



AEROSPACE INFORMATION REPORT	AIR1277™	REV. B
	Issued 1976-05 Revised 2005-02 Reaffirmed 2024-10	
	Superseding AIR1277A	
(R) Cooling of Military Avionic Equipment		

RATIONALE

AIR1277B has been reaffirmed to comply with the SAE Five-Year Review policy.

TABLE OF CONTENTS

1. SCOPE 5

1.1 Purpose 5

1.2 Field of Application 5

2. REFERENCES 5

2.1 Applicable Documents 5

2.1.1 SAE Publications 5

2.1.2 U.S. Government Publications 6

2.1.3 U.S. Army Publications 7

2.1.4 NATO Publications 7

2.2 Related Publications 8

2.3 Definitions 12

2.4 Abbreviations 14

3. INTRODUCTION 15

4. DESIGN REQUIREMENTS 15

4.1 General Requirements 15

4.1.1 Contract Specification 15

4.1.2 Military or Government Specifications 16

4.1.3 System Design Process 16

4.2 Avionic Thermal Design Considerations 16

4.2.1 Reliability 16

4.2.2 Temperature Effect on Avionic Performance 21

4.2.3 Environmental Requirements 21

4.2.4 Avionic Thermal Control 23

4.2.5 Avionic Integrity Requirements 23

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Documents

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4.3	Airframe Systems	24
4.3.1	Thermal Control Requirements	24
4.3.2	Trade-off Studies	24
4.3.3	Environmental Requirements	24
4.3.4	Moisture Condensation	24
5.	INTERFACE BETWEEN AVIONICS, ECS, AND AIRCRAFT	25
5.1	Interface Cooling Requirements	26
5.2	Life Cycle Cost	29
5.3	Ram and Compartment Cooling Air	30
5.4	Air and Liquid Cooled Systems	30
5.4.1	Forced Air Cooling	30
5.4.2	Liquid Cooling Systems	32
5.5	Fuel Heat Sink	35
5.6	Installation	36
5.7	Weight	36
5.8	Commercial-off-the-shelf (COTS) Avionics	38
6.	AVIONIC THERMAL CONTROL HARDWARE DESIGN/SELECTION	38
6.1	Line-Replaceable-Unit (Weapon Replaceable Assembly) Thermal Design	38
6.1.1	Passively Cooled (Natural Convection/Radiation) LRUs	40
6.1.2	Actively Cooled (Forced Convection) LRUs	44
6.1.3	Cold Wall-Cooled LRU Thermal Design	50
6.2	Cold Plate Design	55
6.2.1	Basic Cold Wall Configurations	57
6.3	Heat Exchanger Design	59
6.3.1	Plate Fin Heat Exchangers	59
6.3.2	Weight and Other Considerations	62
6.4	Specialized Thermal Control Technologies	62
6.4.1	Thermoelectric Coolers	62
6.4.2	Heat Pipes	64
6.4.3	Immersion Cooling	69
6.4.4	Expendable Liquid Coolants	70
6.4.5	Liquid Coolant Within Board	70
6.5	Thermal Analysis Methods	71
6.5.1	Thermal Modeling Techniques	71
6.5.2	Finite-Difference Modeling Techniques	72
6.5.3	Finite-Element Modeling Techniques	73
6.5.4	Computational-Fluid-Dynamics (CFD) Simulation	74
6.5.5	ECS Simulation	74
7.	AIRFRAME THERMAL CONTROL HARDWARE	74
7.1	Heat Sink Hardware	75
7.1.1	Ram Air	75
7.1.2	Fuel	75
7.1.3	Expendable Liquid Heat Sinks	76

7.1.4	Thermal Storage	76
7.2	ECS Hardware	77
7.2.1	Transport Loops	77
7.2.2	Fluid Refrigeration	78
7.3	Thermal Analysis Methods	80
8.	THERMAL TESTING	81
8.1	Thermal Testing of Avionics	82
8.2	Thermal Testing of Cooling Systems and ECS	82
9.	AVIONIC THERMAL MANAGEMENT CASE STUDIES	83
9.1	FLIR Turret Thermal Control	83
9.1.1	Design for Operation at High Altitude	85
9.1.2	Design Verification Testing	87
9.1.3	Problems Associated With Forced Convection Cooled Avionics	87
9.2	Liquid-Cooled, Phased Array Radar System	88
9.2.1	Critical Design Issues	89
9.2.2	Temperature Gradient from Module-to-Module Across the Array	89
9.2.3	Absolute Temperature of Module Components	90
9.2.4	Temperature Cycling	90
9.2.5	Module/Cold Plate Thermal Resistance	91
10.	NOTES	91
FIGURE 1	Integrated Circuit Failure Rate as a Function of Junction Temperature	19
FIGURE 2	Relative Performance of CMOS Devices as a Function of Temperature	22
FIGURE 3	Direct Liquid Cooling with Integral Cold Plate	33
FIGURE 4	Indirect Liquid Cooling with Integral Cold Plate	34
FIGURE 5	Difference Between Integrated Circuit Junction Temperature and Cooling Air Supply Temperature as a Function of Dissipated Power	39
FIGURE 6	Values of Heat Transfer Coefficient for Different Modes of Heat Transfer	43
FIGURE 7	Direct Air-Cooled Chassis (PWB Card Rack)	45
FIGURE 8	Combined Direct and Indirect Cooled System	45
FIGURE 9	Cold Wall/Thermal Plane Interface for Edge-Cooled PWB	47
FIGURE 10	PWB Chassis with PWBs Edge-Cooled by Conduction to Air-Cooled Cold Wall	47
FIGURE 11	PWB Populated with Dual-In-Line (DIP) Packages Mounted in Thermal Plane Card Rail with Interface to Cold Wall	48
FIGURE 12	Leadless Ceramic Chip Carrier (LCCC) and Metal Core Substrate	48
FIGURE 13	Chassis Populated with Air-Cooled Flow-Through Modules	49
FIGURE 14	Cross Section of Flow-Through Module	50
FIGURE 15	Three Common Cold Wall Configurations	51
FIGURE 16	Liquid-Cooled Cold Wall with Machined, Rectangular-Section Channels	53
FIGURE 17	Isometric Cross Section of Plate Fin Heat Exchanger Construction	60
FIGURE 18	Thermoelectric Cooler	64
FIGURE 19	Basic Construction of Heat Pipes	65
FIGURE 20	Operating Temperature Ranges for Various Heat Pipe Working Fluids	66

FIGURE 21	Basic Heat Pipe Configurations.....	66
FIGURE 22	ISEM-2A Heat Pipe Module	68
FIGURE 23	Heat Pipe Application to Standard Electronics Module (SEM).....	68
FIGURE 24	SEM-E Temperature Profile With and Without Heat Pipe	69
TABLE 1	Failure Mechanisms Accelerated by Increased Temperature	17
TABLE 2	Temperature Effects on Military Electronic Equipment Reliability	21
TABLE 3	Cabin, Avionics and Total ECS Heat Load Trends	27
TABLE 4	Typical Coolant Temperatures	28
TABLE 5	Typical Avionic Mass/Weight.....	37
TABLE 6	Helicopter Cooling Capacities and ECS Mass/Weight	37
TABLE 7	Comparison of Methods of Cooling Electronic Modules.....	40
TABLE 8	Typical Card Guide Thermal Resistance Values.....	55
TABLE 9	Thermal Testing for Avionic Systems and Aircraft ECS and Cooling Systems	81

1. SCOPE:

This SAE Aerospace Information Report (AIR) contains information on the thermal design requirements of airborne avionic systems used in military airborne applications. Methods are explored which are commonly used to provide thermal control of avionic systems. Both air and liquid cooled systems are discussed.

1.1 Purpose:

This document describes guidelines for the configuration and design of military aircraft subsystems that provide cooling to airborne avionic systems and recommendations for the basic cooling concepts, analytical methods and design practices used for the thermal design of those airborne avionic systems. The efficient design of the interface between the airframe system and the avionic system is considered.

1.2 Field of Application:

This document is intended to apply to both designers of airborne avionic equipment and of airborne environmental control systems.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publication shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP217	Testing of Commercial Airplane Environmental Control Systems
AIR1168/10	Thermophysical Characteristics of Working Fluids and Heat Transfer Fluids
AIR1706	The Advanced Environmental Control System (AECS) Computer Program for Steady State Analysis and Preliminary System Sizing
AIR1811	Liquid Cooling Systems

2.1.1 (Continued):

AIR1812	Environmental Control Systems Life Cycle Cost
AIR1823	Environmental Control System Transient Analysis Computer Program (EASY)
AIR1957	Heat Sink Thermal Management

2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094 or at <http://assist.daps.dla.mil/online/start/>.

AFGS-87145A	Environmental Control, Airborne, Department of Defense, Washington, DC, October 1, 1992. Note: This is a controlled distribution document.
JSSG-2009	Joint Service Specification Guide, Air Vehicle Subsystems, Department of Defense, Washington, DC, October 30, 1998
MIL-E-18927E	Environmental Control Systems, Aircraft, General Requirements For, Department of Defense, Washington, DC, August 18, 1983, (currently Amendment 2 dated December 19, 1986)
MIL-HDBK-175	Microelectronic Device Data Handbook, Department of Defense, Washington, DC, May 1, 1968
MIL-HDBK-217F	Reliability Prediction of Electronic Equipment, Department of Defense, Washington, DC, December 2, 1991
MIL-HDBK-251	Reliability/Design, Thermal Applications, Department of Defense, Washington, DC, January 19, 1978
MIL-HDBK-310	Global Climatic Data for Developing Military Products, Department of Defense, Washington, DC, June 23, 1997, (supersedes MIL-STD-210)
MIL-HDBK-454	General Guidelines For Electronic Equipment, Department of Defense, Washington, DC, April 28, 1995, Notice 1, May 28, 1997 (supersedes MIL-STD-454M)
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MIL-STD-810F	Environmental Engineering Consideration and Laboratory Test, Department of Defense, Washington, DC, January 1, 2000
MIL-STD-883E	Test Method Standard, Microcircuits, Notice 4, Department of Defense, Washington, DC, December 18, 2000
MIL-STD-2218	Thermal Design, Analysis, and Test Procedures for Airborne Electronic Equipment, supersedes MIL-T-23103A (AS) dated April 29, 1971, Department of the Navy, Washington, DC, May 20, 1992
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2.1.3 U. S. Army Publications: Available from www.usapa.army.mil/USAPA_PUB_search_P.asp.

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2.1.4 NATO Publications: Available from Global Engineering Documents, 15 Inverness Way, East Englewood, CO 80112.

STANAG 2895	Extreme Climate Conditions and Derived Conditions for Use in Defining Design/Test Criteria for NATO Forces Material, February 15, 1990
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2.3 Definitions:

AVIONIC: Pertaining to airborne electronic equipment.

AVIONICS: Airborne electronic equipment.

CARD GUIDE: Retaining element that holds PWB in place in electronic chassis.

CASE TEMPERATURE: Outside temperature of case of semiconductor package.

COLD PLATE: Plate cooled internally that is a mounting surface for electronic modules.

COLD WALL: Integral wall of chassis containing internal cooling passages.

DERATING: Operation of integrated circuits at lower than maximum recommended operating conditions.

DIRECT-AIR-COOLED: Convection cooling where the air comes into direct contact with the components.

FLOW-THROUGH MODULES: Modules with internal passageways for coolant flow.

HEAT EXCHANGER EFFECTIVENESS: The actual heat transfer rate divided by the maximum possible rate and is calculated as follows:

$$\epsilon = \frac{C_h(T_{hi} - T_{ho})}{C_{\min}(T_{hi} - T_{ci})} = \frac{C_c(T_{co} - T_{ci})}{C_{\min}(T_{hi} - T_{ci})} \quad (\text{Eq. 1})$$

where:

T = temperature
C = heat capacity, Wc_p
W = mass flow
 c_p = specific heat capacity, constant pressure
 $C_{\min}$ = smaller of C_h and C_c magnitudes

2.3 (Continued):

subscripts:

c = cold flow

h = hot flow

i = inlet

o = outlet

INFANT MORTALITY: Early life failures of electronic components.

JUNCTION TEMPERATURE: Temperature of the active element of an integrated circuit.

MODULE: Electronic package containing multiple junctions.

MOUNTING SURFACE: Base or bottom of the case that is in contact with the PWB temperature.

PELTIER EFFECT: Occurs whenever electrical current flows through two dissimilar conductors. The junction of the two conductors will either absorb or release heat depending on the direction of current flow. The Peltier effect is most frequently utilized in solid-state thermoelectric modules to pump heat from a lower temperature to a higher temperature for the purpose of cooling a device at the lower temperature.

SEEBECK EFFECT: When two pairs of dissimilar metals are joined together (a junction), an emf will exist between the two junctions that is primarily a function of the temperature difference between the two junctions. (This principle is used in thermocouples.)

THERMAL PLANE: A surface, typically on an avionic circuit board, used to conduct heat usually to the sides of the board. Its thickness is usually small compared to its length and width.

UNIT: An assembly of avionic components, usually in a protective enclosure, often referred to as a "black box."

2.4 Abbreviations:

CFD	Computational Fluid Dynamics
CFE	Contractor Furnished Equipment
CMOS	Complementary Metal Oxide Semiconductor
DIP	Dual-In-Line Package Containing Semiconductor Device
emf	Electromotive Force
ECS	Environmental Control System
EMI	Electromagnetic Interference
FLIR	Forward Looking Infra Red
GFE	Government Furnished Equipment
IC	Integrated Circuit
ICD	Interface Control Drawing/Document
IGBT	Insulated Gate Bipolar Transistor
IR	Infra Red
LRM	Line Replaceable Module
LRU	Line Replaceable Unit
MCT	Metal Oxide Semiconductor Control Thyristor
PAO	Polyalphaolefin
PWB	Printed-Wiring-Board
RTV	Room Temperature Vulcanizing
SAE	Society of Automotive Engineers

2.4 (Continued):

SEM-E Standard Electronic Module - E Size

TEC Thermoelectric Cooler

WRA Weapon Replaceable Assembly

3. INTRODUCTION:

Current military design practices are reviewed with regard to the relationship between thermal control of avionics and component reliability as affected by temperature and moisture. Attention is given to the recent emphasis on improved system reliability, reduced life cycle cost and avionic integrity. Basic design requirements based on military specifications and military environments are reviewed. Typical avionic system heat loads are portrayed and potential airborne heat sink possibilities are reviewed on a conceptual basis. Following these introductory sections, the thermal design, analysis and testing of airborne avionic systems are treated with emphasis on cooling methods and analysis techniques. Following the discussions of design of avionic systems, the design of the ECS, provided by the aircraft is discussed. Emphasis is also placed on the design of the interface between the avionic system and the aircraft ECS, which serves as the vehicle cooling system.

Military avionic systems include not only digital processing equipment, but also radar, electro-counter measure equipment, radios of various frequency bands and electromagnetic, infrared, visual and acoustic sensors. These disparate equipment have some unique cooling requirements, but many of the same cooling methods and requirements apply to all of them. The majority of this document discusses these common cooling methods and requirements. The final section presents a detailed treatment of specific equipment. It provides an example of how the unique requirements are treated.

4. DESIGN REQUIREMENTS:

4.1 General Requirements:

The thermal design requirements that a military electronics system must meet are specified or determined in three principal ways.

- 4.1.1 Contract Specification: The contract specification will usually provide limits for system performance, reliability, weight, geometry, and vehicle thermal interface definition. Vehicle thermal interface data usually includes a preferred cooling approach, cooling media supply conditions, interface with the cooling media, altitude and ambient environment conditions, mounting surface temperature, chassis surface touch temperature, and exhaust temperature limits. The contract will also identify deliverable thermal data items and thermal testing requirements.

4.1.2 Military or Government Specifications: The contract specification usually lists a number of military or government specifications that serve as basic guidelines for the system design. These documents cover the full range of environmental conditions for:

- various classes of equipment,
- worldwide climatic extremes,
- electronic equipment designs for airborne, ground-based, and shipboard applications,
- system thermal testing, and
- certain cooling equipment specifications.

In most cases, specific requirements in the contract specification will supersede any referenced documents.

4.1.3 System Design Process: The third source of cooling system design requirements is the system design process. Many thermally critical components are not identified until the design has begun. This requires thermal control concepts be developed as needed to satisfy the overall system functional requirements. Examples of this include the allocation of allowable power dissipation, weight, volume, and geometry for heat sinks, cooling fans, heat exchangers, ductwork, insulation, and many other thermal control items. Temperature limits of elements such as temperature-sensitive optical materials, high-power motor windings, gyroscopes, cryogenic coolers, cameras, and lasers are often not defined until later in the system design schedule.

4.2 Avionic Thermal Design Considerations:

4.2.1 Reliability:

4.2.1.1 Need for Thermal Control – Reliability: Most semiconductor failure mechanisms are chemical in nature. As such, these failures are accelerated by increases in temperature. Some failures are only indirectly dependent upon temperature, indicating that increased temperature is not the prime cause of failure and there are a few failures that are not related to temperature at all. The failure mechanisms that are accelerated by increased temperature are given in Table 1.

TABLE 1 - Failure Mechanisms Accelerated by Increased Temperature

Chemical reactions	Dielectric breakdown
Diffusion effects	Electromigration
Material decomposition	Thermal stresses (distortion)
Ion movement	Thermal cycling (fatigue)
Surface charge movement	Material creep

4.2.1.1 (Continued):

Most of these failure mechanisms may be described in terms of chemical transport and reaction kinetics. For this reason, the Arrhenius equation gives the failure rate as:

$$\lambda = \lambda_o e^{-E_a/kT} \quad (\text{Eq. 2})$$

where:

λ = failure rate

E_a = activation energy of the electro-chemical process related to the failure, J (ft-lbf)

k = Boltzmann constant, 1.3807×10^{-23} J/K (5.65×10^{-24} ft-lbf/°R)

T = absolute temperature, K (°R)

λ_o = constant

This expression may be used to express the failure rate as an exponential function of temperature.

- 4.2.1.2 Reliability and Time-to-Failure: The reliability engineering discipline is rather young as an engineering technology in a developmental sense. Even from the orientation of mathematical-statistical application, reliability theory is skimpily developed. Yet there are some rather circumscribed reliability techniques that almost attain the status of law within the field of reliability engineering. One such technique is reliability prediction using exponential failure rate models.

Although the assumption of the exponential failure rate model for electronic systems and devices is generally supported, mechanical systems and devices, in consideration of the concept of wearout, can rarely be logically modeled as exponential. In practice, reliability engineers continue to use it, perhaps because it simplifies the mathematics.

It may also be argued that the reason the same reliability prediction technique became popular for both electronic and mechanical systems is that design life, in general, has been increasing along with electronic system life expectancy. Since the mathematical techniques of reliability engineering grew up with the missile-launching era of technology, they tended to be oriented with the major reliability problems encountered with missile launching, which were electronic component failures.

4.2.1.2 (Continued):

Thus, the technique of screening out the early life failures (infant mortality) in order to achieve the constant failure rate of electronic devices and the lack of infant mortality in mechanical devices both serve to influence thinking that failure rates are asymptotically small and may be simply added together to get system failure rates. There are some flaws in this approach, but the scope of this overview does not permit addressing them.

4.2.1.3 Component Failure Rate Predictions: Component failure rate predictions may be obtained from MIL-HDBK-217F or manufacturer's data on more recent parts. Morrison, et al, [1982a] [1982b] provide correction factors for components that are not primarily cooled by free convection or radiation to the surrounding air.

4.2.1.4 Junction Temperature Effect on Component Reliability: There are several component temperatures of interest to the designers of electronic systems - case temperature, mounting surface temperature and junction temperature (see 2.3). Although failure rate normally varies as an exponential function of component junction temperature (see 4.1.1.1), the magnitude of the variation depends strongly on the type of component.

Figure 1 graphically portrays the failure rate for three types of integrated circuits: digital, linear, and hybrid ICs as a function of the junction temperature over a range from 80 °C (176 °F) to 110 °C (230 °F). The digital components exhibit a very low failure rate as the junction temperature increases from 90 °C (194 °F) to 110 °C (230 °F). Above 90 °C (194 °F), linear components show a marked failure rate increase and in the order of several failures per million hours at a temperature of 100 °C (212 °F). The failure rates of hybrid devices increase from approximately 13 per million hours at 80 °C (176 °F), to 21 per million hours at 90 °C (194 °F), to 33 per million at 100 °C (212 °F), and to 55 per million at 110 °C (230 °F). It is apparent from this figure that the lower the component temperature, the higher the performance and reliability of the electronic components within normal operating conditions of the equipment. Very cold operating temperatures may also be a reliability and operating problem for some equipment. Although it is generally rarely encountered except during start up in very cold climates, it can not be ignored for aircraft that are supposed to operate in all weather.

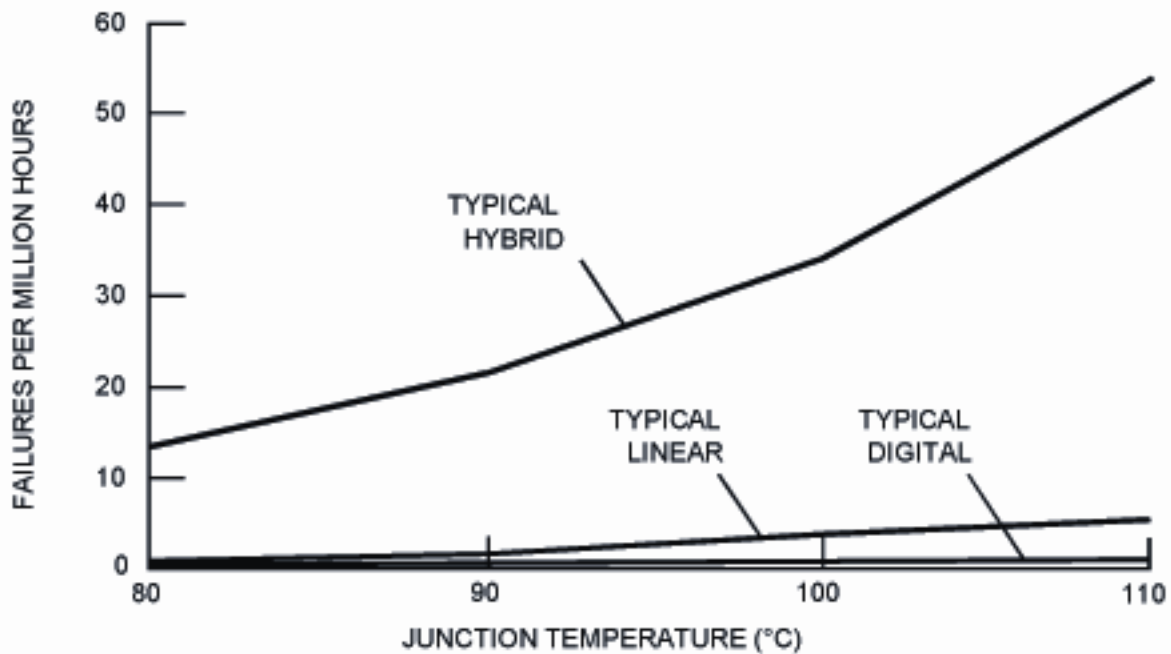


FIGURE 1 - Integrated Circuit Failure Rate as a Function of Junction Temperature

4.2.1.4 (Continued):

High temperature is deleterious to most electronic parts. It causes deterioration that can result in catastrophic failure. The time to failure of each part is a statistical function of its electrical stress level and the complex interrelationship of thermal history and chemical structure. A common source for reliability predictions for military electronic parts is MIL-HDBK-217F. As an aid in estimating the expected reliability improvement due to lower temperatures, figures are presented for various electronic assembly types under differing environmental conditions. These curves highlight the large range of reliability levels associated with different part-type populations. The basis of these curves is the predicted failure rates from MIL-HDBK-217F. As defined in that handbook, the environments are airborne, uninhabited, fighter (AUF); airborne, inhabited, fighter (AIF); ground, fixed (GF); and ground, benign (GB). The prediction assumes that each part operates at the same electrical stress ratio and temperature. No two electronic assemblies are alike and therefore these figures should be used only for a qualitative estimate of the effect of temperature on failure rate.

4.2.1.4 (Continued):

The predicted dependence of failure rate on temperature has been observed in the field. For avionic equipment, studies by the US Air Force concluded that temperature effects cause 20% of field failures. A recent study of avionic equipment concluded that, while the reliability of equipment cooled by free convection is sensitive to temperature, the reliability of more complex equipment cooled by forced-convection is more sensitive to temperature. While Figure 1 relates component reliability to junction temperature, it is also possible to relate the overall system reliability to the temperature and flow rate of the coolant provided by the aircraft ECS. Reducing the temperature of avionic cooling by 15 °C (27 °F) has increased the overall reliability of F-15 avionics by more than 40%, according to analyses based on approximately 85,000 aircraft flight hours, according to Hugge (1994). This study used data from the F-15C/D and F-15E aircraft, which have some of the same avionic systems, but different ECS.

Cyclic variation of temperature, due to thermal cycling and thermal shock, induces cyclic stresses in equipment that may induce mechanical failure due to fatigue. A desirable cooling system is one that maintains near-constant environment temperatures by use of automatic control but is subject to a trade-off with mission needs and economics.

A summary of the effects of temperature on the reliability of military electronic equipment is shown in Table 2.

- 4.2.1.5 Humidity Effect on Component Reliability: Humidity encountered during flight, or in extended storage, has been found to be a significant contributor to failures in electronic equipment. It can produce corrosion from galvanic action and may foster microbiological growth. Moisture absorption may also lead to physical and electrical changes which can degrade the equipment performance. The design of the cooling system should therefore protect the equipment from such effects.

If ram air is utilized for direct cooling of avionic equipment, it should be realized that it contains varying amounts of moisture at low altitude. This may cause equipment malfunctions due to condensation, if the equipment is cooled to low temperatures at high altitude and subjected to warm moist air at low altitude.

- 4.2.1.6 Conclusion: As seen above reliability is usually the primary driver in determining the degree of thermal control required. The effect of temperature on electronic equipment reliability is shown in Table 2. Overall system reliability requirements will be established in the equipment detail specification for Government Furnished Equipment (GFE) or in the vehicle detail specification for Contractor Furnished Equipment (CFE). For CFE the avionic system developer will breakdown overall system requirements to the individual equipment.

TABLE 2 - Temperature Effects on Military Electronic Equipment Reliability

Condition	How Manifested	Principal Effect	Failure Mode
Steady State - Hot	Ambient Exposure Equipment Induced Mission Induced	Aging/Discoloration Insulation Deterioration Oxidation	Property Changes Shorting Rust
		Expansion Reduction of Viscosity Softening/Hardening	Physical Damage Physical Wear Seizing/Lubricant Loss
		Evaporation/Drying Chemical Changes Cracking/Crazing	Dielectric Breakdown
Steady State - Cold	Ambient Exposure	Contraction	Wear/Binding
	Mission Induced	Viscosity Increase Embrittlement	Loss of Lubricity Cracking
		Ice Formation	Property Change Resilience Loss Seal Leaks
Thermal Cycling	Ground Operation Mission Operation	Temperature Gradients Expansion/Contraction	Mechanical Failures
Thermal Shock	Mission Profile Geography/Season	Temperature Gradients	Mechanical Failures Cracks/Ruptures

- 4.2.2 Temperature Effect on Avionic Performance: With the decreasing size and increasing operating speed of avionic devices, temperature can be a factor in the performance of the devices. Figure 2 shows the influence of the temperature of a CMOS device on the gate speed, which is a measure of performance.
- 4.2.3 Environmental Requirements: These requirements define under which conditions the avionic thermal control system must operate to meet the reliability requirements defined in 4.1.1. Equipment designed for the interior of conventional aircraft can normally be categorized into one of the classes designated in MIL-HDBK-5400. Specifying a standard class allows equipment to be used on multiple platforms, as well as allowing the aircraft cooling system to be designed to a standard output. Classes 1, 1A and 1B are generally used for subsonic, non-high performance aircraft or for equipment installed in pressurized compartments of supersonic aircraft. Class 2 is generally used for high performance fighter aircraft or for equipment installed in unpressurized compartments of aircraft. Classes 3 and 4 are generally used for high altitude aircraft, such as reconnaissance aircraft. For unusual applications, the design environment should be tailored to the specific environment the equipment will see on the intended platform. Equipment requiring forced cooling also need to be tailored to the cooling media of the intended platform. MIL-STD-810 provides test procedures and guidance for establishing environmental tests. Some of these procedures test the thermal design.

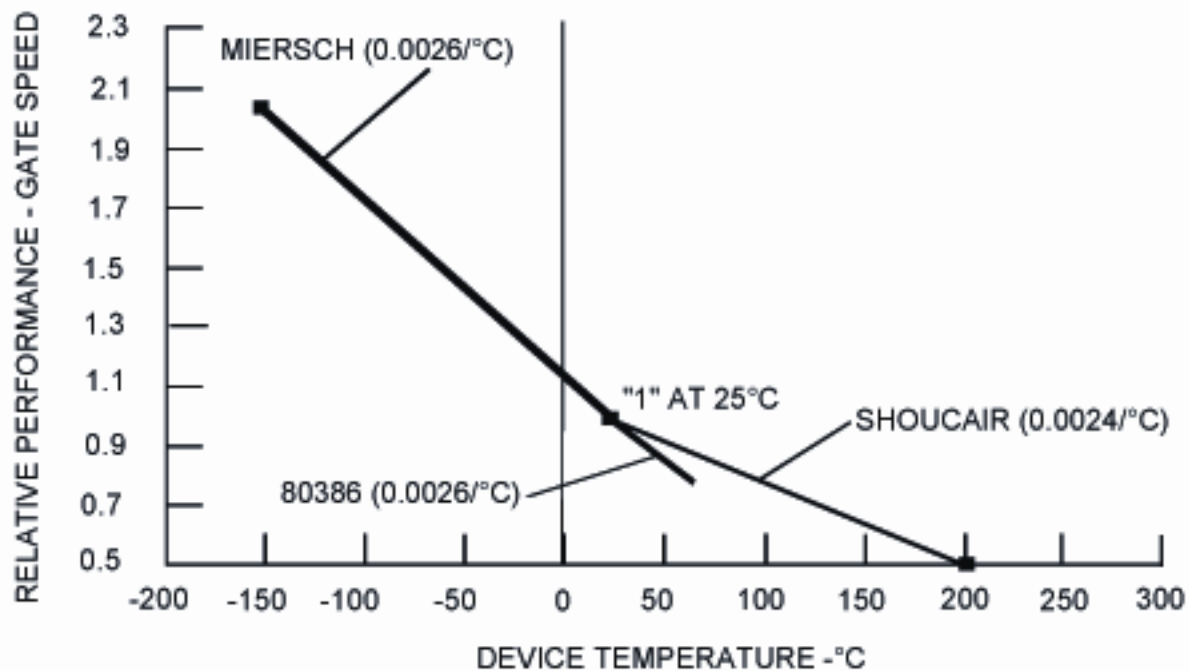


FIGURE 2 - Relative Performance of CMOS Devices
as a Function of Temperature

- 4.2.3.1 Temperature-Altitude: Normally the MIL-HDBK-5400 classification is determined by defining the maximum altitude at which the intended platform will operate or by the maximum altitude expected in the compartment in which the equipment is installed. The class that equals or exceeds this altitude is selected. The altitudes provided in MIL-HDBK-5400 are 4500, 9140, 15 240, 21 340, and 30 480 m (15,000, 30,000, 50,000, 70,000 and 100,000 ft). Except for the 30 480 m (100,000 ft) condition, specifying the altitude will automatically specify a temperature environment. For 30 480 m (100,000 ft), the choice is between equipment normally operating up to 95 °C (203 °F) or 125 °C (257 °F). Once the class is determined, Table I of MIL-HDBK-5400 should be reviewed to determine if the full range of environmental conditions specified meets or exceeds the actual operating conditions of the intended platform.
- 4.2.3.2 Humidity: The MIL-HDBK-5400 humidity condition should be used except in unusual applications. The requirement is that the equipment shall withstand humidity up to 100%, including conditions where condensation takes place in and on the equipment. The equipment shall withstand the above conditions during operating and non-operative conditions.

- 4.2.3.3 Other Environmental Considerations: Other environmental factors may pertain to electronic, particularly to external equipment or equipment contained in bays open to the external environment. The aircraft manufacturer should define the environment in which the equipment will operate. MIL-HDBK-5400 also provides a list of many other environmental factors. MIL-STD-810 provides guidance on test levels for these various factors. These factors should be reviewed for their potential effect on the equipment, particularly if it is externally mounted. For example aircraft designed to operate mostly in a maritime environment should consider more severe salt-fog requirements. Whereas equipment designed for a land based helicopter should consider more severe sand and dust requirements.
- 4.2.3.4 Environments for Reliability Determination: Although the avionics needs to be designed to operate in the maximum environmental conditions listed above, the equipment on the average will be operating in a more benign environment. This environment will have the greatest impact on avionic reliability. It will be dependent on the mission of the aircraft, the performance of the aircraft ECS and the thermal design of avionic equipment. The actual thermal environment will have to be obtained from the individual vehicle design.
- 4.2.4 Avionic Thermal Control: The avionic system thermal control system is required to deliver to the individual equipment the temperature and coolant flow rate required to maintain equipment semiconductor junction temperatures at the levels required to meet reliability and performance requirements. Specific thermal control requirements are contained in various specifications. Some thermal design criteria is provided in Requirement 52 of MIL-HDBK-454, which is a tri-service document. MIL-STD-2218, also approved by all services, provides detail thermal control analysis, design, and test requirements. Since the numerical values in this standard are based on a MIL-HDBK-5400 Class 2 environment, it must be tailored to the specific operating environment of the equipment. Performance requirements are normally defined by the equipment manufacturer.
- 4.2.5 Avionic Integrity Requirements: The United States Air Force has recently addressed several of the above issues, including reliability and environmental requirements, under the encompassing topic of integrity in MIL-HDBK-87244. This reference should be consulted as a guide in establishing integrity requirements for the U.S. Air Force and other military programs.

4.3 Airframe Systems:

- 4.3.1 Thermal Control Requirements: In order to meet reliability requirements for the overall aircraft, the aircraft cooling system will have to maintain the thermal environment used by the avionic system to predict reliability for the majority of the flight envelope. During extreme transients or in extreme environmental conditions, the aircraft should maintain the avionic system within its worst case thermal design condition. Extreme environmental conditions are considered to be those listed as operational requirements in MIL-HDBK-310, AR 70-38 or STANAG 2895. MIL-E-18927 provides the Navy's requirements for the airframe cooling requirements for cooling avionics. (The cooling system is normally a part of the aircraft ECS.) The Air Force requirements are established by tailoring AFGS-87145 to each aircraft using the guidance attached to that specification. Future aircraft may use JSSG-2009 to establish airframe thermal requirements.
- 4.3.2 Trade-off Studies: At the aircraft system level, trade-offs should be performed to balance the impact of the size, weight and power requirements of the aircraft cooling system versus the impact of the reliability of the avionics. Two measures usually used are life cycle cost and take-off gross weight. AIR1812 provides information on life cycle cost. MIL-HDBK-87244 also provides guidance for performing trade-off studies.
- 4.3.3 Environmental Requirements: The environment under which the vehicle's thermal control system must operate and the mission profiles, also called operating scenario, of the vehicle are established in the aircraft detail specification, also known as the weapon system specification. MIL-HDBK-781 provides detailed information in establishing operational scenarios for various types of aircraft, if for some reason the mission profiles have not already been established for the vehicle being considered.
- 4.3.4 Moisture Condensation: Condensation is caused when humid air comes into contact with the surfaces of equipment whose temperature is less than the dew point of the surrounding air. "Overcooling" occurs when at high altitude the equipment is cold soaked at low temperatures either from ambient air or refrigerated air. When the aircraft descends the humid cooling-air at lower altitudes will cause condensation on the equipment. The problem is lessened on the internal supply duct surfaces through the use of the high pressure water separation process for equipment cooled by the ECS air.

5. INTERFACE BETWEEN AVIONICS, ECS AND AIRCRAFT:

The avionic cooling load on modern aircraft significantly influences the overall ECS configuration. In many cases, the avionic load is a major heat load cooled by the ECS. Avionic heat loads tend to increase with each new generation of a particular aircraft type and throughout the production phase and operational service life of an aircraft model. A typical ECS impacts aircraft performance, fuel consumption and stealth characteristics due to system weight and the use of ram air, engine bleed air and other aircraft power sources. Therefore, it is beneficial to pursue and select an ECS approach that minimizes aircraft impact while providing adequate growth for future avionic heat loads.

The type of cooling provided has an important effect on avionic equipment design, performance, and reliability. Many different approaches are used for cooling avionic equipment including the use of ambient (ram) air, pressurized compartment exhaust air, direct ECS cooling, conduction to the airframe (directly or with a heat pipe), liquid coolant (including fuel) transport loops and cascaded temperature levels. Similarly, numerous approaches to cooling individual pieces of equipment are possible: natural free convection, forced convection, conduction to surrounding structure and internal air-to-air or liquid-to-air heat exchangers. Each of these approaches has inherent advantages and disadvantages, not only on the design of the avionic equipment and the environment provided, but also on the overall weapon system.

Considerable effort is required to reduce or minimize the life cycle cost of avionic equipment and the overall weapons system. The awareness of the significant impact of the operational environment on avionic equipment life cycle cost has resulted in a continued effort by industry and the military customers to provide improved avionic cooling.

Optimal thermal design of avionic equipment must be sought which will provide the avionic equipment with suitable environments, while at the same time minimizing the aircraft impact caused by providing such environment. This calls for a cooperative effort on the part of both avionics and ECS designers on the following issues:

1. Thermal requirements of avionic equipment
2. Available heat sinks
3. Interface between the airframe and avionic equipment
4. Equipment installation
5. Pressure drop requirements for forced air or liquid cooled equipment

5. (Continued):

In terms of thermal control the division of responsibility between the avionic system and the vehicle cooling system (ECS) is not always clear. In general, the interface is taken as the heat exchange point between the avionic cooling medium and the aircraft supplied heat sink. Many times there is no real avionic thermal control system and a cooling medium is supplied directly from the aircraft system to an individual equipment box. Other times there is a separate avionic cooling system consisting of a fan or pump and a distribution system.

5.1 Interface Cooling Requirements:

The heat dissipated by avionic equipment constitutes a major portion of the total ECS heat load on modern fighter, bomber, and cargo aircraft. Table 3 shows the typical range of cabin, and avionics heat loads for military aircraft. These values are for general comparison. Generally cabin heat loads include personnel, solar and kinetic heat loads. Sometimes displays and other electronics in the cabin will be included. Different coolant inlet temperatures for avionic equipment are used depending on the particular aircraft and the cooling system used. Table 4 shows typical coolant inlet and outlet temperatures for the various avionic cooling systems. Cooling air supply temperatures are typically reduced at higher altitudes to enable lower airflow rates in order to conserve engine bleed air.

As shown in Table 4, there is a wide variation in the avionic coolant inlet temperatures used on current military aircraft. Many of the current air cycle systems maintain a higher inlet temperature at low altitudes than they do at high altitude.

To adequately design the avionic cooling system, it is necessary to properly define all interfaces between the ECS and avionics. Effort to define these interfaces needs to be initiated early in the aircraft development program. All interfaces are best documented through interface control drawings/documents (ICDs) which are established by an Interface Control Working Group (ICWG). Periodic meetings of the ICWG should be held to discuss the interfaces and establish coordinated ICDs.

Past experience has shown the need to design the ECS with excess cooling capacity for avionics that are typically added throughout the life of an aircraft. A growth cooling capacity of 25% for avionics has been designed into some recent military aircraft. However, experience has shown that this is not necessarily enough to cover all future changes in avionics, especially on fighter aircraft where 100% growth has occurred on some programs. Typical interface cooling requirements that need to be established are as follows:

- The location and size of coolant inlets and outlets.
- Heat dissipation in all modes of operation.
- Ambient temperature and humidity environment versus altitude.

5.1 (Continued):

- Required coolant flow versus inlet temperature.
- Normalized coolant pressure drop versus mass flow rate.
- Avionic Bay Temperature
- Growth allowance.

TABLE 3 - Cabin, Avionics and Total ECS Heat Load Trends

Aircraft Type	Initial Operational Year	Cabin Heat Load (kW)	Cabin Heat Load (Btu/hr)	Avionic Heat Load (kW)	Avionic Heat Load (Btu/hr)
Bombers					
B-58	1958	12.9	44 100	35.5	121 100
B-52H	1961	16.6	56 700	18.5	63 000
B-52H (Upgrade)	1980	12.2	41 800	118.2	403 700
B-1B	1985	52.1	180 000	170.9	583 700
Cargo					
KC-135A	1957	22.7	77 500	10.1	34 500
C-5A	1968	69.0	235 400	21.6	73 600
C-17	1991	44.4	151 200	14.4	49 200
Fighter					
F-105D	1959	6.4	21 800	8.9	30 400
F-111A	1966	10.8	36 800	14.1	48 200
F-14A	1970	14.1	48 000	25.6	87 400
F-15A/D	1973	3.0	10 400	26.2	89 300
F-15E	1986	4.8	16 500	46.3	158 000
F-16	1975	5.4	18 300	15.9	54 400
F/A-18A	1980	7.3	25 000	18.8	64 000
F/A-18E		7.3	25 000	28.0	95 600

NOTE: These are approximate numbers for comparison purposes only.

TABLE 4 - Typical Coolant Temperatures

System Cooling Approach	Altitude (meters)	Altitude (feet)	Inlet Temp (°C)	Inlet Temp (°F)	Max Continuous Outlet Temperature (°C)	Max Continuous Outlet Temperature (°F)
Ram Air			-54 to +49	-65 to +120	+55 to +71	+131 to +160
Cabin Exhaust Air			+21 to +38	+70 to +100	+55	+131
Air Cycle Air						
Fighters:						
F-4	<7600	<25,000	+29	+85	+63	+145
	>7600	>25,000	+4	+40		
F-15 A/B/C/D	<3300	<11,000	+28	+83	+71	+160
	>10500	>34,500	+2	+36		
F-15E	<7600	<25,000	+4	+40	+71	+160
	>13000	>42,500	-18	+0		
F-16	<9500	<31,000	+2	+35	+60	+140
	>9500	>31,000	-18	+0		
F-18 A/B/C/D	<7600	<25,000	+4	+40	+71	+160
	>13000	>42,500	-18	+0		
Helicopters			+30	+86	+60	+140
Liquid Cooling Loop						
F-15			+45	+115	+63	+145
B-1			+32	+90	+71	+160
Recirculated Air						
B-1			+32	+90	+60	+140
C-17			+6 to +32	+42 to +90	+49	+120

* The inlet temperature is +4 °C (+40 °F) up to 7600 m (25,000 ft), it decreases linearly from +4 °C (+40 °F) to -18 °C (0 °F) from 7600 m (25,000 ft) to 13,000 m (42,500 ft), and stays constant above 13,000 m (42,500 ft) at -18 °C."