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NRL REPORT NO. E-3145

REVISED

48843

CABLE THERMO CURVES



NAVAL RESEARCH LABORATORY

*Washington, D.C.*

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NRL REPORT NO. E-3145

# CABLE THERMO CURVES

W. H. Askew

Second Printing, 1948  
with revised graphs

Approved by:

A. T. McClinton, Head, Engineering and Evaluation Section  
W. C. Hall, Superintendent, Electricity Division

Problem No. 33E02-07

July 14, 1947



NAVAL RESEARCH LABORATORY

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*Washington, D.C.*

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**ABSTRACT**

This report gives the results of an investigation made to determine the short-time current-carrying capacities of aircraft cables using visual indication of smoke as the limiting factor. The tests were made on three wire sizes (AN No. 0, AN No. 8, and AN No. 20) in various ambient temperatures on cable from six manufacturers. Curves were obtained showing the highest current which can be continuously carried by each size of cable at different ambient temperatures without the occurrence of smoke. Thermal curves, with smoking and delayed-smoking values, were obtained for various current-overload applications. Procedure is given for interpolating smoking and delayed-smoking curves for wire sizes and ambient temperatures not experimentally obtained. Results of this investigation indicate that, for most of the cable used in the investigation, the maximum conductor temperature and the continuous-current values specified in AN-W-14a would cause the insulation to smoke.

**PROBLEM STATUS**

This report concludes the work on this problem, and, unless the Bureau advises otherwise, the problem will be closed one month from the mailing date of this report.

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## CABLE THERMO CURVES

### AUTHORIZATION

The information resulting from this investigation was requested by BuAer letter Aer-E-3122-MAK, F36-2(13), Serial No. 245704, dated 18 August 1945, Project Directive TED No. NRL 31E77, "Cable Thermo Curves."

### INTRODUCTION

Much of the electrical equipment in aircraft is used, or draws its greatest current, for short time intervals. When the voltage drop is not a limiting factor, considerable weight and space can be saved by the use of small size cables to carry, for these short periods, currents much higher than those which could safely be carried continuously. If overloads are to be applied to the cables, it is necessary that protective devices be installed to make certain that the interval of application will not exceed the safe time limit. The characteristics of these protective devices must be correlated with short-time ratings of the cable.

If there is not proper coordination between protective equipment and cable ratings, the cable can easily be overloaded. The most obvious result of this overloading is the emission of smoke from the cable insulation. This is undesirable in a plane owing to the psychological effect on the pilot or crew.

The purpose of this investigation was to determine the continuous and short-time current-carrying capacities of aircraft cable, using visual evolution of smoke as the limiting factor; and to obtain thermal curves resulting from overload applications. This information is needed for determining the necessary circuit-breaker ratings.

Investigations covering thermal characteristics of certain types of aircraft cable have been made by three manufacturers (General Electric Company\*, Belden Manufacturing Company†, and Rockbestos Products Corporation‡), but the information obtained was not sufficient for computing the desired circuit-breaker calibration curves.

---

\* B. W. Jones and J. A. Scott of General Electric Company, "Short-Time Current Ratings for Aircraft Wire and Cable", AIEE Technical Paper 46-145, May 1946

† Belden, "Short-Time Overloads on Low Tension Aircraft Cable," Progress Report, April 28, 1945

‡ H. S. Moore, Rockbestos Products Corporation, letter to AIEE Subcommittee on Aircraft Cable, April 28, 1945

This investigation was conducted on samples of cable obtained from the following manufacturers:

Belden Manufacturing Company  
 Electric Auto-Lite Company  
 General Electric Company  
 General Motors Corporation  
 Rockbestos Products Corporation  
 Whitney Blake Company

The conductor in all the cable tested consisted of strands of tinned copper. Figure 1 contains other data pertaining to the cable insulation.

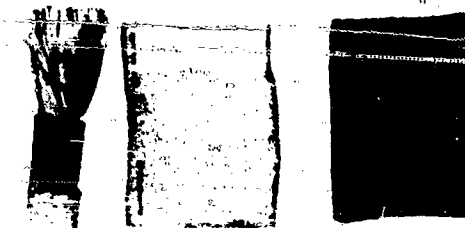
#### DEFINITIONS

Certain terms used throughout this report are defined as follows:

- a) **Maximum Continuous Current** - The highest current which can be carried continuously by a specified cable at given ambient conditions without producing visible evidence of smoke.
- b) **Overload** - Any value greater than the maximum continuous current.
- c) **Smoking Time** - The time required to produce visible evidence of smoke when an overload is continuously carried by a cable.
- d) **Delayed-Smoking Time** - The longest interval of time an overload can be continuously carried by a cable without visible evidence of smoke occurring after the current circuit is opened.

#### METHODS OF CONDUCTING INVESTIGATION

The investigation was conducted on single cables in ambient temperatures of 0, 25, and 45 degrees centigrade in still air at approximately sea-level altitude. AN cable sizes No. 0, No. 8, and No. 20 were selected for the tests.



BELDEN MANUFACTURING CO.  
AIRVINE

Braid - Cotton

Braid - Coating - Ethylenic polymer  
 saturant cellulose-  
 acetate base lacquer

Separator - None

Filler - None

Primary Insulation - Vinyl Chloride



GENERAL MOTORS CORP.  
Packard Electric Division  
Type 1000-C-Vinylite

Braid - Cotton

Braid Coating - Lacquer

Separator - None

Filler - None

Primary Insulation - Vinylite



**ELECTRIC AUTO LITE CO.**

- Braid - Cotton
- Braid Coating - Unknown
- Separator - None
- Filler - None
- Primary Insulation - Vinylite



**GENERAL ELECTRIC CO.  
"DELTABESTON"**

- Braid - Cotton
- Braid Coating - Unknown
- Separator - Paper, on Sizes 8-0 only
- Filler - Asbestos
- Primary Insulation - Polyvinyl Chloride



**ROCKBESTOS PRODUCTS CORP.  
"FIREWALL"**

- Braid - Cotton
- Braid Coating - Cellulose Nitrate Type  
Lacquer
- Separator - None
- Filler - None
- Primary Insulation - Layers of Cellulose  
Acetate Butyrate Tape Covered with  
Impregnated Felted Asbestos



**WHITNEY BLAKE CO.  
"STRATOCABLE"**

- Braid - Cotton
- Braid Covering - Unknown
- Separator - None
- Filler - None
- Primary Insulation - Whitney Blake PS-11



Figure 1 - Types of Cable Used for the Investigation

A preliminary investigation showed that the most practical method of determining the temperature of the conductor at any time during the tests was by calculating the increase in resistance as indicated by the change in voltage drop across a section of the cable, the current being held constant by variable carbon-pile resistors paralleled as necessary for the various overloads.

It was found that thermocouples were unsatisfactory for determining the temperature of the conductor during overload applications owing to the problems arising in inserting the junction at the proper position in the conductor and because of the thermocouple lag. Thermocouples were used, however, as a check against the voltage drop in determining when the temperature of the cable had stabilized below any smoking point.

Except when the applied overloads were very high, it was found that a given cable sample could be used several times without noticeable change in the smoking time, delayed-smoking time, or temperature rise. When the sample was used more than once, subsequent tests were made only after the temperature of all parts of the cable had stabilized at room ambient temperature.

Since the appearance of smoke determined the length of time the cable could carry a specified current, it was necessary to have an accurate method of detecting the smoke. An investigation showed that the best results were obtained by partially darkening the room, and using a small desk-type fluorescent lamp placed about three inches above the cable. While making measurements for determining maximum continuous currents and delayed-smoking values, the lamp shade would accumulate the first faint whiffs of smoke, thus making detection easy. (During this part of the investigation, the time at which smoke appeared was not a factor.) A piece of photographer's cloth was hung about three feet behind the light and a small strip of this cloth was suspended just below the light, about two inches in front of the cable. A photograph of this arrangement is shown in Figure 2.

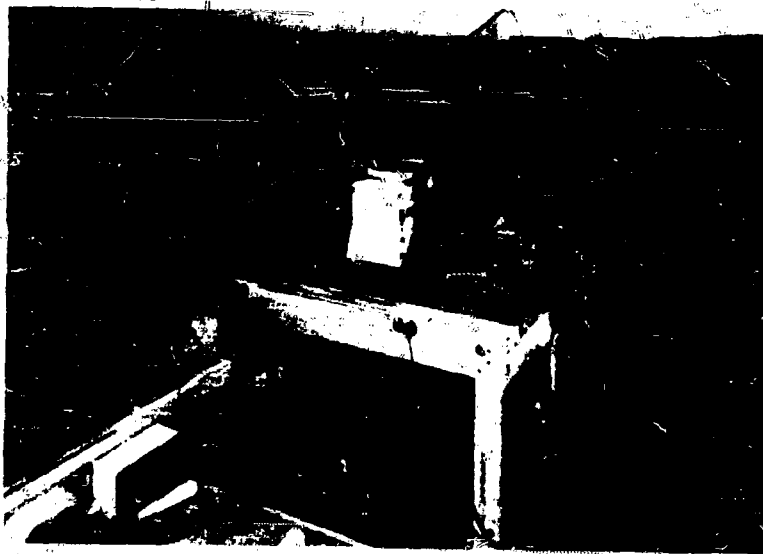


Figure 2 - Photograph of Equipment

Figure 3 is a schematic diagram of the test circuit. The by-pass circuit consisted of three parallel cables, each of the same size as the cable under investigation, but three times its length. This circuit was used for the initial setting of the variable resistors. Carbon piles were used for the variable resistors since their change in resistance partially compensated for the change in resistance of the cable. This made it easier to maintain a constant current through the cable. Weights of 20 pounds for Size No. 0; 5 pounds for Size No. 8; and 1 pound for Size No. 20 cable were hung over a pulley with a cord connecting the weight to the cable. Thus, any slack caused by elongation due to temperature rise was taken up by the weight, and the tension kept constant. These weights were not sufficient to cause stretching of the cable.

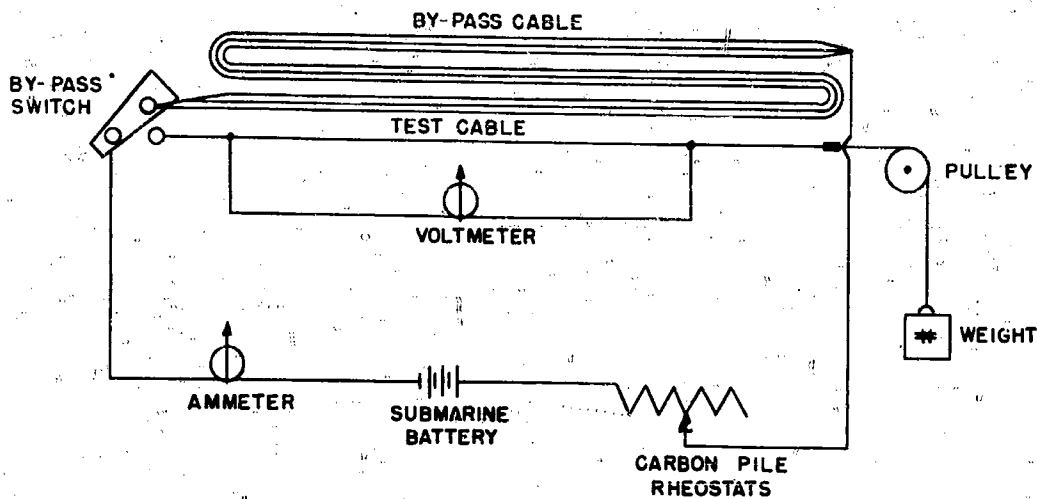


Figure 3 - Schematic Wiring Diagram

#### DISCUSSION OF RESULTS

Figures 4, through 6 show the conductor temperature versus time curves for overloads applied to the various manufacturers' cables on AN Sizes No. 0, No. 8, and No. 20 in a 25 degree centigrade ambient temperature. Smoking and delayed-smoking values are also shown on these graphs. Figure 7 shows thermal curves with smoking-time and delayed-smoking-time values obtained from application of the same current at different ambient temperatures on General Electric Size No. 8.

It will be noticed that the grouping of thermal, smoking-time and delayed-smoking-time curves by manufacturers' names is not always constant for the different sizes of cable used during the investigation. This is probably due to different graduated scales used by these companies to determine the relative amounts of primary insulation and braid components for the various sizes of cable. For example, it was found that the weight ratio of primary insulation and/or braid, to the total weight of the cable might be nearly equal on one size for cable from four of the manufacturers; whereas, when the same type of comparison was made using another size, this weight ratio would be about the same for possibly only two companies; and for a third size, these ratios would be different for all of the manufacturers.

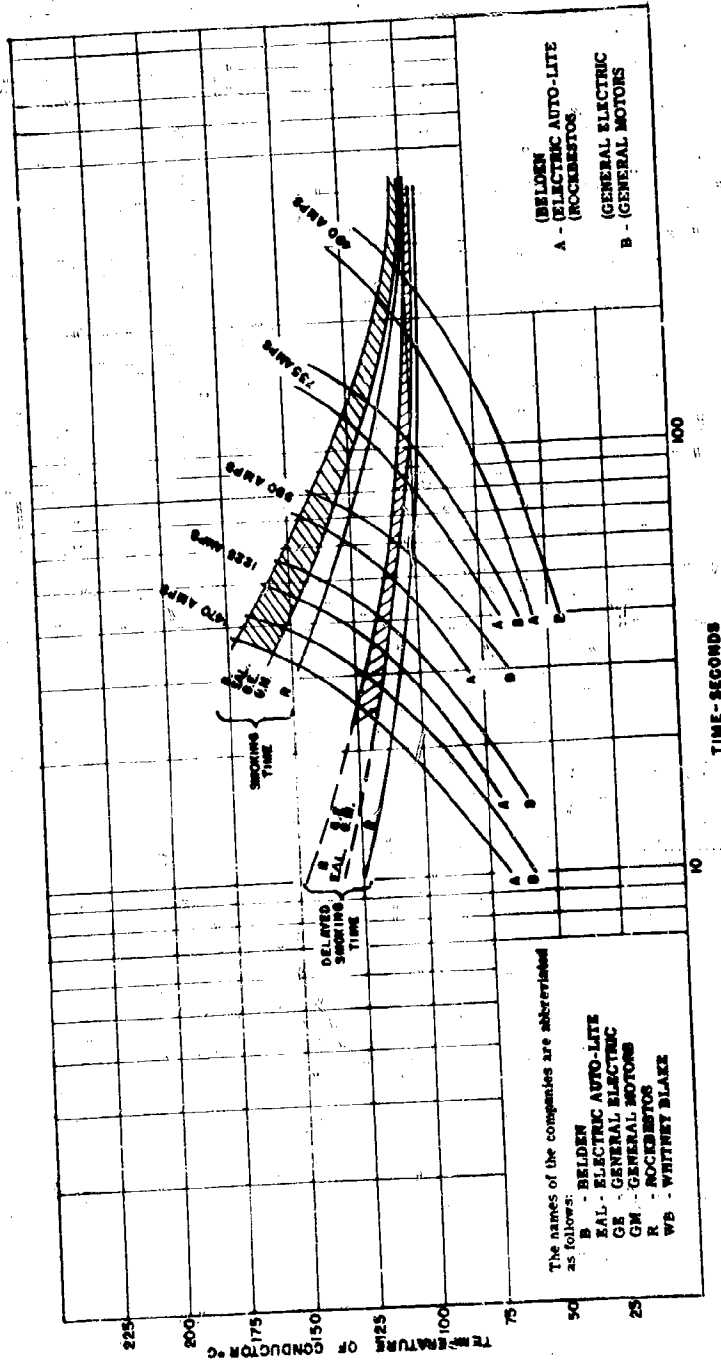


Figure 4 - Temperature Versus Time Curves with Smoking and Delayed-Smoking Values for Cable Size AN Number 0 at 25°C Ambient Temperature

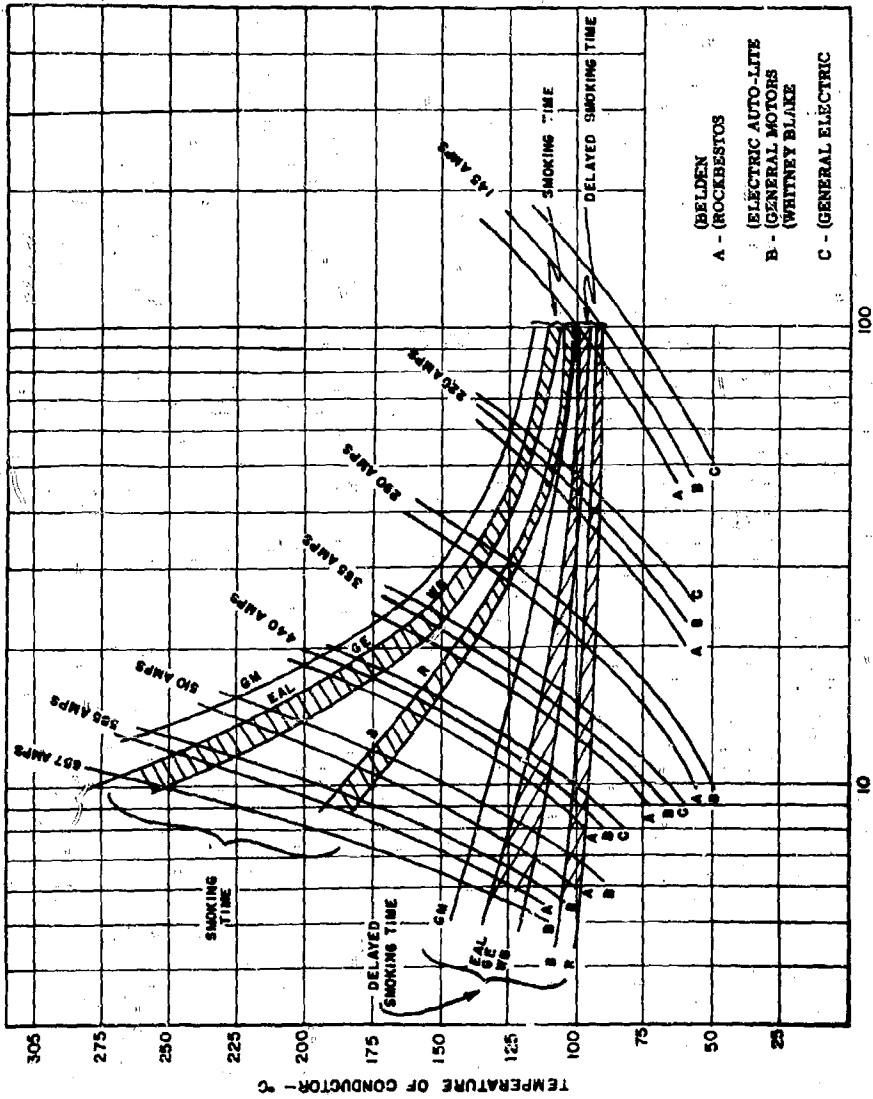


Figure 5 - Temperature Versus Time Curves with Smoking and Delayed Smoking Values for Cable Size AN Number 8 at 25°C Ambient Temperature

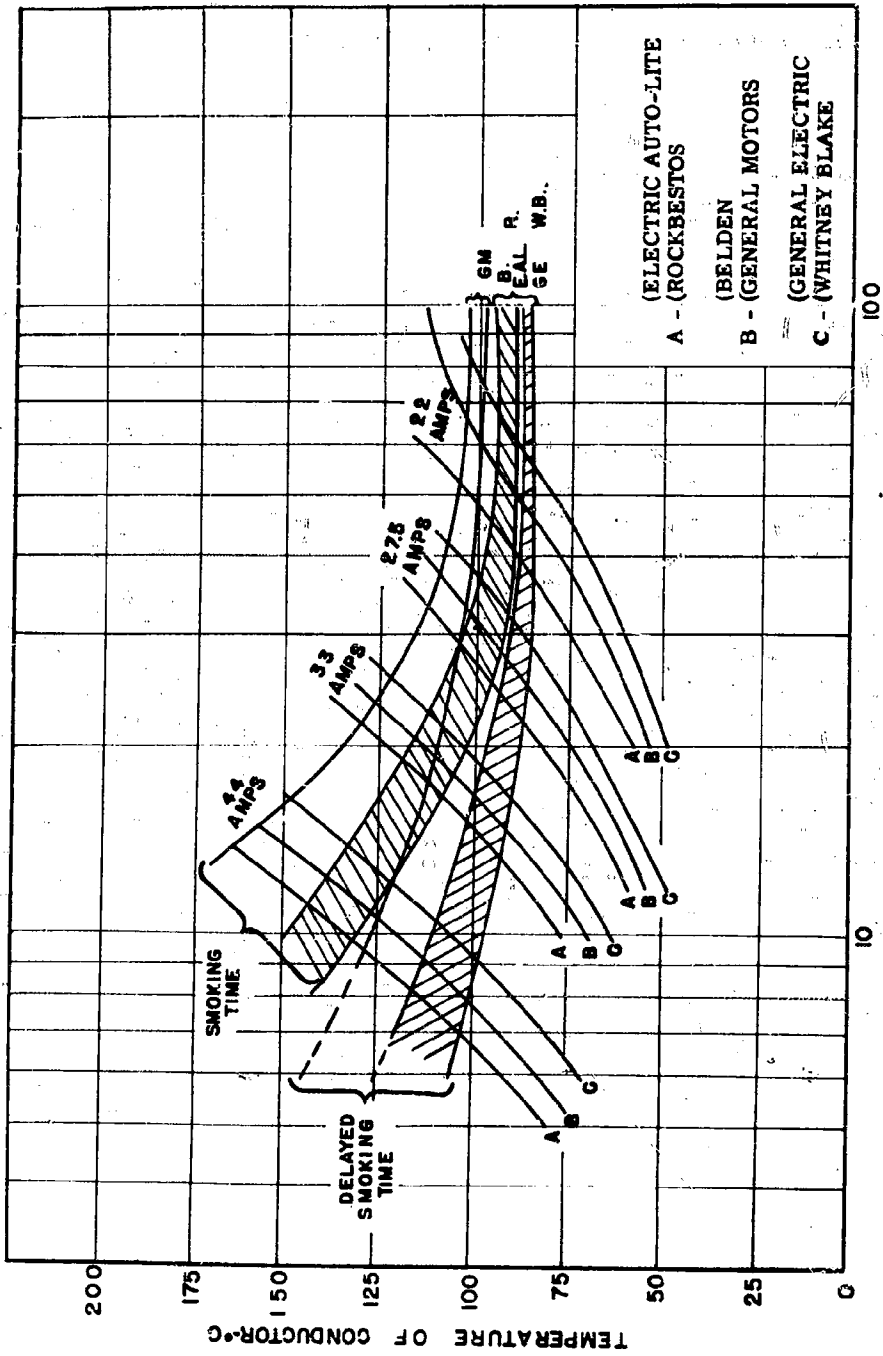


Figure 6 - Temperature Versus Time Curves with Smoking and Delayed-Smoking Values for Cable Size AN Number 20 at 25°C Ambient Temperature

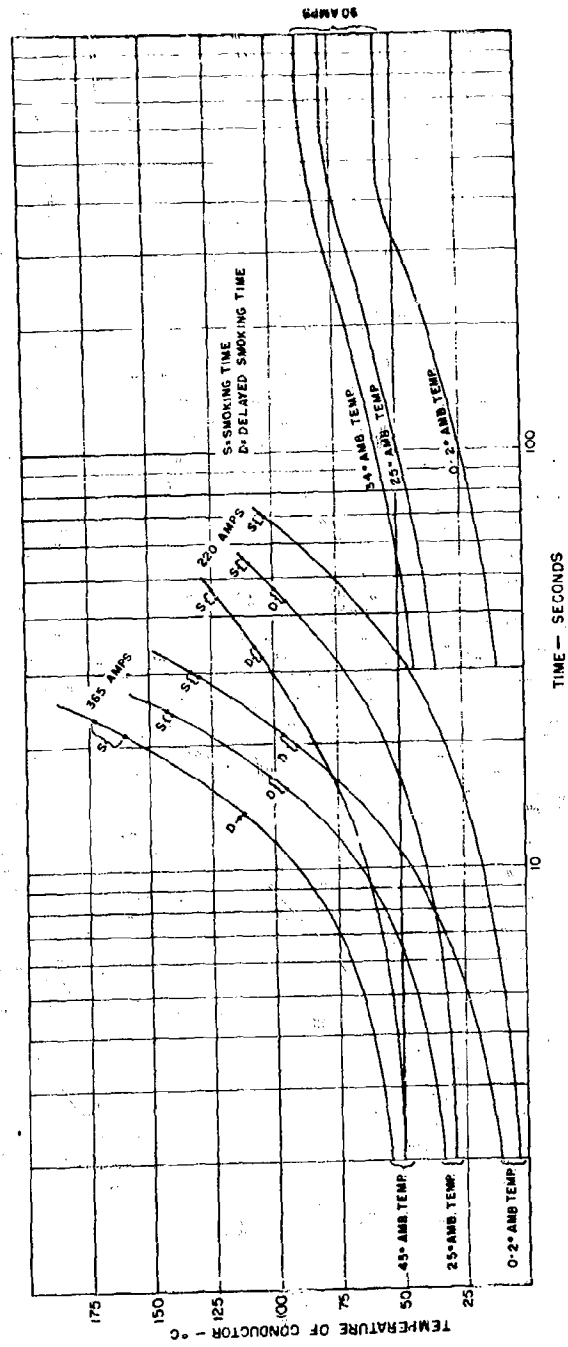


Figure 7 - Temperature versus Time Curves at Different Ambient Temperatures for General Electric Cable AN Number 8

Several tests were made to show the effect of increase in insulation thickness (outside diameter). The results are shown in Figure 8. No attempt was made to determine the thickness of any material added or removed, but attention is directed to the fact that every material added decreased the operating temperature of the conductor, and that the type of outer surface apparently had little effect. This indicates that the heat dissipated from the cable by conduction and convection is very large compared to that dissipated by radiation.

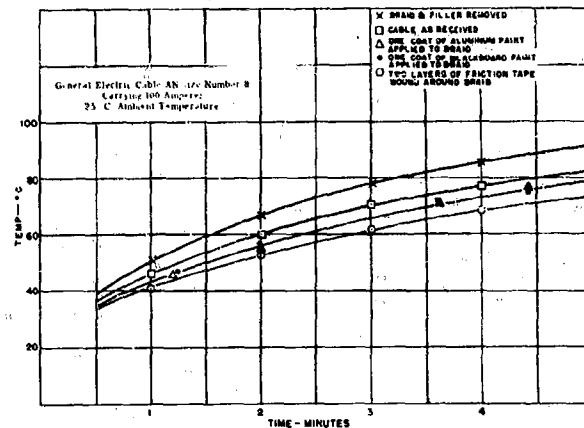


Figure 8 - Temperature Versus Time Curves Showing Effect of Change of Insulation

Table 1 shows the temperatures at which the conductors of various cables stabilized when carrying the current indicated.

TABLE 1

Cable Identification	25° C Ambient Temperature Current Applied (Amperes)	Temperature of Conductor When Stabilized (°C.)
Belden No. 8	92	91.5
General Electric No. 0	305	89.8
General Electric No. 8	102.5 - 107.5	95.4 - 104.2
General Electric No. 20	19	93.0
General Motors No. 0	330	101.4
General Motors No. 8	102.5 - 107.5	99.8 - 107.1
General Motors No. 20	20	105.2
Rockbestos No. 8	92.5 - 95.0	90.4 - 92.7
Rockbestos No. 20	17	84.5

These currents are the highest that the respective cables could carry without causing the insulation to smoke while operating in an ambient temperature of 25 degrees centigrade. It should be noted that the conductor temperatures listed in Table 1 are lower in nearly all cases than the value given in Army-Navy Aeronautical Specification AN-W-14a, Wiring; Installation of Aircraft. The current ratings given on page 3 of this specification are stated as being based on a maximum conductor temperature of 100 degrees centigrade in an ambient temperature of 57.2 degrees centigrade.

Maximum continuous current without smoking is plotted against cross-sectional area of the conductor in Figure 9. This curve represents the average maximum continuous current for all the types of cable investigated, considered collectively for each wire size in an ambient temperature of 25 degrees centigrade. In Figure 10 maximum continuous current is plotted against ambient temperature.

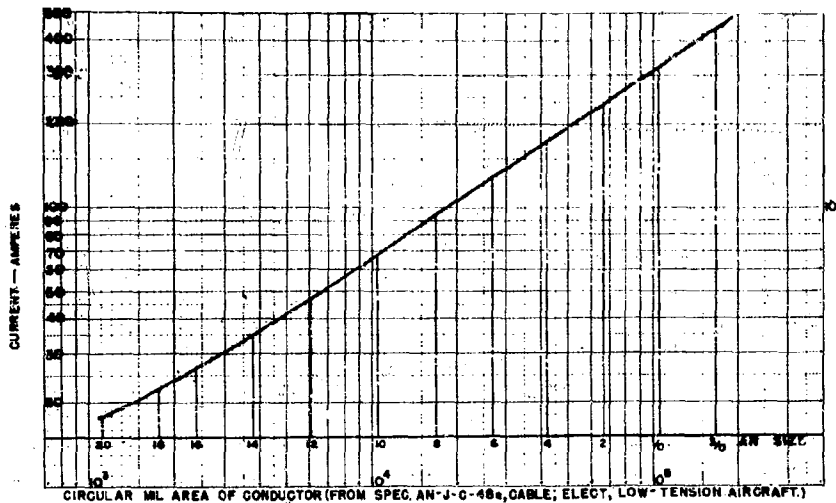


Figure 9 - Recommended Continuous Current Ratings for Low Tension Aircraft Cable Meeting the Requirements of Specification AN-J-C-48a, When in Ambient Temperature of 25° C

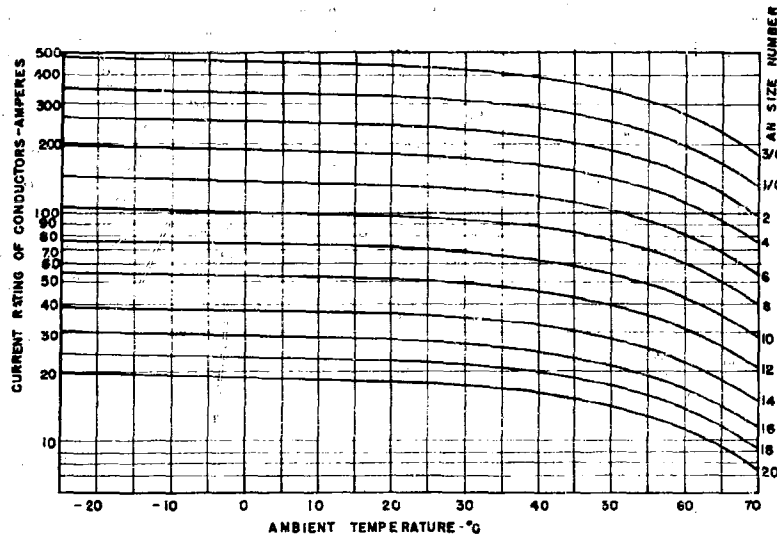


Figure 10 - Recommended Continuous Current Ratings for Low Tension Aircraft Cable Meeting the Requirements of Specification AN-J-C-48a

The curves for Sizes No. 0, No. 8, and No. 20 represent average values measured for the six types of cable investigated; curves for the intermediate sizes are drawn parallel through values at 25 degrees centigrade obtained from Figure 9.

In Figures 11 through 16 smoking time and delayed-smoking time are plotted against current for the types and sizes of cable used during this investigation.

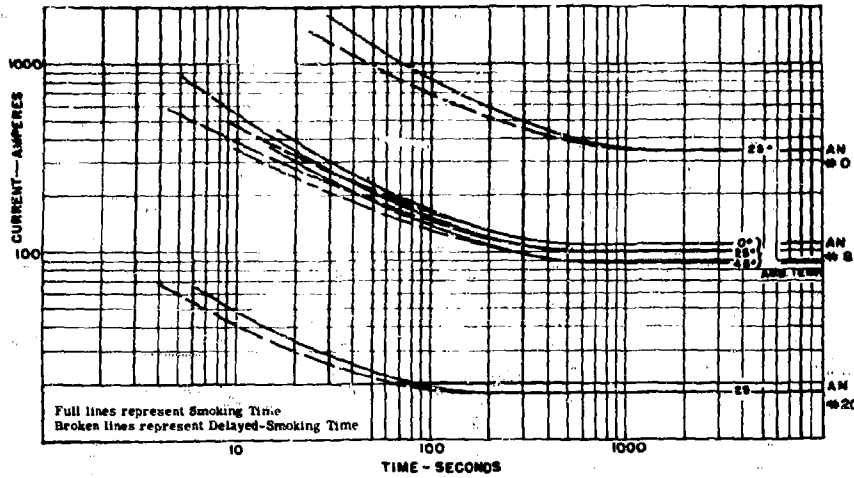


Figure 11 - Graph for Belden Airvine Cable

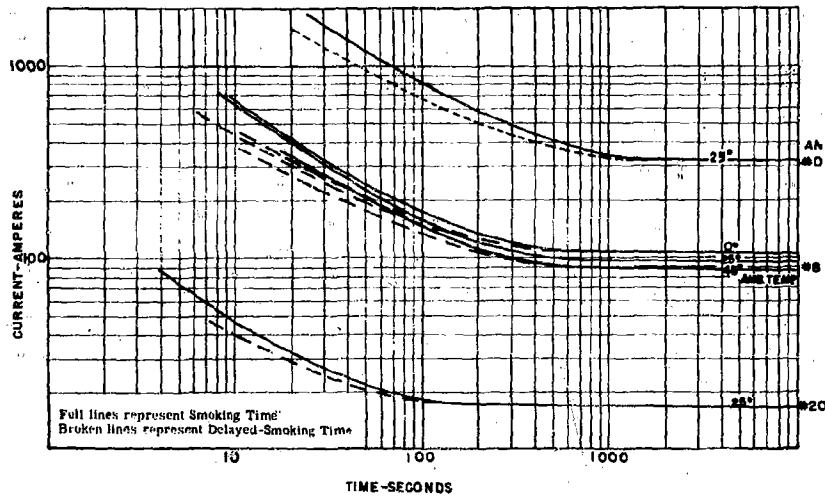


Figure 12 - Graph for Cable from Electric Auto-Lite Co.

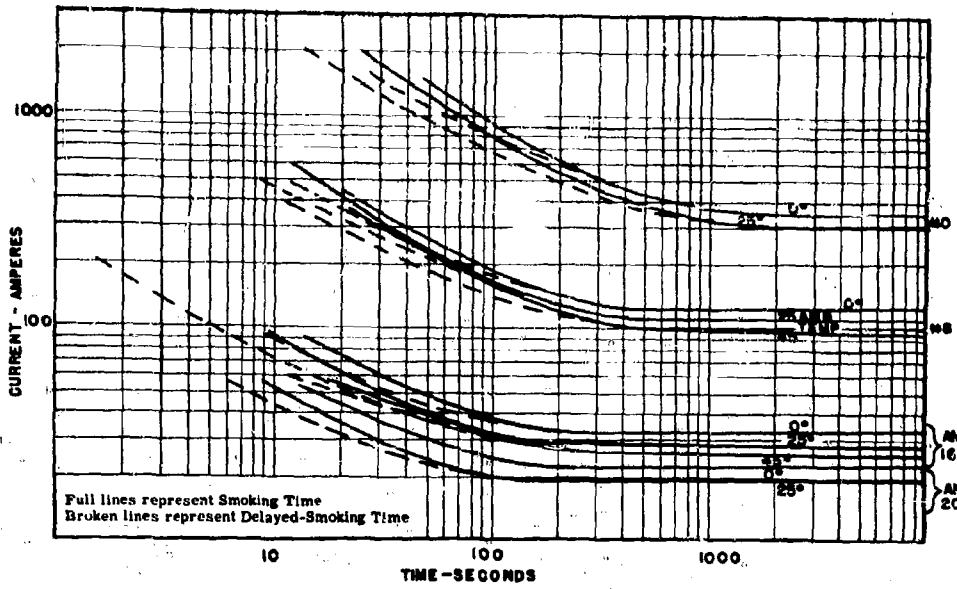


Figure 13 - Graph for General Electric Deltabeston Cable

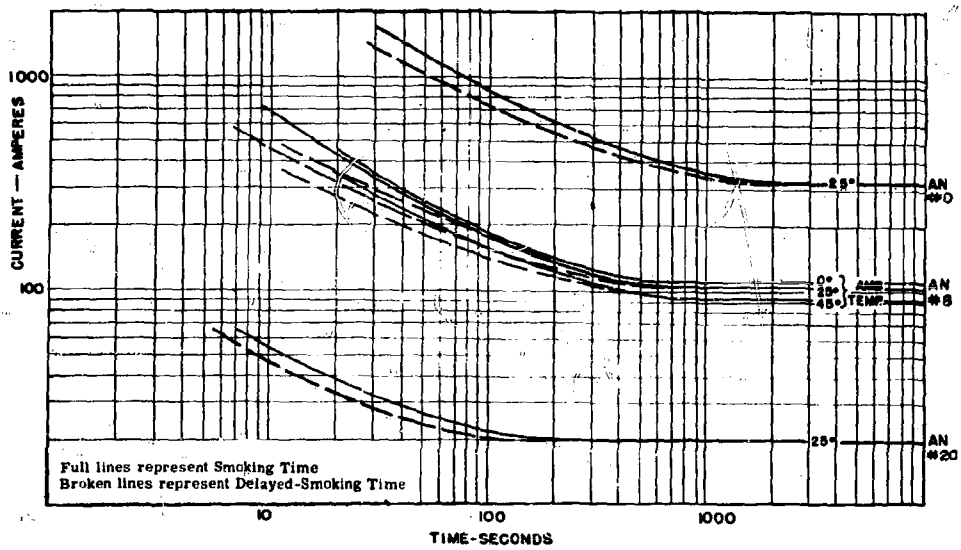


Figure 14 - Graph for Cable from General Motors Corporation

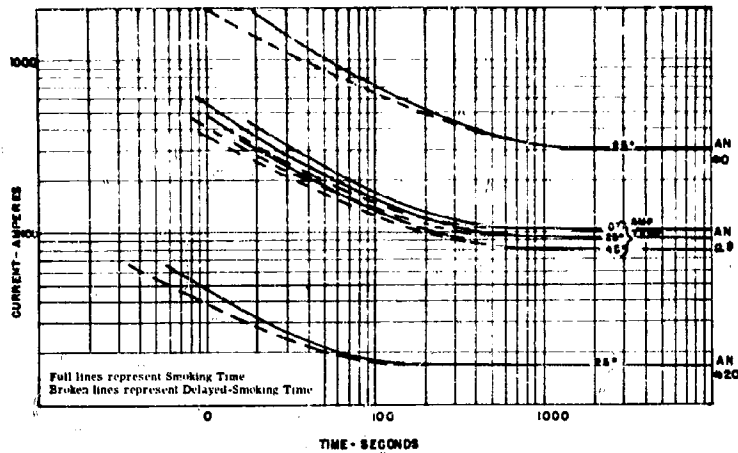


Figure 15 - Graph for Rockbestos Firewall Cable

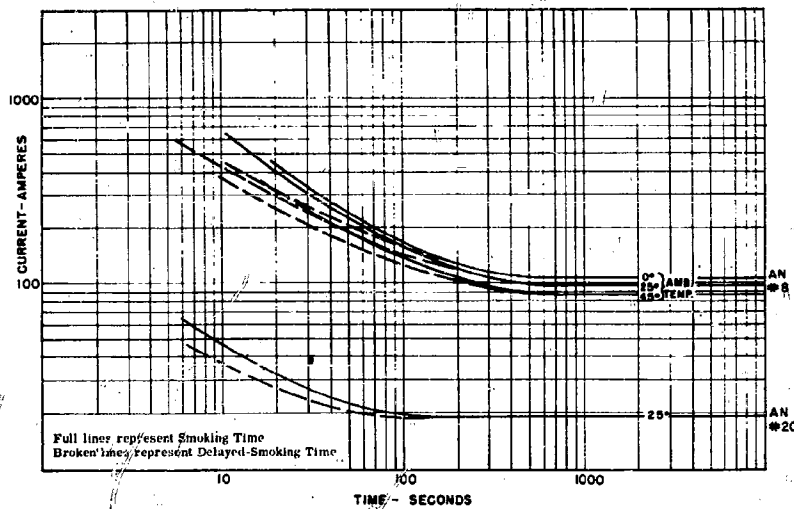


Figure 18 - Graph for Whitney Blake Stratocable

The smoking and delayed-smoking curves are drawn asymptotically to the maximum continuous current for each cable size and ambient temperature. Values were obtained for Size No. 8 in 0, 25, and 45 degree centigrade ambient temperatures, and for Sizes No. 0 and No. 20 at 25 degrees centigrade on cable from the six manufacturers (Whitney Blake Size No. 0 was not available). In addition, maximum continuous current and several smoking and delayed-smoking values were obtained on General Electric Cable Sizes No. 0, No. 16, and No. 20 at 0 and 45 degrees centigrade. Data was not obtained for time periods of less than approximately five seconds because of limitation in the accuracy of control and measurement.

The curves for AN Sizes No. 0, No. 8, and No. 20 of Figure 17 represent the average values obtained on cable from the six manufacturers. The shapes of these curves from approximately ten thousand seconds to five seconds are based on experimental data. Below one second the curves are based on calculations of the heat energy required on a no-loss basis to raise the temperature of the wire size in question to a value of 150 degrees centigrade. A maximum conductor temperature of 150 degrees centigrade was accepted as the maximum safe temperature for the shorter time periods (General Electric Company's report). The curve from ten thousand seconds to five seconds is extrapolated from five seconds to one second to join the calculated curve at this point. The curves for other wire sizes were drawn with the same shape as that for AN Sizes No. 0, No. 8, and No. 20, and asymptotic to the line representing maximum continuous current for the respective cable sizes as found on Figure 9.

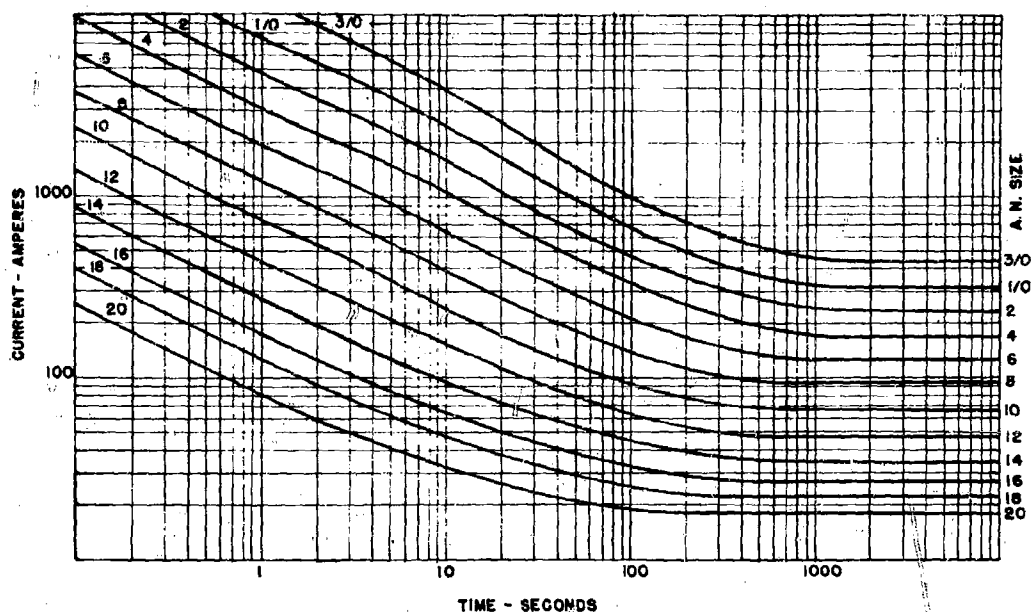


Figure 17- Recommended Short-Time Current Ratings in 25°C Ambient Temperature for Low-Tension Aircraft Cable Meeting the Requirements of Specification AN-J-C-48a

It should be noted that the continuous-current values given in Figure 10 do not agree with the values given in Table 1 of Specification AN-W-14a. Agreement of these two sets of values should not be expected since those given in this report, the maximum values that the cables can carry without smoking, may impair the cable insulation; whereas, those in Specification AN-W-14a should neither cause smoking of, nor damage to, the cable insulation. A comparison of these values, however, shows that the continuous currents listed in the specification are higher than those given in this report. This variation is contrary to what would be expected.

A study of the data on smoking time and delayed-smoking time revealed that there is a definite relationship between the two. This is illustrated by the curve of Figure 18.

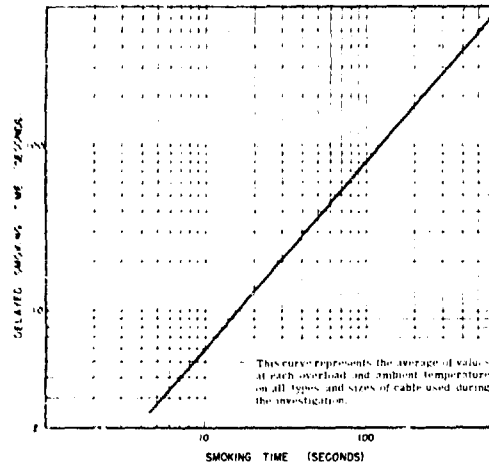


Figure 18—Relationship Between Smoking and Delayed-Smoking Values

Data for this curve was obtained from the numerous curves presented in this report. It represents all cable sizes, currents, ambient temperatures, and manufacturers. The equation of the curve is

$$T_d = 0.46T_s^{1.12}$$

where  $T_d$  is the delayed-smoking time and  $T_s$  is the smoking time. This relationship applies satisfactorily for time periods up to five minutes, and is useful in determining the delayed-smoking time from smoking time values, the latter being more easily obtained.

#### CONCLUSIONS

The following conclusions are based on the results of this investigation:

- The maximum safe conductor temperature of 100 degrees centigrade given in Specification AN-W-14a is too high for present aircraft cable.
- The short-time ratings for AN cable for time intervals between one and ten thousand seconds duration are as shown in Figure 17.
- The relationship between delayed-smoking time and smoking time for periods up to five minutes is given by the equation

$$T_d = 0.46T_s^{1.12}$$

where  $T_d$  is the delayed smoking time and  $T_s$  is the smoking time.

## RECOMMENDATIONS

a) It is recommended that the curves of Figure 17 be used for the short-time rating of AN cable for time intervals between one and ten thousand seconds. It is recommended that for periods of time less than one second the maximum current be based on calculations of the heat energy required on a no-loss basis to raise the temperature of the wire size in question to a temperature of 150 degrees centigrade.

b) It is recommended that the maximum safe conductor temperature of 100 degrees centigrade given in Specification AN-W-14a be removed and that the maximum current values given for single conductors in free air listed therein be replaced by the values in Figure 10 of this report.

\* \* \*

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Naval research laboratory. Report No. E-3145 (Revised)

Cable thermo curves, by W. H. Askew. Washington, The Laboratory.

July 1947

17 p. illus.

27 cm.

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Abstract: Report gives results of investigation to determine the short-time current-carrying capacities of aircraft cables using visual indication of smoke as the limiting factor. Curves are given showing the highest current which can be carried by each size cable at different ambient temperatures without the occurrence of smoke. Maximum conductor temperature and continuous current values specified in AN-W-14a would cause insulation to smoke.

1. Cables - testing. 2. Cables - insulation for. 3. Aircraft - equipment - cables. I. Askew, W. H. 6

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**ABSTRACT:** *Aircraft Control Cables, & Electric Current*

Results are given of an investigation made to determine the short time current carrying capacities of aircraft cables using visual indication of smoke as the limiting factor. Curves were obtained showing the highest current which can be continuously carried by each size of cable at different ambient temperatures without the occurrence of smoke. Thermal curves, with smoking and delayed smoking values were obtained for various current overload applications. Results indicate that in the majority of cases the maximum conductor temperature and the continuous current values listed in specifications would cause the insulation to smoke.

EO 10501 dd 5 NOV 1953

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<b>FUNCTION:</b> Distribution Equipment (5)	<i>NTIS, auth: ONR ltr, 29 Oct 70</i>

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