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INCH-POUND

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DEPARTMENT OF DEFENSE
DESIGN CRITERIA STANDARD

THERMAL DESIGN, ANALYSIS AND TEST CRITERIA FOR AIRBORNE ELECTRONIC EQUIPMENT

AMSC N/A

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FOREWORD

1. This military standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Warfare Center Aircraft Division Lakehurst, Systems Requirements Department, Code SR3, Lakehurst, NJ 08733-5100 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. This standard contains requirements for thermal design and cooling analyses, thermal design verification tests and preproduction qualification tests for airborne electronic equipment. It also contains guidelines for test methods for verification testing of the thermal and cooling design, and for preproduction qualification temperature and humidity tests.

4. The requirements of this standard are oriented toward maximizing the reliability and minimizing the life cycle cost (LCC) of avionics equipment by achieving component temperatures consistent with reliability and LCC goals.

5. This standard is intended for use in conjunction with a detail equipment specification which will be used to tailor this document to fit the needs of the specific application. This document is appropriate to all phases of an acquisition program, i.e., from concept formulation, through development, to preproduction testing.

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1. SCOPE

1.1 Purpose. This standard establishes requirements for thermal design and cooling analyses, thermal design verification tests, and preproduction qualification tests for airborne electronic equipment. These thermal design requirements are provided to ensure that the equipment will operate satisfactorily without manual adjustment under any mode of operation in the aircraft. It also establishes guidelines for test methods for verification testing of the thermal and cooling design and preproduction qualification temperature and humidity tests to ensure that the equipment meets its performance requirements and reliability criteria. This document defines a thermal design process establishing and validating the following:

a. Equipment cooling methods and coolant flow requirements.

b. Allowable component temperature and component power, based on derating requirements to achieve lowest component temperatures consistent with reliability and life cycle cost (LCC) requirements.

c. A thermal design analysis which defines the temperatures, heat sources, heat paths and heat sinks of all temperature critical components for worst-case power, environmental temperature-altitude and coolant flow (where applicable) conditions.

d. Thermal design, verification and preproduction qualification tests.

1.2 Tailoring. Application of this document is via tailoring. Department of Defense (DOD) policy is to selectively apply and tailor standardization documents to ensure their cost-effective use in the acquisition process. Individual requirements (sections, paragraphs or sentences) shall be evaluated to determine the extent to which they are most suitable for a specific acquisition and the modification of these requirements to ensure that each achieves an optimal balance between needs and cost. Tailoring of data requirements consists only of the exclusion of those sections, paragraphs or sentences in an approved document's information requirement or Data Item Description (DID). Each program office should carefully consider within DOD and Service guidelines, the benefits and costs of imposing this standard on each specific acquisition. Contractors may propose specific application and tailoring of this document and related information requirements (DIDs, etc.) as specified in 6.1.

1.3 Thermal design data. Data associated with compliance to this standard shall be in accordance with 4.5 and 6.2.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards and handbooks. The following specifications, standards and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

MILITARY

MIL-E-5400	Electronic Equipment, Aerospace, General Specification for
MIL-T-18303	Test Procedures; Preproduction, Acceptance, and Life for Aircraft Electronic Equipment, Format for

STANDARDS

MILITARY

MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production
MIL-STD-810	Environmental Test Methods and Engineering Guidelines

HANDBOOKS

MILITARY

MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-251	Reliability/Design Thermal Applications

(Unless otherwise indicated, copies of federal and military specifications, standards and handbooks are available from the DODSSP Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.1.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

PUBLICATIONS

NAVMAT P 4855-1	Navy Power Supply Reliability Design and Manufacturing Guidelines, December 1982

(Copies of the NAVMAT publication are available from DODSSP Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.2 Order of precedence. In the event of a conflict between the text of this standard and the references cited herein, the text of this standard shall take precedence. Nothing in this standard, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 The following definitions shall apply:

a. Abnormal operation - All electronic equipment and devices are being operated through their normal duty cycles at maximum supply voltages with a loss of coolant or an increase in ambient temperature or both for short periods of time not exceeding 10 minutes.

b. Adiabatic conduction interface - No heat transfer between contacting surfaces.

c. Ambient cooled equipment - Ambient cooled equipment dissipates its heat to its ambient environment (without ventilation induced by the vehicle). Equipment containing fans or blowers to circulate ambient air through the unit shall be classified as ambient cooled.

d. Ambient temperature - Ambient temperature is the temperature immediately surrounding the equipment.

e. Component - A piece-part used in the production of an electronic subsystem, such as an integrated microcircuit, diode, transistor, capacitor, flat pack, resistor, relay, switch, transformer, etc.

f. Continuous operation - A steady state condition under normal operation.

g. Design flow rate - Design flow rate is the minimum flow rate necessary to maintain all components within the unit at specified temperature requirements.

h. Detail equipment specification - A specification that establishes the performance, design, development, installation, test and demonstration requirements for the equipment and sets forth operational and environmental requirements for the equipment appropriate for its intended use.

i. Forced (externally) cooled equipment - Forced cooled equipment is that equipment designed to be cooled by gas, including air and ram air, or liquid, supplied by the aircraft vehicle subsystems with sufficient pressure to flow through the unit and remove the dissipated heat.

j. Ground operation - A normal operating condition at sea level ambient temperature and pressure.

k. Intermittent operation - A transient condition. An abnormal operating condition in which the characteristics of the ambient temperature and external cooling provisions (if any) change for a specified period of time as specified in MIL-E-5400. All electronic components are being operated through their normal duty cycles at nominal supply voltages.

l. Normal operation - All electronic equipment and devices are being operated through their normal duty cycles at nominal supply voltages.

m. Sea level ambient pressure and temperature - Sea level ambient pressure is defined as 14.7 psia ± 5 percent. Sea level ambient temperature is defined as 59°F ± 2°F (15°C ±1°C).

n. Stabilization - A stabilized thermal condition has been attained when the indicated temperature of the component with the largest thermal time constant varies at a rate less than 3.6°F (2°C) per hour.

o. Standby operation - A steady state condition in which some electrical power is continuously applied to some or all devices and components.

p. Start-up operation - A transient condition. Prior to start-up, all electronic components and devices, and any external cooling provisions, are shut off. In start-up operation all electronic components and devices are being operated through their normal duty cycles at nominal supply voltages. The end of start-up operation occurs when steady state conditions exist.

q. Thermodynamic requirements - Thermodynamic requirements are the electronic equipment ambient and component temperature, pressure and water content and, where applicable, the coolant temperature, pressure drop, flow rate and water content.

r. Water balance - Water balance is a mass conservation balance on all water entering and leaving the test system.

4. GENERAL REQUIREMENTS

4.1 General. Time, temperature, moisture content, pressure altitudes, class definition and percentages listed herein are default values and should be changed to be compatible to the envelope and cooling system of the aircraft in which the equipment will be installed as specified by the detail equipment specification.

4.2 Thermal design requirements.

4.2.1 Cooling methods. It shall be analytically or experimentally determined if the equipment should be ambient cooled or forced cooled based upon the ability of the cooling method to satisfy component temperature and reliability criteria. Single node analytical modeling is not sufficient. All equipment shall, if practicable, be designed to be cooled by free convection and radiation for the ambient conditions defined by the detail equipment specification. Airborne electronic equipment which is not amenable to ambient cooling shall be designed to be forced cooled with air supplied from the aircraft environmental control system. If cooling with air supplied from the aircraft environmental control system is not possible, alternate methods shall be pursued. All analytical and experimental data determining the requirements for environmental control system air cooling or alternate methods such as liquid, evaporative, change of phase material, heat pipes, or ram air shall be submitted to the acquisition activity for review and approval. The selection of the cooling method shall be part of, and integrated with, the circuit design and reliability allocation process.

In the event air vents or condensate drains are required, they shall be protected as necessary to preclude entry of harmful foreign material or electromagnetic interference. The use of supplementary devices such as fans, integral coolant loops, relief valves, or other such apparatus may be employed only with specific approval of the acquisition activity. The equipment shall not make use of aircraft structure or fuel as a heat sink without the specific approval of the acquisition activity.

Cooling media shall not be allowed for heater power dissipation. Airflow in excess of that necessary to maintain maximum allowable exhaust temperatures must be demonstrated by analysis or test as necessary and approved by the acquisition activity. Cooling requirements are to be finalized by the thermal design verification test to ensure adequate cooling consistent with reliability and life cycle cost requirements and ensure that the cooling is not excessive. The use of insulation and reflective coatings to reduce ambient heat loads is prohibited unless approved by the acquisition activity.

4.2.2 Cooling media impingement. For forced cooled equipment, direct impingement of cooling media on electronic components shall not be permitted without specific approval of the acquisition activity.

4.2.3 Design environment.

4.2.3.1 Operating. The equipment shall operate satisfactorily within the temperature-altitude environment specified by MIL-E-5400 for Class 2 design or as defined in the detail equipment specification.

4.2.3.2 Storage and non-operating. In an installed non-operating mode or storage for longer than 24 hours, the equipment shall withstand exposure to any combination of temperature and altitude within the range of -71°F (-57°C) to 203°F (95°C) from sea level to 70,000 feet (0.65 psia) pressure altitude.

4.2.3.3 Surrounding air pressure. Cockpit equipment shall be designed to withstand pressures from 0.65 to 21.0 psia and non-cockpit equipment shall be designed to withstand pressures from 0.65 to 14.7 psia. Cockpit equipment shall operate continuously at pressures between 5.65 and 14.7 psia and intermittently between 1.54 and 5.65 psia, and non-cockpit equipment shall be designed to operate between 0.65 and 14.7 psia. The surrounding air pressure may vary at rates as high as 3.0 psia for cockpit equipment and 5.0 psia for non-cockpit equipment.

4.2.4 Cooling requirements (forced cooled equipment).

4.2.4.1 Air cooled equipment.

4.2.4.1.1 Conditioned air supply temperature. Forced cooled equipment utilizing environmental control system air as the coolant shall be capable of operating and meeting reliability criteria when provided with cooling air within the following temperature ranges:

a. In-flight from -65°F (-54°C) to 131°F (55°C).

b. Aircraft ground cooling from -50°F (-46°C) to 131°F (55°C).

c. Bench testing from 0°F (-18°C) to 131°F (55°C).

4.2.4.1.2 Ram air supply temperature. Forced cooled equipment utilizing ram air as the coolant shall be capable of operating and meeting reliability criteria when provided with cooling air within the following temperature ranges:

a. In-flight from -80°F (-62°C) to 131°F (55°C).

b. Aircraft ground cooling from -50°F (-46°C) to 131°F (55°C).

c. Bench testing from 0°F (-18°C) to 131°F (55°C).

The ram air temperature shall be calculated as follows:

$T_{ram} = T_{amb}(1 + .2M^2) - 460$ where:

T_{ram} = Ram air temperature in °F

T_{amb} = Ambient air temperature - °R

M = Aircraft Mach number

4.2.4.1.3 Airflow rate design. The cooling airflow rate per kilowatt (kw) of heat dissipation absorbed by the equipment cooling air shall be as defined on figure 1. The maximum allowable equipment air discharge temperature shall be 160°F (71°C) during normal operation.

The actual allowable exit temperature of air shall be that which satisfies the LCC and reliability requirements of the electronic unit. The heat dissipation absorbed by the cooling air is defined as Q_t (Btu/hr) where:

$$Q_t = Q_e + \sum_{i=1}^{n} h_i A_i (T_{amb} - T_i) + \sum_{i=1}^{n} \sigma F_e F_a A_i (T_{su}^4 - T_i^4)$$

Q_e = Electrical heat dissipation - Btu/hr.

h_i = Free convection heat transfer coefficient for surface i - Btu/ft²hr°R

A_i = Equipment convection and radiation heat transfer area of surface i in contact with external ambient - ft²

σ = Stefan-Boltzmann constant, $.1714 \times 10^{-8}$ - Btu/ft² hr°R⁴

T_{amb} = Ambient Temperature -°R

T_i = Temperature of surface i - °R

T_{su} = Temperature of surrounding surfaces - °R

F_e = Radiation Emissivity factor - dimensionless

F_a = Radiation Area view factor - dimensionless

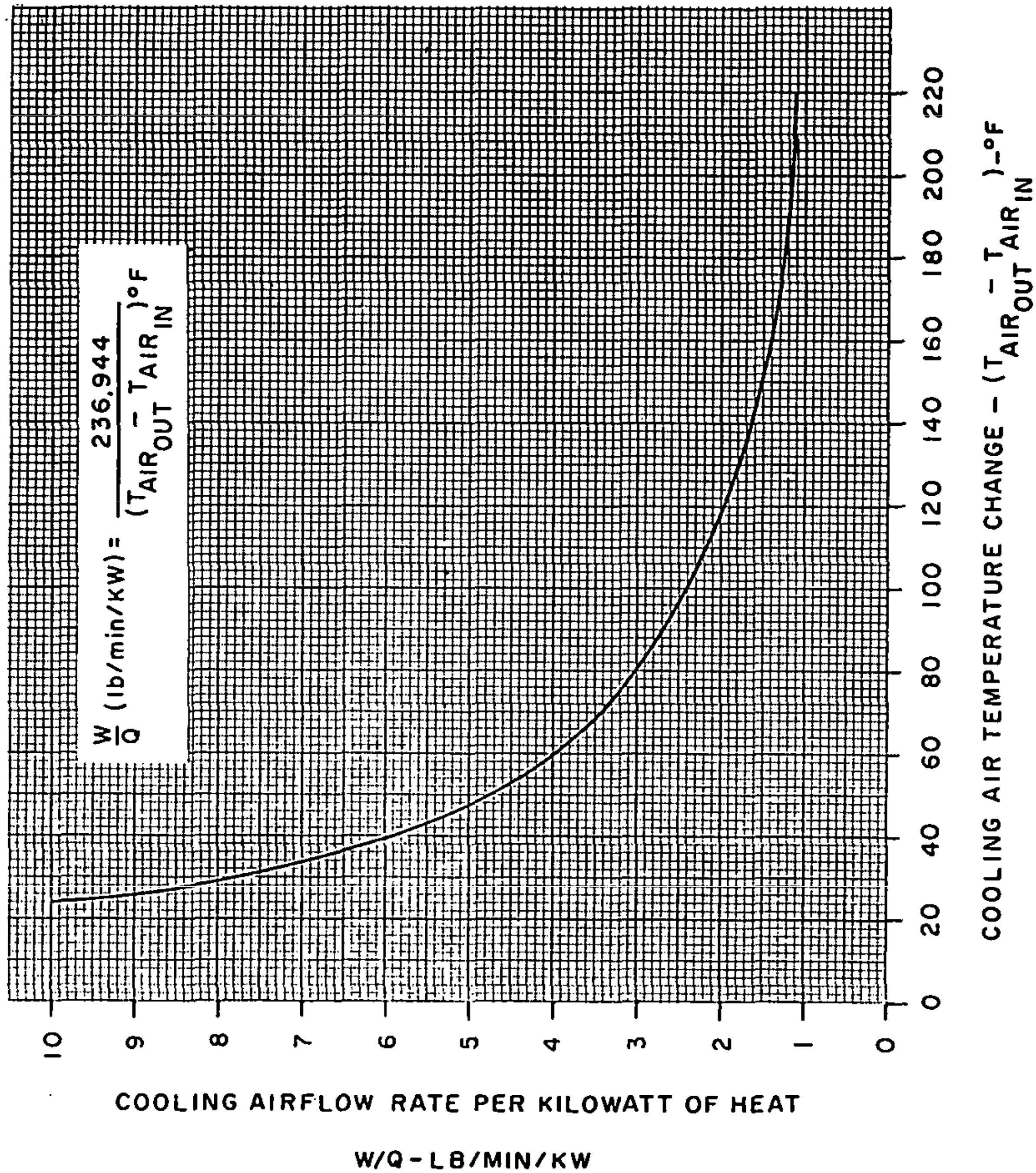


FIGURE 1. Cooling airflow rate per kilowatt of heat versus cooling air temperature change.

The equation assumes an adiabatic conduction interface between the aircraft mounting surface and the electronic equipment. Conduction interfaces will be assumed to be adiabatic unless otherwise defined by the acquisition activity.

The design airflow rate for the allowable cooling air temperature rise compatible with the aircraft cooling supply temperature is defined as follows:

$W_d = (W/Q) \times (Q_t/3412)$ where:

W_d = Design cooling airflow rate - lb/min

Q_t = The heat dissipation absorbed by the cooling air = Btu/hr.

W/Q = Airflow rate per kilowatt of heat absorbed by cooling air from figure 1 - lb/min/kw.

4.2.4.1.4 Structural safety margin. Forced cooled equipment shall be structurally capable of withstanding a cooling airflow rate two times greater than the design flow rate for sea level ambient pressure and an air supply temperature of 131°F (55°C) without damage. This factor decreases linearly to 1.5 times at a pressure altitude of 70,000 feet (0.65 psia) and an air supply temperature of 80°F (27°C).

4.2.4.1.5 Pressure drop. The cooling air pressure drop is defined as the difference between the static pressure entering the unit, and that exiting the unit. The corrected pressure drop ($\sigma\Delta P$) of each forced cooled unit shall not exceed 2.0 inches of water (in. H_2O) at the design flow rate corresponding to a coolant temperature of 60°F (16°C) and an ambient temperature of 160°F (71°C) at an ambient pressure of 14.7 psia where:

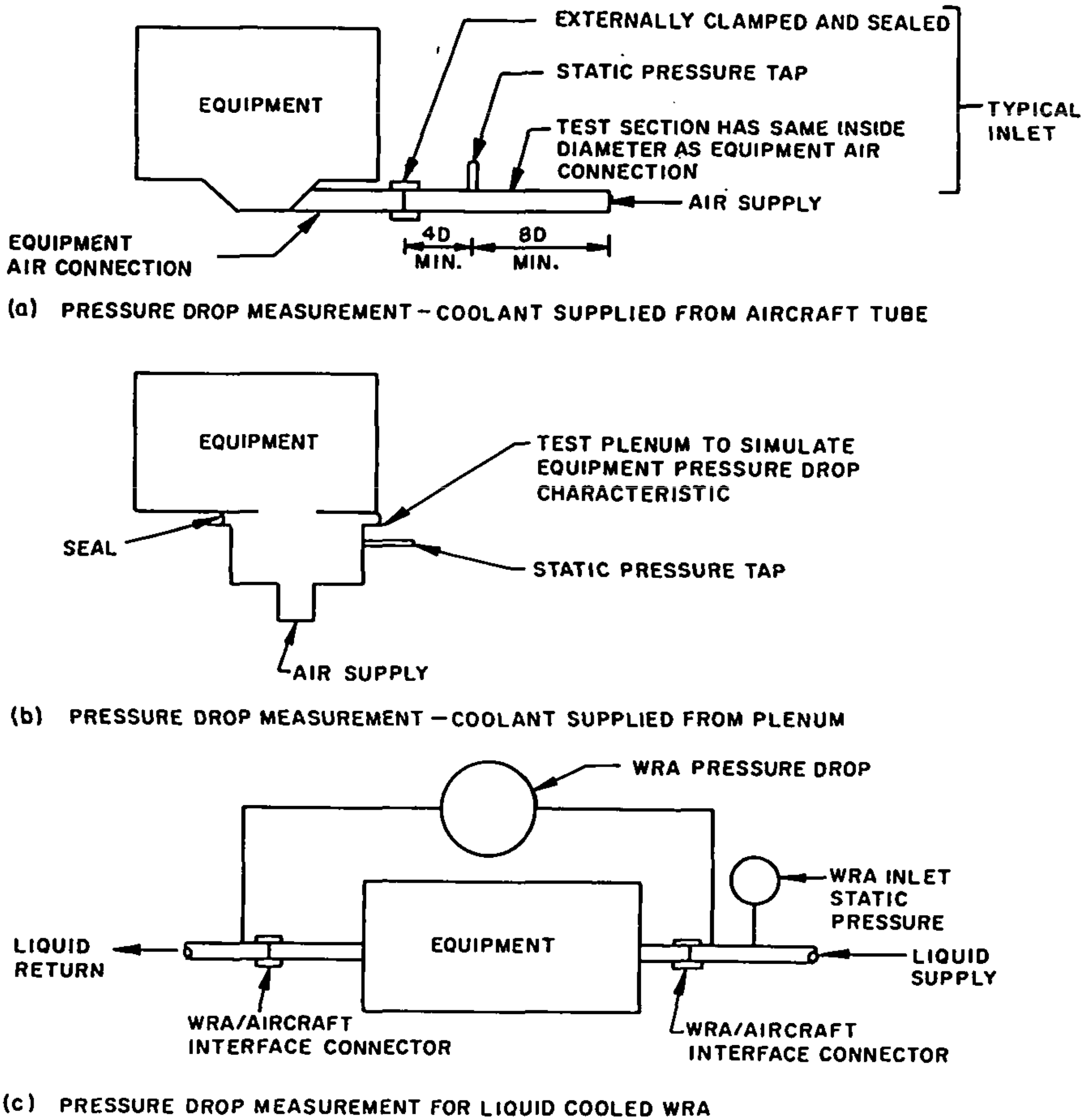
$\sigma\Delta P$ is the corrected pressure drop - in. H_2O

ΔP is the measured static pressure drop - in. H_2O

σ is the coolant density ratio, $\frac{\rho \text{ operating}}{\rho \text{ standard}}$ (0.0765 lbs/ft^3)

The specified pressure drop shall be measured by a method proposed by the contractor and approved by the acquisition activity, or in accordance with figure 2a when the unit is supplied from a tube in the airframe or in accordance with figure 2b when the unit is supplied from a plenum in the airframe. When the plenum is supplied as part of the unit or an assembly of separately cooled units, the specified pressure drop shall be measured in the tube to the plenum in accordance with figure 2a.

Since measurement is made of the static pressure at the inlet, these values must be corrected to $\sigma\Delta P$ for comparison to the specified maximum allowable pressure drop. The corrected pressure drop of production equipment shall not vary more than 10 percent from a nominal test value established by the contractor. Pressure loss adjusting devices may be incorporated only if approved by the acquisition activity.



(a) PRESSURE DROP MEASUREMENT – COOLANT SUPPLIED FROM AIRCRAFT TUBE

(b) PRESSURE DROP MEASUREMENT – COOLANT SUPPLIED FROM PLENUM

(c) PRESSURE DROP MEASUREMENT FOR LIQUID COOLED WRA

FIGURE 2. Equipment pressure drop measurement techniques.

4.2.4.2 Liquid cooled equipment.

4.2.4.2.1 Liquid supply temperature. Liquid cooled equipment shall be capable of accepting coolant at the following supply temperatures during continuous operation:

a. In-flight 32°F (0°C) to 104°F (40°C).

b. Aircraft ground cooling from -40°F (-40°C) to 131°F (55°C).

c. Bench testing from 0°F (-18°C) to 131°F (55°C).

4.2.4.2.2 Liquid flow rate design. The liquid coolant flow rate shall be determined in a manner equivalent to that described in 4.2.4.1.3 for air cooling. Suitable corrections for coolant specific heat characteristics shall be applied in the use of figure 1. The maximum allowable coolant discharge temperature shall be 160°F (71°C) during normal operations.

4.2.4.2.3 Structural safety margin. Liquid cooled equipment shall be structurally capable of withstanding inlet pressure associated with liquid flow rates 2 times greater than the design flow rate and a liquid supply temperature of 131°F (55°C) without damage. To prevent excessive pressure because of coolant expansion, suitable liquid coolant expansion devices shall be installed in each liquid cooled assembly that may be disconnected from the system coolant accumulator during installation, removal or equipment servicing.

4.2.4.2.4 Pressure drop. The equipment pressure drop is defined as the difference between the inlet and exit static pressure. The specified pressure drop shall be measured by a method proposed by the contractor and approved by the acquisition activity or in accordance with figure 2c.

The maximum pressure drop shall not exceed 20 psia at the design flow rate and supply temperature. The static pressure drop of production equipment shall not vary more than 10 percent from the nominal test value established by the contractor. Pressure loss adjusting devices may be incorporated only if approved by the acquisition activity.

4.2.5 Transient thermal requirements.

4.2.5.1 Warm-up. All equipment shall be capable of satisfactory operation, without realignment or manual adjustment, within the time specified in the detail equipment specification after non-operational stabilization at -65°F (-54°C). When energized, forced cooled equipment will be supplied with -50°F (-46°C) coolant based on the design flow rate for a 160°F (71°C) ambient and a 131°F (55°C) supply temperature.

4.2.5.2 Temperature shock. All equipment shall be capable of withstanding temperature shocks where the ambient temperature rapidly changes at a rate of 1.8°F/second (1°C/second) between extremes of 160°F (71°C) and -65°F (-54°C).

Forced cooled equipment shall be capable of sustaining temperature shocks consisting of stabilization at -65°F (-54°C) followed immediately by application of coolant flow at 131°F (55°C), the quantity being 2 times the design flow rate for a 160°F (71°C) ambient. Power (maximum specified voltage) will be applied simultaneously with the coolant flow. Forced cooled equipment shall also be capable of sustaining temperature shocks consisting of stabilization at 160°F (71°C) followed immediately by the application of coolant flow at -65°F (-54°C), the quantity being 2 times the design flow rate for a -65°F (-54°C) ambient. Power (minimum specified voltage) shall be applied simultaneously with the coolant flow.

4.2.5.3 Temperature-altitude. While operating, the equipment shall be capable of withstanding any combination of temperature and altitude transients from the continuous to intermittent operating environments defined by MIL-E-5400 for Class 2 equipment or as modified by the detail equipment specification. Prior to initiation of the transient condition, the equipment shall be considered at thermal stabilization while operating in the maximum continuous environment. During transient operation, the boundary conditions change in 5 minutes to the intermittent levels and durations as required for the intended equipment application.

4.2.6 Humidity requirements. The equipment shall meet the humidity requirements of MIL-E-5400. Forced air cooled equipment shall be capable of operating, at the maximum specified voltage, with the saturated cooling air containing liquid moisture droplets. The forced cooling air requirements are:

a. Air temperature	60°F (16°C)
b. Air flow	Design flow rate for 160°F (71°C) ambient
c. Liquid water content	125 grains of water per lb. dry air entrained in air at 100 percent relative humidity.

4.2.7 Ducting. The location and dimensions of cooling air inlets and exhausts shall be approved by the acquisition activity.

4.2.8 Air leakage. Forced air cooled equipment shall have a cooling air leakage rate less than 5 percent of the design flow rate when operating at 60°F (16°C) inlet temperature, 160°F (71°C) ambient, at the approximate design flow rate, at an ambient pressure corresponding to 70,000 feet (0.65 psia) pressure altitude.

4.2.9 Equipment heat dissipation. The equipment heat dissipation shall be defined for the following modes of operation where applicable:

Mode of Operation	Heat Dissipation - Watts
Normal	
Continuous	________
Ground	________
Standby	________
Transient	
Start-up	________
Intermittent	________

4.2.10 Thermal protection. All forced cooled equipment shall be provided with an over-temperature indication and protected with thermal interlocks to prevent damage to the equipment due to overheating. Those equipments not necessary for safety of flight or mission completion shall be capable of resuming normal operation when temperature conditions return to a safe operating level. Those equipments necessary for safety of flight or mission completion shall also be provided with a means of manually overriding the interlock by the aircrew. However, in the event that the temperature is elevated to a point beyond the operation of the thermal interlock such that a safety of flight hazard exists, automatic shutdown shall occur regardless of manual override selection. The equipment need not be capable of normal operation after a flight safety shutdown.

4.2.11 Emergency operations. The equipment shall be designed for the following conditions:

a. Loss of cooling - Loss of cooling for a period of 10 minutes shall not damage the equipment nor cause the component part temperatures to exceed abnormal temperature levels indicated in table I. The operation and performance, including shutdown of the equipment by thermal interlocks, if necessary, shall be as defined in the detail equipment specification.

b. Emergency cooling - The equipment shall meet specified performance with a coolant flow rate equal to 75 percent of the design flow rate for a period of 30 minutes.

4.3 Thermal management.

4.3.1 Thermal design and reliability interface. The equipment design shall be thermally optimized to minimize the LCC and maximize the reliability and operational life of the individual parts as defined in the detail equipment specification. As a part of the thermal management program, detailed thermal and reliability design analyses for the final production design shall be conducted down to the individual part level. These analyses shall be used for optimizing piece part selection, placement and design based on component junction temperatures and coolant flow rate, where applicable. MIL-STD-454, Requirements 35 and 52, MIL-HDBK-251, MIL-HDBK-217, MIL-STD-785 and NAVMAT P 4855-1 should be used as guidelines for thermal and reliability design and analyses.

4.3.2 Component derating. Derating shall be in accordance with the requirements of the detail equipment specification. It shall be shown that all components will operate at temperatures consistent with their reliability requirements. The individual component temperatures shall not exceed values established in the thermal and reliability analyses. The part temperatures specified in table I are to be used as preliminary design guidelines pending the availability of detailed thermal and reliability results of 4.3.1.

TABLE I. Preliminary design guidelines for allowable junction temperature.

Operating Condition	Microcircuits	Power Device
Normal	221°F (105°C)	257°F (125°C)
Abnormal	239°F (115°C)	302°F (150°C)

4.4 Thermal design, cooling and overtemperature protection analysis. The following specific information shall be generated as a minimal effort.

4.4.1 Power dissipation and component selection. A power dissipation table of the entire unit by component (where applicable), showing values for all components and their locations shall be constructed. The power dissipation listed per component shall account for the total power dissipated in the unit, exclusive of heaters. Methods used for determining power dissipation, including duty cycles, shall be specified by the contractor. Sample calculations shall be included if determined by analysis. Every effort should be made to make an accurate estimate of the power dissipated. Where possible, the effect of component duty cycle on the total power dissipated in the unit shall be considered. Include with each component's listing, the manufacturer's recommended minimum and maximum operating temperature for the applicable level of power dissipation and for the performance accuracy and reliability required. Component derated temperatures to meet the reliability requirements shall also be listed.

4.4.2 Analytical thermal model. A realistic analytical model shall be developed for each electronic unit. The models shall be used to predict operating surface temperatures (or junction temperatures, whichever is applicable for component derating) taking into account all the environmental conditions including such effects as coolant flow variation, flow distribution, pressure drop and ambient temperature and pressure, as applicable. Thermal resistances from ambient to part surface (case) to junction or other internal temperature critical location shall be derived. The models shall be capable of predicting part temperature to within $\pm 9^{\circ}$F ($\pm 5^{\circ}$C). A steady state analysis shall normally be employed; however, satisfactory component operating temperatures may be demonstrated by a transient analysis. All analyses shall be updated as the design progresses. The thermal models shall consider the following thermal conditions.

4.4.2.1 Component operating temperature predictions. Component operating temperatures shall be determined for the following thermodynamic conditions.

a. Those conditions within the range of the operating environment that result in maximum component temperatures for continuous and intermittent operation.

b. Those conditions within the range of the operating environment that result in minimal component temperatures for continuous operation. This analysis shall apply to those components with manufacturer recommended minimal operating temperatures as defined in 4.4.1 above the minimal ambient operating temperature of the electronic unit.

4.4.2.2 Cold plate wall temperature predictions. For all cold plate cooled equipment, including fan and forced cooled equipment, cold plate wall temperatures shall be determined.

4.4.2.3 Forced cooling analysis. Required flow rate versus inlet temperature, and pressure drop ($\sigma\Delta P$) versus flow rate shall be plotted or tabulated.

4.4.2.4 Overtemperature sensor locations. For equipment with over-temperature sensors, selected locations and set points to provide specified protection shall be established (see 4.2.10).

4.4.2.5 Temperature sensitive component analysis. Each electronic unit shall be analyzed to ascertain those components which will operate near their limiting temperatures and which would significantly affect the unit's specified performance reliability and LCC. Special attention shall be given to those components which are temperature sensitive in operation or which must have special cooling provisions to achieve their design mean-time-between-failure and electrical performance requirement.

The analysis shall consist of an overall thermal balance within and outside the unit to determine the local cooling air temperatures and a local heat balance on the specific components.

4.5 Thermal analysis report. Where required by Contract Data Requirements List (CDRL), a thermal analysis report shall show thermal design and cooling methods, identify critical components, major heat sources, heat paths, heat sinks and the initial data of 4.4.1. The initial report and updates shall be formally submitted to the acquisition activity prior to each design review. All thermal analyses shall be completed and approved by the acquisition activity prior to critical design review and before the design is released for production. All thermal analysis data submittals shall provide sufficient information to permit a comprehensive and meaningful evaluation of the equipment thermal and cooling design and shall include but not be limited to configuration sketches, dimensions, basis for all assumptions, thermal properties, power dissipation including duty cycles, component case and junction temperature data, coolant flow rate, inlet and outlet temperatures, pressure drop data, coolant properties data, fan, pump and cold plate design data (where applicable), sample calculations, references for all derived equations, and test data (if any) (see 6.2).

4.6 Thermal design verification tests. Thermal design verification tests shall be required to verify the methodology and assumptions used in the thermal analysis, including component junction temperatures, power dissipation and, where applicable, cooling flow rate requirements. In addition, these tests shall include validation of all applicable thermal design related requirements detailed in the equipment specification such as warm-up time, laboratory cooling, ground cooling and over-temperature sensor(s).

Where assumed analytical values are used in predicting individual component or module temperatures and flow distribution, such values shall be confirmed by individual component or module test at a time sufficient prior to pre-production test to permit redesign if necessary. When these values cannot be confirmed by testing at the component or module level, tests may be conducted at the next higher level of assembly. Correlation between tests and analysis shall be less than ±9°F (±5°C).

The analysis of 4.4.2 and sub-paragraphs shall be verified by adequately instrumenting the electronic unit to measure operating surface temperatures. All data recorded for thermal testing shall be submitted to the acquisition activity at the specified time with sufficient detail to make the data meaningful for engineering review and approval (see 6.2).

4.7 Preproduction qualification tests. Preproduction qualification tests shall be required to ensure satisfactory thermal and operational performance of the equipment during the environmental conditions specified in MIL-STD-5400 and the detail equipment specification. All data recorded for preproduction qualification testing shall be submitted to the acquisition activity at the specified time with sufficient detail to make the data meaningful for engineering review and approval (see 6.2).

5. DETAILED TEST REQUIREMENTS AND PROCEDURES

5.1 Thermal design verification tests.

5.1.1 Scope. This section establishes the detailed test requirements and procedures for tests specified as part of the verification program (see 6.2).

5.1.2 Test procedures. MIL-T-18303 shall be used as a guide for preparation of test procedures. When approved test procedures are available from previous contracts, such procedures will be provided and may be used when their use is approved by the acquisition activity. However, the acquisition activity reserves the right to require modification of such procedures, including additional tests, when deemed necessary.

5.1.3 Test configuration. All operating tests shall be performed in a manner simulating the equipment's installed arrangement in the aircraft to simulate a free convection and radiation environment. Unless specified by the detail equipment specification, the air velocities immediately surrounding the unit due to chamber air circulation shall not be greater than those caused by air movement due to natural (free) convection effects.

5.1.4 Temperature measurement. The thermal analyses (see 4.3) shall be used for instrumentation locations. Thermocouples shall be the standard temperature sensors for this standard. The thermocouples shall be of a size equal to or smaller than 30-gauge thermocouple. Wherever the application of the thermocouple may appreciably affect the temperature field on a component, particular attention shall be given to using smaller gauge thermocouples and to the method of application to the part. When the use of thermocouples is not feasible, the use of infrared thermal imaging techniques shall be considered.

5.1.5 Ambient cooled equipment. Ambient cooled equipment shall be tested under all modes of operation at the maximum steady state temperature specified in the detail equipment specification for each of the following altitudes:

a. Sea level.

b. Maximum pressure altitude.

c. The most critical temperature and altitude, if different from (a) and (b) above.

For these tests, the chamber shall simulate the aircraft installation and shall be controlled to the specified ambient temperatures. The air temperature immediately adjacent to the equipment and the simulated internal structure temperature shall be monitored, but not controlled. The temperature of all components identified in 4.4.2.5 shall be monitored and recorded during these tests. The equipment shall be monitored for electrical performance including power dissipation measurements, to assure satisfactory performance under all modes of operation. The maximum power dissipations determined from this testing plus a 5 percent tolerance shall become the new specification values as defined in 4.2.9. The duration of each test shall be the time required to attain steady state conditions but shall not be less than (1) hour. The tests shall validate that the unit's thermal design is consistent with its reliability requirements.

5.1.6 Forced cooled equipment. The coolant flow rate and pressure drop requirements for each forced cooled unit, under all modes of operation, shall be established over the range of applicable cooling air temperatures and ambient temperatures. The required coolant flow rate is defined as the minimal flow rate necessary to maintain all critical components within 3°F (1.6°C) of its derated temperature for reliability requirements and shall not exceed the design flow rate of 4.2.4. Tests 1, 2 and 3 below shall be performed at the altitude condition analytically determined to be most temperature critical. The remaining tests shall be conducted at sea level. The following is a tabulation of the inlet temperature of the coolant and ambient temperature to be used in the cooling performance tests.

Test No.	Inlet Temperature (°F)	Ambient Temperature (°F)
1	-65	160
2	0	160
3	62	160
4	131	160
5	-65	-65
6	131	-65

For these tests, the chamber shall simulate the aircraft installation and shall be controlled to the specified ambient temperatures and pressures. The air temperature immediately adjacent to the equipment, and the simulated internal structure temperature shall be monitored but not controlled. If Tests 1, 2 and 3 are performed at sea level, an additional test shall be performed at 70,000 feet (0.65 psia) pressure altitude with an inlet temperature of 60°F (16°C) and ambient temperature of 160°F (71°C). Thermal stabilization shall be achieved during all cooling tests. The coolant pressure drop shall be measured and the corrected values shall conform to 4.2.4.1.3 or 4.2.4.2.2, as applicable. The temperatures of all components identified in 4.4.2.5 shall be monitored and recorded during these tests. The equipment shall be monitored for electrical performance including power dissipation measurements, for all modes of operation to assure satisfactory operation during the cooling tests. The maximum power dissipations determined from this testing plus a 5 percent tolerance shall become the new specification values as defined in 4.2.9. The duration of each test shall be the time required to attain steady state but shall not be less than one (1) hour. The tests shall validate that the unit's thermal design is consistent with its reliability requirements.

Other tests may be substituted for these cooling performance tests, subject to acquisition activity approval, if it is felt that they represent more critical cooling conditions. Leakage flow shall be measured and shall conform to 4.2.8. The results of this test shall establish and replace the design flow rate initially determined in 4.2.4. All changes relative to coolant flow rate as a result of these tests shall be subject to approval of the acquisition activity. The tests shall validate that the unit's thermal design is consistent with its reliability requirements.

5.2 Preproduction qualification tests.

5.2.1 Scope. This section establishes the detailed test requirements and procedures for tests specified as part of the preproduction qualification program (see 6.2).

5.2.2 General. The equipment shall satisfy the temperature testing requirements of MIL-E-5400 and the detail equipment specification. The environment shall be compatible with the aircraft throughout its operational profile. Test instrumentation shall be provided to monitor ambient temperature and pressure, component temperatures, coolant temperature, flow rate and pressure drop. The thermal analysis (see 4.4) and thermal design verification tests (see 4.6) shall be used to establish the detail instrumentation requirements for temperature and altitude testing.

5.2.3 Equipment configuration. The equipment test configuration shall be in accordance with 5.1.3.

5.2.4 Humidity test. The humidity test shall be performed in accordance with MIL-E-5400 and the detail equipment specification. The equipment shall be energized and a performance check made during the low temperature portions of alternate cycles. During operation, forced cooled equipment shall receive coolant at the design flow rate and corresponding coolant inlet temperature.

5.2.5 Entrained water test (air cooled equipment only). The equipment shall demonstrate satisfactory operation for five (5) hours without realignment or adjustment when operated with moist internal cooling air as specified in 4.2.6. The equipment shall be continuously monitored during the test. The method of obtaining the specified humidity conditions of 4.2.6 shall be left to the discretion of the contractor subject to acquisition activity approval. A water balance shall be established in the test stand to ensure compliance to this requirement. After testing, the unit shall remain in a room ambient condition and shall be disassembled and inspected for corrosion after two (2) weeks.

5.2.6 Structural safety margin. Each internally forced cooled unit shall be operated at 70,000 feet (0.65 psia) pressure altitude for one (1) hour with cooling air at a temperature of 131°F (55°C) and an amount equal to 1.5 times the established design flow rate for 160°F (71°C) ambient. No structural deformations shall be permitted which would cause a loss of reliability and increase leakage.

5.2.7 Temperature and altitude tests. The equipment shall satisfy the temperature and altitude test requirements and procedures of MIL-E-5400 for Class 2 equipment except as modified or by the detail equipment specification.

5.2.8 Temperature shock tests.

5.2.8.1 Ambient cooled equipment. Ambient cooled equipment shall be tested as specified in the detail equipment specification.

5.2.8.2 Forced cooled equipment. Forced cooled equipment shall be tested in the following manner:

a. Hot shock.

(1) The equipment shall be cold soaked and stabilized at -65°F (-54°C) (non-operating).

(2) The chamber door shall be opened, the unit shall be immediately supplied with power and 131°F (55°C) coolant at 2 times the corresponding flow rate for 160°F (71°C) ambient. Equipment performance shall be satisfied when temperature stabilization is reached.

(3) Power and flow shall be stopped, the chamber door closed, and the chamber cooled to -65°F (-54°C) again as soon as possible.

(4) This test shall be repeated 3 times.

b. Cold shock.

(1) The equipment shall be hot soaked and stabilized at 160°F (71°C) (non-operating).

(2) The chamber door shall be opened, the unit shall be immediately supplied with power and -65°F (-54°C) coolant at 2 times the corresponding flow rate for 160°F (71°C) ambient. Equipment performance shall be satisfied when temperature stabilization is reached.

(3) Power and flow shall be stopped, the chamber door closed, and the chamber heated to 160°F (71°C) again as soon as possible.

(4) This test shall be repeated 3 additional times.

5.2.9 Failure criteria. Failure of the equipment to meet any one of the conditions specified in failure criteria defined in MIL-STD-810 shall constitute an equipment failure.

6. NOTES

(This section contains information of a general or explanatory nature which may be helpful, but is not mandatory).

6.1 Intended use. This standard is intended for use in conjunction with a detail equipment specification and will be invoked to the extent specified in the detail equipment specification. The detail equipment specification will be used to tailor this document to fit the needs of the specific application. This standard amplifies and modifies the requirements of MIL-E-5400, MIL-STD-810 and MIL-STD-454, Requirement 52 to include the specific requirements of the aircraft.

6.2 Data requirements. The following Data Item Descriptions (DID's) must be listed, as applicable, on the Contract Data Requirements List (DD Form 1423) when this standard is applied on a contract, in order to obtain the data, except where DOD FAR Supplement 27.475-1 exempts the requirement for a DD Form 1423.

Reference Paragraph	DID Number	DID Title
4.5	UDI-T-21341A	Data, Cooling Design
4.6, 4.7, 5.1.1, 5.2.1	DI-NDTI-80809A	Test/Inspection Reports

The above DID's were those cleared as of the date of this standard. The current issue of DOD 5010.12-L, Acquisition Management Systems and Data Requirements Control List (AMSDL), must be researched to ensure that only current, cleared DID's are cited on the DD Form 1423.

6.3 Subject term (key word) listing.

Altitude test
Ambient cooling
Failure criteria
Forced cooling
Humidity test
Qualification test
Temperature test
Test configuration

Custodians:
Army - CR
Navy - AS
Air Force - 11

Preparing activity
Navy - AS

(Project GDRQ-0067)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
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I RECOMMEND A CHANGE:

1. DOCUMENT NUMBER MIL-STD-2218	2. DOCUMENT DATE (YYMMDD) 920520

3. DOCUMENT TITLE
THERMAL DESIGN, ANALYSIS, AND TEST PROCEDURES FOR AIRBORNE ELECTRONIC EQUIPMENT

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)* (1) Commercial (2) AUTOVON *(If applicable)*	7. DATE SUBMITTED *(YYMMDD)*

8. PREPARING ACTIVITY

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c. ADDRESS *(Include Zip Code)* CODE SR3 LAKEHURST, NJ 08733-5100	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340