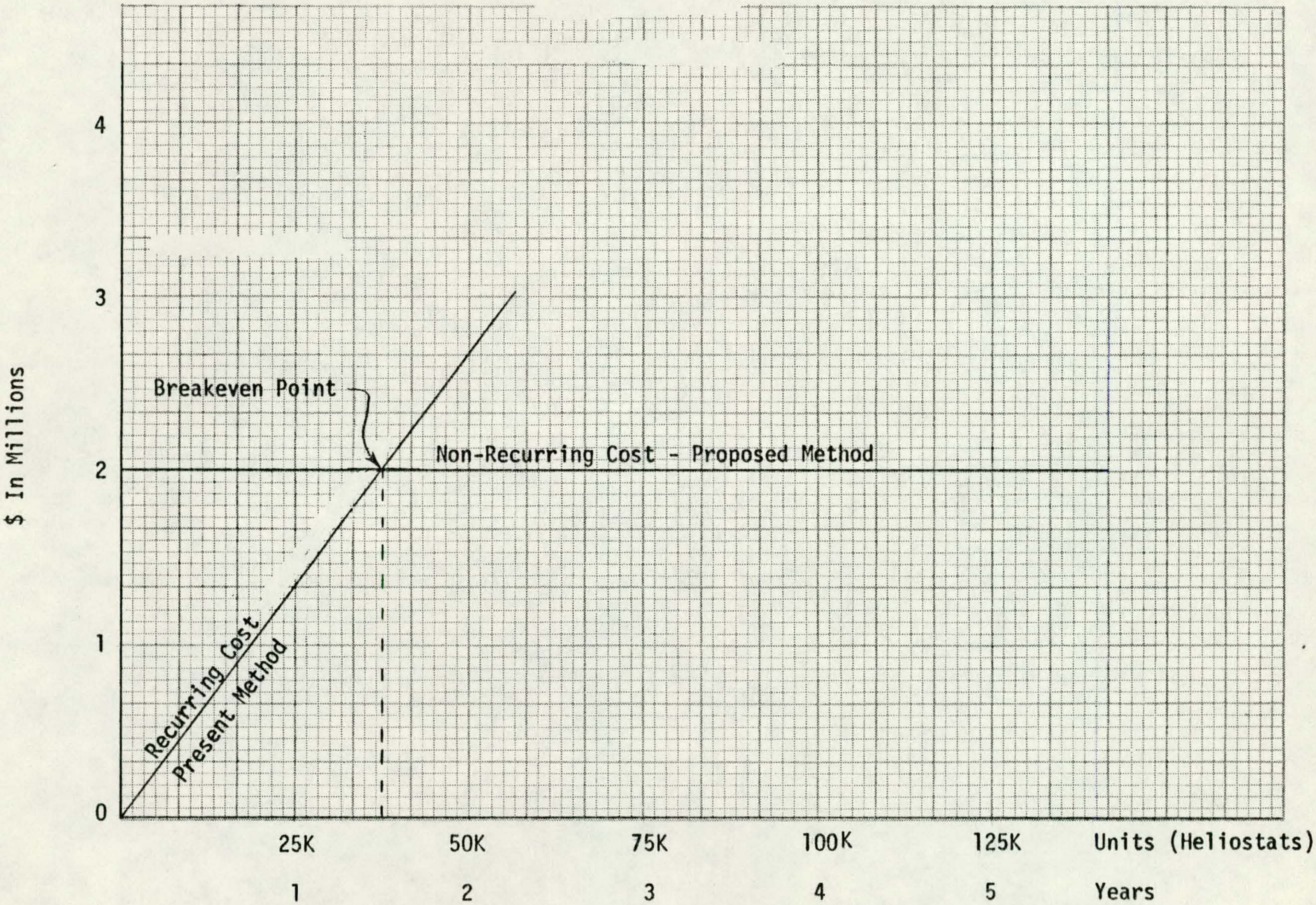

Figure 3.2.2.5-1 Breakeven Chart Mirror Line Integration

3.2.2.6 M-4 Float Glass Line Integration - Float glass plants are characterized by very large production rates which are not at all suited to the 25,000 unit per year production rates, and probably not for 250,000 units per year. However, at production rates of 500,000 units per year and up vertical integration might make sense. This trade study was conducted to determine whether vertical integration at very large production rates is beneficial. Results are summarized in Table 3.2.2-7.

It should be noted that a float glass manufacturer may be willing to invest in a new facility at less than optimum heliostat production levels. This decision would consider other market uses for glass in the Southwest area, in addition to the heliostat program requirements.

Moreover, the problem of transporting the glass remains essentially unaltered. Hence, the benefit from integrating a float glass plant is marginal, at best for even the highest production rates.

The fusion glass recommended for the mirror is made in a plant of typical capacity much less than that of a float glass plant. Current fusion glass plants would have a characteristic capacity of about 50,000 units per year. A trade study was conducted to determine whether it is profitable to integrate a fusion glass plant into the factory. Results are summarized in Table 3.2.2-8.

Integrating the fusion glass plant has additional advantages of eliminating handling and possibly cleaning steps. Moreover, it is possible that automated handling can allow the use of thinner, higher reflectivity mirrors.

Table 3.2.2-7

FLOAT GLASS LINE INTEGRATION (M-4)

OBJECTIVE:	To determine point in time and production rate to incorporate a float glass line into the heliostat production facility.
BASELINE, JULY 77:	Procure glass from existing glass manufacturing facilities.
ALTERNATE METHOD:	Include a float glass line in the heliostat production complex.
CONSIDERATIONS:	Effect on Transportation, Handling and Storage between glass supplier, mirror vendor and fabrication/assembly facility.
RESULTS:	Considering transportation, handling, and shipping container materials, float glass line integration appears to offer little economy at production rates of 250,000 units per year. Breakeven of an integrated float glass plant would occur in approximately 3.2 years at this rate. (See Breakeven Chart Figures 3.2.2.6-1).
OTHER CONSIDERATIONS:	Utilization of a dedicated and integrated float glass line would be at approximately 25% to 50% of its capacity at 250,000 units per year production. Consequently it appears that integration should occur at levels of 500,000 or greater units per year.

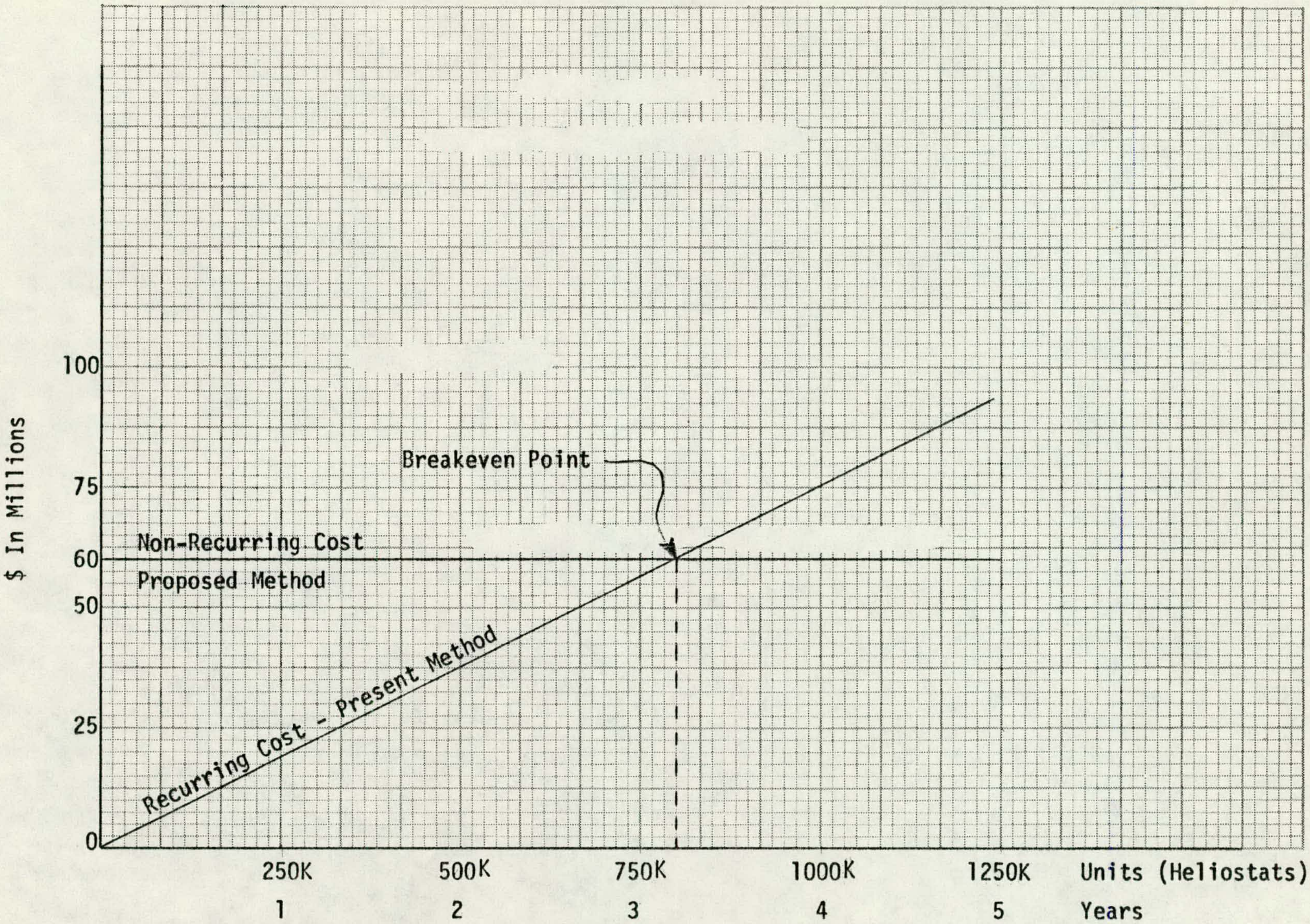

Figure 3.2.2.6-1 Breakeven Chart Float Glass Plant Integration

Table 3.2.2-8

FUSION GLASS LINE INTEGRATION (M-4)

OBJECTIVE:	To determine point in time and production rate to incorporate a fusion glass line into the heliostat production facility.
BASELINE, JULY 77:	Procure fusion glass from existing manufacturing facilities.
ALTERNATE METHOD:	Include a fusion glass line in the heliostat production complex.
CONSIDERATIONS:	Place fusion glass line into an uninterrupted sequence with the mirror fabrication lines. Effect on transportation, handling, breakage and storage between glass supplier, mirror vendor, and fabrication/ assembly facility.
RESULTS:	Considering transportation, handling and shipping container materials, fusion glass line integration appears to offer little economy until production reaches production levels of 100,000 units or greater. Breakeven of fusion glass integration would occur in approximately 4.1 years at 50,000 units per year production. (See Figure 3.2.2.6-2) It should be noted that estimates of current fusion glass capacity is approximately 50,000 units per year.

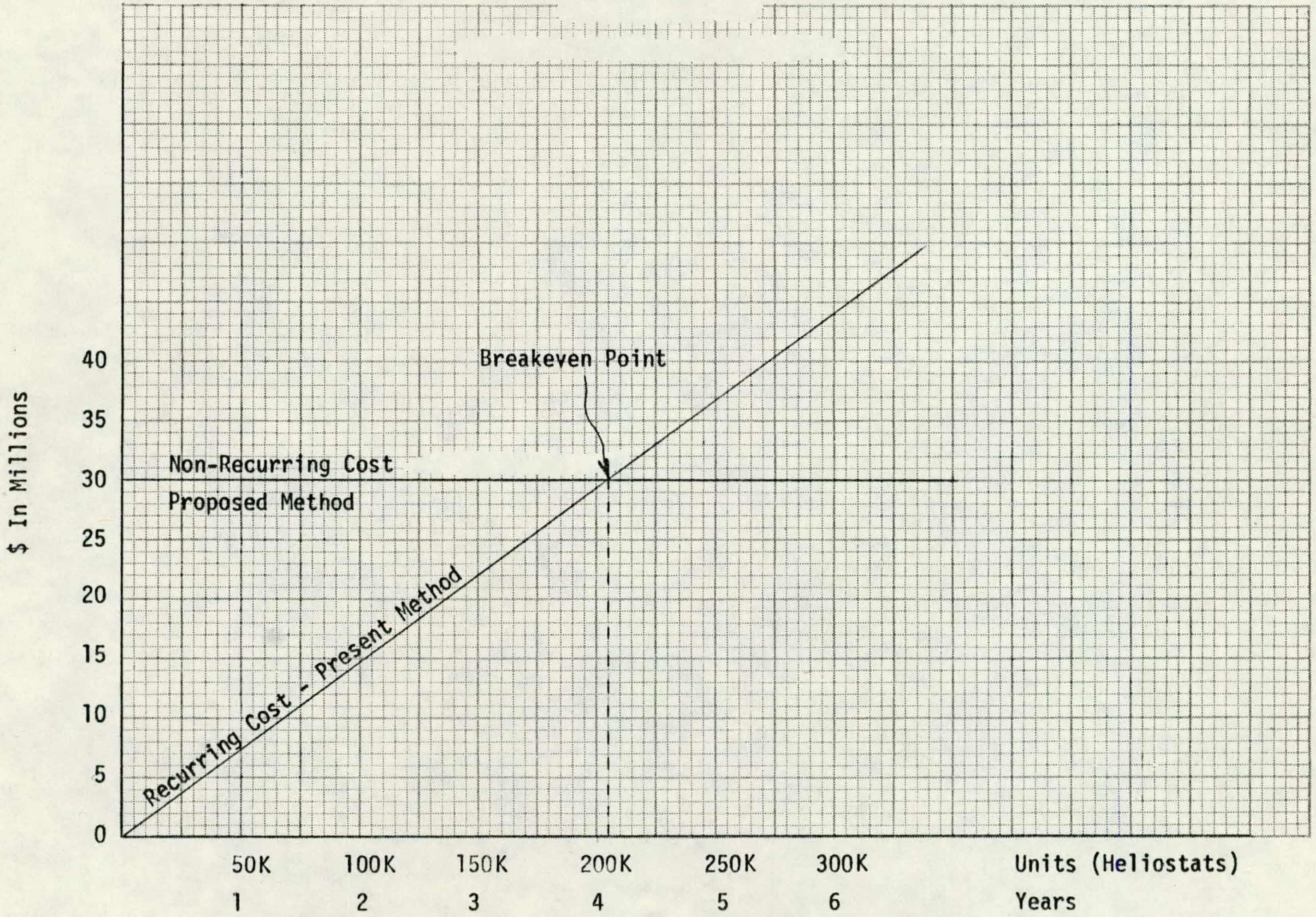

Figure 3.2.2.6-2 Breakeven Chart Fusion Glass Plant Integration

3.2.2.7 M-7 Adhesive Application - A trade study was conducted to determine whether costs could be reduced by alternate adhesive application methods. Results were summarized in Table 3.2.2-9.

The design changes resulting from the preliminary design activities has lead to a requirement for adhesive spray for the low cost laminated mirror module and extrusion for the bonding of the mirror modules to the support structure.

Table 3.2.2-9

ADHESIVE APPLICATION (M-7)

OBJECTIVE:	To determine potential cost savings obtained by spray application of adhesives.
CANDIDATES:	Baseline - Apply adhesive to components with an extruding dispenser. Alternate - Apply adhesive to reflector panel components with a nozzle spray system.
CONSIDERATIONS:	Obtain data from industry on existing systems which have been in use for similar applications. A primary consideration is the in-process adhesive loss due to adhesive mixes. OSHA requirements for toxic gas emission.
APPROACH:	Detailed estimate of labor, tooling, materials, and facilities.
RESULTS:	The configuration of the reflector and support structure that was chosen, necessitates the use of both sprayed and extruding types of application of the adhesive. In both cases, the equipment that has been chosen for the application will be designed to provide for a minimal waste of the adhesive material.

3.2.2.8 M-8 Site Factory Requirement - The site factory was required for the initial baseline design because the one piece reflective unit could not be economically transported offsite. Hence, this trade study focused on the relative merit of a site factory final assembly compared to assembly of transportable units on the foundation. Results are summarized in Table 3.2.2-10.

The study showed that costs may be significantly reduced, without operational penalty, provided economic installation approaches can be devised. The installation approach described in Section 4.4 is extremely economical. Moreover, several operational advantages accrue to the approach deleting the site factory, as indicated in Table 3.2.2-10.

Table 3.2.2-10

M-8 - SITE FACTORY REQUIREMENT

OBJECTIVE:	To lower cost through deletion of site factories by assembly of heliostats on pedestals.
BASELINE, JULY '77:	Baseline - Site factories to complete final heliostat assembly. Transport the completed unit from the site assembly building directly to the installed heliostat foundation.
ALTERNATE METHOD:	Alternate - Assemble sub-assemblies directly onto the installed heliostat foundation.
APPROACH:	Detailed estimate of labor, equipment, facilities, and transportation costs.
RESULTS:	D-5 Trade Study "Methods of Reflector Attachment" resulted in selection of a two segment heliostat configuration. This resulted in the elimination of a site factory as a requirement. That is, the current design concepts provide for a modular assembly (Drive Unit Assembly and Reflector Assembly) that can be assembled at the site. The elimination of the requirement for a site factory reduces several potential problems in addition to site factory costs. Potential problems avoided are the restrictions on location such as available labor force, utility availability (gas, water, etc.) and environmental impact. The current design approach provides sufficient latitude so that if a site factory offers advantages in relation to a specific site, the site factory could be installed.

3.2.2.9 Flexspline Optimization - Alternate methods of forming the flexspline (see Figure 3.2.2.9-1) for the harmonic drive were considered to reduce costs. Results are summarized in Table 3.2.2-11.

General note - Costs for the alternatives described in the following paragraphs include only those labor, material, equipment and facility costs that are not common to the two approaches. It is assumed that the broaching is the gear forming for the alternatives.

Baseline - Machined and Fusion Welded Assembly - Manufacturing the flexspline by this method assures the use of .375" steel tubing machined to a .312" thickness in the gear area and .150" in the remaining area of the flexspline. The round top plate will be stamped from a .150" steel sheet stock and fusion welded to the flexspline body. The gear portion of the assembly is broached.

Alternate Method (-3) - Deep Draw Can and Weld Gear End - Use .156 steel blank and deep draw (hydraulic press) the cap and thin wall portion of the flexspline including required holes. Use .375 steel tubing for gear portion of the flexspline and inertia weld to thin wall. Finish machine spline assembly and broach gear. This approach requires approximately the same fabrication labor but lower material costs.

Table 3.2.2-11

FLEXSPLINE OPTIMIZATION

OBJECTIVE: To reduce materials and labor costs by analyzing fabrication and assembly methods, including machinery, welding and deep draw approaches.

BASELINE, JULY 77: FLEXSPLINE BASELINE ASSEMBLY
Machine steel tube complete including spline (thick) area. Stamp out steel cap and fusion weld to the cylinder. Broach spline in thick area of tube.

DEEP DRAW STEEL CAN AND ADD SPLINE END
Purchase steel blank and deep draw can shape upper flexspline including pierced center hole. Saw spline end section of steel tubing and inertia weld to deep draw part. Broach spline at steel tubing end.

APPROACH: Detailed Estimates

- Cost of Materials
- Thickness variations of applicable steel tubing
- Comparative welding methods
- Forming and Machinery tradeoffs
- Manufacturing labor, equipment, tooling and space
- Transportation

RESULTS: Initial cost comparisons indicate that consideration should be given to the deep draw, inertia weld and machine assembly as an approach. Cost ratios are as follows:

Baseline (-1) - machined and fusion weld assembly -1.00
Alternate method (-3) - deep draw and inertia weld assembly -.48

While the deep draw method offers cost reduction potential, further development is required for technical applicability. This is now underway.

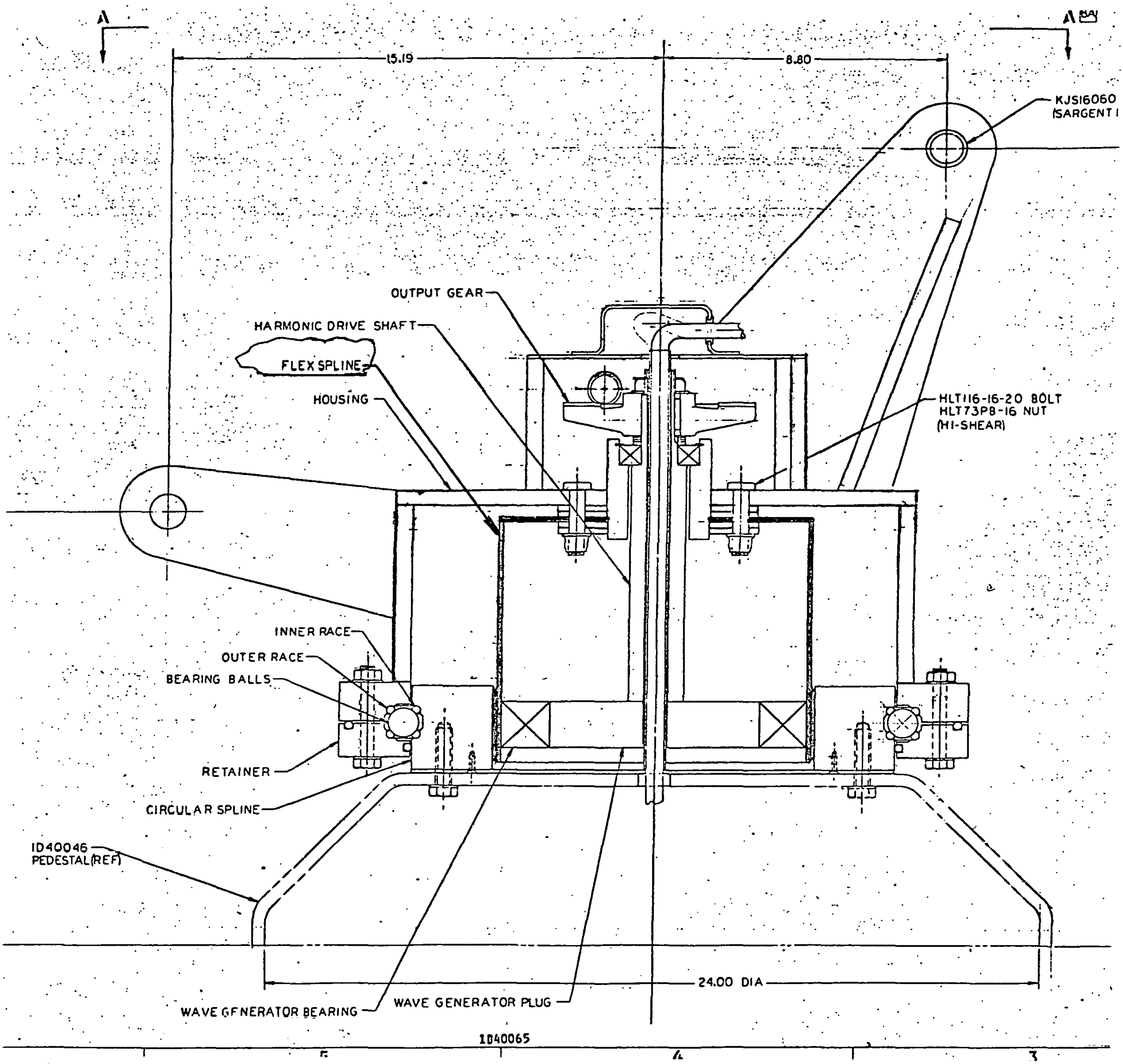

Figure 3.2.2.9-1 Flexspline Assembly

3.2.2.10 Wave Generator Assembly - The wave generator plug of the harmonic drive was examined to determine whether costs could be reduced by alternate forming methods. Figure 3.2.2.10-1. Results are summarized in Table 3.2.2-12.

Baseline - Weld and Machine Assembly (-1) - A steel disc is sawed from a round bar, drilled then welded to a steel tubing shaft. An ellipse is machined on this disc which then becomes the wave generator. Labor and materials cost of this approach are greater than of the alternative. Equipment cost is lower. Manufacturing methods lend themselves to automation techniques.

Alternate Method (-3) - Powdered Metal Form and Inertia Weld - The wave generator portion of this assembly is press formed, and then inertia welded to a steel tubing shaft. While material costs less than the baseline, equipment cost of the powdered metal approach is appreciably higher.

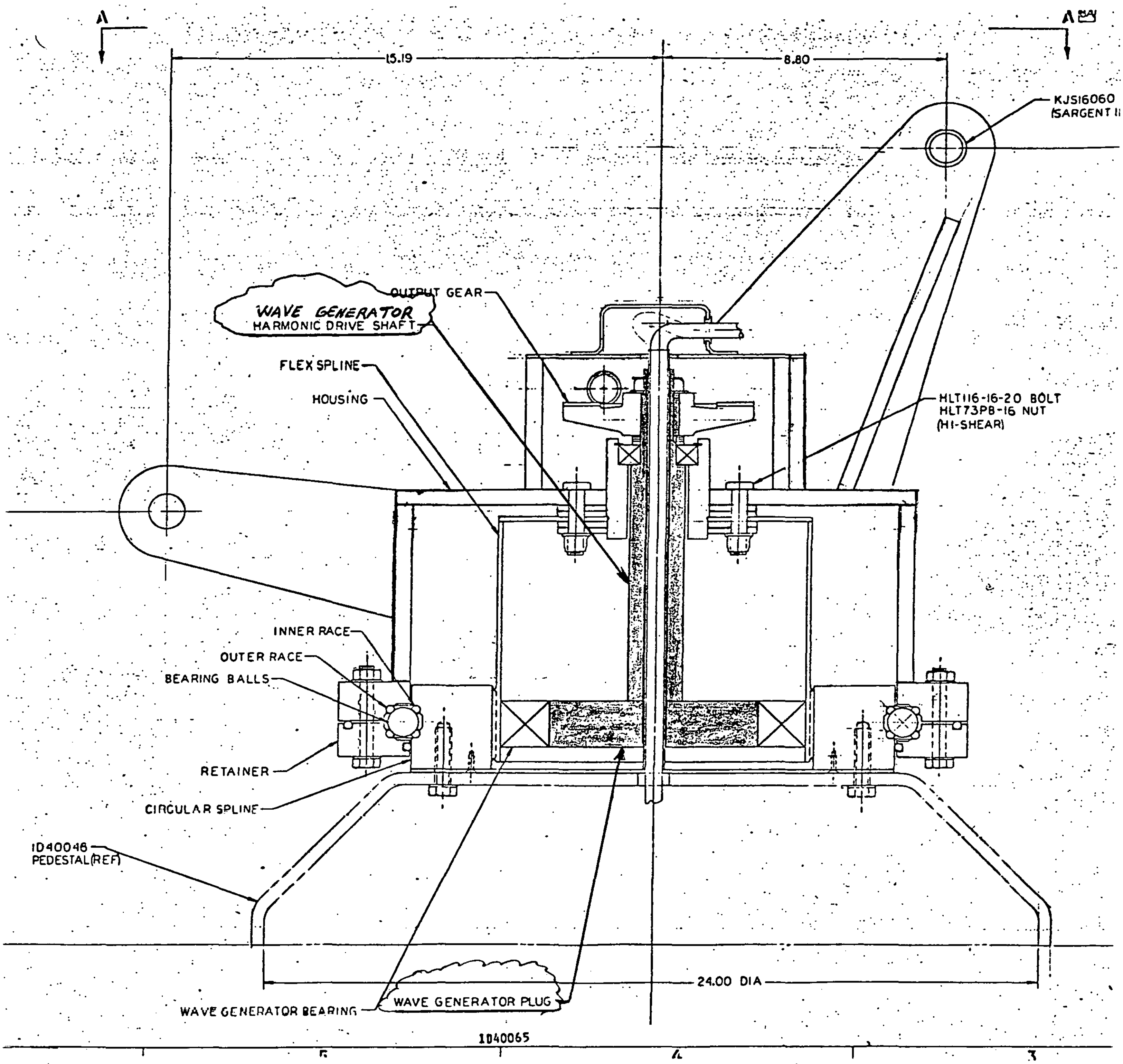

Figure 3.2.2.10-1 Wave Generator Assembly

Table 3.2.2-12

WAVE GENERATOR ASSEMBLY

OBJECTIVE: To evaluate selected approaches for possible cost reduction in selection of manufacturing methods, materials and equipment.

BASELINE: Weld and Machine Assembly (-1) - Weld a steel tubing shaft to a steel, round flat disc and machine required ellipse shape.

Powdered Metal Form and Inertia Weld (-3) - Form elliptical wave generator from powdered metal and inertia weld to steel tubing shaft.

APPROACH: Detailed Estimates

- Cost of materials
- Welding methods comparison
- Minimizing machining operations
- Cost of space, tooling and equipment
- Manufacturing labor

While the powdered metal concept offers advantages in terms of achieving a net shaped part with less metal removal labor, current technology for achieving the size part is questionable. Powdered Metallurgy technology needs to be monitored for application. Our investigation with numerous industry sources indicate that this appears feasible by the 1985 time frame.

3.2.2.11 Gear Forming Processes Trade Study Summary - The gear teeth in both the flexspline and the circular spline (see Figure 3.2.2.11-1) were examined to determine whether alternate production methods could significantly reduce costs. Alternates are described below and results are summarized in Table 3.2.2-13.

Summary - Trade studies on the three alternate methods of gear forming are supportive to the overall flexspline trade studies. As a result of these gear forming studies, broaching was the assumed method in the flexspline cost trade studies (reference 3.2.2-12). This method was assumed as the manufacturing approach for circular spline.

Hobbing Flexspline Gears - At the 25,000/year production level, cost studies indicated a requirement for 7 hobbing machines. It was estimated that one operator per shift could man these machines.

Alternate 1 - Broaching Flexspline Gears - At the same production level, one broaching machine and one operator/shift are required. As a result, the equipment cost contribution to total unit cost is much lower than found in the hobbing approach.

Alternate 2 - Shaping Flexspline Gears - To do an equivalent amount of work as the two alternatives above, three shapers and one operator/shift are required. Equipment cost contribution to total manufacturing cost is less than in the baseline method and more than in the alternative broaching method.

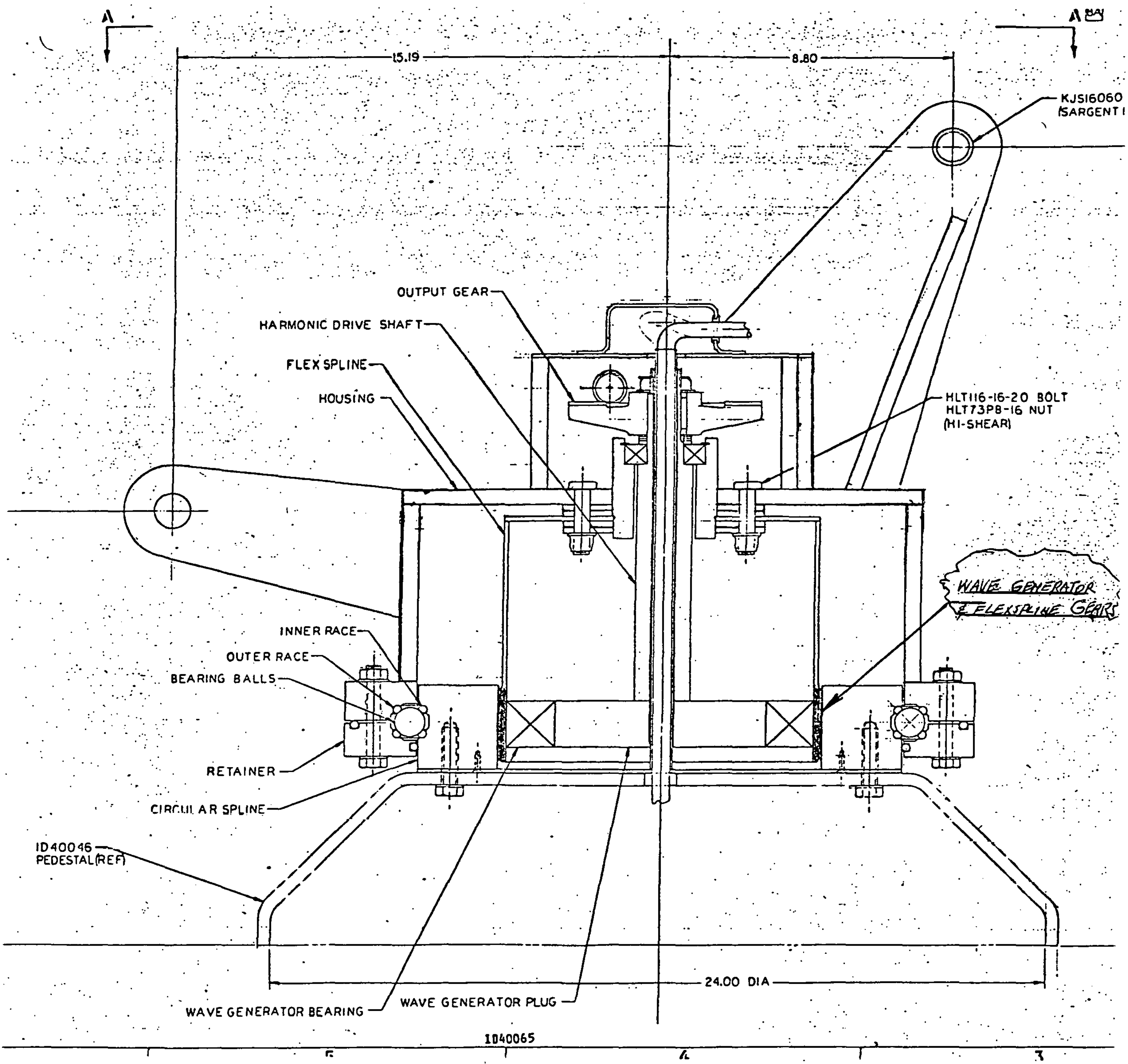

Figure 3.2.2.11-1 Gear Forming Process
Wave Generator and Flexspline Gears

Table 3.2.2-13

GEAR FORMING PROCESSES

OBJECTIVE:	To reduce manufacturing costs of gear forming.
CANDIDATES:	Baseline - The initial method analyzed assumed use of hobbing machines for fabricating the gear section of the flexspline. Alternate 1 - The second method of gear forming assumed a vertical broaching machine. Alternate 2 - The third method of manufacturing gear is shaping.
APPROACH:	Detailed Estimates • Cost of materials • Manufacturing labor • Equipment, tooling and space
RESULTS:	Analyses indicate the three methods are technically feasible for fabricating gears. Trade studies indicate that broaching is the most cost effective method. Cost ratios of the trade studies are as follows: Baseline (-1) Hob -1.00 Alternate (-2) Broach - .38 Alternate (-3) Gear Shaper - .48 Material cost is the same for three methods. However, as described in the proceeding summary, labor and equipment costs are lower with the broaching method. The recommended baseline approach is broaching.

3.2.2.12 Turret Bearing Selection - The turret bearing (see Figure 3.2.2.12-1) which supports the azimuth drive was also examined to determine whether alternate approaches might reduce cost and production complexity. Results are summarized in Table 3.2.2-14. An additional benefit of the alternate wire race bearing is the elimination of precision machining steps on the housing and circular spline.

Baseline Precision Ball Bearing - This preloaded and sealed ball bearing has precision inner and outer races and utilizes 1/2" steel balls. It is available from several companies and for costing purposes was selected from the Kaydon KG series. It would be installed in precision ($\frac{125}{\surd}$) machined bearing housing areas of the circular spline and the azimuth drive housing. In addition to the bearing cost (approximately $150.00 each), precision machining and assembly labor is required.

Alternate - Wire Race Ball Bearing - This design consists of four hardened steel formed wires or rods assembled into machined grooves of the bearing cavity. These wires form a four point contact for low carbon steel balls. After the balls are assembled into the cavity, a retainer with its wire race in position is placed over the ball assembly and tightened by locking bolts until metal to metal contact is reached. At that point, a preset bolt torque is applied to each locking bolt, preloading the assembly to prevent axial and radial shake. For purposes of this estimate, McGill Manufacturing Company, Bearing Number BB-2149 was selected as an appropriate design. However, procurement would involve only bulk components ($\frac{15}{16}$" steel balls and two sizes of wire races) with assembly at the heliostat production facility. In addition to cost savings, there are several sources of supply.

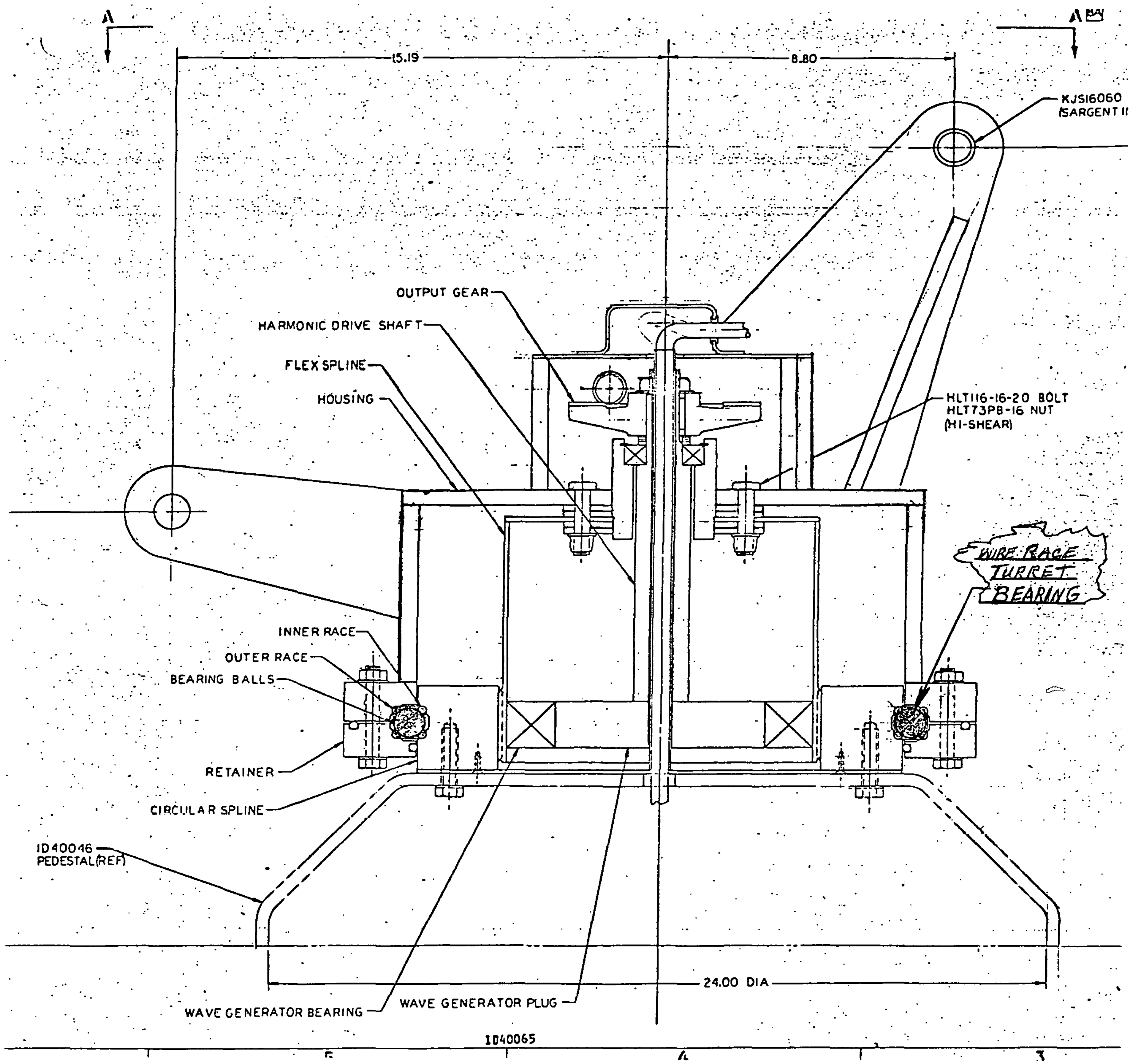

Figure 3.2.2.12-1 Turret Bearing Assembly

Table 3.2.2-14

TURRET BEARING SELECTION

OBJECTIVE:	To reduce cost of bearings and installation.
BASELINE, JULY 77:	Precision Ball Bearing and Races - Assured a four point, preloaded, sealed bearing required precision balls, inner and outer races, precisely machined housing and retainers in which the bearings/races are contained.
ALTERNATE:	Wire Race Ball Bearing - Two inner and two outer formed wire races are installed in the bearing housing. It is preloaded during assembly, removing the close tolerance requirements of a preassembled and preloaded bearing.
CONSIDERATIONS:	Moment carrying capability and function are critical considerations. In addition to purchased bearing cost, machining and assembly costs can be reduced.
APPROACH:	Detailed Estimates o Manufacturing labor o Equipment and tooling o Bearing cost o Bearing availability o Materials
RESULTS:	Trade study results are that the wire race bearing is more cost effective (ratio of .20 to 1.00). It has been selected as the baseline design.

3.3 MANUFACTURING PLANS

The completion of the design and manufacturing trades discussed in Section 3.2 resulted in the development of basic engineering design and commercial production concepts. The development of the trade-off study alternatives required the preparation of manufacturing approaches. The manufacturing approaches for the alternatives selected became baseline plans.

Manufacturing plans were documented process flow charts, as well as the analyses supporting the trade studies. Plans have been based on utilizing the appropriate level of automation and materials handling for 25,000/year production. These plans are reported in this Section. Arthur D. Little participated in this plan development with MDAC Manufacturing and Industrial Engineers. We have recognized and addressed key issues in our plans, such as:

(1) Glass Handling - It is recognized that handling concepts for both .060" Formed Fusion and .1875 Float Glass will require some development, for volume production. In particular, the transportation, packaging and handling of .060" Fusion Glass to minimize breakage will continue to receive the attention of Manufacturing and Packaging Specialists. Both Pittsburgh Plate Glass Company and Dow Corning Glass have provided assistance in this area. In addition, we have been working with glass handling equipment suppliers to select the best method of handling glass with minimum damage.

(2) Ability to Utilize Available Industry Sources - Both the design and manufacturing concepts provide for utilization of industry sources. With the exception of fusion glass, multiple sources of supply are available for virtually all component parts of the design. For example, roll-formed parts are available from numerous sources. Additional design changes were introduced to reduce supplier dependence; e.g., the redesign of the drag link from a casting to a weldment.

(3) Reduce Touch Labor Cost - A basic concept in our plans has been to minimize labor where tooling and equipment could be economically utilized. It has been our experience that when production volume can justify the use of tooling and equipment, savings occur not only in labor cost; but in related areas such as reduced scrap and rework, less handling damage and better product consistency. The sum total of these improvements are in reality productivity increases. Areas of the design and manufacture continue to be reviewed for

application of equipment to achieve further productivity improvement. Manufacturing has worked closely with special equipment and process manufacturers to evaluate equipment and tooling concepts that could be included in our plans. This has resulted in manufacturing plans that utilize methods that are well known and proven in industry application. These include processes such as fusion welding, machining, broaching, and adhesive bonding.

(4) Design Simplification For Low Cost Manufacturing - An important element in both the Engineering and Manufacturing approach has been simplification of parts design to reduce manufacturing costs. This has been implemented in two ways. One method has been elimination or combination of parts required for a specific function. Examples of this are the Oldham coupling in the azimuth drive, and the pedestal dome mount redesign. These redesigns are discussed in Section 3.2 Trade Studies. A second method is simplification of parts and assemblies. Examples include the redesign of the azimuth drive housing and drag link castings to a weldment which simplified the design and resulted in the use of 1/2" low carbon flat plate stock for both parts. In a similar approach the electronics design has been simplified so that standard processes and equipment are available to permit good commercial manufacturing practice to be utilized. The printed wiring boards represent standard two-sided through_hole plated design which are generally standard in industry. The design accommodates automatic component insertion and flow soldering. These techniques are standard within commercial electronics.

Effort is continuing in areas of reviewing costs and design for future simplification and reduction.

3.3.1 Make-or-Buy

Make-or-Buy in the context of this report refers to the form in which parts and materials are delivered to the heliostat production facility. Where proprietary or patented processes are incorporated in the facility a licensing or joint venture arrangement is assumed.

The Make and Buy plan that has been developed for the 25,000 units per year production plan is displayed in Table 3.3.1-1. The decisions that were used to formulate the plan were as follows:

Table 3.3.1-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
o Collector - (Field of Heliostats)						M
	o Heliostat - (Includes Controller)					M
		o Reflector Panel - (Two Panels make Reflective Unit)				M
			o Mirror Module			M
					o Back Lite	B
					o Adhesive	B
				o Reflective Surface		M
					o Front Lite	B
					o Silver	B
					o Copper	B
			o Support Struture			M
					o Inboard Cross Beam	B
					o Outboard Cross Beam	B
					o Diagonal Beams	B
					o Outboard Angle	B
					o Joint Fitting	B
					o Stringer	B
					o Adhesive	B
		o Drive Unit				M

Tab. ..3.1-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
			o Azimuth Drive			M
				o Housing		M
					o Shell	M
					o Retainer	M
					o Cover	M
					o Bolt	B
					o Oil	B
					o Seal	B
					o Bushing	B
					o Ball	B
					o Base Plate	B
					o Stand Pipe	B
					o Bearing	B
					o Bearing Race	B
				o Circular Spline		M
				o Flex Spline		M
					o Membrane	B
					o Tube	B
					o Spline	B
					o Doubler	B

Table 3.3.1-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
				o Wave Generation		M
					o Plug	M
					o Bearing	B
					o Drive Shaft	M
				o Motor (Typical)		M
					o Motor	B
					o Helicon Pinion	B
					o Motor Controller	B
					o Incremental Encoder	B
				o Input Reducer		B
			o Pedestal			M
				o Dome		M
				o Tube		B
				o Access Cover		B
				o J-Box Cover		B
			o Elevation Drive			M
				o Main Beam		M
					o Tube	B
					o End Plate	B
					o Fitting	M
					o Bushing	B

Table 3.3.1-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
				o Drag Link		M
					o Bushings, Pins, Etc.	B
				o Stowage Actuation		M
					o Stowage Jack	B
					o Motor	B
				o Tracking Actuator		M
					o Tracking Jack	B
					o Motor	B
		o Foundation				M
				o Collar		B
				o Re Bar Cage		M
				o Concrete		B
		o Heliostat Electronics				M
			o Heliostat Controller			B
					o Power Supply	B
					o Processor	B
					o Housing	B
					o Line Driver	B
					o Line Receiver	B
					o Circuit Board	B
				o Data Receiver		B
				o Data Transmitter		B

Table 3.3.1-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
			o Motor Controller			B
					o Triac	B
					o Resistor	B
					o Capacitor	B
					o Board	B
					o Line Receiver	B
			o Control Sensor			M
					o Hall Sensor	B
					o Disc	B
					o Line Driver	B
			o Pedestal Junction Box			M
					o Box	B
					o Circuit Breaker	B
					o Cable Clamp	B
	o Collector Controller					B
		o Console				B
			o Key Board			B
			o Cathode Ray Tube			B
			o Control Panel			B
		o CPU				B
		o Storage				B
		o Field Interface				B
		o MCS Interface				B

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
			o Mode			B
		o Time Pickup				B
	o Field Electronics					M
		o Power Distribution				M
				o Primary Feeder		M
					o Cable	B
					o Terminator	B
				o Secondary Feeder		M
					o Cable	B
					o Terminator	B
			o Power Distribution Module			M
				o Transformer		B
				o Foundation		M
				o Distribution Panel		M
					o Circuit Breaker	B
					o Bus Bar	B
					o Enclosure	B
		o Data Distribution				M
				o Primary Data Cable		M
					o Cable	B
					o Terminator	B

Table 3.3.1-1

PROTOTYPE HELIOSTAT HARDWARE TREE

SUBSYSTEM	ASSEMBLY	SUBASSEMBLY	COMPONENT	SUBCOMPONENT	PART	GUIDELINE MAKE/BUY
			o Data Distribution Interface			B
				o Logic Network		B
					o Data Receiver	B
					o Data Transmitter	B
					o Terminator	B
					o Demultiplexer	B
					o Multiplexer	B
					o Processor	B
					o UART	B
				o Panel		B
				o Housing		B

1. MAKE - Parts manufactured at the heliostat production facility.
2. BUY - Parts purchased from industry sources.
3. MAKE DECISIONS - Were based on the following factors:

A. Important to insure schedule compliance. This would include azimuth drive assembly, and reflector assembly.

B. Cost effective. This would include mirroring of the fusion glass. (Reference Cost Trade-Off Study M-2 Section 3.2)

C. Assure process control. This would include glass laminating and bond operations.

4. BUY - Decisions were based on the following factors:

A. Item is commercially available throughout industry. Example would include roll formed parts.

B. MDAC would have to acquire a capability for which less than optimum capacity would be utilized. For example, at the 25,000/year level a fusion glass facility could not be effectively operated or utilized.

The "Make/Buy" decisions that have been reached represent a balance between those activities that should be concentrated in the heliostat production facility and those items that can be acquired from numerous commercial industry sources. It permits the most effective use of capital investment in areas of production of heliostats and not duplication of additional industry capability that would not be fully utilized.

We are currently developing the Make/Buy decisions for 250,000 units per year production.

3.3.2 Process Flow Overview - 25,000 Heliostats/Year Production

Manufacturing plans are described in this section for the two major hardware elements to be delivered to the field; the reflector panels and the drive/control unit (drive unit plus heliostat electronics).

3.3.2.1 Reflector Panel Subassembly

The reflector panel subassembly (See Figure 3.3-1) comprises one-half of the reflective unit. Each reflector panel is comprised of six mirror modules and a support frame. The mirror modules are made of second surface silvered fusion glass laminated to float glass. These modules are bonded to a support structure assembly which consists of roll formed parts that have been welded together as a subassembly prior to bonding to the mirror modules.

3.3.2.2 Drive/Control Unit

The drive/control unit (See Figure 3.3-2) includes the drive unit and the heliostat electronics subassemblies. Components of the drive unit are the pedestal, azimuth drive, and elevation drive. The pedestal is made of a diameter tube flared at the bottom. The top of the pedestal is closed by a draw-pressed dome on which the azimuth drive assembly will mount. The major azimuth drive elements are a housing, welded from plate stock, harmonic drive elements, turret bearing; and an input reducer. The elevation drive consists of a main beam, drag link, stowage and tracking actuators. The main beam is 16" diameter tube with end plates and fittings welded. The drag link is formed and welded from plate stock. The actuators are purchased, assembled and checked-out as part of the drive unit assembly prior to shipment to the site. The heliostat electronics subassembly major elements are the pedestal junction box, heliostat controller, motors, and cabling. These elements are installed in the drive unit in the factory, prior to shipment to the field.

3.3.3 Reflector Panel

The reflector panel manufacturing flow is illustrated in Figure 3.3-1.

The fusion glass is received from the supplier, stacked vertically on a reusable A frame. The glass is mechanically removed from the frame using an automatic unstacking machine. This machine is hydraulically powered and uses positive vacuum cups for holding the glass sheet during transfer. The equipment eliminates operators from the glass handling operations thus providing an increased safety factor.

Two unstacking machines will be used for the fusion glass loading to the conveyor in order to maintain a minimum distance between the pieces of glass and maximum mirror line utilization.

The glass is moved on a roller bed motorized conveyor at approximately fourteen feet per minute through all mirroring processes. First the top surface of the glass is cleaned by a series of cup brushes using cerium oxide in slurry form. Three double row oscillating scrubbing units each with twenty-eight (28) 6" diameter nylon rotary brushes in two staggered rows, are oscillated across the conveyor by a gear motor drive. Brushes will be V-belt driven by a 3 hp motor. A slurry tank is included and located on right side of machine. Pull out scrubbers will be used to ease servicing and changing of brushes. Three 8" cylinder brushes (2 top - 1 bottom) will clean the glass after the scrubber section.

After cleaning, a demineralized water rinse and a silver sensitizer (stannous chloride) are applied by spray pipes across the conveyor line.

The silvering section is equipped with a variable traverse mechanism to move the spray manifold across the conveyor. Solutions will be applied by low pressure airless spring dispensed by a proportionating console. An air blast separator will be used to contain the solutions in this section. Silver is deposited in chemical form as silver nitrate with chemical reaction caused by use of an alkali and reducer. A second traverse mechanism will lay down a film of pure copper by airless galvanic copper sprays. Demineralized water

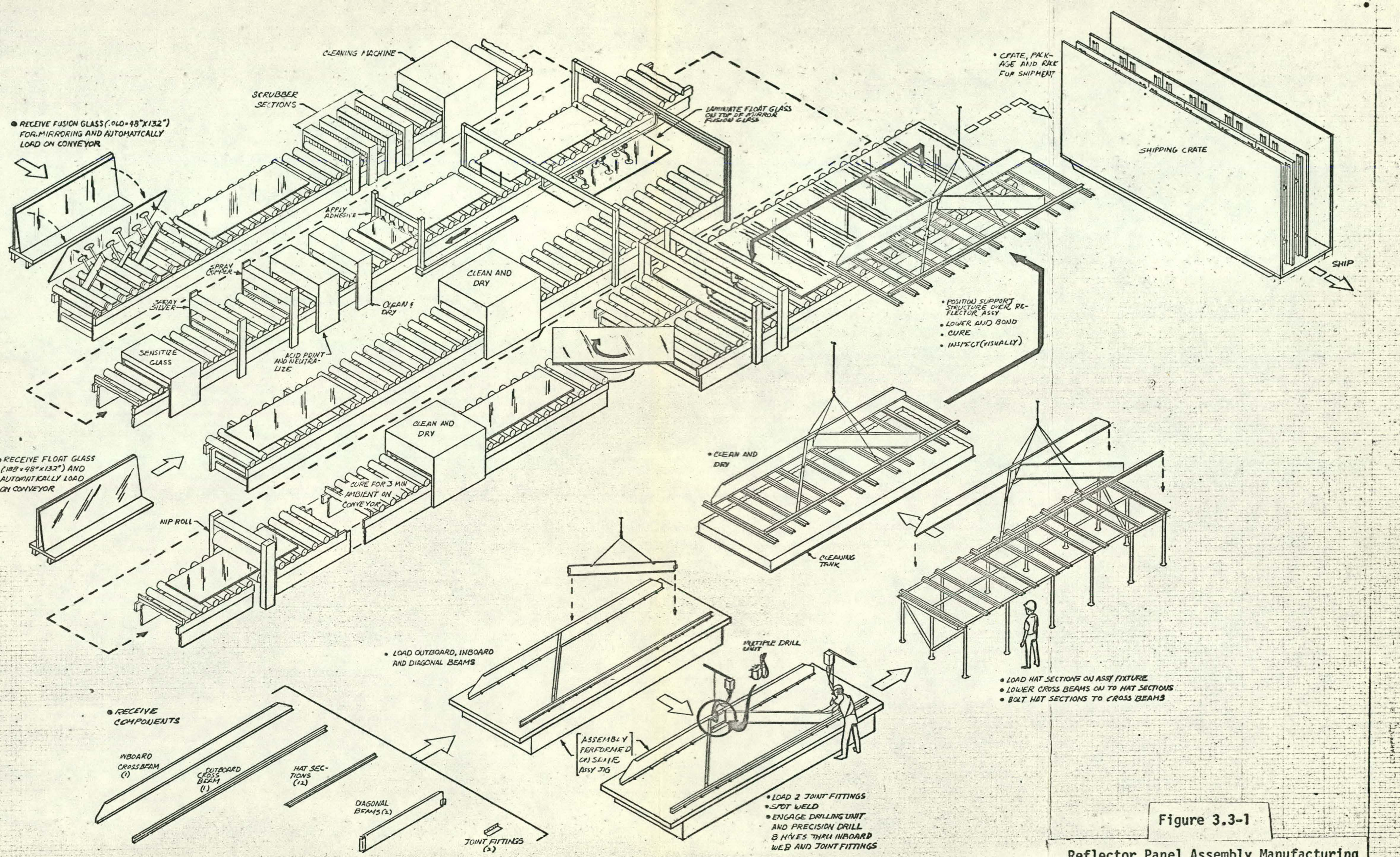

Figure 3.3-1

Reflector Panel Assembly Manufacturing

sprays will thoroughly rinse the copper backing. The copper coating is applied to prevent oxidation of the silver.

The mirror proceeds into a "face down" cleaning machine consisting of eight solid printing rollers with special neoprene covering, and stainless journals revolving in a stripping solution contained in a stainless tank with a PVC shut-off valve. Last two are squeegee rolls. The acid solution will be rinsed from the mirrors by use of spray nozzle equipped pipes. A special catch pan will be supplied under washer and drying section.

Washing and drying will consist of two 8" diameter cylindrical nylon brushes on bottom side, four solid rollers, four neoprene ring rollers, and a 20 hp blower connected to four blast gates and air blast drying tubes. The air source is dry, filtered air.

The mirror at this point is ready for adhesive application and laminating to the float glass. The adhesive section is equipped with a variable traverse mechanism to move the airless spray manifold across the moving mirror. An air blast separator will be used to contain the adhesive spray in this section. Exhaust equipment will remove any overspray. The coverage will be shielded to prevent adhesive accumulation build-up.

Parallel with the mirroring line, the float glass is being prepared for laminating to the mirrored fusion glass. The float glass goes through the same cleanning and drying operations as the fusion glass. The glass is now ready for laminating to the mirrored glass.

At this point the float glass backlite is lifted (automatic unstacking machine) and positioned on the mirrored glass. The mirrored glass has been staged and positioned on the line to accept the backlite for laminating.

The assembly is run through a series of nip rollers, ambient cured on the conveyor, and fed to three bonding fixtures. The mirror modules are then positioned in groups of six on the fixture for structure bonding.

The mirror receives a mechanically dispensed application of adhesive. The support structure is vacuum lifted from an adjacent conveyor line and positioned on the mirror modules. The reflector panel is ambient cured and vacuum lifted from the assembly line and placed on shipping rack for transfer to site.

Special exhaust systems will be necessary to remove toxic vapors emitted by the acids, solvents, and adhesives. The exhaust system will be mandatory and possibly require scrubbers before the exhaust is released to the outside environment.

Special attention will be given to glass handling and transfer through the production lines. Glass handling equipment will be completely automatic and will include unstacking machines for removing large sheets of glass from vertical storage, and placing them on a horizontal conveyor for processing through the production line. Air float tables, an important piece of handling equipment, are used for transfer. Additional handling equipment includes a 90 degree conveyorized transfer unit.

The reflector support structure process flow shown in Figure 3.3-1, is composed of a inboard cross beam, two diagonal beams and a outboard cross beam all formed from galvanized steel. Two steel joint fittings are used to reinforce the attachment of the diagonal beams to the inboard beam. Twelve galvanized steel hat section stringers are attached to the inboard and outboard cross beams with rivets and provide support for the six minor modules.

The details are purchased formed, and palletized and are delivered to the fabrication area after receiving inspection. The inboard, outboard and diagonal beams are loaded into separate punch presses that automatically punch the rivet holes.

The parts proceed on a overhead monorail to a weld and drill station. The parts are lowered into a floor mounted fixture and secured. Spot welding of the inboard and outboard areas is accomplished simultaneously. After welding, the bolt holes for attachment to the drive unit are jig-bored.

The welded structure is removed from the weld fixture and proceeds on the monorail to two stringer attach stations.

The 12 stringers are loaded and clamped in position in the assembly fixture. The welded structure is lowered onto the stringers and clamped in place and automatically riveted.

The structure is removed from the tool and is moved by monorail to a dip clean, rinse and air dry station, prior to bonding the structure to the mirror modules.

3.3.4 Drive Unit Fabrication and Assembly

Table 3.3.4-1 below identifies the major processes used to fabricate and assemble the drive unit. The detailed flow of the drive components are as shown in Figure 3.3-2.

Table 3.3.4-1

MAJOR PROCESS SUMMARY

	DRIVE UNIT ASSEMBLY					
			ELEVATION DRIVE ASSEMBLY			
PROCESS	PEDESTAL DOME ASSEM.	AZIMUTH DRIVE ASSEM.	ELEVATION JACK	STOWAGE JACK	DRAG LINK	CENTER BEAM
Tube Sawing	X	X				X
Tube Sizing	X					
Flame Cutting	X	X			X	X
Press Blanking		X				
Press Forming		X			X	
Welding	X	X			X	X
Turning		X				
Milling		X			X	X
Drilling	X	X			X	X
Broach		X				
Assembly	X	X	X	X	X	X

This section will highlight the key fabrication methods, types of equipment involved in each of the above processes and significant features associated with the equipment.

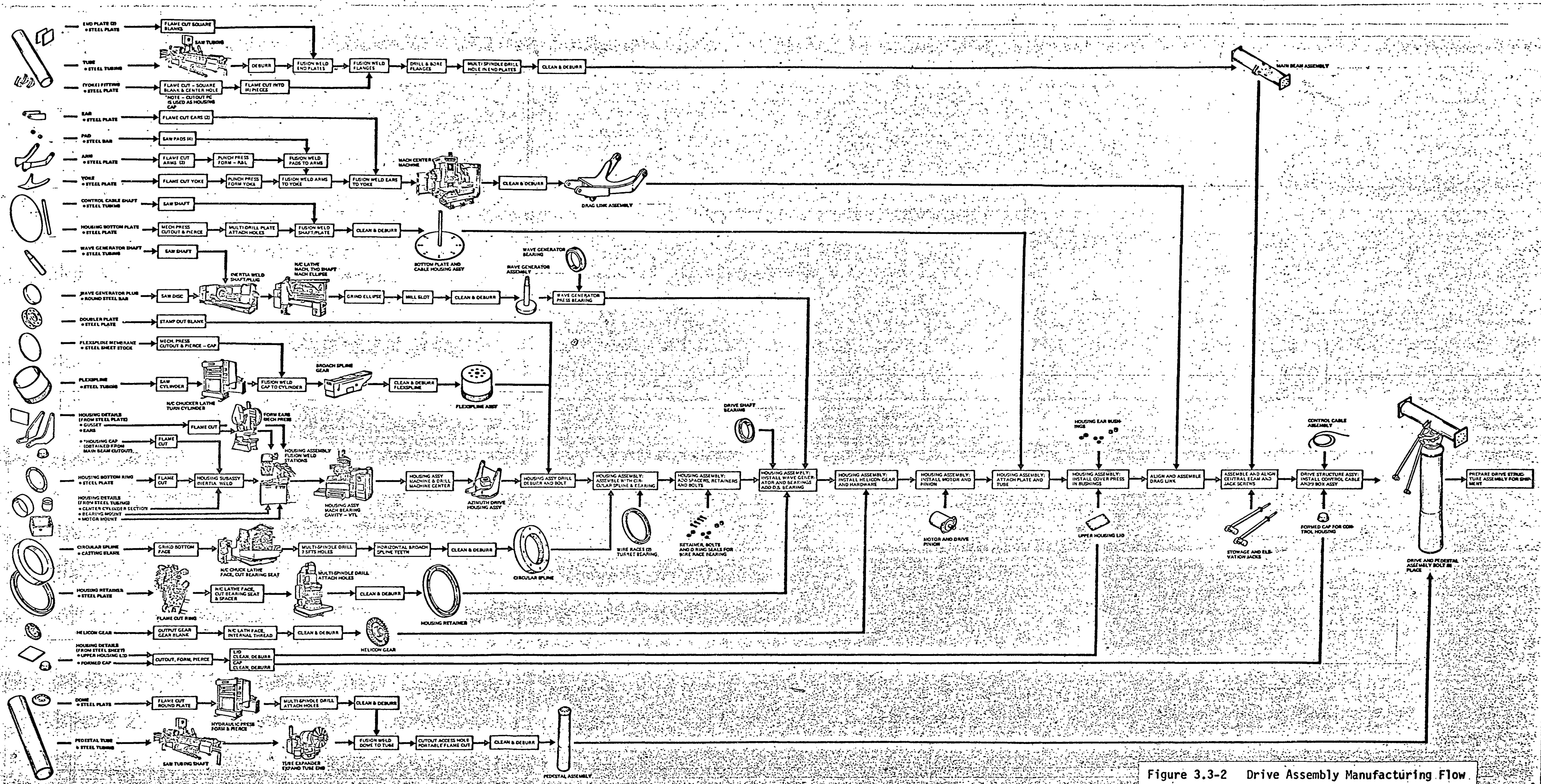

Figure 3.3-2 Drive Assembly Manufacturing Flow

3.3.4.1 Parts Fabrication

There are several tubular shaped sections in the drive structure assembly. The largest tubes, the torque tube of the main beam and the pedestal tube are purchased to correct length and are sawed only as needed to square the ends/for subsequent welding operations. The remainder of the tubular sections are contained in the azimuth drive assembly and are also welded before final machining. The sawing setup and cutting operations are so fast that they can readily supply all tubular shape production requirements on a daily basis without necessitating large in-process storage quantities. The equipment used to saw all large tube stock will be similar to a Marvel Series 25 band saw with automatic work handling tables. Smaller, thick walled stock as well as bar stock will be cut using a power hack saw similar to a Marvel Series 6/64A with automatic in-feed and clear features.

The tube sizing area will contain a tube expander station (similar to a 350 ton Arrowsmith hydrosizer station). The station will form the truncated conical sections which force the tubes radially outward to permanent set diameters. The wedges are fitted with shoes to shape the conical sections of the tubes to matching outside and inside fit. The tubes will be staged from the saw area in gravity feed ready racks and will be automatically fed to and from the expander station in a horizontal mode. The expander station will be constantly monitored by digital readout to provide for fast change-over between the two diameters, and assure process control.

Flame cutting consists of two four head flame cutting units similar to the LINDE CM56 mechanized cutting systems. The cutting gases utilized are a mixture of oxygen and acetylene. The units will operate by template tracer control. The flame cutting area will contain venting to ensure exhaust of all gases. All plate stock is stored outside in open racks adjacent to the cutting area. Heavy plate stock is hoisted by magnetic chucks to roller conveyors for staging to cutting tables.

In order to minimize material waste, combinations of cuts in plate stock to accommodate different parts will be made. For example, the 16 inch diameter cap section for the azimuth drive housing will be made from the cull obtained in cutting out the flange sections of the center beam that fit around the 16 inch diameter center beam tube.

To reduce handling, cutout sections drop into a cross conveyor container for placement into transport bins for in-process storage. A portable flame cutting unit supports this area for breakup of cull from the plate stock after it has passed under the cutting carriage. This unit will also cut the access holes in the pedestal. The cutout sections will be used for the access hole covers.

Press blanking consists of an uncoiler, coil-straightener, stock slitter and a stamping press. An overhead crane will hoist coil stock to the uncoiling station of the stamping line. Coiled stock minimizes material shipping, storage and handling costs. Two 300 ton mechanical presses form the ear sections of the azimuth drive housing and the side and mid sections of the drag link. Another hydraulic press deep draws the dome section of the pedestal. Ear sections are formed in left and right hand sets and two mid sections of the drag link are formed in one setup to minimize labor and process time.

Two types of welds are utilized in the welding process. These are inertia welding and fusion welding. Inertia welding equipment (similar to Manufacturing Technology Model 180B) is used to join the drive shaft to the wave generator plug. A second inertia welder (similar to a Manufacturing Technology Model 400B) is used to join the main circular sections of the azimuth drive housing. The drive shaft sections and the sections of the azimuth drive housing are well suited to inertia welding. No special preparation of the weld surfaces is required with inertia welding. It is a fast operation and forms repeatably good weld joints. No automated loading or unloading equipment is envisioned at the 25,000 per year level, however, it can be readily adapted to the equipment at higher levels of production.

The main fusion weld stations contain automatic weld positioners and weld heads to facilitate repeatable welds. The area will require venting since the welding is primarily on galvanized surfaces.

The main beam weld production line contains five stations. The first station welds the side plates onto the sawed tube ends. The second station welds the flanges onto the tube wall. The third station drills the reams the flanges from fixed radial positioned carriages which slide parallel to the tube center line (See Figure 3.3.4-1). The fourth station simultaneously belt sands the sides of the plates for parallelism. The fifth station multi-spindle drills and taps the reflector panel mounting hole patterns into the side plates. This station will be located from the drilled flange holes.

The welding of the dome to the pedestal takes place directly after the tube expander operation. A fixed multiple drill station drills the bolt pattern into the dome end for bolt up to the azimuth drive.

These two production lines minimize transport and handling by bringing the processes to assembly. Following these lines the units are directly hoisted to the assembly area.

Numerically controlled chucker lathes (similar to the Warner Swasey NC-35C) will be used to machine the turret bearing diameters of the retainer and the circular spline. In order to assure concentricity between the turret bearing raceways and the gear diameter of the circular spline as well as maintain their squareness to the pedestal attach plane, these surfaces will be turned, bored and faced respectively in one setup. The retainer will also be machined in one setup. The flex spline will have its housing mounting diameter and wave generator bearing diameters bored in the same setup to assure concentricity and establish diameters for the subsequent gear forming operations. The drive housing will be turned on numerically controlled vertical turret lathes, again machining all critical diameters in the same setup.

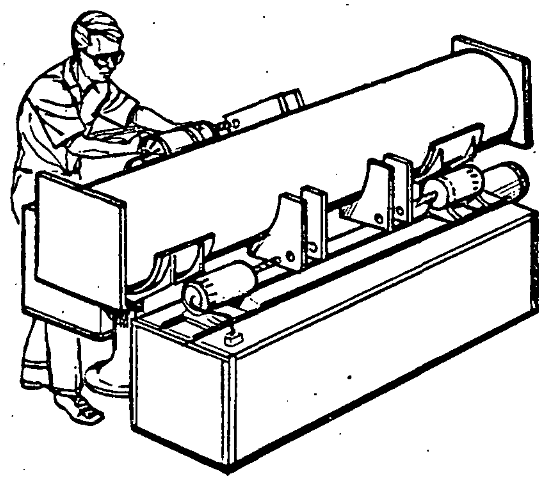

Figure 3.3.4-1 Flange Drill Station

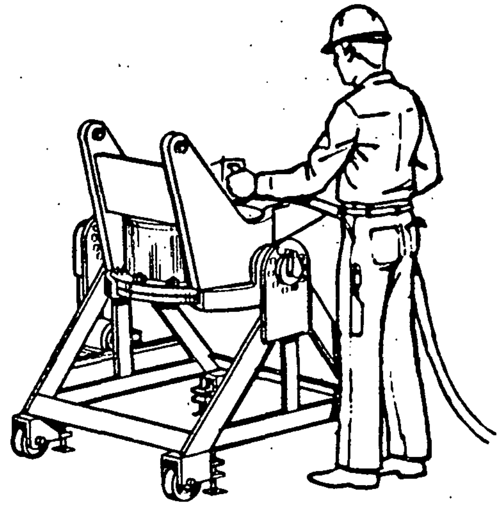

Figure 3.3.4-2. Motorized Three Position Carrier Azimuth Drive

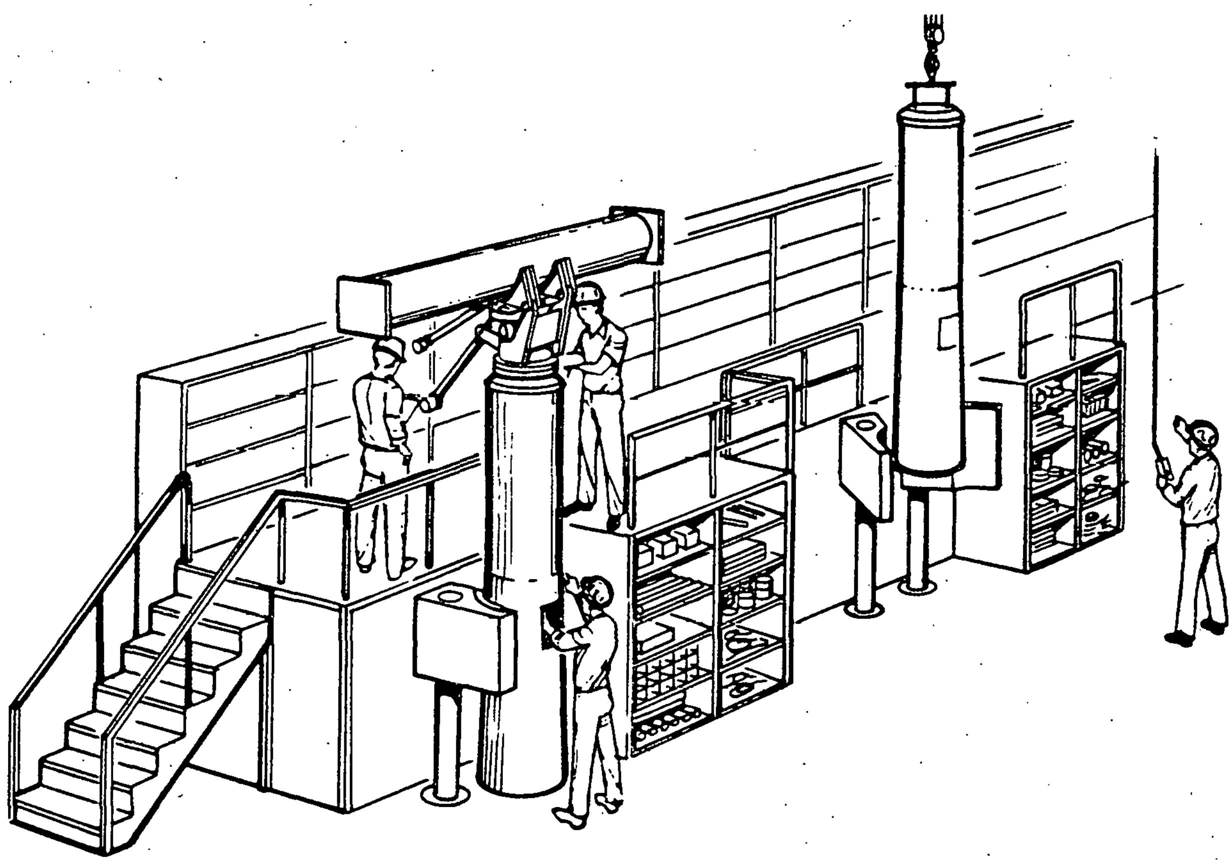

Figure 3.3.4-3. Final Assembly Joining Area Drive Unit to Pedestal

3.3.4.2 Drive Assembly

The drive housing, doublers and flex spline are assembled onto a mobile assembly fixture. See Figure 3.3.4-2

A wire race is installed into the housing. The circular spline with two preassembled wire races is lowered by a handling fixture into position between the flex spline and the housing. The ball bearings are installed between the wire races. The circular spline is further lowered until the ball bearings are in contact with the three wire races. The mobile assembly fixture is transported to the next assembly station for the bearing retainer installation. The retainer with its wire race and two "O" rings is positioned over the circular spline onto the housing. Bolts are then installed through the retainer and housing and torqued to the proper preload setting. The wave generator and drive shaft assembly is lowered into the unit with a portable electromagnetic chuck. The threaded end of the drive shaft is then captured with a sleeve allowing the unit to be inverted for the shaft bearing installation. The drive shaft bearing and snap ring is installed. The helicon gear is then assembled into the drive shaft.

The motor and pinion are assembled into the helicon gear and secured to the motor mount surface. The cover plates are installed readying the unit for the drive structure and electrical installation.

The elevation components are then assembled onto the azimuth drive assembly. This is accomplished by hoisting the drag link up so that the pivot points are in line. The drag link is centered and secured in line with the azimuth drive by through bushings.

After the drag link is lowered to rest on the azimuth housing, the main beam is brought to the station by overhead monorail. The flanges of the beam are then lowered to align with the pivot points of the drag link and housing, centered and secured by bolts.

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The milling operations will be accomplished utilizing equipment (similar to Kearney Trucker 4 axis M-200 machining centers). These mills straddle the four pivot location ear sections of the azimuth drive housing and drill and ream the attach holes. The motor mounting face will be milled and drilled for the motor seat, shaft and mounting screws. The top of the drive housing will be face milled, drilled and tapped for the cap. The mill fixture will hold the housing and locate it on the turret bearing diameter. The drag link weld assembly is similarly machined on this equipment.

The broach station forms the gear sections of the flex spline and circular spline. The equipment is push type; i.e., broaches are extended through the inside diameter of the circular spline as a male broach set and over the outside diameter of the flex spline as a female set. Each broach set will be constructed of removable sections holding each tooth layer to facilitate replacement for rework.

A precision post and plug tool positions the flex spline and guides the broach, keeping the gear wall constant during the broach cycle and extracts it from the plug during the return stroke.

Multiple drill head equipment is used to drill major bolt hole patterns and tap the circular spline section (equipment similar to the Zagar Open Side Multi-Spindle drill). A special multihead drill station is used to drill the bolt hole location between the flex spline and the azimuth drive housing.

The flex spline and doublers are positioned over the housing register diameter in the inverted position. A clamping ring nests the flex spline and doublers while the drill heads drill past clearance holes in the clamping ring through the doublers, flex spline and housing. The drilled assembly is then removed for deburr and final preparations for the drive assembly operations.

While the main beam remains hoisted by the monorail, the jack screws with pre-assembled motors are hoisted up to the trunnion attach points of the structure, pinned in place by bushings and manually positioned to their respective drive points in the forward flanges of the drag link and center beam for bolting.

The elevation and azimuth drive assembly is then hoisted to the pedestal joining area where the pedestal has been positioned by monorail and lowered onto the pedestal. As shown in Figure 3.3.4-3, a platform allows operators to work at drive height as well as access hold height. Guide pins are used to align the hole pattern of the circular spline section on the drive with its corresponding hole pattern in the dome section of the pedestal. After the pins are removed, the joint is secured by driving bolts up through the dome into the circular spline. All tools utilized in this position are portable, hand-operated equipment. This completes the major mechanical assembly of the drive structure.

The junction boxes, the heliostat controller and cables are then installed to the drive structure. The drive unit is then hoisted to the truck loading dock for direct loading into the truck trailer for transport.

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3.3.5 Electronic Components

This section reports on the manufacturing plan developed for the heliostat controller, data, distribution interface and pedestal junction box. While the electronic components have been designated as "buy" items (reference Make/Buy Section 3.3.1), the purpose of the plan is to describe the manufacture of the unit.

3.3.5.1 Heliostat Controller - The design and manufacturing concept for the unit is the result of coordinated effort between the design and manufacturing groups. The design approach utilizes proven state-of-the-art manufacturing; e.g., flow solder, automatic component insertion.

The heliostat controller uses two-sided printed wiring boards with plated through holes. The boards are designed to facilitate automatic component insertion.

The housing for the heliostat controller is injection molded with the mounting bracket and printed wire board guides incorporated into the basic mold.

The molded box design will be common to both the heliostat controller and data distribution interface box. The manufacturing plan utilizes automatic equipment to maximize production and reduce inspection to in-process surveillance.

The heliostat controller electronic components will (by 1985) be single chip packages or hybrid packages consisting of multiple chips and the possible addition of discrete components that do not lend themselves to miniturization. It is anticipated that costs of microcomputers, by this time, will be reduced by their generalized use.

As reported in Section 2, the heliostat controller electronics consists of a power supply; a single chip microcomputer; four discrete capacitors; and a hybrid microcircuit package containing two line drivers; two line receivers, and three flip flops.

Although the cost and development state of these items may not make them competitive as microcircuits today, it can be anticipated based on recent history that technical growth will make this feasible by 1985.

As shown in Figures 3.3.5-1 and 3.3.5-2, the components are automatically inserted into the printed wiring boards, the component leads trimmed and clenched. The assembly is placed on a conveyor which travels through fluxing, preheating, flow soldering, and cleaning. The completed board is subjected to periodic surveillance to assure process compliance.

The injection molded box will eliminate typical labor required with a metal box containing card guides and mounting bracketry added as separate operations. The box could be made of plastic or metal and will have the card guides and mounting bracketry molded integral to the box. The board assemblies will be installed from the bottom and will have one-half of the bottom attached to the card connector with the connector extending through the "half bottom" for connection. As mentioned earlier, the box design is common for the heliostat controller and the data distribution interface boxes. This reduces the cost of tooling for the molded box. The heliostat controller only has one printed wiring board and associated connector and, therefore, has a dummy half bottom to complete the box closure.

The half bottom has a connector knockout to provide a closure when a connector is not used or a simple knockout when a connector is used. In addition, it contains a vent hole to prevent condensation on the inside of the box. The half bottoms are retained by two screws installed into the box rim.

3.3.5.2 Data Distribution Interface - The assembly contains two identical printed wiring boards which are similar in construction to the heliostat controller boards. The boards will be installed with the components facing, thus allowing them to nest and reduce the overall size of the box.

The manufacturing operational flow is the same as the heliostat controller, but requires a separate numerical control program tape for the automatic component insertion machine.

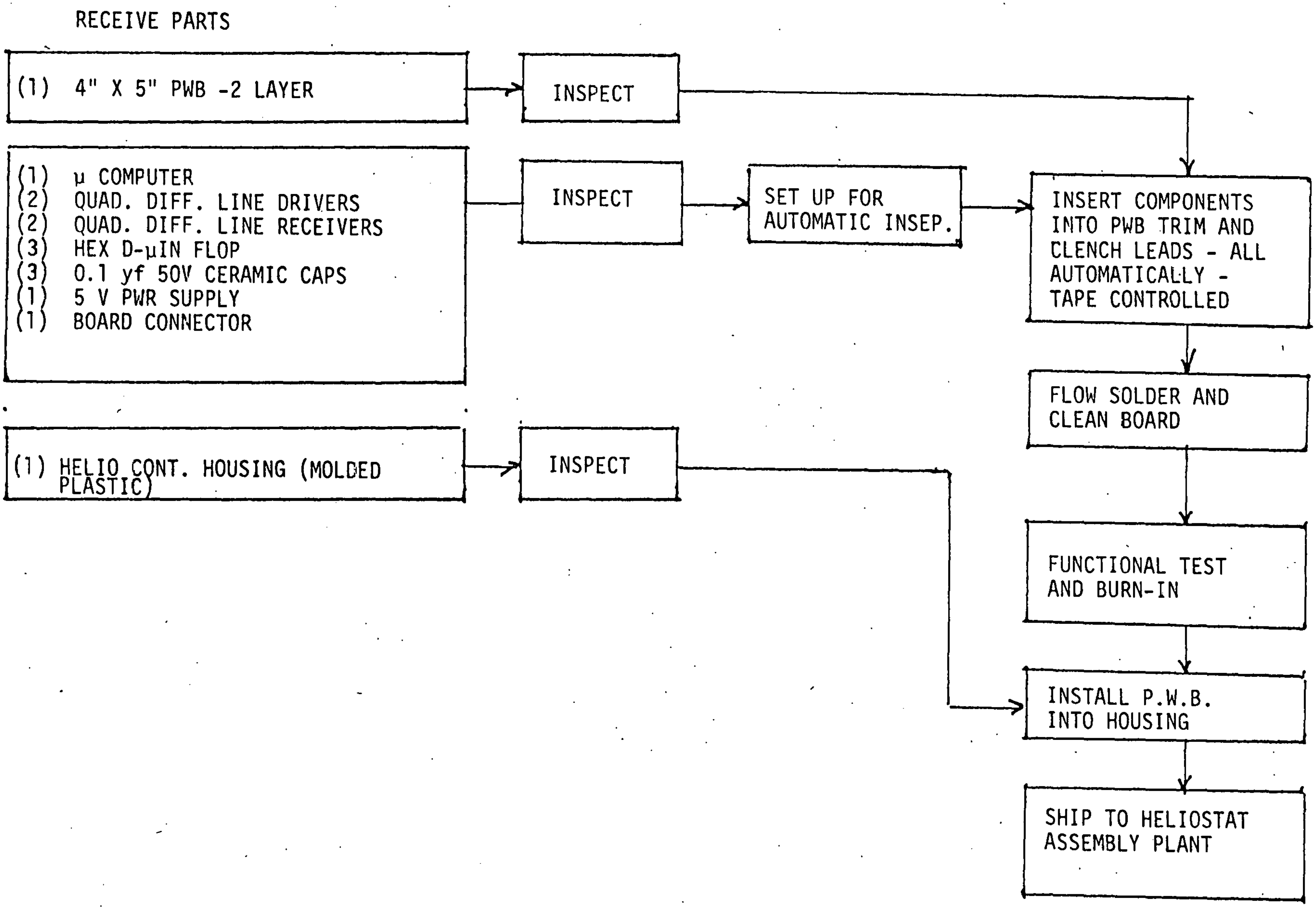

Figure 3.3.5-1 Heliostat Controller Manufacturing Flow Chart

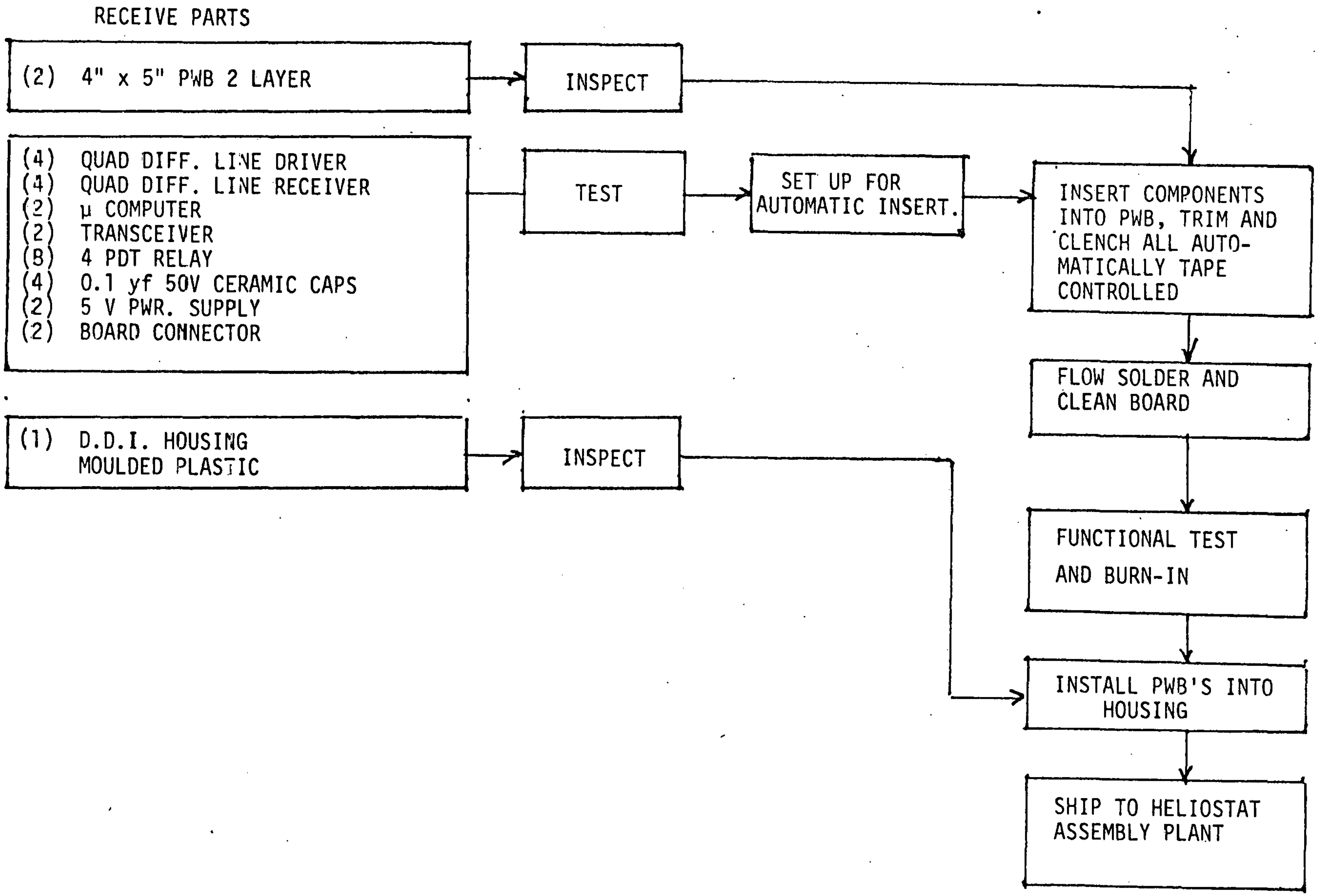

Figure 3.3.5-2 Data Distribution Interface (DDI) Manufacturing Flow Chart

3.3.5.3 Circuit Breaker Junction Box - At the point the field wiring enters the pedestal, a cut out is provided to accommodate the field wiring junction, the circuit breaker, and the fiber optic connector.

A bracket will be provided which acts as a mounting base for the circuit breaker and a support for the fiber optic's connector as this is the interface between the heliostat and the field wiring/fiber optic's.

In addition to the support bracket, an internal protective cover will be required to provide personnel protection from the 480 volt terminations after the wire installations are made.

The cutout will also contain a cover to protect the box from the weather and animals. The cover will not be water-tight, but it will be designed to prevent water flow into it.

Cable-Harness Assembly - The cable harness preparation area consists of work stations at which complete pedestal wiring harnesses are assembled and tested for continuity. These wiring harnesses consist of the following:

- A 9' (108") special cable comprised of 3 insulation (600') copper power conductors wrapped (twisted) around a central core containing a pair of 1 mm optical fibers for the data transmission/control system. Entire cable jacketed for protection and integrity
- A 7' (84") cable assembled at the work station consisting of a 3/C power cable and motor control conductors to connect the H/C and stowage motor
- A 5' (60") cable as above to connect the H/C and elevation motor
- A 1' (12") cable as above to connect the H/C and azimuth motor.

Harness assembly involves cable end preparation and attachment of a 25 pin connector for interfacing with the H/C, optical fiber end preparation and attachment of connectors, and attachment of motor connectors for power and control cables (Figure 3.3.5-3). Following completion of a harness, a short

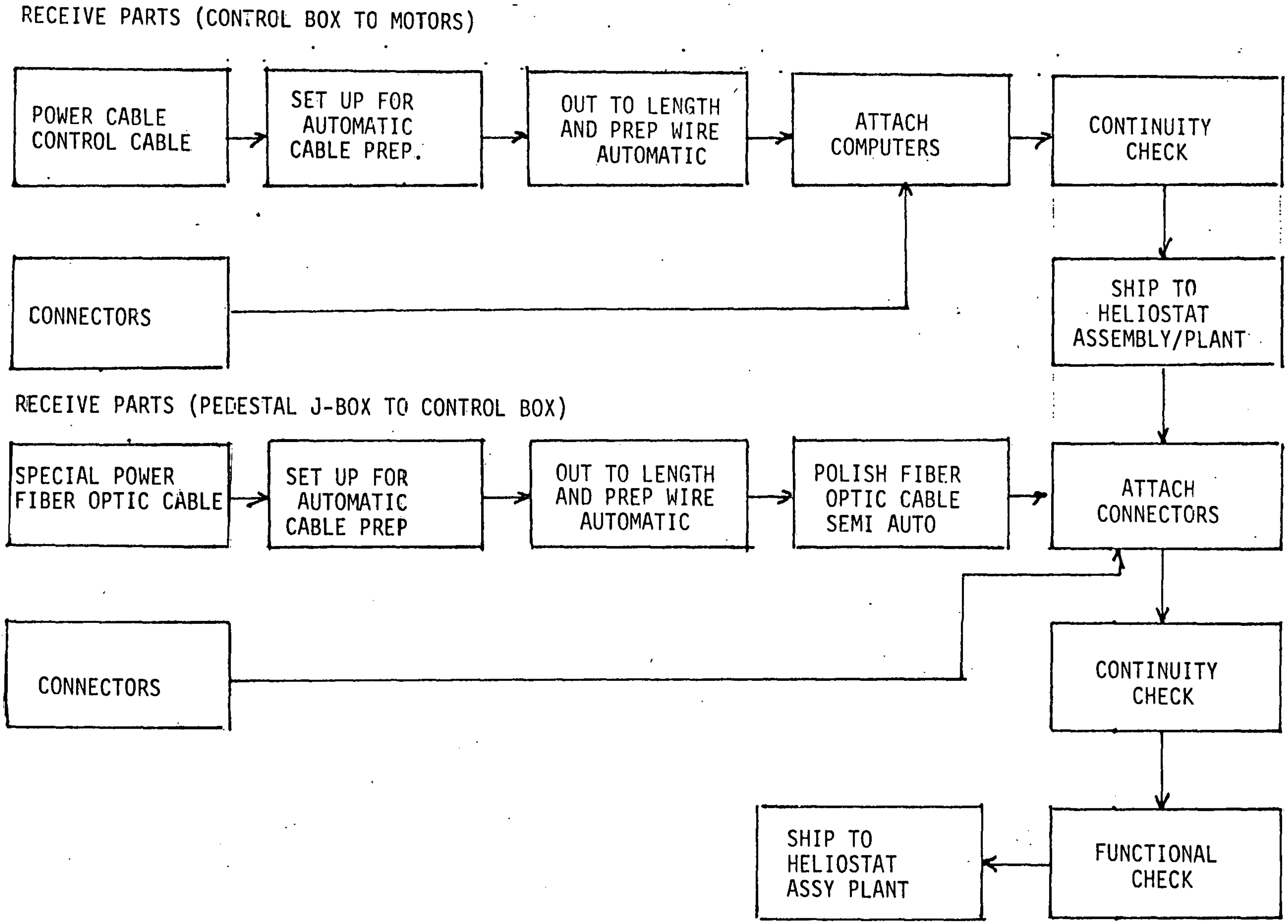

Figure 3.3.5-3 Heliostat Control Harness Manufacturing Flow Chart

electrical and optical test is made for continuity, and the harnesses are sent to the systems functional test bench.

3.3.6 Quality Assurance

The quality assurance concept for 25,000 heliostats per year production should provide for hardware verification at the highest possible assembly level. Proof of hardware acceptability is thus confirmed by performance rather than detail inspection. The quality assurance concept is based on the following preventive controls being imposed:

- Incoming Material - Receiving inspection prevents accepting large quantities of unusable parts or materials.
- Manufacturing - Production inspection guards against producing quantities of unusable parts.
- Test - Finished article testing minimized field rework of heliostats.

Product quality must be a goal recognized by all plant personnel. Manufacturing personnel must be responsible for the quality of the product. This responsibility is a management philosophy that begins with the training of new personnel.

3.3.6.1 Receiving Inspection

The primary motive for inspecting a supplier's product in a production plant is to prevent schedule delays. Reputable suppliers will replace unusable material, however, the replacement material may have a long lead time and therefore may tend to impact schedule. The discrepancies one would expect are more in the clerical vein than from hardware fabrication. Inspection as a minimum consists of checking incoming material for identification and damage. This inspection consists of:

- Identification to the purchase order, including dimensional inspection where necessary, such as motors.
- Supplier certification, test data, coupons as applicable for material such as, weld rod and adhesives.
- Shipping and handling damage.

Sampling techniques should be applied for this inspection. Sampling techniques are proven quality approaches that are based on past supplier performance.

Source inspection must be considered for material that has the following typical characteristics:

- Long Lead times.
- Large quantity in the shipment.
- Possibility of entire shipment not being to specification requirements.

Two materials fall into this category: glass and steel. The supplier's history, capability and inspection methods, as well as the impact to production, should be evaluated in determining the applicability of accepting the material at the supplier's facility.

Electronic components received from suppliers can be segregated into two categories:

- Functional assemblies
- Functional parts or components

Functional assemblies, such as the drive motors and encoders, should be tested at the supplier. The test itself should be evaluated and approved, and either test data or certification that the items successfully met the test requirements should be forwarded with each shipment. Since motor failure,which can be detected during drive system functional tests, is a four bolt removal and replacement operation, additional (redundant) testing at receiving inspection is not recommended.

Determination of the receiving inspection requirements for functional electronic parts or components must be made based on the following:

- Quality of the part - commercial, supplier screened, military specification, etc.
- Cost of inspecting/testing at receiving inspection; includes test equipment costs.
- Failure history of the part.
- Past experience/reputation of the supplier.

- Impact to the production line for nonconforming parts, cost to rework, etc.
- Other considerations after receipt, such as burn-in, subassembly test, etc.

While the above considerations are not all inclusive, they do provide a base for determining the degree of inspection at receiving.

Once the plan for each part or component has been developed, the plan should not remain static. It should be reviewed for modifications to effect cost savings based on feedback information from the in-house tests and field site(s).

3.3.6.2 Manufacturing

As previously indicated, manufacturing must accept responsibility for product quality. The trade-off for the requirement for inspection must be made in concert with and knowledge of the fabrication process. Each operation should be evaluated with respect to the cost of having the machine operator check the parts or having the parts inspected. Generally, an automated operation such as a numerical control machine with a self-checking feature would require minimal or no inspection as compared to one having the self-checking feature.

The philosophy for inspection at the fabrication level is to assure that each individual process stays within the tolerance zone. Emphases should be placed on preventive controls rather than corrective actions.

Consistent with the above philosophy, automated, semiautomated, or manually operated systems, processes, or operations should be proved and completed by First Article Inspection of first product and followed by periodic inspection of the system, process or operation (frequency of periodic inspection development required).

Fabrication operations most adaptable to the above are:

- Tools and fixtures required to fabricate detail parts of the harmonic drive system, the reflector panel assembly and the support structure.

- Controller fabrication and the associated equipment such as the Printed Wiring Board automatic insertion machine, wave soldering process and the automatic test equipment.

3.3.6.3 Testing

A quality heliostat drive system with controllers is mandatory for obtaining a failure free installed heliostat. With this acknowledgment, functional testing of all units must be performed. The drive assembly complete with linear actuators, the three motors, and heliostat electronics installed in place would be tested as a unit. The test equipment would operate the drive system through all of its functional parameters and verify that the drive system and controllers were correctly assembled and functioning correctly. In addition, any anomalies are recorded on a tape printout which identifies the anomaly and its cause.

The heliostat controller and data distribution interface should be functionally tested prior to installation. The test equipment for both units should consist of simulators designed to verify all paramters of input and output command signals.

The optical quality of the reflector subassembly is equally important to overall heliostat performance. Reflective surfaces would be measured to insure flatness (or reflective image) requirements. Two concepts have been reviewed for application to this task. They are:

- The Digital Image Radiometer - Adjacent Vidicon Imaging (Figure 3.3.6-1) is used. The reflector unit on a horizontal is viewed by a digital image radiometer which observes a reflected image pattern. The desired image pattern is known, and deviations from this pattern, as received by the radiometer can be used to determine conformance.

- A laser concept, as depicted in Figure 3.3.6-2 uses a Laser Linear/ Angular Interferometer system to scan the mirror surface as it moves on the production line. This system utilizes the interaction of a reference laser beam and a reflected laser beam from the mirror surface. The resultant

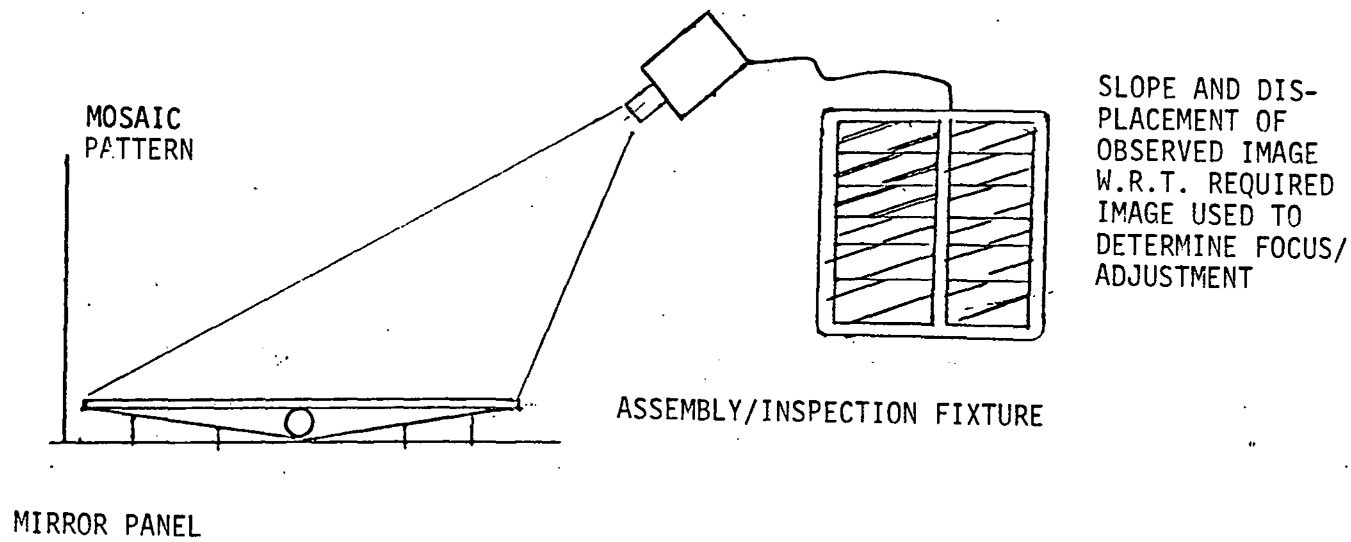

FIGURE 3.3.6-1 - DIGITAL IMAGE RADIOMETER

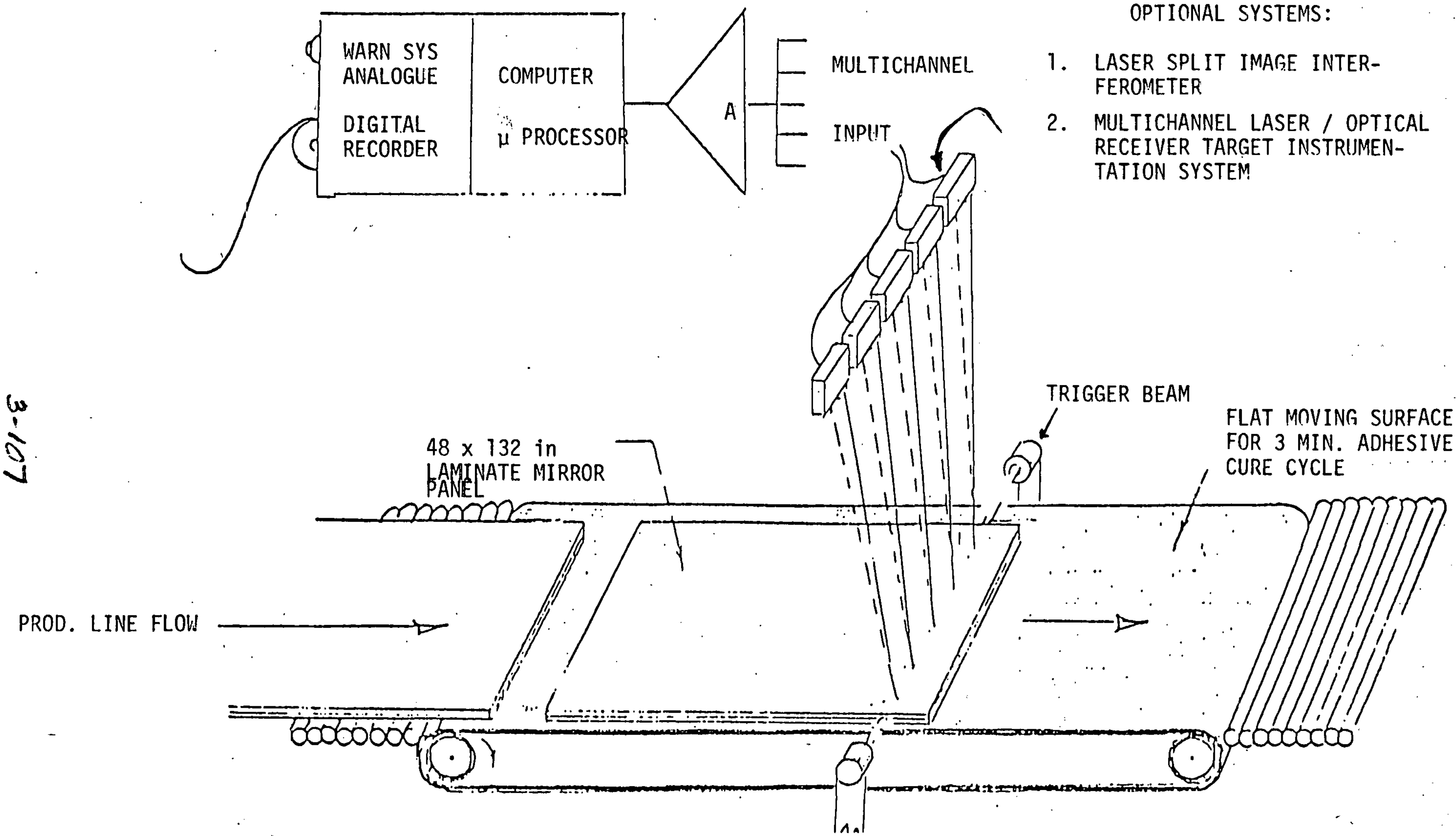

FIGURE 3.3.6-2 - LASER (LINEAR ANGULAR INTERFEROMETER)

angular deviation and laser intensity variations between the two beams are detected and interpreted by the associated electronics to provide data for slope and reflectivity requirements.

Final acceptance criteria as outlined above for these functional systems, in combination provides maximum assurance that the installed heliostat will function as intended.

3.4 PRODUCTION PLANT CONCEPT

This section reports on the manufacturing facility, equipment and manpower requirements developed to support the 25,000 heliostat per year production.

Key assumptions made relative to the plant were as follows:

- Production operations are based on Make/Buy decisions (Reference Section 3.3.1).
- Plant concept is based on Manufacturing Plan as discussed in Section 3.3.
- The plant construction incorporates environmental and OSHA controls required.
- The Production Plant is sized to operate on a manual 5 day, 2 shift basis.

The Production Plant Layout concept to manufacture the major heliostat subassemblies, e.g., the Drive Unit Assembly and the Reflective Panel Assembly is depicted in Figure 3.4-1. The plant size required to support the 25,000 production rate is 62,500 square feet. The physical plant is divided in two major production areas, that do not necessarily need to be co-located. For purposes of this report a co-located layout has been presented. However, there is rationale that warrants separating these functions. This will be evaluated and discussed in subsequent reports.

The Production Plant concepts for both assemblies differ considerably. The Reflector Panel Assembly represents a high degree of automation and mechanized material handling. This is warranted by factors such as volume of production. There is a significant quantity of reflector panel subassemblies being processed. For example, with 12 sheets of .060 fusion glass and 12 sheets of .1875 Float Glass per heliostat (at 25,000 heliostats per year) 300,000 lites of <u>each</u> type of glass is handled or 600,000 lites per year. Thus means that on the average a lite of glass must be put into production every <u>22.5</u> seconds. The mirroring line must produce mirrored lites every 45 seconds. Lamination of .060 fusion and .1875 Float Glass must be completed every 45 seconds. Reflector panel subassemblies must be completed every 4.5 minutes to keep pace with plant

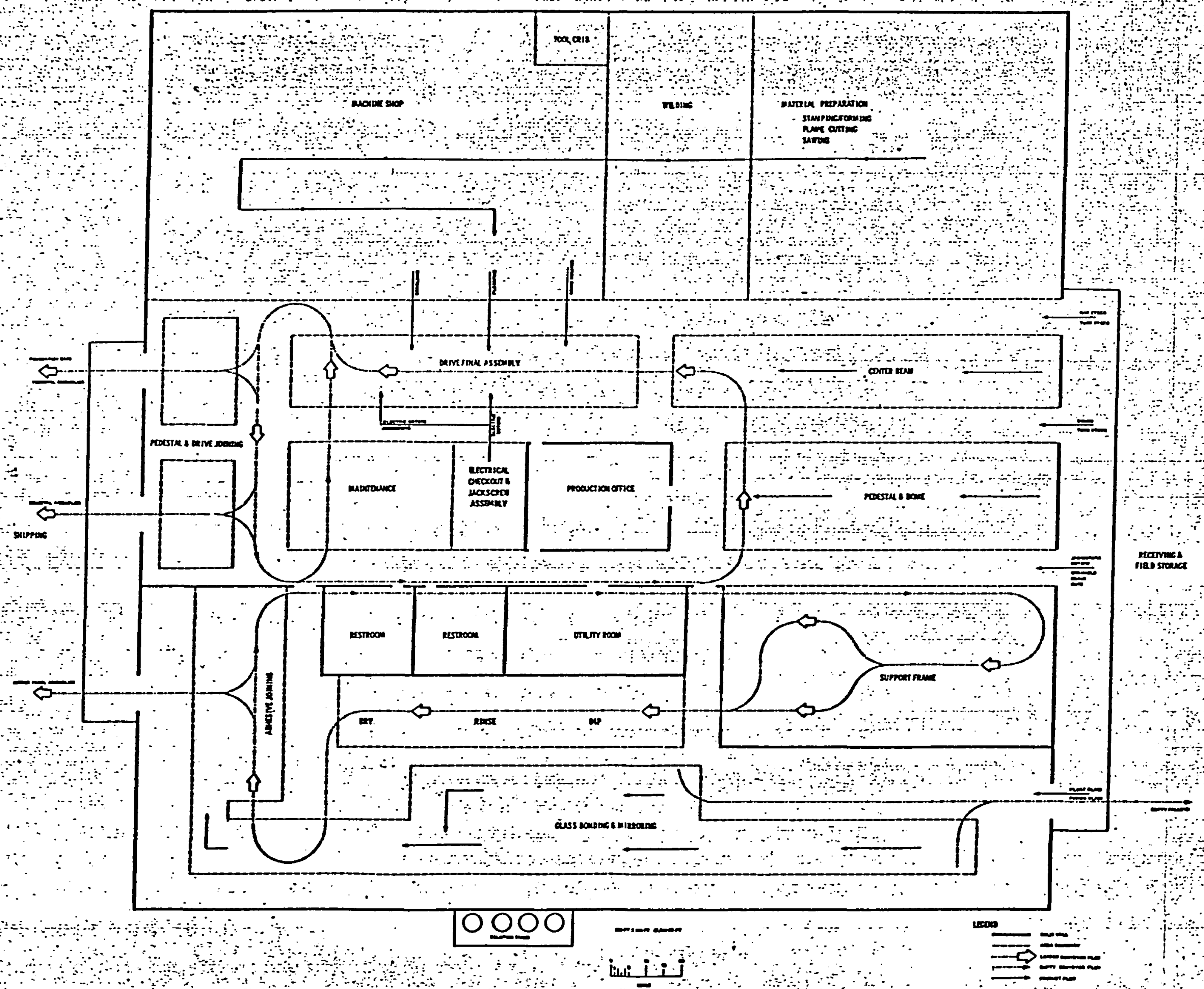

Figure 3.4-1 Block Flow Plant Layout

output requirements of one heliostat completed every 9 minutes.

A Drive Unit Assembly must also be produced every 9 minutes. However, production of this assembly, is considerably less than the Reflector Panel Assembly.

The skills required to support both types of manufacturing are clearly different. The Reflector Panel requires material handlers and assemblers, primarily, while the Drive Unit requires machinist-type skills primarily. These are outlined in Section 3.4.3 Manpower Summary.

3.4.1 Plant Layout

Figure (3.4-1) depicts in block flow the plant layout for the drive unit and reflector panel fabrication and assembly activities. As noted in the plant concept, the facility houses both activities. It is essential that the reflector panel line is operated under clean room conditions. This requires a separation of the panel line from the entire drive unit area and from the weld up area of the reflector panel framework as well. Since the majority of the glass will be stored outside, the glass wash areas are located outside of the panel line area to further ensure cleanliness along the mirroring activities. Low cost air curtain passage ways between these areas will maintain the clean requirements with no inconvenience to operator traffic.

Floor space requirements for under roof glass storage is based on a one shift line supply for both the fusion and float glass lines. This enables material handlers sufficient time for periodic loading of the A-frames from the field into the glass queues with minimum under roof construction costs.

As shown in the layout the glass line flow is continuous and straight line from raw storage to shipping which minimizes total square footage as well as material handling. In support of the main conveyor flow, overhead monorails will return empty A-frames back to the field to glass suppliers, deliver the support frames to the glass and deliver the assembled panels to the shipping area.

The mirroring line is located directly adjacent to an outside wall to minimize plumbing costs between outside tank supply and in-house application.

The drive fabrication and assembly activities are also aligned along straight line flows between raw storage and shipping. The stamping sawing and flame cutting areas are situated directly adjacent to outside storage areas to minimize flow distance and under-roof storage requirements. These areas, as well as the welding and machining process areas following, will contain overhead air filtering equipment to supply continuous clean air circulation.

3.4.2 Major Equipment Requirements

Major equipment requirements are summarized in Tables 3.4.2-1 and 3.4.2-2 for the drive and reflector panel activities. The major concentration of equipment is in the drive unit activities where metal forming, joining, removal and assemblies take place. Wherever practical, automatic handling equipment has been included to minimize operator handling effort, especially where operation cycle times involve manual loading or unloading. For example, shuttle-type loaders allow machining simultaneous to loading and unloading of hardware on the numerical control machining centers and vertical turret lathes. This also allows individual operators to service more than one machining activity. Automatic positioners and gravity fed conveyors allow the large bulky items such as the center beam and pedestal to simply roll to their next station rather than be handled between station activities. Where items require several positions for assembly, such as on the azimuth drive, specialized equipment allows multiple part orientation by single operators. Handling equipment and tooling such as these reduce the total cost of major machine tool investment.

Table 3.4.2-1

PROTOTYPE HELIOSTAT DRIVE UNIT
PRELIMINARY EQUIPMENT CONFIGURATION - 25K/YEAR

Major Equipment	Number Required
Flame cutter	2
G&L vertical turret lathe	2
Numerical control lathe	2
Automatic lathe	1
Hydrosize machine	1
Punch press line w/coil straight	1
Hydraulic press (300 ton)	2
Deep Draw Press	1
Small press	1
Multi-drill station	5
Numerical control milling machine center K&T	4
Conventional mill	1
Fusion welder	6
Inertia welder	2
Marvel saw	2
Broach	1
Automatic Clean Deburr Station	1
Cam grinder	1
Total	36

Minor Equipment	
Material handling (Conveyors, hoists)	350 Ft.

Table 3.4.2-2

PROTOTYPE HELIOSTAT REFLECTOR

PRELIMINARY EQUIPMENT CONFIGURATION - 25K/YEAR

Major Equipment	Number Required
Adhesive application-bond station	3
Mirroring line	
Deionized water system & heater	

Minor Equipment	
Conveyor	400 ft
Monorail	600 ft
Assembly jig	2
Clean & dry station (Beam & glass)	2
Nip roller Station	1
Glass handling equipment	

3.4.3 Direct Labor Manpower

Direct labor manpower by labor classification is summarized in Tables 3.4.3-1, 3.4.3-2 and 3.4.3-3. As discussed in the plant concept, the skill level for the drive activities are higher than the reflector panel activities. However, it should be considered that both activities may eventually require only four distinct classifications, namely, material handler, welder, equipment monitor and assembler, which should be available and/or readily trainable in the Southwest during the next decade. The indirect skills have not been included here since the direct skills are significant for labor costing and trade-offs whereas indirect tend to be factored percentages of the direct labor base.

Table 3.4.3-1

PROTOTYPE HELIOSTAT DRIVE UNIT
TOUCH LABOR MANNING - 25K/YEAR

Item	Touch Manning	Skills/Classification
Center Beam/Torque Tube Fab	18	6 "B" welders 8 General machinists 4 Material handlers
Pedestal & Foundation Cap Assembly	12	4 "B" welders 6 General machinists 2 Material handlers
Flame Cutting	8	4 Numerical control machinists 4 Material handlers
Stampings/Press	10	8 General machinists 2 Material handlers
Saw Cutting	6	4 General machinists 2 Material handlers
Broaching	1	1 General machinist
Inertia Welder	1	1 "B" welder
Fusion Welder	6	6 "B" welder
Final Assembly (Pedestal, Drives, T Tube)	6	3 "A" assemblers 3 "B" assemblers
Drive Assembly (Azimuth)	10	10 "B" assemblers
Clean, Deburr and Degrease	4	4 Process machine operators
Drilling	4	4 General machinists

Table 3.4.3-1

PROTOTYPE HELIOSTAT DRIVE UNIT
TOUCH LABOR MANNING - 25K/YEAR

Item	Touch Manning	Skills/Classification
Turning	8	2 Numerical control machinists 6 General machinists
Milling	4	2 Numerical control machinists 2 Material handlers
Subtotal Drive	98	8 Numerical control machinists 37 General machinists 17 "B" welders 4 Process machine operators 3 "A" assemblers 13 "B" assemblers 16 Material handlers

Table 3.4.3-2

PROTOTYPE HELIOSTAT REFLECTOR
TOUCH LADOR MANNING - 25K/YEAR

Item	Touch Manning	Skills/Classification
Support Structure Fab	6	4 "B" press operators 2 Material handlers
Support Structure	12	4 "B" welders 3 "B" assemblers 5 Material handlers
Reflective Surface/Support Structure	18	6 "B" assemblers 8 Material handlers 4 Packers
Reflective Panel Fabrication	16	2 "B" assemblers 2 Chemical operators 8 Line tender-coating operators 4 material handlers
Subtotal Reflector	52	4 "B" press operators 4 "B" welders 11 "B" assemblers 19 Material handlers 2 Chemical operators 4 Packers 8 Line tender-coating operators

Table 3.4.3-3

PROTOTYPE HELIOSTAT ELECTRICAL ASSEMBLY

TOUCH LABOR MANNING - 25K/YEAR

Item	Touch Manning	Skills/Classification
Electronic/Harness Area	9	4 "B" assemblers 2 "C" assemblers 3 Test technicians
Subtotal Electrical	9	4 "B" assemblers 2 "C" assemblers 3 Test technicians
TOTAL	159	8 Numerical control machinists 37 General machinists 4 "B" press operators 21 "B" welders 4 Process machine operators 3 "A" assemblers 28 "B" assemblers 2 "C" assemblers 3 Test technicians 35 Material handlers 4 Packers 2 Chemical operators 8 Line tender-coating operators

NOTE: Manning requirements based on two shifts (8 hrs/shift), five day/week

3.5 TRANSPORTATION CONCEPT

This section contains a report of the approaches being developed for packaging, transportation and handling of both incoming materials and completed assemblies.

Our basic objectives in this area are:

1. Develop Handling Methods For Glass - As discussed in Section 3.1 the handling of .060" fusion glass is considered an important issue. Our manufacturing and packaging specialists have been working with companies such as, Pittsburgh Plate Glass, as well as companies specializing in developing and manufacturing glass handling equipment.

2. Minimize Packaging Costs - It is recognized that in volume production, it is essential to utilize packaging that reduces material costs and labor to package and unpackage, while providing the protection the parts require. We have worked with potential suppliers of material to develop a cost effective approach. At receiving, the next operational requirement for that material is reviewed, so that minimum labor can be expended to ready the material/ assembly for the next operation.

3. Develop In-Process Handling - Packaging Specialists have been working with Manufacturing Engineers and providing assistance in developing the best handling approach for the factory operations.

The following is a summary of the assumptions and approach that has been developed for 25,000/year production.

3.5.1 Assumptions For 25,000 Heliostats Per Year Production

Transportation - It was assumed that the heliostat factory is within a fifty-mile radius of the site. Without knowledge of available rail spurs, truck transportation is more flexible and economical than rail transportation. When more specific site locations are defined, proper cost trades relative to optimizing transportation cost and method will be performed. Motor freight classification of items will be evaluated to reduce costs from class rates to point to point, rates, where feasible. In addition, Freight All Kinds (FAK)

Table 3.5-1

NATIONAL MOTOR FREIGHT CLASSIFICATION DATA FOR MAJOR ITEMS

	NMFC ITEM	NMFC ARTICLE NAME	CLASS RATES LTL	TL
Reflector Panel Assembly	137440 Sub 2	Mirrors, NOI, not bent, exceeding 120 united in. but not exceeding 15-ft length or 7-1/2-ft width.	125	70
Drive Assembly	133300 Sub 1	Machinery Group, Machinery NOI	100	45
Cross Beams	104420	Iron or Steel, Beams, NOI	50	35
Main Beam	133390	Machinery Group, Machine Parts NOI	85	45
Pedestals	133390 Sub 4	Machinery Group, Machine Parts NOI	85	45

rates utilizing piggy back shipments will be studied. Table 3.5-1 shows present National Motor Freight Classification Data for major items.

Packaging - Packaging is designed for protection of the part, and optimum loading of a standard truck trailer. All packaging can be handled with conventional forklift type equipment. In all concepts, cushioning material is placed between metal to metal interfaces, e.g., strap to part, to prevent abrasion.

3.5.2 Approach For 25,000 Heliostats Per Year Production

3.5.2.1 Incoming Material - Incoming raw material includes: glass, steel channels (cross beams), steel hat sections (stringers), and steel tubing (pedestal and main beam). Suppliers' handling and packaging methods were studied to aid in formulating our recommendations.

Glass - Glass is packed on metal A-frame type fixtures to take advantage of the material's high compression edge strength. The A-frame can be forklifted. Handling individual sheets presents a special problem due to their large area (four feet by eleven feet) and thickness (1/16 and 1/8 of an inch). A sheet will be handled with vacuum equipment which supports the sheet over its entire area. The sheet is brought to a horizontal attitude, and placed upon a voller conveyor to move through the various factory processing operations, e.g., mirroring and bonding.

Safety Considerations - In handling glass proper protective clothing and procedures will be strictly enforced. Where lifting devices are used, redundant systems shall be mandatory to reduce the occurence of accidents. Proper lighting continuous safety measures will be monitored.

Shock Sensitive Equipment - Calibration equipment, controllers, junction boxes, and other electrical equipment will be cushion packed in fiberboard or wooden containers (depending on weight) for protection from shock and vibration. The containers will be palletized to provide forklift capability.

3.5.2.2 Factory To Site Shipments - The heliostat will be shipped from the factory to the installation site as three subassemblies: two reflector panel assemblies and the drive assembly.

Reflector Panel Assembly - Each panel assembly is handled from its mirror side, with the Reflector Panel Assembly Installation Equipment (See Figure 4.4.3-1). As shown in Figure 3.5-1, the panels are vertically suspended on a base support structure assembly with the larger inboard cross beam down. Each panel is secured through the inboard cross beam to the support structure. After the base is loaded a cushioned holddown assembly is installed across the top of the panels and strapped to the base. The loaded base assembly (four reflectors) weighing approximately 6000 pounds is forklifted onto a lowboy trailer and secured to the bed. The load is covered with a flexible, opaque tarpaulin to prevent glare hazards for other vehicles. A lowboy trailer is used to keep the load under the fourteen foot height restrictions.

Drive Assembly - This assembly is approximately 163 inches long and weighs approximately 1900 pounds. The assembly is loaded and unloaded with the Drive/Pedestal Assembly Installation Equipment (See Figure 4.4.4-1). It is shipped with the actuators attached, facing up. Specially fitted forty foot flat bed trailers will be utilized for the factory to site shipment of this assembly. A welded metal rack (approximately thirty feet long, two feet wide, and five feet high) is secured along one side of the trailer. Wooden blocking is secured to the trailer bed to provide stops for the main beam. The main beam is placed on the bed at a 24 degree angle to the side of the trailer to provide for nesting and higher load density. The pedestal is pointing up and to the aft, at a 40 degree angle to the horizontal to keep the load under height restrictions. The main beam is strapped to the wooden blocking to provide holddowns, and the pedestal is supported by the metal rack. The trailer is loaded starting at the aft end. Twelve assemblies can be loaded on one trailer.

Formed Steel - The cross beams are relatively long (approximately twenty feet), relatively thin (.0785 inch) steel channels. Each beam weighs approximately 140 pounds. They are placed flat on wooden 2x4's, reverse nested, formed into a bundle of 5000 to 7500 pounds, and strapped across 1x4 holddowns. The bundles are stacked, with a forklift, onto a trailer forming a high density load.

The stringers are approximately 130 inches in length, relatively thin (.04 inch) steel hat sections. They are handled in the same manner as the cross beams. The stringers are strapped in bundles of 2500 to 5000 pounds. The bundles are unloaded with a forklift, for handling by the factory conveyor system.

The pedestal is 24 inch diameter steel tubing, weighing approximately 400 pounds. The main beam is 16 inch diameter steel tubing, weighing approximately 120 pounds. They are placed across wooden 2x4's, and strapped over 1x4 hold-downs. By unitizing, fewer lifts are needed per truckload. Individual pedestals and main beams can be handled with either a forklift or an overhead crane.

Steel plate for the drive assembly, will be received on pallets or strapped to wooden 2x4's.

Incoming Parts - Incoming parts include: electric motors, actuators, and various bearings and bushings. Bearings and other small parts are individually wrapped and bulk packed in fiberboard cartons. This container is then palletized.

The electric motors are individually packed in fiberboard boxes. These unit containers are then palletized to provide for handling with a forklift. The actuators are approximately sixty inches long and weigh fifty pounds. The actuators will be strapped to a pallet, having cover blocks which also provide for stacking. The pallets are stacked by forklift, and each stack is strapped together.

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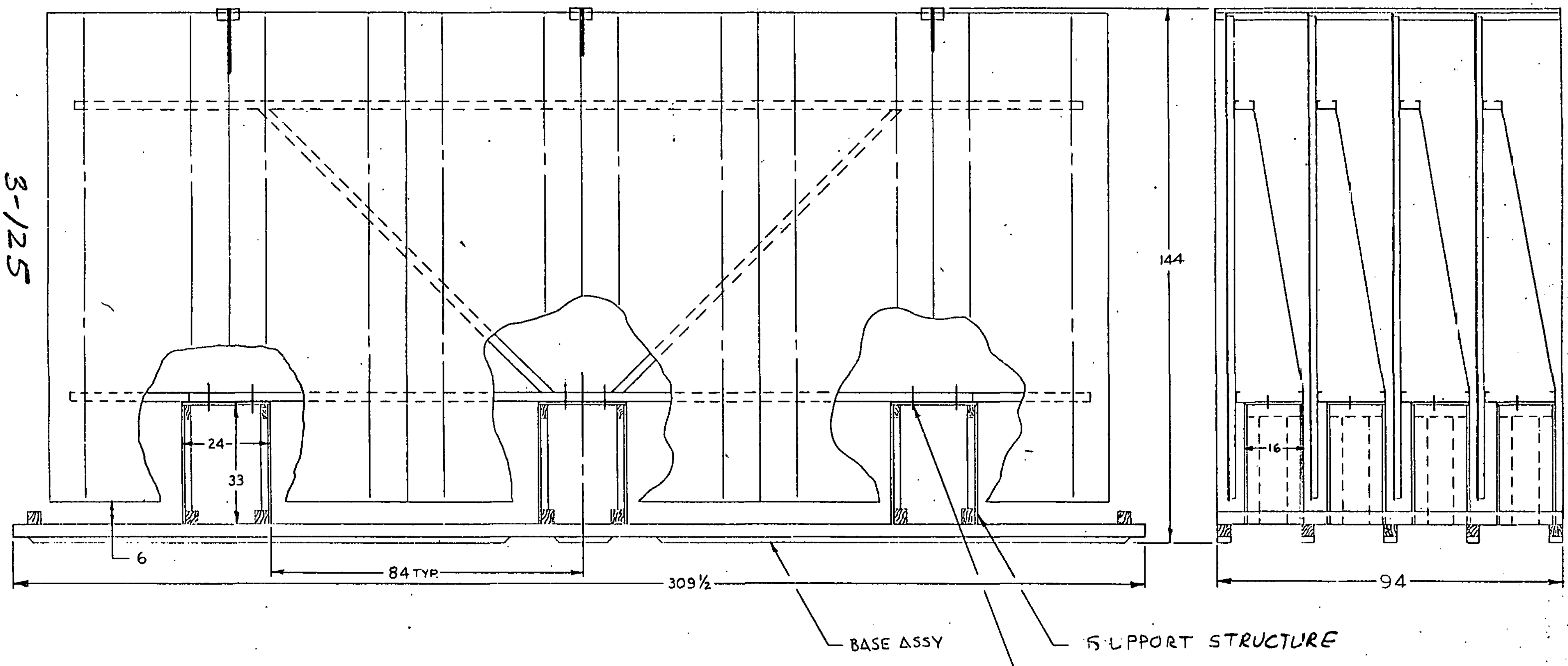


REFLECTOR PANEL ASSY
SHIPPING & HANDLING
FIXTURE
SCALE: 1/20

FIGURE 3.5-1

3.6 PRODUCTION CONCEPT FOR 250,000 HELIOSTATS/YEAR

Production concepts are being developed relative to changes in areas of;

- Make or Buy - e.g., Fusion glass Integration
- Manufacturing Plans - e.g., automation concepts in fabrication and assembly
- Production Plant - review alternatives relative to decentralization, e.g., centralized drive unit assembly, facility and decentralized reflector panel assemby and facilities.

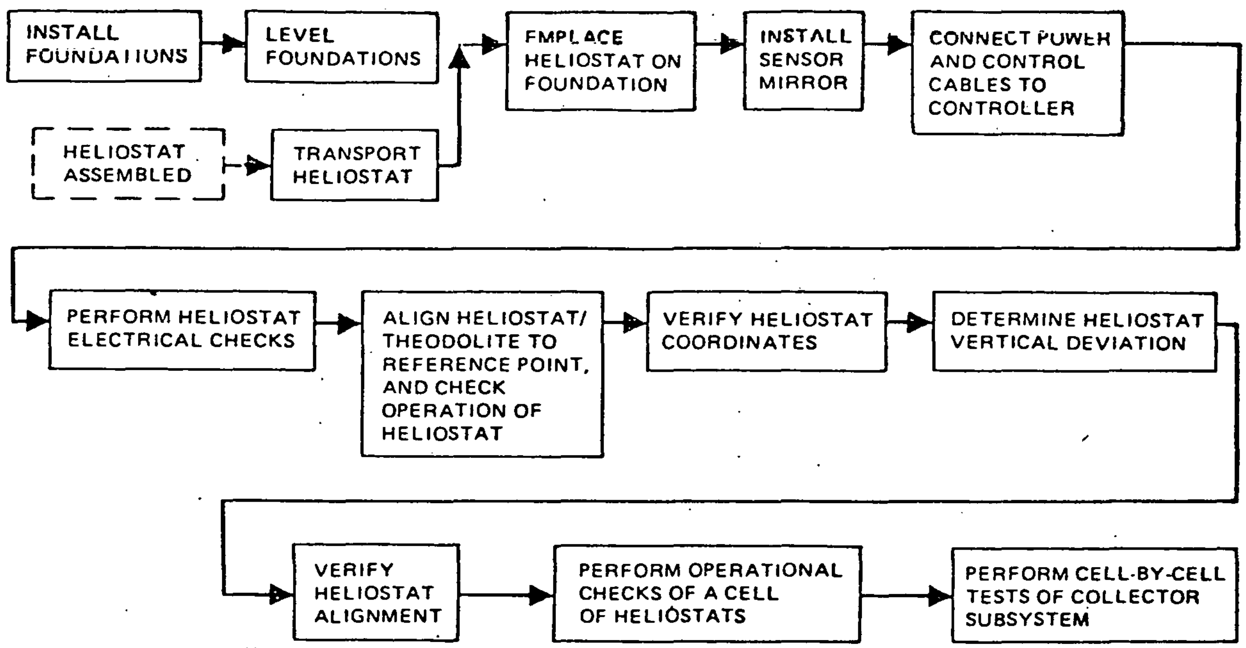
These changes will be developed in subsequent reports.

Section 4

INSTALLATION AND CHECKOUT CONCEPTUAL DESIGN

4.1 INITIAL BASELINE PROCESS

The initial baseline Installation and Checkout (I&C) process is shown below for a typical heliostat:



In the field, some of these tasks would be performed in parallel. Checkout would have been accomplished by using a mobile test set to verify the integrity of the field controller/individual heliostat interface. A subsystem level test verifying proper tracking, slew-off, and stowage performance on a cell-by-cell basis would be verified. Final system checkout to verify proper subsystem interfacing and total system performance would then have been performed.

4.1.1 Installation and Checkout Requirements

The objectives of the installation and checkout procedures were to accomplish, in a timely, well-organized, and cost-effective manner, the emplacement and performance verification of heliostats, corresponding to relatively high production rates. Heliostats are to be installed to within one foot of the reference position, two degrees of vertical, and three degrees of a reference North-South line.

4.1.2 Initial Baseline Process Description

The baseline process is described in Section 4.1. The rationale for the I&C process was to keep at-site activities relatively simple and less time-consuming by prefabricating heliostat parts, and employing automatic checkout test equipment.

However, as detailed design of the heliostat as well as special I&C equipment evolved, and as manpower requirements associated with I&C tasks were developed, a number of trades were identified. To satisfy the objectives of cost effectiveness in satisfying high production volumes, the greatest potential for cost reduction was seen to be in the following design areas:

- Transportation guidelines in determining optimum heliostat size
- Benefits of no sensor alignment in control optimization
- Pedestal vs site assembly,

and in the following I&C areas:

- Optimun on-site transportation
- Optimum checkout procedure
- Scheduling and manloading optimization.

These trades are discussed in Sections 4.2 and 4.3.

4.2 DESIGN AND MANUFACTURING TRADE STUDY SUPPORT RESULTS

This section summarizes the analyses that were performed in support of design and manufacturing trade studies.

4.2.1 Trade Study D-1 Optimum Reflector Size

The purpose of this trade study was to evaluate the implications of reflector size. Conclusions reached from the installation and checkout point of view are that the two piece reflector panels in the current design is compatible with all modes of transportation and state-of-the-art handling equipment.

4.2.2 Trade Study D-4 Control Optimization

Eliminating the need for gimbal axis encoders removed an additional alignment requirement, that of aligning the encoder to the heliostat. The savings resulting from this design change are not separable from those resulting from refinement of the design and alignment and checkout procedures. The total impact is delineated in trade study I-2 (Paragraph 4.3.2).

4.2.3 Trade Study M-8 Factory Requirement

In this trade study, the I&C cost differences were negligible and did not influence the outcome of the trade, i.e., deletion of the site factory.

4.3 INSTALLATION AND CHECKOUT TRADE STUDY RESULTS

Originally, two trade studies were to be discussed in this section. However, Trade Study I-1 was deleted because the design change to in-situ heliostat assembly obviated the need to study the transportation of a completed heliostat.

4.3.1 Trade Study I-1 Optimum On-Site Transportation

(DELETED)

4.3.2 Trade Study I-2 Collector Checkout

The original objective of this study was to select an optimum checkout procedure based on the pilot plant techniques for use on the low cost commercial plant. As the hardware and software evolved, the designs changed so much that a direct comparison of the checkout procedures could not be made. Instead, a new checkout procedure has been developed to complement the low cost commercial equipment design.

Initial Baseline Approach (Figure 4.3.2-1) - The checkout procedure developed for this installation involves setting the heliostat reference, to a known benchmark, physically setting the encoder to match the heliostats reference and finally, making an operational checkout of a cell of heliostats (24). In this open-loop approach, there is no tracking in the true sense of the word. The mechanical alignment of the hardware is refined to a predetermined set of heliostat movement algorithms. The steps of this procedure accomplish that objective. First, the relationship of the heliostat to true north and level is determined. Next, the exact geographical axis location (X, Y & Z) is determined. The corrections to this alignment are incorporated into the guidance software/hardware to improve the accuracy of movement for each heliostat.

Prototype Heliostat Approach (Figure 4.3.2-2) - In this approach, the same type of stepping from coarse to fine tracking adjustment occurs. However, there are two methods used to achieve the correction. For about half of the heliostats (the northern part of the field), the positioning is favorable to the interactive man/machine alignment procedure. For the Southern part of the field, the automatic search mode makes the best use of resources even at a time penalty of 35 percent. In either case, after initial offset errors are removed, the alignment is done in three steps, followed by short tracking periods (120 sec, 80 sec, 80 sec). The image positioning is checked after each track period with a digital image radiometer (DIR), which senses the deviation of the heliostat image centroid from its optimum track. The DIR then feeds correction data to the heliostat controller for updating the heliostat position and movement algorithm variables. The three alignments are accomplished within 7.4 minutes, and effectively zero out any installation tolerances in position and tilt so that the heliostats assume proper track of the sun.

Summary Results - The significance of this trade study is the large reduction in the absolute checkout time for heliostat checkout.

In the original approach that evolved from the Pilot Plant, the alignment was basically a physical/mechanical process that aligned the mirror surface and

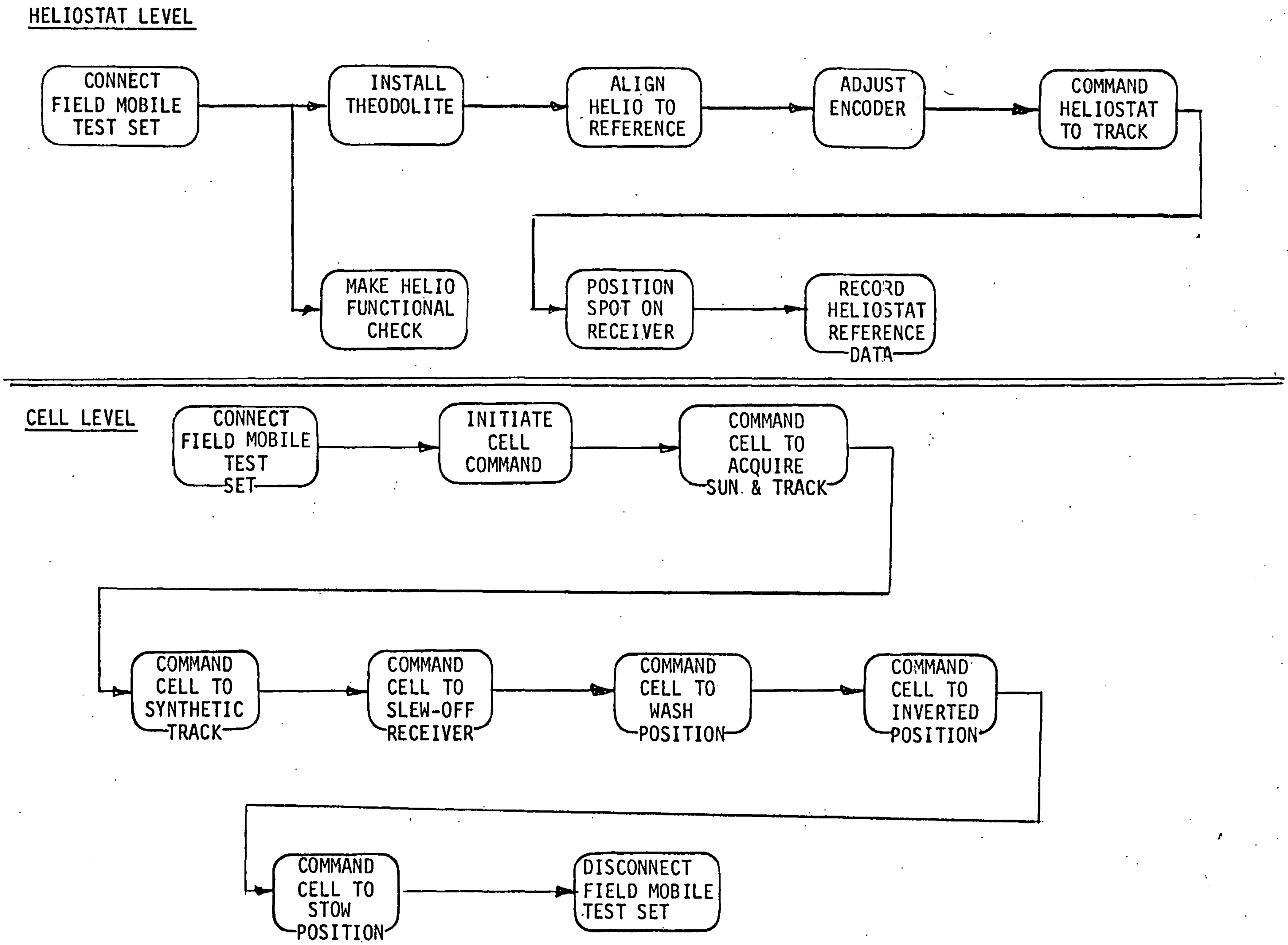
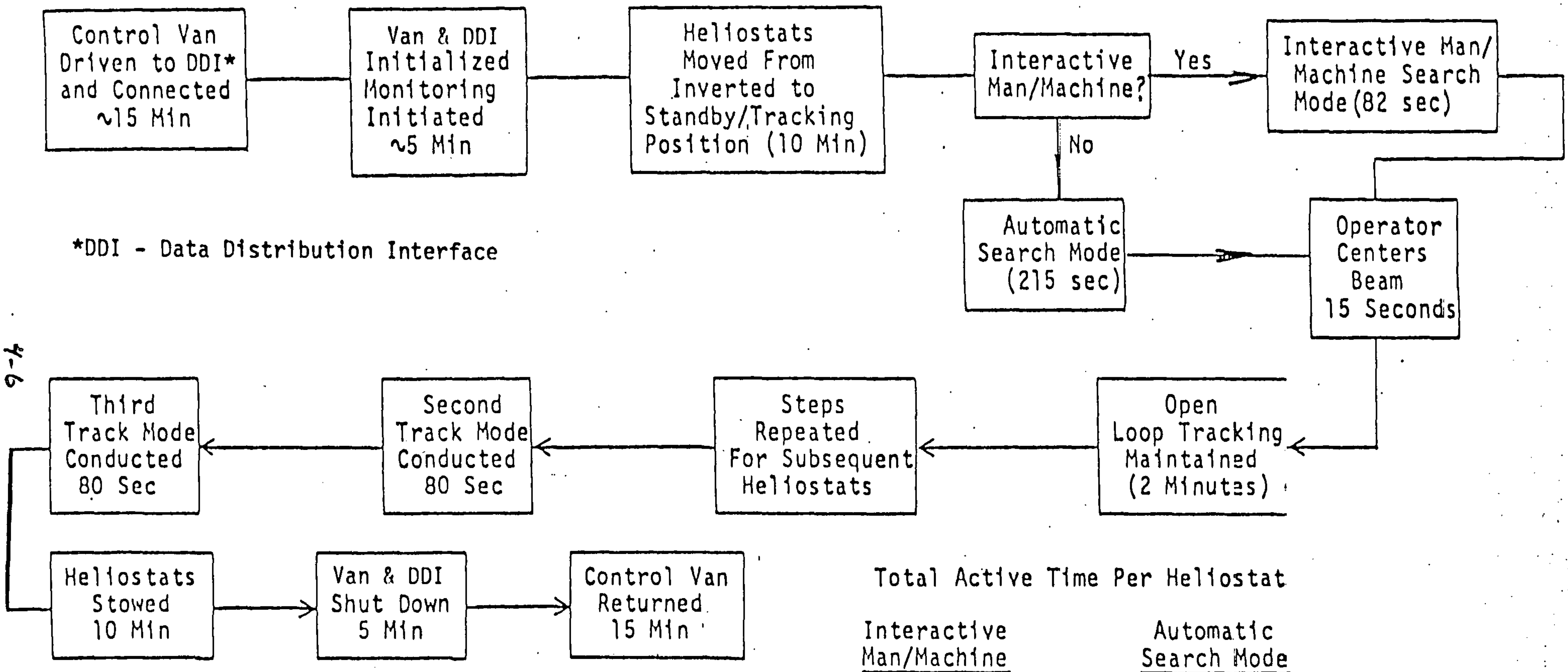


Figure 4.3.2-1 Alignment and Checkout - Pilot Plant



*DDI - Data Distribution Interface

Personnel	Responsibilities
Operator	Operate van, center beam of target
Technician	Inspect array, direct operator during initial acquisition. Maintain equipment.
Engineer	Optional. Required in early stages to train operator, solve field related problems, update program.

Total Active Time Per Heliostat

Interactive Man/Machine	Automatic Search Mode
82	215
15	15
120	120
80	80
80	80
377 Sec	510 Sec

Total setup/shutdown time: 1 hour

Figure 4.3.2-2 Initial Alignment Procedure Block Flow Diagram - Prototype Heliostat position encoders to benchmarks. For the prototype heliostat approach, there is no physical or mechanical adjustment. Installation position and angular areas are compensated electronically in software. Use of the DIR is the main reason that the prototype heliostat checkout approach is feasible. Not only is the positioning of the image of the reflector on the target determined, but also the centroid and power distribution of that image. With the automatic algorithm updating capability, the checkout activity can almost be considered closed loop. The time comparison of the two approaches is shown in Table 4.3.2-1.

4.4 INSTALLATION CONCEPT DESCRIPTION

The heliostat installation concept is to build up the heliostat in the field from subassemblies assembled and checked out in the factory. This concept maximizes the benefit of factory assembly (with its attendant high accuracies and good efficiencies) and simplifies the field installation by simplifying and minimizing those tasks which must be performed in the field.

4.4.1 Subassembly Description

There are four basic installations required for the collector. These are: the foundation, drive unit, reflector panels, and cable installation.

Foundation - The foundation is formed in place by drilling 0.61 m x 6.71 m (2 ft x 22 ft) holes, installing a prefabricated rebar cage with a tapered form both of which extend four feet above grade, and filling with concrete. The rebar cage and the tapered form are brought to the site on standard flat bed and utility-type vehicles.

Subassembly	Dimensions	Weight	Special Operation
Rebar Cage	0.61m (2') dia. x 7.64m (25') long	195 kg (428.2 lb.)	Vert within 2°
Tapered Form	0.61 m (2') dia. x 1.22 m (4') long	31.5 kb (69.3 lb.)	Vert within 2°

TABLE 4.3.2-1

HELIOSTAT ALIGNMENT AND CHECKOUT

INITIAL BASELINE	TIME PER HELIOSTAT (MIN)	PROTOTYPE	TIME PER HELIOSTAT (MIN)
Set heliostat ref. determine & verify	48	Auto Search Alignment (1/2 field)	8.5
Heliostat Positioning	10	Manual Search Alignment (1/2 field)	6.3
Initial Ops Check	7.5	Average Alignment	7.4
Total C/O Align (open loop)	65.5	+Apportioned Setup time/ cell	2.5
		Total C/O & Align (open loop)	9.9

TIME SAVING PER HELIOSTAT = 65.6 min (initial baseline)
-9.9 min (prototype)
55.6 min (reduction in alignment time)

Drive Unit - These units come factory assembled and checked out, 12 to a flat bed trailer. The drive units are placed over the tapered foundation and loaded with 3000 lbs. of force, then vibrated to ensure proper seating.

Subassembly	Dimension	Weight	Special Operation
Drive Unit	0.61m (2') dia	365 kg (803 lb.)	Positioned within 0.305 m (1') cube and ± 3° to North-South

Reflector Panel - These units consist of six identical laminated mirrors assembled on a support structure. Two reflector panels are bolted to the central torque tube main beam of the drive unit to provide the full reflective unit for each heliostat.

Subassembly	Dimension	Weight	Special Operation
Reflector Panel	290.5'L X 132"W X 20" D	1528 lbs.	Positioning accomplished by jig-drilled mating holes

Cable (Power/Control) - The power and control cabling will come to the field in precut lengths with factory installed power wire terminals and optical connectors, rewound on the original spools. The power and fiber optic control cables will be in the same armored sheathing so that only one cable needs to be buried. The cable will run from the power distribution and data distribution interfaces to heliostat groups, and then serially from heliostat to heliostat. Electrical and optical connections will be made at each heliostat.

Subassembly	Dimensions	Weight	Special Operations
Field Cabling	3 conductor #8 AWG copper + 1 fiber optic cable within an armored sheath	0.386 lb/ft	Connect power and optical leads into and out of heliostat J-Box

4.2.2 Foundation Installation

The foundation installation is required to be quick, economical and accurate to two degrees of vertical. The foundation must give proper support to the heliostat in normal operations and resist jacking, rotation and other positional movements that may result from environmental conditions (winds, temperature, rain, earthquake, etc.). A 0.61 m (2 feet) diameter drilled pier embedded 6.71 m (22 feet) meets these requirements. The drilled pier has a 1.22 m (4 feet) extension above grade formed by a galvanized steel, tapered tube section filled with concrete. The pedestal will be force mounted on this pier extension. The heliostat drive system can be factory mounted on the pedestal using this system. The procedure for emplacing these drilled pier foundations uses standard construction techniques. The cast in place concrete pier foundations can be used with any variety of soil conditions. The pier hole is excavated by drilling an open hole, if the sidewalls do not collapse, the required reinforcing and concrete are placed as required to fill the hole. If the soil conditions are conducive to sidewall collapse, the pier can be placed by the Intrusion-Prepakt method, regardless of the sidewall stability. In this method, the hole is drilled and concrete grout displaces the soil as it is removed from the hole in a single operation. Then reinforcing is forced into the grouted hole before the mortar begins to set. In any case, the pier is installed with the four foot extension above grade which is subsequently encircled by a galvanized sheet steel tapered tube section and filled with concrete. The equipment required to emplace the heliostat foundations are: hydraulic cranes for lifting and manipulating iron work, flat bed tractor/trailers for hauling the bracing materials. Hole drilling and concrete hauling equipment are used but are contracted for and included in the price of the service.

4.4.3 Drive Unit/Pedestal Assembly Installation

The drive unit subassembly is fully assembled and checked out at the factory. The factory checkout uses grease as a lubricant so that the drive unit need not have the oil drained before shipment.

The positioning requirements for the pedestal are as follows: the reference mark must be within $\pm$ 2° of true North, the pedestal must be within 2° of local vertical, and the joint between the mating parts (foundation and pedestal) must be close to 0.8 mm (1/32 inch) or less. The drive unit installation equipment is illustrated in Figure 4.4.3-1. The machine is capable of lifting the drive unit from the flatbed trailer, rotating to vertical, and rotating to a

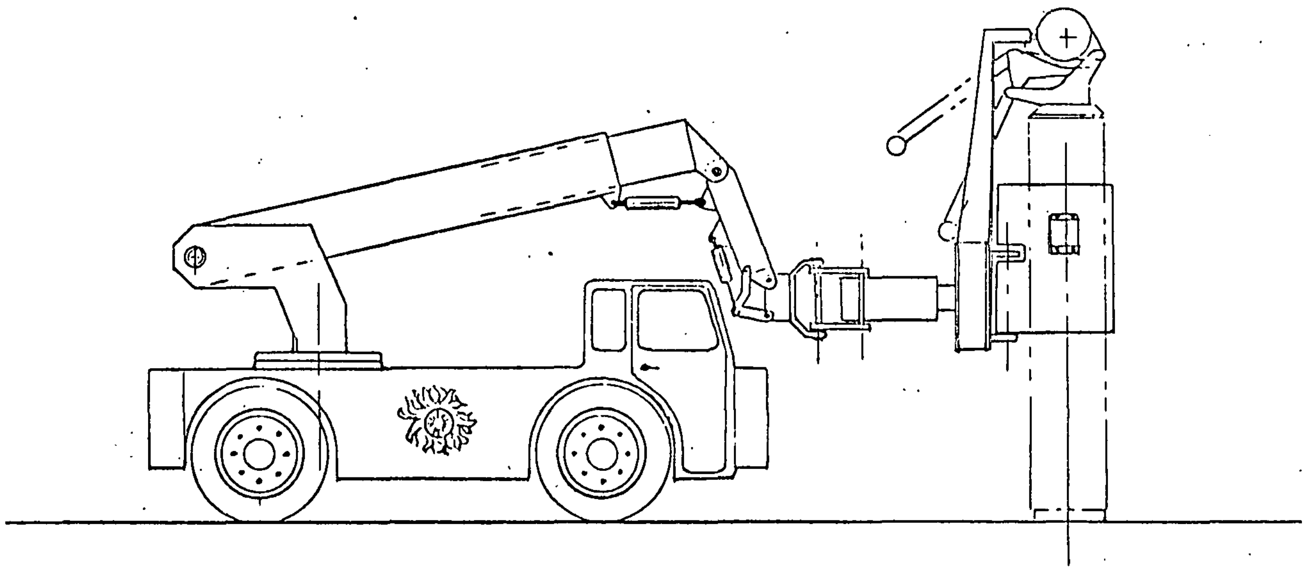


Figure 4.4.3-1 Drive Unit Installation Machine

reference North-South alignment. A steroscopic TV monitor assists the operator in placing the drive unit on the foundation. Loading and vibrators are incorporated to seat the drive unit on the foundation. The following procedure is used for installing the drive unit/pedestal assembly:

1. Lift the drive unit from the flatbed trailer with the drive unit installation machine to the vertical position.

2. Lift the bottom end of the pedestal over the foundation and lower it over the tapered portion of the foundation.

3. Adjust the position of the drive unit to true North.

4. Engage the pedestal setting assembly of the pedestal installation machine, increase pressure and vibrate until the joint between the material surfaces is 1/32 inch or less.

5. Check the drive unit for verticality and adjust to $\pm$ 2° of local vertical.

6. Fill the drive unit with oil.

The equipment required to do the drive unit/pedestal installation is a flatbed trailer (mod) and pedestal installation machine. Based on the scheduling constraint and the task time requirements (Ref Section 4.6), there is a requirement for two sets of installation equipment and crews required to absorb the 25,000 drive unit/pedestal assemblies at one site. The crews will be made up of the following personnel: 1 millwright, 1 laborer and 1 equipment operator.

4.4.4 Reflector Panel Installation

Installation of the reflector panels to the drive unit is straightforward. All the critical positioning and aligning are done at the factory by either precision assembly, machined surface mating or jig-drilled holes. The only field requirement is to install the mirrors in an expeditious manner so that 104 pairs of panels are absorbed in the field per day.

The procedure to do this installation uses a large piece of equipment called a reflector installation machine, Figure 4.4.4-1. This device carries reflector panels and provides manipulating devices that pick up and position individual panels during the installation process. Covered work platforms for personnel are also provided.

The installation sequence is:

1. Two pallets of reflector panels are loaded on the sides of the reflector installation machine.

2. The machine is positioned over the installed drive unit/pedestal assembly.

3. The reflector manipulator engages the reflector panel, picks it up and moves the panel to a position that will allow the mating to the drive unit flange under the guidance of the operator.

   NOTE: The manipulator allows movement in several directions: panel swiveling and rotation, full lateral positioning and limited fore and aft (36 inch) positioning.

4. When the flanges are within mating distance, eight bolts are installed to secure the reflector assemblies to the drive units.

5. The manipulator is disengaged from the reflector, workstands are retracted and the machine moves on to the next pedestal. Reflector panels are supplied to the machine during every fourth pedestal encounter in the present design.

Equipment requirements for the reflector installation task are: the special purpose installation machine and hi-lift forklift to reload the reflector magazines in the installation machine. Based on the scheduling constraint of 104 heliostats per day, there is a requirement for five sets of installation equipment and crews.

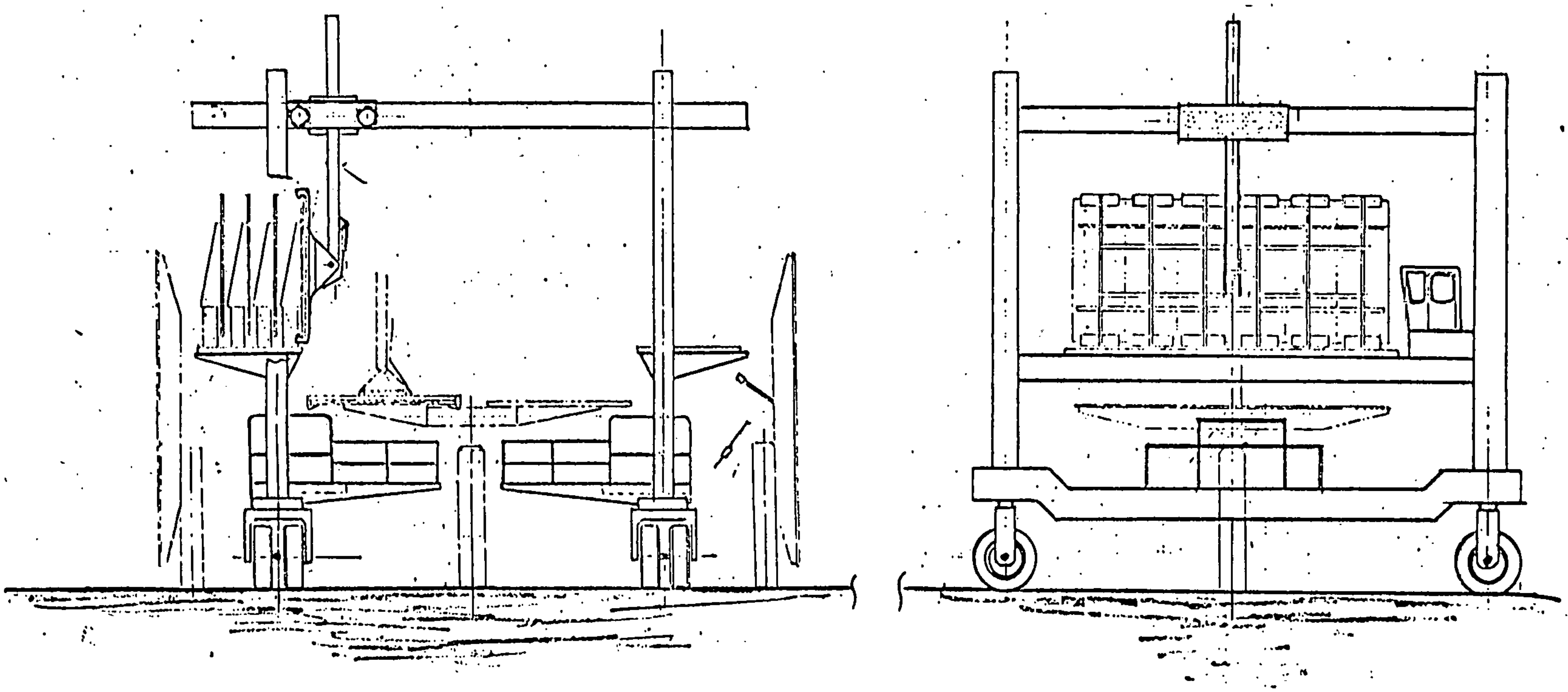


Figure 4.4.4-1 Reflector Installation Machine

The crews will consist of the following:

2 millwrights	1 forklift driver
2 laborers	1 equipment operator (forklift)

4.4.5 Cabling Installation

The inter-heliostat field cabling is a single armored cable containing three #8 electrical conductors and one fiber optic cable.

The requirements for the installation of this cable are based on the amount and type of vehicular traffic, rodent damage possibility and other damage causing activities over the collector field 30-year life cycle. Based on these and the National Electrical Code (NEC) requirements, the inter-heliostat wiring must be buried at least 24 inches deep, and the primary power cables must be buried 30 inches deep. An additional requirement exists that the cables must not be trained in a straight or taut manner to allow slack for settlement and earth moving after installation. Most of these requirements are stated as safety regulations at various government levels (N.E.C., OSHA). While some variances may be acceptable, prudence in adhering to these codes will result in meeting the system lifetime requirements at reasonable cost.

The procedures involved in installing these cables are aimed at doing the task in the minimum time and with the fewest men. The original concept was to excavate a trench one foot wide by 27 inches deep, place two inches of sand, lay the cable, cover with two inches of sand and then backfull and tamp the trench. Further study indicated that the effort involved might be reduced if the cable was "plowed in." This involves using a machine that slices a "V" groove in the soil to the desired depth, and then feeds the cable into the bottom of the groove before the soil is allowed to fall back in place. The advantage with this method is that the task is done in one automated operation. Cables could be emplaced at a 250 ft/hr rate with the automated approach where the trencher rate was only 100 ft/hr. There are 951,000 feet of branch circuit wiring to emplace. Thus the total field would require about 3,804 task hours for the automated approach versus about 9,510 task hours for the trench method.

Machinery requirements are also higher for the trenching method. At least three machines are required for each cable installation crew; a ditch witch type vehicle, a cable installation vehicle and a skip loader/backhoe. For the automated approach, one multifunction vehicle will do the job.

The crew requirements for the automated approach consist of: a plow operator/driver and two laborers to assist the operator.

4.5 ALIGNMENT AND CHECKOUT CONCEPT DESCRIPTION

The basic heliostat alignment concepts are: to verify the basic operation of the heliostat with respect to its components and other subsystems and to adjust the tracking software to compensate for installation physical tolerances.

4.5.1 Alignment

The requirements for individual heliostat alignment are that the unit track the sun accurately enough so that the solar image is on its nominal aim point each day of the year from sunrise to sunset. Since this is done open loop, there is no operational feedback to indicate misalignment. The accuracy of the initial alignment and subsequent alignments determines the relative efficiency of the heliostat over its life cycle.

No mechanical adjustments are required for the heliostat after installation. The alignment is done by initializing and adjusting software relationships in the heliostat controller to reflect the differences between the programmed placement of the heliostat and the actual position of the unit. New initial position information is input on the first alignment, and on two subsequent alignments angular track errors (verticality and skew) are removed.

During the alignment task, there can be no severe weather conditions that might interfere with accuracy. The wind must be below 26 mph so that a steady image will be projected on the target. Temperature extremes (< 32°F and > 120°F) must be avoided as the image characteristic might change enough to cause the digital image radiometer to misread the centroid signature of the heliostat. As with other heliostat installation and checkout tasks, the alignment must take minimum time and manpower.

The procedure for aligning a heliostat follows the task flow shown in Figure 4.3.2-2. The control van is connected into the data distribution interface once for 24 heliostats as the heliostats read positioning information off a common optical data bus. The group of the heliostats are then activated, moved to standby positions and established on track. At this point, the activities of the alignment branch into two categories: interactive man-machine alignment in the northern half of the field and automatic search in the southern half.

The man/machine technique involves affixing a sighting mirror to the edge of the heliostat to allow viewing the position of the image with respect to the alignment target on the tower. A verbal command is then given to the alignment operator in the control van that brings the spot onto the target. Once the spot is on the target,the digital image radiometer is used to establish the exact position and provide the necessary positional updating information.

The automatic search technique will be used in the southern portion of the field due to the fact that the heliostats will be in a nearly horizontal position during the normal tracking of the sun. This makes it inconvenient to attach a sighting mirror and observe the solar image without another piece of equipment to raise a member of the alignment crew to the proper position. The automatic alignment involves moving the heliostat in an expanding spiral search pattern until the target is intercepted, see Figure 4.5.1-1. After the target is intercepted, the Digital Image Radiometer is used to set the exact position and provide updating as in the man/machine technique.

The interactive man/machine approach takes an average time of 377 seconds to complete the alignment. The automatic procedure takes an average time of 510 seconds to complete due to the need to search for the target so the interactive man/machine technique will be employed whenever possible.

The alignment procedures outlined above are expected to be 100 percent reliable with respect to software. The only condition that could cause the alignment to be unsatisfactory is equipment failure. If this occurs during alignment, the correction will be handled just like any unscheduled maintenance action.

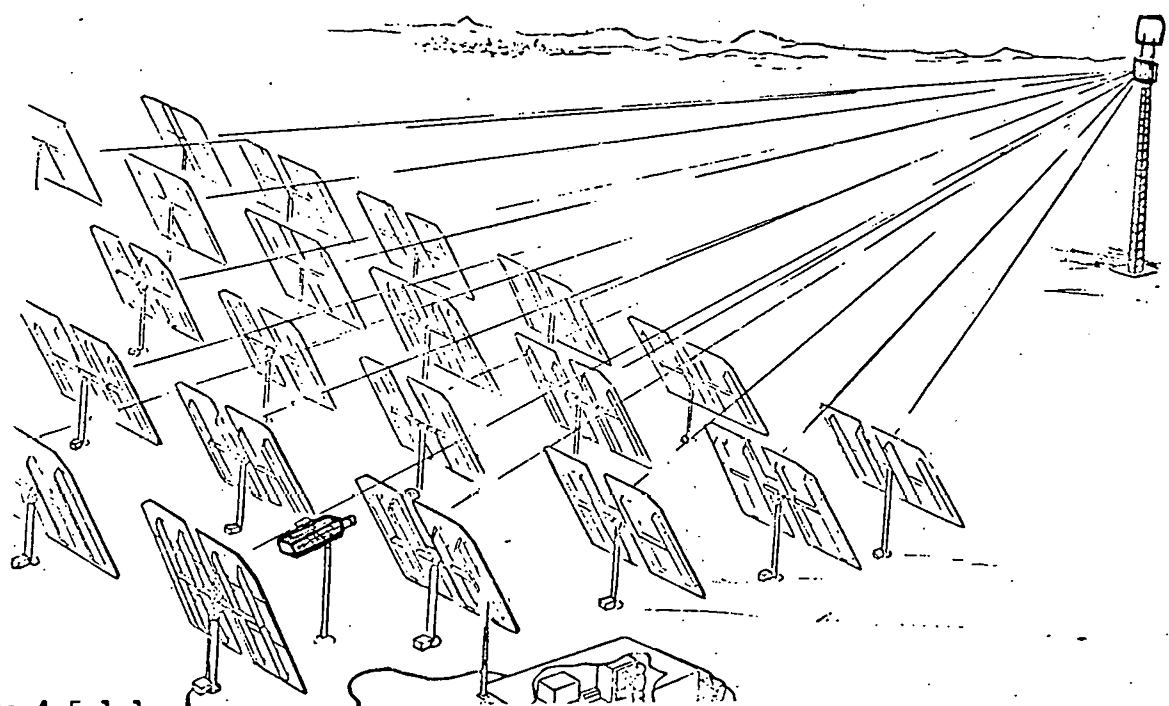


Figure 4.5.1-1

The equipment required to perform the alignment includes the van mounted test set, the target that is permanently emplaced on the tower, the digital image radiometers (which are permanently located at six strategic locations in the field), and a sighting mirror for the man/machine procedure.

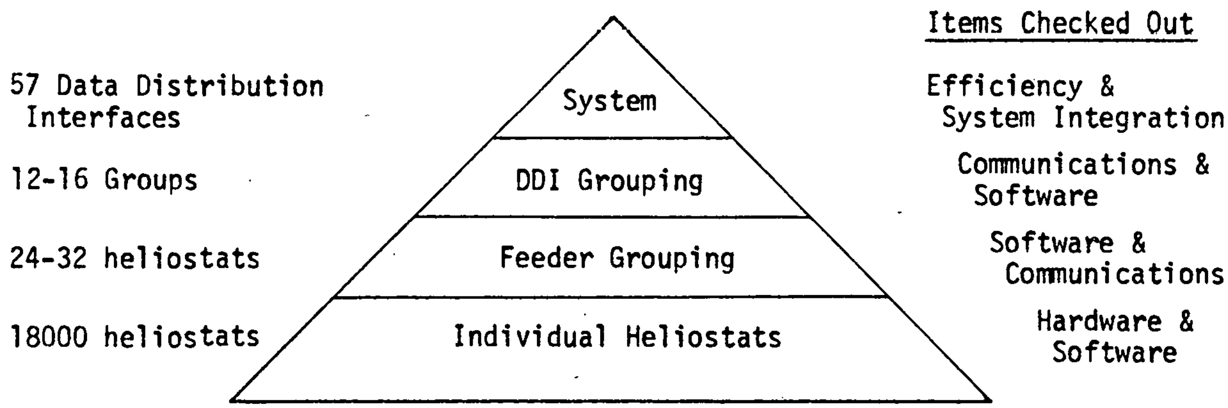
The personnel involved with this task will be two technicians and a field engineer. Based on the scheduling constraints and task time requirements (Ref. Section 4.6), there is a requirement for 3 crews, 3 control vans and 3 sighting mirrors to complete the task.

4.5.2 Checkout

The requirements for checkout transcend several levels of equipment. The basic purpose of checkout is to ensure that each element of the system is functioning according to specifications. To do this properly, the checkout philosophy has to be a "bottoms up" approach. The hierarchy of checkout is first at the individual heliostat level, then the group of heliostats or a single feeder, at the data distribution interface level, and finally at the system level.

The checking of the data distribution interface verifies the power and communications loops from the heliostat array controller to the distribution center and the ability of the data distribution interface to correctly address heliostats and generate its interior commands (e.g., stow, unstow).

System level checkout is accomplished in conjunction with the checkout of the overall plant and includes interface verification. This philosophy builds a fully checked out system based on thoroughly checked out components.



At the heliostat level, checkout will verify that the heliostat is tracking (accomplished in parallel with alignment), and the image quality is satisfactory (automatically determined by the digital image radiometer during alignment. A general physical inspection for lubrication leaks and installation damage will also be performed.

The group of heliostats on a single secondary feeder is checked to see that the data and power transmission from one heliostat to the next down the chain is correct. Particularly, the sent and received signals at the data distribution interface are correct. This checkout may be done from the master control room in a manual operating mode,or by interaction with the data distribution interface in the field.

The checking of the data distribution interface verifies the power and communications loops from the heliostat array controller to the distribution center and the ability of the data distribution interface to correctly address heliostats and generate its interior commands (e.g., stow, unstow).

System level checkout is accomplished in conjunction with the checkout of the overall plant and includes interface verification. This philosophy builds a fully checked out system based on thoroughly checked out components.

4.6 INSTALLATION AND CHECKOUT RESOURCE UTILIZATION ANALYSIS

A short study was undertaken to determine the best method of allocating personnel, and special equipment to sites for I&C activities. The following two production rates were considered:

a) 25,000 heliostats/year for 10 years
b) 250,000 heliostats/year for 10 years

Three constraints were imposed on the study:

- Production rate must be exactly satisfied by installation schedule; e.g., no backlogs or surpluses of heliostat parts at site. This means a daily installation average rate of 104 units.
- 18,000 heliostats/field
- 40-hour weeks; 48 weeks/year.

The following objectives, in descending order of priority, were established:

- Satisfy demands and constraints.
- Minimize number of crews and equipments.
- Minimize inter-site movements of equipment and people.
- Finish sites successively to provide visibility and control of problem areas.

Based on satisfying the objectives under priorities as assigned above, the following approaches were determined to be the most attractive:

a) For the 25,000 production rate, with five crews installing reflector panel assemblies, activate one site at a time.

b) For the 250,000 production rate, with 46 crews installing reflector panel assemblies, activate one site at a time.

4.6.1 Supporting Data and Assumptions

The data used to support this study includes I&C analyses results, collector hardware design, and special support equipment design. The foundation preparation and installation resources and production rates were defined by our subcontractor, Stearns-Roger. The costs associated with heliostat foundations are not considered in this part of the study, because they are already charged against CBS 4440.

Certain assumptions were used to frame the study. The major assumptions made are:

- Heliostat assembly and installation will be accomplished by performing the following tasks in the sequence shown, and using the resources allocated to each task.
- Field cables will be cut to length and terminals installed in the production facility.
- Alignment of heliostats will be performed by software changes; i.e., no mechanical adjustment at the heliostat.
- All foundations will be installed and cured prior to start of heliostat I&C.

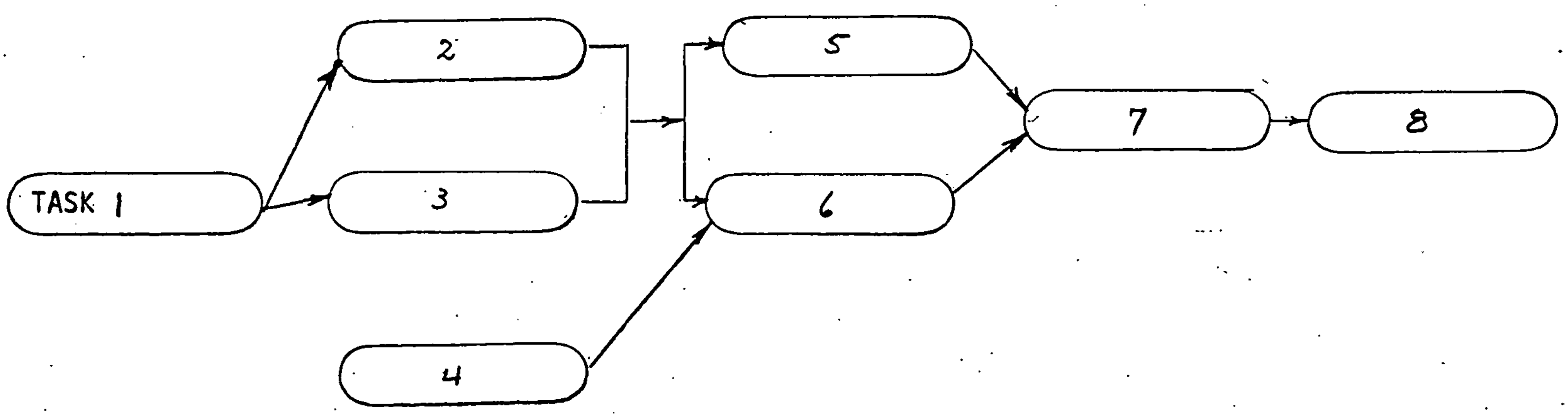


Figure 4.6.1-1 Installation Task Sequence

Task #		Time/Heliostat	Resource Allocation
1.	Pedestal Excavation, Iron & Concrete	30 min/heliostat	Coverd in CBS 4440
2.	Cable Installation	18 min/heliostat	1 Cable Plow 1 Cable Plow Operator 2 Laborers
3.	Drive Unit Installation	18 min/heliostat	1 Pedestal/Drive Assy Installation Equipment 1 Installation Equipment Operator 1 Millwright 1 Laboror
4.	Power Transformer/ Distribution Panel Installation	90 min/312 heliostats	1 Millwright 2 Laborers 1 Truck 1 Forklift 1 Truck Driver
5.	Reflector Panel Installation	21 min/heliostat	1 Reflector Panel Assy Installation Equipment 1 Installation Equipment Operator 1 Hi-Lift Forklift 1 Forklift Operator 2 Millwrights 2 Laborers
6.	Sensor/Calibration Equipment I&C	8 hrs/3000 heliostats	1 Field Engineer 1 Electrician 1 Volt-Ohm Meter 1 Oscilloscope
7.	Connect, Check & Close Out	15 min/heliostat	1 Electrician 1 Laborer 1 Test Set
8.	Align Heliostat	10 min/heliostat	1 Field Engineer 2 Technicians 1 Mobile Field Test Station

4.6.2 Study Results

a) 25,000 heliostats/year production rate

At this rate, MDAC determined that the only two logical approaches to crewing were as follows:

Alternative A1. With five crews installing panels, work on sites one at a time.

Alternative A2. With onw crew at each site installing panels, work on five sites at a time.

The required equipment and personnel for each alternative are as follows:

Resource	Required Level of Equipment/Personnel	
	Alt. A1	Alt. A2
Cable Plows	4	5
Pedestal/Drive Assembly Installation Equipment	2	5
Trucks	1	1
Forklifts	1	1
Reflector Panel Installation Equipment	5	5
Hi-Lift Forklifts	5	5
Test Sets	4	5
Mobile Field Test Stations	3	5
Laborers	26	32
Millwrights	13	16
Equipment Operators	16	20
Truck Drivers	1	1
Field Engineers	4	6
Electricians	4	5
Technicians	6	10

Better Choice

b) 250,000 heliostats/year production rate

At this rate, MDAC determined that logical approaches were as follows:

Alternative B1. With 46 crews installing panels, work on one site at a time.

Alternative B2. With 23 crews installing panels at each site, work on two sites simultaneously.

Alternative B3. With one crew installing panels at each site, work on 46 sites simultaneously.

The required equipment and personnel for each alternative are as follows:

Resource	Required Levels of Equipment/Personnel		
	Alt. B1	Alt. B2	Alt. B3
Cable Plows	40	40	46
Pedestal/Drive Assembly Installation Equipment	18	18	46
Trucks	1	2	2
Forklifts	1	2	2
Reflector Panel Installation Equipment	46	46	46
Hi-Lift Forklifts	46	46	46
Test Sets	33	34	46
Mobile Field Test Stations	22	22	23
Laborers	225	228	280
Millwrights	111	112	140
Equipment Operators	150	150	184
Truck Drivers	1	2	2
Field Engineers	23	23	24
Electricians	33	34	46
Technicians	44	44	46

Best Choice (Alt. B1)

4.7 INSTALLATION AND CHECKOUT SUMMARY

A summary of the installation and checkout procedures is presented in Table 4.7-1. The procedures take advantage of design changes to facilitate low cost installation and checkout and utilize MDAC developed low cost alignment procedures.

TABLE 4.7-1

INSTALLATION AND CHECKOUT CHANGE SUMMARY

Section	I&C Consideration	Was	Is	Effect
4.2 and 4.5	Checkout procedure	Gimbal axis encoders, hardware mechanically zeroed at intervals	Software algorithms constants reset at intervals	Alignment done quickly, reliably, and accurately with a semiautomated technique
4.4	Installation concepts	Pre-assembled heliostats	Pre-assembled, pre-checked reflector panels and pedestals assembled *in situ*	Simplifies field activities
4.4	Subassembly concepts:			
	• Foundation	I&C procedures undefined	Formed in place, prefabricated rebar cage, form for top; brought to site on standard-type vehicles	Fast, simplified foundation installation. Standard types of transportation & handling equipment, standard construction techniques
	• Drive Unit/Pedestal	Bolted to foundation	Factory-assembly & checkout jammed onto foundation stub	Fast, simplified installation
	• Reflector Panels	Came from factory mated to pedestal	Critical positioning and alignment with D.U./pedestal done through machined surface mating	Site alignment activities limited to those of beam positioning
	• Cabling	I&C procedures undefined	Power & fiber optic control cables in same sheathing. Implaced by special hi-speed plow. Length and terminations tailored at site.	Simple, fast installation.
4.6	Resource Allocation and Scheduling	No previous definition	Crew, equipment, sequences defined and optimized.	Cost and schedule efficiency.

Section 5

OPERATIONS AND MAINTENANCE CONCEPTUAL DESIGN

Development of operations and maintenance (O&M) support processes is driven by two primary concerns: (1) achieving/maintaining specified system availability, and (2) providing the necessary support capability with minimum expenditures for labor and materials. The redundant nature of the collector subsystem, coupled with a basic design which does not rely on maintenance to achieve minimum availability, provides the opportunity to concentrate efforts on the latter requirement. There is little risk that the required availability will not be satisfied; i.e., selection of O&M support concepts with the potential for lowest cost will not jeopardize system availability. This factor has provided a significant influence on the development of cost effective collector O&M concepts.

5.1 INITIAL BASELINE PROCESS

This section identifies the O&M requirements associated with the initial baseline heliostat design, and describes the depth to which analyses were conducted to identify the O&M concepts applicable to a full-scale commercial plant.

5.1.1 Operations and Maintenance Requirements

The Collector Subsystem O&M requirements include the scheduled and unscheduled maintenance tasks associated with the hardware design configuration and the necessary support resources to accomplish these tasks. Task requirements have been categorized by the familiar on-line maintenance, off-line on-site maintenance, and off-line off-site maintenance designations.

5.1.2 Initial Baseline Process Description

The initial baseline O&M requirements were determined by a hardware analysis to identify maintenance significant components and related maintenance tasks. Maintenance significant items for the initial baseline are identified in

Table 5.1-1. The table includes a brief description of the scheduled and unscheduled maintenance requirements which were defined in greater detail and quantified for a 10 MWe pilot plant. Within the scope of previous collector subsystem development programs, the O&M requirements for a 100 MWe commercial plant were derived by scale-up of 10 MWe pilot plant requirements. Maintenance concepts developed in this manner were not always best suited for full-scale commercial operations. Two specific concepts developed for pilot plant support were identified as not providing the most cost effective means for supporting commercial operations. First, a review of the method proposed for washing of mirrors indicated that a faster and/or automated process was justified for the larger quantity of heliostats for the commercial plant and would result in significant cost savings over the 30 year operational life. The second potential cost savings area involves the repair locations for failed equipment subsequent to removal from the system. Off-site repair was selected for pilot plant support due to low quantities of reparable items and short time duration. For commercial application, the higher quantities per site, multiple sites, and 30-year operational life, would tend to make on-site repair and/or special repair areas more attractive for specific hardware items. In addition to these specific areas, the definition of maintenance cost impact for other trade studies provides the opportunity to influence design perturbations and further reduce maintenance costs.

5.2 DESIGN/MANUFACTURING TRADE STUDY SUPPORT RESULTS

This section summarizes the operations and maintenance impact analyses that were made in support of design and manufacturing trade studies.

5.2.1 Trade Study D-2 Low Cost Reflector

Review indicated that O&M costs are primarily related to reliability rather than physical design configuration. The high reliability, approximately equal for all configurations, leads to the conclusion that O&M costs were not impacted.

TABLE 5.1-1

MAINTENANCE SIGNIFICANT ITEM LIST

COMPONENT	CORRECTIVE MAINTENANCE	SCHEDULED MAINTENANCE
Field Controller	Remove and replace on failure. Minor repair on-site.	None
Heliostat Controller	Remove and replace on failure. Minor repair on-site.	None
Elevation and Azimuth Drive Assemblies	Remove and replace on failure.	Lubrication
Elevation and Azimuth Drive Motor and Reducer	Remove and replace on failure.	None
Elevation and Azimuth Shaft Encoder	Remove and replace on failure.	None
Elevation and Azimuth Shaft Turn Pick-off	Remove and replace on failure.	None
Pedestal J-Box	Remove and replace detail parts on failure. Remove and replace box for major damage.	None
Pedestal	Structural repair. Remove and replace for major damage.	None
Reflector Panel	Remove and replace. Discard. Clean (in addition to scheduled requirements due to severe weather conditions).	Clean
Reflection Structure	Structural repair. Remove and replace for major damage.	None
Field Cables	Electrical Repair. Remove and replace for major damage.	None

TABLE 5.1-1

MAINTENANCE SIGNIFICANT ITEM LIST

COMPONENT	CORRECTIVE MAINTENANCE	SCHEDULED MAINTENANCE
Power Distribution Panel	Remove and replace detail parts. Replace panel for major damage.	None
Power Transducer	Remove and replace on failure.	None
Test Support Station	Remove and repair components on failure.	Calibrate test equipment, inspect, clean, adjust and lubricate CRT/Keyboard, Tape Reader, and Recorder

5.2.2 Trade Study D-3 Drive Optimization

Proposed design changes were analyzed to determine impact on maintenance. Most changes that were functionally acceptable and desirable from the standpoint of reducing material and/or assembly costs also exhibited reduced maintenance requirements, either in the form of fewer manhours to repair or reduction of maintenance actions by improved reliability and lower failure rates. Changes include deletion of the Oldham coupling, low cost bearing retainers, and drive train changes.

An analysis was performed to determine the impact on maintenance of introducing different motor and linear actuator configurations. Since there are three applications for drive motors and two for actuators, there is the possibility of reducing acquisition costs through selection of minimum performance components for each application. The analysis indicated nonrecurring logistics costs for each motor configuration for support planning, training, maintenance documentation, and parts introduction equaled $1810. Recurring costs for inventory maintenance and supply administration, and procurement support equaled $228 per year. Similar costs for the linear actuator equaled $2120 and $304 per year, respectively. These values were used within the overall trade study and balanced against the acquisition cost savings identified for the alternative design configurations.

5.2.3 Trade Study D-4 Control Optimization

Major changes and refinement of control hardware and software have resulted in significant reduction of maintenance, including scheduled and unscheduled requirements. Notable reductions are related to deletion of gimbal axis encoders and requirement for manual realignment or recalibration. Approximately 540 corrective maintenance hours per year per site could be directly related to deletion of encoders. However, this is only a fraction of the total which cannot be readily identified because of interaction with other corrective requirements and the absence of previous definition of alignment/calibration requirements for a commercial site.

5.3 OPERATIONS AND MAINTENANCE TRADE STUDY RESULTS

5.3.1 O-1 - Optimum Repair Level Analysis

The purpose of this trade study is to reduce maintenance costs by determining the most cost effective means of repairing each Line Replaceable Unit (LRU) and/or determining if the LRU should be discarded upon failure rather than repaired.

5.3.1.1 Discussion

The collector subsystem LRU's, as identified at the Project Baseline Freeze, were subjected to the Optimum Repair Level Analysis (ORLA) process as shown in Figure 5.3.1-1. The disposition of four LRU's was determined as a result of the initial screening step as follows: (1) the reflector panel (mirror) is obviously a discard item in the event of breakage; (2) the power transformer, digital camera, and camera heater/cooler, all having an expected failure rate of less than one per year per site, should be surveyed for extent of damage and a decision made at the time of failure to either scrap/salvage, repair locally or repair at the manufacturer's facility. The remaining LRU's were analyzed via the ORLA computer model with results as shown in Figure 5.3.1-2. The analysis of the azimuth drive assembly is reviewed here to provide a better understanding of the results. The relative costs for each of the support options for the azimuth drive assembly are shown on Sheet 2 of 12. (NOTE: Columns titled Depot Repair and Intr. Repair are equivalent to Solar Program Designations of Off-Site and On-Site Repair, respectively.) A clear cut decision for on-site (INTR) repair is indicated by the subtotal cost of $1,028,339. The sensitivity tests provide the capability to examine the life cycle cost impact of varying the indicated input values; if a factor is found to be critical (i.e., variation results in selecting a different repair option), the source of that factor should be re-examined for validity and/or may indicate an area for potential maintenance cost reduction. All values indicated are relative and should not be construed as life cycle costs.

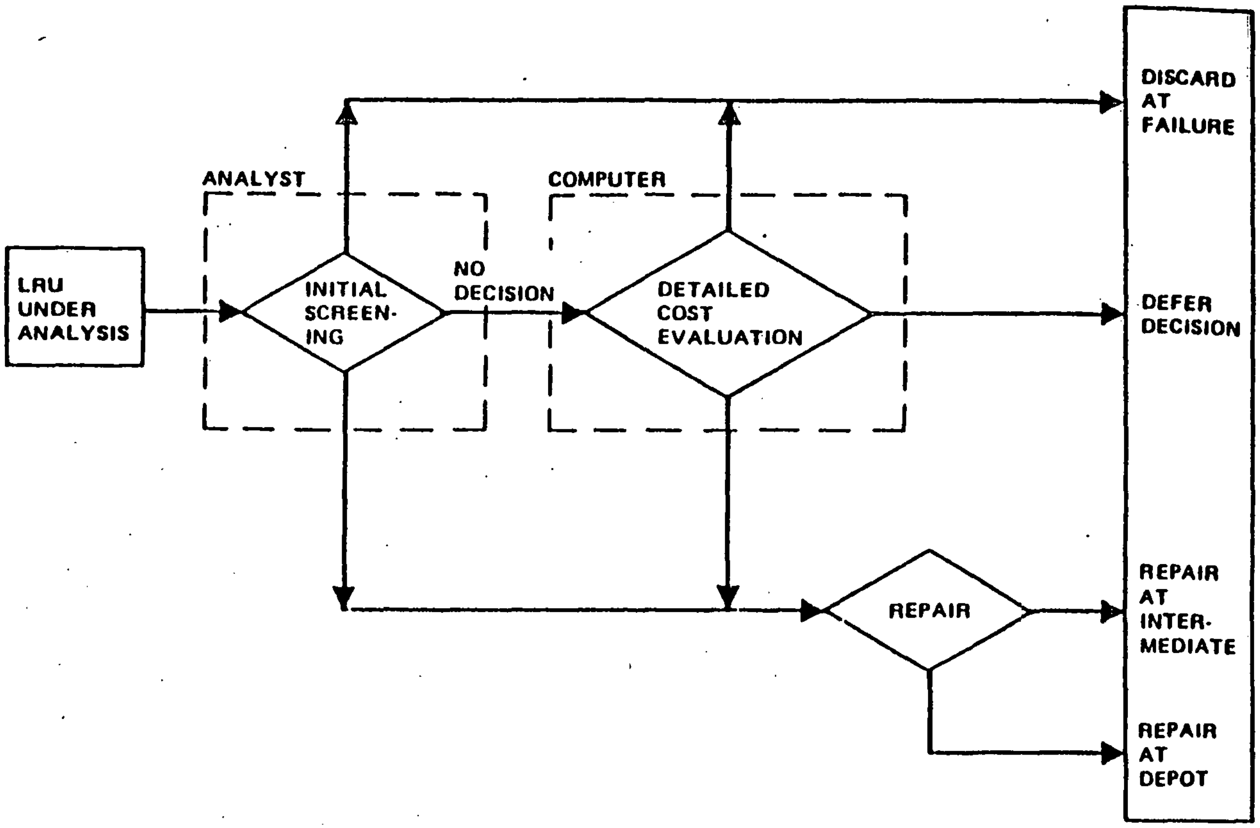


Figure 5.3.1-1 Optimum Repair Level Analysis (ORLA) Methodology

4318
5529

PASS NR 1 PROTOTYPE HELIOSTAT COMMERCIAL SITE

LIFCY	360
PCTOS	0.000
NHRPM	275
NWPDB	100
NBRDB	6

5 REPAIRABLE ITEM(S) WILL BE ANALYSED

ITEM NR 1 DRIVE ASSEMBLY AZIMUTH 575.00 DOLLARS

CW	0 POUNDS	(RE-USABLE CNTR WEIGHT)
NULBS	461.0 POUNDS	(WEIGHT OF RPR ITEM)
NUPWS	180	(QUANTITY PER NHA)
PCTON	1.000	(OPERATE TO FLT.HR.RATIO)

1 FAILURE MODES WILL BE ANALYZED

MODE NR 1 ASSEMBLY FAILURE PASS 1 ITEM 1

F	MEAN TIME BETWEEN REPAIR------------------	340136
A	MAN-HOURS REQUIRED TO REPAIR--------------	5.5
I	NR PAGES DEPOT LEVEL TECH DATA------------	10.0
L	NR PAGES INT.LEVEL TECH DATA--------------	10.0
	TRAINING RATE--PER MAN-WEEK---------------	500.0
	MAN-WEEKS OF TRAINING(DEPOT LEVEL)--------	1.0
M	MAN-WEEKS OF TRAINING(INT.LEVEL)----------	1.0
O	INT.LEVEL SPECIAL AGE COST----------------	7500.
D	INT.LEVEL FACILITIES COST-----------------	15000.
E	DEPOT LEVEL SPECIAL AGE COST--------------	7500.
	DEPOT LEVEL FACILITIES COST---------------	15000.
D	REPAIR PARTS COST PER REPAIR--------------	95.0
A	NEW ASSEMBLIES INTRODUCED-----------------	3
T	NEW PARTS INTRODUCED----------------------	14
A	WEIGHT OF INT.LEVEL SPECIAL AGE-----------	500
	WEIGHT OF REPAIR PARTS PER REPAIR---------	32.0
	NUMBER OF LINE ITEMS TO STOCK-------------	17
	NUMBER OF AUTOMATIC TEST STEPS------------	0
	MEAN TIME TO AUTOMATICALLY TEST-----------	0.00
	COST INT.LEVEL AGE.HIGH MTBD--------------	7500.
	COST INT.LEVEL AGE.LOW MTBD---------------	7500.
	COST DEPOT LEVEL AGE,HIGH MTBD------------	7500.
	COST DEPOT LEVEL AGE,LOW MTBD-------------	7500.

Figure 5.3.1-2 Sheet 1 of 12

OPTIMUM REPAIR LEVEL ANALYSIS OF DRIVE ASSEMBLY AZIMUTH

PASS 1 ITEM 1 MODE 1 ASSEMBLY FAILURE

COST ELEMENTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
SPARES	$ 16150.	$ 1088.	$ 3012471.
SAFETY STOCK	4184.		
SUPPLY ADMIN	0.	9180.	
PART INTRODUCTION	1758.	1758.	
REPAIR PARTS	497713.	497713.	
PKING + SHIPPING	2536792.	88272.	1265105.
AGE	1250.	7500.	
FACILITIES	2500.	15000.	
LABOR	447208.	402545.	
TRAINING	325.	4850.	
TECHNICAL DATA	433.	433.	
SUB-TOTAL	$ 3508513.	$ 1028339.	$ 4277576.

SENSITIVITY TESTS

+.50 X MTBD	$ 2342265.	$ 698796.	$ 2853143.
-.50 X MTBD	$ 7010760.	$ 2017956.	$ 8555153.
+.50 X REPAIR MH	$ 3732117.	$ 1229611.	$----------
-.50 X REPAIR MH	$ 3284919.	$ 827066.	$----------
+.50 X TRAINING	$ 3508676.	$ 1030764.	$----------
-.50 X TRAINING	$ 3508351.	$ 1025914.	$----------
+.50 X UNIT COST	$ 3767537.	$ 1277739.	$ 5783812.
-.50 X UNIT COST	$ 3249490.	$ 778939.	$ 2771341.
+.50 X AGE COST	$ 3509138.	$ 1032089.	$----------
-.50 X AGE COST	$ 3507888.	$ 1024589.	$----------
+.25 X FLEET SIZE	$ 4384075.	$ 1275743.	$ 5346970.
-.25 X FLEET SIZE	$ 2632952.	$ 780935.	$ 3208182.
+.21 X UTIL.RATE	$ 4243985.	$ 1236158.	$ 5175867.
-.21 X UTIL.RATE	$ 2773042.	$ 820519.	$ 3379285.

ITEM NR 2 JACK ASSEMBLY TRACKING 198.00 DOLLARS

CW	0 POUNDS		(RE-USABLE CNTR WEIGHT)
NULBS	60.0 POUNDS		(WEIGHT OF RPR ITEM)
NUPWS	180		(QUANTITY PER NHA)
PCTON	1.000		(OPERATE TO FLT.HR.RATIO)

1 FAILURE MODES WILL BE ANALYZED

MODE NR 1 ASSEMBLY FAILURE PASS 1 ITEM 2

F	MEAN TIME BETWEEN REPAIR------------------	366300
A	MAN-HOURS REQUIRED TO REPAIR--------------	3.0
I	NR PAGES DEPOT LEVEL TECH DATA------------	10.0
L	NR PAGES INT.LEVEL TECH DATA--------------	10.0
	TRAINING RATE--PER MAN-WEEK---------------	500.0
	MAN-WEEKS OF TRAINING(DEPOT LEVEL)--------	.5
M	MAN-WEEKS OF TRAINING(INT.LEVEL)----------	.5
O	INT.LEVEL SPECIAL AGE COST----------------	2500.
D	INT.LEVEL FACILITIES COST-----------------	7500.
E	DEPOT LEVEL SPECIAL AGE COST--------------	2500.
	DEPOT LEVEL FACILITIES COST---------------	7500.
D	REPAIR PARTS COST PER REPAIR--------------	45.0
A	NEW ASSEMBLIES INTRODUCED-----------------	1
T	NEW PARTS INTRODUCED----------------------	14
A	WEIGHT OF INT.LEVEL SPECIAL AGE-----------	200
	WEIGHT OF REPAIR PARTS PER REPAIR---------	12.0
	NUMBER OF LINE ITEMS TO STOCK-------------	15
	NUMBER OF AUTOMATIC TEST STEPS------------	0
	MEAN TIME TO AUTOMATICALLY TEST-----------	0.00
	COST INT.LEVEL AGE,HIGH MTBD--------------	2500.
	COST INT.LEVEL AGE,LOW MTBD---------------	2500.
	COST DEPOT LEVEL AGE,HIGH MTBD------------	2500.
	COST DEPOT LEVEL AGE,LOW MTBD-------------	2500.

OPTIMUM REPAIR LEVEL ANALYSIS OF JACK ASSEMBLY TRACKING

PASS 1 ITEM 2 MODE 1 ASSEMBLY FAILURE

COST ELEMENTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
SPARES	$ 5164.	$ 348.	$ 963243.
SAFETY STOCK	1338.		
SUPPLY ADMIN	0.	8100.	
PART INTRODUCTION	1460.	1460.	
REPAIR PARTS	218919.	218919.	
PKING + SHIPPING	306609.	30629.	152895.
AGE	417.	2500.	
FACILITIES	1250.	7500.	
LABOR	226503.	203886.	
TRAINING	163.	2425.	
TECHNICAL DATA	433.	433.	
SUB-TOTAL	$ 762261.	$ 476200.	$ 1116138.

SENSITIVITY TESTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
+.50 X MTBD	$ 509667.	$ 325091.	$ 744464.
-.50 X MTBD	$ 1520799.	$ 929982.	$ 2232276.
+.50 X REPAIR MH	$ 875515.	$ 578144.	$----------
-.50 X REPAIR MH	$ 649006.	$ 374257.	$----------
+.50 X TRAINING	$ 762342.	$ 477413.	$----------
-.50 X TRAINING	$ 762179.	$ 474988.	$----------
+.50 X UNIT COST	$ 874971.	$ 585834.	$ 1597760.
-.50 X UNIT COST	$ 649550.	$ 366567.	$ 634516.
+.50 X AGE COST	$ 762469.	$ 477450.	$----------
-.50 X AGE COST	$ 762052.	$ 474950.	$----------
+.25 X FLEET SIZE	$ 951895.	$ 589646.	$ 1395172.
-.25 X FLEET SIZE	$ 572626.	$ 362755.	$ 837103.
+.21 X UTIL.RATE	$ 921554.	$ 571495.	$ 1350527.
-.21 X UTIL.RATE	$ 602968.	$ 380906.	$ 881749.

ITEM NR 3 DRIVE MOTOR AZIMUTH 70.00 DOLLARS

CW	0 POUNDS		(RE-USABLE CNTR WEIGHT)
NULBS	17.0 POUNDS		(WEIGHT OF RPR ITEM)
NUPHS	180		(QUANTITY PER NHA)
PCTON	1.000		(OPERATE TO FLT.HR.RATIO)

1 FAILURE MODES WILL BE ANALYZED

MODE NR 1 ASSEMBLY FAILURE PASS 1 ITEM 3

F	MEAN TIME BETWEEN REPAIR------------------	295858
A	MAN-HOURS REQUIRED TO REPAIR--------------	2.5
I	NR PAGES DEPOT LEVEL TECH DATA------------	10.0
L	NR PAGES INT.LEVEL TECH DATA--------------	10.0
	TRAINING RATE--PER MAN-WEEK---------------	500.0
	MAN-WEEKS OF TRAINING(DEPOT LEVEL)--------	.5
M	MAN-WEEKS OF TRAINING(INT.LEVEL)----------	.5
O	INT.LEVEL SPECIAL AGE COST----------------	2500.
D	INT.LEVEL FACILITIES COST-----------------	5625.
E	DEPOT LEVEL SPECIAL AGE COST--------------	2500.
	DEPOT LEVEL FACILITIES COST---------------	5625.
D	REPAIR PARTS COST PER REPAIR--------------	10.0
A	NEW ASSEMBLIES INTRODUCED-----------------	1
T	NEW PARTS INTRODUCED----------------------	8
A	WEIGHT OF INT.LEVEL SPECIAL AGE-----------	200
	WEIGHT OF REPAIR PARTS PER REPAIR---------	3.0
	NUMBER OF LINE ITEMS TO STOCK-------------	9
	NUMBER OF AUTOMATIC TEST STEPS------------	0
	MEAN TIME TO AUTOMATICALLY TEST-----------	0.00
	COST INT.LEVEL AGE,HIGH MTBD--------------	2500.
	COST INT.LEVEL AGE,LOW MTBD---------------	2500.
	COST DEPOT LEVEL AGE,HIGH MTBD------------	2500.
	COST DEPOT LEVEL AGE,LOW MTBD-------------	2500.

OPTIMUM REPAIR LEVEL ANALYSIS OF DRIVE MOTOR AZIMUTH

PASS 1 ITEM 3 MODE 1 ASSEMBLY FAILURE

COST ELEMENTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
SPARES	$ 2260.	$ 152.	$ 421621.
SAFETY STOCK	585.		
SUPPLY ADMIN	0.	4860.	
PART INTRODUCTION	855.	855.	
REPAIR PARTS	60232.	60232.	
PKING + SHIPPING	107556.	9484.	53634.
AGE	417.	2500.	
FACILITIES	938.	5625.	
LABOR	233699.	210359.	
TRAINING	163.	2425.	
TECHNICAL DATA	433.	433.	
SUB-TOTAL	$ 407138.	$ 296925.	$ 475256.

SENSITIVITY TESTS			
+.50 X MTBD	$ 272495.	$ 203610.	$ 316996.
-.50 X MTBD	$ 811470.	$ 577152.	$ 950511.
+.50 X REPAIR MH	$ 523987.	$ 402104.	$----------
-.50 X REPAIR MH	$ 290288.	$ 191746.	$----------
+.50 X TRAINING	$ 407219.	$ 298138.	$----------
-.50 X TRAINING	$ 407056.	$ 295713.	$----------
+.50 X UNIT COST	$ 438676.	$ 327117.	$ 686066.
-.50 X UNIT COST	$ 375599.	$ 266733.	$ 264445.
+.50 X AGE COST	$ 407346.	$ 298175.	$----------
-.50 X AGE COST	$ 406929.	$ 295675.	$----------
+.25 X FLEET SIZE	$ 508221.	$ 366982.	$ 594070.
-.25 X FLEET SIZE	$ 306054.	$ 226868.	$ 356442.
+.21 X UTIL.RATE	$ 492047.	$ 355773.	$ 575059.
-.21 X UTIL.RATE	$ 322228.	$ 238077.	$ 375452.

ITEM NR 4 DRIVE MOTOR ELEVATION 75.00 DOLLARS

CW	0	POUNDS	(RE-USABLE CNTR WEIGHT)
NULBS	18.0	POUNDS	(WEIGHT OF RPR ITEM)
NUPWS	180		(QUANTITY PER NHA)
PCTON	1.000		(OPERATE TO FLT.HR.RATIO)

1 FAILURE MODES WILL BE ANALYZED

MODE NR 1 ASSEMBLY FAILURE PASS 1 ITEM 4

F	MEAN TIME BETWEEN REPAIR----------------	295858
A	MAN-HOURS REQUIRED TO REPAIR-------------	2.5
I	NR PAGES DEPOT LEVEL TECH DATA-----------	10.0
L	NR PAGES INT.LEVEL TECH DATA-------------	10.0
	TRAINING RATE--PER MAN-WEEK--------------	500.0
	MAN-WEEKS OF TRAINING(DEPOT LEVEL)-------	.5
M	MAN-WEEKS OF TRAINING(INT.LEVEL)---------	.5
O	INT.LEVEL SPECIAL AGE COST---------------	2500.
D	INT.LEVEL FACILITIES COST----------------	5625.
E	DEPOT LEVEL SPECIAL AGE COST-------------	2500.
	DEPOT LEVEL FACILITIES COST--------------	5625.
D	REPAIR PARTS COST PER REPAIR-------------	10.0
A	NEW ASSEMBLIES INTRODUCED----------------	1
T	NEW PARTS INTRODUCED---------------------	8
A	WEIGHT OF INT.LEVEL SPECIAL AGE----------	200
	WEIGHT OF REPAIR PARTS PER REPAIR--------	3.0
	NUMBER OF LINE ITEMS TO STOCK------------	9
	NUMBER OF AUTOMATIC TEST STEPS-----------	0
	MEAN TIME TO AUTOMATICALLY TEST----------	0.00
	COST INT.LEVEL AGE,HIGH MTBD-------------	2500.
	COST INT.LEVEL AGE,LOW MTBD--------------	2500.
	COST DEPOT LEVEL AGE,HIGH MTBD-----------	2500.
	COST DEPOT LEVEL AGE,LOW MTBD------------	2500.

OPTIMUM REPAIR LEVEL ANALYSIS OF DRIVE MOTOR ELEVATION

PASS 1 ITEM 4 MODE 1 ASSEMBLY FAILURE

COST ELEMENTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
SPARES	$ 2422.	$ 163.	$ 451737.
SAFETY STOCK	627.		
SUPPLY ADMIN	0.	4860.	
PART INTRODUCTION	855.	855.	
REPAIR PARTS	60232.	60232.	
PKING + SHIPPING	113883.	9485.	56789.
AGE	417.	2500.	
FACILITIES	938.	5625.	
LABOR	233699.	210359.	
TRAINING	163.	2425.	
TECHNICAL DATA	433.	433.	
SUB-TOTAL	$ 413668.	$ 296937.	$ 508526.

SENSITIVITY TESTS

+.50 X MTBD	$ 276850.	$ 203618.	$ 339187.
-.50 X MTBD	$ 824530.	$ 577176.	$ 1017053.
+.50 X REPAIR MH	$ 530517.	$ 402116.	$----------
-.50 X REPAIR MH	$ 296815.	$ 191758.	$----------
+.50 X TRAINING	$ 413749.	$ 298150.	$----------
-.50 X TRAINING	$ 413586.	$ 295725.	$----------
+.50 X UNIT COST	$ 445308.	$ 327134.	$ 734395.
-.50 X UNIT COST	$ 382027.	$ 266740.	$ 282658.
+.50 X AGE COST	$ 413876.	$ 298187.	$----------
-.50 X AGE COST	$ 413459.	$ 295687.	$----------
+.25 X FLEET SIZE	$ 516383.	$ 366997.	$ 635658.
-.25 X FLEET SIZE	$ 310952.	$ 226877.	$ 381395.
+.21 X UTIL.RATE	$ 499949.	$ 355787.	$ 615317.
-.21 X UTIL.RATE	$ 327387.	$ 238087.	$ 401736.

ITEM NR 5 HELIOSTAT CONTROL ELECTRONICS 98.00 DOLLARS

CW	0 POUNDS	(RE-USABLE CNTR WEIGHT)
NULBS	2.0 POUNDS	(WEIGHT OF RPR ITEM)
NUPWS	160	(QUANTITY PER NHA)
PCTON	1.000	(OPERATE TO FLT.HR.RATIO)

1 FAILURE MODES WILL BE ANALYZED

MODE NR 1 CIRCUIT CARD FAILURE PASS 1 ITEM 5

F	MEAN TIME BETWEEN REPAIR----------------	606060
A	MAN-HOURS REQUIRED TO REPAIR-------------	3.5
I	NR PAGES DEPOT LEVEL TECH DATA-----------	15.0
L	NR PAGES INT.LEVEL TECH DATA-------------	15.0
	TRAINING RATE--PER MAN-WEEK--------------	500.0
	MAN-WEEKS OF TRAINING(DEPOT LEVEL)-------	1.0
M	MAN-WEEKS OF TRAINING(INT.LEVEL)---------	1.0
O	INT.LEVEL SPECIAL AGE COST---------------	25000.
D	INT.LEVEL FACILITIES COST----------------	7500.
E	DEPOT LEVEL SPECIAL AGE COST-------------	25000.
	DEPOT LEVEL FACILITIES COST--------------	7500.
D	REPAIR PARTS COST PER REPAIR-------------	15.0
A	NEW ASSEMBLIES INTRODUCED----------------	1
T	NEW PARTS INTRODUCED---------------------	10
A	WEIGHT OF INT.LEVEL SPECIAL AGE----------	300
	WEIGHT OF REPAIR PARTS PER REPAIR--------	.5
	NUMBER OF LINE ITEMS TO STOCK------------	11
	NUMBER OF AUTOMATIC TEST STEPS-----------	0
	MEAN TIME TO AUTOMATICALLY TEST----------	0.00
	COST INT.LEVEL AGE,HIGH MTBD-------------	25000.
	COST INT.LEVEL AGE,LOW MTBD--------------	25000.
	COST DEPOT LEVEL AGE,HIGH MTBD-----------	25000.
	COST DEPOT LEVEL AGE,LOW MTBD------------	25000.

OPTIMUM REPAIR LEVEL ANALYSIS OF HELIOSTAT CONTROL ELECTRONICS

PASS 1 ITEM 5 MODE 1 CIRCUIT CARD FAILURE

COST ELEMENTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
SPARES	$ 1545.	$ 104.	$ 286150.
SAFETY STOCK	400.		
SUPPLY ADMIN	0.	5940.	
PART INTRODUCTION	1057.	1057.	
REPAIR PARTS	44105.	44105.	
PKING + SHIPPING	6177.	771.	3080.
AGE	4167.	25000.	
FACILITIES	1250.	7500.	
LABOR	159717.	143766.	
TRAINING	325.	4850.	
TECHNICAL DATA	650.	650.	
SUB-TOTAL	$ 219392.	$ 233742.	$ 291230.

SENSITIVITY TESTS	DEPOT REPAIR	INTR. REPAIR	DISCARD
+.50 X MTBD	$ 149815.	$ 170890.	$ 194250.
-.50 X MTBD	$ 431336.	$ 422488.	$ 582460.
+.50 X REPAIR MH	$ 299251.	$ 305626.	$----------
-.50 X REPAIR MH	$ 139534.	$ 161859.	$----------
+.50 X TRAINING	$ 219555.	$ 236167.	$----------
-.50 X TRAINING	$ 219230.	$ 231317.	$----------
+.50 X UNIT COST	$ 242417.	$ 255847.	$ 435305.
-.50 X UNIT COST	$ 196367.	$ 211638.	$ 147155.
+.50 X AGE COST	$ 221476.	$ 246242.	$----------
-.50 X AGE COST	$ 217309.	$ 221242.	$----------
+.25 X FLEET SIZE	$ 272378.	$ 280929.	$ 364037.
-.25 X FLEET SIZE	$ 166406.	$ 186556.	$ 218422.
+.21 X UTIL.RATE	$ 263900.	$ 273379.	$ 352388.
-.21 X UTIL.RATE	$ 174884.	$ 194106.	$ 230072.

ITEM NR 2 DATA DISTRIBUTION INTERFACE 125.00 DOLLARS

CW	0	POUNDS	(RE-USABLE CNTR WEIGHT)
NULBS	2.0	POUNDS	(WEIGHT OF RPR ITEM)
NUPWS	114		(QUANTITY PER NHA)
PCTON	1.000		(OPERATE TO FLT.HR.RATIO)

1 FAILURE MODES WILL BE ANALYZED

MODE NR 1 CIRCUIT CARD FAILURE PASS 2 ITEM 2

F	MEAN TIME BETWEEN REPAIR------------------	412372
A	MAN-HOURS REQUIRED TO REPAIR--------------	3.5
I	NR PAGES DEPOT LEVEL TECH DATA------------	15.0
L	NR PAGES INT.LEVEL TECH DATA--------------	15.0
	TRAINING RATE--PER MAN-WEEK---------------	500.0
	MAN-WEEKS OF TRAINING(DEPOT LEVEL)--------	1.0
M	MAN-WEEKS OF TRAINING(INT.LEVEL)----------	1.0
O	INT.LEVEL SPECIAL AGE COST----------------	100.
D	INT.LEVEL FACILITIES COST-----------------	0.
E	DEPOT LEVEL SPECIAL AGE COST--------------	100.
	DEPOT LEVEL FACILITIES COST---------------	0.
D	REPAIR PARTS COST PER REPAIR--------------	13.0
A	NEW ASSEMBLIES INTRODUCED-----------------	1
T	NEW PARTS INTRODUCED----------------------	12
A	WEIGHT OF INT.LEVEL SPECIAL AGE-----------	0
	WEIGHT OF REPAIR PARTS PER REPAIR---------	.5
	NUMBER OF LINE ITEMS TO STOCK-------------	13
	NUMBER OF AUTOMATIC TEST STEPS------------	0
	MEAN TIME TO AUTOMATICALLY TEST-----------	0.00
	COST INT.LEVEL AGE,HIGH MTBD--------------	100.
	COST INT.LEVEL AGE,LOW MTBD---------------	100.
	COST DEPOT LEVEL AGE,HIGH MTBD------------	100.
	COST DEPOT LEVEL AGE,LOW MTBD-------------	100.

OPTIMUM REPAIR LEVEL ANALYSIS OF DATA DISTRIBUTION INTERFACE

PASS 2 ITEM 2 MODE 1 CIRCUIT CARD FAILURE

COST ELEMENTS	DEPOT REPAIR	INTR, REPAIR	DISCARD
SPARES	$ 13.	$ 1.	$ 3421.
SAFETY STOCK	5.		
SUPPLY ADMIN	0.	7020.	
PART INTRODUCTION	1258.	1258.	
REPAIR PARTS	356.	356.	
PKING + SHIPPING	57.	7.	29.
AGE	17.	100.	
FACILITIES	0.	0.	
LABOR	1487.	1336.	
TRAINING	325.	4850.	
TECHNICAL DATA	650.	650.	
SUB-TOTAL	$ 4173.	$ 15581.	$ 3450.

SENSITIVITY TESTS	DEPOT REPAIR	INTR, REPAIR	DISCARD
+.50 X MTBD	$ 3533.	$ 15014.	$ 2301.
-.50 X MTBD	$ 6096.	$ 17283.	$ 6899.
+.50 X REPAIR MH	$ 4916.	$ 16250.	$----------
-.50 X REPAIR MH	$ 3430.	$ 14912.	$----------
+.50 X TRAINING	$ 4336.	$ 18006.	$----------
-.50 X TRAINING	$ 4011.	$ 13156.	$----------
+.50 X UNIT COST	$ 4362.	$ 15759.	$ 5160.
-.50 X UNIT COST	$ 3984.	$ 15402.	$ 1739.
+.50 X AGE COST	$ 4181.	$ 15631.	$----------
-.50 X AGE COST	$ 4165.	$ 15531.	$----------
+.25 X FLEET SIZE	$ 4654.	$ 16006.	$ 4312.
-.25 X FLEET SIZE	$ 3692.	$ 15155.	$ 2587.
+.21 X UTIL.RATE	$ 4577.	$ 15938.	$ 4174.
-.21 X UTIL.RATE	$ 3769.	$ 15223.	$ 2725.

Figure 5.3.1-2

5.3.1.2 Conclusions

With the exception of the printed circuit boards, on-site repair was indicated as the most cost-effective. The significant factors contributing to the on-site repair decision appear to be the relatively high packaging and shipping costs for off-site repair, and relatively low support equipment and facilities cost penalty for establishing a repair capability at each site. The computer model runs shown were based on six sites within a 500-mile radius of the assumed off-site repair facility. Other runs were made based on 50 sites within a 500-mile radius without any change in designated repair location.

The heliostat control printed circuit boards appear to be a reasonably firm candidate for off-site repair. Deployment of additional sites would strengthen this decision. However, sensitivity tests indicate an increase in repair manhours or a decrease in unit cost make the discard option more attractive. Therefore, this decision should be re-examined in the future for possible change. The data distribution interface circuit boards appear to be discard items primarily due to the low number of failures per year. A greater number of deployed sites would tend to make off-site repair feasible. Also, an increase in failure rate on unit cost and/or a decrease in repair manhours would support an off-site repair decision.

There does not appear to be "break points" at which a change in designated repair locations would occur; i.e., the higher production rates (with some probable reduction in unit costs) and/or the increased number of sites deployed do not tend to change the repair locations except as noted. There does appear to be merit for a single company that operates two or more sites in immediately adjoining areas to pool its on-site off-line repair tasks at one site providing a low cost packaging, handling, storage, and intersite transportation scheme can be devised.

Repair locations as determined by this trade study are documented on the analysis sheets presented in paragraph 5.4, Operations and Maintenance Concept Descriptions.

5.3.2 Trade Study 0-2 Reflector Cleaning

The purpose of this trade study was to determine the least costly method of cleaning the heliostats so as to maintain field efficiency.

5.3.2.1 Analysis

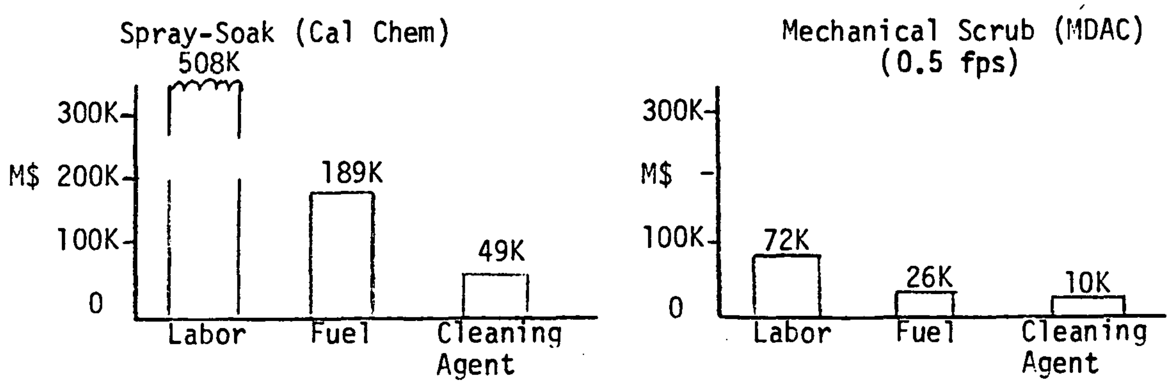
The initial effort was to develop several cleaning approaches that would do the job. These approaches are shown in the following pages. As the analysis proceeded, it became obvious that the cost sensitivity was not directly related to the method, but rather to the task time. If the task time seemed to be driven by the method, new procedures could always be invented within any specific method to reduce the task times to an acceptable level.

After giving attention to the task time sensitivity, MDAC found that the related cost curves (and breaks whenever the crew requirements would decrease) and equipment types had very little effect on the life cycle cleaning costs. This relationship held until the crew requirements decrease to two per field, when the only changes were in fact the equipment costs (acquisition, O&M). The cleaning method choice became subjective in nature rather than economic.

The two MDAC equipment concepts for spray-soak and mechanical scrub are illustrated in Figures 5.3.2-1 and 5.3.2-2. The spray-soak uses two trucks passing at one-minute intervals. The first truck applies the wash solution, and the second applies a high pressure de-ionized water rinse. The mechanical scrubber uses a water flush, a soft bristle brush scrub, and a de-ionized water flush.

The set of bar charts below summarizes the significant costs in the various cleaning schemes.

Annual Recurring Cleaning Costs



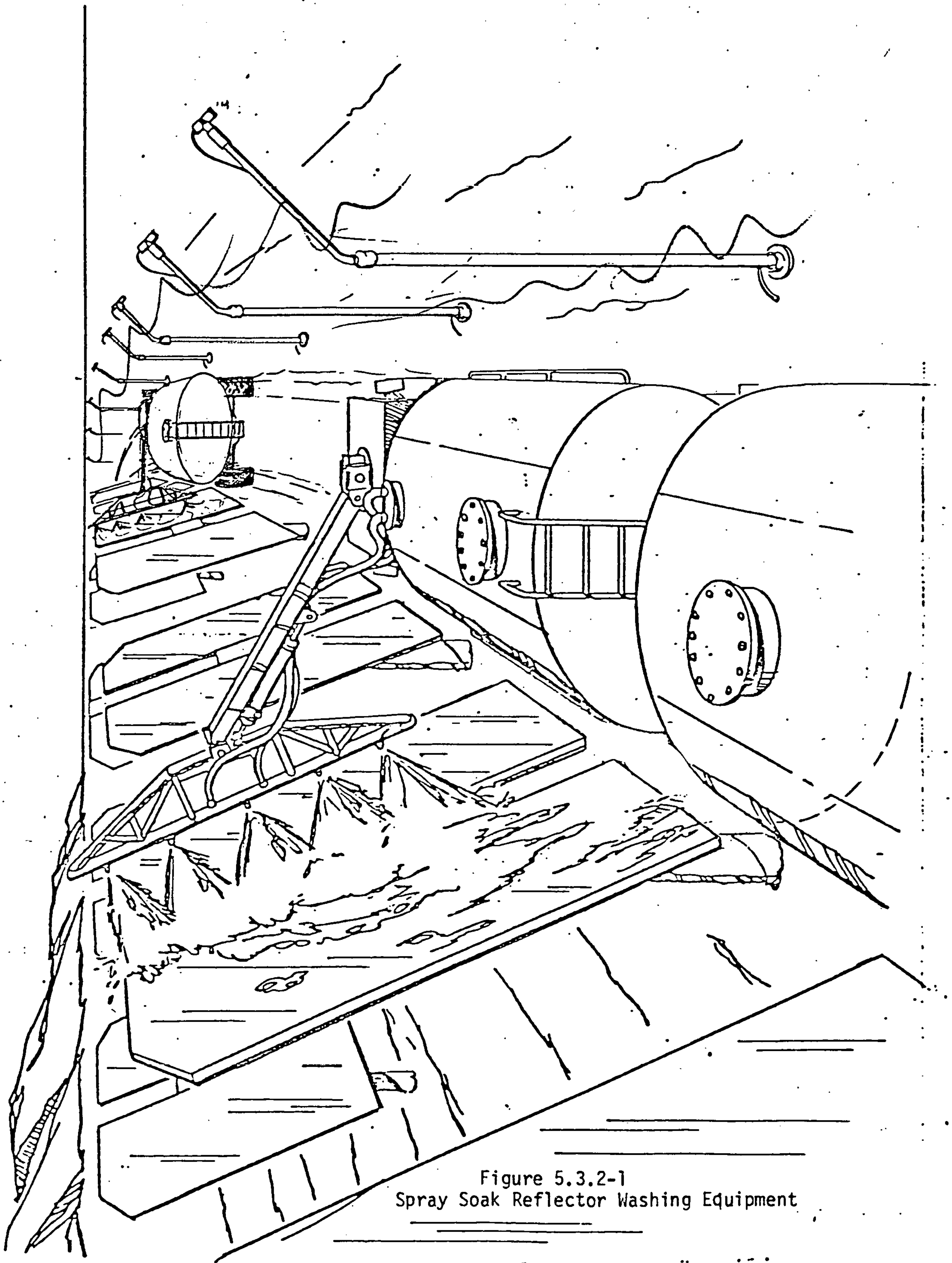


Figure 5.3.2-1
Spray Soak Reflector Washing Equipment

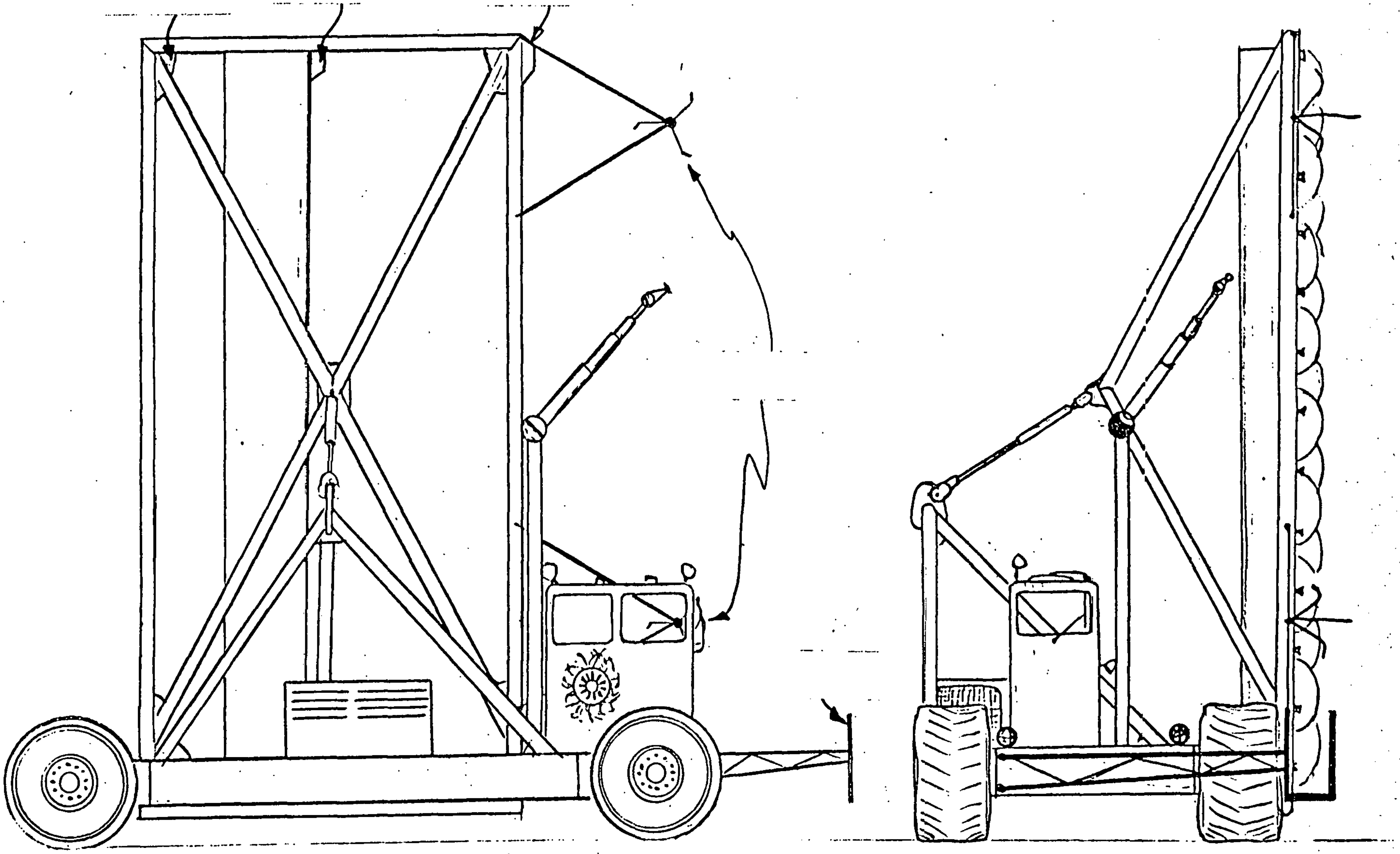
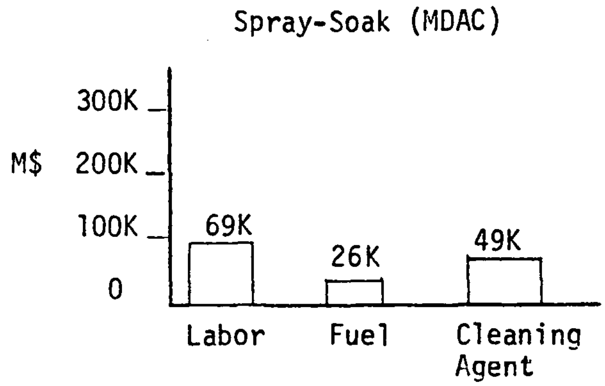
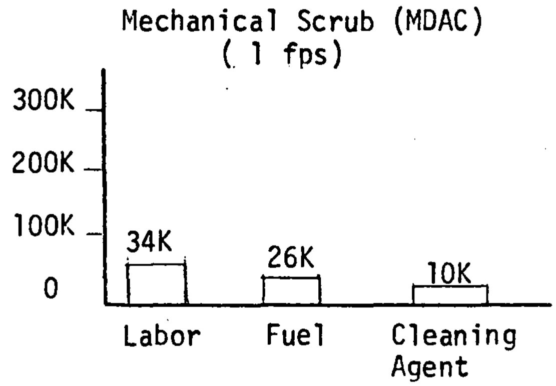


Figure 5.3.2-2

Mechanical Scrub Reflector Washing Equipment





Note that labor cost is directly proportional to task time, fuel cost is related to the task time by the number of machines, and their operating time and cleaning agent cost is a function of the percentage of active cleaning agents used in the wash solutions.

5.3.2.2 Risks

All of the approaches considered have very little technical risk. The spray-soak method has been tested and cleaning effectiveness is good. The mechanical scrubbing method has not been tested so far, but should be effective. The spray-soak methods use a man to drive the machines around the field, which could pose a threat to damaging the heliostats as the task is boringly repetitive. The mechanical-scrub scheme requires the machines to be in close proximity to the heliostats so the steering and head positioning is done by an automatic system to assure consistent cleaning. The secondary benefit of these automatic systems is that operator fatigue is reduced by placing him in a monitor role so that he is better able to respond to any abnormal situation.

The environmental impact of each cleaning method is important. In the Cal-Chem approach, all cleaning agents are collected so there is no environmental deterioration. This collection, however, is one of the major factors that increase the time and cost for the cleaning task in that approach. In the MDAC spray-soak method, the cleaning agents are not collected and fall to the ground, at a rate of 160 grams/m^2/month. Of this amount, the cleaning concentrate contents is only 1.4 grams/m^2/month. These agents are bio-degradable in the long run, but their short-term environmental impact has not been determined.

The mechanical scrub method uses deionized water as the cleaning agents. This water also falls to the ground. Water is used at a rate of 37.8 liters per heliostat for wash and rinse, and results in 183 grams/m^2/month being dumped on the ground. Again short and long term effects of this moisture must be determined on local flora and fauna.

5.3.2.3 Conclusions

With life-cycle costs as the basis for comparison, the approach with the shortest task times will be the best. Table 5.3.2-1 provides a summary of the projected 30-year life cycle costs of the four methods analyzed. In cases where the task times are equal, there is a slight acquisition cost penalty for the mechanical scrub approach which is offset by the lower cleaning solution cost. Therefore, direct cost comparisons come out even.

There are no other factors like environmental impact, damage incidence, and maintenance frequency that could force the selection one way or the other.

TABLE 5.2.3-1

LIFE CYCLE COST COMPARISON OF HELIOSTAT CLEANING METHODS

MECHANICAL SCRUB VS SPRAY SOAK

(30-YEAR LIFE CYCLE)

	MECHANICAL SCRUB		SPRAY-SOAK	
	1/2 fps SPEED	1 fps SPEED	CAL CHEM (>.1 fps)	MDAC (1 fps)
Vehicle Investment (Replace Every 10 Years)	$1,440,000	$ 720,000	$ 1,440,000	$ 600,000
Diesel Fuel	$ 790,920	$ 790,920	$ 5,686,200	$ 789,840
Cleaning Solution °deionized water	$ 275,400	$ 275,400	$ 240,570	240,570
°active cleaner	$ ---	$ ---	$ 1,239,300	$1,239,300
Operator Labor	$2,160,000	$ 1,036,800	$15,265,800	$2,073,600
Maintenance Labor	$ 182,520	$ 182,520	$ 1,312,200	$ 182,520
TOTAL	$4,848,840	$ 3,005,640	$25,184,070	$5,125,830

5.4 OPERATIONS AND MAINTENANCE CONCEPT DESCRIPTION

Data derived from the various trade studies and maintenance analyses are recorded on Logistics Support Analysis Worksheets. The worksheets for collector subsystem maintenance significant items, as identified at the Project Design Freeze point, are provided in Table 5.4-1. Reference is made to this data to determine requirements for scheduled and unscheduled maintenance, spares and repair parts, maintenance manhours, support equipment, and facilities.

5.4.1 Reflector Cleaning

Previous studies and testing programs indicate reflector cleaning is required approximately every 30 days to maintain acceptable reflectivity levels. The reflection cleaning trade study (Reference paragraph 5.3.2) indicates the initial baseline process is not a cost-effective method when compared to other alternatives. Three apparently acceptable and approximately equal alternatives are described in the study, one of which may eventually be the final solution. In keeping with a conservative approach, the method described as spray-soak, MDAC (1 fps speed) has been selected as the new baseline. This approach is considered to present the least risk in that the spray-soak method has been tested with acceptable cleaning effectiveness and the cleaning equipment is the least complex. Manhour and cost projections will be based on this method.

The basic spray-soak method requires application of an acidic wash solution to the heliostats while in a near vertical position. Approximately one-minute dwell time is then allowed for the wash solution to act on the contaminated surface, after which time the surface is rinsed with de-ionized water. The new baseline method implements these requirements using two trucks with spray heads that move continuously across the field at approximately one foot per second ($\approx$.68 mph). The lead truck contains the acidic washing solution and sprays the solution on the heliostat as it passes. The lag truck is about one minute (two heliostats) behind the lead truck to allow for soak time. The lag truck sprays the heliostat with de-ionized water to rinse off the cleaning solution to complete the task. Runoff is not collected and falls on the ground.

TABL .4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: DRIVE ASSY, AZIMUTH System: FROTOTYPE HELIOSTAT

Weight: 461 LBS Repair Decision: ON-SITE

Prelim Cost Est: $575.00 Method: ORLA MODEL

Qty: 18,000/SITE MTBF: 340,136 Sys MTTR: 4.0

R&R MHRS: 19.2 Repair MHRS: 5.5

Description:

The Azimuth Drive Assembly supports the reflector structure and provides the means for producing azimuth rotation for solar tracking, emergency slewing, and routine positioning for stowage and maintenance. The drive train includes a heliocon gear input reducer and a harmonic drive output stage which provides an overall gear reduction of 39,200:1.

5-28

Maintenance Concept:

The complete assembly is removed and replaced upon component failure. Bench repair of removed assemblies is accomplished by replacement of defective gear train components. The harmonic drive section is lubricated by heavy duty oil and the input reduction gear cavity is packed with grease. Scheduled servicing/lubrication is not planned. General area/ corrosion control inspection will include verification that grease and oil seals are not leaking.

Support Equipment:

Replacement of the drive assembly requires a mobile crane to hoist and remove the reflector support structure and a forklift to remove and replace the drive assembly. Hoisting can be accomplished with universal slings.

Bench repair requires a portable or overheat hoist and a holding fixture to support assembly/disassembly, a means verifying input/output torque, and standard precision mechanical inspection tools for checking wear tolerances and backlash.

Facilities:

No special facilities are required. Bench area floor space of approximately 400 ft^2 should be adequate.

NOTE: MTBF = mean time between failures
MTTR = mean time to repair
R&R = rest and recuperation

TABLE 4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	JACK ASSEMBLY, TRACKING/STORAGE	System:	PROTOTYPE HELIOSTAT
Weight:	60 LBS	Repair Decision:	ON-SITE
Prelim Cost Est:	$198.00	Method:	ORLA MODEL
Qty: 36,000/SITE	MTBF: 366,300	Sys MTTR:	2.2
		R&R MHRS: 4.4	Repair MHRS: 3.0

Description:

The Jack Assembly is a ball screw, translating tube configuration which requires no backlash adjustment. The design includes a single stage input gear reduction. An integral drive motor mount is provided and the input pinion is on the drive motor shaft. The tracking and storage jack assemblies are interchangeable.

5-29

Maintenance Concept:

The Jack Assembly is removed and replaced upon component failure. Bench repair of removed assemblies is accomplished by replacement of defective components. Scheduled lubrication is not planned; however, the condition of grease seals will be verified as part of general area/corrosion control inspections. Evidence of loss of grease or entry of moisture/contaminants will initiate corrective maintenance.

Support Equipment:

A restraining device or safety link is required to prevent rotation of the reflector structure during replacement of either tracking or storage jack. Bench repair requires a holding fixture, a means for checking input torque versus output, and standard precision mechanical inspection tools for checking wear tolerances.

Facilities:

No special facilities are required. Bench area floor space of approximately 200 ft^2 should be adequate.

TABLE 4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: DRIVE MOTOR, AZIMUTH | System: PROTOTYPE HELIOSTAT

Weight: 17 LBS | Repair Decision: ON-SITE

Prelim Cost Est: $70.00 | Method: ORLA MODEL

Qty: 18,000/SITE MTBF: 295,858 | Sys MTTR: 1.7

R&R MHRS: 3.4 Repair MHRS: 2.5

Description:

The Azimuth Drive Motor is mounted on the drive assembly housing and provides the power for azimuth tracking. The Line Replaceable Unit (LRU) includes the 1/4 HP motor, the drive electronics components, and the incremental encoder.

Maintenance Concept:

The Drive Motor Assembly is removed and replaced upon component failure. Bench repair of removed assemblies is accomplished by replacement of the incremental encoder, drive electronics, and motor components. Motor bearings are permanently lubricated and no scheduled maintenance is required.

Support Equipment:

Replacement of the motor assembly does not require any special tools or equipment. Bench repair requires a controlled input power source and a means of measuring output torque and RPM. A holding fixture, common tools and standard test equipment are required for disassembly/assembly and verification of incremental encoder operation.

Facilities:

No special facilities are required. Bench area floor space of approximately 150 ft^2 should be adequate.

TABLE 5.4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	DRIVE MOTOR ELEVATION/STORAGE	System:	PROTOTYPE HELIOSTAT
Weight:	18 LBS	Repair Decision:	ON-SITE
Prelim Cost Est:	$75.00	Method:	ORLA MODEL
Qty: 36,000/SITE	MTBF: 295,858	Sys MTTR:	1.9
		R&R MHRS: 3.8	Repair MHRS: 2.5

Description:

The Elevation and Storage Drive Motors are mounted on the tracking and storage jack assemblies, respectively. The motors are interchangeable. The Line Replaceable Unit (LRU) includes the 1/3 HP motor, the motor controller components and the incremental encoder.

Maintenance Concept:

The Drive Motor Assembly is removed and replaced upon component failure. Bench repair of removed assemblies is accomplished by replacement of the incremental encoder, motor controller and motor components. Motor bearings are permanently lubricated and no scheduled maintenance is required.

Support Equipment:

Replacement of the motor assembly does not require any special tools or equipment. Bench repair requires a controlled input power source and a means of measuring output torque and RPM. A holding fixture, common tools, and standard test equipment are required for disassembly/assembly and verification of incremental coder operation. Bench support equipment is also utilized for azimuth drive motor repair.

Facilities:

No special facilities are required. Bench area floor space is shared with azimuth drive motor repair area.

TABLE 5.4 .

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	HELIOSTAT J-BOX	System:	PROTOTYPE HELIOSTAT
Weight:	10 LBS	Repair Decision:	ON-LINE
Prelim Cost Est:	$47.00	Method:	TASK ANALYSIS
Qty: 18,000/SITE	MTBF: 862,069	Sys MTTR:	1.6
		R&R MHRS: -	Repair MHRS: 3.2

Description:

The Heliostat J-Box is a dust and waterproof electrical junction box, located near the base of the pedestal, which houses the terminal strips and circuit breaker for terminating/interconnecting the field power and data cables with the heliostat power and data wiring.

Maintenance Concept:

Replacement of the J-Box is not anticipated, except for major physical damage. The box is repaired in-place by replacement of electrical components or weather seals.

Support Equipment:

No special equipment required.

Facilities:

None required.

TABL 4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: HELIOSTAT CONTROL ELECTRONICS System: PROTOTYPE HELIOSTAT

Weight: 1 LB Repair Decision: OFF-SITE

Prelim Cost Est: $98.00 Method: ORLA MODEL

Qty: 18,000/SITE MTBF: 606,060 Sys MTTR: 1.3

R&R MHRS: 2.6 Repair MHRS: 3.5

Description:

The Heliostat Control Electronics respond to heliostat array controller commands and calculate positioning commands for heliostat movement. The microprocessor based circuitry is contained on a circuit card installed in an electronic J-box located on the azimuth drive assembly housing. The J-box cover is easily removable for access to the circuit card which is a 4" by 5" two-layer board with conformal coating for moisture protection.

Maintenance Concept:

The circuit card is removed and replaced upon component failure. Fault detection and isolation is accomplished by operational indications, heliostat array software routines, and the mobile test van. Bench repair is accomplished by replacement of defective components.

Support Equipment:

Replacement does not require any special tools or equipment other than the mobile test van. Bench repair requires a circuit card test station and an electronic bench repair and inspection station.

Facilities:

No special facilities required. Bench area floor space of approximately 200 ft^2 should be adequate.

TABLE ..I-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: HELIOSTAT POWER/DATA CABLES System: PROTOTYPE HELIOSTAT

Weight: - Repair Decision: ON-LINE

Prelim Cost Est: - Method: TASK ANALYSIS

Qty: 5/HELIOSTAT MTBF: 9,090,909 Sys MTTR: 1.8

R&R MHRS: - Repair MHRS: 3.6

Description:

The Power/Data Cables carry the three-phase power and data for control of the heliostat drive motors and include the cables from the pedestal J-box through the hollow harmonic drive shaft to the heliostat electronics J-box and from the electronics J-box to the three drive motors. Data transmission between the J-boxes is by fiber optics. All other cables are electrical.

Maintenance Concept:

The Heliostat Cables are repaired in-place by standard electrical and optical fiber repair methods and replacement terminals and ion connectors. Procurement of spare cable assemblies is not planned. In the event repair is not economical due to major damage, a complete cable assembly can be fabricated from bulk wire/optical fiber and spare cable terminations.

Support Equipment:

No special support equipment required. Repair accomplished by standard electrical and optical fiber repair tools and test equipment.

Facilities:

None required.

5-54

TABLE -1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	DATA DISTRIBUTION INTERFACE (DDI)	System:	PROTOTYPE HELIOSTAT
Weight:	1 LB	Repair Decision:	DISCARD
Prelim Cost Est:	$125.00	Method:	ORLA MODEL
Qty: 57/SITE	MTBF: 206,186	Sys MTTR:	1.6
		R&R MHRS: 3.2	Repair MHRS: (3.5)

Description:

The DDI Electronics provides the communications data interface between the heliostat array controller and the heliostat controller. Two identical microprocessor based logic networks (two 4" by 5" two-layer circuit boards) are installed in a J-box, located at the power transformer/power distribution panel sites, to provide communications redundancy in the event one channel fails.

Maintenance Concept:

5-35

The DDI circuit cards are replaced upon component failure. Fault detection and isolation is accomplished by operational indications, heliostat array software routines, and the mobile test van. Bench repair is accomplished by replacement of defective components.

Support Equipment:

Replacement does not require any special tools or equipment other than the mobile test van. Bench repair requires a circuit card test station and an electronic bench repair and inspection station.

Facilities:

No special facilities required. Bench area floor space of approximately 200 ft^2 should be adequate.

TABL_ _.4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	POWER TRANSFORMER	System:	PROTOTYPE HELIOSTAT
Weight:	2,600 LBS	Repair Decision:	OFF-SITE
Prelim Cost Est:	$6,150.00	Method:	TASK ANALYSIS
Qty: 57/SITE	MTBF: 500,000	Sys MTTR:	2.4
		R&R MHRS: 8.3	Repair MHRS: *

Description:

Power for heliostat operation is distributed through a system of 57 transformers rated at 225 KVA with 4160 volt primary and 480/277 volt secondary windings. Each transformer supplies power to 12 to 16 groups of heliostats by branch circuits which feed approximately 24 heliostats each.

Maintenance Concept:

5-36 The Power Transformer is removed and replaced for internal electrical failure. Units removed for failure are surveyed for extent of damage and dispositioned for salvage and/or rebuilt at the manufacturer's facility or specialized repair area.

Support Equipment:

Removal and replacement of the transformer requires use of a forklift or mobile crane and universal hoisting slings.

Facilities:

Manufacturer's facility.

*Scrap/salvage if labor and materials exceed 65 percent of unit cost.

TABLE ..4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	POWER DISTRIBUTION PANEL	System:	PROTOTYPE HELIOSTAT
Weight:	-	Repair Decision:	ON-LINE
Prelim Cost Est:	-	Method:	TASK ANALYSIS
Qty: 57/SITE	MTBF: 66,667	Sys MTTR:	1.6
		R&R MHRS: -	Repair MHRS: 3.2

Description:

The Power Distribution Panel is a 480 volt three-phase load center containing a 100 amp main circuit breaker and 12 to 16 branch circuit breakers of 40 amps each.

Maintenance Concept:

5-37 The Power Distribution Panels are repaired in-place by replacement of circuit breakers.

Support Equipment:

No special support equipment required. Repair is accomplished using common tools and test equipment.

Facilities:

None required.

TABL_ _.4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: FIELD POWER/DATA CABLES

System: PROTOTYPE HELIOSTAT

Weight: -

Repair Decision: ON-LINE

Prelim Cost Est: -

Method: TASK ANALYSIS

Qty: 18,063/SITE

MTBF: 4,545,454

Sys MTTR: 3.5

R&R MHRS: -

Repair MHRS: 7.0

Description:

The Field Power/Data Distribution Network includes the primary cable runs from the power house to the power transformers and data distribution interfaces and secondary runs from these points to the heliostats. The primary cables contain three conductor copper cables and two circuit fiber optic cables within the same jacket. The secondary cables contain the power conductors and a single fiber optic circuit. The cables are direct buried.

Maintenance Concept:

The Field Power/Data Cables are repaired in-place by standard electrical and optical fiber repair methods and replacement of terminals and/or connectors. Procurement of spare cable assemblies is not planned. In the event repair is not economical due to major damage, a complete cable assembly can be fabricated from bulk cable and spare cable terminations.

Support Equipment:

No special support equipment required. Repair accomplished by standard electrical and optical fiber repair tools and test equipment.

Facilities:

None required.

TABLE 5.4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	PEDESTAL	System:	PROTOTYPE HELIOSTAT
Weight:	-	Repair Decision:	ON-LINE
Prelim Cost Est:	-	Method:	TASK ANALYSIS
Qty: 18,000/SITE	MTBF: 9,090,909	Sys MTTR:	1.0
		R&R MHRS: -	Repair MHRS: 2.0

Description:

The Pedestal is fabricated of 24 inch diameter spiral welded steel pipe with a wall thickness of 0.1046 inch and is 125 inches long. The lower 48 inches of length is expanded to produce a slight taper (0.14 inch diameter per foot) to obtain a wedbed, slip-joint attachment with the foundation on installation. The pedestal is hot-dip galvanized after fabrication.

Maintenance Concept:

Repair in-place utilizing standard structural repair processes.

Support Equipment:

No special support equipment required.

Facilities:

None required.

TABLE -.4-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name:	REFLECTOR STRUCTURE	System:	PROTOTYPE HELIOSTAT
Weight:	1,300 LBS	Repair Decision:	ON-LINE
Prelim Cost Est:	-	Method:	TASK ANALYSIS
Qty:	18,000/SITE MTBF: 8,333,333	Sys MTTR:	1.5
		R&R MHRS:	- Repair MHRS: 3.0

Description:

The Reflector Support structure is fabricated from galvanized steel sheet in two sections which bolt to a tubular center beam attached to the drive unit assembly. The structure supports each reflector mirror by a pair of hat-section stringers which are bonded to the glass when the reflector is assembled. Six reflector mirrors are installed in each support structure section or a total of twelve per heliostat.

Maintenance Concept:

The Reflector Structure is repaired in-place utilizing standard structural repair processes.

Support Equipment:

No special support equipment required.

Facilities:

None required.

TABLE 5.4-1
LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: MIRROR MODULE System: PROTOTYPE HELIOSTAT

Weight: 147 LBS Repair Decision: DISCARD

Prelim Cost Est: - Method: TASK ANALYSIS

Qty: 216,000/SITE MTBF: 10,000,000 Sys MTTR: 2.0

R&R MHRS: 5.0 Repair MHRS: -

Description:

Each mirror module measures 48 by 132 inches and is made up of laminated glass. The front sheet is a .060 inch thick pane of fusion glass which is mirrored on its inner surface. The back sheet is 3/16 inch float glass bonded to the front glass with polyurethane adhesive.

Maintenance Concept:

The Reflector Panels are removed, replaced and discarded upon failure. Minor cracks may be repaired in place by adhesive bonding of a mirror patch on the front of the mirror module.

Support Equipment:

Removal and replacement requires a mobile crane and a mirror handling and hoisting sling.

Facilities:

None required.

TABLE I-1

LOGISTICS SUPPORT ANALYSIS WORKSHEETS

Item Name: HELIOSTAT ARRAY CONTROLLER System: PROTOTYPE HELIOSTAT

Weight: - Repair Decision: SERVICE CONTRACT

Prelim Cost Est: - Method: TASK ANALYSIS

Qty: 1 MTBF: TBD Sys MTTR: TBD

R&R MHRS: ______ Repair MHRS: ______

Description:

The Heliostat Array Controller (HAC) is located in the MCS building and provides the interface between MCS and the collector field. The HAC and backup will consist of two off-the-shelf commercially available mini-computers with support peripheral and interfacing equipment. The hardware includes the operation console consisting of a keyboard, cathode ray tube, and control panel; a control processing unit; a storage unit; field interface; MCS interface, and a time pickup unit.

Maintenance Concept:

It is expected that the HAC will have interchangeability with MCS central processing units and other components, and will be maintained as a subsystem/group. At this time, the baseline maintenance concept is assumed to be via a commercial service contract.

Support Equipment:

Furnished by service contraction.

Facilities:

No special maintenance facilities required.

5.4.2 Unscheduled Maintenance

The on-line unscheduled maintenance tasks and maintenance manhours per task for the collector subsystem maintenance significant items are shown in Table 5.4.2-1. The estimated elapsed maintenance time (EMT) and skill requirements are also indicated. Task elements considered include fault isolation, access time, component removal and replacement, and test/checkout time subsequent to fault correction.

Table 5.4.2-2 summarizes the on-line maintenance manhour requirements per year based on the predicted maintenance actions per year (MA/yr) and the task manhours shown in Table 5.4.2-1. The equipment quantity per site and the mean time between maintenance actions (MTBMA) as derived from the reliability analyses are provided for reference.

The off-line unscheduled maintenance requirements are summarized in Table 5.4.2-3. The indicated on-site and off-site repair locations are justified as noted in the optimum repair level analyses (reference paragraph 5.3.1). Maintenance manhours per task and total manhours per year per repair location are provided.

5.4.3 Spares and Repair Parts

5.4.3.1 Spare LRU's

A preliminary spares analysis was conducted based on the hardware configuration at the Project Design Freeze point. Results of this analysis to identify spare LRU quantities are presented in Table 5.4.3-1. Repairable LRU's, upon failure, are removed from the system, placed in the repair cycle, and subsequently returned to spare stock inventory upon completion of repair. Initial spares quantity for these items is the sum of the pipeline quantity and a 30-day contingency supply. The pipeline quantity is equal to the maximum number of items in the repair pipeline at any given time and is based on the failure rate and the repair cycle time. A repair cycle time of five days is projected for on-site repair and 30 days for off-site repair. The 30-day contingency quantity is equal to the number of predicted failures in a 30-day period, and provides a cushion in the event unpredictable delays occur in the planned repair cycle

TABLE 5.4.2-1

ON-LINE CORRECTIVE MAINTENANCE MANHOURS PER TASK

				Manhours				
	Maintenance Significant Item	Task	EMT	Elect Tech	Mech Tech	Equip Oper	Rigger	Total
1.	Drive Assembly, Azimuth	R&R	4.0	4.0	8.0	4.4	2.8	19.2
2.	Jack Assembly, Tracking	R&R	2.2	2.2	2.2			4.4
3.	Jack Assembly, Storage	R&R	2.2	2.2	2.2			4.4
4.	Drive Motor, Azimuth	R&R	1.7	1.7	1.7			3.4
5.	Drive Motor, Elevation	R&R	1.9	1.9	1.9			3.8
6.	Drive Motor, Storage	R&R	1.9	1.9	1.9			3.8
7.	Heliostat J-Box	Repair	1.6	3.2				3.2
8.	Heliostat Control Electronics	R&R	1.3	2.6				2.6
9.	Heliostat Power/Data Cables	Repair	1.8	3.6				3.6
10.	Field Power/Data Cables	Repair	3.5	7.0				7.0
11.	Data Distribution Interface	R&R	1.6	3.2				3.2
12.	Power Transformer	R&R	2.4	4.8	2.4	1.1		8.3
13.	Power Distribution Panel	Repair	1.6	3.2				3.2
14.	Heliostat Array Controller	Repair	1.0	(Service Contract)				
15.	Pedestal	Repair	1.0		2.0			2.0
16.	Reflector Structure	Repair	1.5		3.0			3.0
17.	Reflector Panel	R&R	2.0		4.0	1.0		5.0
18.	Digital Camera	R&R	1.5	3.0				3.0
19.	Camera Cooler/Heater	R&R	1.5	3.0				3.0

TABLE 5.4.2-2

ON-LINE CORRECTIVE MAINTENANCE MANHOURS PER YEAR

Maintenance Significant Item	Qty	MTBMA	Ma/Yr	Elect Tech	Mech Tech	Equip Oper	Rigger	Total
1. Drive Assembly, Azimuth	18,000	18.9	175	700	1,400	770	490	3,360
2. Jack Assembly, Tracking	18,000	20.4	162	356	356			712
3. Jack Assembly, Storage	18,000	20.4	8	18	18			36
4. Drive Motor, Azimuth	18,000	16.4	201	342	342			684
5. Drive Motor, Elevation	18,000	16.4	201	382	382			764
6. Drive Motor, Storage	18,000	16.4	10	19	19			38
7. Heliostat J-Box	18,000	47.9	69	221				221
8. Heliostat Control Electronics	18,000	33.7	98	255				255
9. Heliostat Power/Data Cables	90,000	101	33	119				119
10. Field Power/Data Cables	18,057	244.8	13	91				91
11. Data Distribution Interface	57	3,617.9	1	3				3
12. Power Transformer	57	8,771.9	0.4	2	1	1	1	4
13. Power Distribution Panel	57	1,169.6	3	6				6
14. Heliostat Array Controller	1	1,000	4	(Service Contract)				
15. Pedestal	18,000	505.1	7		14			14
16. Reflector Structure	18,000	462.9	7		21			21
17. Reflector Panel	216,000	46.3	71		284	71		355
18. Digital Camera	6	16,162	.2	1				< 1
19. Camera Cooler/Heater	6	6,460	.02	.1				< 1
			1,060	2,515	2,837	842	490	6,684

TABLE 5.4.2-3

OFF-LINE REPAIR MAINTENANCE MANHOURS

	Maintenance Significant Item	Repair Location	Ma/Yr	Mnhr Per Repair	On-Site Mnhrs	Off-site Mnhrs
1.	Drive Assembly, Azimuth	On-site	175	5.5	963	
2.	Jack Assembly, Tracking	On-site	162	3.0	486	
3.	Jack Assembly, Storage	On-site	8	3.0	24	
4.	Drive Motor, Azimuth	On-site	201	2.5	503	
5.	Drive Motor, Elevation	On-site	201	2.5	503	
6.	Drive Motor, Storage	On-site	10	2.5	25	
7.	Heliostat Control Electronics	Off-site	98	3.5		343
8.	Heliostat Array Controller	On-site	(Service Contract)			
9.	Power Transformer	Off-site	0.4	10.0		4
10.	Digital Camera	Off-site	0.2	3.0		1
					2,504	348

TABLE 5.4.3-1

SPARES REQUIREMENTS - LINE REPLACEABLE UNITS

	Maintenance Significant Item	Sys. Qty	Ma/Yr	Repair Loc	Pipe-line Qty	30-Day Cont.	Initial Spares	Discard Factor	Replace-ment Spares/Yr
1.	Drive Assembly, Azimuth	18,000	175	On-site	3	15	18	.05	9
2.	Jack Assembly, Tracking	18,000	162	On-site	3	14	17	.05	8
3.	Jack Assembly, Storage	18,000	8	On-site	1	1	2	.05	1
4.	Drive Motor, Azimuth	18,000	201	On-site	3	17	20	.05	10
5.	Drive Motor, Elevation	18,000	201	On-site	3	17	20	.05	10
6.	Drive Motor, Storage	18,000	10	On-site	1	1	2	.05	1
7.	Heliostat J-Box	18,000	69	In-place	0	0	0	0	0
8.	Heliostat Control Electronics X	18,000	98	Off-site	8	8	16	.05	5
9.	Heliostat Power/Data Cables	90,000	33	In-place	0	0	0	0	0
10.	Field Power/Data Cables	18,057	13	In-place	0	0	0	0	0
11.	Data Distribution Interface	57	1	Discard	0	1	2	1.0	1
12.	Power Transformer	57	0.4	Off-site	1	1	2	.25	0.1
13.	Power Distribution Panel	57	3	In-place	0	0	0	0	0
14.	Heliostat Array Controller	1	4	(Service Contract)					
15.	Pedestal	18,000	7	In-place	0	0	0	0	0
16.	Reflector Structure	18,000	7	In-place	0	0	0	0	0
17.	Reflector Panel	216,000	71	Discard	0	6	77	1.0	71
18.	Digital Camera	6	.2	Off-site	1	-	1	.05	-
19.	Camera Cooler/Heater	6	.02	Discard	1	-	1	1.0	.02

process and also accounts for a non-linear failure rate. The initial spares quantity for non-reparable LRU's (discard at failure) is set at the predicted number of failures per year plus the 30-day contingency quantity. The initial spares quantity is procured and stocked at the repair location at the start of first year of operation.

The discard factor represents the number of failures which result in discard of the LRU instead of repair, primarily due to the extensive damage. The product of the number of failures per year and the discard factor equals the number of replacement LRU's to be procured at the beginning of the second and subsequent years.

5.4.3.2 Repair Parts

Identification of line item repair parts and quantities cannot be made at this time with an acceptable degree of confidence. Repair parts costs are projected as 10 percent of the repairable item unit cost per repair.

5.4.3.3 Inventory Control and Management

Spare LRU's to support on-line maintenance and repair parts for on-site, off-line maintenance will require indoor storage. Temperature or environmental conditioning is not a critical factor. Approximately 800 square feet of floor space should be adequate inventory control, warehousing, receipt and issuing of spares should be integrated with similar on-site functions and is the equivalent of approximately a one-man level of effort.

5.4.4 Scheduled Maintenance

Scheduled maintenance requirements are summarized in Table 5.4.4-1. Particular attention has been given to reducing scheduled maintenance to that specifically required. The lubrication requirements of the Harmonic drive is cited as an example. The traditional method would be to check the oil level periodically which requires approximately two minutes, including access time. Physically checking oil level is eliminated in favor of visual inspection for oil leaks which is included in the general area inspection. Assuming a conservative one minute differential, this approach saves 300 manhours per year for an 18,000 heliostat field.

Table 5.4.4-1

SCHEDULED MAINTENANCE

REQUIREMENT	TASK	FREQUENCY	MANHOURS PER TASK	MANHOURS PER YEAR
SUBSYSTEM EQUIPMENT				
Heliostat Field	Area/Corrosion Control Inspection	Annual	1200	1200
Heliostat Reflectors	Clean	30 Days	338	4056
Heliostat Array Controller	Inspect & Service	(SERVICE CONTRACT)		
SPECIAL SUPPORT EQUIPMENT				
Handling Sling	Load Certification	Annual	2	2
Mobile Test Van				
Printer, Tape Reader, CRT/ Keyboard, Recorder, etc.	Inspect & Service	Weekly	2	104
Measurement Equipment	Calibrate	6 Months	6	12
				5,374

The general area inspection includes visual checks for corrosion, weathering, structural integrity, glass breakage/cracks, condition of seals and/or bonding, oil leaks, animal and bird intrusion/damage, and vegetation growth. Although indicated as annual, the general area inspection is not intended to be a "once a year" inspection of the total field. The objective being to "sample" the field on a regular basis to discover incident conditions which, if not corrected, can become major problems. Monthly inspection of approximately one-twelfth of the field is recommended--preferably in circumferential sections.

Maintenance Support Equipment

The following support equipment is required for corrective and scheduled maintenance tasks:

• Mobile Crane	Heliostat hoisting
• Forklift	Miscellaneous heavy equipment handling
• Hoisting Slings - General Purpose	Heliostats and miscellaneous equipment hoisting
• Pickup Truck	General purpose
• Reflector Washing Equipment	Heliostat reflector cleaning
• Collector Field Test Station	Subsystem and component level fault isolation and test

5.5 OPERATIONS AND MAINTENANCE CHANGE SUMMARY

During the course of the study, design changes in both hardware and maintenance processes contributed to cost reductions for collector subsystem maintenance. A summary of the significant changes is provided in the following subsections. These changes are tabulated in Table 5.5-1.

5.5.1

The results of the optimum repair level analyses show that most reparable components can be most economically repaired at site-located repair facilities. Two factors were crucial in these repair-policy decisions: 1) transportation costs, and 2) minimum requirements for special support equipment at the repair location. The economic benefits derived from this change in the maintenance process will be evident when a life cycle cost analysis is completed.

5.5.2

While no verified reflector cleaning process has yet been developed, several methods have been developed, each using different equipment. The baseline method, developed by a supplier, could use any process eventually developed. However, the method of stopping at each heliostat for from seven to eight minutes is far too costly (see Table 5.3.2-1, Spray Soak Cal Chem). Consequently, the method selected is the one using two spray trucks working in tandem. The first truck applies a cleaning solution on the surface of the reflector; the second truck follows at a distance commensurate with the soak time required of the cleaning solution and rinses the solution and loosens soil from the reflector surface using deionized water. This method shows a cost reduction over the baseline method of approximately five to one.

5.5.3

Hardware design changes resulting in reduced complexity and lower parts count have increased predicted reliability. Of course, the higher reliability figures have reduced the number of annual maintenance actions projected. Also, the lowered complexity of the design contributed to shorter repair task time.

Table 5.5-1

OPERATIONS AND MAINTENANCE CHANGE SUMMARY

REQUIREMENT	WAS	IS	EFFECT
Off-Line Repair	Optimized for Pilot Plant and Applied to Commercial Plant - (All Off-Site)	Optimized for Commercial Plant	Majority of Items Repaired On-Site - Reduced Maintenance Support Costs
Reflector Cleaning	Single Tanker Truck Carrying Both Wash & Rinse Solutions. Stop at Each Heliostat to Wash, Then Rinse.	Separate Trucks for Wash & Rinse Solutions. "Drive Through Technique" One Minute Spacing Between Wash & Rinse Trucks	Reduce Cleaning Time by a Factor of 7. Reduce Overall Cleaning Cost by Approximately 5.
Unscheduled Maintenance	Initial Baseline Hardware - Remove & Replace or Repair In-Place, Whichever Most Cost Effective.	Low Cost Configuration - Remove & Replace or Repair In-Place Whichever Most Cost Effective	Lower Parts Count & Reduced Complexity Equals Higher Reliability & Fewer Maintenance Actions & Less Time per Task
Scheduled Maintenance	Initial Baseline Hardware	Low Cost Configuration - • Eliminate Scheduled Lubrication in Favor of Inspect for Oil Leaks • Recalibration Check Performed by Software	• Reduce Lubrication Manhours by Approximately 50 Percent • Fast, Accurate. Less Costly.

5.5.4

Scheduling maintenance tasks impacts costs severely since any scheduled task must be performed 18,000 times during each periodic requirement. Two design improvements during the study have contributed to lowered periodic maintenance requirements.

The lubricant seals in the drive mechanisms now have a predicted life of at least 30 years. Use of these seals coupled with the low working stress imposed on the drives, permits deletion of all periodic lubrication tasks. The possible need to lubricate drive units as corrective maintenance action remains. Such action would come as the result of a seal failure and the fault would be indicated by the presence of oil or grease stains external to the drive units.

The second cost reduction is in the periodic recalibration of the heliostats. This requirement cannot be eliminated, but improvements in the method of accomplishing the recalibration reduces the task time and the manhours required. This cost reduction comes from the application of automated checks of the heliostats and performing necessary recalibration through software changes rather than mechanical adjustments.

Section 6

SPECIFICATION VERIFICATION AND OPTIMIZATION

This section contains a review of the requirements of DOE Specification 001 and other requirements felt to be important to MDAC. The evidence of compliance of the preliminary design is given, together with the sources of data. Areas requiring additional test verification are indicated, together with the development/implementation phase or stage at which MDAC would recommend such verifications.

6.1 OPTIMIZATION OF REQUIREMENTS

Several heliostat configuration parameters can affect the field layout. Among these are the clearout circle (the zone swept out by the heliostat as it rotates about its azimuth axis), the mirror reflectivity, the mirror area, and the ratio of mirror area to clearout circle area.

MDAC developed a simplified computer program to estimate the aggregate effect of these parameters on the field layout. Results from this computer program were used to help select the heliostat configuration. The program and results are described in Paragraph 6.1.1.

The total effect of tracking and beam quality errors leads to an interception factor at the receiver which depends on these errors, the heliostat location, and the time and day. The errors are functions of wind speed and direction, heliostat orientation, and ambient temperature.

MDAC has also performed some additional requirements optimization of effects of the above variables on beam errors and received power. Results are described in Paragraph 6.1.2.

6.1.1 Configuration Analyses

The collector field is laid out in a series of concentric circles, as indicated in Figure 6.1.1-1. The heliostats are positioned along rays eminating from the tower. Heliostats in each row are aligned along the gap between the heliostats in the next row inward. The field configuration is called a radial stagger.

Since the number of heliostats per circle is a constant, the azimuthal spacing between heliostats increases with increasing radius from the tower. In order to retain reasonable packing densities of heliostats, it is necessary to periodically restart the azimuth spacing as illustrated in Figure 6.1.1-2. The zone in which the azimuth spacing is restarted is called a slip plane. The prototype heliostat field layout is assumed to have a circumferential road in the slip plane.

Changing the heliostat configuration has an effect on the field layout in some portions of the field. The circle centered on the azimuth axis and containing the superimposed plan views of the heliostat when face up and face down (Figure 6.1.1-2) is called the clearout circle. The clearout circles of adjacent heliostats should retain an average 0.3 m (1 ft) clearance to assure that heliostats do not physically contact. The clearout circle and the mirror area contained within a clearout circle are both dependent on heliostat configuration.

The computer program STATFLD was written in order to provide heliostat field layouts and allow comparison of the effect on field sizing of various input parameters. The field layouts are based on a radial stagger array with circumferential roads placed where the number of rays is to be expanded. The circumferential roads eliminate the need for deleting and shifting heliostats as was required previously. A main access road to the south is also used.

The tower height may be fixed or may be determined by the program to give an elevation angle at the outermost row of 11°, resulting in a heliostat field envelope geometrically similar to that of the 100 MW field designed by the University of Houston. Average atmospheric attenuation and shadowing and blocking can also be considered.

Input parameters are:

- Mirror area per heliostat
- Total effective mirror area
- Mirror width
- Clearout circle
- Circumferential road width
- South road width
- Maximum elevation angle
- Tower height (optional)
- Maximum and minimum azimuth spacing

The output values consist of:

- Total mirror area
- Total number of heliostats
- Tower height,

and for each row:

- Radius
- Elevation angle
- Spacing to first and second row inward
- Azimuthal spacing
- Number of heliostats
- Diagonal distance to nearest heliostat
- Total arc (degrees).

The operation of STATFLD is described below.

1. The radius of the first circle is found based on tower height and required elevation angle.

2. The azimuthal spacing is set to the minimum.

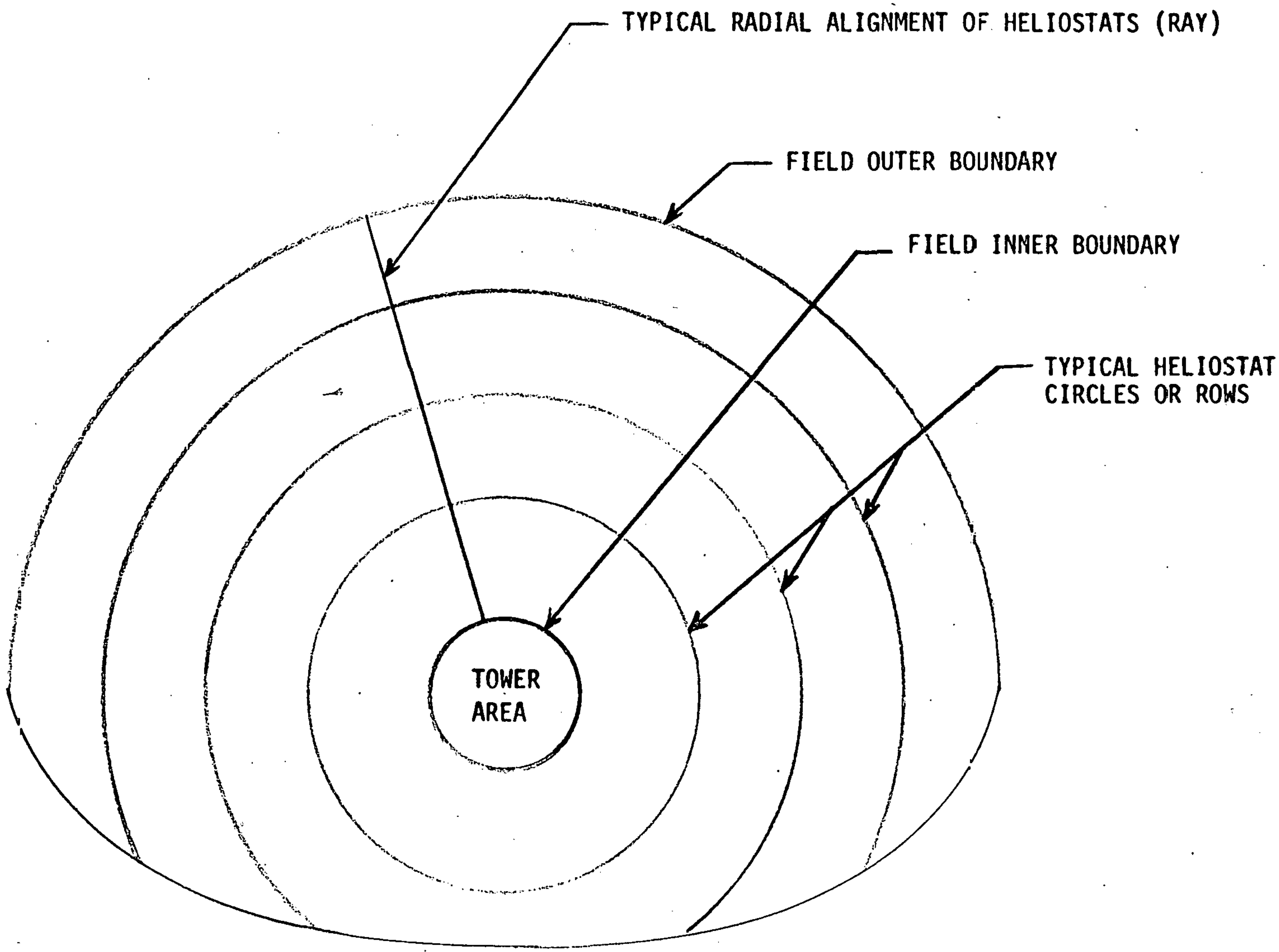


Figure 6.1.1-1 Commercial Collector Field Layout

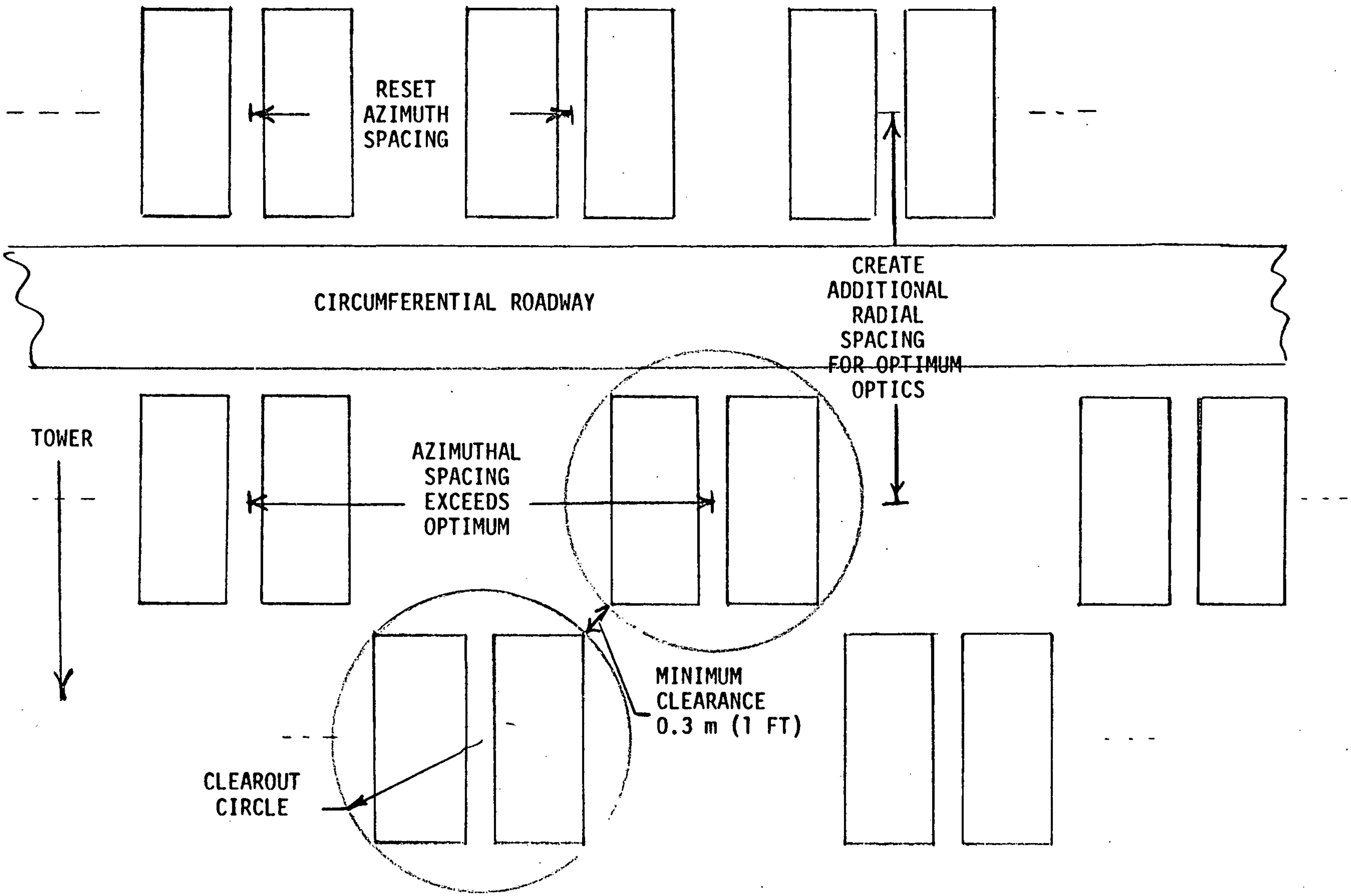


Figure 6.1.1-2 Resetting Azimuth Spacing

3. The radius of subsequent rows is determined by using an algorithm for optimal spacing, based on University of Houston optimization results, and determining the radius necessary for physical clearance of heliostats. The larger of the two radii is selected.

4. The azimuthal spacing of each subsequent row is fixed since the angular spacing of rays does not change until a slip plane or circumferential road is inserted. When the azimuthal spacing exceeds the maximum value specified, that row is replaced with a circumferential road.

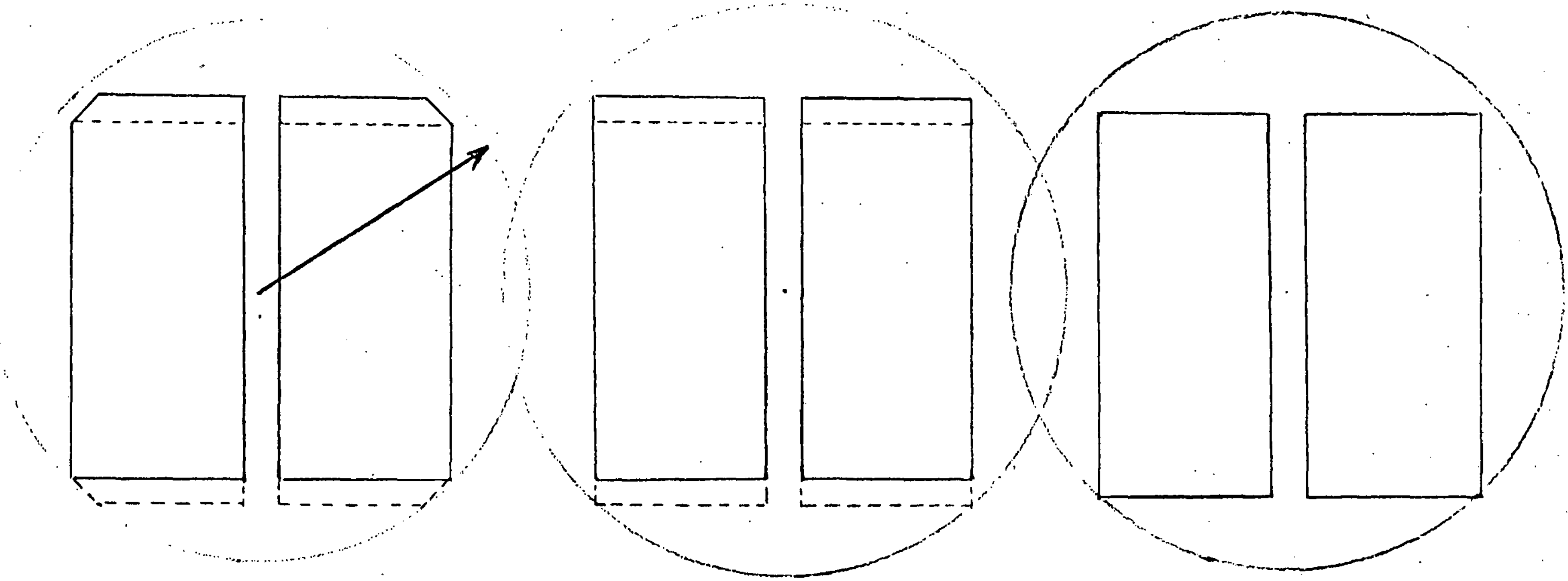
5. The next row radius is computed and azimuthal spacing is set to the minimum.

6. Steps 3, 4, and 5 are repeated until the required mirror area is matched to the input value.

7. If requested, the tower height is modified based on the elevation angle of the last row of heliostats and the entire field is once again computed. This process is repeated until the elevation angle of the last row is approximately 11 degrees.

STATFLD was used to determine the impact of using square corners for the mirror modules on the field layout. Figure 6.1.1-3 illustrates the three cases considered. Because the reflective unit centroid cannot be located directly above the azimuth axis in both the face-up and face-down positions, the circle swept out by the heliostats is affected by clipping two of the corners or by shifting the mirror centroid to be over the elevation axis.

Table 6.1-1 shows results from STATFLD for these three cases. While the clipped corner configuration does have the minimum clearout circle, it does so at a loss of 0.3 m^2 reflector area. With the reflector centroid over the elevation axis, the increased reflector area (hence fewer heliostats) almost exactly compensates the field impact of the greater clearout circle. The clipping is an extra cost operation which wastes material and reduces the reflector area. Hence, the analysis leads to the conclusion that the corners should not be clipped.



a) Clipped Corners, Clearout Circle Radius, R = 5.23 m (206")

b) Square Corners, Centroid over Azimuth Axis, Clearout Circle Radius, R = 5.61 m (221")

c) Square Corners, Centroid over Elevation Axis, Clearout Circle Radius, R = 5.44 m (214")

NOTE: Dashed line indicates inverted position

Figure 6.1-1 Impact of Configuration on Clearout Circle

Table 6.1-1

EFFECT OF CONFIGURATION ON FIELD LAYOUT

	Configuration	Area (m^2)	No. of Heliostats	Field Radius (m)
A)	Clipped Corners	48	17,763	1,035
B)	Centroid Over Elevation Axis	48.31	17,649	1,032
C)	Centroid Over Azimuth Axis	48.31	17,649	1,059

With the reflector centroid over the azimuth axis, the field size must grow by about 25 m. This small difference should be considered only if there is no net benefit in loads or structural design which result from the location of mirror centroid. Since there are loads and structures benefits of placing the centroid over the azimuth axis, Configuration C was chosen.

STATFLD also has the capability of weighting the mirror area by the beam attenuation factor which is appropriate to the slant range. This factor becomes potentially important in considering the effects of filling or partially filling in the slot and effects of changes in mirror reflectivity.

STATFLD was run for configurations with a full slot, a half slot, and no slot (non-inverting). Table 6.1-2 shows the results. The tower height was allowed to vary, maintaining an elevation angle from the outermost heliostat of 11 degrees. In addition, the effect of a one percent improvement in reflectivity is estimated based on the above data. The "tower cost effect" column is the reduction in tower cost allocated to the heliostats and normalized to a cost of $\$65/m^2$.

The amplification factor defined in Table 6.1-2 is a factor which relates the direct improvement of a one percent increase in reflectivity (or equivalent area gain within the clearout circle) to the total improvement including reduction of beam attenuation and reduction of tower cost. The amplification factor is calculated to be about 1.23. Hence, a one percent improvement in reflectivity of a heliostat at $\$65/m^2$ has a direct equivalent cost reduction of $\$0.65/m^2$ and a total effect of $0.65 \times 1.23 = \$0.80/m^2$.

Table 6.1-2

AMPLIFICATION FACTOR

Configuration	Area (m^2)	No. of Heliostats	Field Area Ratio	Tower Height (m)	Tower Cost Effect (Fraction of Heliostat Cost)
Full Slot	48.31	17,725	1.0	259	1.0
Half Slot	50.91	16,775	.9973	253	.9911
No Slot	53.51	15,950	.9967	247	.9821
Equivalent Effect of 1% Reflectivity Change	48.79	17,545	.9997	∿ 258	.9983

$$\text{Amplification Factor} = \frac{\text{Effective Cost Reduction}}{\text{Direct Cost Reduction}}$$

$$= \frac{\left(\frac{\text{Area Ratio}}{\text{Field Area Ratio x Tower Cost Effect}}\right) - 1}{\text{Area Ratio} - 1}$$

$$= 1.23$$

Additional calculations were made to determine the effect of different maximum azimuthal spacings (Step 4, above). The differences noted which result from maximum spacing ratios (spacing/heliostat width) from 2.2 to 2.58 appeared to be well under computational uncertainty.

6.1.2. Requirements Optimization Studies

Requirements optimization was undertaken in two areas: the allowable backlash in the linear actuators and the degree of curvature to be used in mirror modules.

The effect of actuator backlash was determined using a Monte Carlo simulation of single heliostat dynamics, including drive backlash, hysteresis, stiffness, etc.

The time of day, wind direction and gust velocity are three examples of the variables that were randomly selected. The sensitivity of beam error to actuator for a backlash single heliostat is shown in Figure 6.1.2-1. The CONCEN program was used to determine the amount of spillage that would occur with this beam error. The resulting spillage is shown in Figure 6.1.2-1. Increasing the backlash to that of a ball screw would increase the power spillage 0.3%, which is equivalent to approximately $23 per heliostat.

Curvature in the mirror modules was used to minimize the beam spread at the receiver due to thermal expansion effects. The objective of this study was to define the panel curvature at the bonding temperature of 21°C (70°F) which keeps the image at the receiver at its smallest over the total operating temperature range (0 to 40°C or 32 to 104°F). Figure 6.1.2-2 illustrates the approach.

If a small curvature is established in the mirror at the bonding temperature, the mirror will become more concave as the temperature rises. Perfect focus will be achieved at a temperature of 25 to 30°C or 77 to 86°F. Above this temperature range, the mirror will be over focused. The image height, assuming perfect optics, at 40°C (104°F), is set equal to the under focused image height at 0°C (32°F), and the problem solved to provide the minimum image height and the curvature at the bonding temperature.

The required curvature was found to be about 2,000 m (6,800 ft). The maximum image height at the target was 13 m (40 ft). The height at the minimum temperature would be about 18 m (59 ft) if the panel were bonded flat at 21°C (70°F). Hence, even the very small curvature recommended is beneficial.

The above analysis also indicates a potential benefit to be derived from using a structural support which matches the thermal expansion coefficient of the float glass more closely than the steel stringers presently used. Advanced composites appear attractive in this regard and will be considered.

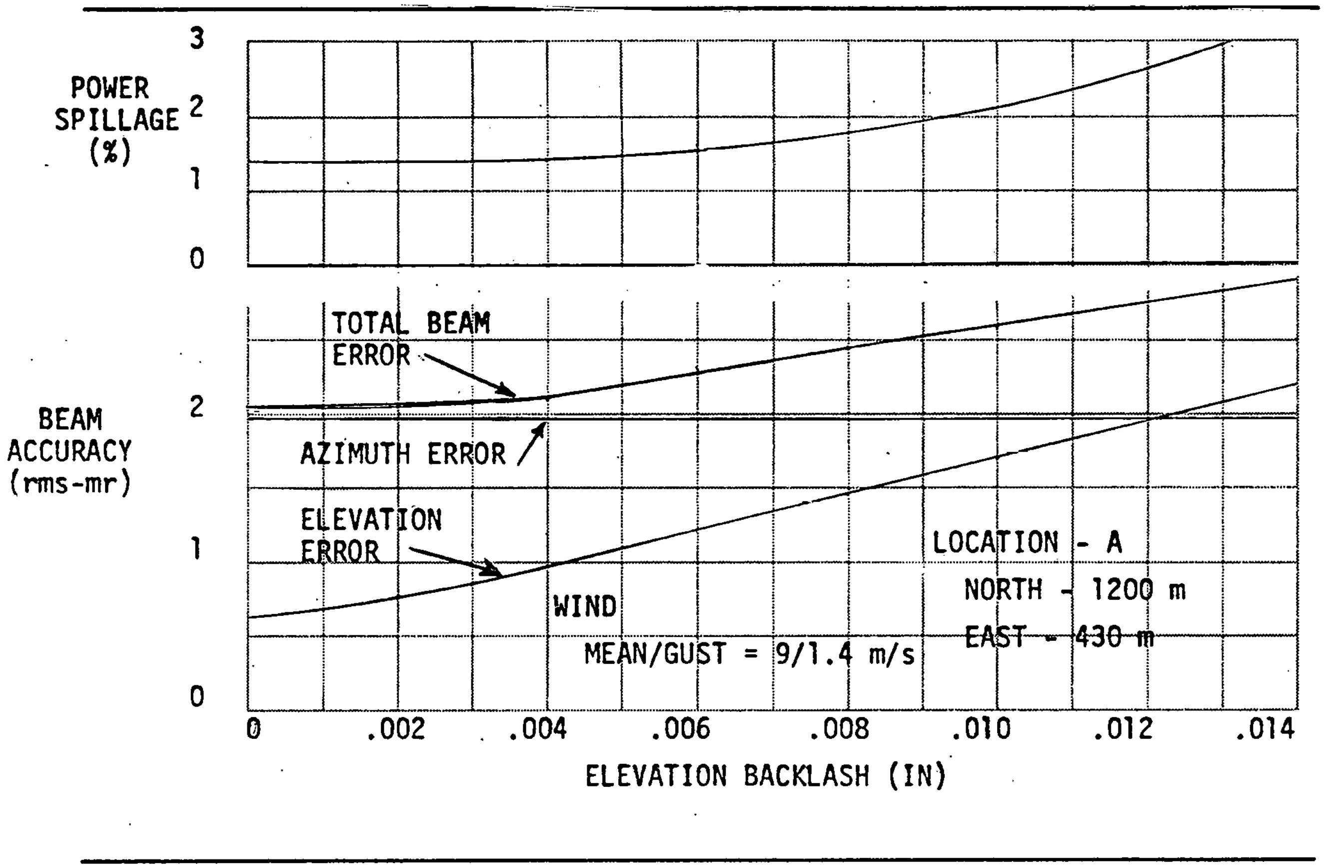


Figure 6.1.2-1 Effective Backlash on Beam Error and Power Loss

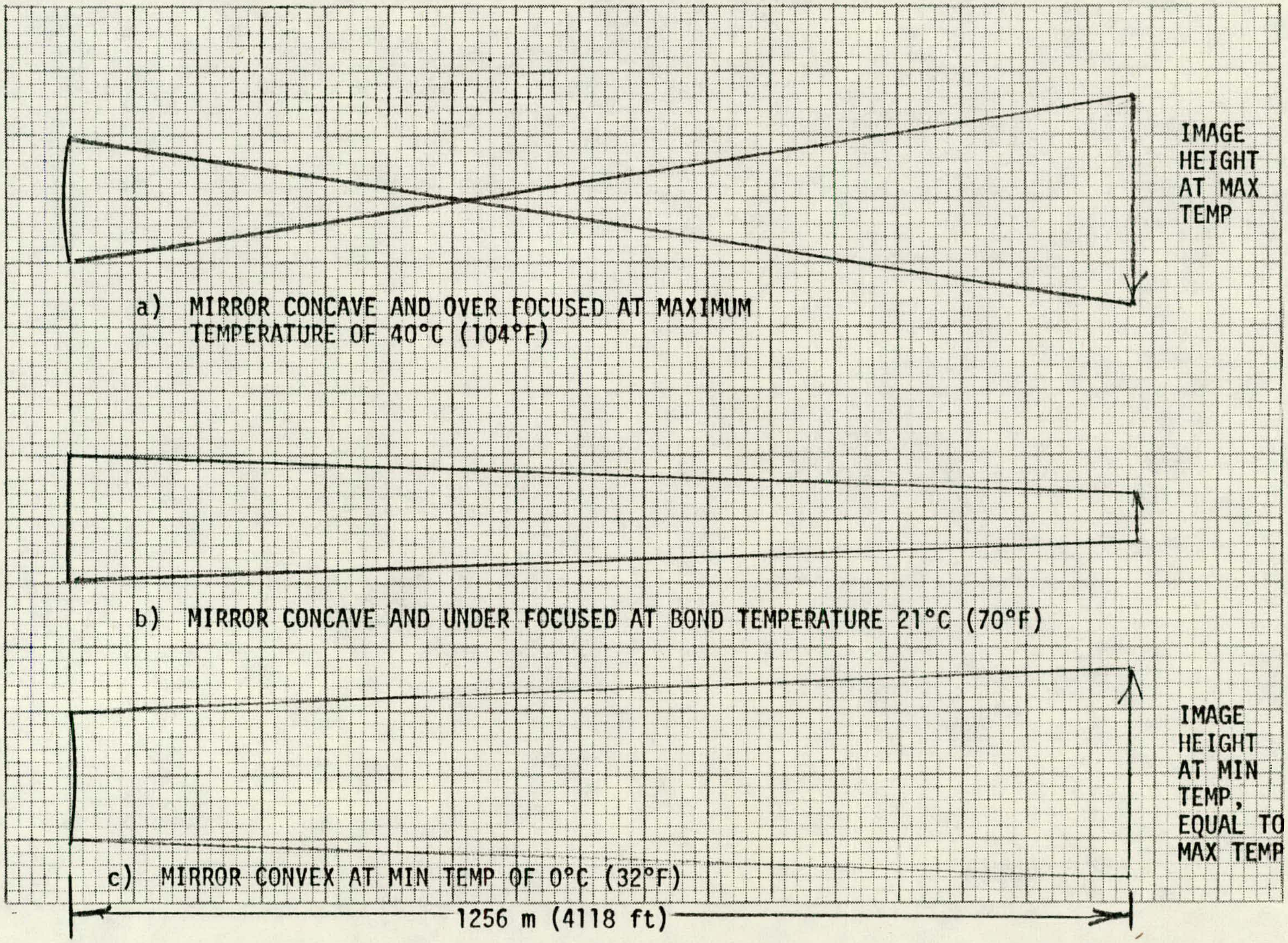


Figure 6.1.2-2 Mirror Curvature Requirement

6.1.3 Availability

The availability of a single heliostat was calculated by utilizing the MTBF and MTTR results from Table 6.1.3-1. The failures per day rate was calculated for each heliostat component by dividing the operational hours per day by the MTBF. A value of 10 hours per day was used for the dynamic components (motors, actuators, electronics), 24 hours per day for static components (pedestal, reflector), and 0.5 hours per day for stowage elements. The failures per day were then multiplied by the MTTR to obtain the average downtime hours per day. This value is then used to calculate the individual component availability and the heliostat availability.

The downtime of the heliostat due to field component failures is calculated in a similar manner. The results show that the heliostat will be "down" about 0.000368 hours per day on the average due to heliostat component failures, and 0.000325 hours per day on the average due to field component failures, or a total of 0.000693 hours per day on the average. This converts to an availability of 0.999931 for a 10 hour day.

Table 6.1.3-1

COLLECTOR AVAILABILITY

	MTBF (HRS)	F/DAY (10^{-6})	MTTR (HRS)	H/DAY (10^{-6})
Drive Assembly, Az	340,136	29.4	4.0	117.6
Jack Assembly, Track	366,300	27.3	2.2	60.6
Jack Assembly, Stowage	366,300	1.37	2.2	3.0
Drive Motor (2)	295,858	67.6	1.8	121.7
Stowage Motor	295,858	1.69	1.9	3.2
Heliostat Junction Box	862,069	11.6	1.6	18.6
Heliostat Control Electronics	606,060	16.5	1.3	21.5
Heliostat Cables (5)	9,090,909	5.5	1.8	9.9
Pedestal	9,090,909	2.64	1.0	2.6
Reflector Structure	8,333,333	2.88	1.5	4.3
Reflector Panel	10,000,000	2.4	2.0	4.8
Data Distribution Box	206,186	48.5	1.6	77.6
Power Transformer	(Redundant transformers-failure does not cause outage)			
Power Distribution Box	66,667	150	1.6	240
Field Cables	4,545,454	2.2	3.5	7.7

10-Hour Operating Day; 24-Hour Actual Day; .5-Hour Stowage Day

6.2 SYSTEM PERFORMANCE

The system performance is a measure of the amount of redirected energy from the heliostats that is incident on the receiver. The subsystem requirements are specified by categorizing the performance errors into two groups. Those that cause an error in the direction of the reflected beam are called beam pointing errors, and those that cause a spreading of the beam are called beam quality errors. These performance errors are discussed below.

Beam Pointing - Beam pointing error includes such things as atmospheric refraction, control dynamics(including effect of wind on drives), heliostat alignment, etc. Heliostat alignment includes azimuth axis tilt after installation, elevation axis non-orthogonality, position error after installation, latitude and longitude errors and time error. A heliostat alignment scheme is used to reduce these errors. A description of the error source, subsystem requirement and analysis method are indicated in Table 6.2-1. Structural support errors include bending of the pedestal, drive systems, mirror module support structure, and foundation as a consequence of gravity and winds acting upon the heliostat. The center-of-gravity offset and the wind blowing across the reflective surface result in a moment which deflects the support structure. Bending of the support structure produces a beam pointing error.

Beam Quality - The theoretical beam shape from a single heliostat is determined by the slant range, the angle of reflection, the number, size,shape, cant angle and curvature of the mirror segments and the angular location of the sun. Any deviation of the mirror surface from the nominal flat or cylindrical curvature will cause a difference in beam size from the theoretical size. Surface slope errors arise from glass surface waviness or deformation due to mounting errors, temperature effects, wind loading, or gravity loading. The error sources, description, estimation method and subsystem requirements are shown in Table 6.2-2.

Heliostat Performance - Because of geometrical conditions, the performance of a heliostat is dependent upon the location of the heliostat relative to the receiver, environmental conditions, and time of day. MDAC has investigated the performance for the different reference locations shown in Figure 6.2-1 and different environmental conditions. The beam pointing

Table [illegible].2-1

BEAM POINTING ERRORS - CHARACTERISTICS (Page 1 of 2)

Error Source	Description	Estimation Method	Subsystem Requirements
Tower/Receiver	Movement of tower caused by temperature and winds, foundation settling.	Analysis by Stearns-Roger.	Horizontal movement of receiver will be less than 3 inches (σ).
Control Dynamics			
A. Motor Granularity	A. Varying loads will cause different number of motor turns per motor pulse.	A. SRE and open loop test data incorporated in simulation.	A. Motor turn control will be less than 2 turns.
B. Sensor Granularity	B. Only single motor resolution.	B. Model sensor in simulation.	B. Sensor will count each complete motor turn.
C. Drive System With & Without Winds	C. Drive backlash, stiffness, and hysteresis add variation in movement. Winds add to drive variation.	C. SRE and open loop test data incorporated in simulation.	C. Harmonic drive initial backlash will be less than 0.5 mrad peak-to-peak. Stiffness will be greater than 10×10^6 in-lb/rad and less than 12.5×10^6 in-lb/rad. Single input turn will produce less than 0.2 mrad of azimuth gimbal movement. Jack drive initial backlash from all sources will be less than 0.002 in. (1σ). Total stiffness will be greater than 180,000 lb/in and less than 260,000 lb/in. Single input turn will produce less than 0.3 mrad elevation gimbal movement. Temperature difference on drive loop will not produce more than 0.2 mrad max angle change.
Heliostat Alignment	Errors in time, latitude, longitude, azimuth and elevation reference, position pedestal tilt and non-orthogonality produce a beam error.	Previous alignment tests.	Alignment scheme will reduce all these errors to less than 0.8 mrad (σ).

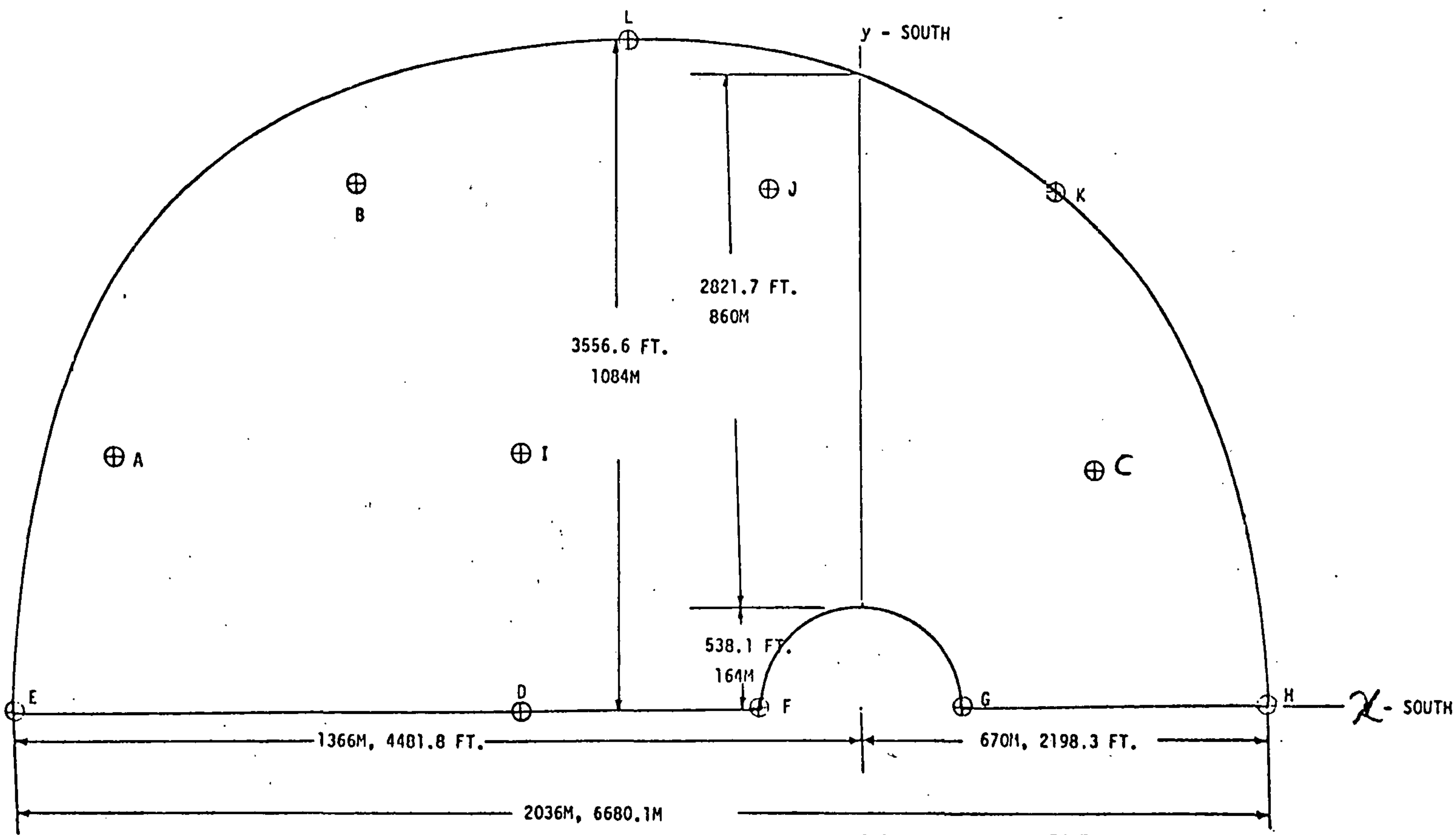
Table 6.2-1

BEAM POINTING ERRORS - CHARACTERISTICS (Page 2 of 2)

Error Source	Description	Estimation Method	Subsystem Requirements
Refraction	Atmospheric refraction of beam from sun to heliostat and heliostat to receiver.	LOWTRAN atmospheric refraction computer code.	A software model will correct sun to heliostat refraction to less than 0.4 mrad (1σ).
Foundation	Wind and gravity loads produce an elastic/plastic deformation of the foundation. Plastic deformation is also a function of soil settlement characteristics.	Structural analysis	A maximum allowable foundation settlement or plastic displacement of 0.05 mrad (1σ) and an elastic displacement of 0.5 mrad (1σ) must be included in allowable structural deflection limit.
Support Structure/ Main Beam	Wind and gravity loads produce elastic deformation.	NASTRAN analysis and wind tunnel data.	An equivalent EI of 5.0×10^9 and 1.8×10^9 lb-in^2 for the main beam and cross beams, respectively.
Pedestal	Wind and gravity loads produce elastic deformation.	NASTRAN analysis and wind tunnel data.	An equivalent EI of 9.3×10^9 lb-in^2.

Table 6.2-2
BEAM QUALITY - CHARACTERISTICS

Error Source	Description	Estimation Method	Subsystem Requirements
Mirror Module Deformation From Temperature	Materials have different thermal coefficients of expansion.	NASTRAN analysis	A change from reference temperature of ΔT shall not produce an error slope greater than $1.1x10^{-6}\ \Delta T\chi$, where χ is the distance from center of panel.
Mirror Module Deformation From Gravity	Mirror module and support structure deflect under gravity.	NASTRAN analysis	Slope from gravity on surface shall not produce errors more than A sin ψ where A is TBD and ψ is elevation angle.
Mirror Module Deformation From Wind Loads	Mirror module and support structure deflect under wind loads.	NASTRAN analysis	Winds on surface shall not produce error slopes greater than TBD envelope for winds below 12 m/s (27 mph) and any angle of attack.
Surface Waviness	Mirror surface has characteristic waviness.	Previous analysis and SRE test data	After mounting glass, error slope at evenly measured points less than 1 inch apart over surface of panel shall be less than 0.55 mrad (1σ).
Specular Dispersion	Mirror surface has some specular dispersion.	SRE measurements	Before glass is mounted, 95% of reflected beam shall be within 4 mrad of centerline.
Panel Alignment	Mirror normal of panel is not parallel to heliostat normal because of manufacturing tolerance.	Analysis of construction tolerance	Panel normal shall not deviate more than 0.5 mrad (1σ) from heliostat normal as a result of panel construction and mounting.



LOCATION	METERS x	METERS y	FEET x	FEET y
A	-1200	430	-3937.2	1410.8
B	-800	860	-2624.8	2624.8
C	400	430	1312.4	1410.8
D	-550	0	-1804.6	0
E	-1366	0	-4481.8	0
F	-164	0	-538.1	0
G	164	0	538.1	0

LOCATION	METERS x	METERS y	FEET x	FEET y
H	670	0	2198.3	0
I	-550	430	-1804.6	1410.8
J	-164	800	-538.1	2624.8
K	300	800	984.3	2624.8
L	-400	1084	-1312.4	3556.6

Figure 6.2-1 Heliostat Reference Locations

accuracy for a representative set of these locations is shown in Table 6.2-3. A Monte-Carlo simulation of a single heliostat dynamics, including drive backlash, hysteresis, stiffness, etc., was used to transform the error sources into reflected beam errors. The time of day, wind direction and gust velocity are examples of variables that were randomly selected. Beam error is expressed in a coordinate system centered at the heliostat, with one axis horizontal and one axis through the receiver.

A representative beam shape at the receiver is shown in Figure 6.2-2 for a heliostat at location D. The density pattern was calculated using the MDAC simulation called CONCEN. The mirror segments are canted and curved along the long axis for focusing at the maximum range of the array. The numbers on the figures represent the relative beam intensity, with 1 being 10% of the maximum. Since no beam errors were included in the calculation, the image shape shown in Figure 6.2-2 represents the theoretical beam shape. The effects of the beam quality errors listed in Table 6.2-2 upon the image size are illustrated in Figure 6.2-3. The amount of power outside the theoretical beam size plus 1.4 mr is less than 2.5%.

Table 6.2-3

ESTIMATE OF BEAM POINT ACCURACY

Error Source	Beam Pointing Accuracy (mrad-rms)					Comment
	Location A Az/El	Location B Az/El	Location C Az/El	Location F Az/El	Location H Az/El	
1. Tower/Receiver	0.90/0.20	0.90/0.20	0.90/0.20	0.90/0.20	0.90/0.20	Tower movement from wind.
2. Motor Turn Granularity	0.15/0.12	0.18/0.17	0.21/0.28	0.26/0.26	0.28/0.28	Command ± 1 turn (σ).
3. Sensor Granularity	0.12/0.12	0.04/0.05	0.06/0.08	0.07/0.07	0.08/0.08	Count each motor turn.
4. Drive System						Drive Characteristics:
A. No Winds	0.45/0.21	0.43/0.21	0.15/0.24	0.39/0.13	0.11/0.15	Azimuth backlash = 1.1×10^7 N-m/rad Elevation backlash ≈ 0.5 mrad
B. Mean (Gust) = 9 m/s (1.4 m/s)	1.89/0.73	2.26/0.60	0.62/0.10	1.28/0.45	1.06/1.12	Elevation Stiffness = 24,000 N-m
5. Alignment	0.40/0.55	0.50/0.35	0.75/0.40	0.75/0.45	0.80/0.45	Error after alignment correction, initial errors of tilt = 2 degrees (σ), non-orthogonality = 3 mrad, time = 2 sec (σ), latitude = 0.05 degree (σ), position = 3 inches (σ)
6. Refraction	0.00/0.34	0.00/0.34	0.00/0.34	0.00/0.34	0.00/0.34	Refraction error left after algorithm correction, caused by temperature, pressure, and atmospheric content variation.
7. Foundation	0.31/0.32	0.35/0.36	0.57/0.70	0.64/0.62	0.69/0.68	Foundation settlement = 0.05 mrad (σ) Elastic displacement = 0.5 mrad (σ).
8. Gravitational	0.30/0.40	0.15/0.52	0.10/0.90	0.25/0.87	0.05/0.97	Residual algorithm correction of deadweight bending of drive and pedestal.
9. Pedestal/Support Structure Max Wind = 12 m/s (27 mph)	0.06/1.09	0.01/0.18	0.02/0.07	0.09/0.79	0.08/0.11	Moment created by wind causes pedestal/foundation bending.
TOTAL RSS VALUE	2.22/1.58	2.55/1.06	1.46/1.33	1.91/1.55	1.77/1.75	

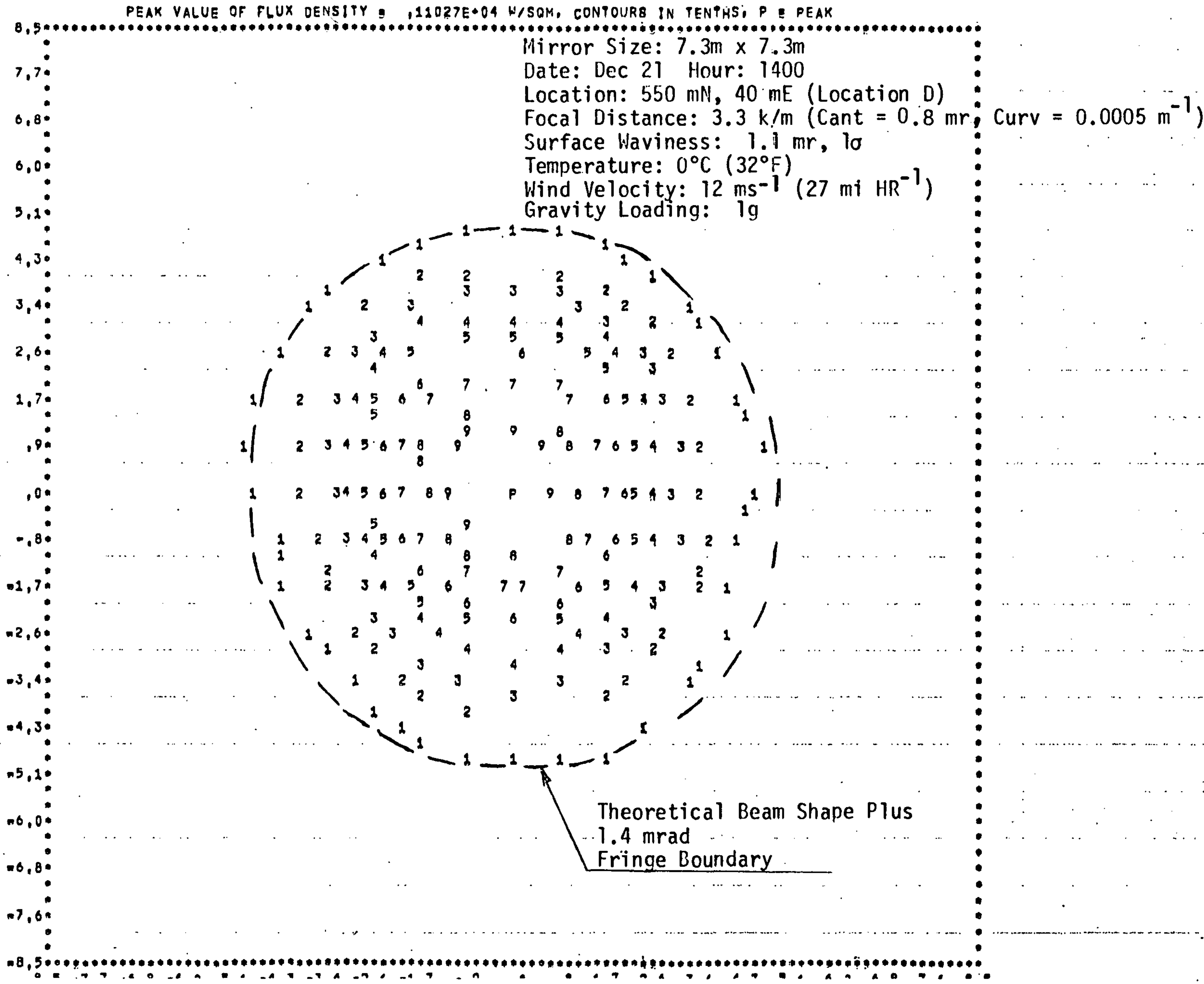


Figure 6.2-3 Beam Shape with Errors

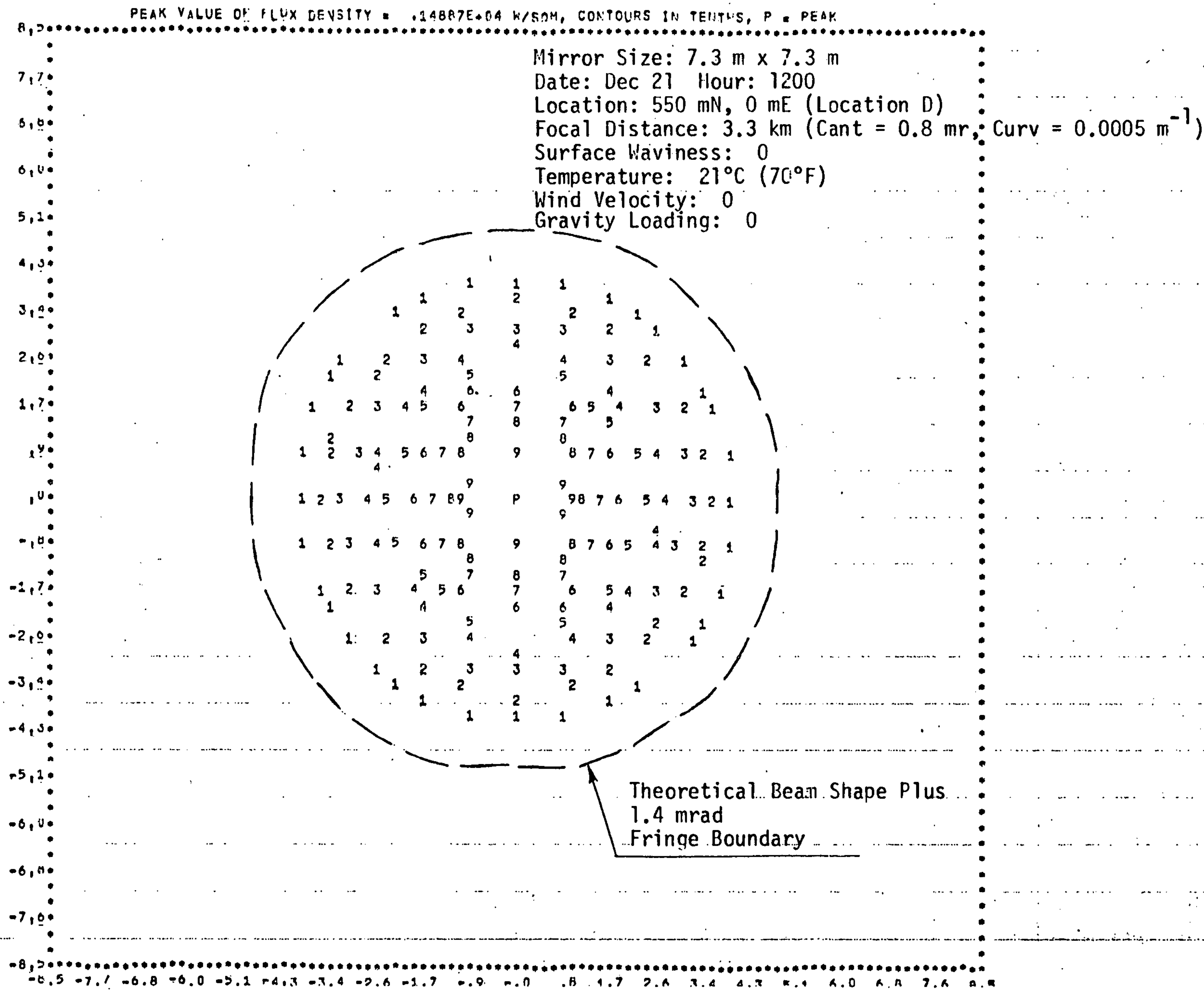


Figure 6.2-2 Theoretical Beam Shape - No Errors

6.3 SPECIFICATION VERIFICATION SUMMARY

The use of a baseline perturbation technique on a mature initial baseline design concept has assured that the final baseline design meets the performance, design, and environmental specifications of Specification 001. The design treated in Section 2.0 satisfies all of these specifications. Table 6.3-1 summarizes the performance and design requirements and cross references the sections which treat each specification or its verification.

Table 6.3-1

VERIFICATION OF SPECIFICATION 001

PARAGRAPH NUMBER	REQUIREMENT	VERIFICATION
	PERFORMANCE	
3.1.1.1	Heliostat Availability Greater than 0.97	Analysis, Greater than 0.099. See Section 6.1.3.
3.1.1.2	Interchangeability	Design for All Locations is the Same, No Field Adjustment Required
3.1.1.3	Protect Against Electrical Transients	Transient Suppressors Used, Optical Data Transmission and Switching Used
	ENVIRONMENTAL	
3.1.2.1	Wind	
	• Operational Limit TBD	Initiate Stowage at 16.1 m/s (36 mph) (No Change from Reference 1)
	• Survival Wind, 40 m/s (90 mph), Angle of Attach = ± 10°	Analysis, Section 2.4
	• Dust Devils, 17 m/s (40 mph)	Analysis, Section 2.4
3.1.2.2	Temperature	
	• Survive -30°C (-22°F) to +50°C (+120°F)	Analysis, Section 2.4
	• Performance Optimized from 0°C (32°F) to 40°C (+104°F)	Analysis, Section 6.1.2
3.1.2.3	Earthquake, Seismic Zone #3 (UBC)	Analysis, Section 2.4

Table 6.3-1

VERIFICATION OF SPECIFICATION 001 (Page 2 of 5)

PARAGRAPH NUMBER	REQUIREMENT	VERIFICATION
3.1.2.4	Snow, 250 Pa (5 lbs/ft^2)	Much Less than Survival Wind
3.1.2.5	Rain	Test, Reference 1
3.1.2.6	Ice, 50 mm (2 inches)	Test, Reference 1
3.1.2.7	Hail, 20 mm (3/4 inch) at 20 m/s (65 fps), 25 mm (1 inch) at 23 m/s (75 fps)	Test, Section 2.3.3
3.1.2.8	Sand Storm per MIL-STD-810B	Test, Reference 1
3.1.2.9	Lightning	Transient Suppressors Incorporated, Heliostat Grounded through Foundation
	<u>HELIOSTAT PERFORMANCE</u>	
3.2.1	Operating Periods	Control and Drive Allow Operating from Sunrise to Sunset
3.2.2	Target	Heliostat Evaluated Against All Three Targets - Section 7
3.2.3	Field Positions	Heliostat Evaluated at Required Positions - Section 7
3.2.4	Reflectivity	Clean Reflectivity Projected to be 0.92 to 0.95 - Section 2.2.2
3.2.5	Reflective Area	Area Selected at 49 m^2 (528 ft^2)

Table 6.3-1

VERIFICATION OF SPECIFICATION 001

PARAGRAPH NUMBER	REQUIREMENT	VERIFICATION
	DRIVE AND CONTROL	
3.3.1.1	Fail-Safe Operation	Loss of Data Link Does Not Result in Loss of Tracking - Stowage by Manual Command Loss of Power is Unlikely. Each Heliostat is fed from Two Transformers. If Power is Lost, a Portable Power Supply will Effect Safe Stowage.
3.3.1.3	Limit Controls as Required	Electronic Limit Controls Provided via the Control System
3.3.2.1	Tracking Accuracy Controlled	Analysis and Test Data, Section 6.2
3.3.2.2	Acquisition Within 180 sec.	Slew Rates of 0.2 deg/sec Insure Rapid Acquisition in Less than 60 sec.
3.3.2.3	Continuous Tracking During Intermittent Clouds	Automatically Provided by Open Loop Control
3.3.2.4	Provide for Aiming Strategy	Automatically Provided by Software
3.3.2.5, 3.3.2.6	Shutdown Safely	Follow Prescribed Control Algorithm Shutdown within 15 Minutes
3.3.3.1	Manual Control	Available from Master Control, Data Distribution Interface and Heliostat
3.3.3.2	Alignment Control	Accomplish as in Initial Alignment, Section 4.5

Table 6.3-1

VERIFICATION OF SPECIFICATION 001

PARAGRAPH NUMBER	REQUIREMENT	VERIFICATION
3.3.4.1	Failure Indication	Loss of Reference, Data or Power Detected by Heliostat or Data Distribution Interface and Reported. Inability to Track Also Reported.
3.3.4.2	Emergency Shutdown	All Heliostats off Target Within 30 Seconds
3.5	PHYSICAL CHARACTERISTICS	
	Access Space	Spacings are Adequate for Access by Maintenance Personnel ard Vehicles
	Safe Stowed Positions	Normal Stowage Vertical, Face Down Stowage Available for Extended Shutdown and High Winds
	Easy Removal for Maintenance	Maintenance Analyses, Section 5.4
	30-Year Design Life	Test, Reference 1
3.6	Design for Reliability	Analysis, Test - Section 5.4
3.7	MAINTENANCE	
	Reflector Design for Easy Cleaning	Laminated Glass Mirror is Readily Cleaned, Chemically Inert
	Easy Service and Repair	Maintenance Analysis, Section 5.4
	Normal Skills	Maintenance Analysis, Section 5.4

Table 6.3-1

VERIFICATION OF SPECIFICATION 001

PARAGRAPH NUMBER	REQUIREMENT	VERIFICATION
3.8	Standard Materials and Processes	Commercially Available Materials and Processes Used in All Parts
3.9	Electrical Transient Protection	Provided by Transient Suppressors, Optical Data Transmission, and Optical Switching
3.11	Interchangeability	All Parts Interchangeable with No Field Adjustments
3.12	<u>SAFETY</u>	
	•Minimize Hazards	Conformance with Safety Codes (OSHA, NEMA, etc)
	•Fail-Safe	Provisions Include: • Redundant Power Source • Heliostats Continue to Track if Data Lost • Redundant Data Paths to Secondary Feeder • Manual Stowage Capability
	•Safe Stow Capability	Face Down or Vertical Stowage Available
	•Local Heliostat Lockout	Switch Provided on Heliostat and at Data Distribution Interface
	•Hazard and Fault Indication	Automatically Available from Return Data Stream
	•Safety Regulations	Analysis for Compliance

REFERENCES

1. Central Receiver Solar Thermal Power System. R. W. Hallet, Jr. and R. L. Gervais. SAN-1108-76-8. MDC G6776. October 1977.

2. Design, Fabrication, and Test of a Heliostat for a Central Receiver Solar Thermal Power Plant. J. B. Blackmon. Report NSF/RANN/SE/GI-39456/TR/75/2. September 1975.