



# AEROSPACE INFORMATION REPORT

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## Liquid Cooling Systems

### RATIONALE

AIR1811A has been reaffirmed to comply with the SAE five-year review policy.

### FOREWORD

Changes in this revision are format/editorial only.

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## 1. SCOPE:

This publication is applicable to liquid cooling systems of the closed loop type and the expendable coolant type in which the primary function is transporting of heat from its source to a heat sink. Most liquid cooling system applications are oriented toward the cooling of electronics. Liquid cooling techniques, heat sinks, design features, selection of coolants, corrosion control, and servicing requirements for these systems are presented. Information on vapor compression refrigeration systems, which are a type of cooling system, is found in Reference 1.

### 1.1 Purpose:

The purpose of this Aerospace Information Report (AIR) is to provide guidelines for the selection and design of airborne liquid cooling systems.

## 2. REFERENCES:

1. "General Requirements for Application of Vapor Cycle Refrigeration Systems for Aircraft." SAE ARP731A, April 15, 1973.
2. A. E. Bergles, R. C. Chu, and J. H. Seely. "Survey of Heat Transfer Techniques Applied to Electronic Equipment." ASME-72-WA/HT-39, November, 1972.
3. "Cooling of Modern Airborne Electronic Equipment." SAE AIR1277, May, 1976.
4. "Reliability/Design Thermal Applications." MIL-HDBK-251, January 19, 1978.
5. K. H. Token, E. C. Garner, R. S. Cook, and J. E. Stone. "Heat Pipe Avionic Thermal Control." AIAA-80-1511, July, 1980.
6. "Environmental Test Methods." MIL-STD-810C, Military Standard, 10 March 1975.
7. A. F. Knight. "Choice of Fluids for Cooling Electronic Equipment." Electro-Technology; Vol. 71, No. 6, Pages 57-63, June, 1963.
8. D. J. Kelly. "Resistance of Materials to Hydraulic Fluid." Machine Design, January 21, 1971.
9. "SAE Aerospace Applied Thermodynamics Manual." SAE ARP1168, October, 1969.
10. W. Kays and A. L. London. "Compact Heat Exchangers." 2nd Edition, McGraw-Hill, New York, 1964.

### 3. BACKGROUND:

Liquid cooling systems offer many significant advantages over air cooling systems.

A major application of liquid cooling systems is for avionics in military aircraft. This use is the result of sophisticated, high performance electronic components in small packaging sizes, and the need for high reliability of avionic systems.

Liquid cooling can be accomplished by direct contact of the liquid with heat producing components, or indirectly via heat exchange devices.

In either case, the liquid transports heat to a heat sink. In airborne systems, the heat sink can be ambient or ram air, fuel, an expendable or heat storage material, or a refrigeration system.

Expendable systems are typically used in remotely piloted vehicles or drones, for avionics cooling and as a supplemental heat sink for a refrigeration system transport loop.

### 4. LIQUID COOLING TECHNIQUE:

A major reason to use liquid for cooling is that it is more efficient than cooling with a gas, such as air. It may be used to remove heat directly or indirectly from the heat source and it may absorb heat as it changes phase and is expended.

#### 4.1 Benefits:

Liquid cooling systems provide superior localized cooling than either air or gas cooling. A larger heat transfer coefficient is obtainable with liquid versus air or gas, resulting in smaller differences between component temperatures and coolant supply temperatures. The smaller temperature difference allows components to operate at lower temperatures. This improves component reliability and reduces maintenance costs.

Relative heat transfer coefficients for two liquid cooling methods compared to two air cooling methods are presented in Figure 1. (See Reference 2 or 3.) The higher heat transfer coefficients of liquid cooling systems permits larger power densities to be adequately cooled. Also, liquid cools low power density equipment more efficiently than air cooling. Heat transfer coefficients generally increase with increased fluid velocity. However, pressure losses increase with increased velocity.

The heat capacitance (mass flow rate times specific heat) of a cooling fluid is a significant factor. The large heat capacitance and high density of liquids results in smaller heat sink components and transport lines sizes. This generally reduces weight, therefore, lowers aircraft fuel penalties.

Disadvantages of liquid cooling systems also should be analyzed for each potential application. Major areas to be considered are maintenance, potential leaks, fluid contamination, logistics, and potential fire hazards.

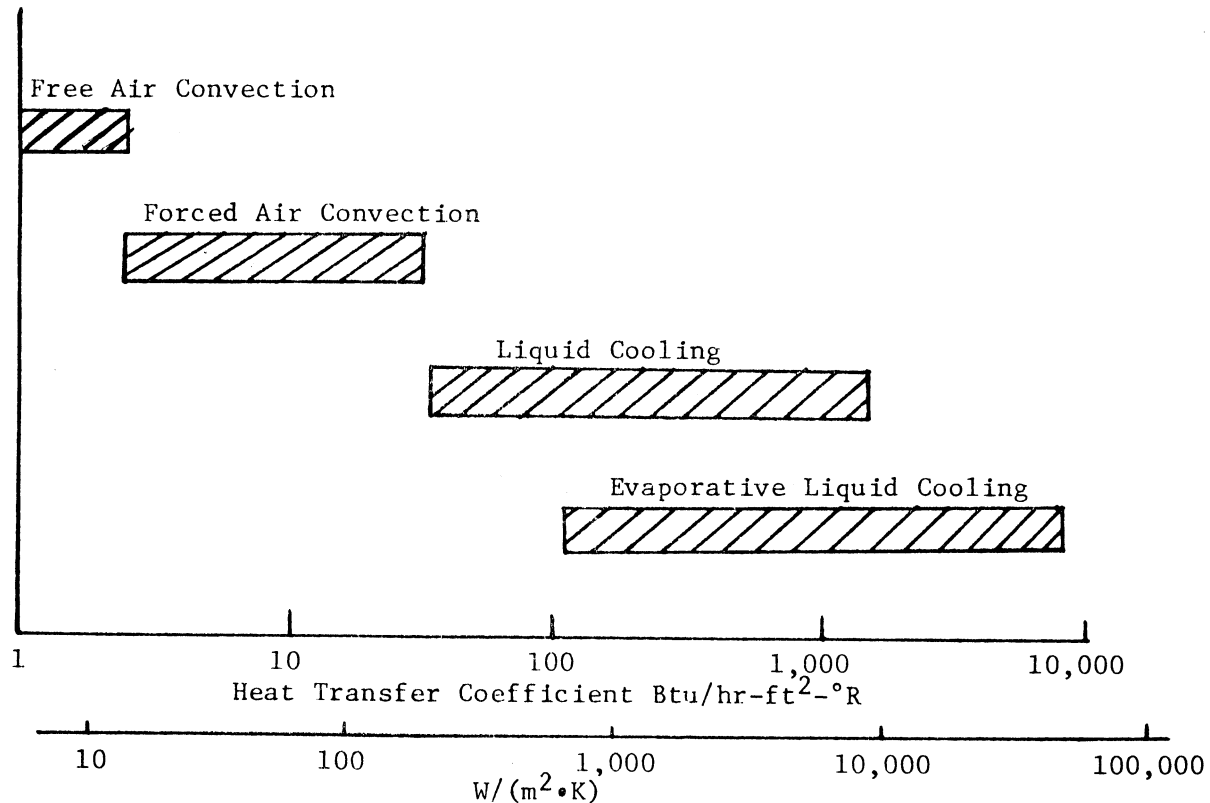


FIGURE 1 - Cooling Methods Versus Heat Transfer Coefficients

#### 4.2 Types of Liquid Cooling Systems:

Direct, indirect, and expendable cooling systems are addressed in this AIR.

- 4.2.1 Direct: Liquid may be used to remove heat directly from the heat source. This provides the minimum thermal resistance from the heat source to the liquid. An example of direct liquid cooling of avionic components on circuit boards is shown in Figure 2.

A major consideration of direct liquid cooling is compatibility of all parts being cooled with the liquid. Other design considerations are thermal expansion, liquid pressure, maintenance and servicing provisions, and controls for normal operation and failure conditions.

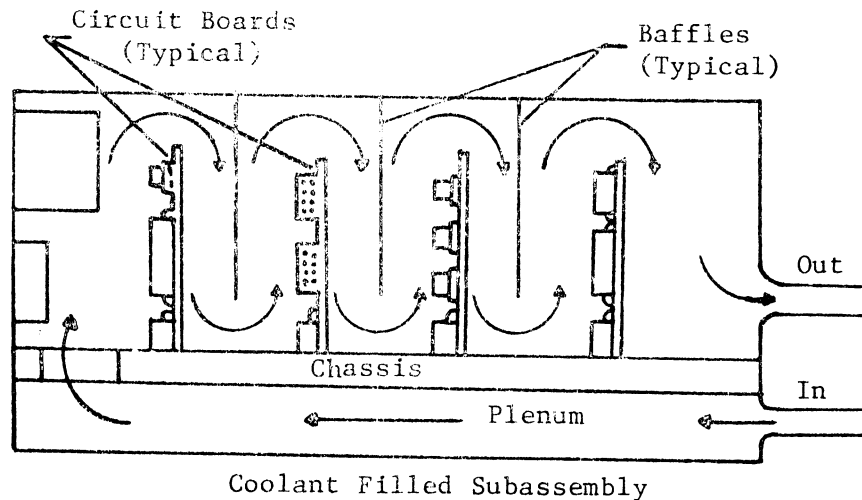


FIGURE 2 - Direct Liquid Cooling

- 4.2.2 Indirect: In this method, heat is transferred to the liquid in a liquid cooled cold plate, via an intermediate device. Conduction is the common method for transferring heat from components and subassemblies to a liquid cooled cold plate. An advantage of indirect liquid cooling over direct cooling is that a heat producing component can be removed for servicing without disturbing (i.e., opening) the liquid loop.

The cold plate can be an integral part of the assembly being cooled, or it can be designed to readily separate from the assembly being cooled (i.e., a non-integral design). An example of an integral indirect cooling design is shown in Figure 3 (from Reference 4). An example of a non-integral indirect cooling design is shown in Figure 4 (from Reference 5).

Indirect cooling designs require an important thermal design consideration which is not necessary for direct cooling designs. Heat must be transferred from the heat source to the liquid. This heat should be transferred with a minimal total thermal resistance. There are two types of thermal resistances in this heat transfer path.

One thermal resistance is across one or more interfaces. An objective of the indirect design is to allow removal of a component subassembly (as in Figure 3) or removal of an assembled unit (as in Figure 4). It is important that mating surfaces of an interface are flat and are held together with sufficient pressure. A low thermal resistance design becomes more important as heat transfer rate increases per unit area of the interface. A thin, high thermal conductivity material (e.g., silver filled silicone rubber) can be used between the two surfaces to fill the small asperities, thus decreasing overall thermal resistance.

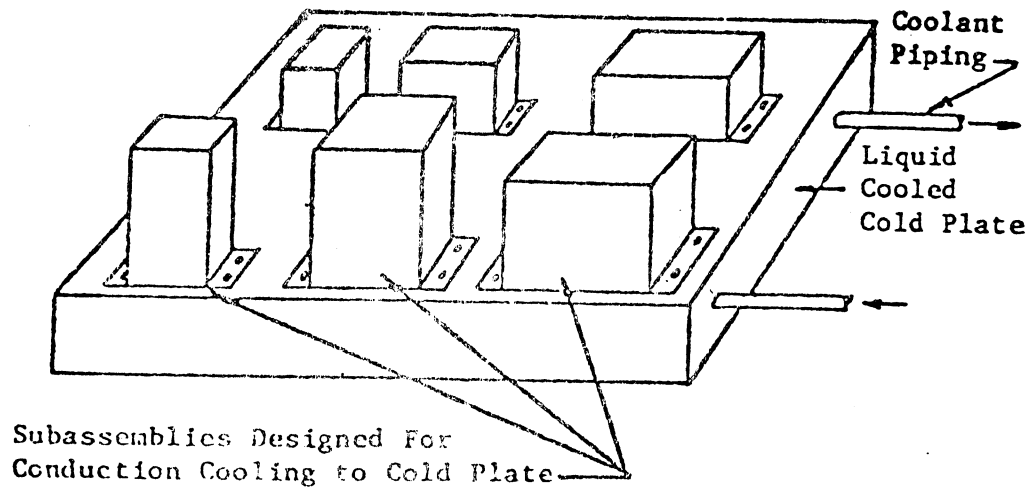


FIGURE 3 - Indirect Liquid Cooling With Integral Cold Plate

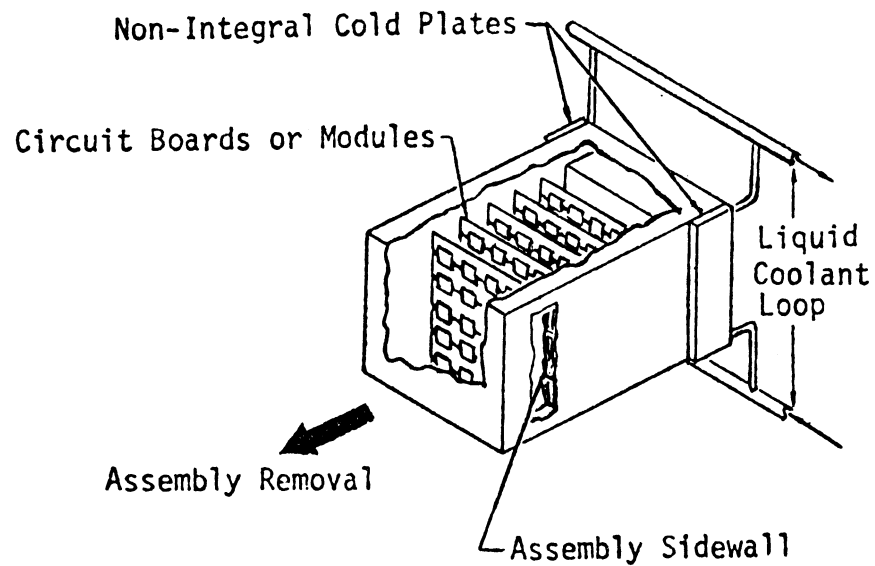


FIGURE 4 - Indirect Liquid Cooling With Non-Integral Cold Plate