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ELECTRONIC EQUIPMENT COOLING BY THE DRAW-THROUGH METHOD IN COMMERCIAL JET TRANSPORTS

1. PURPOSE

To set uniform standards of providing adequate and effective "draw-through"* cooling of electronic equipment installed on commercial jet transports and thus improve reliability of operation through controlled environment.

To minimize operational penalties and dirt contamination caused by overcooling, and to prevent a reduction in reliability because of undercooling.

2. SCOPE

This publication formalizes the applicable design concepts considered acceptable for "draw-through" cooling of electronic (avionic) equipment installed in subsonic and supersonic commercial jet transports. Methods other than draw-through cooling are covered in AIR 728A for high Mach number aircraft.

3. GENERAL

3.1 Background: Commercial jet transports are becoming increasingly dependent on electronics for navigation, guidance, communication and other airplane subsystem control functions. The dissipation of heat from these pieces of electronic (avionic) equipment is a problem requiring coordinated effort by both the avionic equipment as well as the airframe manufacturer. The environment in which avionic equipment is installed, the average temperature within the equipment cases, and the method of cooling employed, have a distinct bearing on the reliability and operational life of the equipment.

3.2 Methods of Cooling: There are several methods of cooling the avionic equipment; the simplest of which is free or natural convective cooling by the ambient air surrounding the equipment. In most cases, however, forced air convective cooling is more appropriate, with the air being drawn either through the equipment case or around it. Cold plate cooling using air or some other heat transport fluid is also of potential value. This report will, however, limit its discussion to the concept of forced air convective cooling by the "draw-through" method.

The current practice is to allocate a small area within the pressurized shell of the airplane for installation of most of the avionic equipment on specially constructed racks (see Fig. 1 for a typical installation). Being in the pressurized area, the equipment is normally subject to pressures equivalent to -1000 ft to 8000 ft altitude, and under abnormal conditions such as depressurization, up to 30,000 ft altitude for short time periods. Conditioned air in the passenger and/or crew compartment is used to circulate through the equipment cases for cooling. Avionic equipment when specially designed for such usage, is also installed in unpressurized areas of the airplane. Localized cooling methods are used as needed.

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* Draw-through cooling method is where ambient air surrounding the "black-box" is drawn through the case, over the components to be cooled, and then exhausted overboard through a ducting system.

3.3 Draw-Through Cooling: Typical of the first and second generation subsonic jet transports, this method relies on forced circulation of coolant air around the components mounted within the case of the equipment. As standardized by ARINC 404 (1) the ambient air within the electronic equipment compartment is drawn through the equipment mounted on specially designed racks with built in air collection manifolds. Air movement is provided by blowers on ground or at low differential pressures, and by cabin to outside ambient differential pressure.

While draw-through cooling provides a reasonably efficient means of cooling the electronic components by the use of conditioned air in the cabin, it should be noted that it has the disadvantage of exposing these components to contaminants in the air. Contamination can, of course, be also minimized by using cabin supply air.

3.4 Method of Internal Air Circulation and Collection: To force the cooling air through the equipment cases and overboard, a duct system and a pressure differential are required, the latter under all conditions of flight and ground operation.

a. During pressurized flight conditions, the cabin pressure differential is available.

b. During unpressurized flight conditions, the pressure differential may be produced by exhausting the duct system to a low pressure area or by use of a fan.

c. During ground and taxi operations, a fan in the airplane may be required depending upon the temperatures and heat loads.

3.5 Direction of Air Circulation Inside Equipment Cases: The location of exhaust holes in the equipment cases offers several possibilities. The most natural position, of course, is in the top to take advantage of the "stack effect" of the heated air. However, exhaust holes in the top of the components require ducting above them in addition to supporting structure below. Even if the shelves are used as exhaust plenums for the equipment immediately below, some interconnecting ducting is still required since standard equipment cases are available in two different heights. The sealing problem at the junction of cases and ducts is complicated by the relative motion between the two as both are shock-mounted.

Locating the exhaust holes in the back of the equipment has the same drawbacks as does locating them on top, in that when the front faces of the equipment are kept in one plane for ease of maintenance, the variation in depth of the standard cases prevent the aft faces from being in one plane. More important, present day radio racks use the area behind the shelves for junction boxes and terminal panels and several of the equipment cases project over the disconnect plug. The conversion of these spaces into exhaust plenums entails a prohibitive amount of rework on existing installations.

Positioning the exhaust holes in the bottom of the components eliminates most of the problems mentioned above. It makes possible the use of the shelf as a plenum. No ducting is required between plenum and components since rigid mounting of the equipment on shock-mounted shelves standardizes the clearance between the two and by preventing relative motion between them, simplifies sealing. Also, when new pieces of equipment are installed in the present free convection cooled radio racks, the holes aid cooling by permitting some internal air circulation. Of course, use of this "down draft" principle means that the air flow within the cases is bucking the stack effect, but this is a negligible factor.

(1) Air Transport Equipment Cases and Racking, ARINC Specification No. 404, May 1956, Aeronautical Radio, Inc., Washington, D. C.

3.6 Standard Seal: Because the location and size of the equipment exhaust holes depends, among other things, upon the type of seal around them, it was necessary that some standard seal be developed. In the search for such a seal, two facts soon become apparent.

a. Hard-surfaced seals withstand wear well, but require the equipment cases to be smooth and flat in the vicinity of the exhaust holes to prevent leakage.

b. Soft seals are able to mold themselves to slight irregularities in the case surfaces, this making a good seal, but do not wear well.

Since both sealing and wearing qualities are essential, the seal shown in Fig. 2 was developed. This seal is made of rubber to give good sealing characteristics and has nylon fabric bonded to it in the area which contacts the equipment cases to protect it against wear.

A 1-3/4 diameter seal of this design was tested while mounted underneath a 15 lb box with a pressure differential across it of 8 in. of water, maintained a leakage rate of less than 1 CFM. After wear was simulated by 400 sliding contacts with a 60 lb box, a repetition of the test showed no increase in leakage rate.

3.7 Equipment Case Exhaust Holes:

3.7.1 General Considerations: Because of the small leakage rate exhibited by the standard seal, it is possible to enclose large areas on the bottom of the equipment cases with it. This allows the equipment designer a large measure of flexibility in locating the individual components. The exhaust holes can then be located in such a manner as to draw the cooling air flow directly over those components which produce the most heat, thereby employing the cooling air with maximum efficiency.

3.7.2 Standard Size: The exhaust holes should have a maximum diameter of approximately 1/8-in. to prevent foreign objects from entering the equipment cases. Groups of these holes would then be positioned within the sealed area on the case bottom and the inlet louvers in the case arranged to produce the desired flow paths, as shown in Fig. 3. The number of holes in a case or in a grouping would depend upon the cooling air flow requirements of an equipment or of a component respectively.

3.7.3 Standard Location: In establishing a standard area on the case bottoms to be enclosed by the seal, there are two factors to consider:

a. From the standpoint of the equipment manufacturers, it would be best to make the entire bottom of the case available for locating exhaust holes.

b. From the standpoint of the airframe manufacturer, the larger the seal area becomes, the larger the shelf plenum must be to accommodate it, resulting in a heavier shelf and increased difficulty in sealing the shelf plenum.

A compromise solution has been made possible by equipment manufacturer's studies which indicated that very little if any advantage would be gained by exhaust holes located anywhere within 7 in. of the front of the case. Investigations were carried out on the use of the standard seals to enclose large rectangular areas on the case bottoms. These investigations revealed that when used with 3/4 ATR* and larger equipment, the rear edge of the seal was often caught and rolled back by the rear edge of the equipment case as the latter was slid into place. This situation was remedied by tapering the rear of the seal into a shallow "V" rather than running it parallel to the rear edge of the case.

Application of the standard seal to the various ATR sizes so that the largest possible useful areas were enclosed produced the standard exhaust hole areas shown in Fig. 4. These dimensions also pertain to the inside surfaces of the enclosing seals.

The equipment designer may locate exhaust holes anywhere within these areas as he sees fit, making sure that the case bottom is smooth and flat for at least 1/2 in. all around the areas to provide good sealing and prevent damage to the seal. The portion of the case bottom which will contact the seal as the case is slid

* Austin Trumbull Radio

in or out should be smooth and free of any protrusions. It then becomes the responsibility of the airframe manufacturer to design a shelf with a plenum and seal to accommodate the equipment.

3.8 Dirt and Tar Contamination:

3.8.1 General Considerations: The mechanics of internal air circulation and collection aggravates the problem of contamination accumulation (dirt, lint, dust, smoke, oil vapors, etc.) within the cooling system. If not cleaned at regular intervals, this buildup can be expected to restrict air flow passages and deteriorate system cooling performance. Contamination can also be found as a problem in the ducting system in addition to within the avionic black-box due to particular duct installation features.

3.8.2 Accumulation of Contamination:

a. Duct systems should be designed with a minimum of discontinuities and obstructions. Where these are required, they should be designed to minimize the tendency to accumulate contaminants. Use of closely spaced flow straighteners in the duct system for example is a design error to be avoided.

b. Cooling systems may be designed to exhaust dust-laden air immediately downstream from the cooled electrical and electronics equipment. Partial or complete use of this option during design will reduce contaminant accumulation.

3.8.3 Removal of Contamination: Steps should be taken during design to identify all areas which are likely to accumulate contaminants. Access should be provided to all these areas to facilitate cleaning.

Equipment cooling exhaust air may be utilized for other purposes. The design considerations stated above apply equally to these subsystems since deterioration here will reduce equipment cooling. Electronic equipment cooling exhaust air should not be circulated through occupied compartments or live cargo areas because of possible toxicity hazard.

3.8.4 If at all possible, filtering of the cooling air to remove cigarette tars should be avoided. The use of a single filter requires sealing the entire rack while the use of individual filters complicates considerably the cooling air flow system for all the other unfiltered items of equipment in the rack. If it is not possible to avoid the use of a filter for some piece of equipment, it might be desirable from a weight and maintenance standpoint to provide that piece of equipment with a completely separate cooling air ducting system.

3.8.5 Alternate Designs to Solve Contamination Problem: To overcome contamination problems created by draw-through cooling, consideration should also be given to the area-cooling and the cold plate cooling methods.

4. TYPICAL INTERNAL CIRCULATION SYSTEM

Fig. 5 is a sketch of a commonly used internal circulation equipment cooling system. It is recognized that individual shelf design may differ from the sketch in detail parts, but not in areas affecting equipment interchangeability.

Equipment is rigidly mounted on shock-mounted shelves, each of which has a built-in plenum running the entire length of the shelf. All shelf plenums empty into the main plenum running up the side of the radio rack, thus leaving the area behind the equipment for junction boxes and terminal panels. Since the shelves are shock-mounted, flexible ducts are required to connect shelf plenums to the main plenum as shown in Section A-A. From the main plenum air is dumped overboard or away from the equipment rack.

The suggested means of installing standard seals on the shelf plenums is shown in Section B-B. It is also necessary to provide a recessed seat for the seal. This may be done either by shimming up the seal as shown on the left (Fig. 5, Section B-B), or by dishing out the plenum top as shown on the right. Because the heat loads differ in equipment of identical ATR size and the pressure differential available to force air through the equipment varies from one type of airplane to another, the shelf plenums are fitted with orifices as shown in Fig. 5. individually tailored to produce the desired air flow through each equipment so that cooling air is not wasted. It is also common practice to include some means of detecting a loss of cooling air flow, especially when depending upon the fan.

5. DESIGN DATA FOR INTERNAL CIRCULATION

As a result of discussions with various companies involved in the problem of equipment cooling, an initial design figure for efficient cooling has been established at 15 to 30 lb per hr per 100 watts at an 8,000 ft cabin altitude. Assuming that the cooling air carries away all the heat generated, its change in temperature as it passes through the equipment for a flow rate of 30 lb per hr per 100 watts is:

$$\Delta t = \frac{3.41Q}{WC_p}$$

$$\Delta t = \frac{3.41 \times 100}{30 \times .241}$$

$$\Delta t = 47.1\ ^{o}F$$

Δt = Temperature rise (^{o}F)
Q = Heat rejection (Watts)
W = Cooling air flow (lbs/hr)
C_p = Specific heat of air (BTU/lb ^{o}F)

Thus, cabin air entering the equipment at 80 F would leave it at 127 F, within the 130 F limit which is considered good current practice.

As was mentioned previously, use of the "down draft" method of internal circulation means that the desired direction of air flow is being opposed by the natural stack effect of the heated air. Engineering studies have determined however, that stack effect is a negligible factor, since the pressure differential it creates is less than 0.001 in. of water for temperature differentials as high as 55 F within the case.

Since the pressure drop through each equipment and its associated orifice in the shelf plenum will be the same for all air flow paths, it is necessary to establish a maximum permissible pressure drop for individual equipment which will be consistent with the cooling air flow defined above. One equipment manufacturer has found such a figure to be of the order of 1.0 to 1.5 in. of water. It might be mentioned however, that a major operator in a rework of present equipment, achieved adequate cooling with a pressure drop of only 0.2 in. of water.

6. RECOMMENDATION

It is recommended that the cooling air provisions as outlined in this AIR be incorporated in the specification for new equipment in civil transport aircraft of the present day and the immediate future whenever the draw-through cooling method has been selected and where the equipment is packaged per ARINC 404.

PREPARED BY
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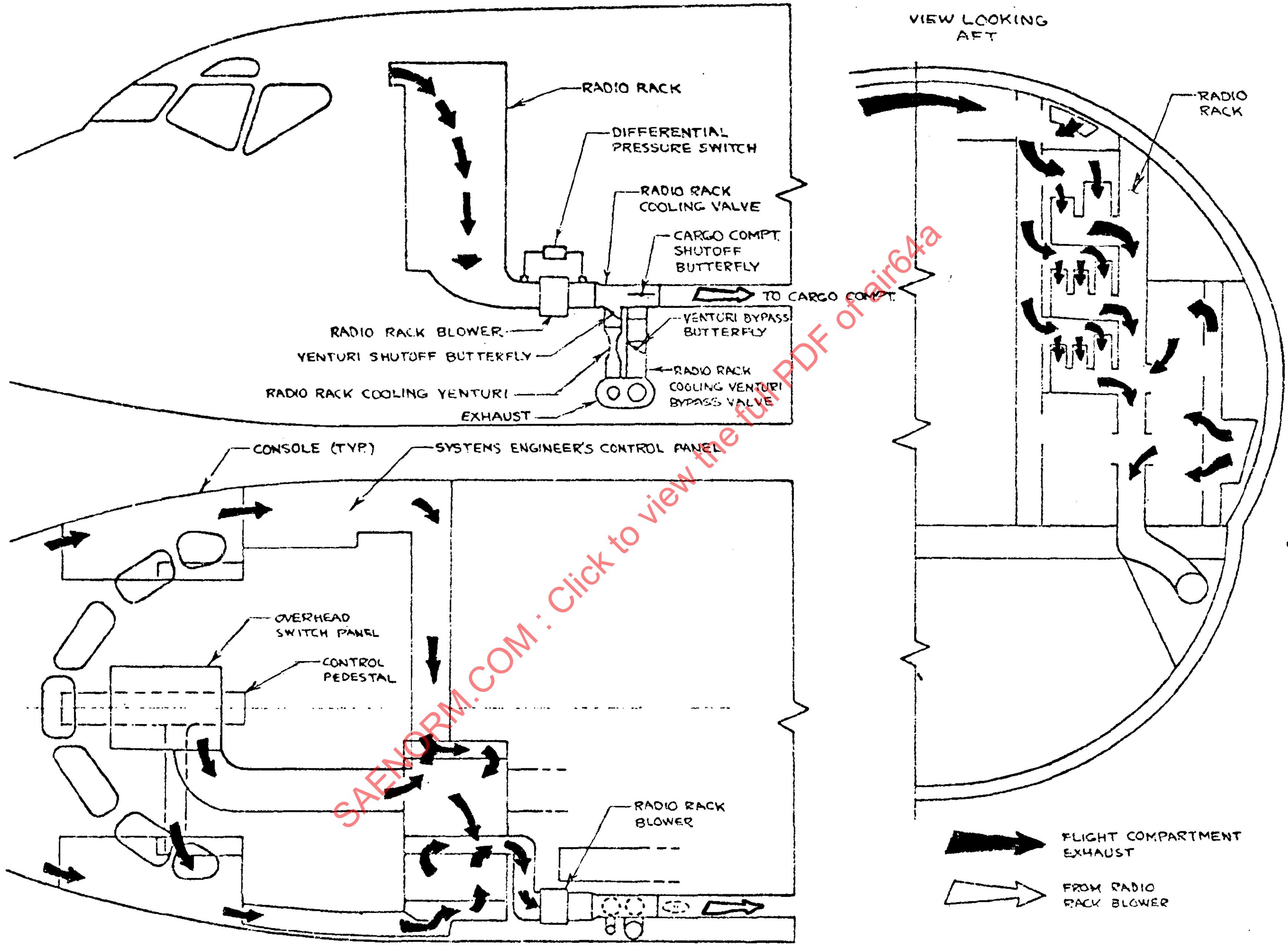

FIGURE 1. ELECTRONIC EQUIPMENT COOLING ~ DRAW-THROUGH METHOD

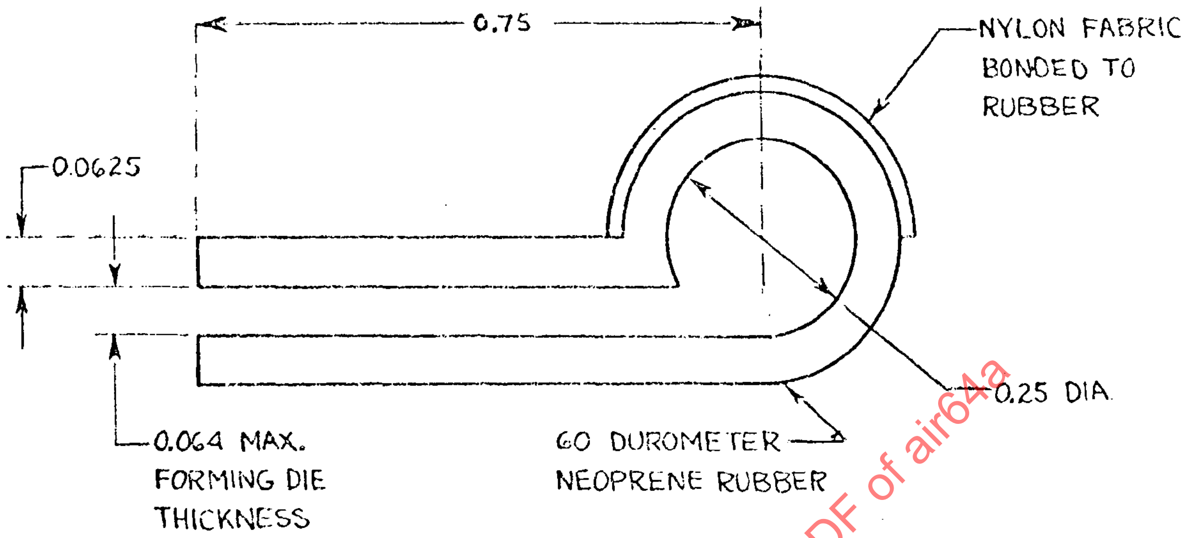

FIGURE 2

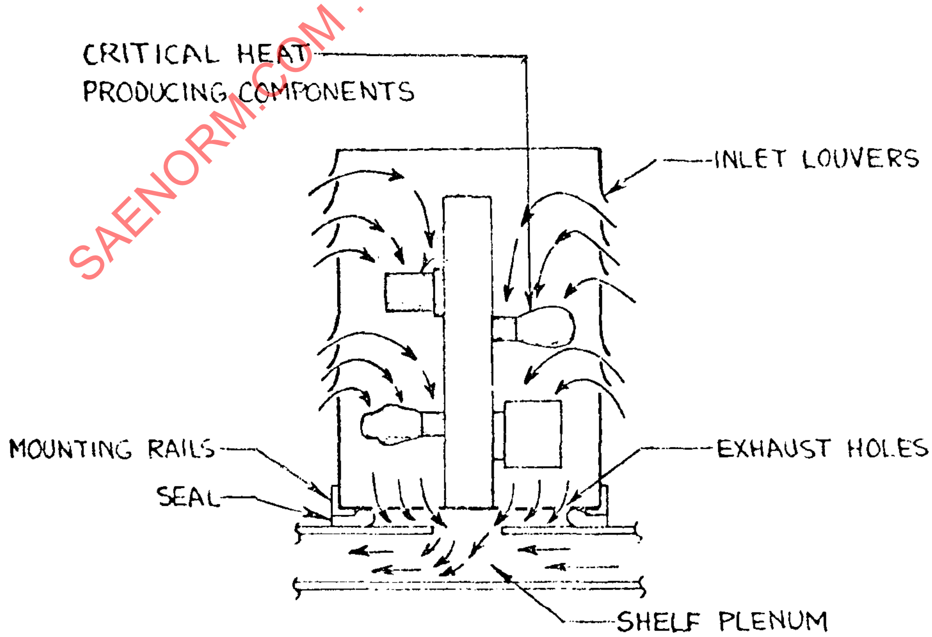

FIGURE 3