NRL REPORT 3587

CURRENT AND TEMPERATURE RISE IN AIRCRAFT CABLES

PART I — SINGLE CABLES UNDER STEADY-STATE CONDITIONS

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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ABSTRACT

In investigating the factors affecting the choice of an optimum aircraft electrical system it was found that quantitative information on many phases of system operation was lacking. One of the areas in which knowledge is needed is the current rating of cables. No sound basis for the rating of cables in bundles is generally available. Present ratings for single aircraft cables do not provide significant aid for the grouped-cable problem because the ratings are entirely empirical.

As a step toward solving the bundle-rating problem, an analysis of relations between current and temperature rise for the case of the single cable in air is presented. Two methods for determining the continuous current necessary to produce a given rise in conductor temperature are discussed. The basis of the methods is the simultaneous solution of the heat-transfer relations applicable to the cable. The convection coefficients needed were determined experimentally for sea level and for simulated altitude conditions. The study provides methods for computing the current capacity of single cables at sea level and at various altitudes, which are of general validity and will serve as a basis for an analysis of the grouped-cable problem.

PROBLEM STATUS

This report is an interim report on NRL Problem No. E01-08R and concludes the work on the steady state relations between current and temperature rise for single cables. An investigation of the relations between current and temperature rise in bundled cables is now in progress.

AUTHORIZATION

NRL Problem No. E01-08R, formerly NRL No. 31E112, based on BuAer letter to NRL, Aer-E-312-JWA, F36-1(1) Serial 313857 dated 20 December 1945.

CURRENT AND TEMPERATURE RISE IN AIRCRAFT CABLES

Part I - Single Cables Under Steady-State Conditions

INTRODUCTION

Reliable current ratings are one of the prerequisites for the design of any electrical system. The grouping of cables in bundles in aircraft provides a current-rating problem whose solution is needed. As a preliminary step, an analysis of the relations between the continuous current and temperature rise for the case of the single cable in air was undertaken. Existing studies of the current capacity of single aircraft cables are wholly empirical and are of little value for predicting bundle ratings.

Study of the single-cable problem shows that the continuous current necessary to produce a given conductor temperature may be predicted when certain properties of the cable and its environment are specified. Two methods for finding the current will be described. In the first, two expressions for the current are obtained from the equations for the flow of heat (a) through the insulation and (b) from the outer cable surface to the surrounding air and structure. The desired value is then found by the simultaneous graphical solution of the two current expressions. In the second method, the two heat-transfer relations mentioned previously are combined into a single equation which may be used to determine the temperature of the outer cable surface. When this temperature is known, the current may be computed directly with either heat flow equation.

Both methods require that the convection coefficient be known as a function of (a) the cable diameter and (b) the temperature difference between the outer cable surface and the ambient air. The convection coefficients were determined experimentally for the range of diameter and of temperature difference normally encountered. Measurements were obtained at air pressures corresponding to sea level, 20,000, and 60,000 feet.

ASSUMPTIONS AND REVIEW OF HEAT TRANSFER RELATIONS

When an electric current flows in a conductor, the heat generated is transmitted through the insulation by conduction and then transferred to the surrounding air and walls by convection and radiation. If the cable insulation is to be prevented from deteriorating too rapidly and safe operation of electric circuits is to be maintained, the insulation temperature must not exceed some predetermined value. Because the conductor temperature is very nearly uniform, and the temperature of the insulation approaches the conductor temperature at their common boundary, the thermal limitation on the current capacity can be stated as a maximum conductor temperature. Maximum conductor temperature is the only criterion affecting current capacity which will be considered in this analysis.

The following assumptions are made: (a) The cable is suspended horizontally in air. (b) It consists of a cylindrical conductor with one or more concentric layers of insulation.

(c) Steady state conditions apply. (d) Heat transfer from the outer cable surface is by natural convection and radiation.

The rate at which heat is conducted radially through the insulation per unit length of cable is given by

$$P = \frac{2\pi K(T_1 - T_2)}{\log_e(b/a)} \tag{1}$$

This quantity also must be equal to the rate at which heat is produced in the conductor:

$$P = I^2 R_{T_1} \tag{1a}$$

where

I = current

R_{T_1} = conductor resistance per unit length at temperature T_1

K = thermal conductivity of the insulation

T_1 = conductor temperature

T_2 = temperature of the outer cable surface

b = over-all cable radius

a = conductor radius.

The rate at which heat is transferred from the outer cable surface by convection per unit length can be expressed as

$$P_c = 2\pi bh(T_2 - T_3) \tag{2}$$

where

h = convection coefficient

T_3 = temperature of the air at a point where the temperature gradient has become negligibly small. Figure 1 indicates the approximate temperature distribution in the neighborhood of a cable carrying current.

Finally, the power radiated per unit length from the cable exterior may be expressed by

$$P_r = 2\pi bse(T_{2k}^4 - T_{3k}^4) \tag{3}$$

where

s = Stefan's constant

e = emissivity

T_{2k} = temperature of the outer insulation surface in degrees absolute

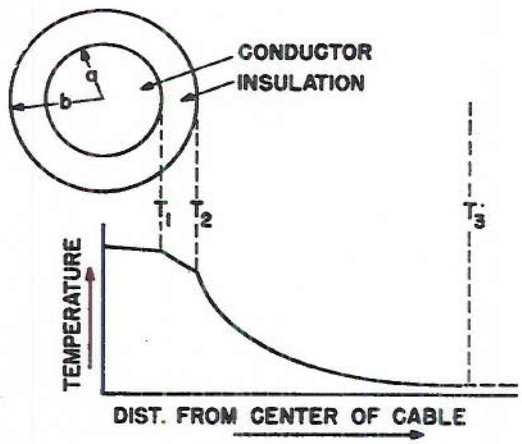

Figure 1 - Approximate temperature distribution in and about a cable carrying current

T_{3k} = temperature of the surrounding walls in degrees absolute. It will be assumed that the wall temperature is the same as that of the air at a point where the temperature gradient has become negligible.

If the radiation coefficient, r, is defined to be the power radiated by unit area for unit difference in temperature between the cable surface and the ambient air, i.e. if

$$r = \frac{se(T_{2k}^4 - T_{3k}^4)}{T_2 - T_3} \tag{4}$$

the power radiated per unit length can be rewritten as

$$P_r = 2\pi br(T_2 - T_3). \tag{5}$$

The total power transferred per unit length from the cable exterior becomes

$$P = P_C + P_r = I^2 R_{T_1} = 2\pi b(h + r)(T_2 - T_3) \tag{6}$$

PREDICTING THE CURRENT

We now wish to determine the current which will produce a given conductor temperature, T_1, in a particular cable suspended in air at a specified ambient temperature, T_3. It will be assumed for simplicity that the insulation consists of a single layer. One expression for the current may be obtained from equation (1)

$$I = \left[\frac{2\pi K(T_1 - T_2)}{R_{T_1} \log_e(b/a)}\right]^{\frac{1}{2}}, \tag{7}$$

In this equation T_1, R_{T_1}, b, and a are given constants while K is a function of insulation temperature. Because experimental measurements show that K changes slowly with temperature, and because small changes in its value affect the current capacity in a negligible way, K will be considered as a constant for any given insulation. (The effect of a change in K on the current rating will be illustrated later.) The first step in finding the current is to plot I as a function of T_2 with the aid of (7).

A second expression for the current can be obtained from (6).

$$I = \left[\frac{2\pi b(h + r)(T_2 - T_3)}{R_{T_1}}\right]^{\frac{1}{2}}. \tag{8}$$

In this equation b, T_3 and R_{T_1} are given constants; r is a function of $(T_2 - T_3)$ and T_3; h is a function of $(T_2 - T_3)$ and cable diameter 2b for any specified air density. For each value of T_2 arbitrarily selected, we find the corresponding value of r from (4). In order to apply (4) the emissivity of the outer cable surface must be known. Since the emissivity of most nonmetallic materials lies between 0.8 and 1.0, e may be assumed arbitrarily to have the value 0.9 without introducing a large error. The calculated r values for the range needed are plotted in Plate 1 where e is taken as 0.9. The convection coefficient, h, was determined experimentally as a function of $(T_2 - T_3)$ and b. A description of the method by which h was determined is given in Appendix 1. Plate 2 is a plot of h as a function of 2b for various $(T_2 - T_3)$ values at one atmosphere of pressure. For the curves shown, the convection loss was found by subtracting the computed radiation loss from the measured total dissipation. Plate 2 is used to find the value of h corresponding to an arbitrarily chosen T_2. The current can now be plotted as a function of T_2 with the aid of equation (8). The intersection of the two curves of current versus T_2 determines the desired current since it satisfies the two conditions of heat transfer.

The method described has been applied to size AN 18, AN 8, and AN 0 aircraft cables in Plates 3, 4, and 5 respectively. Because values of K were not available they had to be obtained by measuring b, a, P, T_1 and T_2 and substituting in (1). The experimental method used to determine K is described in Appendix I. Since the insulation of each cable consisted of a layer of plastic and a layer of impregnated cotton braid, the thermal conductivity found was an effective value for the composite insulation. Values for r and h were taken from Plates 1 and 2 respectively. The computation details for the case illustrated in Plate 3 are given in Appendix 2. The actual measured current shown in each plate demonstrates the degree of accuracy obtained by using the graphical solution. Methods which make use of the same principle have been applied in determining power cable ratings and to the problem of computing the heat loss from insulated pipes. [1,2,3]

ALTERNATIVE METHOD FOR PREDICTING THE CURRENT

A second procedure for determining the current necessary to produce a given conductor temperature will now be considered. The current required could be computed directly with equations (7) and (8) if T_2 were known. Thus, in (8) the unknown quantities are h, r and T_2. When T_2 is known, r can be obtained from equation (4) or Plate 1 and h from Plate 2. It will now be shown how T_2 may be predicted graphically with the aid of the heat transfer relations given earlier.

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[1] *Schurig, O. R. and Frick, C. W., "Heating and Current Capacity of Bare Conductors for Outdoor Service," General Electric Review, Vol. 33, No. 3: 141-157, March 1930*

[2] *McMath, J. P.C, "How to Determine Current Capacity for Cables and Buses in Still Air," Electrical World, Vol. 126, No. 13: 140, September 28, 1946*

[3] *Fishenden, Margaret and Saunders, Owen A., "The Calculation of Heat Transmission," Book. His Majesty's Stationery Office, London, 1932*

For the assumed conditions the rate of heat dissipation at a given atmospheric pressure is fixed when b, a, K, T_1, and T_3 are specified. The fixed heat dissipation establishes T_2, h, and r uniquely. The relations which must be satisfied by the eight quantities can be derived as follows. From equation (1)

$$T_1 - T_2 = \frac{P \log_e(b/a)}{2\pi K} \tag{9}$$

and from (6)

$$T_2 - T_3 = \frac{P}{2\pi b(h + r)} . \tag{10}$$

Dividing (9) by (10)

$$\frac{T_1 - T_2}{T_2 - T_3} = \frac{(h + r)\, b \log_e(b/a)}{K} . \tag{11}$$

From (11) and the fact that

$$T_1 - T_3 = T_1 - T_2 + T_2 - T_3$$

it follows that

$$\frac{T_2 - T_3}{T_1 - T_3} = \frac{1}{\frac{(h + r)\, b \log_e(b/a)}{K} + 1} = \frac{1}{Z + 1} \tag{12}$$

$$Z = \frac{(h + r)\, b \log_e(b/a)}{K} . \tag{12a}$$

With the aid of (12), a family of curves depicting a as a function of b may be drawn. The parameters K, T_1, and T_3 are fixed for the family; the ratio $(T_2 - T_3)/(T_1 - T_3)$ is fixed for each member curve. The convection coefficients needed in plotting these graphs are obtained from Plate 2, and the radiation coefficients are calculated with equation (4) or taken from Plate 1. In Plate 6 two families of three curves each are shown. The computation details for one of the curves plotted in Plate 6 are given in Appendix 3. For the family of solid curves T_1, T_3, and K are 75° C, 25° C, and 0.0040 watt in^{-1} °C^{-1} respectively; the dashed lines are plotted for 75° C, 25° C and 0.0030 watts in $^{-1}$ °C^{-1}. $(T_2 - T_3)/(T_1 - T_3)$ values are 0.78, 0.82, and 0.86. This graph may be used to find T_2 for a cable of any conductor size and a wide range of insulation thickness where the values of K, T_1, and T_3 are those indicated. For example, the ratio $(T_2 - T_3)/(T_1 - T_3)$ for a cable whose a, b, K, T_1, and T_3 values are 0.100 in., 0.150 in., 75° C, 25° C and 0.0040 watts in^{-1} °C^{-1} respectively is found in Plate 6 to be 0.84, and therefore T_2 is 67° C. The number of curves per family which it may be desirable to plot depends on the range of $(T_2 - T_3)/(T_1 - T_3)$ values to be encountered. It will be shown that for typical aircraft cables from size AN 20 to AN 0 that $(T_2 - T_3)/(T_1 - T_3)$ lies between 0.74 and 0.91 for temperature differences, $T_1 - T_3$, from 15° to 100° C. The quantity Z, which appears in equation (12) as a function of b, a, K, h, and r can be considered as a function of b, a, K, T_1, and T_3 because h and r are fixed when the latter five parameters are specified. If $T_1 - T_3$ is held fixed at 15° C, and b and a are allowed to take on pairs of values found in representative aircraft cables, then Z lies between 0.10 and 0.24 for all cable sizes from AN 20 to AN 0. The reason for the small range of Z values is that both h and $\log_e(b/a)$ decrease as b increases. That b/a decreases as b increases results from the fact that the requirements of mechanical and dielectric strength permit conductor size to increase more rapidly than insulation thickness. In addition, the value of K for typical aircraft cables lies between 0.0028 and 0.0040 watts in^{-1} $^0C^{-1}$. If $T_1 - T_3$ is fixed at 100^0 C, Z will have values in the interval from 0.16 to 0.35 for the range of cable sizes and thermal conductivities previously described. The data cited concerning the spread of Z values makes it evident that $(T_2 - T_3)/(T_1 - T_3)$ is confined to the range given above; therefore, it should be sufficient to plot b versus a for three values as has been done in Plate 6.

Since one family of curves is needed for each combination of K, T_1, and T_3, the total number of families required in order to determine T_2 for all aircraft cables under operating conditions will depend on the range of K, T_1, and T_3 values encountered and on how rapidly $(T_2 - T_3)/(T_1 - T_3)$ varies with these parameters. The approximate limits within which the thermal conductivities of the insulation of representative cables fall, have already been given. The effect of a change in K on $(T_2 - T_3)/(T_1 - T_3)$ can be observed by studying Plate 6. The two sets of curves plotted there were based on K equal to 0.0030 and 0.0040 watts in^{-1} $^0C^{-1}$; T_1 and T_3 are the same for both families. Consider a cable whose conductor and insulation radii are 0.100 and 0.144 inch. When the thermal conductivity of the cable is 0.0030 watts in^{-1} $^0C^{-1}$, $(T_2 - T_3)/(T_1 - T_3)$ equals 0.82. If the thermal conductivity is increased to 0.0040, $(T_2 - T_3)/(T_1 - T_3)$ becomes 0.855 as may be seen in the graph. The corresponding values of T_2 are 66^0 and 67.8^0 C. With r and h values obtainable from Plates 1 and 2, all the parameters necessary are known, and the current capacities of the cable for both cases may be calculated by equation (8). The ratio of the two currents is found to be

$$\frac{I_{(K = 0.0040)}}{I_{(K = 0.0030)}} = 1.03.$$

An increase in K of 33 percent has thus resulted in a 3 percent increase in current capacity. It can be verified by checking other points in Plate 6 that the effect of the change in thermal conductivity on the current capacity just described holds generally to a very good approximation. In view of the small effect of a change in K on $(T_2 - T_3)/(T_1 - T_3)$, sets of curves based on the two K values, 0.0030 and 0.0040 watts in^{-1} $^0C^{-1}$, are all that need be plotted.

Most aircraft cables may be operated safely at conductor temperatures in the interval 100^0 C ± 10^0 C. If $(T_2 - T_3)/(T_1 - T_3)$ changes slowly with T_1 it would appear sufficient to plot the curves of b versus a for only one value of T_1, namely, 100^0 C. Since it may be expected that the development of improved insulating materials will lead to higher permissible conductor temperatures it is of interest to observe the effect of a change in T_1 on $(T_2 - T_3)/(T_1 - T_3)$. The effect of changing T_1 by 25^0 C can be ascertained by comparing Plates 6 and 7. Comparing points with identical coordinates in Plates 6 and 7 we note that $(T_2 - T_3)/(T_1 - T_3)$ decreases one to two percent.

The range of ambient temperatures which cable in aircraft may encounter extends from -55^0 C to 57^0 C approximately. The effect of changing T_3, while $T_1 - T_3$ is held constant, may be seen by comparing Plates 6 and 8. An examination of points with identical coordinates in both plates shows that, for the same K, $(T_2 - T_3)/(T_1 - T_3)$ decreases one or two percent when the ambient temperature is increased from 25^0 to 50^0 C. It would, therefore, appear sufficient to plot families of curves for three values of T_3: -50^0, 0^0, and 50^0 C. The effect on $(T_2 - T_3)/(T_1 - T_3)$ of changing T_3 and holding T_1 constant can be seen by comparing Plates 7 and 8. Comparison of points with identical coordinates in both plates shows that $(T_2 - T_3)/(T_1 - T_3)$ changes by less than 1 percent when T_3 is increased from 25^0 C to 50^0 C and T_1 is held at 100^0 C.

Plate 7 was used to determine $(T_2 - T_3)/(T_1 - T_3)$ for the three cables described in Plates 3, 4, and 5 under the same given conditions. The agreement between the actual measured values and those obtained from Plate 7 is shown in the accompanying table.

Nominal Wire Size	Given By Plate 7	From Actual Measurement Of T_1, T_2 And T_3
18 (Plate 3)	0.81	0.805
8 (Plate 4)	.85	.851
0 (Plate 5)	.83	.831

The current capacity of the three cables was then calculated with the aid of equation (8) and the surface temperature based on the predicted temperature ratios given in the table above. The calculated currents and those obtained by actual measurement are listed below.

Nominal Wire Size	Calculated Current (Amperes)	Measured Current (Amperes)
18	25.2	25.4
8	98.0	98.7
0	336.	337.

A complete discussion of the accuracy which can be attained by the two methods of predicting the current would require an analysis of the effect of each parameter appearing in equations (7), (8), and (12) on the estimated current. It may be pointed out that the effect of errors in each of the parameters is reduced by the square root which occurs in (7) and (8). An estimate of errors which are likely to be made in b, a, h, r, and K makes it reasonable to expect errors in current prediction up to five percent. In the three applications of each method presented, errors in the predicted current were under 1 percent as recorded in the table above and in Plates 3, 4, and 5.

CURRENT CALCULATIONS FOR MULTILAYER INSULATED CABLE

The first method of finding the current may be extended to the case where the insulation consists of two or more layers of insulation. If there are two layers with appreciably different thermal conductivities, three expressions for the current may be obtained. For this case,

$$I = \left[\frac{2\pi K_1(T_1 - T_2')}{R_{T_1} \log_e b'/a}\right]^{\frac{1}{2}} \qquad (13)$$

$$I = \left[\frac{2\pi K_2(T_2' - T_2)}{R_{T_1} \log_e b/b'}\right]^{\frac{1}{2}} \qquad (14)$$

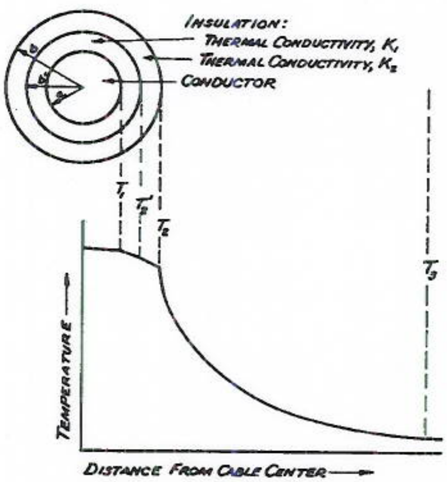

Figure 2 - Approximate temperature distribution for cable insulated with two layers

$$I = \left[\frac{2\pi b}{R_{T_1}} (h+r)(T_2 - T_3)\right]^{\frac{1}{2}} \qquad (15)$$

where equations (13) and (14) come from the heat-conduction relations for the inner and outer insulation layers respectively. The new symbols in these equations are:

K_1 = thermal conductivity of the inner layer

K_2 = thermal conductivity of the outer layer

T_2' = temperature at the boundary between the two layers

b' = radius from the cable center to the boundary between the two layers.

Figure 2 illustrates the cable with two layers of insulation. Equation (15) is identical with (8). In order to find the current which will produce a given T_1, (13) and (15) are used to plot I as a function of T_2' and T_2 respectively. From these two curves one pair of T_2' and T_2 values are obtained for each current value. If these paired values of T_2' and T_2 are now substituted in (14), and I is plotted as a function of T_2, a curve is obtained whose intersection with that of (15) gives the desired current.

For the general case of multilayer insulation, there will be as many expressions for the current as there are layers plus an additional equation derived from the relation for transfer of heat from the outer surface to the surrounding air and walls. These expressions can be solved for the current in a manner analogous to that described above.

EFFECT OF ALTITUDE ON CURRENT-TEMPERATURE RISE RELATIONS

The measurement of the convection coefficients at pressures corresponding to 20,000 and 60,000 feet as well as at sea level makes it possible to determine the current needed to produce a given conductor temperature for altitude conditions. The two methods described earlier in this report are applicable. The convection coefficients for 20,000 and 60,000 feet for $T_2 - T_3$ values of 30° C, 50° C and 70° C are plotted as a function of over-all cable diameter in Plate 9. For convenience in applying the second method, conductor radius is plotted as a function of b for 20,000 feet in Plates 10 and 11 and for 60,000 feet in Plates 12 and 13.

While the current capacity of a given cable at a particular altitude is a function of the five parameters, T_1, T_3, b, a, and K, the results of measurements on typical aircraft cables provide a good estimate of what may be expected generally. For eight cables, which included sizes from AN 20 to AN 0, the relative current values necessary to produce the same rise in conductor temperature are as shown:

Altitude	0	20,000 feet	60,000 feet
Relative Current	100	93 ± 2	82 ± 2

RESULTS

1. Study of the relations between current and conductor temperature rise has provided a method for determining the current capacity of single aircraft cables which is of general validity. Thus, changes in current rating which become necessary as a result of cable improvements can be found with little or no additional experimental work. Examples of changes in cable design which would affect the current capacity would include (1) higher permissible insulation temperatures, (2) higher thermal conductivities of the insulation and (3) thicker insulation.

2. The measurement of the convection coefficients at pressures corresponding to 20,000 and 60,000 feet makes it possible to compute single cable ratings for altitude conditions with the methods given.

3. The investigation of the single cables is serving as a basis for the analysis of the problem of rating cables in bundles. Upon completion of this phase of the work a report will be issued.

ACKNOWLEDGMENT

The experimental measurement of the convection coefficients presented in this report was conducted by Mr. W. K. Gardner and Mr. R. E. Kidwell.

* * *

APPENDIX I
Measurement of h and K

From equation (6) the convection coefficient can be written as

$$h = \frac{P}{2\pi b(T_2 - T_3)} - r$$

In order to determine h experimentally, T_2, T_3, b, and P were measured; r was calculated with equation (4). In the latter calculation the surface emissivity of the cable was assumed to be 0.9. The heat-dissipating cable was suspended horizontally in the center of a closed chamber which measured 9 by 12 by 8 feet. The cable on which the measurements were made consisted of a five-foot section at the center of a 16-foot cable length. T_2 was found by measuring the change in resistance of a A.W.G. No. 44 wire wound on the cable. The fine wire, cemented to the outer cable surface to make it an integral part of the cable surface, was wound the entire length of the test section with a pitch of approximately three turns per inch. The resistance of the coil was found by measuring its potential drop with a type K-2 Leeds and Northrup potentiometer and comparing with the drop across a standard resistance in series with the coil. T_3 was the average temperature of four thermocouples located nine inches from the cable section in its horizontal plane. Over-all cable diameter, 2b, was taken to be the average of at least 15 micrometer measurements. P was determined by measuring the resistance of the cable section. This resistance was found by measuring its potential drop and comparing with the drop across a standard resistance in series with it. The power source consisted of a submarine battery of approximately 6000 ampere-hour rating. It is estimated that temperature measurements were accurate to within 0.5°C. Measurements of h were obtained for a range of cable diameters from 0.090 to 0.510 inches and for temperature differences, $(T_2 - T_3)$, extending from 10° to 80° C. Measurements were obtained for two ambient temperatures, 25° and 50° C for the sea level conditions. All the altitude measurements were made in an ambient of 25° C.

The thermal conductivity of the cable insulation was obtained by measuring the quantities required by the relation

$$K = \frac{P \log_e (b/a)}{2\pi(T_1 - T_2)}$$

derived from equation (1). P, b, and T_2 was measured as above, and a was an average of at least 15 micrometer readings. T_1 was determined from the measurement of the resistance of the cable section.

* * *

APPENDIX II
Computation Details for Plate 3

Given:

$T_1 = 99.3^\circ$ C b $= 0.0557$ in

$T_3 = 24.9^\circ$ C a $= 0.0249$ in

K $= 0.0035$ watts in^{-1} $^\circ$C^{-1} $R_{T_1} = 0.000598$ ohms in^{-1}

To determine I:

$$I = \left[\frac{2\pi K (T_1 - T_2)}{R_{T_1} \log_e b/a}\right]^{\frac{1}{2}} = [45.7 (99.3 - T_2)]^{\frac{1}{2}}$$

If arbitrary values are assigned to T_2, corresponding values of I may be calculated as shown in the accompanying table.

Assumed T_2 (°C)	$T_1 - T_2$ (°C)	I^2 (amp²)	I (amp)
94.3	5	228.5	15.1
89.3	10	457	21.4
84.3	15	686	26.2
79.3	20	914	30.2
74.3	25	1142	33.8

I can be plotted as a function of T_2 using the values given in this table.

$$I = [2\pi b (h + r) (T_2 - T_3)]^{\frac{1}{2}}$$

$$I = [585 (h + r) (T_2 - 24.9)]^{\frac{1}{2}}$$

If arbitrary values are assigned to T_2, corresponding values of I may be calculated as shown in the accompanying table.

Assumed T_2 ($^{\circ}$C)	$T_2 - T_3$ ($^{\circ}$C)	h (Watts in^{-2} $^{\circ}C^{-1}$ From Plate 2)	r (Watts in^{-2} $^{\circ}C^{-1}$ From Plate 1)	h + r Watts in^{-2} $^{\circ}C^{-1}$	I^2 (amp^2)	I (amp)
94.9	70.0	0.01375	0.00500	0.01875	768	27.7
84.9	60.0	.01330	.00477	.01805	634	25.2
74.9	50	.01290	.00455	.01745	510	22.6

A second curve of I as a function of T_2 is obtained from the values shown in this table. The intersection of the two curves gives the desired current.

* * *

APPENDIX III
Computation Details for One Curve Plotted in Plate 6

Given

$$T_1 = 75^\circ C \qquad T_1 = 25^\circ C$$

$$K = 0.0040 \text{ watts in}^{-} \, {}^\circ C^{-1}$$

$$(T_2 - T_3)/(T_1 - T_3) = 0.78$$

To calculate a as a function of b:

The computation is simpler if equation (11) is used. It will be necessary to express $(T_1 - T_2)/(T_2 - T_3)$ in terms of $(T_2 - T_3)/(T_1 - T_3)$. From (11) and (12)

$$\frac{T_2 - T_3}{T_1 - T_3} = \frac{1}{\dfrac{T_1 - T_2}{T_2 - T_3} + 1}$$

and, therefore,

$$\frac{T_1 - T_2}{T_2 - T_3} = \left[\frac{T_2 - T_3}{T_1 - T_3}\right]^{-1} - 1$$

For the present case,

$$\frac{T_1 - T_2}{T_2 - T_3} = (0.78)^{-1} - 1 = 0.282$$

Substituting in

$$\frac{T_1 - T_2}{T_2 - T_3} = \frac{(h + r) b \log_e b/a}{K}$$

we have

$$\frac{1.128 \times 10^{-3}}{h + r} = b \log_e b/a$$

which will now be evaluated for the given conditions over the range of b values needed for aircraft cable. In the present case

$$T_2 - T_3 = 0.78\,(T_1 - T_3) = 39^{\circ}C$$

r and h values will be selected for $(T_2 - T_3) = 39^{\circ}C$ from Figures 2 and 3 respectively. In addition, h will be chosen corresponding to the particular value of b indicated in the table below.

b	h	r	$\frac{1.128 \times 10^{-3}}{h + r}$	a
(inches)	(watts in^{-2} $^{\circ}C^{-1}$)	(watts in^{-2} $^{\circ}C^{-1}$)	(watts in^{-2} $^{\circ}C^{-1}$)	(inches)
0.050	0.01295	0.0043	0.0654	0.0135
.100	.00960	.0043	.0812	.0444
.150	.00815	.0043	.0906	.0820
.250	.00640	.0043	.1040	.1652

conductor radius, a, may now be plotted as a function of b.

* * *

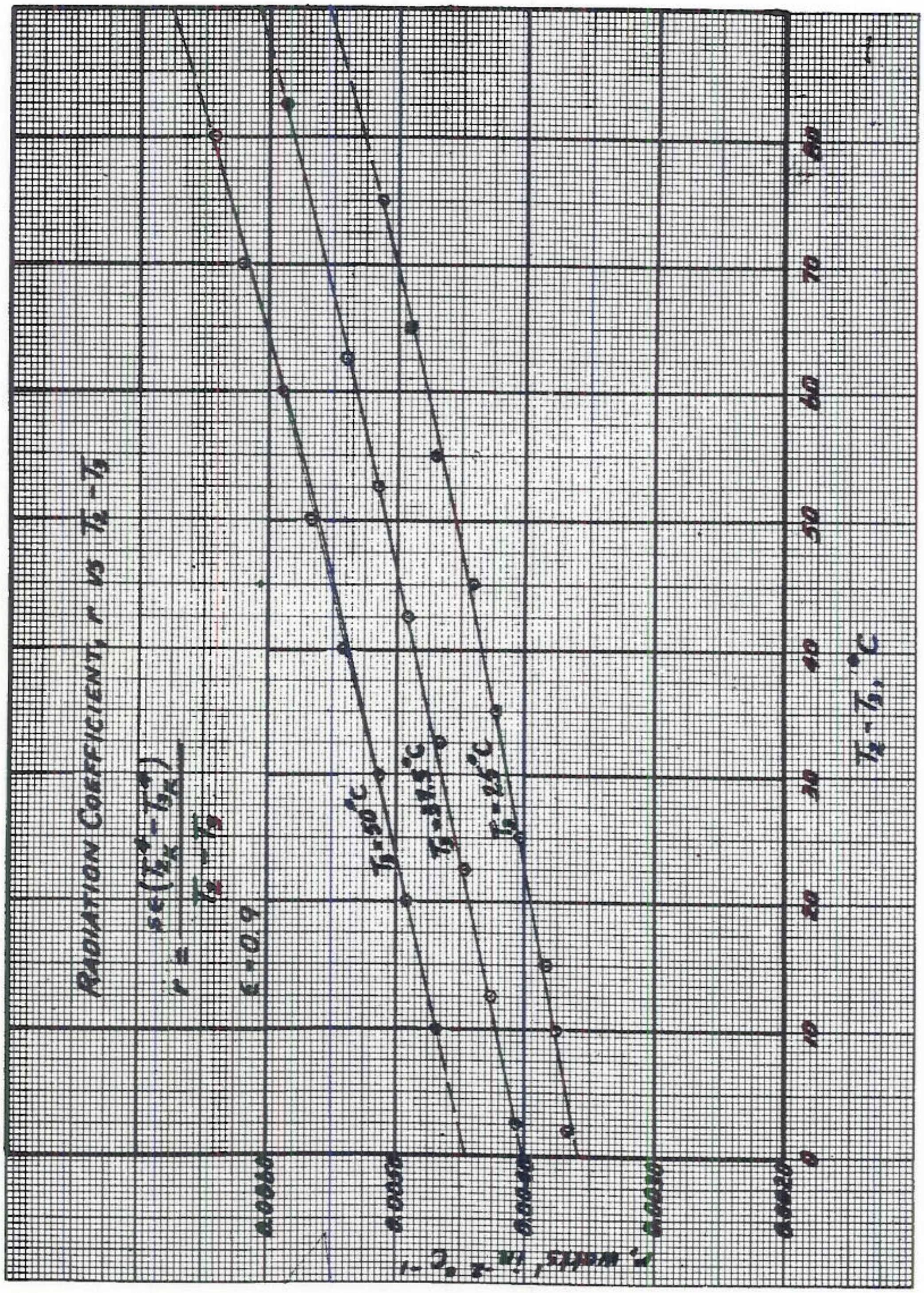

Plate 1 - Calculated radiation coefficient versus surface temperature rise

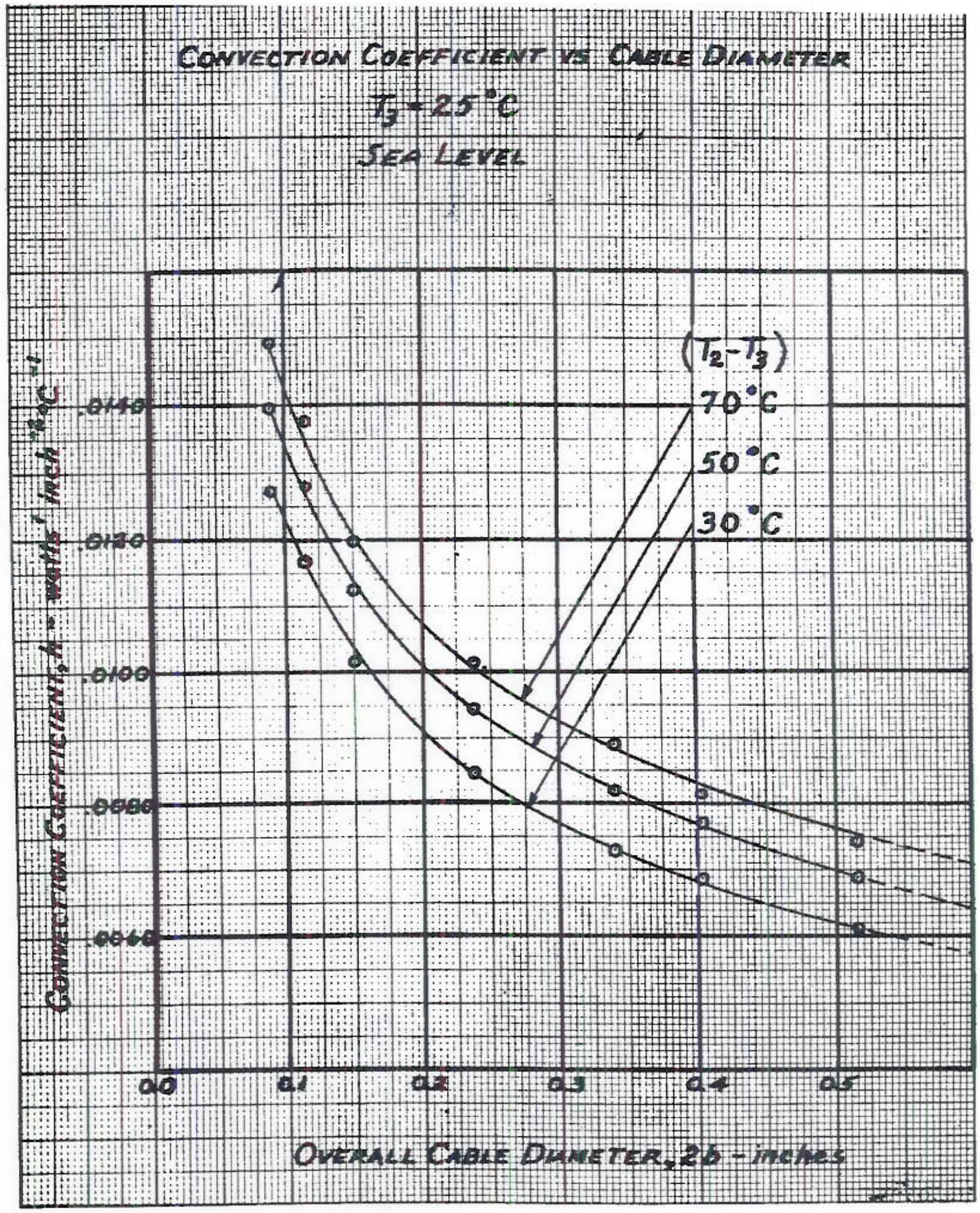

Plate 2 - Measured convection coefficient versus cable diameter for sea level conditions

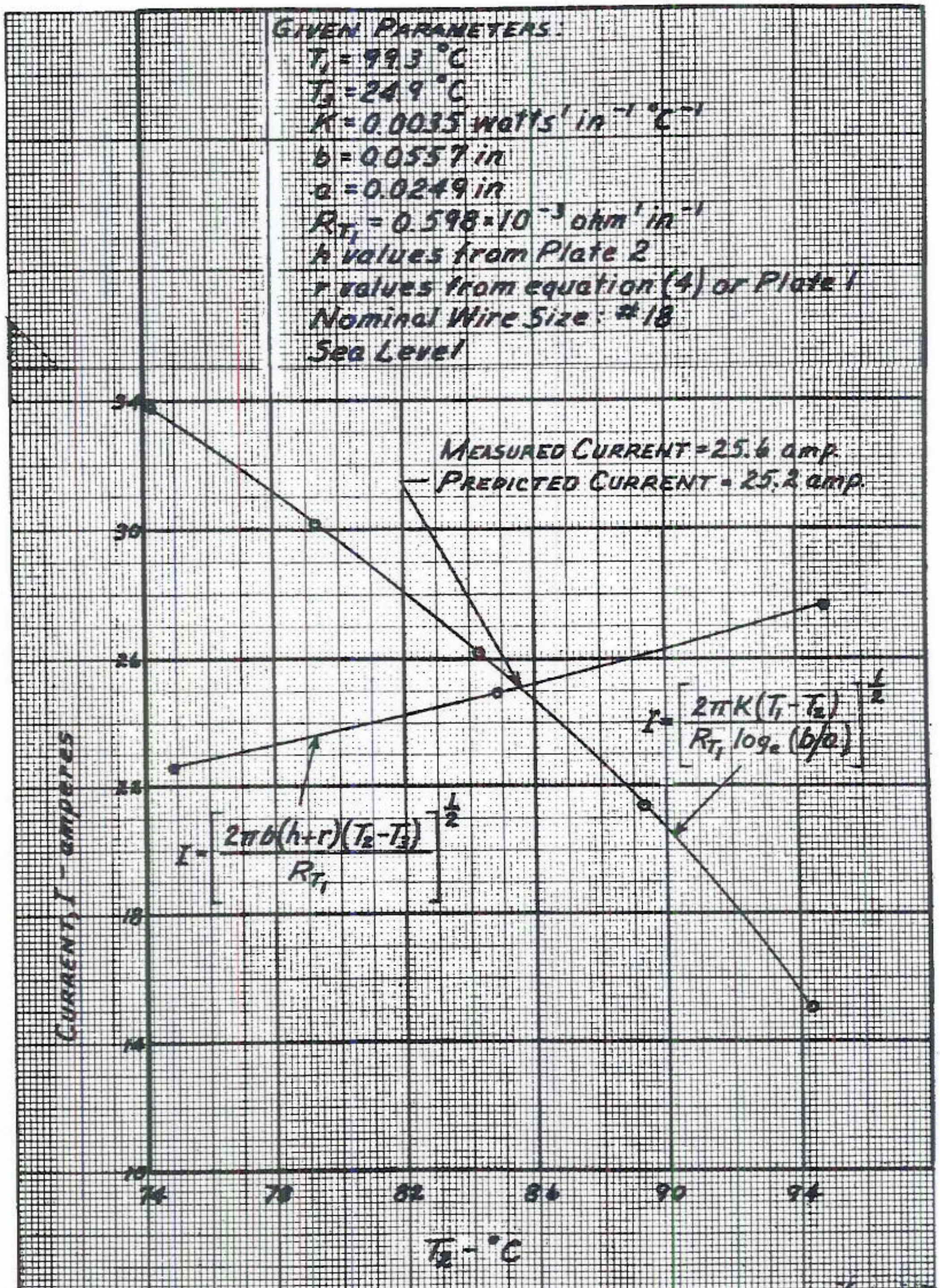

Plate 3 - Graphical solution for the current satisfying given conditions of heat transfer. Nominal wire size: 18

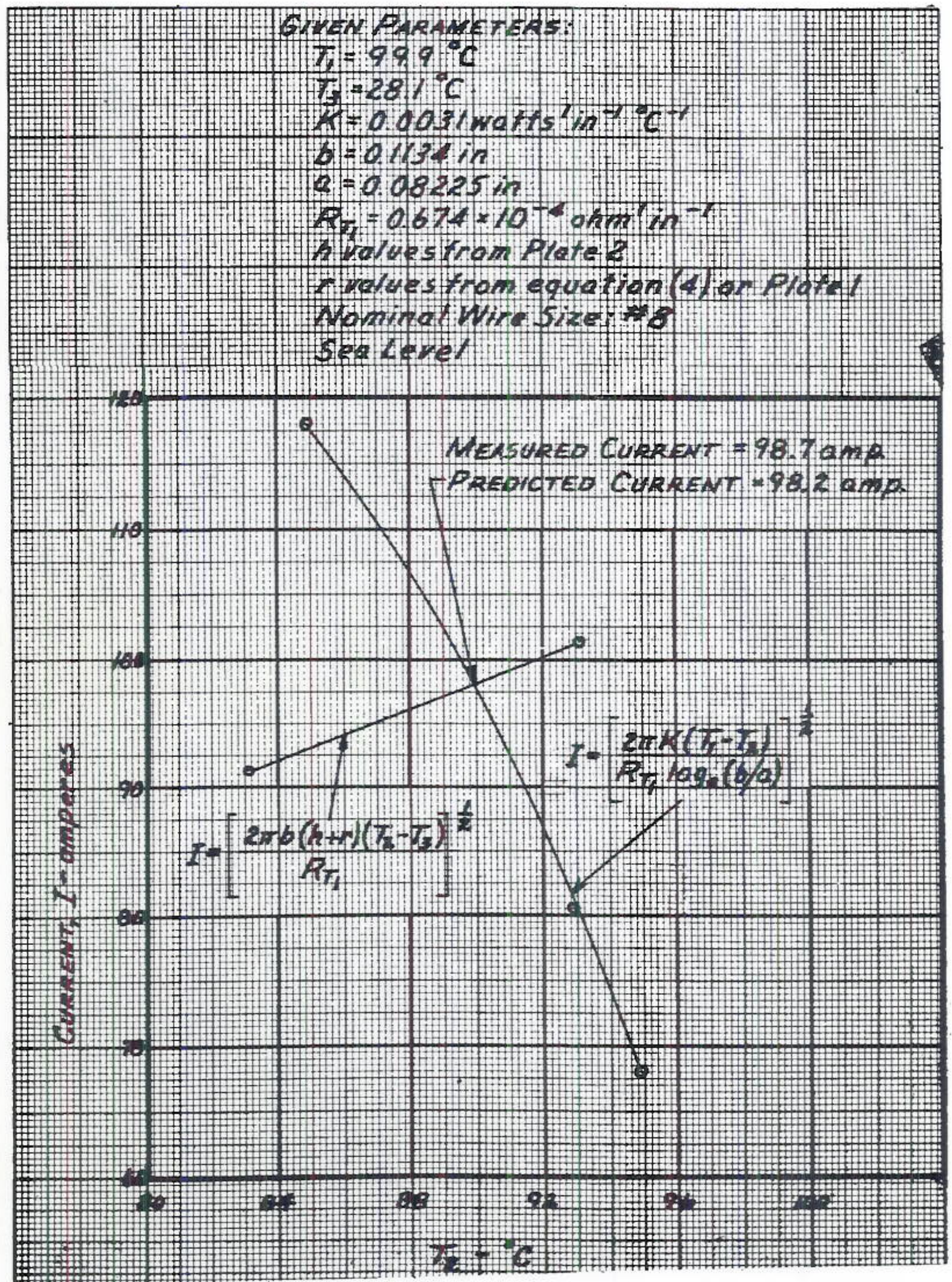

Plate 4 - Graphical solution for the current satisfying given conditions of heat transfer. Nominal wire size: 8

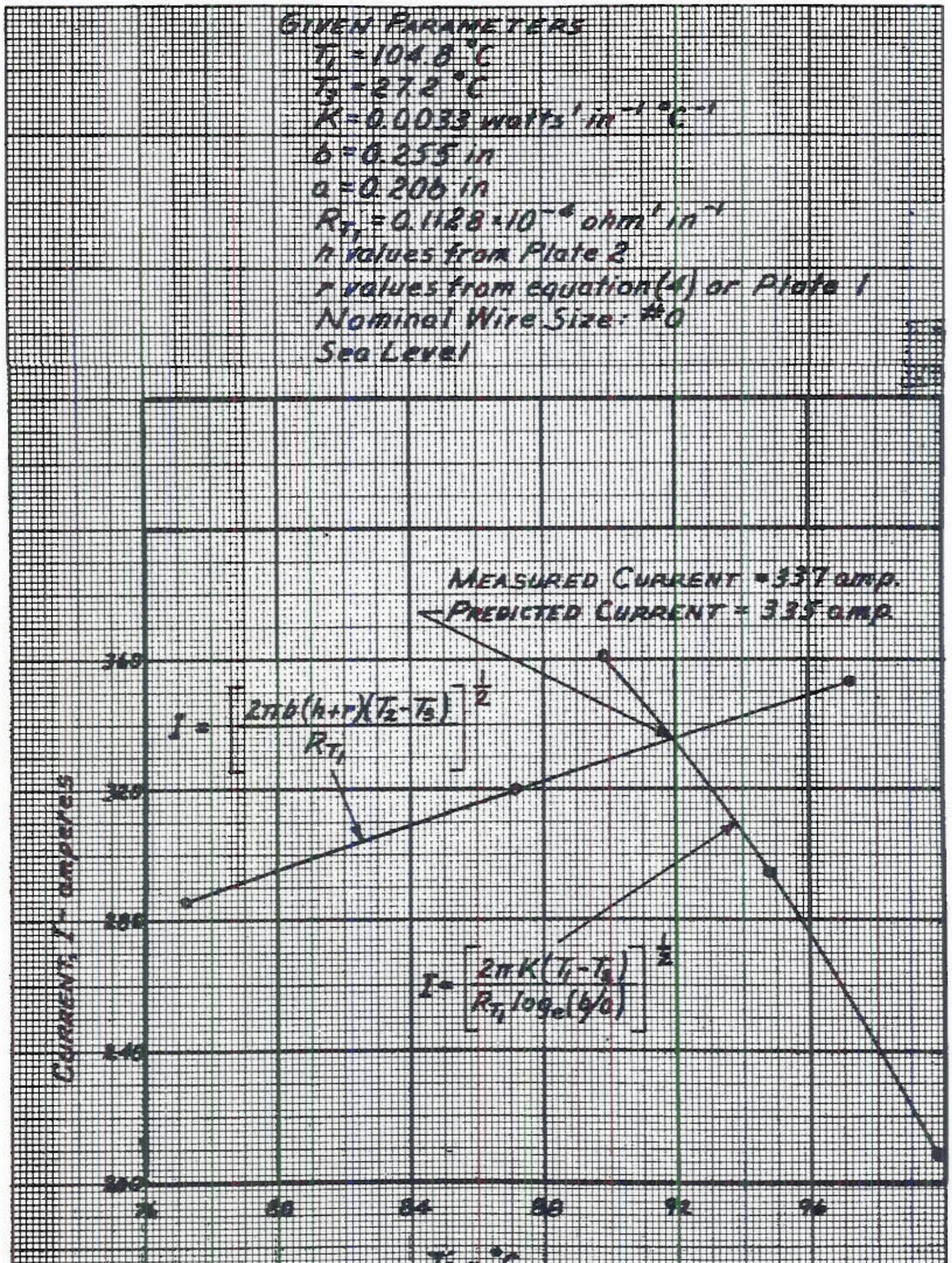

Plate 5 - Graphical solution for the current satisfying given conditions of heat transfer. Nominal wire size: 0

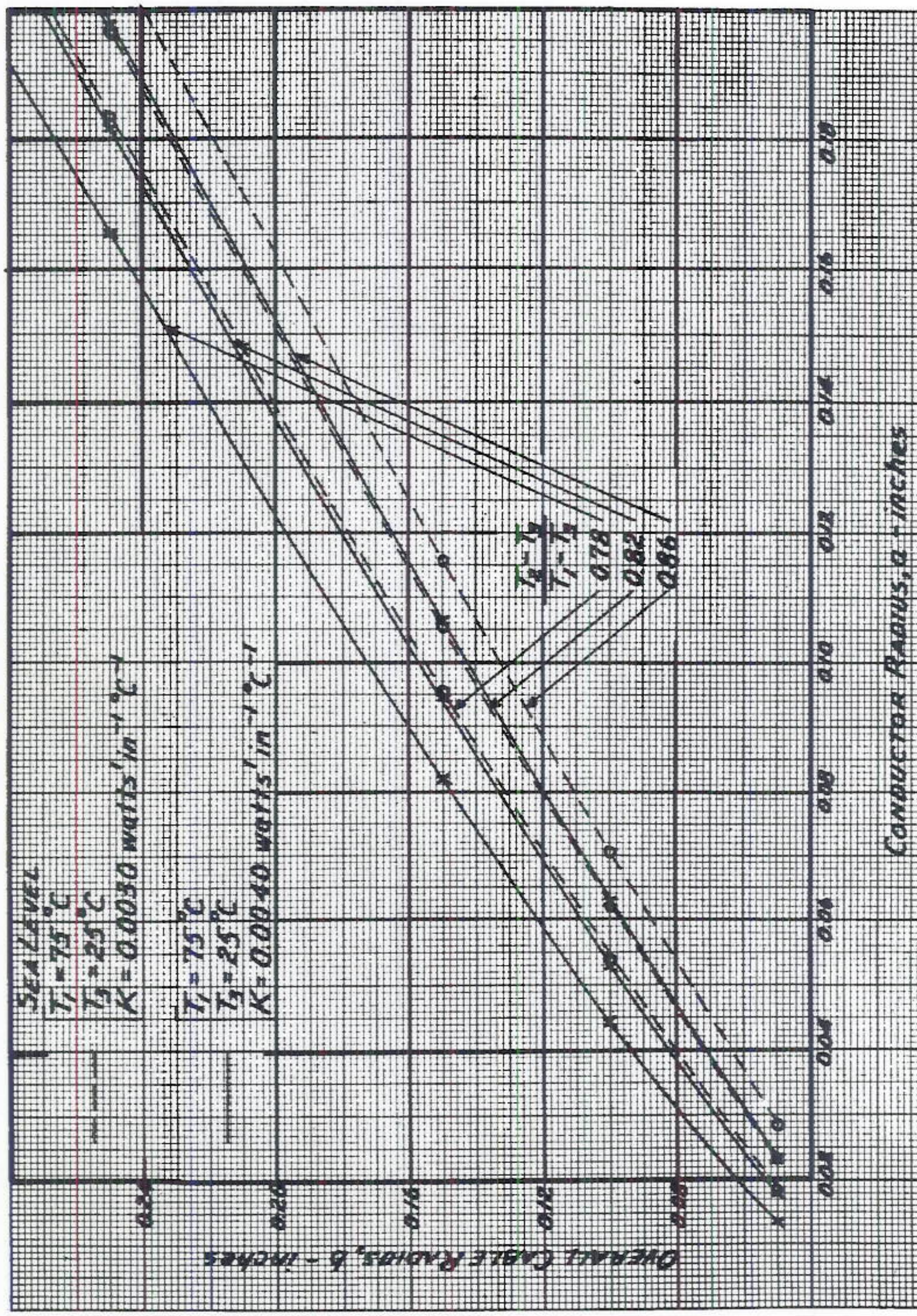

Plate 6 - Conductor radius versus cable radius for specified heat transfer conditions

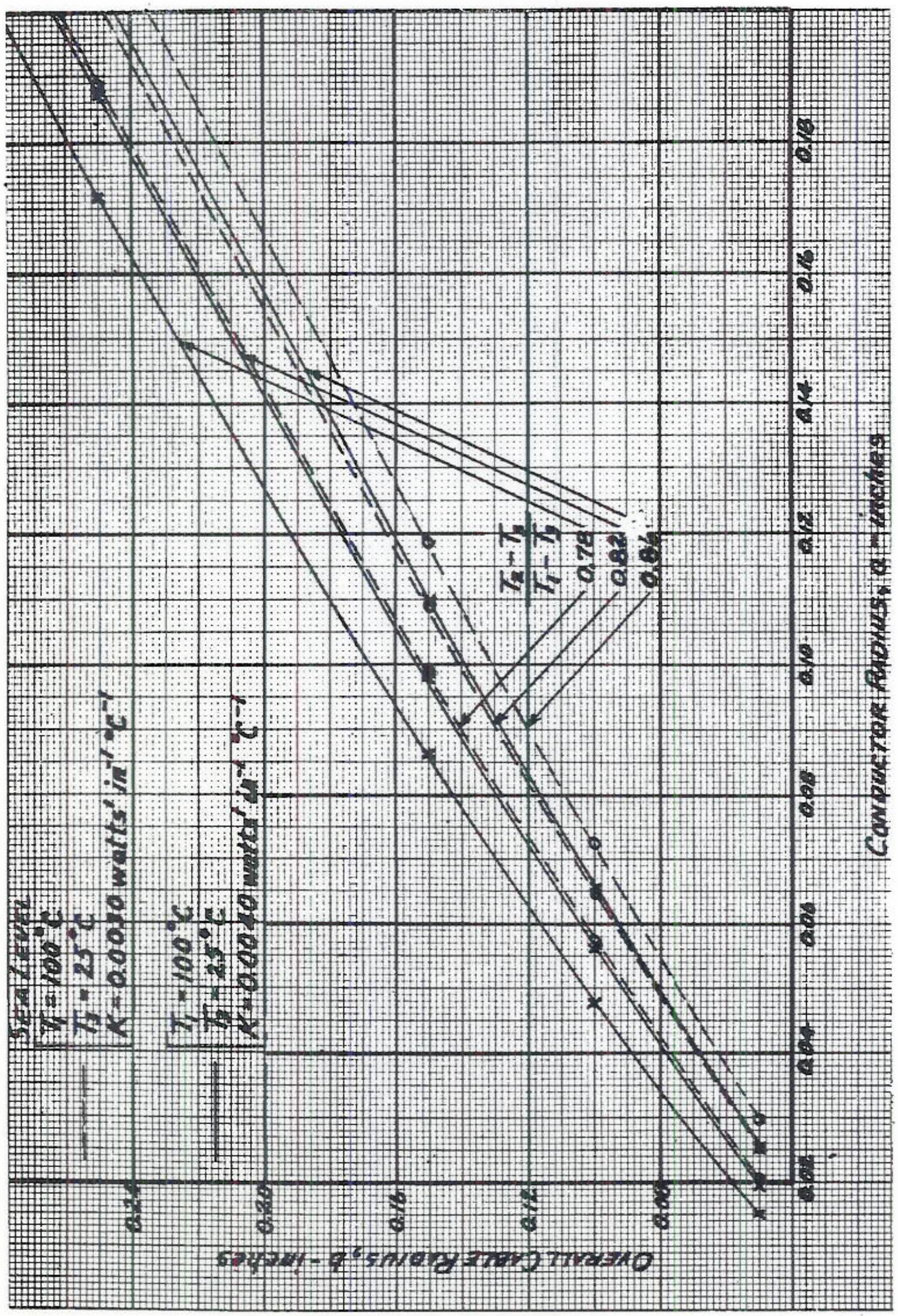

Plate 7 - Conductor radius versus cable radius for specified heat transfer conditions

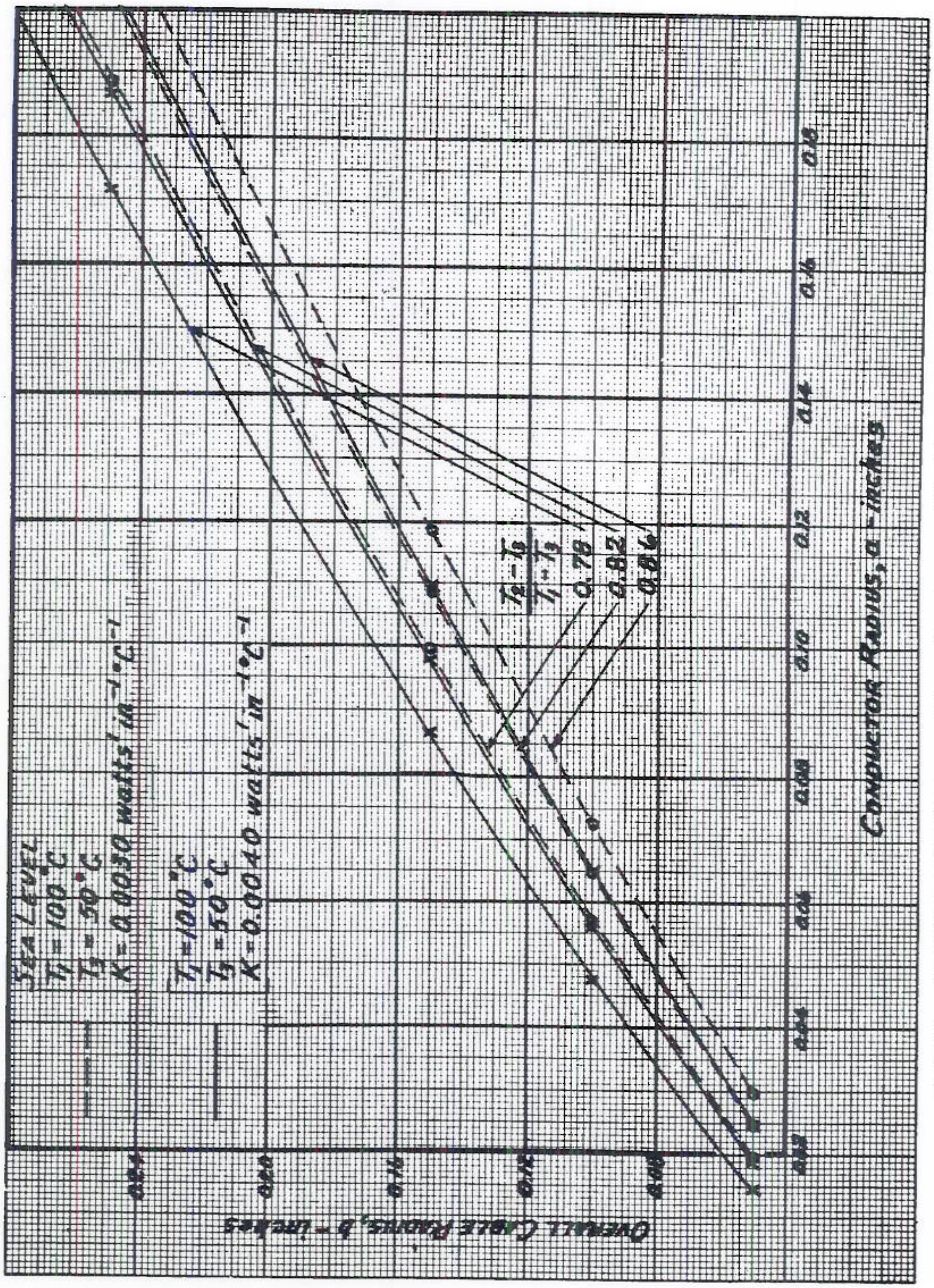

Plate 8 - Conductor radius versus cable radius for specified heat transfer conditions

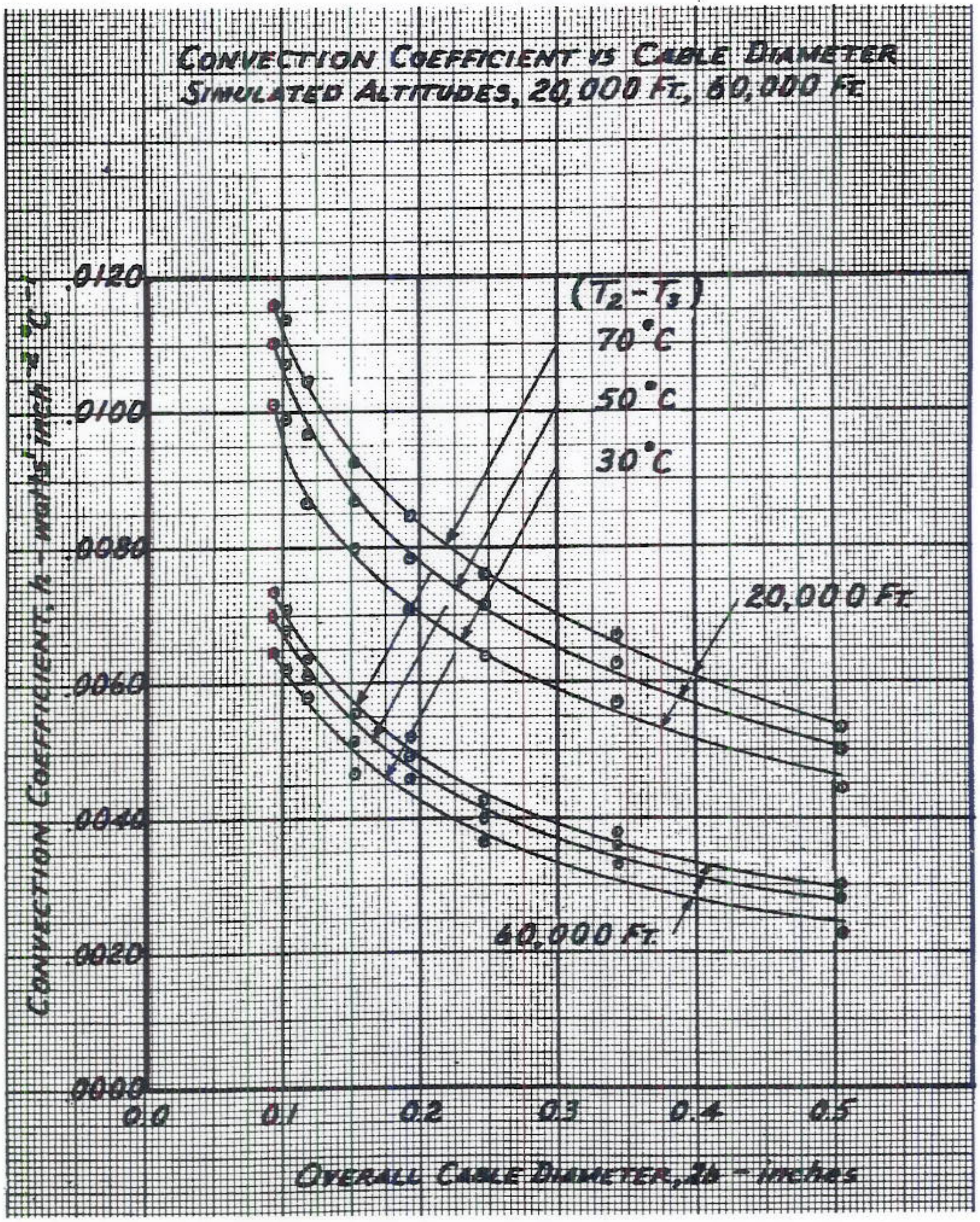

Plate 9 - Measured convection coefficient versus cable diameter for simulated altitude conditions

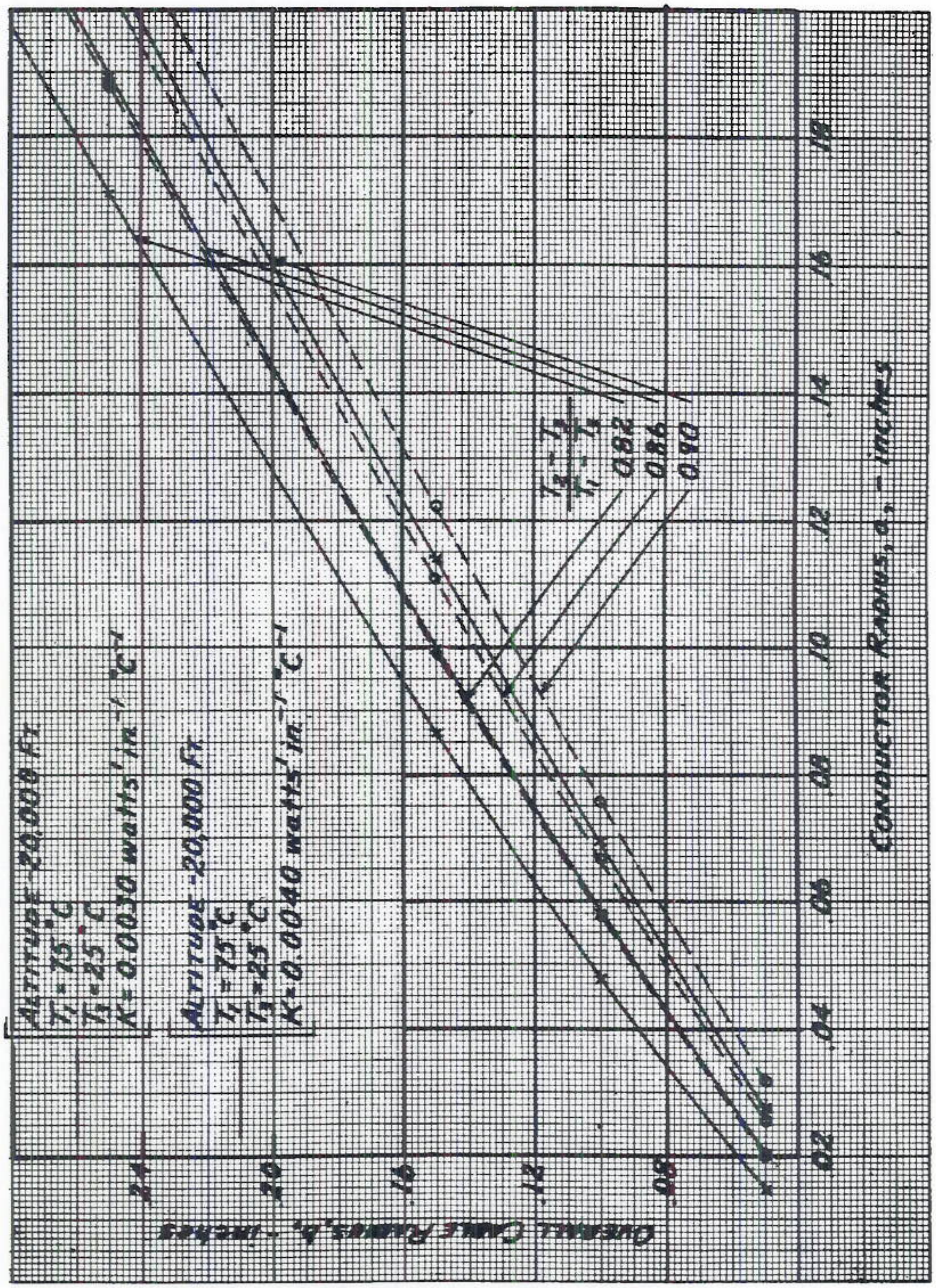

Plate 10 - Conductor radius versus cable radius for specified heat transfer conditions

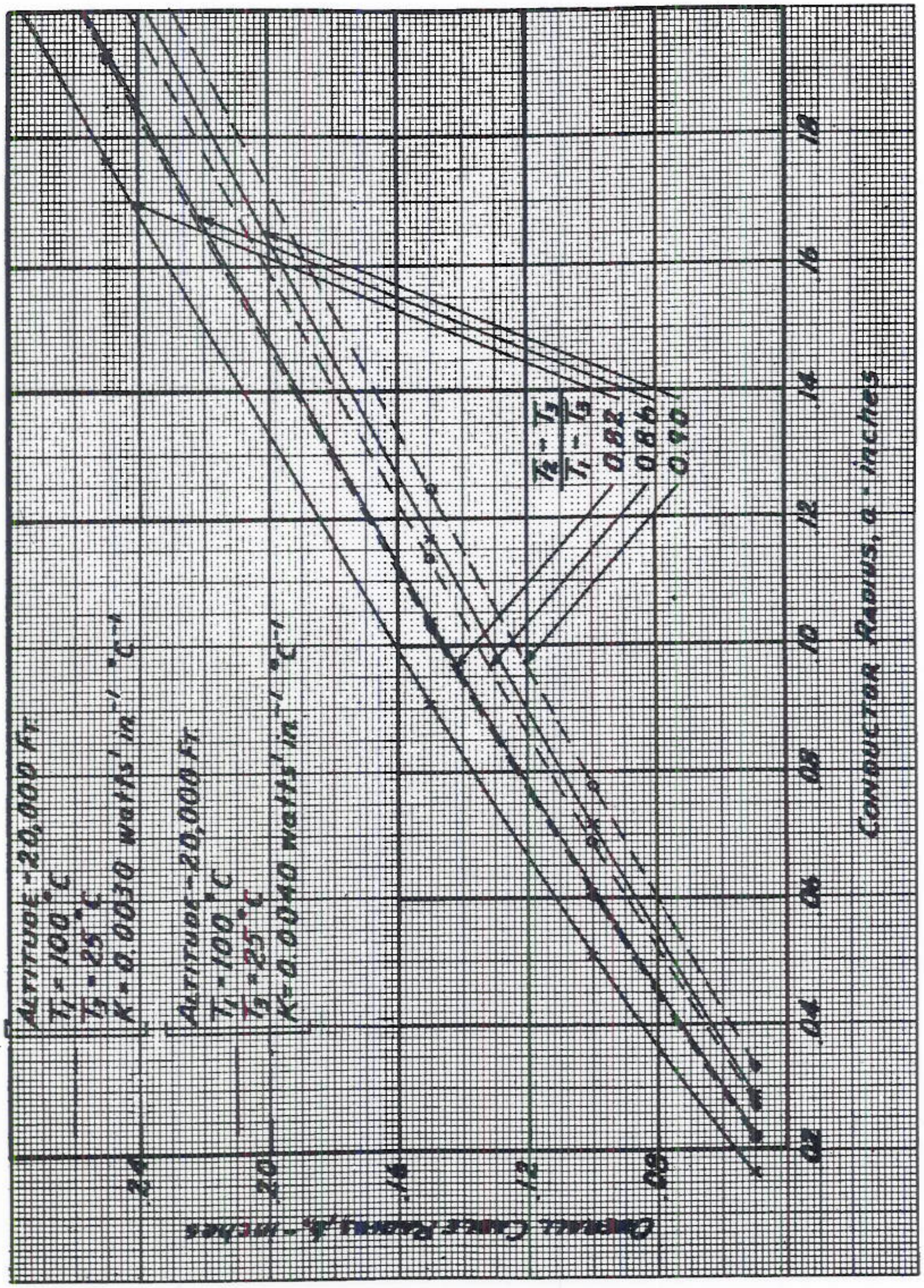

Plate 11 - Conductor radius versus cable radius for specified heat transfer conditions

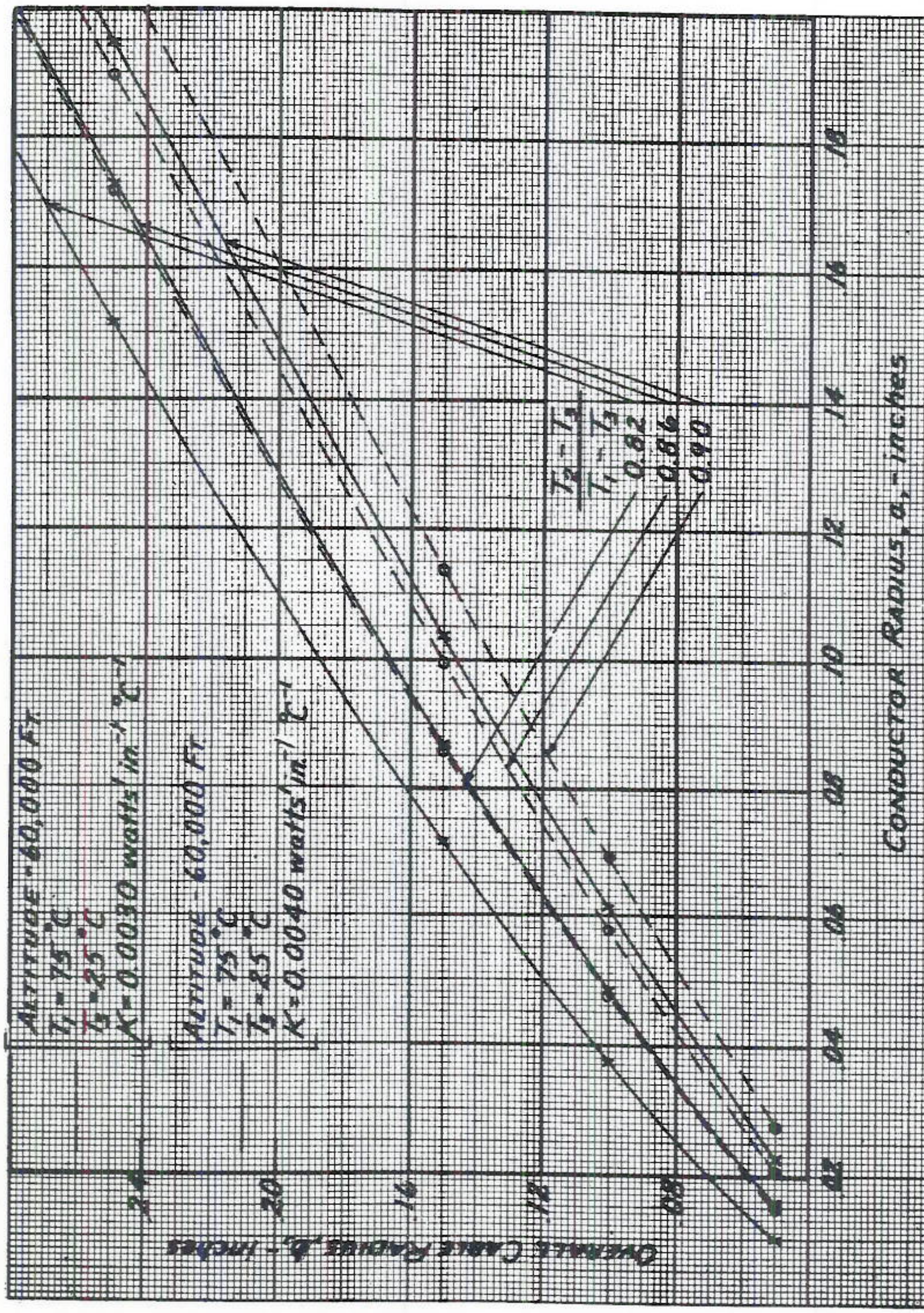

Plate 12 - Conductor radius versus cable radius for specified heat transfer conditions

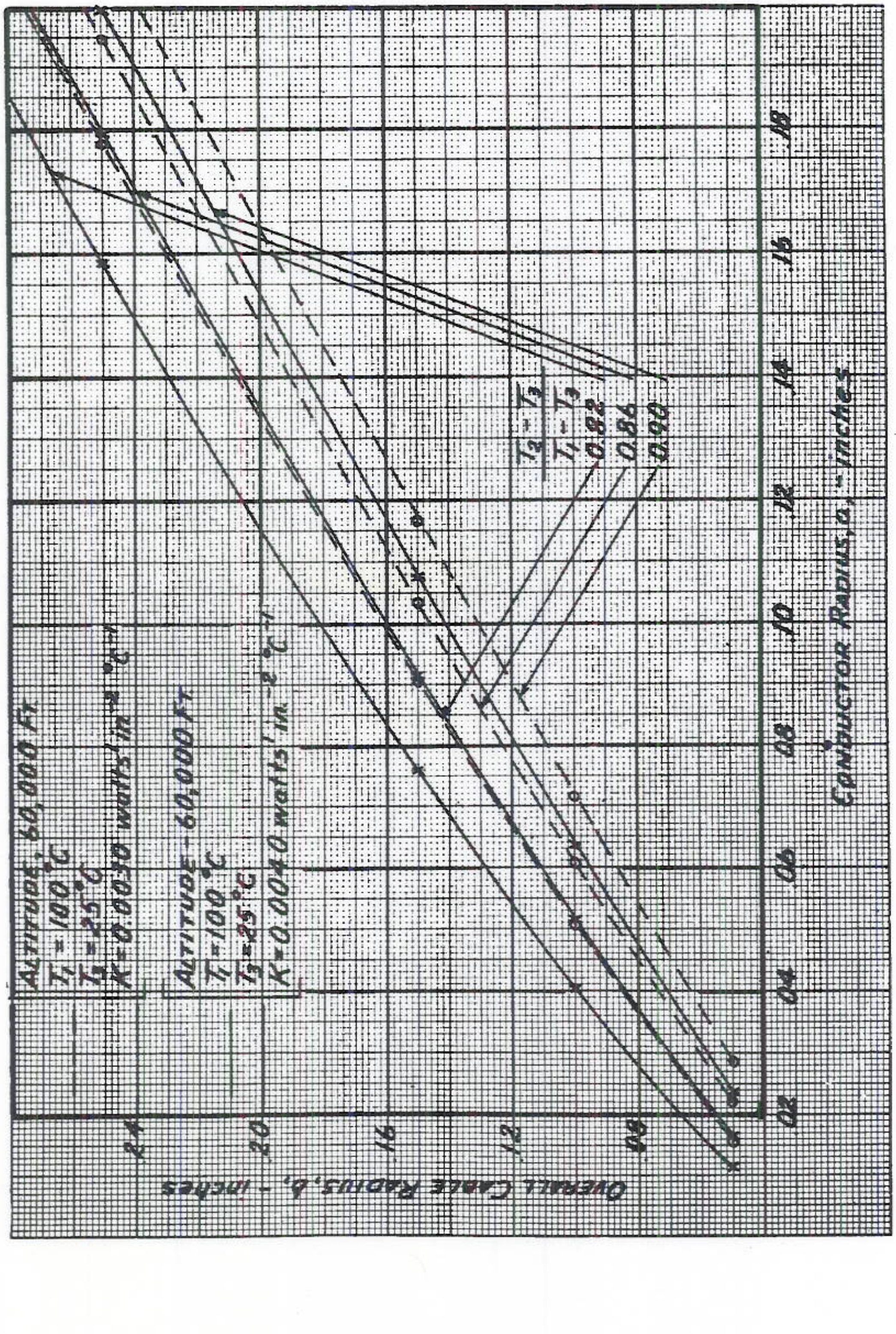

Plate 13 - Conductor radius versus cable radius for specified heat transfer conditions