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AEROSPACE RECOMMENDED PRACTICE

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THE CONTROL OF EXCESS HUMIDITY IN AVIONICS COOLING

1. PURPOSE

1.1 The purpose of this document is threefold: (1) to review the problem of moisture in avionics equipment, (2) to outline methods for correcting conditions of excess moisture in existing avionics installations, and (3) to recommend design practices for new avionics cooling system installations which will minimize the adverse effects of moisture.

1.2 The problem of moisture in avionics has been brought into focus by the widespread use of air cycle refrigeration in forced-cooled "black-boxes," and by the lack of recognition of the moisture sensitivity of most avionic circuitry.

1.3 This document does not relieve the avionics designer of his obligation to meet any other humidity requirements which may be applicable to the avionics. Because the air conditioning system is inoperative when the aircraft is parked or stored, the aircraft and its equipment must withstand the effects of the outdoor environment (e.g., high humidity, fog, rain, and surface condensation).

2. SUMMARY OF THE PROBLEM

2.1 The Effects of High Humidity and Moisture

2.1.1 The immediate effect of exposure of unprotected avionics equipment to high humidity and moisture[1*] is electrical current leakage which produces malfunctions ranging from erroneous signal voltages to overheating and fire.[2, 3] The malfunction may be of a temporary nature which vanishes when the equipment is dry, or it may be a permanent effect, depending on the magnitude and duration of the current leakage. The fault may cause erroneous signals which may be difficult to detect.

2.1.2 A familiar example of temporary disablement can be found in compact, high impedance computer circuits where microvolt level signals may be carried through multi-pin connectors along with circuits at the one-volt level and higher. Due to the high impedance it is possible to generate an enormous error in the low level signal circuit with a very small current leakage between the connector pins in the presence of moisture. The circuit may recover when dry, function normally, and exhibit no permanent damage, although repeated exposures to moisture may eventually cause permanent malfunctioning as a result of metallic corrosion or deterioration of electrical insulation.

2.1.3 If the current leakage in a d-c circuit is sufficiently large, a permanent electric fault may be produced in the dielectric material by bridging it with electro-deposited metal.[3] The fault may destroy one or more components as a result of excessive temperature.

2.1.4 Equipment which is protected against faulting in moist conditions, so that it can be exposed repeatedly without malfunction, must also be protected against corrosion which may in time cause open circuits or faulting.[4]

2.2 Sources of Moisture

2.2.1 A condition of excessive humidity exists whenever (1) the relative humidity of the cooling air is near saturation, or (2) the cooling air contains liquid moisture (fog and/or water on the air duct walls), or (3) the surface temperature of the avionic equipment is below the dew point of the cooling air, causing condensation to form directly on the internal surfaces of the equipment.

*Superscripts refer to items listed in the Bibliography, p. 16.

Examples of conditions (1) and (2) are found in aircraft forced-air cooling systems where, at low flight altitudes, vapor cycle refrigeration usually delivers chilled air at high relative humidity, and where air cycle refrigeration frequently delivers fogged air and running water from the wet duct surfaces.

An example of condition (3) is found where the cooling air temperature in flight at high altitude is below the ambient dew point encountered at ground level. Thus, parts of the equipment which produce very little heat may become "cold soaked" in flight, and when the aircraft descends to ground level, the equipment is exposed to moisture-laden air and surface condensation occurs.

2.2.1.1 Condensation can occur on the external surfaces of the equipment during low altitude operation during or after ground checkout if the cooling air temperature is below the ambient dew point. Though the exposure of "cold soaked" equipment to moist ambient air is a transient condition, a thorough wetting of the equipment can occur, and the moisture may not evaporate for some time after the exposure.

2.2.1.2 The natural environment may also produce damaging "wet" conditions in the avionics equipment. A typical humid climate to which the equipment may be exposed in an aircraft parked out-of-doors is a cyclic variation from 80% relative humidity for a few daylight hours to 100% relative humidity with fog or rain during the remaining daylight hours and all night.

3. NATURAL AND INDUCED ENVIRONMENTS

3.1 In Manufacturing, Shipping and Storage - It is common practice for avionics manufacturers to assemble and test their products in air conditioned, dirt-free "clean rooms" and then to package and ship the equipment in sealed containers using dessicants to insure against the deleterious effects of moisture while in transit or in storage. Thus, the natural environment which is excessively humid at times is replaced by an ideally clean and dry environment during manufacturing, shipping, and storage.

3.2 Installed in Aircraft Parked on the Ground

3.2.1 The natural environment prevails when the aircraft is parked out-of-doors and when the installed avionics equipment is exposed to the humidity of the ambient air. High relative humidity is a common state of the atmosphere in almost any climate, cool or warm, particularly during the night. Examples of daily variations in temperature and humidity for several American cities[5] are given in Table 1.

3.2.2 Table 1 shows August (1960) weather at Houston International Airport, illustrating a typical hot-humid climate. Note that the relative humidity, which was averaged for the month at each hour shown, cycled from a high of 96% at 6:00 a.m. to a low of 70% at noon. Extremes of relative humidity exceeded the averaged values. This is indicated by the summary of hourly observations in the last two columns of the Table, which report a relative humidity of 90 to 100% in 340 out of a total of 774 hourly observations (46% of the time), and rain and fog on 106 hourly occasions (14% of the time).

3.2.3 The weather at Miami International Airport, though less humid than Houston, exhibits a similar day/night humidity cycle. Likewise, the weather at Seattle, Los Angeles, and Washington, D.C. shows the typical cycle of high relative humidity during pre-dawn hours and reduced humidity during the day.

3.2.4 Note that in all examples the dew point temperature, which is the index of absolute moisture content of the air, is very nearly constant night and day. The relative humidity cycles are usually generated by the daily variation in air temperature (dry bulb), and not by large changes in the moisture content of the air. This is graphically illustrated on Fig. 1, which shows hourly and daily variations of temperature and humidity at Houston.

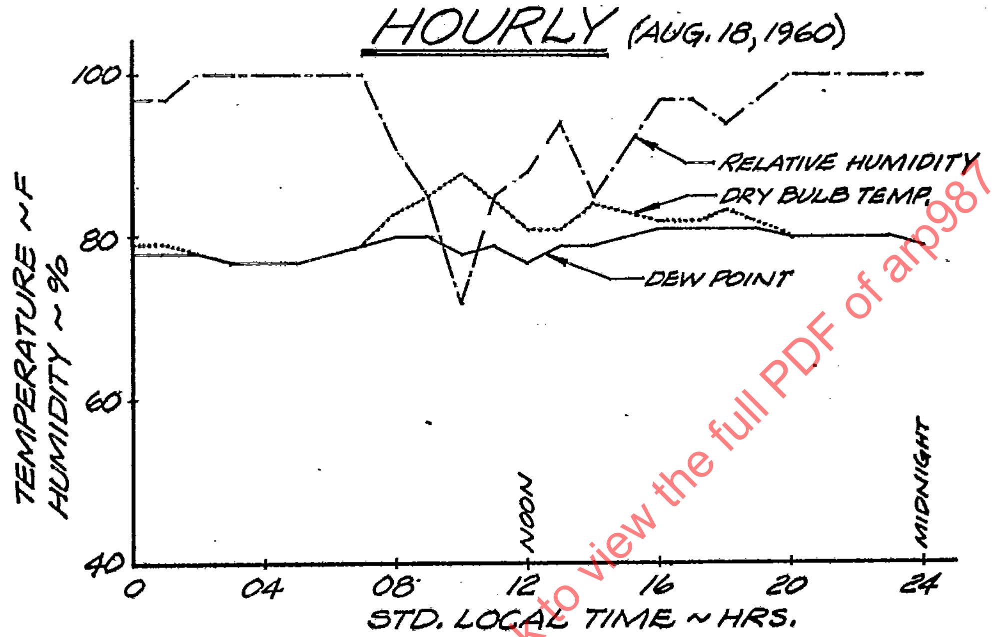
3.2.5 It is significant that even though the atmospheric moisture content as indicated by the dew point at Miami, Seattle, Los Angeles, and Washington is less than that at Houston, the drier cities nevertheless experienced a substantial number of hours of high relative humidity, including fog and rain.

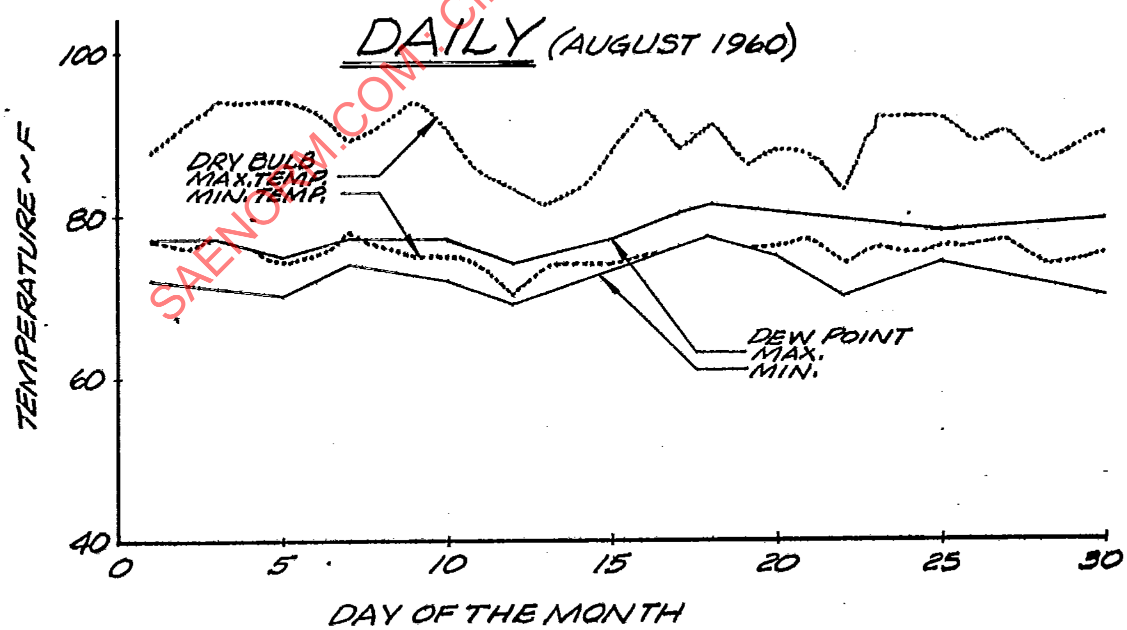
TABLE I

Airport	Averages of Temperature and Humidity for August 1960				Hourly Observations of Humidity	
	Hour CST	Dry Bulb deg F	Dew Point deg F	Relative Humidity %	Relative Humidity %	Number of Hourly Observations
Houston International	Midnight	78	75	92	100-90	340 (Rain 64, Fog 42)
	6 a.m.	76	75	96	80-89	166
	Noon	86	75	70	70-79	123
	6 p.m.	84	75	75	50-60	100
					30-49	15
Miami International	EST					
	1 a.m.	80	74	83	100-90	71 (Rain 46, Fog 0)
	7 a.m.	80	74	84	80-89	185
	1 p.m.	87	74	65	70-79	283
	7 p.m.	83	74	75	50-69	202
					30-40	3
Seattle-Tacoma	PST					
	4 a.m.	56	52	86	100-90	165
	10 a.m.	61	52	74	80-89	204
	4 p.m.	69	51	57	70-79	136
	10 p.m.	60	52	77	50-69	163
					40-59	60
					0-29	16
Los Angeles International	PST					
	4 a.m.	64	60	89	100-90	204 (No rain, Fog 9)
	10 a.m.	72	62	72	80-89	240
	4 p.m.	71	63	74	70-79	210
	10 p.m.	65	61	87	50-69	90
					30-49	0
Washington, D. C.	EST					
	1 a.m.	74	69	84	100-90	143 (Rain 37, Fog 71)
	7 a.m.	73	68	85	80-89	139
	1 p.m.	84	67	57	70-79	137
	7 p.m.	81	68	67	50-69	283
					30-49	42

VARIATION OF TEMPERATURE & HUMIDITY

HOUSTON INTERNATIONAL AIRPORT
HOUSTON, TEXAS





SOURCE OF DATA:
U.S. WEATHER BUREAU.

FIGURE 1.

3.3 Proposed Design Data for the Natural Environment - Design values of atmospheric humidity at sea level, as suggested by John L. McDonald,[6] are indicated on the psychrometric chart of Fig. 2. The frequency of concurrent maximums of wet and dry bulb temperatures is indicated by the probability lines which were obtained from world-wide weather data. Figures on these lines indicate the percent of time during which the coincident wet and dry bulb temperature will not be exceeded during the four hottest months of the year in the hottest locations. It is apparent from these data that an atmospheric dew point between 85 and 88 F should be adequate for design purposes based on world-wide operation.

3.4 Induced Humid Environments in Service

3.4.1 Typical aircraft avionic equipment units are compact assemblies. Many require forced-air cooling while in operation, particularly in military combat aircraft. The weight and space economics which influence the avionics designer also press the cooling system designer to employ the lowest possible air temperature for cooling purposes in order to minimize the penalties of system weight and operating weight due to airflow quantity. The use of low air temperature induces a condition of high relative humidity during operation at low altitude where the ambient air dew point equals or exceeds the cooling air supply air temperature.

3.4.2 Vapor cycle refrigeration is used generally in ground cooling units and in some aircraft systems for avionics cooling. Fig. 3 presents an example of the temperature and moisture history of ambient air which is refrigerated by a vapor cycle system and circulated through forced-cooled avionics equipment. Ambient air at 100 F and 100 gr/lb absolute humidity is refrigerated from its initial state, denoted by (1) in Fig. 3, to 40 F at point (3). The temperature of the air-vapor mixture reaches the saturation temperature (dew point) of 67 F at point (2) in the cooling process, and moisture is condensed on the cold heat exchanger surfaces during further cooling to point (3). The condensed moisture is drained off, and the air at 100% relative humidity (saturated) is delivered through the supply duct—point (3) to point (4). Heat transfer in the duct warms the air 3 F and thus reduces its relative humidity a small amount. The refrigerated air at 43 F enters the avionics equipment at 88% RH at point (4) and is warmed to 95 F by 1 kw of heat rejected from the avionic circuits. Thus in the region of air inlet, the avionics is not only exposed to 88% RH, but non-heat producing circuits and components in this region are exposed to a temperature of 45 F, which is considerably below the ambient dew point of 67 F. Local condensation can be expected on external surfaces during operation, and when the avionics and the cooling air supply are shut down, local condensation from infiltrating ambient air may occur on internal surfaces. Thus, parts of the equipment which are exposed to high humidity during operation may become wet and remain damp for a period of time after operation.

3.4.3 A more adverse environment at the avionics air inlet is provided by the use of air cycle refrigeration without moisture control in lieu of a vapor cycle as described above. A cloud of condensate is produced within the airstream as the air releases its thermal energy in the expansion/cooling process through a turbine. The air/vapor mixture falls to the 67 F dew point at the saturation line (point 2 of Fig. 4) and continues to cool to 40 F at the turbine discharge—point (3)—while moisture is condensing in the form of a cloud of fog droplets. The density of this fog cloud depends on the degree of cooling below the dew point, and in this example the cloud is very dense. Some coalescing of the very small droplets occurs on duct walls, elbows and obstructions, and produces flowing rivulets and some large droplets in the ducts. The water removal problem is made difficult by the minute size of the fog droplets, and usually only 80% of the liquid can be coalesced, trapped, and drained. Thus, in this example, 50.4 grains of the 63 grains of condensate is removed in the water separator. Duct heat transfer raises the temperature to 42 F at point (4) and re-evaporates a portion of the residual cloud. The remainder of the cloud at point (4) is delivered to the avionics with the cooling air, and its subsequent evaporation contributes to the 1 kw cooling capacity, which is the same as in the previous example of vapor cycle cooling. Note that the discharge temperature from the avionics is 88 F compared to 95 F in the previous example, due to the cooling effect of the evaporating moisture cloud. The relative humidity of the cooling air is seen to be in excess of 100% within the avionic unit until about 25% of the heat rejection is absorbed from the unit.

3.4.4 Some avionics cooling systems utilize exhaust air from the aircraft cabin where a moderate temperature and humidity is normally maintained for the occupants. In these installations air cycle or vapor cycle systems may deliver humid air to the cabin; but after being heated by the thermal loads in the

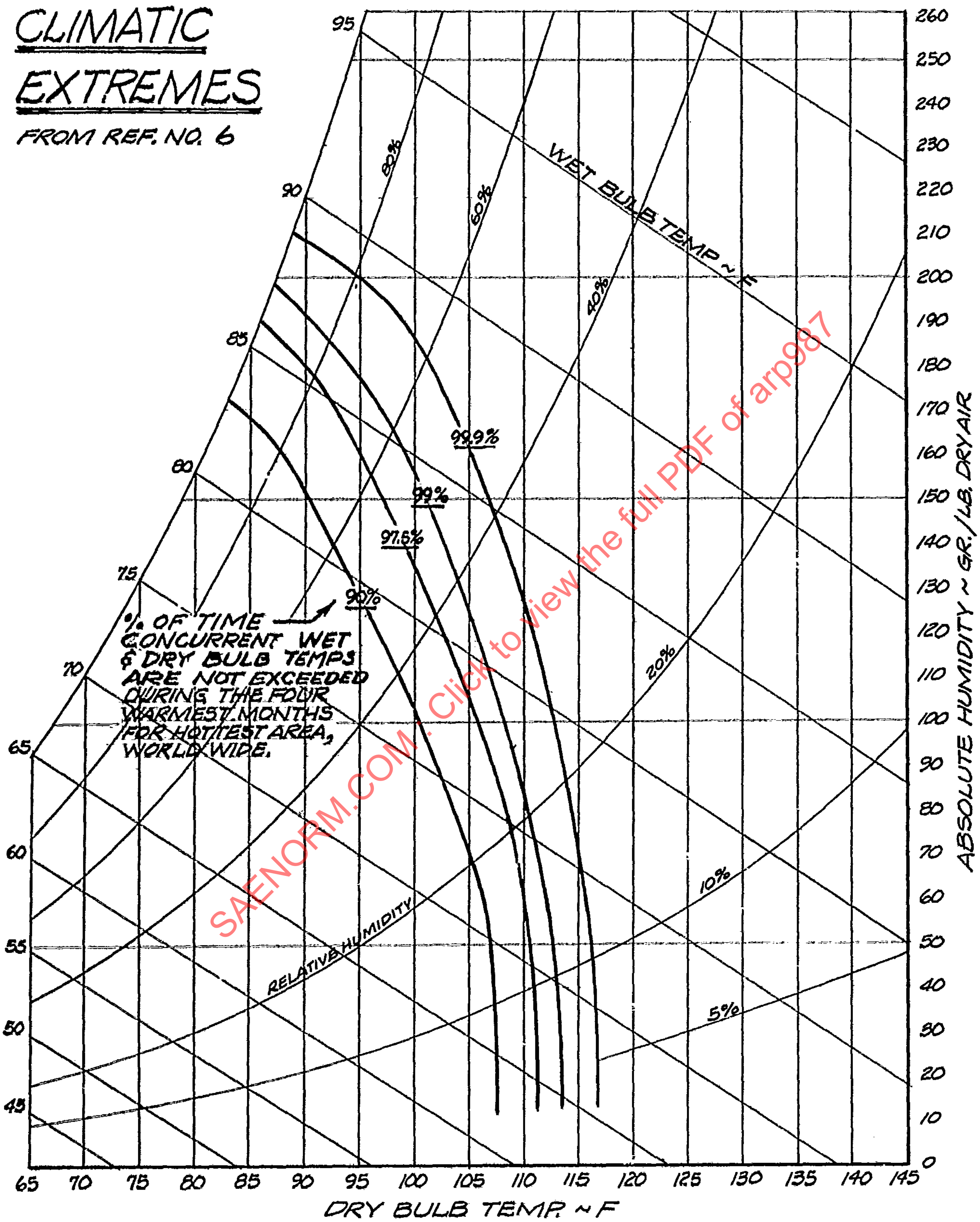
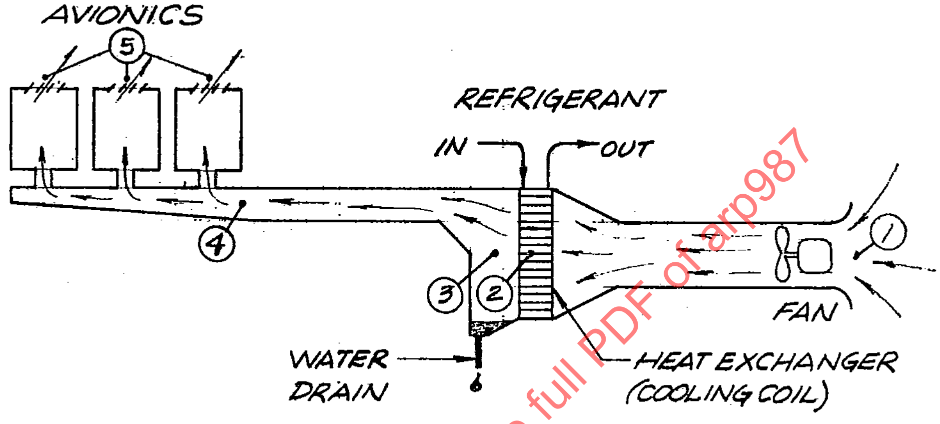

CLIMATIC
EXTREMES
FROM REF. NO. 6
WET BULB TEMP ~ F
95
90
85
80
75
70
65
60
55
50
45
80%
60%
40%
20%
10%
5%
RELATIVE HUMIDITY
99.9%
99%
97.5%
90%
% OF TIME CONCURRENT WET & DRY BULB TEMPS ARE NOT EXCEEDED DURING THE FOUR WARMEST MONTHS FOR HOTTEST AREA, WORLD WIDE.
ABSOLUTE HUMIDITY ~ GR./LB. DRY AIR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
DRY BULB TEMP. ~ F

FIGURE 2.

AVIONICS COOLING
WITH
VAPOR CYCLE REFRIGERATION
WITHOUT REHEAT



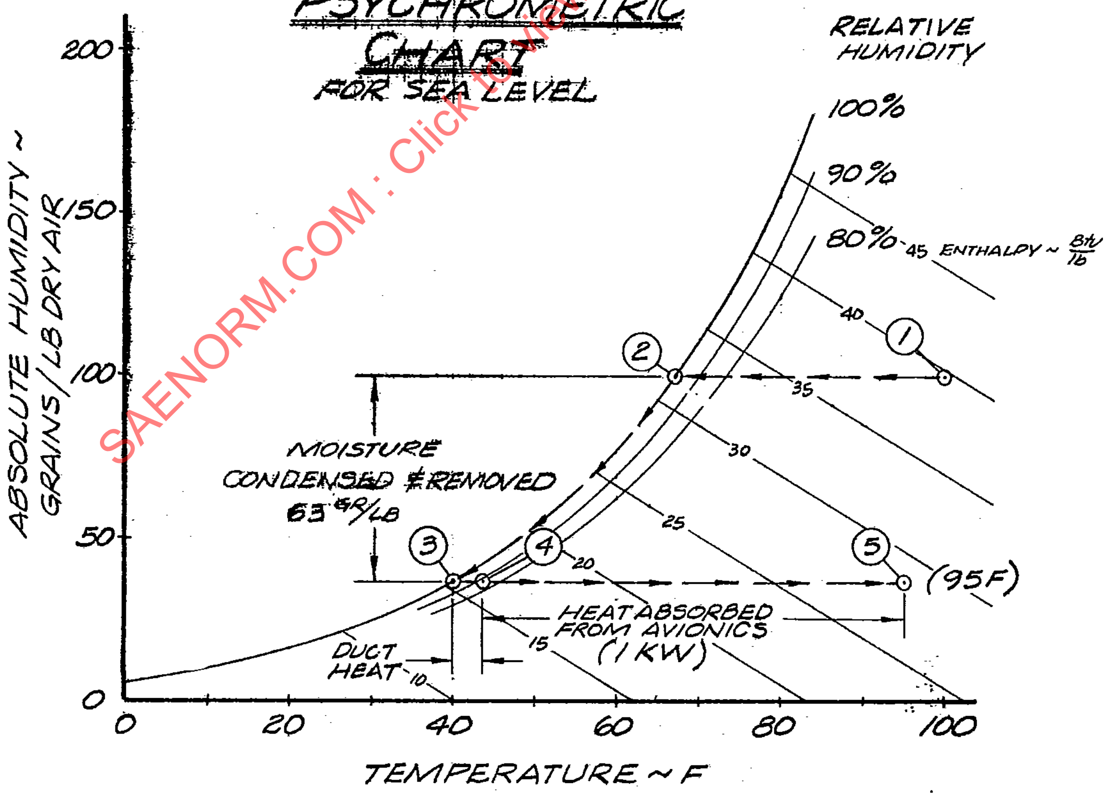
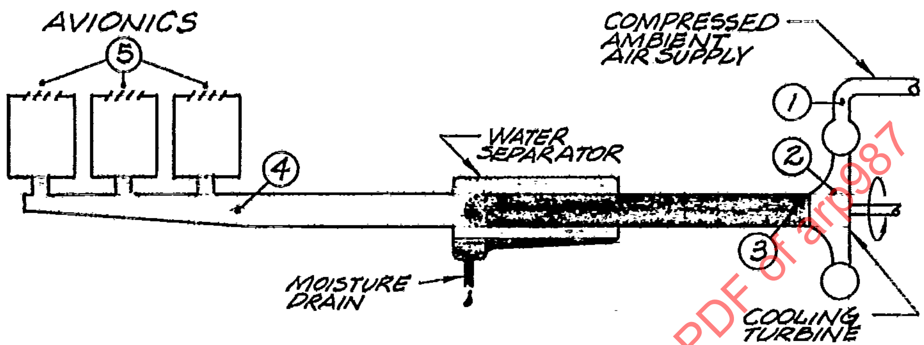


FIGURE 3

AVIONICS COOLING WITH AIR CYCLE REFRIGERATION

NO REHEAT



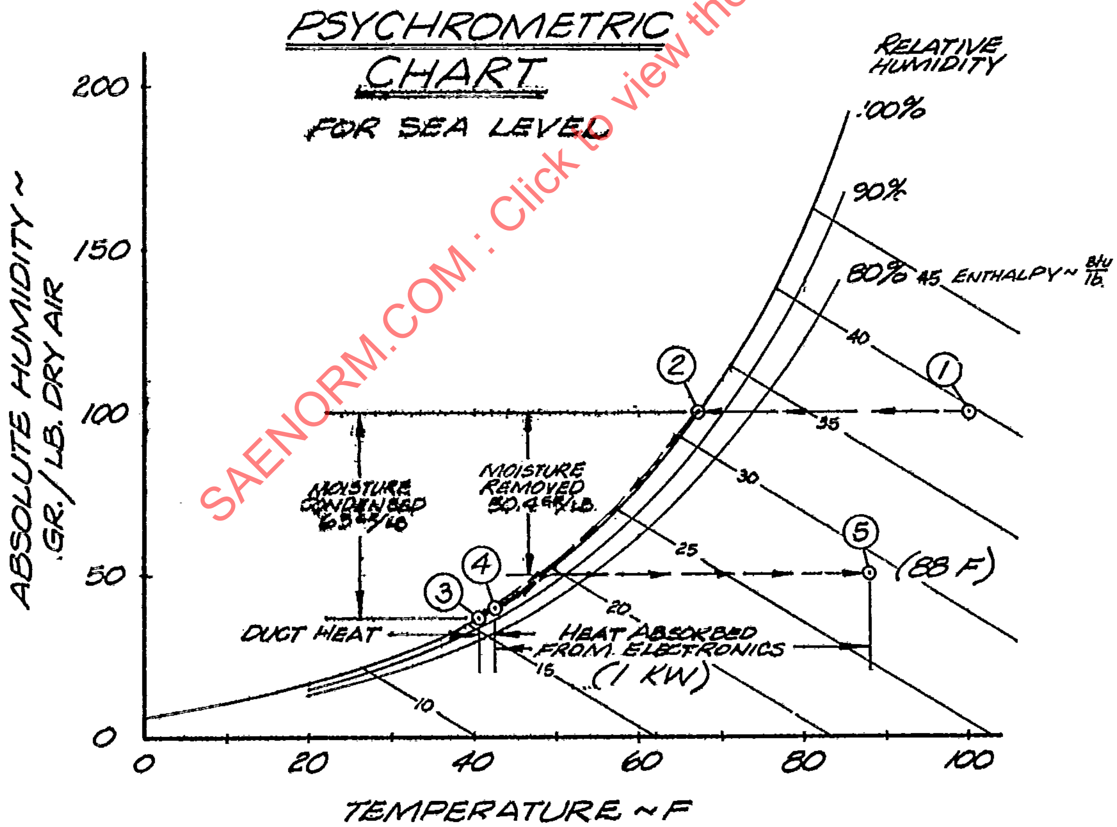


FIGURE 4

cabin, the air is delivered in a relatively dry condition to the avionics bay. Moisture production due to night and day temperature cycles in aircraft parked out-of-doors remains a problem in these systems if the equipment is not adequately isolated or insulated from the exterior surfaces of the aircraft. The cabin exhaust air also creates a more severe dirt and dust problem than would exist in a directly cooled system. This is a result of the presence of aerosols from smoking and of dust and lint from clothing and carpets.

4. ENVIRONMENT CONTROL IN "OPEN" EQUIPMENT

4.1 Moisture resistant coatings and reduction of the relative humidity of the cooling air will eliminate malfunctions of the avionics equipment due to moisture damage. Systems can be designed or corrected by applying the techniques noted in the following paragraphs:

4.2 Improving Existing Systems - The recommendations made in this section are intended as "minimum change" modifications to control humidity in existing systems for improved avionics life and reliability. See paragraph 4.3 for new design.

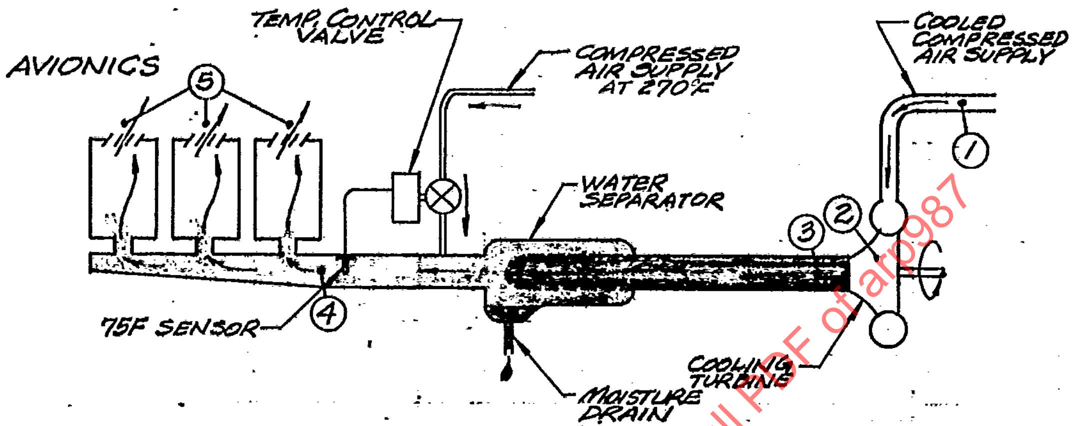
4.2.1 Air Cycle Refrigeration Systems - A reheat system can be installed in an existing air cycle system to maintain the air at a temperature above the maximum dew point specified for the application. Typically, this temperature may range from 60 F to 90 F, depending on where the aircraft is to be operated, the type of avionics and degree of moisture protection, whether or not a water separator is installed, and aircraft system limitations. A dual temperature control system which takes advantage of the low humidity at altitude could be used. This would employ a high setting for low altitude where humidity is high, and a low temperature setting at high altitudes where the ambient air is very dry. The reheat may be furnished by a controlled bypass of turbine engine bleed air (see Fig. 5). The increase in total delivered airflow, which may be required to offset the increase in cooling air supply temperature, can be provided by the bypass air itself if it is not too hot. The selection of the point in the system from which to tap the bypass air (e.g., upstream or downstream of a heat exchanger,) can be made after determining the flow increase required to satisfy avionics cooling with warmer air. It should also be noted that the greater the quantity of bypass used, the higher will be the humidity of the mixture delivered to the avionics, since the bypass has not been subjected to moisture removal.

4.2.1.1 In the example shown on Fig. 5, the air is cooled, as in paragraph 3.4.3, to 40 F and 63 gr/lb of fog, and the water separator removes 80% or 50.4 gr/lb of the fog. Controlled reheat with air at 270 F raises the cooling air temperature to 75 F and increases the moisture content by 10 gr/lb, as shown at point (4), and increases the delivered air flow 22%. The relative humidity of the delivered air is 45% at point (4), and the temperature rise to absorb 1 kw from the avionics is less than the previous examples as a result of the increased airflow.

4.2.1.2 In humid climates where the ambient dew point exceeds 75 F, ambient, moisture condensation on the cooler parts of the avionics may continue to be a source of malfunctions after shut-down. However, during the period when the aircraft taxies from the end of the runway after landing, the capacity of the air cycle system is usually limited by reduced engine power; thus, the desired cooling air temperature increase will perhaps be furnished by virtue of the diminished cooling capacity.

4.2.1.3 If the cooling system does not already have a water separator and if there is not sufficient space in the aircraft to install one, a significant improvement is obtainable by installing reheat provisions alone, as indicated by Fig. 6. The liquid moisture can be eliminated during most operations, even though the relative humidity will remain high in hot-humid climates. This modification requires more bypass air because no water is removed and because all of the water droplets must be re-evaporated. If the bypass air temperature is 270 F (as in the example of Fig. 5) and if the cold flow from the turbine remains unchanged, an airflow increase of 38% is necessary to evaporate the fog. Thus the temperature rise to remove the 1 kw of avionic heat is less than the previous examples.

AVIONICS COOLING WITH AIR CYCLE REFRIGERATION & REHEAT



PSYCHROMETRIC CHART

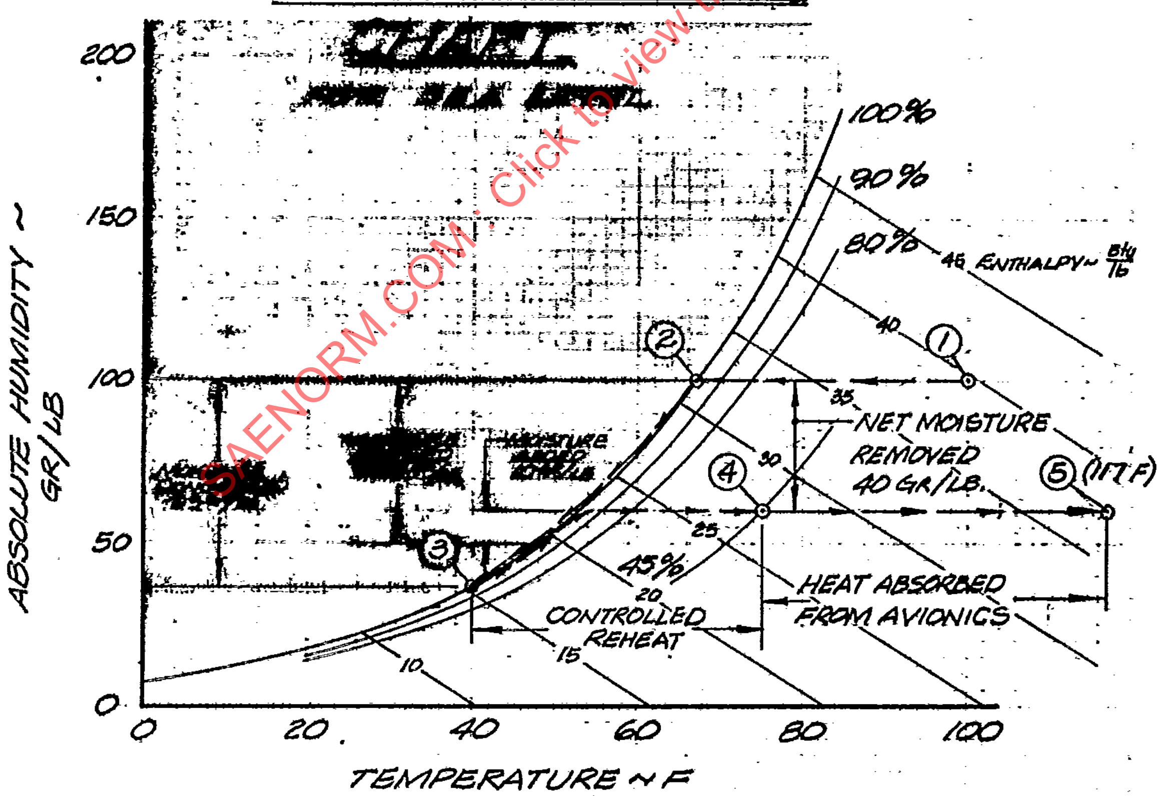
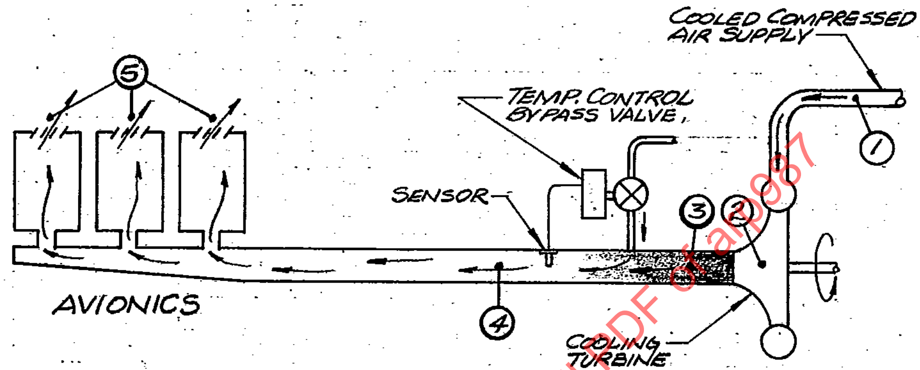


FIGURE 5

AVIONICS COOLING WITH AIR CYCLE REFRIGERATION

REHEAT ONLY



PSYCHROMETRIC CHART

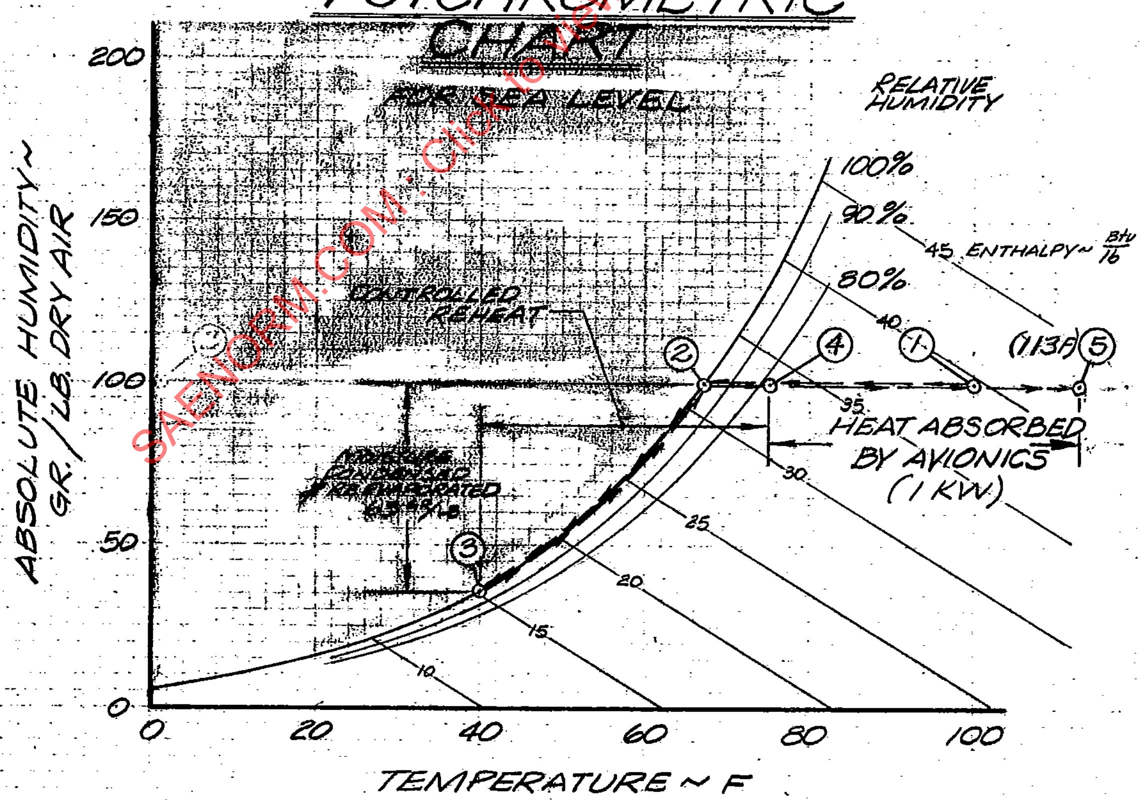


FIGURE 6

4.2.2 Vapor Cycle Refrigeration Systems - Reheating to 75 F or more should be provided in existing systems which have low delivery temperatures. This can be accomplished by an increase in the air flow through the evaporator or by adding recirculated compartment air. Vapor cycle is most commonly used in ground refrigeration units for avionics cooling. Ground units with controllable discharge air temperatures should be posted with clearly written operating instructions to insure the use of the proper air temperature for each aircraft which it is intended to service. If the ground unit cannot readily be modified for air temperature control, then instructions to operate with "blower only" for a period of 5-10 minutes after refrigerated air operation and before ground unit shutdown are advisable to evaporate any condensation on the avionic equipment after a ground run. During the period of operation with uncooled blower air, the avionics should be shut down to guard against overheating.

4.2.3 Parked Aircraft - When an aircraft is stored for several days out-of-doors in moist climates, it is beneficial to "dry out" the electronics periodically by forcing warm air through them. This can be accomplished either by using the "blower only" of a ground unit, or the aircraft system may be used if it can be regulated to deliver warm air. It may be advantageous to remove the avionic equipment from the aircraft and store it indoors where it will not be continually exposed to conditions of high relative humidity if outdoor storage of the aircraft is to extend for long periods. However, there is the possibility of damage during handling, storage and replacement, and the aircraft cabling and connectors remain in the aircraft.

4.2.4 Moisture-Resistant Coatings - All exposed circuits and components should be protected with a moisture resistant coating such as epoxy or polyurethane. These materials must be applied with great care to insure against chipping and peeling, and should not be applied to removable connectors. Generally, the plastic coating serves as an inhibitor rather than a positive moisture barrier. This is due to the probability of voids in the coating which are created during application or by rough handling, vibration, or severe temperature changes in service. Removable plastic moisture covers should be used over connectors wherever feasible to keep them dry. Data and instructions on the application of moisture resistant coatings can be found in items 4 and 7 in the bibliography.

4.3 New Design

4.3.1 The recognition of the moisture problem in new design should include a thorough knowledge of the avionics to be cooled, method of packaging, and actual demonstrated tolerance to conditions of high humidity. It should be recognized that current MIL-Spec testing of avionics does not necessarily simulate actual operating conditions, and that in spite of humidity tests to demonstrate a qualified product, much of the existing avionic equipment is adversely affected by high humidity and condensation. Sealed units cooled by heat exchange through "cold plates" are the least susceptible to the effects of moisture, because the outside air does not contact any of the electric circuits. In a typical avionic installation, however, it is not likely that all units of the system will be packaged in this manner.

4.3.2 Air Cycle Refrigeration - The use of air cycle systems for the direct cooling of avionics equipment should be permitted only with adequate moisture control. The delivered air must be totally void of entrained moisture, as specified in MIL-E-18927[8] for military applications. Several approaches to moisture control are available to the cooling system designer. Two of these are:

(a) Designing the system to produce air as cold as possible (above freezing), and providing a moisture separator and some form of controlled reheat. (Paragraph 4.3.2.1)

(b) Designing an indirect cooling system in which the refrigerated air is passed through a heat exchanger to absorb avionic heat from a recirculating coolant air or liquid stream. (Paragraph 4.3.2.2)

4.3.2.1 Reheat Systems - Reheating the refrigerated air to decrease the relative humidity at the avionics air inlet may be accomplished by a controlled hot air bypass, as discussed in paragraph 4.2.1. It may also be accomplished by mixing with recirculated compartment air. A variety of configurations are available to the designer, a few of which are described in the following paragraphs:

(a) Fan-forced recirculation - A fan can be used to circulate the mixed air through forced cooled units as shown in Fig. 7a. Temperature regulation can be provided by a system which consists of a sensor in the mixed air stream and a controller which throttles the refrigerated air