TECHNICAL REPORT
71-12-CE

DEVELOPMENT OF A HEAT AND MASS TRANSFER TEST FACILITY

by
R. E. Larson and L. T. Banner

North Star Research
and
Development Institute
Minneapolis, Minnesota

Contract No. DAAG 17-70-C-0048

June 1970

CLOTHING AND PERSONAL LIFE SUPPORT EQUIPMENT LABORATORY
[illegible]

Approved for public release,
distribution unlimited

AD________________

TECHNICAL REPORT
71-12-CE

DESIGN OF A HEAT AND MASS TRANSFER TEST FACILITY

by

R. E. Larson and L. T. Banner
North Star Research and Development Institute
Minneapolis, Minnesota

Contract No. DAAG 17-70-C-0048

Project reference:
1J062110A533

Series: C&PLSEL-80

June, 1970

Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The objective of the program was to design a heat and mass transfer test facility and fabricate a skin-simulator model, which is an important part of the test facility. This facility was designed to allow experimental determinations of the transfer of heat and moisture through composite clothing systems under a variety of simulated external and internal ventilating flow conditions.

INTRODUCTION

During experimental studies carried out for the U. S. Army Natick Laboratories by the Litton Applied Science Division, a heat and mass transfer test facility was designed and fabricated. Various experiments were carried out to measure heat and moisture transport through a standard 8.8-ounce cotton sateen fabric. A description of the test facility is included in the final report on that program.* A similar facility is required for studies to be carried out at Natick. Because the key personnel who carried out these studies are now at North Star Research and Development Institute, Natick Laboratories contracted with North Star to design an improved version of the Litton equipment. In addition, the skin simulator model, which is an integral part of the facility, was to be fabricated.

The research program consisted of two phases:

- o Phase 1 - Design of heat and mass transfer test facility
- o Phase 2 - Fabrication of skin simulator model.

A detailed cost and design analysis was made for all of the components in the test facility and consideration was given to the supporting instrumentation and test components required for the system. The cost data is shown in Table 1. Design drawings were prepared that were adequate for construction of the flow facility with the assistance, and under the supervision, of the principal investigator.

During Phase 2, the skin simulator model components were fabricated and assembled. Included in the skin simulator model is a porous outer surface instrumented with thermocouples, main and guard heater elements, water supply and distribution systems, and temperature instrumentation at selected locations within the skin simulator model.

The details of the facility design, along with specifications for supporting information and cost data, are presented in the following sections of the report.

TEST FACILITY

General Description

The major component of the test facility is a special wind tunnel that has two separate airflow passages. The upper airflow passage directs air over the top of the clothing ensemble, simulating an external airflow. The lower flow passage direcrs air between the clothing ensemble

*Larson, R. E., et. al., Investigations of Heat and Mass (Water Vapor and Liquid) Movement through Clothing Systems, Contract No. DA 19-129-AMC-683(N), U.S. Army Natick Labs Technical Report 69-31-CM (September 1968).

Table 1. Budgetary Cost Data for Heat and Mass Transfer Test Facility

Basic Test Facility	
Wind Tunnel Components	$15,000
Ducting	1,000
Air Conditioning Unit	8,000
Windows (two visual, two high quality)	1,000
Blowers	200
Actuating Valves	800
Instrumentation (pressure, temperature)	1,000
Test Section Probing Components	
Probe Actuating Mechanism	300
Probe Holder	200
Temperature Probe	200
Mass Flux Probe	200
Hot Film Probe	100
Supporting Instrumentation	
Recorder (Hewlett Packard Model 7100B)	1,500
Cold Junction Reference (Pace Eng. Model BRJ-13)	1,000
Thermocouple Switching Unit (Omega Model LTR 4-40)	100
Hot Film System (Thermo Systems, Inc.)	
Monitor and Power Supply (Model 1050)	1,250
Linearizer (Model 1055)	1,050
Hygrometer (Modern Controls Model IRD2)	6,500
Water Supply System (flow meters, valves, tubing)	300
Control System for Simulator	500
Total Estimated Cost (March 1970)	$40,200

and the skin simulator model, simulating an internal ventilating flow. Provisions are included to allow independent variation of the flow velocities through the two channels. Temperature and pressure instrumentation are placed in both channels to monitor the conditions of the entering airflows.

An overall view of the facility is shown in Figure 1. In essence, it is a two-channel wind tunnel incorporating a special air-conditioning unit to deliver a wide range of temperature and humidity conditions in the two streams. An outline specification of the air-conditioning unit giving the extreme values of temperature and humidity in each stream is presented in Table 2. Shown in Figure 2 is a schematic drawing of the air-conditioning unit.

The test facility is designed to simulate conditions over a range representative of Arctic to tropical environments. The secondary flow, which can be considered as simulating conditions in a ventilated suit, is designed to heat or cool as required, depending upon the specific external environmental conditions. In both flows, water vapor concentration may be varied to give humidity conditions over the full temperature range from essentially "dry" to saturated.

Air circulation is provided by two centrifugal blowers; flow control is by two electro-pneumatically operated rubber-lined butterfly valves. The flow diversion valves are manually operated, rubber-lined, butterfly valves.

Test Section

Basically, the test section consists of a rectangular channel with two flow passages; the separation of the two air streams is maintained by the fabric sample. The sample is mounted in a frame and held in place by a forward anchoring clamp and a rearward tensioning device. Provision is made for sealing along the sides of the frame. The unit is formed of aluminum plate, screwed together; the permanent joints are sealed with epoxy cement. Minor components are either aluminum or stainless steel. Both side walls are removable, facilitating installation of the fabric sample and instrumentation probes.

Actuation Mechanism

The bottom panel of the test section has a rectangular opening into which the skin simulator model is inserted. The skin simulator model is carried on an actuating device working through a handwheel-operated jack screw. The complete actuator assembly is attached to, and becomes an integral part of, the test section. Skin-to-clothing gaps from zero (contact) to a maximum of 1.7 inches may be obtained. Design drawings of the test section and actuating mechanism are shown in Figures 3 and 4.

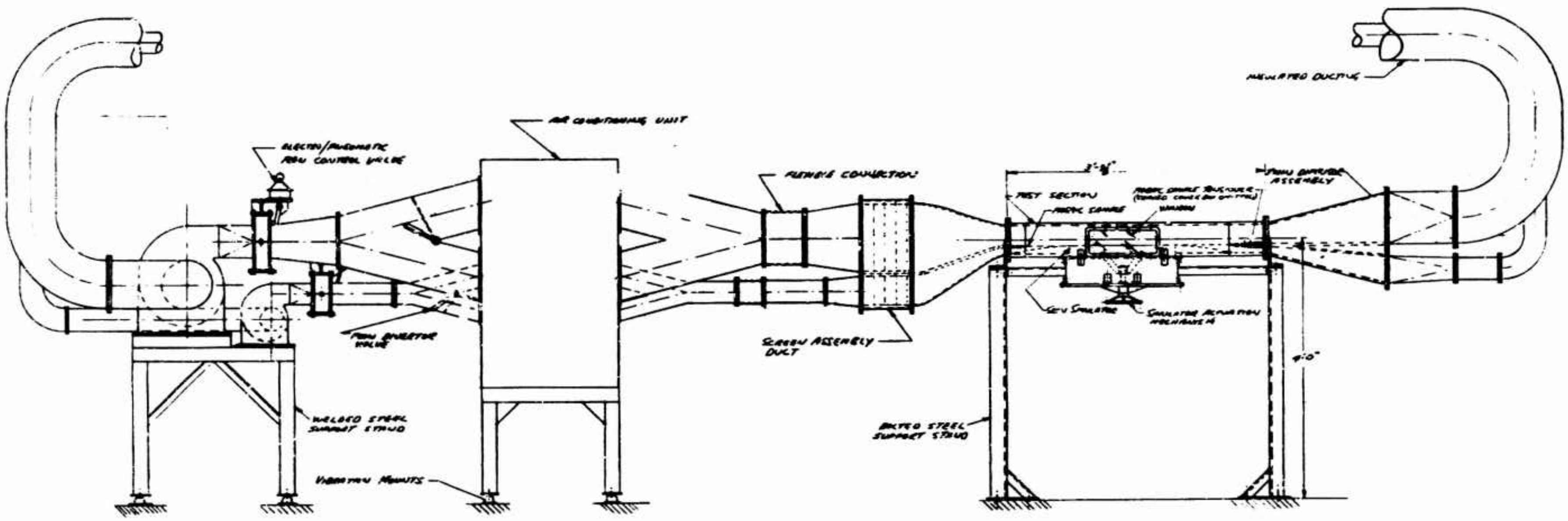


FIGURE 1. OVERALL VIEW OF TEST FACILITY

Table 2. Specifications for Air Conditioning/Refrigeration Unit

1. General

Integral air conditioning/refrigeration unit to supply two sources of air to closed circuit wind tunnel.

Unit to contain humidifier and to extract moisture injected at maximum rate of one gallon per hour into test section downstream of unit.

2. Flow Rates

Channel #1	800 cfm max
Channel #2	200 cfm max

3. Temperature Range (°F)

Heating cycle:	Channel #1	Inlet 100	Outlet 120
	Channel #2	Inlet 100	Outlet 50
Cooling cycle:	Channel #1	Inlet 20	Outlet -40
	Channel #2	Inlet 20	Outlet 120

Unit also to be capable of bringing room temperature air to working temperature range in reasonable time, 30 min max.

4. Humidity Range

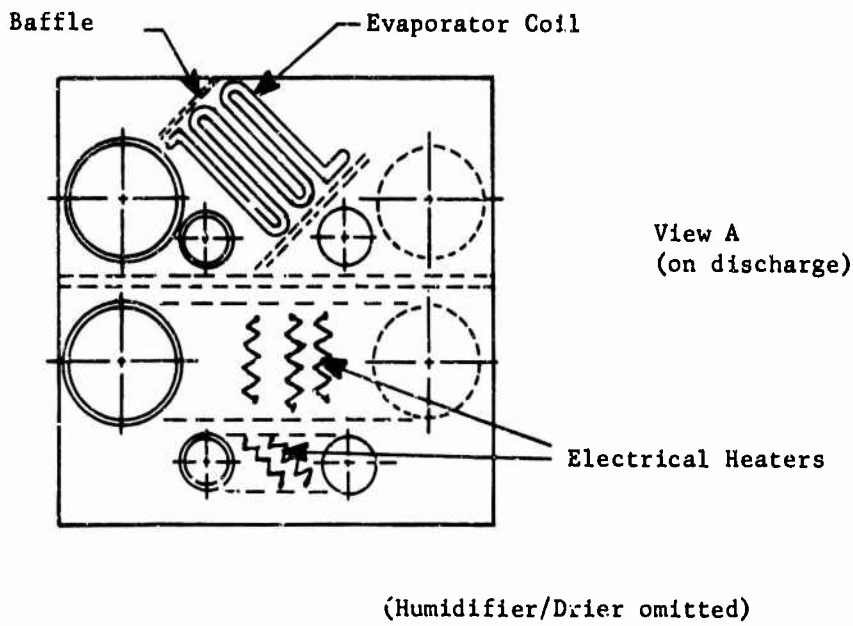
Saturated to "dry" over full temperature range on both delivered air streams.

5. Pressure Drop

Estimated pressure drop data to be supplied with quotation. Measured drop on or before delivery.

6. Controls and Instrumentacion

All normal operational controls, switches, and safety devices to be supplied. Instrumentation by purchaser for temperature, humidity, and airflow rates.



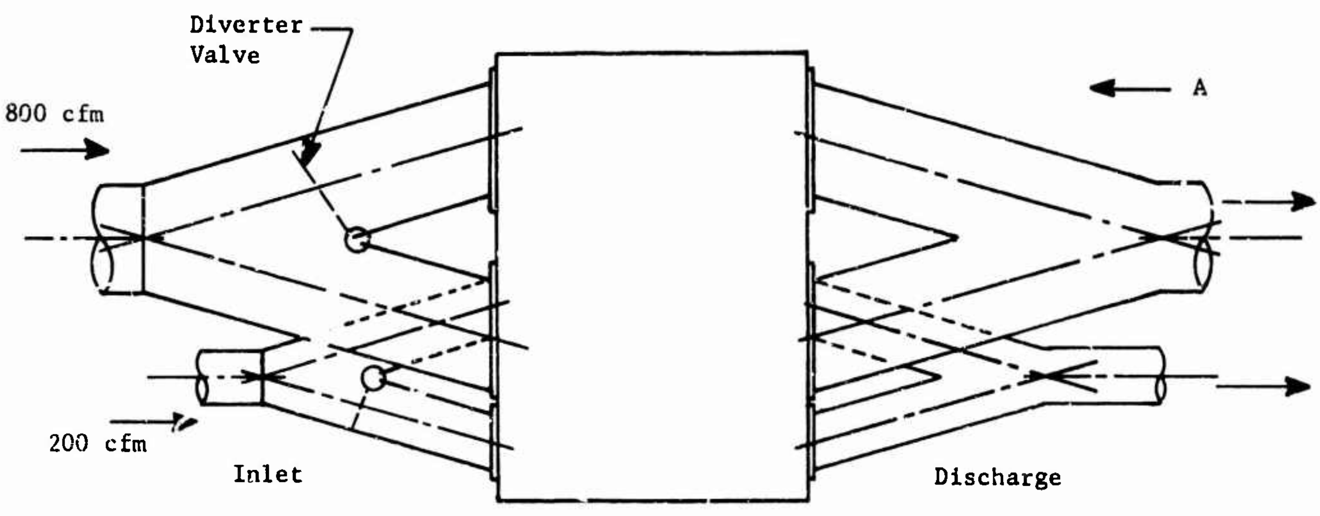


FIGURE 2. SCHEMATIC DRAWING OF AIR CONDITIONING UNIT

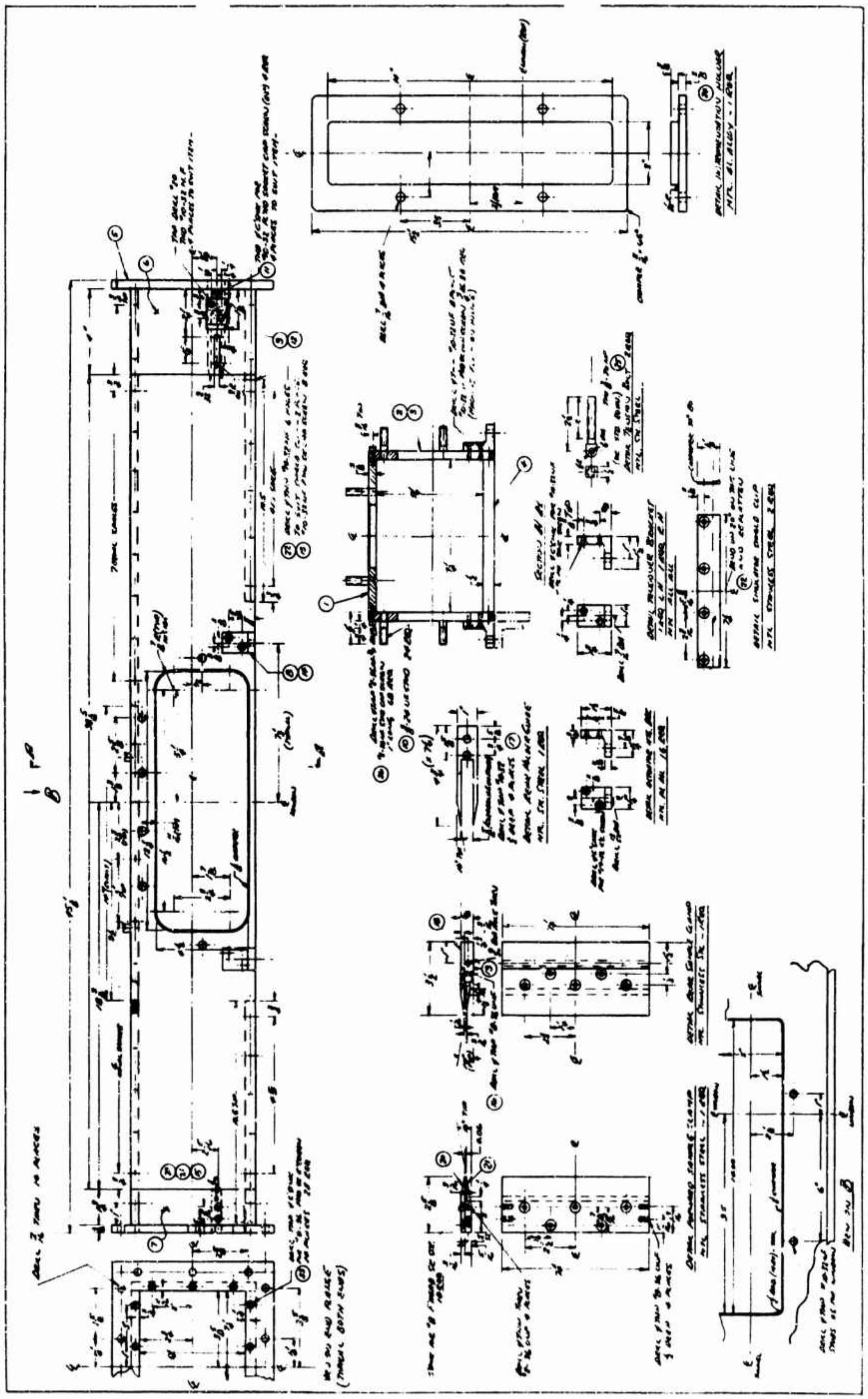


FIGURE 3. TEST SECTION

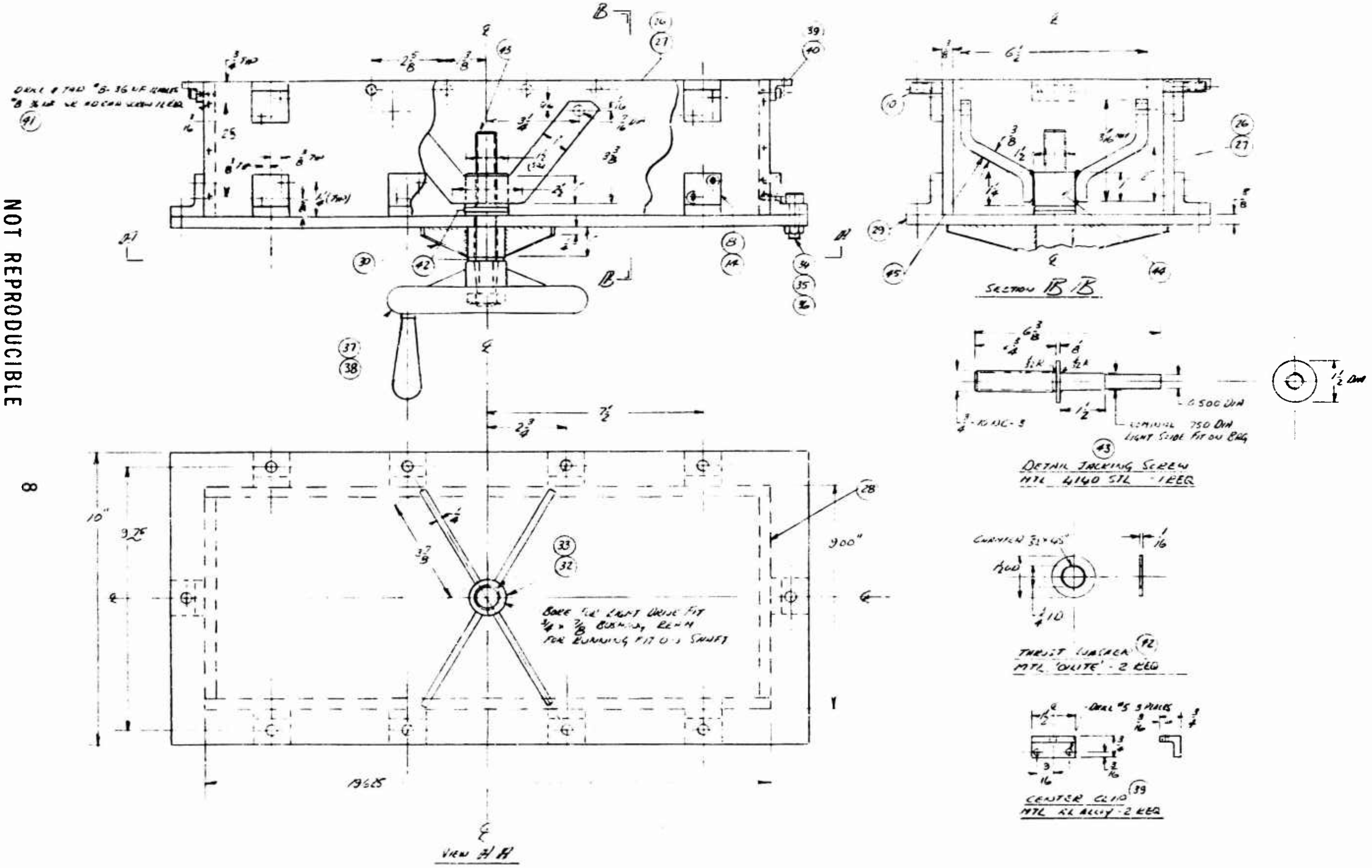


FIGURE 4. SKIN SIMULATOR ACTUATING MECHANISM

General Remarks

Observations of the flow may be made on a routine visual basis, or with an interferometer. For the former, a set of plate glass windows is used, and for the latter, a set of optical-quality quartz windows is available.

A probe-traversing device is carried on a removable insert which is, in turn, mounted on the upper test section wall. This probe-traversing device incorporates a dial micrometer gage, enabling positioning to an accuracy of 0.0001-inch.

Following usual wind tunnel design practices, the facility incorporates an aerodynamically designed diffuser and inlet contraction, both of which incorporate flow separators.

Four screens are spaced immediately upstream from the contraction. Their purpose is to reduce gross turbulence to a level commensurate with the need to simulate atmospheric flow conditions.

The remainder of the facility reflects typical wind tunnel design practice, except that the return ducting is insulated to prevent heat loss or gain, depending on test configuration.

SKIN SIMULATOR MODEL

An assembly drawing of the skin simulator model is shown in Figure 5. The simulator has been designed so that it may be completely disassembled to effect any necessary repairs -- particularly heater unit replacement necessitated by burnout.

The fundamental element of the model is a sintered metal porous upper surface, which corresponds to the skin. Simulation of perspiration is provided by a water supply and distribution system to induce a uniform transpiration rate over the test area. A series of electrical heaters to simulate energy input to the skin layer from the body and to control temperature and minimize heat loss comprise the remainder of the simulator model.

The simulator is divided into three lengthwise sections: the center section is the testing section proper (see Figure 6). The upstream and downstream segments serve to establish uniform temperatures on the surface and control the oncoming and departing air flows.

Extraneous heat losses from the testing section are essentially eliminated by a primary guard heater placed under the main heater and separated from it by a teflon slab; and by peripheral heaters also located on inward-facing teflon slabs. The teflon slabs provide thermal insulation and permit a zero temperature gradient to be established across them by the guard heaters. These conditions indicate zero heat flow, and

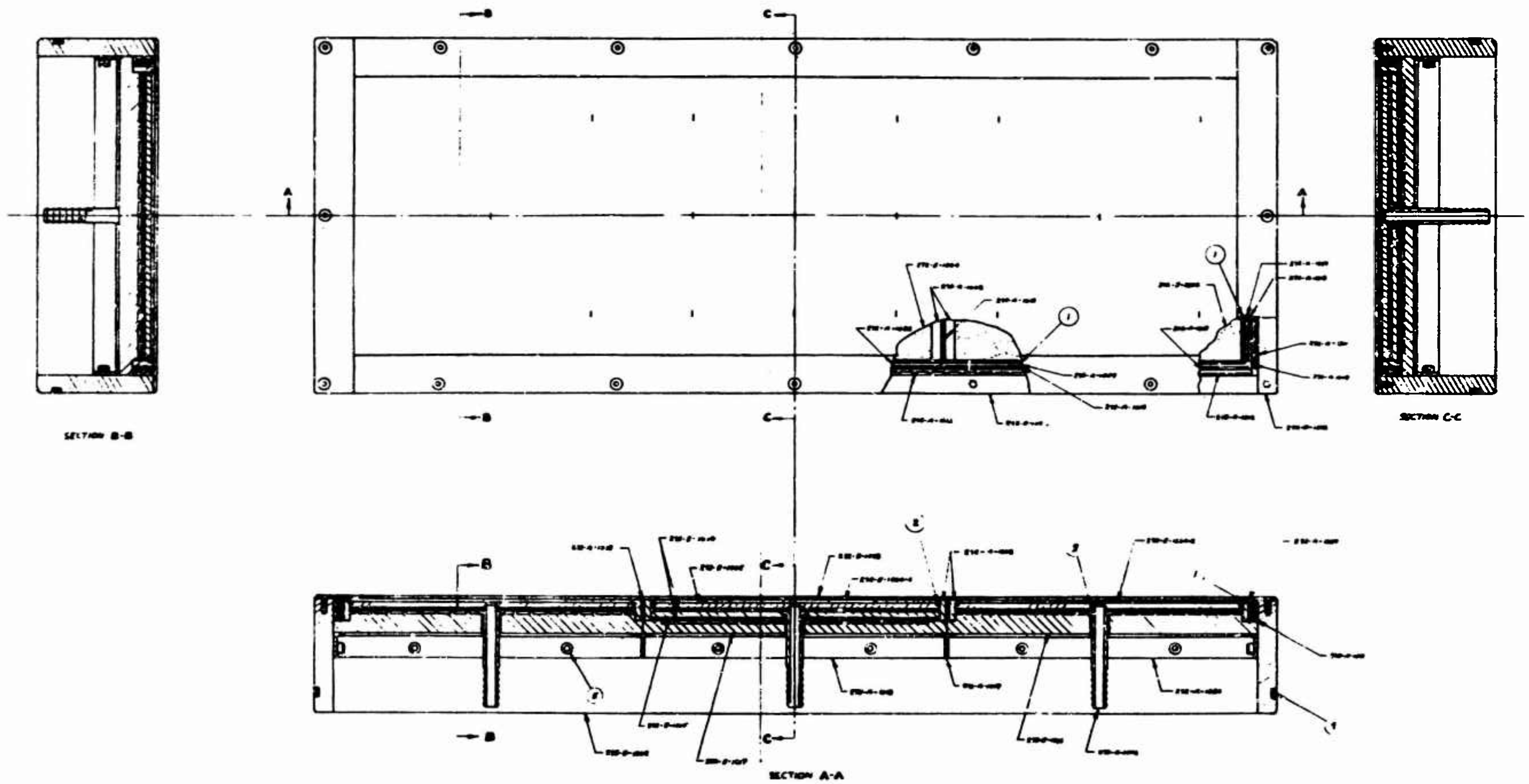


FIGURE 5. SKIN SIMULATOR MODEL ASSEMBLY DRAWING

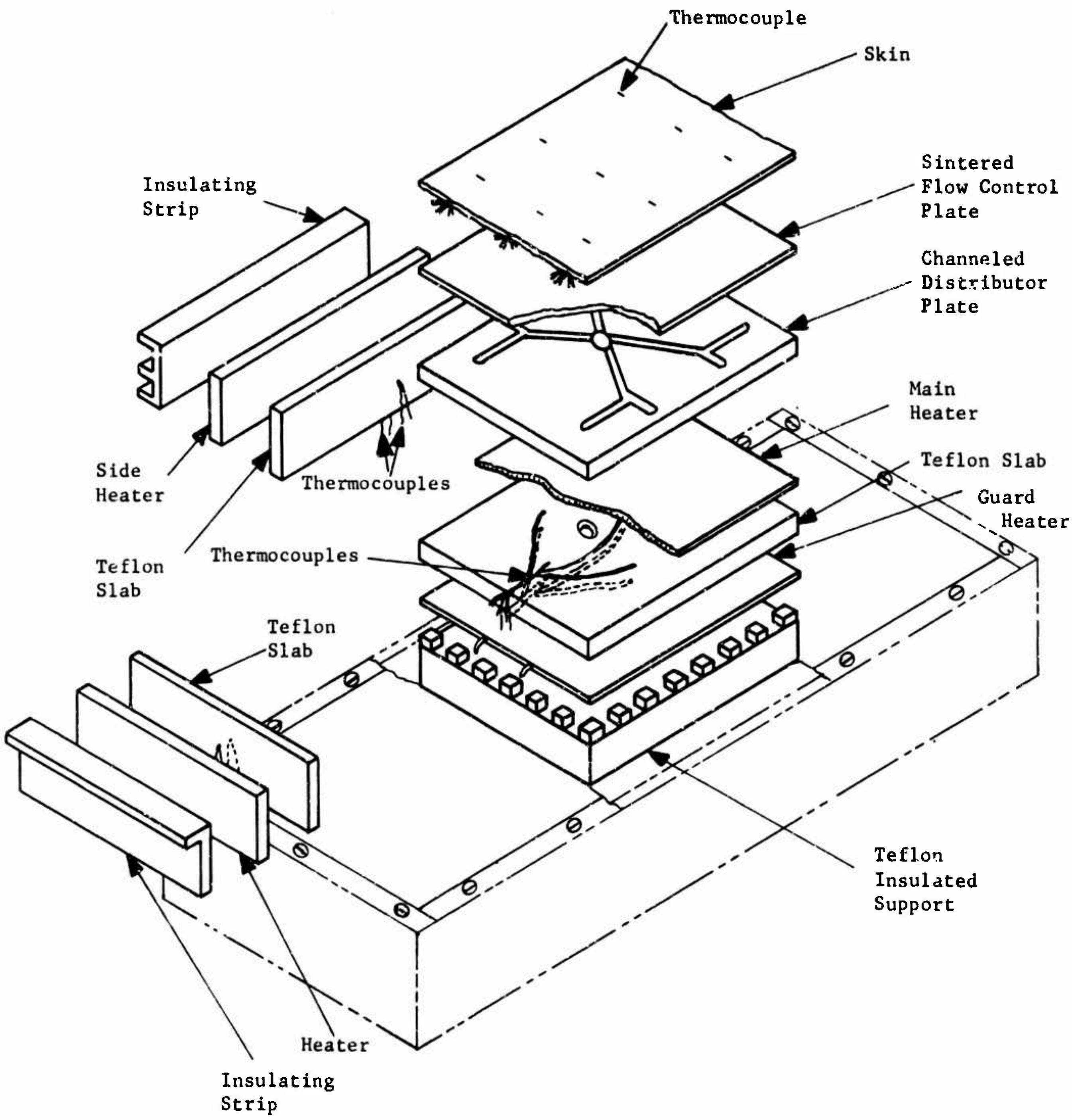


FIGURE 6. CENTER TEST PANEL OF SKIN SIMULATOR MODEL

therefore zero loss, which in turn indicate that all of the energy from the main heating element will pass through the skin segment. From there, the energy is transferred to the air layer and through the clothing sample by a combined process of conduction and convection.

Additional heaters under the forward and rearward skin panels, along the forward and rear sides, and the leading and trailing edges do not act as guard heaters as such, but are used to establish transverse and longitudinal temperature uniformity.

The main water supply is gravity fed and controlled with an adjustable-height stand pipe. The flow rates to each section are controlled by needle valves and measured by flow meters. Uniformity of distribution is ensured by a channelled plate in conjunction with a secondary sintered metal panel in each section, located against the under surface of the main porous plate (skin).

INSTRUMENTATION

Measurement

Properties in the two streams are measured by standard pitot-static and thermocouple probes. Humidity is measured using either mass-flux probes that direct a portion of the flow to a hygrometer, or by thin-film elements located in the probe itself. This latter method will require further development.

Temperatures on the skin simulator surface are measured by 19 fine (0.005-inch diameter) copper-constantan thermocouples, of which nine are in the center testing section. A schematic diagram of the instrumentation is presented in Figure 7.

Details of thermocouple installation are shown in Figure 8. It will be noted that the length-to-diameter ratio of the lead from the junction is in excess of 10. It will also be noted that the insulation comes to the bottom of the groove. Intimate contact is effected through epoxied connections to the plate. All of these features will ensure accurate sensing. Additional thermocouples are used to monitor the guard heater slabs and provide indications of internal temperatures.

Measurements of the temperature, water vapor concentration, and velocity as gradients above the skin are made as suggested previously, with probes carried on a traversing head. The probe holder may be positioned at several streamwise locations to determine longitudinal variations in the foregoing properties.

Additional measurements may be made by interferometric methods, for which purpose the facility has been made compatible with the Mach-Zehnder interferometer at Natick.

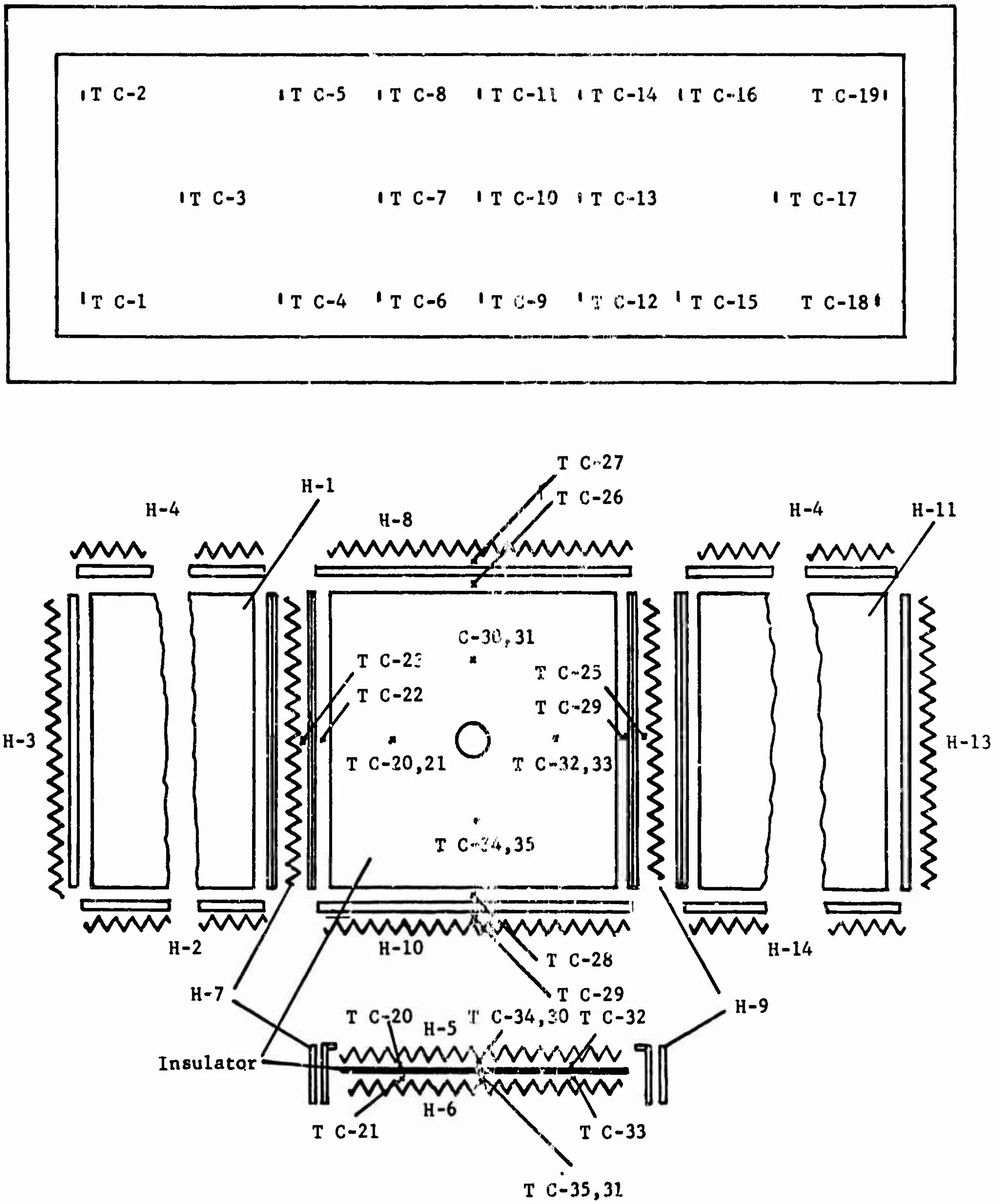


FIGURE 7. INSTRUMENTATION DIAGRAM FOR SKIN SIMULATOR UNIT

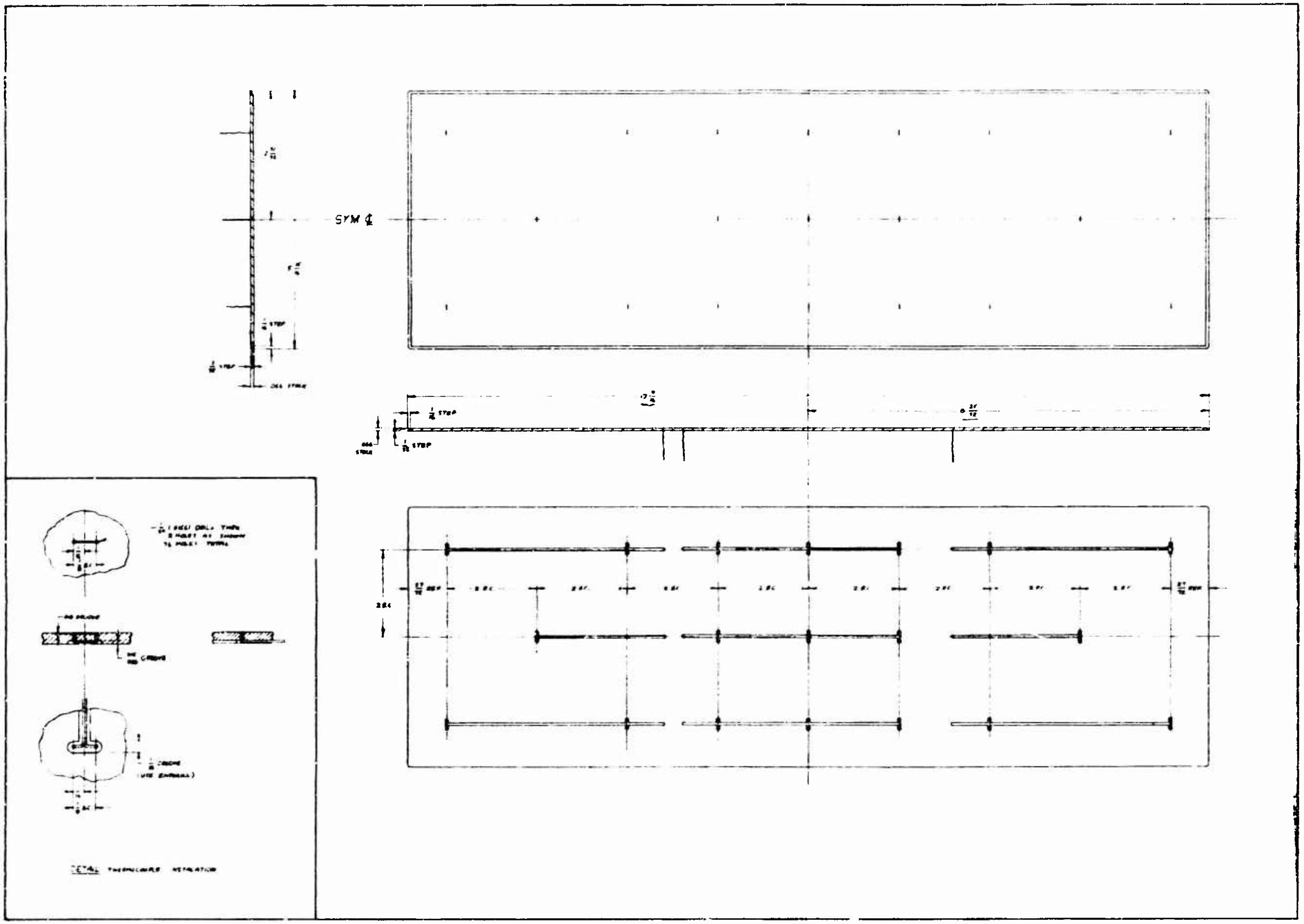


FIGURE 8. INSTRUMENTATION DRAWING FOR SURFACE OF SKIN SIMULATOR

Control Circuitry

An important part of the facility will be the electronic circuitry that is required to control the heat dissipation in the skin-simulator unit and measure the temperatures, both on the skin simulator surface and internally in the unit. Because of advances in integrated circuitry, it will be possible to build a unit that will be capable of automatic control of energy dissipation. To minimize interference with the operation of other system electronic circuitry, dc power was selected for use in the simulator model.

During the experiments carried out at the Litton Applied Science Division, it was found that one convenient mode of operation was to maintain the skin simulator surface temperature at a selected value and measure the changes in electrical-energy dissipation as the external and internal flow conditions were changed. These studies, along with other heat and mass transfer investigations carried out on flat plates, show that the heat and mass transfer coefficients vary in the streamwise direction. The maintenance of a constant temperature in the streamwise direction would require a continuous variation of heat generation at each station along the surface in the flow direction. As a reasonable compromise, the porous plate is divided into three segments, each with an independent power control system.

Figure 9 shows the main and guard heater power input control systems. A single dc power supply provides energy for both the main and guard-heater systems. The thermocouples on the skin simulator surface elements direct their outputs into integrated circuits. These circuits activate silicon-controlled rectifiers, which vary the power dissipated in each element. The power dissipated in each element is measured using integrated circuitry, and the power indications are directed into a switching unit.

Also shown in Figure 9, are the guard-heater control system (represented by a single circuit). The guard-heater system will consist of three guard heaters positioned below the three main heaters, three guard heaters on each side of the skin simulator and one guard heater at the leading and one at the trailing edge of the simulator. To minimize the complexity of the power control systems, the front, middle, and rear guard heater pairs on each side of the simulator will be connected in parallel. It can be anticipated that spanwise symmetry will exist in the unit, and it will not be necessary to provide independent control for each side. However, independent control will be required for the front and rear guard-heater units.

The temperature indications on both sides of an insulating layer separating the guard heaters from the porous plate are directed into an integrated circuit. A signal proportional to this temperature difference drives a silicon-controlled rectifier, which varies the power dissipated in the guard heater to maintain a zero temperature difference across the insulating layer.

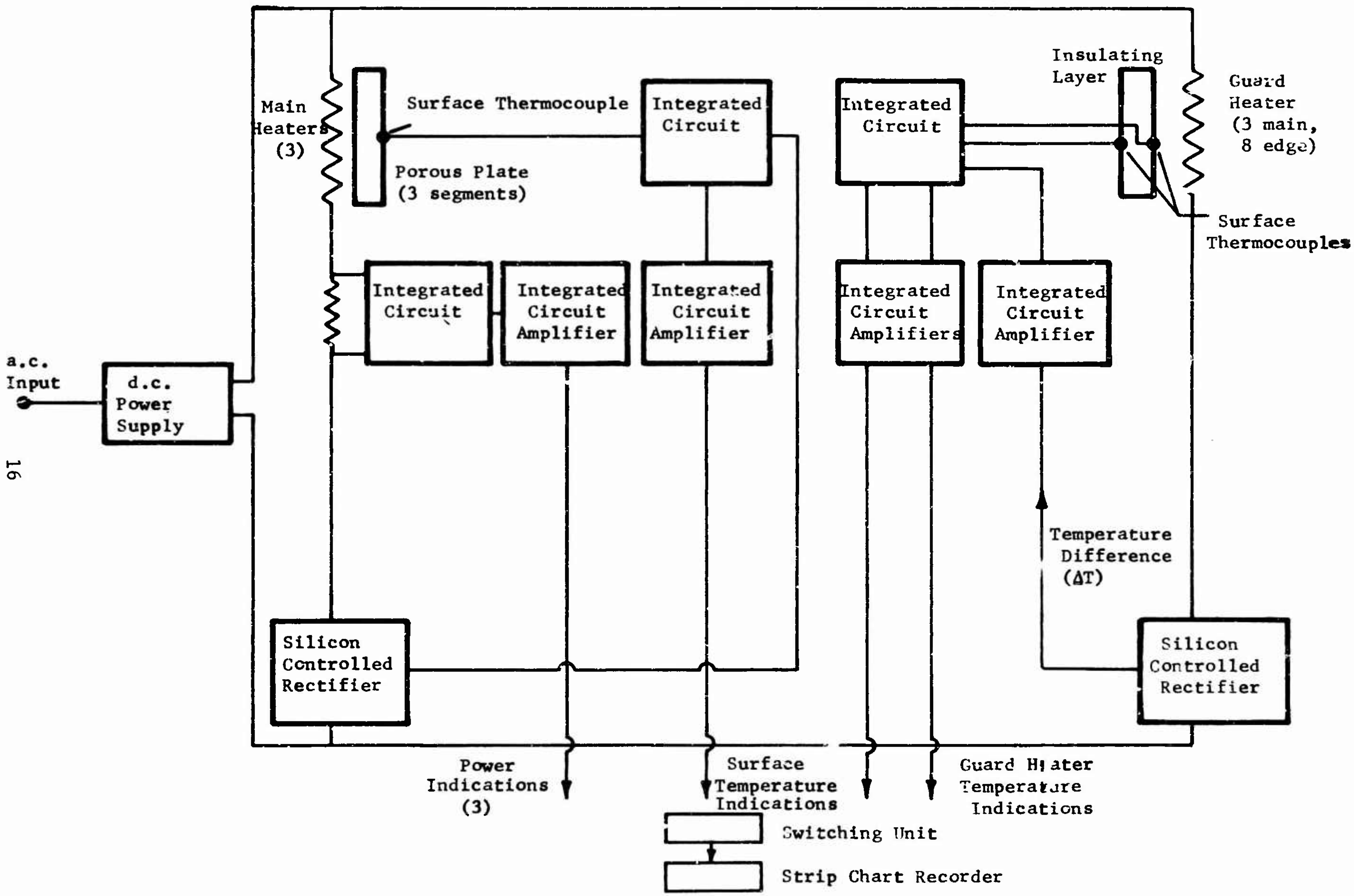


FIGURE 9. MAIN AND GUARD HEATER TEMPERATURE INDICATION AND CONTROL SYSTEMS

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) North Star Research and Development Institute Minneapolis, Minn.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Design of a Heat and Mass Transfer Test Facility

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final

5. AUTHOR(S) (First name, middle initial, last name)

R. E. Larson, and L. T. Banner

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June, 1970	16	None

8a. CONTRACT OR GRANT NO. DAAG 17-70-C-0048	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 1J062110A533	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	71-12-CE (C&PLSEL-80)

10. DISTRIBUTION STATEMENT

Approved for public release, distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Natick Laboratories Natick, Mass.

13. ABSTRACT

The objective of the program was to design a heat and mass transfer test facility and fabricate a skin-simulator model, which is an important part of the test facility. This facility was designed to allow experimental determinations of the transfer of heat and moisture through composite clothing systems under a variety of simulated external and internal ventilating flow conditions.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Design	8				8	
Fabrication					8	
Cost analysis	8				8	
Test facilities	4		8		9	
Heat transfer	4		4			
Mass transfer	4		4			
Tests	4		4			
Simulation			8		4	
Skin (anatomy)			9		4	

Unclassified
Security Classification