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THE EVOLUTION OF USAF ENVIRONMENTAL TESTING

V. J. JUNKER

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FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
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FOREWORD

This report was prepared in the Vehicle Dynamics Division, Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Project 1370, "Dynamic Problems in Flight Vehicles," Task 137010, "Environmental Criteria Evaluation and Application." Mr. Virgil J. Junker was the project engineer.

Appreciation is expressed to the following individuals for their assistance in researching the history of various natural and induced environments; Mr. E. C. Theiss, low temperature; Mr. M. P. Ornstein, sunshine, rain, and salt fog; Mr. W. L. Haskin, explosive atmosphere; Mr. D. L. Earls, vibration; Mr. E. H. Schell, shock; Mr. R. W. Sevy, acoustical noise; and Mr. E. A. Tolle, acceleration.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published only for the exchange and stimulation of ideas.

HOWARD A. MAGRATH
Chief, Vehicle Dynamics Division
Air Force Flight Dynamics Laboratory

ABSTRACT

This report presents supporting data and background information on the origination and development of natural and induced environmental tests intended for USAF aerospace and ground equipment.

The information provided in the discussion portion of the test writeups is intended to give the designer, application engineer, and those individuals responsible for specifying test requirements a clearer understanding of the interpretation, application, and relationship of tests as called out in various environmental test documents.

The growth of environmental criteria and test procedures is traced from the first Army Air Force . specification No. 41065 dated 7 December 1945 to MIL-STD-810A (USAF) dated 23 June 1964. Included also in this report are discussions on environmental test specifications MIL-T-5422, MIL-E-5272, and MIL-E-4970.

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CHAPTER I

SECTION 1

INTRODUCTION

Simulated natural and induced environmental tests for evaluating USAF material have evolved gradually over a period of nearly thirty years. Devising some tests was comparatively simple while the development of others has been more complex. For example, with the coming of the space age, the simulation of certain environments of outer space is a challenge to both earth bound facilities and application engineering.

Along with tests which have been developed scientifically, there are those which have resulted from trial and error. The trial and error method may continue to be a necessary procedure for the environmental engineer conducting laboratory tests intended to be comparable to those environments experienced under actual field service conditions. It is understandable that the designer, in specifying environmental test requirements for his device may question the origin, validity, and proper application for a certain test. The objective of this report is to provide information on the technical growth of environmental tests which may be of assistance to the equipment designer, the application engineer, and those individuals responsible for specifying environmental test requirements.

Prior to 1940 environmental testing as it is known today was practically non-existent. With World War II came the requirement for world-wide military operations involving all types of vehicles, ground support equipment and aircraft operating under a wide variety of environmental conditions. Improper packaging, handling, transportation, storage, and arctic, desert, and jungle operations resulted in extensive damage to vehicles and equipment. During the war years environmental testing at Wright Field, Ohio, was greatly increased. However, such testing was conducted by individual laboratories on those items of hardware within their jurisdiction. There were few standard procedures for performing tests among the various laboratories. This expanded test effort revealed deficiencies in environmental test chambers and associated facilities. As a result industry was motivated to speed the development of environmental facilities having greater capability.

As the workload increased, especially for qualification approval testing of new devices, Wright Field began to assign routine environmental testing to industry. As a result many new independent testing laboratories were established.

Almost immediately, laboratories performing tests in accordance with the multitude of military individual equipment specifications were frustrated by varying requirements for the same type test and inconsistencies in specifying like requirements from one test program to another. Remedial action was obviously needed. After some time, through the cooperation of the various laboratories of Wright Field, the first environmental test document was issued as Army Air Force Specification No. 41065, "General Specification for Environmental Test of Equipment," dated 7 December 1945. The principal objective of this initial effort was to standardize testing by reducing the number of test procedures for the same environment to the hopeful figure of one. However, each laboratory's insistance that a certain test procedure was necessary for a particular item of hardware resulted in as many as ten or twelve optional procedures for performing the same test. Eventually, through recognition of common problems and a better understanding of the end effects resulting from exposure to the environment, the number of procedures was gradually reduced.

On 1 December 1949 specification MIL-T-5422 (BuAir) "Environmental Testing of Aircraft Electronic Equipment" was issued by the Navy as a companion environmental test specification to MIL-E-5400 "General Specification for Aircraft Electronic Equipment." In addition to the single environment tests, as outlined in Army Air Force Specification 41065, MIL-T-5422 (BuAir) also contained, for electronic equipment either operating or nonoperating, a temperature-altitude cycling test intended to simulate the varying conditions of temperature and altitude encountered during a typical aircraft mission. This additional test was later included in MIL-E-5272 and was subsequently carried forward to MIL-STD-810 (USAF). During 1952 MIL-T-5422 (BuAir) was coordinated with the Air Force and on 11 May 1953 was, therefore, reissued by the Aeronautical Standards Group (ASG) as MIL-T-5422C (ASG). In compliance with a general order to change all Army Air Force specifications to "MIL" documents AAF 41065 was, on 16 August 1950, re-issued as MIL-E-5272 (USAF) "Environmental Testing, Aeronautical and Associated Equipment" without significant technical change. MIL-E-5272 (USAF) was subsequently coordinated with the Navy and on 16 September 1952 became MIL-E-5272A. By this act two coordinated ASG environmental testing specifications became current and, with the exception of differences in titles and language, both contained almost identical test procedures. Combining the two specifications appeared logical. However, by this time each specification had been widely referenced in many procurement documents. It was argued that combining the two specifications under a new title and number would result in utter confusion. In consideration of these facts the duplication was condoned.

In early 1960 a study was initiated to determine what measures could be taken to bring about the standardization of environmental testing. Attention was focused on five specifications: MIL-T-5422, "Environmental Testing for

Aircraft Electronic Equipment"; MIL-E-5272, "Environmental Testing, Aeronautical and Associated Equipment"; MIL-E-4970, "Environmental Testing, Ground Support Equipment"; MIL-A-26669, "Acoustical Noise Tests for Aeronautical and Associated Equipment"; and MIL-S-27507, "Shock Test, Saw Tooth Pulse," which was about to be published. The result of the study clearly indicated the need for up-grading test procedures and criteria and establishing a single standard environmental test document. Work was begun to accomplish this aim and, on 20 December 1961, the first draft copy of MIL-STD-810 (USAF), "Environmental Test Methods for Aerospace and Ground Equipment" was circulated within the Air Force for coordination. The Standard was issued on 14 June 1962.

It was then determined that the Standard should be submitted to the three services via ASG for review and acceptance as a fully coordinated document. However, prior to this action, it was decided that the Standard should be revised to include the very latest engineering input. This effort resulted in MIL-STD-810A (USAF), dated 23 June 1964. The changes included in the A revision are contained in Appendix I to this report. Also included in the A revision are transition tables which show those MIL-STD-810 (USAF) tests to be used in lieu of like tests given in MIL-T-5422 (ASG), MIL-E-5272 (ASG), and MIL-E-4970 (USAF).

The requirements of specification MIL-E-4970 (USAF) "Environmental Testing, Ground Support Equipment" have been included in MIL-STD-810 (USAF) and MIL-E-4970 has been cancelled. Until such time as the use of MIL-STD-810 (USAF) is adopted by the Navy, MIL-E-5272 (ASG) and MIL-T-5422 (ASG) will apply; but only in cases of Air Force-Navy joint procurement of like items. MIL-STD-810 (USAF) should be used for the environmental testing of subsystems and equipment of all future USAF weapon systems.

Although extensive research was accomplished in acquiring the material contained in the following sections, certain details, reasons for technical changes, etc., have escaped the author, however, it is believed that sufficient information is included to accomplish the purpose of this report. In presenting this background information, data are given for each type test in chronological order as to purpose, early problems, test development, discussion of present procedures, and relation to other tests.

CHAPTER II

SECTION 1

LOW PRESSURE (ALTITUDE)

1. Purpose

The low pressure test is conducted to determine the deleterious effects of low pressure on unpressurized aerospace and ground equipment. Ground equipment may be exposed to low pressure while being air transported or when operated at elevated ground sites. Unpressurized aerospace equipment is required to perform satisfactorily under all low pressure mission conditions.

2. Recognition of Problem

Low pressure became a recognized problem when aircraft began flying at altitudes higher than a few thousand feet above sea level. Low pressure problems vary in severity from aircraft flying in the earth's atmosphere to the near perfect vacuum of space encountered by space vehicles. Adverse effects resulting from reduced pressure are:

a. Leakage of fluids from sealed enclosures
b. Rupture of pressurized containers.
c. Evaporation of lubricants.
d. Galling or cold welding.
e. Arcing or corona in electrical and electronic equipment.
f. Decreased efficiency of convective cooling.
g. Outgassing of various materials.
h. Changes in aerodynamic characteristics of the flight vehicle.

3. Development of Low Pressure Test

The low pressure test, like other environmental tests, has varied from one specification to another over the years. Requirements outlined in test procedures for ground support and aerospace equipment, with emphasis on the latter, have steadily increased in severity to be coincident with the vehicle mission. The first Army Air Force environmental specification No. 41065, dated 7 December 1945 specified a maximum altitude of 50,000 feet, or less if so stated in the individual equipment specification. MIL-E-5272 (USAF) dated 16 August 1950 offered a wide variety of altitudes up to 85,000 feet, low temperatures to -65°C with dewpoint specified. MIL-E-5272 A and B specified altitudes to 50,000 feet at -54°C with no mention of dewpoint. In MIL-E-5272C (ASG) the temperature remained at -54°C but various altitudes to 100,000 feet were given. MIL-T-5422E (ASG), dated 13 April 1959, does not contain an altitude test per se. In its place is a temperature-altitude mission profile type test with a choice of temperatures ranging from +260°C to -62°C and altitudes to 80,000 feet. Again, no mention is made of dewpoint control. (The altitude-dewpoint relationship appearing in specifications from 1947 through 1950 was included to provide an effective test to determine electrical motor and generator brush wear which was an especially troublesome problem. Through proper design the problem of brush wear was eventually solved and the requirement for dewpoint control was dropped.) MIL-E-4970, now superseded by MIL-STD-810 (USAF), provided tests for ground support equipment. Altitude conditions of 50,000 feet for non-operating air transportation and 6,000 or 10,000 feet operating, whichever specified, were included. The latter requirement was intended for ground operation at high mountain sites. A temperature of +77°F was specified. In preparing the low pressure test (altitude) for MIL-STD-810 (USAF) the primary concern was the standardization of the wide spread of altitude and temperature requirements in existing specifications. The requirements contained in the final product are intended to reconcile these differences.

4. Discussion of Present Altitude Test

With the advent of space vehicles, no set limit, short of a perfect vacuum, can be specified for installed equipment operation. In consideration for this fact, Method 500, Procedure II of MIL-STD-810 (USAF) simply states that "the test chamber internal pressure shall be reduced to the lowest pressure for which the item is designed to operate." The temperature-altitude test of MIL-T-5422 was retained intact and included in MIL-STD-810 (USAF) as Method 504. The 50,000 feet non-operating air transportation requirement for ground equipment stated in MIL-E-4970 was retained in MIL-STD-810 (USAF), Method 500 as Procedure I. However, the 6,000 feet altitude requirement, with equipment operating, was dropped in preference to the 10,000 feet test since it could not be guaranteed that an equipment supposedly designed for operation at 6,000 feet would never be operated at 10,000 feet. (An altitude of 50,000 feet is established as the probable maximum altitude encountered by equipment when air transported.)

The low temperature requirement in both MIL-E-5272C (ASG) and MIL-STD-810 (USAF) is -65°F. The temperature of -65°F is derived from a -70°F average outside air temperature at altitudes from 37,500 feet to 80,000 feet, (as shown on the ICAO Standard Atmosphere graph), with an allowance of 5°F for temperature rise due to aerodynamic heating and/or equipment generated heat. For altitude testing of ground equipment under operating conditions, MIL-E-4970 specified a temperature of +77°F, which is analogous to ambient room conditions. Rather than specify this temperature, which implies precise control, MIL-STD-810 (USAF) leaves the temperature uncontrolled in consideration for the fact that it will not usually differ greatly from +77°F.

The requirement for conducting a corona or electric arc survey with the test item operating as pressure is increased is unique to MIL-STD-810 (USAF). This survey is not included in MIL-E-5272 or MIL-E-5422.

5. Relation of Altitude Test to Other Tests

In this basic test, temperature and pressure are co-related. Low pressure is also a factor of the explosive atmosphere test. Low pressure can be included as part of any combined environment test. Since the purpose of this test is to attain the specified vacuum, other environments are either ignored or uncontrolled.

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SECTION 2

HIGH TEMPERATURE

1. Purpose

The high temperature test is conducted to determine the resistance of aerospace and ground equipment to elevated temperatures that may be encountered during service life either in storage without protective packaging or under service conditions.

2. Recognition of Problem

Many types of equipment are affected by high temperature, but not all in the same way. The characteristic permanent set which is imposed during normal operating conditions upon packings, gaskets and other synthetic rubber parts in aircraft hydraulic and pneumatic systems is severely aggravated by temperatures above +130°F. The most severe trouble encountered with present synthetic rubber seals is the extraction of the plasticizer during exposure to heat by vaporization and leaching. Binding of parts in equipment of complex construction, such as bombsights and various instruments, may occur. This, in general, is the result of using dissimilar metals and the close tolerances which must be maintained between moving parts to insure accuracy. Fuel and hydraulic valves or similar units may bind or lose an effective seal if constructed of dissimilar metals. For example, a steel valve core seated in an aluminum housing would lose an effective seal. Bearing difficulties resolve primarily into differential contraction and expansion of materials and lubrication. A bronze bushing on a steel shaft may result in excessive clearance at high temperatures. Ball and roller bearings are not seriously affected by differential contraction and expansion; however, all lubricated surfaces may be left dry and without protection because of considerable change in properties of the lubricant resulting from evaporation at high temperatures. Synthetic rubber, plastic, and plywood tend to discolor, crack, bulge, check and craze; closure and sealing strips become gummy and stick to contacting parts.

3. Development of High Temperature Test

A high temperature test was included as part of the first Army Air Force environmental test specification 41065 dated 7 November 1945. The test specified a temperature of +160°F and a total test time of 15 hours. In test specifications that followed, the test time was increased, in some cases, to as long as 50 hours. In MIL-E-5272C (ASG) the test time was established as 48 hours as a compromise among the various test periods. The temperature of +160°F and a test time of 48 hours is presently specified in MIL-STD-810 (USAF), Method 501. The temperature of +160°F represents the probable high temperature extreme for storage and transportation. Operation of Ground equipment can also experience this temperature due to heat developed through operation. The temperature of +52°C (+125°F) is representative of the highest temperature of the ambient air. The temperature of +71°C (+160°F) results from the addition of +19°C (+35°F) due to direct solar radiation. In addition, higher temperatures can result from the operation or confinement within cases or enclosures. When location or operating characteristics will result in higher temperatures, the requirement should be stated in the individual equipment specification.

4. Discussion of Present High Temperature Test

The high temperature test is recommended for all classes of aerospace and ground equipment. In the absence of well-defined system criteria regarding compartment temperatures, intended heat exchangers, ram air available for cooling, etc., general test procedures can, only at best, give general guidance and test levels for performing the average test. Test Method 504 of MIL-STD-810 (USAF) recognizes the ever increasing severity of equipment operating temperatures. Five equipment classes are indicated ranging from +55°C (+131°F) to +260°C (+500°F). Other classes will be added as the need arises.

5. Relation of High Temperature Test to Other Tests

High temperature combines and reacts with other environments as follows:

a. With vibration--accelerated fatigue.
b. With low pressure--sputtering, outgassing.
c. With high humidity--accelerated fungus growth.
d. Salt fog--accelerated corrosion.
e. Solar radiation--elevation of equipment temperature.

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SECTION 3

LOW TEMPERATURE

1. Purpose

Low temperature testing is conducted to determine the effects of low temperature on aerospace and ground equipment. Low temperature is encountered from ground level to all altitudes. The adverse effects of low temperature on equipment can be operational or mechanical. Operational effects may not cause a system to fail, but can prevent it from fulfilling its intended mission.

For example, snow and ice prevent an aircraft from taking off even though all systems function perfectly. Mechanical effects can actually prevent a system from functioning properly, e.g., freezing of lubricants causing a pump or motor to malfunction.

2. Recognition of Problem

A need for an extensive low temperature program was indicated prior to World War II. Congealing of lubricants caused operating difficulties at sub-zero temperatures. Tires and other rubber parts were easily cut and cracked. Some types of solder would disintegrate when subjected to vibration at low temperatures. Canvas and leather became stiff at low temperatures and were easily cracked and torn. Differential contraction caused buckling of aircraft skins and caused leaks in hydraulic systems. Ice and snow caused structural damage and moisture problems.

3. Development of Low Temperature Test

Low temperature testing was first begun under the Army Air Corps at outdoor exposure sites. These tests were conducted from 1930 through 1938 at Selfridge & Oscoda, Michigan, and in New England for the purpose of determining the ability of aircraft and crews to operate in cold climates. In 1938 the Air Corps Cold Weather Experimental Station was established at Ladd Field, Alaska.

In 1941 Wright Field, Ohio, was designated as the coordinating agency in the design and development of low temperature equipment. In the same year results of a world wide temperature study indicated that -65°F should be regarded as the minimum temperature requirement for operating conditions. A temperature of -85°F was indicated as a probable extreme for storage in some areas.

During the winter months of 1942 to 1943, extensive testing at Ladd Field showed that aircraft and ground equipment, and associated auxiliary and accessory equipment, would not operate satisfactorily in temperatures below -25°F (-32°C). During 1941 and 1942 new greases were developed for low temperature operation. In 1944 test results indicated that aircraft and equipment were suitable for operation to about -40°F (-40°C).

In 1944 equipment and associated replacement parts, which qualified for low temperature operation were marked with a yellow dot.[1] Even with its

[1] Design of Aircraft and Aeronautical Equipment for Operation in Extreme Climatic Conditions, TN-TSEESE-1.

shortcomings, the yellow dot procedure served the purpose of providing improved equipment suitable for low temperature operation. The first environmental test specification, Army Air Force Specification Nr. 41065, dated 7 December 1945, contained three test methods with a minimum temperature requirement of -85°F (-65°C) for exposure only. The minimum equipment operating temperature was -65°F (-54°C). The three procedures simulated storage and operation in arctic climates, storage and operation in continental United States (operation at -30°F), and low temperature storage followed by operation in a sheltered environment (+40°F) after a two hour period at +40°F.

Investigation of low temperature effects on equipment continued through the winter of 1946-47. At this time low temperature testing became a part of the normal development cycle of aircraft systems and associated equipment. As early as 1943, requirements for aircraft operation at -65°F outside air temperature were established by the Director of Military Requirements in directives dated 14 and 22 March 1943. This action was prompted by the outbreak of World War II which required the operation of AAF aircraft in the arctic.[1] The goal was to provide satisfactory operation to 165°F (-54°C). Three low temperature test procedures appeared in Air Force Specification MIL-E-5272, dated 16 August 1950. Procedure I required operation of the test item at -65°F for 72 hours followed by operation while at that temperature. This procedure was used when there was a possibility that an item which produced proper temperature distributions and heat flows at -65°F might not operate properly at the higher temperatures. Procedure III required exposure to -85°F for 48 hours then exposure to -65°F for 24 hours or longer, if required, for test item stabilization. Operation was required at -65°F at the end of the exposure period. Both storage and operating conditions were simulated by this procedure. Investigation has shown that most airborne equipment will not encounter temperatures below -65°F (-54°C) because of the heat rise within the aircraft. Ground equipment, in some instances, could be stored in area where the temperature could be as low as -80°F (-62°C).

In September 1952, Specification MIL-E-5272 was revised to MIL-E-5272A, with Procedure II of the low temperature tests of MIL-E-5272 eliminated. This procedure required equipment to be exposed to and operated at each of the four following temperatures: 0°F (-18°C), -20°F (-29°C), -40°F (-40°C), and -65°F (-54°C). The elimination of the higher temperatures was based on the assumption that if equipment could operate at -65°F (-54°C) temperature, satisfactory operation could be reasonably assured at the higher temperatures. (If operation of the equipment were required at any other low temperature, due to the intended use of the equipment, the individual equipment specification should so state.) MIL-E-5272A also changed the exposure requirement from -85°F (-65°C) to -80°F (-62°C).

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[1] AMC Cold Weather Tests, Page 1, Paragraph 2.

MIL-E-5272A was revised in June 1957 to MIL-E-5272B. No changes were made in the low temperature test procedures. In April 1959 MIL-E-5272C was prepared. No change was made to the low temperature test requirement of Procedure I. However, In Procedure II, the exposure time of 48 hours at -80°F (-62°C) was increased to 72 hours.

In June 1962 MIL-STD-810 (USAF) was issued which covers aerospace and ground equipment exposed to low temperature (without protective packaging) during storage or service use.

As a result of the low temperature testing experience gained at Wright Field in the many years past, and based on criteria established in MIL-STD-210A, the following conditions were established as standard:

-80°F (-62°C) for transportation and storage
-65°F (-54°C) for world wide operation
-40°F (-40°C) for operation in continental United States
+35°F (+ 2°C) for equipment operated in temperature-controlled areas

4. Discussion of Present Low Temperature Tests

At present, low temperature testing in accordance with MIL-STD-810 (USAF) "Test Methods for Aerospace and Ground Equipment" will provide the lowest natural temperature conditions aerospace and ground equipment can be expected to experience except for possible extreme conditions in the Antarctic or operations involving cryogenic fluids.

In MIL-E-4970A, now superseded by MIL-STD-810 (USAF), all three test procedures required a non-operating 72 hour exposure to -80°F (-62°C). This requirement was included to simulate conditions of shipment and storage of equipment that might be exposed to this low temperature. The requirement for a 72 hour exposure period is necessary. Past testing experience has shown that large massive equipment requires this long to attain temperature stabilization. Actual shipping and storage time is not usually known and could well exceed 72 hours. Therefore, a minimum requirement of 72 hours is considered reasonable. Operation of equipment at various low temperatures specified in the three test procedures of MIL-E-4970 took into consideration the location in which the equipment was intended to be used. In MIL-E-5272C the requirement for a 72 hour exposure period at -80°F (-62°C) is the same as for that stated above. The operational requirement, however, concedes operation at the higher ambient temperatures if satisfactory operation can be demonstrated at -65°F (-54°C). The proper procedure to use depends on the intended location of the equipment.

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MIL-STD-810 (USAF) is basically a combination of MIL-E-4970 (USAF) and MIL-E-5272C and takes into consideration the lowest temperature under which the test item is designed to operate. The requirement of exposure to -80°F (-62°C) is still a necessity. MIL-STD-810 (USAF) requires a minimum exposure of not less than 48 hours at -80°F. It was reasoned that most test items would, for all practical purposes, have reached stabilization after 48 hours, and that little could be gained by exposure for an additional 24 hours. However, experience has shown that some massive test items actually do require up to 72 hours to reach a practical degree of stabilization. Also, congealing of oils and greases is a progressive action extending over hours or days. Differential contraction and other low temperature effects cannot be complete until stabilization at a low temperature is complete. The exposure time of a low temperature test must be sufficiently long to insure the effects which will occur during operational use will, also, occur during the test. Investigations of changes in organic materials, such as lubricants, plastics, and rubber, and test experience have indicated that seventy-two hours is usually a correct time duration.

The rapidly expanding use of cryogenic fluids has opened a whole new area of low temperature operations. Cryogenic engineering has developed as a specialized field of knowledge and items such as pumps, valves, storage vessels, and connecting pipes are designed and used according to cryogenic engineering practices. These items are tested by installing them in cryogenic systems.

Cryogenic temperatures are also required for simulation of the heat sink of space. The walls of a test chamber may be cooled by gaseous or liquid nitrogen, liquid hydrogen, or liquid helium. Cryogenic engineering has thus become important in environmental testing even though test items are seldom required to operate at cryogenic temperatures. Some items which operate in or near cryogenic systems may actually need to be tested at cryogenic temperatures.

Test Method 517 of MIL-STD-810 (USAF) requires a test chamber wall temperature of -195°C (-320°F). This is the only current general environmental test procedure which requires use of cryogenic temperatures.

5. Relation of Low Temperature Tests to Other Tests

In low temperature testing temperatures usually considered are 35°F (2°C) or below. Therefore, low temperatures can be combined with the following:

Humidity--Humidity decreases with temperature, but low temperature induces moisture condensation and, if the temperature is low enough, frost or ice.

Low Pressure--This combination can accelerate leakage through seals, etc.

Salt Fog--Low temperature reduces the corrosion rate of salt fog.

Solar Radiation--Low temperature will tend to reduce the effects of solar radiation and vice versa.

Sand and Dust--Low temperature often increases dust penetration.

Fungus--Low temperature reduces fungus growth. At subzero temperatures, fungi will remain in suspended animation.

Shock, Vibration and Acceleration--Low temperature tends to intensify the effects of shock, vibration and acceleration. It is, however, a consideration only at very low temperature. The damage threshold at low temperature will be determined by the type of material involved.

Explosive Atmosphere--Temperature has very little effect on the ignition of an explosive atmosphere. It does, however, affect the air-vapor ratio which is an important consideration.

Ozone--Ozone effects are reduced at lower temperatures, but ozone concentration increases with lower temperature.

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SECTION 4

TEMPERATURE SHOCK

1. Purpose

The temperature shock test is conducted to determine the effects on aerospace and ground equipment of sudden changes in temperature of the surrounding atmosphere. Cracking or rupture of materials due to sudden dimensional changes by expansion or contraction is the principal difficulty to be anticipated. This could occur in service to aerospace equipment during rapid altitude changes and to ground equipment being moved from heated storage buildings to low temperature outdoor areas, or vice versa.

2. Recognition of Problem

An item of equipment may be exposed to the heat of the desert and tropics on the ground and a few minutes later exposed to the extreme low temperatures of high altitude. Because of their location, many items of equipment will not be severely affected by extreme variations in temperature, nor will items be affected which generate their own heat. Other items that are exposed to the air-stream or located in an unheated compartment will be more seriously affected. It is therefore possible for an item of equipment to be subjected to a maximum ambient temperature traverse of 125°C (225°F) within a few minutes. This rapid change in ambient temperature of an item of equipment, known as temperature shock, may cause malfunction in items of equipment due to rapid differential contraction of dissimilar materials such as metals, plastics, etc., composing the item.

3. Development of Temperature-Shock Test

A temperature-shock test did not appear until 16 August 1950 in MIL-E-5272 (USAF). No record can be found as to how this test was developed, but it may be logically assumed that as higher performance aircraft, probably fighters, were introduced into the USAF arsenal the problem outlined in Paragraph 2 above was recognized. The test was included in all subsequent revisions to MIL-E-5272 with no technical change and as such was carried forward to MIL-STD-810 (USAF) as Method 503. This test is not included in MIL-T-5422 "Environmental Testing for Aircraft Electronic Equipment."

4. Discussion of Present Temperature Shock Test

Attention is invited to the fact that the extremes of -40°C (-40°F) and 85°C (185°F) are not intended to be in agreement with other temperature extremes called out in MIL-STD-810 (USAF). The primary purpose in establishing these extremes is to provide a thermal traverse of 125°C (225°F) within a few minutes.

It has been suggested that the test item be allowed to reach temperature stabilization rather than specify the soak period of four hours. The contention is that stabilization for small items may be reached in a time period of far less than four hours, thereby shortening the test time and conversely, that large bulky items may require longer time periods for stabilization. It is pointed out that the purpose of this test is not to determine long term effects at the temperature extremes, but rather the temperature-shock effect. Where temperature stabilization is required, Methods 501 and 502 of MIL-STD-810 (USAF) are recommended.

5. Relation of Temperature-Shock Test to Other Tests

Temperature per se is naturally concurrent with many environments, i.e., humidity, pressure, shock, vibration, etc. However, for the purpose of this test, these other environments are either ignored or uncontrolled.

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There is no bibliography.

SECTION 5

TEMPERATURE-ALTITUDE (CYCLING)

1. Purpose

The temperature-altitude test applies to aerospace equipment and is conducted to determine the ability of such equipment to operate satisfactorily under simultaneously applied varying conditions of low pressure, high and low temperature, and high relative humidity.

2. Recognition of Problem

Prior to World War II, flight testing was the commonly accepted method for determining operational suitability of electronic equipment. With the development of a wide variety of specialized electronic devices during the war, it became advisable to devise a simulated laboratory method for testing equipment. A test was needed to simulate the environmental conditions to be encountered during a typical mission performed by aircraft of that period. Deleterious effects to be anticipated include leakage of gases or fluids from sealed enclosures, rupture of pressurized containers, congealing of lubricants, cracking or rupture of materials due to contraction or expansion, short circuiting of electrical wiring.

and other damaging effects which might be expected from exposure to any of the above environments singly. In addition, equipment dependent on a convection type cooling system may be affected due to the reduction of efficiency of heat dissipation in less dense air.

3. Development of Temperature-Altitude Test

This test first appeared in MIL-T-5422 "Environmental Testing for Aircraft Electronic Equipment" and was included in the "A" revision to MIL-E-5272 dated 16 September 1952. With the exception of the addition of five equipment classes related to temperature-pressure operating extremes, few changes have been made to the test to the present date.

4. Discussion of Present Temperature-Altitude Test

This and the low pressure solar energy test of MIL-STD-810 (USAF) are the only tests in present environmental test specifications and standards which attempt to accomplish a combined or mission profile type test. With the expectation that MIL-STD-810 (USAF) would supersede all other environmental test documents, this test was included to satisfy the users of MIL-T-5422 and MIL-E-5272. It was realized that the test was custom designed for a specific type of flight vehicle, and that the conditions of low pressure, temperature cycling, etc., were inadequate for high performance vehicles, rockets, satellites, and space vehicles. This situation was partially remedied with the inclusion of Method 517 in MIL-STD-810 (USAF).

The test combines, over a specified time period, high humidity, temperature extremes, low pressure, and equipment "on-off" duty cycles. Only the absence of the temperature shock, mechanical shock, vibration, acceleration, and explosive atmosphere environments prevent this procedure from being a total mission profile test.

5. Relation of Temperature-Altitude Test to Other Tests

Included in the temperature-altitude test are the following environments which prevail in combination to varying degrees in consonance with the cycling rate.

High Temperature--to +260°C (+500°F)
Low Temperature--to -62°C (-80°F)
Low Pressure--to 100,000 feet
Moisture--formation and melting of frost during cycling from low to high temperature.

SECTION 6

SUNSHINE TEST

1. Purpose

The sunshine test is conducted to determine the deleterious effects of radiant energy on aerospace and ground equipment. The sunshine test is applicable to any item of equipment which may be exposed to sunshine during service at the earth's surface or in the lower atmosphere (below 100, 000 feet). For the purpose of this test, only the terrestrial portion of the solar spectrum is considered.

2. Recognition of the Problem

The effects of radiant energy dealt with here may be divided into two general classifications which are heat effects and photo chemical effects. Heat effects on exposed equipment can raise the internal temperature of the equipment substantially above the ambient temperature. Temperatures in excess of $+160^{\circ}F$ have been recorded in parked aircraft exposed to sunshine while the ambient air temperature was in the 90's. The photo chemical effects of sunshine may cause fading of colors, deterioration of paints, plastics, fabrics and natural rubber. Compound effects of sunshine cannot be overlooked. For example, solar heat may physically deform a plastic material while the photo chemical effect darkens the material and reduces transparency. The discoloration of heat reflective coatings by the photo chemical effects of sunshine may cause increased heat absorption and excessive internal temperature of enclosed equipment. Another example of a compound effect is the deterioration of protective paint by sunshine resulting in loss of protection against corrosion.

3. Development of Sunshine Test

The recognition of these problems prompted the requirement for a sunshine test. The solar frequency spectrum from 7, 800 angstroms (infrared) to 3, 800 angstroms (ultraviolet) has been accurately measured as well as the energy distribution throughout this spectrum. The principal concern was, and still is, the development of energy sources capable of providing a true match with this portion of the solar spectrum. In March of 1945 an Air Force contract was let for the development of a sunshine test facility to be located at Wright Field. The contract required the simulation of those wavelengths of ultraviolet that produce the maximum catalytic effect with relation to corrosion, etc., and those wavelengths of infrared that produce the most internal heating effect. Those broad requirements were stated in recognition of the inability to exactly simulate sunshine. Due to the availability of sunshine data for the Washington, D.C. area, it was mutually agreed between the contractor and the Government that this data be used. Type RS-4 sunlamps were used as energy generators. When the facility was placed in operation, it fell short of contractual requirements. A serious deficiency in the amount of ultraviolet light and a surplus of infrared were the principal causes of dissatisfaction. Another objectionable feature was that the radiation intensity was computed for 100 watts per square foot at four feet from the lamp tips. Since the lamps were fixed vertically, it was impossible to vary the height to adjust for the height of tall test items. For this reason, the specification was modified to permit a tolerance of 100 to 140 watts per square foot. The original RS-4 sunlamps were replaced with GE UA-11B ultraviolet lamps to overcome the deficiency in the ultraviolet range. The UA-11B lamps emit more UV radiation in proportion to infrared than the original RS lamps and this brought the spectral distribution of the test facility closer to natural sunshine. The sunshine test contained in Army Air Forces specification 41065, dated 7 December 1945 specified 100 to 140 watts per square foot with 50 to 84 watts above 7800 angstroms and 4 to 8 watts below 3, 800 angstroms. The facility ambient temperature and test exposure time were not specified. The above requirements remained essentially unchanged in subsequent revisions to 41065, as incorporated in MIL-E-5272 (USAF). MIL-E-5272A dated 16 September 1952 included a requirement for maintaining the test chamber temperature at +113°F. This temperature was considered the extreme likely to be encountered in desert operations. In MIL-E-5272C (ASG) dated 13 April 1959 the exposure period of 48 hours was added. These same requirements were specified in MIL-E-4970 and were carried forward without change to MIL-STD-810 (USAF) as Method 505. Not all sunshine testing has been done in the laboratory. Outdoor exposure sites have been employed for many years by the manufacturers of various products such as rubber, plastics, fabrics, paints and other finishes. The results of these weathering tests, however, provided little or no data for establishing a sunshine test per se since they also included degradation resulting from rain, hail, sleet, snow, wind and aerosols. In 1951 an effort was initiated to investigate effects resulting from solar exposure at an outdoor site where the climate was most conducive to sunshine. This Air Force program was conducted under contract with the University of New Mexico at Las Cruces. Solar data were collected from June 1951 to October 1956. Materials were mounted to racks slanted at 45° facing the south. Some of the more important findings resulting from the tests were:

a. The amount of deterioration can be correlated statistically with the amount of energy received from the sun.
b. Materials should be exposed for a given number of gram calories per square centimeter rather than for a predetermined period of time.

4. Discussion of Present Sunshine Test

As was previously stated, the solar spectrum and energy distribution has been scientifically and accurately measured. The primary problem lies in the state-of-the-art for the development of energy sources which will provide a more perfect match. The present test gives accurate simulation of the radiant heat effects of natural sunshine. The ultraviolet effects simulate natural sunshine in a general way and are considered to be representative for wide area irradiation. Wide area irradiation requires a bank of lamps spaced close together. The physical size and configuration of carbon arcs is not well adapted to operation in banks. Methods of using an intense point source of light, which is projected through an optical system and spread over a wide test area, are used on a limited scale. The point source is not efficient, however, since the optical system absorbs from 85 to 90 percent of the radiation source input energy.

The use of a plasma jet as a radiation source has been proposed. The light beam from the plasma would be split into its various wavebands and blended into the exact proportions of daylight. The illuminated area would cut off radiations above 2,000A(far ultraviolet). (Although present requirements specify 3,800 angstroms as the lower limit, far ultraviolet and X-ray below 2,000 angstroms would be required to simulate full solar radiation in space.) Sophisticated means could be employed to overcome this deficiency, however, the principle reason for not adopting this technique is the estimated cost of one million dollars for fabrication and installation.

As can be seen, continuing effort to precisely match the sunshine spectrum with optimum energy at all discrete wavebands can result in costly facilities, baring some break-through resulting in reduced cost.

Occasionally, the question is posed as to why an oven type test for enclosed equipment can not be used to replace the sunshine test. Such a test is unsatisfactory since in an oven there is a uniform ambient temperature. If the test item is allowed to remain in the oven long enough, the test item will reach equilibrium at the oven ambient temperature.

In a sunshine test the heat effect is due to radiation. It is directional and produces temperature gradients through the test item. The temperature will vary from a "low" equal to ambient air temperature to a "high" many degrees above ambient.

Since the sunshine test (terrestrial) has been in use, there has been virtually no feedback of information from the services to the laboratory relative to the service suitability or unsuitability of items which were accepted on the basis of having passed the sunshine test. If problems do exist, the revelation of such information could form the basis for a better evaluation of the test.

5. Relation of Sunshine to Other Tests

Although the sunshine test is rarely performed in combination with other environmental tests, the following relationships can exist:

Sunshine and Fungus--Because of the resulting heat from solar radiation, this combination probably produces the same combined effects as high temperature and fungus.

Sunshine and Sand and Dust--It is suspected that this combination will produce high temperatures.

Sunshine and Vibration--Under vibration conditions, solar radiation deteriorates plastics, elastomers, oils, etc., at a higher rate.

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SECTION 7

RAIN TEST

1. Purpose

The rain test is conducted to determine the efficiency of protective covers or cases designed to protect equipment from the elements. This test is applicable to all items of unsheltered ground equipment and may apply in certain special cases to sheltered and vehicle installed equipment. The simulated rain, as used in this test, is not wind driven and is, therefore, unsatisfactory as a rain erosion test. Rain erosion testing of items such as radomes, nose cones, etc., require special test procedures.

2. Recognition of Problem

Rain is a source of moisture which has a deleterious effect on most material. It can cause a direct malfunction of electric and electronic equipment through short circuiting. Frozen rain inside equipment may cause delayed deterioration and malfunction through the swelling or cracking of parts. High humidity resulting from rain can cause corrosion and support fungus growth.

3. Development of Test Procedure

The requirement for a rain test preceded the formal adoption of a standard rain test chamber by a number of years. Army Air Force specification 41065 dated 7 December 1945 specified a rain test requiring 4 ± 1 inch of rainfall per hour at a temperature of $60 \pm 10^{\circ}F$ for a total test time of two hours. A rainfall of 4 ± 1 inch per hour was considered the average maximum for the temperate zone. This quantity has remained unchanged to the present time. Although the temperature stated has varied from one specification to another over the years, it was the contention then, and still is, that the temperature of the water introduced as rain is of little importance so long as the rain remains a liquid.

The test time of two hours has remained unchanged through the years primarily because the test time may be varied by the individual equipment specification.

For the first time in MIL-E-5272 (ASG) dated 13 April 1959 the rain drop size was specified to be not less than 1.5 millimeters in diameter. This requirement was added to prevent the water from being introduced into the rain chamber as a mist. The present requirements of MIL-STD-810 (USAF) Method 506 Rain Test specifies rainfall of 4 ± 1 inch per hour, minimum drop size of 1.5 millimeters diameter, test time not less than two hours, and water at a temperature of from 51.8 to $95^{\circ}F$. The temperature of the water was raised at the request of many test organizations who draw their water supply from storage tanks and piping exposed to sunshine. It is not intended that an added burden be imposed to require cooling of the water to meet a lower temperature.

This test, similar to some others such as sunshine, was not impeded through a lack of knowledge of the environment, effects, and measurement but rather in the development of a facility capable of simulating natural rainfall. Through World War II and the years that followed extensive investigation and experimentation was conducted at Wright Field regarding uniform dispersal, temperature, droplet size, velocity, types of nozzles and spray heads, etc.

This work led to the development of a satisfactory facility and was published as specification MIL-C-8811 titled "Chamber, Rain Testing" dated 10 July 1957.

4. Discussion of Present Rain Test

The rain test given in MIL-STD-810 (USAF) Method 506 is considered adequate for testing enclosed equipment. Little concern is expressed over the technical considerations of the rain test except that the rain shall not be introduced into the chamber as steam or frozen water.

5. Relation of Rain Test to Other Tests

Rain, as a source of moisture or humidity, will promote the growth of fungus. In general, rain as an environment is seldom considered as having a definite relationship to the other environmental tests.

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SECTION 8

HUMIDITY (CYCLING)

1. Purpose

The humidity test is conducted to determine the resistance of equipments, components, and systems to the effects of exposure to warm humid atmospheres such as are encountered in tropical areas. The descent of aircraft from the cold upper atmosphere to base also causes moisture problems even in temperate climates. Corrosion of metals and swelling of hygroscopic materials are among the effects of exposure to humid atmospheres.

2. Recognition of Problem

Military operations in both continental and island tropical areas during World War II revealed serious deterioration to all types of material and equipment including aircraft resulting from exposure to humidity. These problems occurred under both storage and service use conditions. In addition to improved methods of packaging and storage, the development of moisture resistant coatings and finishes were needed. Tests to determine the adequacy of protective media were gradually developed.

3. Development of Humidity Test Procedures

In 1943 the Army Signal Corps developed a standard humidity test cycle (Reference SC-D-16286-B). Ten days of this cycle produced deterioration which correlated well with field deterioration in tropical areas. Essentially the same cycle is still used in MIL-STD-202B, Method 106A, "Moisture Resistance." A portion of the test also contains a low temperature-vibration cycle which is often omitted in individual equipment specifications. Army Air Force specification 41065 dated 7 December 1945 included a humidity test consisting of a five-day exposure period and a relative humidity of $95 \pm 5\%$. During six hours of each day the test chamber was heated to $160 \pm 3^{\circ}F$. During the remaining eighteen hours the sealed chamber was allowed to cool to some temperature under $100^{\circ}F$. This test was an attempt, based on limited knowledge, to accelerate the corrosion process by using a high vapor pressure (95% relative humidity at $160^{\circ}F$). The daily temperature cycling was used to cause condensation on the test item and to force moisture into partially enclosed spaces.

During 1945 and 1946 the Tropical Science Mission studied Air Force operations in tropical and semi-tropical areas around the world. Many equipments and components which had deteriorated during transportation, storage, and service use were brought to Wright Field, Ohio, and examined. As a result of this investigation the humidity test was extended to fifteen days and appeared as such in Army Air Force specification 41065 dated 3 November 1947. Items tested in the laboratory showed deterioration corresponding closely to that of similar items exposed to the natural environments. The test in the "B" revision dated 13 January 1949 was essentially the same.

By contrast, humidity tests appearing in Navy specification MIL-T-5422 (BuAir) and in specification JAN-M-745 (now obsolete) required a thirty day exposure at a temperature of $25^{\circ}C$ ($77^{\circ}F$) and $95 \pm 5\%$ relative humidity. The temperature was required to vary $5^{\circ}C$ during each hour so that a relative humidity of 100% with condensation was produced at least once during each hour.

In 1950 tests were performed to determine whether the ten day period of standard cycle SC-D-16286-B or the thirty day period of MIL-T-5422 (BuAir) and JAN-M-745 provided the most realistic test. Comparative experiments showed that the standard cycle provided the more severe test. In this experiment the low temperature-vibration portion of the cycle was omitted.

Specification MIL-E-5272 (USAF) dated 16 August 1950 contained three humidity test procedures. Procedure I was the fifteen day test of Army Air Force specification 41065B. Procedure II was the thirty day test of JAN-M-745, and Procedure III was a fifteen day exposure to 95% relative humidity at 120°F with no temperature cycling (steady state). As will be discussed later, this test, slightly modified, eventually appears in MIL-STD-202B as Method 103A "Humidity, (Steady State)." Specification MIL-E-5272A dated 16 September 1952 contained the same three procedures.

During 1953 and 1954 the Wright Air Development Center conducted a program to compare the effectiveness of the various humidity test procedures. The four methods studied were Procedure I of MIL-E-5272A, Procedure III of MIL-E-5272A, Method 106 of MIL-STD-202, and a modification on Procedure I of MIL-E-5272A using 120°F as the maximum cycling temperature. This investigation indicated that the test performed in accordance with Method 106 of MIL-STD-202 produced the most corrosion of metals and that the test of Procedure I of MIL-E-5272A was the most severe for water absorbing materials. However, the results of experiments performed by the Wright Air Development Center showed that Procedure I of MIL-E-5272A provided the best test for both corrosion of metals and water absorbing materials. Little doubt was left that the tests of MIL-E-5272A, Procedure I and MIL-STD-202, Method 106 were superior to other tests in use at that time. In addition, these experiments revealed that corrosion rates became nearly constant after ten days when employing either of the more severe test methods.

In specification MIL-E-005272B (USAF) dated 5 June 1957, Procedures I and III of MIL-E-5272A were retained. Procedure II, which specified the thirty day test period, was not included based on the finding that the ten day period was equally effective and Procedure I was reduced to ten days. These two tests were subsequently carried forward to MIL-E-5272C (ASG), and allowed a choice of either the cycling or steady state humidity test.

MIL-STD-810 (USAF) dated 14 June 1962 uses only Procedure I of MIL-E-5272 (ASG). The inclusion of the cycling test in preference to the steady state test is based on the result of work conducted at the Aeronautical Systems Division which showed that, for components and equipment, greater moisture penetration was attained due to the breathing action accomplished by the cycling test than was possible with the humidity under static pressure as in the steady state test.

Specification MIL-T-5422E (ASG) also employs the ten day cycling test except that the maximum temperature is specified as 122°F rather than 160°F.

MIL-STD-202B, Method 106A dated 14 March 1960, provides a primary and an alternate moisture resistance test. Both tests are similar to the original

Signal Corps standard cycle. MIL-STD-202B also contains a steady state humidity test as Method 103A which consists of test item exposure to 90% to 95% relative humidity at 40° ± 2°C for a period of either four or ten days. This test finds its greatest use in the investigation of the hygroscopic characteristics of various materials.

4. Discussion of Present Humidity Tests

Of the tests that survived the research work performed in the early 1950's, Procedure I of MIL-E-5272C (ASG), Method 507 of MIL-STD-810 (USAF), and Method 106A of MIL-STD-202B have proven to be the most severe. All three are essentially the same test. Procedure III of MIL-E-5272C (ASG) may be valuable for testing the amount of water absorbed by certain materials but it is suspected that the reason for its retention lies in the fact that it is referenced in many individual equipment specifications.

It is reasonable to expect that a test item which corrodes when subjected to one of the above humidity tests would sooner or later corrode in a natural tropical environment. The same item would also probably corrode after repeated exposure to water condensation upon return of an aircraft from the cold regions of the atmosphere to a warm, not too dry, landing area. The probability that an item which has passed a good humidity test will still corrode in service use exists but appears rather unlikely. Experience has shown that the humidity test is one of the more difficult environmental tests for an item of equipment to pass.

The requirement for the water condensing in a humidity chamber to have a ph value between 6.5 and 7.5 is open to discussion. Distilled water may have a ph value as low as 5.0, and water condensing from the atmosphere in a jungle area would probably contain dissolved gases. A strict control of the ph value is necessary for uniform test results, but investigation should be made to determine whether the presently specified values are the ones which should be used.

5. Relation of Humidity Test to Other Tests

Corrosion of structural metallic parts and hardware resulting from humidity will accelerate failure when the test item is subjected to vibration and mechanical shock. Humidity combined with high temperature and sand and dust will promote the growth of fungus. Humidity is a natural ingredient of the fungus and salt fog test.

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SECTION 9

FUNGUS

1. Purpose

The fungus test is conducted to determine the resistance of aerospace and ground equipment to deterioration caused by metabolic activities of fungi. The test involves exposure of components, equipment, and materials to fungi in an environment highly conducive to fungus growth. The test item passes the test only if no fungus growth is evident on the test item after at least twenty-eight days of exposure.

2. Recognition of Problem

Destruction of materials by microorganisms was recognized as a problem many years before World War II, but the small proportion of American military operations conducted in tropical areas made this destruction relatively unimportant. With expanded operations in the tropics during World War II the deterioration of supplies and equipment became serious. It was actually not until the years immediately following the war that good fungicides and equipment designed to be fungus resistant came into use.

Fungi are heterotrophic plants which obtain food from the materials on which they grow. Items which may be attacked by fungi include textiles, plastics, leather, rubber, wood, paper, paints, varnishes, electrical insulation, and certain optical parts and coatings. Dirt and impurities which are on a surface may support fungus growth even though the surface material itself will not. Fungus growth may etch surfaces or leave hard to remove films.

Although fungus may not always cause malfunctions, the odor and general appearance resulting from fungus growth may cause personnel to doubt the reliability of their equipment. This may result in the premature disposal of otherwise operationally sound equipment.

3. Development of Fungus Test Procedure

Various tests of materials for fungus resistance were used by industry and Government for many years prior to World War II, but general agreement on how to test military items was not reached until 1945. A Tropical Room built by the Army Corps of Engineers in 1944 was probably the first large size fungus test chamber which used procedures similar to those of present fungus tests.

One species of fungus may attack a certain material under certain environmental conditions while others will not. This makes it necessary to use more than one species of fungus in a test. Six groups of fungi representing a variety of growth characteristics were selected by mycologists for inclusion in the fungus resistance test of Army Air Forces Specification No. 41065 dated 7 December 1945. The groups contained species of fungi actually found in tropical areas.

When beginning the fungus resistance test of AAF Specification 41065, a spore suspension made from cultures was sprayed on the test item. The test chamber was then maintained at a temperature between 82 and 86°F for twenty-eight days. Specifications 41065A and 41065B, which appeared in 1947 and 1949 respectively, contained essentially the same procedure.

Specification MIL-E-5272 (USAF) dated 16 August 1950 used basically the test of 41065, but also outlined the procedure to be used in preparing the spore suspension. MIL-E-5272 (USAF) used only five groups of fungi and prescribed a temperature of 86°F with 95% relative humidity. The change to five groups of fungi did not actually discard one group of 41065 because at least one of the alternate species of each group in 41065 was included in a group of MIL-E-5272 (USAF). The conditions of temperature and relative humidity specified were those considered by mycologists to provide optimum growing conditions for the fungi used in the test. Specification MIL-E-5272A contained the same fungus resistance test as MIL-E-5272 (USAF) with the addition of an eight hour limit on the length of time the spore solution could be kept before use. This restriction was imposed as the result of testing experience.

During the period 1953 to 1957 many investigations concerning fungus growth and fungicides were made by the National Academy of Sciences and the Army Signal Corps. The Air Force conducted experiments to determine optimum conditions for fungus growth in test chambers. As a result of new knowledge, the fungus resistance test in Specification MIL-E-005272B (USAF) contained a more detailed procedure with limits on the age of the culture from which the spores were obtained and limits on the length of time the spore solution could be kept before use.

Further experience gained from 1957 to 1959 resulted in a reduction to four groups of fungi in Specification MIL-E-5272C (ASG). At least one of the alternate species of each of the five groups in the test of MIL-E-005272B (USAF) was included in a group of the MIL-E-5272C (ASG) test. Procedure I of the fungus test of MIL-STD-810 (USAF) is the fungus resistance test of MIL-E-5272C (ASG) with the addition of a sample of a known nutrient to be included in the chamber to insure that the fungus is capable of active growth during the test. Procedure II of MIL-STD-810 (USAF) is intended for testing small samples of material. This procedure uses Specification MIL-T-8261A (USAF) and contains a considerable amount of useful detail for fungus testing of materials.

4. Discussion of Present Fungus Test

The fungus test procedures used today were developed by qualified mycologists and are the result of both experiment and experience. Fungi are living organisms whose growth rate can be accelerated only slightly and whose sensitiveness to various environmental factors cannot be directly controlled. This places certain limits on test conditions which cannot be changed arbitrarily. The temperature and relative humidity used in the test provide optimum or near-optimum growth conditions for the fungi specified. Experience has shown that the specified length of time is necessary for valid test results. In most cases the cost of continuing the test for twenty-eight days is low compared to the cost of failure of the test item in the operational environment. After a period of time the action of moisture and bacteria may cause conditions which will support fungus growth where it would not have occurred before. The fungus test merely indicates that an item can resist fungus growth for a time equal to the duration of this test. The test item may or may not remain free of fungus growth for longer periods of time in actual service. However, some indication of fungus resistance is highly desirable for military hardware.

Even though materials which support fungus growth are known and can be avoided in the construction of equipment, the equipment should still be subjected to a fungus test to assure that no fungus supporting material has been inadvertently used. Subjection of equipment or systems to a fungus test will also help demonstrate the general suitability of the test item for use in tropical areas.

Recent reports have indicated that bacteria and fungus growth still occur in fuel tanks. Fungus testing of all parts and components used in fuel systems would help solve this problem.

Conspicuously missing from the present fungus test criteria is a clear definition of what constitutes failure. This is not easy to determine because of the complicating corrosion effects of high humidity.

5. Relation of Fungus Tests to Other Tests

The fungus test can also be considered a humidity test for many items. However, the constant temperature and relative humidity conditions of the fungus test do not provide the breathing of equipment which occurs during a humidity test in which the temperature is cycled. Another difference between the fungus test and the humidity test is that temperatures up to +160°F are used in the humidity test compared to a temperature of +86°F used in the fungus test. It might be found that twenty-eight days of low amplitude temperature cycles around +86°F would provide corrosion as great as that produced during the ten days of the present humidity test.

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SECTION 10

SALT FOG

1. Purpose

The salf fog test is conducted to determine the resistance of aerospace ground and aerospace equipment to the effects of a salt atmosphere. Damage to be expected from exposure to salt fog is primarily corrosion of metals. In some instances salt deposits may result in clogging or binding of moving parts. In order to accelerate this test and thereby reduce testing time, the specified concentration of moisture and salt is greater than is found in service. The test is applicable to any equipment exposed to salt fog in storage or usage conditions.

2. Recognition of Problem

Military operations in seacoast and island areas as well as on aircraft carriers revealed serious damage from salt fog to metallic aircraft components and ground support equipment. The deterioration of unprotected light metal components in particular presents difficult maintenance problems. Laboratory tests to determine the relative suitability of materials, coatings and the possible adverse effects of fabrication techniques on aircraft and equipments were needed. A salt fog test conforming to Federal Specification QQ-M-151 was adopted to supply this need.

3. Development of Salt Fog Test Procedures

The salt fog test was first described by J. A. Capp in 1914.[1] The salt fog test is, therefore, the oldest of the environmental tests. The test was widely adopted by the electroplating industry to detect inadequate plating thickness and/or porosity of plated coatings. The paint industry later adopted the test to detect discontinuities in protective coatings. While salt fog testing was widely adopted, there was great variation in test procedures with proportional variation in test results.

The Bureau of Standards and ASTM combined efforts to establish a uniform test. Their effort resulted in the general adoption of a 20% salt solution in a facility operated at +95°F. The reasons given for these two parameters were:

a. When corrosion rates were plotted against various solution strengths, it was observed that the curve was nearly linear in the 20% region. It

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[1] Proceedings of American Society for Testing Materials 14(II)474.

was argued that better correlation between laboratories would result if tests were conducted in the linear portion of the curve.

b. The +95°F temperature standard was adopted to enable operation of a salt fog test facility in almost any part of the country with a simple heating set-up. This also eliminated the need for refrigeration.

c. Specifications QQ-M-151, 27 November 1936, AN-QQ-S-91, 12 December 1938, Army Air Force Specification 41065, 7 December 1945, MIL-E-5272 (USAF), 16 August 1950, MIL-E-4970 (USAF), 1 June 1955, MIL-STD-202B, 24 October 1956, were based on the 20% salt solution. When salt fog testing was applied principally to the testing of coatings, there was little complaint about the 20% salt solution; however, when applied to equipment testing the concentration of the salt solution became a matter of controversy. The 20% salt solution had a disproportionally greater effect on light metals and also greater stimulation of galvanic action in susceptible equipment. Another argument was that a 20% solution caused clogging of the nozzle. Although the nozzle clogging was an indication of improper functioning of the apparatus, complaints grew. By 1956 Federal Test Method Std. No. 151, Method 811, provided for an optional test using a 5% or a 20% test solution. Military Specifications based on Federal Std. 151 in general adopted the optional solution strength. MIL-STD-810 (USAF), 14 June 1962, Method 509, provides for a 5% solution strength unless otherwise specified.

Efforts were made to standardize other parameters such as fog density and saturation of incoming air to fog nozzles. In detail the specifications varied but little from one another; however, wide tolerances left room for variable test results.

4. Discussion of Present Test

Although salt fog is the oldest environmental test, it is probably the most controversial. The controversy stems from misconceptions of what the test is supposed to accomplish. The test was originally adopted to determine the probable relative behavior of two materials intended for use in marine atmospheres and is considered to be valuable for this purpose. The USAF is currently using a salt fog test conforming to MIL-STD-810 (USAF), Method 509. The usefulness of the test for the evaluation of equipments is dependent to a considerable degree on the skill and knowledge of the evaluator. The salt fog test reproduces the natural forces of saline deterioration in kind if not in degree. The evaluator should examine an equipment after exposure to observe evidence of improper design such as water traps as well as covers which may fail to exclude salt fog from unprotected components. These observations must be compared with observations on related equipment that has been exposed to a natural salt fog environment.

The question of correlation of laboratory tests with natural environment is constantly raised. It should be realized that the corrosivity of natural salt fog environment varies from day to day and hour to hour even in the same place. The prospects of devising a uniform laboratory procedure to exactly simulate a complex variable such as world-wide natural marine atmosphere are remote. An incalculable amount of time and money has already been spent for this purpose. Occasionally, by varying one or more parameters of the salt fog test, a researcher gets results that coincide with natural exposure. However, these tests only apply to his particular test samples for the time and place where exposure was conducted. For an example of this see footnote 1.

5. Relation of the Salt Fog Test to Other Tests

Salt fog is capable of producing corrosion of susceptible equipment. Humidity and fungus can also cause corrosion; however, their effects differ from salt fog effects and the tests are not interchangeable.

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[1] Federal Specification QQ-M-151, p. 1.

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SECTION 11

SAND AND DUST

1. Purpose

The sand and dust test is conducted to determine the resistance of aerospace and ground equipment to blowing fine sand and dust particles.

2. Recognition of Problem

Because of the abrasive character of sand and dust, items of hardware having moving parts are vulnerable. Electrical and electronic equipments containing components such as relays, variable capacitors, switches, high-tension electrodes, insulators, etc., are particularly susceptible to dust. World War II studies of U. S. Army ordnance ground equipment revealed a high failure rate in electrical systems due to a dust glaze formed over electrical contacts. Aircraft engines were particularly vulnerable to sand and dust entering through unprotected air intakes.

3. Development of Sand and Dust Test

The problem of sand and dust as related to their effect on military equipment and operations no doubt dates to antiquity. Although antedated by many other reports and surveys, War Department Field Manual FM 31-25 on Desert Operations dated March 1942 recognized the sand and dust problem. The problem became critical during the World War II North African campaign where the allied offensive was seriously curtailed by heavy losses to both land and air vehicles through injection of sand and dust into engines and various other equipments. The urgent need for a solution is evidenced by the intensive studies conducted during World War II. The Australian Government's Division of Aeronautics conducted a sizeable research program. Dust storms were flown into and the dust concentrations at various altitudes were measured. Air Force survey teams were sent to the desert areas of the United States southwest. Towards the end of the war the Air Force Tropical Science Mission collected a number of soil samples from various world areas including Egypt, Tunisia, Hawaii, Philippine Islands, and the islands of Biae, Canton, New Guinea, and Kwajalein. Particle size, concentration, velocity, and temperature requirements were established from these samples and tests introduced into various military specifications. As late as 1956, a comprehensive research program was accomplished by contract for the Air Force[1] to continue the effort for improving the realism and economy of Air Force sand and and dust test procedures.

4. Discussion of Present Sand and Dust Tests

The sand and dust test contained in various military specifications has seen little change over the years. A side-by-side comparison of the test controlling factors taken from various specifications is shown in Table I.

5. Relation of Sand and Dust Test to Other Tests

A deposit of dust on wet or oily surfaces will support the growth of fungi.

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[1] The Dust Environment and Its Effects on Dust Penetration, WADC TR 56-556, ASTIA Document AD 110472.

Table I

Comparison of Sand and Dust Test Control Factors

for Various Specifications

Control Factor	MIL-STD-810A (USAF)	MIL-E-5272C (ASG)	MIL-T-5422E (ASG)	MIL-E-4970 (USAF)
Time and Temperature	2 hrs. at 77°F 2 hrs. at 160°F Note 1		6 hrs. at 77°F 6 hrs. at 160°F	
Relative Humidity	◁——— 30% ———▷			
Air Velocity in ft./min.	100 to 500 Note 2	100 to 500	100 to 300	2, 300 Note 2
Dust Concentration gram/cu. ft.	0.1 to 0.25 Note 1		0.1 to 0.5	

Note 1. Changes in total test time and dust concentration in MIL-STD-810 as compared to other specifications are based on research accomplished in footnote 1.

Note 2. The air velocity of 100 to 500 feet/minute is intended to provide a dust cloud rather than the driving force of 2, 300 feet/minute. The MIL-STD-810 test is designed for equipment installed inside an aircraft and is not performed to determine abrasion. It now appears justifiable that the velocity of 2, 300 feet/minute also be included in MIL-STD-810 for unsheltered ground support equipment. Also, U. S. Army Frankford Arsenal engineers recommend a higher air velocity and larger particle size to more closely correspond to field conditions.

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[1] The Dust Environment and Its Effect on Dust Penetration WADC-TR-56-556, ASTIA Document AD 110472.

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SECTION 12

EXPLOSIVE ATMOSPHERE

1. Purpose

Aerospace and ground equipment operated in or near flight vehicles may be exposed to fuel vapors. Operation of the exposed items must not cause fires or explosions either on the ground or during flight. Items intended for use in or near flight vehicles are, therefore, tested by operating them in ignitible fuel-air mixtures in a test chamber to insure that the item will not ignite the mixture.

2. Recognition of Problem

Fuel vapors are often detected in and near aircraft. This fact and the observance of occasional sparks from electrical and electronic equipment indicated that safety precautions were needed. Explosive atmosphere tests were first included in some electrical equipment specifications in 1938. Since that time safety problems have increased and tests have become more complicated.

3. Development of Explosive Atmosphere Test Procedures

The first test for determining the ignition characteristics of a test item was developed by the Bureau of Standards. Test items were placed in a chamber with a pan of gasoline. After sealing the chamber, heat was applied to the pan to evaporate the gasoline. A blower mixed the fuel vapor with the air in the chamber. The test item was operated, and if this operation did not cause an explosion, the fuel-air mixture was deliberately ignited by a chamber spark plug to demonstrate that the mixture had been ignitible during the test. A paper rupture disc was used to relieve the high pressures of the explosion. The test chamber was not capable of simulating altitude.

In 1948 and 1949 a study was made by the Air Force to determine the scope for explosive atmosphere testing and to devise better test procedures. Of sixty radio and radar equipments tested, twenty-eight caused explosions when operated in potentially explosive fuel-air mixtures. The chamber used simulation to slightly above 40,000 feet. Tests showed that some equipments which did not appear hazardous at low altitudes might still cause explosions at altitudes above 30,000 feet because of arcing and corona which occur only at high altitudes. The explosive atmosphere test procedures which appeared in Army Air Force Specification No. 41065B were based on knowledge gleaned from these experiments.

The first procedure was intended for use in testing equipment not enclosed in cases designed to contain explosions occurring inside the case. The second procedure was intended to test the capability of cases to contain an internal explosion.

Specification MIL-E-5272 (USAF), dated 16 August 1950, contained explosive atmosphere test procedures similar to Army Air Force Specification 41065B except that two complete tests were required in each procedure. One test was conducted with a somewhat low percentage of fuel vapor (lean mixture), and the other test was conducted with a somewhat high percentage of fuel vapor (rich mixture). Specification MIL-E-5272A (USAF), dated September, 1952, used the original test procedure of Army Air Force Specification 41065B, except that the fuel was injected at a simulated altitude of 10,000 feet above the desired test altitude. This assured vapor penetration into partially enclosed spaces as the chamber pressure was increased to that of the test altitude. Specification MIL-E-5272A (USAF) permitted the use of butane as an alternate to gasoline. Butane does not present some of the condensation problems of gasoline.

Research was done in 1954 and 1955 to determine the ignition properties of propane, butane, and aviation gasoline. It was found that gasoline was more easily ignited than the gases under the established procedures. As a result, MIL-E-005272B (USAF) dated 5 June 1957, specified aviation gasoline only with the requirement that three fuel-air mixtures would be used, i.e., rich, intermediate, and lean. Testing experience gained from 1957 to 1959 at WADC indicated that slowly varying the chamber altitude from 5,000 feet above to 5,000 feet below each test altitude would accomplish the same purpose as conducting three separate tests with rich, intermediate, and lean fuel-air mixtures. The knowledge gained was included in the explosion-proof test procedure of Specification MIL-E-5272C (ASG) dated 13 April 1959.

The possibility of using jet fuels for conducting explosive atmosphere tests was investigated in work done from 1956 to 1959. It was found that jet fuels were so involatile that reliable test results could be obtained only if temperatures above 160°F were used in the test chamber. Many items of equipment will not operate properly at these high temperatures, thus making tests with jet fuels difficult. Another reason for using gasoline rather than cause of ignition, therefore, gasoline provides a good test for most test items. Work done at the Bureau of Mines indicated that the minimum spontaneous ignition temperatures of jet fuels are much lower than those of aviation gasolines. Analysis of work done during the past ten years[1] indicates that use of a single component fuel such as hexane might improve test procedures and test validity.

4. Discussion of Present Explosive Atmosphere Tests

The test procedures described in specifications MIL-E-5272C (ASG), MIL-T-5422E (ASG), MIL-STD-202B, and MIL-STD-810A (USAF) are essentially the same.

MIL-STD-810A (USAF) implies that either aviation gasoline or jet fuel will be used. With the simulated altitude varied from 5,000 feet above to 5,000 feet below each test altitude, the one part fuel vapor to thirteen parts air by weight ratio will produce satisfactory fuel-air ratios for either jet fuels or aviation gasoline. This ratio may not be correct for all other fuels.

The simulated altitude is varied above and below each test altitude in order to compensate for variations when calculating the quantity of fuel which should be injected into the test chamber. Changes in relative humidity and temperature can affect the fuel-air ratio. A major problem is that of producing the optimum fuel-air ratio, adjusting temperature, pressure, and relative humidity to simulate the most hazardous explosive atmosphere the test item may encounter in operational use.

5. Relation of Explosive Atmosphere Test to Other Tests

Low Pressure--The explosive atmosphere test can be used as a brief check for proper operation of a test time under low pressure conditions. Occasionally a test item which has passed an altitude test will still produce arcing during the explosive atmosphere test.

High Temperature--The high temperatures (up to 160°F) used in the test create favorable conditions for arcing and corona.

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SECTION 13

IMMERSION (LEAKAGE)

1. Purpose

The immersion test is a gross leak test. It is conducted to determine the integrity of hermetic and gasket seals, and is applicable to all items of aerospace and ground equipment incorporating such features. The immersion test is essentially a quality control test and is intended only as a measure of effectiveness of the seal following the test. The test is not analogous to a particular natural or induced environment.

2. Recognition of Problem

Following assembly of a device intended to be sealed, some means must be employed to determine the effectiveness of the seal or to readily detect a defective seal, partially closed seam or molded closure. Defects of these types can result from faulty construction or from mechanical damage such as might be produced during manufacture and handling.

3. Development of Immersion Test

The first Army Air Force environmental test specification, No. 41065 "General Specification for Environmental Test of Equipment" dated 7 December 1945, did not contain an immersion test. It was during this time period that hermetically sealed devices were introduced into the A. F. inventory. A seal test was included as part of the test program in the individual equipment specifications. During this period the feeling grew that the test should be included in a general test specification rather than in each individual equipment specification. Although not an environmental test, the seal test was included in the first issue of MIL-E-5272 (USAF) dated 16 August 1950 and subsequently in MIL-E-4970 (USAF) dated 1 June 1955. MIL-T-5422, which was closely copied from MIL-E-5272, does not include a seal test. The test was carried forward to MIL-STD-810 (USAF) as Method 512.

4. Discussion of Present Status of Immersion Test

During the preparation of revision "A" to MIL-STD-810 (USAF) the immersion test was re-examined. After careful consideration, the Air Force preparing activity determined that the test should be discontinued based on reasons as follows:

> This test was intended to determine the integrity of hermetic seals and gaskets employed by various devices. Such a test must be accomplished by the equipment manufacturer as part of his production line quality control. Requirements and methodology for this type of testing should be as specified in the detail equipment specification and as provided for in MIL-Q-9858, Quality Control System Requirements.
>
> This test, as originally included in MIL-STD-810 (USAF) cannot be construed to be an environmental test.

The coordination of the "A" revision to MIL-STD-810 drew no adverse criticism to the discontinuation of this test.

5. Relation of Immersion Test to Other Tests

As previously discussed, the immersion test is a quality control inspection type test and is not necessarily related to other environments other than effects induced by shock or vibration.

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SECTION 14

ACCELERATION TEST

1. Purpose

The acceleration test is conducted to determine structural soundness and satisfactory performance of aerospace equipment in a field of steady state acceleration other than gravity.

2. Recognition of Problem

There was little need for acceleration testing a few decades ago. Induced acceleration was so insignificant that the effect on equipment operation was negligible. Although no special problems existed, engineers were quite aware of the effects of acceleration on operational integrity of such mechanisms, as escapements, spring loaded valves, and release devices. Deleterious effects of induced acceleration, or deceleration on structures, equipment, and humans became important as the result of early experiments with rocket sleds and by dive bombers performing a pull out maneuver. High performance aircraft and rockets introduced during World War II presented still more problems.

3. Development of Acceleration Test Procedures

Although there was a general awareness of problems associated with acceleration, it was not until the issuance of the "B" revision of Army Air Force Specification 41065 dated 13 January 1949 that an acceleration test was included. Initially the requirements of the test specified only that an apparatus with a rotating arm capable of acceleration as a continuous force through the range of 0 to 20 g be used. The actual test g level and time duration was left to the individual equipment specification. Additional requirements were included in MIL-E-5272 (USAF) and revisions "A," "B," and "C" thereto, as new criteria were developed. Basic MIL-E-5272 (USAF) contained two acceleration test procedures. Procedure I, primarily intended to simulate stresses induced by a maneuvering aircraft, was difficult to perform and seldom used. The test specified that following stabilization of the centrifuge rotational speed for a period of not less than one minute at the specified g level the test item be rotated 90 degrees about a vertical axis and maintained for a period of not less than one minute while maintaining radial acceleration. Procedure II, designed to test the operational integrity of the test item, resembled Procedure I in most respects except that the test item could be rotated through each of its three major axes in successive steps. Of the two procedures, the latter test was most commonly used. These same two tests were carried forward to MIL-E-005272B (USAF) without change. With the promulgation of MIL-E-5272C (ASG), the difficulty in performing Procedure I, and certain weaknesses in Procedure II were recognized. Procedure I was included unchanged for use by those capable of performing the test. Procedure II was discontinued and a new Procedure III was prepared; the intent of which was to provide a more workable test. This procedure contained the following basic requirements:

a. That the test item be tested in turn for one minute in each direction along each of its three orthogonal axes

b. That the acceleration along all axes be 14 g if the mounting position of the test item is not known, 14 g along the vertical axis downward and 6 g in all other directions if the mounting position is known

c. That the specified g level be applied to the geometric center of the test item

d. That the centrifuge arm be at least five times as long as the test item.

4. Discussion of Present Acceleration Test

The acceleration test contained in MIL-STD-810 (USAF) Method 513 encompasses the general requirements of preceeding acceleration test such as test time duration, minimum size of centrifuge, axes and directions of mounting of the test item, etc. The determination of test levels was based on the assumption that in most cases the thrust and thus the acceleration is one of the initial parameters determined or specified in the planning or developing of a weapon system or aerospace vehicle. These determinations are usually reached long before the development of supporting hardware. Therefore, when the design factors are specified for the supporting equipment, the location and g levels anticipated would be known. The multipliers given are based on actual data. However, these data are based on scanty field measurements and test envelopes developed from past experiences. The envelopes given represent the approximate severity of the upper quantile of data considered and do not cover extreme or unusual environmental conditions. Tables 513-I and 513-II in MIL-STD-810 (USAF), Method 513 were developed with the close cooperation of the Ballistic Missile Division, USAF, and NASA personnel. The data are based on existing measurements and what is assumed to be a reasonable extrapolation of near future requirements. Irrespective of the particular care exercised in developing these tables it is emphasized that the data are not definitive or mandatory. The envelopes are presented to the design engineer as suggested g level estimates which are considered reasonable in the absence of known data.

5. Relation of Acceleration Test to Other Tests

In performing the acceleration test separately and unrelated to other natural and induced environments, the results should be considered only as an estimate of structural and operational suitability of an equipment.

In reality, the acceleration test is closely related to any other environment which can change stress levels or induce motion into the test item. Further, sustained acceleration usually intensifies or even accelerates effects of other environments such as vibration, noise, and shock. Temperature gradients and extremes should also be considered as a related environment. Any environment which can affect the stress resisting ability of the test item such as abrasion, salt fog, particle impacts and sputtering should not be ignored.

These related environments should be seriously considered for inclusion, as applicable, in any test involving sustained acceleration. It is only through such a combined test that a true assessment can be made of an equipment as related to its intended mission.

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SECTION 15

VIBRATION

1. Purpose

The vibration test is conducted to determine the susceptibility of aerospace and ground equipment to the dynamic stresses encountered in transportation and operational use.

2. Recognition of Problem

Vibration effects are difficult to anticipate because of the problem in analyzing attenuation or amplification of applied loads.

Anything which can conceivably shake or jar loose is suspect. Electrical or electronic parts may arc due to displacement or distortion of high voltage elements. Relays or contact points may open, bounce, or close. Vibration may cause fatigue and failure of mounting bases, oscillation of instrument indicating pointers, bouncing of motor and generator or brushes, and loosening of nuts, screws, etc.

3. Development of Vibration Test Procedures

Although a recognized problem, the vibration environment received little scientific treatment until World War II. Testing accomplished early in the war left much to be desired in the standardization of requirements and procedures. Various laboratories employed different philosophies and test techniques for hardware falling within their responsibility.

The vibration test procedures contained in Army Air Force Specification 41065 dated 7 December 1945 represented the first attempt to standardize test methods. The g levels and other conditions specified applied primarily to reciprocating engine aircraft of that period. Although the frequency range specified was from 10 to 2,500 cps vibration machines available in 1945 were incapable of generating frequencies above 85 cps.

MIL-E-5272 (USAF) dated 16 August 1950 recognized vibration resulting from both reciprocating and jet engines. In converting MIL-E-5272 (USAF) to MIL-E-5272C (ASG), it was necessary to delete some test procedures and modify others to meet naval requirements. Along with MIL-E-5272, intended for aeronautical and associated equipment, was MIL-T-5422 used only for aircraft electronic equipment. A third specification, MIL-E-4970, provided tests for ground support equipment.

In preparing the vibration tests for MIL-STD-810 (USAF), it was necessary to reconcile the differences among these three specifications. Also included was new criteria for ground and air launched missiles and space vehicles which, prior to this time, had not been considered.

4. Discussion of Present Vibration Tests

Certain newly developed vibration criteria are unique to MIL-STD-810 (USAF). For example, a family of vibration test curves are offered which vary in severity, depending on the location of the equipment within the vehicle. Also included is a new requirement that the test item demonstrate proper operation during vibration cycling and resonance dwell; ground launched missiles excepted.

Air launched missiles are considered for the first time in the vibration test. During the first test phase the missile is exposed to a vibration test such as that imposed on the equipment located within the aircraft. This is justified by the fact that the missile is attached directly to the aircraft and is essentially a piece of aircraft hardware until it is launched.

The vibration test curves of Method 514, intended for testing aircraft hardware, are similar to the curves of previous specifications. The frequency range of applied vibration is still 5 to 500 cps for all test curves except for equipment to be mounted directly onto an aircraft engine. The 500 cps frequency limit has been retained because the vast majority of measured data recorded at various equipment locations throughout modern aircraft have indicated insignificant amplitudes at higher frequencies. The test curve required for engine mounted hardware extends to 2000 cps because significant amplitudes have been recorded on some newer high thrust engines within this extended frequency range.

The vibration test curves for equipment to be installed in helicopters were basically unchanged from Specification MIL-T-5422E (ASG). Data recorded aboard recently developed helicopters did not indicate a need for change. The test curve for equipment designed for installation on vibration isolators, but to be tested without the isolators, was modified at the lower frequencies. A double amplitude of only 0.01 inch at frequencies below 65 cps is an unrealistically low value compared to measured data.

The aircraft vibration curves which apply to air launched missiles specify vibration levels and frequencies on the basis of the aircraft test environment at the missile location on the aircraft. These are comparatively long duration tests employing sinusoidal cycling and resonance dwell testing representing the aircraft environment. The missile receives a free flight vibration test, consisting of both a sinusoidal cycling test through a frequency range extending to 2000 cps, and a random vibration test, representative of the rocket engine generated vibration. For the free flight vibration tests, the severity of the test level varies according to the thrust to weight ratio. This approximates measured data. Greater thrust missiles and greater thrust to weight ratios produce increasingly severe vibration.

The vibration tests for ground launched missiles are categorized so that the least severe vibration exists in the forward compartments. The tests increase in severity towards the rear of the largest booster. Vibration levels, generally, are within a 5 to 10 g range of severity for equipment locations forward of the boosters, increasing in severity in the booster stages according to the amount of power or thrust delivered. Sinusoidal cycling and random vibration tests are required. Both types of vibration often prevail in solid rocket boosters. The random vibration test spectrum of Method 514 is shaped to provide an acceleration spectral density with the primary energy in the frequency range between 100 cps and 1000 cps. The acceleration spectral density curve is rolled off above

1000 cps, which is in general agreement with data at most locations on high thrust rocket boosted vehicles. This effect usually is more pronounced as the size of the booster increases and there are generally higher vibratory acceleration levels at lower frequencies as the booster increases in size.

The vibration tests for equipment to be installed in ground vehicles remain essentially unchanged from Specification MIL-E-4970 (USAF). The upper frequency limit of the test curves may be reduced for items of equipment which weigh more than approximately 140 pounds. A 60 cps upper frequency limit is the maximum required for items which weigh 300 pounds or more.

The vibration tests of Method 514 which apply to items to be shipped by common carrier, and to items of ground equipment which otherwise do not recieve a vibration test, are practically the same as the tests specified in MIL-E-4970 (USAF). The upper frequency limit of the test curve, which has a 500 cps upper limit, may be reduced for items of equipment which weigh 100 pounds or more.

5. Relation of Vibration Test to Other Tests

Temperature extremes are considered to be the only factor which, when combined with vibration, contribute to malfunction or failure.

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SECTION 16

ACOUSTICAL NOISE

1. Purpose

The acoustical noise test is conducted to determine the effects on aerospace equipment of acoustic sound fields that are characteristic of jet aircraft, missiles and other such high performance vehicles. The present acoustical noise test is not intended to be a substitute for, but rather an extension of the conventional sinusoidal or random vibration test.

2. Recognition of Problem

In aircraft employing reciprocating engines, vibration is transmitted through the vehicle structure to the various equipments. The early 1940's saw the development of vibration isolators to protect equipments from this source of mechanically induced excitation. The sound field, as a source of excitation, resulting from piston engines was not of sufficient magnitude to be of concern; however, the introduction of jet and rocket engines presented a new problem. The intense sound field generated by such engines can excite the structure to which the equipment is mounted or result in air induced vibration which impinges directly on the surface of the equipment.

Analysis of acoustic noise fields reveal frequencies of at least 3,000 cps and greater. For bulky test loads the generation of these higher frequencies often exceeds the simulation capability of existing vibration shakers. The energy developed at these higher frequencies can have destructive effects on small or miniaturized devices containing components with high natural frequencies and low internal damping. Examples of such microphonic devices are electron tube elements, piezoelectric crystals, semi-conductor and solid state device junctions and terminations, and miniaturized relay parts.

3. Development of Acoustic Noise Test

The acoustic noise test is one of the more recent additions to the environmental family. Research work necessarily preceeded the formulation of a test procedure. In 1959, under Air Force contract, an acoustic research facility was constructed for generating high intensity sound from 50 to 10,000 cps with a power output of 22,000 watts resulting in a sound pressure level of approximately 174 db.

Experiences gained and results of tests performed in this facility provided the criteria for the first acoustic noise test specification MIL-A-26669 (USAF) dated 14 July 1959. In preparing MIL-STD-810 (USAF), the MIL-A-26669 acoustic noise test was included as test Method 515. When MIL-STD-810 (USAF) was released, MIL-A-26669 was cancelled.

4. Discussion of Present Acoustic Noise Test

The acoustic test can be especially valuable in the higher frequency regions, for example, above 500 cps. When the test item is mounted directly to the shaker table, energy will be introduced only through the test item mounting lugs. It can not be assured that the high frequency input at the mounting lugs will be transmitted, without attenuation, to small parts within the test item which may be susceptible to high frequency excitation. A high frequency sound source, on the other hand, may work directly on the part.

5. Relation of Acoustic Noise Test to Other Tests

Temperature extremes are considered to be the only factor which, when combined with acoustic noise, contribute to malfunction or failure.

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SECTION 17

SHOCK TEST

1. Purpose

The shock test is conducted to determine whether the structural integrity and performance of aerospace and ground equipment are satisfactory with respect to the mechanical shock environment expected in handling, transportation and service use.

2. Recognition of Problem

The service and transportation environment consists of a great variety of mechanical shocks many of which can be severe enough to damage equipment. Rough handling shocks caused by production line handling, transportation handling, warehouse handling and handling by service and maintenance personnel are a serious problem. Rough landing impacts in aircraft and crash landing impacts provide two different conditions to be guarded against. Staging shocks due to explosive separation in space vehicles provide a wide range of input shocks plus many other types of shock.

3. Development of Shock Procedure

The first Air Force specification to contain a shock test was revision "B" to Army Air Force Specification 41065. The shock tests were specified at 175 g at a duration of .003 seconds, 40 g at a duration of .010 seconds and 15 g at .015 seconds. Such a specification today appears to be rather crude since it did not define either the pulse shape or the machine characteristics. The wording of the specification could be interpreted in various ways and there would be no equivalency between tests performed under the various interpretations. Each equipment was subjected to all three shocks. Each shock was applied three times in each of six axial directions (a practice still used in MIL-STD-810 (USAF)).

On 16 August 1950, 41065-B was superseded by MIL-E-5272 (USAF). This specification required shock machines in accordance with specifications JAN-S-44, 7201 (USAF) and 6683 (Navy). The JAN-S-44 used an elastic leaf spring to provide a half sine shock pulse. Durations are controlled by varying the table load (including test item) and changing springs to change the spring rate. The 7201 machine provided an inelastic shock of rather complex waveform. The shock was controlled by allowing penetrators (2 inch wide boards) on the table bottom to impact on a loose, level sand surface. The number of boards used controls the depth of penetration into the sand and, therefore, controls,the duration. The acceleration is controlled by adjusting drop height. The 6683 machine is the Navy light-weight high-impact shock machine. This machine has a vertical drop hammer and a pendulum hammer capable of producing shocks of complex waveform in three mutually perpendicular directions on an equipment. The shock magnitude is controlled by the drop heights of the hammers.

For the JAN-S-44 and the 6683 machines, magnitudes and other variables were as specified in the individual equipment specification. Procedure II specified the 7201 machine and also the magnitudes and duration. A 15 g, 11 millisecond test was specified for the first time. This test was derived from environmental data on aircraft landings and is intended to simulate landing shock conditions. The equipment was required to survive this environment in an undamaged condition. A 30 g, 11 millisecond test was also specified. Dummy equipment could be used and damage was allowed so long as the equipment did not tear loose from its mounting position. This test was devised to assess mounts and restraining devices used to prevent equipment from breaking loose and killing or seriously injuring personnel involved in survivable crashes.

MIL-E-5272C (ASG) was issued on 13 April 1959. This specification included one major change in the JAN-S-44 requirements. A 50 g, 8.5 millisecond test was introduced to be used when the individual equipment specification did not choose the values.

The procedure in MIL-S-4456 was changed to require a filter with a band pass of 5 to 100 cps in the instrumentation. Such a filter removed all components of higher frequency and the waveform of the machine appeared to be a half sine. This placed restraints on the frequency characteristics of the instrumentation for the first time. The filter simplified measurement of decelerations and durations involved and introduced some standardization. It also improved reproducibility of the records. It has the disadvantage of distorting the waveform with possible misinterpretation of the results.

MIL-E-4970 (USAF) for ground support equipment was first published on 1 June 1955 and divided ground support equipment into four catagories for test purposes. For vehicular equipment expected to operate under shock conditions, a 10 g, 11 millisecond shock on the MIL-S-4456 machine was specified with the equipment not operating. The justifying data for this test is not readily available but one might assume that it is at least partially based upon measured data from the Munson test course at Aberdeen Proving Grounds. Two procedures were given for testing equipments in transit cases or packages. The first of these called for a 20 g, 11 millisecond shock on the sand pit machine. In view of the shipping environment, this hardly seems adequate. The second method called for flat drops on each of three mutually perpendicular faces. Drop heights varied from 12 inches for items over 500 pounds to 42 inches for items less than 20 pounds. The logic behind this test is also not available, but it is noted that the maximum height is approximately the height of the tailgate of a truck. It is also noted that more care is used in handling heavy items than light items. The specification appears similar to those in use in the packaging industry and may have been derived from a packaging specification. A test for whole vehicles was included. The vehicles were driven or towed over washboard, Belgian block and single corrugation courses at varying speeds up to 20 miles per hour. Mobility tests of MIL-M-8090 are specified for those vehicles to which these requirements were not applicable. MIL-M-8090 requires roadability tests over fairly smooth roads to rough terrain and Belgian blocks. The severity of this test depends upon the end use of the vehicle. The test course provides the shock inputs. Bench handled equipment was given a test in this specification. This test simulated rough handling by maintenance and repair personnel. It consisted of raising one end or side of the equipment four inches while the opposite end or side remained on a level table and then dropping it. It is doubtful if this test involves any environmental measurements. It appears, therefore, to be based upon such factors as experience and apparently reasonable assumptions of shock possibilities.

MIL-E-4970A (USAF) was published 3 March 1959. In this specification the requirements for washboard, Belgian block, etc., tests were eliminated. The 20 g, 11 millisecond test was required for all transit cased or packaged equipment. Alternate tests were allowed when a suitable machine was not available. The alternate procedures included a somewhat expanded series of drop tests. These tests were similar to those of MIL-P-7936, a packaging specification for aeronautical parts and equipment. The alternate procedure also called for one of two impact procedures for items over 200 pounds or having any dimension greater than 60 inches. The pendulum impact test was performed by suspending the item from at least 16 feet height on ropes, cables or chains. The center of gravity is raised and the test item is released so that impact occurs against a barrier when the item reaches the bottom of the pendulum arc. The other impact test consisted of mounting the test item on a rail-guided cart on an inclined plane. A barrier was mounted perpendicular to the plane at the bottom of the plane. The cart was then pulled up the plane and released to coast down the track and impact the attached test item against the barrier at the bottom. Impact velocity was controlled by the vertical height from which the cart is released. These two tests are common in the packaging industry and are designed to simulate velocity shocks incurred during railroad humping and switching operations.

In addition to these specifications, other general specifications for equipment included shock requirements and many individual equipment specifications had a variety of shock requirements. Most of these were similar to requirements in the above specifications. In addition to these, packaging shock specifications are stated in many documents. The most notable of these are MIL-P-116 and MIL-P-7936. Shock tests to insure air transportability of equipments are incorporated in MIL-A-8421. Shocks of 1.5 g and 3 g for 100 milliseconds are specified for flight and taxiing loads. Shocks of 4.5 g and 8 g for 100 milliseconds are specified for crash landing loads.

In the early 1940's M. A. Biot developed a method of reducing earthquake data to a form which shows the effect of the earthquake motion on the response of single degree of freedom systems having natural frequencies covering a range of interest. Plots of the maximum values of response versus the frequency of the system were made and referred to as earthquake spectra. In 1948 Walsh and Blake applied the method to other shock motions and called the resultant plot a shock spectrum. The shock spectrum gives a direct indication of the damage potential of a shock when applied to an equipment whose natural frequencies lie within the spectrum. The spectra of many shock motions have been determined and reported. The study of the spectra of these motions has led to some very important new concepts for specifying an equipment shock test. Industrial contractors have developed documents specifying the shock spectrum rather than the machine or the motion. In other cases the shock motion (pulse) has been specified for the reason that it produces a nearly ideal test spectrum. The most important of these was industry developed specification GM43.5-40. This specification requires that the shock spectrum of the test motion have a value of at least 100 g's in both positive and negative directions between the frequencies of 100 and 700 cps. Although this specification avoids the problem of specifying a pulse, a preference is given for a terminal peak sawtooth which rises to 100 g in six milliseconds and drops abruptly to zero. Since the natural frequencies of all the elements and components are not usually known, it is desirable that the shock test induce equal acceleration responses throughout the range of probable natural frequencies of the equipment. A study of the shock spectra of various unsymmetrical pulses shows that the spectrum requirement can be met by a large number of unsymmetrical pulses. Symmetrical pulses have acceleration values of zero at repetitive intervals throughout the negative spectrum and cannot meet the requirement. This, of course, rules out the use of half-sine pulse machines. The ideal sawtooth pulse has the additional advantages of having a more nearly constant acceleration throughout the frequency range and the negative spectrum is the mirror image of the positive spectrum. In a practical sawtooth, the acceleration cannot drop abruptly to zero due to elastic rebound which cannot be completely eliminated in any realistic test. This effect causes the negative spectrum values to decrease as frequency increases. Some proponents of the sawtooth use the ideal spectrum as a reason for testing in one direction only on each axis, since responses in both directions (positive and negative) are excited to equal acceleration amplitudes.

4. Discussion of Present Shock Test

MIL-STD-810 (USAF), published 14 June 1962, included three major departures from previous military shock specifications. The most important departure from previous specifications was the removal of the requirements for use of specific shock machines. It is believed that specifying the test machine discourages the development of newer, more efficient machines and methods. Instead of specifying the machine, the waveform is specified. As a result, a large variety of shock machines are now capable of producing MIL-STD-810 (USAF) shocks. Some of these machines are great improvements over those specified in MIL-E-5272 and other previous documents. Reproducibility is much better in the newer machines, in fact, in one experiment with one manufacturer's machine, a nearly perfect reproducibility was obtained.

A high degree of versatility is also present in many of the modern shock machines. Many of these machines can produce a large variety of waveforms. The most versatile with respect to waveform are pneumatic hydraulic and electrodynamic shaker types. The modern shock machines also present much higher impedances to the test item in the range of natural frequencies of most test items.

Fundamental table resonance above twenty kilocycles for the smaller shock machines are possible. One further important advantage of specifying the pulse characteristics (particularly simple pulses) is the fact that the shock pulses can be represented as simple mathematical forcing functions as follows:

Half-sine: $a = A \sin \omega t$

Sawtooth: $a = \frac{At}{T}$

where: a is acceleration, ft/sec/sec; A is acceleration peak value, ft/sec/sec; ω is circular frequency, rad/sec; t is time in seconds; T is pulse duration, seconds; and $0 \leq t \leq T$.

This feature enables an equipment designer to use any one of several mathematical design procedures. The acceleration time function may be used directly for the solution of the differential equations of motion of systems.

Another important departure from previous specifications is in the specification of certain characteristics of the measuring system including frequency response. This is an important advance in specifying shock tests because it recognizes the important role the instrumentation plays in shaping the recorded pulse. These requirements are meant to provide a minimum fidelity record of the voltage analog of the shock motion. This eliminates past practices of shaping the output signal to look like a half-sine wave with a low-pass or band-pass filter.

The third most important departure from previous specifications is the introduction of the high intensity 100 g, six millisecond terminal peak sawtooth shock test. This marks a significant advance because this test is based on the results of research into the shock spectrum method of analyzing and applying data. This test was considered to be useful for small, dense, hard-mounted electronic items in aerospace vehicles.

Following the basic issuance of MIL-STD-810 (USAF), several deficiencies and errors were discovered. These discoveries resulted from the MIL-STD-810 Dynamics Conference held at the Aeronautical Systems Division on 5-6 December 1962. For instance, an examination of the shock spectrum of MIL-STD-810 (USAF) half-sine pulses indicated that the relative motion spectrum has amplitudes somewhat less than the amplitude of the input pulse for frequencies greater than 125 cps and that these amplitudes decrease rapidly as the response frequency increases. From the standpoint of shock damage, it is the relative motion spectrum which has the greatest importance. It is also noted that the response amplitudes vary widely as a function of frequency. This condition would be satisfactory if the 11 millisecond, half-sine pulses were truly representative of the environment. It is, however, illogical to believe that the actual environment is composed entirely of the half-sine pulses. In actual practice, equipments receive many and varied shocks between the production line and the scrap pile at the end of their useful life. It is entirely probable that elements of equipments having natural frequencies as high as 700 cps may be excited to significant relative response amplitudes. At the time the original 11 millisecond half-sine tests were fostered, the significance of the shock spectrum was not well understood. With increasing availability of information concerning the shock spectra of various shock motions, the sawtooth test and several methods for producing it were developed. The logic behind this test was explained in Paragraph 3. In view of the foregoing, the half-sine test was eliminated in revision "A" to MIL-STD-810 (USAF) and replaced by a test capable of providing significant responses in the test item. Also in revision "A", Procedure II was deleted as an entirely unrealistic transit test. This can be readily understood when it is realized that this test represents a free-fall drop of only 3.5 inches on rubber pads, whereas an actual drop may be as high as 36 inches onto a concrete surface as an example of rough handling by truck drivers or other handlers in the transit phase. In lieu of this test Procedure III is substituted.

5. Relation of Shock Tests to Other Tests

In the large majority of cases the effects of shock will be essentially unmodified by other environments; a few environments, however, have a very decided effect on shock tests. At extreme low temperatures, isolation materials may increase stiffness and fail to isolate shocks. Other materials may become brittle and highly susceptible to shock damage. High temperatures will cause the opposite effects, i.e., a decrease in stiffness of isolators and also a decrease in stiffness of elements of the equipment under test. This condition can cause bottoming of isolators and collision of adjacent parts. In plastics and visco-elastic materials in general, the combination of shock and high temperature can cause irreversible deformations.

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SECTION 18

LOW PRESSURE-SOLAR ENERGY

1. Purpose

Space environments are simulated in ground facilities to determine whether aerospace vehicles such as satellites, instrumentation packages, spacecraft, and space stations can withstand the deleterious effects of combined space environments. Such environments include solar radiation, low pressure, temperature gradients, and natural heat sink conditions.

2. Recognition of Problem

It was realized early in space vehicle development that a large percent of failures were probably due to inadequate testing to the environments of lift-off and earth orbit. It was also realized that the highest order of reliability would be necessary before the system could be man rated.

One of the major problems has been, to provide in one facility, all of the environments to be encountered by a space vehicle from launch to landing.

Some environments of space such as weightlessness, micrometeorite hits, etc., will be extremely difficult if not impossible to attain in an earth bound laboratory.

3. Development of Low Pressure-Solar Energy Procedure

Space environment testing has developed since 1957 at a rapid rate. Most testing is related directly to a specific program having a satellite or other space vehicle as the final product. This testing is supervised by the particular government agencies and industrial companies concerned. Some general guidance is required in order to establish test procedures which will allow comparison of results.

Test Method 517 of MIL-STD-810 (USAF) dated 14 June 1962 was the first Military Standard intended for general usage to contain a test procedure for some of the space environments. Since the exact requirements for a particular test depend on the intended mission of the test item, the procedure outlined in MIL-STD-810 (USAF) offers only general guidance and is intended mainly to focus attention on the problems which should be considered. Test Method 517 is based on suggestions made by the Air Force's Space Systems Division and the Arnold Engineering Development Center.

4. Discussion of Low Pressure-Solar Energy Test

Testing which requires simulation of space environments may be divided into the categories of materials, temperature distribution determination, and equipment operation.

Laboratory scale materials testing often permits more complete determination of space environmental effects than is possible when conducting large scale tests on complete assemblies. For example, effects of far ultraviolet light (1 to 2000A) on materials can be investigated with small samples of material. Production of this far ultraviolet light is possible for a small test area, but is not considered economically feasible for large test areas. Investigations conducted by the National Research Corporation for Arnold Engineering Development Center have shown that far ultraviolet light has little effect on most materials of engineering interest. This means that production of far ultraviolet light in large space chambers is usually not necessary. Other types of materials testing include sublimation studies, fatigue testing, meteorite penetration studies, and evaluation of effects of nuclear radiation. The environmental testing of materials is not usually considered in general specifications or standards. These specifications are intended for use in testing equipments and systems. Knowledge of the properties of materials must be used to select materials which will allow the equipment or system to perform its mission in the operational environment.

Space environmental testing is often conducted for the dual purposes of checking equipment operation and establishing temperature distributions across and through the test time. Production of pressures lower than 1×10^{-4} mm. of Hg. and simulation of thermal sources and sinks found in space is necessary to establish proper temperature distributions for a test item. Known materials properties and the flight path of the intended mission can be used to predict the approximate temperature of a spacecraft, but the accuracy of these predictions may be improved by proper simulation of solar thermal radiation, planet albedo and thermal radiation, and the heat sink of black space.

Since the effeciency with which a given material absorbs, reflects, and radiates light and heat depends on the wavelength of the energy involved, it is necessary to reproduce the spectral distribution of the heat sources in order to produce correct test item temperatures. Recent developments have made possible rather close simulation of the solar spectrum. A suggested spectral distribution for possible inclusion in future specifications is presented in Table II.

Table II

Solar Electromagnetic Energy Distribution

Wave Length Band (angstroms)	% of Total Energy	Allowed Variation of Band Energy %
1800-2500	0.2	±15
2500-3300	2.8	±10
3300-5000	20.0	±10
5000-7000	26.0	±10
7000-9000	17.0	±10
9000-11000	11.0	±10
11000-15000	12.0	±10
15000-30000	11.0	±10

Total energy shall correspond to actual total energy at the distance from the sun of the intended mission of the test item with a tolerance of ±3%.

The far ultraviolet part of the solar spectrum contains a small enough amount of energy to be neglected for thermal tests. Light in the far ultraviolet region may occasionally be required for evaluation of instruments sensitive only to this radiation.

The solar electromagnetic radiation flux would be constant across the area of the beam intercepted by a space craft, but the sun would occupy only a small part of the field to which the space craft would radiate. This condition is difficult to simulate in a ground facility. A collimated beam is required, but the portion of facility wall area used for the entrance of the solar beam should be small.

Simulation of planet albedo and thermal radiation is difficult because of the changing relative positions of the planet and spacecraft during a simulated flight. Production of simulated planet albedo and thermal radiation is necessary only when attempting to determine temperature distributions for the test item for a part of the intended mission near a planet or moon. Each such test will require analysis of the problem and arrangement of the test installation for the particular problem.

The radiation temperature of space when not looking at the sun or a near planet or moon is about 4°K. Production of this very low temperature over large wall areas in space chambers is both uneconomical and unnecessary in most cases. A wall temperature of 100°K is usually sufficiently low to provide temperature variations of less than 5°C from the temperatures of the test item that would exist if the chamber walls were at 4°K.

When temperatures at which the test item will operate during actual usage are considered to be sufficiently well known, and effects of solar radiation are considered negligible, the test item may be maintained at the desired temperature by any suitable means without the necessity of simulating the spectral distribution and geometry involved under conditions of intended use. This means that a relatively simple vacuum chamber may be used to test the operation of equipment at expected operating temperatures and pressures. Proper heat sinks must, of course, be provided for any cooling systems involved.

Equipment operation should be tested at low pressure in order to insure that moving parts do not bind, that cooling systems operate properly, and that electrical characteristics are satisfactory. Maintaining the test item at the highest expected operating temperature during the low pressure test will provide the highest rate of outgassing and place the greatest load on any cooling system. Testing at low temperatures will produce stresses on certain parts and materials. The pressure used during the low pressure tests should be the lowest pressure expected during operational use if it is possible to produce this pressure.

5. Relation of Low Pressure-Solar Energy Test to Other Tests

Tests and facilities designed to simulate conditions encountered by a space vehicle involve sophisticated combined environments of the highest order.

It would be highly desirable to provide facilities or space chambers capable of generating the entire gamut of environmental conditions encountered by a space vehicle from launch to landing; however, such a simulator is not technically feasible.

As previously discussed, conditions which present formidable simulation problems are weightlessness and the velocities required to simulate hits by meteoroids. Although not impossible, the effects on both vehicle and occupant resulting from cosmic and nuclear radiations will be difficult to simulate.

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CHAPTER III

SUMMARY

The environmental tests discussed in the preceeding pages do not comprise all of the required testing of a complete system to the entire gamut of terrestrial and space environments.

Tests involving the earth's weather, i.e., wind, snow, hail, sleet, and lightning are not included. Such tests are accomplished by actual flight testing and exposure at outdoor sites or in the all-weather climatic hangar located at Eglin Air Force Base, Florida.

The environmental tests discussed in this report are, for the most part, treated as individual stresses.

With the exception of the temperature-altitude test, and the low pressure-solar energy test,procedures as now organized do not intentionally combine two or more environments for the purpose of determining mutually debilitating effects.

The philosophy and need for combined environmental testing are open to exploration.

The purpose of this report is to provide a historical document on the development of environmental test methods employed by the USAF. In the pursuit of this effort no new environmental test criteria were developed therefore; data contained herein are not applicable to the updating of existing environmental test specifications.

APPENDIX I

COMPENDIUM OF CHANGES FOR REVISION A TO MIL-STD-810 (USAF)

All references to page, section, paragraph, and line numbers refer to the basic issue of MIL-STD-810 (USAF) dated 14 June 1962.

A considerable number of minor editorial changes were made to clarify intent, correct errors, realign figure numbers, etc. To include such changes here would serve no practical purpose; therefore, only those changes which bear some technical connotation are reported.

Page 3, Section 3, Paragraph 3.2.4, Line 4.

Following the words "...from the test." a new paragraph was inserted as follows:

"Normally the test item shall be removed from the test facility prior to inspection as stated in the various test methods. However, in those instances where the installation of the test item in or on the test facility is complex, costly, or time consuming, the performance of the inspection may be accomplished with the test item inside or on the test facility providing all inspection criteria can be met as stated herein. (If a test chamber is used and the inspection is performed inside the test chamber, the test chamber shall be returned to conditions of room ambient temperature, atmospheric pressure and relative humidity before proceeding with the inspection.)"

The existing sentence is then continued, i.e., "Deterioration, corrosion, etc...."

Reason: To satisfy complaints that the test item must be removed from the test chamber and reconnected to associated test apparatus before final test thereby resulting in additional cost and time.

Page 3, Section 3, Paragraph 3.3.2.

Following subparagraph b. Pressure, changed to read:

When measured by devices such as manometers, plus or minus 5 percent or 0.06 inches Hg, whichever is greater. When measured by devices such as vacuum ion gauges, plus or minus 10 percent to 1 x 10^{-5} torr.

Reason: With reference to the addition of "or 0.06 inches Hg, whichever is greater," when using a mercury manometer at the lower pressures the "thousands of feet scale" becomes greatly compressed and only an approximate reading can be taken. Therefore, a ±5% tolerance of such a reading could result in an error of several thousands of feet. However, this tolerance will be satisfactory at higher pressures where the scale is expanded and can be read with greater accuracy. For the lower pressures a mercury manometer calibrated in inches or millimeters of mercury would normally be used. In this instance a tolerance of 0.06 inches of mercury will be more factual. With reference to the addition of "to 1×10^{-5} torr," it is considered that 10% of any value of pressure lower than 1×10^{-5} torr would be so small as to be meaningless.

Method 503
Temperature Shock

Page 503-1, Paragraph 2, Procedure 1, Line 10

Following the Sentence ending with "(-40°F).", a new sentence was added as follows:

"With the consent of the procuring activity, large or heavy test items shall be transferred from one chamber to the other in the minimum time practicable."

Reason: To satisfy complaints that large or heavy test items could not be transferred in the specified time period of five minutes.

Page 503-1, Paragraph 2, Procedure 1, Line 23

Following the words "test chamber", the remainder of the paragraph was deleted and the following was substituted:

"and stabilized at room temperature. The test item shall then be operated and the results compared with the data obtained in accordance with Section 3.2.1. The test item shall then be inspected as specified in Section 3.2.4.

Reason: Large bulky test items may not return to room temperature within the one hour period as previously specified.

Method 504
Temperature-Altitude (Cycling)

Page 504-1, Paragraph 1

The purpose paragraph was reworded by removing the first three lines and inserting the following:

"1. PURPOSE. The temperature-altitude test is intended primarily for electronic equipment installed in aircraft capable of operation from sea level to 100,000 ft. Before applying this test to other types of aerospace equipment, the test conditions and procedures specified in this test method should be carefully analyzed for applicability. Aerospace equipment installed in space vehicles, satellites, etc., should be tested in accordance with Method 517 of this standard. The temperature-altitude test is conducted to determine the ability of "...continue with original line four.

Reason: Confusion has resulted in attempting to apply this test to space vehicles. The purpose paragraph has been reworded to eliminate this and other misunderstandings. The altitude of 80,000 feet has been criticized as being inadequate for certain conditions of operation. Accordingly, a maximum altitude of 100,000 feet has been established throughout the test method. The adoption of this altitude with associated changes in temperature for Class 3 and 4 equipment brings this test method up to date with changed requirements in MIL-E-5400F(ASG) and upcoming changes to MIL-T-5422 (ASG). Temperatures were reduced in consideration for the fact that those originally stated were unrealistic for storage conditions. The adoption of these changes has resulted in changes to the following figures and tables in this test method:

Table 504-I (Class 3 and 4 Equipments) Table 504-II (Class 3 and 4 Equipments) Figure 504-3 (Class 3 Equipment) Figure 504-4 (Class 4 Equipment)	Equipment non-operating Class 3; high temperature was changed from 150°C to 125°C; and for Class 4, from 260°C to 150°C.

Method 506

Rain

Page 506-1, Paragraph 2, Line 18

In the sentence beginning with "The direction...etc.", the words "capable of variation up to" were deleted.

Reason: The requirement for the capability for 45° rainfall is specified in MIL-C-8811, Chamber, Rain, Testing. The intent here is to specify that the rainfall shall be applied at 45° from the vertical during the test. (Impingement of the water at 45° on the test item, plus line pressure, plus velocity is intended to simulate wind driven rain.)

Method 509
Salt Fog

Page 509-1, Paragraph 2, Subparagraph b

Changed to read as follows:

b. Salt solution reservoir with means for maintaining a constant level of solution.

Reason: The solution in the reservoir reaches the spray nozzle by the suction effect of an air stream moving at right angles to the vertical tube. This suction must overcome gravitational effects which are directly related to the height of the liquid in the tube above the solution in the reservoir. As the solution in the reservoir is consumed, the height to which the solution must rise increases and rate of fogging decreases in proportion. An automatic feeding device should be used to maintain a constant level of salt solution in the reservoir.

Page 509-1, Paragraph 2.1, Last line

The following sentence was added:

The discharge end of the vent shall be protected from strong drafts which can create strong air currents in the test chamber.

Reason: The density of fog in a chamber is influenced by the location of the discharge end of the vent stack. If this end is subjected to strong winds, suction results. This reduces the density of fog in the chamber even though more fog may be generated in the nozzle as the reduced chamber pressure increases the flow of air from the compressed air supply.

Page 509-1, Paragraph 2.3, Line 14

The period following the words "headed water" was removed and the sentence continued as follows:

which should be automatically maintained at a constant level.

Reason: The moisture content of the air is directly related to the length of time the air remains in contact with the water. To assure that the air remains in the water tower for a time sufficient to provide the specified relative humidity, an automatic control should be employed.

Page 509-1, Paragraph 3, Line 5

The sentence beginning with "Unless" and ending with "solids." was deleted and the following was substituted:

Unless otherwise specified, a 5 $\pm$ 0.1 percent solution shall be prepared by dissolving 5 $\pm$ 0.1 parts by weight of salt in 95 parts by weight of distilled water.

Reason: A uniform solution strength is necessary for uniform test results. Method 509, as now written, provides for a 5 $\pm$ 1 percent solution to be prepared by dissolving 5 $\pm$ 1 parts by weight of salt in 95 parts by weight of water. Actually 1 is 20% of 5. The requirement as worded could result in $\pm$ 20 of the prescribed sodium chloride content being used. Modern equipment permits precise control of weight. A broad weight tolerance is unnecessary.

New Page 509-3, Paragraph 4.2, Subparagraph a

Subparagraph "a" was deleted and replaced with the following subparagraph:

a. Nozzle pressures shall be as low as practical to produce fog at the required rate.

Reason: The air pressure involved in the atomization of the salt solution produces directional effects as a strong stream of fog when leaving the nozzle. To prevent this stream from impinging on the specimens, it must be effectively baffled. Air currents that result are considered to be the cause of more severe corrosion rates in some parts of the chamber than in others. The operating pressure to produce spray should be held to the minimum compatible with efficient production of spray. Positioning the supply line within the reservoir close to the surface reduces vertical lift and permits lower operating pressures.

Method 512
Immersion

Page 512-1

The immersion test is discontinued.

Reason: This test was intended to determine the integrity of hermetic seals and gaskets employed by various devices. Such a test must be accomplished by the equipment manufacturer as part of his production line quality control. Requirements and methodology for this type of testing should be as specified in the detail equipment specification and as provided for in MIL-Q-9858, Quality Control System Requirements.

This test, as originally included in this standard, cannot be construed to be an environmental test.

Method 514
Vibration

Page 514-2, Note 2 and 3 under Table 514-1

The second sentence of both notes was deleted.

Reason: There is no engineering reason for raising the lower frequency limit to 15 cps. The inclusion of this statement is a carry over from previous requirements which were based on vibration machine limitations in frequency cycling ranges and double amplitude capabilities below 15 cps.

Page 514-8, Figure 514-5 and Page 514-9, Figure 514-6

Pages 514-8 and 514-9 were deleted and replaced with new pages containing new Figures 514-5 and 514-6 on which the low frequency double amplitude is limited to 1 inch.

Reason: Double amplitudes of vibration are limited to 1 inch maximums based on recent measurements. (Ref. Report No. DPS-999, "Road Shock and Vibration Environment for a Series of Wheeled and Track Laying Vehicles," dated June 1963, H. T. Cline, Development and Proof Services. Aberdeen Proving Ground, Maryland.)

Page 514-15, Paragraph 9.3

The entire paragraph was deleted and replaced with a new paragraph as follows:

9.3 Control and Analysis of Random Vibration. The applied vibration spectrum shall normally be within the tolerances of +40%/-30, between the frequencies of 50 and 1000 cps, and within +100%/-50, between 1000 and 2000 cps. For a power spectral density analysis of the test spectrum, these tolerances may be expressed as $\pm$ 1.5 db and $\pm$ 3 db respectively. Tolerance levels in terms of db are defined as:

$$db = 10 \log \frac{G_1^2/cps}{G_o^2/cps} \text{ or } db = 20 \log \frac{G_1}{G_o}$$

where G_1^2/cps = acceleration power spectral density and G_1 = G rms (over the analyzer bandwidth.) The term G_o defines the specified level.

A wave analyzer shall be used to assure the specified equalization tolerances. The following characteristics shall be reported for the analyzer for each test:

a. Filter bandwidths
b. Integrator time constant
c. Amplitude accuracy

Reason: This paragraph has been rewritten to clarify the equalization tolerances, which are now expressed in terms of percentage, power and voltage, interchangeable.

Page 514-15, Paragraph 9.4

The entire paragraph was deleted and replaced with a new paragraph as follows:

9.4 Vibration Input Control. The vibratory acceleration levels or double amplitudes of the specified test curve shall be maintained at the test item mounting points. When the input vibration is measured at more than one control point, the minimum input vibration shall normally be that of the specified test curve. For massive test items and fixtures, and large force exciters or multiple vibration exciters, the input control level may be an average of at least three or more inputs. Transverse motion measured at the test item attachment points shall be limited to 100% of the applied vibration.

Reason: A statement was added to this paragraph to permit a wider tolerance for massive test items for which it is impossible to control to reasonable tolerances by means of one control point. An average of at least three measured input points is generally considered to be a reasonable approach to control of large items, where there may be a wide variation at several inputs.

Method 516
Shock

The half-sine shock pulse has been deleted. Various figure numbers, paragraphs, and sentences have been changed to reflect this deletion. The g levels stated in the various test procedures previously associated with the half-sine test have been increased to provide approximately the same peak responses (effects) as the former half-sine pulses.

Reason: The engineering activity within the Air Force responsible for technical cognizance of this test method performed a study, and acting on recommendations of authorities on shock testing, determined that the half-sine shock pulse test should be deleted from this standard in favor of the sawtooth shock pulse test. The superior characteristics of the response spectrum of the sawtooth pulse over that of the half-sine shock pulse prompted this action. Changes resulting from this conversion are as follows:

Page 516-4, Procedure II, Transit Test

The entire procedure was deleted and recaptioned as follows:

Procedure II
Transit Test
Discontinued, use Procedure III.

Page 516-4, Procedure III

Changed to read as follows:

Procedure III.
Transit Test
This procedure is applicable to equipment transported by land, sea, or air and should be used when no other transit shock test is specified in the detail or packaging specification. The transit test is applied to determine the ability of equipment to resist damage from shock due to handling associated with transportation. This test procedure is applicable to equipment in the package in the nonoperating condition. In the performance of this test, step a through step c shall be performed where applicable as specified in Table 516-1 followed by step d.

Page 516-5, Procedure IV, Crash Safety Test, Line 9

The sentence beginning with "The shock pulse..." and ending with "...11 milliseconds" was deleted and replaced with a new sentence as follows:

The shock pulse shape shall be in accordance with Figure 516-1 and shall have a peak value (A) of 40 g and a nominal duration (D) of 10 milliseconds.

Page 516-5, Procedure V

The entire paragraph was deleted and replaced with new Procedure V as follows:

Procedure V

High Intensity Test

This procedure shall be used where high acceleration short time duration shock excitation results from handling, stage ignition, separation, re-entry, and high velocity aerodynamic buffeting experienced by missiles and high performance weapon systems. This test shall be utilized for testing such items as small high density electronic equipments and other aeronautical items of small size mounted without shock and vibration isolators.

Two shocks shall be applied to the test item in each direction along each of the three mutually perpendicular axes (12 shocks). The shock pulse shape shall be in accordance with Figure 516-1 and shall have a peak value (A) of 100 g and a nominal duration (D) of 6 milliseconds. The test item shall be operating during and after the test if required by the detail specification. At the conclusion of the test, the test item shall be operated and the results compared with the data obtained in accordance with Section 3.2.1. The test item shall then be inspected as specified in Section 3.2.4.

Other Changes

Page 516-1, Paragraph 1, Line 6

The parenthetical expression (excluding equipment packaged for logistic supply and shipment) was deleted.

Reason: The shock tests of Method 516 may be used for such purposes if no shock test is specified in the individual equipment or packaging specifications.

Page 516-1, Paragraph 2, Apparatus, 2.1 Shock Machine

Following Paragraph "2.1 Shock Machine", a new Subparagraph 2.1.1 was added as follows:

2.1.1 Shock Machine Calibration. The actual test item or a dummy load which may e either a rejected item or a rigid dummy mass may be used to calibrate the shock machine. (When a rigid dummy mass is used, it shall have the same center of gravity and the same mass as that of the test item and shall be installed in a manner similar to that intended for the test item.) The shock machine shall then be calibrated for conformance with the specified wave form. The dummy load shall then be removed and the shock test performed on the actual test item. Provided all conditions remain the same, other than the substitution of the test item for the dummy load, the test shall be considered to meet the requirements of the specified wave form.

Reason: To prevent possible destruction of the actual test item while adjusting the shock machine and to allow the use of a dummy mass for calibration which may otherwise be impossible with the actual test item.

Page 516-1, Paragraph 2.2.2, first line in formula

Changed RC $\geq$ 0.08 to RC $\geq$ 0.2.

Reason: An objection was raised to the fact that a time constant of 0.08 is only marginal. A time constant of 0.2 is easily attainable and will eliminate an unnecessary source of error.

Method 517
Low Pressure-Solar Energy

Page 517-1

A new Paragraph 3.1 was added and a new Table 517-I was substituted.

3.1 Test Discipline.

3.1.1 Reflected and Emitted Thermal Radiation.

When the mission of the test item is such that the flight path will lie sufficiently near a planet or moon for a time period long enough that the temperature of any part of the test item will vary by more than 10°C from the temperature, it would have, if no planet or moon were present, simulation of reflected radiation (albedo) and emitted thermal radiation (planet radiation) from the planet or moon should be attempted in addition to direct solar radiation. Solar radiation shall be applied to the test item in the direction corresponding to that of the Sun in space. The solar electromagnetic energy distribution specified in Table 517-I, knowledge of the flight path, and the planet radiation specified in Table 517-II shall be used in determining the needed thermal radiation.

Total solar energy shall be equal to the applicable value from the Incident Solar Radiation Intensity column of Table 517-II with a tolerance of $\pm$ 3%. The total energy tolerance and the variations of the Table 517-I shall be met over each 1/100 or 0.1 square feet, whichever is greater, of the area of the test space which is intended to be illuminated by simulated solar energy.

Table 517-I

Solar Electromagnetic Energy Distribution

Wavelength Band (Angstroms)	Percent of Total Energy	Allowable Variation of Band Energy
*1,800-2,500	0.2	±15%
2,500-3,300	2.8	±10%
3,300-5,000	20.0	±10%
5,000-7,000	26.0	±10%
7,000-9,000	17.0	±10%
9,000-11,000	11.0	±10%
11,000-15,000	12.0	±10%
15,000-30,000	11.0	±10%

*Due to the cost involved and difficulties in simulation, the need for simulating the 1800 to 2500 angstrom wavelength band should be carefully analyzed.

Table 517-II

Average Radiation Characteristics of Planets

Planet	Incident Solar Radiation Intensity (watts/sq. ft.)	Planet Reflectivity (Albedo)	Planet Thermal Radiation (watts/sq. ft.)	Planet Temp. (°K)
Earth	130.0	0.36	20.7	250
Mars	56.2	0.148	12.0	226
Venus	245.0	0.67	20.3	249
Earth's Moon	130.0	0.072	30.1	284

The simulated planet or moon radiation should be conducted for at least two portions of the trajectory sufficiently near the planet or moon and separated from each other by a distance corresponding to a change of at least 90 degrees in the direction of the radius vector from the planet or moon to the test item. Tolerances on the planet or moon radiation should be such that the resulting temperature variation on the test item is less than 5°C. For simulated solar electromagnetic radiation and other thermal sources uniformity and collimation must be considered. A collimation angle greater than 6 degrees should not be permitted for solar radiation unless a larger angle is justified by special test conditions.

3.1.2 Time-Low Pressure. When the intended mission time of the test item is such that the test item will be exposed to low pressure conditions for periods in excess of 24 hours, the test chamber shall be maintained at a pressure of at least 1×10^{-5} torr for not less than 24 hours. Test items with intended flight times of less than 24 hours should be exposed to low pressure for a time equal to or longer than the actual intended flight time. A pressure of 1×10^{-8} torr or lower should be employed where changes in the physical properties of materials, outgassing, cold welding, etc., are of concern.

Reason for new Subparagraph 3.1.1: For all orbiting vehicles, reflective radiation (albedo) and emitted thermal radiation (planet radiation) has a significant effect on the thermal equilibrium and temperature gradients of the vehicle. Characteristics and tolerances for these types of radiation should be specified. Uniformity and collimation should also be considered. New Subparagraph 3.1.1 was prepared to include these points.

Reason for new Subparagraph 3.1.2: Lower chamber pressures are specified to determine the effects of the space environment for extended periods of time to determine the cross coupling effects of natural and induced environments (e.g., changes in the physical properties of materials and the effect of these changes on performance, outgassing, and cold welding effects).

An appendix has been added to MIL-STD-810A (USAF) containing transition charts which should prove useful for those selecting like tests given in MIL-STD-810 and those called out in the following specifications:

MIL-T-5422 (ASG) Environmental Testing for Aircraft Electronic Equipment
MIL-E-5272 (ASG) Environmental Testing, Aeronautical and Associated Equipment
MIL-E-4970, Environmental Testing, Ground Support Equipment (Specification MIL-E-4970 has been canceled.)

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13. ABSTRACT

This report presents supporting data and background information on the origination and development of natural and induced environmental tests intended for USAF aerospace and ground equipment.

The information provided in the discussion portion of the test writeups is intended to give the designer, application engineer, and those individuals responsible for specifying test requirements a clearer understanding of the interpretation, application, and relationship of tests as called out in various environmental test documents.

The growth of environmental criteria and test procedures is traced from the first Army Air Force specification No. 41065 dated 7 December 1945 to MIL-STD-810A (USAF) dated 23 June 1964. Included also in this report are discussions on environmental test specifications MIL-T-5422, MIL-E-5272, and MIL-E-4970.

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