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ANALYSIS OF ENVIRONMENTAL TEST METHODS FOR AIRCRAFT ELECTRICAL EQUIPMENT

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ABSTRACT

This investigation was authorized by reference (a) for the purpose of developing a standard set of test methods and requirements applicable to aircraft electrical equipment, for inclusion in present specifications. In order that the tests be based on conditions experienced in actual service and be fairly representative of other test agencies' opinions, a bibliography was prepared, test agencies were visited and other sources of information were contacted, either in person or by mail. Results of the investigation indicate that practically all environmental tests for aircraft electrical components in use by the Navy today are empirically founded, and are not adequately correlated with service life. Many of the test requirements and methods recommended in this report are also arbitrary for the same reasons, as it would require many months of laboratory and field work to secure the necessary correlation factors for the various tests. It is, therefore, recommended that the Bureau of Aeronautics secure the cooperation of the Army Air Force and other interested agencies in arranging a series of conferences at which agreements will be reached and plans will be formulated to study test conditions on which information is lacking. Only after correlation factors have been accurately determined for all environmental tests will it be possible to ascertain the service life of aircraft electrical equipment.

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ABSTRACT

AUTHORIZATION

1. This investigation was originated by the Bureau of Aeronautics and was authorized by reference (a).

DEFINITIONS

2. In order to clarify the information presented in this report, the following definitions are given:

(A) Correlation Factor - The ratio of time in actual service of the electrical component to time under a standard controlled test in the Laboratory that would give the same condition, or amount of corrosion or wear.

(B) Amplitude - As used in vibration discussion, this word represents the distance from the mean position to its extreme position.

(C) Total Excursion - As used in vibration discussions, this expression represents the distance from one extreme, or end of travel, to the other extreme.

INTRODUCTION

3. Present specifications for aircraft electrical equipment fail to agree on test methods on the requirements of many of the listed tests, even though the purpose of the test is to determine identical performance characteristics, and even though the electrical components may have similar usage in the airplane and will be subjected to equal service conditions.

4. Accordingly, the Bureau of Aeronautics, by reference (a), authorized this Laboratory to investigate the various tests and requirements of current aircraft electrical specifications for circuit breakers, switches, relays, cutouts, meters and connectors. Based on the information obtained during this investigation, a set of standardized tests and testing procedures for the various tests was to be established and submitted for inclusion in revised AN and Navy Aeronautical specifications.

5. Prior to the late war, little information was available on environmental testing. Some investigations were being conducted on temperature extremes, vibration, humidity and salt fog tests, but no extensive research had been done on these problems. Specifications were revised or drawn up with the test provisions and procedures based on arbitrary values and methods, as there seemed no time during the war years to find the necessary correlation factors for these tests.

6. Laboratory tests, especially those simulating environmental conditions, have disadvantages that should be taken into account when analyzing the final test results. The complex interrelationship of the various conditions that occur simultaneously in nature are not accurately duplicated and sometimes the results are in error. It is known that it is quite possible in testing two items to get contradictory results in the laboratory and in the field. Acceleration of an environmental test leads to results that are often difficult to correlate with service conditions. Finally, the handling which electric equipment normally receives in service, and which often contributes to breakdown, is absent.

7. During this investigation, the question came up of operating the equipment during the various tests. This is important as operation of the equipment may materially effect the test condition; for example, if a component gave off heat during a low temperature test, the ambient temperature of the test chambers, and consequently the sample, may be drastically altered. However, so many variables exist in the performance of components during environmental tests that it was considered best to have the detail specification for the particular component state whether or not this should be done. It should be noted here that the item detail specification should specify operation of the test sample if such operation would increase the severity of the test.

8. While practically all the tests discussed in this report are fairly well known, it may be of interest to review their history and background.

(A) Salt Fog Tests - Commonly known as salt spray tests, the salt fog test is one of the Navy's oldest and most widely known environmental tests and is now also regarded as a necessary test for aircraft components. Salt atmosphere is encountered many miles inland and to a considerable height above sea level. Metallic materials not only show evidence of corrosion when directly exposed to marine atmosphere, but often when packaged, due to penetration of the packaging materials by moist salt air. Factors that influence the rate at which corrosion occurs are as follows:

(1) Temperature - The corrosion rate varies directly with the temperature for individual materials up to a point where the corrosion rate levels off despite further temperature increases.

(2) Relative humidity and impurities in the atmosphere - The percentage of relative humidity and impurities will directly influence the rate of corrosion for various metals.

(3) Oxidizing agents, such as air and water, plus the presence of free oxygen, tend to accelerate electrolytic effects and also induce oxidation actions.

(4) The higher the acid content of the solution, the greater will be the corrosion rate of the metals.

(5) Protective films - Many metals, when exposed to the atmosphere, tend to form protective films on their surface. These films may have either a retarding or an accelerating action. If the formed film covers the surface completely, it will tend to retard the corrosion rate. However, if it is formed unevenly and various surface areas of the basic material are exposed, corrosion will be accelerated at those exposed areas.

(6) Electrical Current Flow - Investigations show that should a D.C. current, powered from an outside source, be allowed to flow through dissimilar metals while they are exposed to a salt atmosphere or salt solution, the electrolytic corrosion is increased in proportion to the applied voltage.

(7) Nature and quanities of impurities occluded by metal surfaces which increase the rate of corrosion.

(B) Humidity Testing - Of all the tests studied during this investigation, the one that deals with the simulation and evaluation of humidity on aircraft electrical equipment is the one that caused the most discussion and conflict of ideas. Humidity was considered one of the most severe environmental conditions encountered by electronic equipment during the early stages of World War II, when the only known solution to this problem was to keep the equipment in operation 24 hours a day so that it would not cool to the ambient temperature, with its attendant condensation of moisture. The action of humidity and salt fog on dissimilar metals in intimate contact is analogous, and in some cases, the end result is the same. However, in some materials the damage done to materials is due to the absorption of moisture under conditions of extreme heat and not as the result of galvanic action. While the action of salt fog is more severe than is humidity in the case of metals, it is not necessarily true in the case of plastics, wood or fabrics. A study of the relative effect of a straight humidity test, where the temperature is held constant, compared with a cycling humidity test, where the temperature is raised and lowered according to a prearranged plan, indicates that the latter is preferable, as it more nearly follows nature, is more severe in its action, and permits greater moisture penetration of the test sample. Due to the lack of a correlation factor, there are a number of different humidity tests in practice at the present time, each test differing in its cycling periods or temperatures, and practically all of the tests possessing arbitrary values.

(C) Fungus Testing - The basic living requirements of fungus are moisture, warmth, food, air, and for most types, shelter from direct sunlight. Fungi do not differ much from other plant or animal life, for some grow in cool habitats while others thrive in very warm climates, some require very little oxygen, and some vary in their needs for humidity and food. But, in general, the types that cause man his greatest trouble are those found in tropical or semi-tropical areas, with high humidities, a good supply of cellulosic materials for food and plenty of oxygen. Lowering the temperature will not kill the plant but will retard its growth, or will keep it dormant so that it will again resume its cycle when exposed to a warm temperature. However, if the fungus is removed from relative humidities above 70 per cent, the life of the spore may return to the reproductive cell, provided the plant has had time to form them, where it may remain dormant, or it may die if the period of exposure to the lower humidity is prolonged. The spores of fungi are so small that an insect walking across equipment may leave in its path enough spores to damage the equipment severely. These spores are harmless until they meet the right conditions, when they germinate. The plant that is formed from the spore must depend on outside food, such as cellulosic material or some proteinetic foods, for its existence. But a layer of organic dust on the surface of glass, metal, or ceramic material is enough nutrient for hundreds of fungus spores to utilize. Thus optical instruments, metal surfaces, insulators, cork, paper, cotton, leather and plastics are not safe from damage due to fungus. The fungus plant breaks down the more complex compounds to somewhat simpler compounds so that it may utilize the carbon that it needs for energy. It is aided in this effort by enzymes that act as a catalyst. The product of the spore's metabolism is an acid that joins with the surrounding moisture and causes leather to become stiff and coated with a heavy growth of fungus, metal to corrode, and glass to become etched. The plants themselves may cause a current leakage across terminals and insulators.

(D) Vibration Tests - A knowledge of the vibration frequencies and magnitudes encountered in aircraft is a prerequisite for engineers engaged in the design of aircraft electrical components, for vibration may interfere with the satisfactory operation of the electrical system by causing chattering contacts of relays and regulators, or by causing mechanical failures of electrical equipment. The vibration response characteristics of an electrical component installed in a plane depends on its mass distribution, flexibility, and damping properties. In general, an accessory with a simple mounting has vibration response characteristics similar to those of a simple system consisting of a mass suspended on a string and provided with a viscous damper. More complex mechanical systems have more than one resonant frequency, and the damping determines the magnification of vibration at any of the resonant frequencies. However it should be noted that damping is effective in reducing the transmission of vibration only at frequencies where the vibration is magnified. At the present time, the most common type of apparatus used for vibration testing of electrical components is the reciprocating shake table driven by an eccentric. Most of the larger vibration tables of this type provide a relatively large excursion, but are limited to a maximum frequency of approximately 60 cycles per second, due to wave form irregularities introduced by backlash in linkages. Higher frequencies may be obtained by testing the sample on electrodynamic motors that operate on the same principle as a radio loud speaker. However, this type vibration unit is limited to light weight samples and small total excursion.

(E) Altitude - Any electrical device installed on an airplane is expected to function satisfactorily at the operating altitude of the plane, which may be up to 50,000 feet or higher. Despite the fact that it is very cold at high altitudes, some difficulty has been experienced in cooling electric equipment, due to the fact that the air density decreases faster than the temperature. At 18,000 feet the air is one-half sea level density; at 36,000 feet the air is one-quarter sea level density. With increase in altitude, the low temperature combined with low density removes much of the moisture from the atmosphere, and the voltage to cause corona is a small fraction of its sea level value, thus increasing the likelihood of insulation breakdown. Due to these factors, it has been estimated that the problem of insulating electric circuits for use at these high altitudes is much more severe than it is at sea level. Commutator arcing that is hardly noticeable at sea level is extremely severe at high altitudes.

(F) Temperature Extremes -

(1) Temperature conditions encountered by aircraft electrical components are far more severe than those encountered by electrical equipment in ordinary applications. The temperature of the atmosphere decreases with increase in altitude up to approximately 60,000 feet, above which the temperature remains constant or tends to increase slightly. While temperatures normally run about -65°F at

60,000 feet, temperatures of -125°F have been encountered at this altitude over the tropics, and temperatures of -90°F have been measured at the earth's surface. This would not be too serious if all the electrical equipment were operating and warm; however, spare equipment is often turned on at these altitudes and must be capable of instant operation despite the low temperature. This also holds true for equipment used during landings, when the plane makes a rapid descent from a high altitude and the landing equipment has had no opportunity to warm up. Due to the above conditions, provisions should be made to expose the components to a temperature of -85°F for a period of time to be designated in the detail specification. This test is based on the assumption that operation will not be feasible at this temperature, but that the equipment must be able to withstand this condition in storage. In conducting a low temperature test, consideration should be given the proper location of measuring elements, as heating effects of the equipment on test often distorts the ambient temperature of the chamber. There is also the danger of temperature error due to moisture accumulation on the measuring elements due either to opening the door of the test chamber, or to the uncontrolled flow of air. The effect of air flow over the test sample has not been fully determined and it is therefore recommended that air velocities within the chamber be held to a minimum except in those cases where a definite measured velocity is required to simulate service conditions.

(2) The electrical components must also be capable of operation in ambient temperatures up to 160°F. When the test sample is operated this temperature is considerably higher. It is common practice to operate the engine compartment at 140°F at all altitudes. This high operating temperature, combined with the low density of the atmosphere at high altitudes, complicates the cooling problem, and is a prime reason for designing equipment that will withstand high temperatures.

(G) Sand and Dust Test - Dust may be encountered as a cloud created a few feet above ground level by moving vehicles, or as a dust storm created by strong winds which drive the particles to considerable heights and in all directions. The dust particles may be abrasive and/or hygroscopic. Most damage to electrical equipment is due to the sand or dust clogging relays, contactors and bearings. Specific information on all the types of sand and dust that may be encountered by aircraft has not been assembled. All known sand and dust tests, therefore, contain arbitrary methods and limits due to this lack of knowledge.

DISCUSSION OF TEST RECOMMENDATIONS

9. The following recommended tests are not to be construed as being the final word on this subject, but rather should be considered interim tests that may be used until more detailed information is secured by long range investigations that will supply a definite correlation factor between laboratory tests and actual performance in service. The recommendations of this report represent an attempt to standardize the tests, make them more practical so that they could be duplicated by all test laboratories, and to bring them up to date. It will be found that in some cases no standard test was recommended. In all such cases, sufficient information was not available to recommend a satisfactory test that would have been an improvement over existing test provisions. The recommended tests are as follows:

(A) Salt Fog Test - The test sample shall be subjected to 200 hours of salt fog if intended for the exterior of the plane, and 100 hours if intended for the interior of the plane. The preparation and operation of the test shall be in accordance with Federal Specification QQ-M-151a. The manner in which the sample shall be mounted and operation of the sample, when considered necessary, shall be specified in the detail specification. The time periods stated above were recommended by the Chemistry Division of the Naval Research Laboratory and are considered generally applicable. If it is believed that these time periods might be too long for certain electrical items, it is recommended that the Bureau of Aeronautics adjust the time periods, to a lesser value, for all electrical items. Federal Specification QQ-M-151a is recommended because it gives a more detailed account of the preparation of the salt solution than does the more familiar AN-QQ-S-91 Specification.

(B) Humidity Test -

(1) The apparatus shall consist of a test chamber capable of maintaining an internal temperature of 71 plus or minus 2°C (160 plus or minus 3°F) and an internal relative humidity of 95 plus or minus 5 per cent. The test chamber shall be capable of being sealed so as to retain the total moisture content in the test space. The heat loss from the chamber shall be sufficient to reduce the internal temperature from the above specified operating temperature to not more than 38°C (100°F) within a period of 18 hours from the time of removal of

the source of heat. The test procedure consists of placing the test sample in the test chamber where the temperature and relative humidity have been raised to the specified values. At the end of a 6 hour period the heat shall be shut off and the chamber sealed. At the end of an additional 18 hour period the chamber shall be unsealed and the heat again applied. This cycle shall be repeated a sufficient number of times to extend the total time of the test to 120 hours. At the end of the 120 hour period the equipment shall be examined, tested or operated in accordance with the requirements of the detail specification.

(2) This test has been adapted from Army Air Forces Specification No. 41065 of 7 December 1945, because it is simple in operation and can be run in all humidity chambers, thus permitting the manufacturer to perform his own tests instead of relying on Government test laboratories.

(C) Fungus Testing - Very few aircraft electrical component specifications contain fungus test requirements, although there is a definite need for such a test, as proven during the past war. The proposed fungus test was set up to fill this need and is based on accepted laboratory practices. The test consists of exposing the test sample to one of the test procedures shown in enclosure (A), which were recommended by the Chemistry Division of the Naval Research Laboratory. The Appendix lists four alternative procedures, each of which is applicable to certain sizes and types of equipment. The detail specification of the article undergoing tests shall designate which of the four given fungus tests is to be used.

(D) Vibration Tests - Present vibration test provisions are inadequate in that their frequency range of 10 to 55 cycles per second does not cover the frequencies encountered in modern aircraft, which may be in the hundreds of cycles per second. It is also known that most electrical components, with the major exception of those mounted on the engine, do not have vibration amplitudes as large as those stated in present specifications. However, no satisfactory vibration test provisions could be recommended at this time without extensive actual service field measurements and development of new vibration test equipment. It is therefore recommended that present vibration requirements be retained until satisfactory vibration specifications are issued by the AN Board, except in so far as the Bureau of Aeronautics can establish uniformity in present specification requirements.

(E) Altitude - The test sample shall be placed in an altitude corresponding to 50,000 plus or minus 1,000 feet, and shall be tested as required by the detail specification. Operation under combined conditions of altitude and temperature shall depend entirely on actual operating requirements of the equipment and shall be stated explicitly in the detail specification for the equipment. With the ceilings of aircraft being increased constantly, it has been difficult to establish any other than an arbitrary figure for high altitude tests. The specified altitude, 50,000 feet, is purely an arbitrary figure and it should be revised as the performance of aircraft at altitude is improved.

(F) High Temperatures - Exposure of the test sample to a temperature of 71 degrees plus or minus 2°C (160° plus or minus 3°F), with a relative humidity of 30 per cent or less. The time period shall be given by the detail specification for the particular item under test. Operation of the sample during the test shall be designated by the detail specification when considered necessary. The 71°C temperature is generally accepted as representative of the operating temperatures encountered in the engine compartments of aircraft during flight.

(G) Low Temperature - Expose the test sample to a temperature of minus 65 degrees plus or minus 2°C (minus 85° plus or minus 3°F) for a time period, then raise the temperature to minus 54 degrees plus or minus 2°C (minus 65° plus or minus 3°F) for an additional time period, both time periods to be designated by the detail specification. The detail specification shall designate operation of the sample during the latter temperature when considered necessary. Exposure to minus 65°C, without operation, is to simulate storage conditions and will determine any deteriorating effects this low temperature might have on the components.

(H) Sand and Dust - It is recommended that present requirements for this test be retained until issuance of satisfactory specification requirements by the AN Board. Much information must be secured on this environmental condition before a satisfactory laboratory test can be set up. Information must be obtained on the proper type sand to be used (desert, volcanic, seashore, etc.), the shape and size of the sand particles, the density of the sand and dust cloud and a satisfactory method of controlling it, air velocities, relative humidity and method of controlling it within the chamber, and a correlation factor for an accelerated test.

(I) Dielectric Test - Test components having a rated operating voltage of 30 volts or less shall be subjected to an R.M.S. voltage of 500 volts, 60 cycles for one minute. Components with an operating voltage higher than 30 volts and less than 130 volts shall be subjected to an R.M.S. voltage of 1000 volts, plus twice their rated voltage, for one minute. Substitution of a test, consisting of 120 per cent of the proper hy-pot voltage for one second, is permissible.

CONCLUSIONS

10. It is apparent from the results of this investigation that there is a definite need of a thorough revision of the various environmental tests included in the specifications for aircraft electrical components. The results of this project disclosed a general lack of definite information on most of the environmental test conditions and test limits, indicating the need of a long range investigation designed to gather the needed information.

RECOMMENDATIONS

11. It is accordingly recommended that the Bureau of Aeronautics secure the cooperation of the Army Air Force and other interested agencies in arranging a series of conferences at which agreements will be reached and plans will be formulated to study test conditions on which information is lacking. The Naval Research Laboratory is interested in this problem and will be glad to contribute to these conferences.

REFERENCES

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(g) "Some Navy Electronic Problems," J. B. Dow, AIEE Transactions, March 1945.

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(j) "Preferred Practices for Electric Control Devices for Aircraft," F. W. Hottenrcth, AIEE Transactions, April 1945.

(k) "Potential Breakdown of Small Gaps Under Simulated High-Altitude Conditions," M. J. Delerno, AIEE Transactions, March 1944.

(l) Handbook of Chemistry and Physics, Chemical Rubber Publishing Co.

APPENDIX

A Suggested Procedure for Evaluating the Mold Resistance of Aircraft Electrical Equipment

1. Scope - The purpose of this specification is to provide a laboratory means of estimating the resistance of material to the growth of fungus. It is not intended to differentiate between active toxicity and the simple inertness resulting from the use of materials which are nutritionally non-available.

2. Requirements - None (Requirements pertaining to specific items will be found in the specification appropriate to the item).

3. Organisms - The organisms listed below are recommended for use in the test. Other species may be used in addition to, or in place of the following at the discretion of the procuring agency.

(a) Aspergillus niger
(b) Penicillium luteum
(c) Rhizopus nigercans
(d) Chaetomium globosum

Stock cultures of the organisms may be maintained on slants of Czapek's agar containing dextrose or sucrose as the carbon source. The Chaetomium, however, grows best if cellulose in the form of a strip of sterile filter paper is placed upon the agar. A satisfactory formulation for Czapek's agar is given below:

NaNO	3.0 gms.
K_2HPO_4	1.0 gm.
$MgSo_4 \cdot 7H_2O$	0.5 gm.
KCl	0.5 gm.
$FeSO_4 \cdot 7H_2O$	0.01 gm.
Sucrose (or dextrose)	30.0 gms.
Agar	15.0 gms.
Water sufficient to make 1000 ml.	

4. Procedure - Four alternative procedures are described herein. Each is applicable to certain sizes and types of equipment and material. The method applicable to a specific item or material shall be designated in the appropriate specification.

(a) General

In no case shall the test specimens be sterilized. Washing of the specimens, followed by thorough rinsing in distilled water is permissible if other tests are not compromised thereby. The spore suspension is prepared by washing each of the agar slants with several successive portions of Czapek's mineral solution. The composition is the same as that given above, except the agar and sugar are omitted. The addition of a few drops of a wetting agent (Aerosol or Tergitol) minimizes the tendency of the spores to clump. The washings from the several slants are combined and strained through cheesecloth.

(b) Methods

Method I - (For small items such as short lengths of wire, specimens of plastic, or other items which can be conveniently accommodated in the petri dish and on which no performance measurements are to be made.)

The specimen shall be placed upon a Czapek's mineral agar, that is, an agar of the composition given above except that the sugar is omitted. A small quantity of the inoculum shall then be pipetted or sprayed upon the specimen on the agar plate. The dishes shall then be incubated for 28 days at a temperature of 25 to 30°C. At the conclusion of this time they shall be examined for evidences of fungal growth.

Method II - (Applicable to somewhat larger items which cannot be accommodated in a petri dish.)

The specimen shall be sprayed with the spore suspension, or a sufficient quantity of the liquid shall be pipetted over the surface of the item. After inoculation the specimens shall be placed in any suitable closed vessel which permits the maintenance of a saturated atmosphere. A laboratory desiccator or a Mason jar with water in the bottom are illustrative of acceptable vessels. The specimen shall be maintained therein by any suitable means which allows free access of the humid air to the specimen, without, however, permitting immersion in the water. It may be suspended for example, or it may rest on an inert support such as a glass rod to preclude the inundation of the specimen by the humidifying liquid. After incubation for 28 days at 25 to 30°C, the specimen shall be examined for evidence of fungal growth.

Method III - (For materials conforming to the general categories described in A and B above, except that performance measurements are to be made.)

The specimens shall be inoculated by the actual transfer of ripe conidial heads from the agar slant. This shall be effected by lightly drawing a sterile inoculating loop across the surface of the culture and touching the spore laden loop at several points on the specimen. This operation shall be repeated for each of the organisms. The specimen shall then be incubated as described under II above.

Method IV - (Applicable to large items such as complete electrical units.)

The items shall be inoculated in a manner similar to that described in Method III above, and incubation shall be performed in any room, chamber, or other device which permits the maintenance of a humidity of 90 to 100 per cent and a temperature of 25 to 30°C. After 28 days of such incubation, the item shall be examined closely for evidences of fungus growth and any other pertinent measurements shall be made.

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