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*IEEE Recommended Practice for*  
**AIRCRAFT, MISSILE, and**  
**SPACE EQUIPMENT**  
**ELECTRICAL INSULATION TESTS**



PUBLISHED BY  
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**CONTENTS**

1. Foreword.....	3
2. Purpose.....	3
3. Scope.....	3
4. Definitions.....	4
5. Testing Order.....	4
6. Application of High-Potential and Insulation-Resistance Tests.....	4
7. Insulation Resistance.....	4
8. High-Potential Insulation Tests.....	5
9. References.....	7



**AIRCRAFT, MISSILE, AND SPACE EQUIPMENT ELECTRICAL INSULATION TESTS**

**1. FOREWORD**

The extremes of flight environment and rigorous reliability requirements make special consideration of insulation testing procedure desirable. Operating temperatures, in some classes of equipment now above 260°C (500°F), are moving upward. Ambient low temperatures below -65°C (-85°F) are currently specified. Vibration conditions producing accelerations in excess of 600 meters per second squared (60g) exist. Environmental conditions that may deteriorate electrical insulation are present through a range and to a degree uncommon in the environment of terrestrial electric equipment. These conditions have created problems that commercial insulation test procedures do not always cover adequately [3].

Flight missions are increasingly dependent on the proper functioning of electric equipment and demand insulation reliability to a degree unique in electrical manufacturing history. The nature of this reliability problem is complicated by the fact that some types including military electric equipment may be stored for long periods prior to use. Since many insulation materials deteriorate to some degree during prolonged storage, it is desirable to retest insulation after such storage and/or use in order to determine positively the flight worthiness of flight electric equipment insulation.

In general, the fact that an electrical insulation at some stage of its manufacture has passed all the required insulation tests is not positive surety that the insulation will not have deteriorated, even in storage, to the point where the equipment is no longer flightworthy. Some of the factors causing electrical insulation deterioration are the following [5].

**1.1 Time-Electrochemical Reactions.** These reactions are with air, moisture, etc.

**1.2 Evaporation of Plasticizers.** The evaporation of plasticizers from plastic insulation materials causes embrittlement leading to subsequent vibration failure of the insulation.

**1.3 Moisture.** Moisture is more likely to damage non-operative equipment since the heat of operation tends to dry out operative electric equipment.

**1.4 Electrolytic Deterioration.** Electrolytic corrosive action to which metals are subject tends also to promote the deterioration of electrical insulation in the vicinity where the corrosive actions occur, due to the metallic salts generated. Many insulating materials themselves, when subjected to potential differences in the presence of high humidity, rapidly deteriorate.

**1.5 Heat.** High temperature deteriorates electrical insulation, and heat greatly accelerates the changes mentioned under several other headings in this list.

**1.6 Thermoplasticity and "Cold-Flow" Effects.** These effects due to temperature and pressure often cause thinning or flowing of insulation to the extent of producing ultimate failure of an originally acceptable insulation thickness. Thermoplastic and "cold-flow" effects are a function of time, vibration, and temperature and may occur very slowly in operation.

**1.7 Inductive Circuit Interruption Voltage Transients.** These may reach peak values of more than 1000 volts [1], [3]. These voltage surges, when present, are likely to puncture insulation if winding pressures, thermoplasticity, or cold-flow effects have reduced insulation thickness below critical values. For many commonly used insulation materials and circuits, insulation thickness of less than 0.002 inch (0.05 mm) may be critical. Failure in 28-volt circuits may not be immediate after such punctures, but ordinarily occurs as the result of repeated interruption transient discharge through the initial puncture causing "tracking" of the insulation around the edges of the hole [3]. Proper high-potential test procedure will often discover these usage-developed faults before failure.

**1.8 "Tracking".** "Tracking," or the buildup of a conductive path across surface gaps due to "carbonization" of an insulator by repeated circuit interruption inductive surge discharges, is a major cause of insulation failures [2].

**1.9 Corona Discharges.** These rapidly deteriorate some types of commonly used electrical insulation [4]. At high altitude, corona discharges occur at much lower voltages than at sea level, making this consideration an important factor in flight equipment insulation deterioration.

**1.10 Surface Contamination**

**2. PURPOSE**

It is the purpose of this Recommended Practice to define acceptable methods of testing electrical insulation in flight electric equipment.

**3. SCOPE**

This Recommended Practice will be limited to the consideration of test procedures applicable to insulation in flight and support equipment or to manufactured components or subassemblies of such equipment. Test procedures will also be recommended for inspection of equipment electrical insulation to determine its flight

worthiness after service, repair, and/or periods of storage. *This Recommended Practice is intended only as a guide to acceptable procedure. It is not intended to be used as a test specification for specific equipment.* The values of test voltages and other test conditions for specific equipment are always determined by the procurement specification for that particular equipment. In this connection attention is directed to Section 6.

#### 4. DEFINITIONS

**4.1 Insulation Breakdown** is a rupture of insulation that results in a substantial transient or steady increase in leakage current at the specified test voltage.

**4.2 Insulation Resistance** is the electrical resistance measured at specified direct-current potentials between any electrically insulated parts, such as a winding and other parts of the machine.

**4.3 Leakage Current** is the current that flows through or across the surface of insulation and defines the insulation resistance at the specified direct-current potential.

**4.4 Maximum Operating Temperature** is the stabilized temperature obtained from operation of the equipment at rated load and duty cycle in the maximum ambient temperature specified for the device under test.

**4.5 Room Ambient Temperature** is considered to be  $20^{\circ}\text{C} \pm 5^{\circ}$  ( $68^{\circ}\text{F} \pm 9^{\circ}$ ).

**4.6 Room Operating Temperature** is the temperature of the equipment expected at rated load and duty cycle in an ambient temperature of  $20^{\circ}\text{C} \pm 5^{\circ}$  ( $68^{\circ}\text{F} \pm 9^{\circ}$ ). An equipment item that has been operated through its normal duty cycle or has stabilized to the approximate normal running temperature may be assumed to be at room ambient operating temperature.

**4.7 Test Voltage** is the voltage applied across the specimen during a test.

**4.8 Test Current in Alternating-Current Circuits** is the normal current flowing in the test circuit as the result of insulation leakage and, in alternating-current circuits, is the vector sum of the inphase leakage currents and quadrature capacitive currents.

**4.9 Insulation Breakdown Current** is the current delivered from the test apparatus when a dielectric breakdown occurs.

**4.10 High-Potential Test** of electric equipment insulation is sometimes referred to as 1) "hypot test," 2) "over-voltage test," and 3) "withstanding voltage test." "High-potential test" is the preferred form. (The use of the wordings "breakdown voltage test" or "dielectric strength test" when describing a "high-potential test" of equipment insulation is incorrect. A "breakdown voltage test" or "dielectric strength test" is not applicable to electric equipment. These tests are only used in testing insulation materials and will not be considered in this Recommended Practice.)

#### 5. TESTING ORDER

Insulation-resistance tests should be made prior to high-potential tests. This is recommended to avoid unnecessary failures by locating defective, damp, or dirty insulation prior to subjecting it to high-potential tests in order that these conditions may be corrected before insulation damage occurs. A high value of insulation resistance is not, by itself, proof that the insulation of the machine does not have cracks or other faults which subsequently may be the source of insulation breakdown. Therefore, insulation-resistance tests may not be regarded as a substitute for high-potential tests, and a suitable high-potential test should be made following an acceptable insulation-resistance test.

Insulation-resistance tests should also be made after high-potential tests. Because insulation-damaging high-potential breakdowns may be difficult to detect, an insulation-resistance test after all high-potential tests is desirable. If the post-high-potential test insulation resistance is lower than the pre-high-potential test insulation resistance, a failure during the high-potential test is indicated. Obviously both insulation-resistance tests must be made at the same temperature or this comparison is not applicable.

#### 6. APPLICATION OF HIGH-POTENTIAL AND INSULATION-RESISTANCE TESTS

It is important to note that insulation test procedures may not be applicable to all types of equipment. In particular, high-potential tests are not applicable to many instruments, electronic devices, and other low-voltage equipment. However, we should distinguish between applicability and desirability of high-potential insulation tests. Since such tests are made to detect insulation flaws and incipient failures due to insulation aging, these tests are as desirable for instruments and electronic devices as for other flight equipment. However, because insulation tests may not be applicable to some flight equipment, such tests should not be made until it is determined that the insulation was specified or designed for the test voltages to be used.

#### 7. INSULATION RESISTANCE

**7.1 Insulation-Resistance Tests.** These are recommended to accomplish the following.

**7.1.1**—To detect hidden moisture, dirt, or other contamination of the electrical insulation that should be eliminated prior to making high-potential tests.

**7.1.2**—To detect excessive leakage currents that may damage the insulation by heating or electrolytic action.

**7.1.3**—To determine specific drying or moistureproofing procedure for electrical insulation. In the case where excessive leakage current is diagnosed as being due to moisture, insulation-resistance tests after drying should be applied to check the correctness of this diagnosis and the effectiveness of the drying procedure.

**7.1.4**—To make certain that no unobserved insulation breakdown or insulation damage occurred during a high-potential insulation test, an insulation-resistance retest after a high-potential test is desirable.

**7.2 Insulation-Resistance Test Voltage.** Some equipment insulation materials have a resistance-voltage characteristic such that low-voltage tests give an unrealistic value higher than actual circuit conditions produce. Realistic insulation-resistance values will result from the following.

**7.2.1**—Tests made at 500 volts direct current or at a direct-current potential two times the line (root-mean-square) voltage, whichever is the greater.

**7.2.2**—Tests made at the maximum operating temperature.

**7.3 Insulation-Resistance Test Current.** This should be limited to not more than 5 milliamperes when the test equipment output is shorted as in an insulation breakdown. (Most insulation-resistance instruments limit output direct current to 4 milliamperes or less.) This limitation is suggested primarily to avoid excessive heating of insulation when the insulation resistance is low.

**7.4 Insulation-Resistance Test Time.** The test voltage should be applied until the resistance value is stabilized before a reading is taken in order to eliminate the time-electrification effects in insulation. These effects are a function of the insulation material and the total capacitance of the insulation system under test. With a given insulation material, insulation systems with a larger capacitance will require a longer stabilization period. The required time of test for automatic insulation-resistance tests, used in production, should be determined by measurement of typical units.

In general, small equipment and cable systems constructed with commonly used aerospace insulation materials will produce a stable insulation-resistance measurement in five seconds or less. Insulation systems with a total capacitance of less than 500 picofarads may be considered as small. Large equipment or cable systems with a larger total capacitance can be expected to require longer periods to stabilize the insulation-resistance value.

**7.5 Insulation-Resistance Value.** The insulation resistance of equipment should not be less than one megohm measured at the maximum operating temperature of the equipment. Below one megohm insulation resistance is generally unstable, and electrolytic deterioration and heating damage to the insulation may result from current flow through the insulation.

Insulation-resistance values are dependent on temperature. The insulation-resistance temperature characteristic of complex insulation systems, common to aerospace equipment, will be consistent for a given insulation system but may be very different for different insulation systems. Therefore, reduced-temperature tests may be used if an equivalent increase in the one-megohm minimum insula-

tion resistance for the specific insulation system to be tested is determined and used. This may be useful for room-ambient-temperature inspection tests.

Typical equipment may have insulation resistances ranging from one megohm to several hundred megohms. A high insulation resistance does not necessarily indicate superior quality or better reliability. Insulation materials with high temperature and mechanical properties, required in some equipment, may have a relatively low insulation resistance. In general, the insulation resistance of a specific item of equipment is a characteristic determined by the construction and materials used.

High values of insulation resistance cannot be maintained in equipment with surface leakage paths such as connectors or terminals exposed to atmospheric or handling contamination. A single fingerprint can reduce an insulation resistance of 100 megohms to a few megohms. Humidity and dust are problems that must be considered.

## 8. HIGH-POTENTIAL INSULATION TESTS

High-potential insulation tests are intended to detect insulation flaws, discontinuities, aging cracks, and deteriorated or inferior insulation. A hole or crack in insulation, through which inductive surge voltage will discharge and ultimately "carbonize" a conductive path, may be detected by a high-potential test of sufficient voltage. (Test voltage substantially under 1000 volts root mean square will not achieve this purpose with customary insulations [2].) The high-potential test voltage is applied between mutually insulated elements of electric equipment and between insulated elements and the frame or "ground."

**8.1 High-Potential Test Conditions.** The specified high-potential voltage test should be applied only to machines and equipment that have been previously inspected to determine that the machine is clean and dry and that the insulation is in a condition fit for a high-potential test. This will usually mean that the insulation resistance has previously been determined to ensure that leakage currents will be limited to a safe value.

**8.1.1 Temperature**—The test may be made at *room operating temperature* for equipment designed to operate in an ambient temperature maximum of 71°C (160°F). This test should be made at *maximum operating temperature* for equipment designed to operate in ambient temperatures above 71°C (160°F).

**8.2 High-Potential Test Voltage.** In specifying the value of a high-potential test voltage the following factors must be considered and accounted for if high-potential tests are to be useful.

**8.2.1 Voltage High Enough to Detect Flaws**—The high-potential test voltage must be high enough to detect flaws, holes, and cracks in the insulation to be tested. It is noteworthy that more than 1000 volts are required to detect surely a small hole in insulation of 0.003-inch (0.08-mm) thickness [2].

**8.2.2 Voltage Lower than 1000 Volts Serves No Purpose**—A high-potential test lower than 1000 volts will not reliably detect small flaws in insulation of even 0.002-inch (0.05-mm) thickness [2]. Therefore, where effective high-potential test voltages cannot be used, it is recommended that high-potential tests be omitted. (While an insulation-resistance test per paragraph 7.2 cannot be relied upon to detect incipient causes of failures, it is the least dielectric test requirement that any equipment should meet.)

**8.2.3 Retest Voltage**—For high-potential retests after overhaul, use, or extended storage the high-potential test voltage should be substantially reduced. Seventy-five percent of the original test voltage is a suitable voltage for high-potential retests. (Refer to paragraph 8.2.)

**8.2.4 Initial Test Voltage**—The high-potential test voltage called for in new equipment specifications must be high enough to allow for a substantial reduction in value for retest and to allow for instrument and test equipment tolerances. The retest voltage is used to determine flight worthiness of equipment after overhaul or long storage and therefore should be adequate to detect common insulation faults in the thicknesses of insulation used [2]. For example, a new-equipment high-potential test voltage of two times the root-mean-square line voltage plus 1000 volts, but not lower than 1500 volts, root-mean-square 60 hertz, will generally meet these requirements.

Repeated application of high-potential test voltages can reduce the dielectric strength of insulation. Whether any significant reduction in dielectric strength occurs depends on the number of tests, the insulation material, and the insulation thickness. Test data discussed in [10] indicate that 0.0005-inch (0.01-mm) thick Mylar tested at 250°F withstood a minimum of 54 standard tests at the suggested initial test voltage of 1500 volts, root-mean-square 60 hertz for a duration of one minute. Similarly, 0.0005-inch (0.01-mm) thick mica withstood 1200 such tests and 0.002-inch (0.05-mm) thick “skived” Teflon withstood 125 such tests. Reference [10] submits evidence that initial high-potential tests at 1500 volts, root-mean-square 60 hertz for one minute could reasonably be limited to ten in number. If repeated tests at the initial high potential are considered likely to be a serious problem with a specific equipment item, then the purchase specification for that item is the correct place to specify the maximum number of such tests to be permitted.

**8.2.5 Lowest High-Potential Test Voltage Defines System Responsibility**—It is not practical to design equipment insulation systems that will withstand all possible circuit interruption transients. In choosing an equipment high-potential test voltage, a boundary is defined between the insulation responsibilities of the equipment manufacturer and the transient-limiting responsibilities of the system designer. The effort to reduce size and improve the efficiency of flight equipment, the extensive use of fast-acting snap switches, and the more efficient use of magnetic materials in inductive equipment all have combined to produce a trend toward higher

circuit interruption transients. The problem of circuit transients that exceed or closely approach minimum high-potential test voltages is a system design and operation problem. In making a judicious choice of a high-potential test voltage it is useful to think of the lowest test voltage (see paragraph 8.2.3) as the division point between the responsibility of the component manufacturer to build insulation that will withstand this specified voltage of possible circuit transients and the responsibility of the system designer to be sure this specified voltage is not exceeded under any conditions of operation. Two times the line voltage plus 1000 volts, or 1500 volts, root-mean-square 60 hertz, whichever is the higher, appears to be a judicious value of flight equipment high-potential test voltage compatible with the state of equipment manufacturing insulation art. Economical circuit interruption transient voltage operating limits should then be safely below (75 percent of this value) 1250 volts as recommended in paragraph 8.2.3 for retest.

**8.3 Alternating-Current Versus Direct-Current High-Potential Test Voltage.** Direct-current high-potential testing has an advantage when applied to large electric machinery. The larger values of alternating current, due to the internal capacitance of the windings to the frame, make an alternating-current test difficult. However, the application of direct current to such testing has been limited because no agreement has been reached as to the value of a direct voltage that will produce insulation stresses equivalent to standard alternating-current high-potential tests and/or to the stresses produced in the insulation in service, such as the circuit interruption transient voltage condition. Literature on the subject suggests that direct voltages as high as 2.3 times the specified high-potential 60 hertz alternating test voltage may be equivalent, but in general any agreement on this subject is lacking. It is to be noted that the tendency for some insulations to show significant increased leakage current as the breakdown point is approached is not exclusively a direct-current test-circuit phenomenon although it is easier to measure small changes of leakage current in a direct-current circuit. It may be further noted that many of the better flight equipment insulations now in use do not show any significant increase in leakage current prior to rupture. While nondestructive high-potential testing is desirable, there is not at present sufficient evidence to warrant describing any present direct-current equipment or methods as nondestructive [9].

**8.4 High-Potential Test Time.** The specified voltage should be applied for 60 seconds or, where desirable and agreed upon, an alternate inspection test may be made using a voltage 20 percent higher than the one-minute test voltage for a period of five seconds.

**8.5 High-Potential Test Current.** This should be limited to a minimum value when the test equipment output is shorted as in an insulation breakdown. This limitation is suggested primarily to minimize insulation and equipment damage when a breakdown occurs. A 25-milliamper

maximum short-circuit current limit is desirable for high-potential test equipment applicable to general flight equipment testing. In the alternating-current testing of large generators or other equipment with high internal capacitance between insulated components, any specific current limitation figure may not be applicable. It would also be desirable for the test equipment to incorporate an automatic feature cutting off the test voltage a few milliseconds after any sudden transient increase in current while preserving the voltage indication at the instant the transient increase in current occurs. Test equipment would thus indicate the insulation breakdown voltage while reducing insulation damage by automatically cutting off the current.

#### 8.6 High-Potential Test-Voltage Rate of Application.

It is desirable to apply the test voltage slowly and controllably to the extent that indication of breakdown will be an immediate signal to the operator for reducing the test voltage. If control of the test voltage is in the primary circuit of a transformer, then a uniform rate of 500 volts per second of increase or decrease of the test potential should not be exceeded. These precautions must be observed in order to avoid damaging transient voltages much higher than indicated values.

**8.7 Humidity.** Dielectric tests should be performed under conditions where the relative humidity does not exceed 85 percent.

**8.8 Altitude.** Altitude does not directly affect the breakdown potential of solid insulation materials. However, high-altitude operation of the equipment does create electrical insulation problems for which no standard test procedure is available. It may be useful to list the altitude effects that bear on dielectric testing of flight equipment.

**8.8.1 Corona Discharges—**These seriously deteriorate many insulations. Corona occurs at much lower voltages when the air density is reduced by altitude or high temperature. Therefore, tests of flight equipment in environmental chambers should be directed toward discovering corona discharges in the equipment [4].

**8.8.2 The Adequacy of Surface-Leakage Distances—**This must be carefully investigated if satisfactory high-altitude operation of flight equipment is to be assured.

**8.8.3 Temperature Change—**A temperature change through an extreme range accompanied by condensation and freezing of condensed moisture normally occurs in

altitude operation and produces critical equipment insulation problems.

It is intended to indicate that the above altitude effects produce insulation problems that are peculiar to the particular equipment under observation and are over and above the effects that standard material-analysis test methods uncover. Thus, corona insulation problems result from conditions arising out of the complete assembly such as the shape and proximity of adjacent conductors mounted on an insulated surface. Again the temperature-moisture-condensation-freezing problem cannot be completely analyzed without simulated altitude testing of the complete assembly. Therefore, the problems involved in testing a specific piece of equipment for high-altitude operation cannot, at present, be broken down into equivalent sea-level laboratory test procedures. The adequacy of all parts of an insulating system that are not solid or liquid dielectrics or hermetically sealed in a stable pressure environment must be checked under simulated altitude conditions in an environmental chamber. Since the high-potential test voltages suggested in this Recommended Practice are intended to detect flaws in solid insulation, they may not be adequate for simulated altitude checking for corona or surface-leakage discharges. The high-potential test voltages used for altitude testing of flight equipment should be more closely related to the actual voltage transient conditions in the circuits in which the equipment is to be used.

## 9. REFERENCES

- [1] Virgel E. Phillips and Walter P. Mitchel, "Peak voltages with D-C arc interruption for aircraft," *AIEE Trans.*, vol. 63, pp. 944-949, December 1944.
- [2] L. B. Kilman and J. P. Dallas, "High-potential testing of aircraft equipment electrical insulation," *Elec. Engrg.*, vol. 75, pp. 540-544, June 1956.
- [3] J. P. Dallas and L. B. Kilman, "Critical failures in aircraft equipment electrical insulation," *Elec. Manufacturing*, March 1956.
- [4] T. W. Dakin, H. M. Philofsky, and W. C. Divens, "Effect of electrical discharges on the breakdown of solid insulation," *Elec. Engrg.*, vol. 73, pp. 812-817, September 1954.
- [5] "Report of advisory staff for aircraft electric systems" sponsored by WADC and BuAer, April 1951, Section 3.13.
- [6] "Test code for D-C aircraft rotating machines," AIEE No. 800, January 1953.
- [7] G. L. Moses, *Electrical Insulation*. New York: McGraw-Hill, 1951.
- [8] "American Standard for Measurement of Voltage in Dielectric Tests," ASA C68.1, 1953.
- [9] L. B. Kilman and J. P. Dallas, "A discussion of D-C high potential test voltage for aircraft electrical insulation," *AIEE Trans. (Applications and Industry)*, vol. 77, pp. 355-359, November 1958.
- [10] L. B. Kilman and J. P. Dallas, "High potential tests for aircraft and missile electrical insulation," *Elec. Manufacturing*, December 1959. *Note:* This publication discusses the effect of repeated high-potential tests on equipment insulation not covered in reference [2].