MCDONNELL DOUGLAS CORPORATION

HELIOSTAT MASS PRODUCTION DEVELOPMENT PROGRAM

FINAL REPORT

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1.0 INTRODUCTION

The McDonnell Douglas Astronautics Company (MDAC) has completed a heliostat mass production manufacturing process development study for the Sandia National Laboratories, Livermore, California. This task was performed under Contract 84-4493A, Amendment 1, using the results of the mass production scenarios developed during performance of the Second Generation Heliostat Contract 83-0024.

This is the final report for the study contract to document the effort performed and results obtained.

2.0 SUMMARY

A major consideration and possible constraint for promoting the commercial use of solar central receiver plants is the cost of heliostat manufacture. As a part of the Second Generation Heliostat Development Program, and with support from General Motors and F. Joseph Lamb Company, MDAC prepared a description of a heliostat production plant sized to output 50,000 units annually. Recognizing the need for development and verification of processes and tooling proposed in the production plant description, Sandia National Laboratories contracted MDAC to recommend items for development during a later funded activity.

2.1 APPROACH

Using as a baseline the MDAC second generation heliostat described in Section 3.0, and the production factory described in Section 4.0, MDAC reviewed all of the processes and tooling used in the factory to produce heliostats. This review culminated with the selection of a number of specific processes and tools, listed in Table 2 of Section 5, which would benefit from development prior to use in their assigned functions within the factory. Selection was guided by the state of readiness for use of each item and its impact on the ultimate price of the heliostat. With the assistance of major MDAC suppliers and General Motors, the selected heliostat requirements were compared to similar production techniques currently in use. This was used to evaluate the amount of development each function might require in order to satisfy its planned application. The results of this evaluation were used by MDAC management to assess the relative importance of the selected development requirements. This assessment is shown in Table 2.

2.2 RESULTS

The outcome of the study effort is a list of process and tooling development requirements considered essential to economical production of heliostats at an annual output rate of 50,000 units. Anticipating that the scope of the development could exceed available funding, the items have been classified as having a high, medium, or low development requirement.

3.0 HELIOSTAT DESCRIPTION

3.1 HELIOSTAT

The collector subsystem, which incorporates this heliostat, consists of multiple heliostat control capability and the heliostat, depicted in Figure 1. The control system incorporates a unique, highly accurate pointing and tracking capability that eliminates absolute encoders and provides return to track capability following power loss to the heliostat field without heliostat realignment.

The major features of the MDAC Second Generation Heliostat configuration shown in Figure 2 are its large uninterrupted surface area with a minimum clearout area for the reflector area provided, and an aspect ratio which allows improved field utilization while achieving significant economies in fabrication and field assembly. Heliostat features are summarized in Table 1.

*Table 1. Heliostat Features

Effective Reflector Area	57 m^2
Reflectivity	89% to 92+%
Pointing Accuracy	Within 1.5 mrad rms
Beam Quality	90% of redirected energy within theoretical +1.4 mrad fringe
Clearout Radius	225 in.
Aspect Ratio	1.27:1
Mirror Focus	Common dual curvature, individual cant
Stow Position	-2 deg. from vertical
Survival Position	Horizontal, face up
Power Interface	208V, 3-phase - 4 wire
Emergency Slew	Sequenced Control through HFC
Field Wire Junction	At controller through fabrication
Operating Environment	0 to 50^{o}C
	0 to 27-mph wind
Operate to Stow Transition	Above 35-mph wind

* Reference Final Report SAND 81-8177, Second Generation Heliostat.

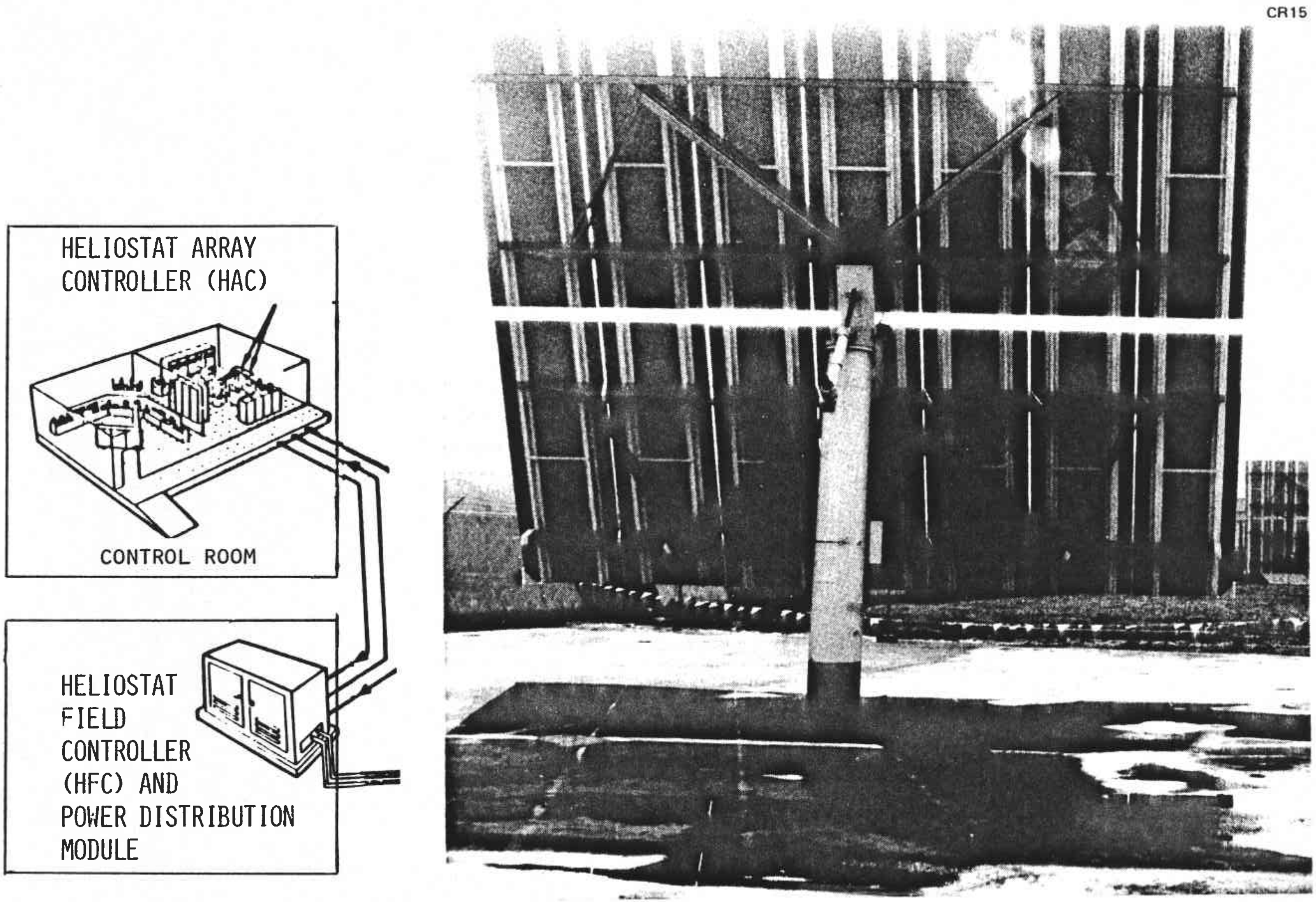

Figure 1 Second Generation Heliostat Subsystem

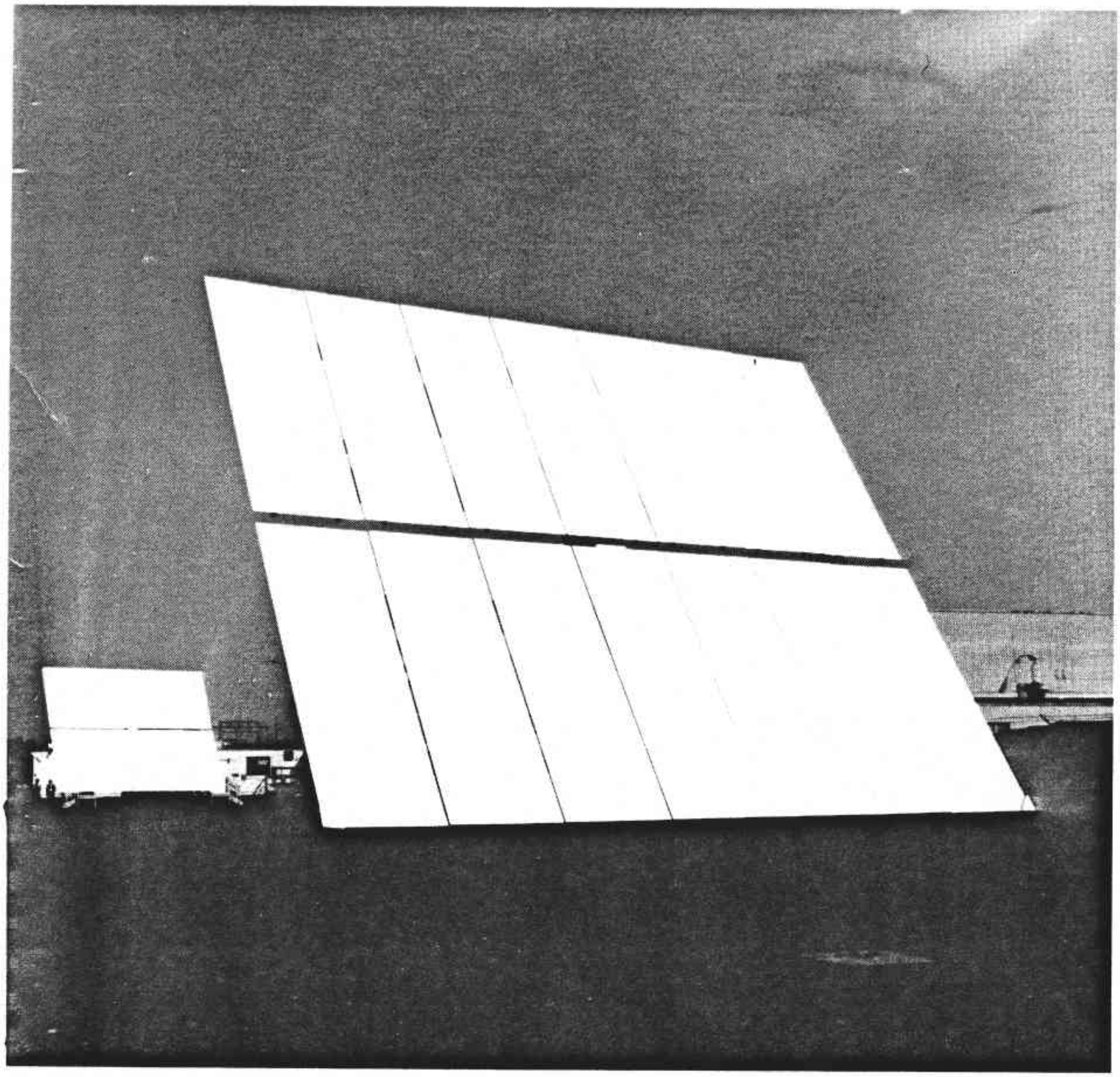

Figure 2 MDAC Second Generation Heliostat

The heliostat is normally stowed in a vertical attitude. The heliostat operates in the tracking mode in winds up to 35 mph on command. Translation to the horizontal survival stow position occurs when winds above 35 mph are expected. In this stow position, wind load capacity exceeds 90 mph.

All wiring is enclosed within the heliostat structure or protection shrouds, and drives are factory lubricated and sealed.

Field installation costs are minimized by factory assembly and alignment. A factory-aligned assembly, which consists of the azimuth and elevation drives, the pedestal and the main beam, and two factory-aligned reflector assemblies with precurved and canted mirrors, is provided for installation on the field assembled foundations.

3.2 ASSEMBLY AND SUBSYSTEM OPERATION EXPERIENCE

Heliostat assembly and installation substantially confirmed the design effort toward minimizing the time and resources required for these tasks. Pedestal drive assembly installation time associated with the production configuration was well within 5 min. Reflector assembly installation required 10 min. each. Factory precanting of mirror modules was performed.

Power consumption for the summer solstice day at Huntington Beach, California, was measured at 775 W/hr, and signal level capability for the heliostat field controller/heliostat controller interface was demonstrated for up to 32 heliostats.

4.0 FACTORY DESCRIPTION

During the course of the Second Generation Heliostat Program, a volume (50,000 heliostats per year) factory design was provided by the General Motors Energy Systems Group. Since the study work reported herein was applied to the production processes incorporated in that design (SAND 81-8177, Vol. II), a brief description of the factory is furnished in this section.

4.1 SITE

The heliostat plant site chosen is in the general area of Tucson, Arizona. The site is fully improved, perimeter fenced, and sized to allow for possible plant expansion. The site dimensions are approximately 1,610 feet by 1,080 feet for a total parcel size of 40 acres.

4.2 PLANT LAYOUT

The plant layout for the 50,000 unit annual volume heliostat production is shown in Figure 3. The plant design is single-story slab construction of high-bay configuration. The plant has floor area of approximately 260,000 square feet.

The plant has facilities for the manufacture of the following operations:

- Mirror laminating
- Support structure pressing and welding
- Reflector panel assembly
- Azimuth drive housing machining
- Flex spline, wave generator, bearing retainer, and circular spline machining.
- Main beam fabrication and welding
- Azimuth and elevation drive assembly
- Electronic/electrical component fabrication and assembly
- Final assembly
- Shipping

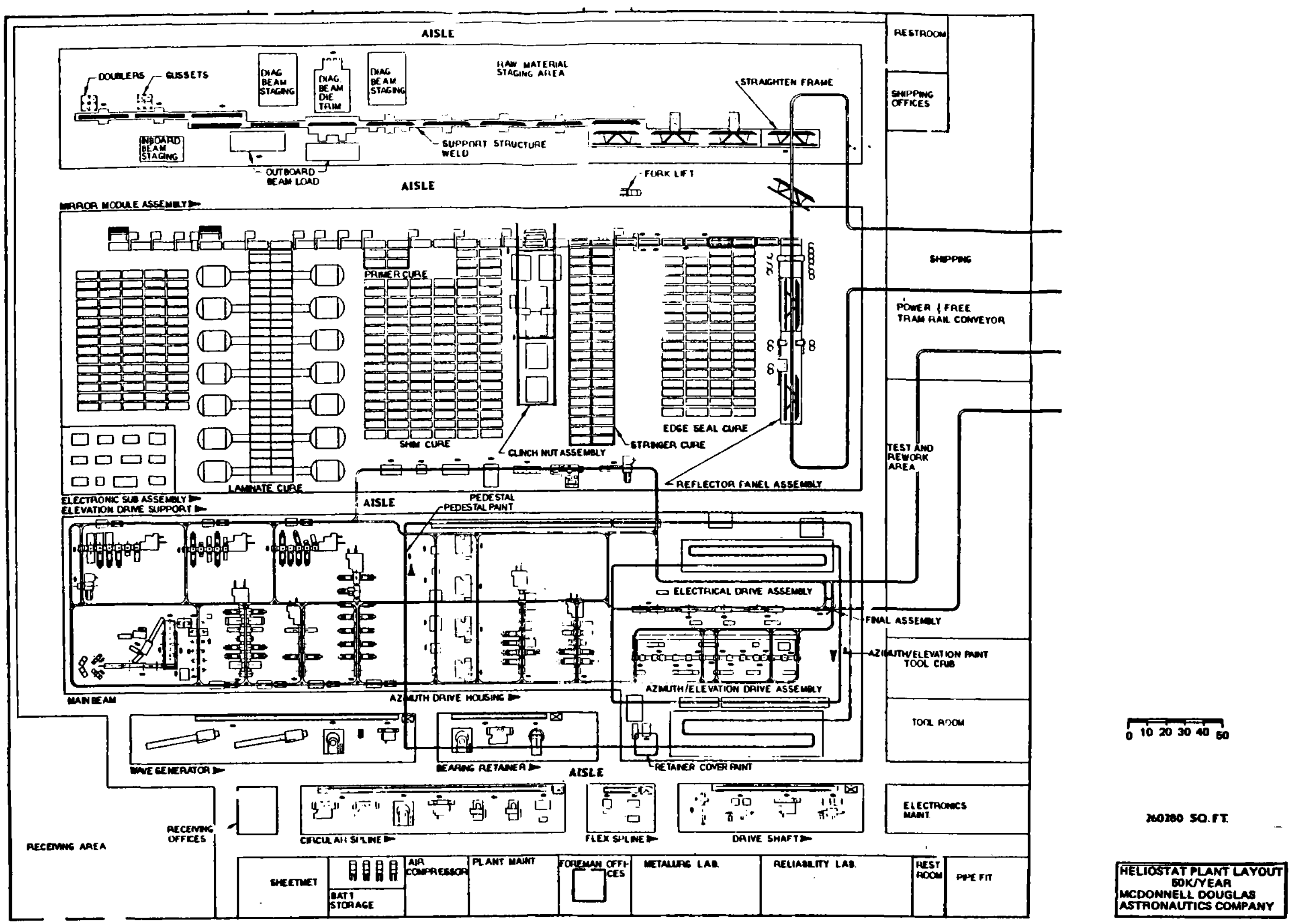

Figure 3 - Heliostat Plant Layout

Major supplier items which are shipped into this plant include the following:

- o Mirrored front lites
- o Float glass back lites
- o Roll formed sections for the support structure
- o Azimuth drive and pedestal weldments
- o Electronic parts, printed circuit boards and wiring
- o Drive motors and the elevation actuator

A major portion of the plant is occupied by the processing equipment for the reflective surface assembly. This processing includes glass laminating which is accomplished using polyvinyl butyral sheet as an adhesive. Curing takes place in the autoclaves. After laminating is complete, shims, stringers, and the edge seal are added and finally the reflective surface assembly is attached to its support structure to become the reflector assembly.

Machining and assembly of the drive components takes place in the various areas at the rear of the plant. The electronic/electrical fabrication occurs in the closed area which is near the final assembly area.

Located nearest the offices and general parking area is the automated weld and assembly line for the reflector support structure.

4.3 PRODUCTION FLOW

A representation of material and processing flow through the plant is shown in Figure 4.

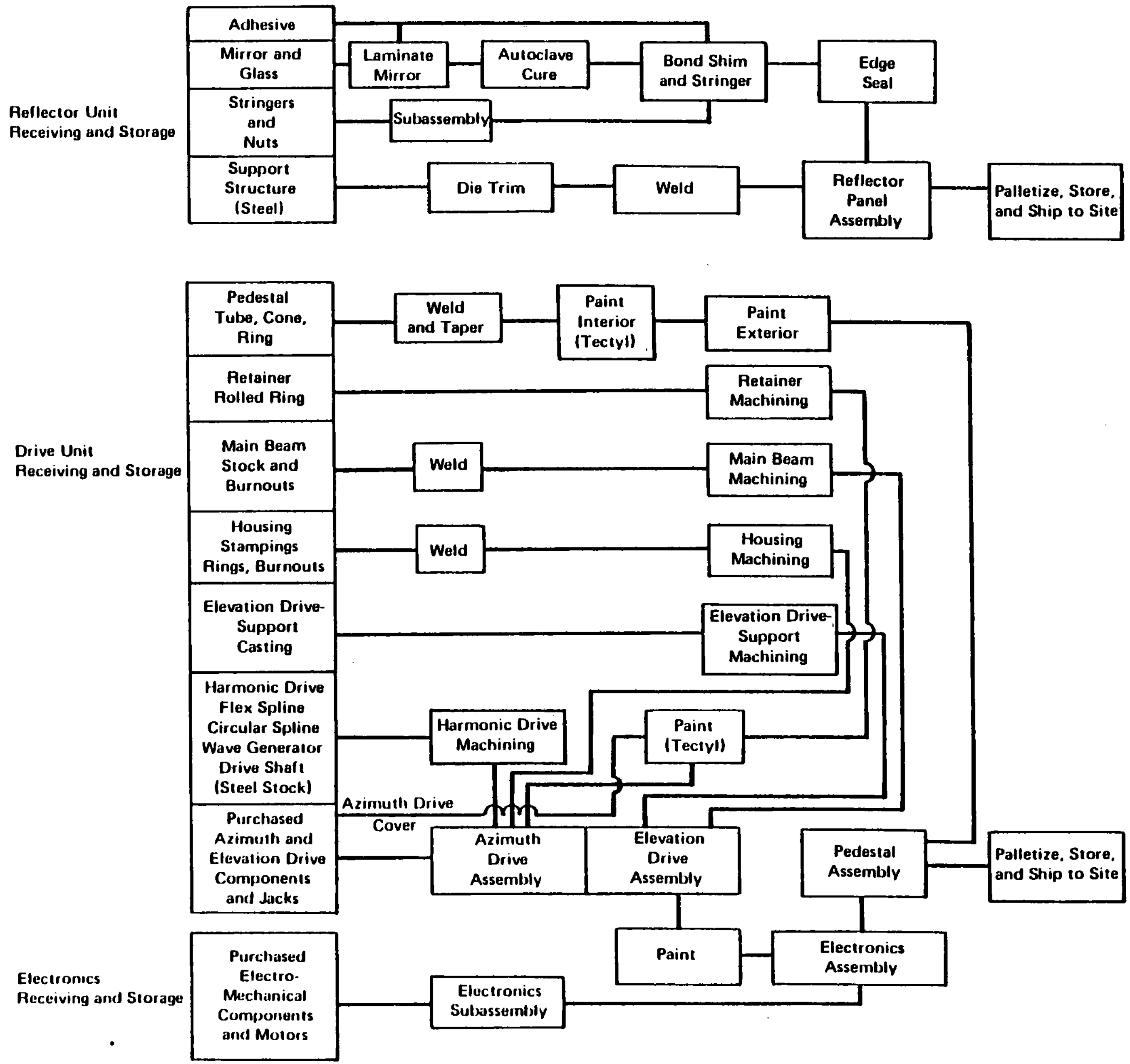

Figure 4 - Production Flow

5.0 METHODOLOGY

In accomplishing the prime task of this study, identification of specialized equipment, tooling and processes that require development in advance of initiating production and deployment of the MDAC Second Generation Heliostat at an annual rate of 50,000 units, a structured approach was used. The factory and processes identified in the Second Generation Heliostat Final Report (SAND 81-8177) are the source from which candidates for development were selected. Secondly, candidates were selected on the basis that each one selected must impact the ultimate price of the heliostat in a significant manner. The third task was to compare the heliostat requirement with similar operations being performed within the state-of-the-art. An example of this effort was the comparison of heliostat reflector structure assembly and welding with the robatic assembly and welding of K-car bodies at the Chrysler Jefferson Assembly Plant in Detroit. The fourth task was an evaluation of the technical risks involved if further development of the selected processes is not accomplished prior to start of heliostat production. The final task was to make a judgemental decision on the relative importance of the selected candidates. Each candidate was assigned a "Development Requirement" rank of High, Medium or Low.

5.1 SELECTION

Following a thorough review of the source document, the following broad candidate items for development were selected:

A. Mirror Module - Handling, laminating, bonding and packaging.

B. Azimuth Drive - Component parts processing, assembly, and installation.

C. Reflector Assembly - Welding and straightening, joining with mirror modules.

D. Heliostat Field Controller - Simplification.

5.2 COMPARISON AND EVALUATION

These tasks (3 and 4) were performed concurrently. The feasibility and technical risk inherent in each candidate were reviewed and evaluated by the appropriate participants in this study. Included among the participants were consultants, vendors, and MDAC engineering and production personnel such as:

A. Corning Glass Works

B. Binswanger Mirror Products

C. Van Huffel

D. USM

E. Design Engineering (MDAC)

F. Materials and Process Engineering (MDAC)

G. Manufacturing Engineering (MDAC)

5.3 RELATIVE IMPORTANCE OF DEVELOPMENT CANDIDATES

A management review of the outputs of the preceding tasks, shown in Table , assigned a classification of relative importance to each development candidate using three designations; High, Medium or Low. These rankings are shown in Table 2 , also.

TABLE 2

MASS PRODUCTION DEVELOPMENT PROGRAM

Part / Function	Mfg. Process Step	Method	Similar To	Technical Risk	Dev. Reqt. High	Dev. Reqt. Med	Dev. Reqt. Low
Vertical Assembly							
o Azimuth Drive							
- Housing	Deep drawn part	Draw die	Cans, tank pressure heads, flashlight case, engine oil pans, engine rocker covers.	Many parts have been deep drawn with appropriate development effort. Existing design has a different material thickness for the bottom plate on the housing. When made as a deep drawn part, material thickness is basically constant. Requires development to determine thickness for loads.			X
- Assy. Flex Spline to Housing	Plug weld	2 station Dollar weld machine Special tooling	Lap joints	Do not know the effect of heat from plug welding would have on the circular spline. Also can hub be eliminated, and if not, can the plug weld be extended through the hub which would create more of a heat problem.		X	
- Flex Spline	Broach teeth	Apex broach mach. Special tooling	Gears, keyways, rifle bore.	This material combination (at least) by USM has not been broached. USM thinks it will broach, but it could tear which would mean material development. There could be some development work required on the broaching tool.	X		
- Circular spline	Broach teeth	Apex broach mach. Special tooling	Gears, keyways, rifle bore.		X		

TABLE 2

MASS PRODUCTION DEVELOPMENT PROGRAM

Part / Function	Mfg. Process Step	Method	Similar To	Technical Risk	Dev. Reqt.		
					High	Med	Low
- Helicon Gear	Ring gear and screw to casted steel base	Alum/bronze cast and assemble		Develop the process of casting aluminum and bronze to form teeth.			X
- Drive Assembly	Shim selection (1D22433 & 1D22485)	Transfer-line-automatic gage	Engine block trans-ferline	Requires some type of automatic gaging system to determine shim thickness to reduce labor and elapsed time.		X	
o Controller	Circuitry	Custom chip	Custom chips	Analyze market for new chips (have a single chip designed/developed) with increased functions capable of handling controller require-ments which would allow a reduc-tion in chips. A compatible circuit would have to be developed.		X	
o Pedestal/Drive/Main Beam Assembly	Installation of foundation	Special tools	Post hole digger	Design/develop fast, economical, special purpose equipment to reduce handling and elapsed time.			X
o Heliostat	Heliostat tracking alignment			Develop analytical algorithm and develop program to align large field, test and verify.		X	

TABLE 2

MASS PRODUCTION DEVELOPMENT PROGRAM

Part / Function	Mfg. Process Step	Method	Similar To	Technical Risk	Dev. Reqt. High	Dev. Reqt. Med	Dev. Reqt. Low
<u>Reflector Assembly</u>							
o Joining	Drive Nuts	Pneumatic wrench	Transmission transfer line	This is a new automated concept of assembling and canting mirror modules in face-down position which has not been tried. 1. Requires proper positioning of modules to accept "K" frame. 2. Control of proper stud placement because of cant: a. Preassembled offline? b. Some type of measurement? c. New type of stud?		X	
	Position "K" frame	Transferline	Transmission transfer line				
	Drive Studs	Computer controlled stud selection and pneumatic stud driver	Body trim line				
	Position Mirrors	Transferline	Transmission transfer line				
o "K" Frame	Welding Stations	Transferline	Automobile frame transfer line	Coordination of welding spots/heads relative to location and heat to minimize distortion.	X		
	Machine for main beam interface	Transferline		Fast economical method to obtain interface tolerance requirement to main beam.			
	Straighten Structure	Transferline		Develop holding points to provide a straightened structure.			

TABLE 2

MASS PRODUCTION DEVELOPMENT PROGRAM

Part / Function	Mfg. Process Step	Method	Similar To	Technical Risk	Dev. Reqt. High	Dev. Reqt. Med	Dev. Reqt. Low
o Mirror Module	Hat Section Bonding	Adhesive applicator		Need fast, inexpensive means to apply adhesive. Equipment must handle multiple bonding jigs.		X	
		Bonding Jig		Needs to be low cost and still capable of providing the proper compound curvature.			
	Glass/Mirror Handl-ing	Special tools		Low cost, fast method of handling glass and laminated mirrors.			X
	Laminating	Autoclave		Investigate/develop new laminating process pinch rolling.			X
o Assembly	Packaging	Crates		Develop crating technique that will allow for vertical shipment with horizontal loading and unloading and meet load requirements on structure.			X
	Handling	Special tools		Develop a handling device/system capable of removing reflector assembly from line rotating it face up and handling it in a horizontal position.			
o Assembly	Installation - reflectors to main beam	Special equipment	Forklift	Design/develop fast, economical special purpose equipment to reduce handling and elapsed time.			X

6.0 CONCLUSIONS

Although curtailed in scope, this study has accomplished a major objective for Phase I. It provides specific and critical objectives for future development activities. These requirements have been identified and the necessity of satisfying them verified by interactive study and analysis performed by MDAC and major heliostat component suppliers.

Definitive costs for proceeding with the development of the processes and tooling identified are not available. However, the benefits to the Solar Central Receiver Program are expected to justify any reasonable development costs.

The McDonnell Douglas Astronautics Company will respond to development requirements as the market evolution justifies. Acceleration of the development through DOE funding should be considered.