MIL-T-23103A (AS)
29 April 1971
SUPERSEDING MIL-T-23103(WEP)
1 APRIL 1963

MILITARY SPECIFICATION

THERMAL PERFORMANCE EVALUATION, AIRBORNE ELECTRONIC EQUIPMENT AND SYSTEMS, GENERAL REQUIREMENT FOR

This specification has been approved by the
Naval Air Systems Command, Department of the Navy.

1. SCOPE

1.1 Scope - This specification covers procedures for acquiring thermal performance data and evaluating the thermal performance of airborne electronic equipment and systems. It shall be the basis for the evaluation of thermal performance during each stage of equipment development. The specification is considered applicable to GFE and CFE and combinations of GFE and CFE for all cooling provision configurations including units intended for operation in a space thermal environment.

1.2 Cooling Provision Configuration - For purposes of consideration in this specification, the following two general categories of cooling provisions are defined:

(a) Ambient Cooling: The unit which makes use of only its immediate surroundings as the major means of dissipating its waste thermal energy shall be considered an ambient cooled unit. The surroundings are defined as the air around the unit, and the radiant environment which the unit sees. Those units which are conductively cooled by a vehicle structure or a vehicle supplied heat sink shall be considered to be in the ambient cooled category.

(b) External Source Cooling: Units which employ a flight vehicle supplied coolant shall be considered to be in the external source cooled category.

2. APPLICABLE DOCUMENTS

2.1 General - The following documents of the issue in effect on the date of invitation for bids form a part of this specification to the extent noted herein:

SPECIFICATIONS

Military

MIL-E-5400	Electronic Equipment, Aircraft, General Specifications For
MIL-T-5422	Environmental Testing, Aircraft Electronic Equipment
MIL-R-18301	Reports: Contractors' Engineering, For Aircraft Avionics Equipment
AR-35	Procedures, Thermal Design, Avionic Systems, General Specification For
AR-37	Avionics Systems Thermal Controls, Performance Evaluation Procedures, General Requirements For

Standards

MIL-STD-12	Abbreviations for Use On Drawings and in Technical Type Publications
MIL-STD-280	Definition of Terms for Equipment Division

2.2 Availability of Documents - When requesting specifications, standards, drawings, handbooks and publications refer to both title and number. Copies of this specification, other applicable specifications, and standards required by contractors in connection with specific procurement functions may be obtained upon application to the Commanding Officer, Publications and Forms Center, Code 105, 5801 Tabor Avenue, Philadelphia, Pa. 19120

All reports listed as publications are available through the Defense Documentation Center for Scientific and Technical Information (DDC), Cameron Station, Alexandria, Virginia 22314.

2.3 Precedence - When the requirements of the contract or specifications are in conflict, the following precedence shall apply:

(a) Contract: The contract shall have precedence over any specification;

(b) Equipment Specification: The specification covering a complete equipment shall have precedence over this specification and specifications referenced herein.

(c) This Specification: This specification shall have precedence over specifications referenced herein for those items concerned with thermal evaluation.

(d) Referenced Specification: Specifications referenced herein shall have precedence over applicable subsidiary specifications referenced therein.

3. REQUIREMENTS

3.1 General Requirements - The contractor shall establish a comprehensive thermal design and evaluation program to insure satisfactory and reliable operation of his equipment when it is exposed to extreme temperature-altitude conditions. This specification forms the basis for evaluating the thermal performance of the equipment by providing for periodic acquisition and reporting of standardized thermal performance limit data and thermal performance evaluation data.

During each of the phases of development, the thermal performance limit data and the thermal performance evaluation data shall be reported as required by 3.4. This data shall be generated by analytical methods during the phases which do not terminate in a packaged unit. As versions of the final equipment configuration evolve, the data obtained through calculations shall be replaced by operating measurement data. The data required in section 4 shall be obtained from thermal evaluation measurements and shall be obtained from the preproduction model or the first equipment offered for acceptance under the contract, whichever is first.

3.2 Implementation of This Specification - This specification deals with the thermal performance of electronic equipment which operates in various temperature-altitude environments. It shall be used whenever a comprehensive evaluation of a unit's thermal performance is required.

3.2.1 Thermal Environmental Parameters - The environmental parameters required to describe the conditions for thermal evaluation are:

(a) Local surrounding temperatures

(b) Local surrounding pressure

(c) Bulk coolant inlet temperature

(d) Coolant flow rate

3.2.2 Thermal Evaluation Requirements - Sufficient steady state thermal evaluation steps will be performed to obtain the data points necessary to plot the unit's thermal performance limit curve(s) typified by figure 4 or figure 6. Each performance limit curve shall consist of a curve joining at least three data points obtained from the steps. The unit shall be operated in the mode which will cause maximum heat dissipation.

3.2.2.1 Thermal Evaluation Required by Ambient Cooled Units - The performance limit curve for an ambient cooled unit is a single curve plotted with ambient temperature as the abscissa and altitude as the ordinate. See figure 4. Data points shall be obtained at the following altitude conditions:

(a) The maximum altitude required by the equipment specification

(b) The local atmospheric pressure

(c) At least one intermediate pressure altitude

The ambient temperature for each of the three pressure conditions shall be that which will cause the most critical part to operate at its maximum allowable temperature as specified in 4.2.3.1.

3.2.2.2 Thermal Evaluation Required by External Source Cooled Units - The performance limit curves for an external source cooled unit are families of curves generated by varying the ambient temperature and pressure parameters along with the additional parameters of coolant inlet temperature and flow rate. The following paragraphs describe the limits for these parameters. The data points are those which would typically be required in order to obtain complete performance limit data. Whenever adequate presentation of the thermal performance limit curves can be accomplished by fewer data points, a proposed alternate technical evaluation schedule shall be submitted to the contracting agency for approval.

3.2.2.2.1 Thermal Evaluation Ambient Temperatures - The ambient temperature data points shall be determined in the following manner.

(a) The maximum specified ambient temperature.

(b) An ambient temperature which will cause the unit to require approximately 66% of the flow found necessary during the corresponding step which employed the maximum specified ambient temperature.

(c) An ambient temperature which will cause the unit to require approximately 33% of the flow found necessary during the corresponding step which employed the maximum specified ambient temperature.

3.2.2.2.2 Thermal Evaluation Ambient Pressures - The ambient pressure data points shall be the maximum specified altitude, the local atmospheric pressure, and an intermediate altitude.

3.2.2.2.3 Thermal Evaluation Coolant Temperatures - The coolant temperature data points shall be as follows:

(a) The maximum specified inlet coolant temperature

(b) The minimum specified inlet coolant temperature

(c) The most useful intermediate coolant inlet temperature

3.2.2.2.4 Thermal Evaluation Coolant Flow Rate - The coolant flow rate used for each data point shall be that quantity of coolant which will cause the most critical part to operate at its maximum allowable temperature as specified in 4.2.3.2.

3.2.2.3 Additional Thermal Data - Additional thermal data shall include at least one transient curve and a data point at the Thermal Design Condition (See 6.2.5.) if not performed in 3.2.2.1 and 3.2.2.2. (See figure 5.)

3.2.3 Simulated Environment - In conjunction with the general thermal performance evaluation procedures required in 3.2.2, it is recommended that additional simulated and combined environmental thermal tests be conducted. These tests should duplicate as closely as possible the exact airframe mounting and flight mission environmental conditions. This type of testing is especially desirable in the case of missile borne equipments with specific transient operating conditions. The data shall be obtained for these simulated environment tests as specified in section 4.

3.3 Required Data - The data obtained in the evaluation procedures of this specification shall be reported on forms similar to those presented in figures 1 through 8. The thermal evaluation setup shall be adequately documented by photographs, schematics, or line drawings in the reports required in 3.4.

These data shall be submitted in accordance with the requirements of the contract or applicable detailed equipment specifications. In the absence of such specific requirements, the data shall be submitted at 3-month intervals. The data shall be identified as to the particular flight vehicle development or production phase it represents.

3.4 Reports - When required by the contract the performance limit and the performance evaluation data shall be reported at the completion of each major phase of the equipment development effort

(See MIL-E-5400.), e.g., preliminary design, development, and production, Reports will be prepared as specified in 4.3, and submitted for review and approval to the Naval Air Systems Command (AIR-53355A) with a copy to the Naval Air Development Center (AEHT).

3.5 Thermal Evaluation Facility

3.5.1 General - The apparatus used in conducting the thermal evaluation shall be capable of producing and maintaining thermal and environmental conditions and limits as per the applicable requirements of section 4 with the equipment operating and non-operating. Facilities shall have characteristics adequate to permit thermal evaluation of equipment in accordance with the procedures listed herein.

3.5.2 Chamber Temperature Control Provisions - The sources for maintaining the chamber environment shall be arranged or suitably baffled so that no surface at a temperature other than the desired ambient is visible to the unit under test. The maximum allowable temperature difference between any two points in the chamber shall be 10°C. The chamber control provisions shall be capable of maintaining the temperature indicated by a selected chamber ambient sensor constant within ±1°C of any selected test temperature. The air velocities immediately surrounding the unit shall be equivalent to those caused by natural air movement due to convection effects.

3.5.3 Coolant Supply System - This system shall be capable of supplying metered coolant flows as required in section 4 of this specification. If the coolant is air, then, unless otherwise specified, it must be dry air. Therefore, care must be taken to insure a sufficiently low moisture content such that there will be neither condensation nor direct impingement of water or ice droplets in and on the equipment. This is accomplished by insuring that the dew point of the coolant air entering in and on the equipment is sufficiently low to preclude such effects. Suitable means for moisture removal such as air dryers and water separators shall be provided.

3.5.4 Measurement Accuracy for Thermal Evaluation - All measurements shall be made with instrumentation and methods whose accuracies have been verified. When thermal evaluation is conducted at the contractor's plant the accuracy of the instrumentation and test equipment shall be verified periodically by the contractor to the satisfaction of the procuring activity.

3.5.4.1 Measurement Tolerances for Thermal Evaluation - The maximum allowable tolerances on the applicable measurements shall be as follows:

(a)	Temperature	°C	±2 degrees
(b)	Altitude	Ft	±5%
(c)	Weight	Lb	±1%
(d)	Coolant Flow	Lb/Min	±5%
(e)	Pressure	PSIA, In. H_2O	±1%
(f)	Power	Watts	±5%

4. PROCEDURES

4.1 General

4.1.1 Responsibility for Thermal Evaluation and Calculations - Thermal evaluation shall be accomplished at the contractor's plant under supervision of the procuring activity or, when so stated in the contract, at a laboratory designated by the procuring activity. Contractors not having facilities satisfactory for meeting the requirements herein may engage the services of a commercial testing laboratory acceptable to the procuring activity. The Government may, at its option, repeat any or all of the tests and calculations performed by the contractor or conduct additional investigations. Inspection records of the examinations and thermal evaluation shall be kept complete and available to the Government. The contractor shall notify the Naval Air Systems Command (AIR-53355A) and the Naval Air Development Center (AEHT) in advance of thermal evaluation.

4.2 Thermal Evaluation and Calculation Procedures

4.2.1 Tabulation of Data for Heat Dissipating and Critical Parts - The equipment manufacturer will identify all temperature critical parts and those parts whose individual dissipation is 1% or more of the total equipment dissipation. This information shall be recorded on a form similar to figure 2, or equivalent, i.e., the use of established automated analysis techniques.

4.2.1.1 Description - Identification of the part type shall be presented under the column headed "description"; i.e., 1/2 watt composition resistor, 2N700 transistor, 6021 electron tube, pulse network, etc. The term "part" shall stand as defined in MIL-STD-280 and shall include encapsulated assemblies, and solid state devices.

4.2.1.2 Schematic Identification - The tabulated data shall include the schematic symbol for each part; i.e., R106, Q127, V701, etc.

4.2.1.3 Location - A general description of the location of the part shall be tabulated, or illustrated.

4.2.1.4 Heat Dissipation - The value for the rate of energy being dissipated by the part during operation at the "Thermal Design Condition" as defined in 6.2.5, shall be tabulated. Preferably this value should be the result of measured data but it may be arrived at through calculations.

4.2.1.5 Electrical Stress Ratio - The value of the electrical stress ratio for each part shall be tabulated. In general, the stress ratio will compare the actual electrical stress on the part when operating at the "Thermal Design Condition," as defined in 6.2.5, with the rated electrical stress at a particular rating temperature. In all cases MIL-HDBK-217 shall be consulted for the applicable definition of a component electrical stress. If available from reliability analyses, this need not be repeated.

In those cases where a part is an encapsulated assembly of basic component parts whose failure rate characteristics are known, the stress levels of the component parts shall be tabulated.

4.2.1.6 Maximum Allowable Surface Temperature - The maximum surface temperature of a part is defined as the maximum hot spot temperature that can be tolerated consistent with the part's function and system or equipment specified reliability requirement. The value for this temperature and its location on the part shall be tabulated for each part. For those parts which are critical or near critical, the basis for the chosen maximum allowable temperature shall be tabulated and reported in detail. Parts which are encapsulated assemblies of basic component parts shall have their maximum allowable surface temperature tabulated. The thermal relationship between the parts in the encapsulation and the encapsulated assembly surface shall be reported in sufficient detail to allow the prediction of the internal part temperatures from the measured encapsulated assembly surface temperature.

4.2.2 Instrumentation - Suitable instrumentation shall be provided to measure the following items (as applicable) during the thermal evaluation program:

(a) Surface temperatures of temperature critical parts. (See 4.2.1.6 and 6.2.4.)

(b) Surface temperature of all parts dissipating more than 1% of the unit total power dissipation. Only representative parts need be instrumented where there are a number of identical parts dissipating similar amounts of power in similar mounting configurations.

(c) Surface temperature of the largest thermal mass item.

(d) Unit external surface temperatures.

(e) Test enclosure wall temperatures.

(f) Air temperature in the local vicinity of the unit.

(g) Air temperature at strategic points inside the unit.

(h) Air pressure in the local vicinity of the unit.

(i) Coolant inlet temperature.

(j) Coolant outlet temperature.

(k) Coolant flow rate.

(l) Coolant static and velocity pressure at unit inlet.

(m) Coolant static pressure at unit outlet.

(n) Unit power input.

(o) Unit power output.

(p) Coolant inlet total moisture content.

(q) Coolant inlet duct sizes and shapes.

(r) Unit thermal time constant (τ) and dead time (L).

(s) Functional and operational performance characteristics.

4.2.2.1 Temperature Measurement - Thermocouples shall be the standard temperature sensors for this specification. The thermocouples shall be of a size equal to or smaller than a 30-gauge thermocouple. Wherever the application of the thermocouple may appreciably affect the temperature field on a part, particular attention shall be given to using smaller gauge thermocouples and to the method of application to the part.

4.2.2.1.1 Surface Temperature Measurement - The temperature sensor shall be located so as to make good thermal contact with the surface to be measured and yet minimize the error due to the presence of the sensor. Where the surface to be instrumented is basically flat, a bead and "collector plate" may be employed. The sensor shall be inserted in a small hole in a collector plate and staked into place. The collector plate will be a small plate of minimum size. The collector plate shall be bonded to the part by means of an easily removable adhesive. Sufficient pressure must be used to produce a very thin film of adhesive. The sensor leads will be insulated electrically from the collector and part, but shall be held in intimate contact with the part and collector for at least 0.25 inch.

Where the surface to be instrumented is curved to an extent which will prohibit the use of the collector plate, or where the addition of the collector plate may greatly influence the surface temperature field, the sensor will be bonded directly to the surface. The quantity of adhesive employed shall be commensurate with the requirements of good thermal contact and a minimum disturbance of the part's temperature field.

All required electronic parts shall be instrumented at the point which will yield the maximum surface temperature. The exact location for any particular part will be chosen by experience and/or some of the methods suggested in the references in paragraph 6.4.

4.2.2.1.2 Surrounding Air Temperature Measurement - The temperatures of the air immediately surrounding the unit shall be monitored by the use of temperature sensors located within three inches of the center of each of the major surfaces of the equipment.

4.2.2.1.3 Coolant Temperature Measurement - Since both coolant inlet and outlet temperatures are used directly in the evaluation procedures, every effort must be made to insure that accurate measuring techniques are used. At any station in the coolant flow, gradients exist. To determine a bulk coolant temperature either mechanical mixing must be supplied or a study of the temperature profile must be made. Suggested methods are presented in 6.3.1. Where the application of those techniques is not practical, publications in paragraph 6.4 may be consulted for recommendations.

4.2.2.2 Coolant Flow Rate Measurements - The coolant flow rate will be measured with any type of meter calibrated to the satisfaction of the contracting agency. In lieu of a specific calibration procedure, an orifice calibrated in accordance with ASME procedures will be considered the standard. Publications in paragraph 6.4 may be consulted for assistance in specific flow measurement techniques.

To insure the accuracy of the flow rate measured data, all lines which supply the coolant to the unit will be checked for leaks. The largest acceptable leak in the coolant supply lines downstream from and including the flow meter shall be 0.5% of the anticipated maximum weight flow rate. The leak rate will be measured (1) when the system is pumped to twice the maximum pressure in the line during the test and (2) when the system is evacuated to a pressure one-half of the lowest absolute pressure in the coolant lines specified in the test schedule. Suggested procedures for determining the leak rate of the coolant supply system are given in 6.3.2.

4.2.2.3 Coolant Pressure Measurement - Steps will be taken to insure accurate pressure measurement of the inlet and the exhaust coolant. Suggested coolant pressure measurement techniques are presented in 6.3.3. Publications in paragraph 6.4 may be consulted for additional information on pressure measurement techniques.

The completed pressure instrumentation system shall be leak tested. A system will be considered leak tight when the leak rate of the system is less than 1% of the captive gas weight per day when tested by the procedures given in 6.3.2.

4.2.3 Thermal Evaluation Procedure - During each thermal evaluation step required by this specification, the equipment shall be operated in the mode which will cause the maximum steady state power dissipation. The equipment shall be checked for satisfactory electrical performance according to the requirements of the detailed equipment specification prior to conducting the thermal performance evaluation. This reference run performance check shall be made in accordance with the approved electrical performance test procedure. A record shall be made of all data necessary to determine the complete operational characteristics. It will then be instrumented and a recheck of the electrical performance made. The equipment shall then be installed in the environmental chamber and a complete check of all instrumentation circuits made. The electrical performance of the unit shall be rechecked and such data recorded as necessary to verify that the operational characteristics were not altered during chamber installation. When the equipment is operating during the thermal evaluation exposure, operation and performance checks shall be made at appropriate time intervals to insure a record of comprehensive electrical performance data for comparison with data recorded during the reference run.

4.2.3.1 Steady State Thermal Evaluation Procedure for Units With Ambient Cooling - Each of the data points required by 3.2.2.1 shall be acquired in the following manner and the data recorded as required in 4.2.3.4.

(a) Adjust chamber to desired pressure altitude and turn on equipment.

(b) Adjust chamber and enclosure wall temperature to maintain the critical part at its maximum allowable temperature. (See 4.2.1.6 and 6.2.4.) The temperature indicated by the critical part sensor shall be maintained within +0°C and -2°C of the designated maximum allowable temperature for the part. Tests should continue for one hour after monitored part temperatures have stabilized. (See 6.2.7 for the definition of stabilization.)

4.2.3.2 Steady State Thermal Evaluation Procedure for Units With External Source Cooling - Each of the data points required by 3.2.2.2 and subparagraphs shall be acquired in the following manner and data recorded as required in 4.2.3.4.

(a) Adjust chamber and enclosure wall temperature to the desired value and turn on equipment.

(b) Adjust coolant inlet temperature to desired value with a minimum flow rate to allow rapid warmup. Adjust chamber pressure to desired value. As equipment warms up, adjust coolant flow to maintain the critical part at its allowable maximum temperature. (See 4.2.1.6 and 6.2.4.) The coolant flow rate shall be adjusted so that the sensor on the critical part indicates a temperature within +0°C and -2°C of the designed maximum allowable temperature for the part. Test should continue for one hour after monitored part temperatures have stabilized. (See 6.2.7 for the definition of stabilization.) In the event that the critical part will not reach its limiting temperature with zero coolant flow, then the chamber and enclosure wall temperature should be adjusted upwards to allow the part to reach its maximum temperature.

4.2.3.3 Thermal Transient Procedure - The transient data required by 3.2.2.3 shall be acquired in the following manner and the data recorded as required in 4.2.3.4.

(a) Adjust chamber and equipment to provide the specified initial conditions.

(b) After monitored temperatures stabilize as defined in 6.2.7, immediately adjust unit operation to the final test condition.

(c) Continue test until stabilized conditions are again achieved or until the critical part instrumentation indicates that its maximum allowable temperature has been reached, at which time the test should be terminated.

4.2.3.4 Thermal Evaluation Data Recording - During the steady state thermal evaluation procedures the data which results from the instrumentation required in 4.2.2 shall be recorded at 30-minute intervals. The coolant moisture content measurement shall be taken only when the moisture content may become critical. During the thermal transient procedure the most critical parts and any other temperatures of interest (i.e., the most representative cases temperature or a changing ambient temperature) shall be recorded at 2-minute intervals during the initial portion of the test. All data shall be recorded on forms similar to those of figure 3.

4.2.4 Data Reduction - The following quantities shall be calculated from the basic steady state thermal evaluation data and reported as shown on figure 3.

4.2.4.1 Average Part temperature - The average part temperature, as calculated below, shall be used in any heat transfer analysis as the reference thermal potential, i.e., equivalent temperature of the unit.

$$t_{p_{avg}} = \frac{\sum_{n=1}^{m} P_n t_{p_n}}{\sum_{n=1}^{m} P_n}$$

4.2.4.2 Ambient Temperature - The ambient temperature which a unit sees is composed of both radiant surface temperatures and the local air temperature. Both under actual installed conditions and during thermal evaluation conditions gradients will exist which may present variations in the thermal ambient which the unit sees. The average ambient temperature shall be defined by the equation below. This temperature shall be used in all calculations and data presentations which require the ambient temperature to be represented by a single number.

$$t_{o_{avg}} = \frac{\sum_{n=1}^{m} A_n \left[(t_o)_n + \left(t_{o_s}\right)_n \right]}{2 A_s}$$

4.2.4.3 Coolant Density - The inlet density of the coolant is required in the calculations specified herein. When an incompressible fluid is used as the coolant, the density will be taken from published data. When a compressible fluid is used, the density will be calculated in the following manner:

$$\rho_1 = \frac{5.2p_1 + 144p_o}{R_g\,(1.8t_{c_1} + 492)}$$

4.2.4.4 Static Pressure Drop - The unit's flow resistance characteristic static pressure drop, shall be presented in the standardized manner given below. This procedure shall apply whenever the coolant behaves as an incompressible fluid. For gases, this equation is applicable when $(p_1 - p_2)$ is less than 10% of the absolute inlet pressure. For those units whose design precludes operation in the incompressible flow region, the standardization procedure shall be omitted. The flow resistance characteristic is used to match the unit with the flight vehicle's coolant supply. (See figure 7.)

$$\sigma\Delta p = \frac{\rho_1}{\rho_{std}}(p_1 - p_2)$$

4.2.4.4.1 Velocity Pressure at Inlet Duct - (See figure 7.)

$$\sigma p_{vi} = \frac{\rho_1}{\rho_{std}}\,p_{vi}$$

4.2.4.5 Coolant Heat Gain (q_c) - The heat absorbed by the coolant is calculated as follows:

$$q_c = 31.6\,wc_p\,(t_{c_2} - t_{c_1})$$

4.2.4.6 External Heat Transfer - The external heat transfer from the unit is calculated as shown below:

$$q_o = P_e - q_c$$

4.2.4.7 Heat Transfer Factor (HTF) - The heat transfer factor represents the overall heat transfer coefficient between the heat dissipating parts and the external ambient. This factor is meaningful for ambient cooled units only and shall be calculated from the Thermal Design Condition Test Data. (See 3.2.2.3.) The HTF is defined as follows:

$$HTF = \frac{P_e}{144\left(t_{p_{avg}} - t_{o_{avg}}\right)A_s}$$

4.2.4.8 Coolant Utilization Factor (CUF) - The coolant utilization factor represents a measure of the coolant heat exchange effectiveness in terms of the utilization of available temperature potential. Using the test data from the Thermal Design Condition Test (See 3.2.2.3.) the CUF shall be calculated as follows:

$$CUF = \frac{P_e}{\left(t_{p_{avg}} - t_{c_1}\right) w c_p}$$

4.2.5 Weight, Volume, and Power Determination - The following items shall be obtained by physical measurement or calculation as most applicable.

All calculations and inherent assumptions for the determination of these items must be documented as part of the reports required in paragraph 4.3. The final results will be recorded on the form shown in figure 3.

(a) Total Weight of the Unit

(b) Cooling Provision Weight - This shall include the total weight of all blowers, pumps, heat exchangers, cold plates, conductive tube shields, thermoelectric modules, etc., which are only present for thermal protection. Those items which perform a structural or other function as well as being part of the cooling design must have a portion of their weight allocated to the cooling provision weight. This allocation should be made on the basis of engineering judgment of the additional weight added by the cooling function of the item over and above what the item's typical weight would be if no cooling provisions were required.

(c) Total Equipment Volume

(d) Cooling Provision Volume - This shall include the total volume of all blowers, pumps, heat exchangers, cold plates, conductive tube shields, thermoelectric modules, etc. which are only present for thermal protection. Those items which perform a structural or other function as well as being part of the cooling design must have a portion of their volume allocated to the equipment cooling provision volume. This allocation shall be made on the basis of engineering judgment of the additional volume added by the cooling function over and above what this item's typical volume would be if no cooling provisions were required.

(e) Total Electrical Power Input to Unit - This shall be the power required for operation under the Thermal Design Condition.

(f) Cooling Provision Electrical Power Input

4.2.6 Performance Limit Data Presentation

4.2.6.1 Ambient Cooling - The data recorded in figure 3 for this type unit shall be presented on graphs similar to figures 4 and 5.

4.2.6.1.1 Steady State Data - A graph similar to figure 4 of limiting pressure altitude and surrounding ambient temperature shall be produced from the steady state thermal evaluation data by the following steps:

(a) The corresponding values of limiting chamber pressure altitude and temperature for the various data points will be plotted as shown.

(b) The graph shall be clearly titled, as shown, with unit name and other descriptive information. The particular governing critical part and its limiting temperature should be indicated. The Thermal Design Condition should be indicated on the graph.

This figure will show the maximum temperature-altitude combinations in which a unit with ambient cooling will operate without the critical part temperatures being exceeded. (See 4.2.1.6 and 6.2.4.)

4.2.6.1.2 Transient Performance Data - A graph similar to figure 5 of part temperature versus time shall be produced from the data, of any transient test of interest, by the following steps:

(a) Those critical part temperatures of major concern (See 6.2.4.) shall be plotted versus time for each data record point. The thermal time constant and dead time of the parts shall be clearly indicated.

(b) Horizontal lines corresponding to the maximum allowable surface temperature (See 4.2.1.6.) for the most critical parts shall be placed on the graph.

(c) The graph shall be clearly titled with the unit name and other descriptive information as shown.

4.2.6.2 External Source Cooling - The data recorded in figure 3 for such a unit shall be presented on graphs similar to figures 5 and 6.

4.2.6.2.1 Steady State Data - A graph similar to figure 6 of limiting coolant inlet temperatures, coolant weight flows, pressure altitude, and ambient temperature shall be produced from the steady state thermal evaluation data by the following steps:

(a) Plot the corresponding value of coolant weight flow for each of the coolant inlet temperatures for each combination of external temperature and pressure.

(b) The graph shall be clearly titled, as shown, with unit name and other descriptive information. The particular governing critical part and its limiting temperature should be indicated. The Thermal Design Condition should be indicated on the plot.

Figure 6 will show the required coolant weight flow for any combination of coolant inlet temperature, external ambient temperature, and pressure for a unit with forced external cooling. The required weight flow is based on maintaining the most critical part at its allowable maximum temperature. (See 4.2.1.6 and 6.2.4.) Interpolation and extrapolation will allow prediction of unit thermal operation under a variety of environmental conditions.

4.2.6.2.2 Transient Performance Data - As in 4.2.6.1.2.

4.2.6.2.3 Static Pressure Drop and Velocity Pressure Graph - The corrected static pressure drop and velocity pressure will be plotted against the corresponding coolant weight flows as shown in figure 7. The graph shall be made on log-log paper.

4.2.7 Thermal Performance Evaluation

4.2.7.1 Thermal Performance Index Calculation and Presentation - The required terms comprising the Thermal Performance Index shall be calculated as follows and reported on a form similar to figure 8.

4.2.7.1.1 Equivalent Weight Penalty Ratio - When a specific aircraft is involved the relative penalty to the flight vehicle imposed by the equipment cooling provisions shall be expressed as the ratio of the equivalent weight penalties due to the cooling provisions (W_{c_e}) to the total equivalent weight of the unit (W_{t_e}). The ratio shall always be shown as an unsimplified fraction with numerator and denominator in their original form. For those items which vary with environmental conditions, the values obtained in the Thermal Design Condition Test shall be used in the calculations as indicated above. In equation form:

Equivalent weight penalty ratio $\frac{W_{c_e}}{W_{t_e}}$

where:

$$W_{c_e} = \frac{W_g}{W_1}\left[W_c + w\left(\frac{W_{cs}}{w_a}\right) + P_c\left(\frac{W_p}{P_a}\right) + W_c\left(\frac{W_{af}}{W_e}\right)\right]$$

$$W_{t_e} = \frac{W_g}{W_1}\left[W_t + w\left(\frac{W_{cs}}{w_a}\right) + P_e\left(\frac{W_p}{P_a}\right) + W_t\left(\frac{W_{af}}{W_e}\right)\right]$$

$$W_e = W_1 - W_{cs} - W_p - W_{af}$$

$$W_1 = W_g - W_f$$

This ratio will be an indication of the relative penalty to the flight vehicle imposed by the equipment cooling provisions. It is expressed as a ratio of the cooling provision weight penalty to the weight penalty for the entire unit. These equivalent weight penalties provide the means for grossly weighing the effects of the various cooling provisions in any specific flight vehicle application. The information will be used to make intelligent decisions as to the most efficient "trade offs" in the equipment thermal design. Any comparison between equipments must, therefore, be based on the same flight vehicle data. The weight penalty calculations are based on the following assumptions:

(a) At the particular time of calculation, the flight vehicle data is assumed fixed with no alteration due to installation or a design change of a particular piece of equipment.

(b) Each pound of the flight vehicle on-board equipment (W_e) is equally responsible for the fuel consumption.

In the event that the flight vehicle provides multiple coolants to the on-board equipment, the (W_{cs}) term shall apply to the specific coolant system under consideration and the (W_a) term shall refer to the corresponding available coolant. If more than one coolant is used in an equipment, the coolant penalty term shall be the sum of the individual coolant system penalties.

When a unit is designed for use in a variety of flight vehicles and no specific vehicle weight data is available, the calculations of this paragraph shall be omitted. In such a case the supplementary factors of 4.2.7.2 shall become the primary evaluation ratios for the Thermal Performance Index.

4.2.7.2 Supplementary Thermal Evaluation Factors - The following supplementary thermal evaluation factors shall be calculated as applicable and reported on a form similar to figure 8. These factors are to be used to evaluate the various features of the equipment thermal design without regard to any specific air vehicle.

4.2.7.2.1 Cooling Provision Weight Ratio - This factor shall be calculated as the ratio of the equipment cooling provision weight (W_c) to the total equipment weight (W_t).

4.2.7.2.2 Cooling Provision Volume Ratio - This factor shall be calculated as the ratio of the equipment cooling provision volume (V_c) to the total equipment volume (V_t).

4.2.7.2.3 Cooling Provision Electrical Power Requirement Ratio - This factor shall be calculated as the ratio of the cooling provision electrical power (P_c) to the total equipment electrical power dissipation (P_e).

4.3 **Reports-** When required by the contract, reports shall be prepared and submitted in accordance with this specification. All the data collected and all calculations generated as a result of this specification shall be a part of the periodic report. The details of the test setups and thermal evaluation procedures shall also be included. Each successive report shall include progressively refined calculated estimates of the required parameters. A report shall be issued at 3-month intervals, unless otherwise specified in the contract.

5. PREPARATION FOR DELIVERY

5.1 Packaging and Packing - Reports required by this specification shall be packed and packaged for delivery in accordance with the contractor's best commercial practice for domestic shipments, except that conformance with security regulations is required where applicable.

5.2 Marking of Shipments - All shipments of reports shall be marked as stated in the contract or as otherwise instructed by the procuring agency.

6. NOTES

6.1 Intended Use - This specification is intended to provide standard procedures to be followed in subjecting airborne electronic equipment to simulated thermal environments for the purpose of evaluating the thermal performance. For variations of thermal evaluation procedures or interpretation of portions of this specification the contractor will contact the Naval Air Development Center (AEHT).

6.1.1 Goals - In order to complete the evaluation of the thermal performance of the unit, it will be necessary to determine whether the values obtained for the Thermal Performance Index terms and the Supplementary Evaluation Factors were poor or excellent. The determination of the excellence of these factors must be based on reference standards or goals. It is anticipated that these goals may vary for the different types of vehicles but neither the values of the goals nor the amount of variation of these goals between vehicles is presently known. Values for the goals can be determined only after this specification has been applied to the equipment designed for the various types of vehicles. Until such time as sufficient data has been compiled to provide the goals for evaluation, the procuring agency may establish tentative values for these goals.

6.2 Definitions

6.2.1 Military Standard Definitions - Definitions contained in MIL-STD-280 shall apply.

6.2.2 Military Specification Definitions - Definitions contained in MIL-E-5400 and MIL-T-5422 shall apply, except when otherwise stated herein.

6.2.3 Abbreviations - Abbreviations defined in MIL-STD-12 shall apply.

6.2.4 Critical Parts - Parts whose surface temperatures are most likely to approach their maximum allowable temperature. The maximum allowable temperature (See 4.2.1.6.) for these parts cannot be exceeded for reliable equipment performance during normal operation and during performance of thermal evaluation.

6.2.4.1 Installed Operating Temperature Check Point(s) - Point(s) accessible on the outer surface of the equipment for monitoring and measuring the temperatures of the most temperature critical part(s) inside.

6.2.5 Thermal Design Condition (TDC) - The thermal environment and electrical operating mode set forth in the equipment specification as the basic thermal design criteria for the unit. If there is no thermal design condition specified as such, then the most severe thermal environment consistent with the detail specifications aircraft mission, and the electrical operating mode which will cause the maximum steady state power dissipation may be considered the Thermal Design Condition.

6.2.6 Average Part Temperature - The average part temperature, computed as specified in 4.2.4.2, is defined as that temperature which represents the thermal potential for heat transfer from the unit.

6.2.7 Stabilization - A stabilized thermal condition has been attained when the indicated temperatures of a majority of the parts (including large thermal mass items) have varied no more than 2°C over a period of 1 hour.

6.2.8 Surface Area - In general, the total unit surface area will be found by summing the individual side projected areas. It is intended that the surface area be based on outline dimensions of the major portions of the package. Areas associated with the vertical sides of fins, for example, are not to be included.

6.3 Suggested Test and Instrumentation Techniques - The methods and techniques described in this section are guides to accurate data collection. It is suggested that they be used whenever practicable.

6.3.1 Coolant Temperature Measurement - A bulk coolant temperature is required for calculation purposes. When adequate mixing of the coolant is employed, one temperature sensor in the coolant would be a sufficient indication of the specific bulk temperature.

However, when the coolant flows in a duct with the inherent thermal and velocity gradients, the bulk temperatures must be calculated. One method of arriving at the bulk temperature involves measuring the coolant temperature at the center line of the duct and the duct temperature at the same station. The duct should be sized to yield a Reynolds Number (R_n) in the neighborhood of 10,000 when the flow rate is in the expected range. The following equation will give the bulk coolant temperature at the station where the measurements were made.

$$t_c = 0.81\ t_{cl} + 0.19\ t_d$$

The duct should be well insulated in order to minimize the temperature difference between the coolant and the duct. The center line thermocouple should be located at a point of well developed flow and as near to the unit as is consistent with the requirement of well developed flow.

The exhaust coolant may be monitored in a similar manner. When the inlet or the exhaust parts from the unit are multiple openings, a manifold fitting should be employed to facilitate the measurement whenever so doing will not significantly alter coolant flow patterns, the performance of the unit, or its pressure drop. In those instances where alteration of the coolant flow path may significantly affect the unit's thermal or pressure drop performance, multiple thermocouples may be used at the coolant parts, in order to obtain a bulk coolant temperature for a station.

6.3.2. Test for Leaks - To insure the accuracy of the data, all lines which will handle fluids will be checked for leaks. (See 4.2.2.2.) When the fluid is a gas, the leak rate may be measured by the pressure decay method as follows:

After the test set up is completed, the lines which will transmit a pressure potential will be closed. Compressed air will be introduced to raise the pressure to double the value of the maximum expected test pressure. By monitoring both the temperature and pressure in the lines, the change of density for a given time interval may be used to calculate the leak flow rate. In a similar manner the leak flow rate will be calculated when the pressure in the lines is reduced to one-half of the lowest expected test pressure by the use of a vacuum pump.

6.3.3 Coolant Static and Velocity Pressure Measurement - The coolant may be supplied to the unit and removed from the unit through ducts. Static and velocity pressure at the inlet and exhaust of the unit may be measured by suitable instrumentation such as piezostatic and/or pitot tubes. The opening of holes into the coolant duct shall be free of burrs and flush with the duct wall.

6.3.4 Time Constant (τ) - The time period for a "first order lag" system element to reach 63.2 percent of its final value for a step change in input.

6.3.5 Dead Time (L) - The period of delay between the change of an input signal and the resulting change in output signal.

6.4 Useful Publications - Listed below are a number of government publications which may be used as reference for design, evaluation, and instrumentation techniques. See 2.2 for information on how to obtain these publications.

DDC-AD38369	Manual of Standard Temperature Measuring Techniques, Units and Terminology for Miniaturized Electronic Equipment.
DDC-AD210948	Design Manual of Methods of Forced Air Cooling Electronic Equipment.
DDC-ATI180190	The Thermal Evaluation of Air-Cooled Electronic Equipment.
DDC-23894	The Thermal Evaluation of Air-Cooled Electronic Equipment - Supplement 1.
Specification AR-45	Airborne Electronic Equipment and Systems Thermal Design and Analysis Procedures.
MIL-HDBK-217	Reliability Stress and Failure Rate Data for Electronic Equipment.
Proposed Specification AR-35	Procedures, Thermal Design, Avionic Systems, General Specification for
Proposed Specification AR-37	Avionics Systems Thermal Controls, Performance Evaluation Procedures, General Requirements for

6.5 Glossary

Term	Definition	Units
A	- External surface area	ft^2
A_s	- Unit total external surface area (See 6.2.8.)	ft^2

Term	Definition	Units
CUF	- Coolant Utilization Factor (See 4.2.4.8.)	dimensionless
c_p	- Coolant specific heat	$\frac{BTU}{lb-°F}$
HTF	- Heat Transfer Factor (See 4.2.4.7.)	$\frac{Watts}{in.^2 -°C}$
L	- Dead Time	hr, min, as applicable
MTBF	- Mean Time Between Failures	hr
m	- Represents all items considered in a series	dimensionless
n	- A particular item in a series	dimensionless
P	- Electrical power dissipation	watts
P_a	- Flight vehicle net electrical power capacity available to items which compose W_e	watts
P_c	- Unit cooling provision power requirements	watts
P_e	- Unit total electrical power dissipation	watts
P_o	- Unit total output power	watts
P_t	- Unit total electrical power input	watts
p	- Pressure	in. H_2O, PSIA, PSFA
p_o	- Ambient pressure (chamber pressure)	PSIA
p_1	- Coolant inlet static pressure rise over the ambient pressure	in. H_2O
p_{1_o}	- Inlet pressure to flow meter	PSIA
p_2	- Coolant outlet static pressure rise over the ambient pressure	in. H_2O

Term	Definition	Units
P_{vi}	- Coolant Inlet Velocity Pressure	in. H_2O
Δp	- Static pressure difference between inlet and outlet coolant	in. H_2O
$\sigma\Delta p$	- Corrected pressure drop	in. H_2O
q_c	- Coolant heat gain	watts
q_o	- External heat transfer	watts
R_g	- Gas constant (53.3 for air)	$\frac{ft}{°R}$
°R	- Absolute Temperature (°F + 460)	°R
R_n	- Reynolds Number	dimensionless
TDC	- Thermal Design Condition	dimensionless
T	- Time	hr, min, as applicable
t	- Temperature	°C
t_c	- Bulk coolant temperature	°C
t_{c_1}	- Bulk coolant inlet temperature	°C
t_{c_2}	- Bulk coolant outlet temperature	°C
t_{cl}	- Coolant center line temperature	°C
t_d	- Duct wall temperature	°C
t_o	- Ambient air temperature	°C
$t_{o_{avg}}$	- Average ambient temperature	°C
t_{o_s}	- Temperature of the enclosure surface	°C

Term	Definition	Units
t_p	- Hot spot surface temperature of a part	°C
$t_{p_{avg}}$	- Average part temperature	°C
t_s	- Unit external surface temperature	°C
V_c	- Volume of cooling provisions	ft^3
V_t	- Volume of unit	ft^3
W	- Weight	lb
W_1	- Dry weight of flight vehicle	lb
W_{af}	- Weight of basic airframe structure and propulsion group	lb
W_c	- Weight of unit cooling provisions	lb
W_{c_e}	- Cooling provision equivalent weight penalty at takeoff	lb
W_{cs}	- Weight of flight vehicle coolant supply system at takeoff	lb
W_e	- Weight of all on-board equipment excluding coolant and electrical power systems	lb
W_f	- Flight vehicle fuel weight at takeoff	lb
W_g	- Flight vehicle gross weight at takeoff	lb
W_p	- Total weight of flight vehicle electrical power plant including distribution system	lb
W_t	- Total weight of unit	lb
W_{t_e}	- Total equivalent weight penalty for unit at takeoff	lb
w	- Coolant flow rate	$\frac{lb}{min}$

Term	Definition	Units
w_a	- Flight vehicle available coolant supply capacity at flight conditions corresponding to Thermal Design Condition	$\frac{lb}{min}$
σ	- Density ratio $\frac{\rho_1}{\rho_{std}}$	dimensionless
τ	- Time constant	hr, min, as applicable
ρ_{std}	- Standard coolant density at 29.92 IN. Hg and 59F (0.0765 for air)	$\frac{lb}{ft^3}$
ρ_1	- Coolant inlet density	$\frac{lb}{ft^3}$
Σ	- Indicates summation of a series	dimensionless

Project No. Misc-N795

EQUIPMENT DATA DATE ________

MANUFACTURER ________________________________

DESIGNATION ____________________ MODEL/SERIAL NO. ________

SPECIFICATION ________________________________

ENVIRONMENTAL CLASSIFICATION ____________ COOLANT ________

DESCRIPTION OF INTERNAL AND EXTERNAL COOLING MODE ________________

SELF CONTAINED BLOWER DATA: (a) EXTERNAL ________________
(b) INTERNAL ________________

ELECTRICAL SCHEMATIC NUMBER (S) ________________

MODE OF OPERATION (TDC) ________ DUTY CYCLE (STANDBY, HOLD MODES, ETC) ________

ENVIRONMENT (TDC) ________________________

OUTLINE DIMENSIONS ________ OUTLINE DRAWING NUMBER ________ TOTAL WEIGHT ________

TOTAL POWER DISSIPATED ______ SUM OF THE IDENTIFIED PART DISSIPATION ________

CRITICAL PARTS: (1) (2) (3) (4) (etc)
(See 4.2.1.6 and 6.2.4)

INSTALLED OPERATING CHECK POINT(S) AND RECOMMENDED OPERATING TEMPERATURES
(See 6.2.4.1) ________________________________

OTHER EQUIPMENT DATA (e.g. sealing, leakage, insulation data, locations and instructions for use of installed operating temperature check point(s)) ________________
____
____

FIGURE 1 - General Equipment and Vehicle Data for (Equipment Name)

Part Description	Schematic Identification	Part Location	Heat Dissipation Watts	Electrical Stress Ratio	Max Allow Surface Temp ° C	Order of Criticality	Basis for Choice of Critical Part Maximum Allowable Temperature (See 4.2.1.6 and 6.2.4)

FIGURE 2 - Equipment Critical Parts and Heat Dissipating Parts List for (Equipment Name)

SHEET 1 OF 3

Item No.	Item	Units		Item No.	Item	Units	
A	ENVIRONMENTAL DATA			16	Temperature at flow meter	°C	
1	Chamber air near unit top, t_o	°C		17	Flow meter indication	in.H_2O	
2	Bottom, t_o	°C		18	Coolant temperature at inlet centerline, t_{cl_1}	°C	
3	Front, t_o	°C		19	Duct wall temperature at inlet, t_{d_1}	°C	
4	Back, t_o	°C		20	Coolant inlet static and velocity pressures P_1, P_{v1}	PSIA or in.H_2O	
5	Right, t_o	°C		21	Coolant temperature at exhaust centerline, t_{cl_2}	°C	
6	Left, t_o	°C		22	Duct wall temperature at exhaust, t_{d_2}	°C	
7	Chamber wall directly opposite unit top t_{o_s}	°C		23	Coolant exhaust static pressure, P_2	in.H_2O	
8	Bottom, t_{o_s}	°C		C	UNIT TEMPERATURES		
9	Front, t_{o_s}	°C		24	Unit external case temp top, t_s	°C	
10	Back, t_{o_s}	°C		25	Bottom, t_s	°C	
11	Right, t_{o_s}	°C		26	Front, t_s	°C	
12	Left, t_{o_s}	°C		27	Back, t_s	°C	
13	Ambient press P_o	PSIA		28	Right, t_s	°C	
14	LCL ATM press	PSIA					
B	COOLANT DATA						
15	Flow meter size	in.					
16	Orifice size	in.					
17	Pressure at flow meter, $P1_o$	PSIA					

FIGURE 3 - Thermal Performance and Evaluation Data for (Equipment Name)

SHEET 2 of 3

Item No.	Item	Units
29	Left, t_s	°C
D	CRITICAL PARTS SURFACE TEMPERATURE (IN ORDER), t_p	
30	1	°C
31		°C
32	M	°C
E	OTHER INSTRUMENTED POINTS, INCLUDING INSTALLED OPERATING TEMPERATURE & CHECK POINT(S) AIR TEMPERATURE INSIDE UNIT	
33	1	°C
34		°C
35	M	°C
F	UNIT INTERNAL PRESSURE	PSIA
G	REDUCED DATA	
	Ambient temperature $t_{o_{avg}}$	°C
	Average part temperature, $t_{p_{avg}}$	°C
	Bulk inlet coolant temperature, t_{c_1}	°C
	Bulk outlet coolant temperature, t_{c_2}	°C

Item No.	Item	Units
	Coolant flow rate, w	lb/min
	Coolant specific heat c_p	BTU/lb°F
	Coolant heat gain, q_c	watts
	Inlet density, ρ_1	lb/ft^3
	$p_1 - p_2 = \Delta p$	in.H_2O
	$\sigma\Delta p$	in.H_2O
	External heat transfer, q_o	watts
	Heat transfer factor, HTF	watts/ $in.^2$ °C
	Coolant utilization factor, CUF	dimensionless
	Time constant (τ) Dead time (L)	hr,min,sec
H	ELECTRICAL MEASUREMENTS ac-dc-pulse	
	Total electrical power input, P_t	watts
	Output power P_o	watts
	Electrical power dissipation, $P_e = P_t - P_o$	watts
	Cooling provision electrical power, P_c	watts

FIGURE 3 - Thermal Performance and Evaluation Data for (Equipment Name)

SHEET 3 of 3

Item No.	Item	Units	
I	OTHER ELECTRICAL PARAMETERS		
J	UNIT'S PHYSICAL PROPERTIES		
	Total equipment weight, W_t	lb	
	Cooling provision weight, W_c	lb	
	Total equipment volume, V_t	ft^3	
	Cooling provision volume, V_c	ft^3	
	Top area	ft^2	
	Bottom area	ft^2	
	Front area	ft^2	
	Back area	ft^2	
	Right area	ft^2	
	Left area	ft^2	
	Total A_s	ft^2	
	Inlet duct size and shape	ft^2	

FIGURE 3 - Thermal Performance and Evaluation Data for (Equipment Name)

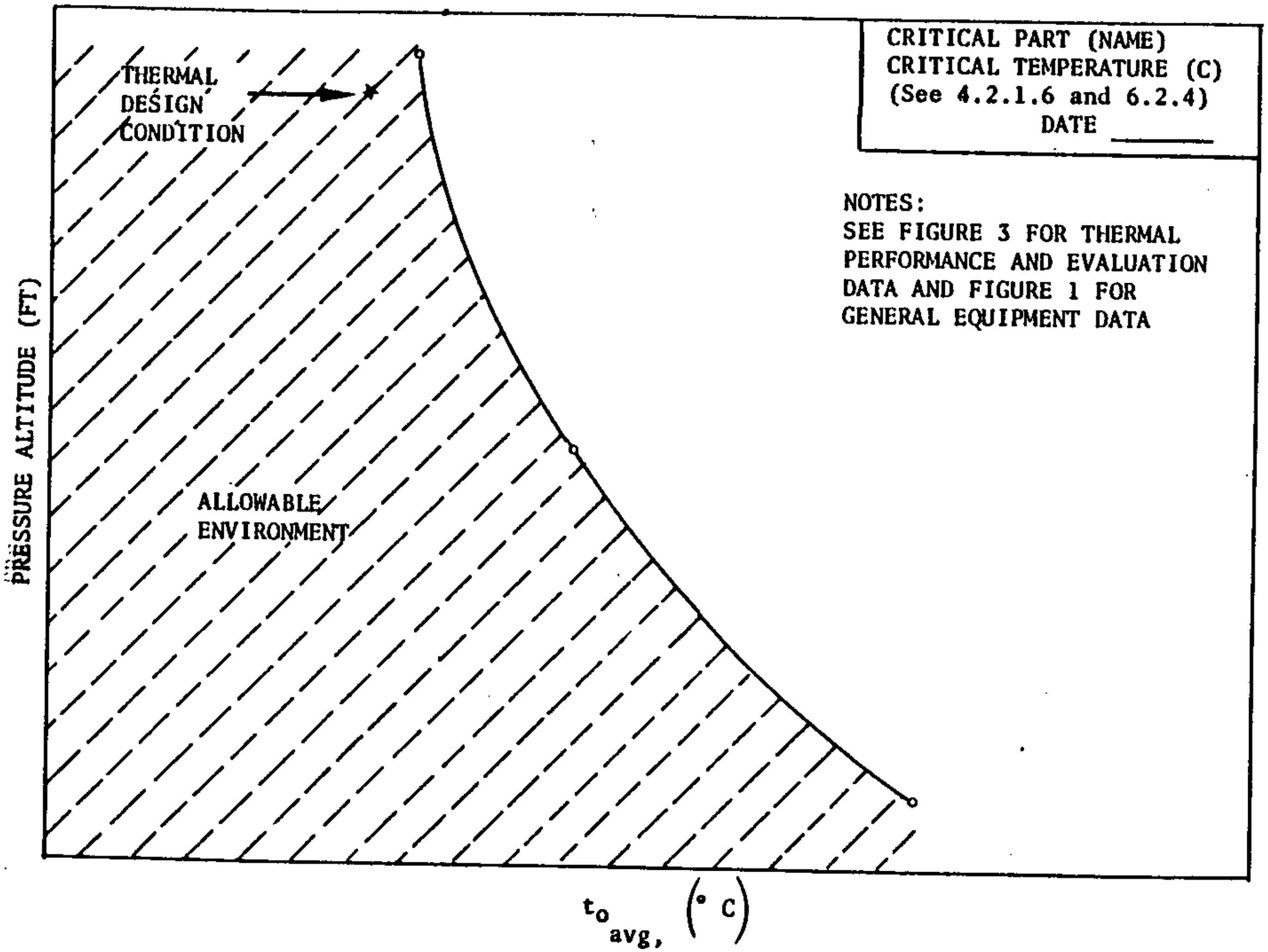

FIGURE 4 - Ambient Cooling Steady State Thermal Performance Limit for (Equipment Name)

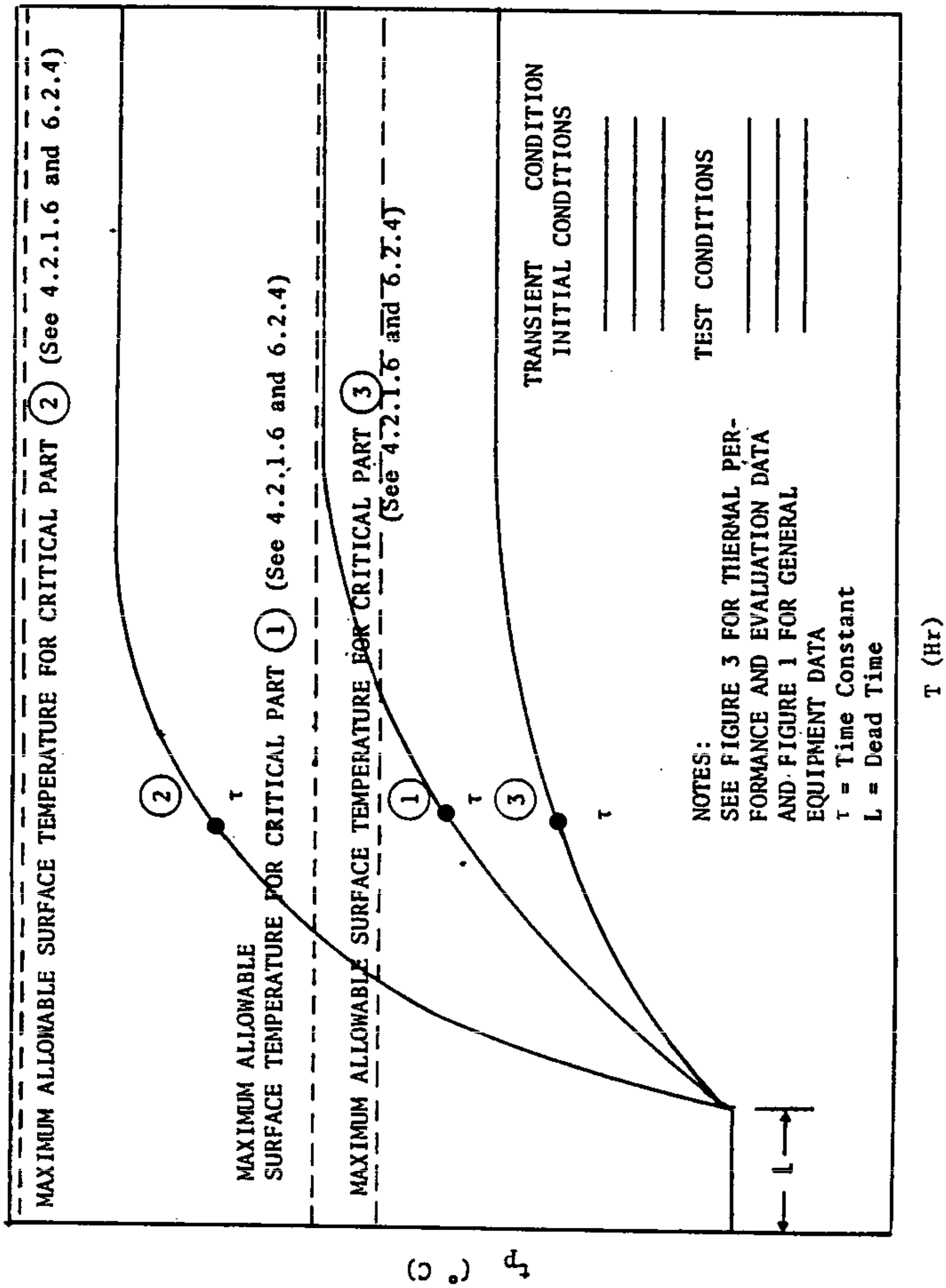

FIGURE 5 - Transient Performance Data for (Equipment Name)

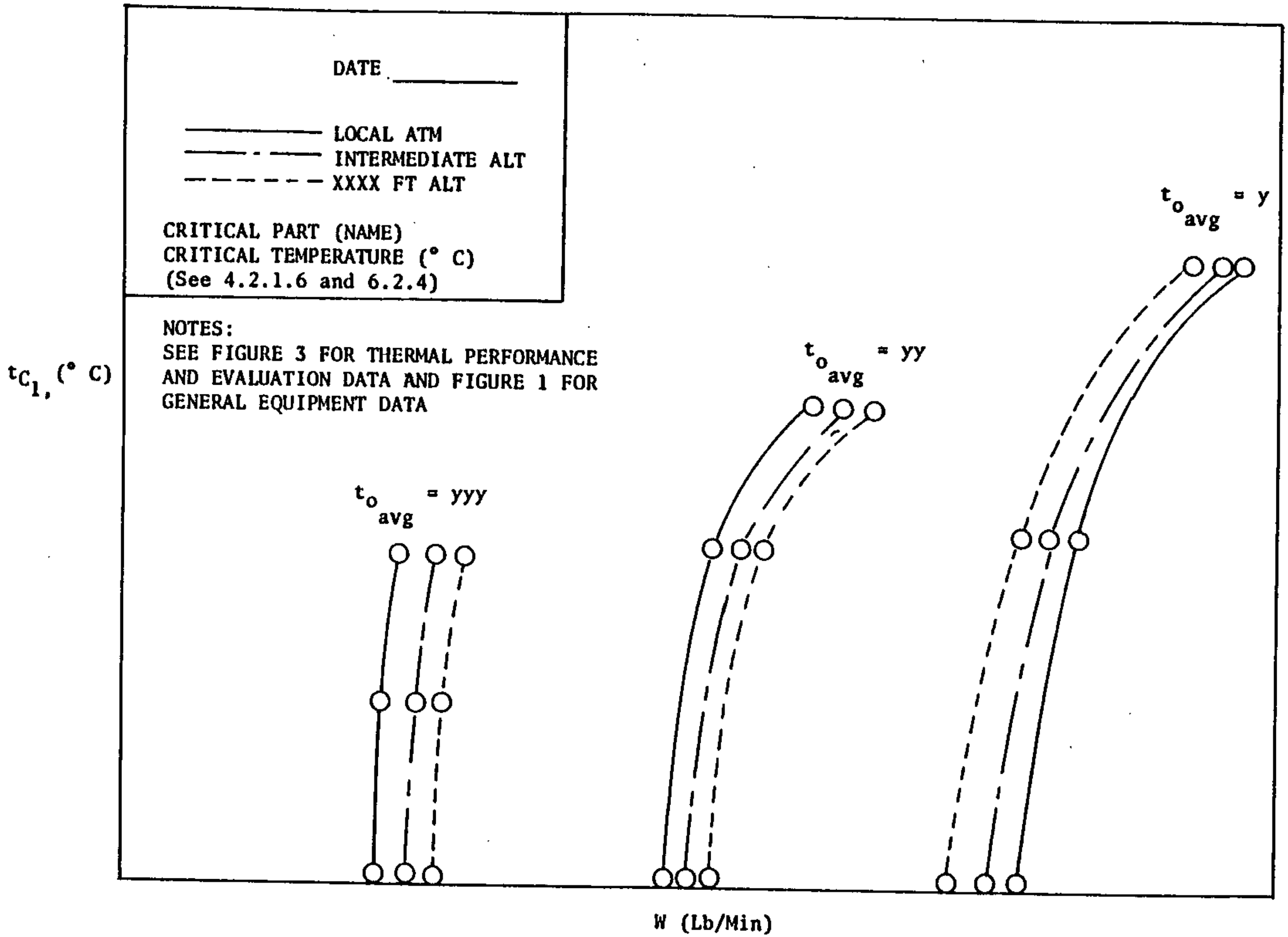

FIGURE 6 - External Source Cooling Steady State Thermal Performance Limit for (Equipment Name)

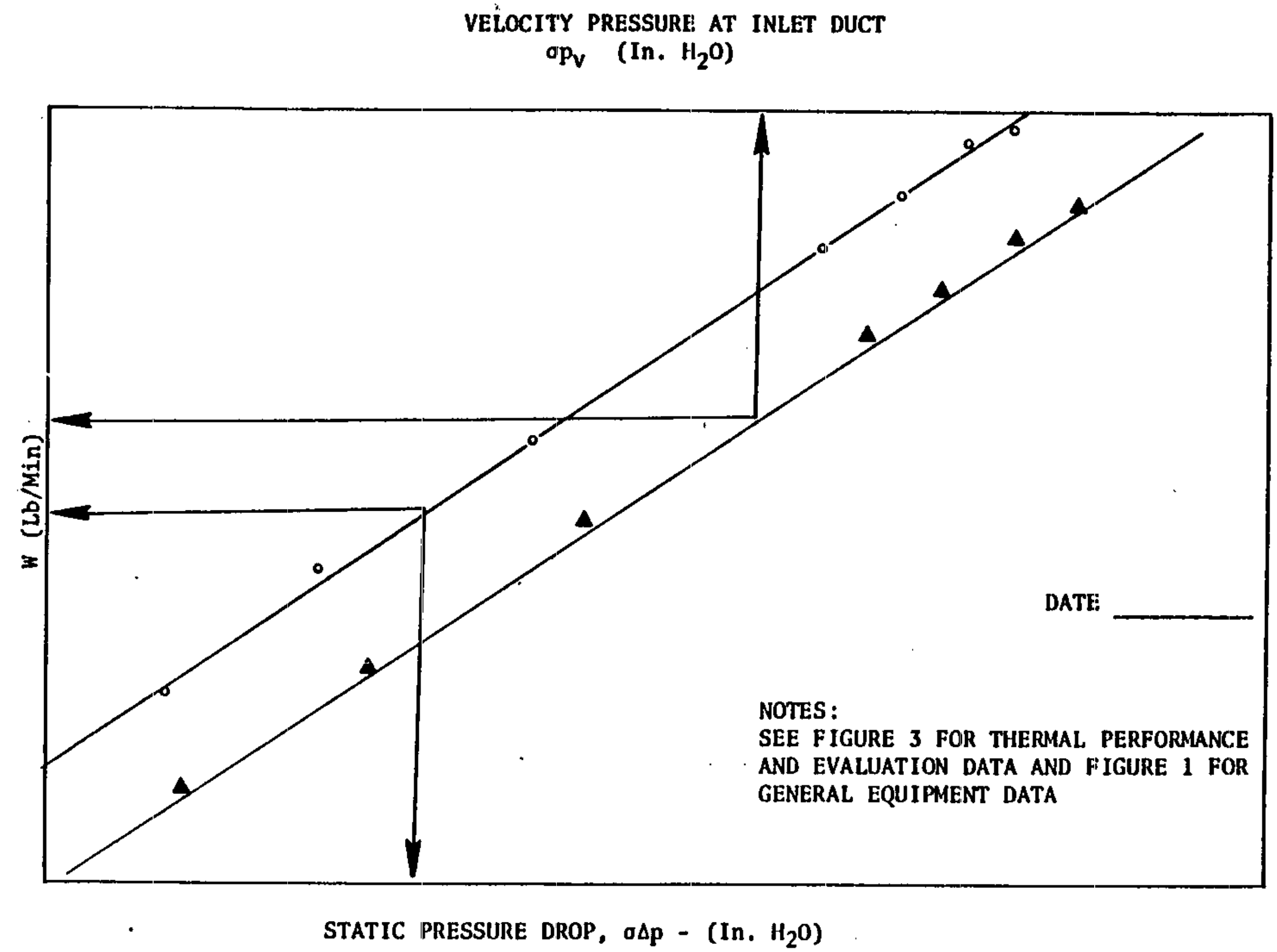

FIGURE 7 - Flow Resistance Characteristic Curve for (Equipment Name)

THERMAL PERFORMANCE INDEX

EQUIVALENT WEIGHT RATIO $= \frac{W_{c_e}}{W_{t_e}} = \frac{(\quad)}{(\quad)} = (\quad)$

SUPPLEMENTARY EVALUATION FACTORS

$\frac{W_e}{W_t} =$ $\frac{P_c}{P_e} =$ $\frac{V_c}{V_t} =$

FLIGHT VEHICLE DATA DATA DATE ______

MANUFACTURER ______

DESIGNATION ______ DEVELOPMENT PHASE ______

P_a ______ W_a ______ W_{af} ______ W_f ______

W_p ______ W_{cs} ______ W_e ______ W_g ______

FIGURE 8 - Thermal Design Evaluation Sheet for (Equipment Name)

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Engineering Division
Standardization Section, Code: Air-52021
Department of the Navy
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