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DEVELOPMENT OF A METHOD OF OBTAINING A UNIFORM ABRASION TEST FOR AIRCRAFT ELECTRICAL CABLE

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ABSTRACT

The trend toward electrical cable without an outer covering of braid over the primary insulation has emphasized the need for a suitable cable abrasion test which will give comparable results on repeated tests, and will be an accelerated test, simple and practical in operation. The investigation to achieve this goal has resulted in a machine which meets these requirements, which provides a uniform abrasive surface that will not become clogged with detritus, which automatically stops when the cable's insulation is worn through to the conductor, and which is equipped with a counter for measuring the length of abradant tape necessary to achieve failure of the cable. Results of abrasion tests of cable conducted on this machine indicate a lack of uniformity of the cable protective coating and of concentricity of the cable's insulation. It is believed, however, that sufficient information has been secured to provide a basis for an abrasion test to be incorporated in aircraft cable specifications. This test method is not aimed to forecast the service life of the cable; it is intended, rather, to be used as a means of comparing the abrasion resistance of various types of cable insulation.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem E02-09 (BuAer Problem 31E124).

DEVELOPMENT OF A METHOD OF OBTAINING A UNIFORM ABRASION TEST FOR AIRCRAFT ELECTRICAL CABLE

INTRODUCTION

This investigation was requested by BuAer Ltr. to NRL, Aer-EL-34-MAK F36-2(8) No. 29779 dated 18 April 1946. The project directive requested that study be made of how aircraft electric power cable is abused in service, of how a laboratory test could be set up to give an accelerated life test that would duplicate as much as possible this abuse, and that a test device be developed that would repeatably give comparable results and yet be as simple as practical in order that other interested parties could easily construct the apparatus.

For some time there has been a decided need for a method of determining the abrasion resistance of the insulation of aircraft electrical cable. The importance of such a test has become more apparent by the present trend toward cable not equipped with a braid, or covering, over the primary insulation. Up to the past year, specifications for aircraft electrical cable have demanded such a braid covering, primarily as a wear-resistant protective cover. Although satisfactory abrasion resistance has been obtained by such a braid covering, many factors, such as scarcity of the braid materials, improvements in the wear resistance of modern plastics used as primary insulation, the need for weight reduction and for lack of moisture wicking in the finished cable have directed a trend toward cable without a braid covering, leaving the primary insulation exposed to the normal wear experienced by the cable. Development of a satisfactory cable abrasion test method that can be incorporated in the cable specifications will tend to improve the wear characteristics of future aircraft cable, and in addition will serve to indicate the relative wear-resistant qualities of the various types of insulation.

It is a generally understood principle that wear tests for cable insulation should possess as many as possible of the attributes of any good test, namely, reliability in the apparatus and its operation, control of the significant factors affecting the test, freedom of results from the personnel equation, results obtained in a brief time and expressed in understandable units, and reproducible results on the machine and on others like it.

One of the most important questions concerning abrasion tests, which so far has not been satisfactorily answered, is the correlation factor, or the extent to which the laboratory abrasion test approximates service life. The number of abuses to which the cable is subjected during its installation and use are extremely numerous and varied; they include such factors as temperature, humidity, tension, compression, flexing, frequency of movement of the rubbing parts, poundings, etc. Abrasion of cable in service is not only due to that encountered during construction of the plane when the cable may be walked on, flexed, pounded, and pulled through conduit with its attendant sharp edges, but also to the wear experienced while installed in the plane, such as pounding, rubbing of two cables together, or of a cable against the plane's structure, bending around sharp turns, vibration, etc.

It may be readily understood from the above conditions that the problem of developing one laboratory machine that will duplicate the above conditions is well nigh impossible to solve. The essential factors of service life are not accurately known, and especially are not known as to their relative importance in the accelerated test expected in a laboratory. It was therefore decided to simplify the test methods and confine attention to one destruction test, abrasion.

The Abrasive Action

Six dominant variables enter into the abrasive action: namely (a) load on the abradant, (b) direction or type of rubbing action, (c) length of rubbing stroke, (d) temperature, (e) humidity, and (f) presence or absence of detritus (abraided pieces clinging to the cable sample at the point of wear).

(a) Load - It is obvious that the pressure between the sample under test and the abradant is a factor of fundamental importance. While no complete set of figures were compiled during this investigation which would indicate the ratio between the load and the rate of wear, sufficient results were obtained to indicate that it is a major factor. Because of the operating smoothness of the suggested machine the load is considered to be nonoscillating. A dead weight was selected as the load because it produced minimum oscillation of the sample. The weight selected for each cable size is based on results of preliminary tests conducted on the developed abrasion device.

(b) Direction and Type of Rubbing - Consideration was given as to proper direction in which the rubbing action should be applied. As most wear is the result of rubbing contact occurring during installation of the cable and, to a lesser degree, by such contact engendered by aircraft vibration, it is apparent that the selection of a lengthwise abrasive action would be satisfactory.

(c) Rate and Extent of Rubbing - The speed of the rubbing action is generally agreed to be an important variable, and no machine is satisfactory that does not give good control of the speed. It is therefore important that the speed of the motor of the suggested machine be relatively constant. The speed of rubbing is also an important factor, since at relatively high speeds the abradant tape tends to jump and meet the sample irregularly, and in addition creates an excessive temperature at the point of contact.

(d) Temperature - The heat developed in a cable sample under test is considered to be an important factor in the life in the insulation, and is dependent on the type of insulation used, the diameter of the cable, the speed of the abradant, and the material used as an abradant. It is therefore important that these variable factors be carefully controlled during the abrasion test. The ambient temperature of the test room should also be controlled and a room temperature of 26° C (79° F) is suggested. In order to achieve further uniformity it is suggested that both the cable samples and the machine be conditioned at this temperature for a few hours before the test. The proposed abrading machine has the advantages of a relatively low speed and a constantly renewed abrasive surface, both of which tend to reduce to a minimum the attendant temperature rise at the point of wear on the cable sample.

(e) Relative Humidity of Test Room - While no test data has been secured on the influence of relative humidity on the results of abrasion tests, it is a recognized fact that it has a definite bearing on the results. Accordingly, tests conducted with the recommended machine have been made in a room with a relative humidity of 35 percent to 50 percent.

(f) Detritus - Granulated material, if left to accumulate at the point of abrasion, will have an important bearing in determining the results of an abrasion test, since it will tend to lengthen the time required to wear through the insulation. The recommended test method solves this problem by carrying away the detritus on the abrasive tape, which is not used again. Neither air suction nor blowing is recommended for this test because they tend to affect the temperature and humidity of the test sample and surrounding air, and because they are difficult to control.

Even under these controlled conditions repeatable, or identical, test results cannot be secured unless the cable under test has perfect concentricity of insulation.

DESCRIPTION OF ABRASION DEVICE

The machine drive motor is operated through the normally closed contacts of a relay having a one-milliampere coil. The relay coil is energized when the cable insulation is worn through, and the conductor comes in contact with the strip of Aquadag painted on the abrasion tape, thus completing the electrical detection circuit and energizing the relay coil. This results in opening the circuit to the drive motor and puts a holding circuit on the relay coil. An annotated sketch of the device is shown in Figure 1 and a dimensional sketch in Figure 2. Photographs of front and rear views of the apparatus are shown in Figures 3 and 4 respectively.

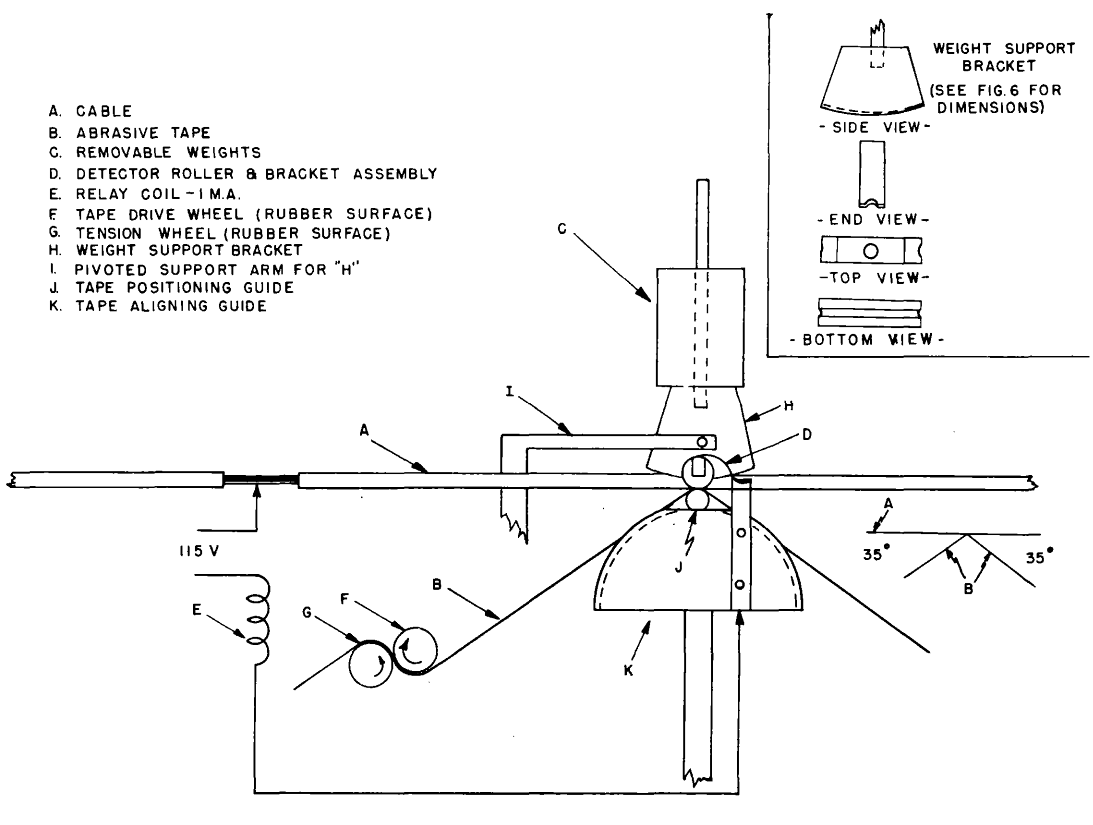

Fig. 1 - Annotated Sketch of Abrasion Apparatus

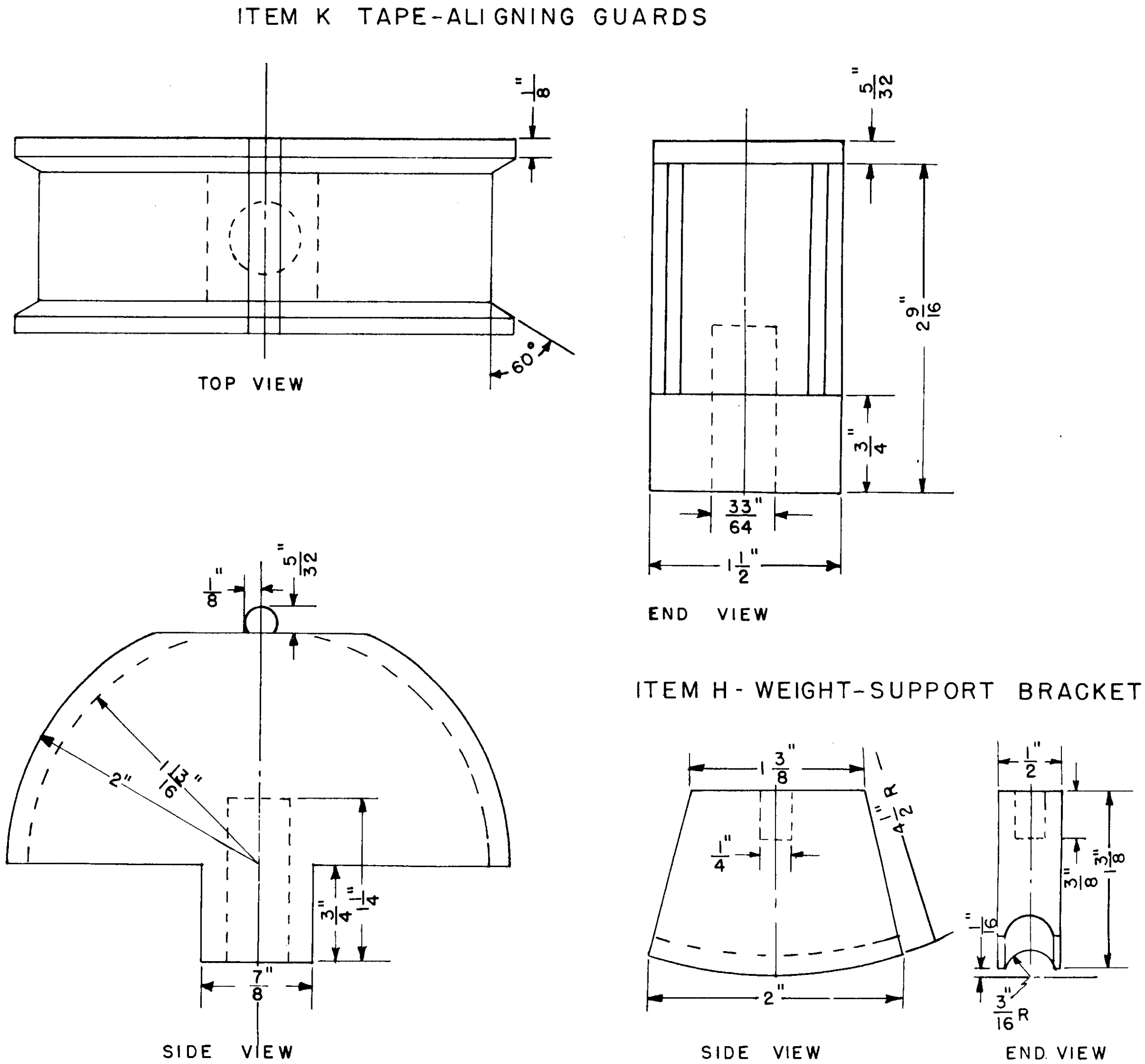

Fig. 2 - Dimensional Sketch of Tape-Aligning Guards and Weight-Support Bracket

The coating of Aquadag solution painted at regular intervals on the abrasion tape is an electrical conductor, and permits an indication as to when the insulation on the cable is worn through to the conductor. The solution is made up of one ounce of Aquadag to one and a half ounces of water, the resulting solution having a consistency of heavy motor oil. It is applied in strips, 3/8 of an inch wide, across the abrasive surface of the tape at an angle of 90^{0} to its edge, each strip spaced approximately six inches apart. The applied coating has an average thickness of 0.0007 inch and an average d-c resistance of 15000 ohms measured across a 3/4-inch length when the solution is air dried. Care should be taken not to apply the Aquadag solution too thickly at one application, or to dry it at temperatures above 80^{0} F, since the coating has a tendency to crack excessively under these conditions, producing a high resistance path. When properly applied, a suitable thickness can be secured in one application without cracking when dried at room temperature.

The tape is driven by a rubber-faced roller wheel (F in Figure 1) at a speed of 22 rpm, supplying the tape at a speed of 60 inches per minute. A rubber-faced wheel (G in Figure 1)

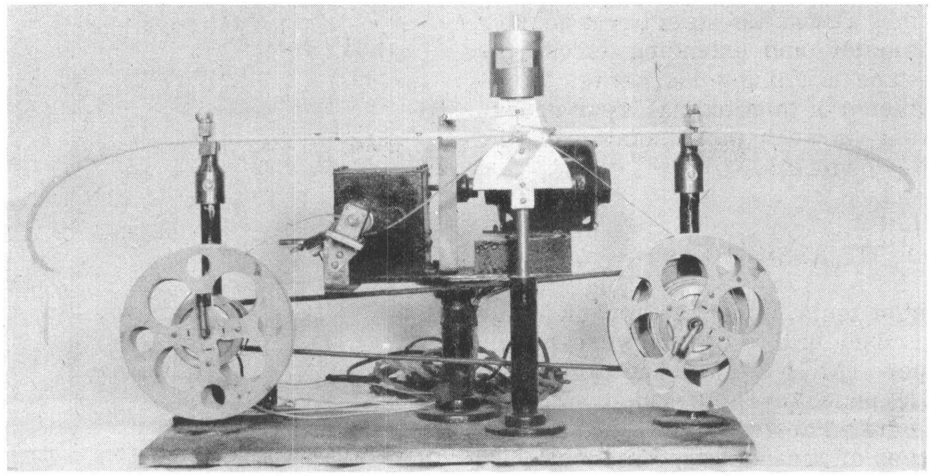

Fig. 3 - Front View of Apparatus

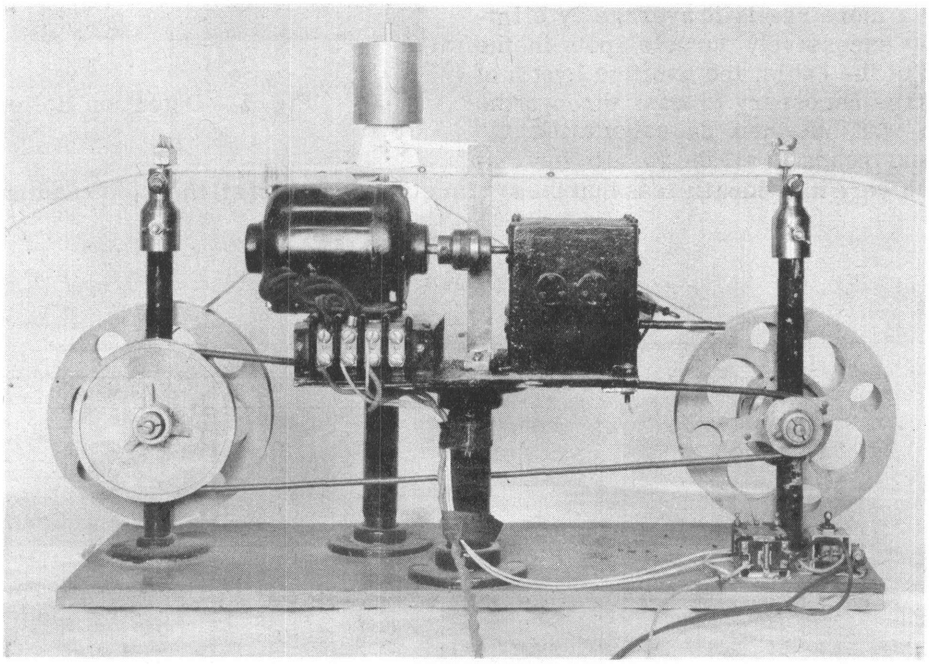

Fig. 4 - Rear View of Apparatus

rotates in a direction opposite to that of the drive wheel, and maintains a tension on the tape. The length of tape necessary to wear through the insulation to the conductor is noted by a counter. The weight at the end of the pivoted support arm (I in Figure 1) is 0.15 pounds when the removable weights are not on the weight-support bracket. As this weight remains relatively constant throughout the tests it is not included in the weight superimposed on the cable during the tests.

The detector roller (Figure 5, and D in Figure 1) completes the electrical circuit from the Aquadag coating on the tape to the relay coil. The tape-positioning guide

(J in Figure 1), a tungsten-steel bar, a quarter inch in diameter, and extending across the face of the tape-aligning guide, serves to reduce the amount of longitudinal wear necessary to wear through the insulation of the cable to the conductor.

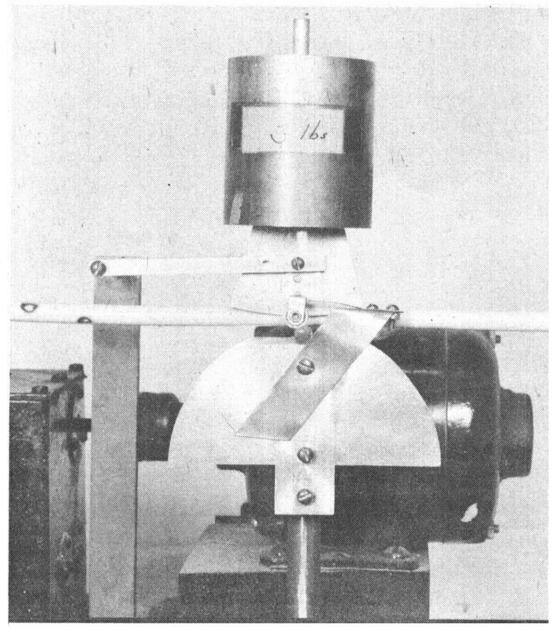

Fig. 5 - Detection Roller

DISCUSSION OF RESULTS

Abrasion tests, using the abrasion machine described in this report, were run on both copper (AN-J-C-48a) and aluminum (AN-C-161) conductor cable made by various manufacturers. Tables 1 and 2 list the number of inches of abradant tape necessary to wear through the cables' insulation, and the maximum, minimum, and average length of tape is given to indicate the spread of the wear resistance of any one cable. In order to achieve a more realistic average by eliminating any excessively durable spots in the insulation of the cable, the average length of abradant tape necessary to wear through the insulation was obtained by calculating the arithmetical means of all the results for that cable which were individually less that the arithmetical means of all the eight readings per cable.

TABLE 1

Abrasion Tests on AN-J-C-48a Cable

	Exhibitor	Inches of Tape		
		Average*	Maximum	Minimum
Size AN-16 (1.0 lb weight added)	A	30	41	30
	B	19	30	17
	E	17	41	11
	F	22	58	17
	I	47	66	47
Size AN-8 (3.0 lbs weight added)	A	22	31	16
	B	17	30	11
	C	20	25	14
	F (cotton braid)	25	41	19
	F (rayon braid)	17	36	11
	H	11	19	11
	I	22	30	19
Size AN-1/0 (4.25 lbs weight added)	A	72	130	55
	B	41	69	36
	C	22	30	19
	D	17	25	14
	E	41	50	36
	F	33	52	33
	G	50	135	36
	I	54	60	52

* Average obtained by calculating the arithmetical means of all the readings for that cable which are individually less than the arithmetical means of all the eight readings per cable.

TABLE 2

Abrasion Tests on AN-C-161 Cable

	Exhibitor	Inches of Tape		
		Average*	Maximum	Minimum
Size AL-1/0 (4.25 lbs weight added)	A	58	110	55
	B	44	60	36
	C	25	44	17
	D	24	41	16
	E	39	71	30
	F (See Appendix B)	31	50	28
	G	67	91	63
	H	77	116	74
	I	44	74	36
Size AL-6 (3.0 lbs weight added)	A	39	63	30
	B	40	52	36
	C	34	44	30
	D	23	28	16
	E	44	85	36
	F (See Appendix B)	60	85	50
	G	30	50	19
	H	43	66	41
	I	25	41	22

* See Table 1.

It should again be noted that the given load (Removable Weight) for each cable size during these tests is not the total load, as it does not include the weight of the pivot support arm and the weight support brackets (Figure 5, and I and H in Figure 1.) Since, however, the weight of these two items remains constant throughout all the tests, they are not included in the specified "Removable Weights" placed on the cable samples undergoing abrasion.

The "Removable Weights" used in this investigation were empirically selected to secure an average length of wear for all sizes of cables. The tests were concentrated on those cable sizes specified as qualification test samples by Specifications AN-J-C-48a (copper conductor) and AN-C-161 (aluminum conductor). These cable sizes and their selected "Removable Weights" were: for the AN-J-C-48a cables, sizes AN-1/0, AN-8, and AN-16, test weights of 4-1/4, 3, and 1 lb, respectively; and for the AN-C-161 cables, sizes AL-1/0 and AL-6, weights of 4-1/4 and 3 lbs.

Measurements obtained during this and previous investigations of cable indicate that there is a relatively large variation in the thickness of any one cable's insulation along its length and around its circumference. In order to secure more representative results during this abrasion investigation, eight abrasion test runs were made on each cable sample, the cable being rotated ninety degrees and advanced two inches for each succeeding run.

An abrasion test was also made on three types of braid removed from their cables. The 1/0 size braids had the same impregnants and coatings as did the AN-8 size braids. In each case the braid was fastened in place over the arc segment of the weight support bracket (H in Figure 1) and 0.5 pound weight added. Break-through of the braid was noted by the electrical detection circuit. Results of the test are shown below:

TABLE 3

Braid Abrasion Tests

	Exhibitor	Inches of Tape		
		Average*	Maximum	Minimum
Braid from AL-1/0 Cable	C (cotton)	29	47	22
	D (glass)	10	11	5.5
Braid from AN-8 Cable	F (cotton)	46	61	41
	F (rayon)	7.5	11	5.5

* See Table 1.

CONCLUSIONS

1. The complexities of the abuses suffered by aircraft cable during its installation and its service life preclude the possibility of devising a simple laboratory machine to determine its abrasion resistance.

2. Reproducibility of test results cannot be obtained on this or any other abrasion device unless the cable insulation is uniform throughout.

3. In general, cotton braid has more abrasion resistance than glass braid, which in turn is on a par with rayon braid. However, the type of saturant and the thoroughness with which it impregnates the braid, and the type and thickness of the braid coating, have a material affect on the abrasion resistance of the braid, and consequently of the finished cable.

4. The one cable having an extruded primary insulation without a braid covering (Exhibitor D of Table 3) had the poorest abrasion resistance of any of the cables submitted to test.

5. The abrasion device described in this report presents certain advantages over, and avoids some of the disadvantages found in, other abrasion machines. This abrasion test device is not designed to be representative of the rather large number of types of abrasion encountered by cable in aircraft, but is intended to give a comparative value of the abrasion resistance of all the types of cable insulation while under controlled laboratory conditions.

RECOMMENDATIONS

It is recommended that the foregoing cable abrasion test method be incorporated in Specifications AN-J-C-48 and AN-C-161.

It is also recommended that the minimum value of abrasion resistance shown in Tables 1 and 2 of this report be weighed heavily when evaluating a cable for abrasion resistance. The importance of this becomes apparent when minimum values are compared with the average values in these tables.

Since tests have proved that the abrasion resistance of cable insulation will vary with changes in test conditions, it is recommended that the following items be standardized in order to secure reproducible average test results:

(a) Abrasive tape - Behr-Manning garnet cloth, grade 4/0 - 150J, one inch wide in rolls of 50 yards length.

(b) Speed of tape - 60 inches per minute.

(c) Aquadag solution - one ounce Aquadag to 1 1/2 ounces water.

(d) Thickness of Aquadag coating on tape - average of 0.0007 inch.

(e) Diameter of tape positioning guide - 1/4 inch.

(f) Angle of tape from horizontal at point of contact - See Figure 5.

(g) Weight of the pivoted support arm and of the weight support bracket - total 0.12 pounds.

(h) Room temperature - 75° F $\pm 3^{\circ}$.

(i) Relative humidity - 45 percent ±10.

(j) Applied weights - as given in description of abrasion device.

* * *

APPENDIX A

Code Letter Designating Manufacturer

AN-J-C-48a Cable (Copper Conductor)

Exhibitor Code Letter	Manufacturer	Mfgs. Designation
A	General Electric Co.	(57332)
B	General Electric Co.	(No. 57333)
C	Rockbestos Prods. Co.	
D	Rockbestos Prods. Co.	
E	Electric Auto-lite Co.	
F	Packard (General Motors)	
G	Belden	
H	Whitney-Blake	
I	General Electric Co.	(YCC No. 31)

AN-C-161 Cable (Aluminum Conductor)

Exhibitor Code Letter	Manufacturer	Mfgs. Designation
A	Packard (General Motors)	
B	Rockbestos Prods. Co.	
C	Rockbestos Prods. Co.	
D	U. S. Rubber	(Neolay)
E	Belden	(Airloy)
F	Electric Auto-lite Co.	
G	General Electric Co.	(YCC No. 28)
H	General Electric Co.	(YCC No. 29)
I	General Electric Co.	(YCC No. 30)

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APPENDIX B

Construction Features of Cables

SPECIFICATION	EXHIBITOR	BRAID (& SATURANT*)	BRAID COATING	SEPARATOR	FILLER	PRIMARY INSULATION
Size AN-J-C-48a	A	Cotton	Unknown	Paper - No. 8 thru 1/0	Asbestos	Extruded polyvinyl chloride
	B	Cotton	Unknown	Paper - No. 8 thru 1/0	None	Extruded polyvinyl chloride
	C	Cotton	Lacquer - Cellulose nitrate type	None	Impregnated felted asbestos	Layers of cellulose acetate tape
	D	Glass	Lacquer - Cellulose nitrate type	None	Impregnated felted asbestos	Layers of cellulose acetate tape
	E	Cotton	Unknown	None	None	Extruded polyvinyl chloride
	F	Cotton	Unknown	None	None	Extruded polyvinyl chloride
	G	Cotton - Ethylenic polymer	Lacquer - Cellulose acetate base	None	None	Extruded polyvinyl chloride
	H	Cotton	Unknown	None	None	Extruded W-B No. PS-11
	I	Glass - Silicone	Varnish - Silicone	None	Cellulose acetate tapes sandwiched between two layers of silicone-impregnated asbestos	
Size AN-C-161	A	Cotton - Resin base	Lacquer - Acetate butyrate	None	None	Extruded copolymer of polyvinyl chloride
	B	Cotton	Lacquer - Cellulose nitrate type	None	Impregnated felted asbestos	Layers of cellulose acetate tape
	C	Glass	Lacquer - Cellulose nitrate type	None	Impregnated felted asbestos	Layers of cellulose acetate tape
	D	None	None	Glass wrap	None	Extruded neoprene
	E	Cotton - Ethylenic polymer	Lacquer - Cellulose acetate base	Paper	None	Extruded vinyl chloride
Size AL-1/0	F	Cotton - Cellulose acetate	Lacquer - Cellulose acetate	None	None	Tape vinyl chloride
Size AL-6	F	Cotton - Cellulose acetate	Lacquer - Cellulose acetate	None	None	Extruded vinyl chloride
	G	Cotton - Nitrocellulose	Lacquer - Nitrocellulose	Paper - No. 8 thru 1/0	None	Extruded polyvinyl chloride
	H	Cotton - Nitrocellulose	Lacquer - Nitrocellulose	Paper - No. 8 thru 1/0	Impregnated asbestos	Extruded polyvinyl chloride
	I	Glass - Silicone	Silicone	None	Cellulose acetate tapes sandwiched between two layers of impregnated asbestos	

* If known.

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