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WELSON & CO., INC.
HARTFORD, CONN.

BW-250

FINAL REPORT

For The

SUIT GLOVE ADVANCED THERMAL PROTECTION PROGRAM

CONTRACT No. NAS 9-11231

1 APRIL 1971

Prepared For The:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
CREW SYSTEMS DIVISION
HOUSTON, TEXAS 77058

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1.0 INTRODUCTION

Current extra vehicular gloves provide thermal protection to the wearer at a sacrifice to mobility comfort and durability. The object of the program, SUIT GLOVE ADVANCED THERMAL PROTECTION, Contract NAS 9-11231, was to investigate alternate thermal conditioning techniques which would allow increased mobility, thermal performance, and greater tactility of the glove.

The program was structured into four major phases in which the study and design effort was concentrated. The first phase consisted of an evaluation of all feasible techniques for active and passive heat transfer from the glove. At the conclusion of Phase A, a report was submitted, indicating two possible approaches consisting of a wire braid/tygon tubing technique and a metal bladder/tygon tubing concept for the active cooling provisions. The overglove designs included a "lobster shell" approach as well as the standard metal cloth design used in the present A7L glove system. During Phase B, these thermal protective assemblies were designed in detail and fabricated for test in Phase C. The results of those tests and the conclusion are presented herein.

The final phase of the program was to have been concerned with the incorporation of all the desirable features gained through the design and testing data. Instead, emphasis was placed upon the possiblity of using a passive approach for thermal insulation. To that end, a glove system was fabricated and tested utilizing ensolite padding at the points of grasp. It was found however, that this approach was not satisfactory in light of the performance of the active systems.

Included in this report in sections 2.0 and 3.0 are the summary findings of this program for the active systems. Section 4.0 presents the data pertinent to the passive system.

2.0 DESIGN CONCEPTS

In Phase A, the design of the Advanced Thermal Protective Glove was divided into two areas; 1) Design of the Active Cooling System and 2) Design of the Overglove. Concept feasibility was determined early in the program through tests conducted on glove finger elements. The results of these preliminary tests are well documented in the monthly progress and the Phase A Reports. The following paragraphs describe the concepts selected for continuation through program development and testing.

2.1 ACTIVE COOLING SYSTEM

The glove active cooling system is an extension of the Liquid Cooling Garment water loop to include the Extravehicular Pressure Glove Assembly. The glove designs pursued during this program assumed an available water flow of 17 pounds per hour to each glove. The glove interface with the LCG was assumed to be within the pressure envelope of the pressure garment assembly so that all connections could be made prior to pressurizing the suit. Figure 1 presents a general schematic of the system. All active system designs considered during this program were of a type mounted on the exterior surface of the glove bladder and were intended to maintain bladder temperatures within safe operating limits.

Two active cooling system designs evolved during the program and were carried through the design, development, and testing phases of the program. The concepts, known as 1) metal finger bladders and 2) metal braid finger elements, differ only in the finger element design and share the same design for the glove penetration, manifold, and palm cooling element. A brief description of these designs follows:

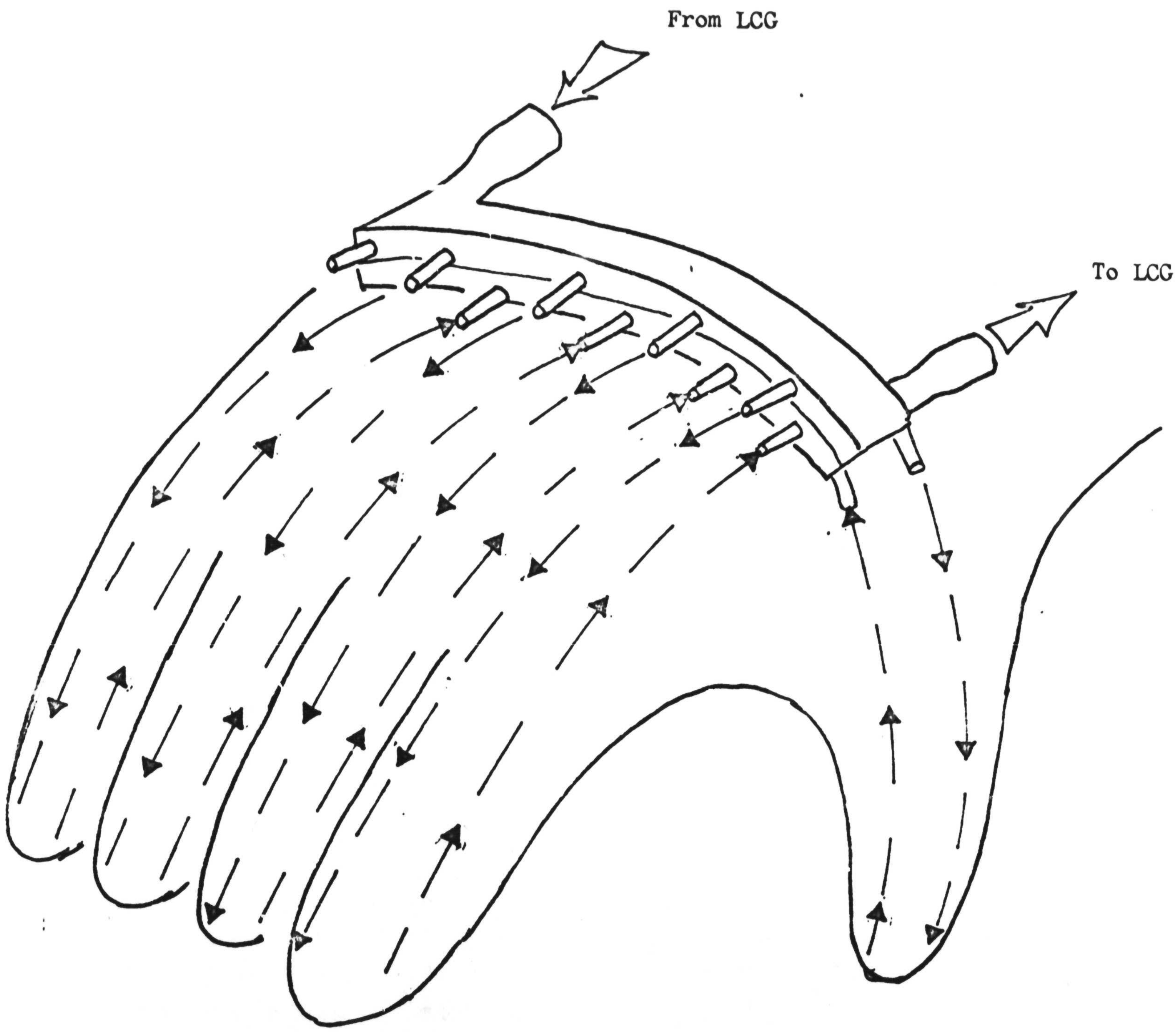


FIGURE 1 ACTIVE COOLING SYSTEM

2.1 ACTIVE COOLING SYSTEM (CONT'D)

a. Glove Penetration - The inlet and outlet water lines penetrate the pressure bladder through the first convolute adjacent to the glove disconnect. A special mounting plate with two contoured $\frac{1}{4}$ inch stainless steel tubes was secured to the glove disconnect with two machine screws. A sealant was applied to the installation to prevent air leakage.

b. Manifold - A pressure drop test was conducted to compare a series connected finger element configuration to a configuration of finger elements connected in parallel by means of an inlet/outlet manifold. The series connected system resulted in a pressure drop of 4.1 psi when tested at 18 psig and 17 lb/hr water flow. The same finger elements connected in parallel through a manifold under the same flow conditions, resulted in a pressure drop of 0.15 psi.

The manifold design chosen for development in this program consists of two segments, inlet and outlet, which are stacked together in place on the glove bladder just aft of the first metacarpal. Each segment is fabricated from .020 brass stock formed into a flat cross section, approximately 1/8 inch thick. Six 1/8 inch thick brass tubes are positioned on each segment to connect with the finger and palm tubing elements. Inlet and outlet flow connections are made through a 5/16 inch brass tube connected to the manifold.

The inlet and outlet flow path between the glove penetration and the manifold is made with 5/16 inch tygon tubing. Connections from the manifold to the finger elements are made with 5/32 inch tygon tubing.

2.1 ACTIVE COOLING SYSTEM (CONT'D)

c. Palm Cooling Element - The palm cooling element, common to both active system designs, consists of a length of 1/8 stainless steel tubing configured to the same contour as the flight glove palm restraint it replaces. The palm cooling element is connected to the inlet/outlet manifold with 5/32 inch tygon tubing.

2.1.1 METAL FINGER BLADDERS

Figure 2 illustrates the design of the active cooling system incorporating the metal finger bladders.

The metal finger bladders are fabricated from .020 brass stock, contoured to the curvature of the bladder fingers, and silver soldered together. Two 1/8 inch brass tubes are soldered in place in each element, providing inlet and outlet water connections.

A complete glove set of metal finger bladders consists of 12 elements; 2 each on the little finger, ring finger, and thumb, and 3 each on the middle finger and index finger. All interconnections and connections to the inlet/ outlet manifold are accomplished with 5/32 inch tygon tubing. The tygon tubing is bonded to the 1/8 brass tubing with Hughson Chemical Co. structural adhesive number A-1955-20. The finger elements and manifold are bonded to the glove bladder with Tescom Zip-Bond Contact Cement.

2.1.2 METAL BRAID FINGER ELEMENTS

Figure 3 illustrates the design of the active cooling system incorporating the metal braid finger elements.

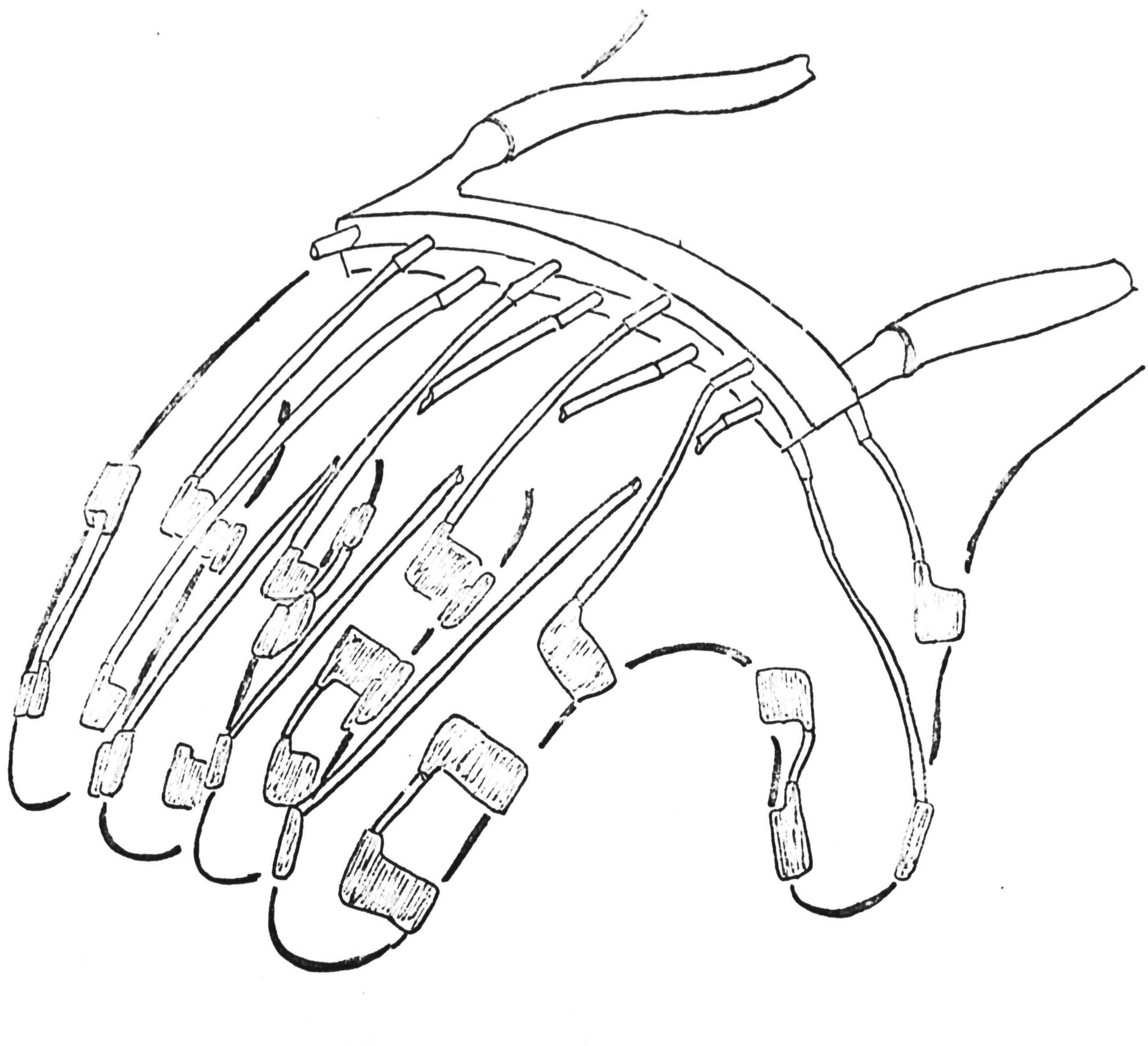


FIGURE 2 BRASS ACTIVE SYSTEM

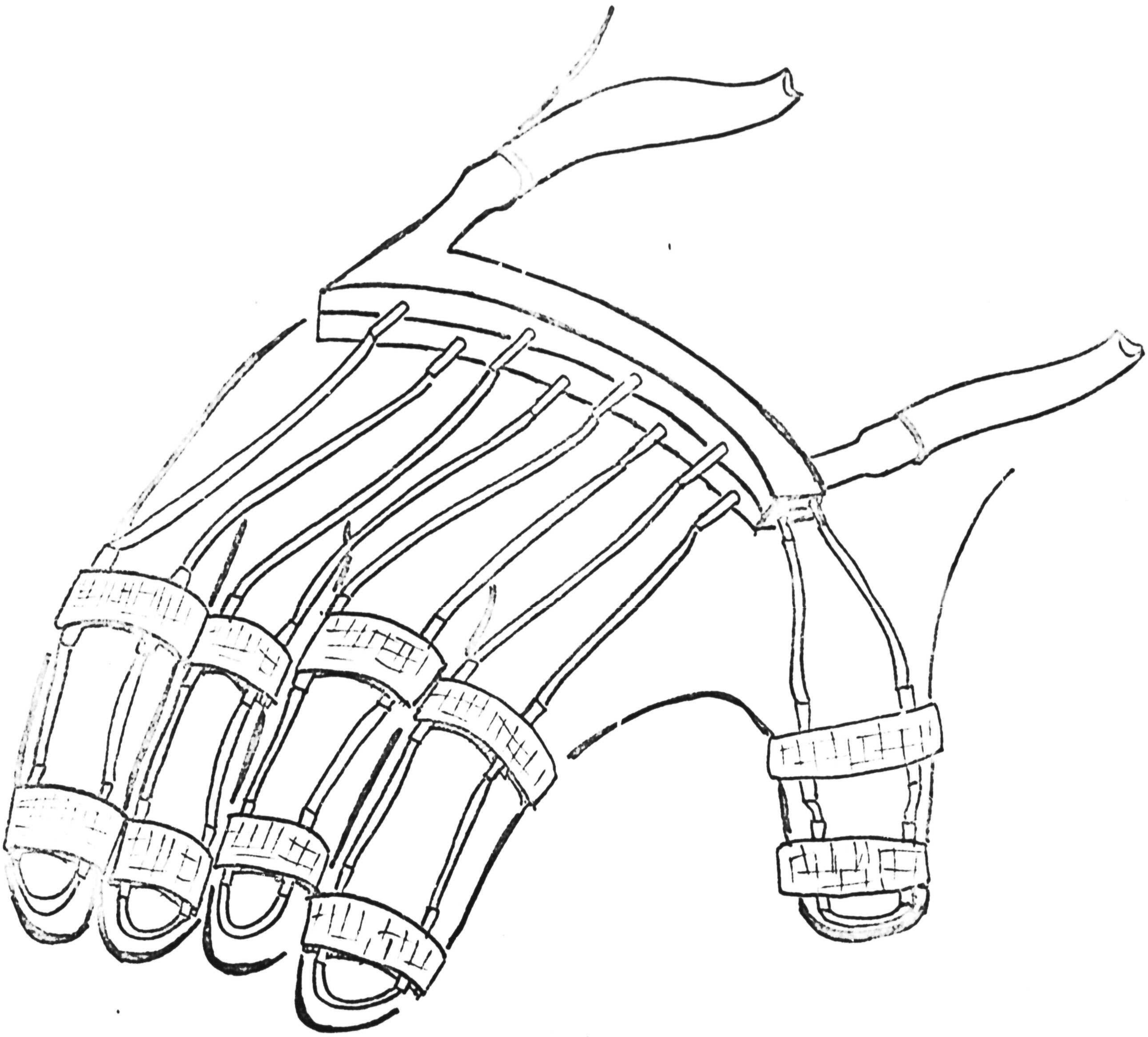


FIGURE 3 BRAID ACTIVE SYSTEM

2.1.2 METAL BRAID FINGER ELEMENTS (CONT'D)

The metal braid used in the fabrication of the finger elements is commercial grade 5/16 inch flat, tinned, copper grounding wire braid. The finger elements are fabricated by soldering the braid into a circular form, the diameter of the glove bladder finger. Two braid rings are then connected together by another piece of braid, forming a complete finger assembly. One-eighth inch copper tubing is soldered to each ring, as shown, to provide the flow path for the coolant water. There are a total of 10 braid rings in each glove set.

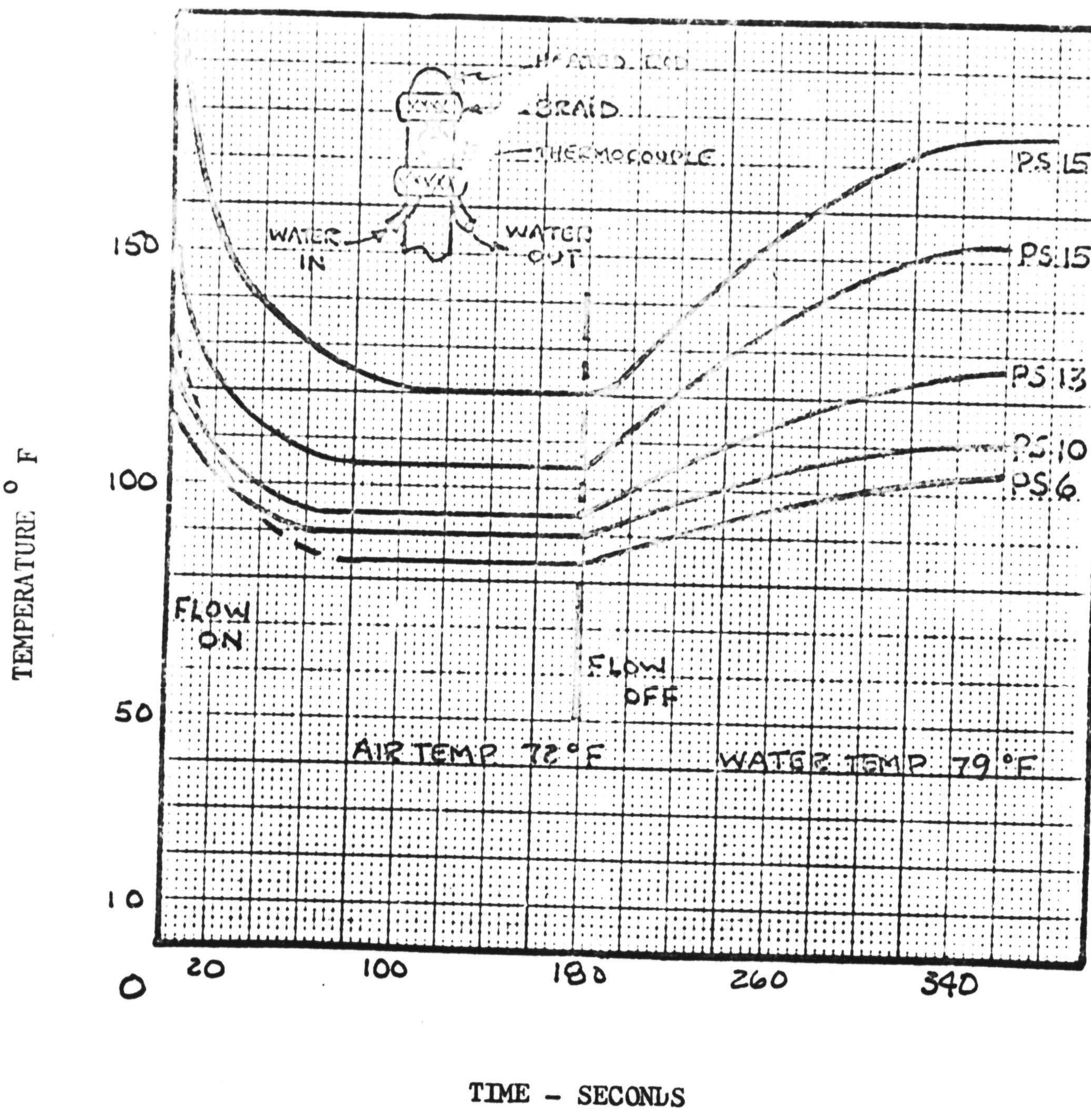
The feasibility of this concept was determined early in the program through a simple test. One finger element assembly was placed on a heating element which was connected to a variable power supply. In this manner, the temperature of the heating element was controlled. A thermocouple was emplaced on the braid section connecting the two braid rings. Water flow was provided to the braid assembly at 74° F.

The test procedure required setting the power supply and monitoring temperature as the heating element warmed. When the desired temperature was reached, water flow was shut off and temperature monitored for the next three minutes.

The feasibility test results are presented in Figure 4 and clearly show the capability of this concept to provide active cooling under high heat loads.

2.2 OVERGLOVE

The objectives of the overglove design activities were primarily the reduction of bulk and improvement in mobility through the elimination of three



P.S. - Voltage Regulator
Power Setting

FIGURE 4 CONCEPT FEASIBILITY TEST

2.2 OVERGLOVE (CONT'D)

layers of super insulation. It was felt that the introduction of the active cooling system in the glove would more than offset the increased heat leak caused by removal of three layers of insulation.

Although two overglove configurations were pursued and carried through the test phase, neither configuration was completed to a level totally satisfying the design objectives. A brief description of each prototype configuration, as tested, follows.

2.2.1 SILICONE TIP OVERGLOVE

This concept is essentially the same as the present Apollo overglove incorporating the fingertip silicone shells for tactility improvement. The concept differs in that a buildup of 4 layers of insulation is used throughout and an abrasion resistance layer of bladder cloth is used between the super insulation and the metallic elements of the cooling system. The palm side of the outer layer is fabricated from Karma cloth with the remainder of the glove beta cloth. Accomodations are incorporated to permit adjustment of the palm restraint.

This overglove proved totally unacceptable from a mobility standpoint because of the restrictions imposed by the short fingers of the glove. The short fingers themselves were a result of tailoring the finger diameters to interface with the available silicone shells.

2.2.2 SEGMENTED OVERGLOVE

This concept features individual finger superinsulation layups which are free to slide over the first metacarpal joint. The intent was to reduce

2.2.2 SEGMENTED OVERGLOVE (CONT'D)

torque for motion at the first metacarpal by eliminating the "length change" problem. The insulation layup is maintained at 4 layers and the outer layer is beta. A full gusset finger design is used without finger-tip shells.

2.2.3 TAILORED OVERGLOVE

A third overglove design was sbumitted after the test phase was completed. This overglove was intended to demonstrate that a good tailored fit was feasible over all the elements of the active cooling system. This overglove was conventional in design with a 4 layer insulation, no finger-tip shells, and beta outer layer. The design did achieve the objective of good fit and improved mobility.

3.0 DESIGN VERIFICATION TESTS

Design Verification Tests were conducted on the prototype gloves in general accordance with the test plan, Welson Document BW-214 The two active cooling system and two overglove designs produced a total of four configurations subject to test. The following paragraphs report the significant test results.

3.1 SYSTEM WEIGHT

A NASA design goal for the Advanced Thermal Protection Glove is 1 pound. The present Apollo type glove bladder, restraint, and glove disconnect weighs approximately 0.7 pound. Added to this for the prototype advanced thermal protection glove is the active cooling system and the overglove. The following listing shows the weights of the four combinations.

3.1 SYSTEM WEIGHT (CONT'D)

	Active System	Plus	Overglove	=	Weight (lbs)
a)	Metal Bladder		Silicone tip		1.75
b)	Metal Bladder		Segment		1.63
c)	Metal Braid		Silicone tip		1.72
d)	Metal Braid		Segment		1.61

3.2 LEAKAGE

3.2.1 AIR LEAKAGE

Both prototype gloves were tested for air leakage induced by the glove water loop penetration. Both gloves satisfied the requirement that leakage not exceed 5 cc/min when tested at 5 psig for 15 min.

3.2.2 WATER LEAKAGE

The requirement for the water loop of the active cooling system is for zero leakage at 18 psig proof pressure. The "braid" concept successfully passed all tests without evidence of water leakage. A neoprene cement was used as the bonding agent between the tygon tubes and the manifolds.

The metal bladder concept leaked on several occasions at the tygon joints at pressures between 18 and 30 psig. A Tescom Corp. contact cement was used as the original adhesive. This was replaced by a neoprene cement with marginal improvement. This concept was put through the cyclic testing for 6000 cycles. The eight leaks that developed during this test were repaired with a Hughson Chemical Corp. adhesive A-1955-20.

The results indicate that the rigid type bond provided by the Hughson adhesive is superior in areas where flexing and tension in the tygon tubes occurs.

3.3 MOBILITY

The four active system/overglove combinations were tested for range and torque. Of primary concern in the tests was the requirement of 90° articulation of the first metacarpal at a torque of 0.2 ft-lb with the glove at 5.0 psig.

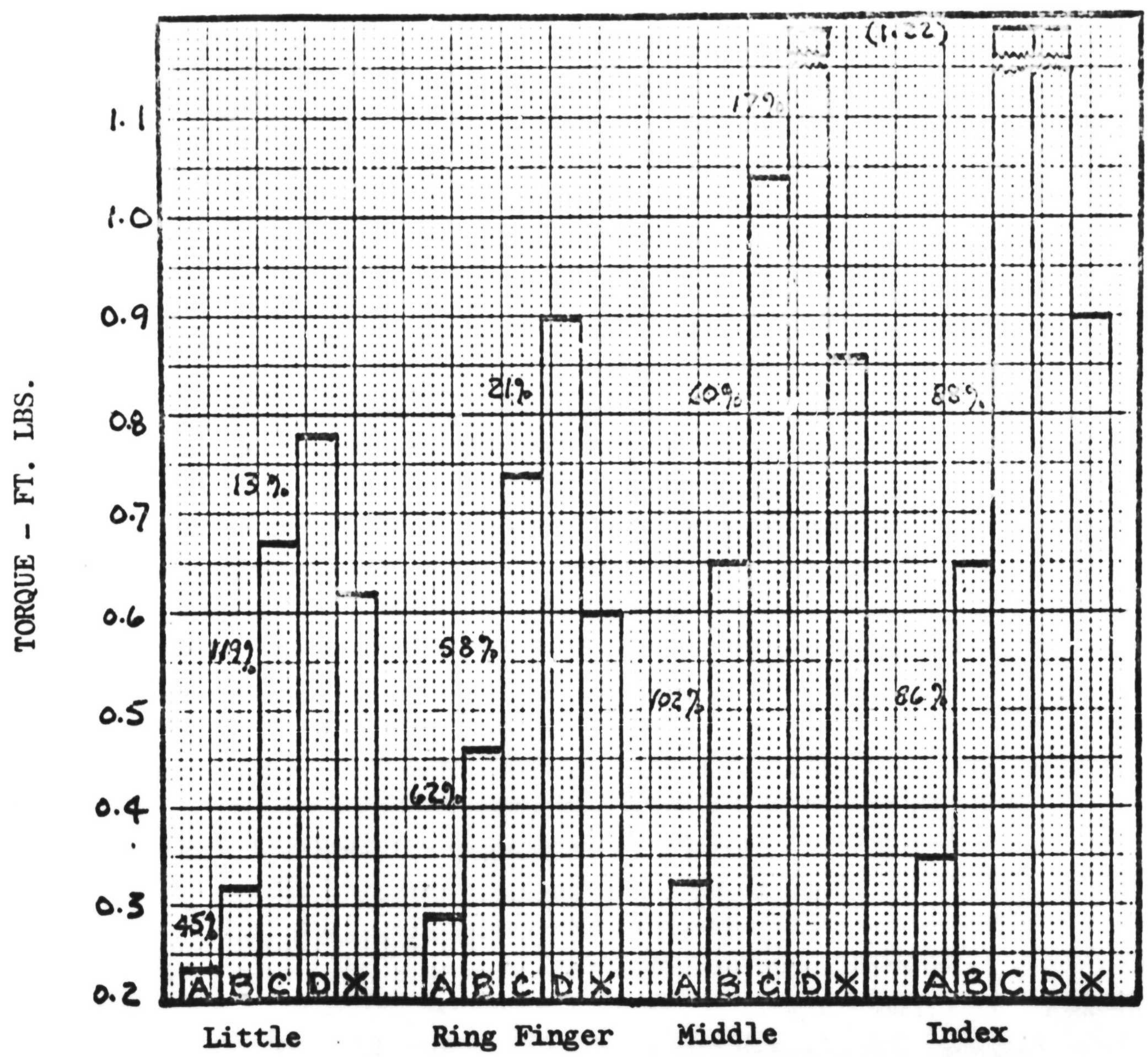
Both glove bladder and active cooling system designs (without overglove) induced torques in the range of 0.2 to 0.3 ft-lb, which was not measurably different from the bladder alone. The addition of the two prorotype overgloves raised the torque values to as high as 1.22 ft-lb. Investigation as to the cause for the high torques revealed the abrasion layer and the outer layer as the major contributors.

Figures 5 and 6 present the torque values for the first metacarpal joint for the two combinations, metal bladder/silicone tip (Figure 5) and metal fabric/segmented (Figure 6). Figure 5 also presents the improvement gained through the tailored beta overglove (column "x" in the figure). This improvement is attributed to a redesign of the overglove finger crotch.

3.4 CYCLING AND COMFORT

The metal bladder active system was cycled through 6000 cycles of full opening and closing of the hand. Three water leaks were detected at 650 cycles, and three leaks at 3700 cycles. No further leaks developed during the next 2300 cycles and the test was terminated. However, two additional leaks were detected during the subsequent proof test.

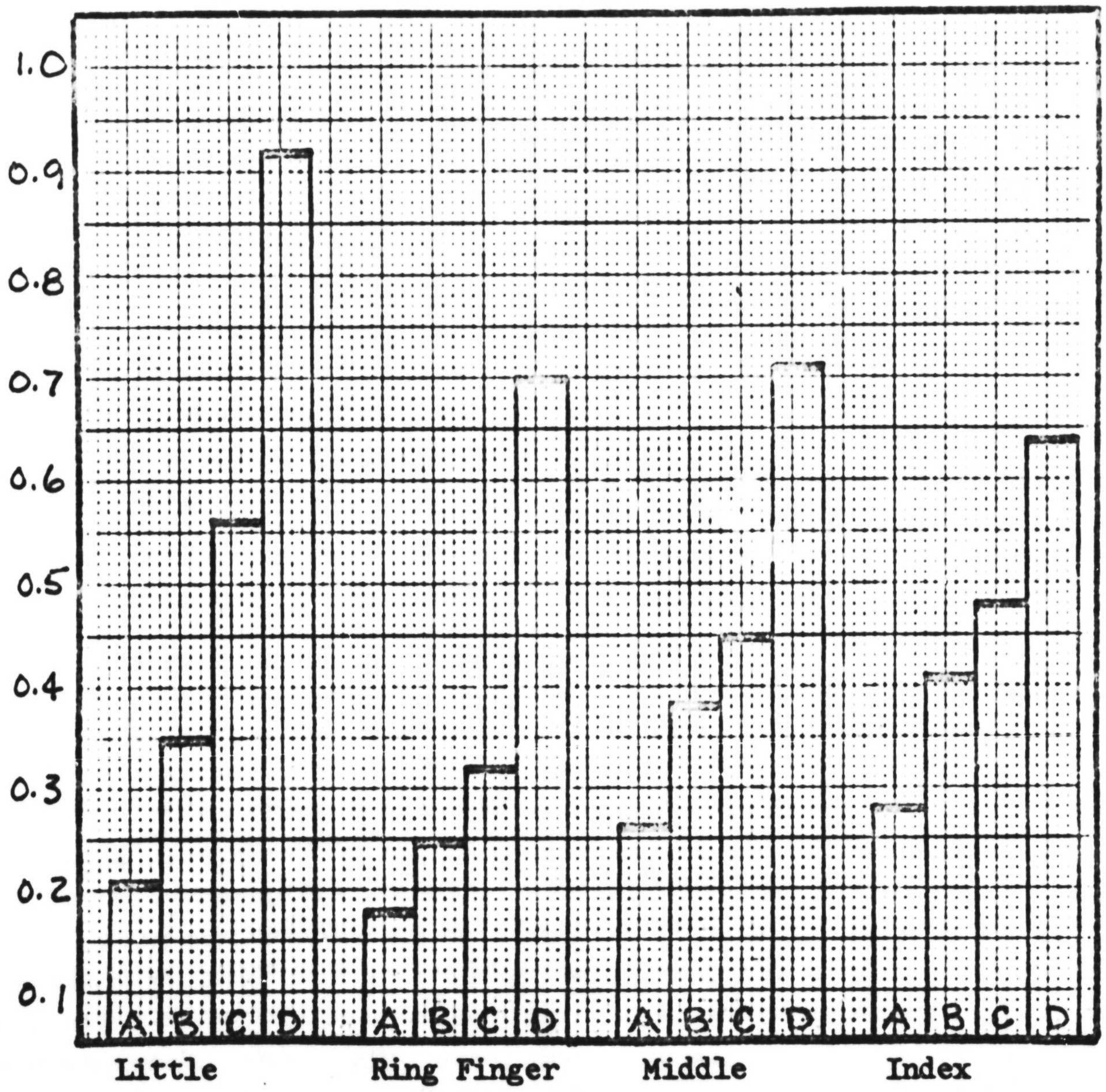
A skin abrasion on the first thumb joint was caused by the bladder rubbing against the skin. This discomfort was due to poor glove fit and the rapid cycling of the glove.



<u>Configuration</u> - Brass/Silicone

A - Bladder Only
B - Add Abrasion Layer
C - Add Insulation
D - Add Outer Cover
X - Brass/Beta Glove

FIGURE 5 TORQUE TEST



<u>Configuration</u> - **Braid/Lobster**

A - Bladder Only
B - Add Abrasion Layer
C - Add Insulation
D - Add Outer Cover
X - Brass/Beta Glove

FIGURE 6 TORQUE TEST

3.5 THERMAL

A total of eight hot tests and eight cold tests were conducted on the combinations of active systems and overgloves. An electrically heated rod served as the hot rod for the high temperature tests (300° F). A liquid nitrogen chilled rod served as the cold rod for the low temperature tests (-320°F). The bell jar pressure was controlled to maintain approximately 5 psi differential across the bladder. The water loop pressure was maintained at 18 psig and water flow varied from test to test between 25 cc/min to 140 cc/min. Inlet water temperature was not controlled and generally approximated room ambient temperature. No attempt was made to simulate lunar thermal radiation. Suit air flow to the glove was also not simulated. Grasping force of the gloved hand about the rod was not measured or controlled.

The location of glove thermocouples is illustrated in Figure 7 and time/temperature plots of the test series are presented in Figure 8 through Figure 23. The figures contained in Appendix A, are arranged in the chronological order of testing which was performed between 15 DEC 70 and 31 DEC 70. For convenience a summary of each test is presented below:

Figure 8 - Hot Test - 15 DEC 70

Configuration: Metal Bladders/Silicone Tip Overglove

Rod Temp: 297-286° F

Water Flow: 25 cc/min

Comments: Although flow was significantly below the allowable 17 lb/hr. (126 cc/min), subject was able to maintain grasp for 5 minutes. The differential temperature between inlet and outlet water reached 8° F, which was the highest value recorded during the series.

3.5 THERMAL (CONT'D)

Figure 9 - Hot Test - 15 DEC 70

Configuration: Metal Bladder/Silicone Tip Overglove

Rod Temp: 312° - 286° F

Water Flow: 41 cc/min.

Comments: Thermocouple data remained in same range as first test. Water differential temperature dropped to a maximum of 4° F as expected because of increased flow.

Figure 10 - Cold Test - 16 DEC 70

Configuration: Metal Bladder/Silicone Tip Overglove

Rod Temp: -320° F

Water Flow: 23 cc/min

Comments: No problems encountered in completing 5 minute test. Differential water temperature data indicated heat gain, rather than heat loss, which could be possible since more tubing is in contact with the "warm" bladder than with the cold rod. However, the phenomenon was not duplicated in subsequent runs.

Figure 11 - Cold Test - 16 DEC 70

Configuration: Metal Bladder/Silicone Overglove

Rod Temp: -320° F

Water Flow: 52 cc/min

Comments: No problems encountered during test

3.5 THERMAL (CONT'D)

Figure 12 - Cold Test - 16 DEC 70

Configuration: Metal Bladder/Segment Overglove

Rod Temp: -320° F

Water Flow: 42 cc/min

Comments: Index finger thermocouple (T4) indicated lower temperature than with silicone tip overglove. Subject feeling was "colder".

Figure 13 - Cold Test - 16 DEC 70

Configuration: Metal Bladder/Segment Overglove

Rod Temp: -320° F

Water Flow: 48 cc/min

Comments: Glove generally felt cold throughout test. T4 thermocouple was inoperative during test.

Figure 14 - Cold Test - 17 DEC 70

Configuration: Metal Braid/Segment Overglove

Rod Temp: -320° F

Water Flow: 60 cc/min.

Comments: This was the first test run with the braid active system. Thumb crotch felt cold. Differential water temperature was noticeably greater indicating more effective heat transfer.

3.5 THERMAL (CONT'D)

Figure 15 - Cold Test - 17 DEC 70

Configuration: Metal Braid/Segment Overglove

Rod Temp: -320° F

Water Flow: 40 cc/min.

Comments: Repeated results of previous test.

Figure 16 - Cold Test - 17 DEC 70

Configuration: Metal Braid/Silicone Overglove

Rod Temp: -320° F

Water Flow: 60 cc/min

Comments: All thermocouple readings were higher with the silicone overglove. As in the hot tests, this indicates that the silicone overglove provided better insulation.

Figure 17 - Cold Test - 17 DEC 70

Configuration: Metal Braid/Silicone Overglove

Rod Temp: -320° F

Water Flow: 70 cc/min.

Comments: Test run was made with hand initially removed from the glove and the glove prechilled. The thumb crotch thermocouple (T3) was monitored initially to observe heat transfer from the hand to the bladder. Test results show a temperature rise from 23° to 50° F in one minute followed by steady state. Run terminated at 3 minutes.

3.5 THERMAL (CONT'D)

Figure 18 - Hot Test - 18 DEC 70

Configuration: Metal Braid/Silicone Overglove

Rod Temp: 286-314° F

Water Flow: 110 cc/min.

Comments: This was first hot test of this configuration. No problems were encountered and full test run was completed. Middle and ring finger felt comfortable; thumb crotch was warm.

Figure 19 - Hot Test - 18 DEC 70

Configuration: Metal Braid/Segment Overglove

Rod Temp: 293-288° F

Water Flow: 90 cc/min.

Comments: The segment overglove again demonstrated less insulative capability than the silicone tip overglove. T-3 temperature was 17° F higher than with the silicone tip overglove.

Figure 20 - Hot Test - 30 DEC 70

Configuration: Metal Bladder/Segment Overglove

Rod Temp: 320° F

Water Flow: 67 cc/min.

Comments: This was first run of this combination. T-4 was cooler (110° F) than in earlier runs with the silicone tip overglove. (Figure 8 & 9 : 140° F). This is probably due to slightly different placement of thermocouples. However, the increase water flow rate would also act to keep T-4 temperature down.

3.5 THERMAL (CONT'D)

Figure 21 - Hot Test - 30 DEC 70

Configuration: Metal Bladder/Segment Overglove

Rod Temp: 290° F

Water Flow: 116 cc/min.

Comments: Glove felt hot throughout test but was bearable. Data was about the same as previous run.

Figure 22 - Hot Test - 31 DEC 70

Configuration: Metal Bladder/Segment Overglove

Rod Temp: 290° F

Water Flow: 136 cc/min.

Comments: Lower temperature readings reflect effect of increased water flow rate. Also, this test run was a "cold" start (i.e. hand was inserted at beginning of timed run as opposed to having hand in the glove for a period of time before timed run)

Figure 23 - Hot Test - 31 DEC 70

Configuration: Metal Bladder/Segment Overglove

Rod Temp: 302° F

Water Flow: 130 cc/min.

Comments: Only T-4 was monitored. Object of test was to grab rod only with thumb and index finger. Index finger felt hot at 1 minute but test continued for 5 minutes.

4.0 PASSIVE SYSTEM DESIGN

Following Welson and NASA DVT of the prototype designs, it was decided by NASA that a passive approach should be investigated. In lieu of the fabrication of a glove in Phase D that incorporated the features of each prototype, the remaining portion of the program was directed to an approach using insulative material at the points of contact with a grasped object.

The design of the system includes ensolite strips cemented to a spandex glove which is placed over the glove bladder. This configuration is similar to the metal bladder approach with twelve segments upon the fingers plus a larger palm segment.

4.1 PASSIVE SYSTEM TESTING

The thermal conductance of the ensolite was tested in the glove box. It was found during feasibility tests, with the same conditions used for the active system DVT, that the wearer cannot grasp a hot object for the required time period. It is possible that with the Welson test equipment, insufficient vacuum levels were present and that the actual performance may improve with a representative environment.

5.0 RECOMMENDATIONS AND CONCLUSIONS

The work performed under this contract has indicated that an active system is necessary for the required temperature extremes. Although the active system approach involves a relatively complex interface with the liquid cooling garment, this provision or a similar active system is necessary

5.0 RECOMMENDATIONS AND CONCLUSIONS (CONT'D)

to transport the high local heat flux.

Such designs as evaporative heat transport gloves and water cooled gloves are presently viewed as the most promising means to achieve the desired thermal performance with the least sacrifice to mobility and tactility. It is recommended that these areas be investigated further so that the design may be refined and the remaining disadvantages reduced or eliminated.

WELSON & CO., INC.
HARTFORD, CONN.

APPENDIX A

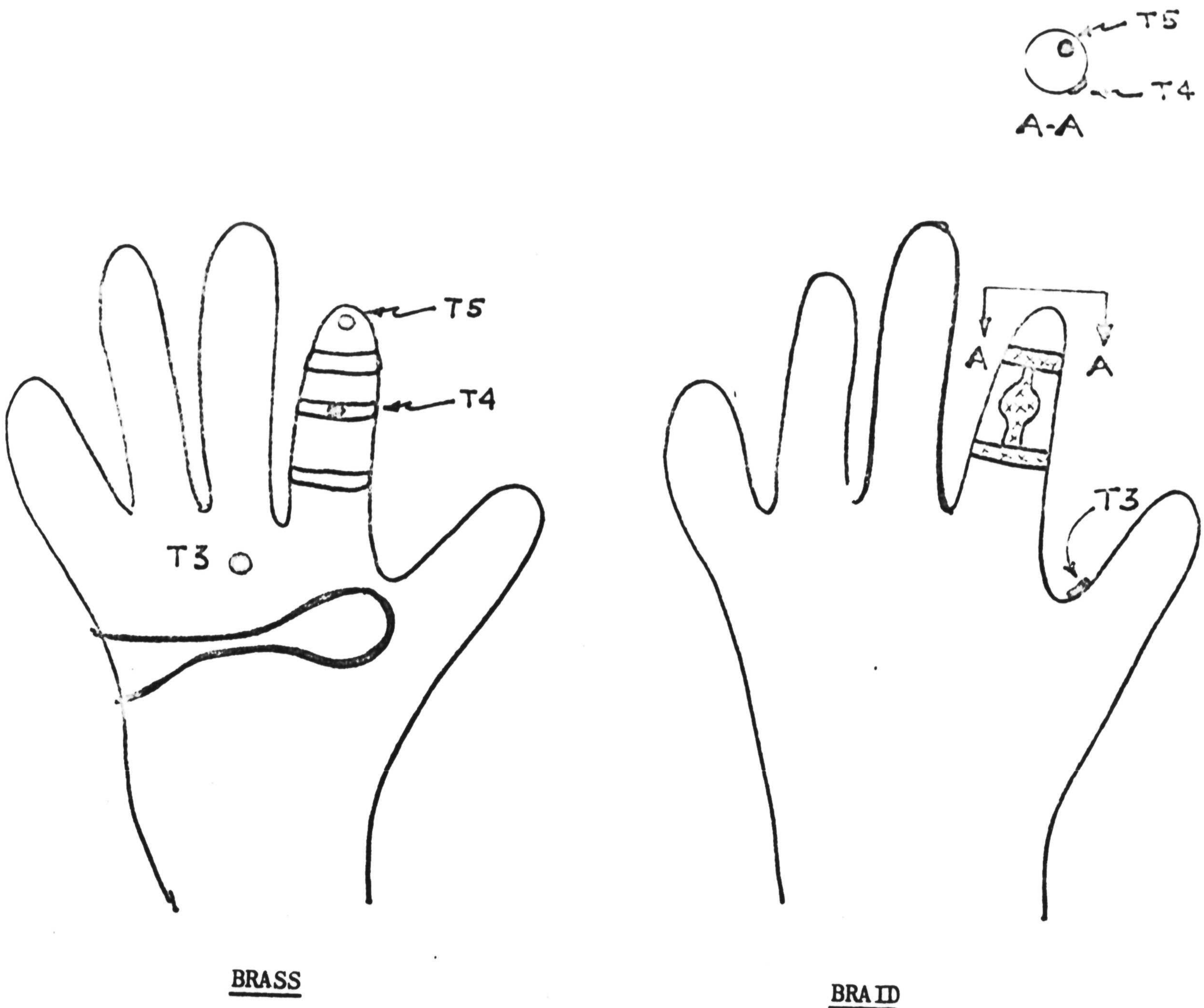
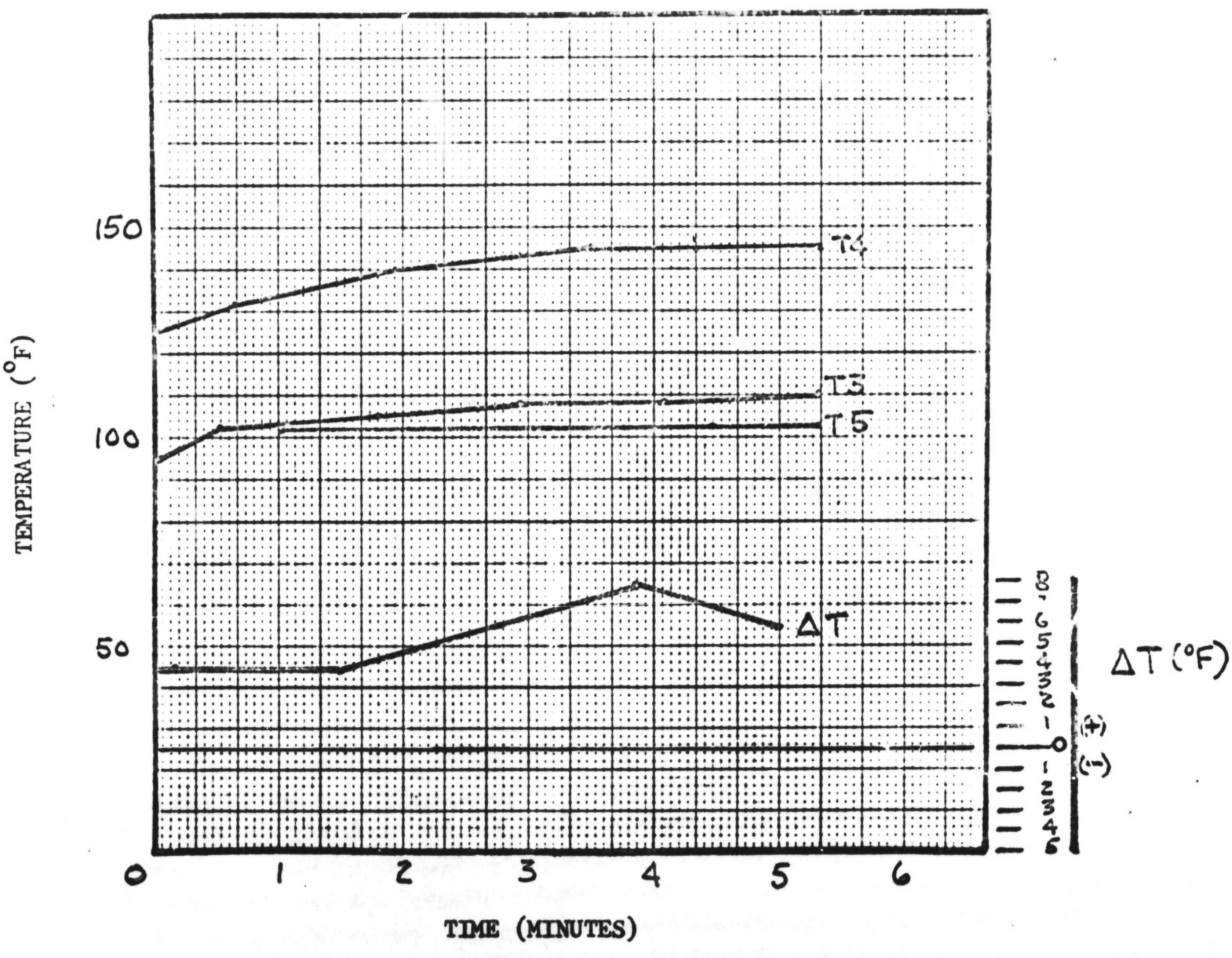


FIGURE 7 THERMOCOUPLE LOCATION



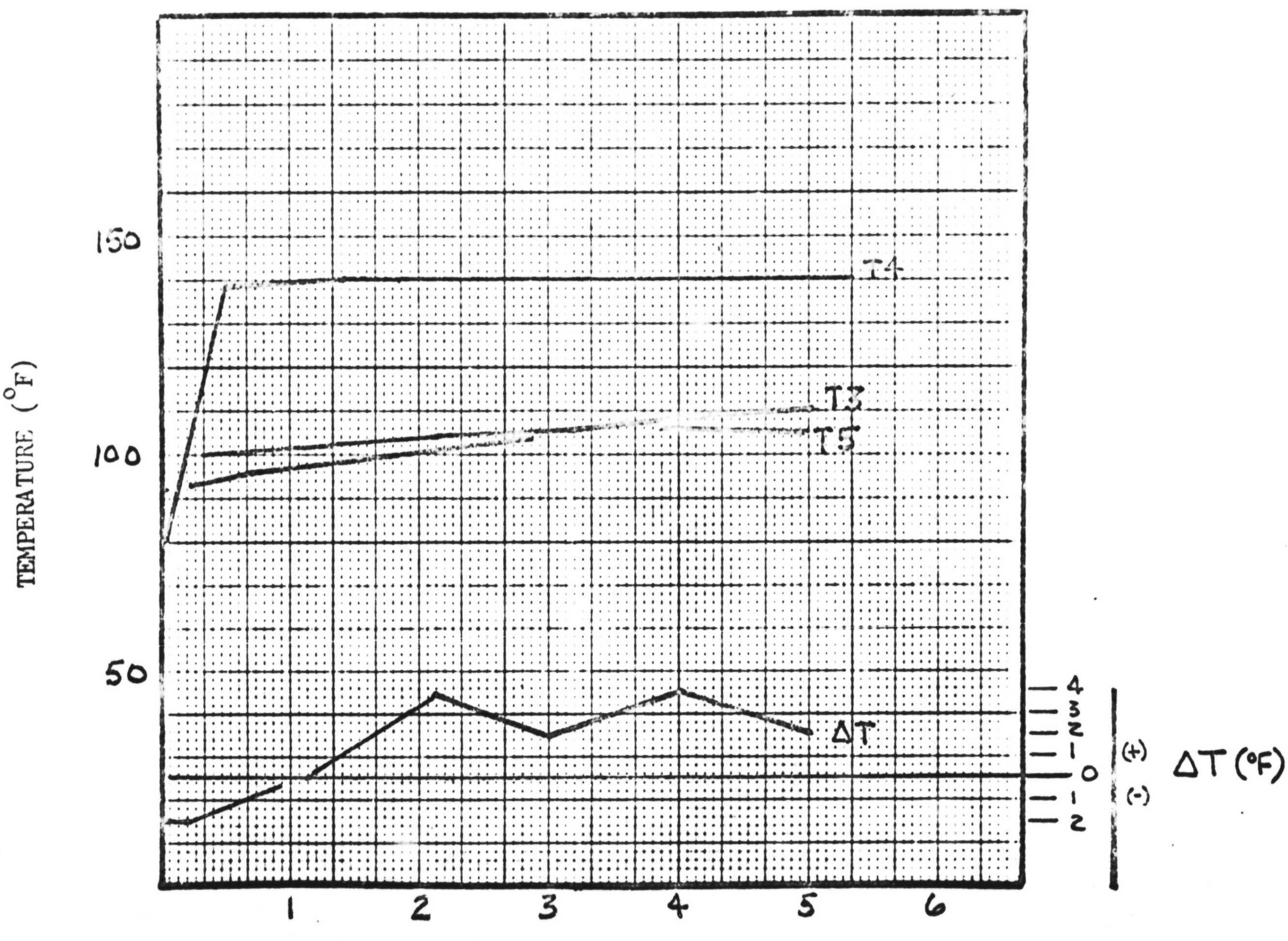
<u>TEST CONDITIONS</u>

Hot Test - 15 DEC 70
Brass Active/Silicone Overglove
T3 - Palm
T4 - Index Finger - Middle Brass
T5 - Index Finger - Tip
Flow - 25 cc/min

T_{ROD} = 297 - 286° F

$T_{INLET\ WATER}$ = 78° F

FIGURE 8 THERMAL TEST



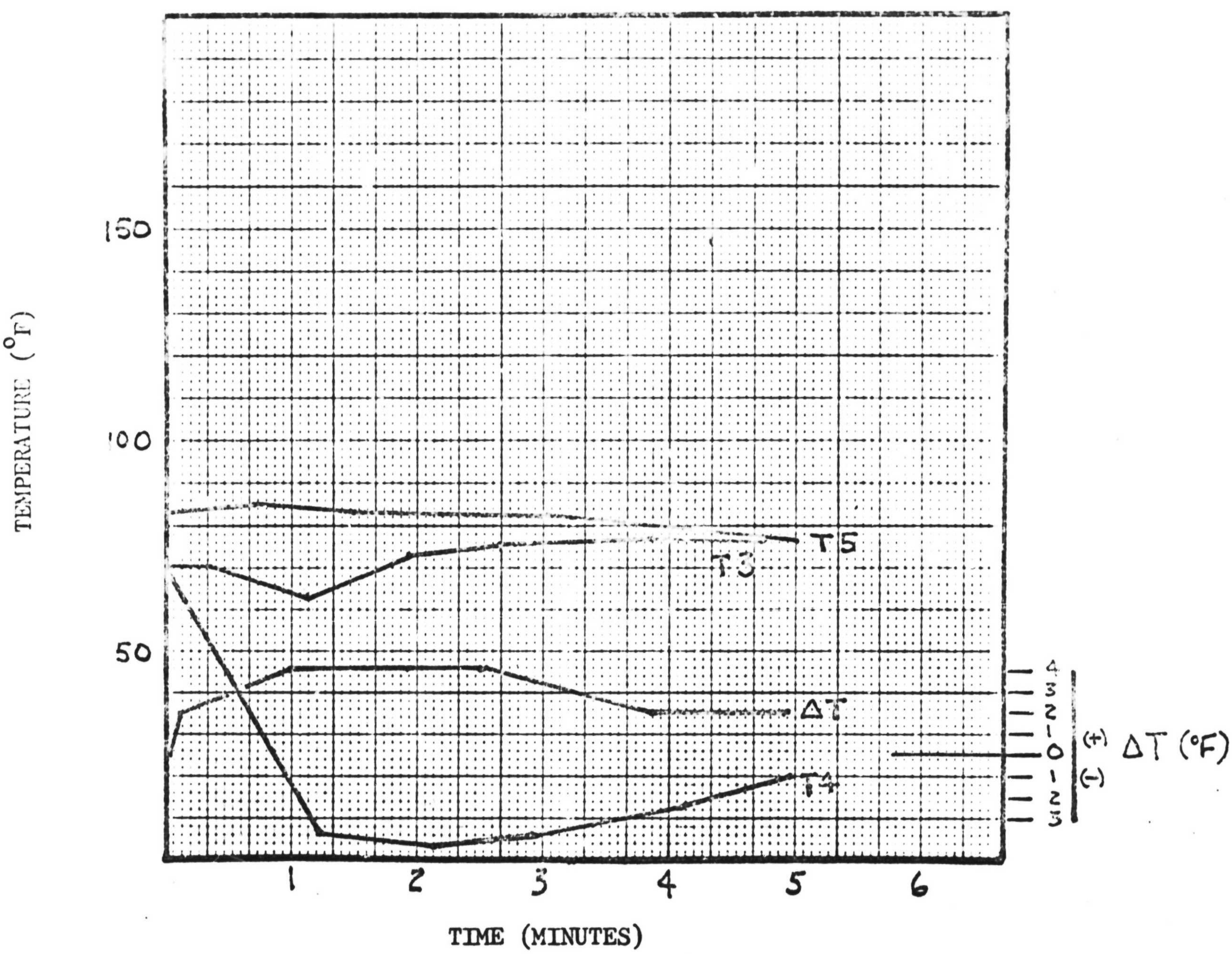
<u>TEST CONDITIONS</u>

Hot Test - 15 DEC 70
Brass/Silicone Overglove
T3 - Palm
T4 - Index Finger - Middle Element
T5 - Index Finger Tip
Flow - 41 cc/min

T_{ROD} = 312 - 286° F

$T_{INLET\ WATER}$ = 78° F

FIGURE 9 THERMAL TEST



TEST CONDITIONS

Cold Test - 16 DEC 70

Brass Active/Silicone Overglove

T3 - Palm

T4 - Index Finger - Middle Element

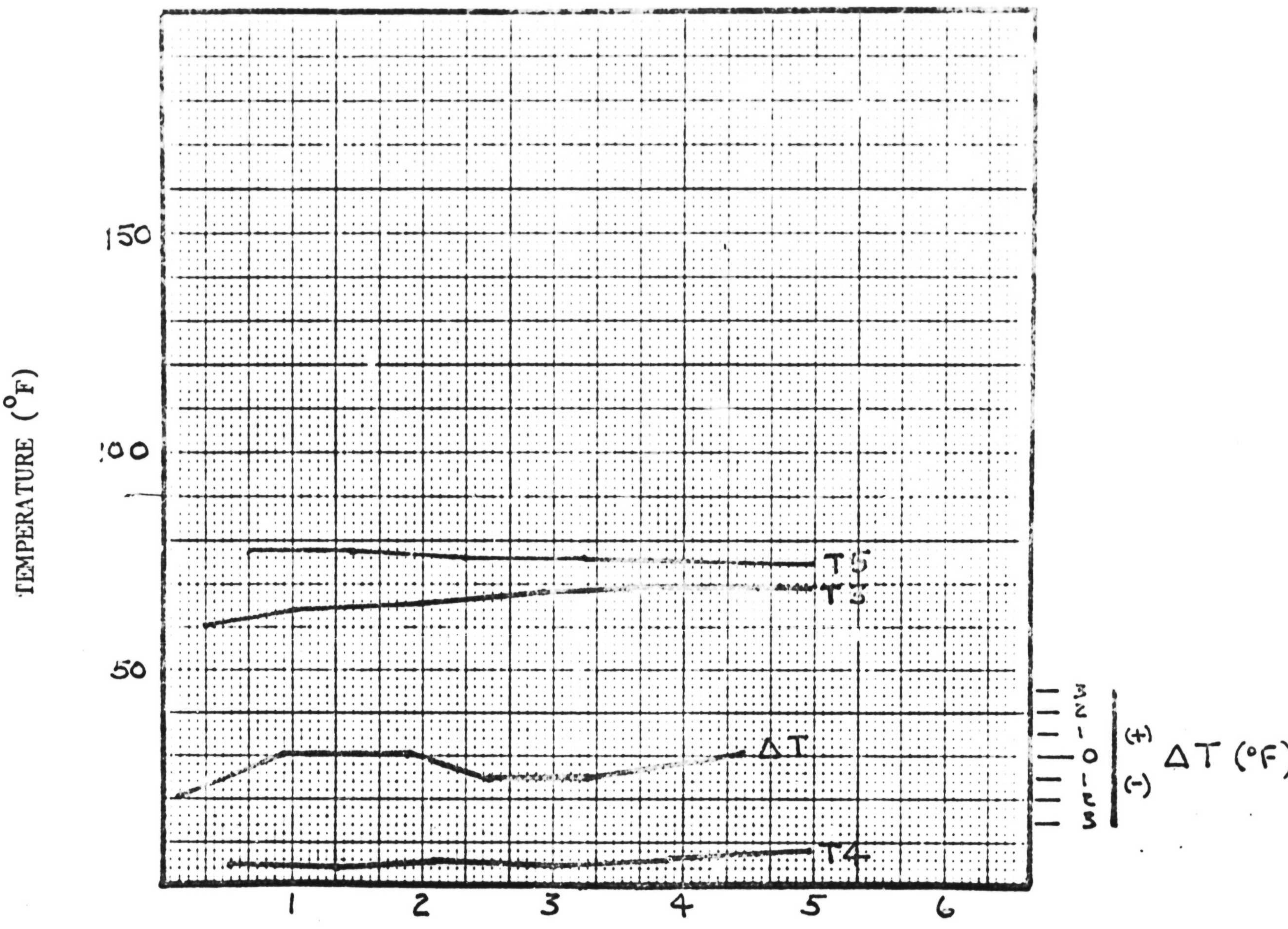
T5 - Index Finger - Tip

Flow - 23 cc/min

$T_{ROD} = -320^{\circ}$ F

$T_{INLET\ WATER} = 72^{\circ}$ F

FIGURE 10 THERMAL TEST



TEST CONDITIONS

Cold Test - 16 DEC 70

Brass Active/Silicone Overglove

T3 - Palm

T4 - Index Finger - Middle Finger

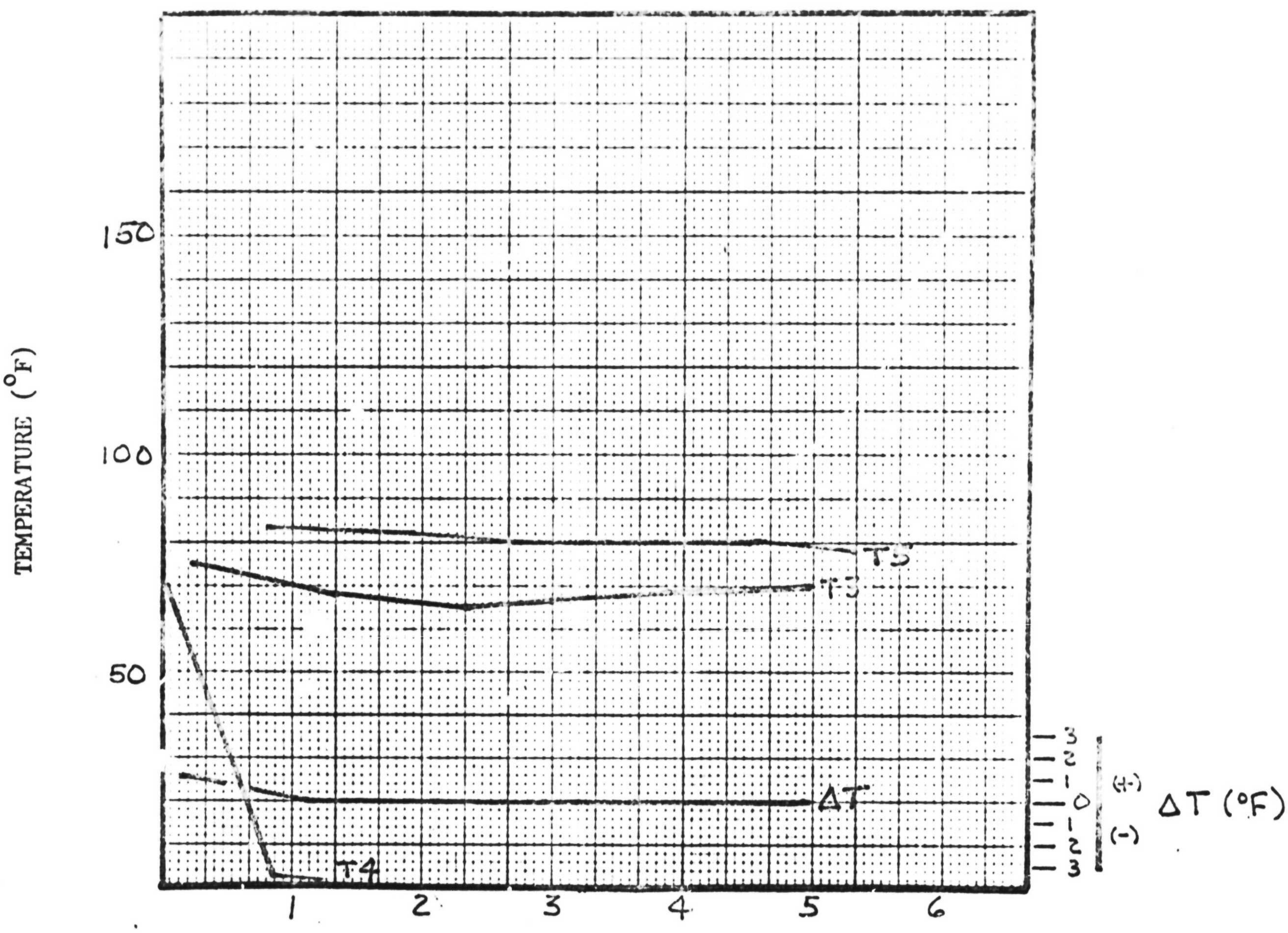
T5 - Index Finger - Tip

Flow - 52 cc/min

$T_{ROD} = -320° F$

$T_{INLET\ WATER} = 71° F$

FIGURE 11 THERMAL TEST



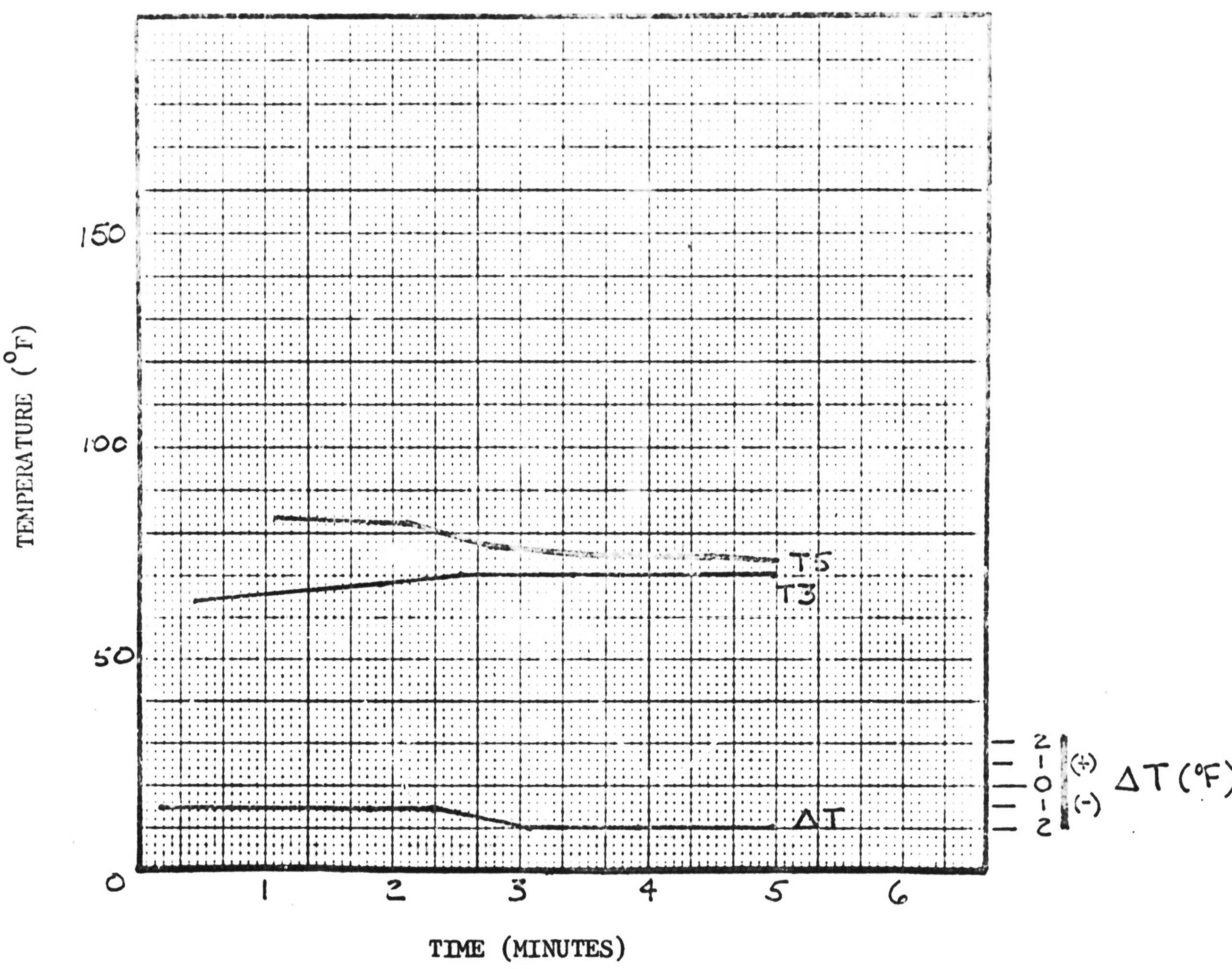
TEST CONDITIONS

Cold Test - 16 DEC 70
Brass Active/Lobster Overglove
T3 - Palm
T4 - Index Finger - Middle Element
T5 - Index Finger - Tip
Flow - 42 cc/min

$LN_2 ROD = -320^\circ$ F

$T_{INLET\ WATER} = 70^\circ$ F

FIGURE 12 THERMAL TEST



TEST CONDITIONS

Cold Test - 16 DEC 70

Brass Active/Lobster Overglove

T3 - Palm

T4 - Inoperative

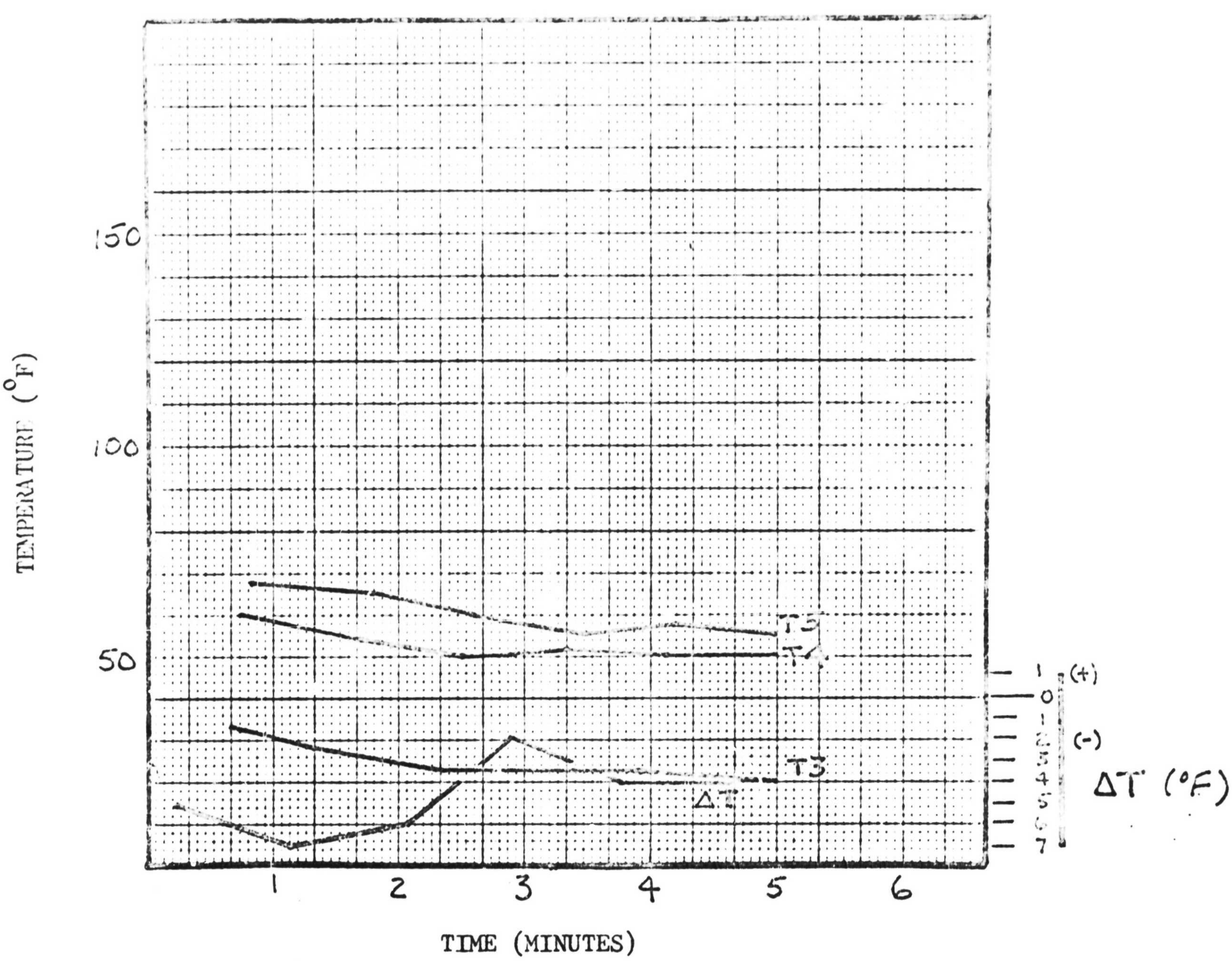
T5 - Index Finger - Tip

Flow - 48 cc/min

T_{ROD} = -320° F

$T_{INLET\ WATER}$ = 70° F

FIGURE 13 THERMAL TEST



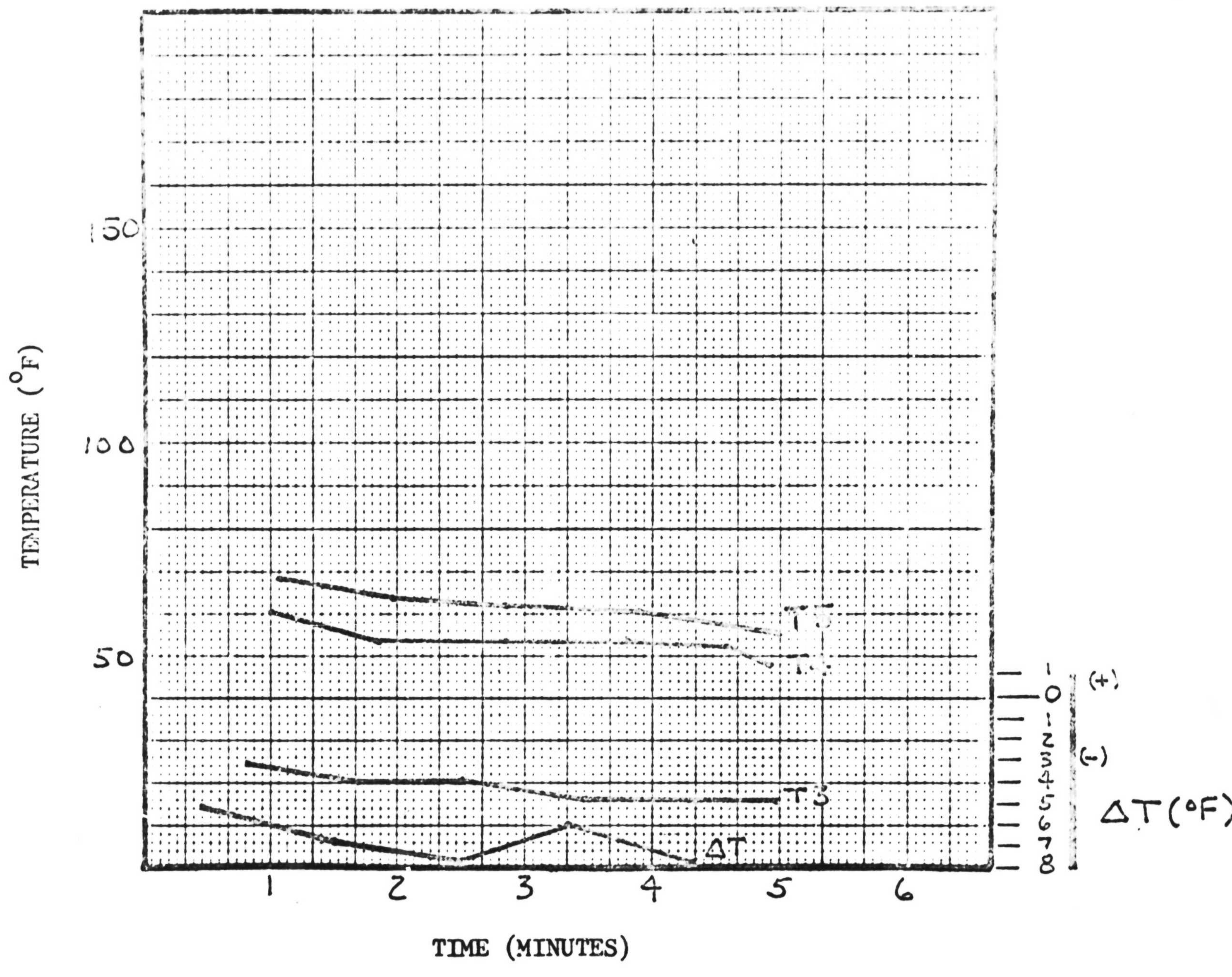
TEST CONDITIONS

Cold Test - 17 DEC 70
Braid/Lobster Overglove
T3 - Thumb Crotch
T4 - Index Finger - Braid Outer
T5 - Index Finger - Braid Inner
Flow - 60 cc/min

$T_{ROD} = -320^{o}$ F

$T_{INLET\ WATER} = 75^{o}$ F

FIGURE 14 THERMAL TEST



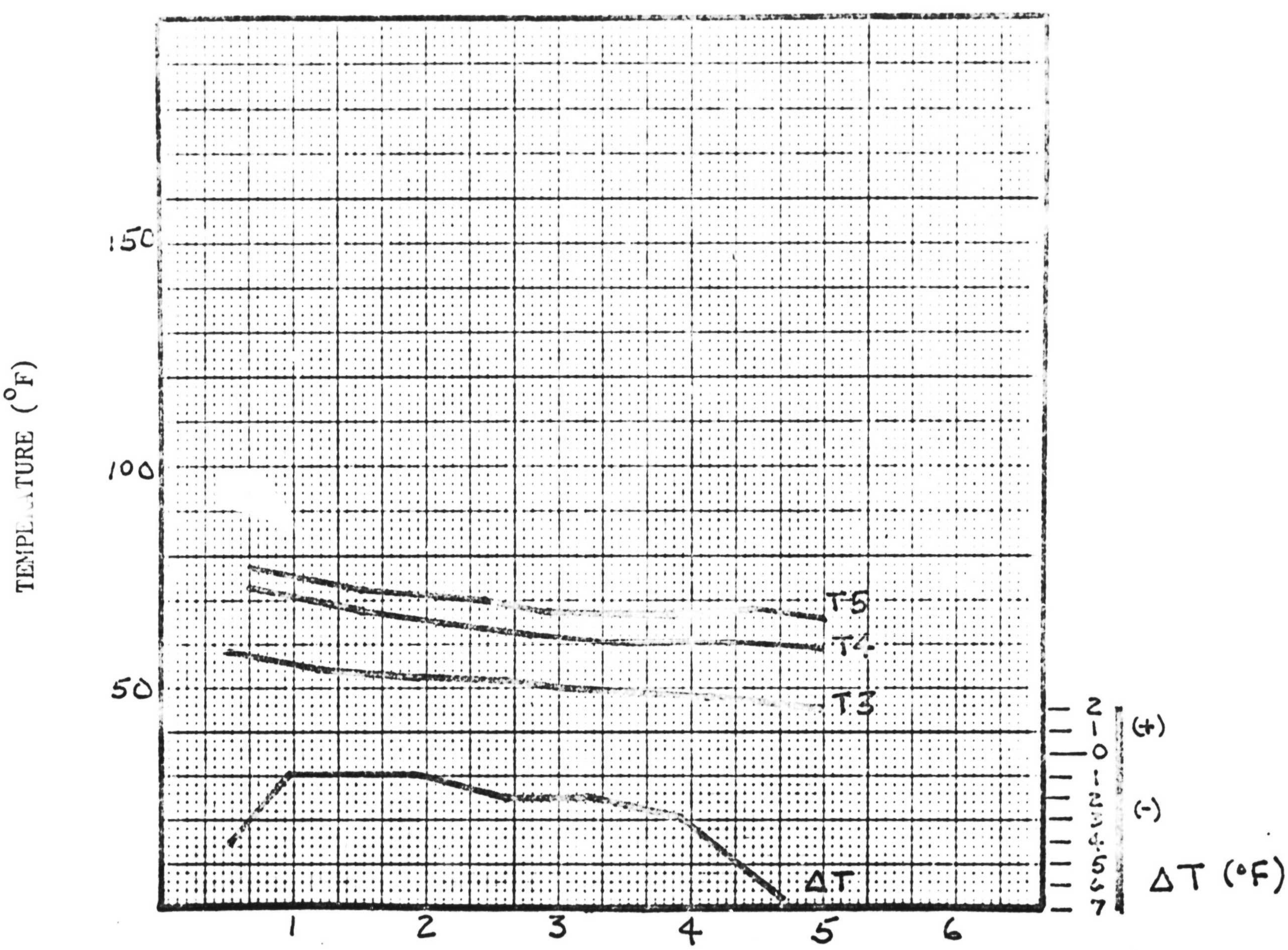
<u>TEST CONDITIONS</u>

Cold Test – 17 DEC 70
Braid/Lobster Overglove
T3 – Thumb Crotch
T4 – Index – Braid Outer
T5 – Index – Braid Inner
Flow – 40 cc/min

$T_{ROD} = -320^{\circ}$ F

$T_{INLET\ WATER} = 75^{\circ}$ F

FIGURE 15 TH ·AL TEST



TIME (MINUTES)

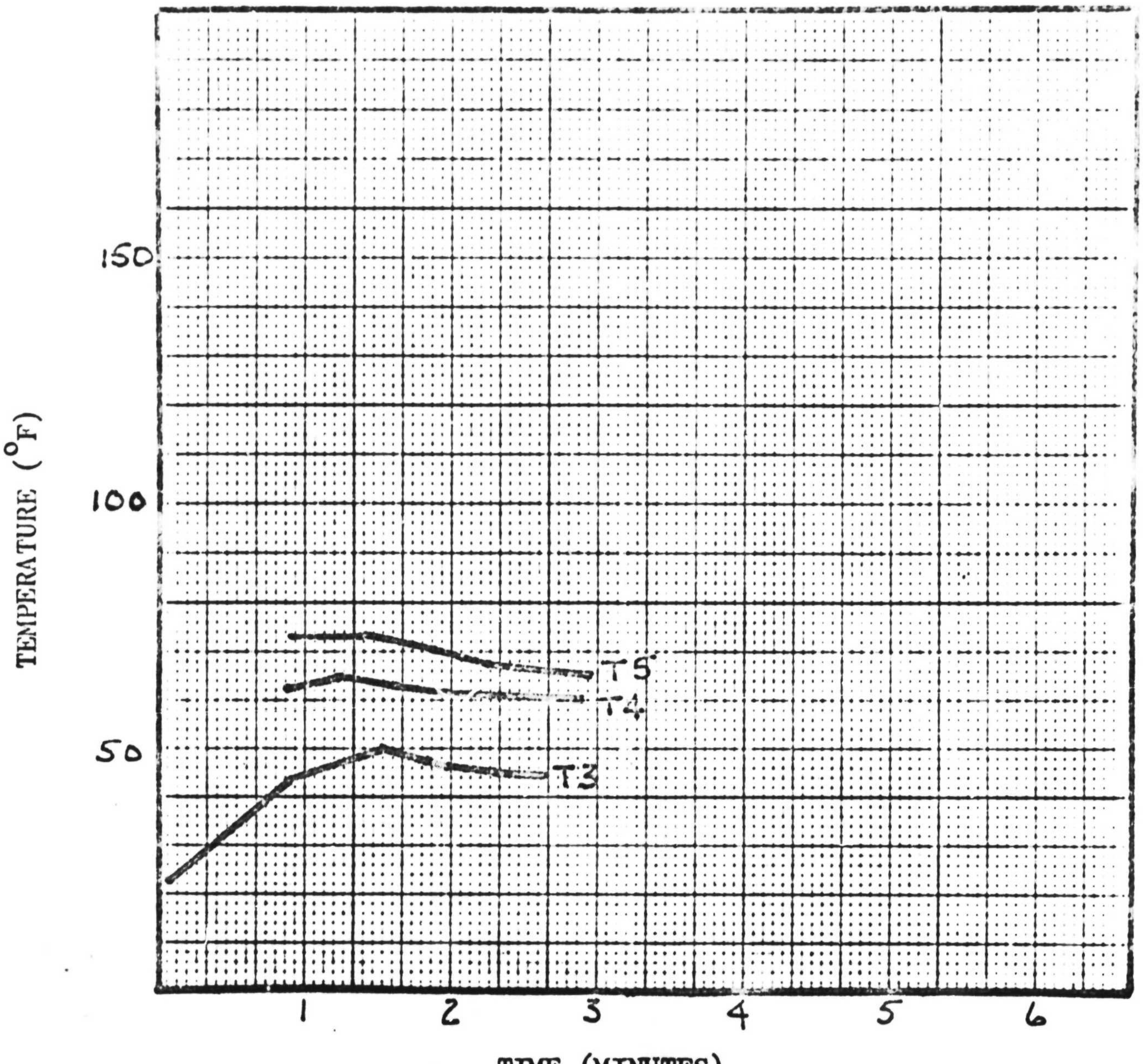
TEST CONDITIONS

Cold Test - 17 DEC 70
Braid/Silicone Overglove
T3 - Thumb Crotch
T4 - Index - Braid Outer
T5 - Index - Braid Inner
Flow - 60 cc/min

$T_{ROD} = -320^{\circ}$ F

$T_{INLET\ WATER} = 73^{\circ}$ F

FIGURE 16 THERMAL TEST



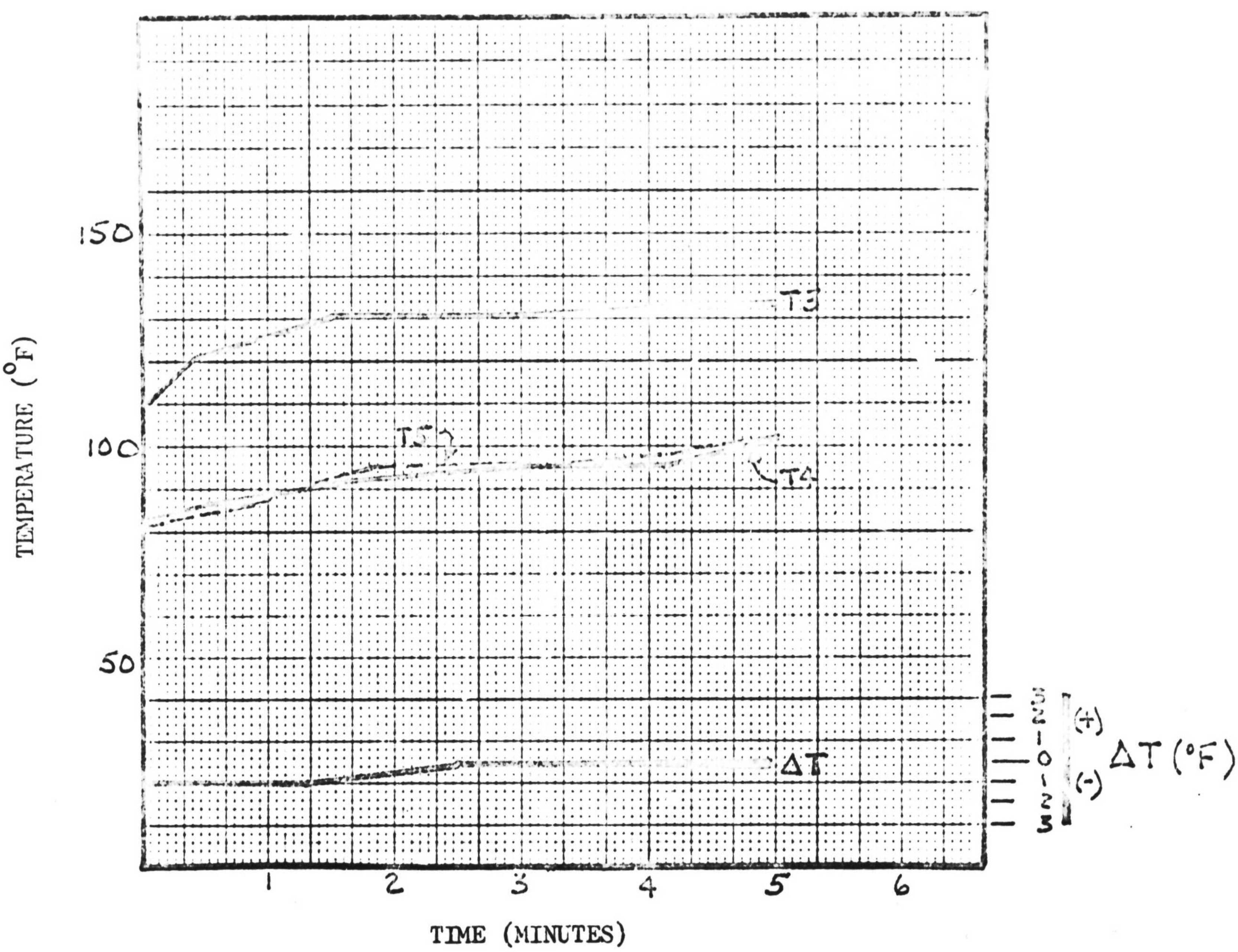
TEST CONDITIONS

Cold Test - 17 DEC 70
Braid/Silicone Overglove
T3 - Thumb Crotch
T4 - Index - Braid Outer
T5 - Index - Braid Inner
Flow - 70 cc/min

$T_{ROD} = -320^\circ$ F

$T_{INLET\ WATER} = 76^\circ$ F

FIGURE 17 THERMAL TEST



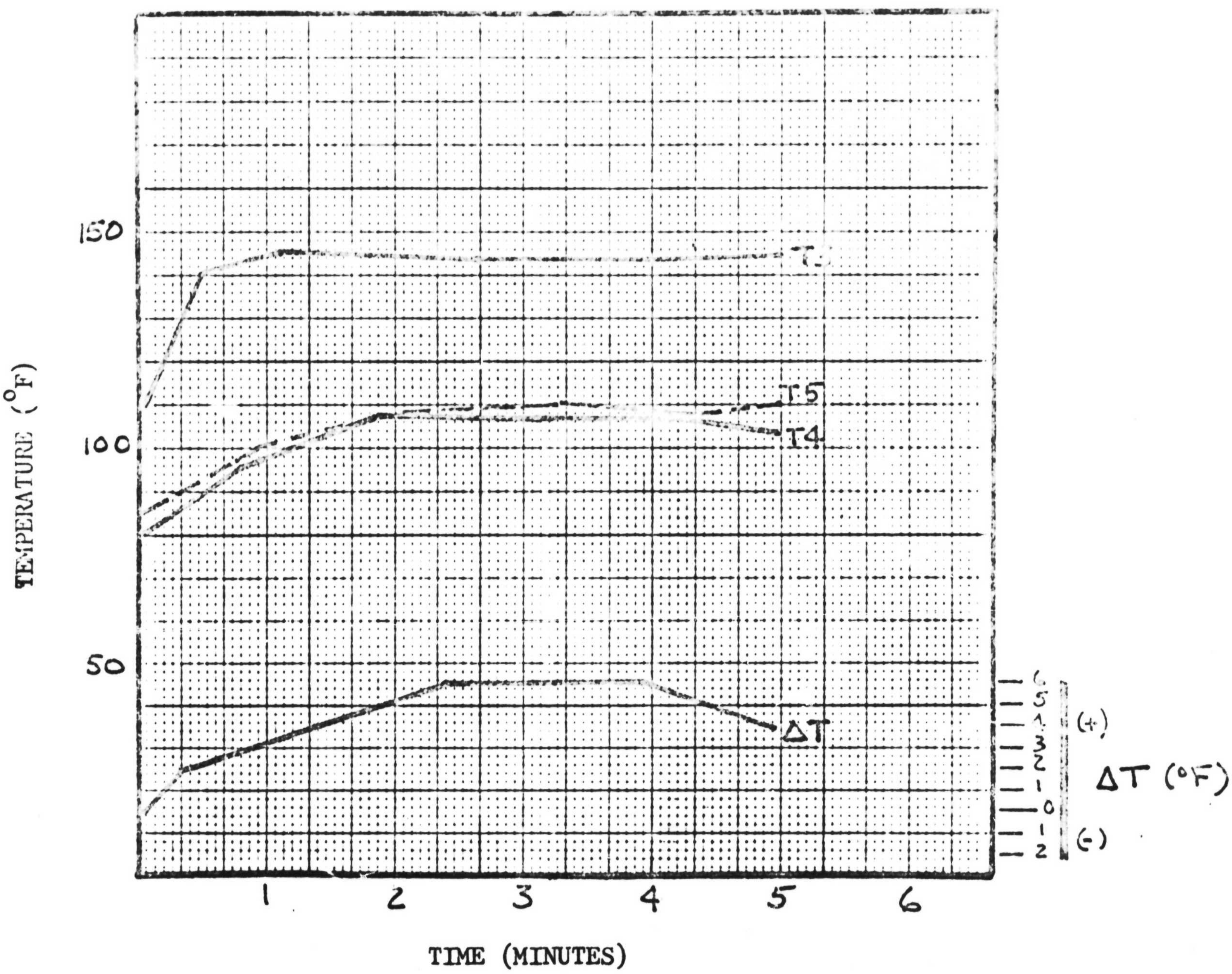
TEST CONDITIONS

Hot Test - 18 DEC 70
Braid/Silicone Overglove
T3 - Thumb Crotch
T4 - Index - Braid Outer
T5 - Index - Braid Inner
Flow - 110 cc/min

$T_{ROD} = 286 - 314^{\circ}$ F

$T_{INLET\ WATER} = 68^{\circ}$ F

FIGURE 18 THERMAL TEST



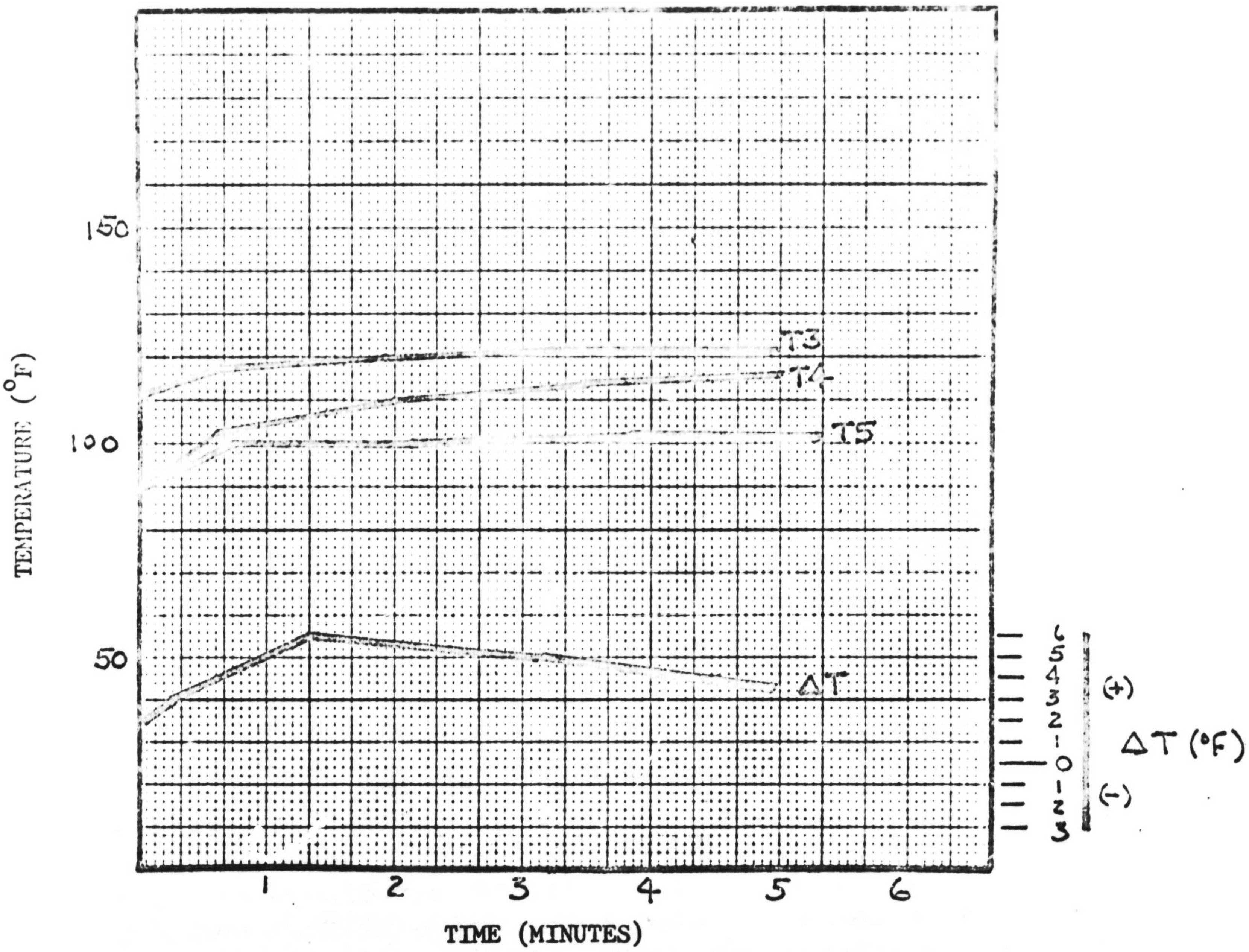
TEST CONDITIONS

Hot Test - 18 DEC 70
Braid/Lobster
T3 - Thumb Crotch
T4 - Index - Braid Outer
T5 - Index - Braid Inner
Flow - 90 cc/min

$T_{ROD} = 293 - 288°$ F

T INLET WATER $= 64°$ F

FIGURE 19 THERMAL TEST



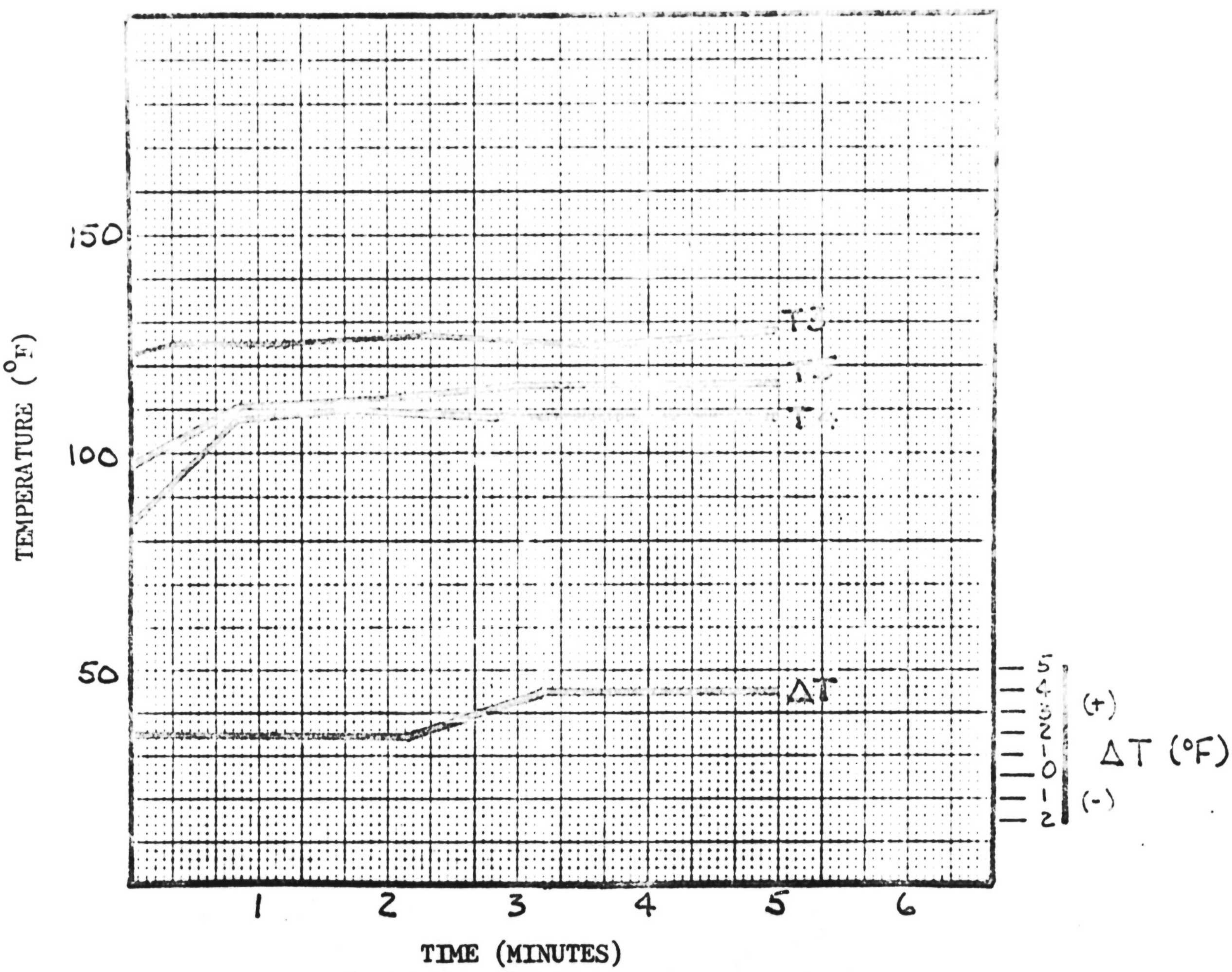
<u>TEST CONDITIONS</u>

Hot Test - 30 DEC 70
Brass/Lobster
T3 - Palm
T4 - Index - Middle Element
T5 - Index Finger - Tip
Flow (Total) 358 cc/5 min 20 sec.
(67 cc/min)

$T_{ROD} = +320°$ F

$T_{INLET\ WATER} = 76°$ F

FIGURE 20 THERMAL TEST

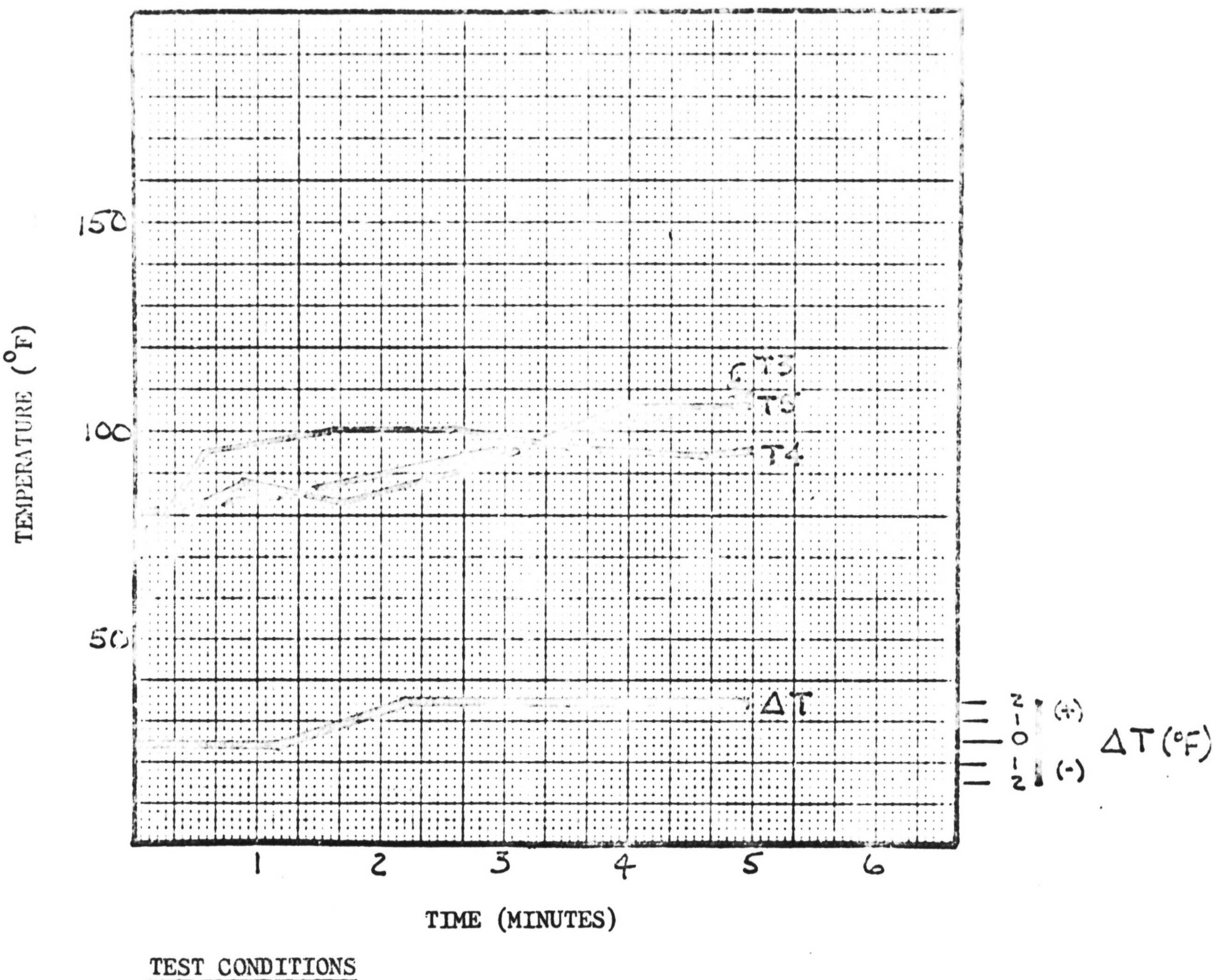


TEST CONDITIONS
Hot Test - 30 DEC 70
Brass/Lobster
T3 - Palm
T4 - Index Middle Element
T5 - Index Finger-Tip
Flow (Total) 650 cc/5 min 35 sec
(116 cc/min)

T_{ROD} = 290° F

$T_{INLET\ WATER}$ - 76° F

FIGURE 21 THERMAL TEST



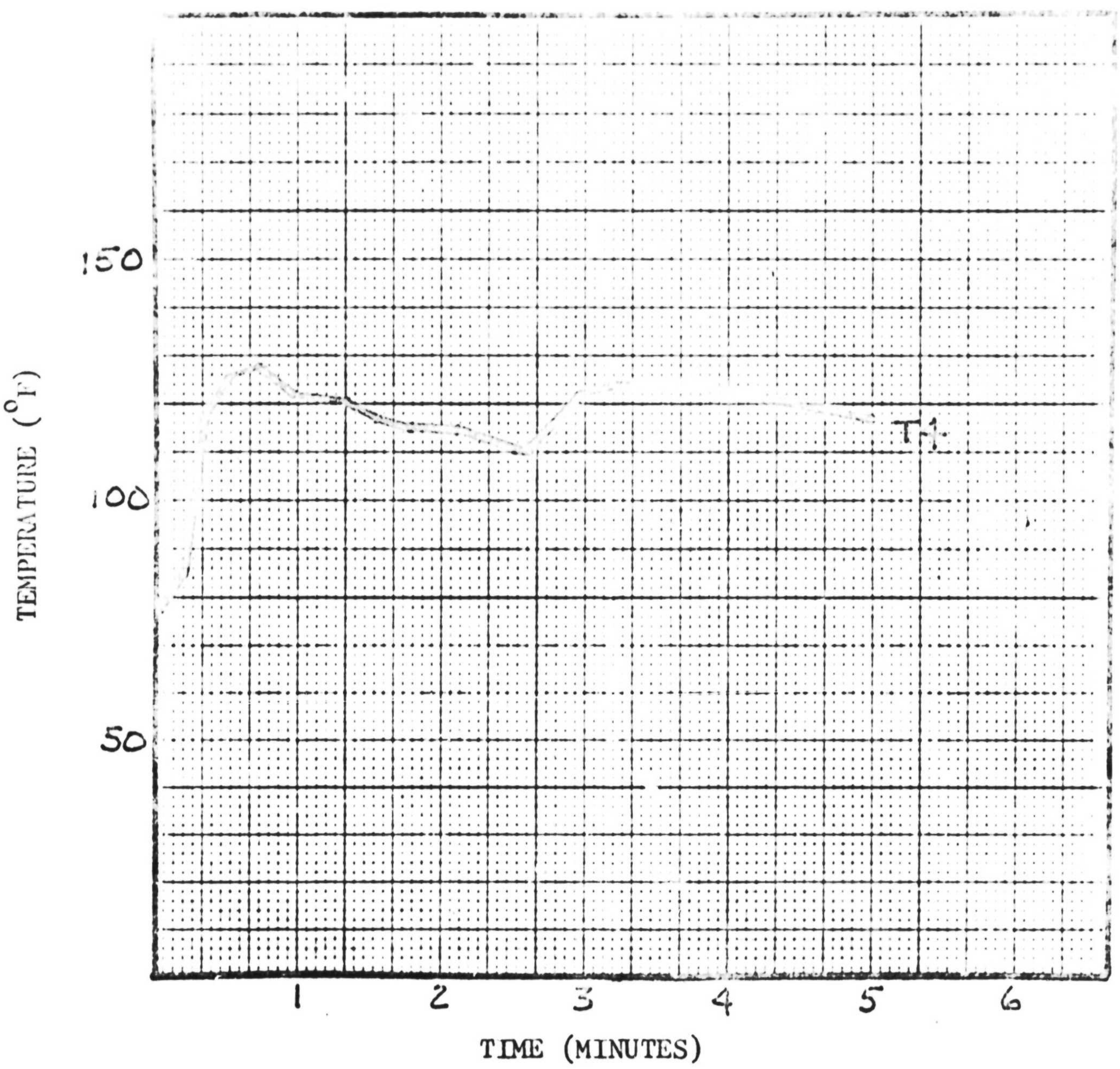
TEST CONDITIONS

Hot Test – 31 DEC 70
Brass/Lobster
T3 – Palm
T4 – Index Middle Element
T5 – Index Finger – Tip
Flow (Total) 1020 cc/7 min 40 sec
(136 cc/min)

$T_{ROD} = 290°$ F

$T_{INLET\ WATER} = 70°$ F

FIGURE 22 THERMAL TEST



TEST CONDITIONS

Hot Test - 31 DEC 70

Index & Thumb Grasp on Brass Elements

Brass/Lobster

T4 - Index Middle Element

Flow - 130 cc/min

$T_{ROD} = 302^\circ$ F

T INLET WATER = 70° F

FIGURE 23 THERMAL TEST