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PROCESS DEVELOPMENT FOR AUTOMATED SOLAR CELL AND MODULE PRODUCTION

TASK 4: AUTOMATED ARRAY ASSEMBLY

Quarterly Report No. 2

In Reference To:

JPL Contract No. 955699

Prepared For:

Jet Propulsion Laboratory
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15 January 1981

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PREPARED BY: JOHN J. HAGERTY

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The JPL Low-Cost Silicon Solar Array Project is sponsored by the U. S. Department of Energy and forms a part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DoE.

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ABSTRACT

Installation of the cell preparation station into its new enclosure is now complete and operation verification tests have been performed. The detailed layout drawings of the Automated Lamination Station have been produced and construction has begun. All major and most minor components have been delivered by vendors. The station framework has been built and assembly of components is underway. The final drawings for the Automated Vacuum Chamber are being completed and the first in-house components are being fabricated.

1.0 INTRODUCTION

Work during this period has involved completing Phase One, as contractually obliged by December 31, and making significant progress on Phase Three (the tasks in the various phases were detailed in the previous Quarterly Report).

Work on Phase One has involved completing the installation of the cell preparation station in its new enclosure and running operation verification tests. Also accomplished under this phase was a 40% reduction of cycle time achieved by rewriting the controlling computer program to incorporate overlapping functions.

Work on Phase Three during the past period included finishing the detailed design of the Automated Lamination Station and starting construction. Design of the Automated Vacuum Chamber is also well advanced and construction will begin shortly.

2.0 TECHNICAL DISCUSSION

2.1 Completion of Phase One

As contractually obliged by December 31, Phase One was completed during this period. This involved installation of the cell preparation station into its new enclosure and, once operational, reducing its cycle time to 10 seconds, or less. This is covered in detail below. Other aspects of Phase One already completed include: improving placement accuracy, improving the solder bond and reducing soldering time. These were covered in the previous Quarterly Report, Section 2.1.

2.1.1 Enclosure, General

The enclosure that houses this system (Figure 1) is of MBA design, custom fabricated by Crystal Mark in Glendale, CA. It consists of two equal sized sections joined on a 30° angle to allow visibility of the entire system in operation.

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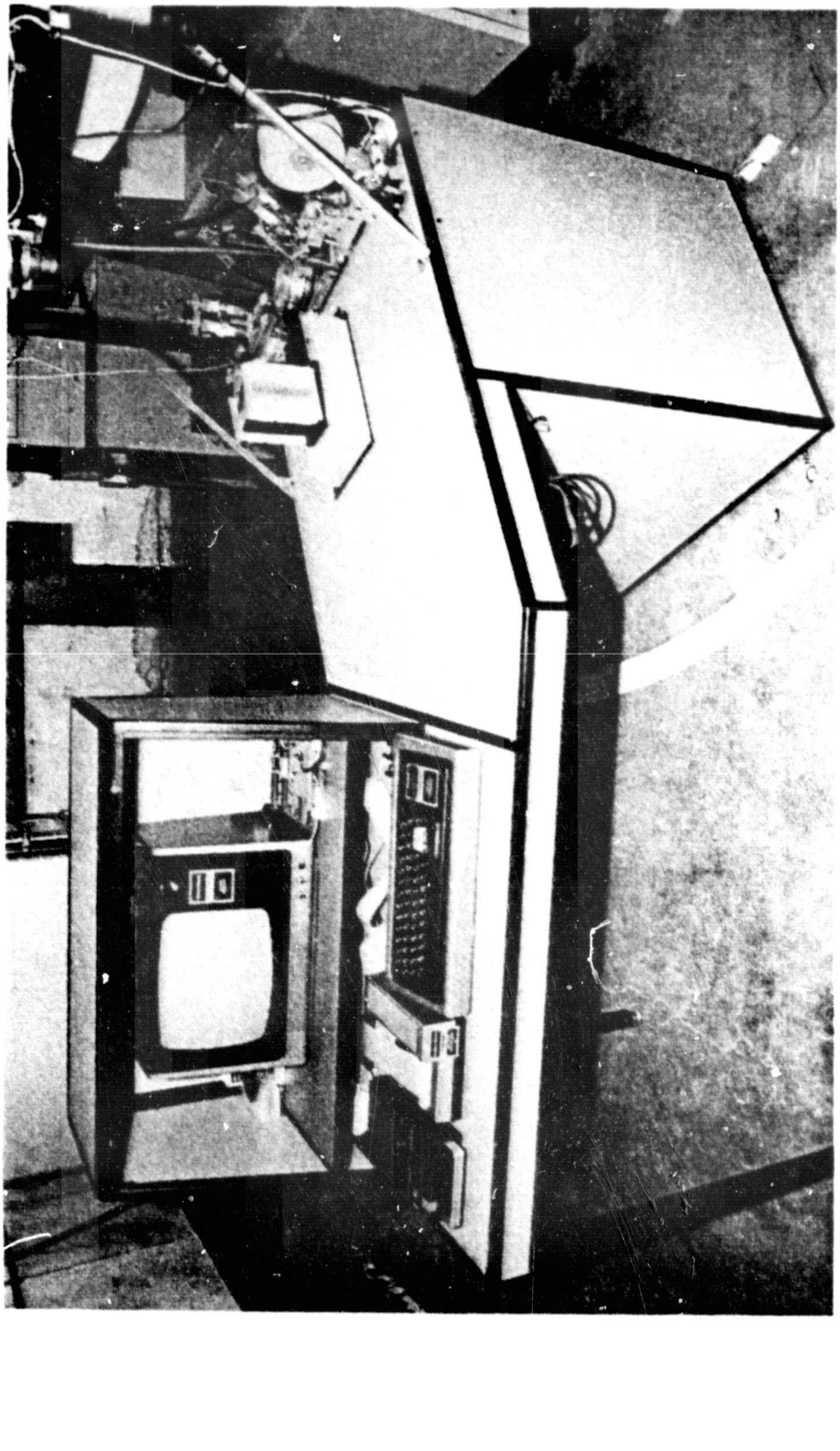

FIGURE 1
CELL PREPARATION STATION IN NEW ENCLOSURE

The operator's section is a standard-height desk on top of which is a lockable console. Within the console is a shelf for the computer's video monitor and storage of manuals. The shelf has been placed 4" above the desk top to put the video monitor at the operator's eye level. The space beneath the shelf is used for storage of the other computer components (keyboard/processor, tape unit and printer). During use these components slide forward onto the operator's desk area. Under the desk's surface is an enclosed cableway 3" deep that runs under the entire desk area and over to the equipment area.

The top of the equipment section is a continuation of the desk level surface. Flush mounted onto it is the cell preparation station itself. Below the surface is an equipment shelf which is infinitely adjustable for height. The actual height is determined by the Siltec cassette unloader which sits on the shelf with its upper half protruding through the desk top. The height of the shelf must be adjusted such that the output belts of the Siltec line up correctly with the vacuum chuck in the preparation station. Beneath the shelf is an open equipment mounting area which will be used as needs dictate.

2.1.1.2 Installation Philosophy

The enclosure that houses the cell preparation station is the operational center of our entire system since it also houses the controlling computer and interface electronics. For this reason we proceeded cautiously with the installation of the electro/pneumo/mechanical elements of the cell preparation station as well as the computer and associated electronics. Care had to be exercised in the placement of components and the routing of cables and tubing not only to conform to standard practices (such as separating power lines from information cables to avoid interference) but to allow for the orderly expansion of the system. This will come when the control and information functions of the lamination station and vacuum chamber must be integrated.

After the enclosure arrived, but before any actual wiring began, we had to decide on an installation philosophy. All wires, cables and tubing had to be routed in a neat and professional manner (of course) yet still conform to the restrictions mentioned above. All electronic, electromechanical and straight mechanical support equipment had to be mounted permanently but still allow for the necessary future expansion without having to rearrange and remount equipment.

On the other hand, it was recognized that this is a prototype machine and that considerable troubleshooting and/or modifications would be necessary. This requires that the machine be easy and flexible to work on. For this reason, none of the electrical cables or pneumatic tubing in the equipment section that must pass through a surface (cabinet wall, desk top, etc.) use hard connections. All of these are accomplished through the use of quick disconnect connectors. This affords easy access to any part of the machine as any panel can be removed without disconnecting any cables and/or tubes. In addition, all of the connections to the preparation station itself contain extended service loops. These allow the entire desk top containing the preparation station to be removed (gaining direct access to the support equipment beneath it) and still have the station be operational. This will considerably expedite troubleshooting.

2.1.3 Installation - Operator's Section

The major decision here was to mount the main computer interface board on the console wall (next to the video monitor, Figure 2), rather than in the equipment section as originally planned. This reduces the interconnect cable length from over 3 ft. to about 1 ft. This should eliminate any possibility of outside interference.

2.1.4 Installation - Equipment Section

The Siltec cassette unloader, as mentioned above, sits in the center of the equipment shelf (Figure 3). To one side of it on the shelf are the two power supplies. One of these is regulated and powers all of the computer interface and other information handling electronics

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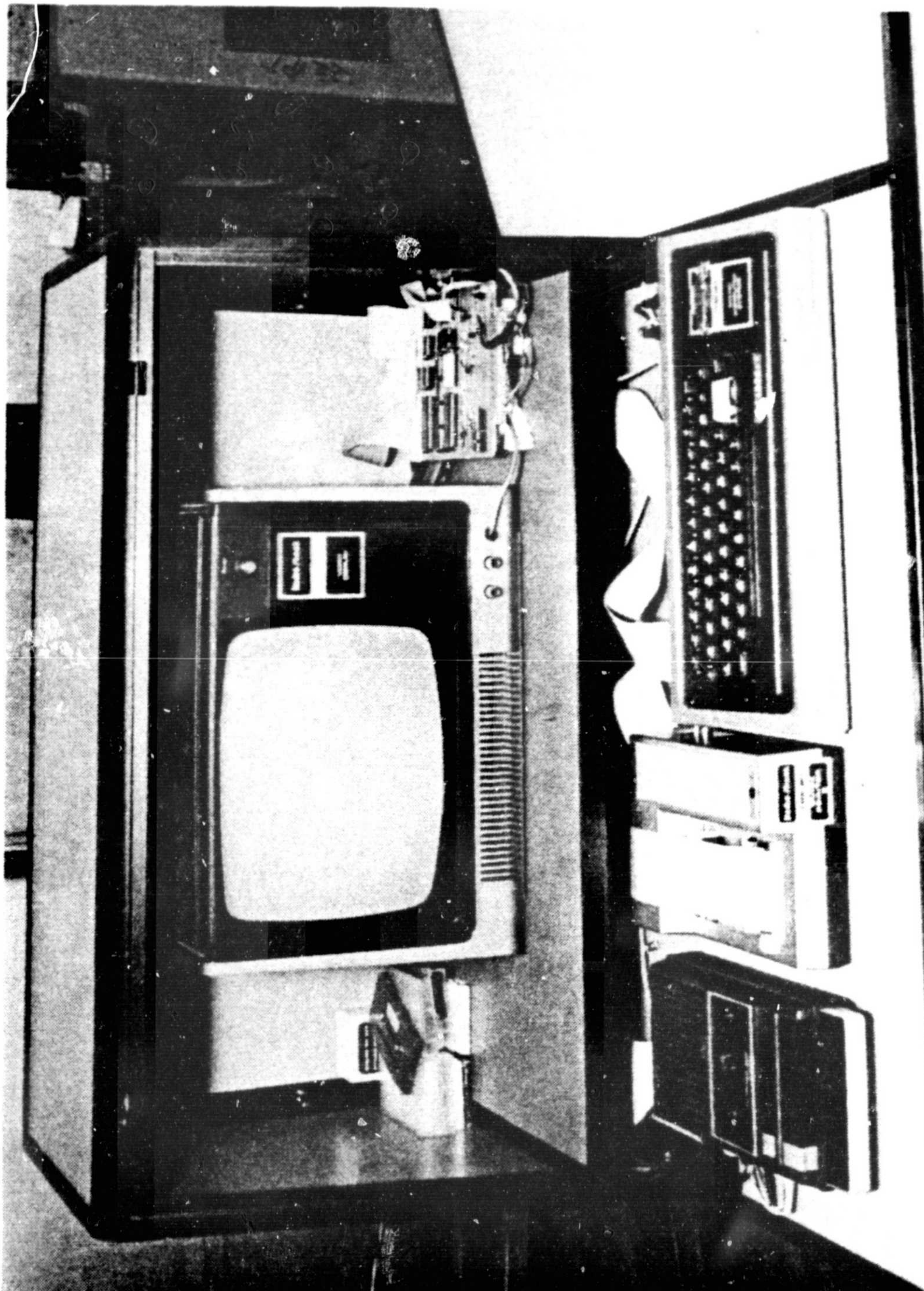

NOTE: Interface Board (next to CRT) has been unmounted from cabinet wall for troubleshooting.

FIGURE 2
OPERATOR'S SECTION

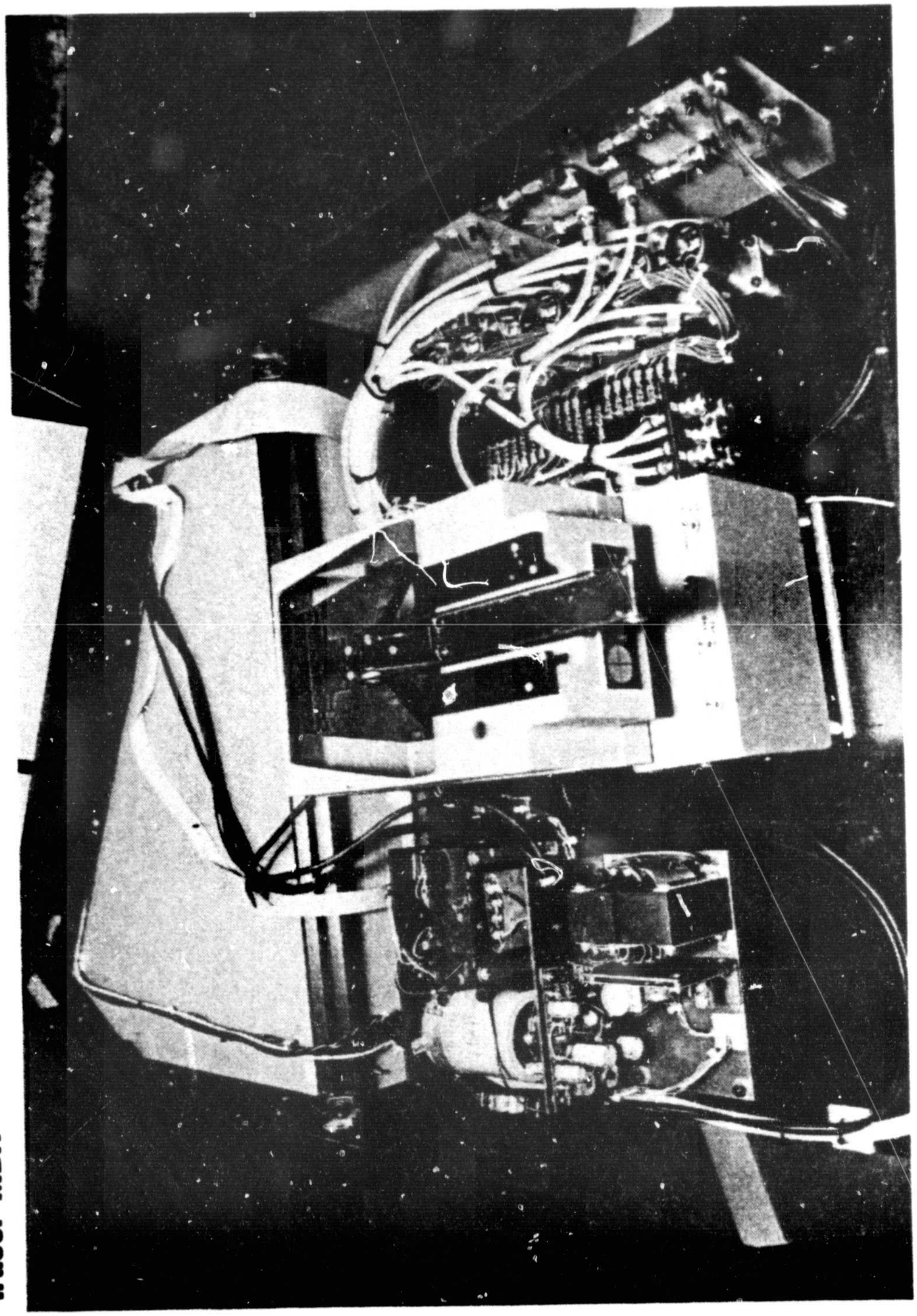

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FIGURE 3
EQUIPMENT SECTION, TOP OF SHELF

(such as the op-amps and A to D converter). The other is unregulated and powers the electro-mechanical devices, i.e., the solenoid valves and stepper motors. These two supplies have enough capacity to satisfy all additional requirements of the Lamination Preparation Station and Automated Vacuum Chamber with the exception of the chamber heaters. While these heaters (described in the First Quarterly Report, Pg. 27) consume approximately 2 kw, they operate off of standard line voltage (115 VAC) so no power supply is needed.

On the other side of the Siltec are the seven solenoid valves. Due to a lack of space in the previous enclosure these were mounted upside down under the shelf. This arrangement made access difficult for both initial wiring and plumbing of the valves and later inspection and modification. The new arrangements makes things much easier to work on.

Underneath the shelf (Figure 4) is a general equipment area that contains both electronics and pneumatics. The electronics consist of the high-current driver board (which takes the computer-level signals and uses them to drive the solenoid valves and stepper motors) and the optical interface board (which takes the very low level signals from the optical sensor and amplifies them for input to the A to D converter). The pneumatics include the eductor (which generates a vacuum for both the chuck and solder paste dispensers) and the main inlet manifold. Also located in this area, on one of the cabinet walls, are the input air connector and valve and the various information/power connectors for cables going to the robot and the Lamination Station and Vacuum Chamber.

Future expansion calls for a second driver board to be mounted in this area which will operate the stepper motors, solenoid valves and control functions of the equipment under development. The solenoid valves themselves will not be mounted in the enclosure, however, as this would mean long runs of pneumatic tubing and a loss of efficiency.

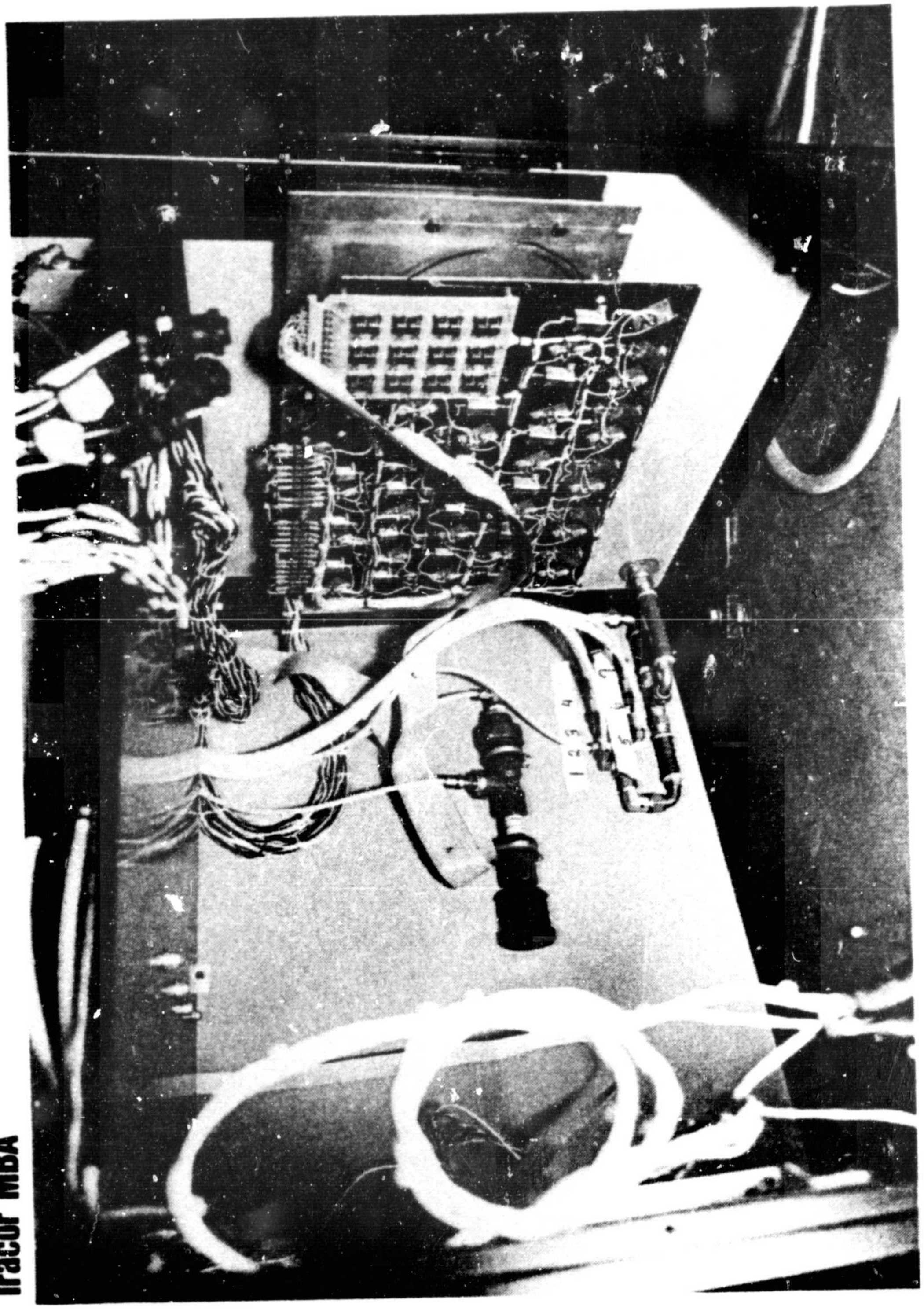


FIGURE 4
EQUIPMENT SECTION, UNDERNEATH SHELF

2.1.5 Verification Testing and Cycle Time Reduction

After installation was complete, the trouble-shooting was minimal with nearly all functions operating correctly "right out of the box" (i.e. requiring no modifications or corrections). This allowed us to begin modifying the computer program earlier than planned.

The first step in this modification was to perform a detailed timing study of the entire cell preparation cycle. This allowed us to determine which steps could be done concurrently (e.g. the ribbon could be feeding while the cell is settling) and which must be done sequentially (e.g. the cell must be oriented before solder paste is applied). Using the results of this study, the program was modified overlapping several operations. The preparation cycle time from start of cycle to robot pickup command is now 8.5 seconds compared to more than 14 seconds previously. It should be noted that this 40% reduction in cycle time was achieved without the use of simultaneous motor operations. Computer control of stepper motors is a non-trivial task requiring the computer to make thousands of calculations per second. Keeping track of more than one motor at a time would require a significant increase in the controlling program's complexity. Even if simultaneous motor operations were used it would decrease the cycle time by only about one second. We feel that the point of diminishing returns has been reached since this small gain would not be worth the large investment in manpower to expand the program. In addition, this would do nothing to reduce the cycle time of the two longest functions: cell settle and orient.

The optical cell orient is working perfectly and will consistently orient the dummy solar cells to within 1°. Although these dummy cells are made of steel (which has different reflective properties than silicon crystal) it was shown in the previous program that the system works equally well with real cells, although lamp positioning is more critical.

The manifold solder paste dispensers are working as designed, with each of the four dispensers (two manifolds for the cell and two needle-type for the leads) having its own flow control. This allows us to compensate for any viscosity differences in the solder paste supply.

Due to a shortage of materials, the "ribbon ramp" function of the solder paste dispensers (see Quarterly Report #1, Section 2.1.3) has not been extensively tested although it has been run enough to prove the basic concept.

2.2 Automated Lamination Station

The Automated Lamination Station consists of three components: a lamination preparation station, an automated vacuum chamber and a vacuum platen and effector for the Unimate robot. Progress on each of these will be discussed separately.

2.2.1 Lamination Preparation Station

The detailed layout drawings of the Lamination Preparation Station have been produced. The final design closely follows the conceptual sketch and description as presented in the previous Quarterly Report, Section 2.3.2, with only a few minor variations. One of these is the position of the top laminate supply roll. In the original concept, the roll was placed above the feeding/cutting mechanism to allow the option of inserting the vacuum chamber from the end as well as the side. In the interest of expediency and the mechanical integrity of the frame, it was decided to restrict the design to side entrance only. This allows us to drop the supply roll down below the feeding/cutting mechanism (as with the bottom laminate) thus achieving a mechanical symmetry at both ends and further simplifying the design. The bottom laminate was originally placed low for clearance as this is the end that the robot approached from.

Construction of the station has begun with the completion of the framework (Figure 5). All of the major, and most minor, components have been delivered by vendors and assembly onto the framework is underway.

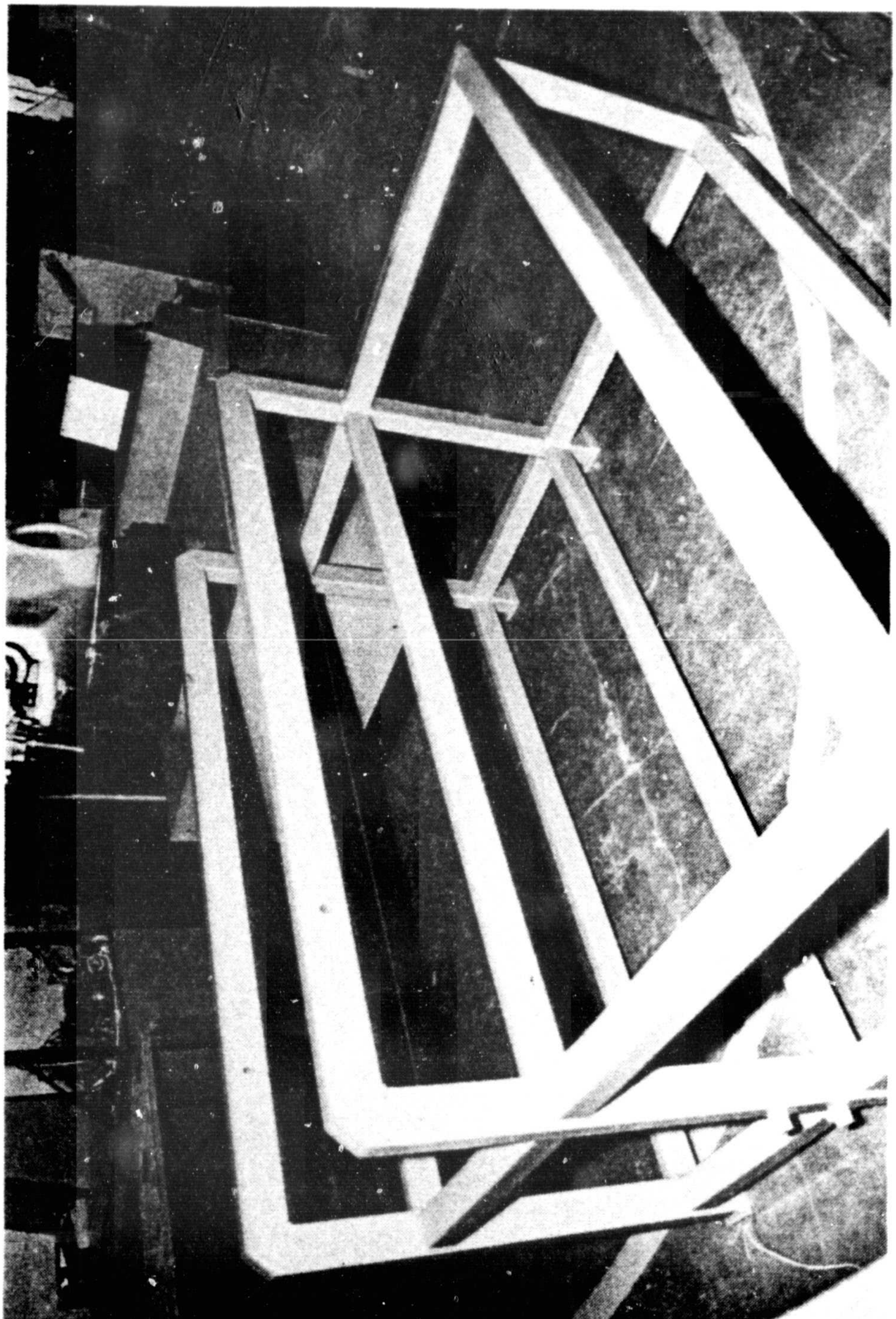


FIGURE 5
AUTOMATED LAMINATION STATION FRAMEWORK

2.2.2 Vacuum Chamber

Detail design work has begun on the automated vacuum chamber. One change has been made to the chamber cover opening mechanism. In the original concept (Figure 13 in Quarterly Report #1) this was a two link (per side) parallelogram hinge. This has been modified by replacing the links with a "roll top desk" arrangement. This consists of lengths of tubing attached lengthwise across the silicone rubber cover connected at the end by extended-pitch roller chain. Large sprockets simply roll the cover up to open the chamber. A pair of constant-force springs are used to close the cover and hold it closed during thermal and vacuum cycling. The advantage of this arrangement is that the vertical clearance required to open the cover is reduced to zero. This means that the chamber can now be opened while it is inside the preparation station's framework allowing us to mount the chamber-opening mechanism (in this case a motor) on the framework rather than on the chamber itself. The rational behind this is twofold: First, in a production situation, it greatly reduces the number of parts needed. On a production line there could be up to 100 chambers for each lamination station. Mounting the chamber opening mechanism on the lamination station rather than the chamber reduces the number of mechanisms required by 100 to 1. Second, and more subtly, it allows the chamber to be unpowered while in the station. The chamber has power and control cables and a vacuum line attached. If the lamination station is being used in a pass-through mode (the chambers can either pass completely through the station, as on a conveyor belt, or can be inserted and removed from the same side) these lines may have to be disconnected to allow passage through the station leaving the chamber powerless.

2.2.3 Vacuum Platen

The vacuum platen was completed very early and has not been changed. However, the pneumatic plumbing required to enable the robot to lay-up and solder cells (with the other end effector) is far too restrictive to be used with the vacuum platen (see the previous Quarterly Report, Section 2.3.1). The plumbing has, therefore, been completely redone to allow the end effectors to be used interchangeably. A manual push-pull valve (operable from outside the robot) is used to switch between the highly controlled, restrictive plumbing needed for lay-up and soldering and the direct, high flow rate required by the vacuum platen.

3.0 CONCLUSIONS AND FUTURE WORK

This program is proceeding on schedule. There have been some delays in parts delivery which are annoying but they should not seriously impact the schedule.

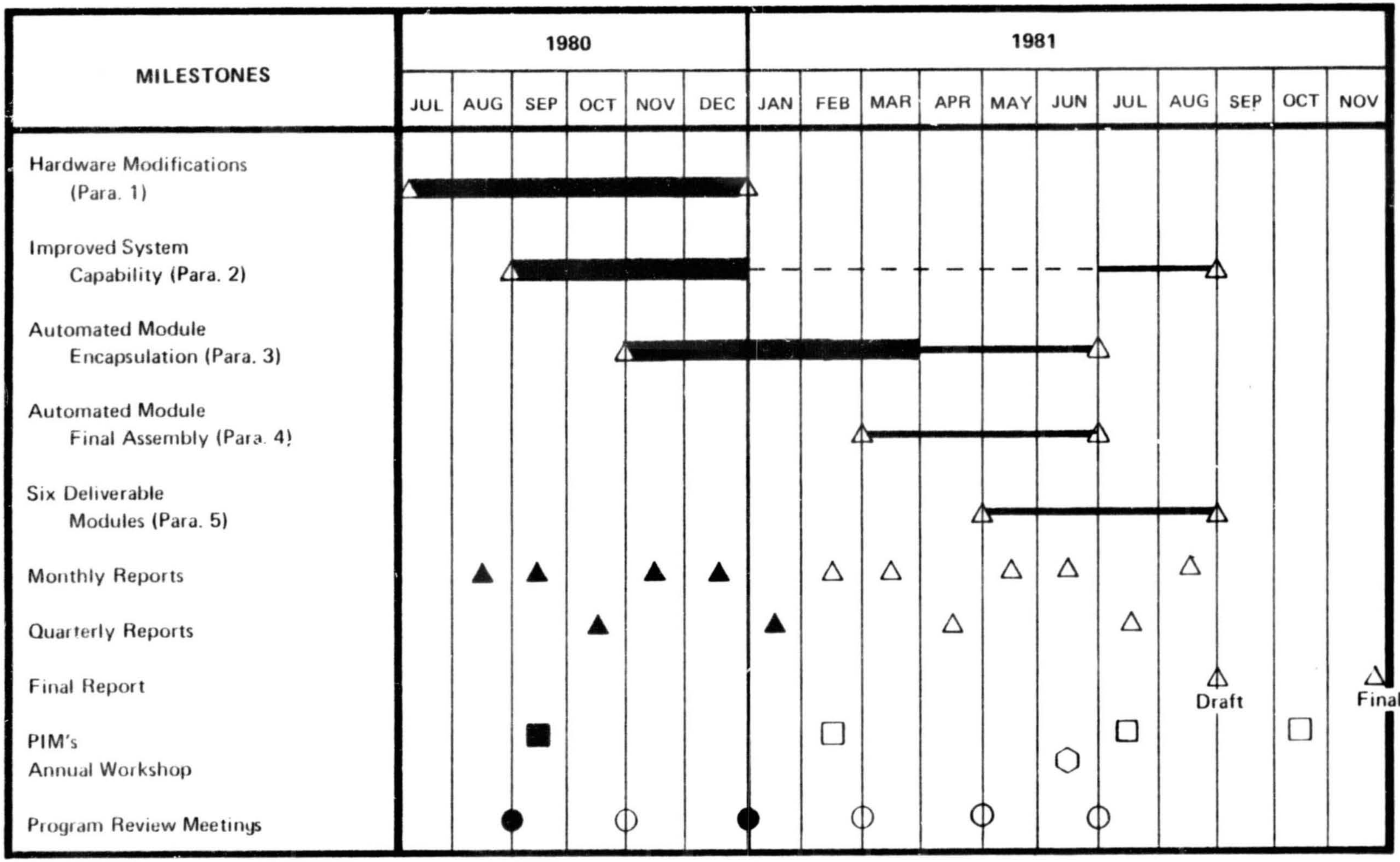
We have finished all of the Phase One improvements which were contractually due on December 31, 1980. The framework for the lamination preparation station has been fabricated and installation of components has begun.

Over the next period we will finish the construction of all Phase Three equipment (i.e. Lamination Station and Vacuum Chamber) and be well into the development of Phase Four. This entails the final module assembly station as described in the previous Quarterly Report, Section 2.4. Implicit in the above is the expansion of the electronic interface equipment necessary to control this new equipment with the existing computer.

4.0 PROGRAM PLAN

Included is a program plan that shows progress-to-date on the various phases as well as their projected completion dates.

ATTACHMENT A



PROGRAM PLAN