DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150570

PROTOTYPE SOLAR HEATING AND COOLING SYSTEMS

Prepared by

AiResearch Manufacturing Company of California
A Division of the Garrett Corporation
2525 West 190th Street
Torrance, California 90509

Under Contract NAS8-32091 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

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This work was done under the technical management of Mr. James W. Clark, Marshall Space Flight Center, Alabama.

16. ABSTRACT

This report is a collection of quarterly reports from the AiResearch Manufacturing Company covering the period July 12, 1976, through December 31, 1977.

AiResearch Manufacturing Company, under NASA/MSFC Contract NAS8-32091, is developing eight prototype solar heating and cooling systems. This effort calls for the development, manufacture, test, system installation, maintenance, problem resolution, and performance evaluation. The systems are 3, 25 and 75-ton size units.

Cost data has been removed from these reports.

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PART A

First Quarterly Report
Data Requirement 500-10

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT

Contract NAS8-32091
76-13296(1)

October 12, 1976

Approved by

J. Rousseau

George McDonald

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama 35812

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SECTION 1

INTRODUCTION AND SUMMARY

INTRODUCTION

A contract for the design and development of solar heating and heating/cooling systems was received by AiResearch on July 12, 1976. This contract covers the design, development, and installation of systems of the following nominal sizes for the applications defined:

Heating systems

Single family residence:	80,000 Btu/hr
Multifamily residence:	800,000 Btu/hr
Commercial installation:	250,000 Btu/hr

Heating/cooling systems

Single family residence:	80 KBTUH/3-ton
Multifamily residence:	800 KBTUH/25-ton
Commercial installation:	250 KBTUH/10-ton

Actual installation sizes will be defined following site selection and could involve multiple units.

As part of the contract, two systems of each type (heating and heating/cooling) and of each size will be fabricated for long-term demonstration under different load/environmental conditions.

This document is the first quarterly report published under this contract and summarizes the activities of the period from July 12, 1976 through October 1,1976. Mr. Jim Clark of the NASA Marshall Space Flight Center is the contract technical manager.

SUMMARY

The significant activities and status of the cost, schedule, and technical aspects of the program are summarized below.

Cost Status

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Schedule Status

The contract was awarded July 12, one month later than had been anticipated at the time the schedule included in AiResearch proposal was developed. Nevertheless, the program milestones as established in the AiResearch proposal were held after receipt of the contract.

As mentioned above, the schedules were revised throughout the reporting period to reflect funding changes requested by NASA. The latest schedules for the heating and the heating/cooling systems are presented in Figures 1-2 and 1-3.

The PDR for the heating systems was held at the AiResearch Torrance facility on September 22 and 23.

Progress under the contract is on schedule although most of the effort has been devoted to subsystem level design activities pending site selection.

At this time it is imperative that the demonstration sites be defined. Detailed site definition must be accomplished by November 1, 1976 to prevent major impact on the overall program schedule.

Technical Status

1. Site Selection

The locations proposed by NASA and defined below are acceptable to AiResearch with the exception of Fresno. The climatic conditions in Fresno would be more suitable for installation of a cooling system than a heating system.

It is suggested, however, for reasons of program economy and effectiveness that two of the demonstration systems be installed at the Dunham-Bush facility in Harrisonburg, Virginia. These two systems could be substituted for the Fresno single family and the Richmond multifamily heating systems.

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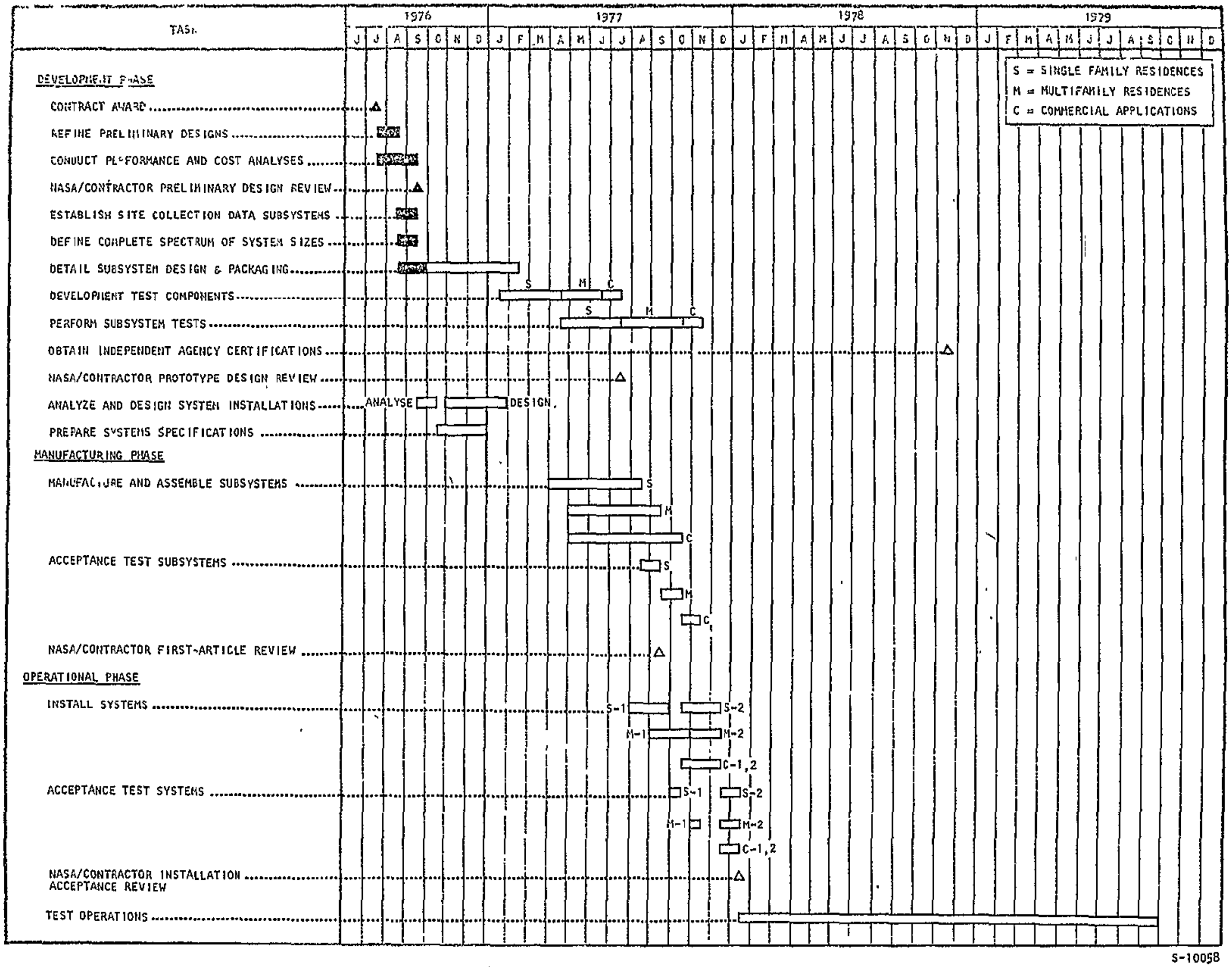

Figure 1-2. Heating System Schedule

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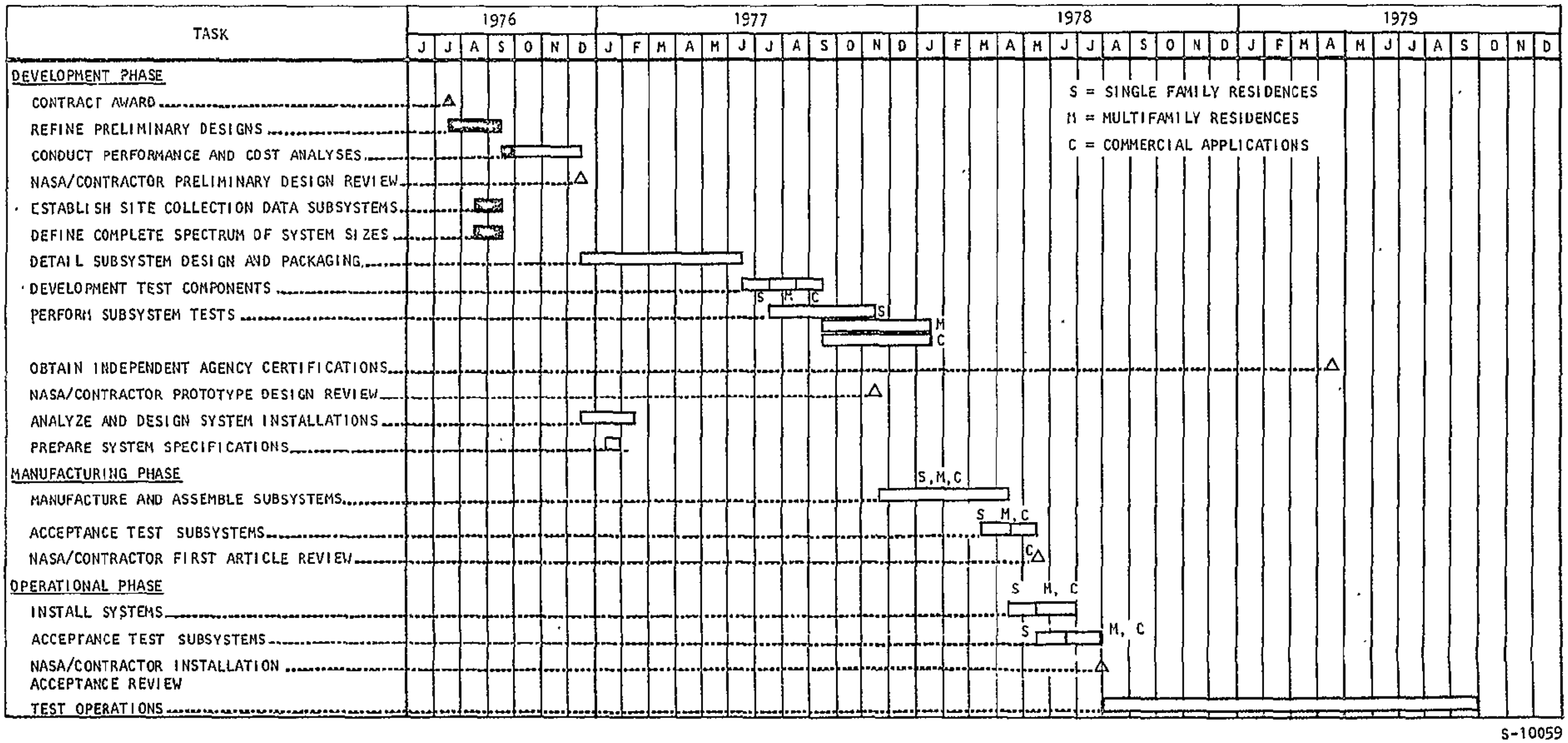

Figure 1-3. Solar Heating/Cooling Systems Development Schedule

Heating systems

Single family residence:	New York (Fresno)
Multifamily residence:	Detroit, Richmond
Commercial applications:	Milwaukee, Syracuse

Heating/cooling systems

Single family residence:	Des Moines, Washington, D.C.
Multifamily residence:	Los Angeles, Columbus, Ga
Commercial applications:	Las Vegas, Houston

2. Heat Pump Sizes

The following heat pump sizes were selected for development:

Single family residence

Heating: 60,000 Btu/hr
Cooling: 3 tons

Multifamily residence

Heating: 600,000 Btu/hr
Cooling: 25 tons

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Commercial applications

Heating: 200,000 Btu/hr
Cooling: 10 tons

3. Preliminary Design Review

The heating systems PDR was held at AiResearch on September 22 and 23, 1976. Twenty-four review item discrepancies (RID's) were presented to AiResearch at that time. Sixteen RID's were answered in writing in the reporting period. The remainder, due at a later date, will be answered as scheduled.

4. Collector Procurement

An RFP for the collector was issued on August 30, 1976. Thirty-two manufacturers were solicited, and thirteen proposals were received September 27. These proposals are being evaluated, and a selection will be made early in November.

5. Program Documentation

Documentation was prepared in accordance with the requirements of DR-500. A number of documents have been approved by NASA. Approval of the remainder awaits completion of review by NASA.

6. System Analysis and Integration

System level activities conducted included the performance of trade studies and sensitivity analyses to refine the system schematics. In the absence of actual site data, the Nashville and Madison locations and residence models were used. System optimization and development of system specifications is essentially dependent upon detailed site data.

7. System Development

Problem statements were generated for all heat pump components, and detail design is proceeding on schedule. The pacing items in the development of the heat pumps are the turbomachine/motors and the motor controls.

8. Testing

Design support testing has been initiated on selected items to generate design data and provide a firm base for detail design. These tests are conducted at the component/subcomponent level and involve: (1) single-tube heat transfer tests, (2) tank thermal stratification tests, (3) bearing/motor tests, and (4) motor control breadboard development. In addition, test setups are being designed for development and certification of the 10- and 25-ton heat pumps.

Section 2 has been deleted

SECTION 3

PROGRAM SCHEDULES

The overall program schedules are included in Figures 1-2 and 1-3 in Section 1. This section includes more detailed schedules (Figures 3-1 through 3-5) of the development status of the critical subsystems and components. The status and progress are given in Section 4.

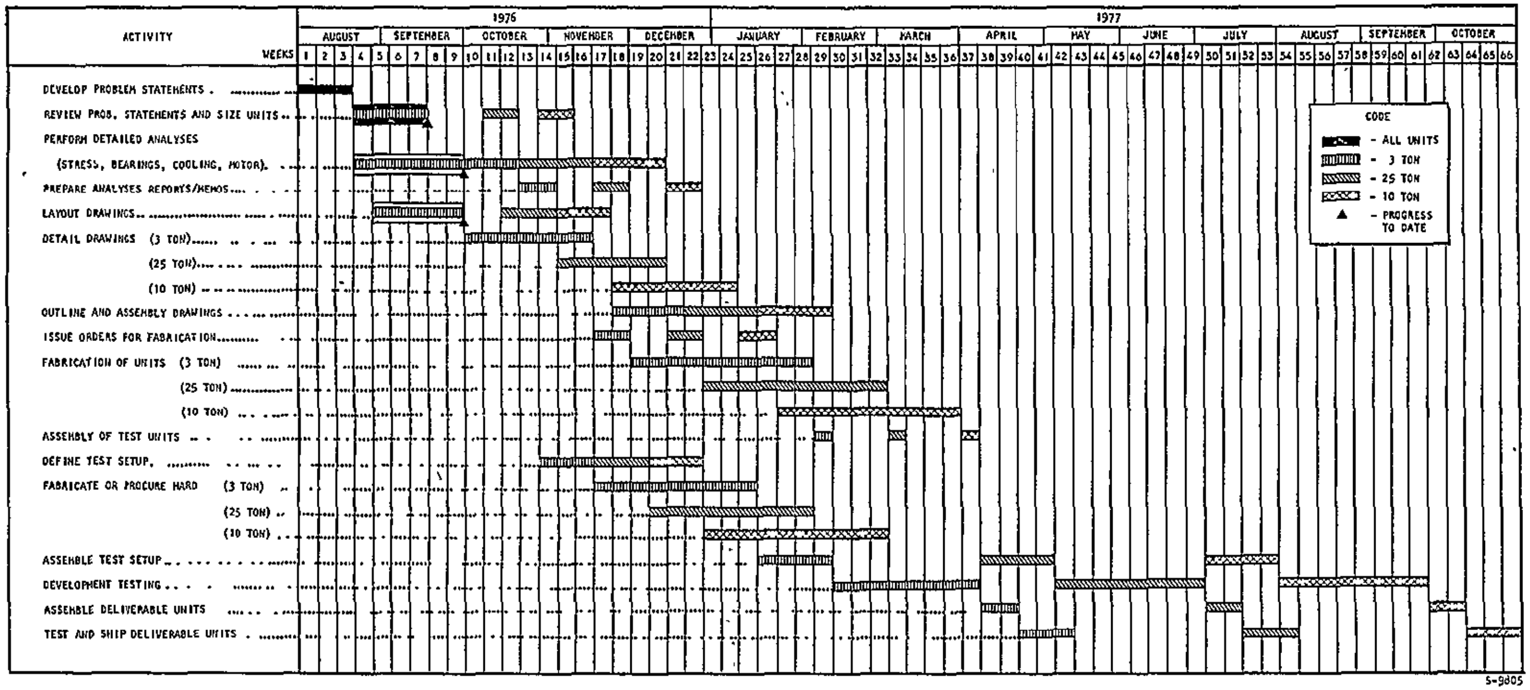

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Figure 3-1. Turbomachine Development Schedule

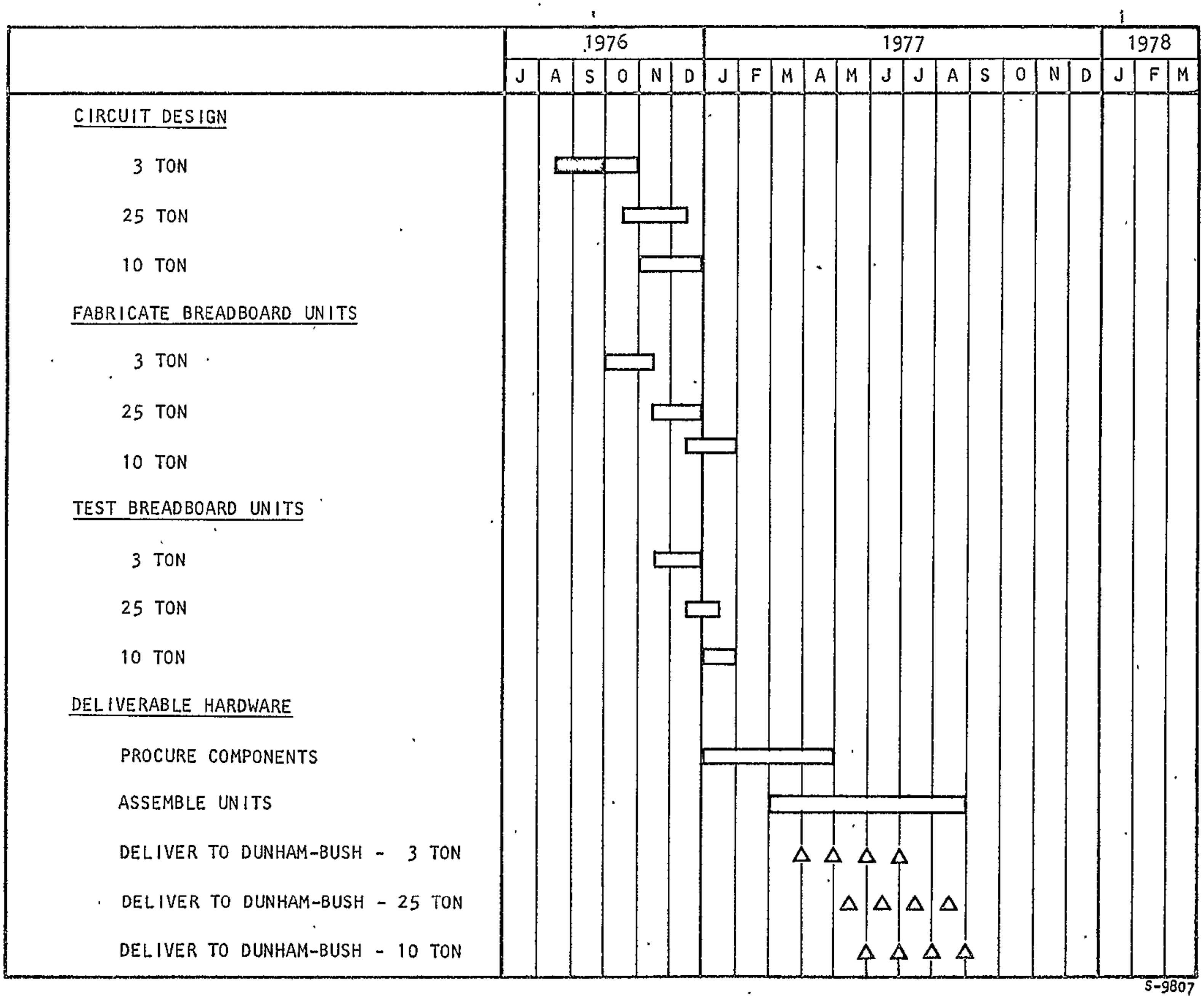

Figure 3-2. Motor Control Development Schedule

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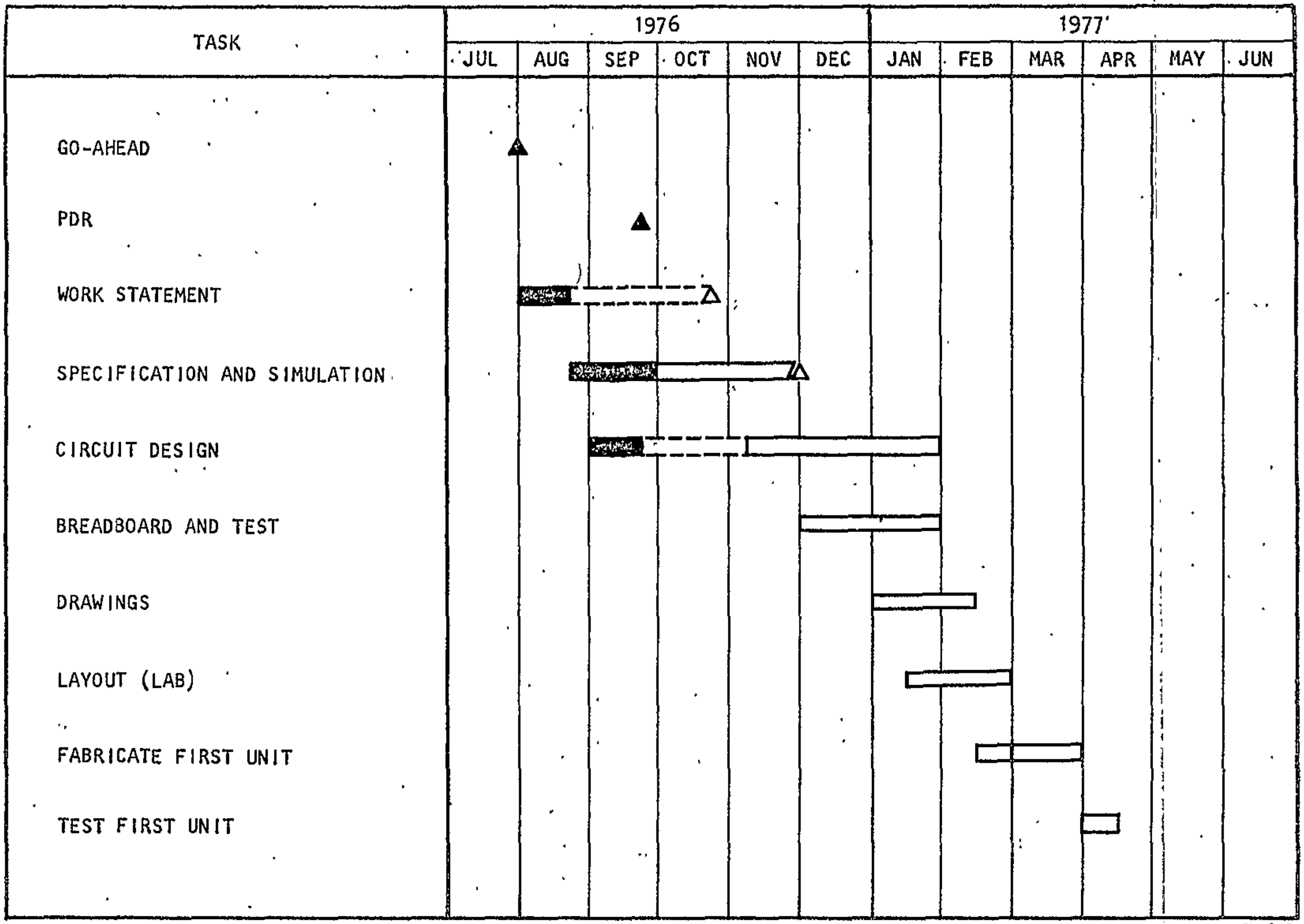

Figure 3-3. System Control Development Schedule

ACTIVITY	ACTIVITY NUMBER	AUGUST				SEPTEMBER					OCTOBER				NOVEMBER					DECEMBER					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LAYOUT DRAWING																									
DETAIL DRAWING																									
ASSEMBLY DRAWING																									
ISSUING ENGR. ORDERS FOR DEVELOPMENT PARTS																									
ISSUING SHOP ORDER FOR DEVELOPMENT PARTS																									
FABRICATION OF DEVELOPMENT PARTS																									
ASSEMBLY OF DEVELOPMENT UNIT																									
WRITING OF TEST PROCEDURE																									
DETERMINE REQUIRED TEST EQUIPMENT																									
PROCURE PARTS AND BUILD TEST RIG																									
RUN DEVELOPMENT TESTS																									
REVIEW DEVELOPMENT TEST DATA																									
INITIATE REQUIRED CHANGES FOR UNITS																									
WRITING OF DEVELOPMENT TEST REPORT																									

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Figure 3-4. Bearing/Motor Test Unit Development Schedule

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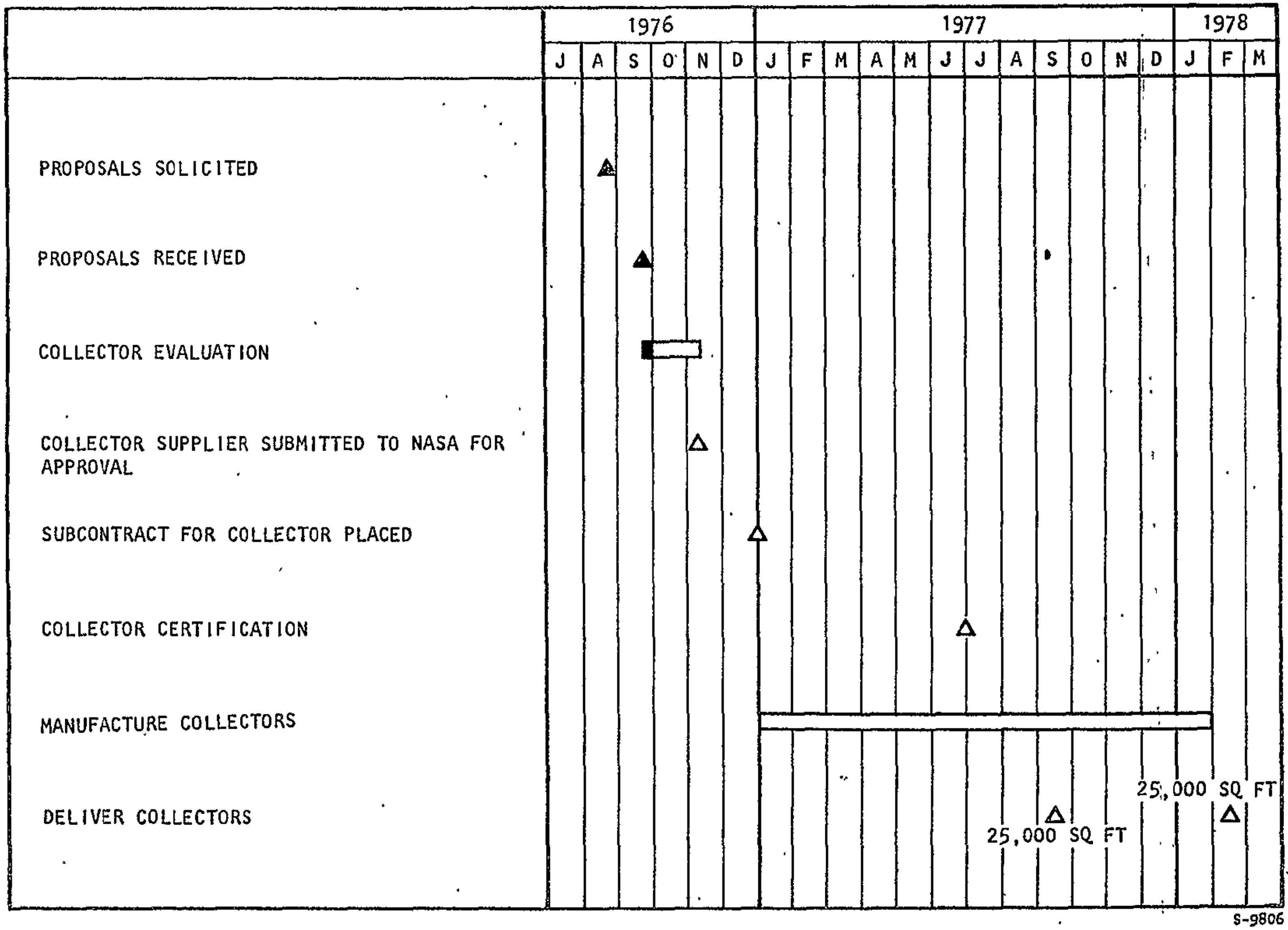

Figure 3-5. Solar Collector Development Schedule

SECTION 4

TECHNICAL PERFORMANCE

INTRODUCTION

Technical status is reported below for all WBS tasks active in the reporting period. The WBS of Figure 4-1 identifies the active tasks with an asterisk (*). Activities during the first quarter were involved with:

- WBS 1.1 MANAGEMENT
  - WBS 1.1.1 Program Direction
    - Meetings, reviews and major events
    - Site selection
    - Heat pump size definition
    - Dunham-Bush contract
    - Preliminary design review
    - Collector procurement
  - WBS 1.1.2 Program planning and control
    - Schedule development
    - Work authorization
    - Program documentation
  - WBS 1.1.3 Quality assurance
    - Quality assurance plan
- WBS 1.2 DEVELOPMENT
  - WBS 1.2.1 System analysis and integration
    - Fluid selection investigations
    - Preheater benefit
    - Interchanger penalties
    - Cooling mode heat pump design point
    - Tank and system heat losses
    - Control scheme refinement
    - Tank manifold concept development
    - Domestic hot water subsystem refinement
    - Material compatibility
    - System instrumentation requirements
    - Heat pump equipment problem statements
    - Hazard analysis (heating mode)
    - Control scheme simulation

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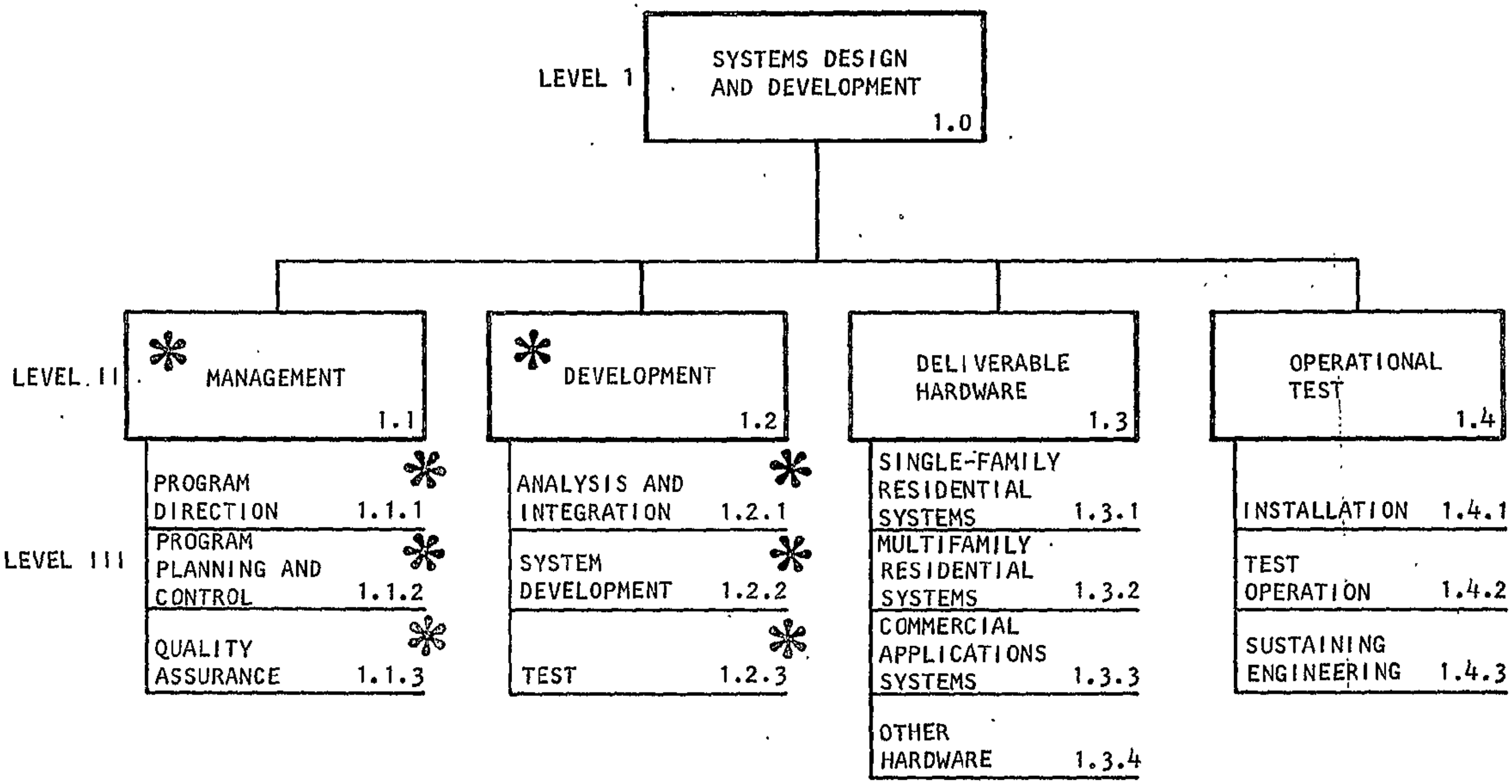

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Figure 4-1. Top-Level Work Breakdown Structure

WBS 1.2.2 System development

Heat exchanger design

Turbomachine/motor design

Motor control design

System control design

Heat pump design

WBS 1.2.3 Test

Single tube heat transfer

Thermal stratification

Bearing/motor test

Motor control breadboard test

Heat pump test equipment

Progress on all these items is described in the following paragraphs.

ACTIVITIES IN REPORTING PERIOD

WBS 1.1, MANAGEMENT

1. WBS 1.1.1, Program Direction

a. Meetings, Reviews, and Major Events

Important events of the last quarter were:

(a) The contract was negotiated in June 1976

(b) The effective date of the contract is July 12, 1976

(c) A kick-off meeting was held at AiResearch on July 27, 1976

(d) A coordination meeting was held at NASA on August 3, 1976 involving the three "System Design and Development" contractors, IBM and NASA

(e) The preliminary design review for the solar heating systems was held at AiResearch on September 22 and 23, 1976

(f) The program quarterly review is scheduled for October 14, 1976 at the AiResearch facility in Torrance

Action items and significant program and technical topics that were discussed or initiated at these meetings are discussed under the appropriate WBS items.

b. Site Selection

At the July 27 kick-off meeting AiResearch was directed to perform a site selection study and to provide NASA with recommendations. The recommendations given NASA included company (AiResearch and Dunham-Bush) buildings and general areas within the U.S. suitable from a climatic and population viewpoint and where the solar systems could be marketed. Following this site survey, NASA identified the sites listed below for review by AiResearch:

Single family heating (80 KBTUH):	New York and Fresno
Single family heating (80 KBTUH): and cooling (3 ton)	Des Moines and Washington, D.C.
Multifamily heating (250 to 800 KBTUH):	Detroit and Richmond
Multifamily heating (250 to 800 KBTUH): and cooling (10 to 25 ton)	Los Angeles, and Columbus, Georgia
Commercial heating (250 to 1600 KBTUH):	Milwaukee and Syracuse
Commercial heating (250 to 1600 KBTUH): and cooling (10 to 50 ton)	Las Vegas and Houston

Except for Fresno where climate data are better suited to testing cooling systems, these sites are acceptable; however, AiResearch would like to request two changes. It is believed that it would be very beneficial to the program to utilize the Dunham-Bush company property in Harrisonburg, Va for two of the operational test sites. One site is a house (unoccupied) which would be appropriate for testing the single family residential system. The other is an office area that would be appropriate for testing the 800,000-Btu/hr solar system in a commercial application. It is proposed that these sites be substituted for the Fresno and the Richmond heating-only sites.

AiResearch proposes that these sites serve as pilot installations for the 80,000- and 800,000-Btu heating systems and that after the first heating season, these two systems be converted to heating/cooling systems for the remainder of the program. These sites would therefore also serve as pilot installations for the cooling portions of the systems. The installation of these systems would be scheduled 30 to 60 days ahead of the installation of the remaining systems.

AiResearch believes that such a plan would offer the following advantages to the program:

- These sites would offer an opportunity to work out any installation problems for both heating and cooling systems prior to starting the other installations because the full engineering staff would be available on immediate call to expedite troubleshooting.

- Similarly, if field problems occur at the other sites, the Dunham-Bush sites would be invaluable for simulating, evaluating, and correcting such problems.

- In the original development plan, it was proposed to retain heating/cooling systems of the 3-ton/80,000-Btu and 25-ton/800,000-Btu size in the Dunham-Bush laboratories to support troubleshooting of field problems. Under the proposed revised plan, it would no longer be necessary to retain this equipment, and it could be utilized to convert the heating systems to heating/cooling systems at the two Dunham-Bush sites. Accordingly, the number of heating/cooling systems in the program would be increased from six to eight at no additional cost to the program. (Heating-only systems would be reduced from six to four.)

Because the sites would be under direct company control, it would be simpler to impose any unusual test conditions that might be necessary for off-design and design limit testing.

Travel costs to support these two operational test sites would be eliminated.

Greater familiarity with system on-site operation would enhance the capability of the design staff to develop more marketable systems.

It is requested that NASA give full consideration to these proposed sites when the test site list is finalized.

It should be emphasized here that detailed site definition should be resolved by November 1, 1976 to prevent major impact on the overall program schedule.

c. Heat Pump Size Definition

A market survey was conducted to define the optimum sizes of heating and heating/cooling systems to be developed under this contract. As a result of these investigations the following sizes were selected:

Single family residence:

Heating = 60,000 Btu/hr
Cooling = 3 tons

Multifamily residence:

Heating = 600,000 Btu/hr
Cooling = 25 tons

Commercial applications:

Heating = 200,000 Btu/hr
Cooling = 10 tons

These capacities are not necessarily those of the overall system. Trade studies conducted previously have shown that for cost effectiveness in the heating mode of operation, for example, the total system capacity is much larger than that of the heat pump: the difference requires the use of auxiliary energy to accommodate peak loads.

The detailed rationale for the selection of these optimum heat pump sizes were presented to NASA with the PDR data package and discussed at the PDR. The heat pump capacities were approved by NASA.

d. Dunham-Bush Contract

A letter-type contract was awarded Dunham-Bush immediately following AiResearch contract award. This initial contract covered the initial phase of the program. The formal contract with Dunham-Bush is being finalized.

e. Preliminary Design Review

The preliminary design review (PDR) of the heating systems was conducted at AiResearch on September 22 and 23, 1976. Twenty-four review item discrepancies (RID's) were assigned to AiResearch. A summary of these RID's showing scheduled completion dates is included as Table 4-1. Sixteen of these RID's were answered in writing in the reporting period. The detailed data necessary to answer the following six (due 10/8/76) are being assembled. Two RID's are scheduled for completion November 1, 1976.

f. Collector Procurement

The requirements for a collector panel suitable for incorporation in the heating and heating/cooling systems were developed. A work statement was prepared and an RFP was issued. This RFP was submitted to 32 collector manufacturers on August 30, 1976. Proposal due date was initially set as September 20, 1976; the closing date was extended by one week.

Thirteen proposals were received and are currently being evaluated. A list of the organizations solicited and those who responded is given in Table 4-2.

2. WBS 1.1.2, Program Planning and Control

a. Schedule Development

The program schedules have been updated throughout the first quarter to reflect funding availability and program requirements. The latest sessions of the program schedule for the heating and for the heating/cooling systems have been presented in Section 3.

b. Work Authorization

Engineering work authorization (EWA) have been released covering all current activities. EWA's are being released on an as-required basis to cover new work tasks as the program develops.

3. Program Documentation

The following documents were prepared in accordance with the requirements of Appendix A of the Statement of Work.

(a) Development Plan--DR 500-1--AiResearch Report No. 76-13047

(b) Verification Plan--DR 500-2--AiResearch Report No. 76-12996

(c) Quality Assurance Plan--DR 500-3--AiResearch Report No. 76-13043

(d) PDR Data Package--DR 500-1--AiResearch Report No. 76-12994

(e) Monthly Progress Reports No. 1, 2, and 3--DR 500-11--AiResearch Report Nos. 76-13110(1), 76-13110(2), and 76-13110(3).

(f) Special Handling, Installation and Maintenance Tool List--DR-500-15--AiResearch Letter CAJWY:6601:0825 to K. Sowell, NASA, dated August 25, 1976

TABLE 4-1

RID's SUMMARY

RID No.	Tracking No.	Subject	Scheduled Completion Date
AR-PDR-H-1	AR-3	Two-Phase Compressor Operation	10/1/76
AR-PDR-H-2	AR-10	Storage Subsystem	10/1/76
AR-PDR-H-3	AR-13	Auxiliary Subsystem	10/1/76
AR-PDR-H-4	AR-14	Domestic Hot Water Subsystem	10/1/76
AR-PDR-H-5	AR-15	Domestic Hot Water Subsystem	10/1/76
AR-PDR-H-6	AR-16	Heating Subsystem	10/8/76
AR-PDR-H-7	AR-17	Domestic Hot Water Subsystem	10/1/76
AR-PDR-H-8	AR-19	Energy Storage Subsystem	10/8/76
AR-PDR-H-9	AR-21	Domestic Hot Water Subsystem	10/1/76
AR-PDR-H-10	AR-23	Energy Storage/Domestic Hot Water Subsystems	10/8/76
AR-PDR-H-11	AR-24	Heat Pump	10/8/76
AR-PDR-H-12	AR-25	Heat Pump	10/1/76
AR-PDR-H-13	AR-26	System Analysis	10/8/76
AR-PDR-H-14	AR-28	Auxiliary Subsystem	10/1/76
AR-PDR-H-15	AR-29	Heat Pump	10/1/76
AR-PDR-H-16	AR-32	Control	10/8/76
AR-PDR-H-17	AR-2	Control Mode Simulation Data	11/1/76
AR-PDR-H-18	AR-27	Instrumentation	10/1/76
AR-PDR-H-19	AR-7	Electrical Energy Transducers	10/1/76
AR-PDR-H-20	AR-9	Preliminary Instrumentation Lists	10/1/76
AR-PDR-H-21	AR-6	Materials Compatibility--Corrosion	10/1/76
AR-PDR-H-22	AR-30	Heat Pump	10/1/76
AR-PDR-H-23	AR-4	Verification Plan	10/8/76
AR-PDR-H-24	AR-1	Quality Assurance Plan	11/1/76

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TABLE 4-2

COLLECTOR MANUFACTURERS REQUESTED TO PROPOSE

Solicited Organization	Proposal Received Oct 1, 1976	Declined to Propose
Acurex-Aerotherm, Calif.	X	
Amatek, Penn.		
American Helio Thermal Corp., Colo.	X	
Calmac Mfg Corp., N.Y.	X	
Chamberlain Mfg Corp., Iowa	X	
Corning Glass, N.Y.		X
Daystar Corporation, Mass	X	
DMG Company, Inc., Calif		X
Energy Converters, Tenn	X	
Energy Systems, Inc., Calif		
Energix Corp., Na		
FMC Engineered Systems Div., Calif		
Fun and Frolic, Inc., Michigan		
General Electric Company, Penn	X	
Grumman Aerospace, N.Y.		X
Halstead-Mitchell, Alabama		
International Environment Corporation, N.Y.		
KTA Corporation, Md		
Libbey Owens Ford, Ohio	X	
Martin Marietta, Colorado		X
Northrop Incorporated, Texas	X	
Owens Illinois, Ohio	X	
PPG Industries, Pa	X	
Raypack, Calif		
Revere Copper and Brass Inc., N.Y.		
Reynolds Metals Co., Calif	X	
Solaray Corp., Hawaii		
Solar Energy Systems, Inc., N.J.	X	
Solar Research Div., Refrigeration Research, Inc. Michigan		X
Solar Systems, Inc., Texas		
Sun Systems, Inc., Illionis		
UOP, Inc., Wolverine Div., Alabama		X

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(g) Hazard Analysis--DR 500-18--AiResearch Report No. 76-13048

(h) Logistic Plan--DR 500-22--AiResearch Report No. 76-13051

(i) Safety and Health Plan--DR 500-24--AiResearch Report No. 13046

(j) New Technology Reporting Plan--DR 500-25--AiResearch Report No. 76-12776

(k) Instrumentation List--AiResearch Report No. 76-13139

(l) Preliminary Design Review Handout--AiResearch Report 76-13203

(m) RID's Disposition Package--AiResearch Letter CAJDM:6480:1001 to Mr. Stan Wade/FA02 dated October 1, 1976

A review of all documents submitted at the time of PDR was conducted. Listed below are comments and/or action items relative to these documents:

The development plan will be revised to include system level acceptance testing and to update the program schedules.

The verification plan will be revised.

Approval of the quality assurance plan was deferred until communication between the NASA responsible NASA QA personnel and the DCAS representatives at AiResearch.

The "Special Handling, Installation, and Maintenance Tool List" was approved.

More time is required by NASA for review of the hazard analysis.

The logistics plan was approved.

Approval of the safety and health plan was deferred.

The new technology plan was approved.

4. WBS 1.1.3, Quality Assurance

The quality assurance plan was submitted in accordance with the requirements of DR 500-3.

WBS 1.2, DEVELOPMENT

1. WBS 1.2.1, Analysis and Integration

a. Fluid Selection Studies

Detailed investigations were conducted to assess the merits of R-12 and R-114 relative to R-11 as the heat pump working fluid. These studies used the heat pump design optimization program available at AiResearch. These studies show the following:

(a) R-12 could be used in the larger-size machine in the heating mode of operation. This would result in smaller heat exchangers at slightly lower performance.

(b) In the cooling mode of operation, R-12 is unacceptable because of the very low COP's achieved with this fluid. In addition, considerable superheat is necessary to assure dry conditions in the turbine. This further decreases the performance of the cooling systems with R-12.

(c) The use of R-114 results in lower COP's by comparison with R-11. In addition, the higher flows necessary with R-114 more than offset the advantages of its higher density in terms of heat exchanger size.

The results of these investigations confirmed the original selection of R-11 as the optimum overall fluid for the solar heating/cooling heat pumps. Detailed data can be found in the PDR data package (AiResearch Report 76-12994).

b. Preheater Benefit

Elimination of the preheater results in very slightly lower solar energy utilization (less than 1 percent) but in an overall cost savings over the life of the system. The cost savings are the result of lower initial and installation cost through elimination of heat exchangers, valves, piping, and controls. Details of these studies leading to removal of the preheater from the baseline system are given in the PDR data package and in the answer to RID AR-PDR-H-6 (Tracking No. AR-16).

c. Interchanger Penalties

The interchanger introduces undesirable thermodynamic penalties that result in reduced performance in terms of solar energy utilization and higher cost. For a fixed collector area, the interchanger will increase total auxiliary and parasitic energy usage by about 5 percent; interchanger cost represents about 2 percent of the initial cost of the system.

The purpose of the interchanger is to isolate the collector loop from the remainder of the system and thus obviate corrosion problems in the collector panels. The desirability of the interchanger still is under investigation and final decision with regard to its incorporation in the system has been postponed pending collector selection. Interchanger penalties will be considered in collector selection, (Reference the PDR data package for details.)

d. Cooling Mode Heat Pump Design Point

The condenser and cooling tower sizes were reduced significantly from those proposed by increasing condensing temperature at design point from a nominal 92° to 94°F. This results in a cooling tower approach temperature of 6.5°F with reduced cooling tower fan and pump power.

Year-round analysis of the residential size heating/cooling system indicates that the total solar energy utilization is about the same with the higher condensing temperature, and the electrical energy usage is slightly reduced due to parasitic power reduction. (See PDR data package for details.)

e. Tank and System Heat Losses

The sensitivity of the system to heat losses was investigated through year-round system performance analysis of the 25-ton/800,000-Btu/hr system using the Nashville multifamily residence as the model. The analysis shows only a negligible effect in the heating mode of operation, primarily because of the low tank-to-ambient temperature difference. In the cooling mode, increasing the heat losses by a factor of 2 will result in a 20-percent increase in the auxiliary power used to drive the air conditioner; however, since the total amount of auxiliary electrical energy is very low (about 300 kwhr per year), this effect is not considered significant.

More detailed studies of heat losses will be conducted following site definition. Reference is made to the PDR data package and to the answer to RID AR-PDR-H-13 (Tracking No. AR-26).

f. Control Scheme Refinement

The control scheme in the heating mode was revised and simplified especially for the 3-ton/60 KBTUH and the 10-ton/200 KBTUH heat pump. The requirement for sensing outside temperature was eliminated for the two units. The revised control schemes were used to initiate system control design activities.

g. Tank Manifold Development

A tank manifold concept was developed to promote thermal energy stratification. A scaled model of a water storage tank has been fabricated for design verification testing and fine tuning of the detail arrangement of the manifold.

h. Domestic Hot Water Subsystem Refinement

The requirements for domestic hot water (DHW) were revised using the latest methods developed by ASHRAE. A detailed evaluation of a dedicated DHW subsystem is currently being conducted for comparison with the integrated concept proposed as baseline.

i. Material Compatibility

Preliminary investigations were made of material compatibility in the various system water loops. The purpose of these investigations is to identify potential problems and to develop suitable solutions prior to system design. This work will continue throughout the design activity. (See RID AR-PDR-H-21, Tracking No. AR-6.)

j. System Instrumentation Requirements

Investigations were conducted to identify the instrumentation required for system evaluation. Preliminary instrumentation lists were prepared for the six systems and submitted to NASA.

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k. Heat Pump Equipment Problem Statement

A careful analysis of the heat pump performance was used to finalize equipment problem statements. Compressor and turbine preliminary designs were reviewed for the residential (3-ton/80,000-Btu/hr), multifamily (25-ton/800,000-Btu/hr), and commercial (75-ton/2 x 10^6-Btu/hr) units. Component problem statements were developed for all components for all sizes to include (1) compressor, (2) turbine, (3) motor, (4) motor control, (5) R-11 boiler, (6) condenser, (7) evaporator, (8) R-11 pump, (9) terminal units, and (10) cooling tower. These data are given in the PDR data package.

In the design of these components, both heating and cooling modes of operation were considered for reasons of hardware commonality--the heating-only machines utilize the same components and the same frame and cabinet as the heating/cooling versions.

l. Hazard Analysis

A hazard analysis was conducted in support of schematic development. The results of this analysis are presented in AiResearch report 76-13048.

m. Control Scheme Model

A simplified thermodynamic model of the overall system was developed for purposes of simulating the system control module interfaces and transient response. This model was incorporated in a transient computer program to be used to determine control stability during

- Normal operation
- On-off switching
- Auxiliary boiler operation
- Auxiliary heat modulation
- Step changes in heat loads and residence temperature

Data from this program should be available early in October.

2. WBS 1.2.2, System Development

As mentioned earlier, problem statements were generated for all sizes of heat pump components. Detail design of the component was initiated as well as the development of the heat pump packages.

a. Heat Exchangers

The preliminary design of all heat pump heat exchangers was completed including boilers, evaporator/condensers, condenser/evaporators, and terminal units. This was done for all size machines. All heat exchangers utilize standard Dunham-Bush basic heat transfer surfaces for which tooling is available. Further, the shells of the shell-and-tube heat exchangers are standard Dunham-Bush shell sizes (dia.).

The performance of the heat pump in the heating and cooling modes of operation is very sensitive to the performance of the heat exchangers. As is current practice in the design of high effectiveness units, basic single-tube heat transfer and pressure drop tests are planned to verify the design of the heat exchangers. These tests are further discussed under WBS Item 1.2.3.

b. Turbomachine/Motor

A layout of the 3-ton/60-KBTUH heat pump turbomachine was completed using a 6-pole motor with the magnets tangentially loaded in the rotor (wedge pole design). All related design analyses for this unit were completed. After the PDR, and prior to initiating detail design, an internal critical review meeting was held to discuss the basic design in terms of producibility, cost, and manufacturing techniques. It was recommended that an investigation be made to determine the possibility of using radially loaded magnets to enhance producibility and greatly decrease cost and assembly time. Preliminary results of this investigation are very encouraging.

Detail design of the unaffected items of the 3-ton/60,000-BTUH turbomachine has been initiated. The detailed analyses for definition of the turbine and compressor wheel aerodynamic passages have been completed for the 10- and 25-ton systems. The layout of the 25-ton machine has been started and detailed motor design analyses are being conducted for this unit. These analyses will be finalized after definition of a design approach for the 3-ton machine.

c. Motor Control

A transistor motor control approach has been selected for the 3-ton/60 KBTUH heat pump motor. The selection of this approach was based on consideration of cost in volume production. A conceptual design has been developed for this system and circuit mechanization has been started. Preliminary circuit designs for the rectifier and the series chopper have been completed.

For the 25-ton/600 KBTUH motor control, the current processed by the unit far exceeds the capability of available transistors. For this reason, the SCR approach was selected. This SCR conceptual design is complete, and detail design of the circuitry is about 70 percent complete.

A internal critical design review of the SCR motor control for the 25-ton unit was held in mid September. The preliminary design of the phase delay rectifier portion of this system has been completed and a breadboard is being assembled.

Trade studies are being conducted on the 10-ton/200 KBTUH motor controller to determine the optimum approach. In this case the current involved appears to be limiting with respect to the use of the transistor approach. Further studies are necessary to definitize the selection. Whichever approach is selected, the 10-ton/200 KBTUH motor control will be a scaled version of one of the other two.

On September 27, Frank Nola and Clyde Jones of NASA visited AiResearch to review the details of the variable-speed motor design and associated electronic control circuitry.

d. System Control

The system control scheme was developed for the three sizes of heat pumps in the heating and cooling modes of operation. A model is currently being developed and refined to assess the validity of the heating mode control scheme and the stability of the system. Preliminary design of the circuitry has been initiated.

The transient computer program developed to simulate control system behavior is about 95 percent completed and will be used to determine control stability during:

Normal operation

On-off switching

Auxiliary boiler operation

Auxiliary heat modulation

Step changes in heat loads and residence temperature

Data from this program should be available early in October.

e. Heat Pump Packages

Preliminary layout packages were developed for the three sizes of heating mode heat pumps. These packages were included in the PDR data package and discussed at the PDR. Work is proceeding on production layouts and details of the air loading portion of the single family unit. Prospective vendors have been contacted to determine cost and lead time of components such as valves, motors, controls, etc.

The heat pump packages include much of the heat transport subsystem, as well as electrical equipment of the electrical subsystem. Further, the auxiliary thermal energy subsystem for the 3- and 10-ton sizes constitutes an integral part of the heat pump packages.

3. WBS 1.2.3, Test

a. Single Tube Heat Transfer Tests

The purpose of these tests is to verify performance prediction and to ascertain the designs prior to fabrication. This approach is common practice in the design of high-efficiency heat exchangers and obviates costly iterations later in the program as well as schedule slips.

Pressure drop tests on the 1/2-in. and 3/4-in. inner-fin tubes and the Wolverine 1/2- and 3/4-in. inner spiral tubes were run using water. These tests were conducted to establish a firm basis for evaluation of the tube pressure drop under phase change operation (inner fins) and to provide accurate design data.

A heat transfer test rig has been designed and a series of tests has been defined to simulate the conditions under which the phase change heat exchangers will operate. The test tubes have been received from Dunham-Bush, and fabrication of the test rig is completed. The 1/2-in. and 3/4-in. inner-fin tubes have been instrumented and are ready for testing. Preliminary runs were made to check out test rig controls and instrumentation. These tests are scheduled for completion mid October.

b. Thermal Stratification Tests

A water storage tank model has been developed to provide experimental data on the effectiveness of manifold designs in promoting thermal stratification. The cylindrical test tank is 2 ft in dia by 3 ft high, and is fabricated of clear plastic so that the flow pattern in the tank can be observed by injecting food coloring in the inlet water stream.

Preliminary tests were conducted using the circular manifold configuration described in the PDR data package. Successful operation was demonstrated with this configuration for the collector loop--water inlet through the top manifold and withdrawl from the bottom. For the heat pump circuit, (water inlet through the bottom manifold) hydrodynamic interference between the manifold and the bottom of the tank, as well as the walls, resulted in rapid mixing; this configuration does not appear acceptable. Currently, alternate manifolding schemes are being investigated for evaluation in the model task.

c. Bearing/Motor Test

A bearing/motor test rig has been designed for evaluation of the bearings to be used in the 25-ton/600 KBTUH machine. The bearings are an existing design, and the motor is roughly the same size as that which will be required for the 25-ton turbocompressor. All drawings of the test rig have been released for fabrication. Fabrication of the bearing/motor test rig is proceeding. Motor rotor fabrication constitutes the pacing item and is scheduled for completion at the beginning of November.

d. Motor Control Breadboard

The development of a breadboard for the 25-ton SCR motor control has been initiated. At this time the breadboard of the phase delay rectifier portion of the SCR system is being assembled.

e. Heat Pump Test Equipment

Layouts of test setups for the 10- and 25-ton heat pumps have been developed and test equipment has been defined to support subsystem development and certification. Vendors have been contacted to determine lead times and equipment cost.

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FUTURE ACTIVITIES

Activities in the next quarter will include the following.

WBS 1.1, MANAGEMENT

1. WBS 1.1.1, Program Direction

The following meetings, reviews, and major events are anticipated:

The quarterly review will be held at the AiResearch plant in Torrance on October 14, 1976.

The cooling system preliminary design review is scheduled for mid December.

It is anticipated that site selection will be finalized by November 1, 1976 to prevent major impact on the overall program schedule.

A formal contract with Dunham-Bush will be signed.

Collector evaluation will be completed and a collector subcontractor will be selected. A contract will be awarded.

2. WBS 1.1.2, Program Planning and Control

Work authorization will be prepared and released as required. The following program documentation will be furnished per Data Requirement No. 500:

(a) DR 500-1, the development plan, will be revised to update the program schedules and to include system level acceptance testing

(b) DR-500-4, system performance specifications, will be prepared following analysis of the demonstration sites and system optimization for the 12 selected sites.

(c) DR 500-7, the preliminary design review package for the cooling systems will be prepared.

(d) DR 500-10, the second quarterly report will be prepared.

(e) DR 500-11, monthly status reports will be prepared and submitted to NASA.

(f) DR 500-27, financial management reports, will be provided monthly.

(g) Documents submitted to NASA for approval during the first quarter will be revised as required.

WBS 1.2, DEVELOPMENT

1. WBS 1.2.1, Analysis and Integration

The major effort will include:

- Collector performance evaluation using the system performance computer program
- Site analysis--following site selection an analysis will be conducted
- To define the peculiarities of the sites that will affect system design and optimization to include (1) heating and cooling loads, (2) area available for collector installation, (3) residence building orientation, (4) potential location of major equipment such as energy storage tank, heat pump package, auxiliary heater, cooling tower, and DHW tank, (5) climatic and insolation data, (6) utility power availability, and (7) economic analysis data
- Using the data generated above, system optimization studies will be conducted to develop performance and size requirements for the major subsystems and to generate the basic data necessary for the preparation of system performance specifications.

  Referring to the schedules of Section 3, it is apparent that site selection will have to be completed prior to November 1, 1976 so as not to interfere with the entire program schedule.

- Subsystem Requirements--The system optimization data will be used to generate problem statements for the various subsystems. The following information will be generated:

  a) Collector sizes

  b) Collector subsystem arrangement

  c) Water storage tank capacity and size

  d) DHW heater size and configuration

  e) Line insulation selection and thicknesses

  f) Auxiliary heater selection and size

- Material Compatibility--As the system detail design proceeds, more detailed data will be available for material studies. Inhibitors/deionizer will be defined and material lists will be prepared to ensure compatibility.

2. WBS 1.2.2, System Development

a. Design Activities

These activities will be initiated for the six heating systems. This will include overall system layouts, piping layouts, electrical schematics, and design of the collector arrays and supporting structure.

b. Heat Pump Component Development

(1) Heat Exchangers

The single tube heat exchanger test data will be analyzed and correlations will be developed to finalize the design of the heat exchangers. Heat exchanger sizes will be used to prepare layouts that will be used in the development of the final heat pump packages.

(2) Turbomachine/Motor

A schedule for the development of the three-size turbomachine is presented as Figure 3-1. The work schedule for the next reporting period is shown on the schedule.

(3) Motor Control

Figure 3-2 is a schedule covering the development of the motor controls for the three size machines. Work to be accomplished in the next quarter is shown.

(4) System Control

Computer simulation of the system control in the heating mode will be completed. The detail design of the circuitry will be completed and a breadboard will be developed. Following breadboard evaluation the detail design of the controller will be initiated. (See Figure 3-3).

(5) Heat Pump Package

Final layouts will be prepared for the three heating systems and details of the support structures and piping will be initiated. Completion of all details is scheduled for February 1977

(6) Miscellaneous Subsystems

The design of many subsystems will be conducted at the system level and at the heat pump package level. This includes (1) heat transport, (2) electrical, (3) energy storage tank, (4) auxiliary energy, and (5) controls subsystems.

(7) System Instrumentation

The instrumentation lists submitted to NASA will be updated following revision of the guidelines and as a result of system definition.

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(7) System Instrumentation

The instrumentation lists submitted to NASA will be updated following revision of the guidelines and as a result of system definition.

3. 1.2.3. Test

a. Single Tube Heat Transfer Tests

These test are scheduled for completion in October. Data will be analyzed and correlated in a form suitable for use in the heat exchanger design computer program.

b. Thermal Stratification Tests

These tests will proceed until a suitable manifold configuration is found that provides plug flow under all operating conditions. A second manifold design is scheduled for testing in October. It is anticipated that this test program will be completed in November.

c. Bearing/Motor Test

Fabrication of the bearing/motor test rig will be completed. The test machine will be assembled and tested. This series of tests is scheduled for completion in the next reporting period. See Figure 3-4.

d. Motor Control Breadboard Test

Fabrication and testing of the breadboard for the transistor control (3-ton) will be completed in the next reporting period. (See Figure 3-2.)

PART B

Second Quarterly Report
Data Requirement 500-10

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT

Contract NAS8-32091

76-13296(2)

January 10, 1977

Approved by

J. Rousseau

George McDonald

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama 35812

CONTENTS

SECTION 1

INTRODUCTION AND SUMMARY

INTRODUCTION

This is the second quarterly report prepared by AiResearch Manufacturing Company of California under Contract NAS8-32091 for the National Aeronautics and Space Administration, Marshall Space Flight Center (MSFC). The report summarizes activities from October 1, 1976 to January 1, 1977. Information contained in this document covers the scope of the December monthly report, which will not be published as agreed at the first quarterly review.

SUMMARY

Significant activities and status of the cost, schedule, and technical aspects of the program are summarized in the following paragraphs.

Cost Status

This paragraph has been deleted.

Schedule Status

No sites have been defined other than geographic locations. As a result of discussions with NASA, AiResearch is proposing to assist in the site selection task under NASA overall direction. It is believed that the entire process can thus be expedited to minimize schedule slippage.

It is estimated that a 12-month period is necessary to cover system design and installation in a typical case. Delays in site identification to date will preclude heating-only system installation as originally proposed. The original heating and cooling system schedule can be met, however, providing the sites are specifically defined within the next few months.

Every attempt will be made by AiResearch to accelerate the system design and installation tasks to minimize schedule slippage.

The latest schedules for the heating and the heating/cooling systems are presented in Figures 1-2 and 1-3.

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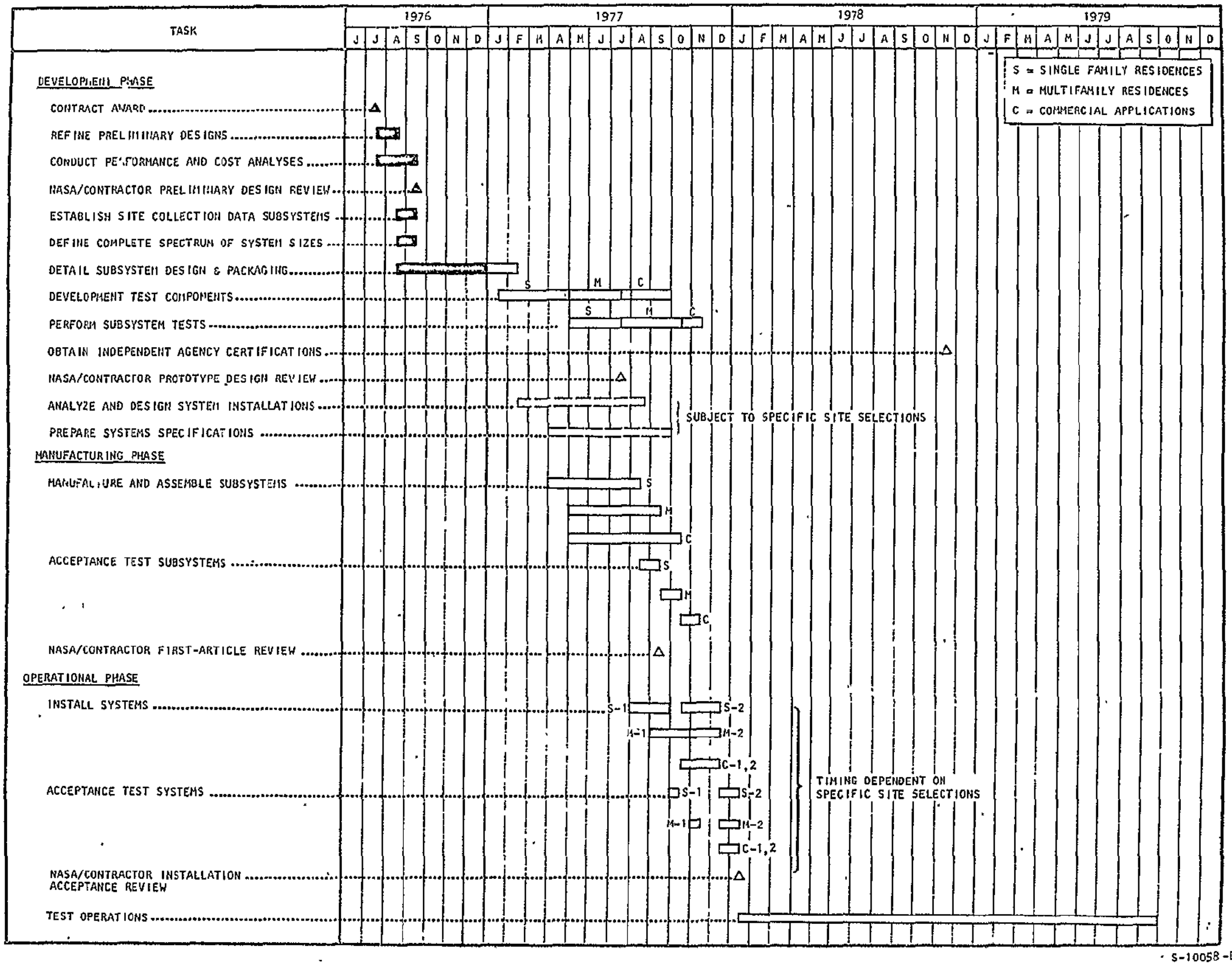

Figure 1-2. Heating System Schedule

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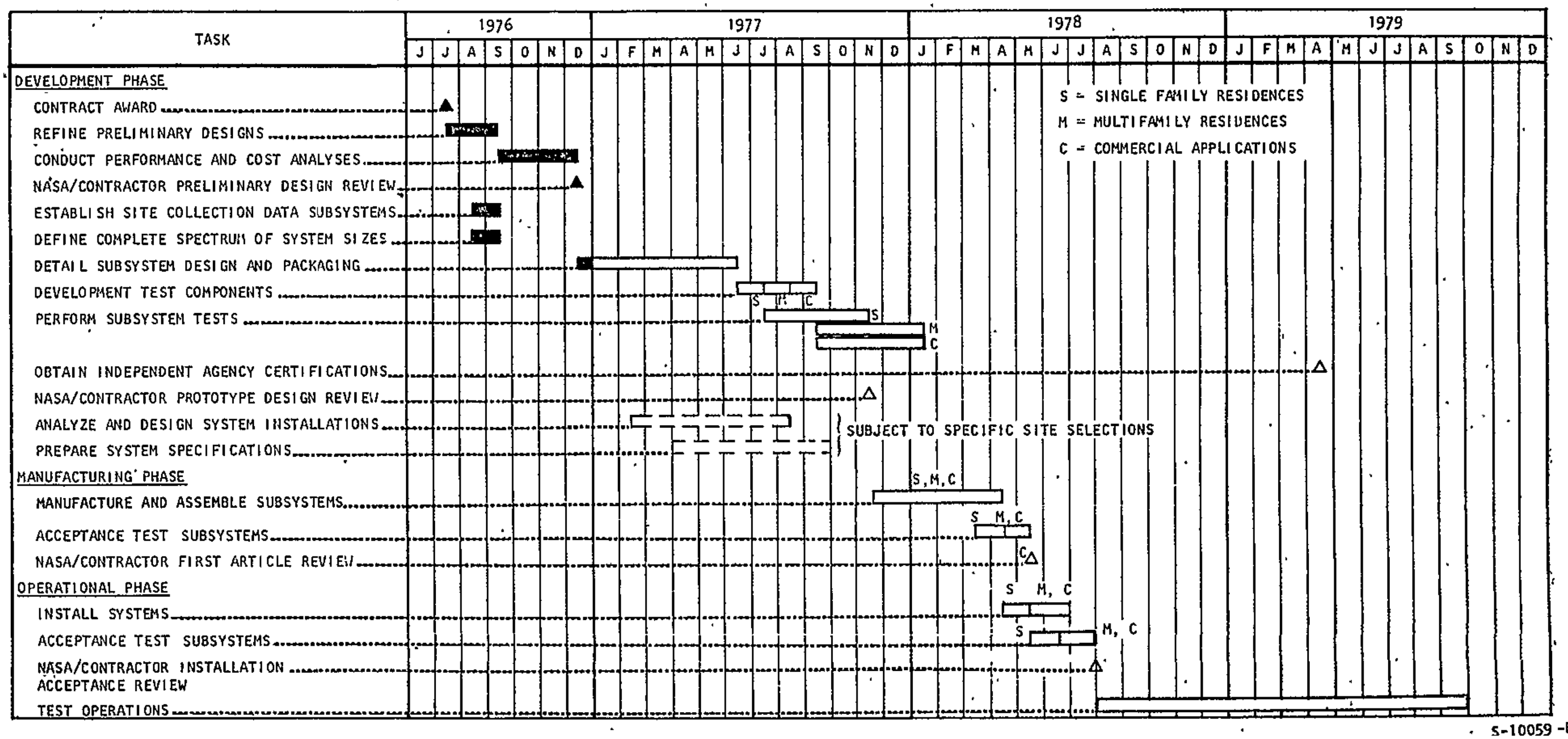

Figure 1-3. Solar Heating/Cooling Systems Development Schedule

Technical Status

1. Site Selection

As mentioned above, AiResearch is proposing to assist NASA in this task in an effort to accelerate the site selection process. The geographic locations will be as determined earlier by NASA.

2. Heat Pump Sizes

In the interest of the overall solar program, the commercial application system size was changed from a nominal 10 tons to 75 tons. In the present solar market the 75-ton unit will probably find many more applications than the smaller tonnage unit would.

The change from 10 tons to 75 tons will have only a minor effect on the overall heating-only system schedule and no effect on the heating-cooling systems.

3. Heating/Cooling System PDR

The preliminary design review for the heating and cooling systems was held at AiResearch on December 16, 1976. Nineteen review item discrepancies (RID's) were assigned to AiResearch. These RID's have been answered in writing and returned to NASA.

4. Collector Procurement

Final evaluation of the candidate solar collectors is being completed. The data generated will be documented in a PDR data package for presentation to NASA in Huntsville early in February.

5. Program Documentation

Documentation was prepared in accordance with the requirements of DR-500. A number of documents have been approved by NASA. Approval of the remainder awaits completion of review by NASA.

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SECTION 3

PROGRAM SCHEDULES

The overall program schedules are included in Figures 1-2 and 1-3 in Section 1. This section includes more detailed schedules (Figures 3-1 through 3-6) covering the development status of the critical subsystems and components. These schedules represent an update of those given in the First Quarterly Report. The component/subsystem schedule changes have only a very minor effect on the overall program schedule. The status and progress are given in Section 4.

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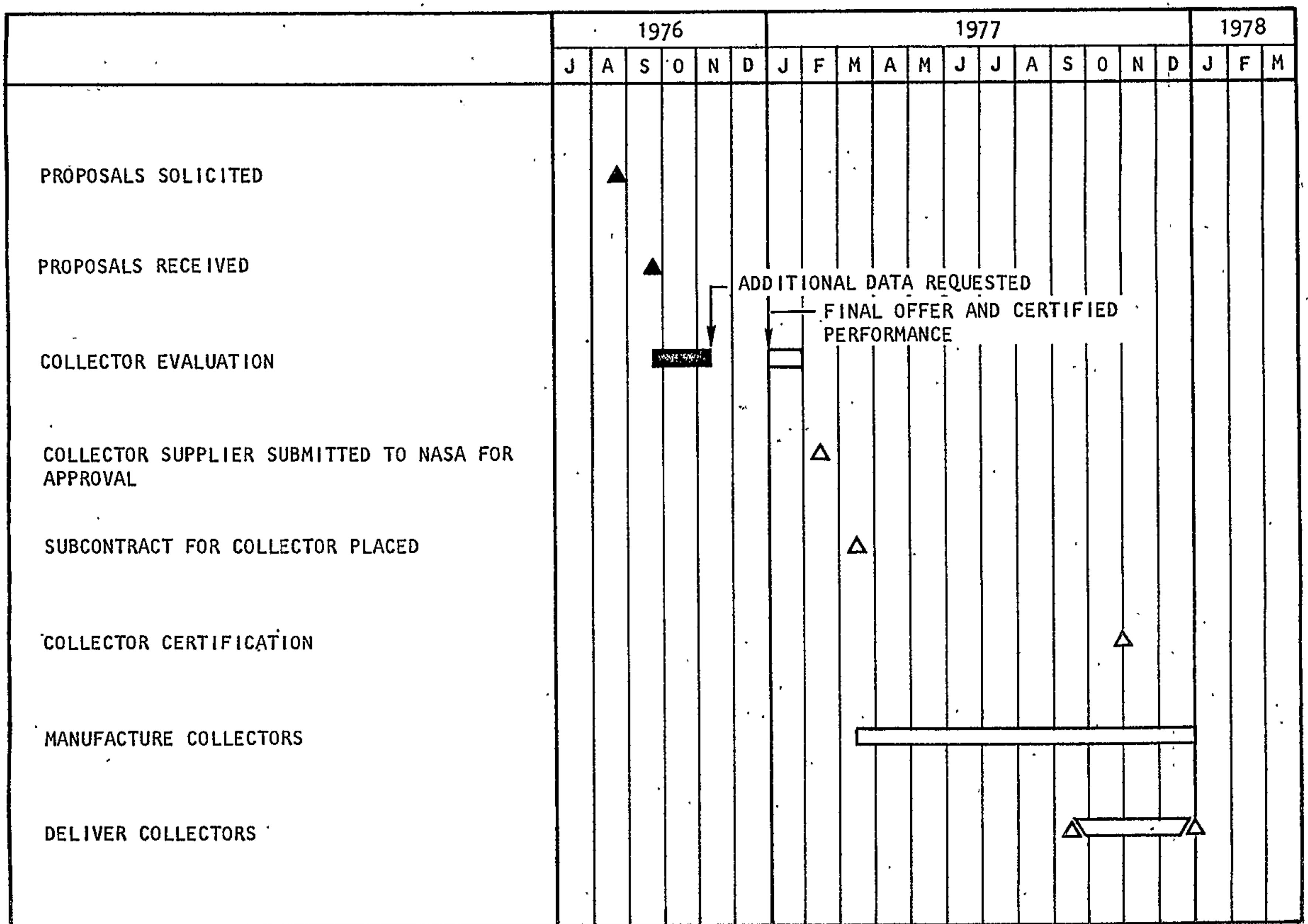

Figure 3-1. Solar Collector Development Schedule

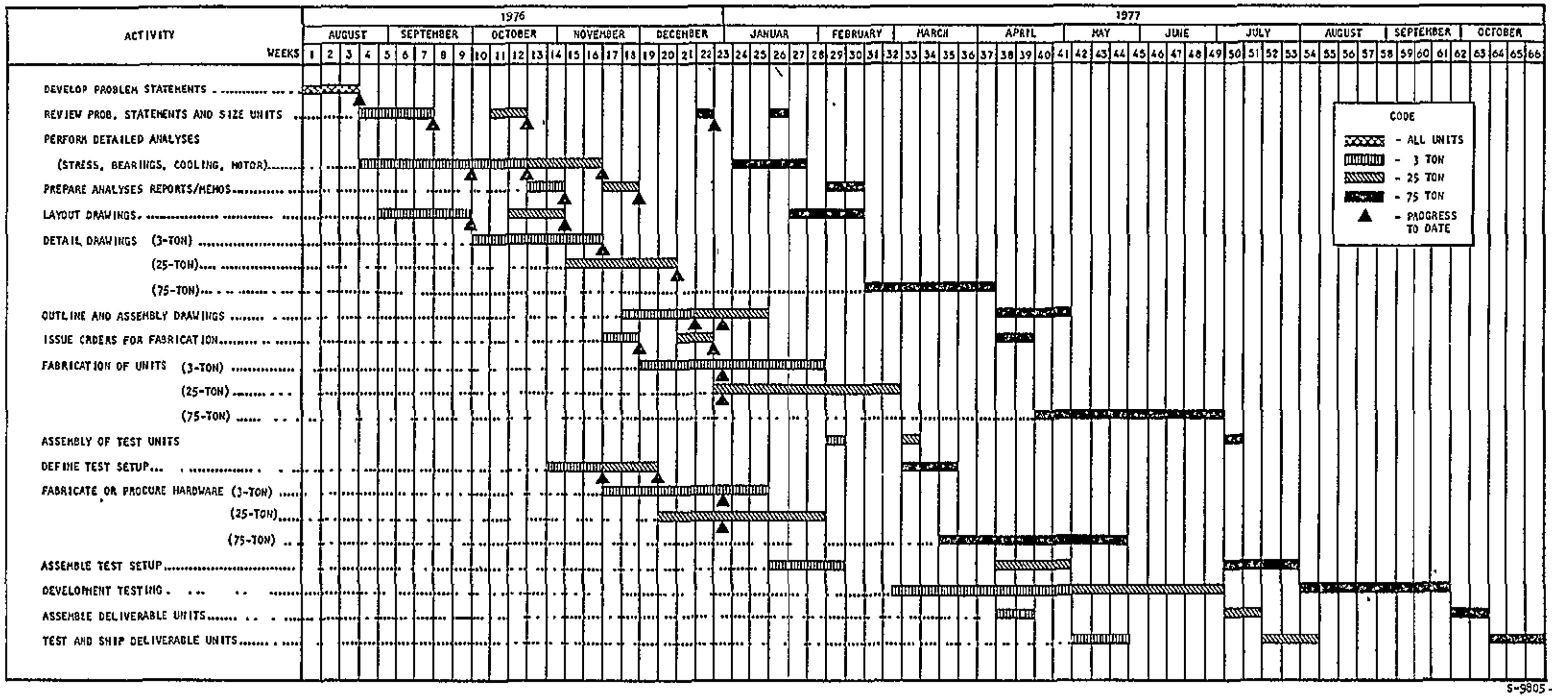

Figure 3-2. Turbomachine Development Schedule

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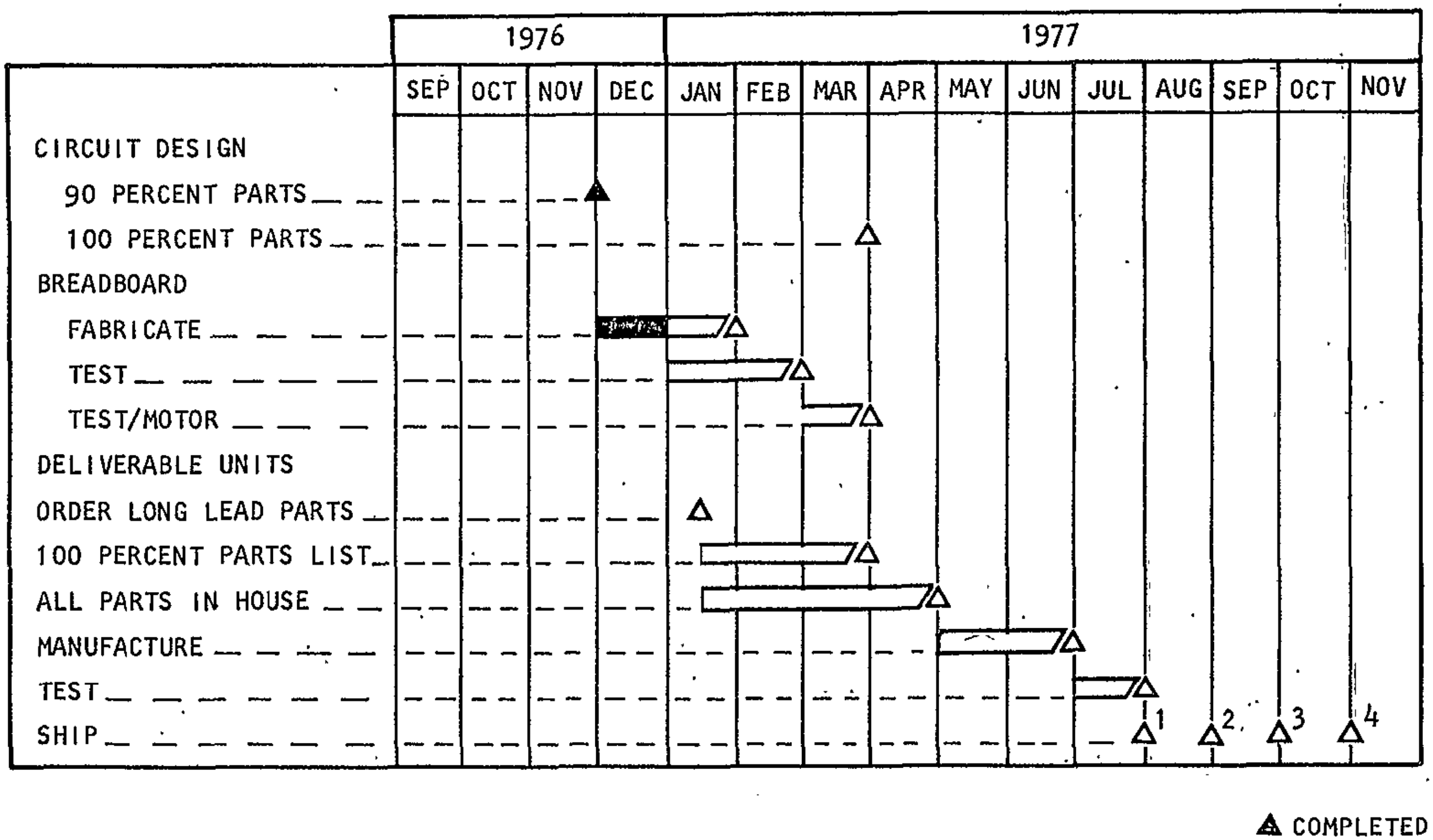

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Figure 3-3. 3-Ton Unit Motor Control Development Schedule

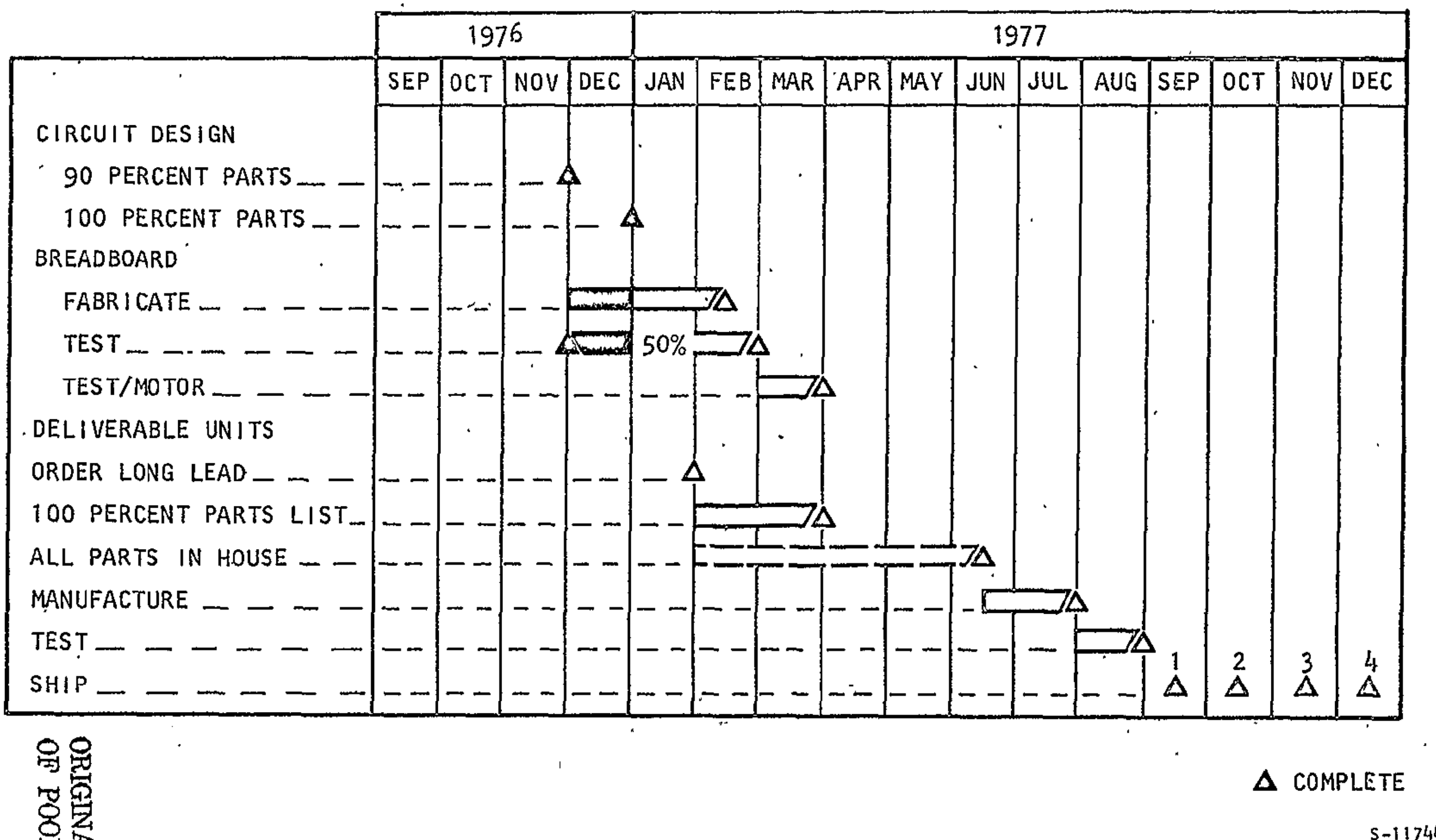

Figure 3-4. 25-Ton Unit Motor Control Development Schedule

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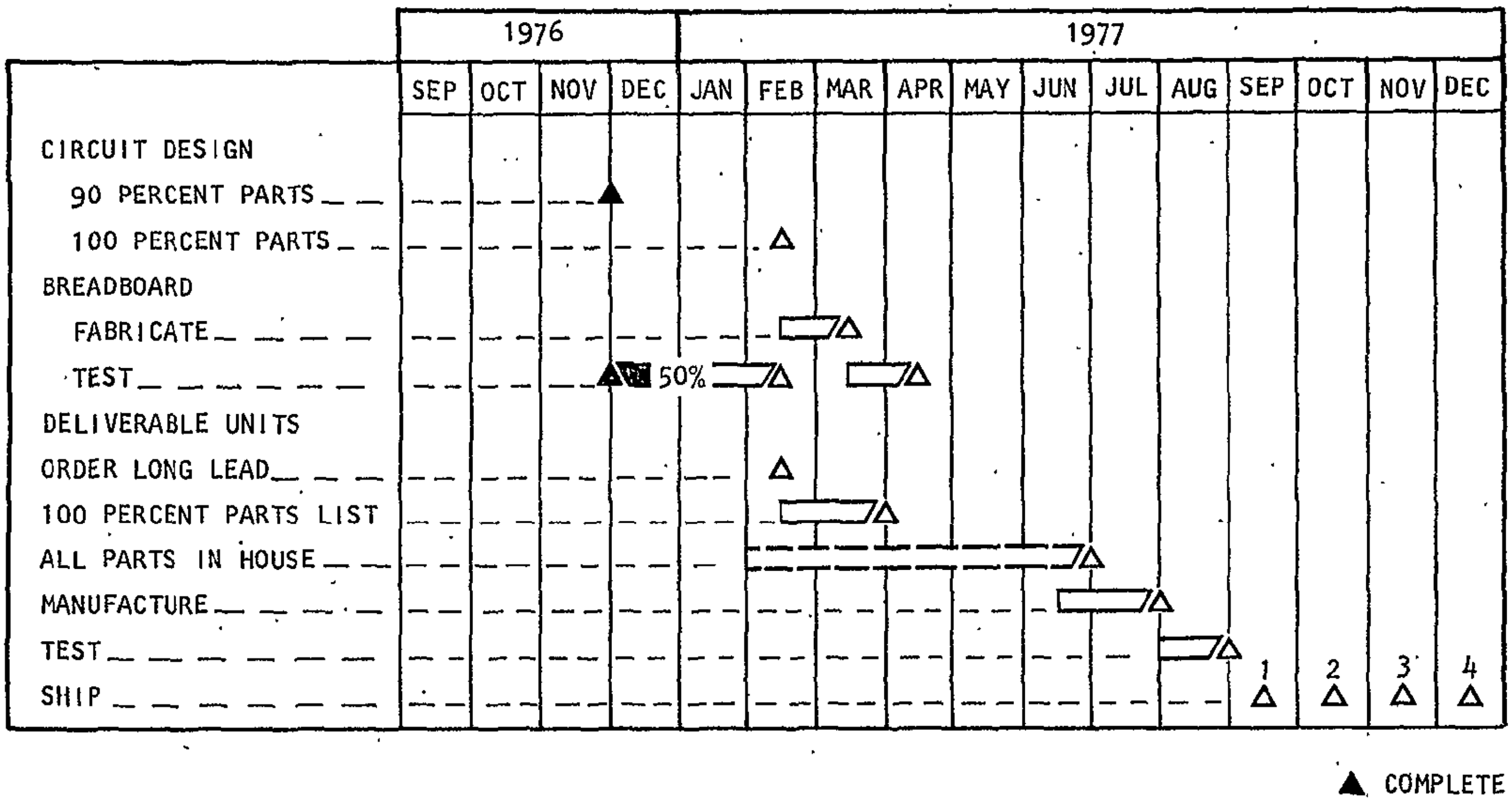

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Figure 3-5. 75-Ton Unit Motor Control Development Schedule

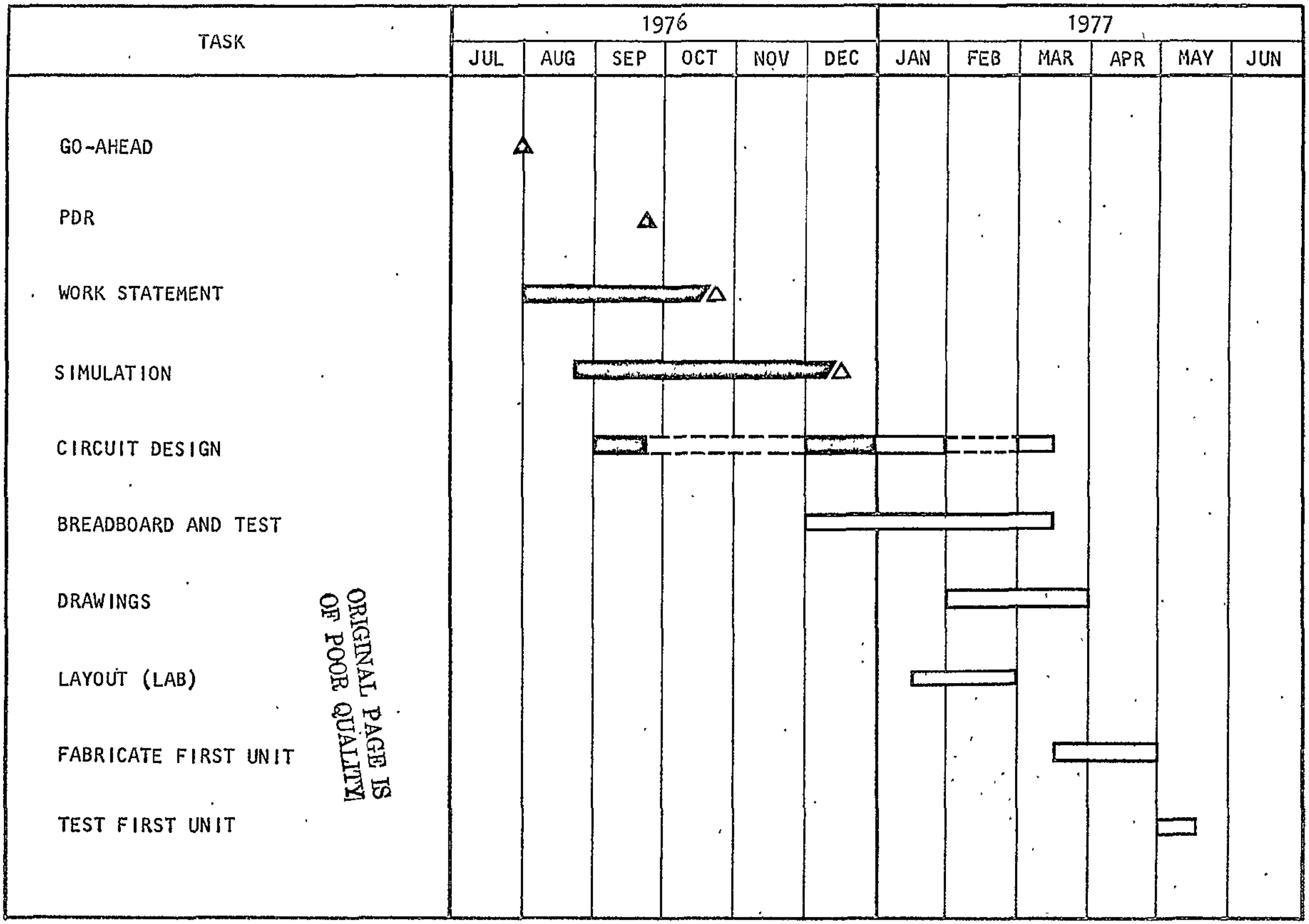

Figure 3-6. System Control Development Schedule

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SECTION 4

TECHNICAL PERFORMANCE

INTRODUCTION

Technical status is reported below for all WBS tasks active in the reporting period. The WBS of Figure 4-1 identifies the active tasks with an asterisk (*). Activities during the second quarter were involved with the following.

WBS 1.1, MANAGEMENT

WBS 1.1.1, Program Direction

Meetings, reviews, and major events

Site selection

Heat pump size definition

Dunham-Bush contract

Preliminary design review

Collector procurement

System instrumentation and data evaluation

WBS 1.1.2, Program Planning and Control

Schedule development

Program documentation

WBS 1.1.3, Quality Assurance

Quality assurance plan

WBS 1.2, DEVELOPMENT

WBS 1.2.1, System Analysis and Integration

System analysis

Control system simulation

Heat pump subsystem

R-11 pump

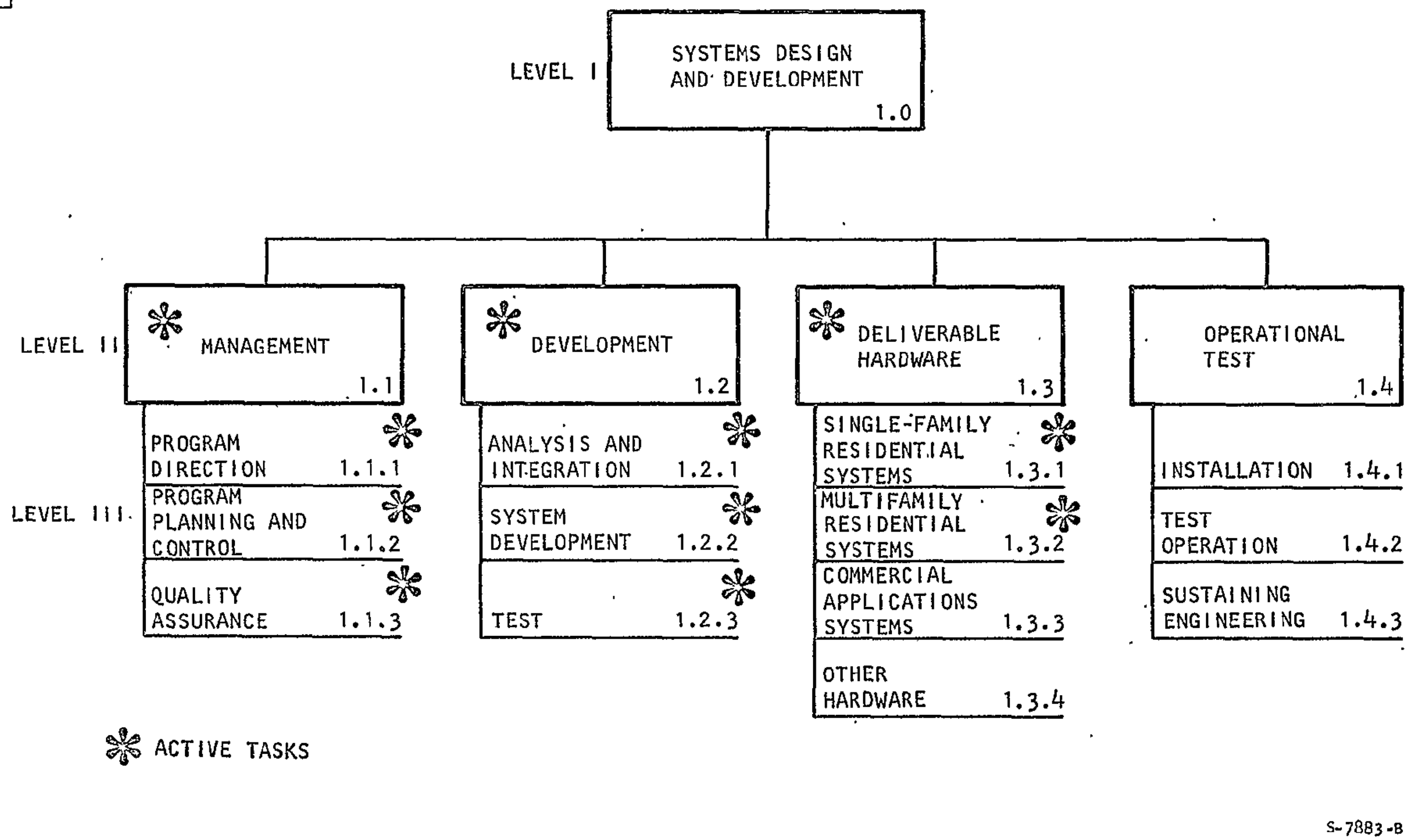

Figure 4-1. Top-Level Work Breakdown Structure

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Heat pump heat exchangers

Collector subsystem

Interchanger

Storage tank stratification

WBS 1.2.2, System Development

Turbomachine/motor design

Motor control design

Heat exchanger design

System control design

Heat pump packages

WBS 1.2.3, Test

Single tube heat transfer

Thermal stratification

Motor control breadboard test

Turbomachine/motor

Heat pump development

Condensate blowoff tank

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Progress on all these items is described in the following paragraphs.

ACTIVITIES IN REPORTING PERIOD

WBS 1.1, Management

1. WBS 1.1.1, Program Direction

a. Meetings, Reviews, and Major Events

Important events of the last quarter were:

(a) The first quarterly review was held at AiResearch on October 14, 1976.

(b) An engineering coordination meeting was held at NASA on October 19, 1976 to cover in detail the answers to some of the RID's assigned to AiResearch at the heating systems PDR.

(c) A presentation was made to ERDA/NASA on December 6, 1976. The AiResearch system concept for solar heating and cooling was reviewed and the economic feasibility of this approach was shown. An overview of this presentation was given at NASA on December 2, 1976.

(d) The preliminary design review for the solar heating and cooling systems was held at AiResearch on December 16, 1976.

(e) The second quarterly review is scheduled for January 11, 1976 at the AiResearch Torrance facility.

Action items and significant program and technical topics that were discussed or initiated at these meetings are discussed under the appropriate WBS items.

b. Site Selection

Site selection delays have become very critical to the progress and schedule of the program. It is estimated that a minimum of 12 months following specific site selection (i.e., street address) is necessary for the activities listed.

(a) Site analysis

(b) System optimization

(c) System design

(d) Preparation of system and subsystem specifications

(e) Contractor bid preparation

(f) Contractor selection

(g) System installation

To assist in the resolution of this problem, AiResearch is submitting a Site Selection Plan to NASA for concurrence as Contractor Change Proposal AIR-1. Under this plan, AiResearch will assist NASA in expediting specific site selections.

The sites will be selected to agree with the following geographical locations; the range of system capacities for each location is given in parentheses.

Single-family heating (80 KBTUH): New York and Oakland.

Single-family heating (80 KBTUH) and cooling (3 ton): Des Moines and Washington, D.C.

Multifamily heating (800 KBTUH): Detroit and Richmond

Multifamily heating (800 KBTUH) and cooling (25 ton):
Los Angeles and St. Louis

Commercial heating (2000 KBTUH): Milwaukee and Syracuse

Commercial heating (2000 KBTUH) and cooling (75 ton):
Las Vegas and Houston

Climatic data for these locations are being generated with NASA concurrence. The services of Beckman, Duffie and Associates were secured for this purpose. Contractor Change Proposal AIR-2, which covers this work, is in preparation.

c. Heat Pump Size Definition

As a result of market surveys conducted early in the program, the following sizes of heat pumps were selected for development.

Single-family residence:

Heating = 60,000 Btu/hr
Cooling = 3 tons

Multifamily residence:

Heating = 600,000 Btu/hr
Cooling = 25 tons

Commercial applications:

Heating = 200,000 Btu/hr
Cooling = 10 tons

Following recent discussions with NASA and ERDA, it appears advantageous to the overall solar energy program to develop a 75-ton commercial application system rather than the 10-ton size listed above. In the near future a 75-ton unit will find many more applications in demonstration programs than a 10-ton unit will. For this reason, and with NASA concurrence, work on the 10-ton unit has been stopped and design of the 75-ton system has been initiated. Design data on the 75-ton heat pump will be supplied to NASA in a separate package.

d. Dunham-Bush Contract

A formal contract with Dunham-Bush is in the final stages of negotiation.

e. Preliminary Design Review (Heating Systems)

The preliminary design review (PDR) of the heating systems was conducted at AiResearch on September 22 and 23, 1976. Twenty-four review item discrepancies (RID's) were assigned to AiResearch. All RID's have been answered in writing.

f. Preliminary Design Review (Heating/Cooling Systems)

The PDR of the heating and cooling systems was held at AiResearch on December 16, 1976. Nineteen RID's were assigned to AiResearch and have been answered in writing.

g. Collector Procurement

Evaluation of the collector proposals received in answer to AiResearch solicitation was completed using data submitted by the prospective contractors. Prior to selection, AiResearch requested from four contractors that certified performance test data be supplied to support the proposed performance data. In addition, final offers were requested. These data have been received and final evaluation is proceeding. The results of this evaluation will be submitted to NASA at a ΔPDR scheduled for early February in Huntsville.

h. System Instrumentation and Data Evaluation

NASA requested that AiResearch provide definition and development of data reduction and evaluation approaches for monthly reports and methods of reporting site and system baseline data.

2. WBS 1.1.2, Program Planning and Control

a. Schedule Development

Program schedules have been updated throughout the quarter to reflect the latest information. The latest versions of the component/subsystem schedules are presented in Section 3. Overall program schedules for the heating and heating/cooling systems are in Section 1.

b. Program Documentation

The following documents were prepared in accordance with the requirements of Appendix A of the Statement of Work. Some of these documents are revisions that include changes incorporated as a result of NASA review.

(a) Development Plan--DR 500-1--AiResearch Report 76-13047, Rev. 1

(b) Verification Plan--DR 500-2--AiResearch Report 76-12996, Rev. 1

(c) Quality Assurance Plan--DR 500-3--AiResearch Report 76-13043, Rev. 1

(d) Safety and Health Plan--DR 500-24--AiResearch Report 76-13046, Rev. 1

(e) Monthly Progress Reports No. 4 and 5--DR 500-11--AiResearch Reports 76-13110(4) and 76-13110(5)

(f) PDR Data Package (Heating/Cooling)--DR 500-7--AiResearch Report 76-13448

(g) First Quarterly Report--DR 500-10, October 12, 1976--AiResearch Report 76-13296(1)

(h) RID's Disposition Packages--

(1) AiResearch Letter CAJDM:6501:1011 to Mr. Stan Wade/FA02, dated October 11, 1976

(2) AiResearch Letter CAJDM: 7009:0107 to Mr. Stan Wade/FA02, dated January 10, 1977

3. WBS 1.1.3, Quality Assurance

The quality assurance plan has been revised to incorporate more details on the AiResearch and Dunham-Bush QA procedures. This plan was published December 16, 1976.

WBS 1.2, Development

1. WBS 1.2.1, Analysis and Integration

a. System Analysis

System analysis was limited to particular aspects of system design and/or operation and was aimed at schematic development and control system concept validation. Considerable work was done to answer the RID's assigned by NASA at the September PDR.

b. Control System Simulation

Control subsystem modeling was completed, and the transient response of the system has been simulated on computer. The system was found stable, and detail design of the subsystem is proceeding. Data on the simulation can be found in answer to RID AR-PDR-H/C-16.

c. Heat Pump Subsystem

The heat pump subsystem schematics were revised to eliminate the water switchover valves and to isolate the cooling mode condenser water loop (cooling tower loop). This change involved only minor subsystem performance changes but affected the development of the package.

Further, to eliminate refrigerant distribution problems in the evaporators/boilers and to assure flow stability, the decision was made to use vertical tube heat exchangers with the refrigerant inside the tubes for all evaporators/boilers.

As a result of these changes, the performance of the subsystem was updated. The data presented in the PDR data package reflect the above changes as well as minor differences due to (1) system piping, (2) motor cooling flow requirements, and (3) updated pressure drop data in the system lines and heat exchangers.

The heat pump packages have been updated to incorporate these changes.

The preliminary design of the 75-ton heat pump has been completed, and problem statements have been developed for all components. Heat pump characteristics in the heating and cooling modes of operation are being prepared and will be supplied to NASA.

d. R-11 Pump

A survey was made of commercially available pumps that could be used as-is or with modification for use in the R-11 Rankine loops. No satisfactory pump could be found; overall efficiencies as low as 2 to 5 percent could be expected using available Chempumps.

Currently, AiResearch is developing, under IR&D program, a hermetically sealed vane pump featuring cammed vanes. This pump has been evaluated in terms of performance and materials for use in the R-11 Rankine power loop and was judged to be about optimum for the intended service. These pumps, adapted to the requirements of the solar cooling system, will be developed in time for incorporation in the systems.

e. Heat Pump Heat Exchangers

All R-11 boilers and evaporators will feature vertical tubes to assure flow stability, eliminate potential flow distribution problems, and enhance performance. Heat exchanger sizes have been supplied to Dunham-Bush for heat pump packaging.

f. Collector Subsystem

The performance of candidate solar collectors was estimated using the overall system computer program. Performance was determined for a complete year using the Madison and Nashville weather data and residence models supplied by NASA. Sensitivity analyses also were conducted to assess the effect of higher cooling-to-heating load ratio.

g. Interchanger

The possibility of using a coiled tube within the water storage tank rather than a separate interchanger and pump between the collector and the storage tank was investigated. The cost of such a heat exchanger was found to be prohibitive in comparsion to an external heat exchanger. This approach has been discarded.

h. Storage Tank Stratification

A new manifold configuration using a 50 percent solidity screen has been devised and will be tested in the next reporting period.

2. WBS 1.2.2, System Development

The effect under this task was concerned with the heat pump components. Details of the work accomplished in the last quarter are presented below.

a. Turbomachine/Motor

(a) 3-Ton Heating/Cooling Unit--All detail drawings have been completed and released for manufacture or procurement. All parts are on order or in the process of being manufactured in-house. The outline drawing has been released, and the assembly drawing will be released very shortly; it was delayed because of balancing information required from manufacturing.

Motor assembly will begin the end of January for the first phase of turbomachine/motor/controller testing. All detailed parts will be complete and available for end-unit assembly before the end of February. All testing, fabrication, and assembly are in accordance with the April/May delivery schedule.

(b) 25-Ton Heating/Cooling Unit--All detailed drawings are complete and released for manufacture. Approximately 60 percent of the parts have been placed on order or released for in-house manufacture. It is anticipated that all parts will be available for assembly by March.

(c) 10-Ton Heating/Cooling Unit--All work was stopped as of Dec 6, 1976.

(d) 75-Ton Heating/Cooling Unit--Problem statements were issued in mid-December. The only accomplishment prior to the holidays was some preliminary motor sizing. Wheel sizing and preliminary layouts for the rotor and motor will be performed during January.

b. Motor Control

(a) 3-Ton Motor Controller--The 3-ton/60 KBTUH heat pump motor will be driven from a transistor inverter controlled by a series chopper. The detailed circuit design for both the inverter and the chopper is 80 percent complete and is scheduled to be completed by February. Some of the circuitry has been breadboarded and checked out satisfactorily. Particular attention has been paid to the development of the power transistor switching circuits for the chopper and inverter. One leg of the 3-phase inverter has been breadboarded and has satisfactorily modulated at 2750 Hz at a current level of 40 A.

The remaining task in the breadboard phase is to complete the breadboard fabrication by January 31 and test the inverter with the rotating machinery. The remaining circuit design task is to interface the motor position sensor with the switching logic and complete the start and shutdown sequencing.

(b) 25-Ton Motor Controller--The 25-ton/600 KBTUH heat pump motor will be driven by a phase delay rectifier/inverter combination. The detailed circuit design is 90 percent complete, and the breadboard fabrication is 60 percent complete and scheduled for completion in February. The PDR logic circuitry has been checked out and operates satisfactorily. The remaining development tasks are to complete the testing of the inverter logic and full load tests of the power section. Testing with a machine is scheduled for March.

(c) 75-Ton Motor Controller--This unit will be a scaled version of the 25-ton controller. Design and testing of the unit will not proceed until development of the 25-ton breadboard is near completion.

c. Heat Exchangers

The preliminary design of all heat exchangers for the 3-, 10-, and 25-ton units was completed using the single-tube heat transfer test data and the latest heat exchanger configuration. The 75-ton heat exchangers are being designed. All this work was performed in close coordination with Dunham-Bush. Sketches of all units were prepared by Dunham-Bush for use in package development and in final definition of fluid ports and mountings. All heat exchangers utilize standard Dunham-Bush heat transfer surfaces and standard Dunham-Bush shell sizes.

One set of heat exchangers will be delivered to AiResearch by the end of January for assembly in the turbomachine test rig.

d. System Control

The system control simulation has been completed, and detail design of the circuitry has been initiated. A digital approach has been selected as optimum in terms of cost for both the current program and for high production in the future. The decision to use a digital approach was based primarily on the large number of pump and valve switches in the system.

Several tooling options have been considered for implementation of the hardware phase of the digital controller. The Motorola 6800 microprocessor has been selected as optimum in terms of cost. An order was placed for the Motorola microprocessor early in December. Motorola will make a development microprocessor available to AiResearch until delivery of this unit.

Detail design of the system has been initiated and is about 30 percent complete. The control subsystem will be identical for all system sizes; the difference will be in the software package.

e. Heat Pump Packages

Updated layouts of the single-family and multifamily residence heat pumps have been developed. These layouts will be updated to include controls, major piping, and valves. Also, the auxiliary thermal energy subsystem is divorced from the heat pump package to provide flexibility of installation and to promote modularity. Details of the frames and structures have been initiated.

3. WBS 1.2.3, Test

a. Single-Tube Heat Transfer Tests

Evaporating/boiling heat transfer tests on the 1/2- and 3/4-in. inner fin tubes have been completed in conditions simulating the actual heat transfer and flow rates of the actual units. The tests were conducted with the tubes in the horizontal and vertical positions. These data are reported in the heating/cooling system PDR data package (AiResearch Report 76-13448).

b. Thermal Stratification Tests

These tests were interrupted pending the results of internal interchanger studies. They will be resumed in the next quarter; high solidity screens will be used in the new configuration.

c. Motor Controller Tests

Testing of the subassemblies of the breadboard systems for both the 3- and 25-ton systems is under way. The 3- and 25-ton units will be tested without motors by February 28. A further month of testing will be required with the motors.

d. Turbomachine/Motor Tests

A test program has been outlined and reviewed with all groups concerned. Testing will begin with the breadboard motor controller tests. The second phase will be testing the unit under load for start/stop characteristics, power consumption, and off-design load motor. The third phase, utilizing the complete R-11 heating and cooling loops, will involve performance testing, bearing testing, and cyclic testing; this will commence in early April and continue for approximately one month.

Testing of the 25-ton unit will proceed in the same way as for the 3-ton unit, with the motor controller testing (Phase I of 25-ton) overlapping the system testing of the 3-ton unit.

e. Heat Pump Development

Factory space has been allocated for the 25- and 75-ton test setups. Details of the test control panel instruments and test area have been completed. Purchase requisitions for part of the test equipment and instruments have been prepared, and a contractor has been contacted to obtain test station installation cost.

Final drafts of the test procedures for the 3-, 10-, and 25-ton systems were prepared and will be submitted to NASA after updating to include the 75-ton heat pump size.

f. Condensate Blowoff Test

A simulated test was conducted of a 3-ton evaporator coil to determine condensate blow-off characteristics with horizontal fins (vertical tube unit). The heat exchanger was tested with the tubes in the vertical position and inclined 6 deg and 12 deg from the vertical in the airflow direction. The test showed that with a 12 deg tilt a small quantity of water accumulates in the heat exchanger. Also, at the design airflow rate (1200 cfm) the increased pressure drop due to the presence of water is as predicted in the analysis.

No eliminators will be necessary downstream of the heat exchanger; however a water barrier will have to be provided between the coil and the insulation.

FUTURE ACTIVITIES

Activities in the next quarter will include the following.

WBS 1.1, Management

1. WBS 1.1.1, Program Direction

   (a) The second quarterly review will be held at the AiResearch plant in Torrance on January 11, 1977.

   (b) A ΔPDR covering solar collector selection is scheduled for early February in Huntsville.

   (c) A major effort will be expended in selecting sites suitable for system installation and evaluation.

   (d) Collector evaluation will be finalized and collector subcontractor(s) will be selected.

2. WBS 1.1.2, Program Planning and Control

   The following program documents will be prepared per Data Requirement No. 500:

   (a) DR 500-7, preliminary design review data package for solar collector evaluation and selection

   (b) DR 500-10, the third quarterly report

   (c) DR 500-11, monthly status reports

   (d) DR 500-27, financial management reports (provided monthly)

WBS 1.2, Development

1. WBS 1.2.1, Analysis and Integration

   (a) The system computer program will be exercised to provide the data necessary for final evaluation of competing collectors.

   (b) Preliminary design of the 75-ton heat pump heat exchanger will be completed.

   (c) Analysis will be performed as necessary in support of the site selection effort.

2. WBS 1.2.2, System Development

a. System Design Activities

System design will be initiated early following site selection, analysis, and system optimization. To expedite the system design efforts A & E firms have been contacted and are evaluated as prospective subcontractors.

b. Heat Pump Development

   (a) Heat Exchangers--Heat exchanger fabrication will be completed with the possible exception of the interchanger, whose size will be standardized according to heat pump size.

   (b) Turbomachine/Motor--The 3- and 25-ton units will be assembled. The motor-bearing assembly will be tested with the motor controllers. Detail design of the 75-ton machine will be about 90 percent complete during the next quarter.

   (c) Motor Controller--Breadboard testing of the three sizes of units will be completed, and dynamic testing of the 3- and 25-ton units with the motors will be completed. Dynamic testing of the 75-ton unit will be started. Long-lead controller components will be ordered for the 12 prototypes.

   (d) System Control--Circuit design will proceed in parallel with development testing of the breadboard. Drawings will be completed in the next quarter, and fabrication of the first unit is scheduled to start in mid-March.

   (e) Heat Pump Packages--Layouts will be completed for the 3- and 25-ton sizes. The 75-ton package layout will be started. Detail drawings will be prepared as necessary. Orders will be placed for all hardware for the 3- and 25-ton sizes. Fabrication of the frame and mounting structures for all 3-ton units will be completed.

(f) System Instrumentation--The preliminary instrumentation lists contained in AiResearch Report 76-13139 will be updated. Final definition of most of the sensors will not be possible prior to final system design.

(g) R-11 Pump--The design will be finalized and fabrication will be started. The first pump for the 3-ton unit will be ready for testing in early April.

PART C

Third Quarterly Report
Data Requirement 500-10

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT

Contract NAS8-32091

76-13296(3)

April 10, 1977

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama 35812

CONTENTS

SECTION I

INTRODUCTION AND SUMMARY

INTRODUCTION

This is the third quarterly report prepared by AiResearch Manufacturing Company of California under Contract NAS 8-32091 for the National Aeronautics and Space Administration, Marshall Space Flight Center (MSFC). The report summarizes activities from January 1, 1977 to April 1, 1977.

SUMMARY

Significant activities and status of the cost, schedule, and technical aspects of the program are summarized in the following paragraphs.

Cost Status

This paragraph has been deleted.

Schedule Status

Two sites were selected for heating-only systems; Hamilton Air Force Base, Novato, California and Washington Park Senior Citizens Recreation Center, Milwaukee, Wisconsin. The latter site was reassessed during an ERDA committee review meeting on March 28-29, 1977. Delays in site selection have caused a slippage in the heating-only systems sites as originally proposed, but AiResearch is attempting to accelerate these system design and installation tasks to minimize further schedule slippage and cost effect.

The latest schedules for the heating and the heating/cooling systems are presented in Figures 1-2 and 1-3.

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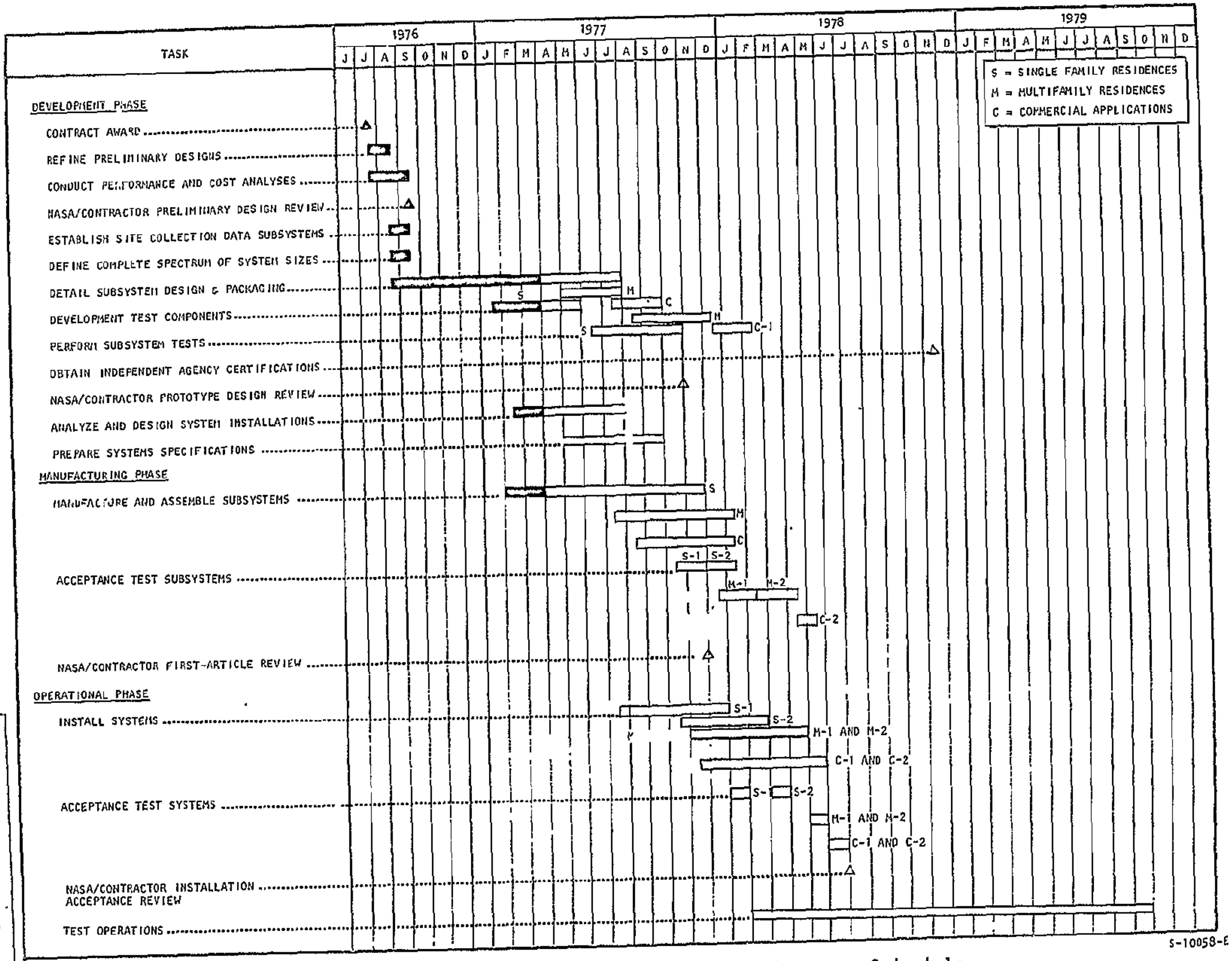

Figure 1-2. Solar Heating System Development Schedule

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AIRESEARCH MANUFACTURING COMPANY
Los Angeles California

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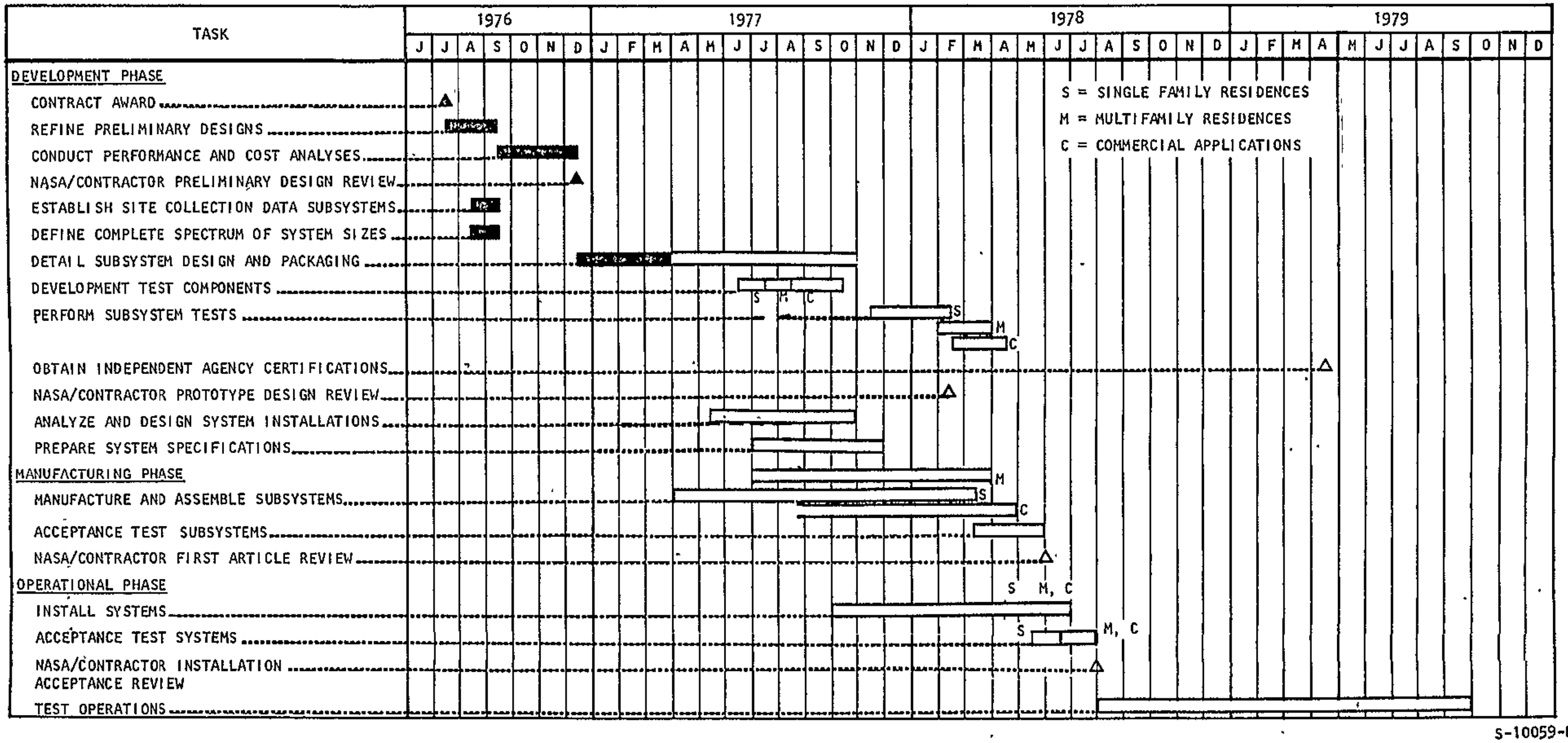

Figure 1-3. Solar Heating/Cooling Systems Development Schedule

Technical Status

1. Site Selection

A single-family residence at Hamilton Air Force Base, Navato, California was selected for evaluation of a (nominal) 80 KBTUH heating-only system. The residence is under the auspices of the U.S. Navy-Public Works Center. This site has been approved by NASA and ERDA and negotiation with the owners has been initiated. System design specific to this site is proceeding.

Other sites are currently under consideration for single-family heating-only (Allaire Park, N.J.) and for multi-family heating-only (Richmond area) systems.

2. Collector Procurement

A recommendation was made to NASA to use the DAYSTAR Corporation solar collector for this program. This recommendation was made as a result of a detailed comparative evaluation of a number of competing collectors. Major selection criteria were cost/effectiveness and durability.

3. Heat Pump Sizes

A program review was held at AiResearch with NASA/ERDA on March 28 and 29, 1977. As a result of this meeting, the number of systems to be developed by AiResearch under this contract was reduced in keeping with available funds. The following system mix was agreed upon tentatively:

	Heating Only	Heating/ Cooling
Single-Family Residence	2	2
Multifamily Residence Light Commercial	1	2
Commercial Application	0	2

4. Program Documentation

Documentation was prepared in accordance with the requirements of DR-500. A number of documents have been approved by NASA. Approval of the remainder awaits completion of review by NASA.

5. Equipment Development

The 3-ton and 25-ton motor/motor controller test rigs will be available for dynamic testing early in April.

All parts are available for assembly of the 3-ton turbomachine which will be ready for integration in a breadboard heating system late in April. The 3-ton test rig is being assembled. Parts for the 25-ton breadboard heat pump will be received in early May.

The 3-ton and 25-ton motor controller breadboard units have been subjected successfully to open-loop testing and will undergo dynamic testing with the motor as mentioned above.

A breadboard version of the system controller has been built and debugged. Programming of the controller is in progress; completion is scheduled for the end of April.

The 3-ton R-11 pump has been built and is under test. Performance is slightly higher than predicted. A 300-hr endurance test is planned for this unit following performance evaluation. All parts are available for assembly of the 25-ton R-11 pump.

6. Heat Pump Subsystem

Design of the 3-ton heat pump is scheduled for completion in April. All parts have been ordered for this unit. The heat exchangers (with the exception of the interchanger) have been delivered to the Dunham-Bush Harrisonburg plant, as well as a mock-up of the turbomachine. Assembly has been started and all parts will be available for completion June 1 including the turbomachine, motor controller and system control.

Design of the 25-ton heat pump is proceeding. Parts have been ordered for this unit and the frame is in fabrication. The motor controller is the pacing item for completion of assembly and is scheduled for delivery August 1.

No work has been done on the 75-ton heat pump; design of the package is awaiting final definition of the heat exchangers.

7. System Design

Design year climatic data were generated for the original twelve installation sites.

Design of the complete system for the Hamilton AFB single family residence heating-only system is proceeding. Collector area and storage tank capacity have been sized to derive 60 percent of the heat load from the sun.

Section 2 has been deleted.

SECTION 3

PROGRAM SCHEDULES

The overall program schedules are included in Figures 1-2 and 1-3 in Section 1. This section includes more detailed schedules (Figures 3-1 through 3-7) covering the development status of the critical subsystems and components. These schedules represent an update of those given in the Second Quarterly Report. The component/subsystem schedule changes have only a limited effect on the overall program schedule. The status and progress are given in Section 4.

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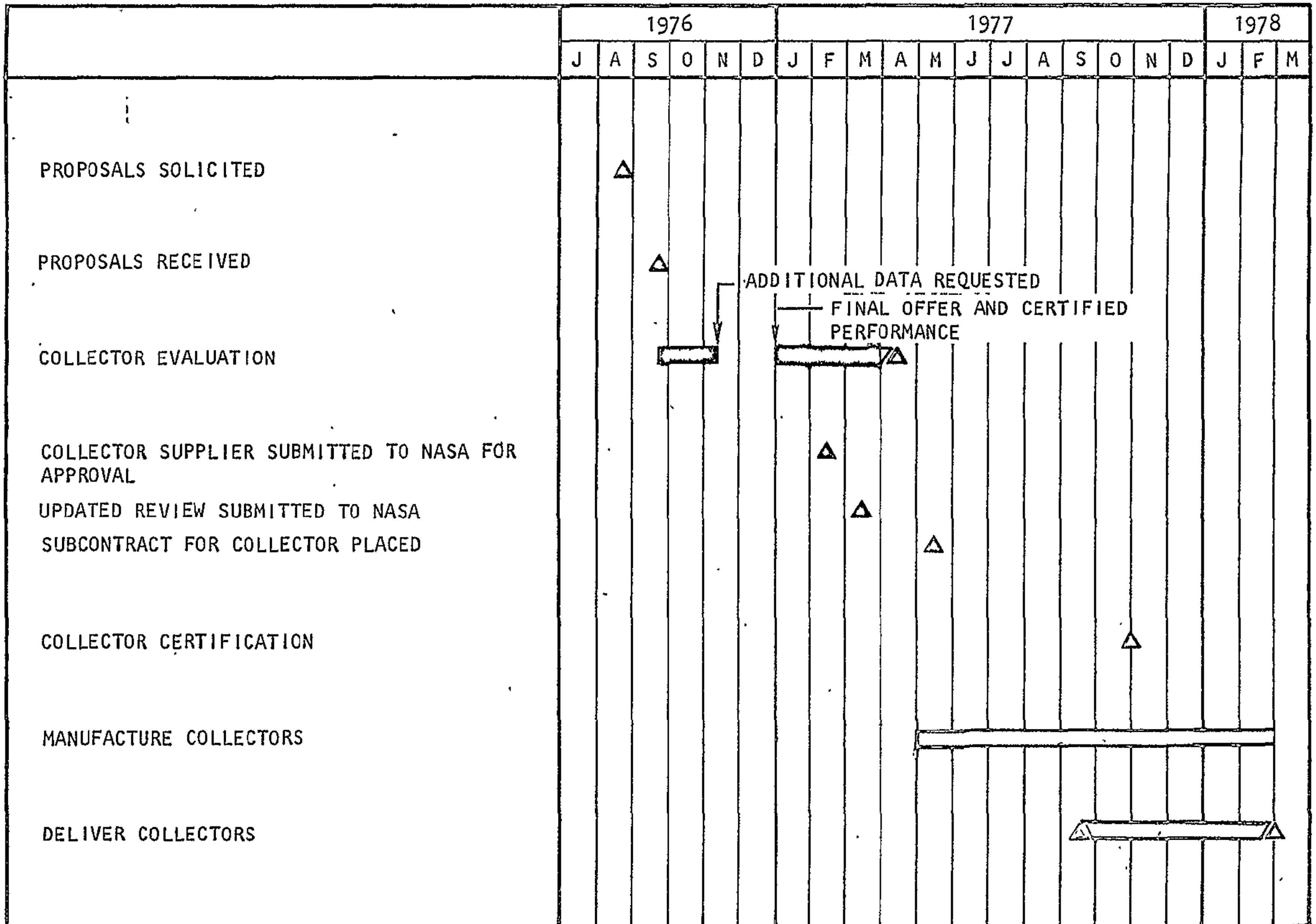

Figure 3-1. Solar Collector Development Schedule

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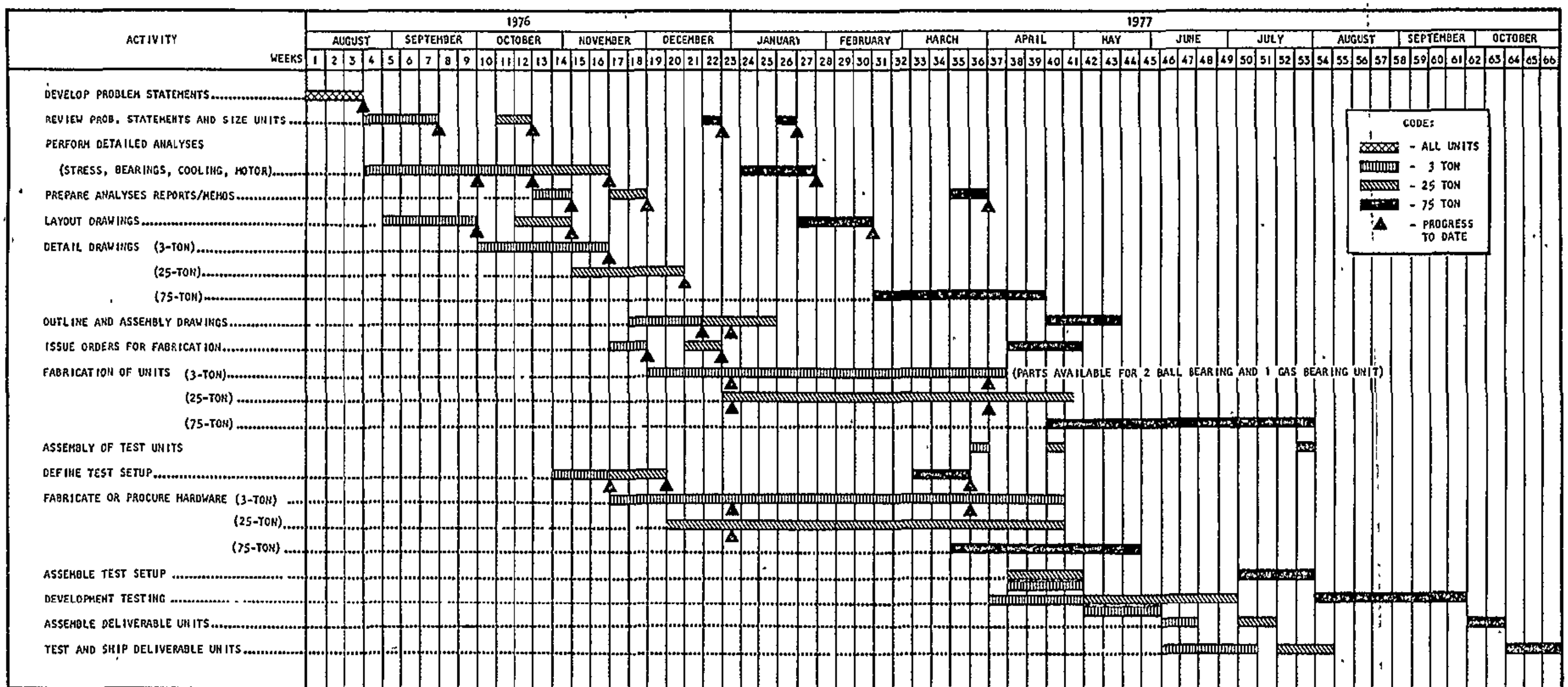

Figure 3-2. Turbomachine Development Schedule

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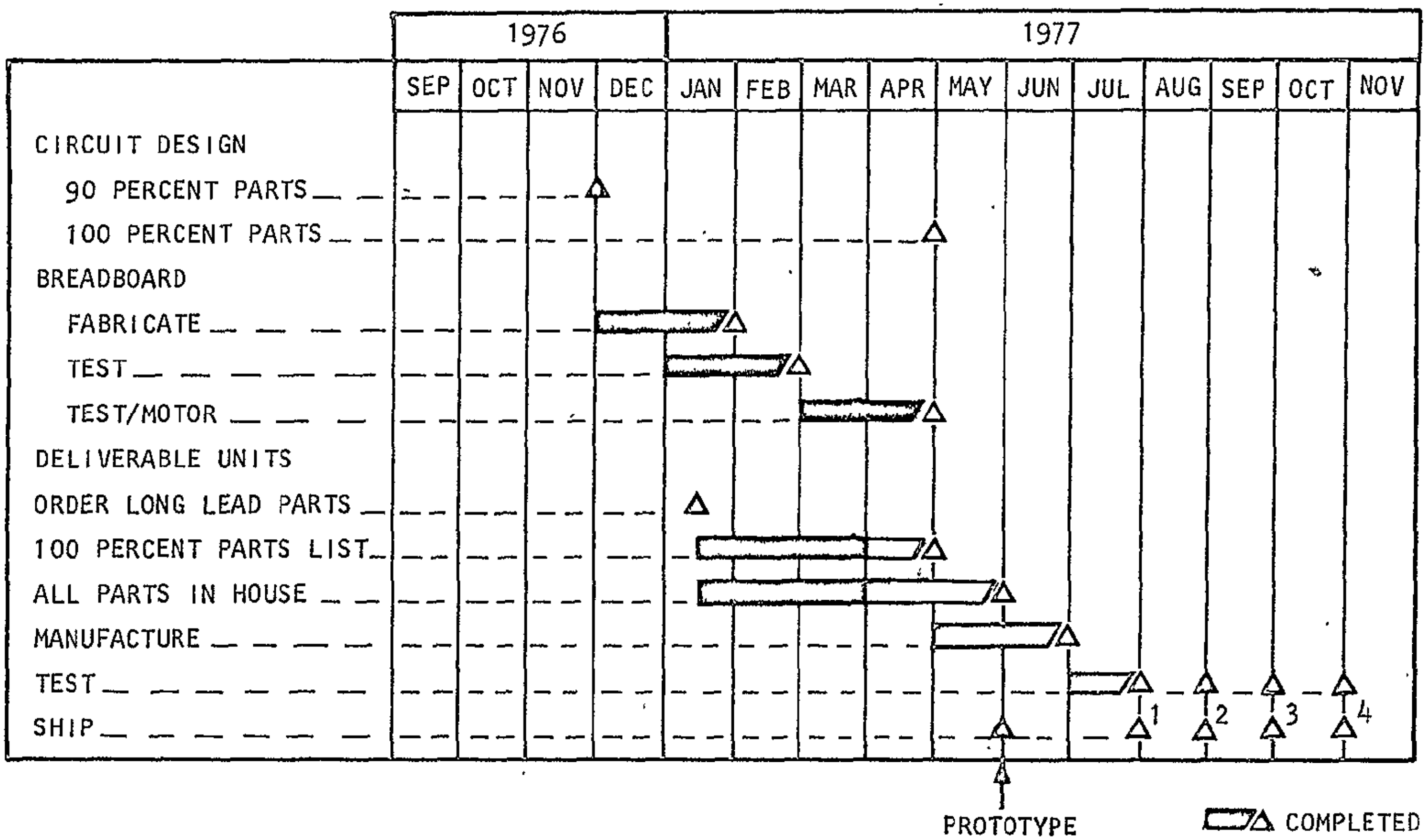

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Figure 3-3. 3-Ton Unit Motor Control Development Schedule

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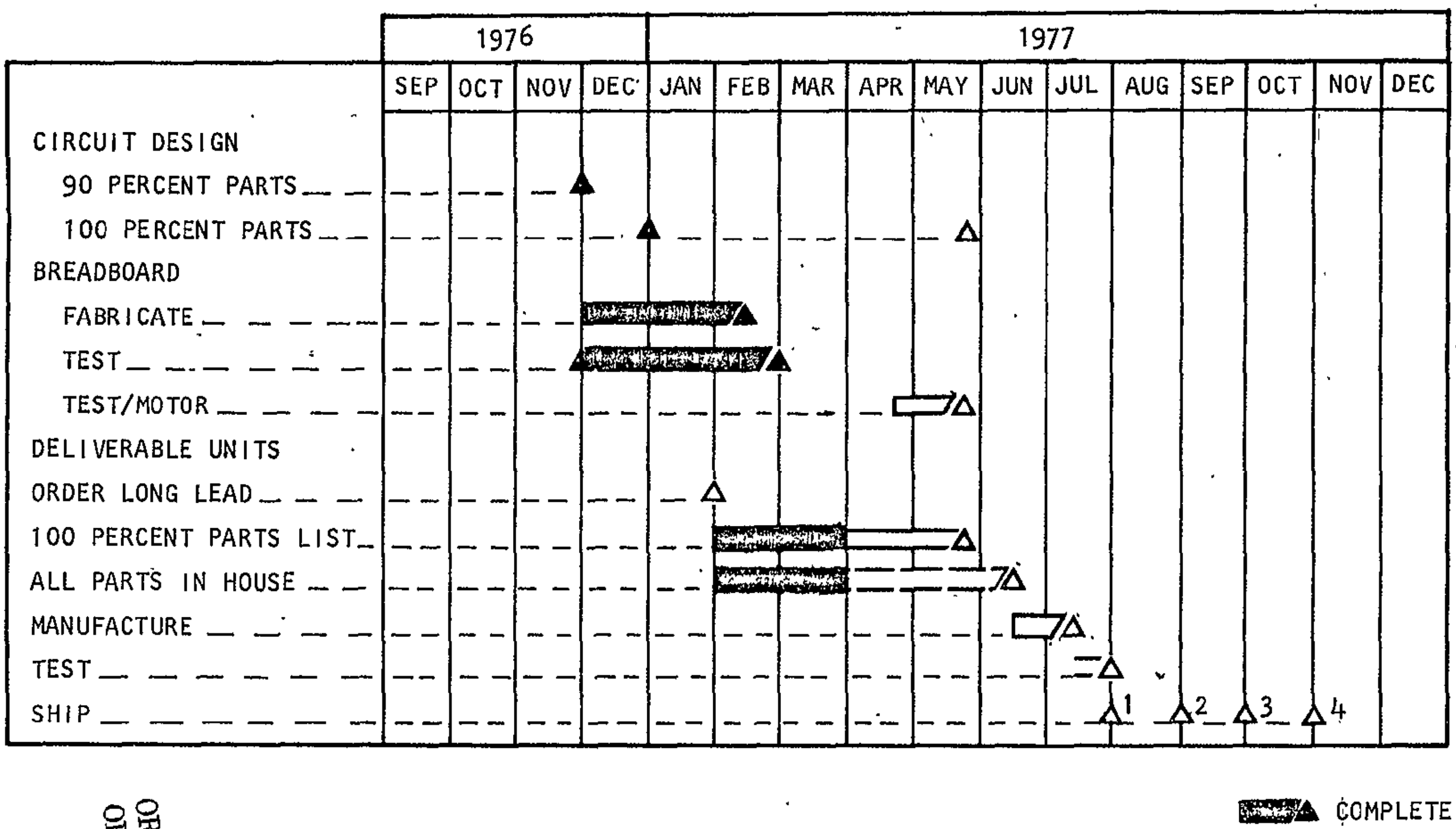

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Figure 3-4. 25-Ton Unit Motor Control Development Schedule

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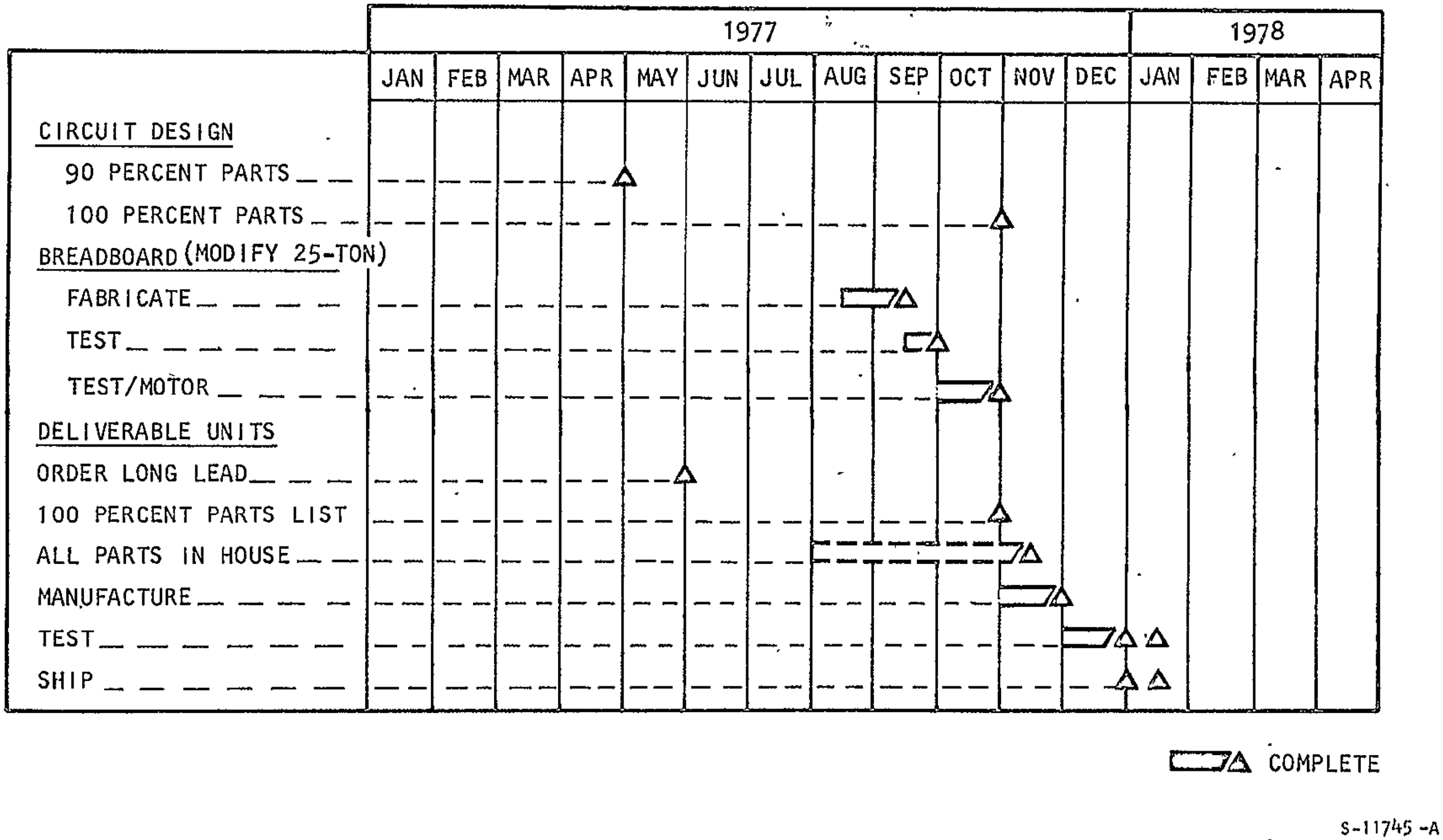

Figure 3-5. 75-Ton Unit Motor Control Development Schedule

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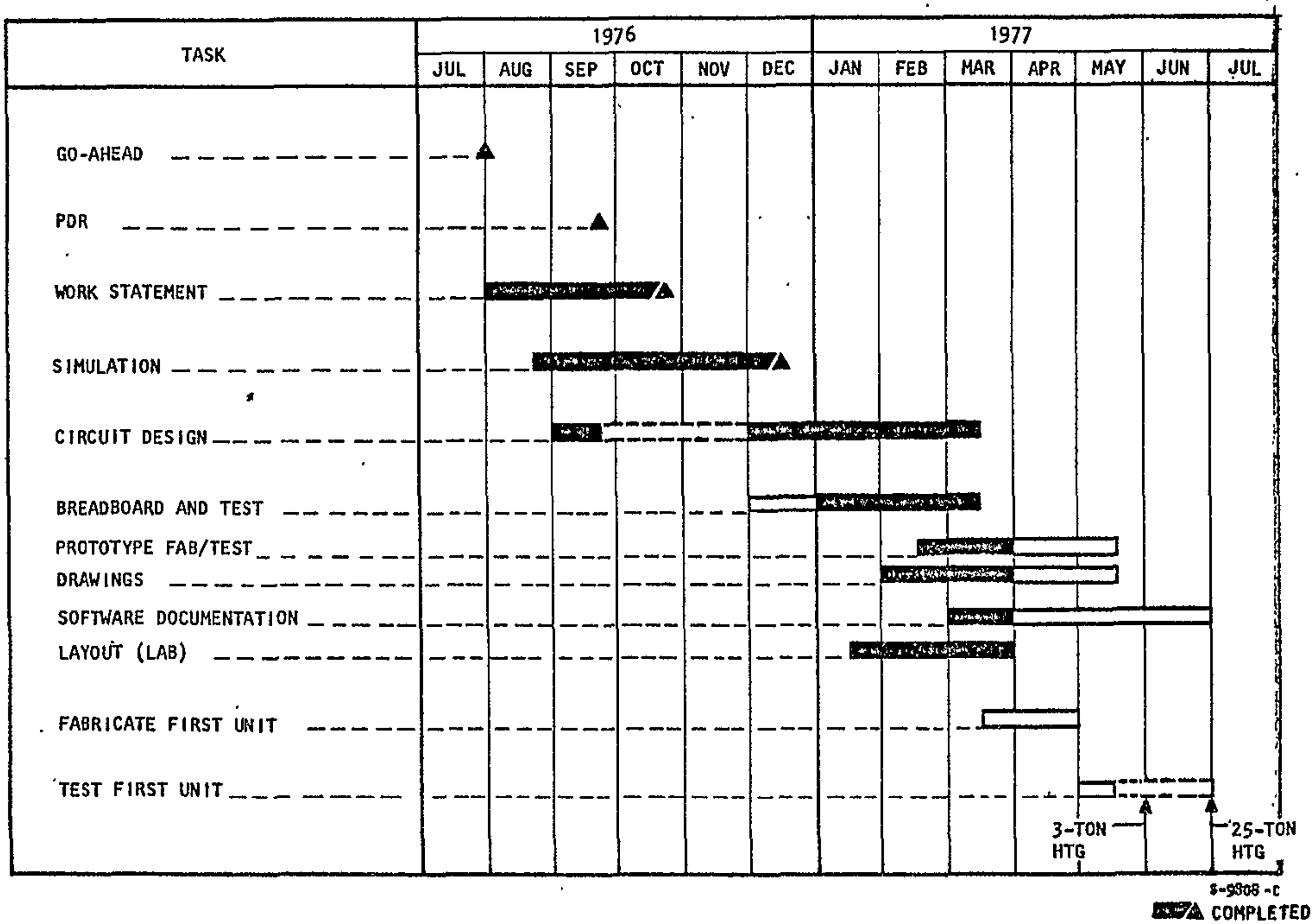

Figure 3-6. System Control Development Schedule

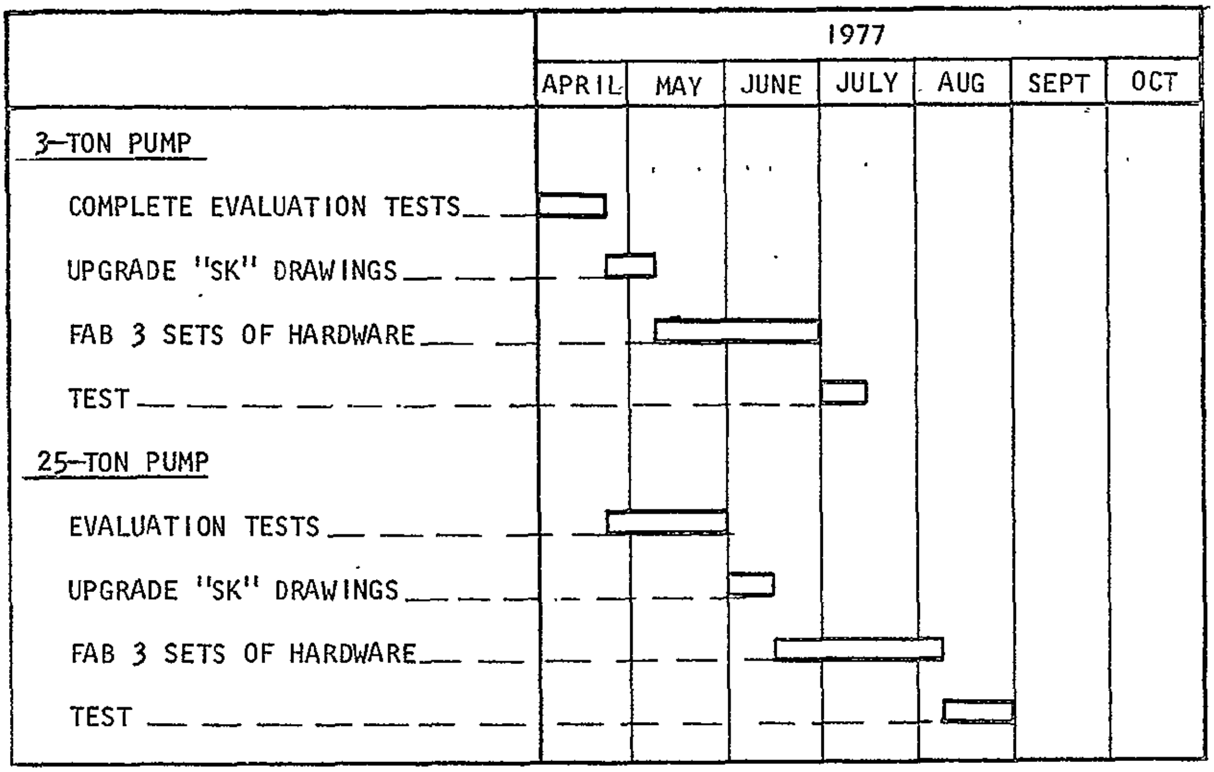

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Figure 3-7. 3-Ton Unit R-11 Pump Development Schedule

SECTION 4

TECHNICAL PERFORMANCE

INTRODUCTION

Technical status is reported below for all WBS tasks active in the reporting period. The WBS of Figure 4-1 identifies the active tasks with an asterisk (*). Activities during the third quarter were involved with the following.

WBS 1.1, MANAGEMENT

WBS 1.1.1, Program Direction

Meetings, reviews, and major events

Site selection and investigation

Collector procurement

WBS 1.1.2, Program Planning and Control

Schedule development

Program documentation

WBS 1.1.3, Quality Assurance

WBS 1.2, DEVELOPMENT

WBS 1.2.1, System Analysis and Integration

System analysis

Control system simulation

Heat pump subsystem

WBS 1.2.2, System Development

Turbomachine/motor design

Motor control design

System control design

R-11 pump

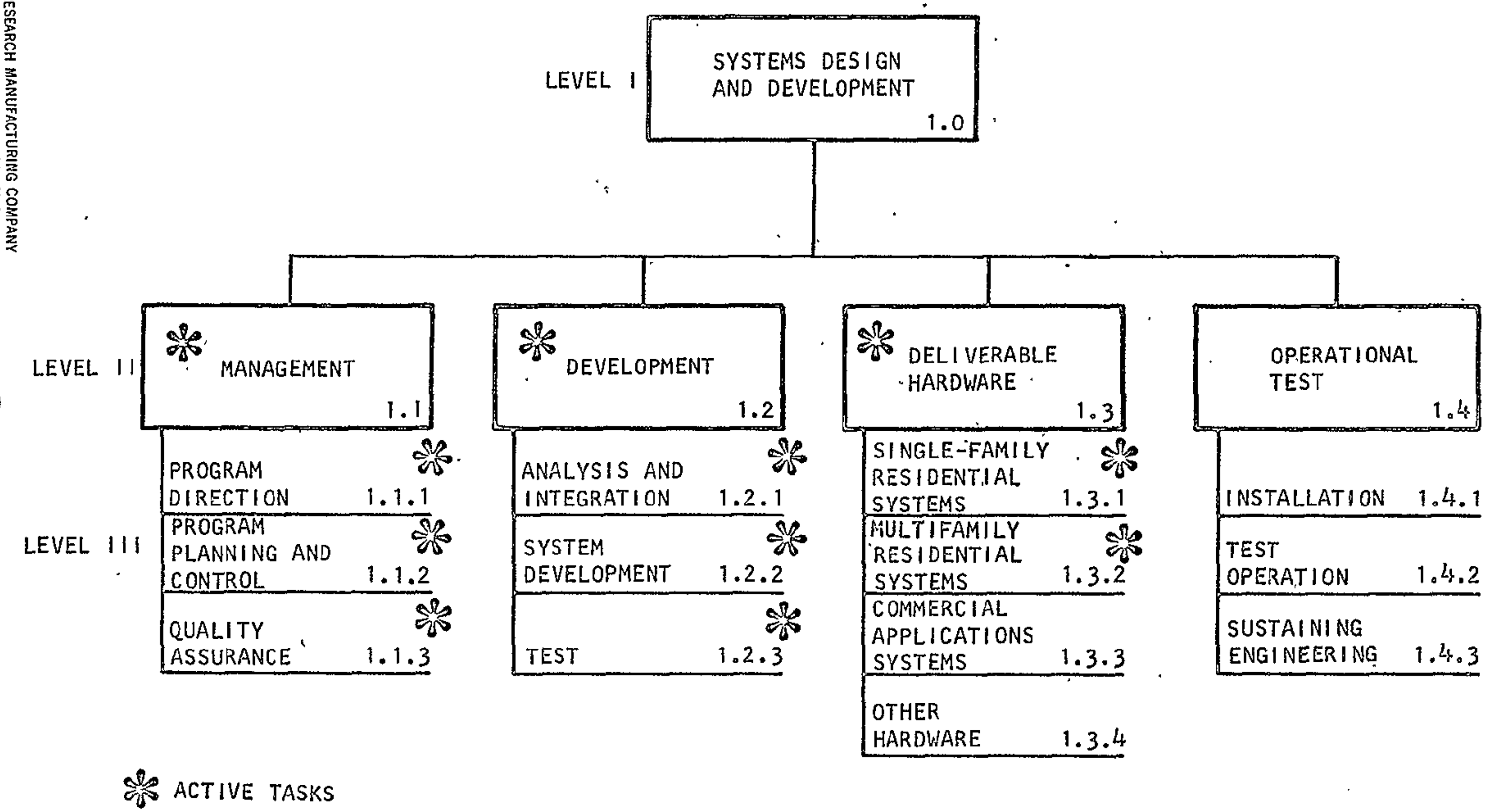

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Figure 4-1. Top-Level Work Breakdown Structure

WBS 1.2.3, Test

Turbomachine/motor

Motor control test

R-11 pump test

WBS 1.3, DELIVERABLE HARDWARE

WBS 1.3.1, Single Family Residence System

WBS 1.3.2, Multifamily Residence System

Progress on all these items is described in the following paragraphs.

ACTIVITIES IN REPORTING PERIOD

WBS 1.1, Management

1. WBS 1.1.1, Program Direction

a. Meetings, Reviews, and Major Events

(a) The second quarterly review was held at AiResearch on January 11, 1977.

(b) An initial trip was made in January to Hamilton Air Force Base, California, to visit a single-family residence as a potential installation site for a solar heating system.

(c) A PDR review covering the solar collector subsystem was held at NASA on February 15, 1977. At this meeting, the selection of a collector was postponed until more detailed data could be obtained on the durability of the candidate collectors.

(d) A coordination meeting was held at AiResearch on the 24th and 25th of February, 1977. The site selection procedures were reviewed by Mr. Jim Clark, NASA Program Manager, who also reviewed overall progress on the program. Review item discrepancies (RID's) pertinent to the PDR meeting of February 15 were presented to AiResearch.

(e) A collector update review was held with NASA on March 22, 1977, at MSFC, Huntsville, Alabama.

(f) An ERDA committee review meeting was held at AiResearch on March 28 and 29, 1977 to reassess the technical and marketing requirements for solar heating and cooling (particularly the latter).

(g) A site owner meeting was held on March 31, 1977 at Hamilton Air Force Base, Novato, Ca., to finalize NASA/site owner terms of agreement.

(h) Five coordination meetings were held with Dunham-Bush in the last quarter.

During the collector update review, AiResearch stated that receipt of field service data from nine current installations indicated that the Reynolds collector was considered an unacceptable risk for this program. Specifically, durability of the Tedlar and Teflon outer and inner covers was not considered adequate, rendering the collector life questionable. The Chamberlain collector was not recommended because of high acquisition and installation costs. The Daystar collector was recommended for the program since it represents the best cost/performance/risk compromise of the candidate collectors.

Program direction on collector selection is still pending; a NASA visit to Daystar is scheduled for April 5 and 6.

The purpose of the ERDA review was to realistically reassess the technical and marketing requirements for solar heating and cooling systems development (primarily cooling). This development effort is under NASA AP32-75-404 correlating with task B-1 under Research and Development in the ERDA-23A National Program Plan. All three contracts (General Electric, Minneapolis Honeywell, and AiResearch) are being reviewed.

It was emphasized that the AiResearch program is not a "demonstration" program, as described in ERDA-23A, but rather a development program under "Research and Development" in ERDA-23A - "to bring solar energy systems to the point at which they are ready for testing and use in residential and commercial demonstrations". Thus, this is the first step toward commercialization. It is prior to "demonstration" and several steps from full commercialization.

Action items and significant program and technical topics that were discussed or initiated at these meetings are discussed under the appropriate WBS items.

b. <u>Site Selection and Investigation</u>

Two sites were originally selected for heating-only systems:

(a) Hamilton Air Force Base--single-family residence. This site has been approved by NASA and ERDA and work is proceeding on installation design.

(b) Washington Park Senior Citizens Recreation Center, Milwaukee, Wiconsin--commercial application.

Surveys have been made in Syracuse for installation of a commercial size heating-only system. Two sites were visited: (1) Clary Junior High School, and (2) Hancock Airport North Finger (Allegheny Airlines loading gates). Data gathered are being analyzed to determine suitability.

At the March 31, 1977 site owner meeting the Hamilton AFB demonstration site was changed from 202 Randolph St. to 581 Bolling Drive.

The alternate house at 581 Bolling Drive was selected as a better choice for several reasons:

(a) Southern solar collection exposure to rear of house necessitating less collector concealment treatment

(b) Less existing roof penetrations

(c) Larger (1580 sq ft.) house

(d) Better topography

On March 1 and 2, a NASA-AiResearch joint survey of sites was conducted in the New York and adjacent areas. Recommended for a heating-only demonstration was a single-family residence located in Allaire Park, N.J. Site survey was also conducted in the Richmond-Norfolk, Virginia, area on March 8, 9 and 10th for selection of a multi-family heating-only system site. NASA is expected to make a site recommendation in the Richmond-area to ERDA in early April.

Preparation of site reports is continuing in support of the site investigation efforts. AiResearch Report 77-13698, Rev. 2, the installation technical information pack for the Hamilton AFB site was delivered to NASA at the March 31, 1977, NASA-site owner meeting.

c. Collector Procurement

Collector procurement is awaiting NASA acceptance of the AiResearch collector update review recommendations discussed previously.

2. WBS 1.1.2, Program Planning and Control

a. Schedule Development

Program schedules have been updated throughout the quarter to reflect the latest information. The latest versions of the component/subsystem schedules are presented in Section 3. Overall program schedules for the heating and heating/cooling systems are in Section 1.

b. Program Documentation

The following documents were prepared in accordance with the requirements of Appendix A of the Statement of Work.

(a) Second Quarterly Report (DR 500-10), January 10, 1977, AiResearch Report 76-13296(2).

(b) PDR Data Package, Solar Collector Subsystem (DR 500-7), AiResearch Report 76-13313.

(c) 75-Ton Heat Pump Design Data (DR 500-7), January 10, 1977, AiResearch Report 77-13515.

(d) Comments on H. C. Rooks Report, March 24, 1977, AiResearch Report 77-13732.

(e) Monthly Progress Reports No. 6 and 7--AiResearch Reports 76-13110(6) and 76-13110(7).

(f) Installation Technical Information Pack for Single Family Residence (Hamilton AFB, Novato, Ca.)--AiResearch Report 77-13698, Rev. 2.

Other publications issued this quarter were:

(a) The IPC verification matrixes for the residential and commercial solar systems were submitted to NASA.

(b) Two change proposals were submitted to NASA in accordance with the format specified:

(1) AIR-1 covers the activities involved in site selection.

(2) AIR-2 covers the work associated with the development of weather data for the 12 geographical locations selected as test sites.

Resolution of these items is pending.

3. WBS 1.1.3, Quality Assurance

The quality assurance plan was reviewed in December to incorporate more details on the AiResearch and Dunham-Bush QA procedures. NASA requested more information on the Dunham-Bush segment. A reply was made by letter to supply the requested material.

WBS 1.2, Development

1. WBS 1.2.1, Analysis and Integration

a. System Analysis

The performance of the heat pump in the cooling mode was plotted over the range of anticipated operating conditions. These detailed subsystem-level parametric data were correlated and simplified performance modes were developed for incorporation in the overall system analysis computer program.

The thermal COP (heating effect/compressor power) of the heat pump in the heating mode of operation was updated using the latest heat exchanger/compressor/motor data. The COP maps also will be used in the overall system analysis computer program.

Climatic design years for the 12 selected sites have been generated, raw data from NOAA have been reduced, and design months have been identified for all locations. Complete design years have been synthesized for the twelve geographic locations defined by NASA for system installation. Using these data, design studies have been conducted for the Hamilton AFB site. Previous optimization studies have indicated that with mature solar system prices, a solar contribution of about 60 percent is optimum on a present value analysis basis. It has been found that 60 percent contribution can be obtained at the Hamilton AFB site with 640 square feet of Daystar collector inclined 55 degrees from horizontal. This data has been furnished the A&E responsible for preparing the detailed installation design.

Preliminary layouts of equipment locations were made for the Hamilton Air Force Base and the Milwaukee test sites. The data were used to estimate duct and pipe sizes, line flows, and insulation requirements. Pressure drop data to be obtained from the A and E drawings will size the water and glycol circulation pumps. These transport loop characteristics will then be incorporated in the system analysis program.

Conceptual drawings have been completed for both test sites. Plumbing and ducting isometric drawings and critical path networks for system design and fabrication were completed for both sites.

b. System Arrangement

Selector valves were incorporated between the heat source water loop (from the water storage tank) and the recirculation loop on the 600- and 1600-KBTUH heating subsystems. Revised schematics of the heating and heating/cooling subsystems are shown in Figures 4-2 and 4-3. These valves will ensure stable operation at low loads and the direct use of solar thermal energy without addition of a preheater. Control system studies leading to the addition of these valves are reported in the answer to RID AR-PDR-H/C-16. Note that this capability is not provided on the 60-KBTUH residential heating system since the terminal unit is an R-11-to-air condenser. Updated schematics of the 60-KBTUH heating-only heat pump and of the 3-ton/60-KBUTH heating/cooling versions are shown in Figures 4-4 and 4-5.

Revised system schematics for the 3 ton/80-KBUTH system and for the larger installations (multifamily and commercial) are presented in Figures 4-6 and 4-7 for the heating and cooling systems.

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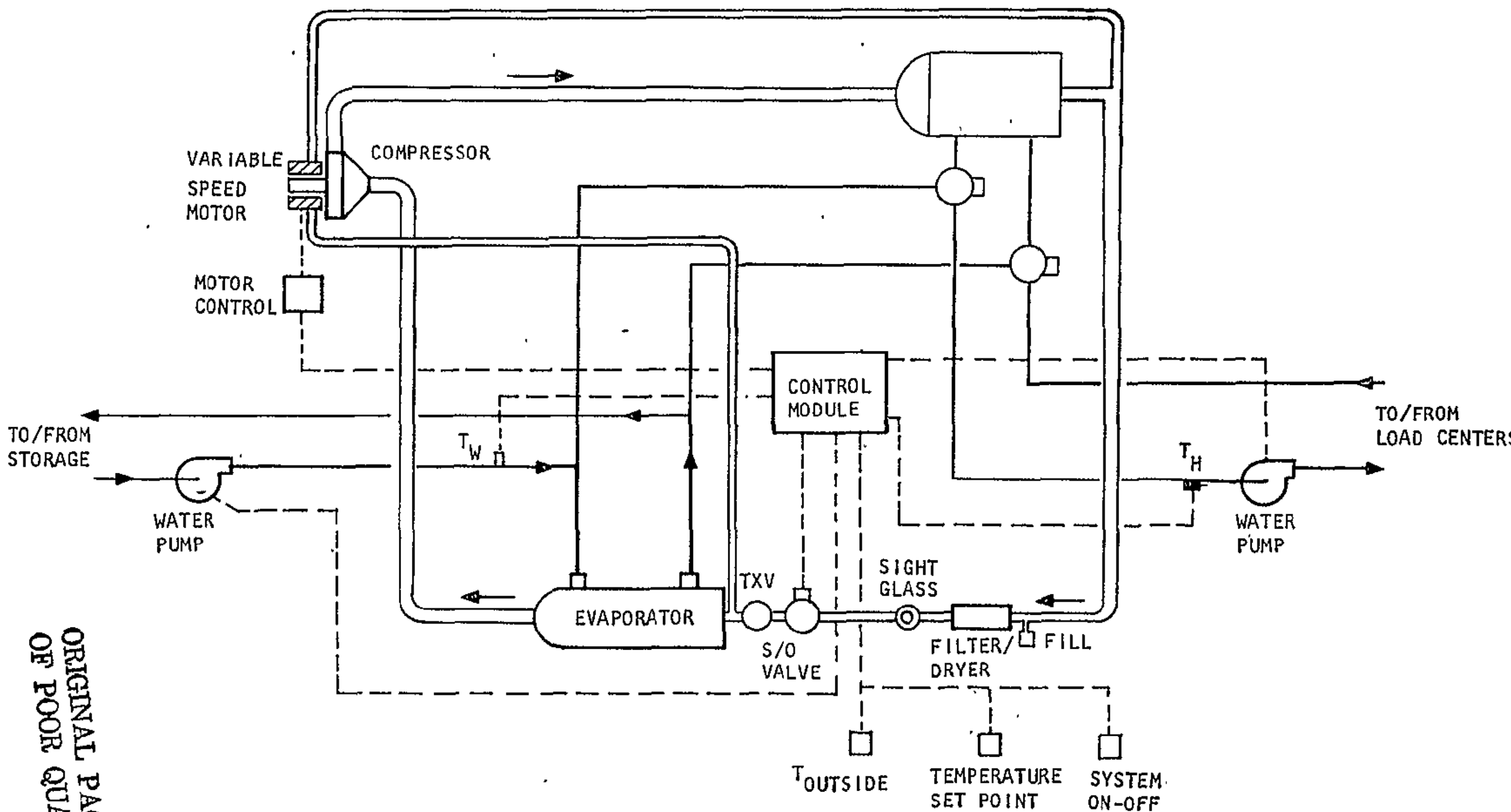

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Figure 4-2. 600- and 1600-KBTUH Space Heating Subsystems Schematic

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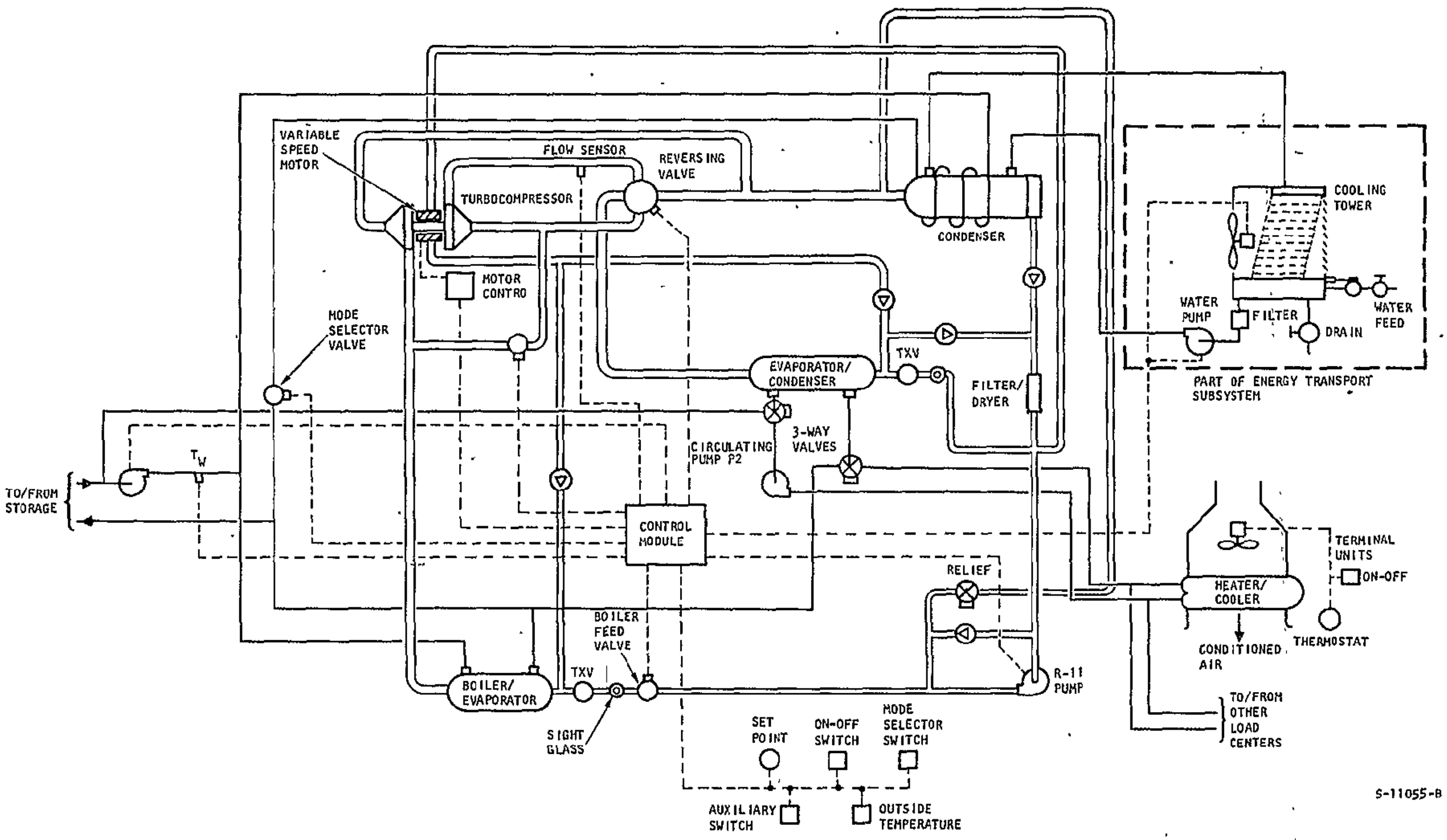

Figure 4-3. 25-Ton/600-KBTUH and 75-Ton/1600-KBTUH Cooling and Heating Subsystems Schematic

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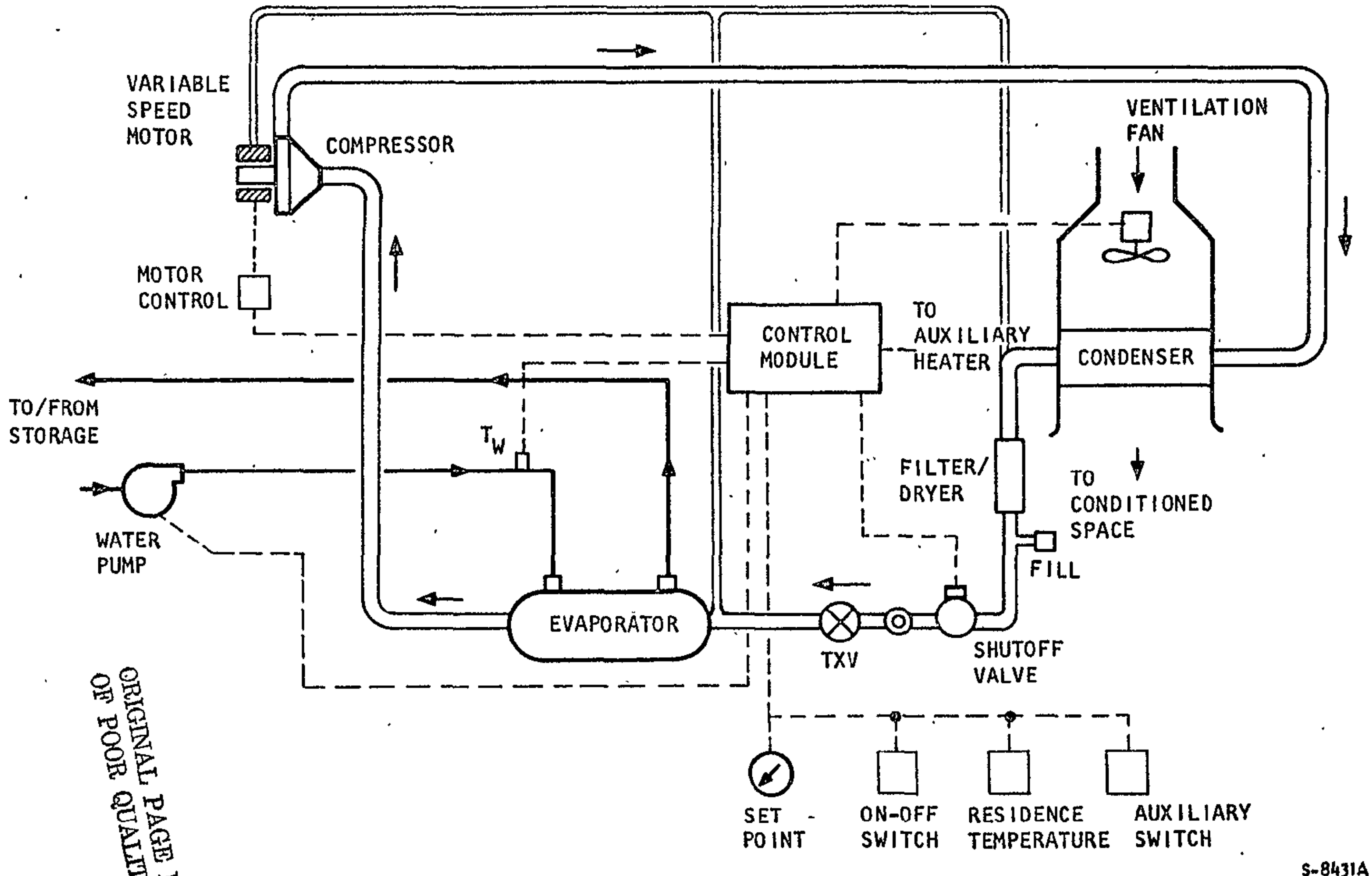

Figure 4-4. Single-Family Residence Space Heating Subsystem

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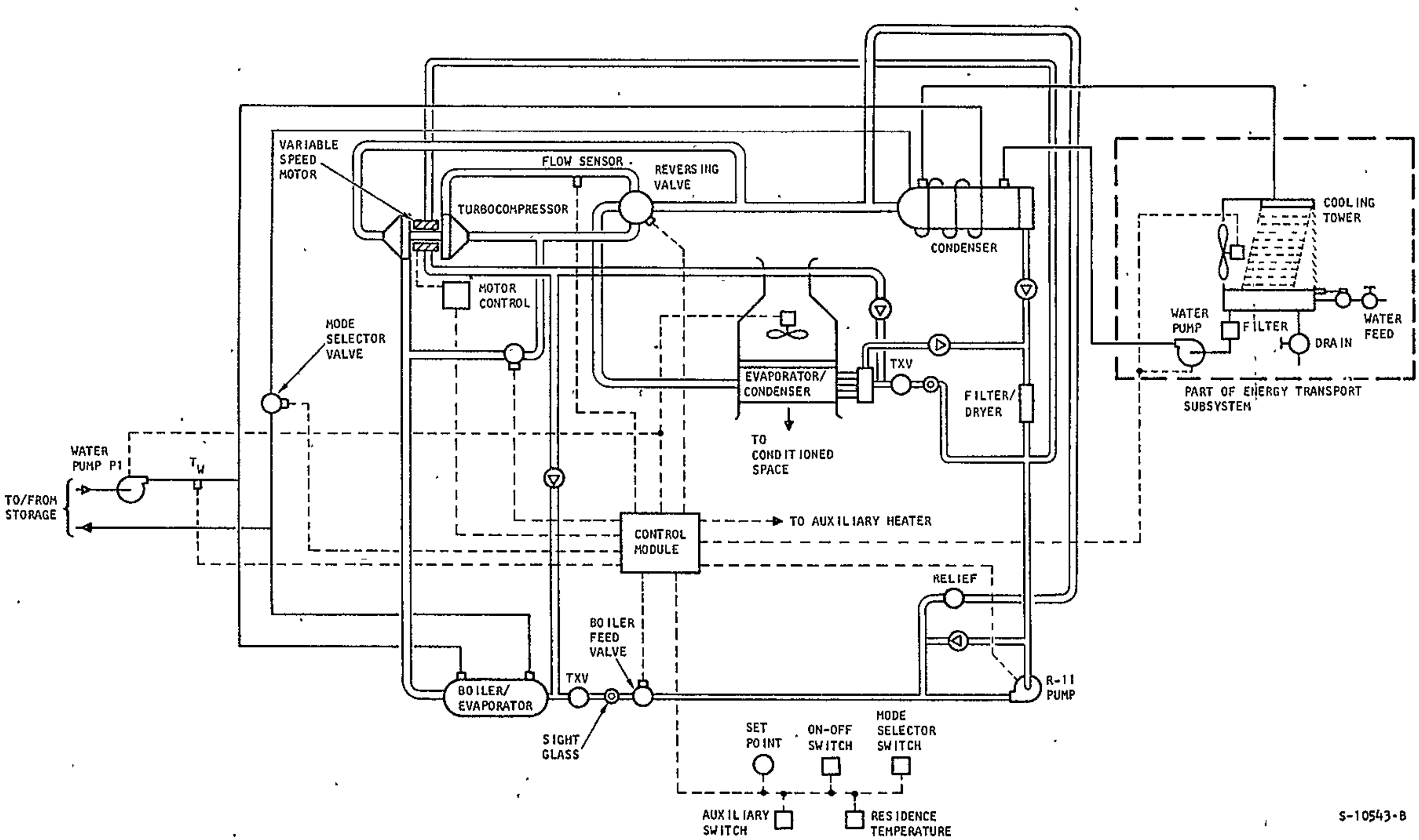

Figure 4-5. Single Family Residence Space Heating and Cooling Subsystem

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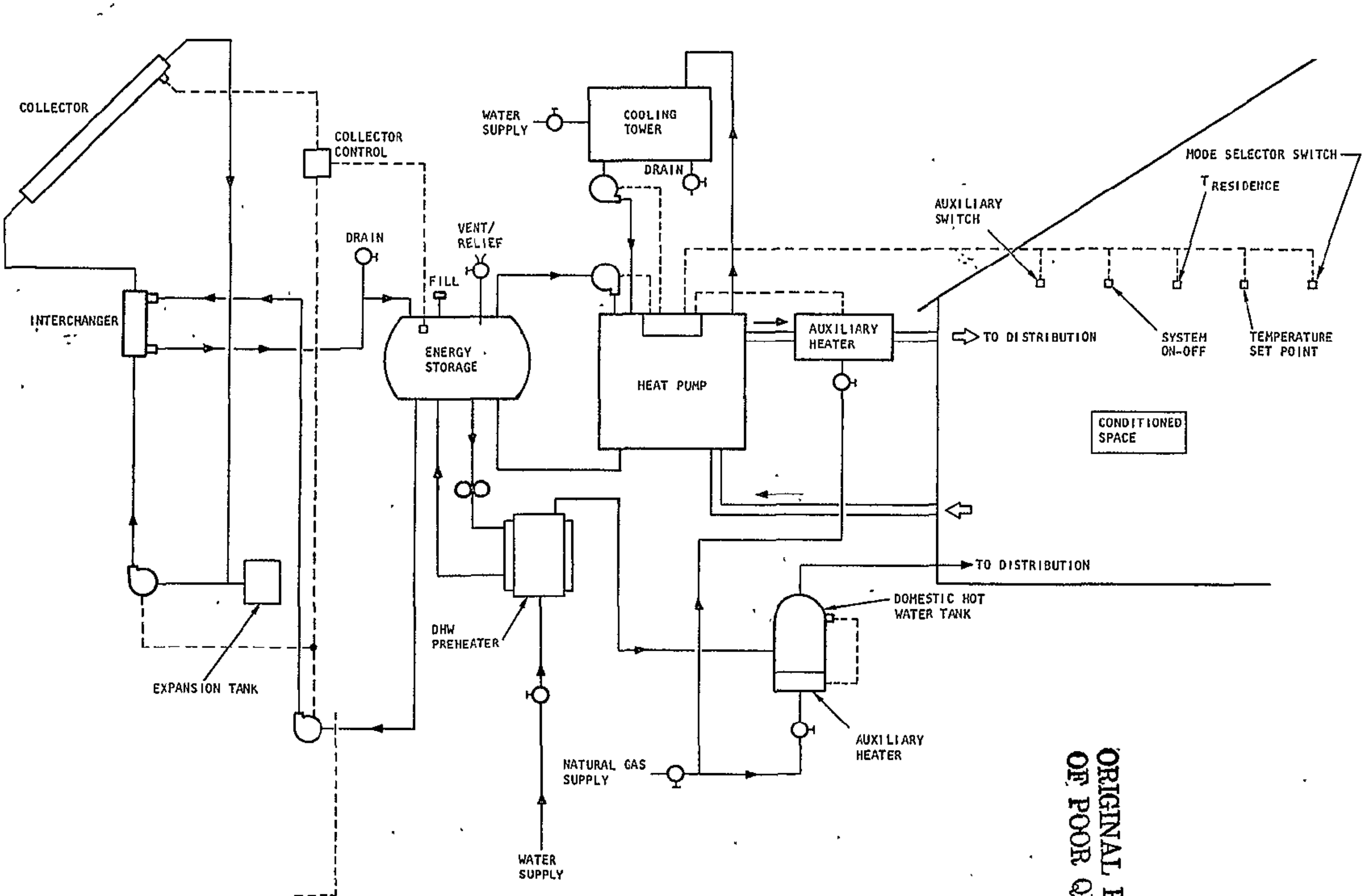

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Figure 4-6. Single-Family Residence Heating and Cooling System

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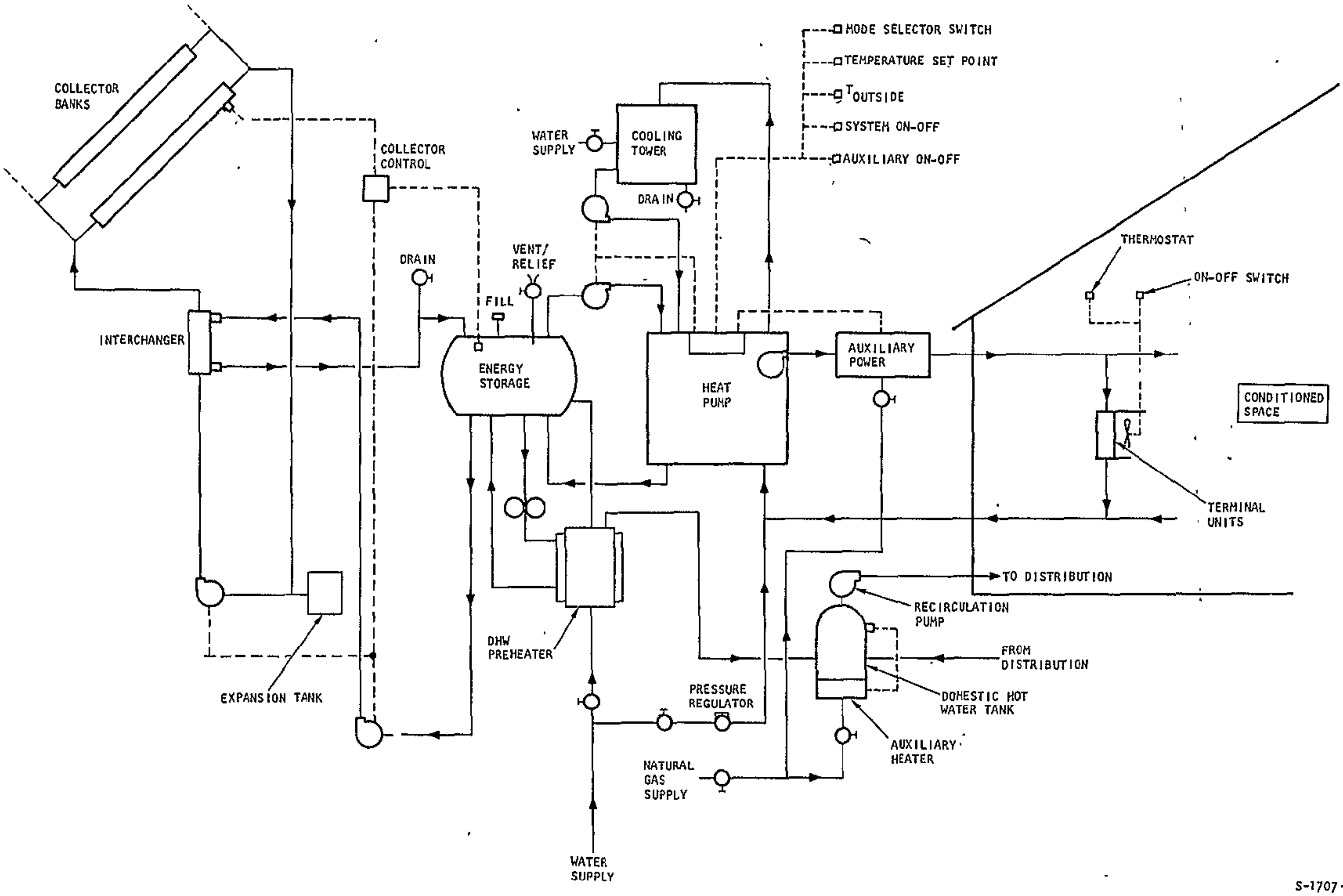

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Figure 4-7. Multifamily, Residence, and Commercial Application Heating and Cooling System.

c. Control System

The development of the control module is evolving in three overlapping phases: (1) breadboard testing, (2) prototype construction, and (3) software development. Results of breadboard testing are continuously utilized in guiding the prototype construction work. Documentation is updated as circuit development passes breadboard testing. Software development is intended to complete all separate control functions in the form of subroutines. An executive (main program) control program appropriate to the particular solar heating and/or cooling system will be developed by merely calling the various available subroutines. Equipment for effecting this recall is shown in Figure 4-8. This organization will isolate future system improvements, evolutions, or changes from propagating throughout the entire software structure causing extensive and time consuming reprogramming efforts.

Most of the control-related subroutines have been coded and assembled. I/O related routines are in progress with assembly expected early in the next quarter. Effort has been concentrated in routines relating to the 3-ton heat-only mode to expedite checkout of the Hamilton AFB system.

d. Heat Pump Subsystem

1. 3-Ton Heat Pump Model 2201288-H-80

A change in specifications for the interchanger to use a glycol-water mixture instead of water required extensive revision in the single family, heating-only 3-ton heat pump subsystem. These changes to the package are about completed. Assembly and detail drawings are complete. Sheet metal parts and the heat exchangers except for the interchanger are fabricated, pumps have been received. Drafting on the heating/cooling heat pump will continue into April.

2. 25-Ton Heat Pump Models 2201288-H-800 and 2201288-HC-825

Drawings for the multifamily heating-only heat pump subsystem, with exception of some of the piping and bills of material, has been completed.

Requisitions have been issued for all purchased components for a heating/cooling heat pump subsystem. Special shop orders have been entered for all fabricated parts.

3. Commercial (75-Ton) Heat Pump Model Nos. 2201288-H-2000 and 2201288-HC-2075

A preliminary design of three water-to-R-11 phase change heat exchangers for the 75-ton unit was recently completed. The boiler/evaporator and the evaporator/condenser utilize a short-vertical-tube shell-and-tube approach and were designed using a single tube heat transfer/pressure drop test data reported in AiResearch Report 76-13448. The condenser is a long horizontal shell-and-tube type. It uses a standard Wolverine high-density, low-fin tubing and a standard Dunham-Bush shell size.

The above design is currently being reviewed by Dunham-Bush for flow control, packaging and cost.

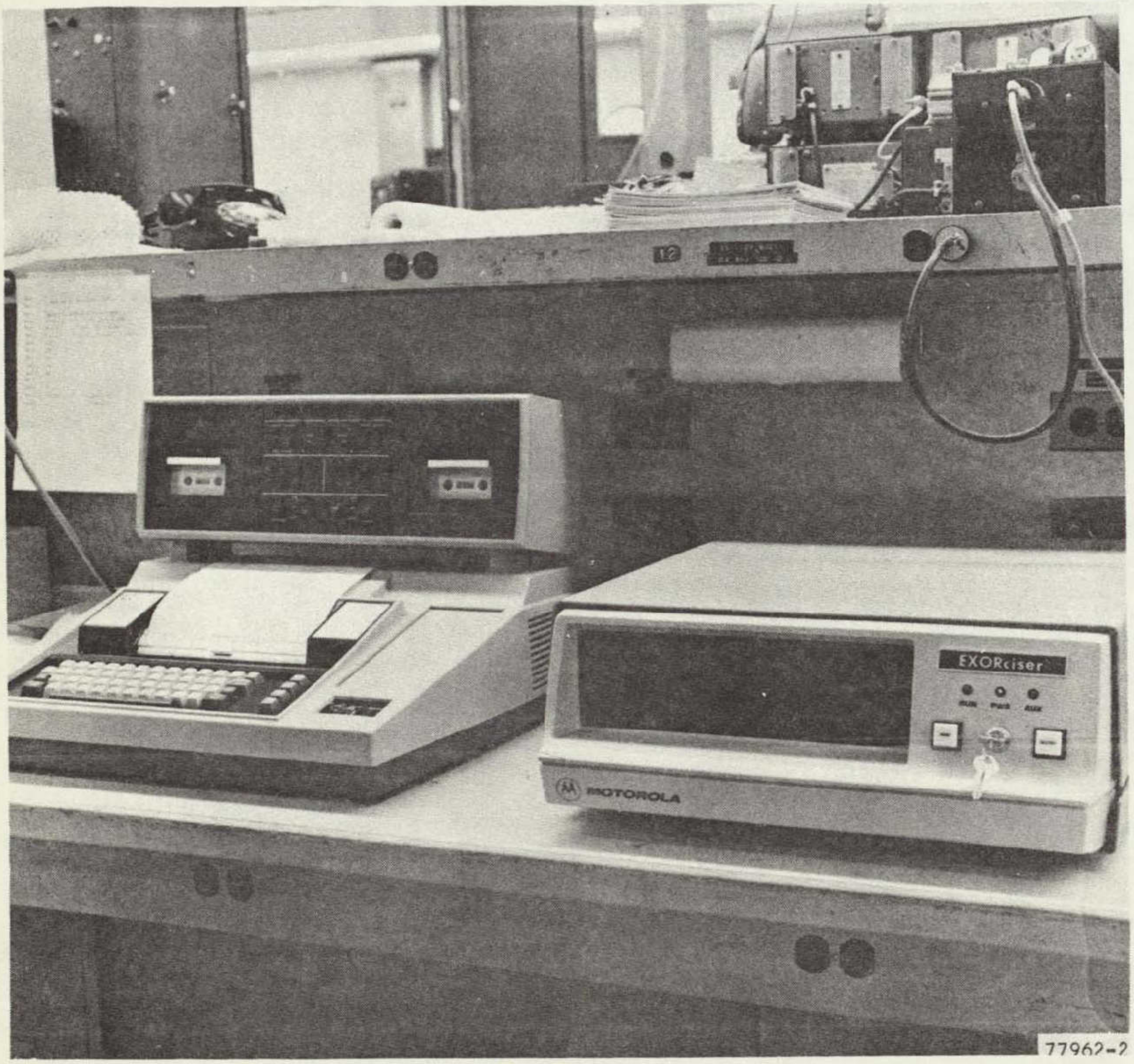

Figure 4-8. T. I. Terminal and Motorola "EXORciser"

2. WBS 1.2.2, System Development

a. Turbomachine/Motors

(a) 3-Ton Unit

All detailed parts have been received. Two center assemblies, complete with ball bearing motors, have been assembled and electrically connected for testing of the motor and motor controller.

The foil bearing total unit will be final assembled early in April. It is contingent on balancing of the completed rotor (see Figure 4-9). A photo of the 3-ton turbocompressor housing is shown in Figure 4-10.

The system test setup for the heating system is progressing. All laboratory parts have been ordered and the heat exchangers have been received from Dunham-Bush. Interconnecting pipes are being fabricated.

(b) 25-Ton Unit

All parts required for the assembly of the ball bearing test units have been received and are in final assembly. Some difficulty has been encountered with the shrinking of the sleeve over the motor totor. Dimensional modifications are being made to facilitate this assembly and a completed rotor should be available early in April. If this is successful, a ball bearing unit can be ready for test in mid-April. Assembly of the second ball bearing unit has been delayed pending solution of the rotor assembly problems with the first unit. All parts are available.

(c) 75-Ton Unit

The layout has been completed and satisfactory stress and thermal solutions have been obtained for the motor and the rotating assembly. All design analysis have been completed.

Detailing is continuing with approximately 90 percent complete and in check. All long-lead items (i.e. magnets, laminations, impeller and turbine) have been released.

b. Motor Control

(a) 3-Ton Motor

The 3-ton motor controller development breadboard system was completed. Static open loop tests were performed. A dynamic analysis was simulated in an analog computer with satisfactory results. An integration test with the motor will be conducted as soon as the motor is available. Long lead items for the four production motor controllers were ordered. Testing of the motor controller with the motor is scheduled for completion in April.

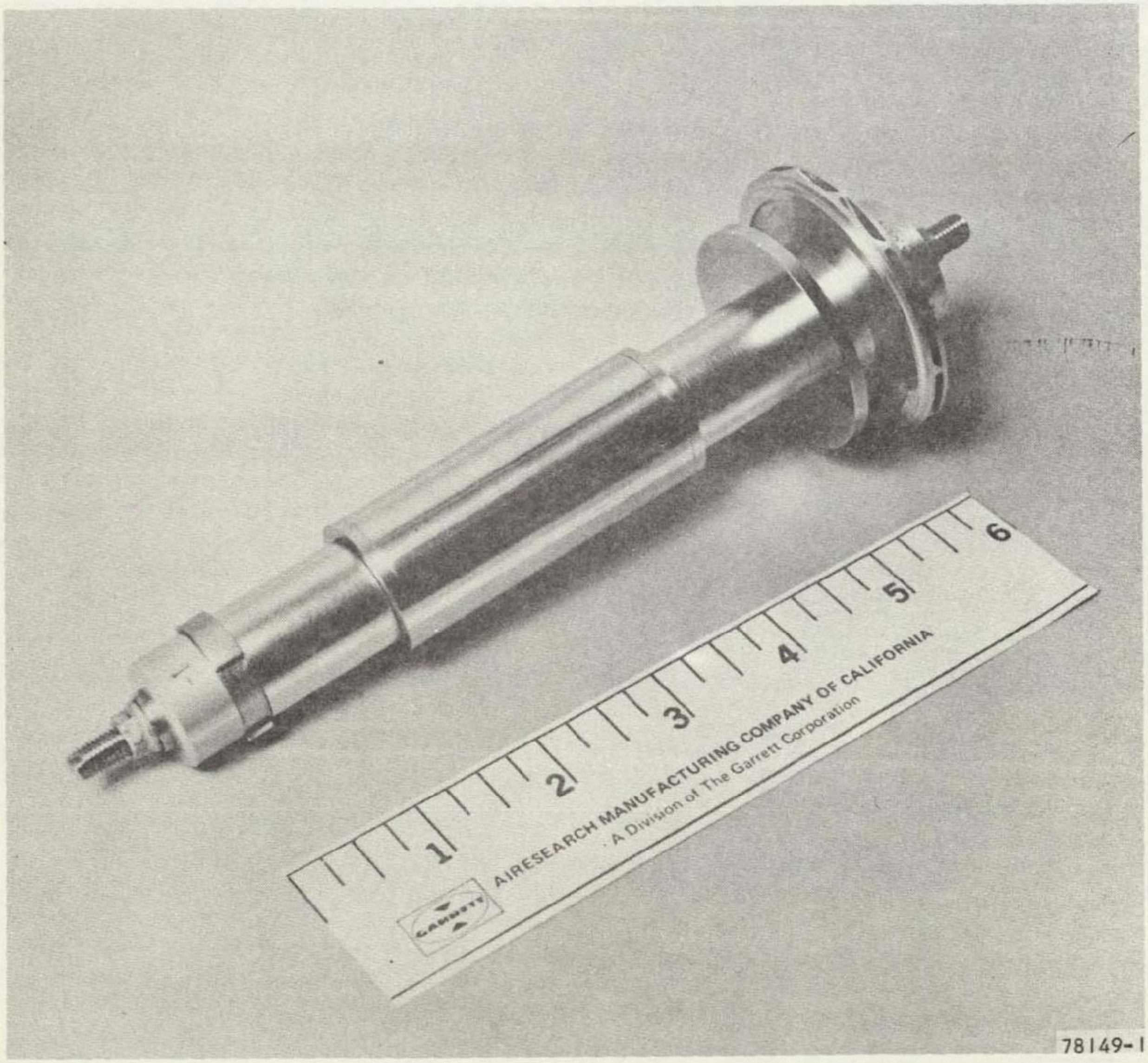

Figure 4-9. Rotor Assembly for the Foil Bearing for 3-Ton Motor Driven Heat Pump Compressor

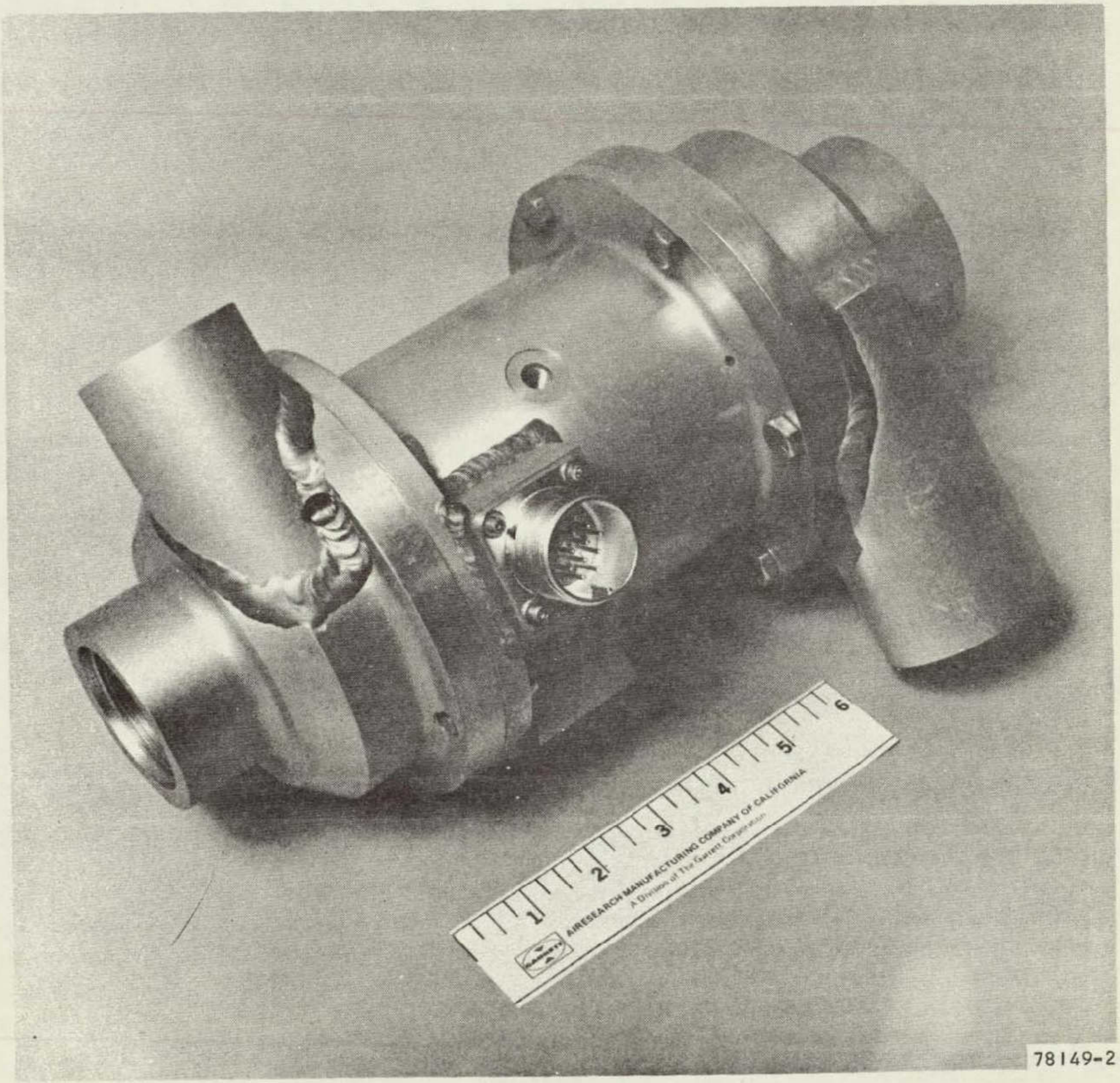

Figure 4-10. 3-Ton Motor Driven Turbocompressor Housing

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(b) 25-Ton Motor Control

The auxiliary commutation scheme has been tested open loop with the inverter (Figure 4-11) driving a resistive load. Current limits (30 amps for 0 to 10 percent speed, and 100 amps above 10 percent speed) have been incorporated into the PDR control.

A stress analysis in the control circuitry has been completed. The remaining tasks on the 25-ton unit are:

a. The completion of the dynamic analysis on the 25-ton motor controller.

b. Mechanization of the speed loop (this task cannot be done until dynamic analysis is completed).

c. Closed loop tests on the controller

(c) 75-Ton Motor Control

Design of the 75-ton motor controller has been initiated. This task is 5 percent complete.

c. System Control

The circuit design activity has been completed and a breadboard unit has been built and debugged (see Figure 4-12). Functional tests of all input/output and control circuits have been completed satisfactorily. Detail testing and high-low temperature worse-case tests have also been completed.

Fabrication of circuit boards, chassis and wiring harnesses for a prototype unit is now complete. Assembly drawings and wiring lists are also complete.

Most of the control related subroutines for the software program have been in progress with assembly anticipated in late April. Effort has been concentrated on routines related to the 3-ton heat-only mode to expedite check out of the first unit scheduled. When the 3-ton heat only subroutines are complete, an executive program will be initiated. This task configures the entire system.

d. R-11 Pumps

(a) 3-Ton Pump

During this quarter, the 3-ton pump was designed, detailed, and hardware fabricated. The design (Drawing SK 71830) consists of a vane pump element driven by a single-phase 115V, 60 Hz motor. The unit is hermetically sealed with the stator and rotor immersed in the Freon, which is circulated through the bearings and housing to assure cool operating. Leads from the primary and secondary stator windings are directed through a hermetic connector to an external 90 mf capacitor which is partially shorted out after starting by a pressure switch on the pump discharge. The prototype stator and rotor were derived from a 1/6 hp industrial motor; the stator was stripped and rewound

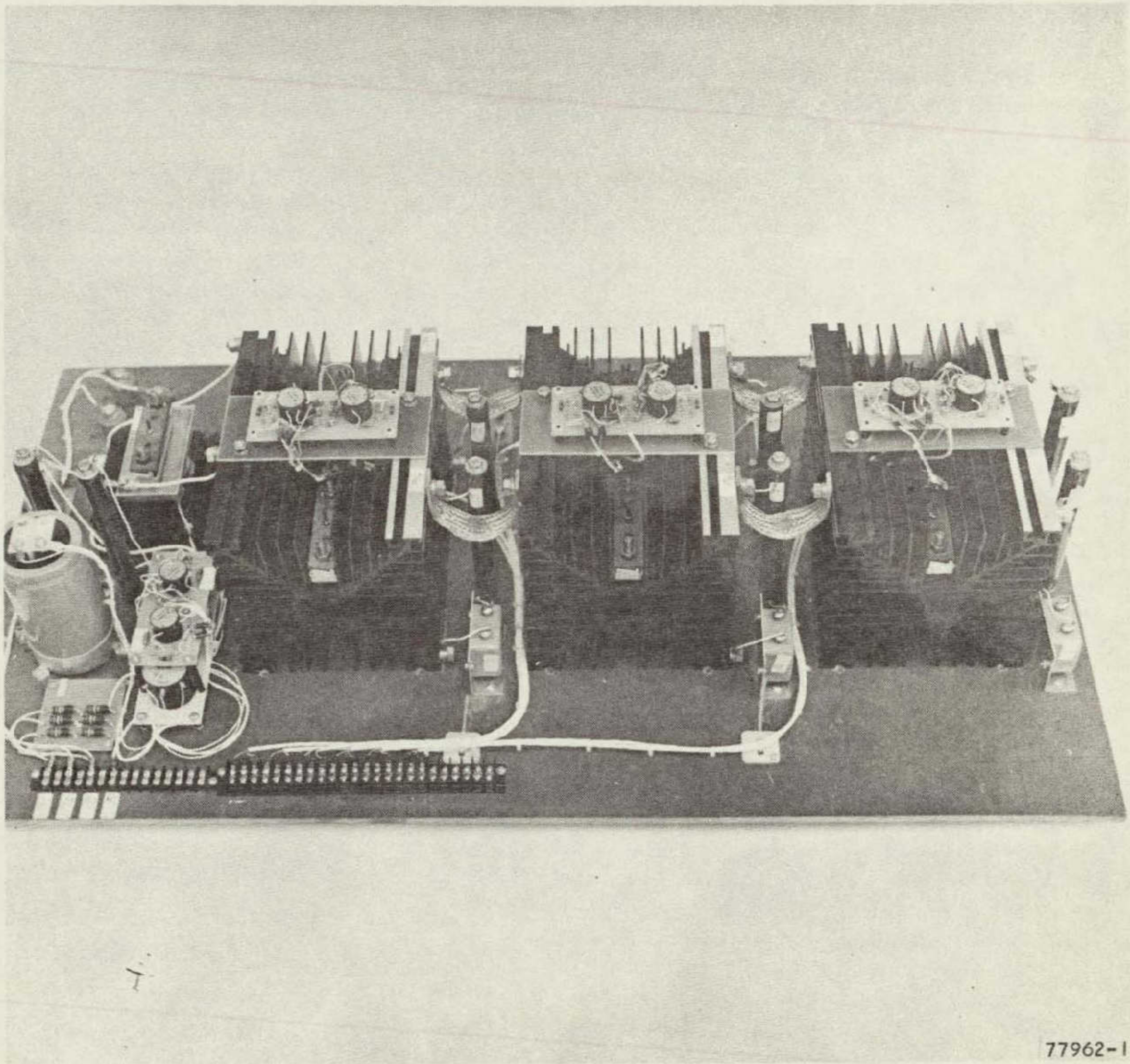

Figure 4-11. Inverter for 25-Ton Heat Pump Motor

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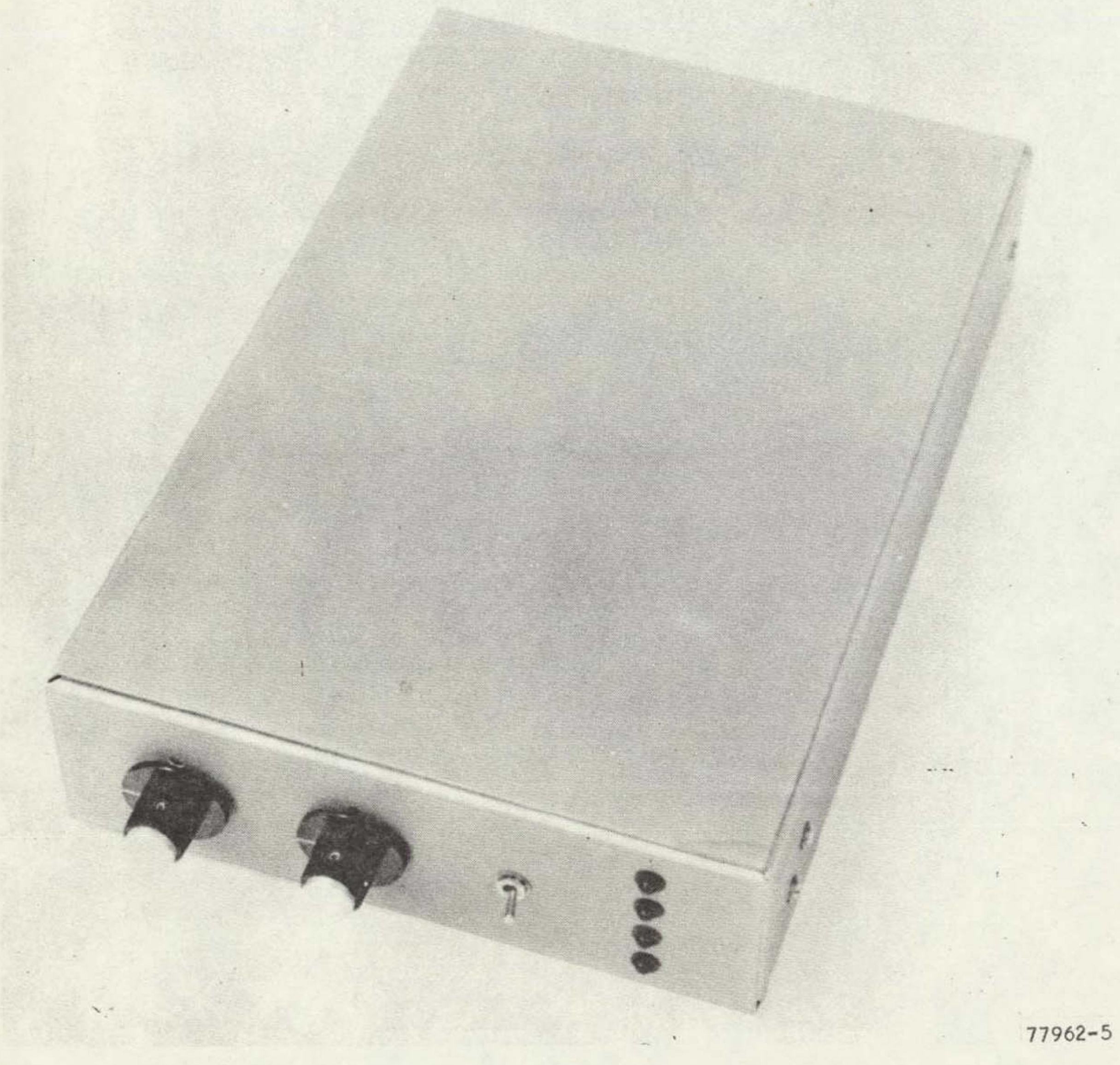

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Figure 4-12. Heat Pump Subsystem Breadboard Control Module

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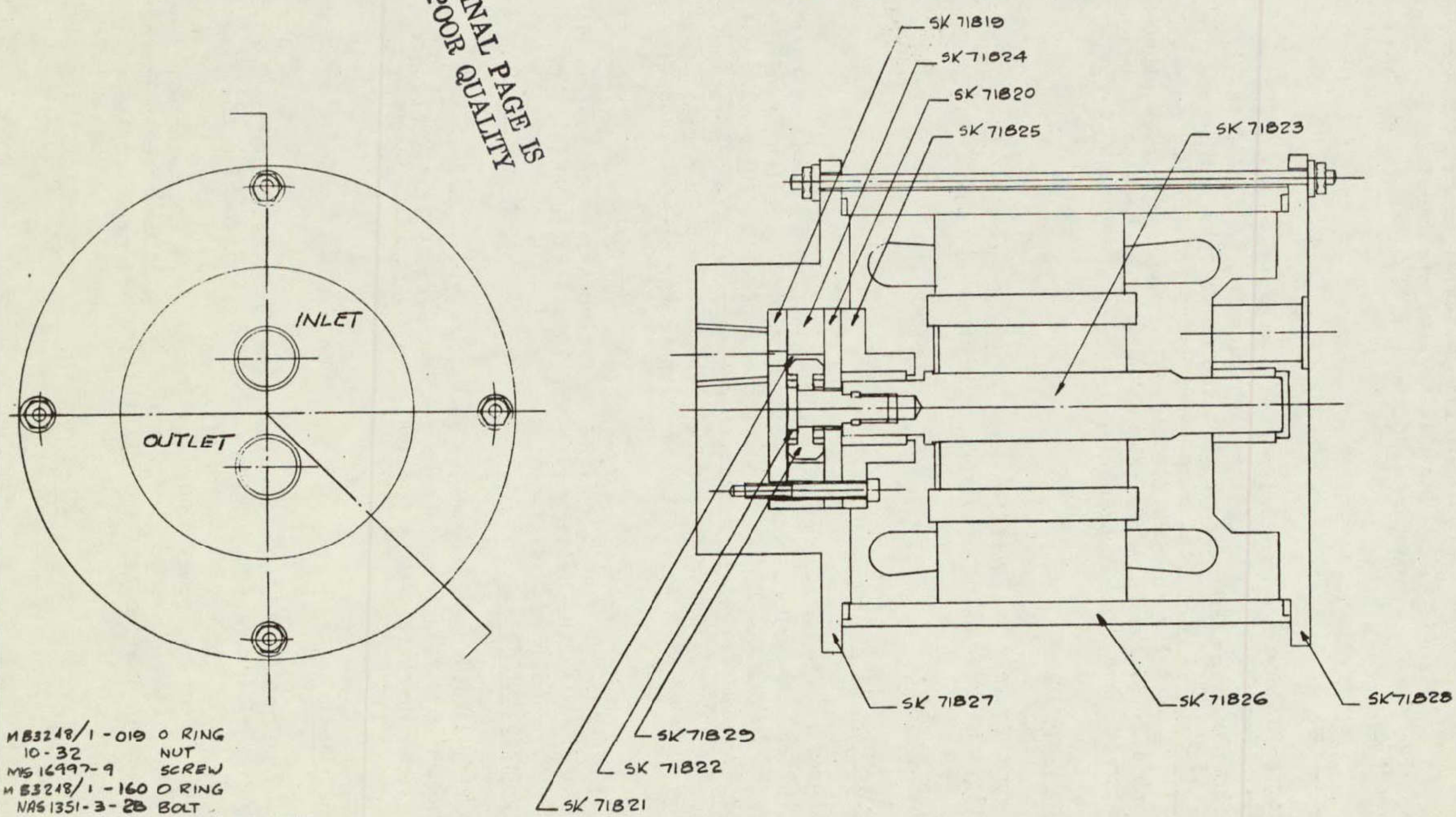

MS3248/1 - 019 O RING
10 - 32 NUT
MS 16997- 9 SCREW
MS3248/1 - 160 O RING
NAS 1351- 3 - 28 BOLT
10-32 x 7.375 THREADED ROD
223- 018- 9025 CONNECTOR.

PART NO

UNLESS OTHERWISE SPECIFIED:
BURR CONTROL PER SC653
STD INTERPRETATIONS PER PI86
IDENTIFICATION MARKING PER SC18

CONTRACT NO	
PREPARED BY	R Brown 1/14/77
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DESIGN	
VALUE ENGR	
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STRESS	
APPD	
DESIGN SUPERVISOR	PROJECT ENGINEER R BROWN
GOVERNMENT APPD	

MATERIAL —

FINISH PROCESS

HEAT TREATMENT

REQD	NEXT ASSY	USED ON
APPLICATION		

AIRESEARCH MANUFACTURING COMPANY OF CALIFORNIA
A DIVISION OF THE GARRETT CORPORATION
TORRANCE, CALIFORNIA

PUMP ASSY, FREON

SIZE	CODE IDENT NO	DWG NO
C	70210	SK 71830

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for a larger power output using insulation material known to be compatible with R-11. The bearings, vanes, and pump sideplates are fabricated from carbon graphite. The housing is aluminum and the cam ring, shaft and rotor and 17-4 PH CRES material.

(b) 25-Ton Pump

During this quarter, the 25-ton pump was designed and detailed. Pump hardware is being fabricated. The design (Drawing SK 72035) is similar in principle to the 3-ton unit except that the normal operating speed is 1160 rpm instead of 1760 rpm. Also, the pump inlet is ported through both sideplates to improve filling of the vane pump element. The pump rotor is supported on bearings on each side of the rotor instead of being cantilevered as in the 3-ton design. Assembly and test is scheduled to start at the end of April.

(c) 75-Ton Pump

Work on this unit is awaiting the results of the tests on the 3-ton and 25-ton units, and evaluation of alternate approaches.

3. WBS 1.2.3, Test

a. Turbomachine/Motor Tests

Testing of the 3-ton heat pump unit was started in March using a breadboard motor controller. A turbocompressor assembled with a ball-bearing rotor was operated under load up to 30,000 rpm without incident. The test setup is shown in Figure 4-13. Quantitative results, based on start/stop characteristics, power consumption and off-design operation, will be obtained in April. Tests of the foil bearing machine will be started when the rotor has been dynamically balanced.

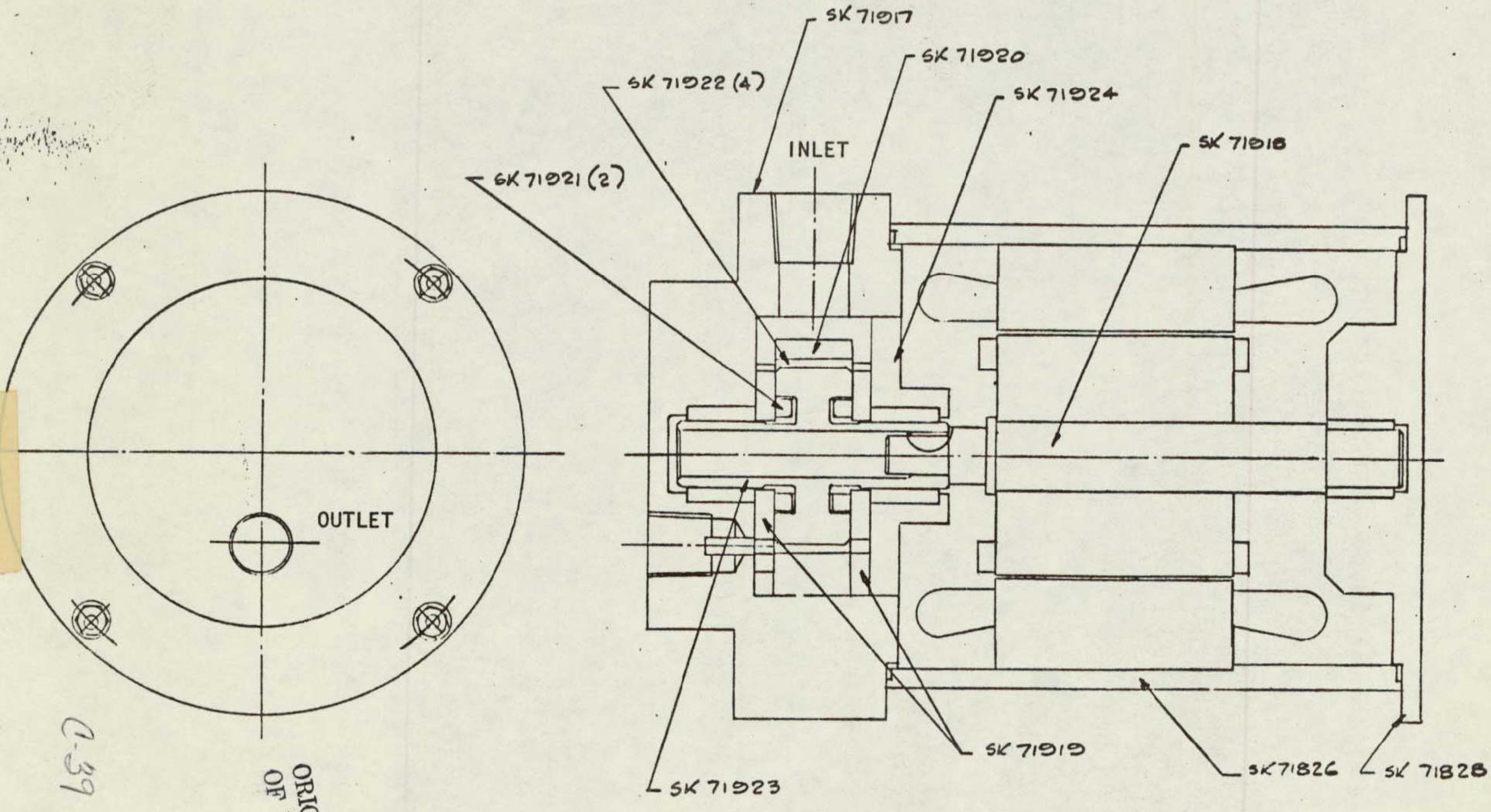
Testing of the 25-ton unit will be conducted as for the 3-ton unit, starting in mid-April, with the ball-bearing version tests to come first.

b. Motor Controller Tests

Breadboard motor controller tests have been limited to static open-loop tests of the 3-ton unit at currents up to 30 amperes. Transient operation to 60 amps has been investigated for 3-second intervals. Closed loop tests are imminent.

c. R-11 Pump Test

A 3-ton heat pump subsystem R-11 pump was first assembled and operated in March. The initial test setup is shown in Figure 4-14, while the disassembled hardware is shown in Figure 4-15. Initial tests showed that the motor was overpower because the no-load power input was 360 watts. The motor was rewound and the pump unit retested; two hours of run time were accumulated. The performance exceeded the design goals except for the inlet pressure which is still being evaluated.



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UNLESS OTHERWISE SPECIFIED:
BURR CONTROL PER SC653
STD INTERPRETATIONS PER PI86
IDENTIFICATION MARKING PER MC18

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APPLICATION		

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PREPARED BY [signature] 4/15/

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DESIGN

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STRESS

APPD

DESIGN SUPERVISOR

PROJECT ENGINEER R BROWN

GOVERNMENT APPD

AIRESEARCH MANUFACTURING COMPANY OF CALIFORNIA
A DIVISION OF THE GARRETT CORPORATION
TORRANCE, CALIFORNIA

PUMP ASSY, FREON
25 TON

SIZE	CODE IDENT NO	DWG NO
C	70210	SK 72035

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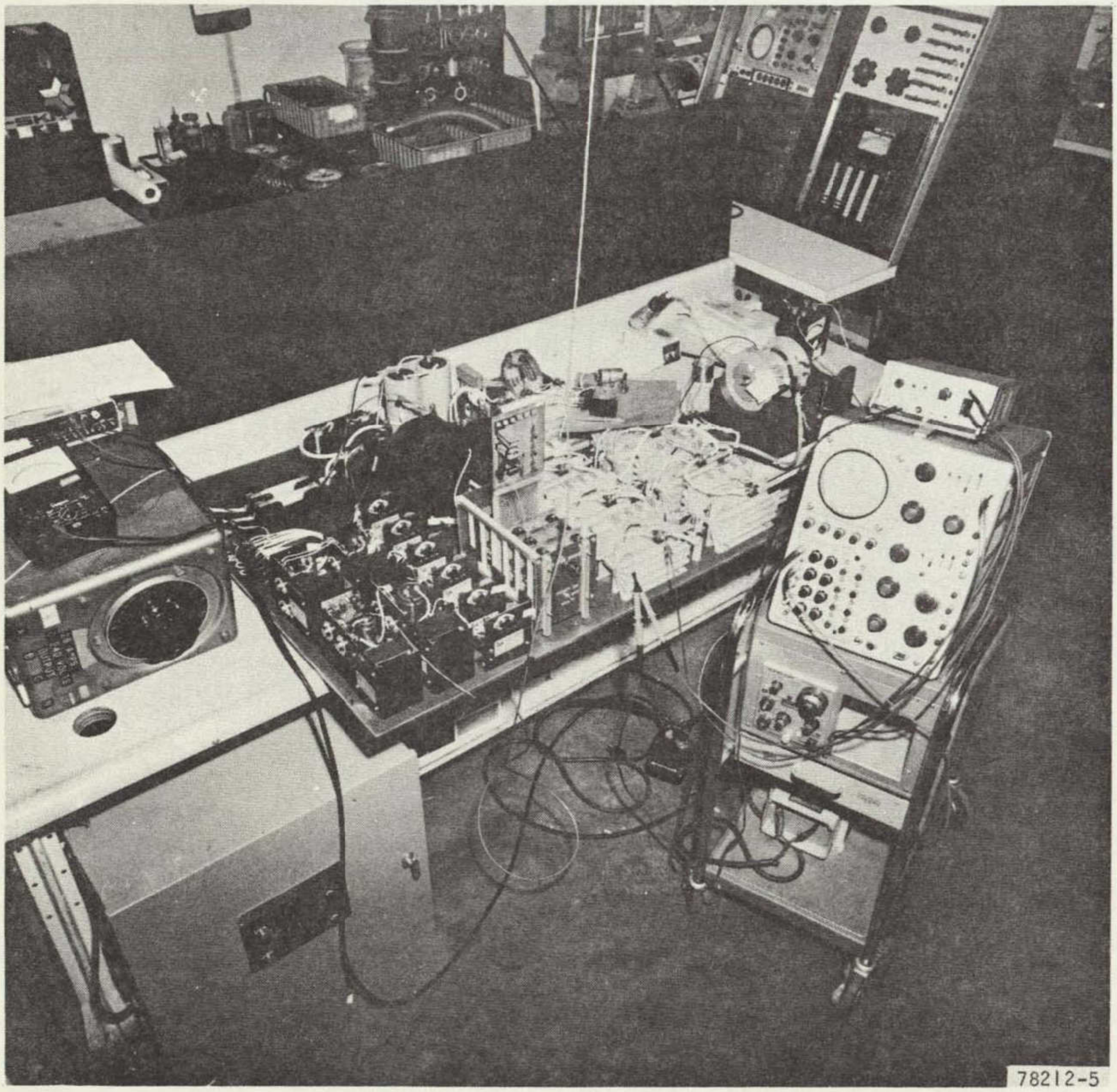

Figure 4-13. 3-Ton Motor Controller Dynamic Test Setup

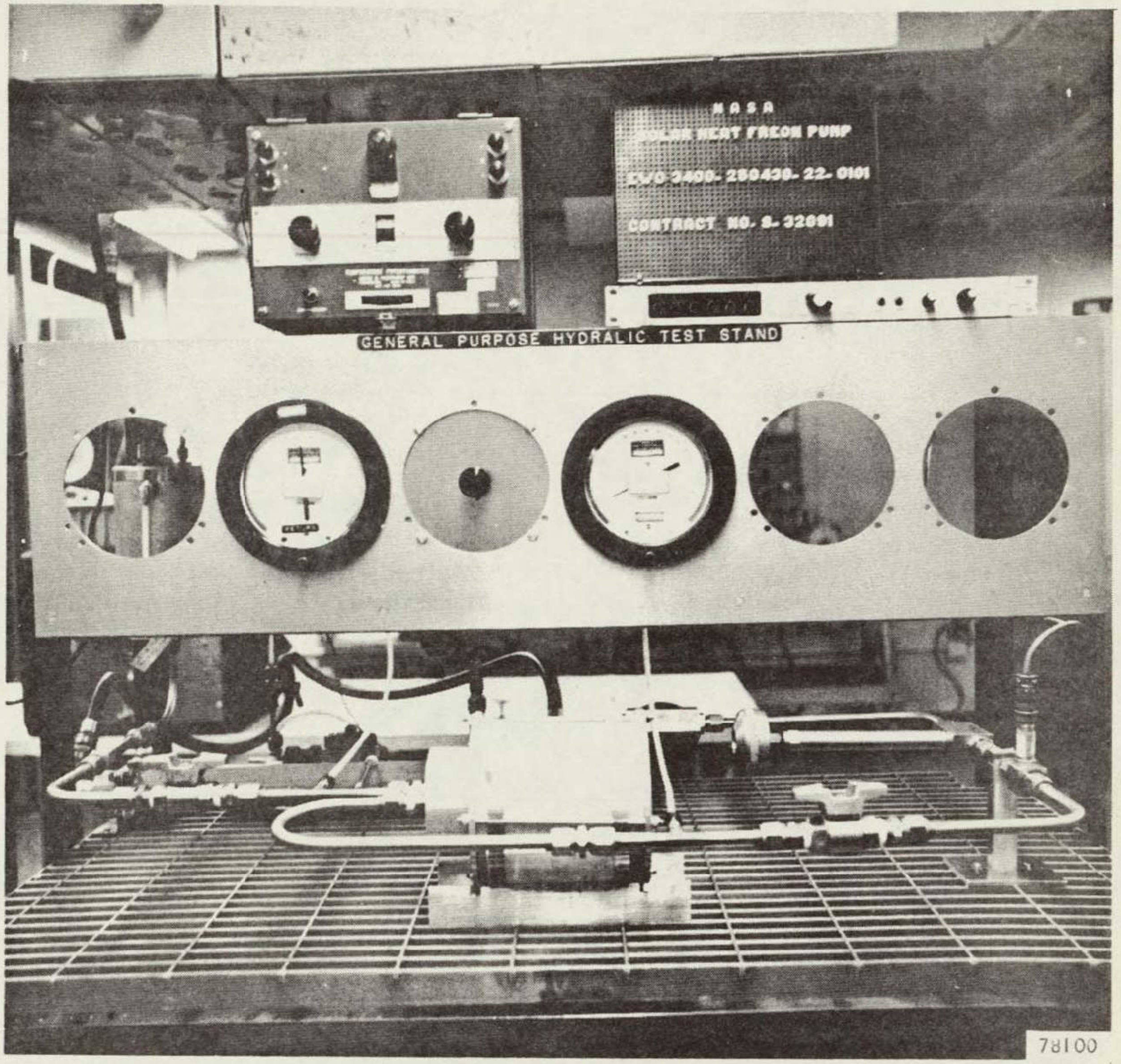

Figure 4-14. 3-Ton R-11 Pump in Test Setup

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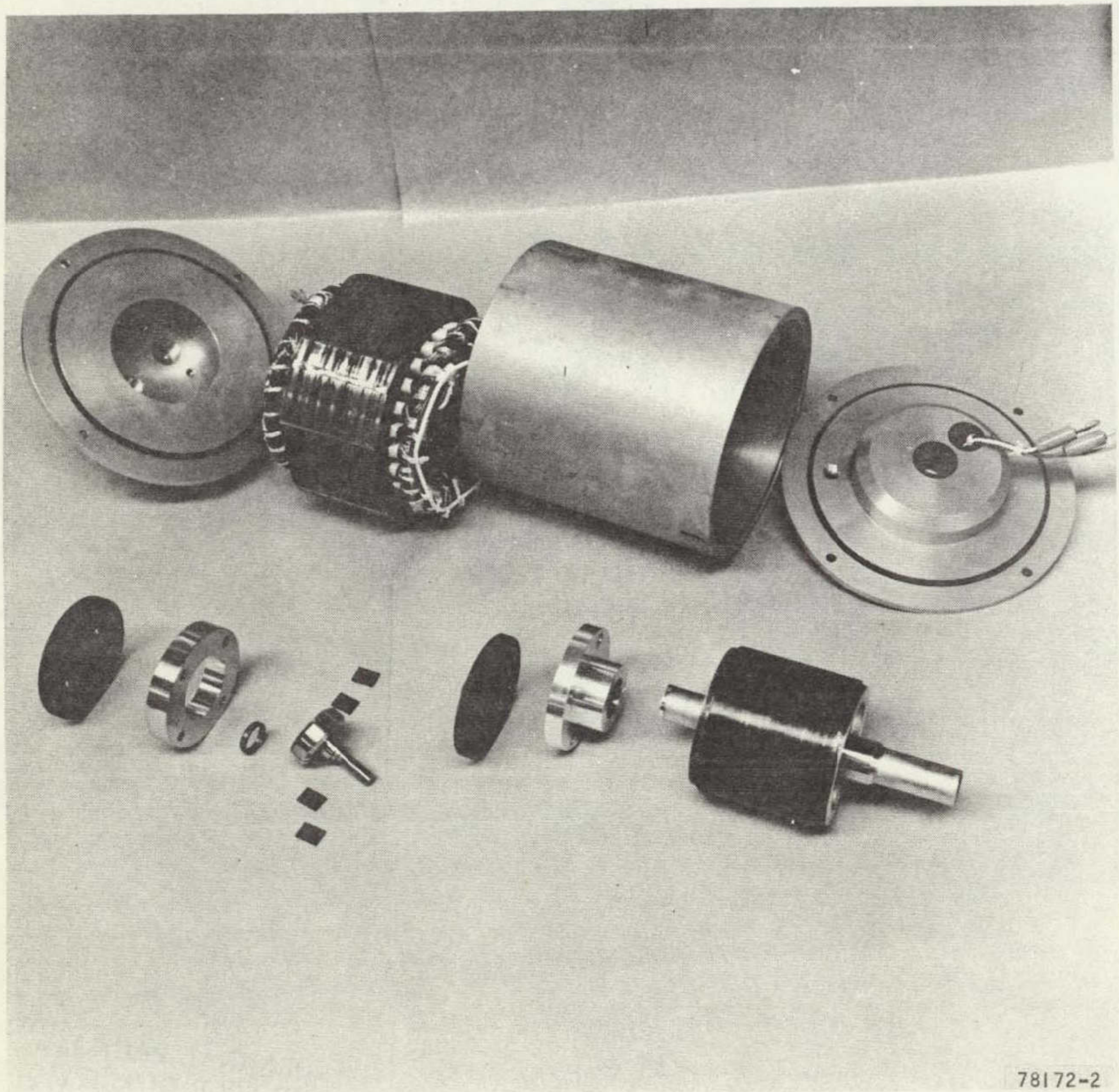

Figure 4-15. Parts Array for 3-Ton Heat Pump System R-11 Pump

FUTURE ACTIVITIES

Activities in the next quarter will include the following.

WBS 1.1 Management

1. WBS 1.1.1 Program Direction

   a) The third quarterly review is scheduled to be held at AiResearch on April 20.

   b) A collector manufacturer will be selected and a subcontract will be negotiated and awarded.

   c) A major effort will be expended in selecting sites suitable for system installation. Currently, the following activities are planned:

      1. A detailed evaluation of the Allaire Park, N.J. single-family residence will be conducted. This site appears suitable for system test and is currently in the approval cycle.

      2. The Hazard Branch library in Syracuse will be surveyed as a potential test site for a light commercial heat system (800-KBTUH).

      3. A visit to Des Moines, Iowa, has been scheduled for April 18 for the purpose of selecting a single-family heating/cooling test site.

      4. A proposal will be prepared by AiResearch to use the Dunham-Bush test house in Harrisonburg as an installation for integrated system development testing. It is recommended that this installation replace the Washington D.C. site for a single family heating/cooling system.

      5. All information supplied by NASA relative to other sites will be evaluated and appropriate action will be taken to expedite site selection and approval by NASA.

   d) Monthly coordination meetings are planned with Dunham-Bush to assess progress and resolve problems.

2. WBS 1.1.2 Program Planning and Control

   a) Schedule Development

   Schedules will be updated as required. NASA will be informed of any significant slippage if any.

   b) Program Documentation

   The following program documents will be prepared.

(1) DR 500-10, the fourth quarterly report

(2) DR 500-11, monthly status reports

(3) DR 500-27, financial management reports (provided monthly)

(4) Installation technical information packs for site owners

(5) DR-500-3, quality assurance revision

(6) Solar collector test plan

(7) Instrumentation plan

3. WBS 1.1.3 Quality Assurance

The quality assurance plan will be revised per NASA direction and implemented through the program.

WBS 1.2 Development

1. WBS 1.2.1 Analysis and Integration

(a) Analyses will be performed as necessary in support of the site selection effort.

(b) Test data will be reduced and system/subsystem performance will be updated using these data.

2. WBS 1.2.2 and 1.2.3 System Development and Test

(a) System Design Activities--The single family residence heating system for the Hamilton AFB installation will be completed. The design of other systems will proceed immediately following as the other sites are selected.

(b) Heat Pump Development

Heat Exchangers--Detail design of the 75-ton boiler/evaporator and evaporator/condenser will be finalized. One set of heat exchangers for the 75-ton/1600 KBTUH will be fabricated for incorporation in the first heat pump prototype.

Fabrication of one set of heat exchangers for the 25-ton/800-KBTUH will be completed and delivered to Harrisonburg for assembly in the development test unit. One each of the heating mode evaporator and condenser will be fabricated and delivered to AiResearch for the turbomachine test rig.

(c) Turbomachine/Motor

The ball bearing version of the motor will be tested with the motor controller. Early in April, the foil bearing motor with compressor will be assembled and tested together with the controller.

Assembly of the complete 3-ton turbomachine and development testing.

Assembly of the heating mode 25-ton motor/compressor and development testing at AiResearch. The complete turbomachine will be tested at Dunham-Bush later.

(d) Motor Controller

The 3- and 25-ton breadboard motor controller dynamic tests with appropriate motors will be completed in the next quarter.

(e) System Control

Prototype software, hardware, wiring and circuit layout will be debugged. Drawings for the prototypes will be completed and the software subroutines and main programs will be documented.

(f) R-11 Pumps

Performance evaluation of the 3-ton R-11 pump will be completed and a 300-hr endurance test will be conducted. Performance will be monitored at regular intervals. Following this test the pump will be disassembled and inspected for signs of wear.

The 25-ton R-11 pump will be assembled and tested for performance verification and durability as for the 3-ton unit.

Use of a centrifugal pump for the 75-ton heat pump will be evaluated.

(g) Heat Pump Packages

Package drawings including R-11 and water piping will be completed for the 3-ton/60 KBTUH unit. Similar work will proceed on the 25-ton/600 KBTUH heat pump. Also, layout of the 75-ton heating/cooling unit will be initiated.

Assembly of the 80 KBTUH heating-only unit will proceed and continue through June. This unit should be ready for testing in June. Assembly of the 800 KBTUH heating-only heat pump will be initiated.

(h) Collector

A collector panel representing the latest configuration developed by Daystar will be fabricated and shipped to NASA for evaluation on the simulator. A test plan covering this series of test will be prepared by AiResearch in coordination with NASA and Daystar.

WBS 1.3 Deliverable Hardware

1. WBS 1.3.1 Single-Family Residence

(a) Turbomachine/Motor

Following development testing four 3-ton prototype turbomachines will be delivered to Dunham-Bush for integration in the heat pump packages. The first unit is scheduled for delivery June 1.

(b) Motor Controller

A prototype motor controller will be assembled following breadboard testing with the motor and delivered to Dunham-Bush on June 1.

Assembly of the first 25-ton motor controller will be started.

(c) System Control

The first prototype will be assembled and tested prior to delivery to Dunham-Bush on June 1.

(d) R-11 Pumps

Upon performance test completion, three deliverable pumps will be built for the subsystem test. This work will include upgrade of the schematic and preliminary layout drawings to prototype unit status. The 25-ton pump will undergo a similar development program.

PART D

Fourth Quarterly Report
Data Requirement 500-10

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT

Contract NAS8-32091

76-13296(4)

July 8, 1977

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Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama 35812

CONTENTS

SECTION I

INTRODUCTION AND SUMMARY

INTRODUCTION

This is the fourth quarterly report prepared by AiResearch Manufacturing Company of California under Contract NAS 8-32091 for the National Aeronautics and Space Administration, Marshall Space Flight Center (MSFC). The report summarizes activities from April 1, 1977 to July 1, 1977.

SUMMARY

Significant activities and status of the cost, schedule, and technical aspects of the program are summarized in the following paragraphs.

Cost Status

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Schedule Status

Three sites were selected for heating-only systems. Single-family system sites were established at Oakland (Hamilton AFB), California, and Allaire Park, N.Y. and a light commercial site was selected for the Clarence Hancock Airport, Syracuse, N.Y. waiting building. The former site was cancelled when the U.S. Navy withdrew from solar participation on June 17, 1977. An alternate site has been suggested at Harrisonburg, Va., as a possible replacement for the Washington D.C. site to expedite the field demonstration program. The latest site status is depicted in Figure 1-4.

The latest schedules for the heating and the heating/cooling systems are presented in Figure 1-2 and 1-3.

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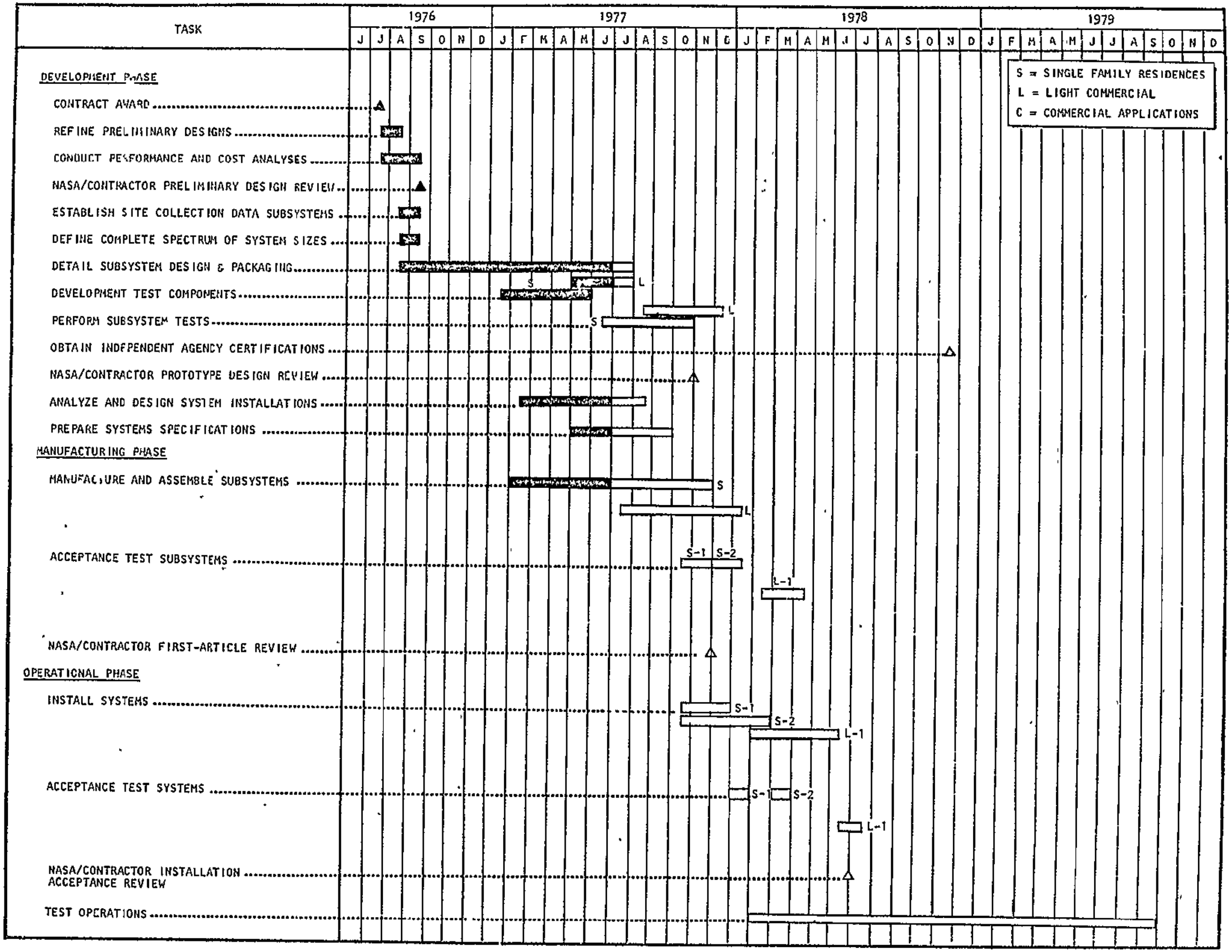

Figure 1-2. Solar Heating System Development Schedule

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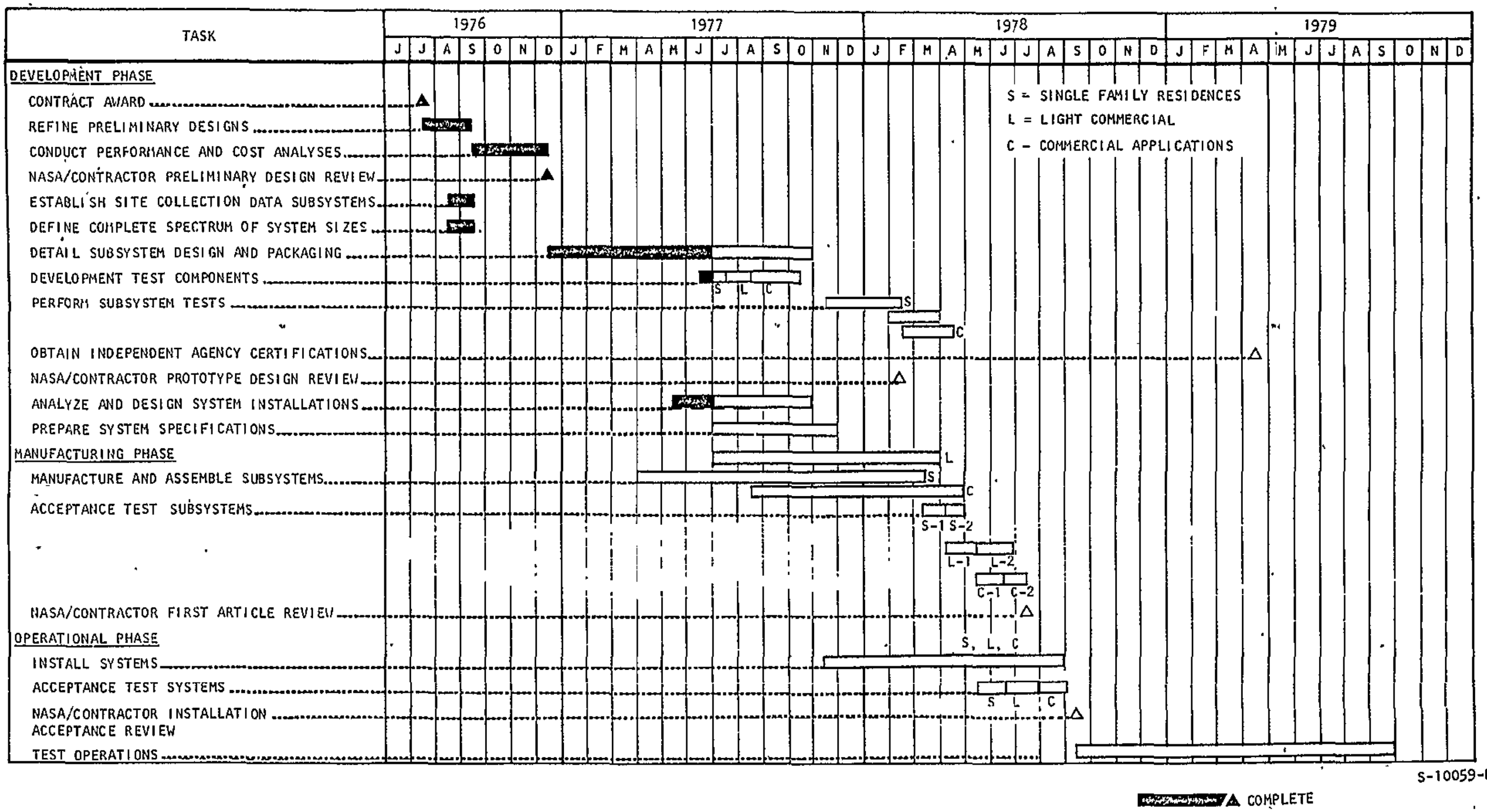

Figure 1-3. Solar Heating/Cooling Systems Development Schedule

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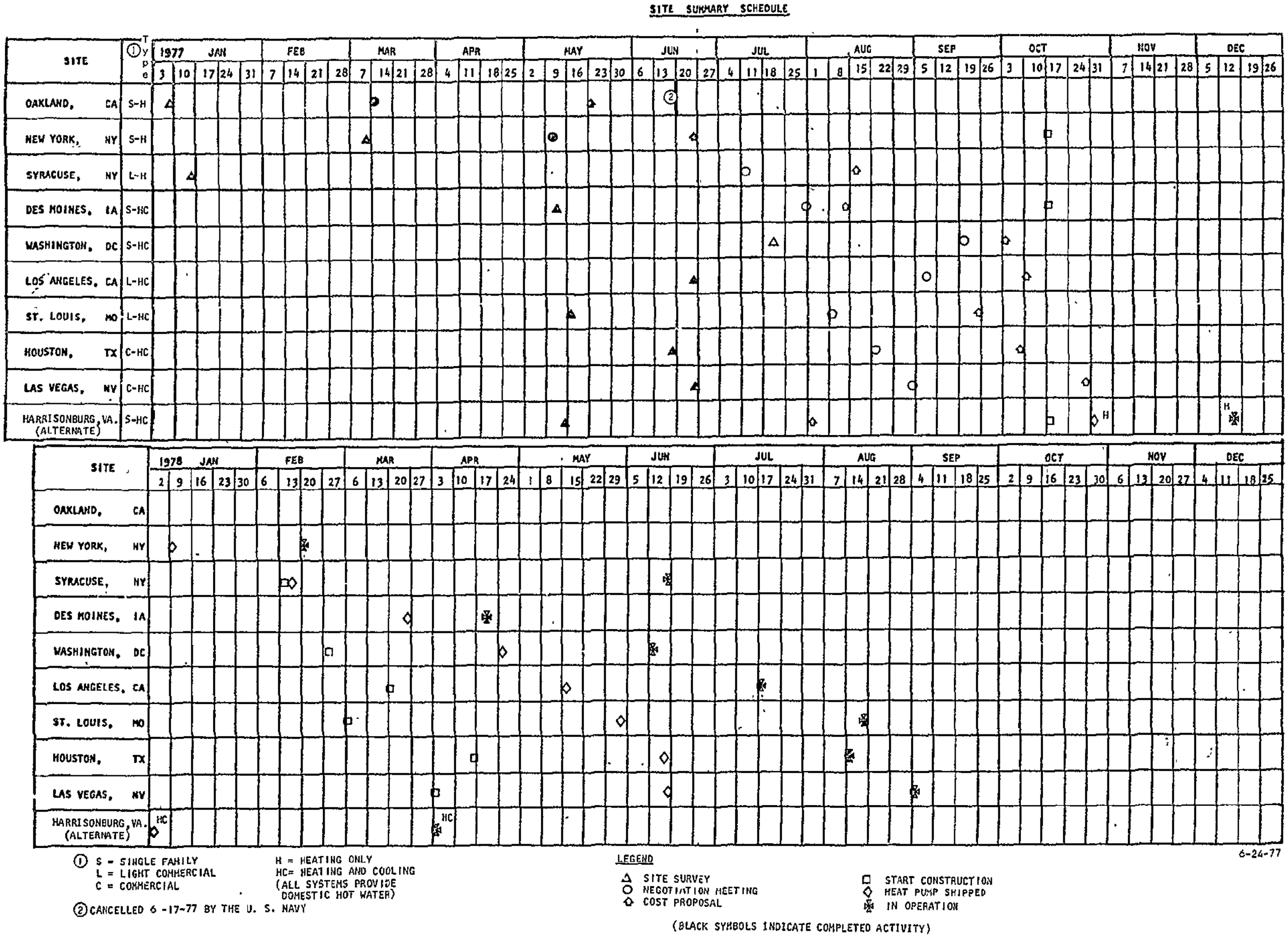

Figure 1-4. Site Schedule and Status

Technical Status

1. Site Selection

A single-family residence at Allaire State Park, New Jersey, was selected for evaluation of a (nominal) 80 KBTUH heating-only system. The residence is under the auspices of the New Jersey Bureau of Parks. This site has been approved tentatively by NASA and ERDA pending receipt of an AiResearch change proposal regarding the required follow-on work and cost estimate. System design specific to this site is proceeding.

Other sites are currently under consideration for single-family heating/cooling (Des Moines, Iowa) and for light commercial heating-only (Syracuse, N.Y.) Surveys of four other sites were made during the quarter but negotiation meetings regarding these sites are still pending.

2. Collector Procurement

Collector panel design has been finalized and a preliminary go-ahead has been made to Daystar. The formal contract is imminent.

3. Program Documentation

Documentation was prepared in accordance with the requirements of DR-500. A number of documents have been approved by NASA. Approval of the remainder awaits completion of review by NASA.

4. Heat Pump Subsystem

Assembly of the 3-ton heat-only heat pump is nearly complete. All parts have been delivered to Dunham-Bush except for the turbomachine and controls (both system and turbomachine). The 25-ton heat-only heat pump assembly is also being delayed by delivery of the turbomachine and controls. Activity on the 75-ton package has been confined to design drawings only to allow analysis of test results of the small heat pumps, and thus, minimize development costs.

5. Equipment Development

The 3-ton and 25-ton turbomachine motor controllers are currently the pacing items for the entire system due to past difficulties in attaining design speed due to problems in the commutation. Solution to this problem appears imminent now that the cause has been identified. Debugging of the system controllers for the two heat pump sizes continues without undue problems.

The 3-ton R-11 pump performance and durability are now satisfactory as shown by a successful prototype endurance test still being conducted. The 25-ton pump motor tested recently produces insufficient torque and improvements in the stator design are being made to correct this difficiency. The mechanical component turbomachines are performing satisfactorily with foil bearings. Operation is quiet and thoroughly predictable.

SECTION 3

PROGRAM SCHEDULES

The overall program schedules are included in Figures 1-2 and 1-3 in Section 1. This section includes more detailed schedules (Figures 3-1 through 3-7) covering the development status of the critical subsystems and components. These schedules represent an update of those given in the Third Quarterly Report. The component/subsystem schedule changes have only a limited effect on the overall program schedule. The status and progress are given in Section 4.

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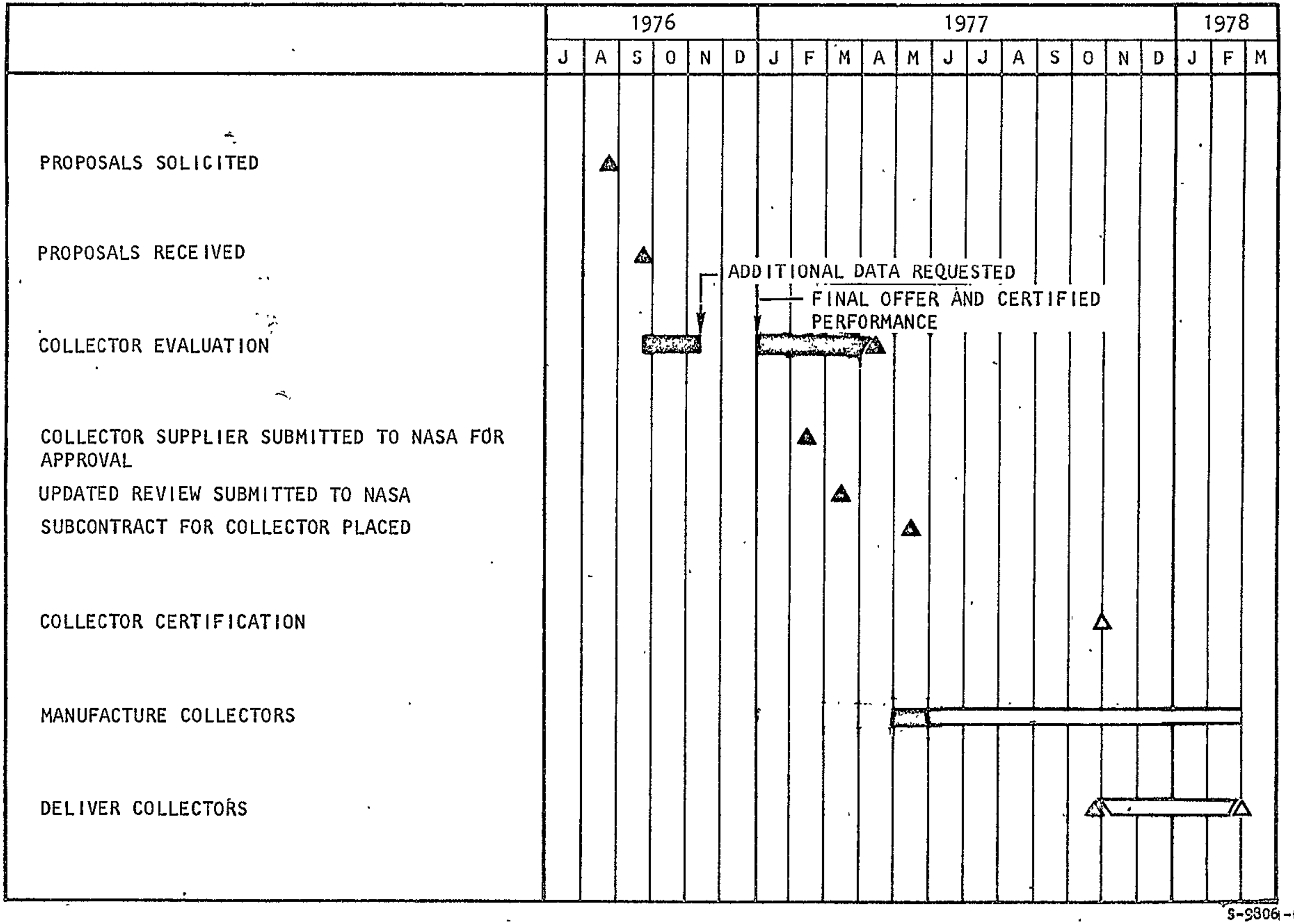

Figure 3-1. Solar Collector Development Schedule

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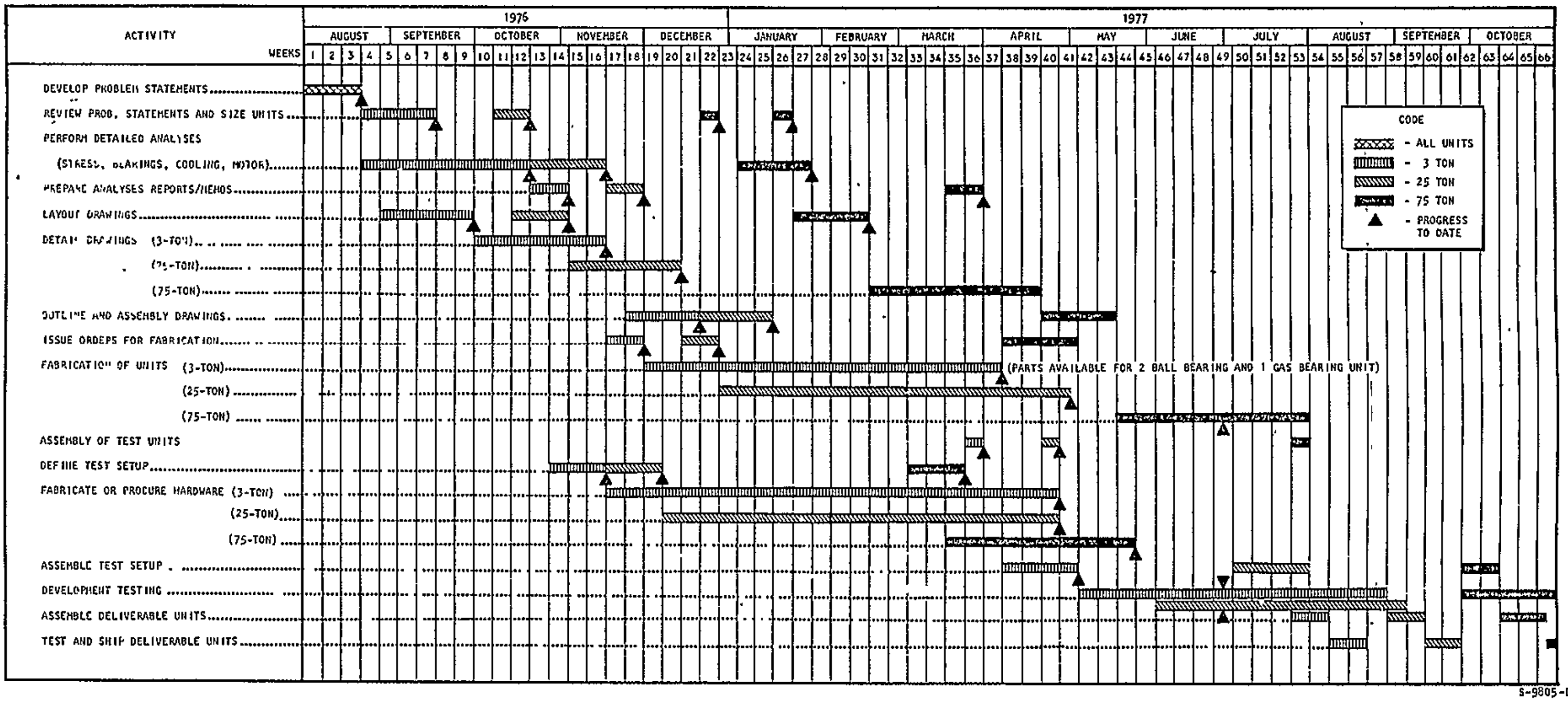

Figure 3-2. Turbomachine Development Schedule

D-10

D-11

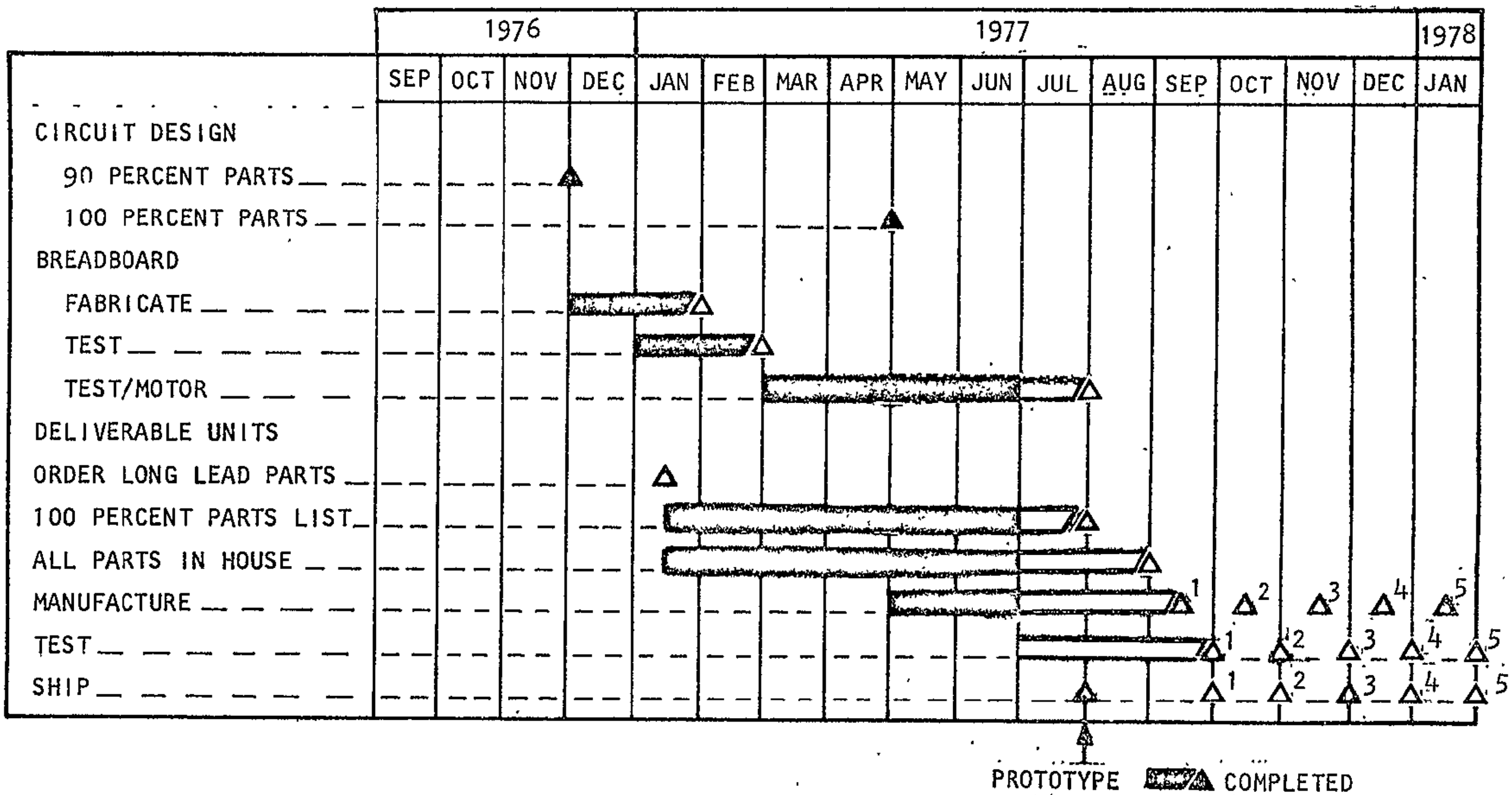

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Figure 3-3. 3-Ton Unit Motor Control Development Schedule

D-12

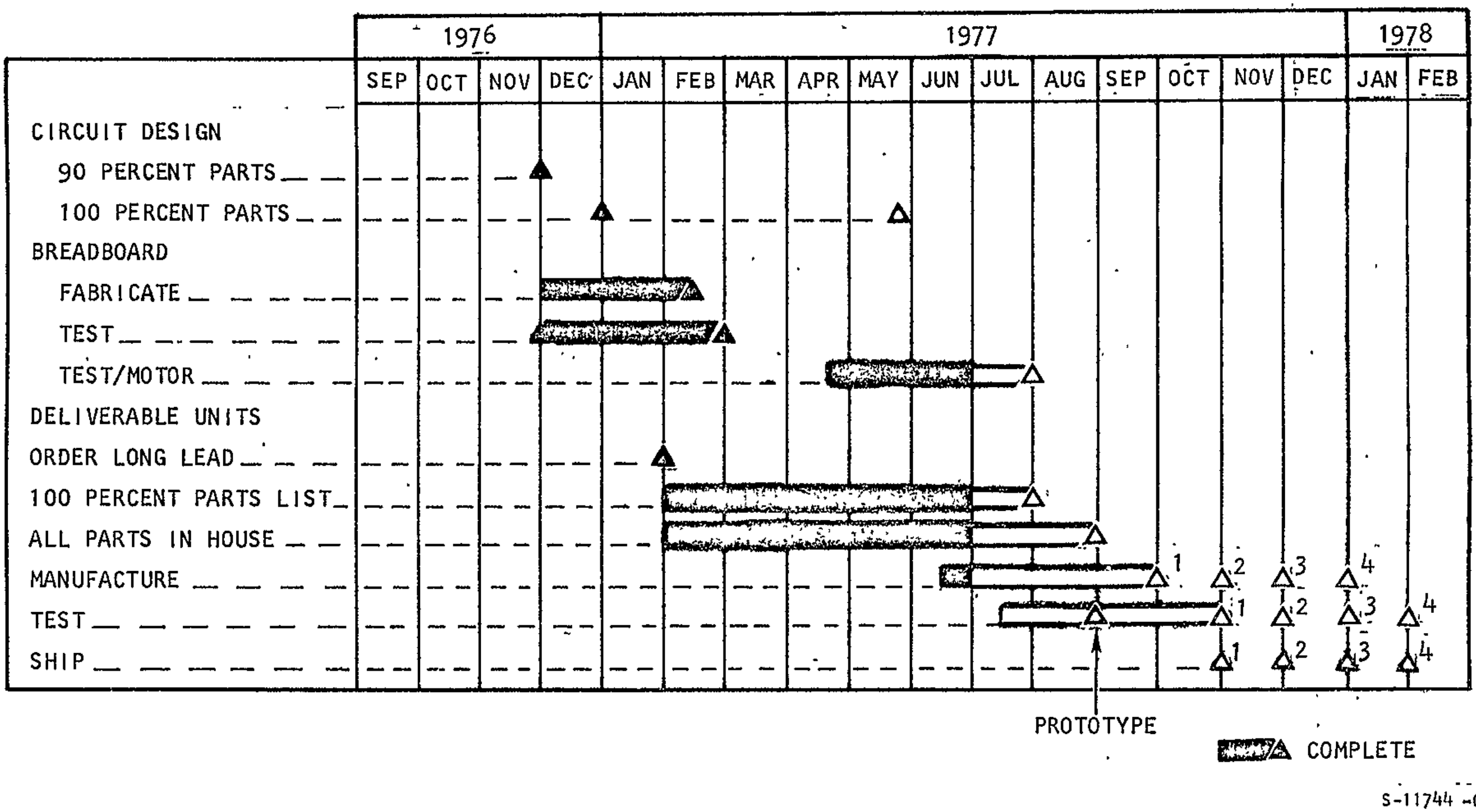

Figure 3-4. 25-Ton Unit Motor Control Development Schedule

D-13

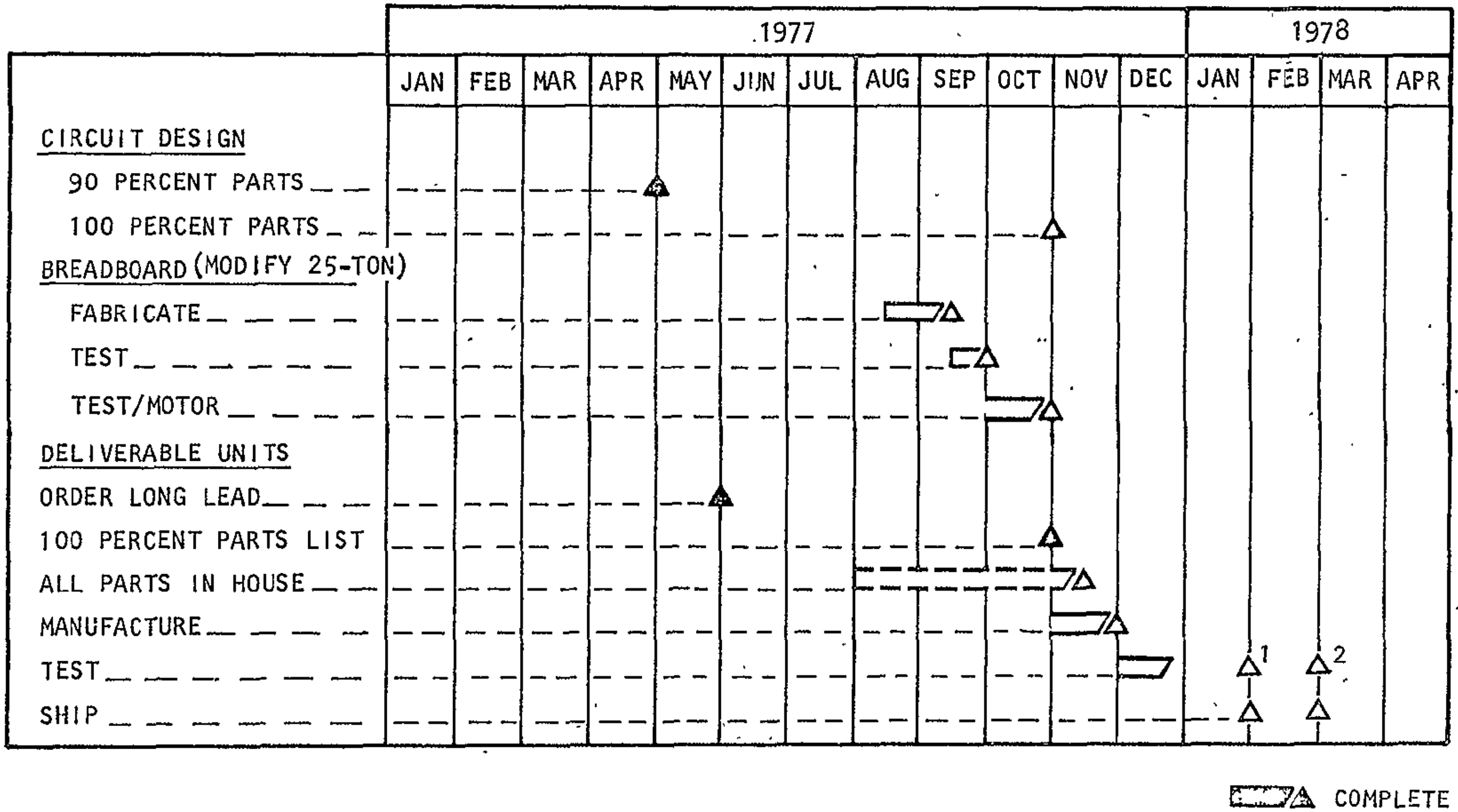

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Figure 3-5. 75-Ton Unit Motor Control Development Schedule

D-14

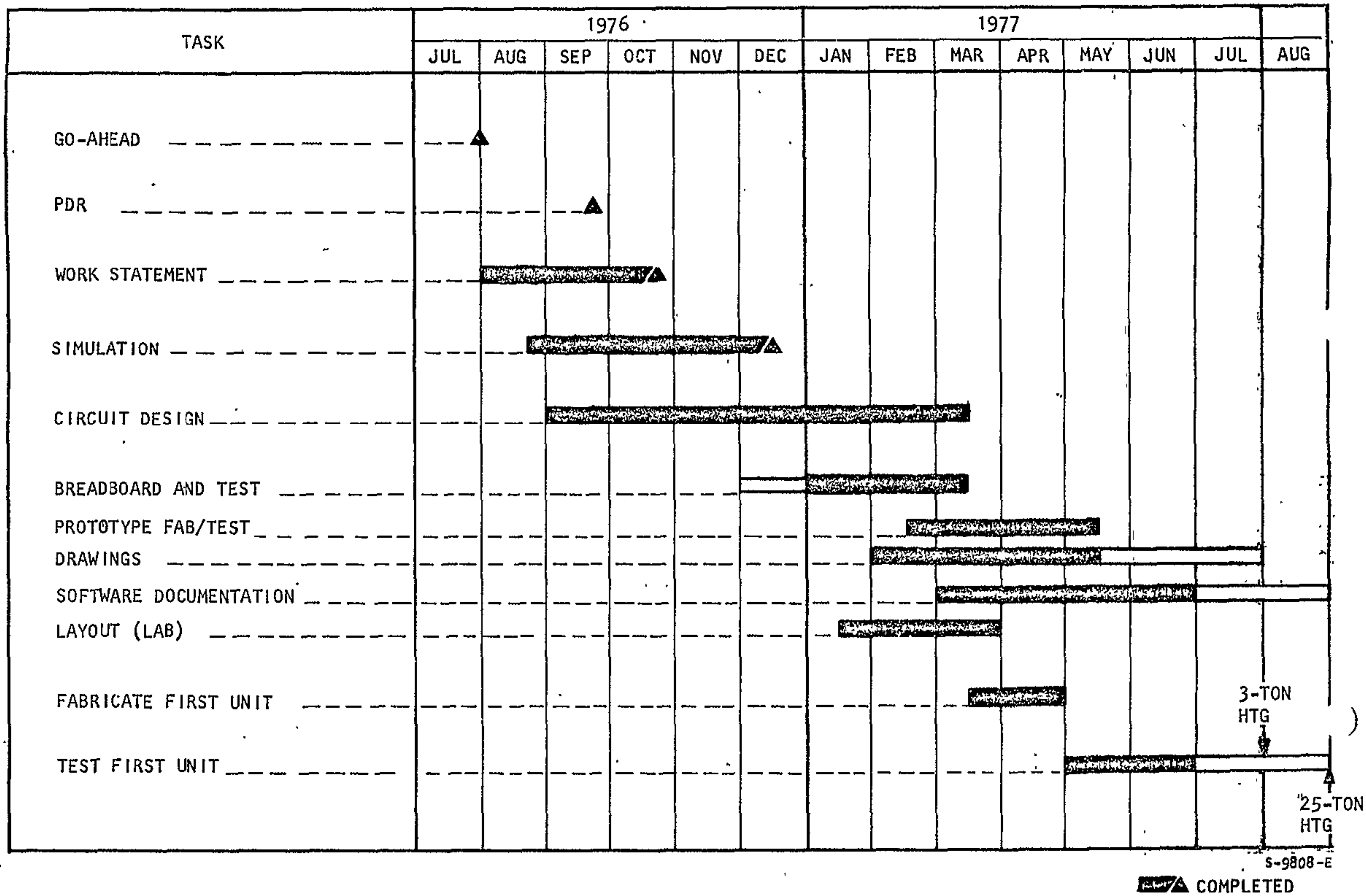

Figure 3-6. System Control Development Schedule

SECTION 4

TECHNICAL PERFORMANCE

INTRODUCTION

Technical status is reported below for all WBS tasks active in the reporting period. The WBS of Figure 4-1 identifies the active tasks with an asterisk (*). Activities during the third quarter were involved with the following.

WBS 1.1, MANAGEMENT

WBS 1.1.1., Program Direction

Meetings, reviews, and major events

Site selection and investigation

Collector procurement

WBS 1.1.2, Program Planning and Control

Schedule development

Program documentation

WBS 1.1.3, Quality Assurance

WBS 1.2, DEVELOPMENT

WBS 1.2.1, System Analysis and Integration

System analysis

Control system simulation

Heat pump subsystem

WBS 1.2.2, System Development

Turbomachine/motor design

Motor control design

System control design

R-11 pump

D-16

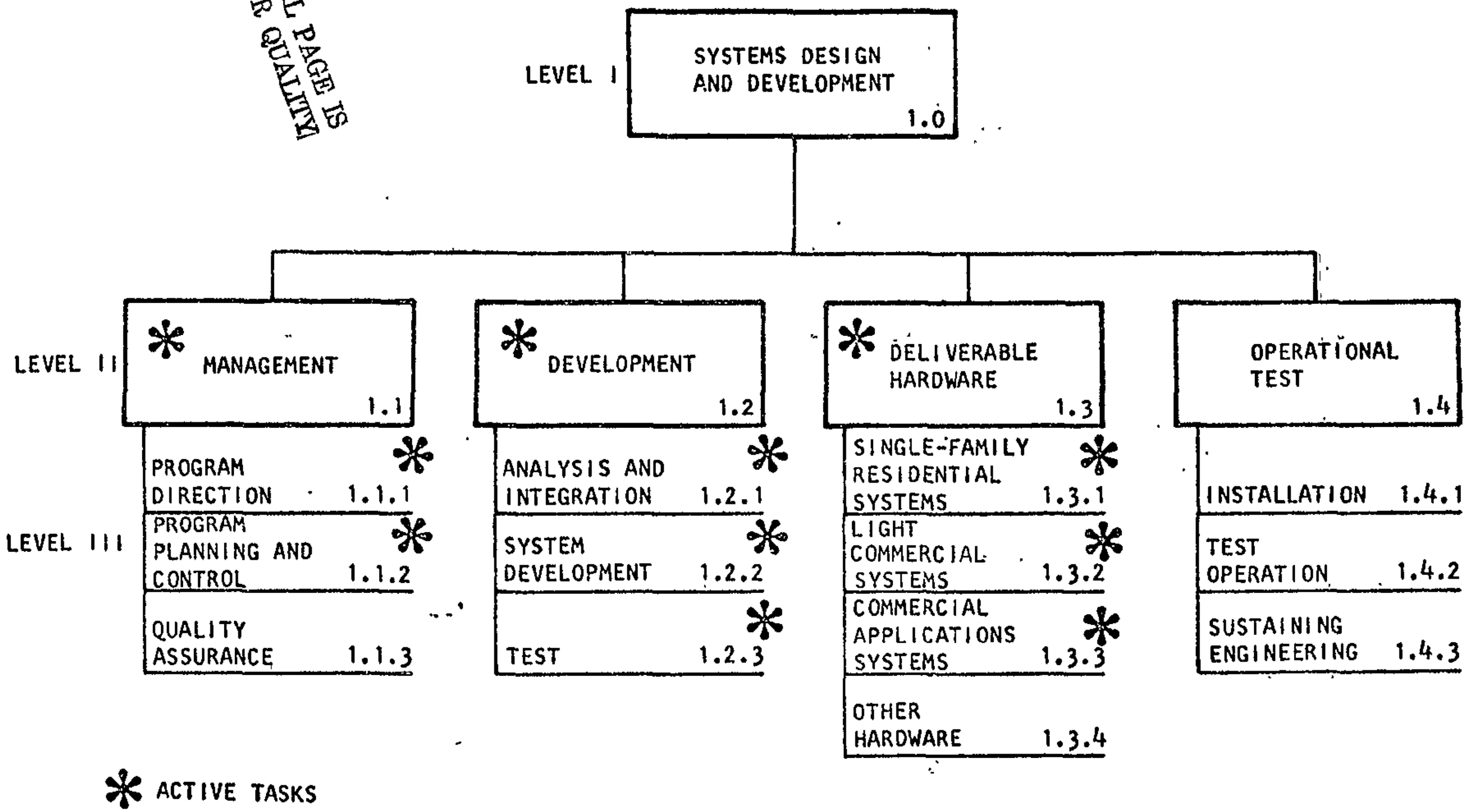

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Figure 4-1. Top-Level Work Breakdown Structure

WBS 1.2.3, Test

Turbomachine/motor

Motor control test

R-11 pump test

WBS 1.3, DELIVERABLE HARDWARE

WBS 1.3.1, Single Family Residence System

WBS 1.3.2, Light Commercial System

Progress on all these items is described in the following paragraphs.

ACTIVITIES IN REPORTING PERIOD

WBS 1.1, Management

1. WBS 1.1.1, Program Direction

a. Meetings, Reviews, and Major Events

(a) A third quarterly review was held at AiResearch with the NASA contract monitor on April 21, 1977 to review cost items, schedule, site installation activities technical status and collector certification testing. As a result of this meeting, it was decided to prepare two change proposals. (See Program Planning and Control.)

(b) Two coordination meetings were held at Dunham-Bush in April to review technical status and schedules.

(c) A coordination meeting was held at AiResearch during the week of May 23rd with Mr. J. Clark, NASA contract monitor, to review activities and program status. The major topics discussed and the actions taken as a result of these discussions are as follows:

- The projected agenda and scheduled date (August 3, 1977) for the Prototype Design Review (PDR) of the heating systems was established.
- The scheduled date for the PDR for the heating and cooling systems was established (November 15, 1977).
- The responsibilities of both NASA and AiResearch in the area of site owners agreements were determined.
- AiResearch was directed to begin the conceptual design of the Syracuse site.

- Mr. Clark directed AiResearch's attention to certain areas of desirable improvement in the coordination of the development, testing, and installation phases of the program. As a result of this discussion AiResearch has established an additional assistant Program Manager whose total time is dedicated to the coordination of these activities.

(d) Negotiations with Daystar Corporation of Burlington, Mass., collector manufacturer, were initiated in May. A visit was made to the Daystar facility by AiResearch quality assurance and purchasing personnel.

(e) A May coordination meeting was held at Dunham-Bush to review technical status.

(f) A site selection and A and E selection review meeting was held at NASA-MSFC on May 10, 1977.

(g) Site visits were made to Allaire Park, N.J. (May 11), Des Moines, Ia. (May 16-17), and the St. Louis, Mo. area (May 17-18).

(h) Site visits were made to the University of Houston and adjacent Houston areas on June 7-10, 1977.

(i) Site visits were made to Las Vegas, Nevada (June 20-22) and Los Angeles, Ca. (June 23-24).

(j) A joint NASA/ERDA/AiResearch meeting was held at ERDA headquarters, Washington D.C. on June 30. The purpose of the meeting was to review the results of the ERDA consultants program review and recommendations. The recommendations applied to marketing and technical questions. AiResearch responded with recommendations for a modified program which would retain the present operational testing baseline but add additional component and subsystem development in parallel. AiResearch was asked to formalize these recommendations.

b. <u>Site Selection and Investigation</u>

The Allaire State Park Chief Ranger residence in Farmingdale, N.J. was approved in April by engineering as an acceptable test vehicle for one of the single-family residence heating-only systems. A site owner interface meeting was held on May 10, 1977 in Farmingdale, New Jersey. The AiResearch site package was presented and a review of the conceptual drawings of the equipment in the basement, the solar collectors (on the ground) and the outside storage tank was made. Location and arrangement of the solar panels was determined. Owner modification work was delineated.

Pertinent residence and field dimensions were measured. Approval of the site by the AiResearch Solar Program Manager was requested by NASA. (It was granted on May 20, 1977.) The owner shall start modification work by September 1, and finish by October 15, 1977. Based on local data, the solar panels were increased from 30 to 40 and the storage tank size from 800 to 1000 gallons. Two tanks may be used instead of one due to limited access to the basement, and the decision was made to mount the tanks inside rather than outside the house.

During May, three sites were investigated in the Syracuse area for a light commercial, heating-only application. A library was rejected for lack of sufficient roof area to mount solar collector panels. The Clary Junior High School was adjudged too large for the light commercial heating-only system. The Hancock Airport North Finger terminal waiting area remained the only viable candidate in that area.

On May 17, 1977, the NASA-AiResearch site team visited the Des Moines, Iowa, Technical High School. The school representatives presented a drawing of a split level single-family dwelling they had designed but had not yet built. The students will design the residence and build it in conjunction with licensed contractors.

The following day, the NASA-AiResearch site team visited two sites at Scott AFB, Illinois, and St. Louis, Mo. The former was rejected as a viable candidate. The St. Louis site is a Parkway School district single-story building with a 1971 addition of 6000 sq ft. This site should not be a candidate for further consideration unless added solar panel accommodations can be made.

A site survey was made to the University of Houston, Texas, during June 7 through June 10, 1977. The University presented 12 candidates. Four were obviously unsuitable. Of the remainder, 4 appeared to be well qualified for the program:

1. The Developmental Arts Building at Clear Lake Campus

2. The athletic office and dressing rooms

3. The University Center Building

4. The computer center

All other sites visited in the Houston area were determined to be not compatible with the intent of the program.

Las Vegas, Nevada, was visited from June 20 through June 22, 1977. The best candidate was a proposed city recreation building to be federally funded. June 23 and 24 were spent reviewing Los Angeles, California, candidates; an existing city recreation hall and an existing Federal Social Security Building. Both of these candidates require approximately a 25-ton cooling load and are still under consideration.

c. Collector Procurement

Collector procurement was delayed by frequent design changes instituted by the manufacturer (Daystar). The collector design has been finalized and a preliminary contract was issued in June. A formal contract will be issued in July.

2. WBS 1.1.2, Program Planning and Control

a. Schedule Development

Program schedules have been updated throughout the quarter to reflect the latest information. The latest versions of the component/subsystem schedules are presented in Section 3. Overall program schedules for the heating and heating/cooling systems are in Section 1.

b. Program Documentation

The following documents were prepared in accordance with the requirements of Appendix A of the Statement of Work.

(a) Third Quarterly Report (DR 500-10), April 10, 1977, AiResearch Report 76-13296(3).

(b) Solar Collector Test Plan, AiResearch Report 77-13966, dated May 6, 1977.

(c) Monthly Progress Reports No. 8 and 9--AiResearch Reports 76-13110(8) and 76-13110(9).

(d) Installation Information Pack for Single Family Residence (Allaire State Park, Farmingdale, N.M.)--AiResearch Report 77-13939.

(e) Site Installation Tasks of AiResearch A and E Staff, June 28, 1977, AiResearch Report 77-14157.

Other publications issued this quarter were:

(a) Two change proposals were submitted to NASA in accordance with the format specified:

(1) AIR-4 covered the impact of IPC changes, collector selection and the use of the Dunham-Bush test house as an alternate site.

(2) AIR-3 covered the Hamilton AFB site costs, schedule and retrofit procedures.

Resolution of these items is pending.

3. WBS 1.1.3, Quality Assurance

A visit was made in May to the Daystar facility by AiResearch quality assurance personnel. The Daystar Corporation at Burlington, Mass., was found to comply with AiResearch quality control and safety requirements.

WBS 1.2, Development

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1. WBS 1.2.1, Analysis and Integration

a. System Analysis

The system computer program was exercised in April to finalize the sizing of the Hamilton AFB single-family residence heating-only system. Using design year weather data, it was found that the solar contribution to the total residence and DHW load is limited to about 52 percent primarily because of collector area limitations imposed by the size of the roof. The collector area selected for this installation is $600/ft^2$ with an 800 gallon water storage tank.

Detailed investigations were made to determine pipe sizes to permit pump selection. Also, insulation thicknesses were determined to minimize losses consistent with the cost of the solar collectors. (Although this site was cancelled on June 17, 1977, the computer analysis data for the single-family residence heating-only system was modified to be applicable to the Allaire State Park, N.J., site. Changes were necessary due to differences in climatic conditions and plumbing line lengths, particularly to the solar collector banks.)

The design year solar and weather information for ten different cities has been processed for use in the current solar heating and cooling computer program. This basic data, when used with suitable scaling factors, can be used to simulate the solar and weather data for any particular city within the boundaries of the original 48 states.

The computer program for these analyses has been revised so that the information required to analyze each new building or location is handled as input data rather than being built into the program logic to increase the program capabilities without having to continually rewrite the basic program. In addition, the cooling section of the computer program has been revised to correspond to the current refrigeration system and also to take into account variations of the house of building latent loads.

The design optimization studies for the Allaire State Park, New Jersey, site have been completed to establish the solar panel area, tilt angle, pitch between rows of collectors, and the storage tank size. Similar design studies have been completed for the Syracuse, New York, airport waiting building heating system, and the single residence Des Moines, Iowa heating and cooling system.

The Des Moines site was used to debug the new cooling mode analysis techniques and humidity calculations. No major computer program modifications are currently under consideration other than possible changes to the format in which the output information is printed.

b. System Arrangement

A layout drawing and parts list has been received in April from Dunham-Bush concerning the 3-ton heating-only Heat Pump Model 2201288-H-80. The layout drawing was included in AiResearch Report 76-13110(8), the Eighth Monthly Status Report as Figure 2. A similar drawing has been received for the 25-ton heating-only Heat Pump Model 2201288-H-800.

c. Heat Pump Subsystem

1. 3-Ton Heat Pump Model 2201288-H-80

Detail and assembly drawings have been completed. Assembly of the heat pump is complete except for the arrival of the turbocompressor, its motor control unit and the system control subassembly. A mockup turbocompressor is presently installed in the heat pump (see Figure 4-2). This heat pump will be converted to a heating/cooling unit approximately 1 month after completion of heating only development tests.

2. 25-Ton Heat Pump Models 2201288-H-800 and 2201288-HC-825

Detail and assembly drawings were completed in June for the heat-only package. The pumps and heat exchangers have been received and are being installed in the frame (see Figure 4-3). Assembly completion date for this heating only package is scheduled for August 1. Conversion of this pack to a heating/cooling model will also require 1 month after completion of development tests.

3. 75-Ton Heat Pump Model 2201288-HC-2075

A layout drawing has been completed except for some piping changes. Detail drawings have been started. Construction of the heat pump package will be delayed to allow analysis of test results of the smaller heat pumps to dictate final design of this unit to minimize costs.

4. Heat Pump Test Setup

The test facility for test of the 3-ton heat pump was completed in May. The 25-ton test facility is nearly complete with the delivery of the G.E. voltage regulation circuit "Inductrol" component. However, the Inductrol distribution panel has not been received as yet although delivery is imminent. The cooling tower and plumbing have been installed and the system has been leakage checked. The steam converters (solar collector simulation) have been installed. Some leaks were found, repaired and the system now is acceptable for test. The Inductrol and transformer units are currently being connected to the electrical supply.

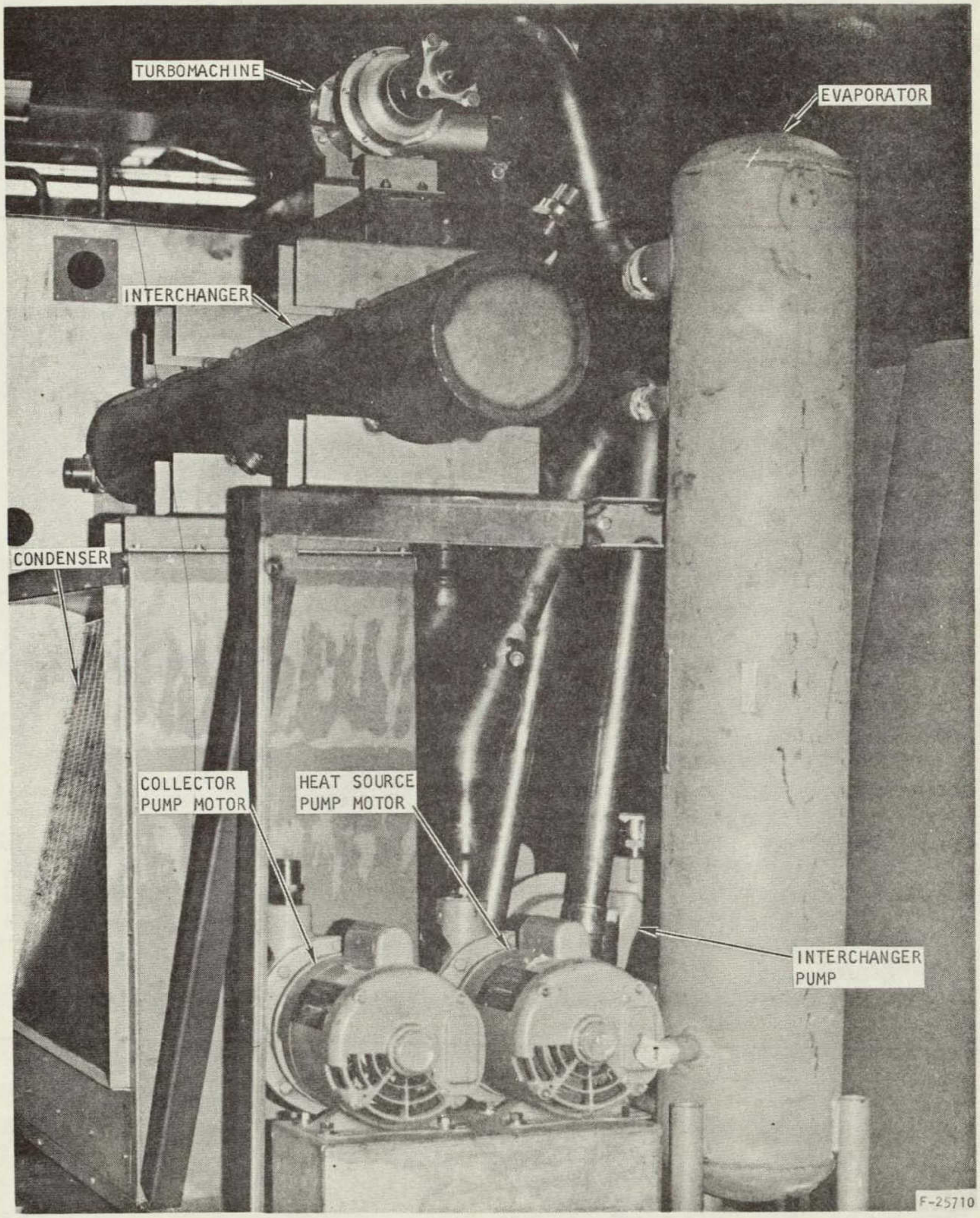

Figure 4-2. Closeup View of Heat Pump Model 2201288-H-80 Without Insulation

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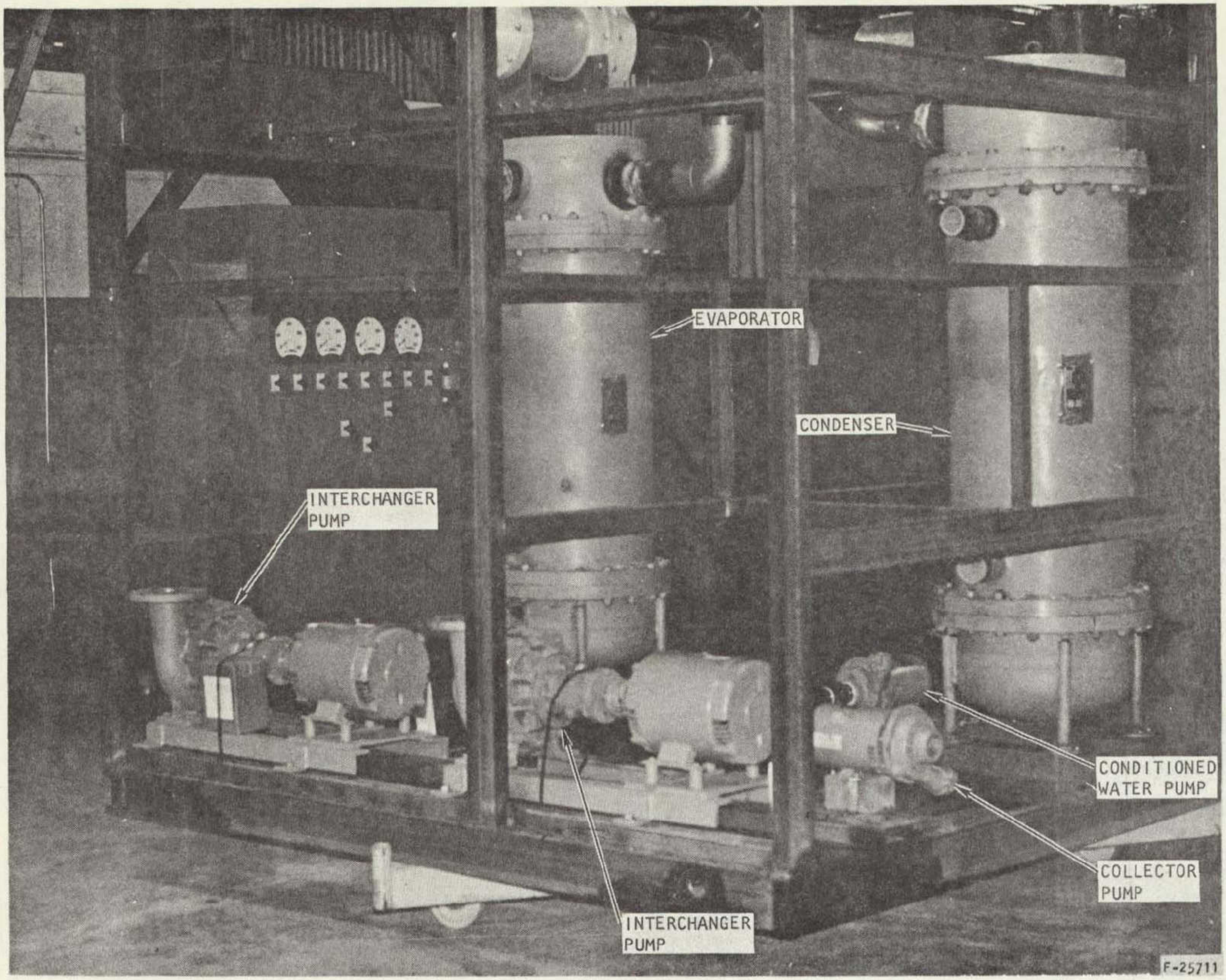

Figure 4-3. Partially Assembled Heat Pump Model 2201288-H-2000

2. WBS 1.2.2, System Development and WBS 1.2.3, Test

(These categories have been combined in this report because almost all development activities consisted of testing.)

a. Turbomachine/Motors

Containment analyses were completed in June for all unit sizes; no additional containment provisions are required.

(a) 3-Ton Unit

Testing of the 3-ton units continues. The 3-ton motor-compressor with foil bearings was installed in the breadboard heating system. The machine was operated at speeds up to 43,000 rpm. Above this speed high noise-to-signal ratios were obtained with the Hall effect position sensor. Another machine was assembled with a Bentley position probe. Higher speeds could not be achieved with this new machine. The compressor-motor was removed from the heat pump test rig for development of the speed sensor(s)/motor controller. With the Bentley probe, the motor was operated to 60,000 rpm; the noise source with this probe was tracked to the signal conditioner for one phase of the 3-phase power used by the motor. During June, controller circuit modifications were incorporated (refer to Section b) which caused the unit to attain design speed (82,600 rpm) with both the Hall effect sensors and the Bentley proximity probes. The former will be used due to lower cost and simpler circuitry.

Testing in the Freon similated heat pump test rig will resume in July and require at least one month.

(b) 25-Ton Unit

Initial problems in shrinking the Inconel sleeve over the motor rotor were solved in May, but the tooling required for the shrinking operation required extensive changes, thereby causing a one-month delay. The ball bearing units became operational in late May. Testing of these units indicated that motor performance is satisfactory and the motor controller functions properly. A unit was assembled with foil bearings and was operated to design speed (41,000 rpm) without incident. Minor control modifications are being made at this time to better control the motor speed and current.

(c) 75-Ton Unit

Fabrication of parts is continuing with completion scheduled early August, 1977.

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b. Motor Controller

(a) 3-Ton Motor Controller

The motor-inverter combination has been tested both with an air bearing machine and a foil bearing machine. Tests in May showed that the inverter was able to control motor speed to approximately 50% of full speed. Higher speed runs could not be conducted due to limitations in the position sensing method. Inverter development reached the stage where the turbomachine assembly finally attained design speed at no load late in June. Previous problems of noise on the position feedback limited the speed. They were solved by changes to the inverter fly-back diode circuit. The fly-back energy was previously allowed to circulate through the machine causing circulating currents which were distorting the back emf waveform, and in turn, were inducing noise in the position pickups. Thus, flyback energy has been temporarily dissipated in resistors in the fly-back path. Further development work in this area is required.

(b) 25-Ton Motor Controller

The 25-ton system motor was assembled and integration of the motor control and motor were completed in May. The breadboard test setup is shown in Figures 4-4 through 4-7. Early tests demonstrated that the control system operated the motor, proving the electronic switching logic was correct. Several advances were made during June on the development of the motor control. These advances included:

1. Optimizing the rotor position sensor for maximum output torque.

2. Completion of open loop testing.

3. Closing of the speed loop and current loop under no-load conditions.

4. Optimization of the SCR firing angle to achieve maximum power factor without commutation failure.

Current development effort is focused on the current inrush during starting with full voltage applied. The current inrush causes the machine rotor to intermittently lock up. This characteristic has been traced to the start commutator which will be further investigated during July.

(c) 75-Ton Motor Control

Design of the 75-ton motor controller has been initiated. This task is 10 percent complete.

c. System Controller

Programming has been completed in May. Basic hardware fabrication has also been completed and functionally checked out. A modification was added to provide for a manual control mode to permit heating of the residence via conventional thermostat control of the furnace and ventilation fan in case of heat pump failure. The manual control is cut out when system is in the "auto" mode where the solar heat pump system is being used.

Effort is still being concentrated in the calibration of hardware and software operation of the system controller and interface unit (Figures 4-8 through 4-14). Simulated temperature inputs are being used to simulate a different operating region of the controller/heat pump package. Certain temperature sensor characteristics have been modified to allow for better system performance. A back-up by a conventional thermostatic control is included to permit removal of system controller for repair.

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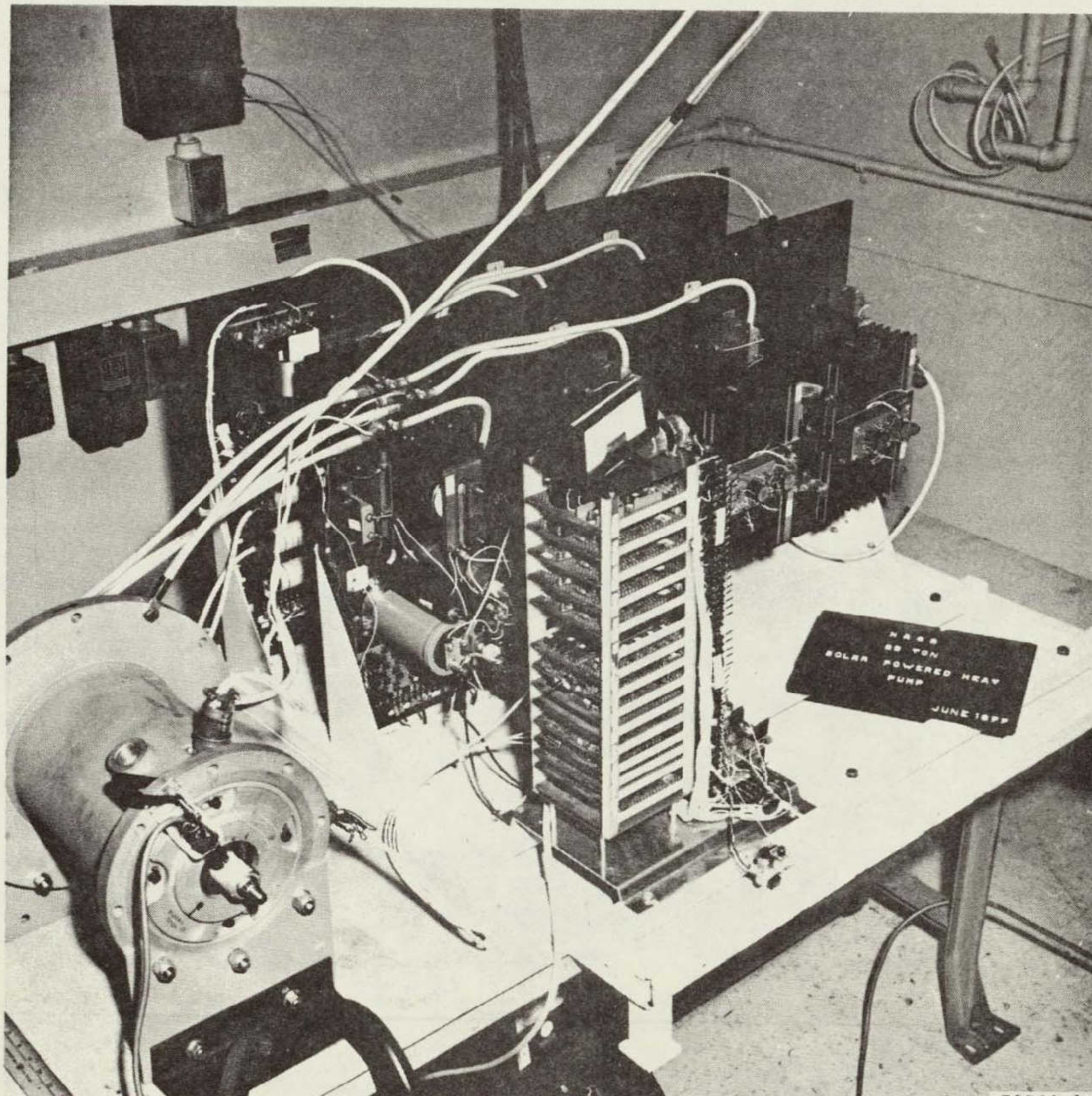

Figure 4-4. 25-Ton Turbomachine Motor/Controller Breadboard Test Setup

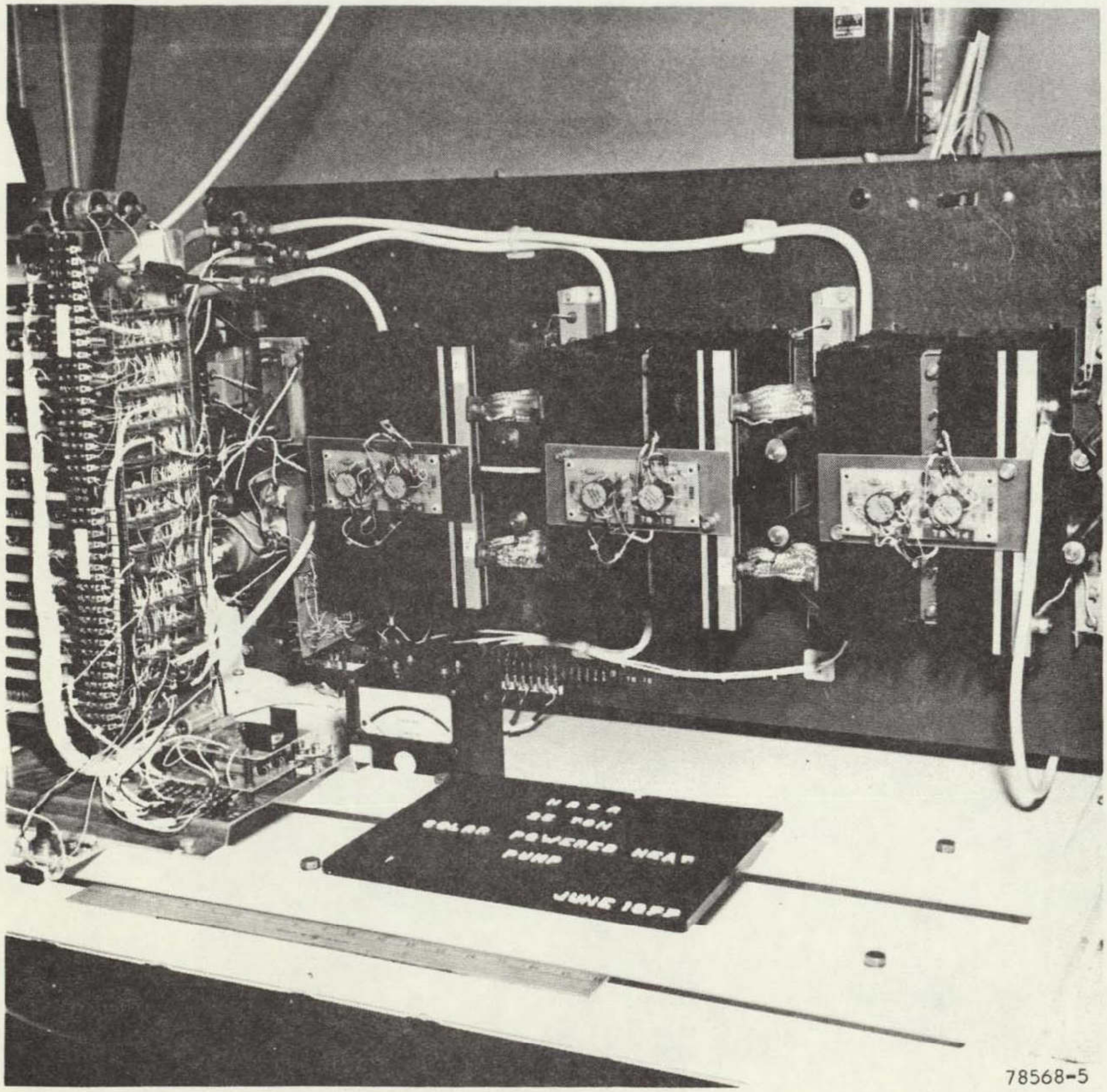

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Figure 4-5. Closeup View of Thyristor Heat Sinks and Printed Wiring Assemblies Used in 25-Ton Turbomachine Motor/Controller Breadboard Test Setup

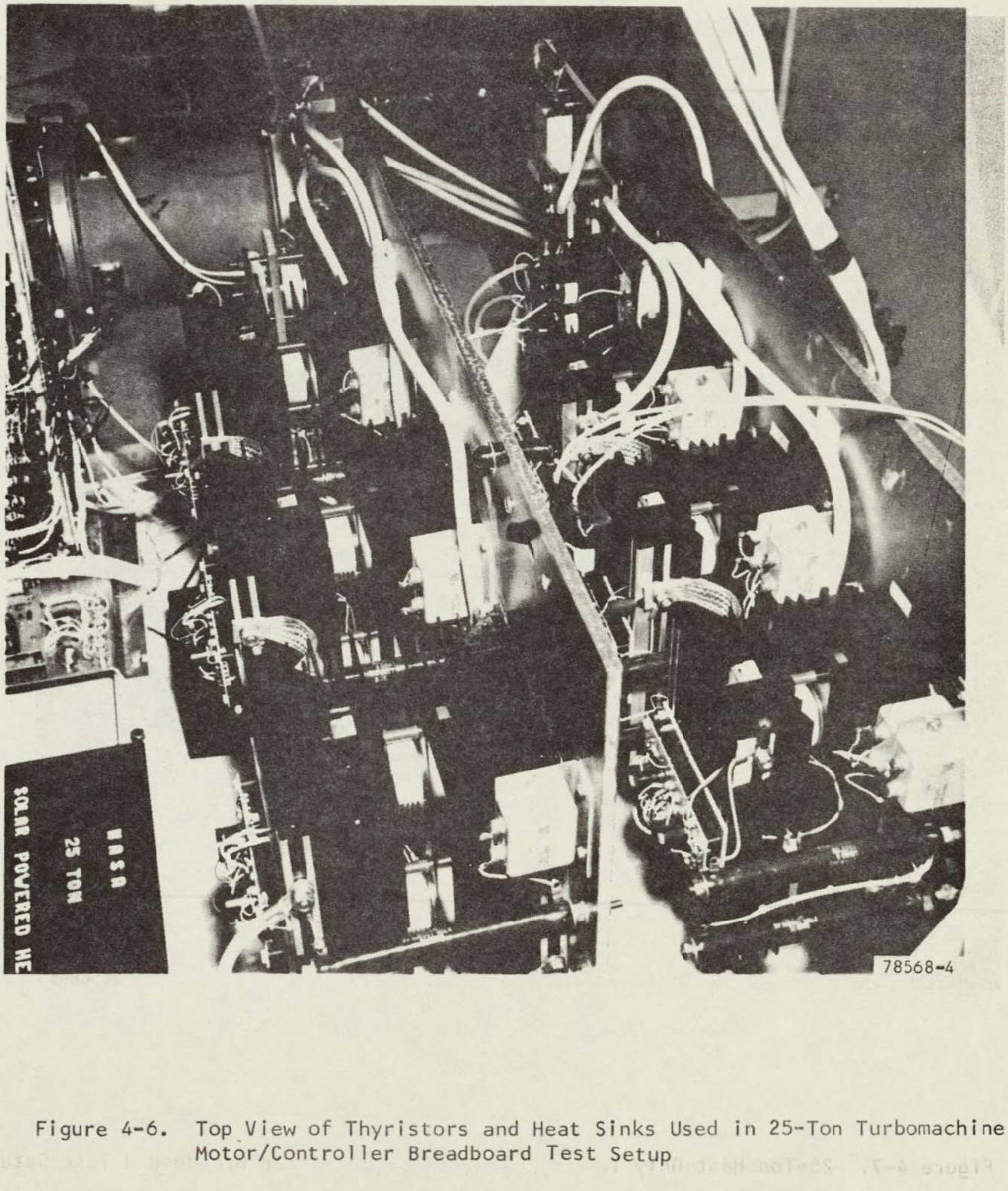

Figure 4-6. Top View of Thyristors and Heat Sinks Used in 25-Ton Turbomachine Motor/Controller Breadboard Test Setup

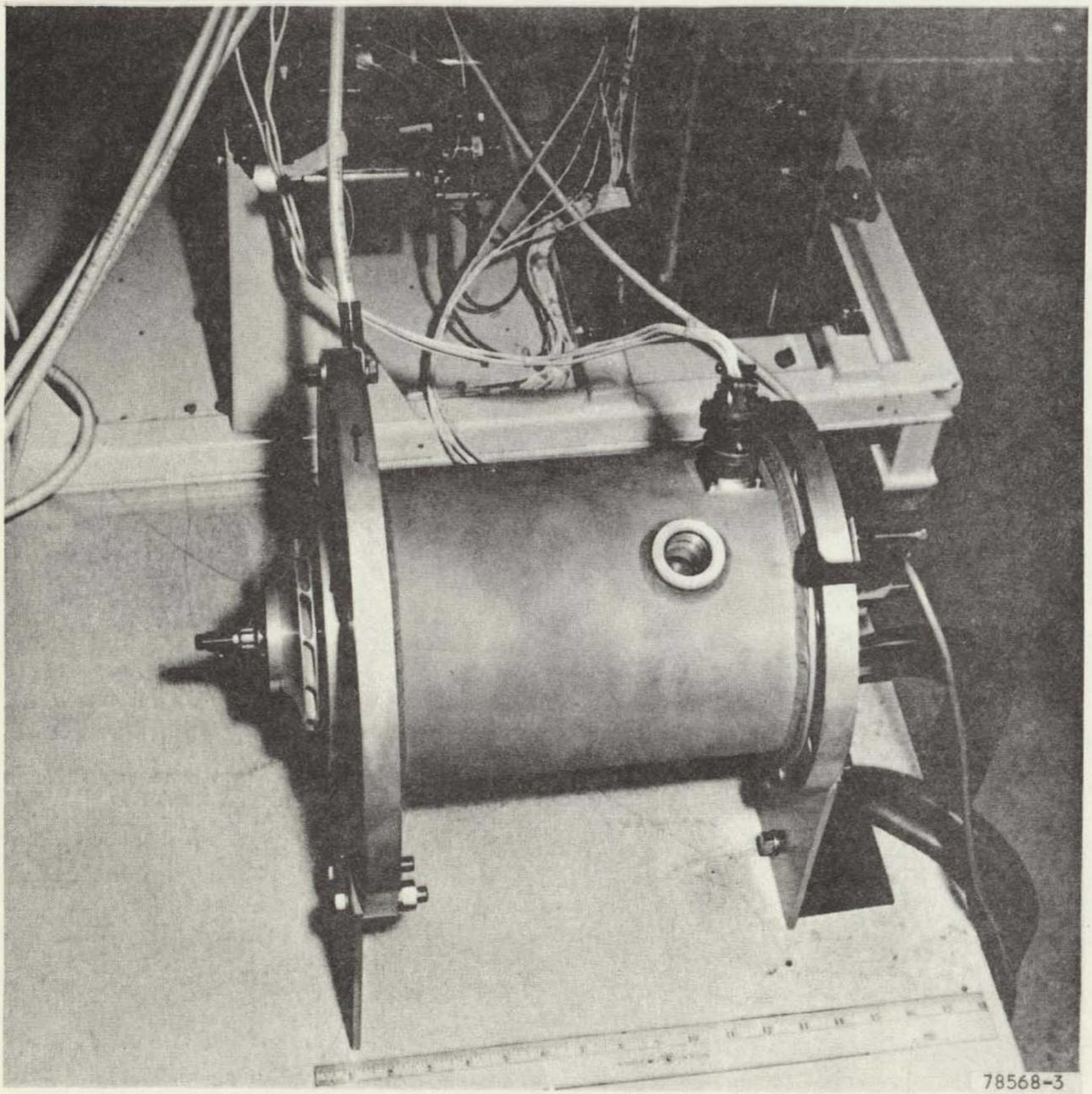

Figure 4-7. 25-Ton Heat-Only Turbomachine Motor/Controller Breadboard Test Setup

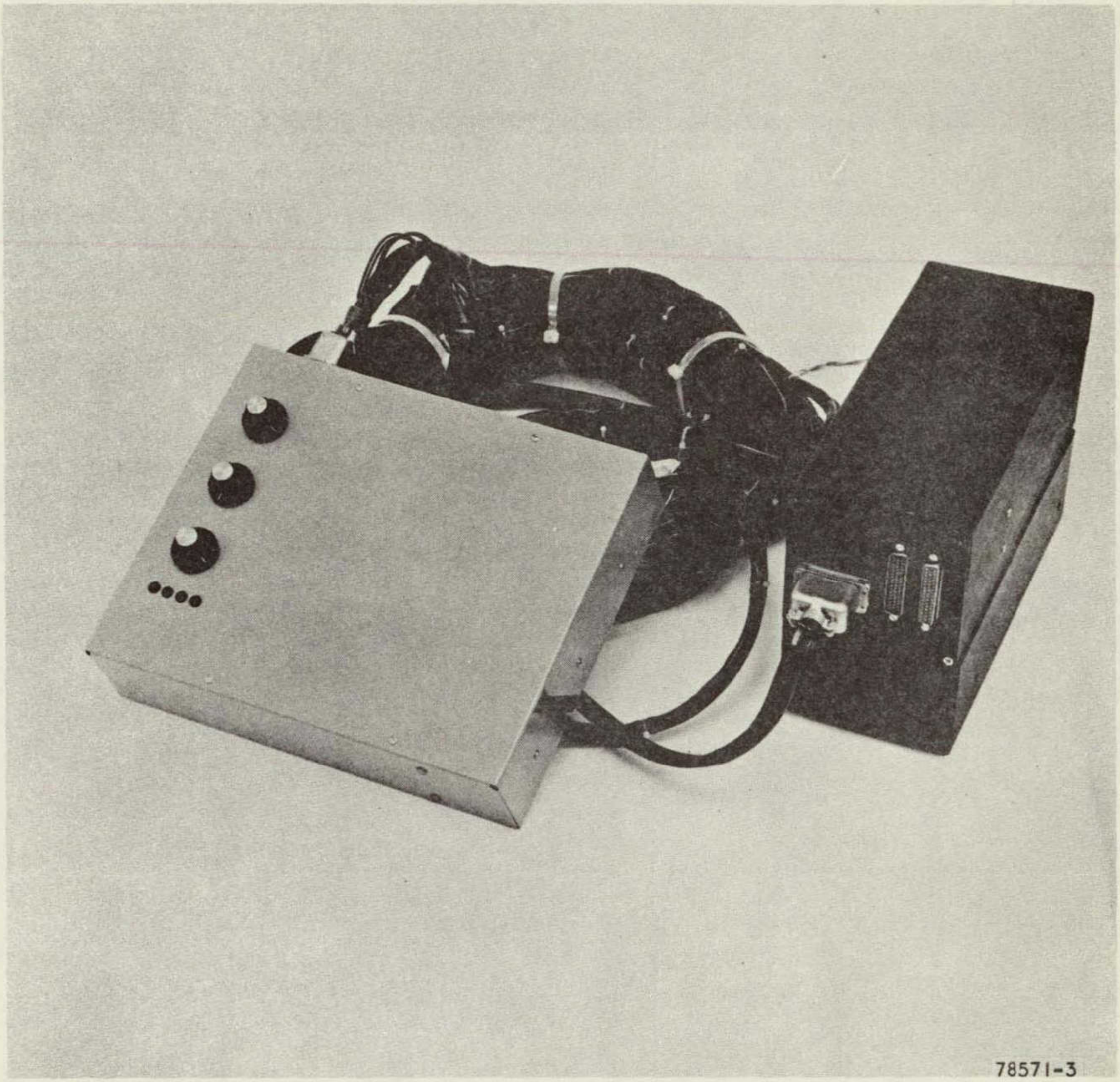

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Figure 4-8. Solar Heating/Cooling Prototype System Controller and Interface Modules

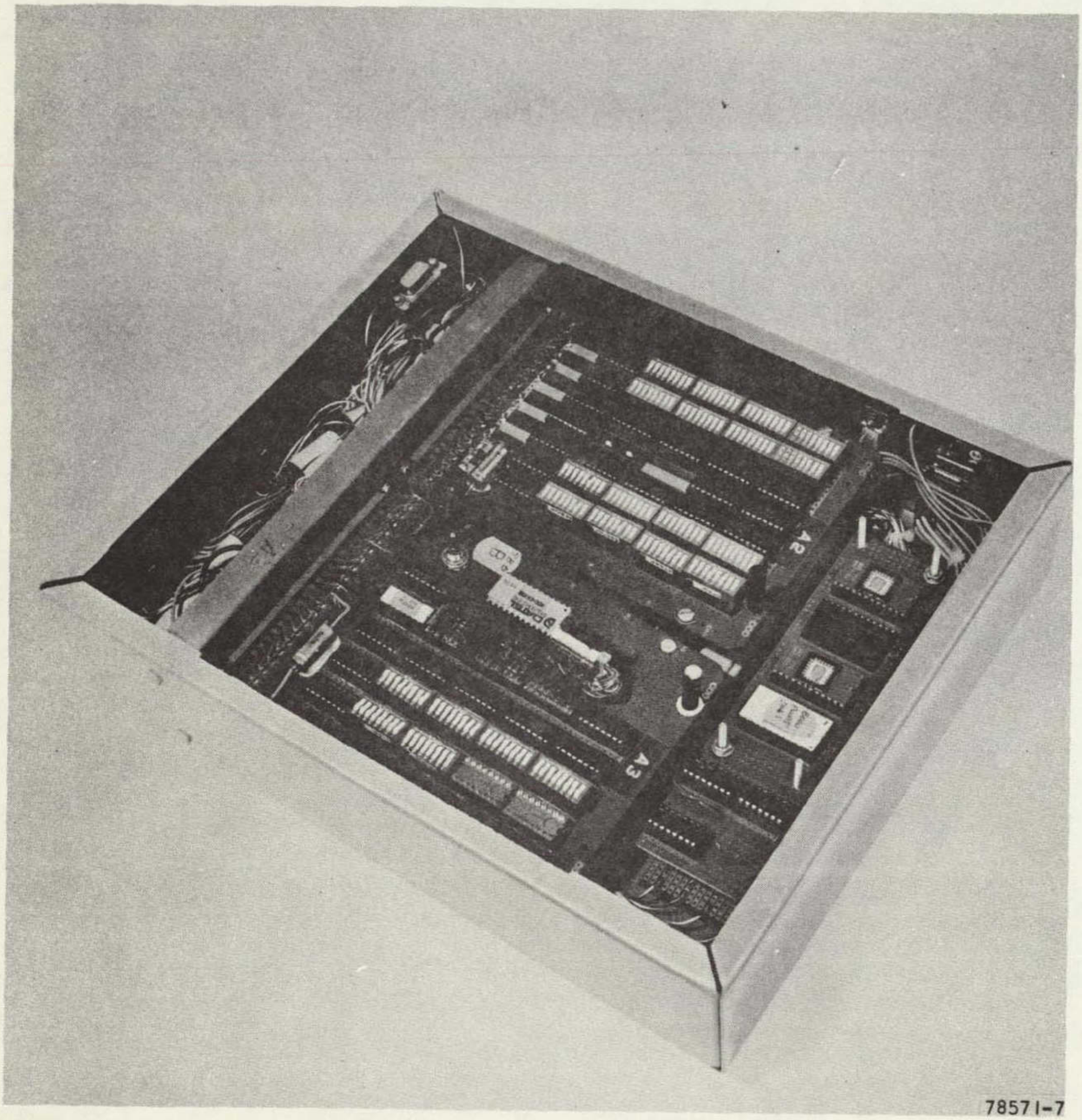

Figure 4-9. Solar Heating/Cooling Prototype System Controller Internal Circuitry

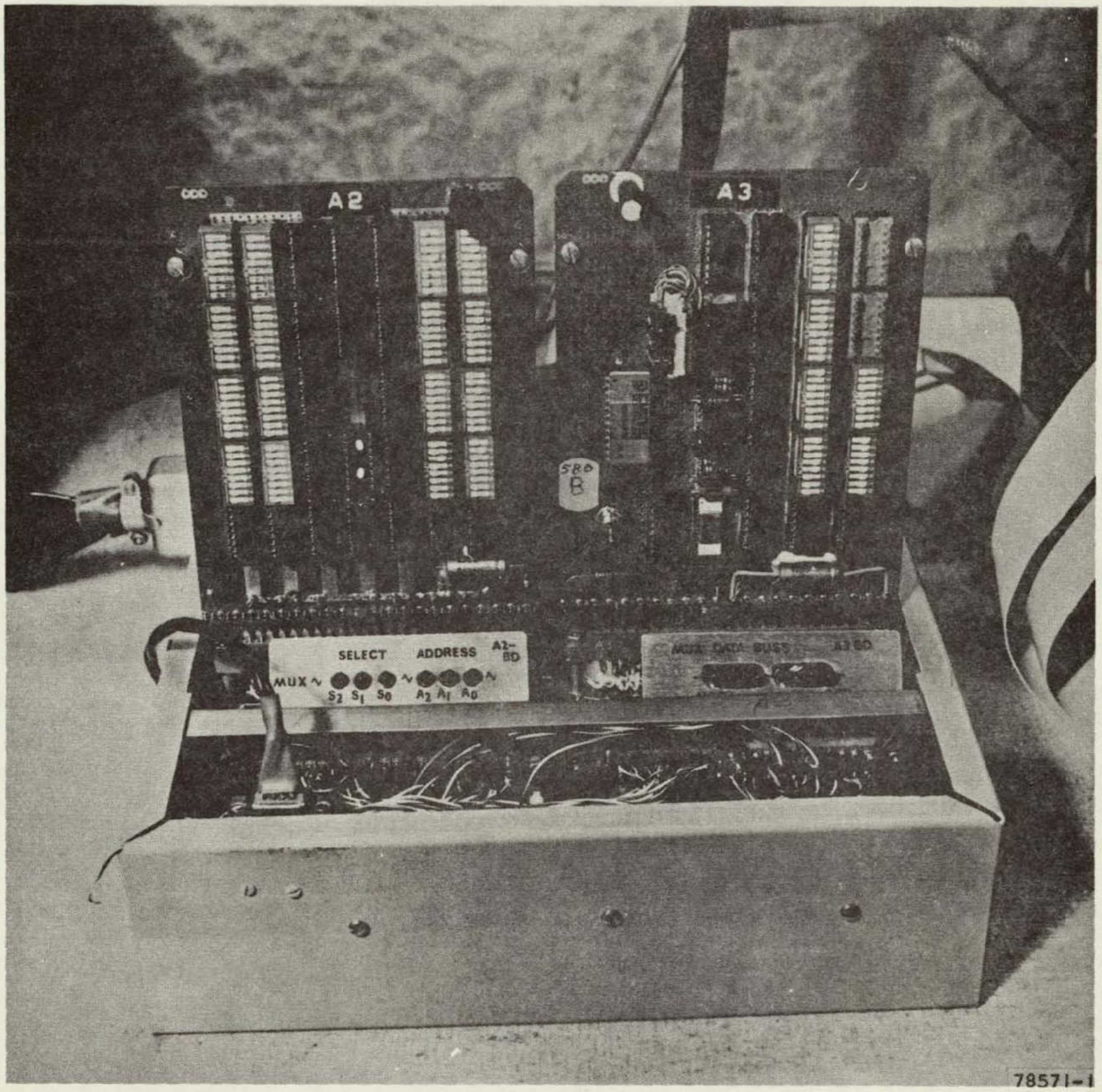

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Figure 4-10. Solar Heating/Cooling Prototype System Controller Circuits Under Test

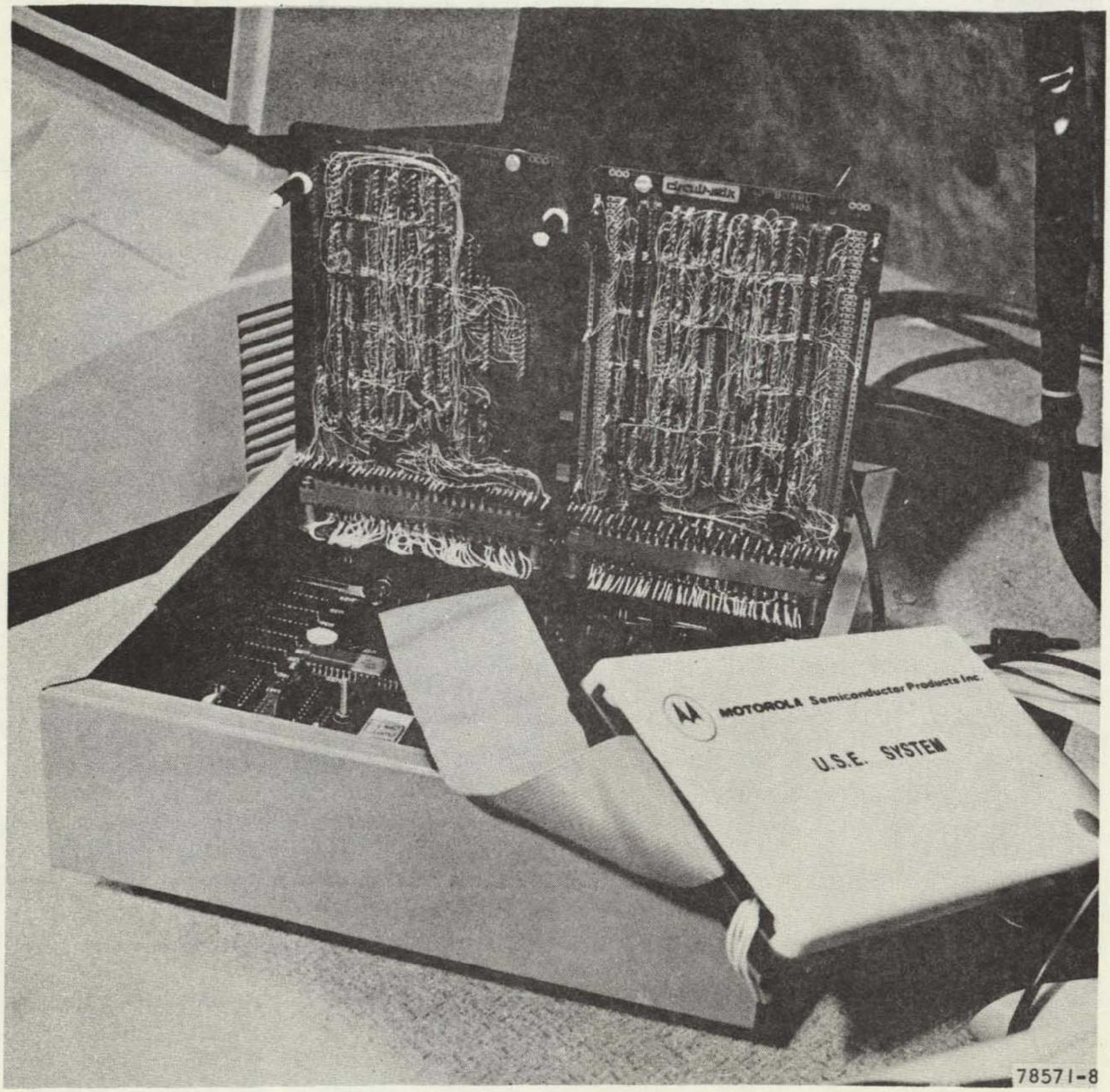

Figure 4-11. Solar Heating/Cooling Prototype System Controller Being Tested in Development System During Software-Hardware Debugging Phase

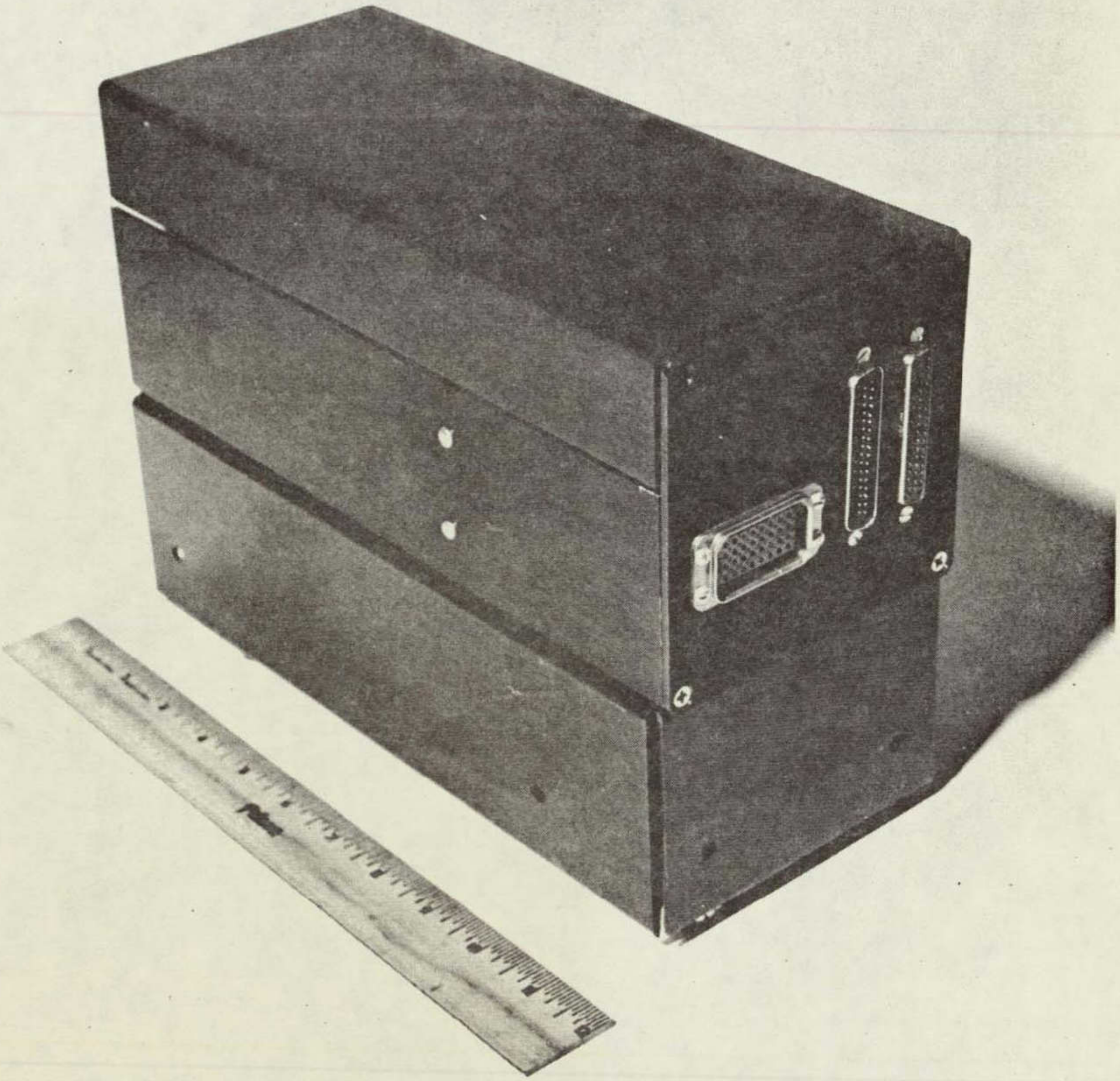

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Figure 4-12. Solar Heating/Cooling Prototype Interface Module

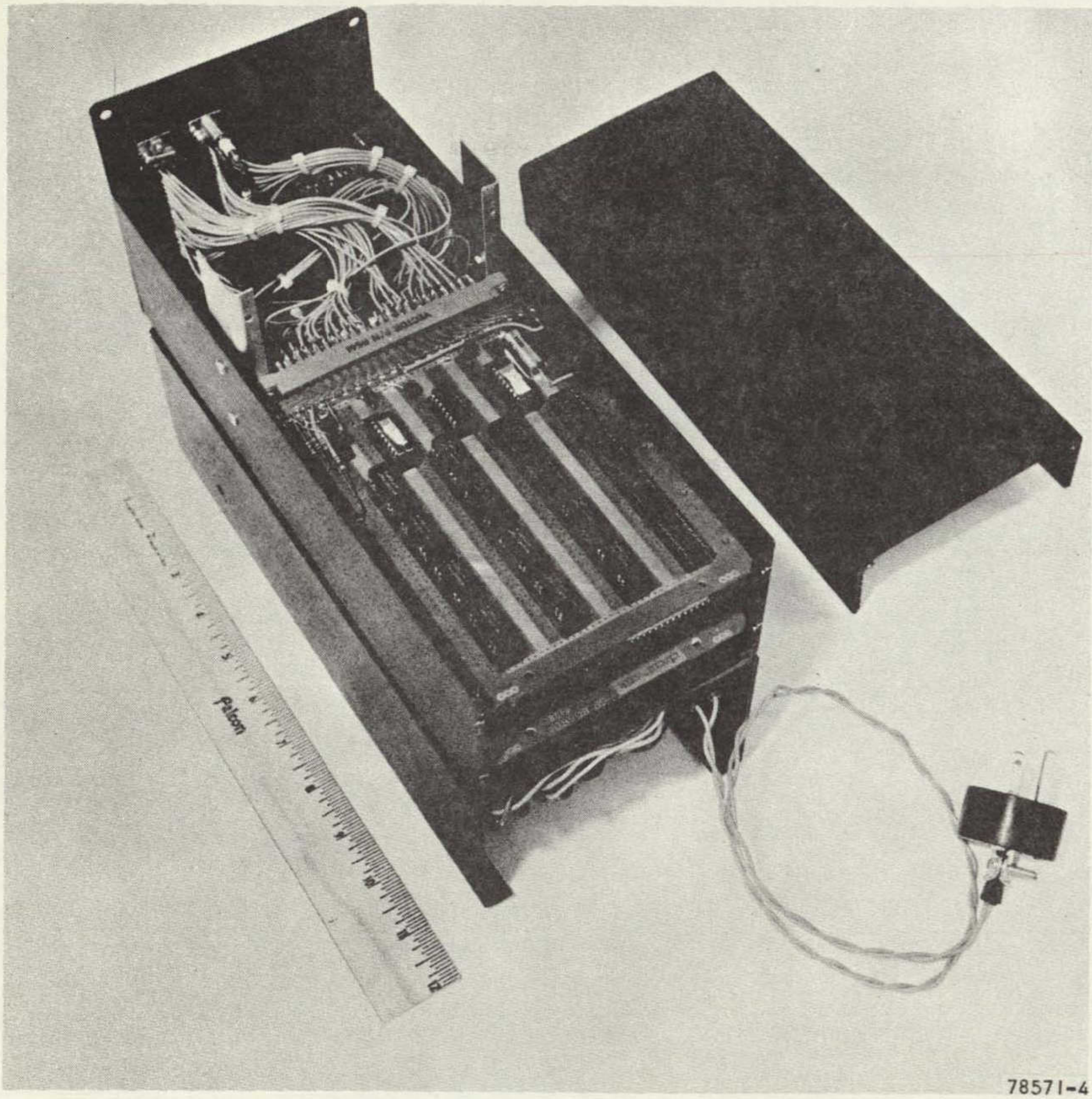

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Figure 4-13. Solar Heating/Cooling Prototype Interface Module Internal View

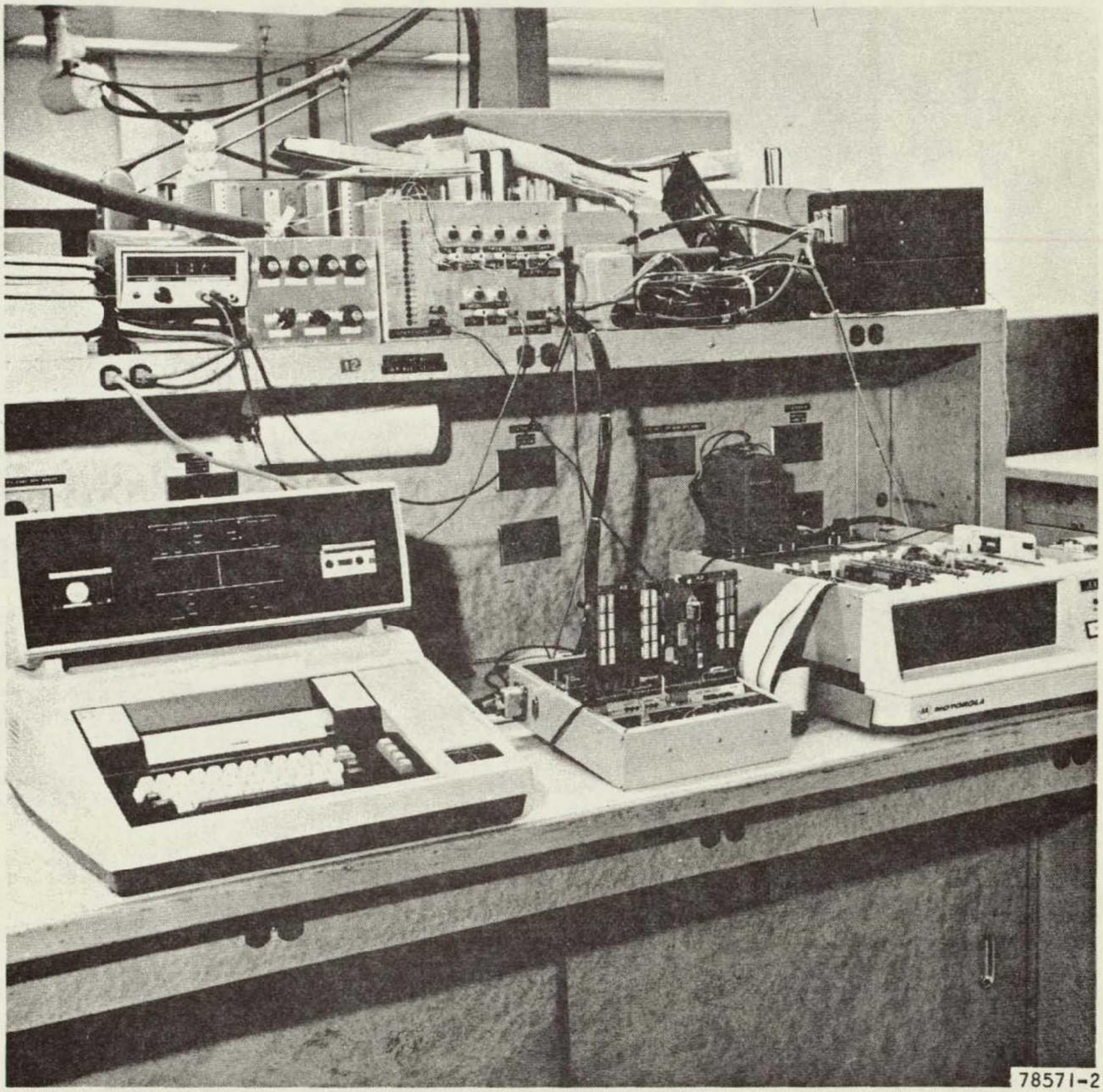

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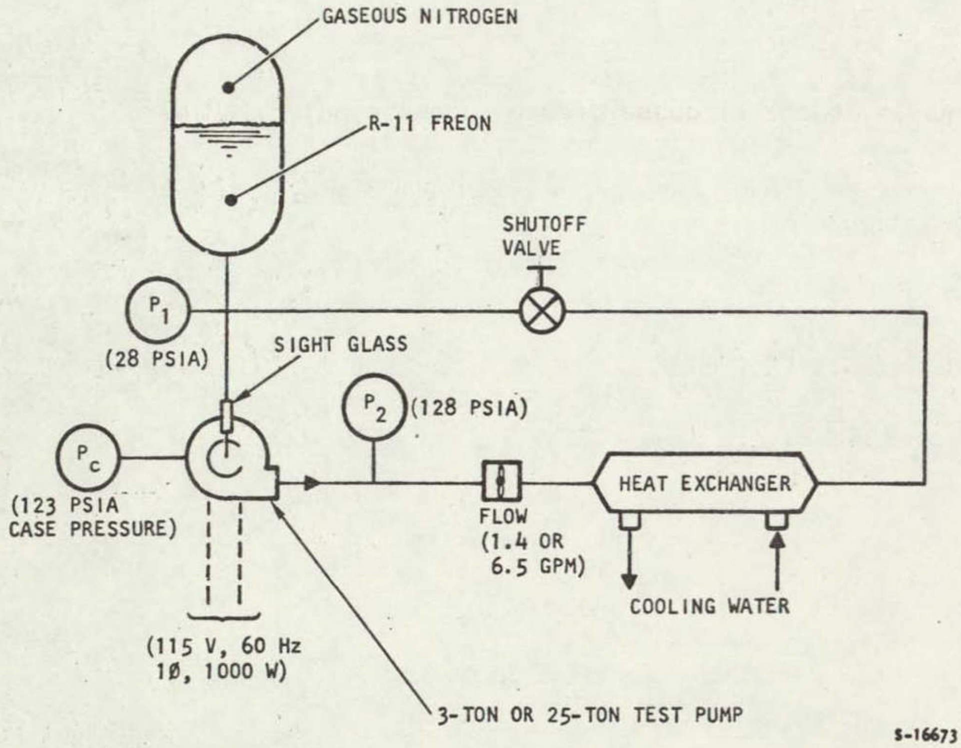
Figure 4-14. Simulated Solar Heating/Cooling System Test Setup

d. R-11 Liquid Pumps

(a) 3-Ton Unit

The test loop was revised to improve the separation of freon vapor from freon liquid in the system and a clear section of line was installed upstream of the pump inlet as shown below.



With inlet conditions well above the freon vapor pressure, bubbles could be seen in the inlet indicating incomplete separation. The appearance of bubbles in the inlet correspond to a decrease in pump performance. The pump was run continuously for 113 hours in April and inspected. No wear was seen on the vane tips, but the center rings controlling vane tracking wore grooves 0.001/0.0015 in. deep on the underside of the vanes. Therefore, 660 bronze vanes were installed in the pump and the pump was operated for 19 hours. Performance was essentially the same as for the carbon vanes. Disassembly showed some bronze particles from the underside of the vanes transferred (cold welded) to the free floating ring O.D. The pump was reassembled with the original carbon graphite vanes. The motor case vent was closed causing the case to be under full pump discharge pressure which resulted in improved undervane pressurization. During the first pump endurance run of 113 hours, there was a 5 percent decrease in flow caused by wear at the vane to floating ring interface. With the revised pressurization system, a run of 71 hours was made at the end of May with an increase of 2 percent in pump flow. Inspection after this run showed a slight burnishing of the bearing surfaces at both ends of the rotor. All parts

FUTURE ACTIVITIES

Activities in the next quarter will include the following.

WBS 1.1 Management

1. WBS 1.1.1 Program Direction

   a) The fourth quarterly review by the NASA contract monitor is scheduled to be held at AiResearch during July 5, 6 and 7, 1977.

   b) The Daystar Corporation will be awarded a finalized subcontract for manufacture of solar collector panels.

   c) A major effort will be expended in the completion of site selection suitable for system installation. Currently, the following activities are planned:

      1. Survey and selection of an A and E firm and a general contractor for the Allaire Park, N.J. site, will be conducted.

      2. A site negotiation meeting will be held in New York during the July 10th week regarding the Syracuse Hancock Airport terminal waiting area light commercial heating-only system to define various duties and responsibilities of the concerned parties.

      3. A return to the St. Louis and Los Angeles sites will be made to survey additional candidate sites.

      4. A site negotiation meeting will be scheduled in early August in the Des Moines area. Licensed contractors in that area will be surveyed for qualifications and experience.

      5. Washington area site surveys will be conducted in late August. Tennessee sites may be considered in lieu of the Washington, D.C. suburbs. (A decision on the use of the Dunham-Bush test house in Harrisonburg, Va., as an alternate for the Washington, D.C. site will be made at this time.)

      6. Analysis of the present Des Moines, Houston and Las Vegas sites will continue. Future sites at these locations will also be considered. Site negotiation meetings should be complete by the fifth quarterly progress report.

      7. A Prototype Design Review will be held on August 2 and 3 to review the items of Section 4.2 of Appendix B to the Contract Statement of Work.

   d) Monthly coordination meetings will continue with Dunham-Bush to assess progress and resolve problems.

2. WBS 1.1.2 Program Planning and Control

a) Schedule Development

Schedules will be updated as required. NASA will be informed of any significant slippage if any.

b) Program Documentation

The following program documents will be prepared.

(1) DR 500-10, the fifth quarterly report

(2) DR 500-11, monthly status reports

(3) DR 500-27, financial management reports (provided monthly)

(4) Installation technical information packs for site owners

(5) Data pack for Prototype Design Review

(6) Preliminary Instrumentation Plan (PIP) for the Allaire Park, N.J. site

3. WBS 1.1.3 Quality Assurance

The revised quality assurance plan will be implemented throughout the program.

WBS 1.2 Development

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1. WBS 1.2.1 Analysis and Integration

(a) Analyses will be performed as necessary in support of the scheduled site selection effort.

(b) Test data will be reduced and system/subsystem performance will be updated using these data.

2. WBS 1.2.2 and 1.2.3 System Development and Test

(a) System Design Activities--The single family residence heating system for the Allaire Park, N.J., installation will be completed. The design of other systems will proceed immediately following as the other sites are selected.

(b) Heat Pump Development

Detail drawings will be completed for the heating-only versions of the 3-ton and 25-ton heat pumps. Detail design of the 75-ton boiler/evaporator and evaporator/condenser will be finalized. One set of heat exchangers for the 75-ton/1600 KBTUH will be fabricated for incorporation in the first heat pump prototype. The 25-ton and 75-ton test setups will be completed within two months.

(c) Turbomachine/Motor

Assembly of the complete heat-only 3-ton turbomachine and development testing will be completed in the next quarter. Assembly of the heat-only 25-ton motor/compressor and development testing at AiResearch will be nearly complete. The complete turbomachine will be tested at Dunham-Bush later.

(d) Motor Controller

The 3- and 25-ton breadboard motor controller dynamic tests with appropriate motors will be completed in the next quarter.

(e) System Control

Debugging of the prototype software, hardware, wiring and circuit layout will be completed. Prototype drawings will be completed and software subroutines and main programs will be documented.

(f) R-11 Pumps

Performance evaluation of the 3-ton R-11 pump will be completed and a 300-hr endurance test will be completed. Following this test, the pump will be disassembled and inspected for signs of wear. The 25-ton R-11 pump will be assembled and tested for performance verification and durability as for the 3-ton unit. A centrifugal pump for the 75-ton heat pump will be evaluated.

(g) Heat Pump Packages

Package drawings including R-11 and water piping will be completed for the 3-ton/60 KBTUH and the 25-ton/600 KBTUH heat pumps. Also, layout of the 75-ton heating/cooling unit will be initiated. Assembly of the 3-ton heating-only unit will be completed in August with the delivery of the turbomachine and controls. The 25-ton heat-only package will be completed one month later.

(h) Collector

A collector panel representing the latest configuration developed by Daystar will be shipped to NASA for evaluation on the simulator.

WBS 1.3 Deliverable Hardware

1. WBS 1.3.1 Single-Family Residence

(a) Turbomachine/Motor

Following development testing, four 3-ton prototype turbomachines will be delivered to Dunham-Bush for integration in the heat pump packages. The first unit is now scheduled for delivery August 1.

(b) Motor Controller

A prototype motor controller will be assembled following breadboard testing with the motor and delivered to Dunham-Bush by August 1. Assembly of the first 25-ton motor controller will be continued.

(c) System Control

The first prototype will be assembled and tested prior to delivery to Dunham-Bush by mid-August.

(d) R-11 Pumps

Upon performance test completion, three deliverable 3-ton pumps will be built for the subsystem test. The 25-ton pump will undergo a similar development program.

PART E

Fifth Quarterly Report
Data Requirement 500-10

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT

Contract NAS8-32091

76-13296(5)

October 10, 1977

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama 35812

GARRETT

AIRESEARCH MANUFACTURING COMPANY
OF CALIFORNIA

CONTENTS

SECTION 1

INTRODUCTION AND SUMMARY

INTRODUCTION

This is the fifth quarterly report prepared by AiResearch Manufacturing Company of California under Contract NAS 8-32091 for the National Aeronautics and Space Administration, Marshall Space Flight Center (MSFC). The report summarizes activities from July 1, 1977 to September 30, 1977.

SUMMARY

Significant activities and status of the cost, schedule, and technical aspects of the program are summarized in the following paragraphs.

Cost Status

This paragraph has been deleted.

Schedule Status

Presently, the solar systems mix is undergoing change. It is anticipated that heating-only heat pump systems will be replaced by heating/cooling systems for purposes of commonality. The sites are also being readjusted to conform to latest owner agreements. A NASA/ERDA meeting is planned for late October to define commercialization goals and tasks, and to review latest operational test site mix. The latest solar heating/cooling systems development schedule (Figure 1-2) reflects the best estimate that can be made at this time regarding delivery and installation dates, but will be revised after the October meeting to agree with future commitments.

Technical Status

1. Site Selection

Site owner/NASA interface meetings were held in Las Vegas and Houston to discuss installation and cost aspects of supplying 75-ton solar powered systems on two recreation type buildings. These two sites are progressing rapidly and effort has been intensified for the 75-ton systems. Site surveys were made in St. Louis, Jefferson City, Los Angeles and Des Moines, with several buildings presently being considered. Site owner enthusiasm for the Des Moines site has oscillated during August and September. It now appears that it will be replaced by a new site in Lawrenceburg, Tennessee.

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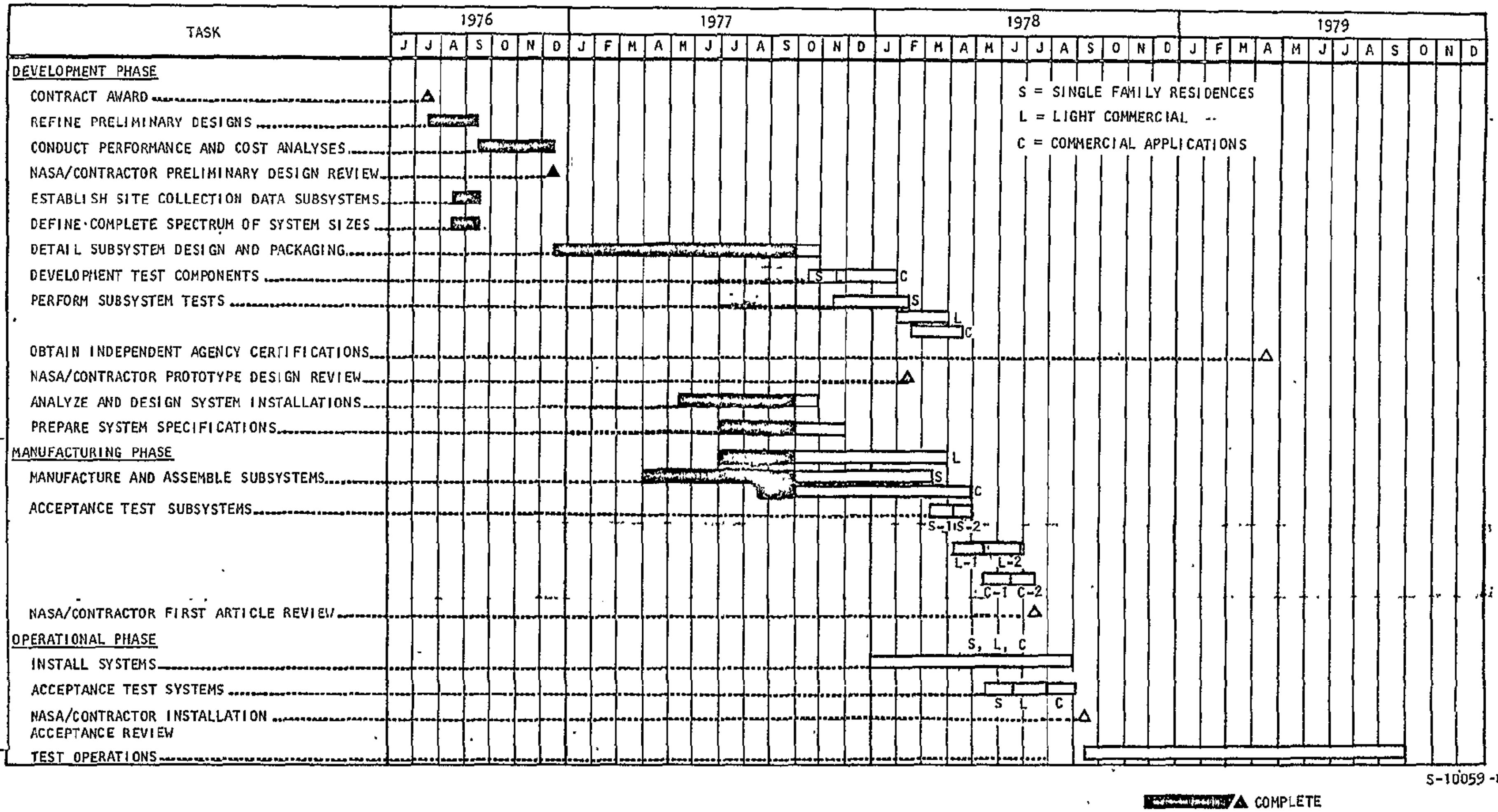

Figure 1-2. Solar Heating/Cooling Systems Development Schedule

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Computer analysis has been completed for Las Vegas and Houston and the local A & E's are working on detail design of the system. Analysis of the St. Louis site is in process anticipating acceleration of this installation.

2. Collector Procurement

Collector panel manufacture and procurement is proceeding on schedule. Delivery is being made directly to NASA/MSFC.

3. Program Documentation

Documentation was prepared in accordance with the requirements of DR-500. A number of documents have been approved by NASA. Approval of the remainder awaits completion of review by NASA.

4. Heat Pump Subsystem

Assembly of the 3-ton heat-only heat pump is nearly complete. All parts have been delivered to Dunham-Bush except for the turbomachine and controls (both system and motor). The 25-ton heat-only heat pump assembly is also being delayed by delivery of the turbomachine and controls. Activity on the 75-ton package has been confined to design drawings and construction of a 1/8 scale mockup to simplify piping and minimize development costs.

5. Equipment Development

Inconsistent starts of the 3-ton and 25-ton turbomachines in the laboratory test loop has shown the presence of foil bearing problems; i.e.---foils were too long, too much oil in the freon and bearing cooling passages of insufficient capacity. These design problems are presently being corrected during bench tests of the turbomachines.

The 3-ton and 25-ton turbomachine motor controllers are currently the pacing items for the entire system dur to past difficulties in attaining design speed due to problems in the commutation. Solution to this problem appears imminent now that the cause has been identified. System controllers for the three heat pump sizes are complete except for final system checkout tests.

The 3-ton R-11 pump performance and durability are now satisfactory as shown by a successful prototype endurance test. A 25-ton pump motor of sufficient torque has been built. Overall efficiency is satisfactory but discharge pressure fluctuations have necessitated corrective action (clearance adjustment and/or minor discharge plumbing changes).

Section 2 has been deleted.

SECTION 3

PROGRAM SCHEDULES

The overall program schedule is included in Figure 1-2 of Section 1. This section includes more detailed schedules (Figures 3-1 through 3-6) covering the development status of the critical subsystems and components. These schedules represent an update of those given in the Fourth Quarterly Report. The component/subsystem schedule changes have only a limited effect on the overall program schedule. The status and progress are given in Section 4.

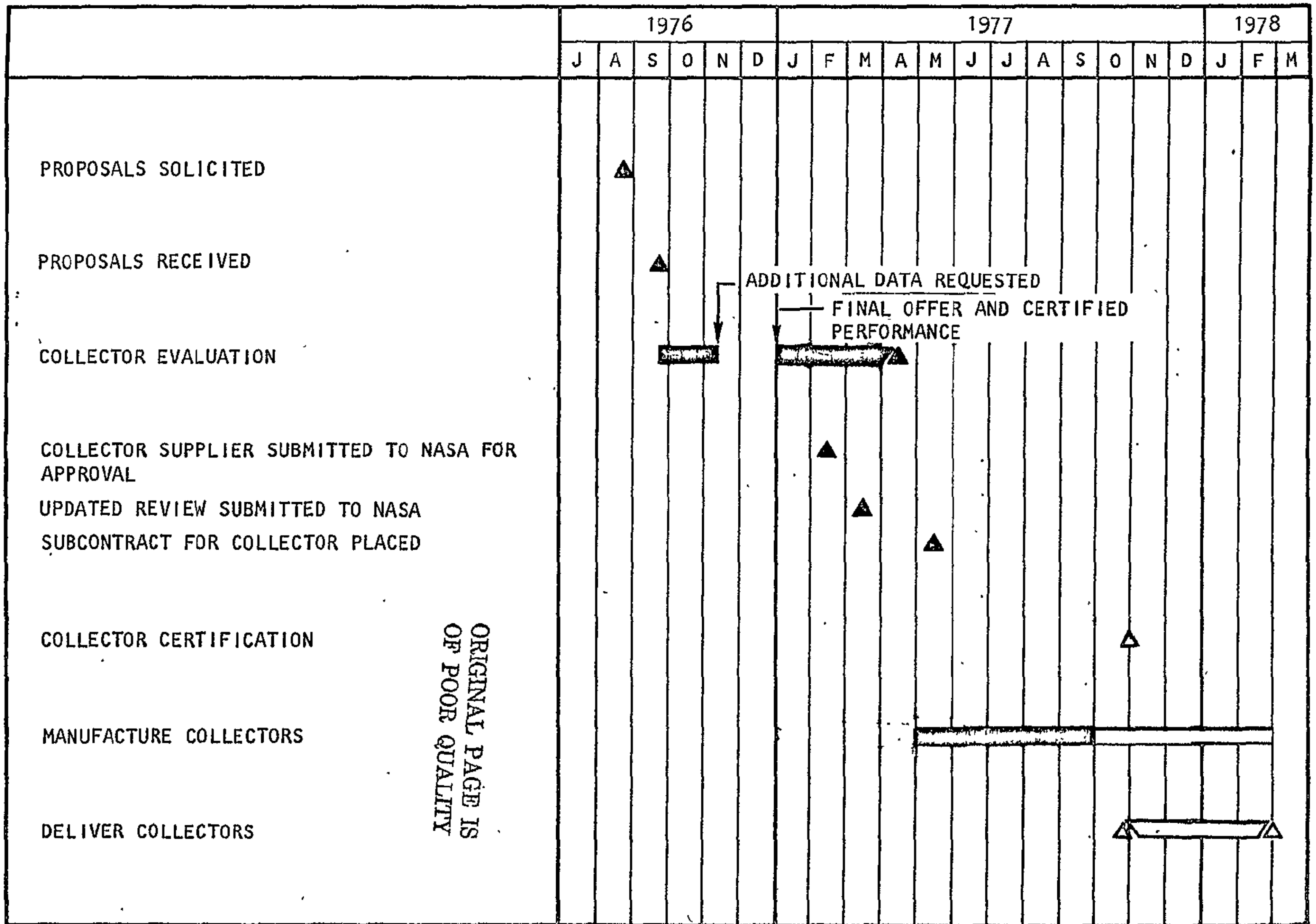
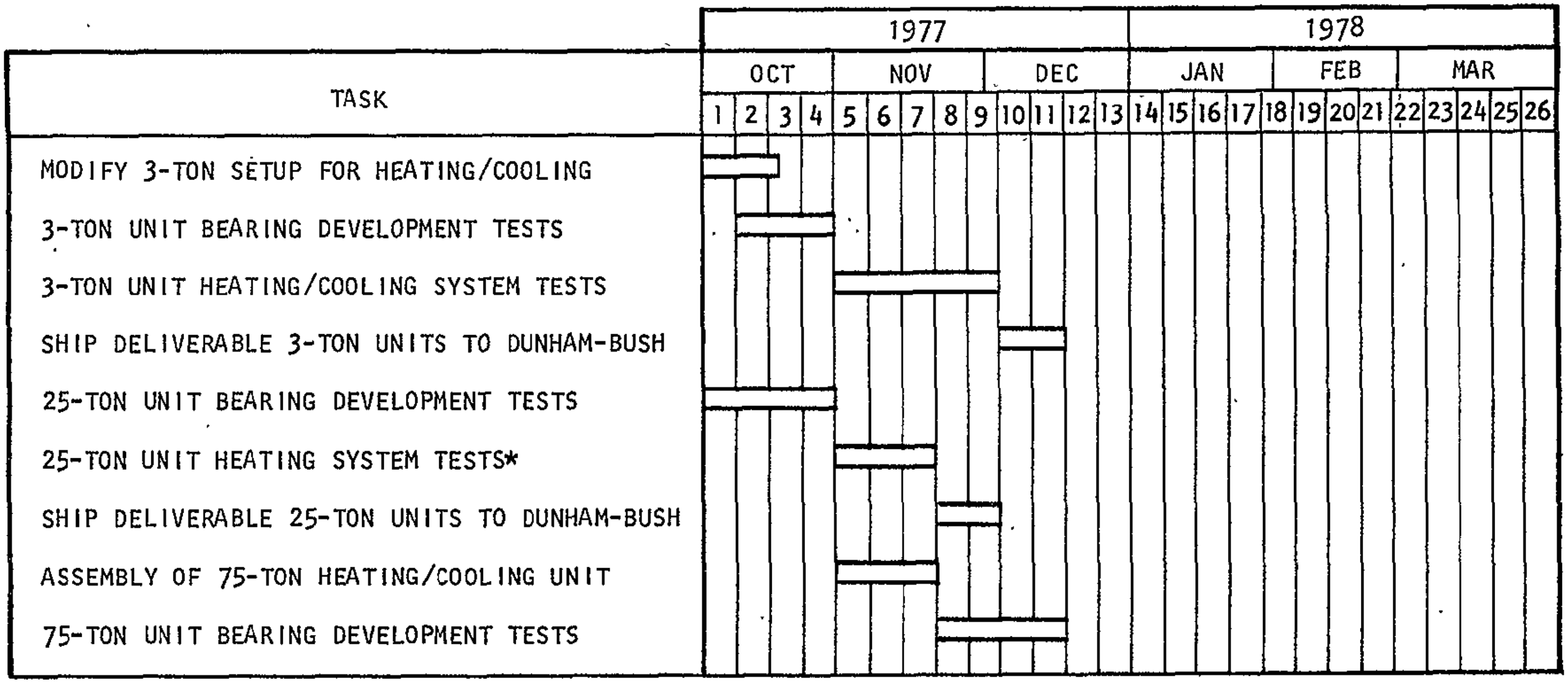


Figure 3-1. Solar Collector Development Schedule

E-8

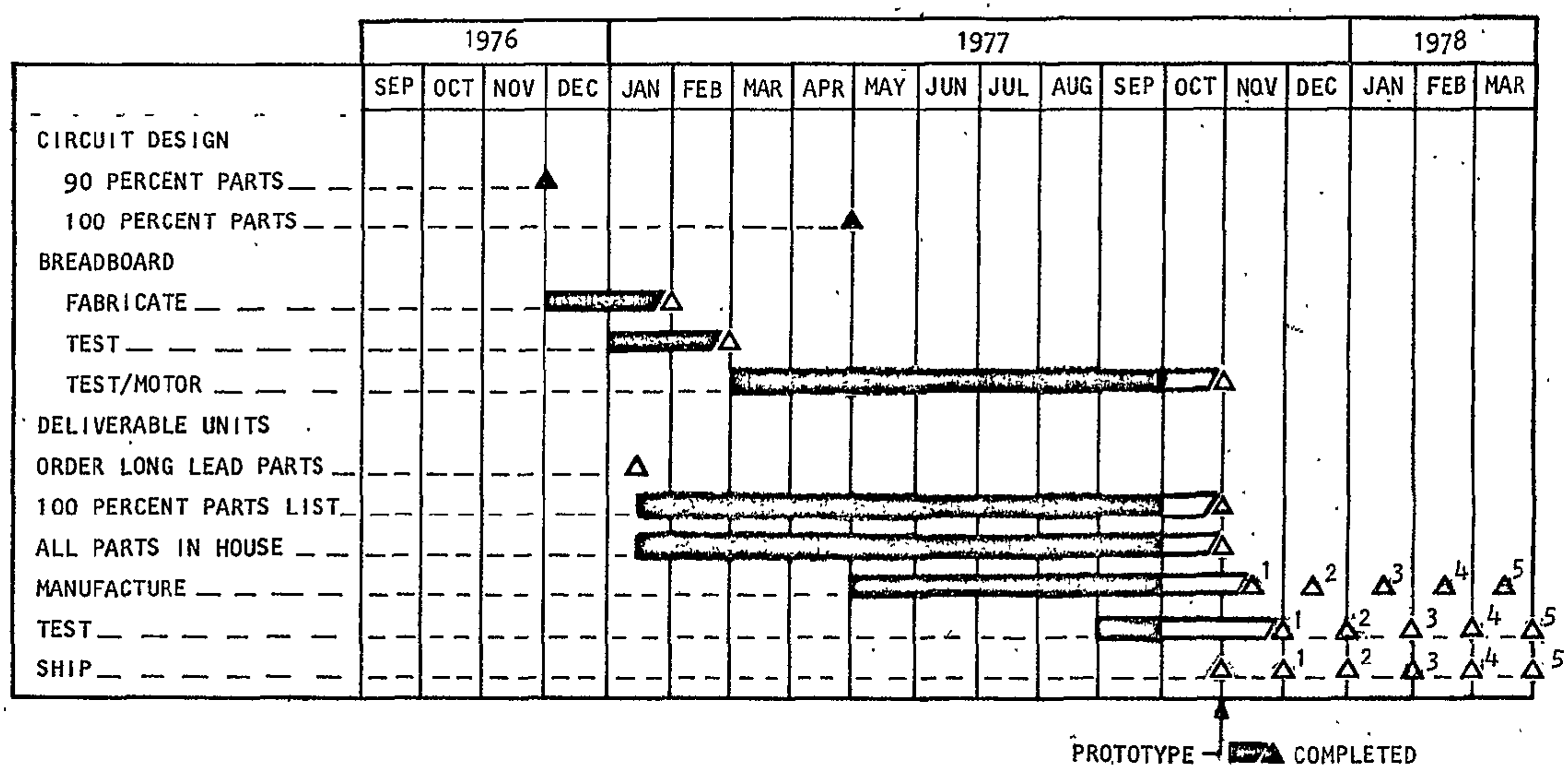


*Cooling system tests to be done at Dunham Bush

S-20118

Figure 3-2. Updated Turbomachinery Development Schedule

E-9



S-11743-D

Figure 3-3. 3-Ton Unit Motor Control Development Schedule

E-10

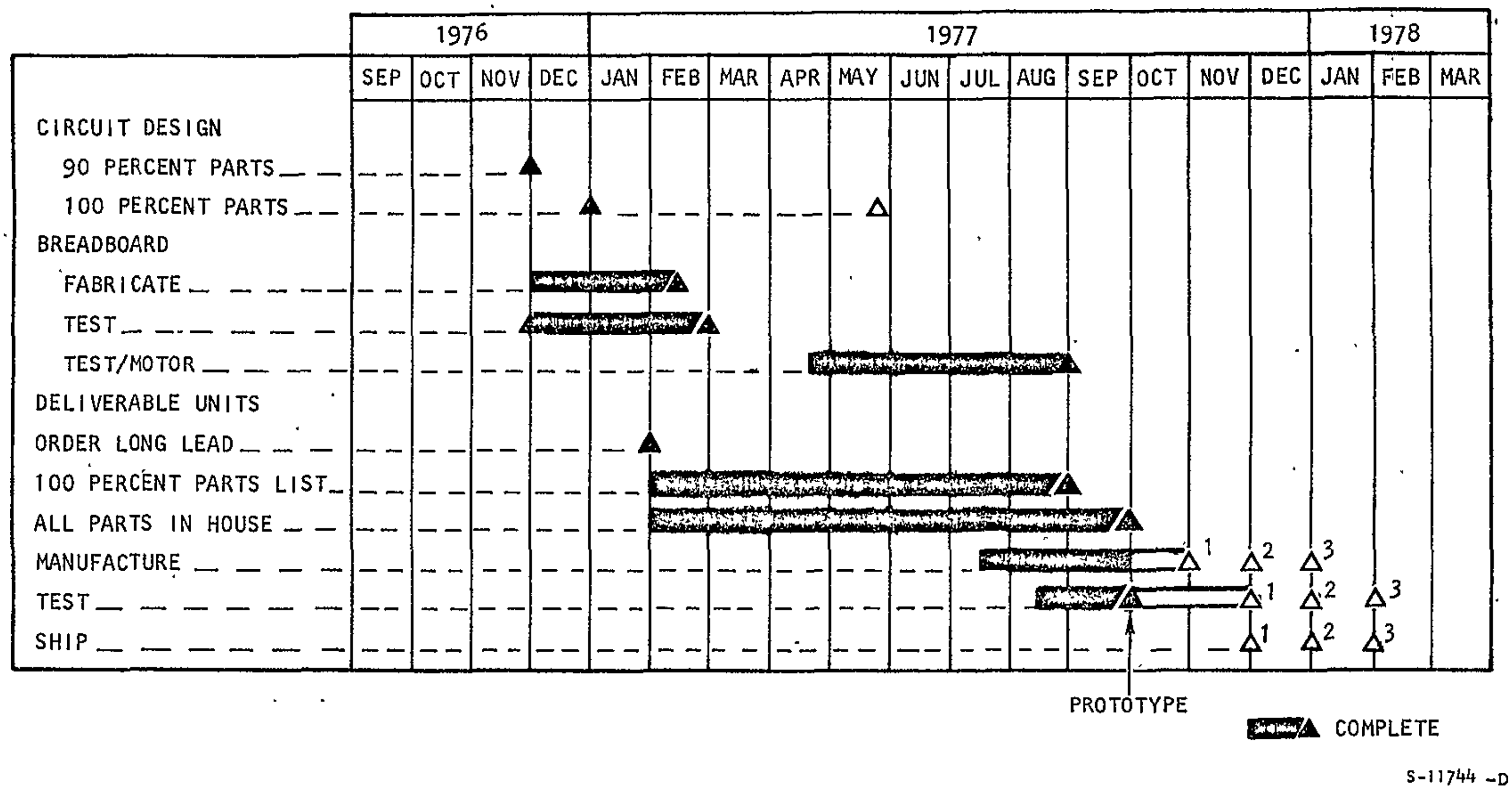


Figure 3-4. 25-Ton Unit Motor Control Development Schedule

E-11

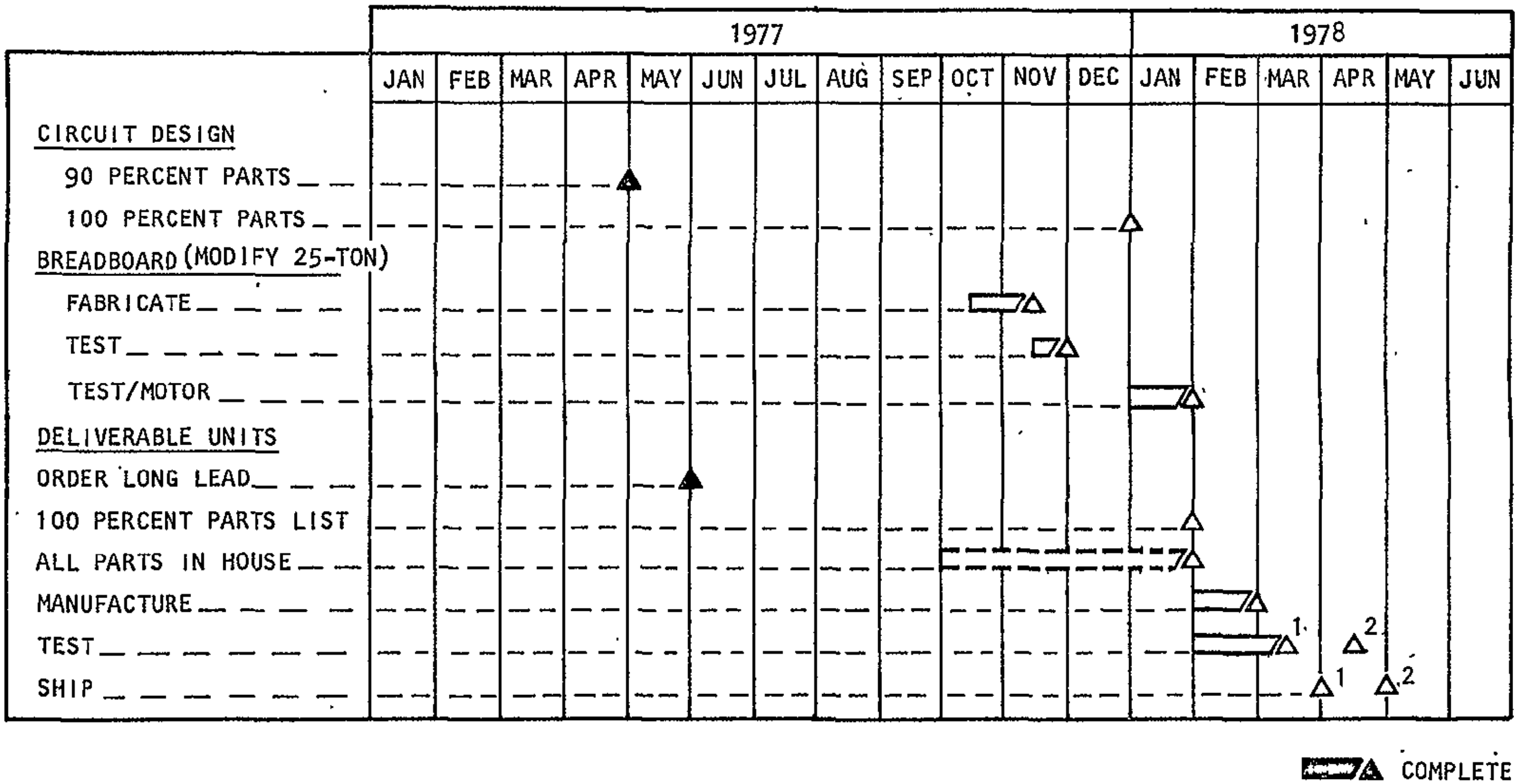


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Figure 3-5. 75-Ton Unit Motor Control Development Schedule

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E-12

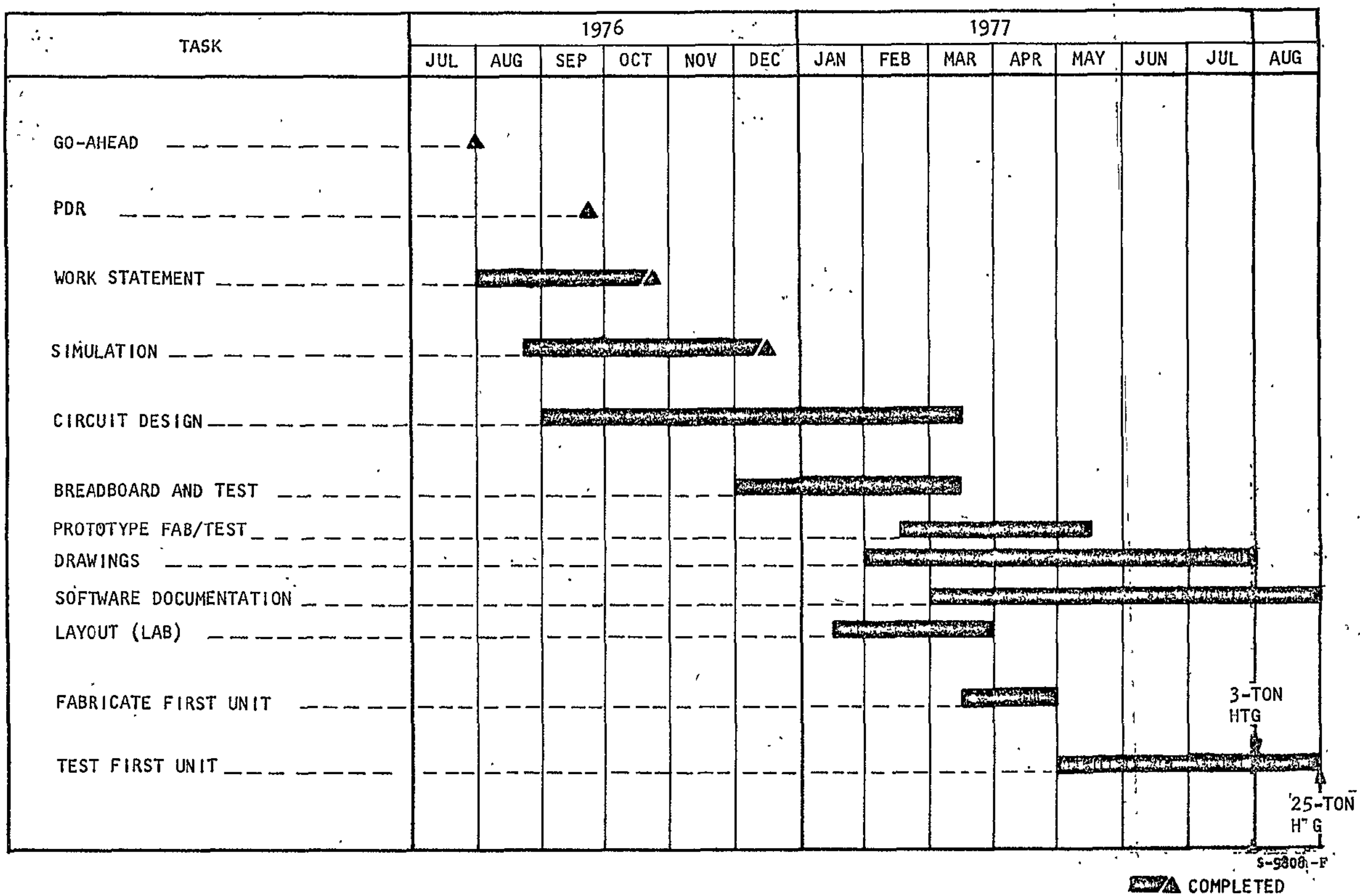

Figure 3-6. System Control Development Schedule

SECTION 4

TECHNICAL PERFORMANCE

INTRODUCTION

Technical status is reported below for all WBS tasks active in the reporting period. The WBS of Figure 4-1 identifies the active tasks with an asterisk (*). Activities during the third quarter were involved with the following.

WBS 1.1, MANAGEMENT

WBS 1.1.1, Program Direction

Meetings, reviews, and major events

Site selection and investigation

Collector procurement

WBS 1.1.2, Program Planning and Control

Schedule development

Program documentation

WBS 1.2, DEVELOPMENT

WBS 1.2.1, System Analysis and Integration

WBS 1.2.2, System Development and WBS 1.2.3, Test

Turbomachine and motor controller

System controller

R-11 liquid pump

Heat Pump Subsystem

WBS 1.3, DELIVERABLE HARDWARE

Progress on all these items is described in the following paragraphs.

E-14

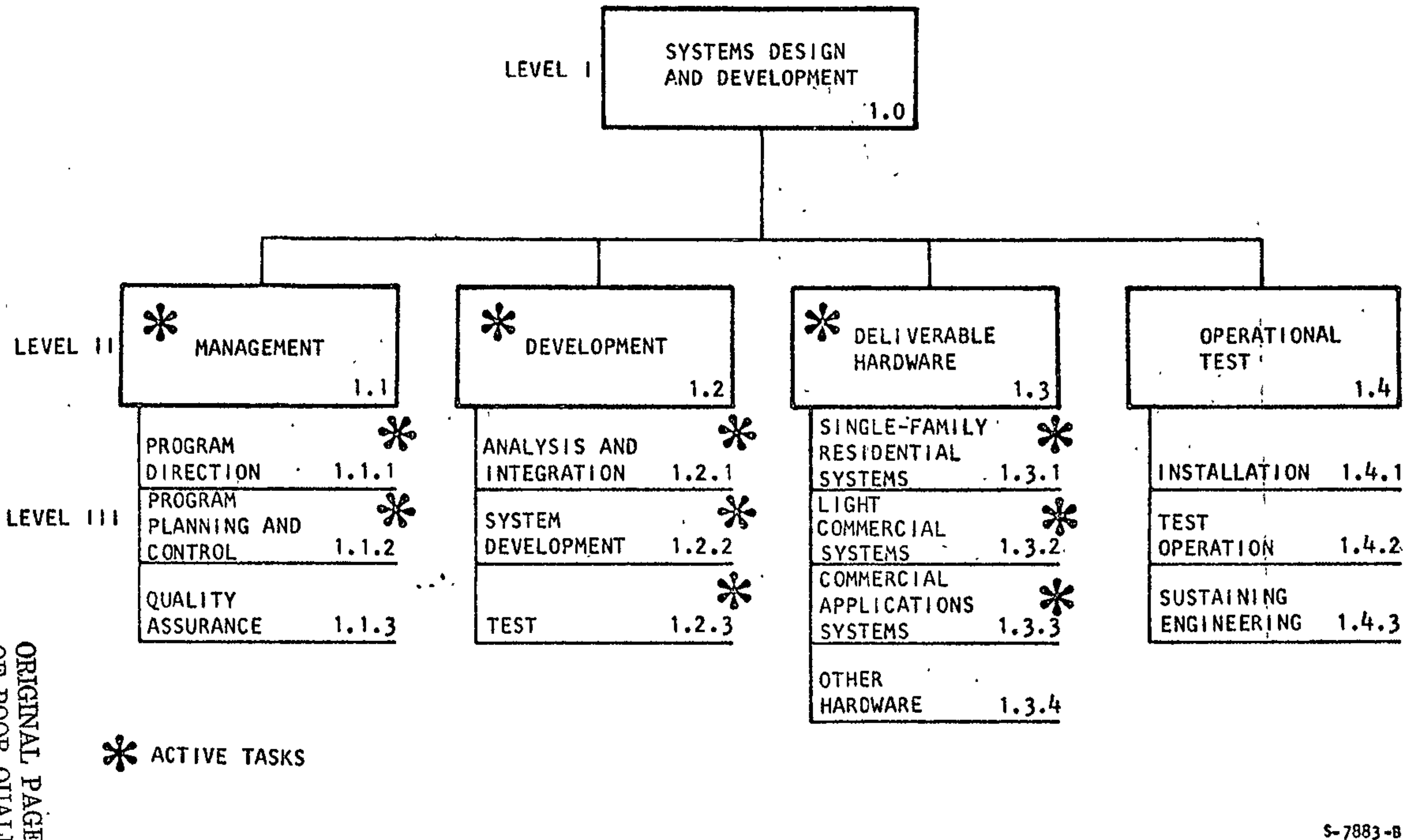

Figure 4-1. Top-Level Work Breakdown Structure

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ACTIVITIES IN REPORTING PERIOD

WBS 1.1, Management

1. WBS 1.1.1, Program Direction

a. Meetings, Reviews, and Major Events

- A coordination meeting was held at AiResearch from July 5 through 7, 1977, with Mr. Jim Clark, NASA contract monitor, to review activities and status.
- NASA/ERDA was supplied with color Vu-Graphs of the solar heat pump major technological components and color photographs of the heat pumps for a program evaluation discussion in early July.
- A site interface meeting was held at Syracuse, N.Y., on July 13-14, 1977.
- AiResearch shipped a complete parts kit for the 3-ton turbocompressor unit to NASA/MSFC in mid-July for NASA Management indoctrination.
- A Prototype Design Review was held at Harrisonburg, Va. on August 2 and 3, 1977 between NASA/MSFC, Garrett/AiResearch and Dunham-Bush to review the design of heating-only systems.
- A rough draft of a "go-forward" proposal of AiResearch plans for system commercialization (with a critique of Evaluation Panel findings) was prepared for discussion with ERDA/NASA representatives in early August.
- A program review meeting was held at AiResearch on August 17 and 18, 1977, with ERDA/NASA representatives John Price, Bill Richardson, Jim Clark and Robert Gunner in attendance. The "go-forward" proposal and site status were reviewed in detail.
- Site visits were made to Las Vegas, Nevada; Houston, Texas; St. Louis and Jefferson City, Missouri, during August 18 through August 24, 1977.
- The rough draft of the "go-forward" proposal Report 77-13904 was revised in accordance with the August 17-18 program review meeting comments and resubmitted on September 23, 1977.
- Report 77-14281, entitled "Solar Heating and Cooling Systems Design and Development" was submitted September 6, 1977 to NASA/ERDA to review the program to date and submit color photos of the prototype hardware.
- Report 77-14281 was resubmitted on September 30, 1977 with the SITE SELECTION section deleted at NASA request.

- A and E solicitation meetings were held in Newark, N.J., Atlantic Highlands, N.J., and Baltimore, Maryland, on September 21-23, 1977, to request proposals from qualified firms for work on the Allaire State Park site.

- Another site survey trip was made to George H. Peck Park, San Pedro, Calif. on September 26, 1977, to visit the Community Center Building for 25-ton cooling and heating consideration. (This site was previously visited in June.)

- A Las Vegas site A and E interface meeting was held on September 30, 1977.

- Three visits were made to Dunham-Bush to review technical status.

- Withdrawal by the site owner during August caused cancellation of the Des Moines, Iowa, operational test site. Replacement sites are now being screened.

b. <u>Site Selection and Investigation</u>

The NASA-AiResearch site team discussed the Syracuse, N.Y., Hancock Airport site with city officials at the City Hall in mid-July. Brochures and drawings were distributed by AiResearch. Proposed alterations to existing equipment were reviewed and owners obligations were discussed. NASA outlined their intent to pay for (1) piping ducting and mechanical controls modifications and (2) solar panel installation. Subsequent discussions revealed two local disadvantages to a solar system; Syracuse in the cloudiest city in the U.S.A. and high winds (up to 100 mph) are not uncommon. The wind factor would require a well-buttressed solar panel support structure. AiResearch Plant Engineering was requested to design this support for site owner use in estimating costs. Following the meeting, a more complete cost estimate was submitted and requests for proposal (Forms 254 and 255) were sent out to local A and E firms.

An alternate plan to the Des Moines owner's concept was prepared by AiResearch along with an isometric of the solar equipment for that site. For the Allaire Park, N.J., site, a new isometric of the solar equipment was made and Forms 254 and 255 were sent to N.Y.-N.J. A and E firms. The isometric and perspective sketches for these three sites were included in the Prototype Design Review Data Package (AiResearch Report 77-14193) submitted July 18, 1977.

Site owner/NASA interface meetings were held in August at Las Vegas, Nevada, and Houston, Texas. Site surveys were made at St. Louis, Missouri, and Jefferson City, Missouri. The site considered for Las Vegas is the Stewart Mojave Recreation Center, a new building. This building is being considered as a 75-ton heating and cooling site. Considerable discussion of methods of cost sharing followed a short technical review. A preliminary agreement was reached, but the city has not yet received the funding to proceed with the building.

A site interface meeting was held at the University of Houston, Houston, Texas and concerned the new Development Arts Building as a site for the second 75-ton heating and cooling system.

The Development Arts Building at the Clear Lake City campus is a new structure and the University of Houston has engaged SIMA for the architectural design and Timmerman Engineers, Inc. (TEI) for the mechanical-electrical design. These firms will act as A and E in the design of the solar system.

NASA indicated that they would prefer to have the same engineering designer design their portion of the project that was being employed to design the balance of the project. NASA further stated that it would be desireable during construction to have Garrett/AiResearch utilize the services for their portion of piping connections and other mechanical work as was successful in obtaining the basic mechanical subcontract. It was determined that the University of Houston will pick up the total A and E fee. Preliminary design will be completed in 30 days by SIMA and TEI. General contract verbage was established for an owners agreement. AiResearch completed Change Proposal AIR-13 leading toward a signed owners agreement and an official NASA go-ahead on this site.

The site selection team then met at Crystal Lake Park, Missouri, to survey sites for a 25-ton heating-cooling system. The site team first considered a street light maintenance building. This site was not deemed a viable candidate because of the large expense to the owner to prepare this structure for the solar system.

The County Gumbo Prison was offered as a site. Because contractor costs could be exorbitant due to work in a secured area, AiResearch Plant Engineering feels that this site should be considered a viable candidate only on the third level.

The third site considered was South County Tech Child Care Center. The building is used for child care instruction and is only part of a very large complex. The AiResearch representatives deemed the structure a prime viable candidate and consider it number one in preference.

A site survey was convened at Jefferson City, Missouri, on August 25th, in the offices of the Missouri Department of Natural Resources (DNR) of the State Office Building. DNR personnel presented no less than 15 building candidates but had no site which fit the 25-ton requirements for this area, but did have an excellent candidate for replacement of the now defunct Des Moines 3-ton system. This site is a new Park Superintendant home which is scheduled to start soon in Northern Missouri.

The University of Missouri, Rolla campus, offered a viable 25-ton site. It is considered to be an excellent backup to the Child Care Center in St. Louis.

The revisit to the Peck Park Community Center Building, San Pedro, Ca., in late September reiterated its advantages and shortcomings. The auditorium has a 50-ton DX (direct expansion) cooling system with 750 KBTUH heating, and two other areas are served by 21-ton DX cooling with 500 KBTUH heating; each are low velocity 6-zone systems. The domestic hot water heating is 200 KBTUH serving the dining area that is used about three times a week. The roof area of 28,000 sq ft is more than adequate, a definite advantage. The most promising area for a 25-ton solar system was the system serving the music room, teen lounge, game room, and club room. This area is now served by a 20-ton DX unit. Space is not available within the mechanical equipment room but there is space directly outside which may be utilized for equipment. Although the load may vary dependent on the activity, this may be one of the better candidates of the six Los Angeles sites investigated in June. The major disadvantage is the high cost of replacing a DX cooling and a natural gas heating system with a solar energy water transport system. Almost none of the components of the present system are suitable for solar system use, and total replacement would be necessary.

A Las Vegas site interface meeting was held on September 30, 1977 to coordinate A and E activities. Mr. Ralph Joeckel of JBA was provided with brochures, a piping isometric drawing, data on AiResearch equipment, a general storage tank configuration and a final data sheet on the site. Mr. Joeckel will size the expansion tank, and AiResearch will provide the tank. AiResearch agreed to provide a final storage tank drawing, a revised heat pump drawing, cooling tower fan wiring, and total power requirements.

c. Collector Procurement

Collector procurement was delayed by frequent design changes instituted by the manufacturer (Daystar). The collector design has been finalized and a preliminary contract was issued in June. A formal contract was issued in July for Model 21B collectors.

2. WBS 1.1.2, Program Planning and Control

a. Schedule Development

Program schedules have been updated throughout the quarter to reflect the latest information. The latest versions of the component/subsystem schedules are presented in Section 3. Overall program schedules for the heating and heating/cooling systems are in section 1.

b. Program Documentation

The following documents were prepared in accordance with the requirements of Appendix A of the Statement of Work.

(a) Fourth Quarterly Report (DR 500-10), July 8, 1977, AiResearch Report 76-13296(4).

(b) Prototype Design Review Data Package (DR500-8), AiResearch Report 77-14193, dated July 18, 1977.

(c) Monthly Progress Reports No. 10 and 11--AiResearch Reports 76-13110(10) and 76-13110(11).

Other publications issued this quarter were:

(d) Report 77-14281, entitled "Solar Heating and Cooling Systems Design and Development" was submitted to NASA/ERDA to review the program to date and submit color photos of the prototype hardware.

(e) Report 77-13904 entitled "Solar Heating and Cooling Recommended Contract Modifications to Achieve Commercialization" was submitted in rough draft form to NASA/ERDA twice.

(f) Change Proposals AIR-4 through AIR-9 were issued during June covering procurement of operational test site weather data, procurement of Daystar collectors, response to H. C. Rooks report, response to ERDA technical/marketing questions, Daystar collector test at MSFC, and reduction in operational test sites, hardware and support. In July, AIR-9, Revision 1, which consolidated all of the above into one Change Proposal, was submitted to MSFC.

(g) Change Proposals AIR-10 through AIR-14 were issued in August to aid NASA in evaluating costs associated with system installations and site modifications at Allaire State Park, N.J., Syracuse, N.Y. Des Moines, Ia., University of Houston, Houston, Texas, and Las Vegas, Nevada, respectively.

(h) Change Proposal AIR-15 was issued to propose a modified delivery schedule for solar equipment.

WBS 1.2, Development

1. WBS 1.2.1, Analysis and Integration

A summary of the computer program logic including mathematical equations in the program, input data nomenclature and typical printouts for the Allaire State Park, N.J., and Syracuse, N.Y., solar heating and cooling system sites was prepared for incorporation into the Prototype Design Review Data Package Report 77-14193 in July.

The program cooling mode of operation for the 75-ton system was debugged in July using concurrent manual analysis. However, since a great deal of the cooling mode operation is not at design conditions throughout the entire year's operation, comparison of the solar contribution to a conventional system operating at its design point is not a valid indication of the solar contribution. Therefore, it was decided in August to optimize the 75-ton system for minimum total power consumption in the cooling mode during the year's operation, and to ignore any comparison to a conventional system. A valid comparison to a conventional system would require evaluation of the conventional system for the entire year on a hour-by-hour calculation similar to solar system calculations.

The 75-ton cooling and heating solar systems for Las Vegas and Clear Lake City (Houston), Texas, were reoptimized on the minimum power basis and the design point was determined from these studies. Preliminary studies were conducted for the 25-ton cooling and heating system at the St. Louis, Mo., site.

2. WBS 1.2.2, System Development and WBS 1.2.3, Test

(These categories have been combined in this report because almost all development activities consisted of testing.)

a. Turbomachine and Motor Controller

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(a) 3-Ton Unit

Component testing of the motor and controller were completed in July. During these tests, the motor was run at design speed, no load, with the motor-controller in a closed electrical control loop mode. By August, all controller development modifications, discovered during these component tests, had been completed, and testing in the freon system was initiated. The compressor motor assembly was run up to 66,000 rpm with normal load, and nominal line voltage applied to the motor controller. Initial test data of the compressor performance indicates conformation of predicted values.

The motor design was found to be slightly off of the predicted characteristics, with a larger than expected back emf causing lower than required speed at the lower tolerance of the input line voltage. This problem was corrected successfully with a slight winding design data change, and all motors have been rewound.

Also discovered during the testing in the freon loop was an increasing torque characteristic after repeated starts. An extensive testing program was initiated, with the problem traced to the foil bearings. A test setup was fabricated to test the motor for magnetically caused side loading, and the test results indicate this side loading was less than predicted, which eliminated this as a cause of the starting problem. Testing was continued, and various types of foils were experimentally tried in the gas bearing assembly. However, an inconsistancy of data required extensive time to determine the source of the problem.

The gas bearing problem was finally found to be caused by three distinct design discrepancies. These were:

a. The gas bearing foils were slightly too long.

b. The freon being used for the tests was too high in oil content (not within the specifications under which the freon was purchased).

c. The bearing cooling passages were insufficient in capacity.

Testing is continuing to insure that all problem areas have been uncovered, and the results are encouraging at this time.

The fabrication of the first controller is 80% complete at the time of this report.

(b) 25-Ton Unit

The start of system testing was delayed in August due to a scheduling difficulty in the installation of a steam heat source, and considerable difficulty in locating and repairing freon leaks in the test setup. Initial testing indicated a similar starting difficulty of the motor to that experienced with the 3-ton unit. A parallel program to that for the 3-ton unit was initiated and the results were identical. Two units with different foil configurations completed 100 and 200 starts in air successfully, and one of these units completed 100 starts in freon without difficulty or signs of increasing torque. Testing of the units in freon are continuing.

The motor controller inrush current problem reported in the last quarterly report has been satisfactorily resolved. This problem was caused by starting of the motor with the PDR phased to the first quadrant. Thus, during the start-up sequence, the PDR output current was limited only by the inductance of the output filter choke and the load until the current loop stabilized. This problem was resolved by forcing the PDR to the forth quadrant before startup. In this manner, the current loop dynamics controlled the rate of rise of the PDR output current.

Fabrication of the first production motor controller is in progress. The unit is 90 percent complete.

b. System Controller

The system controller has been functionally checked out in both the heating and cooling modes in all 3 categories of control capacities, i.e. 3-ton, 25-ton, and 75-ton. There are two system controllers ready and waiting to perform a total system integrated test. Additional subassemblies are being fabricated for the production of 9 additional controllers. All necessary additional hardware for the 9 additional controllers have been ordered. Most parts have been received. The goal is to have all 9 controllers built and tested by the end of December 1977.

c. R-11 Liquid Pumps

(a) 3-Ton Unit

Endurance testing of the 3-ton pump was discontinued on August 2 after 1165 hours to allow testing of the 25-ton unit. The pump was disassembled and inspection of the components did not reveal any wear problems.

(b) 25-Ton Unit

The 25-ton system R-11 pump was run at the design conditions and demonstrated an overall efficiency within design limits. Discharge pressure fluctuations were noted and the unit is being disassembled for inspection to determine the cause. It is expected that the corrective action will be either adjustment of clearance within the unit or minor changes in the discharge plumbing of the test setup.

d. Heat Pump Subsystem

Assembly drawings for the 3 heat pump sizes have been completed and are included herein as Appendix A. Drawings DI-2946 (3 sheets plus parts list) depicts the 3-ton Model 2201288-HC-83 package, Drawings DI-2955 (4 sheets with parts lists included) shows the 25-ton Model 2201288-HC-825 heat pump and Drawings DI-2963 (3 sheets and a parts list) shows the 75-ton Model 2201288-HC-2075 package).

Specification drawings for each heat pump are in preparation at this time. Heat exchangers have been ordered for the 3 prototype 3-ton heat pumps and the 3 25-ton heat pumps. Delivery is anticipated in October.

(a) 3-Ton Heat Pump Models 2201288-H-80 and 2201288-HC-83

Piping for the Model 2201288-H-80 and -HC-83 units originally fed the collector water (ethylene-glycol mixture) to the tube side of the interchangers. The piping was changed in August to direct the glycol mixture to the shell side in accordance with the latest specification. Drawings were changed to reflect this modification. Design and assembly drawings have been completed. Assembly of the prototype heat pump is almost complete and waiting delivery of the turbocompressor and control units. This package will be converted to a heating/cooling unit approximately 1 month after completion of the heating only development tests.

(b) 25-Ton Heat Pump Models 2201288-H-800 and 2201288-HC-825

Piping on these models has been revised in accordance with the previous paragraph. Design and assembly drawings are complete. The water circuits for the Model 2201288-H-800 Heat Pump were tested in August. Some leaks were found and repaired. All systems are ready for operation when the turbomachinery are controls are received.

(c) 75-Ton Heat Pump Model 2201288-HC-2075

A layout drawing has been completed. Detail drawings are 90 percent complete. A 1/8-inch scale model of the 75-ton/1,600,000 Btuh heating/cooling unit was assembled in August to simplify the piping. Construction of the heat pump package is being delayed to allow analysis of test results of the smaller heat pumps to dictate final design of this unit to minimize costs.

(d) Heat Pump Test Setup

The test facility for test of the 3-ton heat pump was completed in May. Installation of the G.E. "Inductrol" voltage regulation circuit and the transformer units in August has completed the 25-ton test facility. The cooling tower and steam converter (simulated solar collectors) systems have been leak checked and all systems are acceptable for heat pump testing.

3. WBS 1.3 Deliverable Hardware

All parts for the single-family residential systems will be received in mid-October with the exception of the turbomachine (see Figure 3-2) and the motor controller (Figure 3-3). All light commercial system components are due in by December with the exception of the forementioned turbomachine and motor controller (Figure 3-4). Commercial systems components are due in-house in the first quarter of 1978.

FUTURE ACTIVITIES

Activities in the next quarter will include the following.

WBS 1.1 Management

1. WBS 1.1.1 Program Direction

   a) A meeting with IBM to discuss data acquisition is scheduled for October 13, 1977. In conjunction with this meeting, an informal quarterly program review will be conducted.

   b) Commercialization of the SHAC system will be the subject of a meeting scheduled for October 27, 1977. The purpose of this meeting is to review previous discussions, define realistic commercialization goals and establish the "go forward" program tasks required.

   c) Monthly coordination meetings will continue with Dunham Bush to assess progress and resolve problems.

   d) Efforts will continue toward completion of the site selection tasks. Planned activities include:

      1. Coordination meetings with Houston and Las Vegas to resolve installation and funding details.

      2. Site negotiations for the St. Louis and Allaire Park installations.

      3. Lawrenceburg, Tennessee, site selection and analysis.

      4. Evaluation of test sites at Dunham Bush in Harrisonburg, Va.

2. WBS 1.1.2 Program Planning and Control

   a) Schedule Development

      Schedules will be updated as required. NASA will be informed of any significant slippage if any.

   b) Program Documentation

      The following program documents will be prepared.

      (1) DR 500-10, the sixth quarterly report

      (2) DR 500-11, monthly status reports

      (3) DR 500-27, financial management reports (provided monthly)

      (4) Preliminary Instrumentation Plan (PIP) for the Houston, Texas, site

      (5) PIP's for other sites as necessary.

3. WBS 1.1.3 Quality Assurance

The revised quality assurance plan will be implemented throughout the program.

WBS 1.2 Development

1. WBS 1.2.1 Analysis and Integration

(a) Analyses will be performed as necessary in support of the scheduled site selection effort, with particular emphasis on new sites.

(b) Test data will be reduced and system/subsystem performance will be updated using these data.

2. WBS 1.2.2 and 1.2.3 System Development and Test

(a) System Design Activities

It is anticipated that heating-only heat pump development activities will be cancelled. System analysis and site design activities of solar heating/cooling systems will be intensified, particularly in the 75-ton class because of Houston site emphasis.

(b) Heat Pump Development

With the completion of the 3 and 25-ton test setups, receipt of the turbomachines and motor controllers in this size at Dunham-Bush in December will begin 1-month system test programs for each package. Maximum effort will be expended to complete assembly of the 75-ton package.

(c) Turbomachine/Motor

Assembly of the complete heating/cooling 3-ton and 25-ton turbomachines and development testing will be completed in the next quarter. Development testing of these machines incorporated in the heat pump subsystems will occur at Dunham-Bush during the first quarter of 1978.

(d) Motor Controller

The 3- and 25-ton breadboard motor controller dynamic tests with appropriate motors will be completed in the next quarter.

(e) System Control

A total system integrated test will be conducted to final check the two system controllers now available. Nine additional controllers will be built and tested by the end of 1977.

(f) R-11 Pumps

The drawings for the 3 ton pump will be modified to incorporate hardware changes made during the development test program. Provision for pump mounting feet and industrial-type electrical connections will also be incorporated in the upgraded drawings.

After release of the drawings, 3 sets of hardware will be ordered for system tests.

On satisfactory completion of the development tests, the drawings will be upgraded to production status and 3 additional pumps ordered.

(g) Collector

Collector panel procurement will continue on schedule.

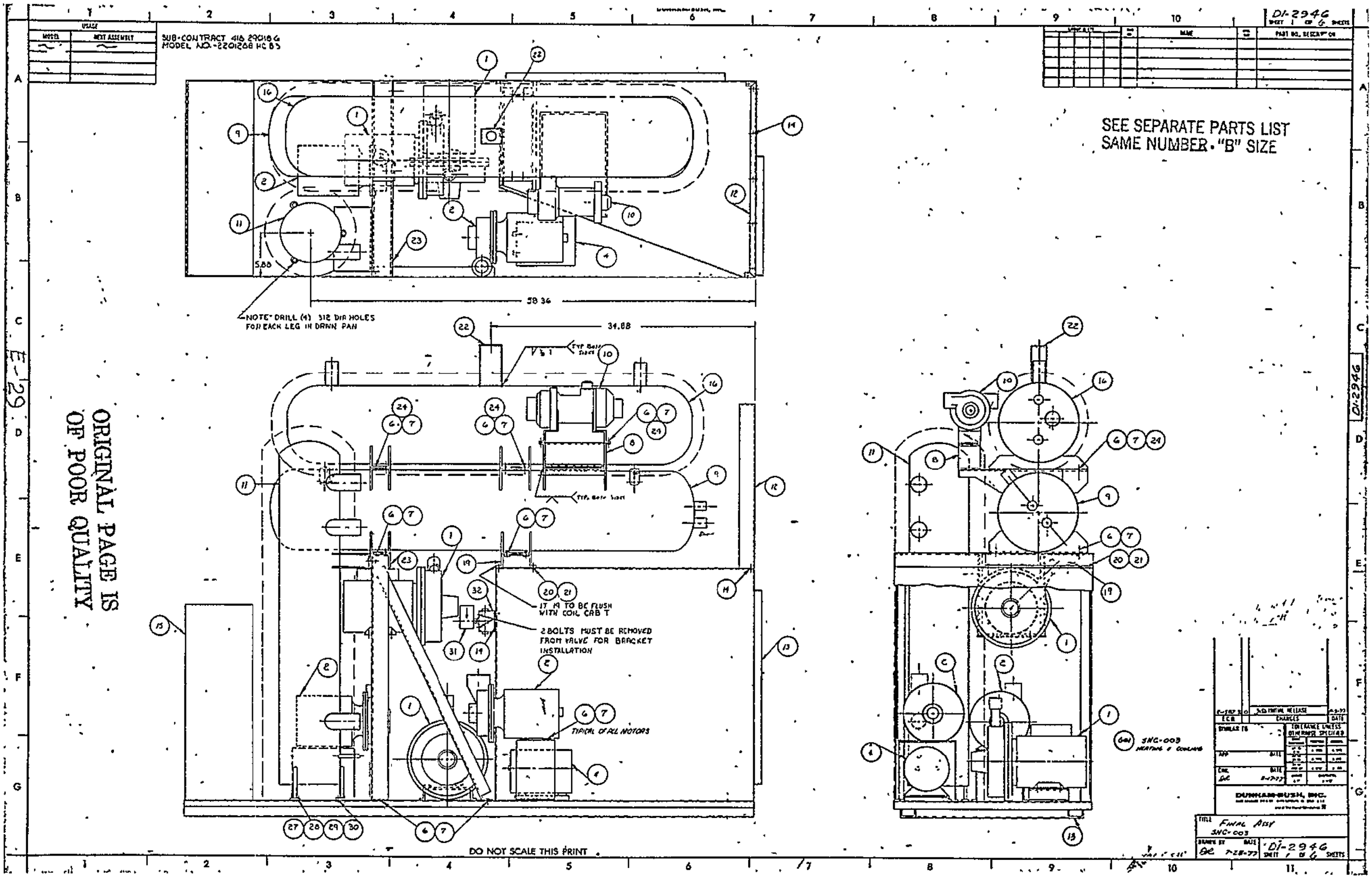
APPENDIX A

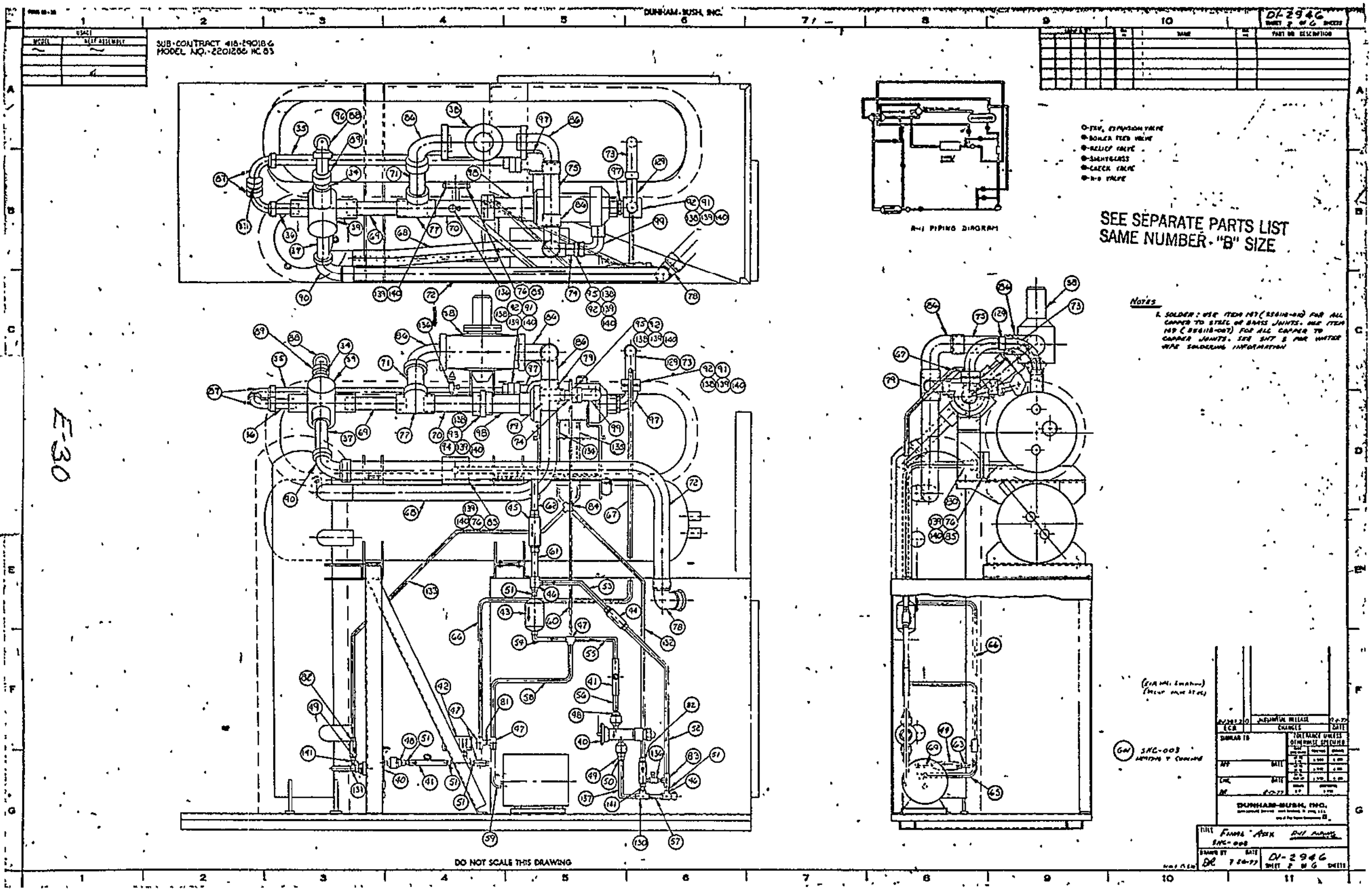
Dunham-Bush Drawings 2946, 2955 and 2963
(total 10 sheets and 2 parts lists)

DRAWING D1-2946 PARTS LIST
(3-TON SOLAR HEATING/COOLING HEAT PUMP)

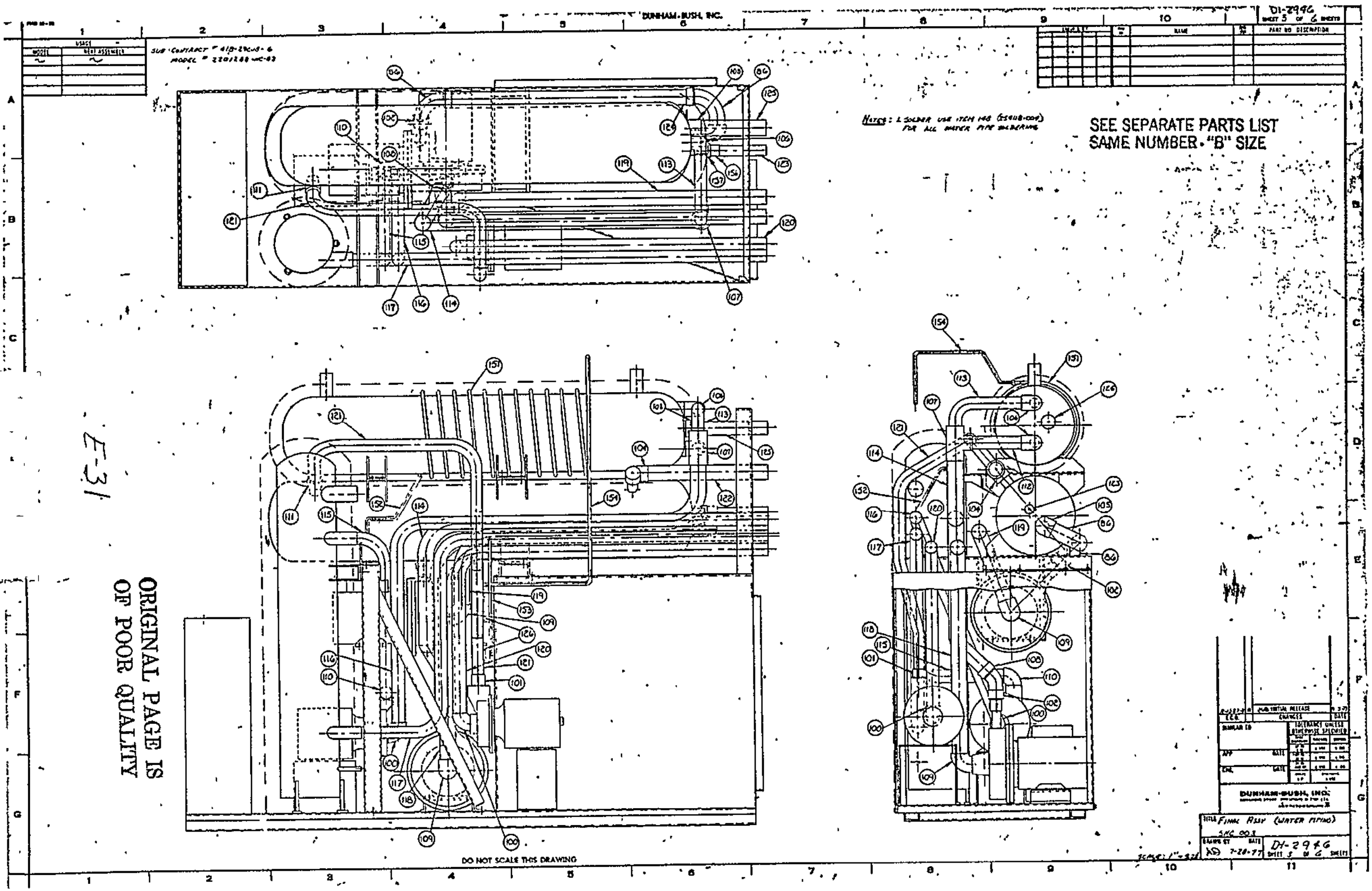
No. Req'd.	Item No.	Name	Part No.
2	1	Pump, inter & cooling T.	B456012-006
2	2	Pump, coll. & heat source	B456003-002
5	3	Relay, control	
1	4	Pump, R-11	B456009-001
41	6	Nut, hex. stl #5/16-18	H5-39-002
41	7	Washer, lock ext. T. 5/16	MS-35335-34
1	8	Support, turbocomp.	C1-12484-G01
1	9	Interchanger	C450039-001
1	10	Turbocompressor	C412003-002
1	11	Boiler/evaporator	C450036-001
1	12	Panel, water conn.	C1-12439-001
1	13	Coil cabnet assy.	D1-2788-G01
9	14	Screw. sht mtl #10 x 3/8	H1-02-406
1	15	Module control	
1	19	Support, interchanger	B1-18778-G01
10	20	Screw, sht mtl, hex #10 - 10 x 5/8	H1-14-210
10	21	Washer, lock, ext tooth, #10	MS35338-43
1	22	Support, R-11 valve	B1-19054-001
1	23	Support, inter assy	C1-12473-G01
12	24	Srew. mach. 5/16 - 18 x 3/4	H3-02-112
1	25	Top, filter rack	B1-18767-001
1	26	Filter rack assy.	B1-18768-G01
12	27	Screw mach. 1/4 20X1	H3-02-016
12	28	Washer, flat 1/4	H6-04-004
12	29	Washer, lock. ext tooth	MS534044
12	30	Nut, hex, 1/4-20, stl.	H5-39-001
1	31	Valve, mode selector	A418016-001
1	32	Brackt mode selector	B1-19060-001
1	33	Line, comp. outlet	B1-18971-006
1	34	Line, rev. valve outlet	B1-18922-004
1	35	Line, comp. outlet	B1-18971-005
1	36	Line, rev. valve inlet	B1-18971-004
1	37	Line, rev. valve inlet	B1-18922-005
1	38	Valve, R-11	A418013-001
1	39	Valve, reversing	A418014-001
2	40	Valve, expansion	R418017-001
2	41	Glass, sight	354519-004
1	42	Valve, boiler feed	A418015-001
1	43	Drier, filter	332211-001
2	44	Valve, check 1/2	A457020-002
1	45	Valve, check 7/8	A457020-003
2	46	Tee, 7/8 x 1/2 x 1/2	A3-79471-021
4	47	Tee, 1/2 x 1/2 x 1/2	E685113
2	48	Reducer, 1 1/8 x 1/2	354618-006
2	49	Reducer, 1 3/8 x 5/8	E685258
1	50	Bushing, flush, 5/8 x 1/2	354618-005
5	51	Line, 1/2 liquid	B1-18912-005
1	52	Line, check valve inlet	B1-19038-002
1	53	Line, check valve outlet	B1-19038-001
1	54	Line, filter drier outlet	B1-19036-002
1	55	Line, sightglass inlet	B1-19036-001
1	56	Line, exp. valve inlet	B1-18912-007
1	57	Line, exp valve outlet	B1-19044-001
1	58	Line, R-11 pump inlet	B1-19037-001
1	59	Line, R-11 pump outlet	B1-19037-003
1	60	Line, comp. R-11 inlet	B1-19046-001
1	61	Line, check valve outlet	B1-19051-001
1	62	Line, cond. R-11 outlet	B1-19045-001
1	63	Line, check valve inlet	B1-19036-003
1	64	Line, check valve outlet	B1-18912-008
1	65	Line, R-11 pump inlet	B1-19042-001
1	66	Line, relief valve outlet	B1-19037-002
1	67	Line, relief valve inlet	B1-19043-001
1	68	Line, boil./evap R-out	B1-19187-001
1	69	Line, rev. valve disch.	B1-18922-003
1	70	Line, comp. inlet	B1-18923-004
1	71	Line, R-11 valve outlet	B1-18923-005
1	72	Line, coil outlet	B1-19186-001
1	73	Line, cond R-11 inlet	B1-19189-001
1	74	Line, turbine inlet	B1-18970-007
1	75	Line, R-11 valve inlet	B1-18923-003
1	76	Flange, 1 1/8 pipe	B43600C-004
1	77	Tee, 2 1/8 x 2 1/8 x 2 1/8	E685277
1	78	Elbow, 2 1/8 x 2 1/8	E685235
1	79	Tee, 2 1/8 x 2 1/8 x 1 1/8	A3-79471-020
1	80	Reducer, 1 1/8 x 7/8	354398-001
1	81	Line, crossover	B1-18912-006
2	82	Check valve, 3/8	A457020-001
1	83	Tee, 1/2 x 1/2 x 3/8	A3-79471-025
1	84	Cross, 3/8 x 3/8 x 2/8 x 3/8	A433102-001
1	85	Gasket	B436002-005
5	86	Elbow, 2 1/8 x 2 1/8	E685083
2	87	Elbow, 1 3/8	E685075
1	88	Elbow, 1 5/8 x 1 3/8	354618-002
1	89	45° elbow, 1 5/8 x 1 5/8	E685079
1	90	Elbow, 1 5/8 x 2 1/8	354618-003
2	91	Flange, 1 3/8	B436002-002
3	92	Gasket	B436002-003
1	93	Flange, 2 1/8	E685278
1	94	Gasket	E630052
1	95	Flange, 1 1/8	B436002-001
1	96	Line, cond. R-11 inlet	B1-18971-007
2	97	Fitting, hydraulic, 1 3/8	A1-46102-G01
1	98	Fitting, hydraulic, 2 1/8	A1-46103-G01
1	99	Fitting, hydraulic, 1 1/8	A1-46160-G01
2	100	Elbow, 1 5/8 x 1 1/2 MPT	A3-79470-059
1	101	Adapter, 1 5/8 x 1 MPT	A3-79467-082
2	102	Adapter, 2 1/8 x 1 1/4 MPT	E685192
1	103	Adapter, 2 1/8 x 2 MPT	A3-79467-007
1	104	Elbow, 1 5/8 x 1 1/2 FPT	A3-79470-062
1	105	Elbow, 2 1/8 x 1 1/2 FPT	A3-79470-061
2	106	Elbow, 1 5/8 x 1 1/4 MPT	A3-79470-063
1	107	Tee, 2 1/8 x 1 5/8 x 1 5/8	A3-79471-022
1	108	Elbow, 2 1/8 x 2 1/8, 45°	A3-79470-039
2	109	Elbow, 2 1/8 x 2 MPT	A3-79470-055
1	110	Elbow, 1 5/8 x 1 MPT	A3-79470-058
1	111	Adapter, 1 3/8 x 1 1/2 FPT	E685180
1	112	Line, cond. bottom inlet	B1-18922-002
1	113	Line, cond. top inlet	B1-19032-001
1	114	Line, C.T. pump, disch.	B1-19026-001
1	115	Line, heat source pump dis.	B1-18914-001
1	116	Line, heat source pump inlet	B1-19213-002
1	117	Line, evap. water dis.	B1-18916-001
1	118	Line, C.T. pump inlet	B1-19214-002
1	119	Line, inter pump inlet	B1-19214-001
1	120	Line, collector pump inlet	B1-19213-001
1	121	Line, collector pump disch.	B1-18917-001
1	122	Line, inter. side disch.	B1-18923-001
1	123	Line, inter. end disch.	B1-18923-007
1	124	Line, inter. pump disch.	B1-18923-006
1	125	Line, condenser disch.	B1-18923-003
1	126	Adapter, 1/4 x 3/8 MPT	354618-017
1 oz	127	Loctite (gaskets)	
4 oz	128	Loctite (fittings)	354200-026
1	129	Line, turbine outlet	B1-19188-001
1	130	Tee, 1/2 x 1/2 x 3/8	354618-012
1	131	Tee, 3/8 x 3/8 x 1/2	354618-013
1	132	Line, comp motor disch.	B1-19190-001
1	133	Line, comp motor disch.	B1-19192-001
1	134	Line, comp motor disch.	B1-19191-002
1	135	Line, comp motor disch.	B1-19191-001
2	136	Valve, charging	60MP135
1	137	Line, exp. valve outlet	B1-19036-005
10	138	Nut, hex, #1/2 - 13, STL	MS51967-13
14	139	Screw, mach, #1/2 - 13 x 2	H3-02-432
14	140	Washer, ext tooth #1/2	E620409
2	141	Line, 3/8 liquid	B1-19192-002
1	142	Plate, data	
1	143	Carton	
*	144	R-11 refrigerant	
1	145	Instructions, install.	
1	146	Control, systems	
110	147	Solder (copper to steel brass)	354118-010
*	148	Solder (water lines)	354118-004
187	149	Solder (copper to copper)	354118-007
*	150	Insulation (pipes)	
1	151	Line, 1/4 coiled	B1-19074-001
1	152	Line, evap. inlet	B1-19215-001
1	153	Line, M.S. valve dis.	B1-19216-001
1	154	Line, M.S. valve, in.	B1-19217-001
1	155	Wiring diagram	
1	156	Reducer, 2 1/8 x 1 5/8	354545-027
1	157	Adapter, 1 5/8 x 1 1/2 FPT	A3-79467-090

*As required


SUB-CONTRACT 418 290186
MODEL NO.-2201208 HC B3
SEE SEPARATE PARTS LIST SAME NUMBER "B" SIZE
5.88
58.36
NOTE: DRILL (4) .312 DIA HOLES FOR EACH LEG IN DRAIN PAN
34.88
17 19 TO BE FLUSH WITH COIL CAB'T
2 BOLTS MUST BE REMOVED FROM VALVE FOR BRACKET INSTALLATION
TYPICAL OF ALL MOTORS
SHC-003 HEATING & COOLING
DUNHAM-BUSH, INC.
FINAL ASSY SHC-003
DI-2946
DO NOT SCALE THIS PRINT



DUNHAM-BUSH, INC.
SUB-CONTRACT 418-290186
R-11 PIPING DIAGRAM
SEE SEPARATE PARTS LIST SAME NUMBER - "B" SIZE
NOTES
DO NOT SCALE THIS DRAWING
DUNHAM-BUSH, INC.
E-30

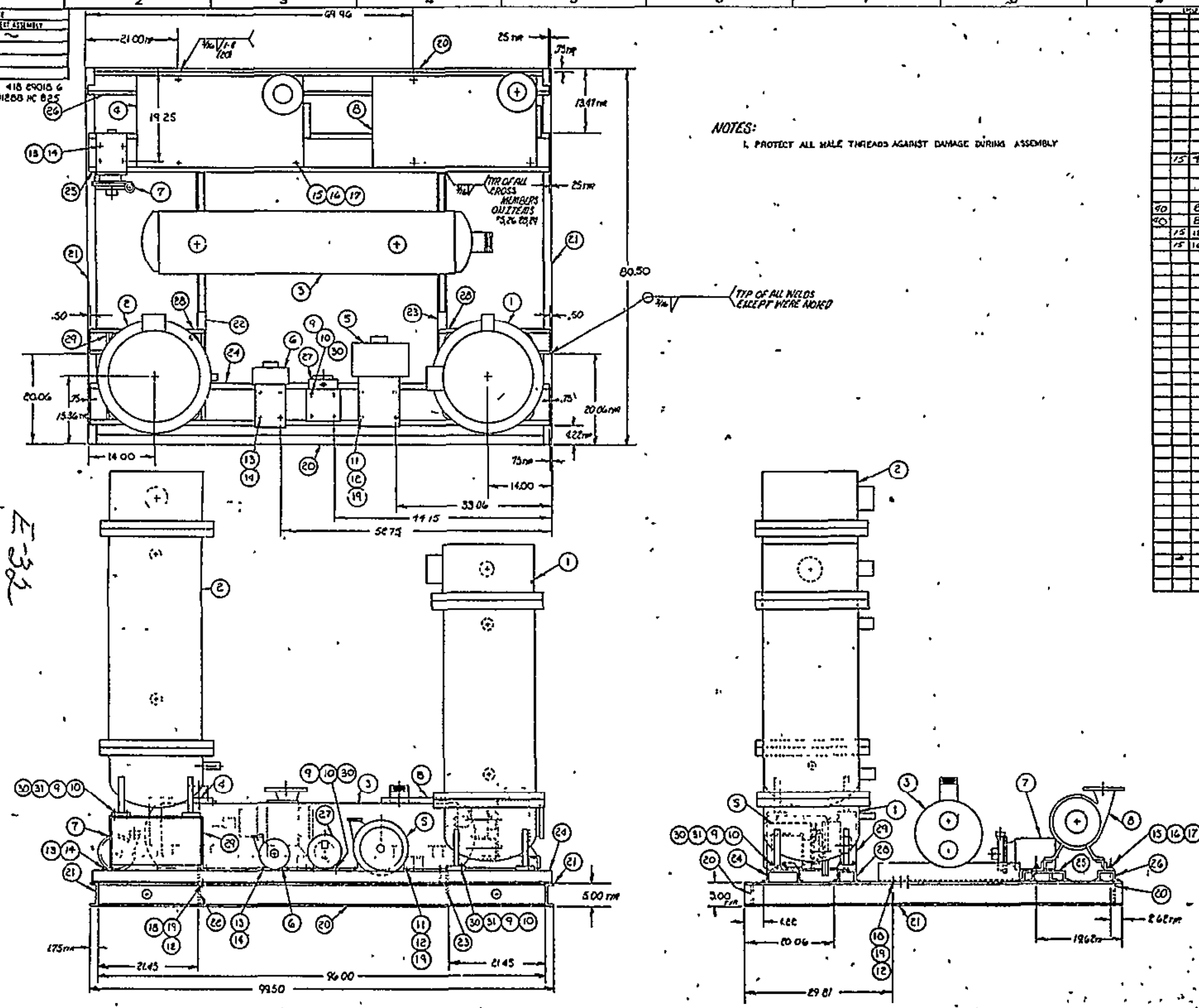

DUNHAM-BUSH, INC.
D1-2946
SHEET 5 OF 6 SHEETS
SEE SEPARATE PARTS LIST
SAME NUMBER "B" SIZE
DO NOT SCALE THIS DRAWING
ORIGINAL PAGE IS
OF POOR QUALITY
E-31
FINAL ASSY (WATER PIPING)
DUNHAM-BUSH, INC.

DUNHAM-BUSH, INC.

D1-2955 SHEET 1 OF 4 SHEETS

USAGE	
MODEL	NEXT ASSEMBLY
SHC 025	~

SUB-CONTRACT 418 29018 6
MODEL NO - E801288 HC 825



NOTES:

1. PROTECT ALL MALE THREADS AGAINST DAMAGE DURING ASSEMBLY

				QTY	ITEM NO.	NAME		PART NO. DESCRIPTION
				1	1	EVAPORATOR, BOILER	C	C450036-003
				1	2	CONDENSER, EVAPOR	C	C450036 005
				1	3	INTERCHANGER	C	C450040-001
				1	4	PUMP, INTERCHANGER	B	B456007 014
				1	5	PUMP, HEAT SOURCE	B	B456006 007
				1	6	PUMP, CIRCULATOR	B	B456003 009
				1	7	PUMP, COLLECTOR	B	B456003 016
				1	8	PUMP, COOLING TOWER	B	B456007 001
				36	9	NUT HEX "1/4 20 STL	A	H5-39-001
				36	10	WASHER, "1/4 Ext. Tooth	A	MS 35335 33
				4	11	SCREWS, MACH "1/4 46 X 1/4	B	H3-02 212
	15	4		31	12	WASHER, 1/4 Ext Tooth	A	E620406
				8	13	NUT, HEX "5/16-18 STL	A	H5-39-002
				8	14	WASHER, "5/16 Ext Tooth	A	MS35335 34
				8	15	SCREW, MACH "5/16 11 X 1 1/4	B	H3-02 520
90		8		48	16	WASHER, "5/8 Ext. Tooth	A	MS35335 39
90		8		46	17	NUT, HEX "5/8-11 STL	A	MS51967-19
	15	12		27	18	SCREW, MACH "3/8 16 X 1 1/4	B	H3 09 220
	15	16		27	19	NUT HEX "3/8 16 STL	A	H5-39 005
				2	20	CHANNEL 5" X 1 3/4"	B	B1-18757 002
				2	21	CHANNEL, 5" X 1 3/4"	B	B1 18757 001
				1	22	CHANNEL 5 X 1 3/4"	B	B1 18757-010
				1	23	CHANNEL, 5" X 1 3/4"	B	B1-18757 021
				1	24	BASE, CIR - HEAT SOURCE	C	C1 12454 G02
				1	25	BASE, INT - COOLING TOWER	C	C1-12453-G01
				1	26	BASE, INT - COOLING TOWER	C	C1-12453 001
				1	27	PUMP, R-11	B	B456008-001
				2	28	BASE, EVAP/BOIL, COND./EVAP	B	B1 18825 001
				1	29	BASE, EVAP/COND.	B	B1 18977 G01
				36	30	SCREW, MACH "1/4-20 X 1/2	B	H3-02 020
				32	31	WASHER, FLAT, "1/4	A	H6-04-002
					32			
					33			
					34			
					35			
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					37			
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					39			
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					43			
					44			
					45			
					46			
					47			

(601) SHC 025 FINISH"
SEE SHEET 2 FOR FRAME ASSY
SEE SHEET 3 FOR WATER PIPING
SEE SHEET 4 FOR REF PIPING

SEE "A" SHEET

ECO		CHANGES	DATE
	A	INITIAL RELEASE	

SIMILAR TO
APP. DATE
CHK. DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED

DUNHAM-BUSH, INC.

Scale - 1" = 10"

TITLE FRAME ASSY. SHC 025

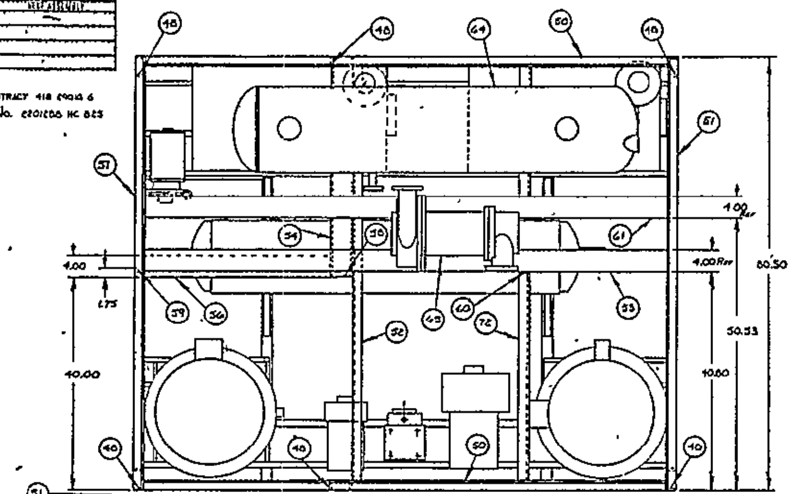
DRAWN BY HB DATE 6-8-77

D1-2955 SHEET 1 OF 4 SHEETS

DO NOT SCALE THIS DRAWING

DUNHAM-BUSH, INC.

Sub Contract 418 69016 6
Model No. 2201ED8 HC 825



Notes
1 Control Box Removed in Top View for Clarity
2 Do not Weld Item no 49 in Place till Item 64 is in Place
3 Do not Weld this Side of Channels.

Qty	Item	Name	Size	Part No. Description
6	48	Channel, 4" x 1¾"	B	B1 18757 003
3	49	Channel, 4" x 1¾"	B	B1 18757 004
2	50	Angle, 1¾" x 1¾"	B	B1 18757 005
2	51	Angle, 1¾" x 1¾"	B	B1 18757 006
1	52	Angle, 1¾ x 1¾"	B	B1 18757 007
1	53	Channel, 4" x 1¾"	B	B1-18757 008
1	54	Channel, 4" x 1¾"	B	B1 18757 009
1	55	Angle, 1¾" x 1¾"	B	B1 18757-011
1	56	Channel, 4" x 1¾"	B	B1 18757 012
1	57	Angle, 1¾" x 1¾"	B	B1 18757 013
1	58	Angle, 1¾" x 1¾	B	B1-18757 014
1	59	Angle, 1¾" x 1¾"	B	B1-18757 015
1	60	Angle, 1¾ x 1¾"	B	B1-18757 016
1	61	Channel, 4" x 1¾"	B	B1 18757-018
1	62	Channel, 4" x 1¾"	B	B1-18757 019
1	63	Channel, 4" x 1¾"	B	B1 18757 020
1	64	Condenser	C	C45004-001
1	65	Turbocompressor	C	C41C004 002
1	66	Control Box		
1	67	Plate, Data		
	68	Crate		
	69	Control, Systems		
	70	Instruction Install.		
1	71	Angle, 1¾" x 1¾"	B	B1 18757 023
1	72	Angle, 1¾" x 1¾"	B	B1 18757 022
	73			
	74			
	75			
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	78			
	79			
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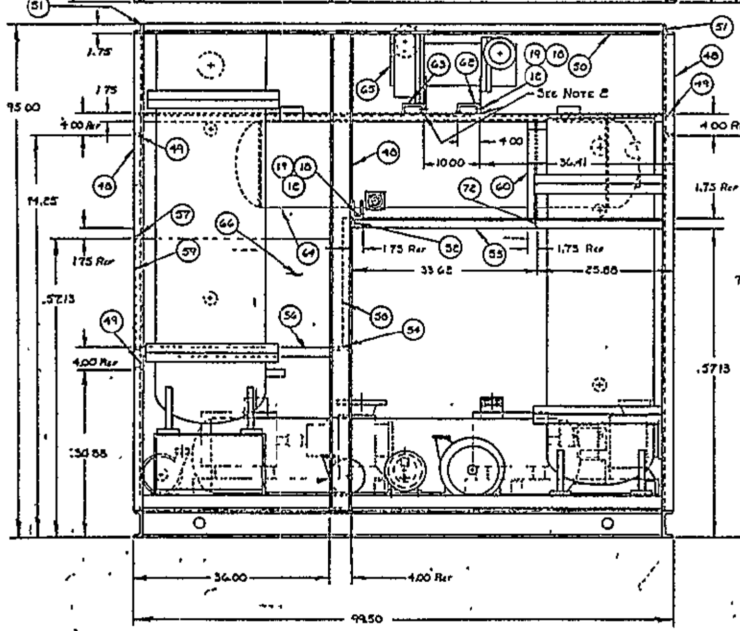
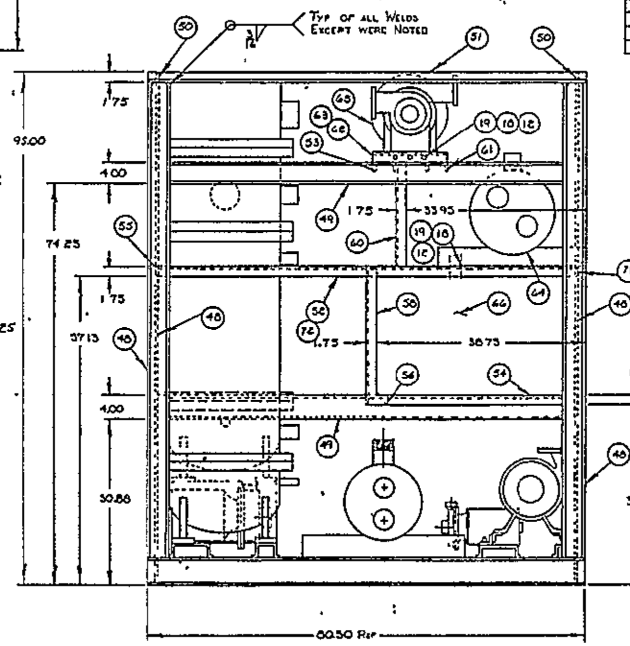
	81			





Typ of all Welds Except were Noted

G01
SHC 025 Finish Per SC 400
See Sheet 1 for Base Assy
See Sheet 3 for Water Piping
See Sheet 4 for Refrig Piping

DO NOT SCALE THIS DRAWING

DUNHAM BUSH, INC.

Title: Frame Assy
SHC 025

Drawn by HD, Date 9-6-77
D1-2955
Sheet 2 of 4 Sheets

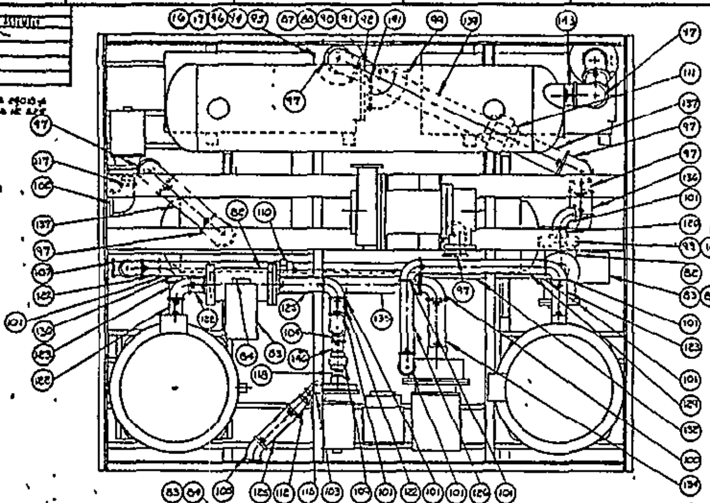
ORIGINAL PAGE IS OF POOR QUALITY

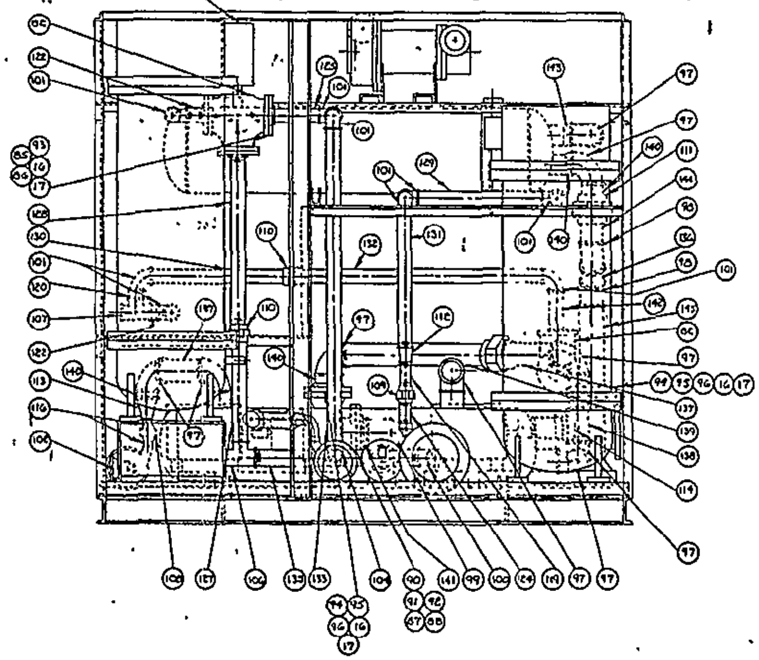
E-33

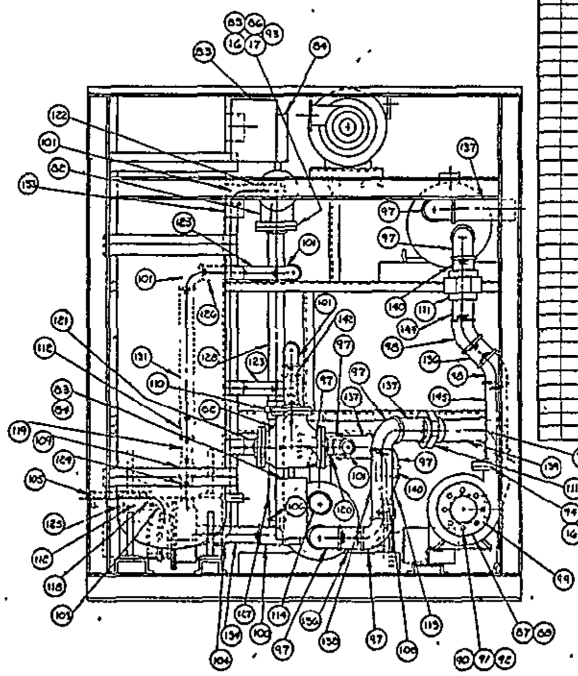
DUNHAM-BUSH, INC.

01-2955 SHEET 3 OF 4 SHEETS

SUB-CONTRACT 148 69013-4
MODEL NO. ED01268 1C 8KE







NOTES:
1. CONTROL BOX REMOVED FOR CLARITY
2. ON ALL THREADED FITTINGS USE ITEM PIPE DOPE, LOCTITE.

			1	142	NIPPLE, 2½ × 8¾	B	354070-040
			1	143	NIPPLE, 4 × 5	B	354098 004
			1	144	NIPPLE, 4 × 7½	B	354618 056
			1	145	NIPPLE, 4 × 16	B	354098 016
			1	146	NIPPLE, 2 × 3	B	354618-058
				147			
				148			
				149			

			QTY	ITEM	NAME		PART NO. DESCRIPTION
			2	82	VALVE, 3 WAY WATER	A	A457048 001
			2	83	MOTOR 3 WAY VALVE	A	A421009 002
			2	84	LINKAGE 3 WAY VALVE	A	A457030 002
			4	85	FLANGE, REDUCING	B	354327 009
			4	86	GASKET, REDUCING FLG.	B	354330 026
			1	87	FLANGE 5" PIPE	B	354326-011
			1	88	GASKET 5" FLANGE	B	354330 031
			1	89	VALVE, MODE SELECTOR	A	A437049 001
			8	90	SCREW MACH ¼-10 × 3	B	H3-02 640
			8	91	WASHER, LOCK ¼	A	MS35335-40
			8	92	NUT ¼-10, HEX STL.	A	MS51967-22
			24	93	SCREW, MACH ⅝-11 × 2½	B	H3-02-540
			2	94	FLANGE 4" PIPE	B	354326-010
			2	95	GASKET 4" FLANGE	B	354330-030
			16	96	SCREW, ⅝-11 × 3 MACH	B	H3-02 546
			9	97	ELBOW 4 × 4	A	354054-013
			2	98	ELBOW 45°, 4 × 4	A	354250 012
			1	99	ELBOW 90°, 5"	B	354054-014
			1	100	ELBOW 90°, 3	B	354054 011
			10	101	ELBOW, 90°, 2½	B	354054-010
			1	102	ELBOW 90° RED 4 × 2	B	354618-014
			1	103	ELBOW 90° RED ST 1½ × 2	A	354535-009
			1	104	ELBOW 90° RED 2½ × 2	B	354042 022
			1	105	ELBOW 45° 2½	A	354250 010
			1	106	TEE, 3 × 3 × 2½	A	354035-104
			1	107	TEE, 2½	A	354093-010
			1	108	UNION, 1½	B	354063-008
			2	109	UNION, 2	B	354063-009
			2	110	UNION, 2½	B	354063 010
			2	111	UNION, 4	B	354063-012
			2	112	REDUCER 2½ × 2	A	354080-027
			1	113	REDUCER, 4 × 1½	A	354080-043
			1	114	COUPLING, 4	A	354114-013
				115	DOPE, LOCTITE PIPE	B	354200-026
			2	116	NIPPLE, 1½ × 1¾	B	354068-001
			1	117	NIPPLE, 2 × 2	B	354033-002
			2	118	NIPPLE, 2 × 2½	B	354033-003
			1	119	NIPPLE, 2 × 5½	B	354033-009
			2	120	NIPPLE, 2½ × 3	B	354070-002
			1	121	NIPPLE 2½ × 4	B	354070-004
			4	122	NIPPLE, 2½ × 4½	B	354070-005
			2	123	NIPPLE, 2½ × 8	B	354070-010
			1	124	NIPPLE, 2 × 5	B	354618-039
			2	125	NIPPLE, 2½ × 10	B	354070-012
			1	126	NIPPLE, 2½ × 15	B	354070-017
			1	127	NIPPLE, 2½ × 20	B	354070-022
			1	128	NIPPLE, 2½ × 32½	B	354618-053
			1	129	NIPPLE, 2½ × 24½	B	354070 057
			1	130	NIPPLE, 2½ × 26	B	354070-033
			1	131	NIPPLE, 2½ × 26½	B	354070-047
			1	132	NIPPLE, 2½ × 46½	B	354618-055
			1	133	NIPPLE, 2½ × 61	B	354618-054
			1	134	NIPPLE, 3 × 9	B	354071-011
			1	135	NIPPLE, 3 × 32	B	354071-031
			2	136	NIPPLE, 4 × 6	B	354098-006
			3	137	NIPPLE, 4 × 12	B	354098 012
			1	138	NIPPLE, 4 × 14	B	354098 014
			1	139	NIPPLE, 4 × 30	B	354098-031
			4	140	NIPPLE, 4 × 2⅞	B	354098-001
			1	141	NIPPLE, 5 × 3	B	354099-001

E-34

G01 SHC-025 - FINISH PER SC 400
SEE SHEET 1 FOR BASE ASSY
SEE SHEET 2 FOR FRAME ASSY
SEE SHEET 4 FOR REFRIG PIPING
SCALE 1" = 10.47

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	SUB-INITIAL RELEASE
SIMILAR TO	TOLERANCE UNLESS OTHERWISE SPECIFIED
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CHK. DATE	

DUNHAM-BUSH, INC.

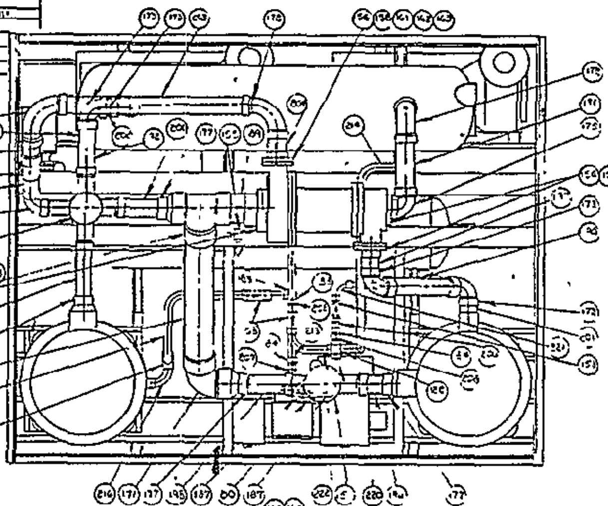
TITLE: FINAL ASSY WATER PIPING SHC-025

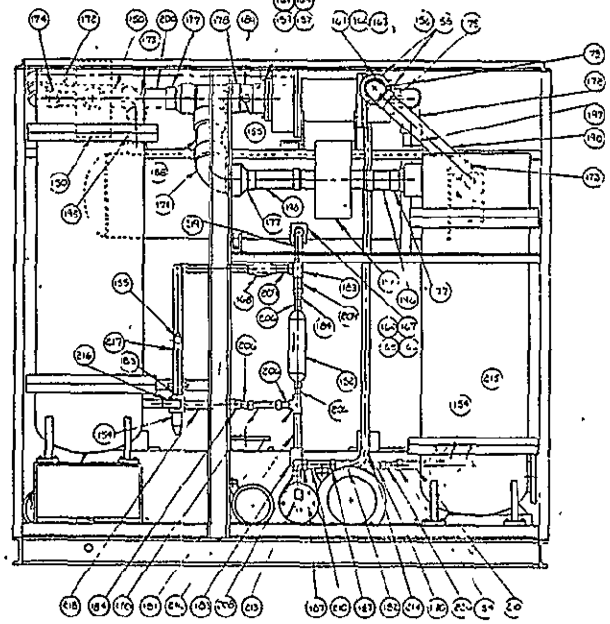
DRAWN BY: HQ DATE: 9-12-77

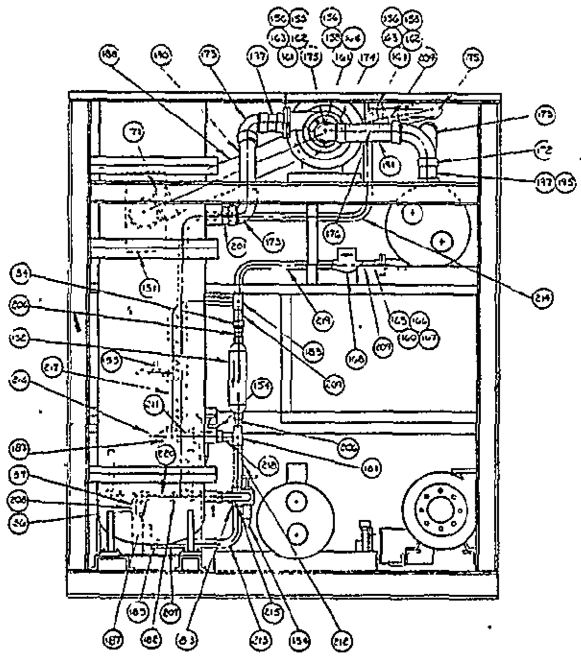
01 2955 SHEET 3 OF 4 SHEETS

DUNHAM-BUSH, INC.

SUB CONTRACT-NAS 9-15418 6
MODEL NO SHC 025







E-35

QTY	ITEM	DESCRIPTION	SIZE	PART NO
2	210	Pipe 1⅛ x 6	B	B1-18971 013
1	211	Pipe, 1⅛ x 3¾	B	B1-18971-016
1	212	Pipe, 1⅛ x 10	B	B1 18971 017
1	213	Line, R11 Pump Inlet	B	B1-19197 003
1	214	Line, Disch Relief Valve	B	B1 19255 001
1	215	Line, Sep/Heat Exch	B	B1-19197-005
1	216	Line, Evap/Cond Exch	B	B1 19197 004
1	217	Line Check Valve Inlet	B	B1 19652 001
1	218	Line, Exp Valve Inlet	B	B1 19197-006
1	219	Line Check Valve Outlet	B	B1-19197 0?1
1	220	Pipe, 1⅛ x 7¼	B	B1 18971 018
1	221	Line, Sightg Ass Inlet	B	B1-19250 001
1	222	Line, Check Valve Ex.	B	B1-19197 002
1	223	Line Comp Motor Inlet		
1	224	Line, Comp Mot Dis.		
1	225	Line Check Valve Inlet		
1	226	Line, Check Valve Dis.		
1	227	Line Check Valve Inlet		
1	228	Line Check Valve Dis.		
1	229	Tee, ⅝	A	E685130

Notes
1 Control Box Removed For Clarity
2 Use Item No 193 (Solder) For Copper to [illegible]
Use Item No 194 (Solder) For Copper to Copper

DI-2955
SHEET 4 OF 4 SHEETS

QTY	ITEM	NAME	SIZE	PART NO DESCRIPTION
1	150	Valve, 4 Way Rev.	A	A419014 002
1	151	Valve, R11	A	A419013 001
1	152	Drier Filter	A	A450020 009
1	153	Valve ... Feed	A	A419014 001
2	154	Valve Expansion	A	A457042 001
2	155	Valve Charging	B	6100135
5	156	Flange 3⅞	B	B1 19437 001
1	157	Flange 5⅞	B	B1 19437 002
3	158	Gasket 3⅞	A	A46104 001
1	159	Gasket 5⅞	A	A46104-002
1	160	Flange 1⅜ Cu Tube	B	3430032 006
21	161	Washer ...	A	1115-5335-36
10	162	Screw Mach ...	B	H3-02 328
10	163	Nut Hex, Std ⅜	A	1155967 010
1	164	Screw Mach ...	B	H3 02-324
4	165	Screw Mach ...	B	H3 02 432
4	166	Washer, Ext Tooth ...	A	E620409
1	167	Gasket 1⅜ Cu Tube Flg	B	E436002 005
3	168	Valve Check	A	A3 657?0 004
2	169	Valve Check	A	A457020 004
2	170	Sightg Ass	A	354519-003
1	171	90° Elbow 5⅞	A	A3 79470-067
2	172	90° Elbow 3⅝	A	A3 79470 010
4	173	90° Elbow 3⅞	A	A3-79470 009
1	174	90° Elbow ...	A	A3 79470 020
1	175	90° Elbow ...	A	A3 79470 021
1	176	Reducer 3⅝ x 2⅝	A	354545-036
4	177	Reducer 3⅞ x 3⅝	A	A3-79464 045
1	178	Tee, 5⅞	A	A3 79471-025
1	179	Connector	A	A3-79467 054
1	180	Connector	A	A3-79467 055
1	181	Tee, Reducing ...	B	354615-006
1	182	Ca... 1⅜	[illegible]	[illegible]
3	183	Tee, ⅞	A	354100 004
3	184	Coupling Red 1⅜ x ...	B	354615 009
1	185	Adapter, 1⅜ x ...	B	354616 010
1	186	Adapter, 1⅜ x ...	B	354615 011
2	187	90° Elbow 1⅜	A	E655071
1	188	Pipe 5⅞ x 29½	B	B1-15473 005
1	189	Pipe 5⅞ x 3	B	B1 15475 004
1	190	Pipe 3⅞ x 21	B	B1 15175 017
1	191	Pipe 3⅞ x 1½	B	B1-15175 015
1	192	Pipe 3⅞ x 16½	B	B1-15173 011
	193	Solder	B	354118-010
	194	Solder	B	354115-027
1	195	Pipe 3⅞ x 5	B	B1-15973-015
1	196	Pipe 3⅞ x 6¼	B	B1-15473 015
2	197	Pipe 3⅞ x 3¼	B	B1 15973-011
1	198	Pipe 3⅞ x 7⅝	B	B1-15173 022
1	199	Pipe, 3⅞ x 1½	B	B1-15973-021
1	200	Pipe, 3⅞ x 4⅞	B	B1-15173 020
1	201	Pipe, 3⅞ x 5	B	B1 15973 006
1	202	Pipe, 3 x 4	B	B1 15973 004
1	203	Pipe, 3⅞ x 35½	B	B1 15473 010
1	204	Pipe, 3⅞ x 5½	B	B1-15973 009
1	205	Pipe 2⅝ x 7½	B	B1 15472 001
6	206	Pipe, 1⅝ x 3	B	B1 15170-004
1	207	Pipe, 1⅝ x 5	B	B1 15170 005
3	208	Pipe, 1⅛ x 2	B	B1 18471 004
3	209	Pipe, 1⅛ x 4	B	B1-18471 004

(G01) SHC-025 Finish per SC NO
See Sheet No 1 for Base Assy
See Sheet No 2 for Frame Assy.
See Sheet No 3 for Water Piping.

SEE A SHEET
INITIAL RELEASE
ECO | CHANGES
SIMILAR TO
APP DATE
CHK DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED

DUNHAM-BUSH, INC.

TITLE Final Assy Refrig Piping SHC 025

DRAWN BY HD DATE 9 14 77
DI 2955
SHEET 4 OF 4 SHEETS

DO NOT SCALE THIS DRAWING

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OF POOR QUALITY

DRAWING DI-2963 PARTS LIST
(75-TON SOLAR HEATING/COOLING HEAT PUMP)

Req'd.	Item No.	Name	Part No.
5	66	Gasket 4", full face	354330-030
21	67	Gasket 5", full face	354330-031
5	68	Gasket 6", full face	354330-032
7	69	Gasket 8", full face	354330-033
3	70	Flange 4", screwed	354326-010
15	71	Flange 5", screwed	354326-011
4	73	Flange 8", screwed	354326-013
2	74	Flange 6" to 5", red	354327-023
1	75	Elbow 5" 22 1/2" screwed	354618-030
1.	76	Elbow 5", screwed 90°	354054-014
2	77	Elbow 5" thd. and screwed 90°	354618-031
1	78	Gasket 3/4" full face	354330-022
1	79	Gasket, 1", full face	354330-023
4	80	Elbow, 2 1/2 weld	354157-007
1	81	Elbow, 5" weld	354157-011
1	82	Elbow, 5" weld	354158-007
2	83	Elbow, 8" weld	354158-009
3	84	Tee, 2 1/2" weld	354159-007
2	85	Tee, red. 8" to 6" weld	354159-013
6	86	Elbow, 2"	354160-004
4	87	Elbow, 2 1/2" weld	354160-005
1	88	Elbow, 5" weld	354160-009
3	89	Elbow, 6" weld	354160-010
2	90	Flange, 8" weld	354397-013
1	91	Reducer, 8" to 5"	354618-035
1	92	Reducer, 8" to 6"	354618-036
2	93	Reducer, 6" to 5"	354618-037
2	94	Reducer, 2 1/2" to 1"	354618-038
1	95	Reducer, 2" to 3/4"	354618-039
2	96	Reducer, 2 1/2" to 2"	354618-040
1	97	Flange, 5" weld neck	354618-041
1	98	Flange, 1" weld neck	354618-042
1	99	Flange, 3/4" weld neck	354618-043
4	100	Flange, 5" lap joint	354618-044
1	101	Flange, 8" lamp joint	354618-045
1	102	Tee, reducing 5" - 5" - 2 1/2"	354618-046
1	103	Cross, 2 1/2 - 2 1/2 - 2 - 2	354618-047
2	104	Cross, 2 1/2 - 2 1/2 - 2 1/2 - 2 1/2	354618-048
2	105	Elbow, reducing 2 1/2 - 2	354618-049
1	106	Elbow, 45°, 2 1/2", 3-rad.	354618-050
1	107	Elbow, 45°, 2 1/2" long rad.	354618-051
2	108	Tee, 2" weld	354159-006
1	109	Elbow, 45°, 2" long rad.	354618-056
1	113	Pipe assy. 8" to 6"	BI-19248-G01
1	114	Pipe assy. 8"	BI-19249-G01
1	115	Line, inlet, turbocompressor	
5	116	Pipe 2" weld 5.22	DI-2963-001
1	117	Pipe 2" weld 5.75	DI-2963-002
1	118	Pipe 2" weld 9.66	DI-2963-003
2	119	Pipe 2" weld 12.13	DI-2963-004
1	120	Pipe 2" weld 15.52	DI-2963-005
1	121	Pipe 2" weld 19.09	DI-2963-006
1	122	Pipe 2" weld 6.40	DI-2963-007
2	123	Pipe 2" weld 11.69	DI-2963-008
1	124	Pipe 2" weld 25.03	DI-2963-009
1	125	Pipe 2" weld 26.73	DI-2963-010
1	131	Pipe, 2 1/2 weld .68	DI-2963-011
1	132	Pipe, 2 1/2 weld 2.28	DI-2963-012
2	133	Pipe, 2 1/2 weld 3.13	DI-2963-013
2	134	Pipe, 2 1/2 weld 3.69	DI-2963-014
2	135	Pipe, 2 1/2 weld 4.88	DI-2963-015
1	136	Pipe, 1 1/2 weld 6.00	DI-2963-016
2	137	Pipe, 2 1/2 weld 7.87	DI-2963-017
1	138	Pipe, 2 1/2 weld 10.20	DI-2963-018
1	139	Pipe, 2 1/2 weld 10.38	DI-2963-019
1	140	Pipe, 2 1/2 weld 11.04	DI-2963-020
2	141	Pipe, 2 1/2 weld 11.44	DI-2963-021
1	142	Pipe, 2 1/2 weld 12.36	DI-2963-022
1	143	Pipe, 2 1/2 weld 13.75	DI-2963-023
1	144	Pipe, 2 1/2 weld 14.32	DI-2963-024
1	145	Pipe, 2 1/2 weld 17.00	DI-2963-025
1	146	Pipe, 2 1/2 weld 17.33	DI-2963-026
1	147	Pipe, 2 1/2 weld 21.04	DI-2963-027
1	148	Pipe, 2 1/2 weld 23.78	DI-2963-028
1	149	Pipe, 2 1/2 weld 24.58	DI-2963-029
1	150	Pipe, 2 1/2 weld 24.72	DI-2963-030
1	151	Pipe, 2 1/2 weld 28.36	DI-2963-031
1	152	Pipe, 2 1/2 weld 54.88	
1	157	Pipe, 5" weld 2.64	DI-2963-032
1	158	Pipe, 5" weld 9.42	DI-2963-033
1	159	Pipe, 5" weld 18.96	DI-2963-034
1	160	Pipe, 5" weld 50.64	DI-2963-035
1	161	Pipe, 5" weld 64.04	DI-2963-036
1	164	Pipe, 6" weld 2.35	DI-2963-037
1	165	Pipe, 6" weld 18.02	DI-2963-038
1	169	Pipe, 8" weld 2.32	DI-2963-039
1	170	Pipe, 8" weld 7.19	DI-2963-040
2	173	Nipple, 4" 3.50	354098-029
8	174	Nipple, 4" 5.00	354098-004
1	175	Nipple, 4" 12.70	DI-2963-041
1	176	Nipple, 4" 4.50	354098-003
1	177	Nipple, 4" 22.78	DI-2963-042
1	178	Nipple, 4" 35.32	DI-2963-043
1	181	Nipple, 5" 4.64	DI-2963-044
1	182	Nipple, 5" 4.90	DI-2963-045
1	183	Nipple, 5" 8.42	DI-2963-046
1	184	Nipple, 5" 8.75	DI-2963-047
1	185	Nipple, 5" 7.78	DI-2963-048
1	186	Nipple, 5" 18.12	DI-2963-049
1	187	Nipple, 5" 18.34	DI-2963-050
1	188	Nipple, 5" 7.56	DI-2963-051
1	189	Nipple, 5" 19.40	DI-2963-052
1	190	Nipple, 5" 21.14	DI-2963-053
1	191	Nipple, 5" 21.62	DI-2963-054
2	192	Nipple, 5" 26.03	DI-2963-055
1	193	Nipple, 5" 25.56	DI-2963-056
1	195	Pipe Assy., 5"	BI-19247-G01
1	196	Nipple, 8" 6.92	DI-2963-057
1	197	Nipple, 8" 40.61	DI-2963-058
1	198	Pipe, cond. manifold outlet	DI-2963-059
1	199	Pipe, cond. manifold inlet	DI-2963-060
*	203	Loctite (Gaskets)	
*	204	Loctite (Fittings)	
1	205	Data Plate	
*	206	R-11 Refrigerant	
1	207	Instructions, installation	
1	208	Control, systems	
*	209	Solder (brass to steel)	354118-010
*	210	Insulation	
1	211	Wiring diagram	

*As required

SUB-CONTRACT NO 418-29018-G
MODEL NO. EE01288- NC- 2075

SEE SEPARATE PARTS LIST
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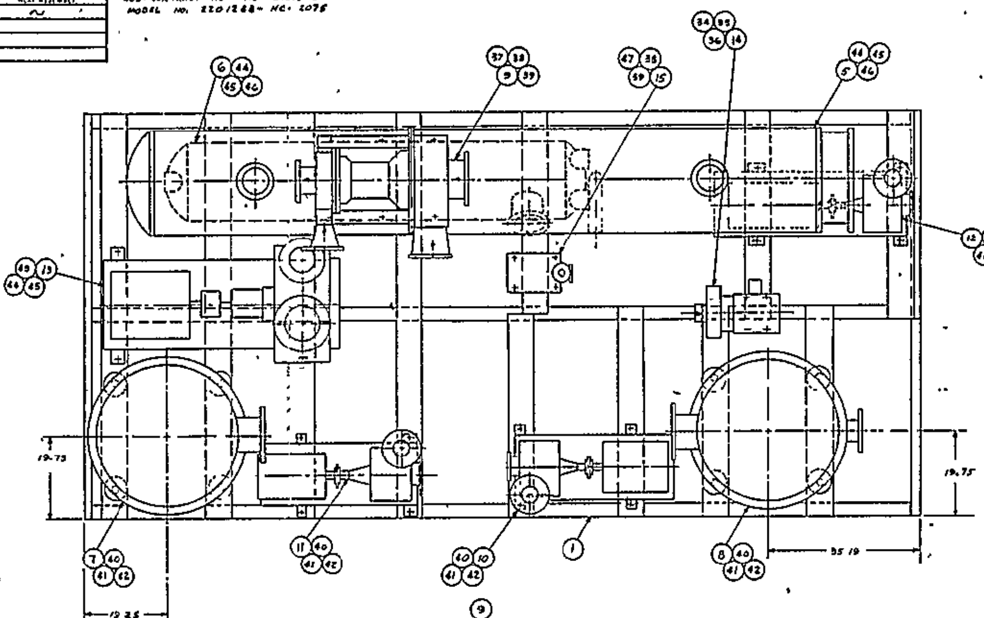


Notes:

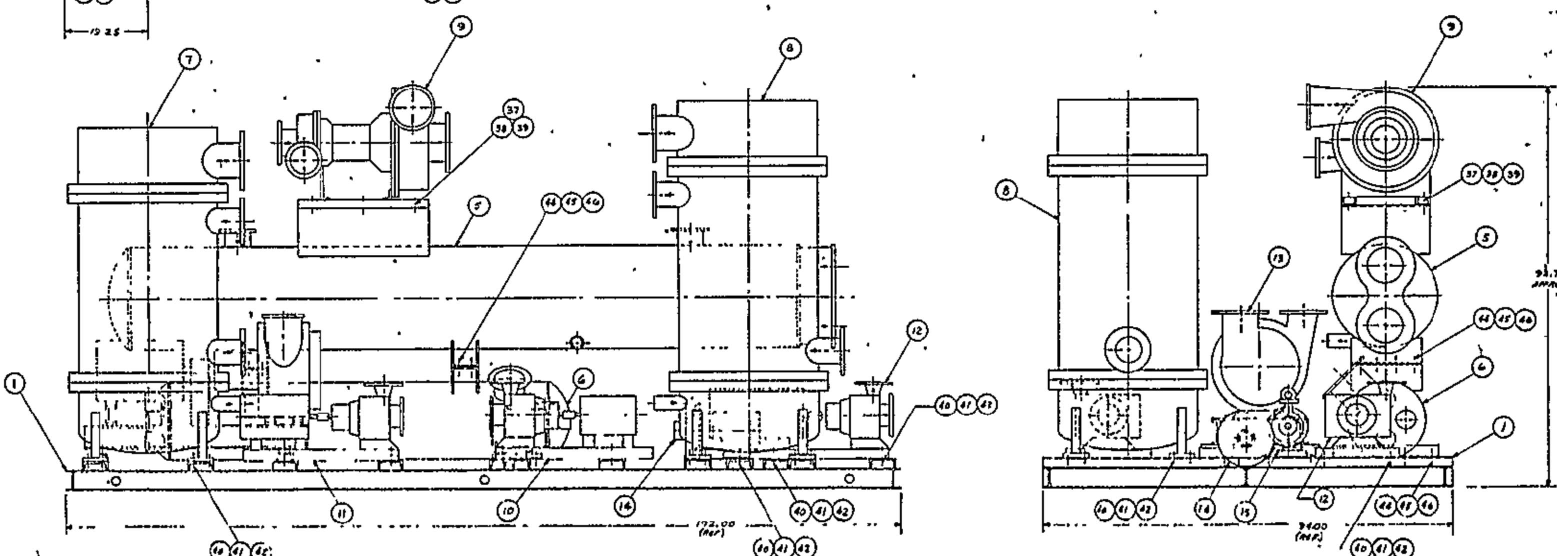
1 USE BOLT SIZES LISTED BELOW FOR FLANGED CONNECTIONS.
FOR ½" FLANGE USE ½-13 x 1¾ BOLT. (ITEM 29)

1"	"	"	½-13 x 1¾	"	"	29
4"	"	"	⅝-11 x 3	"	"	30
5"	"	"	¾-10 x 3	"	"	31
6"	"	"	¾-10 x 3¼	"	"	32
8"	"	"	¾-10 x 3½	"	"	33

2 ALL WELDING TO BE DONE PER AWS. STANDARDS.

3 VALVE BODIES TO BE PROTECTED WITH WET RAG OR DISASSEMBLED BEFORE BRAZING

E-37



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D1-2963 SHEET 1 CONT 2 SHEETS

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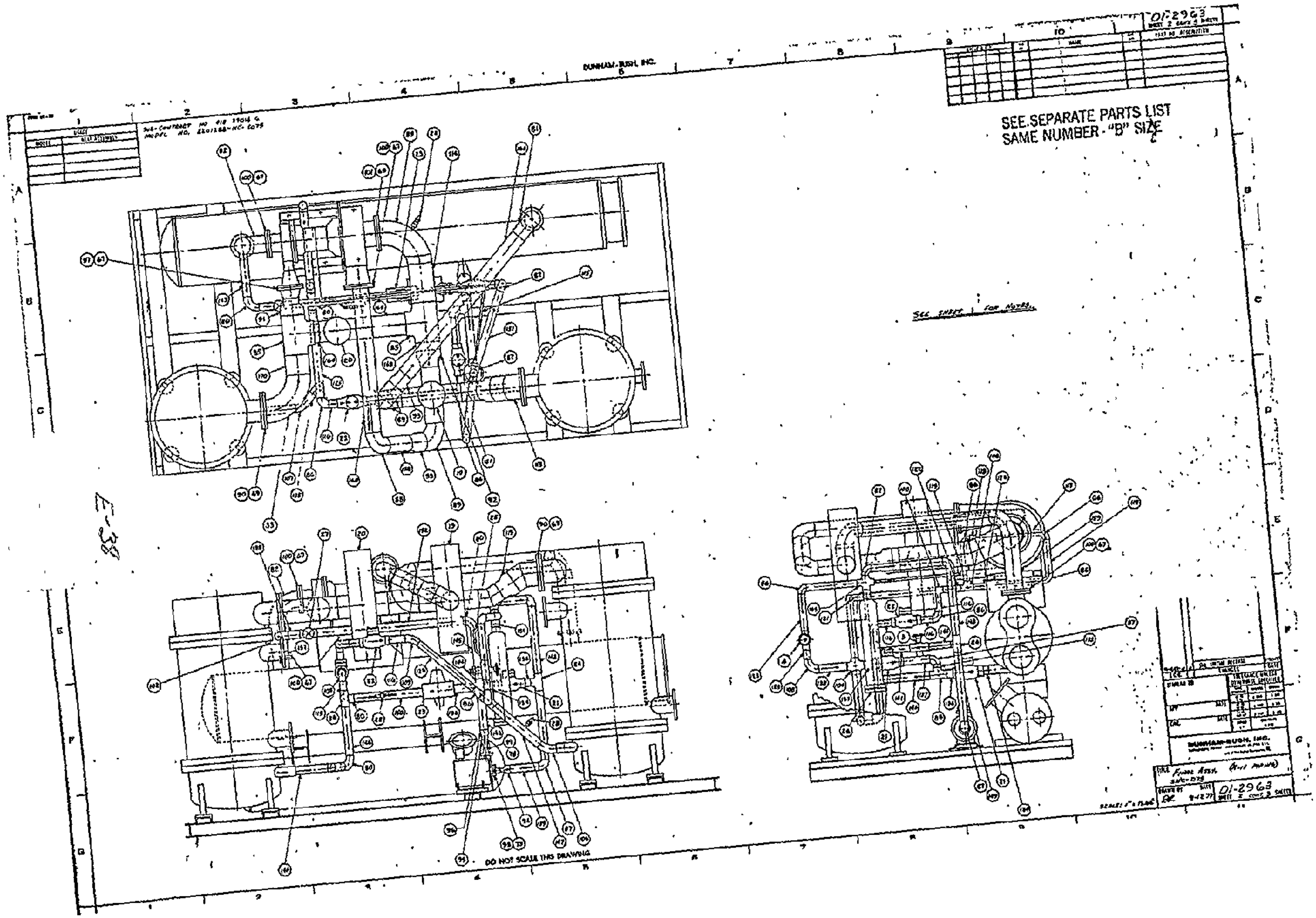
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SEE SEPARATE PARTS LIST
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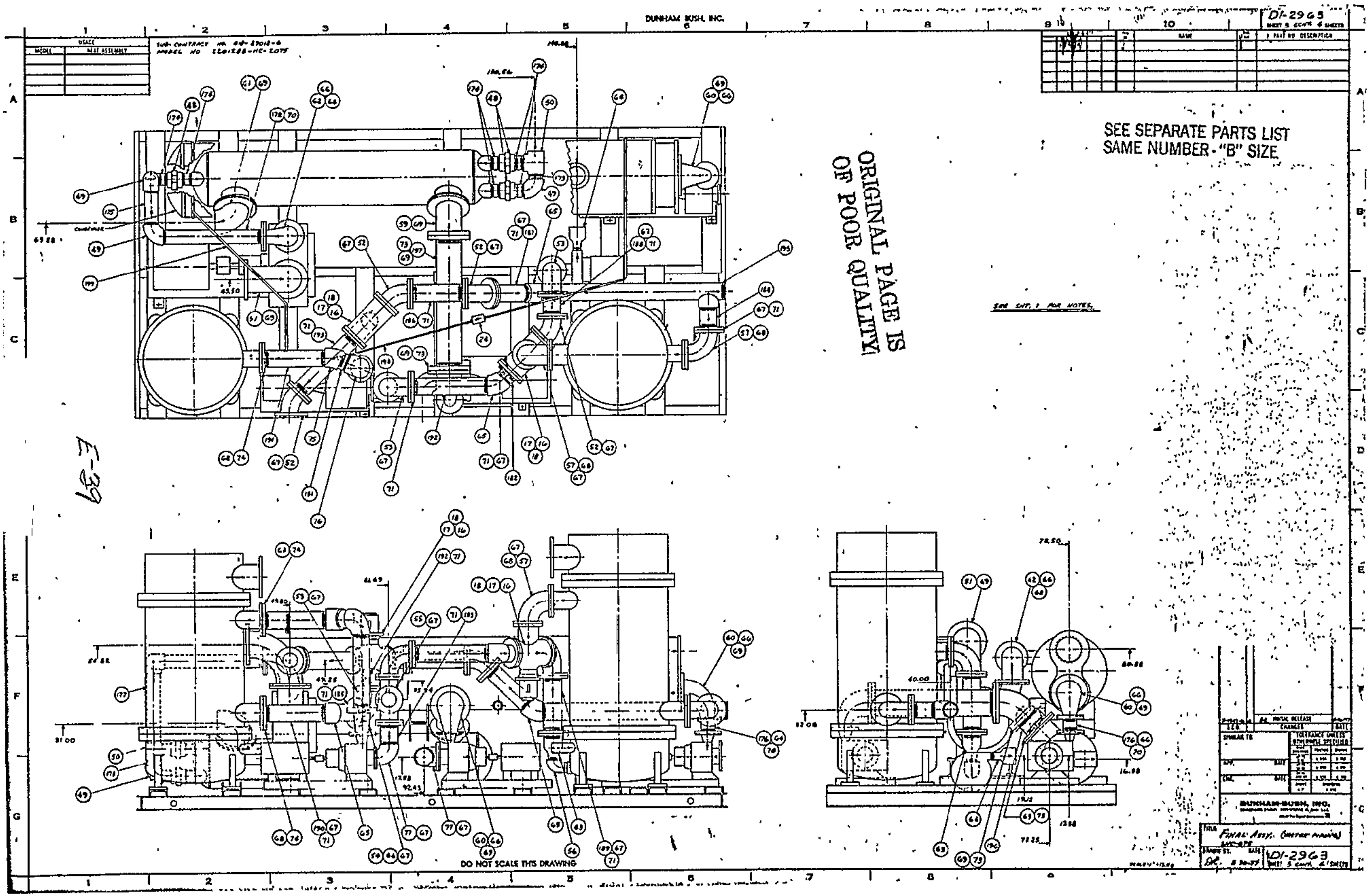
D1-29663



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E-39
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DI-2963

PART F

Sixth Quarterly Report
Data Requirement 500-10

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT

Contract NAS8-32091

76-13296(6)

January 10, 1978

Approved by

P. A. Benson

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama 35812

GARRETT

AIRESEARCH MANUFACTURING COMPANY
OF CALIFORNIA

CONTENTS

SECTION I

INTRODUCTION AND SUMMARY

INTRODUCTION

This is the sixth quarterly report prepared by AiResearch Manufacturing Company of California under Contract NAS 8-32091 for the National Aeronautics and Space Administration, Marshall Space Flight Center (MSFC). The report summarizes activities from October 1, 1977 to December 31, 1977.

SUMMARY

Significant activities and status of the cost, schedule, and technical aspects of the program are summarized in the following paragraphs.

Cost Status

This paragraph has been deleted

Schedule Status

All heating-only heat pump systems have been cancelled as per the agreements reached resulting from recommendations by AiResearch at a meeting in Huntsville on October 7, 1977. NASA (Mr. Larry Marshall) confirmed this decision by telecon approximately one week after the October meeting. AiResearch does not, however, have written confirmation of this decision.

The following is a status of site installation schedules:

This page has been deleted.

Site	Owner Agreement	CP	General
Novato, Ca. (formerly Hamilton)	No	Submitted, not approved	On stop per NASA
Allaire State Park, N.J.	Yes (but no copy at AiResearch)	Submitted, approved for $5000 only	A&E to have bid package by Jan. 18, 1978
Lawrenceburg, TN	No	Submitted, will be approved for $5000 in January, 1978	A&E to start design in January, 1978
Harrisonburg, VA.	No	Submitted, not approved	Awaiting go ahead
St. Louis, MO.	No	Submitted, not approved	Awaiting go ahead
Los Angeles, CA.	No	No	No site has been found
Clearlake, TX.	No	Submitted, not approved	Houston has proceeded and completed design. Bids have been received.
Las Vegas, NV.	No	Submitted, not approved	Las Vegas is proceeding with design. A&E to be partially funded, but not yet under contract

The latest solar heating/cooling systems development schedule (Figure 4-11) reflects the program development delays which have occurred. Since all known development problems are now resolved, this schedule should be realistic. The schedule indicates a shift in priority from the 25-ton system to the 75-ton system because of site schedule requirements. All 25- and 75-ton systems are tested on the same test setup at Dunham-Bush and are scheduled necessarily in series. The solar heating/cooling system development schedule shown in Figure 1-2 has been revised to reflect the latest delivery dates shown in Figure 4-11.

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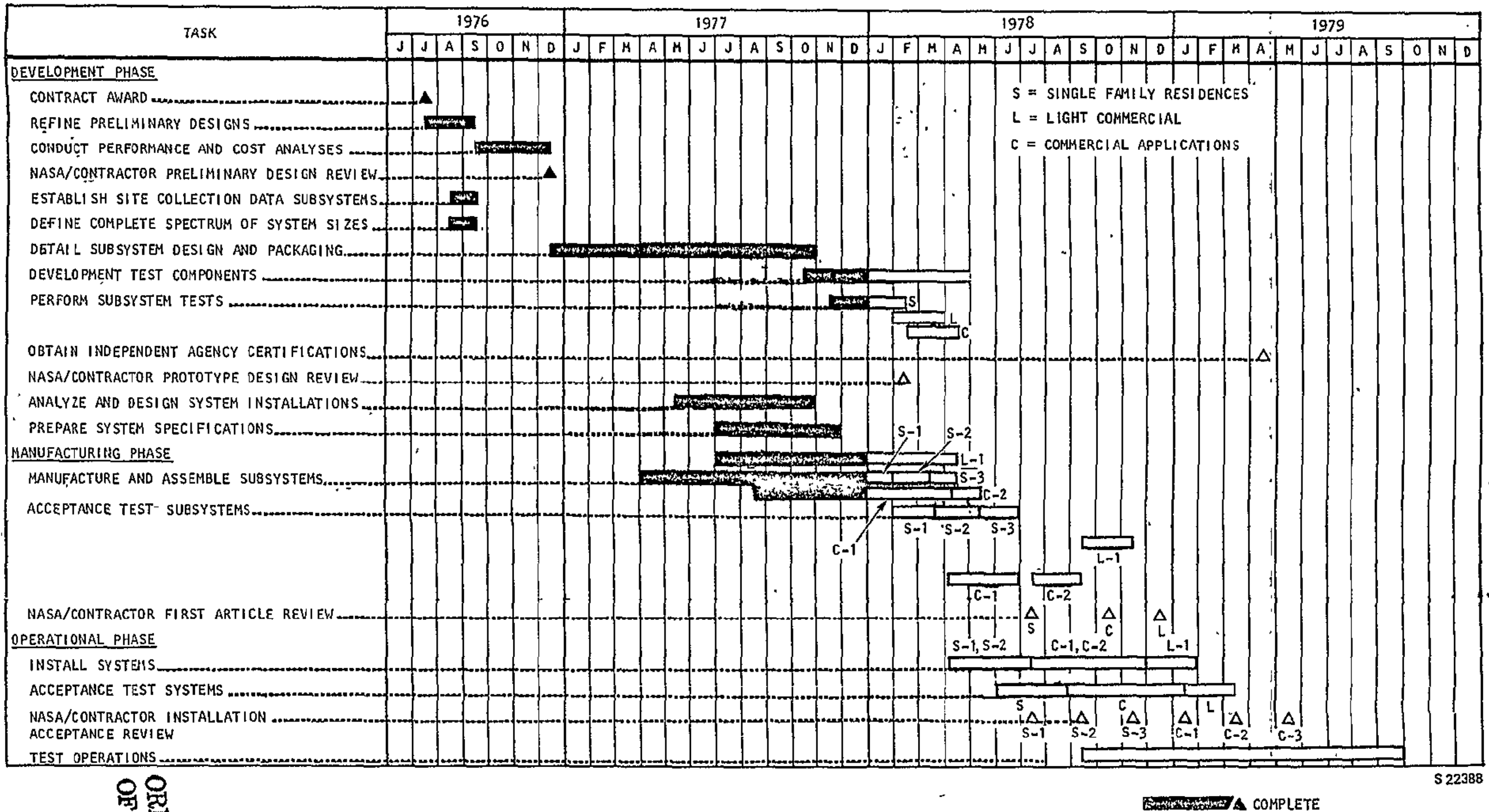

Figure 1-2. Solar Heating/Cooling Systems Development Schedule

F-4

Technical Status

1. Site Selection

Site interface meetings were held at Lawrenceburg, Tenn., Jefferson City and St. Louis, Mo. Preliminary cost estimates were issued for Lawrenceburg and St. Louis. Three meetings were held in Houston. A preliminary Instrumentation System Planning Information package was submitted during the second meeting. Two site coordination meetings were held regarding the Las Vegas site during which time a direct-heat heat exchanger was added to the heating/cooling system.

Visits were made to three southern California locations for consideration as the Los Angeles site. None were recommended at this time. A preliminary design review was held at Allaire State Park N.J. with the newly selected A and E firm, Mueller Associates. This firm was asked to locate a suitable local contractor with help from the N.J. Bureau of Parks.

2. Collector Procurement

AiResearch was advised of a potential delivery delay due to manufacturing problems. A meeting will be held soon to resolve these difficulties.

3. Heat Pump Subsystem

Activity on the 75-ton packages have been intensified as a result of the expedited site schedules for Las Vegas and Houston. All parts have been ordered; delivery is scheduled for January. The 3-ton and 25-ton units still await delivery of the turbomachine and controls. Delivery of four-way reversing valves for the larger packages is delinquent.

4. Equipment Development

Bench tests of the 3 and 25-ton turbomachines demonstrated that T-foil Teflon S bearings with a single-piece center rotor assembly cured the bearing malfunctions of the past quarter. A 25-ton unit bearing failure in October was found to be due to insufficient bearing cooling. Cooling passages were enlarged and an external vent was added to eliminate the problem.

The 3-ton turbocompressor control speed commutation problems were solved by rearrangement of the transistor flyback diodes. Current sensor loop dynamics were changed to improve current source chopper performance. As a consequence, the 3-ton unit has been operated throughout its predicted speed range without further problems.

Speed control problems of the 25-ton unit were solved by using phase control and added filtering in lieu of back emf amplitude control. This change allowed testing from 20,000 through 40,000 rpm under normal load. A new dynamic compensation system has been added to solve system instability on closed loop operation. Testing throughout the required range is necessary to verify fully the dynamic compensation.

Five system controllers have been fabricated and bench tested. System testing of these units awaits finalization of the turbomachine motor controller.

The rotor of the 25-ton unit R-11 pump has been reworked to contain 8 vanes instead of 4. This caused a dramatic reduction in pump noise and pressure pulsations reported previously. The 25-ton pump has now accumulated 360 hours of endurance operation without incident or performance degradation. Detail drawings for both the 3 and 25-ton pumps have been finalized and production pumps are on order for the smaller unit.

SECTION 3

PROGRAM SCHEDULES

The overall program schedule is included in Figure 1-2 of Section 1. This section includes more detailed schedules (Figures 3-1 through 3-6), covering the development status of the critical subsystems and components. Figures 3-7 through 3-14 present schedules and milestones for the eight current solar demonstration sites. These schedules represent an update of those given in the Fifth Quarterly Report. The component/subsystem schedule changes have only a limited effect on the overall program schedule. The status and progress are given in Section 4.

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F-9

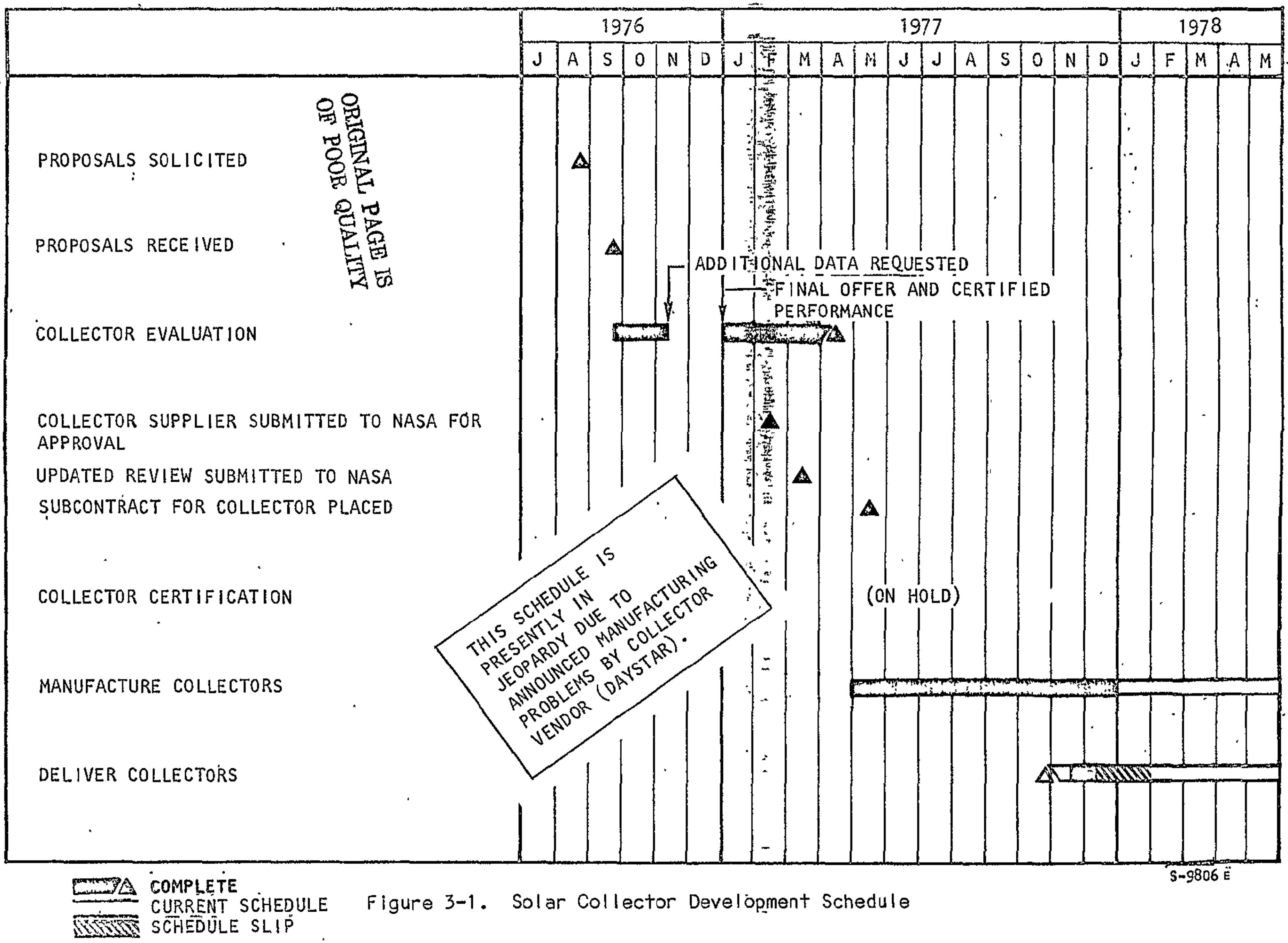
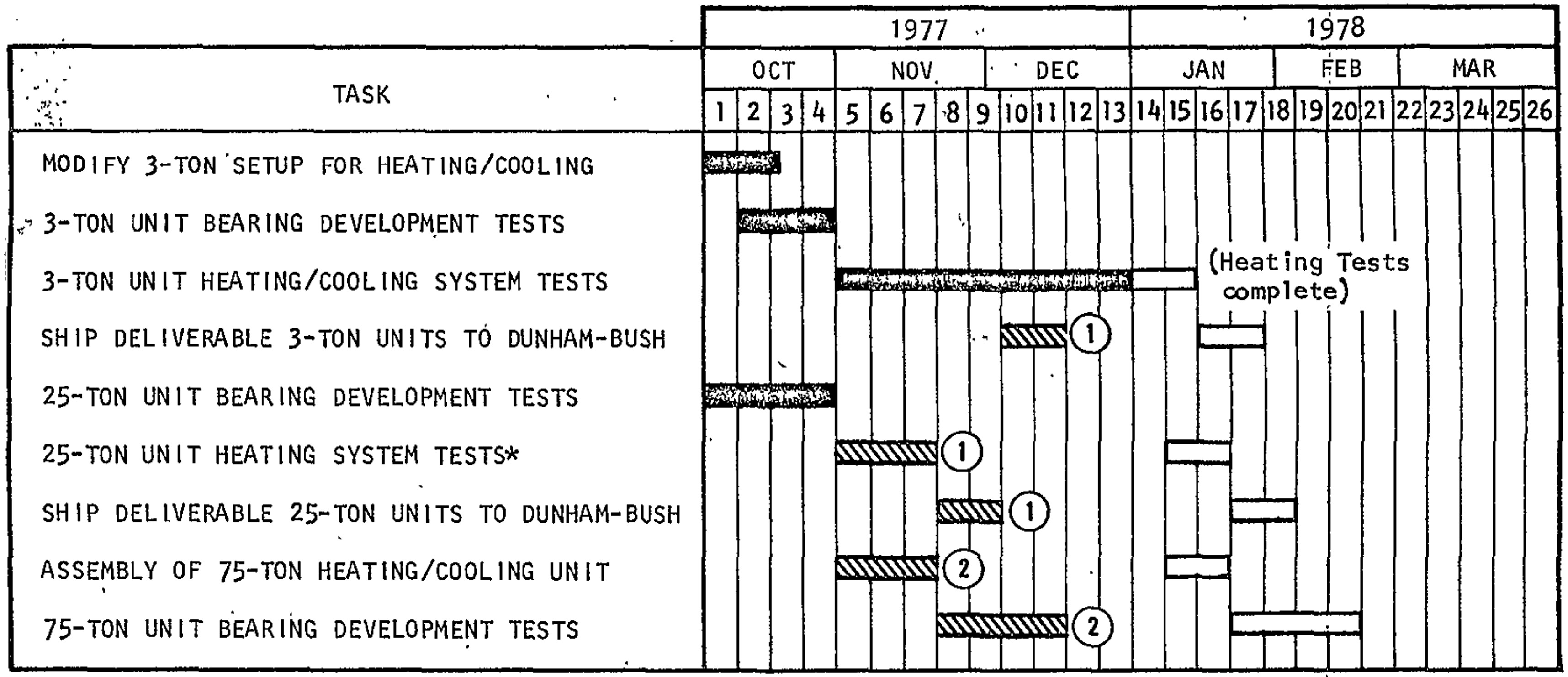


Figure 3-1. Solar Collector Development Schedule

F-10



*Cooling system tests to be done at Dunham Bush

S-20118-A

(1) Delayed due to controller problems

(2) Delayed due to subcontractor subassembly

CURRENT SCHEDULE

SCHEDULE SLIP

COMPLETE

Figure 3-2. Updated Turbomachinery Development Schedule

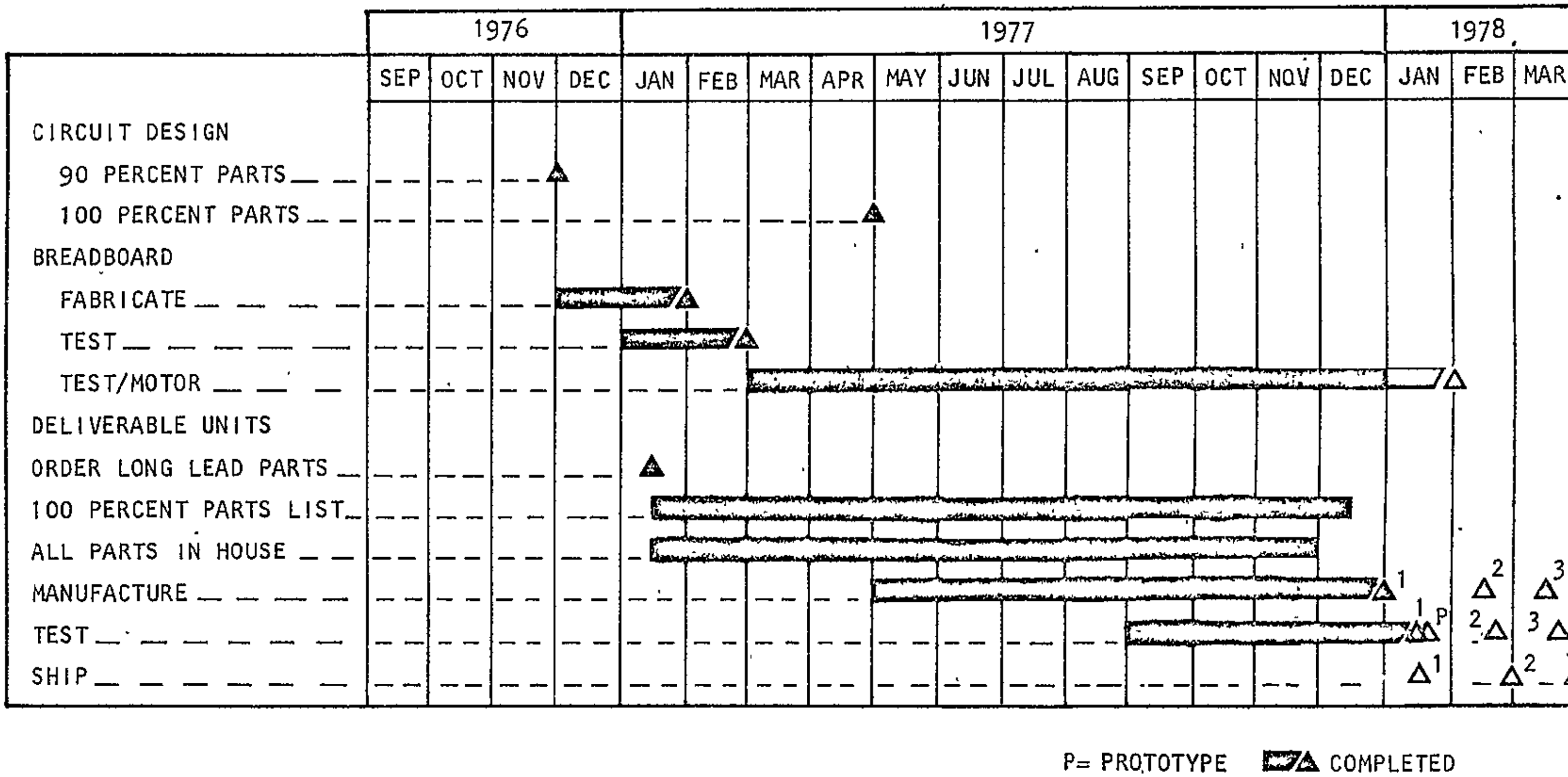


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Figure 3-3. 3-Ton Unit Motor Control Development Schedule

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F-12

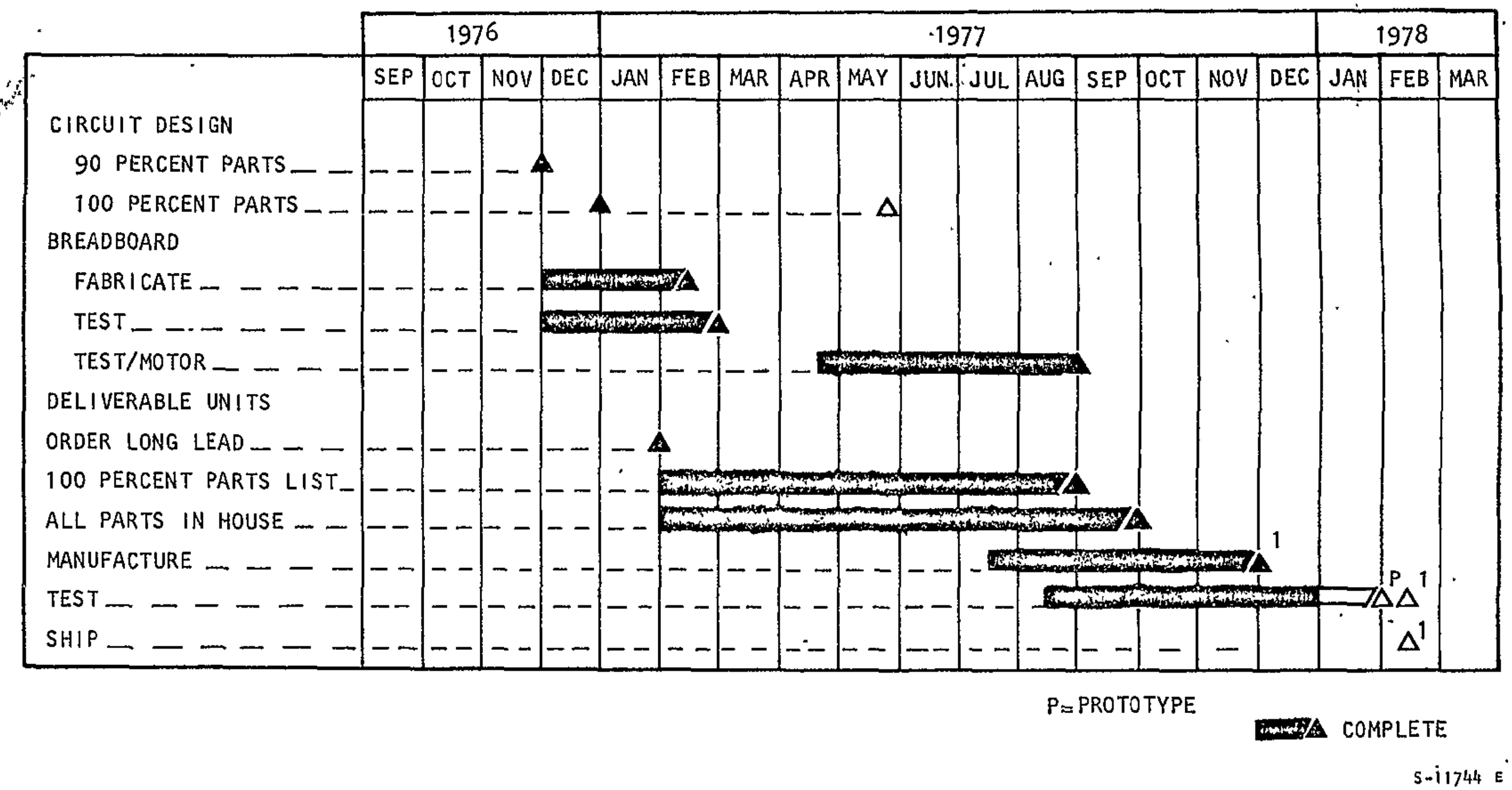

Figure 3-4. 25-Ton Unit Motor Control Development Schedule

F-13

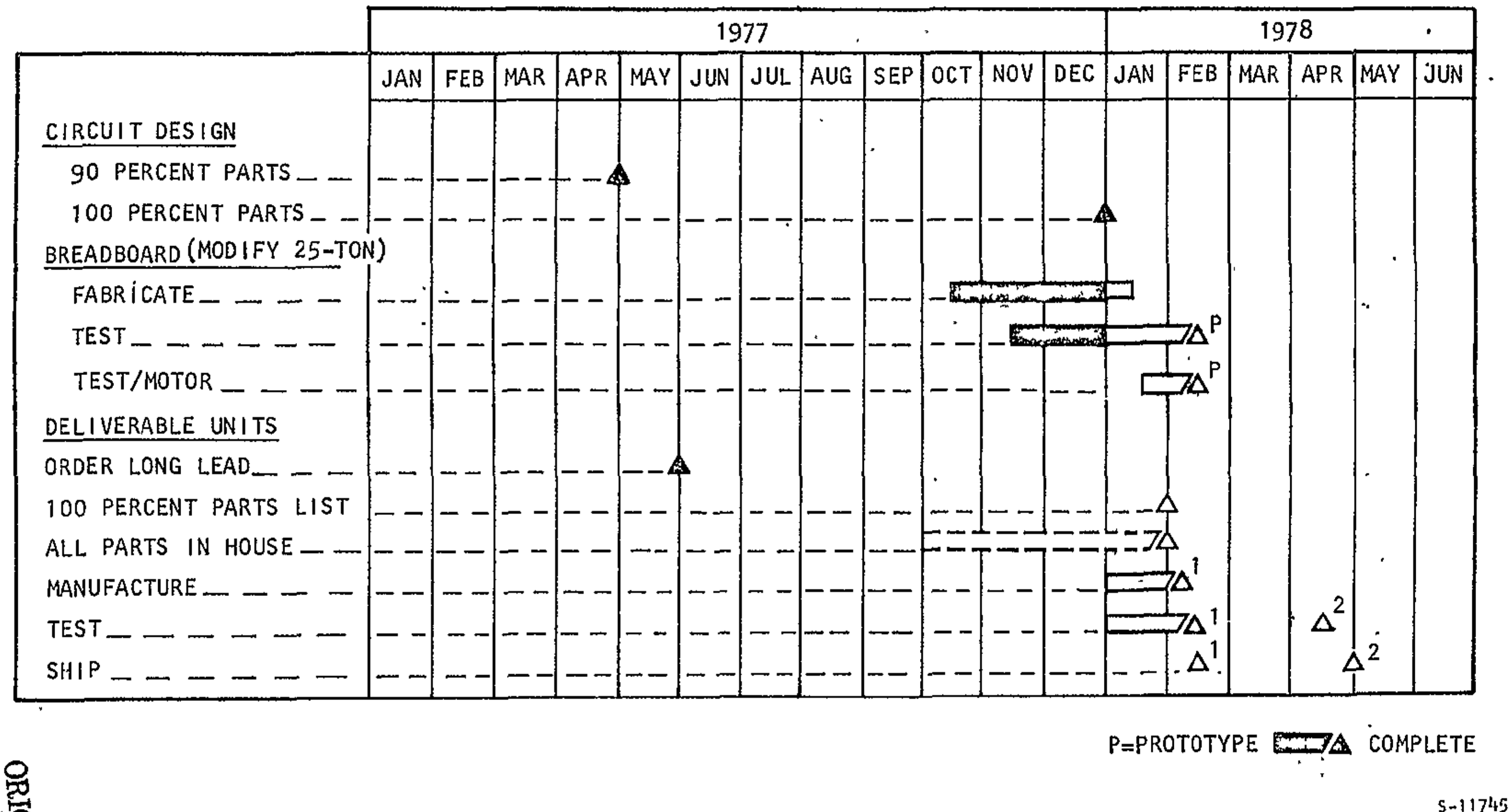

Figure 3-5. 75-Ton Unit Motor Control Development Schedule

F-14

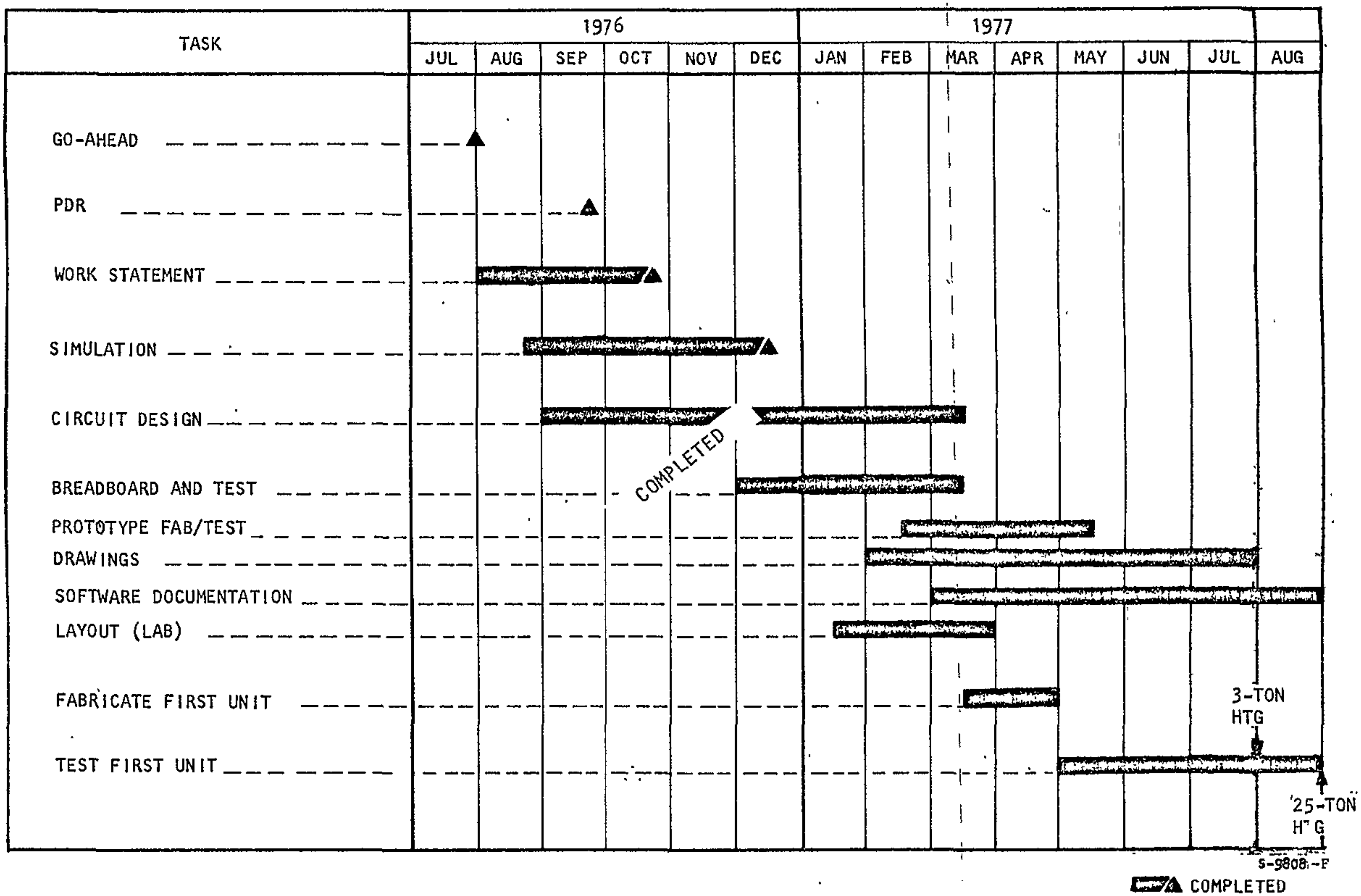

Figure 3-6. System Control Development Schedule

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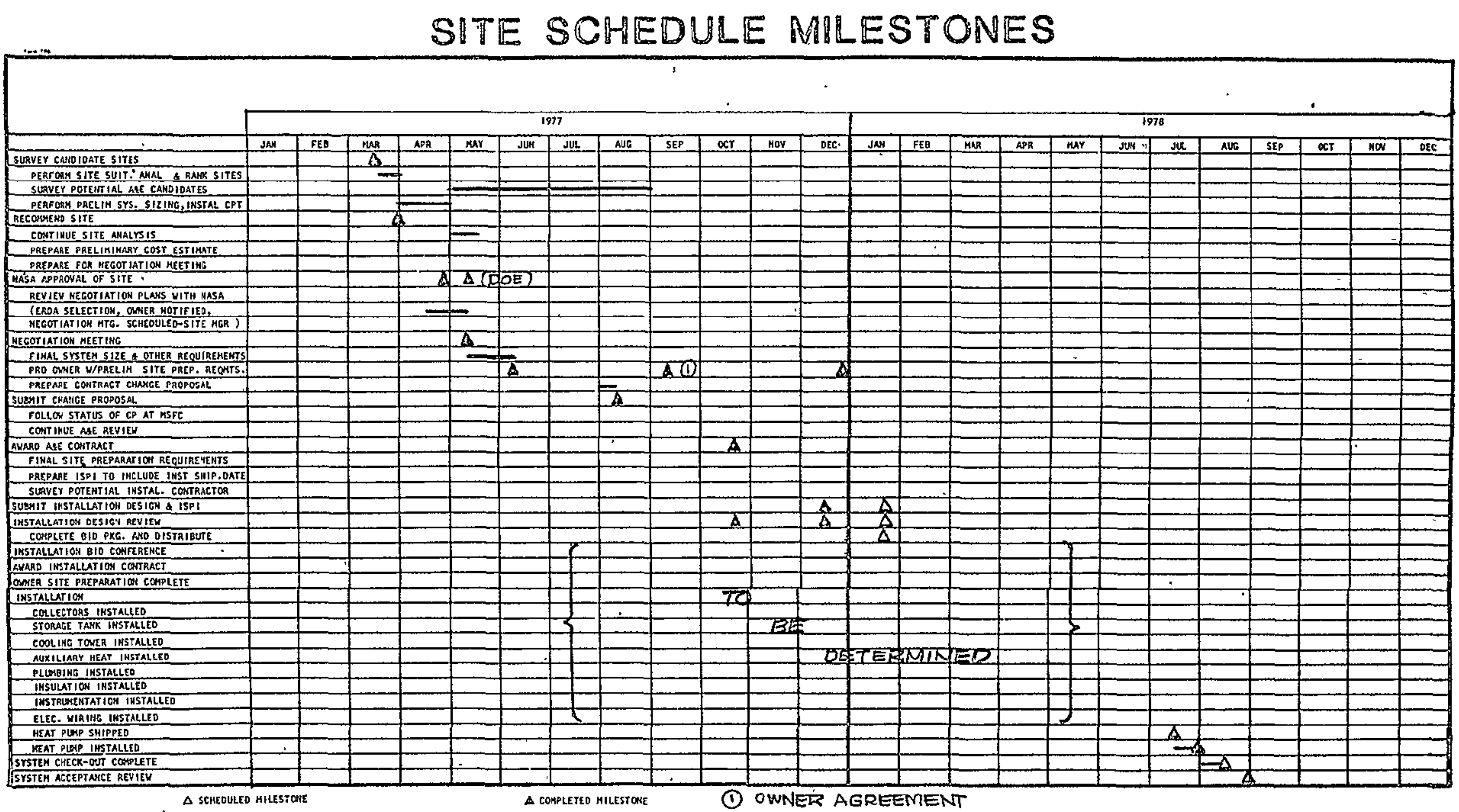

Figure 3-7. Allaire State Park, N.J., Single Family Residence Solar Heating and Cooling System

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F-16

SITE SCHEDULE MILESTONES

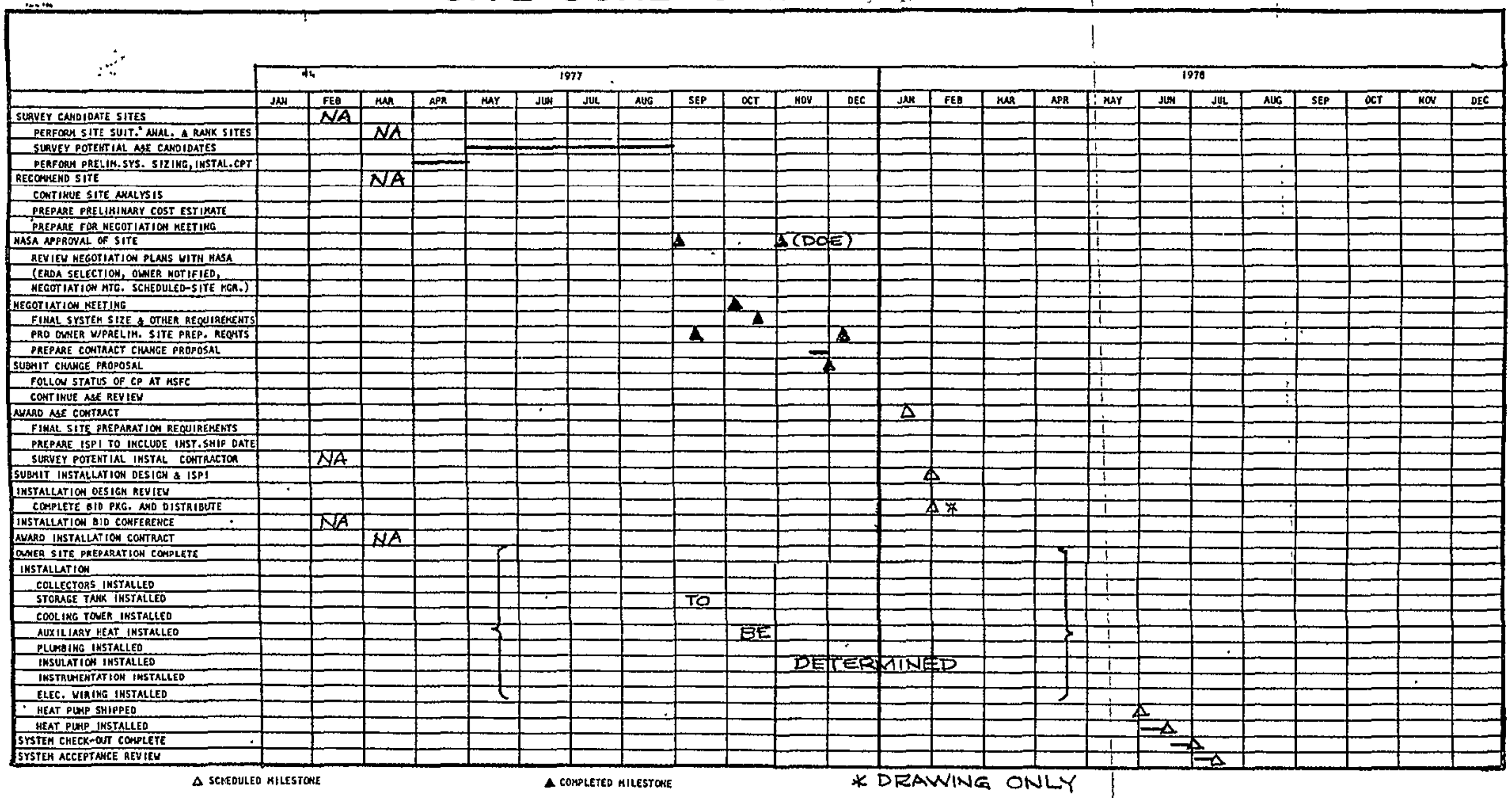

Figure 3-8. Lawrenceburg, Tenn., Single Family Residence Solar Heating and Cooling System

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SITE SCHEDULE MILESTONES

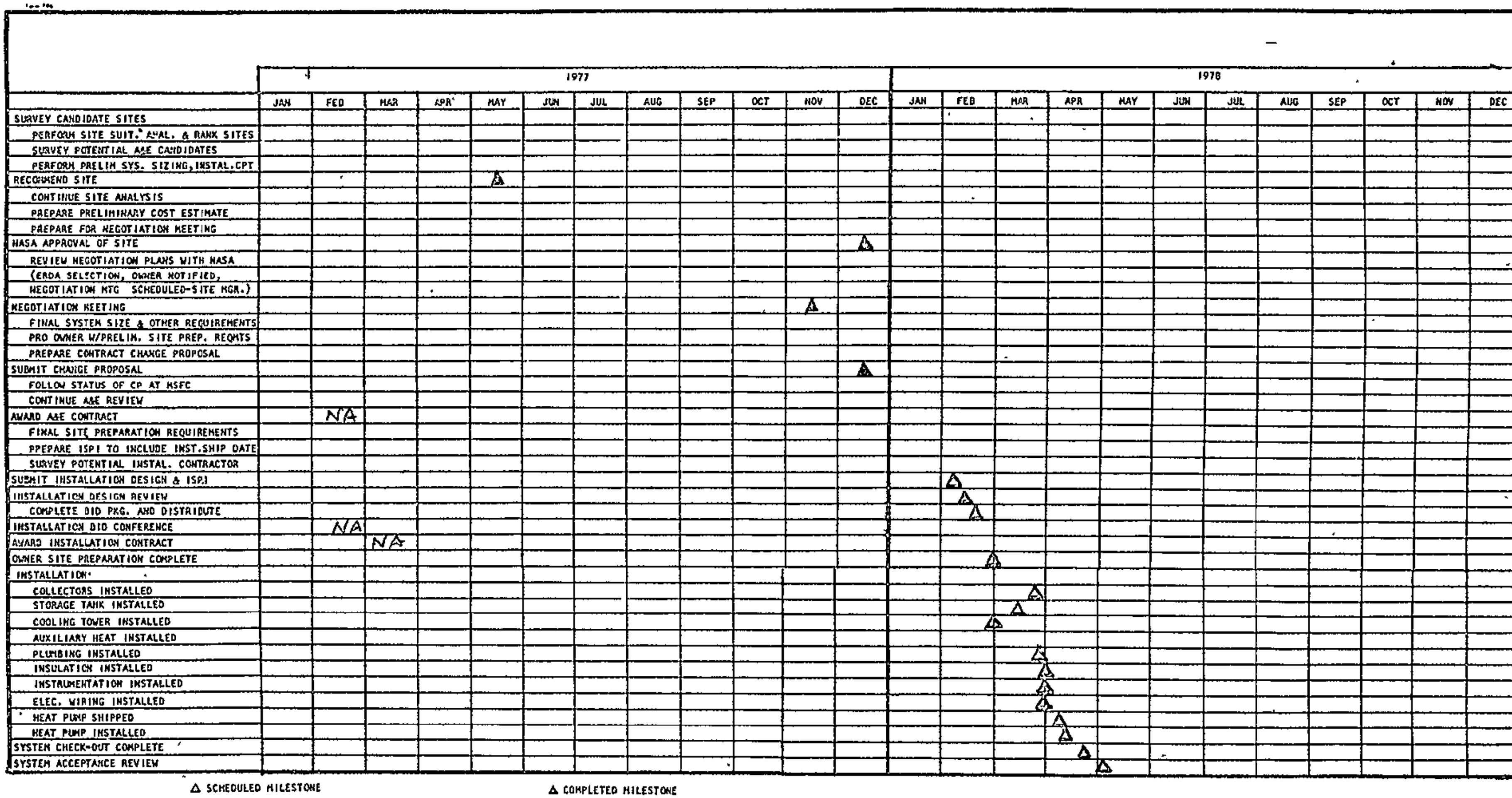

Figure 3-9. Harrisonburg, Va., Single Family Residence Heating and Cooling System

F-18

SITE SCHEDULE MILESTONES

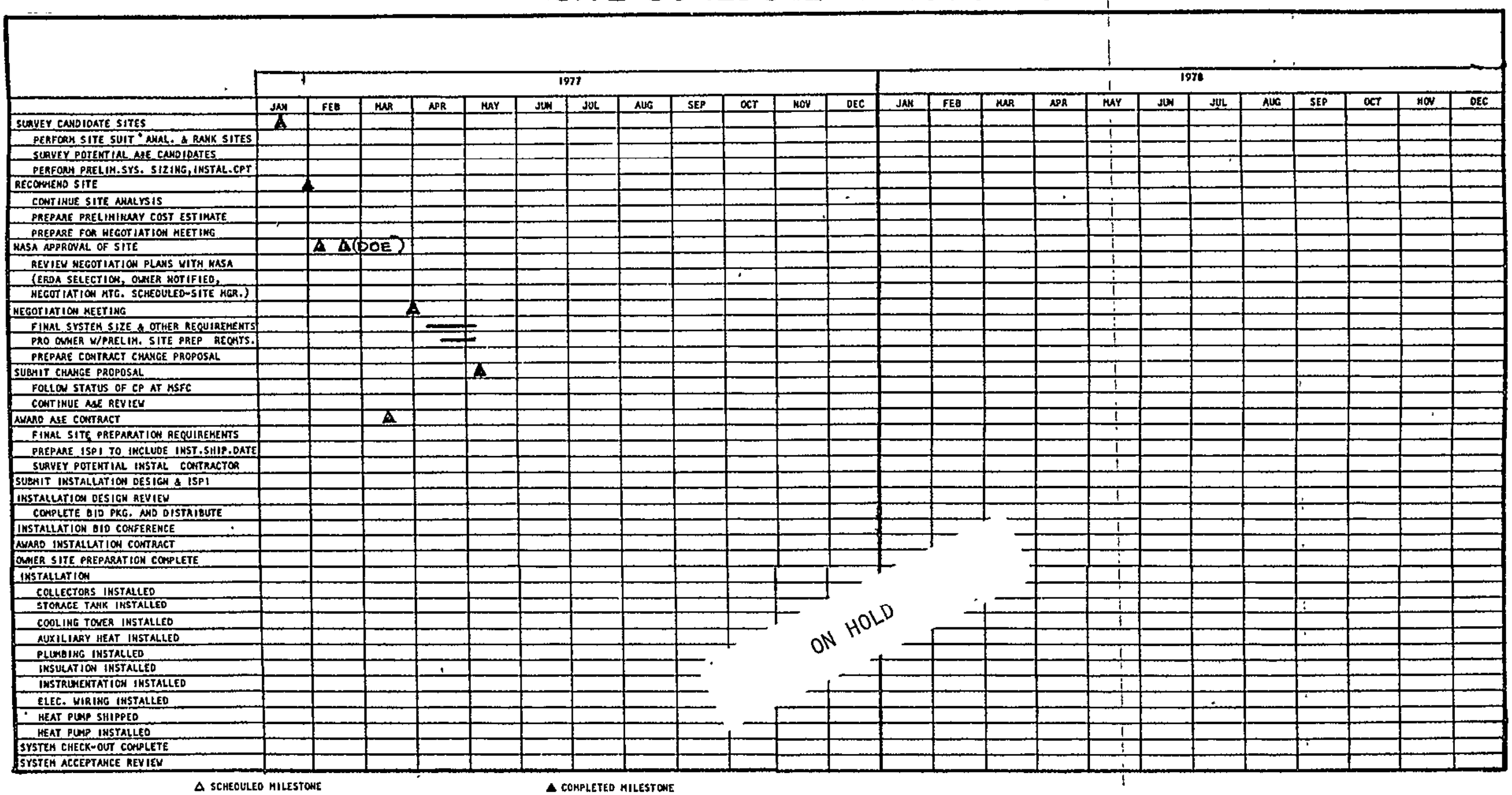

Figure 3-10. Novato, Calif., Single Family Residence Solar Heating Only System

F-19

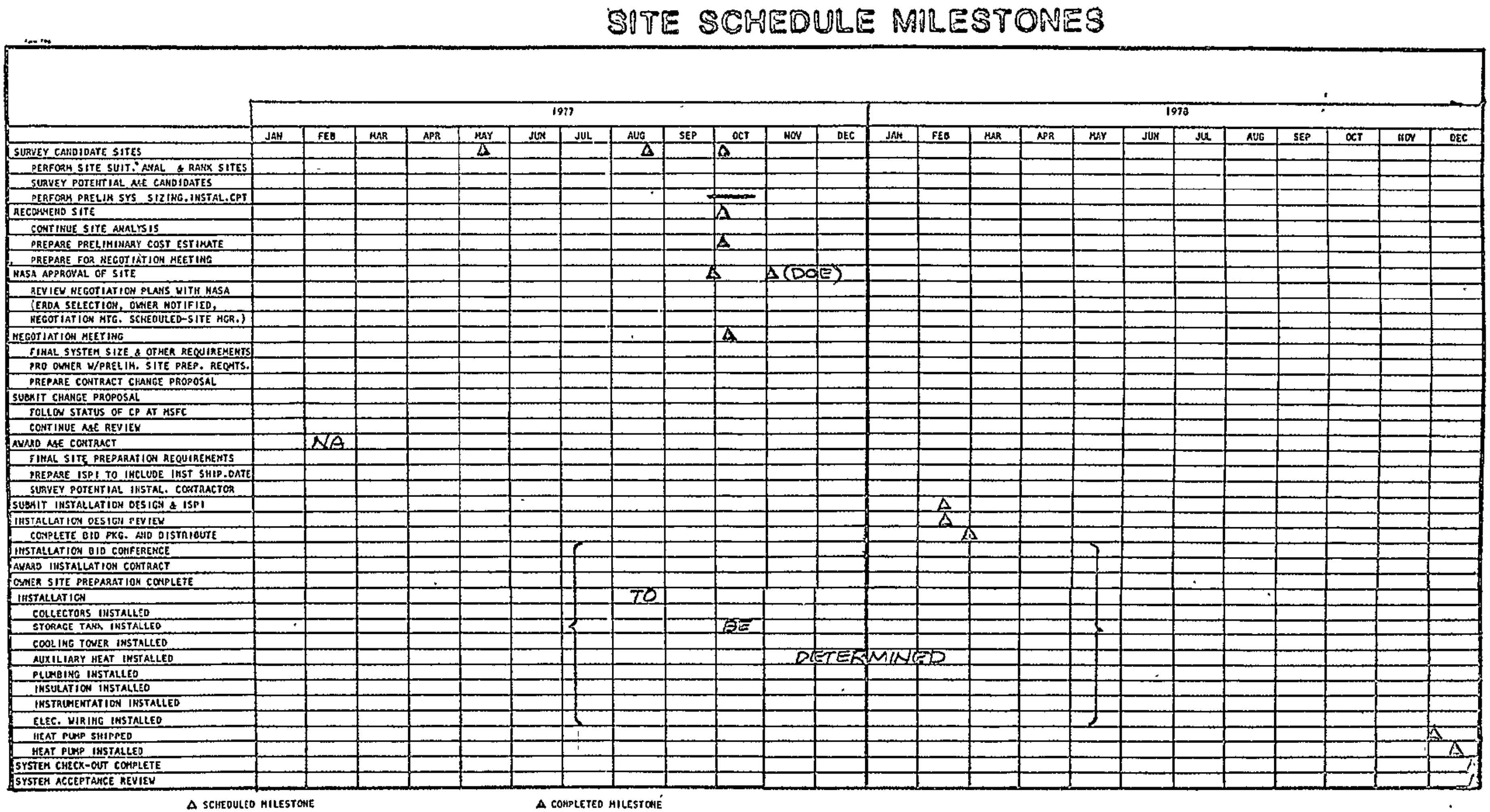

Figure 3-11. St. Louis, Mo., Light Commercial Building Solar Heating and Cooling System

SITE SCHEDULE MILESTONES

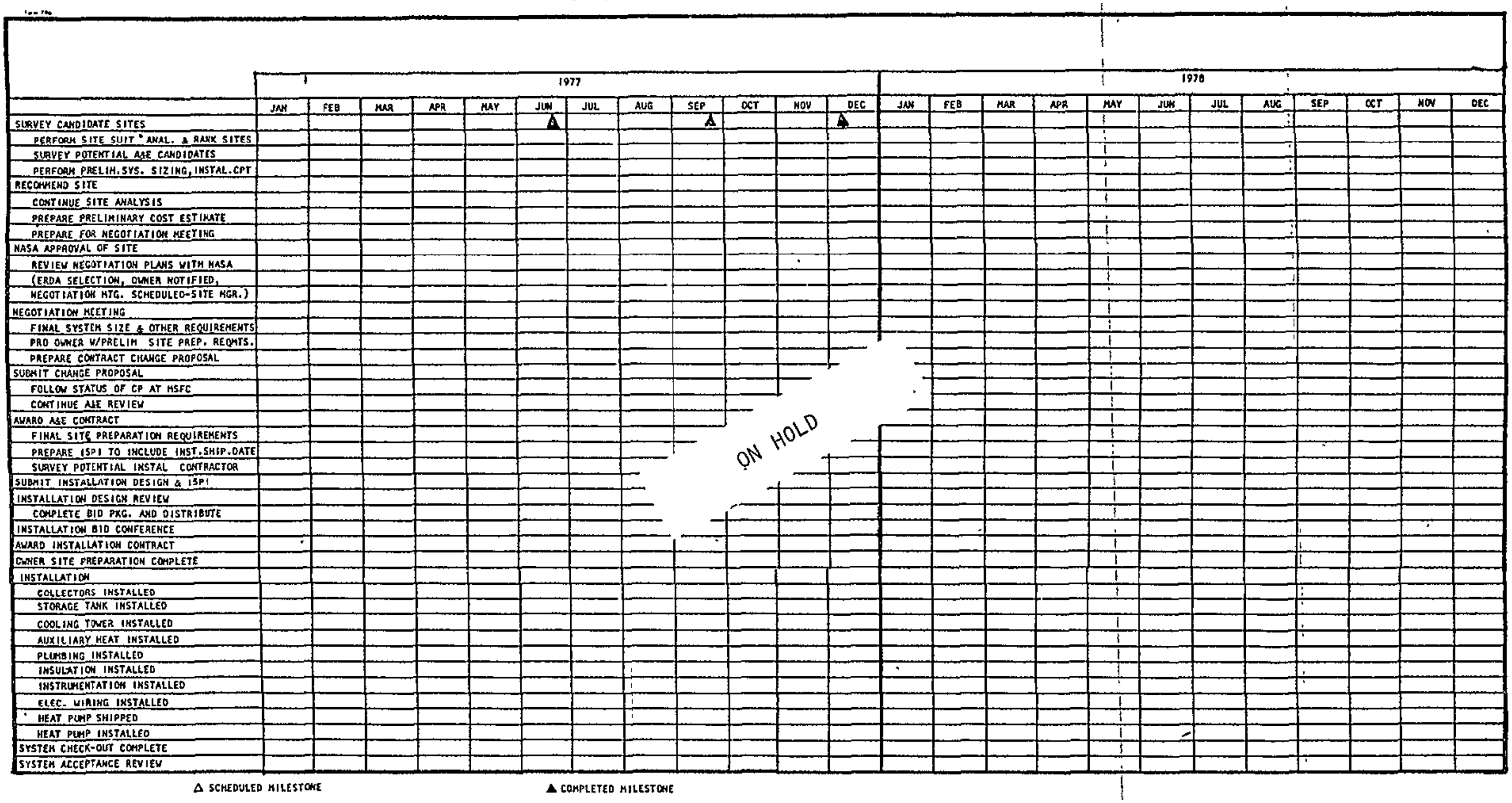

Figure 3-12. Los Angeles, Calif., Light Commercial Building Solar Heating and Cooling System

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F-21

SITE SCHEDULE MILESTONES

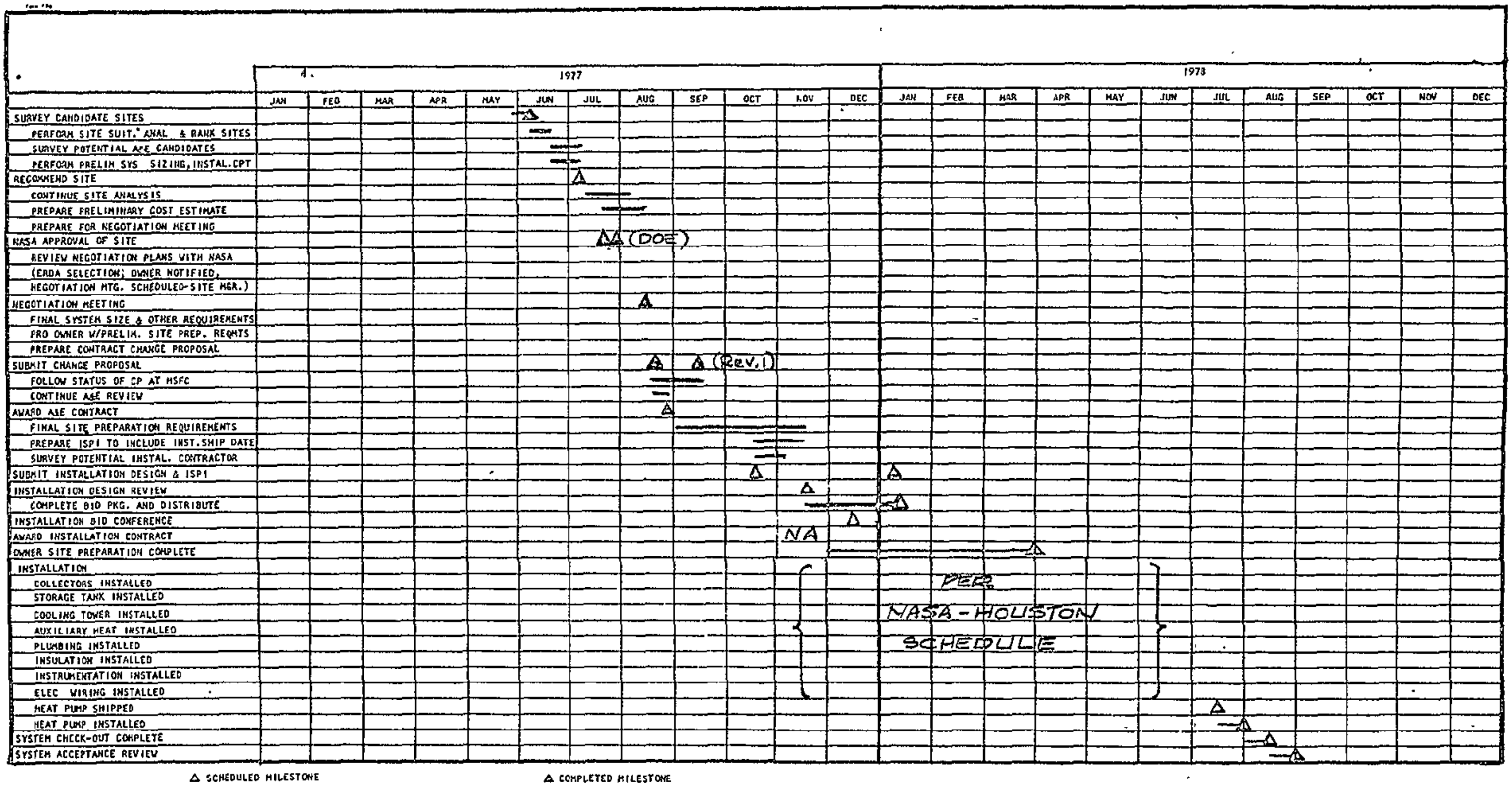

Figure 3-13. Houston, Texas, Commercial Building Solar Heating and Cooling System

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OF CALIFORNIA

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SITE SCHEDULE MILESTONES

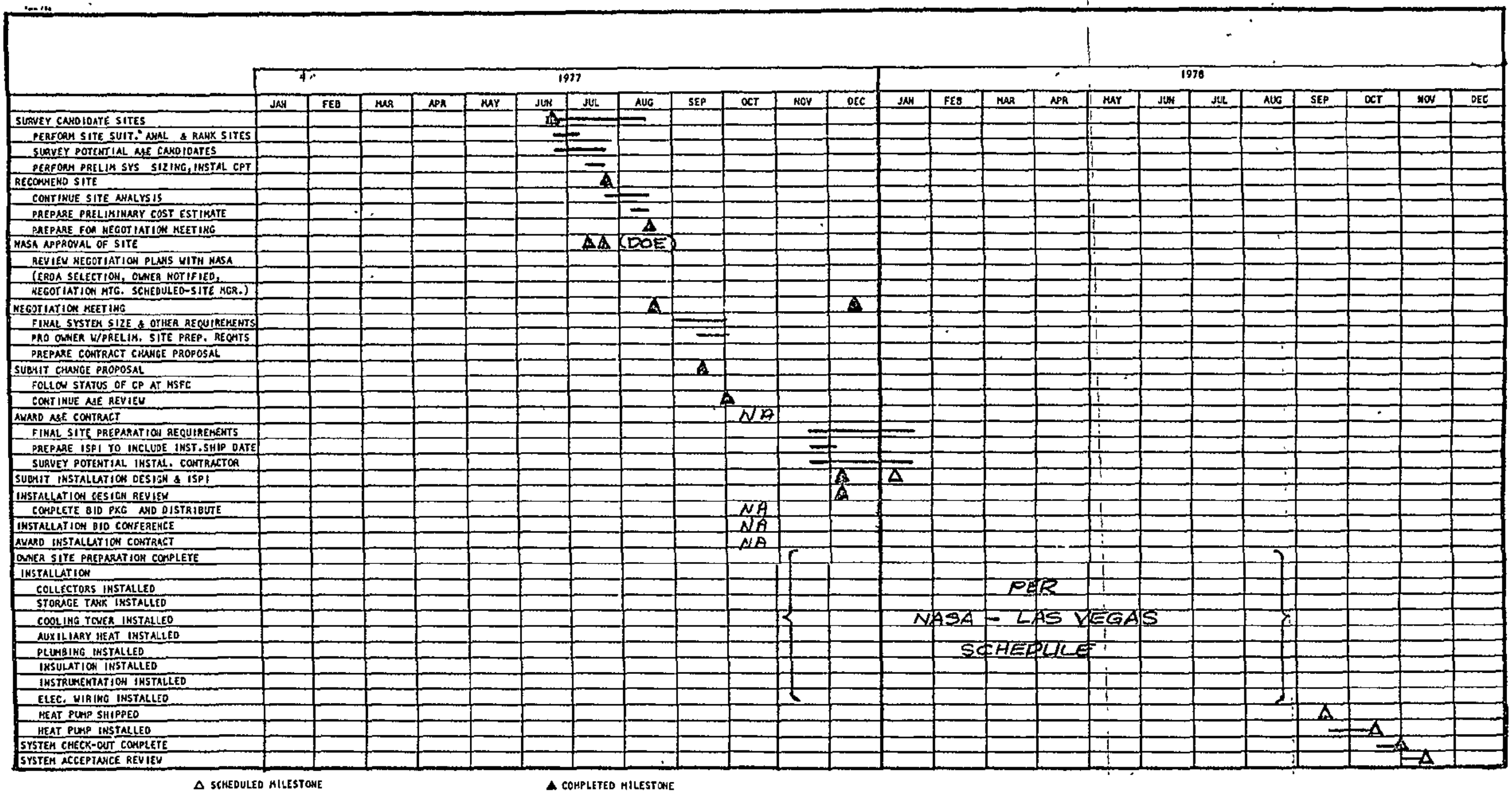


Figure 3-14. Las Vegas, Nevada, Commercial Building Solar Heating and Cooling System

SECTION 4

TECHNICAL PERFORMANCE

INTRODUCTION

Technical status is reported below for all WBS tasks active in the reporting period. The WBS of Figure 4-1 identifies the active tasks with an asterisk (*). Activities during the sixth quarter were involved with the following.

WBS 1.1, MANAGEMENT

WBS 1.1.1, Program Direction

Meetings, reviews, and major events

Site selection and investigation

Collector procurement

WBS 1.1.2, Program Planning and Control

Schedule development

Program documentation

WBS 1.2, DEVELOPMENT

WBS 1.2.1, System Analysis and Integration

WBS 1.2.2, System Development and WBS 1.2.3, Test

Turbomachine and motor controller

System controller

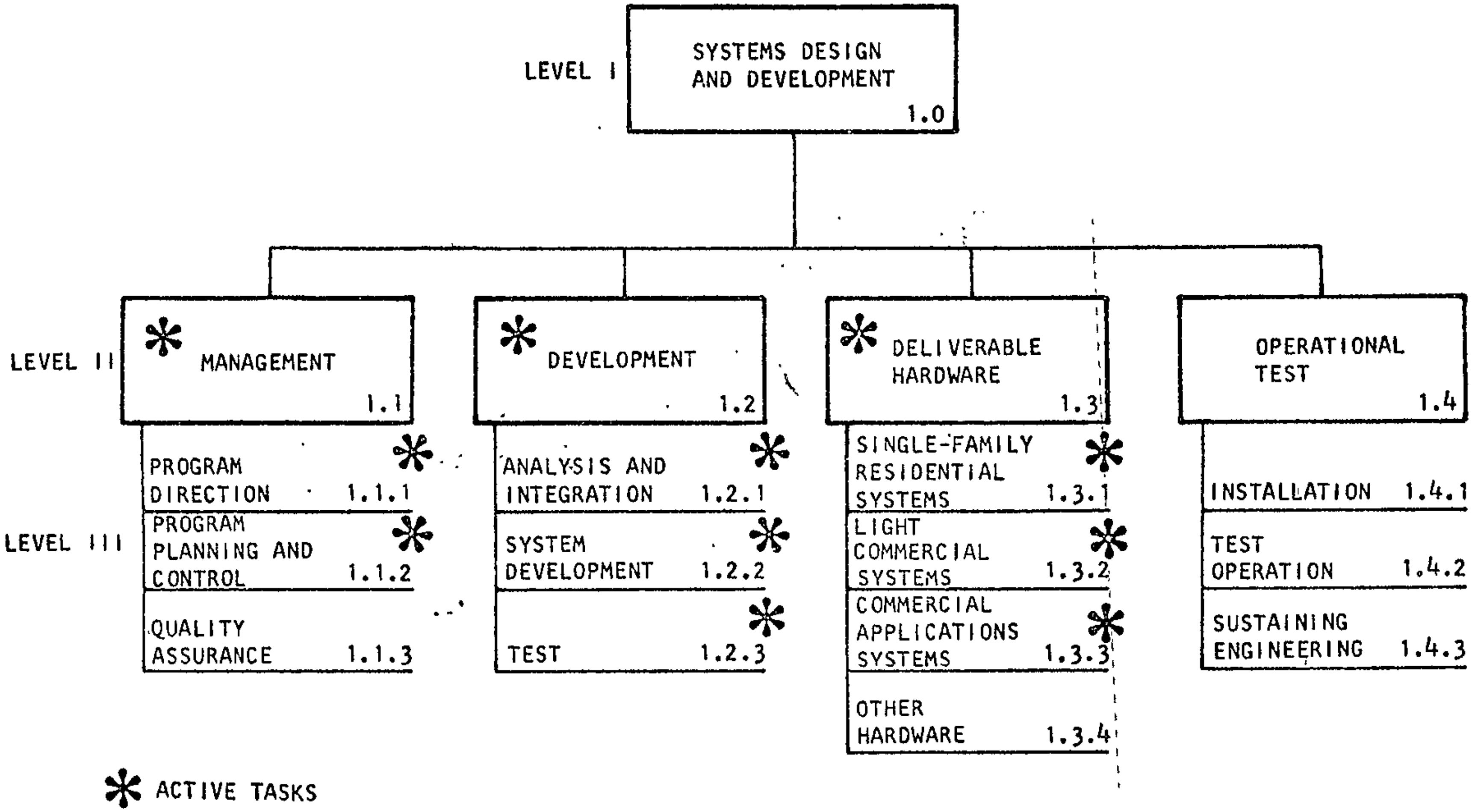
R-11 liquid pump

Heat Pump Subsystem

WBS 1.3, DELIVERABLE HARDWARE

Progress on all these items is described in the following paragraphs.

F-24



S-7883-B

Figure 4-1. Top-Level Work Breakdown Structure

ACTIVITIES IN REPORTING PERIOD

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WBS 1.1, Management

1. WBS 1.1.1, Program Direction

a. Meetings, Reviews, and Major Events

- A coordination meeting was held at AiResearch from October 11 through 13, 1977, with Mr. Jim Clark, NASA contract monitor, to review activities and status.

- A site instrumentation orientation meeting was held on October 13, 1977, at AiResearch with Mssrs. Frank Digeau and George Mizell of IBM, Huntsville, Ala. to review the new edition (October 1, 1977) of ERDA Report "Instrumentation Installation Guidelines". The SDAS (Site Data Acquisition System), OSM (On-Site Monitor), CDPS (Central Data Processing System) and installed sensors were discussed in detail to attain uniformity of input information for the required ISPI (Instrumentation System Planning Information) Package to be prepared by the various site contractors.

- Site interface meetings were held at Lawrenceburg, Tennessee (October 4, 1977), Mark Twain Park, Missouri (October 5, 1977), and St. Louis, Missouri, on October 6, 1977.

- A preliminary design review meeting was held at Houston, Texas, on October 14.

- Mueller Associates of Baltimore, Maryland, was selected as the A and E firm for design work on the Allaire State Park Site in New Jersey.

- Charts to be used in the solar heating/cooling commercialization presentation were submitted on October 20, 1977.

- A meeting was held at the Dept. of Energy Headquarters, Washington D.C., to review AiResearch Report 77-13904, "Solar Heating and Cooling Recommended Contract Modifications to Achieve Commercialization" on October 27, 1977.

- A final design review meeting was held at Houston, Texas, on November 17, 1977. A preliminary Instrumentation System Planning Information (ISPI) package was submitted to TEI and NASA representatives for review. Final piping and component drawings were presented for discussion.

- An engineering coordination meeting was held at AiResearch on December 1 and 2 with Mr. James Clark, NASA contract monitor, to review engineering activities and status. On December 5 through 7, Mr. Clark reviewed contractual status with Mr. John McPherson on AiResearch.

- A site visit was made to Huntington Park, Ca., for a review of the GSA Social Security Building on December 5, 1977. The following day, a conference was held at Irvine, Ca., regarding the merits of the Student Health Center of California State College of San Bernardino as a candidate for a light commercial building heating and cooling system. The site was then visited.

- A site visit was made to Calexico, Ca., on December 7 to view the U.S. border station building as an alternate for the Los Angeles light commercial heating and cooling system.

- A site coordination meeting was held in Las Vegas on December 8 by Mssrs R. Joeckel of JBA and P. Walker of AiResearch. New cost estimates were made based on a new component (the direct-heat heat exchanger) and changes in the storage tank and its expansion tank. NASA representatives James Clark and Robert Gunner were briefed on December 9 regarding the new estimates. A follow-up meeting was held AiResearch in Torrance, Ca., on December 16, to resolve subjects not answered at the first meeting.

- Site visits were made to Houston, Texas, on December 13 for a pre-bid conference and to Allaire State Park, N.J., onDecember 15, 1977 for a preliminary design review.

b. Site Selection and Investigation

The Lawrenceburg, Tennessee, site is a single-family, 3-ton cooling, 80,000 Btu heating, domestic hot water dwelling located on campus at the Lawrenceburg County Vocational School. Presently, the basement excavation has been performed and concrete perimeter footings have been poured. Interface details were settled, i.e.-NASA will furnish all equipment except for the auxiliary electric heating furnace and hot water heater. Preliminary drawings of the storage tank and cooling tower foundation pads were given the site owner so as not to delay construction. TVA is submitted a heat load calculation estimate of the house to the owner. House completion is scheduled for June 1, 1978.

The site team next visited Jefferson City, Missouri, to visit a one-story residence for the park superintendant of Mark Twain State Park. A 3-ton cooling, 80,000 Btu heating, domestic hot water system was contemplated for this site.

The St. Louis Special School District Administrative Office site at Crystal Lake Park is a one-story wing of an existing building. The wing can be retrofitted for a 25-ton cooling/800,000 Btu heating, domestic hot water light commercial solar system. Mr. William Hagen of NASA has recommended the site to the Dept. of Energy (DOE) for approval. Interface detail data and drawings were submitted to the school district members and Wm. Taos and Associates, the local mechanical consultant firm. The school board indicated proposal approval based on a preliminary cost estimate prepared by Wm. Taos and Associates, but final approval will be contingent upon the AiResearch C.P. (AIR-18).

A technical review meeting was then held on October 14, 1977, at the University of Houston. Details of this meeting have been submitted to NASA. As a result of the meeting, AiResearch has submitted storage tank and expansion tank data to TEI, the local A and E firm.

AiResearch Plant Engineering prepared the following documents in November pertaining to solar system site preparation:

1. Conceptual Piping Isometric Drawing H-TX-M2-1 for the University of Houston Development Arts Building, Clearlake City, Texas.

2. Cost estimates for the storage tanks at Houston and Las Vegas, Nevada.

3. Tank drawings and equipment data sheets for Las Vegas.

4. A preliminary cost estimate for Lawrenceburg, Tennessee.

The site visits to southern California locations revealed that the 14,000 sq ft Huntington Park GSA Social Security Building had an adequate (flat) roof area for solar collectors, but the following considerations render it a non-viable candidate site:

1. High cost of modification (since existing units would have to be replaced).

2. Incompatibility of existing units with the AiResearch system.

3. An unwalled air conditioned area prevents isolation of the solar system and makes cost effectiveness monitoring extremely difficult.

The California State College Student Health Center is a single-story unit of 11,500 sq ft with a split-level roof. The present air conditioning system has 2 hot and cold deck multizone units with economizer cycles rated at 26 tons total. The units are served by a central high temperature hot water system and a central chilled water system. The system could be rezoned for two central air handlers that provide either heating or cooling. Disadvantages of this site were critical timing (the system is already out for bid) and local ordnances concerning roof clutter. Because of the orientation of the building, the back side of the solar collector panels might be subjected to 75 mph wind velocities.

The 5000 sq ft Calexico U.S. Border Station building was studied and then visited but was not considered a viable candidate because of insufficient roof area, and cost of modifying the existing air handler, which operates using DX cooling and air cooled condensing.

The following items were discussed at the second Las Vegas site meeting held at Torrance, California, on December 16:

1. The collector panel piping calculated pressure loss was 20 percent high. (AiResearch will provide a bigger collector loop pump.)

2. Manual switchover to the back-up chiller was selected for this site.

3. Special control of the cooling tower fan is required for back-up chiller operation.

4. Operation of the circulation pump during back-up chiller operation will require a change in the heat pump electrical system. (AiResearch will investigate this.)

5. Marked drawings of the heat pump (showing changes to incorporate the external heat exchanger) and the tank (showing heat pump connections) were given to Mr. R. Joeckel.

6. Mr. Joeckel supplied AiResearch with load and pressure drop calculations and a written description of the control scheme.

At the Houston pre-bid conference, AiResearch furnished answers as to storage tank sand blasting, collector panel weight and contractor responsibility relative to collector damage, hoses and clamps.

During the preliminary design review at Allaire State Park, AiResearch made a presentation to N. J. Bureau of Parks personnel describing the Mueller Associates proposed heating and air conditioning system and AiResearch amendments to it. Information was supplied as to the estimated amount of annual space and hot water heating, the cooling tower size, and a description of the heat pump turbomachine. Tom King of Mueller Associates described the relative merits of two underground pipes (Copper-Gard and Terra-Gard) with recommendations for Terra-Gard since O-ring reliability of the Copper-Gard system is suspect. Mueller Associates was requested by AiResearch to locate a suitable contractor with the N.J. Bureau of Parks assisting. Detailed item-by-item changes in the Mueller drawing were then discussed. Miscellaneous items such as collector panel angle (50°), cooling tower loop operating pressure (10 psig), the maximum collector loop operating temperature (230°F), exposed valves (acceptable), storage tank lining (interior painted), stored water (to contain corrosion inhibiters), space and preheater controls arrangement, heat pump tubing (copper throughout), cooling tower dimensions and wet weight (840 lb) were explained in answer to random questions. Electricity costs in the Allaire area were provided by the N.J. Bureau of Parks. This concluded the meeting.

c. Collector Procurement

Daystar has advised AiResearch of a potential delivery delay due to manufacturing problems. A meeting will be held in the near future to resolve the delay.

2. WBS 1.1.2, Program Planning and Control

a. Schedule Development

Program schedules have been updated throughout the quarter to reflect the latest information. The latest versions of the component/subsystem schedules are presented in Section 3, including site schedule milestones. Overall program schedules for the heating/cooling systems are in Section 1.

b. Program Documentation

The following documents were prepared in accordance with the requirements of Appendix A of the Statement of Work:

(a) Fifth Quarterly Report (DR500-10), October 10, 1977, AiResearch Report 76-13296(5).

(b) AiResearch Report 77-13904, entitled "Solar Heating and Cooling Recommended Contract Modifications to Achieve Commercialization", and dated October 14, 1977.

(c) Quarterly Contractor Financial Management Report (DR500-27), dated October 21, 1977.

(d) Twelfth Monthly Status Report 76-13110(12), dated November 10, 1977 (DR500-11).

(e) Monthly Contractor Financial Management Report (DR500-27) for October.

(f) Thirteenth Monthly Status Report 76-13110(13), dated December 9, 1977 (DR500-11).

(g) Monthly Contractor Financial Management Report (DR500-27) for November.

Other publications submitted to the parties listed during the quarter were:

Submittal Date	Addressee	Subject
10-7-77	James Clark NASA/MSFC	Change Proposal AIR 15 - Change in Delivery Schedule
10-24-77	James Clark NASA/MSFC	Minutes of the October 14, 1977 site review meeting at the University of Houston
10-27-77	James Clark NASA/MSFC	1. Solar Collector Field Sizing Criteria 2. "Interface Document" previously given to TEI in Houston, Texas
10-28-77	Gordon Neff, TEI, Houston, Tx.	1. Instrumentation Installation Guidelines, 10-1-77 2. Storage Tank Drawing H-TX-M2-2 3. Expansion tank part numbers and sizing calculations
11-17-77	NASA and TEI	Houston site preliminary ISPI forms.
11-30-77	J. Clark, NASA/MSFC	Change Proposal AIR-16, Solar Installation at Lawrenceburg, Tenn.

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Submittal Date	Addressee	Subject
12-9-77	James Clark, NASA/MSFC	Change Proposal AIR-17 - Reduce site total to 8.
12-9-77	James Clark, NASA/MSFC	Change Proposal AIR-18 - St. Louis, Mo., site installation costs
12-9-77	James Clark, NASA/MSFC	Change Proposal AIR-19 - Dunham-Bush test house site installation costs
~~12-12-77~~	~~James Clark,~~ NASA/MSFC	~~Rev. A to Las Vegas, Nevada, ISPI~~
12-12-77	James Clark, NASA/MSFC	Meeting Minutes of Preliminary Design Review 12/8/77, Solar Heating and Air Conditioning System for Stewart and Mojave Recreational Center, Las Vegas, Nevada
12-21-77	James Clark, NASA/MSFC	Meeting Minutes of Preliminary Design Review 12/15/77, Solar Heating and Air Conditioning System for Allaire State Park Residence, Farmingdale, New Jersey.

WBS 1.2, Development

1. WBS 1.2.1, Analysis and Integration

The study for the 25-ton (light commercial) heating and cooling system at the St. Louis South County Technical School child-care wing was finalized during the quarter.

Analysis efforts since then have been confined to the generation of design data required for the various site ISPI's being released.

2. WBS 1.2.2, System Development and WBS 1.2.3, Test

(These categories have been combined in this report because almost all development activities consisted of testing.)

a. Turbomachine

(a) 3-Ton Unit

Unit configuration testing was completed in November. Test results demonstrate that all units will use T-foil Teflon S bearings with a single-piece center rotor assembly. This configuration was then evaluated in the laboratory system test loop in the heating mode. Testing over the entire speed range (41,000 to 82,000 rpm) was completed in December and compressor performance was as predicted.

Another unit without the single-piece center rotor assembly was performance tested at 50,000 and 60,000 rpm in the heating mode. Results showed that the adiabatic head was low and the surge line was too far to the right on the estimated curve. The low head was attributed to leakage, since it was necessary to increase the seal clearance because of shaft runout. This design was consequently abandoned.

The laboratory system was then converted to the cooling mode in mid-December. Figures 4-2 and 4-3 show the setup. Checkout runs were made to establish the proper R-11 charge, instrumentation and flow management. Performance evaluation of the unit will take place in January.

(b) 25-Ton Unit

Bearing development testing was completed and an optimum foil configuration was selected. A unit was built and installed in the system during October. After approximately 3 hours of operation at low speed (14,000 rpm), the journal bearing on the turbine end failed. The failure was due to overtemperature. Most of the running time was spent debugging the system.

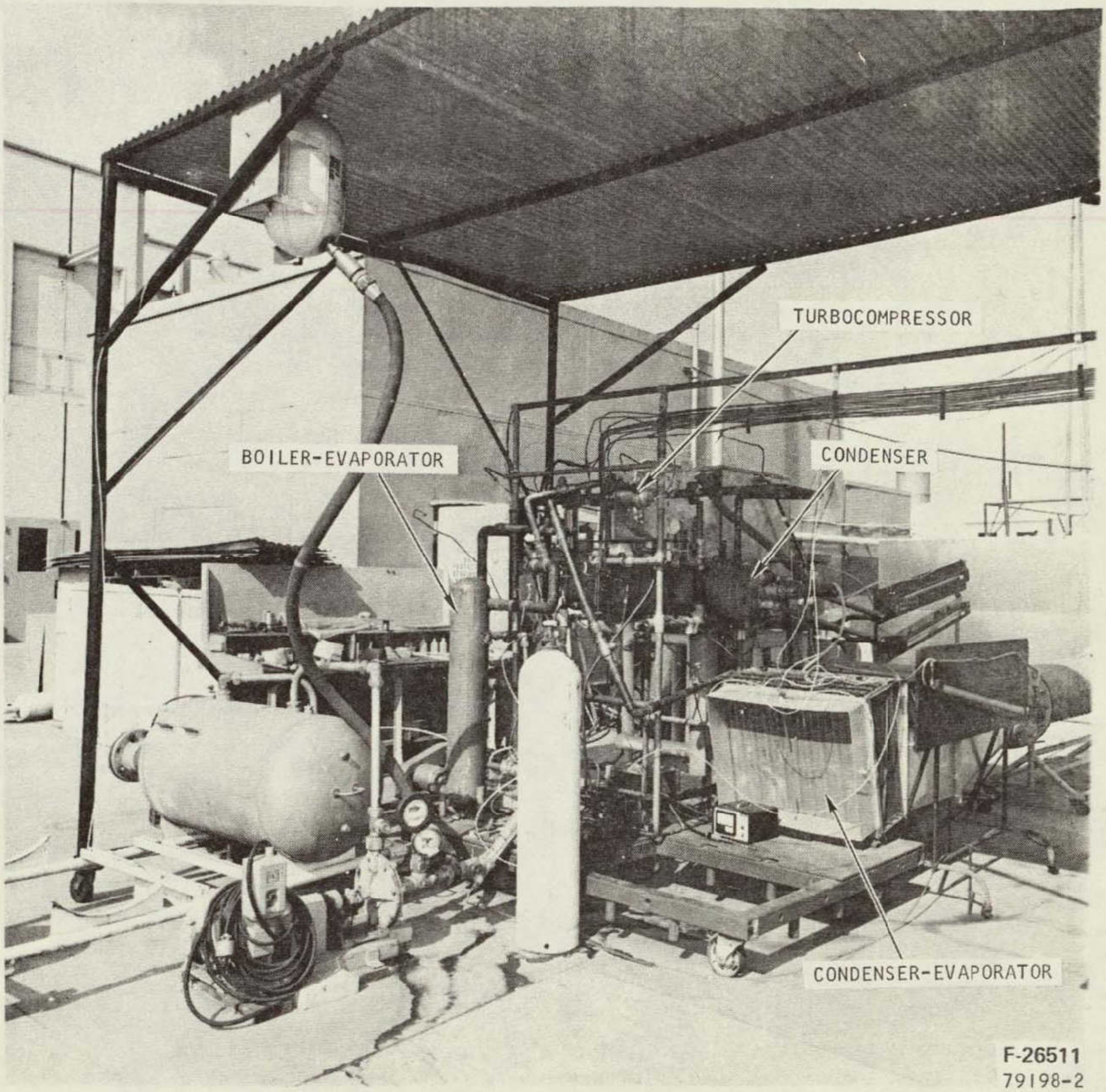

Figure 4-2. 3-Ton Heating and Cooling Laboratory Test System

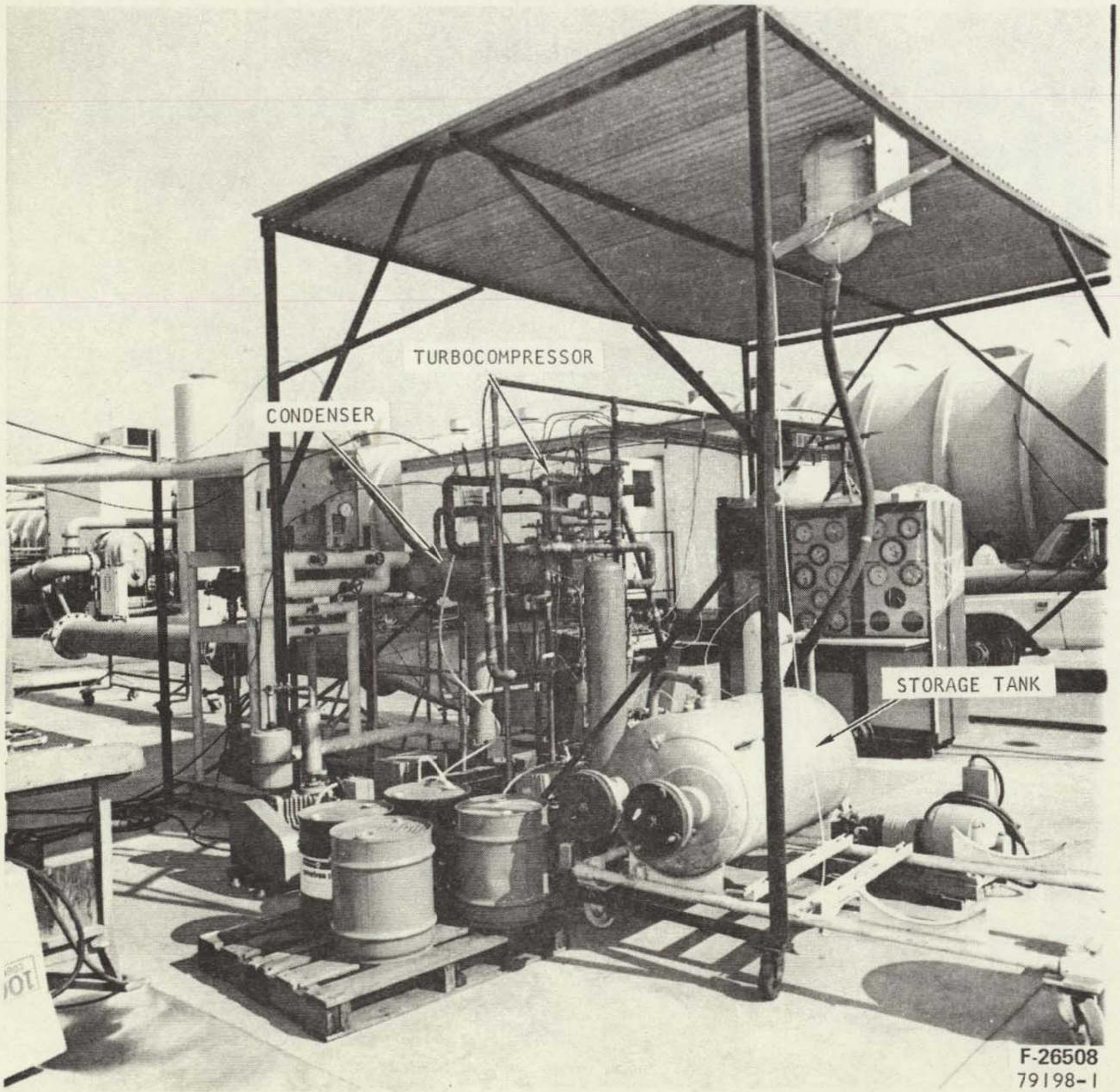

Figure 4-3. 3-Ton Heating and Cooling Laboratory Test System

Cooling passages within the unit were enlarged and an external vent was installed to assure sufficient coolant flow over the journal bearing. The performance of the compressor was satisfactory but the unit was running warm. It was determined that under some operating conditions, no cooling was being supplied to the unit. Modifications were made to the unit to ensure adequate cooling.

Compressor performance testing in the heating mode was then done at 20,000 and 30,000 rpm. Motor controller instability has prevented any extended system testing above 30,000 rpm. The data shows that the wheel chokes at lower flows than predicted and that surge occurs at higher than predicted flows. A diffuser modifications is being made to correct the surge point. This diffuser will be available in January. Figures 4-4 and 4-5 depict the heating-mode laboratory test setup.

(c) <u>75-Ton Unit</u>

All parts are available. The first unit is scheduled for final assembly by mid-January. The inability of subcontractors to perform subassembly tasks on schedule has caused a dealy from the original mid-November date. The major components for this unit were depicted in Figures I through 9 of Status Report 76-13110(12), dated November 10, 1977.

b. <u>Motor Controller</u>

As a result of development efforts in the 3 and 25-ton motor controllers, a patent has been applied for regarding efficiency optimization of line-commutated inverters.

(a) <u>3-Ton Unit</u>

The interface testing of the 3-ton motor controller is continuing. In order to assure continuous load current and eliminate voltage spikes on the inverter switches, the conduction period for the switches are overlapping. The required overlap is a function of load current. The overlap calibration required to run under maximum load has now been completed. The system has now been run at maximum speed and normal load.

The fabrication of first production 3-ton controller is now complete. This unit has been functionally tested using an unloaded motor. It will be tested with nominal load prior to shipment to Dunham-Bush. The fabrication of the second production 3-ton controller is 50% complete.

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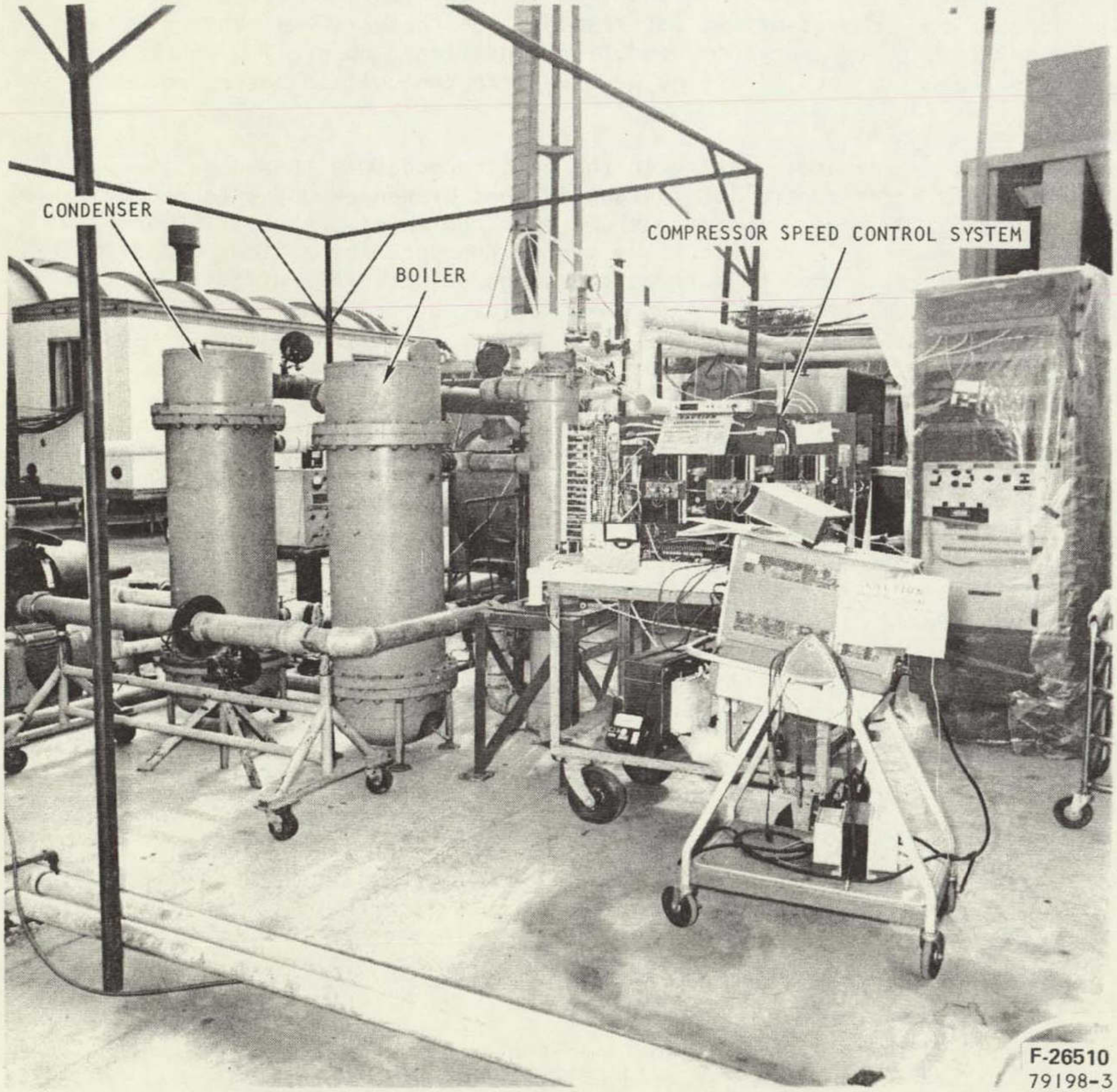

Figure 4-4. 25-Ton Heating Only Laboratory Test System

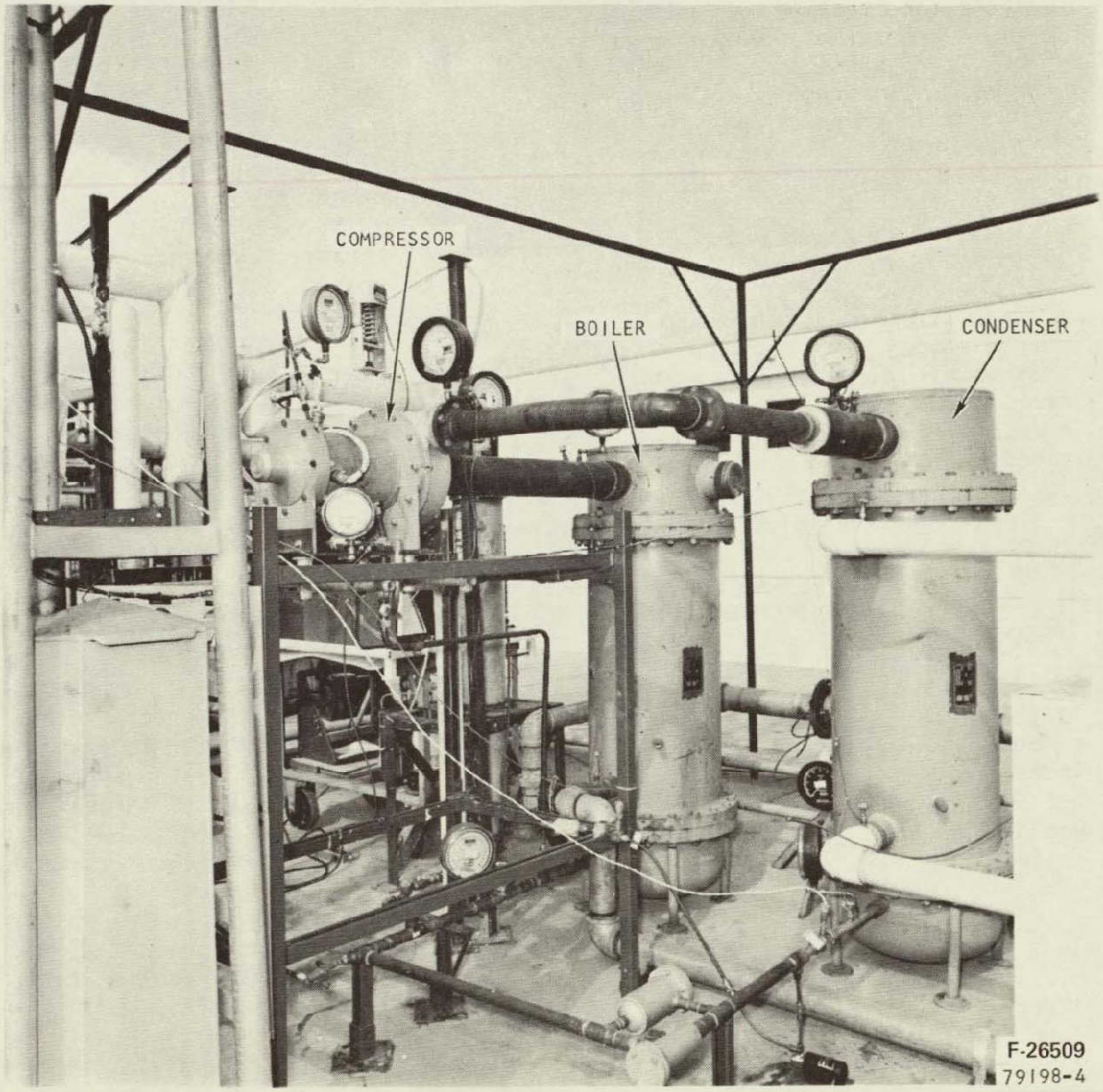

Figure 4-5. 25-Ton Heating Only Laboratory Test System

(b) 25-Ton Unit

Interface testing of the 25-ton controller is continuing. Attempts to operate the motor at maximum speed under nominal load revealed the following problem. The phase control rectifier output ripple frequency beats with the motor current frequency components producing harmonics. The higher beat frequency harmonics are attenuated by the back emf integrator and have little effect on the system operation. The low beat frequency harmonics are reinforced by the integrator and cause modulation of the motor current. This modulation is reflected to the back emf and further reinforced by the integrator.

This modulation causes severe variation of the available commutation time and results in inverter shoot-through.

An attempt was made to use a high pass filter to attenuate the low frequency components. However, the zero had to be placed close enough to the j_ω axis so as not to affect the power factor of the machine at the speed where the commutation mode was shifted from forced commutation to line commutation. As a result, the filtering was not adequate to eliminate the problem at high motor speeds.

The required solution was a high pass filter whose corner frequency could be shifted away from the $j\omega$ axis as the speed increased. Thus, the machine could maintain an adequate power factor at all speeds and the attenuation of the control to low frequency components would be increased as the speed increased.

The implementation of this variable filter caused the integrator output to change as the speed changed. Thus, to maintain control of the inverter, a circuit was developed to track the amplitude of the back emf as the speed increased. This was accomplished by sampling the peaks of the integrated back emf and generating a positive and negative firing-angle control voltage which was proportional to these peaks. These mechanizations effectively minimized the control loop from the loss frequency components.

The controller has now been operated at 40,000 rpm under nominal system load in a current control mode. After further testing, the speed loop instability mentioned in the last report will be resolved. The analysis of the speed instability has been completed and the solution will be tested and incorporated into the production controller.

The first production controller is complete. Testing at nominal load will be accomplished after all system problems have been resolved.

(c) 75-Ton Unit

The fabrication of the 75-ton controller is 95 percent complete. Testing of this controller will commence as soon as a motor is available.

c. System Controller

Five system controllers have been fabricated. Testing of Systems 4 and 5 were completed in December 1977. These five systems will be stored for delivery and final system testing as motors, compressors and motor controllers become available. The schedule build-up of nine system controllers has been stretched out to mid-February. The five available systems will be able to meet all system test and delivery requirements.

d. R-11 Liquid Pump

(a) 3-Ton Unit

The breadboard pump which had accumulated over 1000 hours of operation was reassembled for use in the system tests. Detail drawings for the production pump are complete and 3 pump units have been ordered for delivery in late February.

(b) 25-Ton Unit

Modifications to the pump sideplates to reduce the pressure pulsations in November did not result in any appreciable change. The pump rotor was reworked in December to increase the number of vanes from four to eight. Figures 4-6 and 4-7 show the latest pump configuration. The effect of the rework caused a dramatic reduction in pump noise and pressure pulsations. An endurance test run has been started and 360 hours of operation were accumulated before shutdown for the Christmas holiday. After resolution of the pressure pulsation problem, detail drawings of the production pump were started which are now 25% complete. The motor is presently wound for single-phase, 110 vac power and uses a start/run capacitor. However, the stator is being rewound for 3-phase, 220/440 vac which will improve motor efficiency and eliminate the external capacitors.

(c) 75-Ton Unit

Pumps for 2 commercial heat pumps are being purchased and currently are on order.

d. Heat Pump Subsystems

One single-family and one light commercial heat pump were placed in storage and vendors were requested to cancel undelivered components for these units in accordance with a Change Directive dated 16 December 1977.

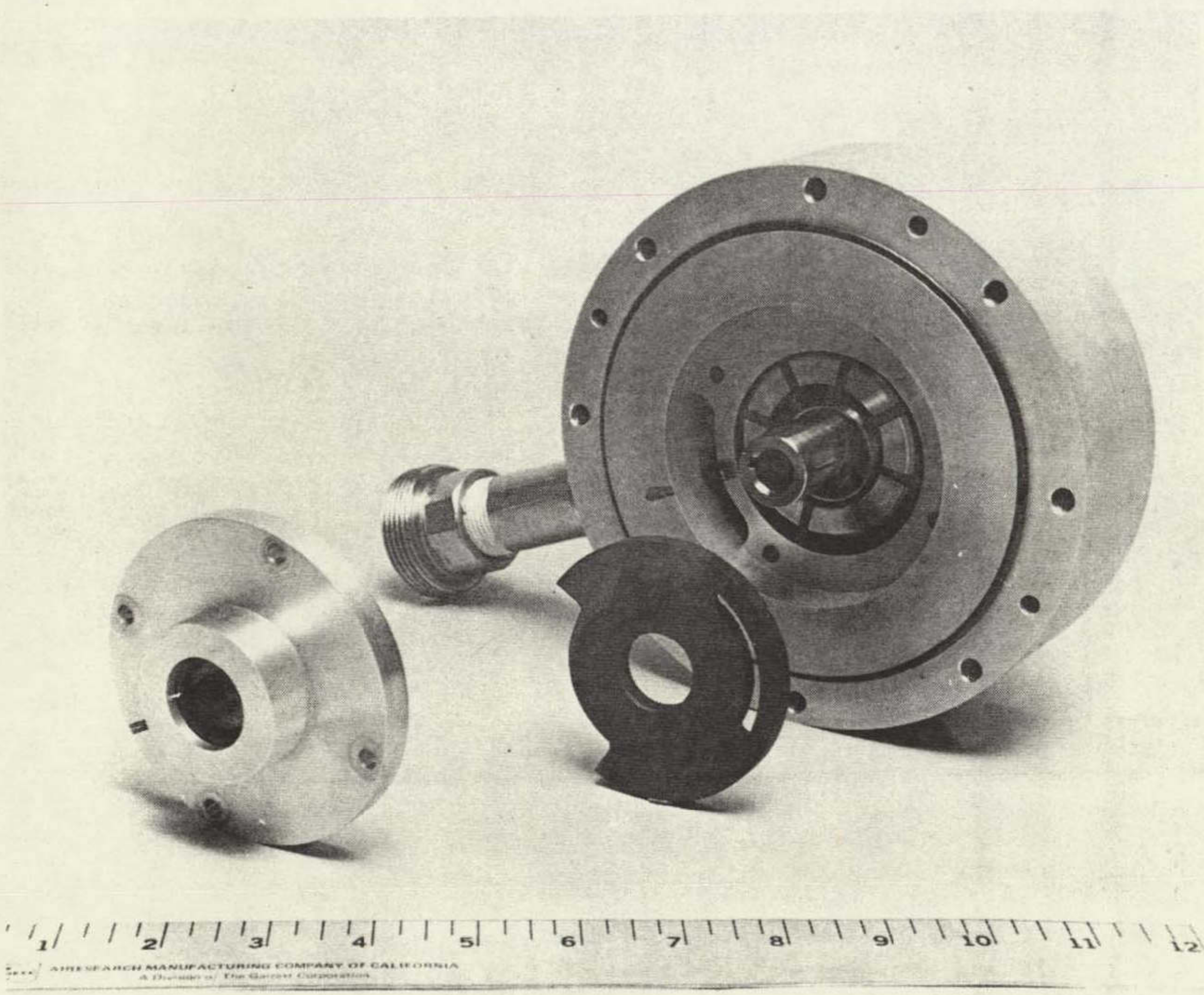

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Figure 4-6. 25-Ton Subsystem Freon Pump

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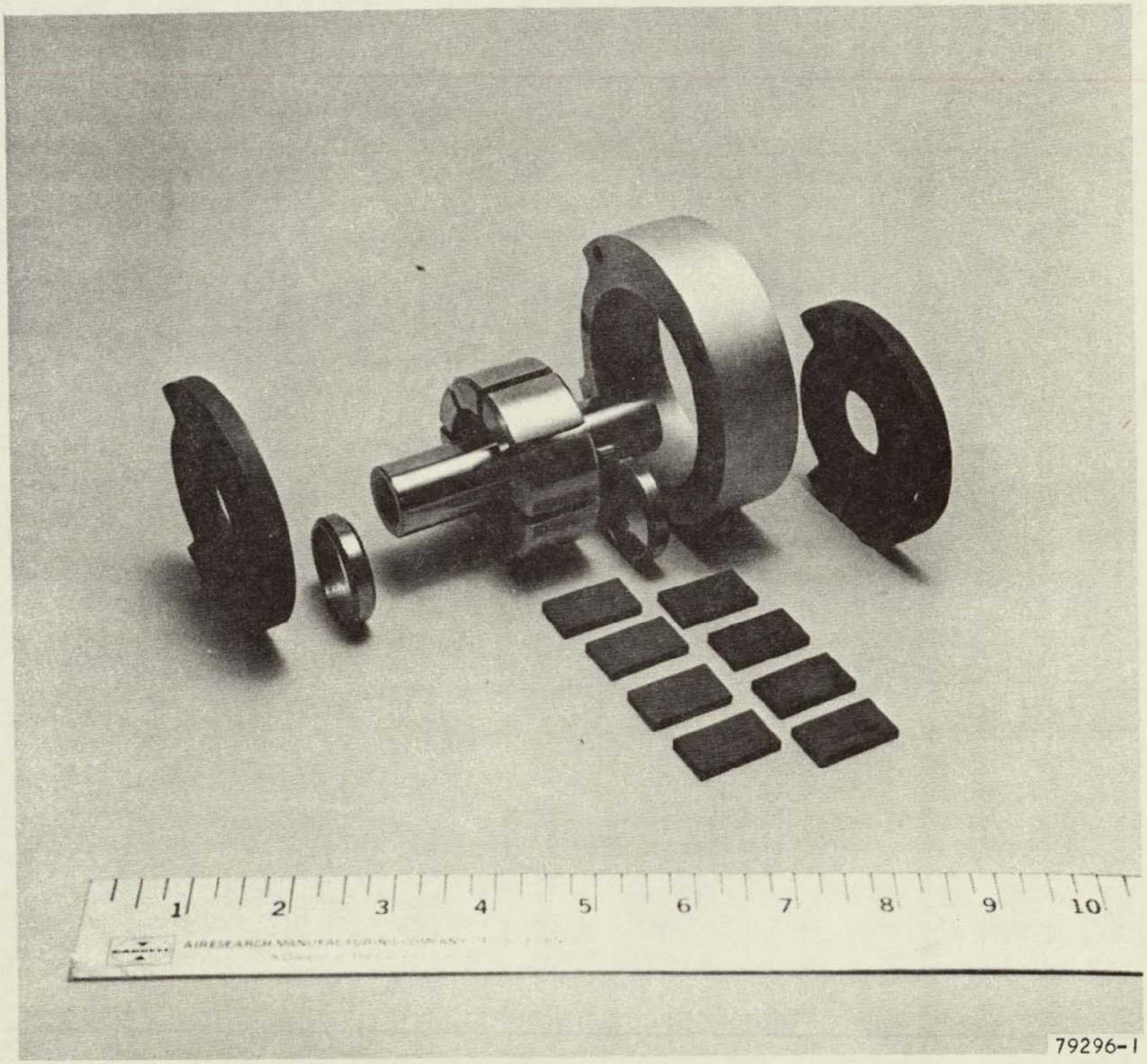

Figure 4-7. 25-Ton Subsystem Freon Pump Rotor, Vanes, Sideplates and Stator

(a) 3-Ton Heat Pump Model 2201288-HC-83

In accordance with a Change Directive dated November 2, 1977, the two prototype heating-only Model 2201288-H-80 units were converted to Model 2201288-HC-83 heating/cooling units. The cabinets and direct expansion coils were assembled on the latter units. Pumps have been mounted and the prototypes are ready for installation of the remaining turbomachinery, controls and piping (refer to Figures 4-8 and 4-9). Two four-way reversing valves were finally received in December. One has been assembled on the 3-ton unit.

(b) 25-Ton Heat Pump Model 2201288-HC-825

The structural frames for the two light commercial units have been assembled. Most of the pumps and heat exchangers have been received.

Figure 4-10 shows the prototype 25-ton heat pump. The one remaining heating-only light commercial heat pump was converted to a heating/cooling model in accordance with the November Change Directive.

(c) 75-Ton Heat Pump Model 2201288-HC-2075

Heat exchangers, pumps, and structural steel have been ordered for the two units. Delivery is scheduled for January. Four-way reversing valves are a delivery problem for this heat pump.

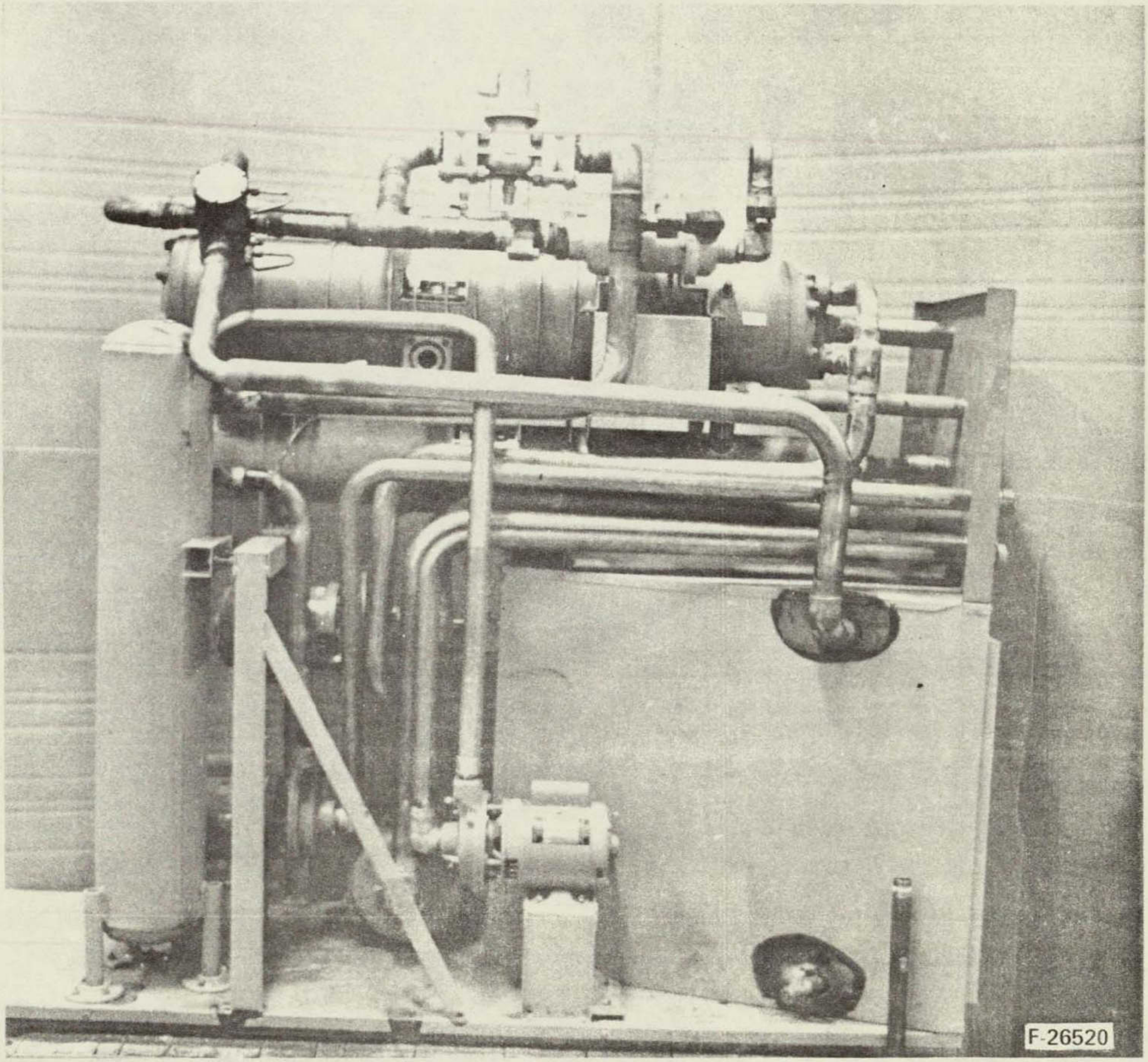

Figure 4-8. 3-Ton Heating and Cooling Subsystem Package

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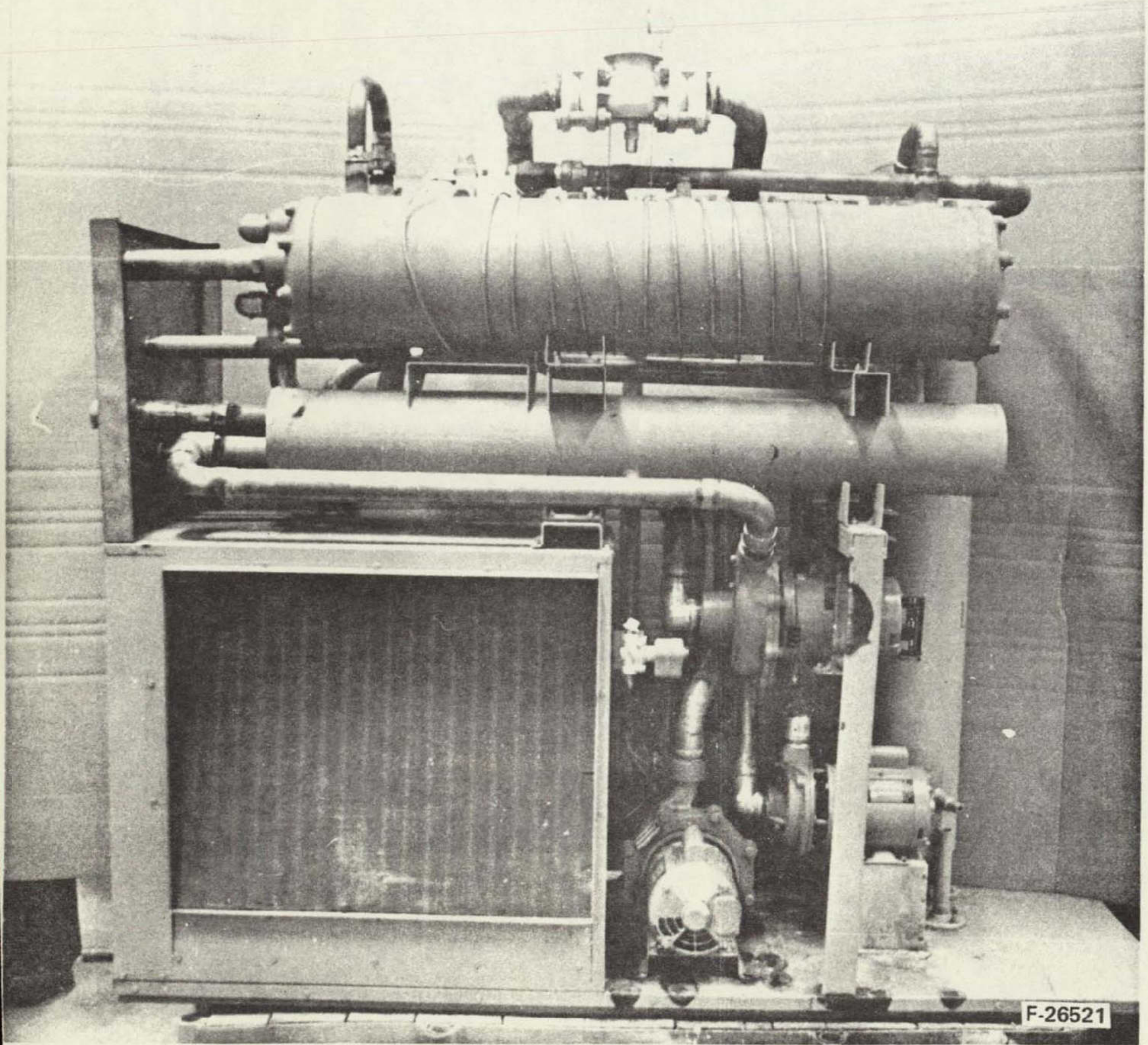

Figure 4-9. 3-Ton Heating and Cooling Subsystem Package (Condenser Side)

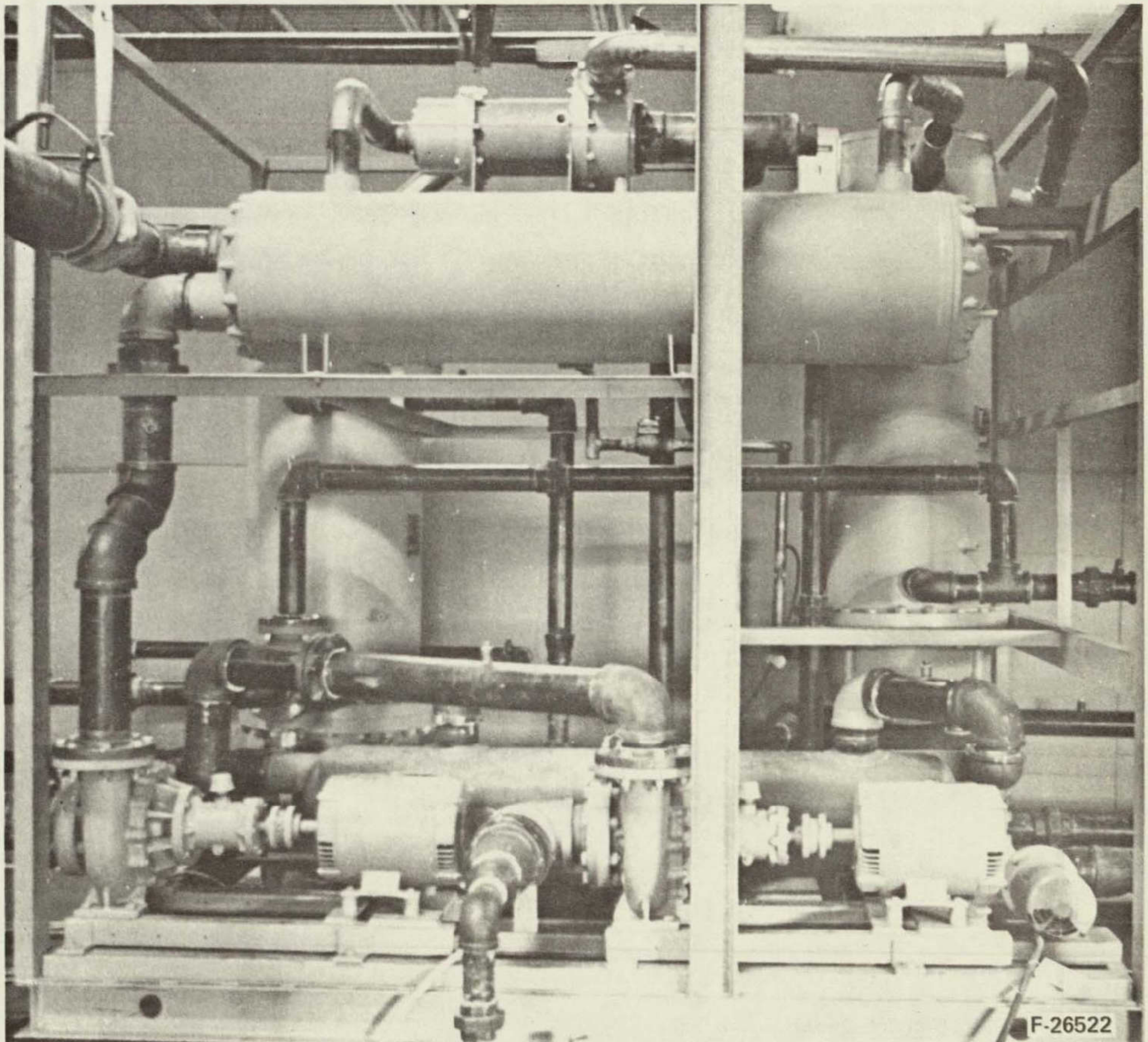

Figure 4-10. 25-Ton Heating and Cooling Subsystem Package

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FUTURE ACTIVITIES

Activities in the next quarter will include the following.

WBS 1.1 Management

1. WBS 1.1.1 Program Direction

   (a) Coordination meetings between NASA and AiResearch will be scheduled as necessary to monitor program costs and progress.

   (b) Commercialization efforts will continue.

   (c) A turbocompressor motor controller meeting will be held in January to review the status of this component.

   (d) Efforts will continue toward completion of site selection and system installation tasks. Coordination and design review meetings will be held with site owner, NADA-DOE and AiResearch as necessary.

   (e) Tasks will be monitored closely to assure that the dates shown in Figure 4-11 are maintained.

2. WBS 1.1.2 Program Planning and Control

   (a) Schedule Development

   A new heat pump component task completion and package delivery schedule has been established. Figure 4-11 that follows presents this schedule.

   (b) Program Documentation

   The following program documents will be prepared.

   (1) DR 500-10, the sixth quarterly report

   (2) DR 500-11, monthly status reports

   (3) DR 500-27, financial management reports (provided monthly)

   (4) Preliminary Instrumentation Plans (PIP) for the Las Vegas, NV, Harrisonburg, VA, Allaire State Park, N.J., and Lawrenceburg, TN.

3. WBS 1.1.3 Quality Assurance

The revised quality assurance plan will be implemented throughout the program.

WBS 1.2 Development

All component development activities will be expedited to coincide with the completion and delivery date shown in Figure 4-11.