N73-27125

NASA TECHNICAL MEMORANDUM

NASA TM X-64767

THE LOAD-CARRYING AND THERMAL CHARACTERISTICS OF FLAT CONDUCTOR CABLE

By George D. Adams
Process Engineering Laboratory

August 1973

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
TM X-64767

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
The Load-Carrying and Thermal Characteristics of Flat Conductor Cable

5. REPORT DATE
August 1973

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
George D. Adams

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
National Aeronautics and Space Administration
Washington, D. C. 20546

13. TYPE OF REPORT & PERIOD COVERED
Technical Memorandum

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Prepared by Process Engineering Laboratory, Science and Engineering.

16. ABSTRACT

The load-carrying and thermal characteristics of flat conductor cable and round wire cables have been investigated with all conductors in each cable under varying loads in air and vacuum environments. The test procedure is described and results are presented in graphic form. Derating factors for both round wire and flat conductor cable are established for operation in a vacuum environment. Rating factors are established for flat conductor cable for use with round wire loading tables. The results of these tests show that single layer flat conductor cable can carry over 150 percent of the load of a conventional round cable of the same conductor size, or that the voltage drop across flat conductor cable will be lower than that of round cable under the same load.

17. KEY WORDS

18. DISTRIBUTION STATEMENT
Unclassified-unlimited

19. SECURITY CLASSIF. (of this report)
Unclassified

20. SECURITY CLASSIF. (of this page)
Unclassified

21. NO. OF PAGES
33

22. PRICE
NTIS

MSFC - Form 3292 (May 1969)

ACKNOWLEDGMENT

The author would like to acknowledge the splendid efforts of Mr. Edward V. Sexton who handled the test apparatus arrangement and monitored the measurements.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

TECHNICAL MEMORANDUM X-64767

THE LOAD-CARRYING AND THERMAL CHARACTERISTICS OF FLAT CONDUCTOR CABLE

INTRODUCTION

The purpose of this test was to determine the load-carrying and thermal characteristics of flat conductor cable (FCC) in single and stacked cable configurations under ambient conditions and in a simulated space environment.

The accurate determination of the temperature distribution in fully loaded electrical cables by mathematical methods is impractical. The solution of the problem in the simplest form is rigorous and of little use to the engineer. From a practical standpoint, the best that can be done is to arrive at an approximation which will show the general nature of the temperature distribution curves.

Currently, the only way to confidently determine the temperature distribution in fully loaded cables is by the experimental method of measuring the change in resistance of the conductors as a function of the change in temperature.

The temperature determinations are made by first establishing the initial resistance, R_1, of each test conductor at the known ambient temperature, T_1, from ohms law ($R = E/I$) by passing a small current which will not heat the cable sensibly above T_1 and then measuring the voltage drop across the conductor. By increasing the current load in increments and allowing the temperature to stabilize at each step, R_2 is then established and the temperature rise can be determined from the equation:

$$T_2 - T_1 = \frac{R_2 - R_1}{R_1 \alpha} \qquad (1)$$

where R_1 is the initial resistance (at T_1), R_2 is the resistance at T_2, T_1 is the initial temperature, T_2 is the unknown temperature, and α is the temperature coefficient of resistance in ohms/ohm/° C, or

$$\Delta T = \frac{\Delta R}{R_1 \alpha} \tag{2}$$

where

$$\Delta T = T_2 - T_1$$

and

$$\Delta R = R_2 - R_1 \quad .$$

It is extremely important that accurate initial measurements be made on every test conductor to provide for variations between the individual conductors and to detect initial defects before the test is started. It is equally important that regular rechecks be made before and during each test run; thus, much of the effort expended on this test was in establishing initial reference measurements of resistance, temperature, and the temperature coefficient of resistance.

A permanent automatic recording of the voltage drop, temperature, and time was made during all tests. This eliminated human error in meter reading and transcribing the data and also provided a permanent record for tracing computation errors and malfunctions that might occur during the test.

Over 3500 temperature readings were made during this test. Of the total, approximately 600 readings were made for instrument verification and recheck purposes.

TEST APPARATUS ARRANGEMENT

The test apparatus was arranged as shown in Figure 1. Figure 2 is a block diagram of the apparatus and Figure 3 is the electrical schematic. Power was supplied by a battery supply that was variable from 0 to 130 volts in 2-volt steps and was capable of delivering 10 amperes of current. Current regulation was provided by three Biddle variable resistances. The current was read on a Weston Model 901 ammeter and the voltage drop was recorded on a Mosley Model 7000A XY recorder. The conductors to be measured were selected in sequence, as shown in Figures 4 and 5, with a 35-position, rotary switch, manually synchronized with a Dekavider Model DV 64 for the recorder X drive. Power for the X drive was provided by a 9-volt battery.

The temperature was measured with a Thermo Electric Minimite thermocouple thermometer. In addition, the ambient temperature, date, and time were continuously monitored with a Bristols Thermohumidigraph.

The accuracies of equipment were as follows:

Instrument	Accuracy (% of full scale)
Thermocouple, Minimite	0.25
Voltmeter; Hewlett-Packard Digital, Model 3440A	0.20
Voltmeter; Fluke, Model 803	0.10
Voltmeter; Recording, Mosely, Model 7000A	0.20
Ammeter; Weston, Model 901	0.25

TEST CABLE PREPARATION

Because AWG No. 27 round wire was not available, selection of two wire sizes, AWG Nos. 26 and 28 stranded wire, was required for comparison with flat conductor cable (4 by 40 mil) of AWG No. 27.

The following cables were prepared for testing:

25 Conductor

Round wire AWG No. 26

Round wire AWG No. 28

Flat conductor cable, 2 inches width, AWG No. 27 equivalent (4 by 40 mil)

75 Conductor

Round wire AWG No. 26

Round wire AWG No. 28

Flat conductor cable, AWG No. 27 equivalent (three 25-conductor cables stacked)

250 Conductor

Round wire AWG No. 26

Round wire AWG No. 28

Flat conductor cable, AWG No. 27 equivalent (ten 25-conductor cables stacked)

The cable cross sections are shown in Figures 4 and 5. These figures also indicate the conductors that were measured.

The round wire was Teflon-coated stranded wire with a nominal insulation thickness of 10 mils. The flat conductor cables were made up of 2-inch, 25-conductor, flat conductor cables with 3 mils of Kapton insulation bonded by FEP Teflon.

The prepared cables were arranged so that all conductors in a cable were connected in a series, and the power line was attached to each end of the series as shown in Figure 3. Each conductor to be measured had appropriate wires attached for measuring the voltage drop in that conductor. These connections were made to a plug-in printed-wiring board for simplicity in connection to the test apparatus.

All cables were 3 feet long and were prepared according to normal mounting procedures, with the flat conductor cable clamped every 18 inches with a small insulated metal clamp. On the 3-foot cable, a clamp was mounted at each end and one in the center. The center clamp was allowed to hang free and the end clamps were mounted on a fiberglass insulator to prevent heat loss through the clamp and mount. The round cables were prepared in round bundles so that each cable bundle was straight and not twisted. Each conductor was straight and maintained its exact radial position throughout the cable length, which was accomplished by threading the conductors through three predrilled conductor aligning plates as shown in Figure 6. The two outer plates were used as mounting plates and the center plate was used to comb the conductor into place as the cable bundle was laced. These plates were made of epoxy fiberglass to minimize heat dissipation at the mounting point. This arrangement is shown in Figure 2. The cable was laced firmly on 1-inch centers and the lacing followed closely behind the combing plate to ensure proper conductor location. Figure 4 is a cross section of the round wire cables showing the conductors to be measured.

The flat conductor cable was prepared with 2-inch, 25-conductor (4- by 40-mil) cables stacked to provide the desired number of conductors as shown in Figure 5. Figure 5 also indicates the conductors to be measured.

TEST PROCEDURES

All instruments used in engineering tests are calibrated at scheduled intervals against certified standards that have known valid relationship to national standards. Records are maintained that show the date of last certification and the due date of the next certification. The instruments used for these measurements display certification seals signed by the certifying agency and were calibrated prior to testing. Each cable was set up in turn in the test unit as shown in Figures 1, 2, and 3. The test was carried out in two steps: (1) The temperature coefficient of resistance was determined and compared with the published values. Uniformity between the cables was then compared. (2) The temperature rise of the individual conductors in each cable was then determined using the temperature coefficient of resistance established in the first step.

Determining Temperature Coefficient of Resistance

Data were recorded for determination of the temperature coefficient of resistance by hooking up each cable as described herein, and placing the cable in an oven. A Hewlett-Packard Model 3440A digital voltmeter with a Model 3444A dc multifunction plug-in unit was substituted for the Weston ammeter to provide for a more accurate reading of the low current that was passed through the cable for this test. A 10 mA current was passed through the cable and the voltage drop was recorded for each conductor at ambient temperature. The oven temperature was then raised to 100°C and the measurements were repeated. The temperature coefficient of resistance was then determined from equation (1), and the initial resistance, R_1, was established and recorded for each conductor.

Measuring Temperature Rise in the Cable

The cable was connected into the test circuit and a verification recording was run at 10 mA current and compared with the initial recording of R_1, then the cable was placed in the draft hood (Fig. 1). With the Weston ammeter in the circuit, a constant current of 250 mA was passed through the cable. The voltage drop across the center conductor was monitored until the voltage ceased to rise. The temperature was allowed to stabilize for at least 10 minutes after the voltage ceased to rise. The voltage drop was then recorded for each conductor by scanning the conductors with the conductor selector switch in step with the X drive decade. The current was increased in 1/4-ampere steps and the procedure repeated at each step until a temperature in excess of 150°C (302°F) was reached.

This procedure was repeated for each test cable in the draft protection hood and in the vacuum chamber at a pressure below 10^{-4} Torr.

From the above voltage current data, the resistance was computed and temperature was determined from equation (1), using the temperature coefficient of resistance as previously determined.

The 250-conductor flat conductor cable was measured in one quadrant only. To determine the influence of convection, this cable was rotated and tested in each of the four quadrants in horizontal and vertical positions.

TEST RESULTS

Temperature Coefficient of Resistance

The temperature coefficient of resistance of all cables tested was found to be 0.00398, which is in close agreement with the published value of 0.00393. The results of this test are shown graphically in Figures 7 through 17.

Temperature Rise Under Full Load — All Conductors Carrying the Same Current

The temperature rise as a function of the current load in the various cables is shown in Figures 7, 8, and 9. The curves for the AWG No. 27

round wire were interpolated from the data on the tested AWG No. 26 and No. 28 wire by using the relative copper cross sections of the wire sizes as a basis of interpolation. From these figures, it can be seen that the current-carrying capacity of the FCC is higher than the capacity of the comparable round wire as shown below:

	Capacity of FCC (In Percent of Round Wire Capacity, Based on Hottest Conductor)	
No. of Conductors	In Air	In Vacuum
25 (1 layer)	150	155
75 (3 layers)	135	150
250 (10 layers)	105	105

From the above information, it appears that with an increase in thickness, the FCC capacity could be expected to decrease and approach the same load capacity of round wire as the cross section approaches the same volume to surface ratio. It is also noted that the load capacity of 25- and 75-conductor cables operating in vacuum is approximately the same as that of the round wire operating in air.

Temperature Rise Profile in Air

Figures 10, 11, and 12 show the temperature rise profile through each of the tested cables in air on the axis as indicated in the figure. The temperature rise profile for each cable layer in the 250-conductor flat conductor cable carrying a 1-ampere load in vacuum is shown in Figure 13, while Figure 14 shows the same profiles for this cable while carrying 1.7 amperes of load in air. For simplicity, only the top five cables are shown in Figures 13 and 14. The difference in temperature between the top cable layer and the bottom layer may be determined from Figure 15 which shows the temperature profile of the center conductors (number 13 conductor) reading from top to bottom through the cable operating in air at 1.7-ampere current.

Temperature Rise Profile in Vacuum

Figure 16 is the same as Figure 12 except that the cables are operating in vacuum and the current is reduced to 1 ampere. The layer profile of the 75-conductor cable operating in air at a 3.5-ampere load is shown in Figure 17 and may be compared with Figure 11, which shows the same cable operating in air at a 2-ampere load.

The Influence of Convection in Various Mounting Positions

There is no evidence that the operating position of flat conductor cable (either horizontal or vertical) significantly influenced the temperature of the hottest wire when operated in air. The only apparent result is that the position of the hottest wire shifted.

This same test was conducted on partially loaded cables and the results were inconclusive. The temperature readings on the loaded conductors varied widely between cables and the temperature appeared to be independent of the conductor size and the cable size. This may be attributed to the variation in the binding pressure between cables and the variation in contact between the individually loaded conductors. These variations were less evident in the fully loaded cables because of the lower temperature gradient between conductors.

CONCLUSIONS

Flat conductor cables can carry heavier loads and/or will have less voltage drop than conventional wiring of the same gage size. This advantage increases as the number of layers decreases.

The current-carrying capacity of flat conductor cable as tested may be uprated from the same size round wire as follows:

	Uprating Factor	
	In Air	In Vacuum
Single Layer Cable	1.50	1.55
3 Layer Cable	1.35	1.50
10 Layer Cable	1.05	1.05

The mounting direction (horizontal or vertical) of flat conductor cable has no appreciable effect on the heat rise of a fully loaded cable in air. In an air environment, convection cooling will shift the position of the hottest wire but has little influence on the temperature of the hottest wire.

When operated in vacuum, all cables must be downrated to 55 percent of the rated capacity in air. Single-layer flat conductor cable may be operated in vacuum at 60 percent of the air-rated load.

The rating factors established herein are considered to be safe values and are below those indicated in the data that are shown in the figures.

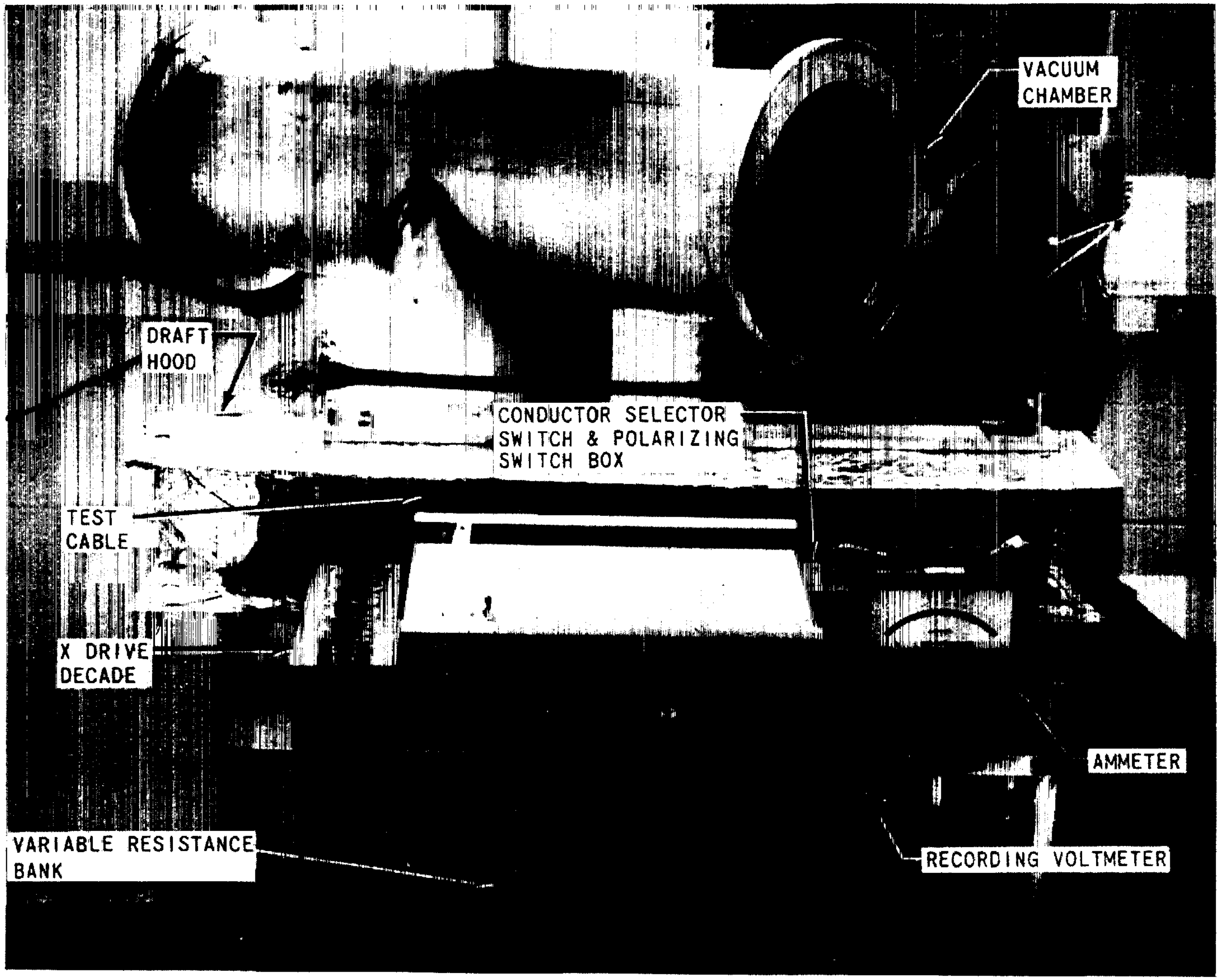

Figure 1. Test apparatus.

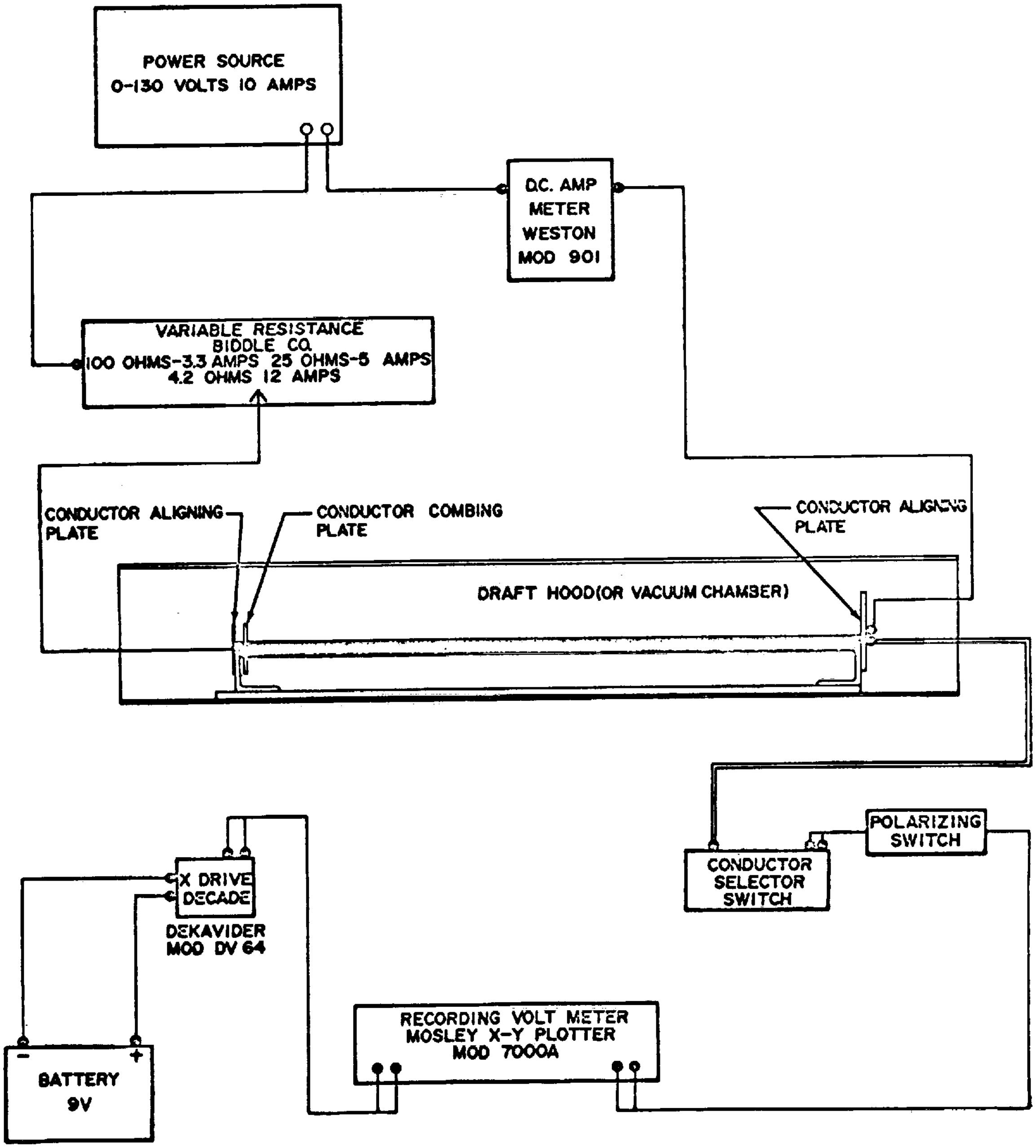

Figure 2. Test apparatus block diagram.

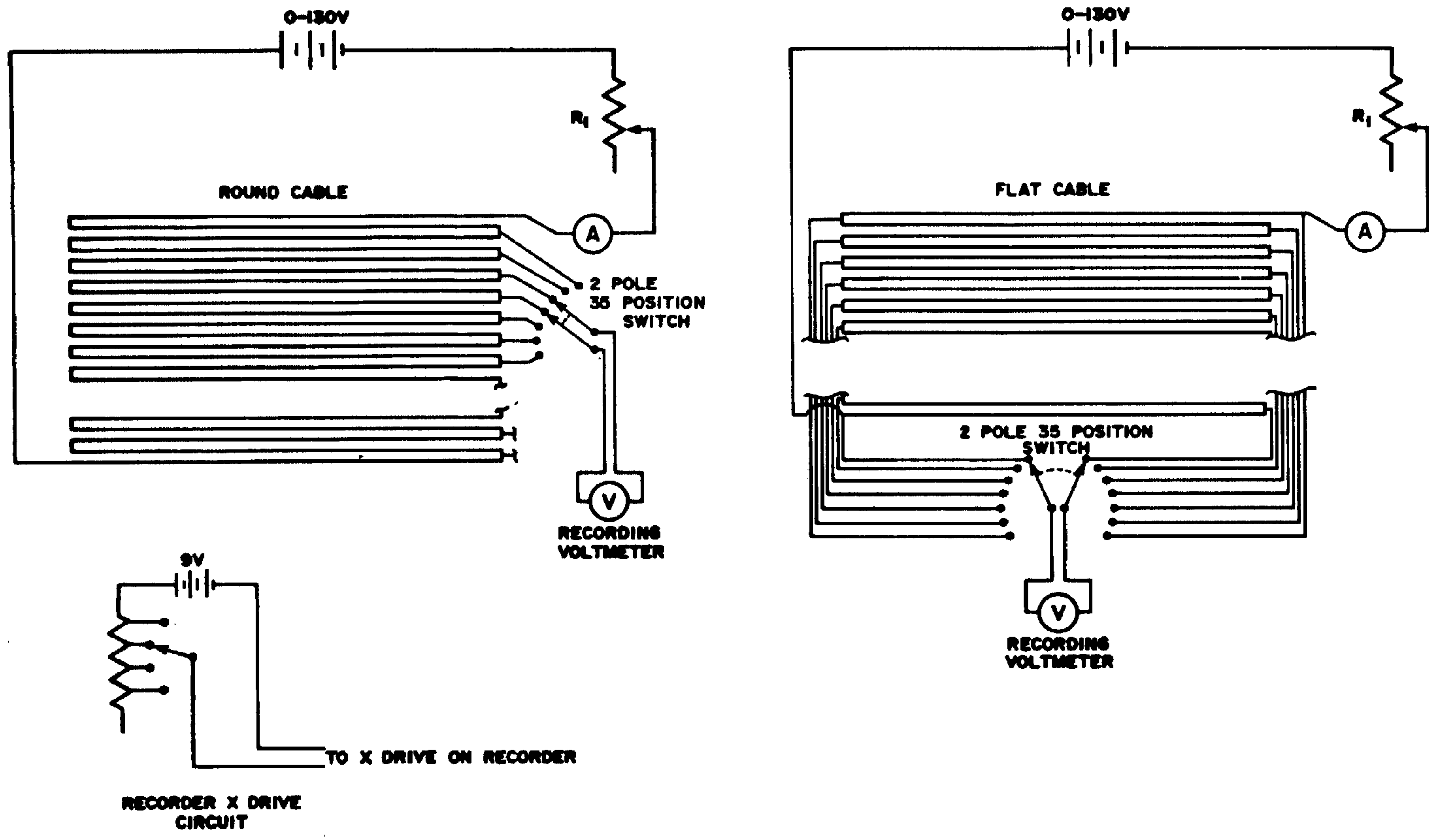

Figure 3. Electrical schematic.

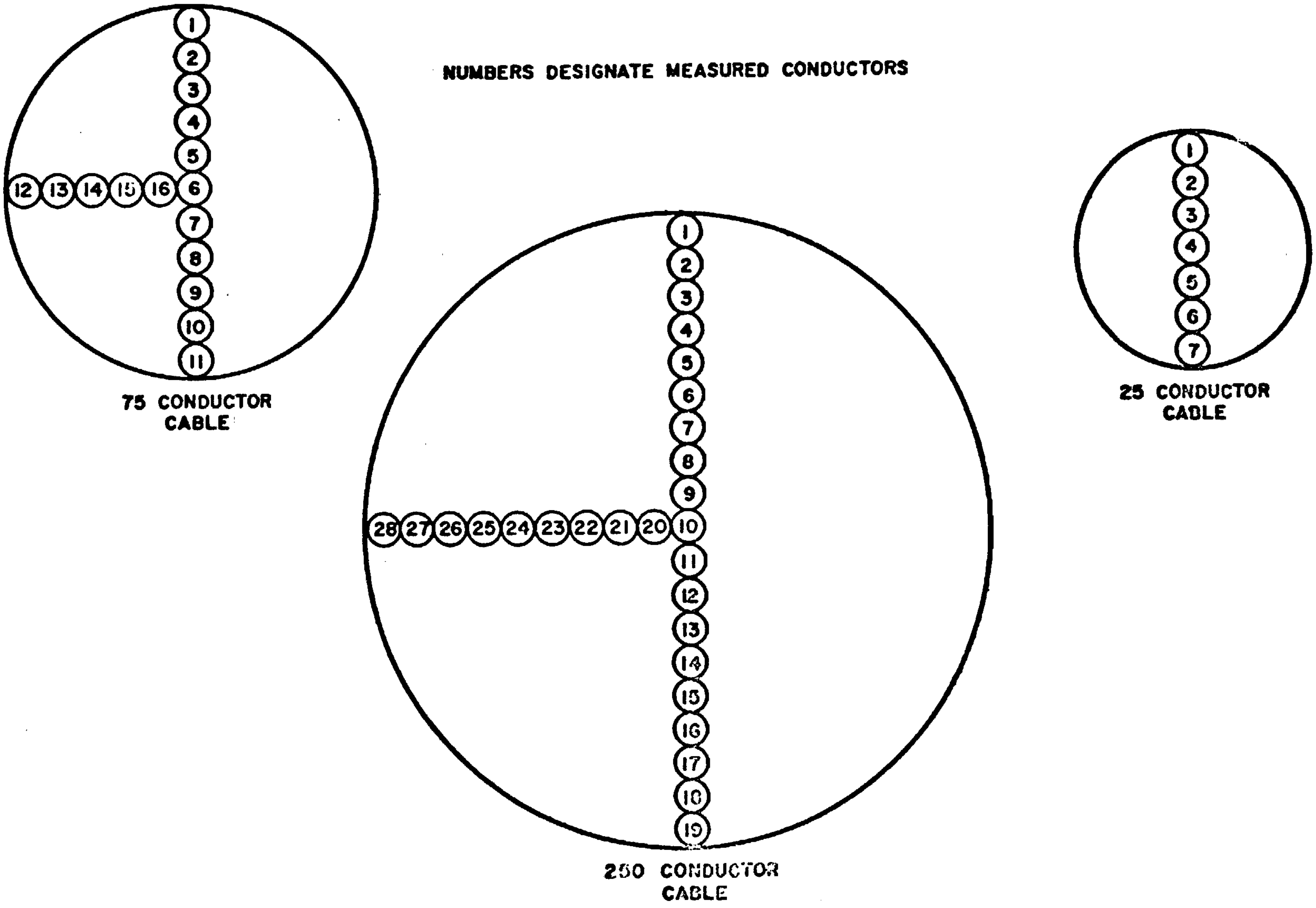

Figure 4. Round cable configuration and conductor designations.

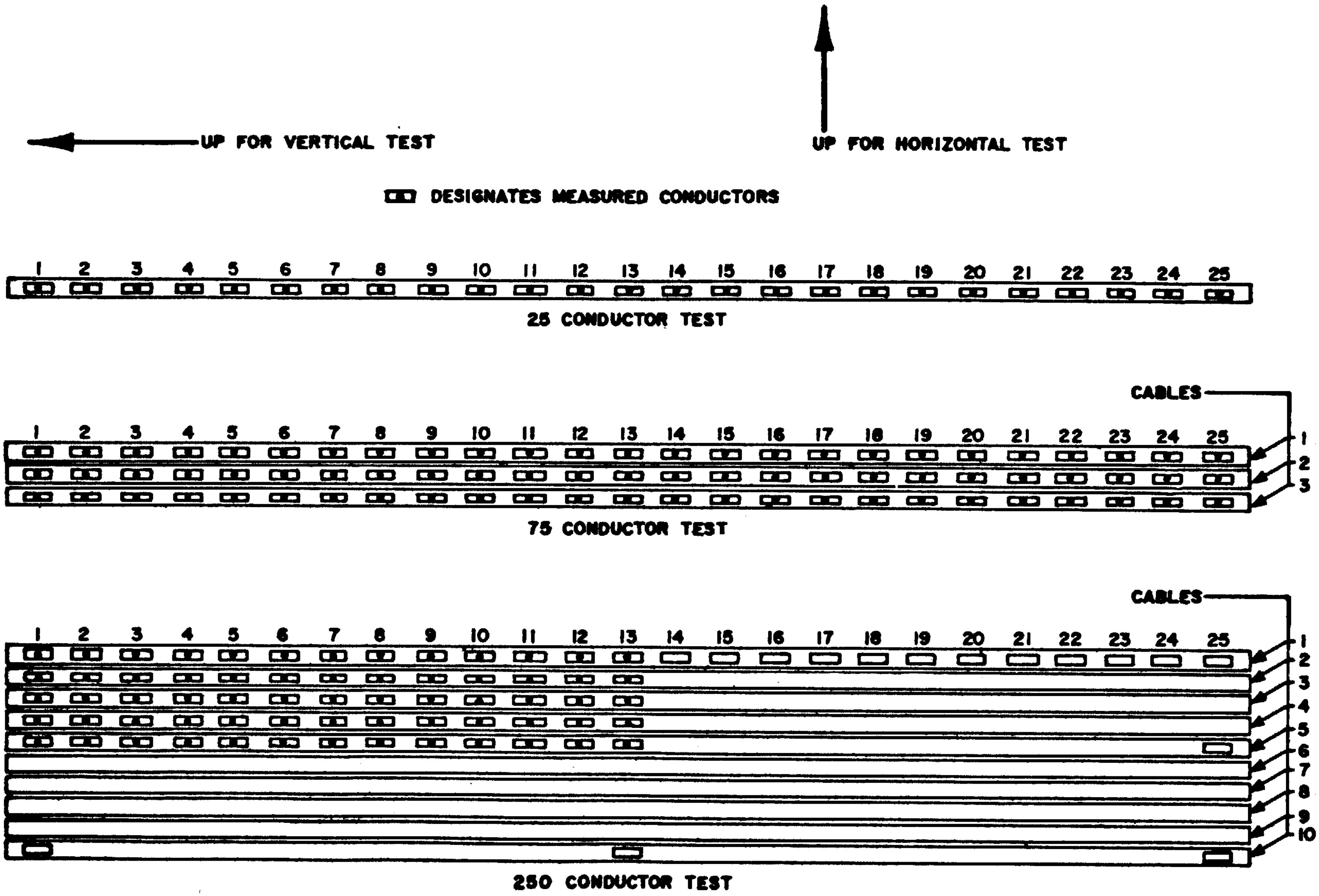

Figure 5. Flat conductor cable configuration and conductor designation.

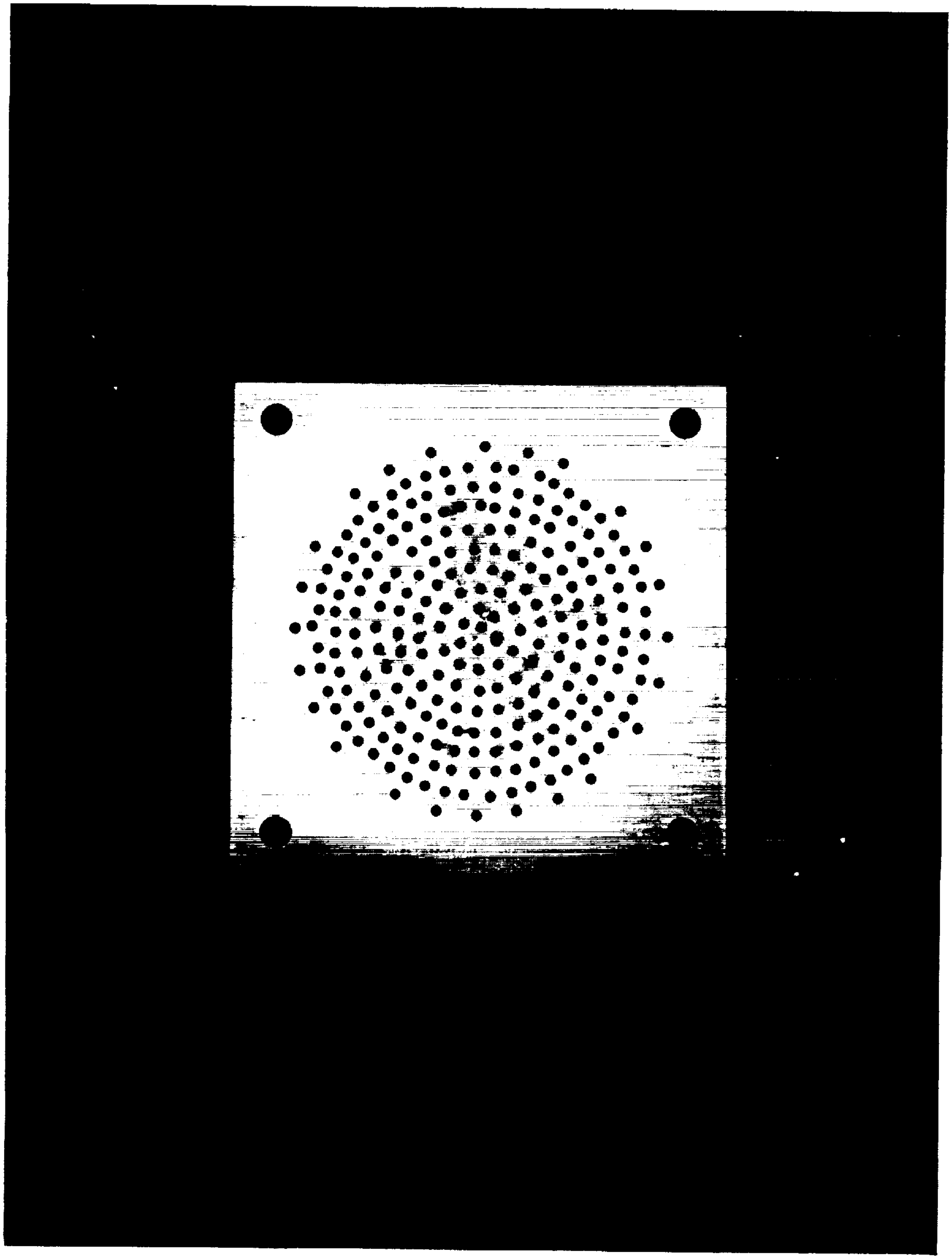

Figure 6. Conductor aligning plate.

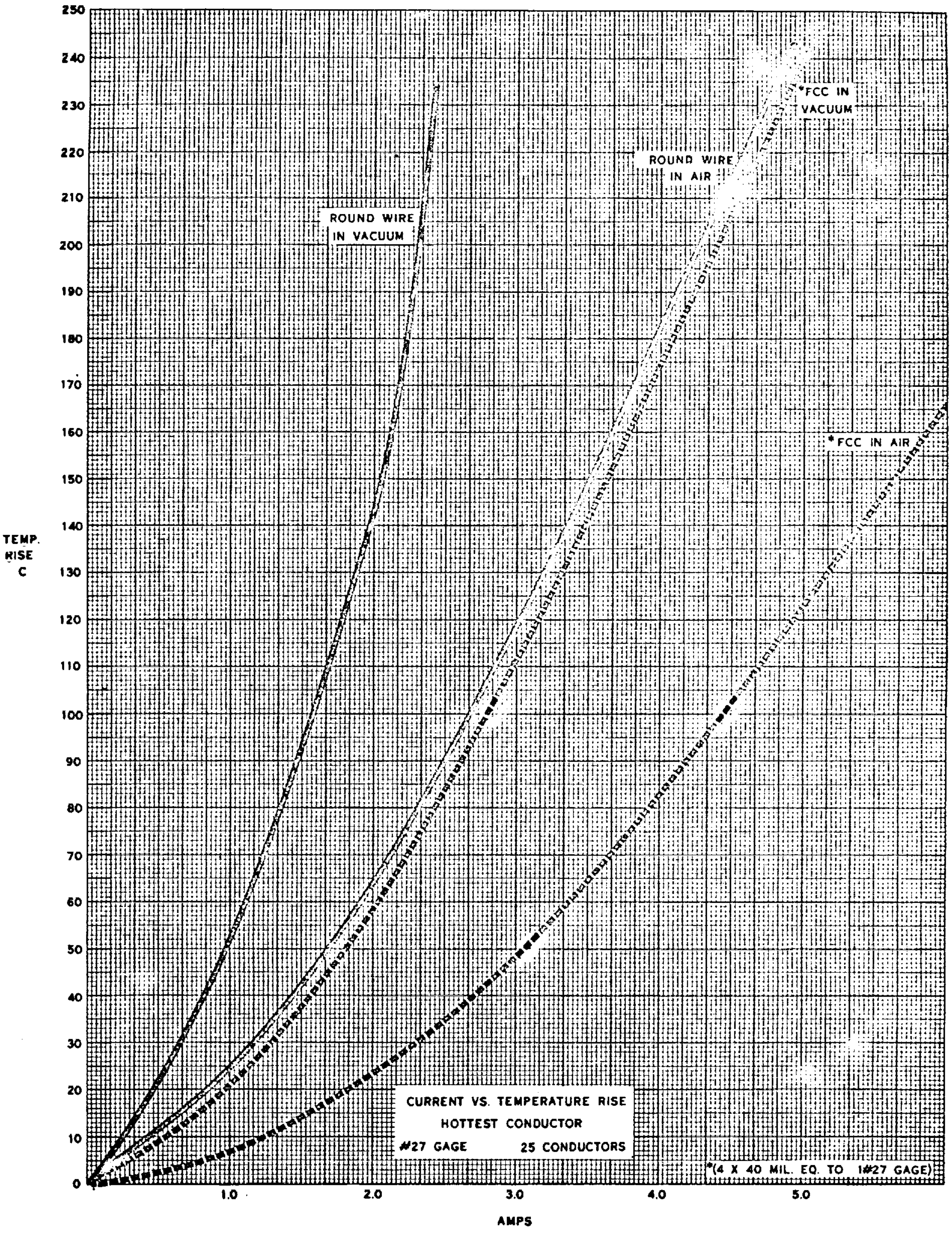

Figure 7. Current versus temperature rise, 25 conductors.

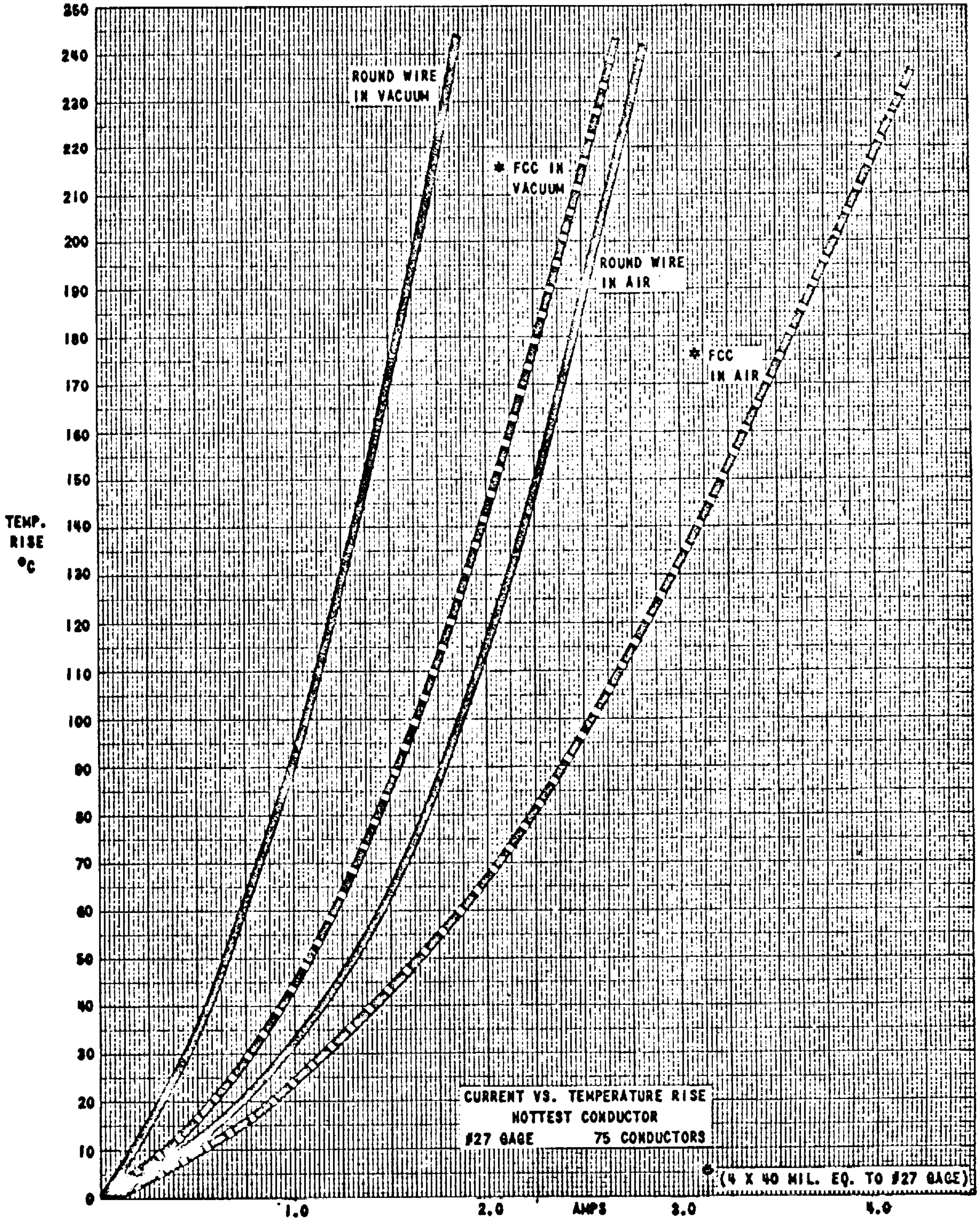

Figure 8. Current versus temperature rise, 75 conductors.

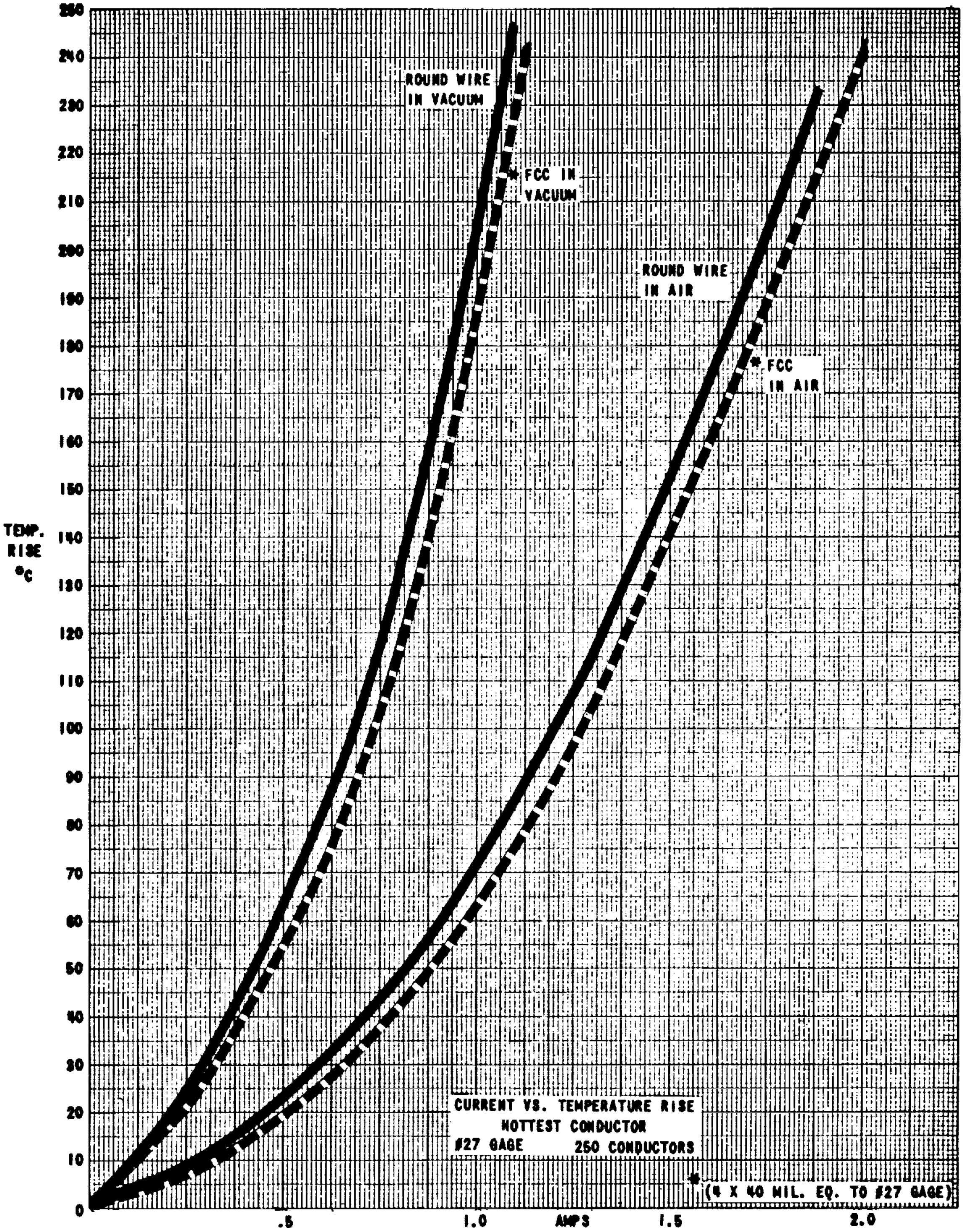

Figure 9. Current versus temperature rise, 250 conductors.

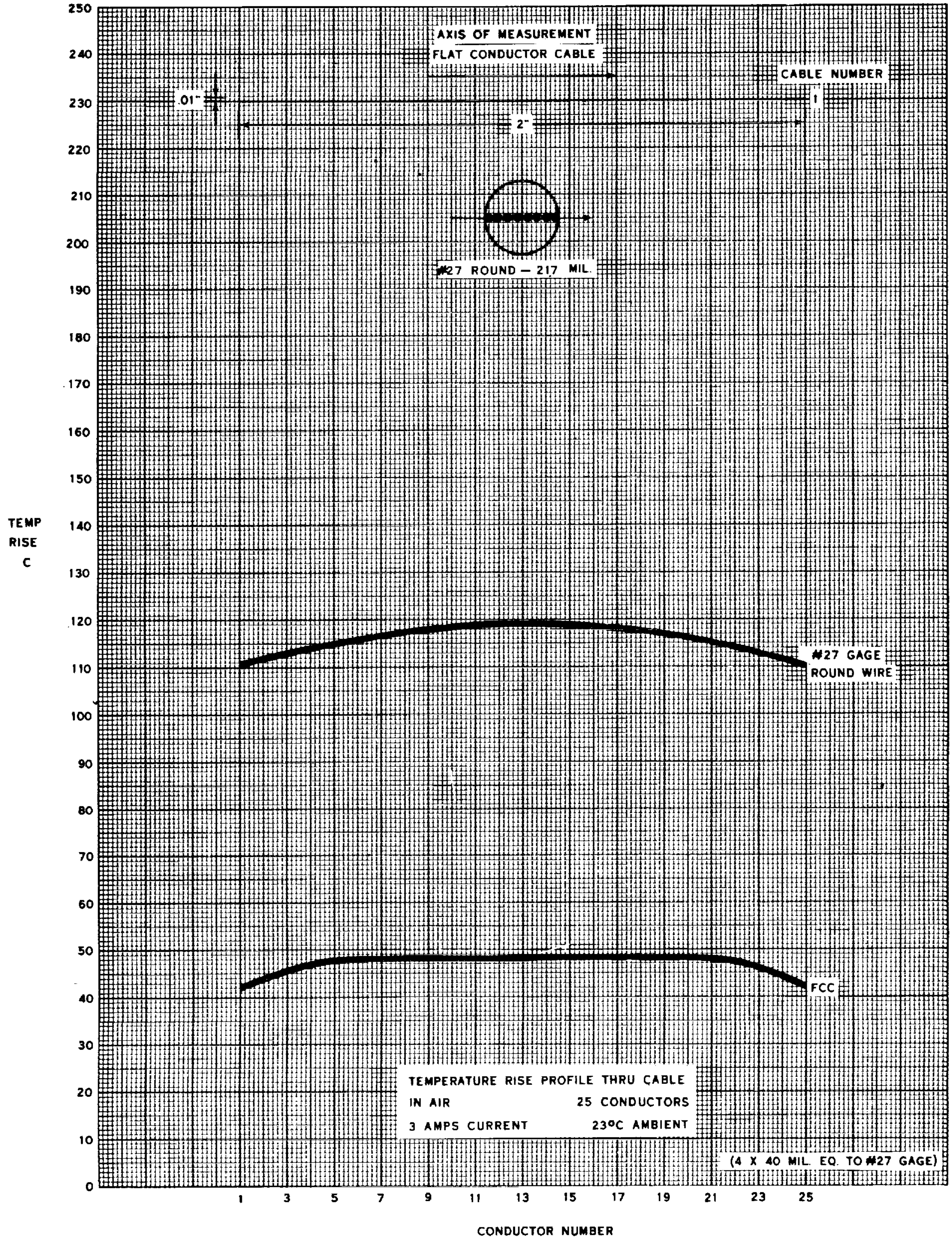

Figure 10. Temperature rise profile through cable in air, 25 conductors.

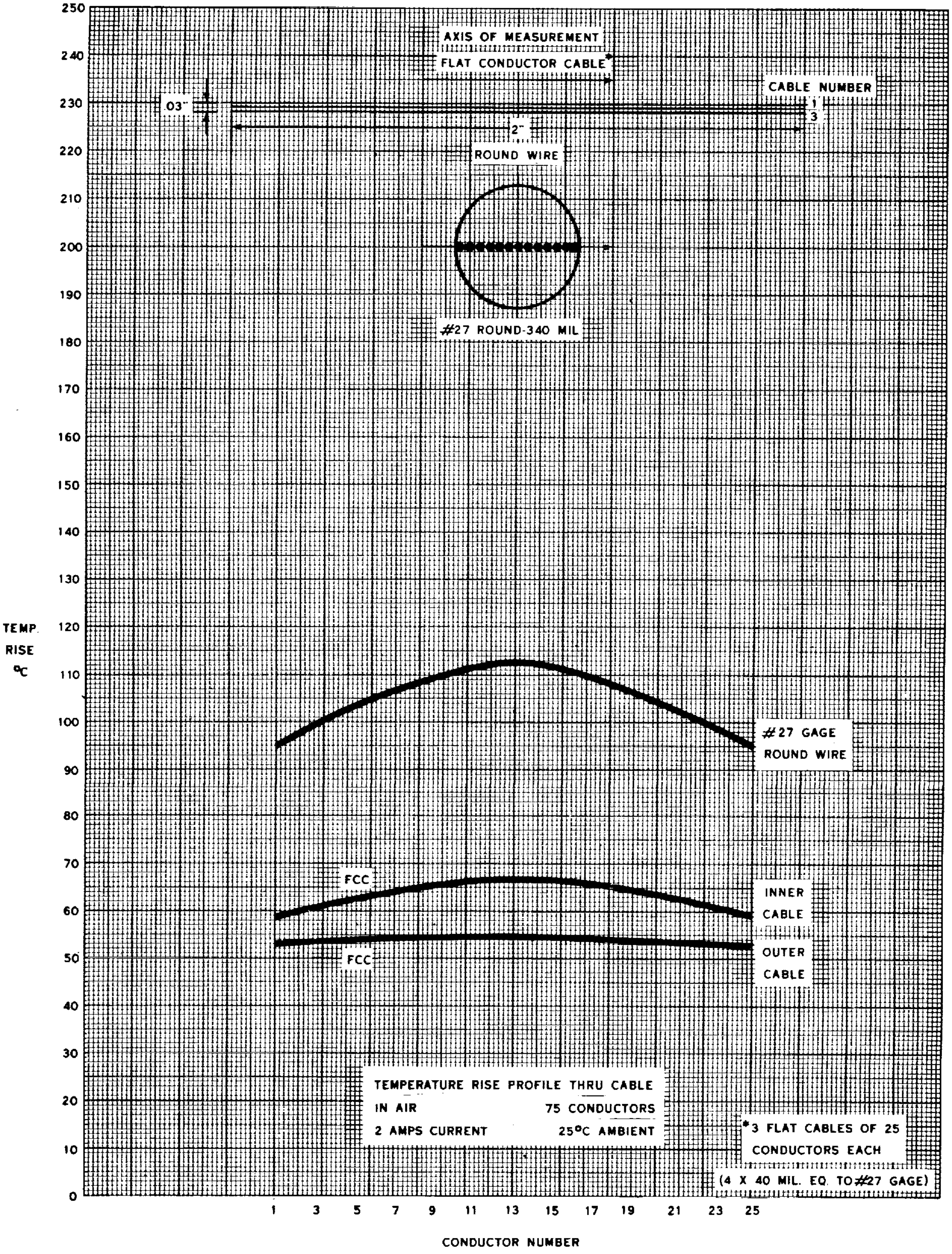

Figure 11. Temperature rise profile through cable in air, 75 conductors.

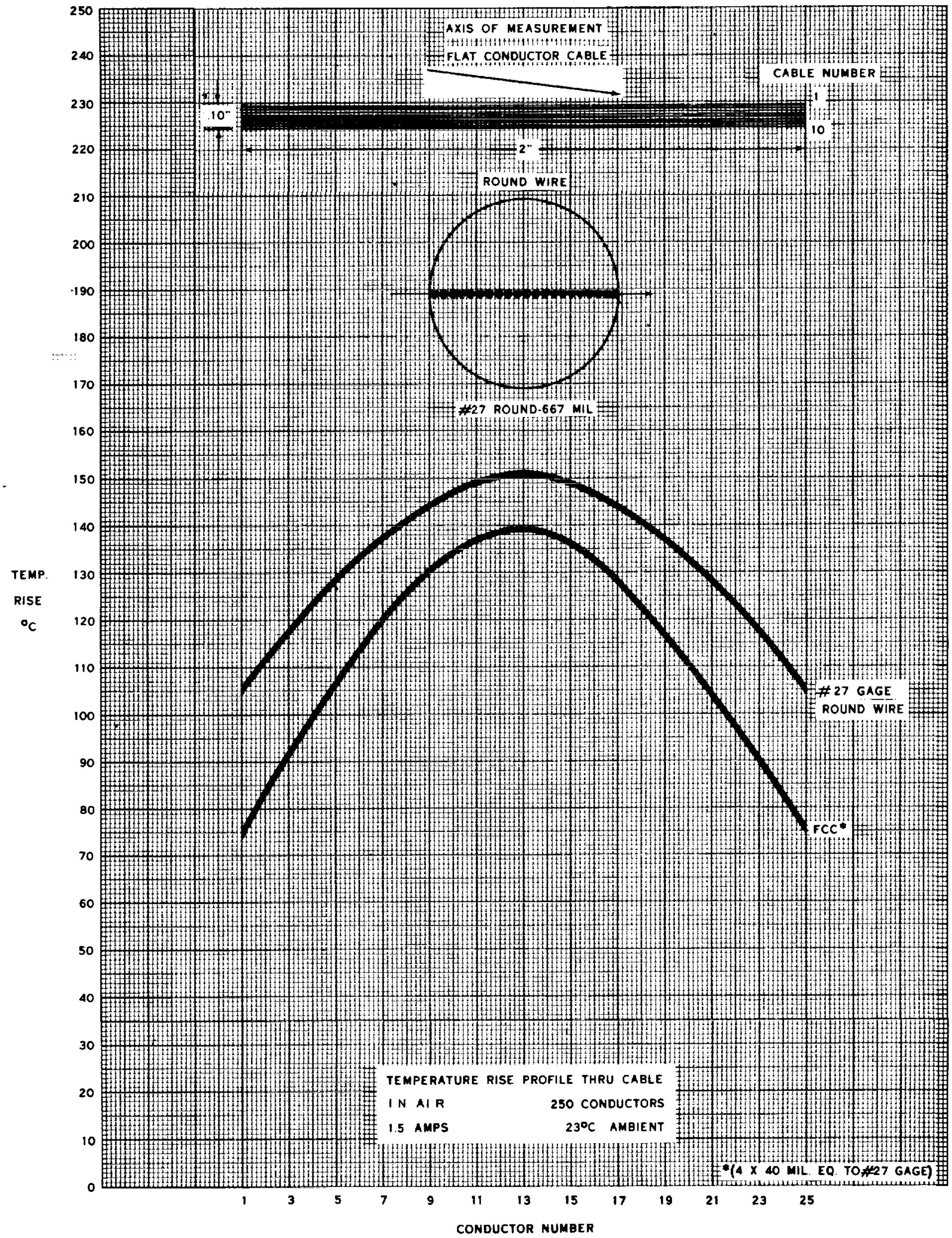

Figure 12. Temperature rise profile through cable in air, 250 conductors.

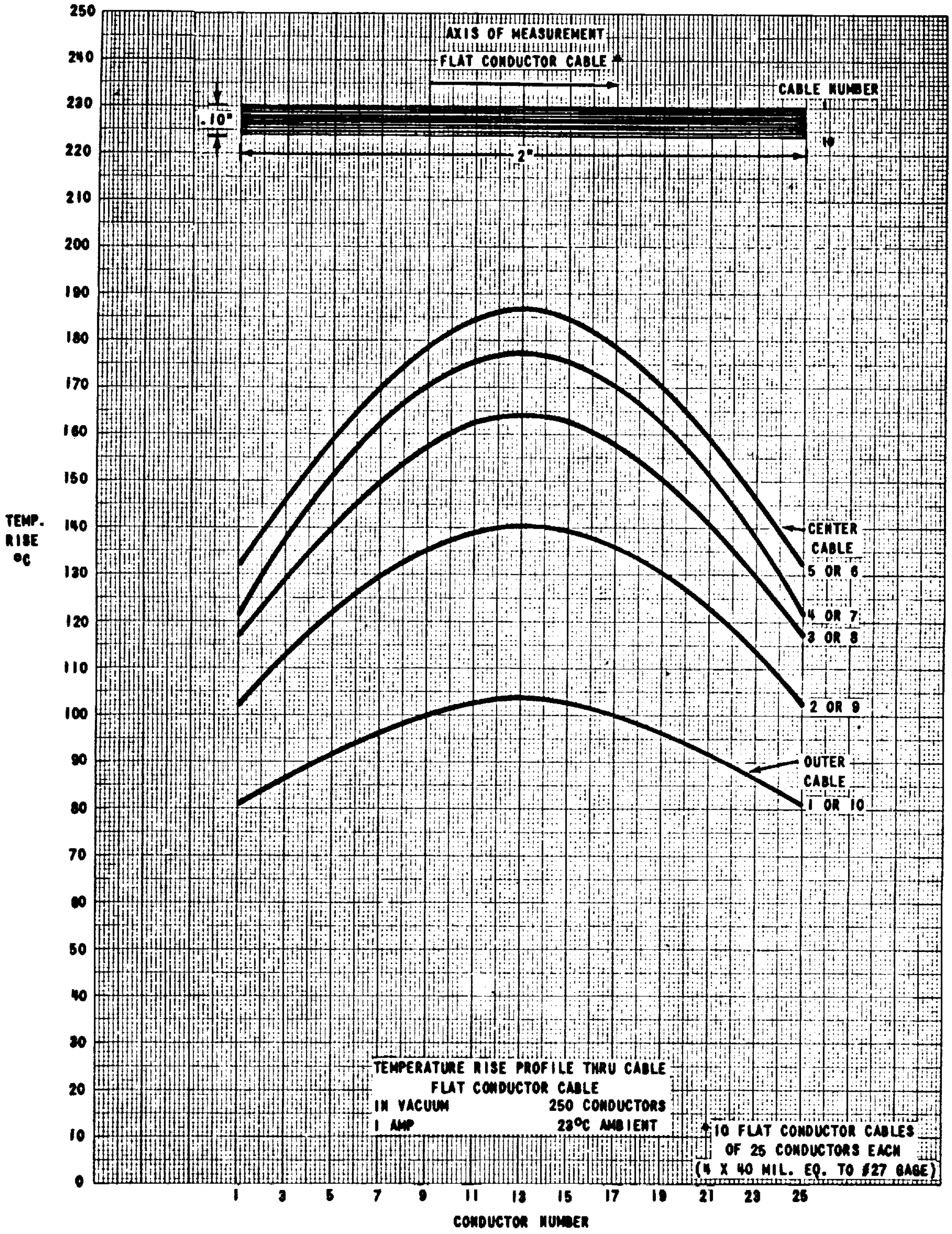

Figure 13. Temperature rise profile through cable in vacuum, 250 conductors.

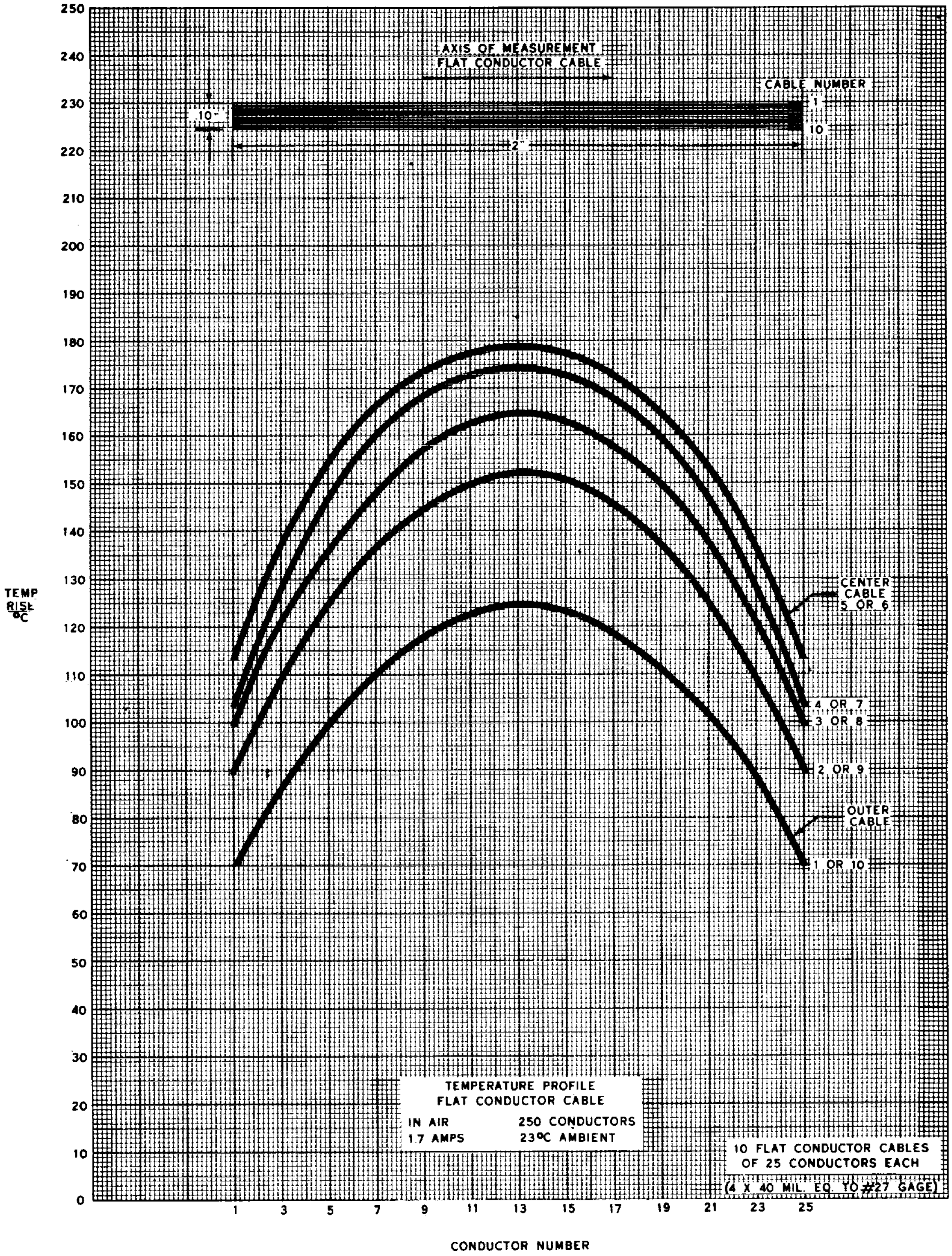

Figure 14. Temperature profile, flat conductor cable in air, 250 conductors.

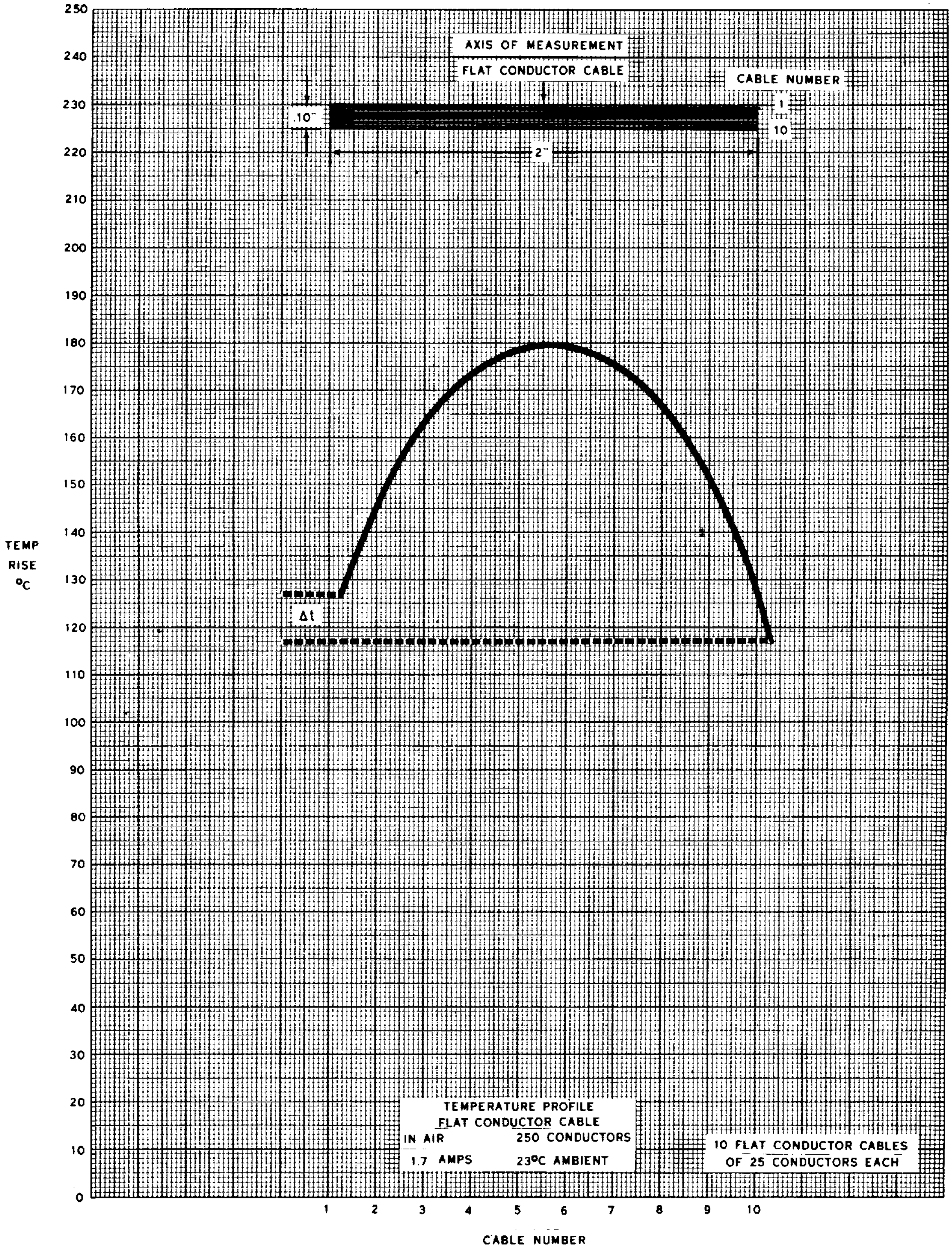

Figure 15. Temperature profile, flat conductor cable in air, 250 conductors.

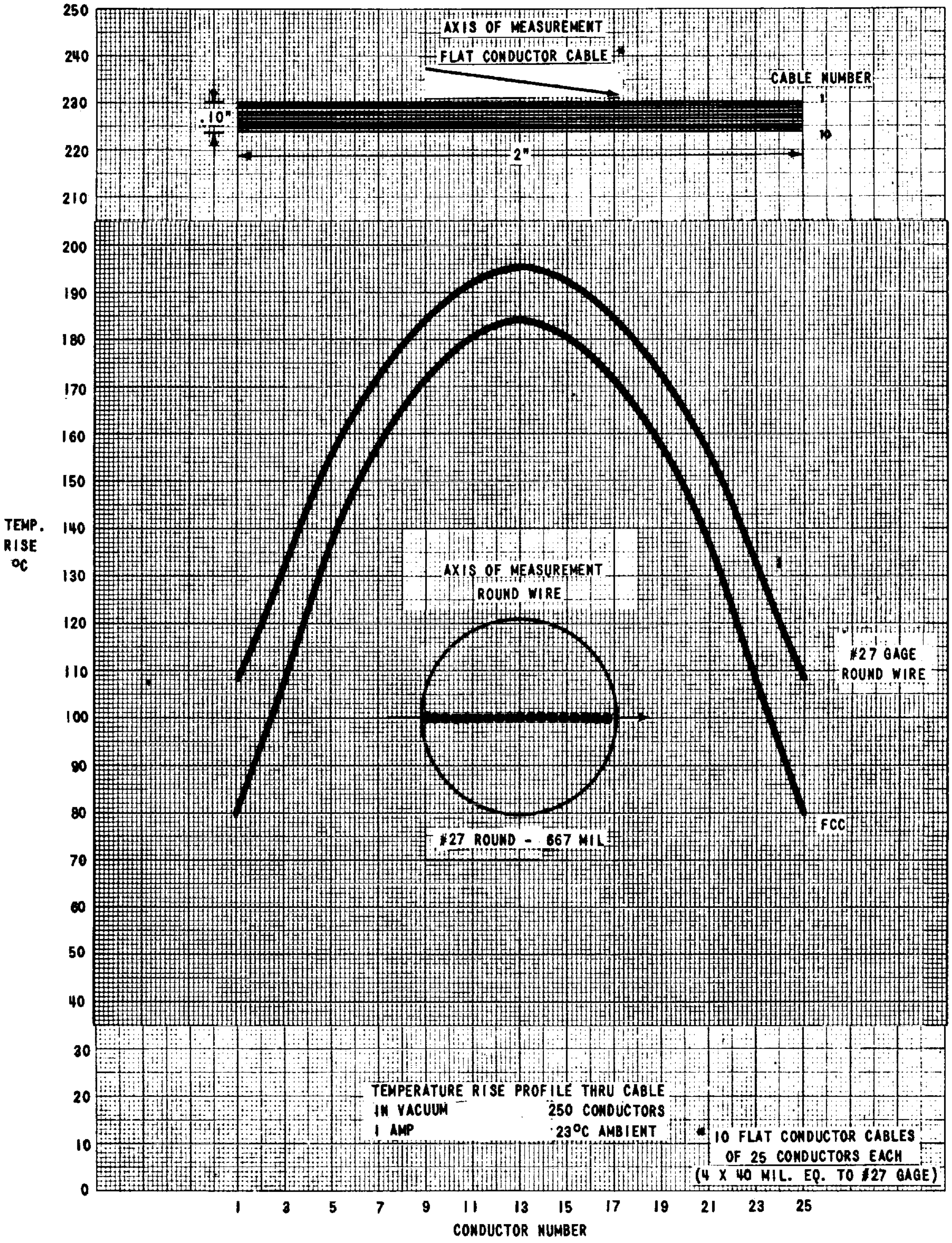

Figure 16. Temperature rise profile through cable in vacuum, 250 conductors.

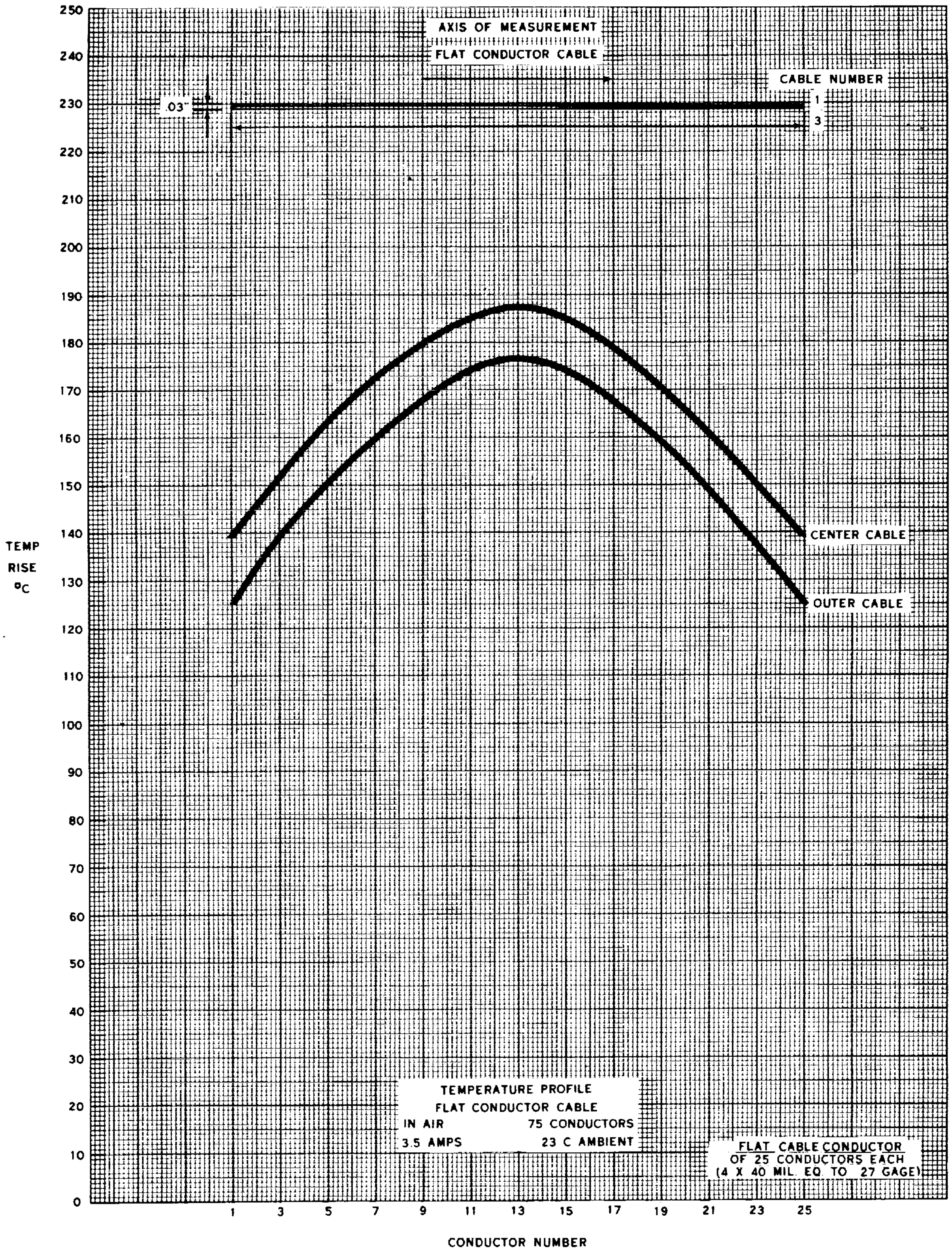

Figure 17. Temperature profile, flat conductor cable in air, 75 conductors.

APPROVAL

NASA TM X- 64767

THE LOAD-CARRYING AND THERMAL CHARACTERISTICS OF FLAT CONDUCTOR CABLE

By George D. Adams

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

W. Angele

W. ANGELE
Chief, Research and Process Technology Division

8/13/73

M. P. L. SIEBEL
Director, Process Engineering Laboratory