COLD PLATE SOFTWARE PROGRAM ANALYZES AIRCRAFT DISPLAY

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Sanders, a Lockheed Martin Co.
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Introduction

Finned heat exchangers, called cold plates, have been used for many years to cool military electronics. High reliability is paramount in military electronics. And in order to achieve such high reliability, direct air/liquid impingement on electronic components is prohibited. Cold plates offer high heat transfer rates due to their large surface areas and the fact that air/liquid coolant is forced through compact flow passages. This results in the ability to cool electronics that have relatively high power density. In addition, since most military equipment is subjected to high levels of vibration and shock loads, the cold plates provide a stiff structure for mounting circuit cards and other assemblies.

Need (benefit) for S/W program

Designing cold plates usually requires many trade studies to determine the optimum design. Length and width of the cold plate are often fixed by the space available on the air craft, ship or other platform where the electronic enclosure is to be installed. The geometry of a cold plate such as the fin height, fin to fin spacing and type of fins is not fixed, but must be selected to give the best thermal performance while still considering the total allowable pressure drop and weight. Cold plates (heat sinks) are typically made of aluminum. They may be manufactured using an extrusion process in which the base plate and fins are made of one piece. When weight and thermal performance are important, the cold plate may be made of relatively thin aluminum sheet metal that is formed into rectangular, triangular or other shapes that enhance the cold plate heat transfer. The face sheets are usually brazed or bonded to the fins in order to channel the air or liquid coolant between the fins. Other materials including copper, advanced metal matrix materials such as aluminum silicone carbide and carbon fiber composites are starting to be used. The selection of the material depends on the required thermal performance, circuit card technology and weight considerations. If the electronics are to be mounted on an air craft, the boundary conditions including cooling fluid temperature and flow rate may vary so that what works best at one condition may not be best at another.

The equations used for predicting thermal and pressure drop performance can be involved and time consuming to solve. These equations need to be solved many times in order to determine the most optimum design. A computer program to solve these equations and with a capability that allows the user to change the cold plate geometry and boundary conditions within the same analysis would considerably reduce the time and effort to converge on an acceptable design.

The cold plate is generally part of an overall thermal design that may include a chassis, circuit boards, a power supply and other parts. Prediction of the temperatures of these other parts as well as the cold plate under both steady-state and transient conditions may be required for a complete thermal analysis. In order to be able to efficiently, quickly and accurately perform these analyses and to account for other modes of heat transfer involving conduction, convection, radiation and fluid flow, a thermal solution using the finite difference approach works best. Once the temperature and pressure drop results are determined, they are best analyzed using XY curve plots and color contour plots. The plots need to be able to show temperature, pressure drop and weight results; with varying geometry such as fin height, fin to fin spacing or fin thickness; as a function of time; at different cooling flow rates or under different ambient temperatures and pressures.

A software program that has all of the aforementioned capabilities and more has been developed by the author. The program called COLDPLATE™ has been used extensively by Sanders, a Lockheed Martin Company, to successfully design and analyze electronic equipment utilizing cold plate heat exchangers.

Example

An airborne cockpit display (Fig. 1) using liquid crystal display (LCD) technology was recently developed by Sanders. Since the loss of the display during flight could be disastrous, the thermal performance of the display is critical. In order to ensure high reliability the following criteria must be met: the individual component operating junction (Fig. 2) temperature must be kept significantly lower than the manufacture's maximum allowable value, the LCD temperature must be maintained within a fixed temperature range, and the cooling air must not come in contact with components.

An additional consideration in the design of the display is its weight. The majority of the enclosure was made of a composite material to save weight even though an aluminum enclosure would have been significantly cheaper.

The primary method of heat removal for the display is by forced convection via an air to fin heat exchanger (cold plate). Cooling air is supplied by the aircraft environmental control system (ECS) which passes through the cold plate without coming in contact with components. The major power dissipating components, the circuit card assemblies (CCA) and the day and night lamps are mounted directly to the cold plate. Components on the CCA are cooled by conduction from the component junction (Fig. 2) to its case. From the component case the power is then conducted through the printed wiring board and adhesive to a conductive heat sink. Once on the heat sink, the power is then conducted to the cold plate. Other parts of the display such as the LCD and LCD driver components which are not in direct contact with the cold plate are cooled by a combination of conduction, convection and radiation to the ambient air and to the cold plate.

The air flow rate supplied (Fig. 3) to the display is a function of both the inlet air temperature and the total display power dissipation. Both flight (ECS) and ground operation must be addressed in designing the cold plate. Maximum allowable pressure drops at three different flow conditions (Fig. 3) also had to be met. The surrounding air pressure in pounds per square inch (PSI) and maximum pressure drop in inches of water at each condition are shown. There were also transient cold start requirements which had to be met, but which are not discussed here.

During the initial stages of the design, numerous configurations of the cold plate were analyzed using COLDPLATE. At that stage of the design, it was assumed that the cold plate was isothermal and the power distribution on the cold plate was uniform. This is generally a valid assumption for purposes of determining the optimum cold plate configuration. Later after the design was refined, the analysis was performed without the assumption of a uniform temperature. This was done by breaking the cold plate into a number of nodes that were interconnected by thermal resistances with the power applied to the nodes based on the proper power distribution.

The design configurations evaluated included different fin heights, fin to fin spacing (fin densities) and fin thicknesses. Design curves such as shown in Figure 4 were used to pick the cold plate configuration that minimized the cold plate temperature and pressure drop. The pressure drop due to friction of air flowing through the fins, the entrance and exit effects of the fins and the pressure drop due to changes in flow air direction, and changes in cross-sectional area were also accounted for using COLDPLATE. Curves similar to those shown in Figure 4, but with the cold plate weight replacing the pressure drop, were also generated to minimize the cold plate weight. Design curves for different types of fins such as rectangular, triangular, wavy, lanced and offset, and pin fins were also evaluated. Once the optimum fin configuration was selected, the cold plate performance was then evaluated at different flow rates to ensure acceptable performance at other operating conditions.
The optimized cold plate configuration selected had aluminum rectangular fins that where .40 inches high, .006 inches thick and had a pitch of 16 fins/inch. The configuration had a pressure drop of 2.2 inches of water for condition C which is well within the maximum allowable value of 3.1 inches of water. This configuration was then used for the detail thermal analysis.

A model of the display that included the cold plate, CCAs, LCD, lamps and enclosure was then constructed from the CAD geometry using MSC/PATRAN. MSC/PATRAN, a product of MacNeal-Schwendler Corporation, is a modeling and post processing tool that is usually used for generating finite element mesh models, but it also has the ability to generate thermal models used in finite difference codes. COLDPLATE has the ability to read the model generated by MSC/PATRAN, analyze it and generate results that can be read by MSC/PATRAN and then displayed as color contour plots. Models can also be generated manually by breaking the assembly into isothermal nodes and interconnecting the nodes with thermal resistors.

Material properties such as thermal conductivity, density, heat capacity and thicknesses were assigned to the display model. Power, convection coefficients, and radiation emissivity and view factor were then added to the appropriate parts of the models. The mesh model was completed, analyzed and the results were evaluated (Figure 5).

Some of the fin parameters such as fin density and fin type that were considered strong candidates for the final design were changed in the cold plate portion of the model to ensure that the most optimum design was picked during the preliminary analysis. These can be easily varied within the COLDPLATE finite difference (non-isothermal) model independent of the MSC/PATRAN model. The flow rates and boundary temperatures were also changed in the model in a similar manner.

The results from the assembly thermal model were then used as inputs (boundaries conditions) for detailed models of each CCA. The CCAs were modeled using a specialized circuit board analyzer that predicts the junction temperatures of all of the components.

The display was built and is in the process of being qualified. Testing to date shows good/excellent correlation between analysis and measurements.

Summary

Cold plates have been used for years for cooling military electronics. They have proven to be reliable and relatively simple to manufacture. Most importantly they have been and will continue to be a very effective approach to cooling electronics. The cold plate is an integral part of a critical thermal management system for an advanced LCD display. An engineering approach to designing and analyzing cold plates using a comprehensive software program has resulted in a successful design.

Figure 1 Cross Sectional View of LCD Display

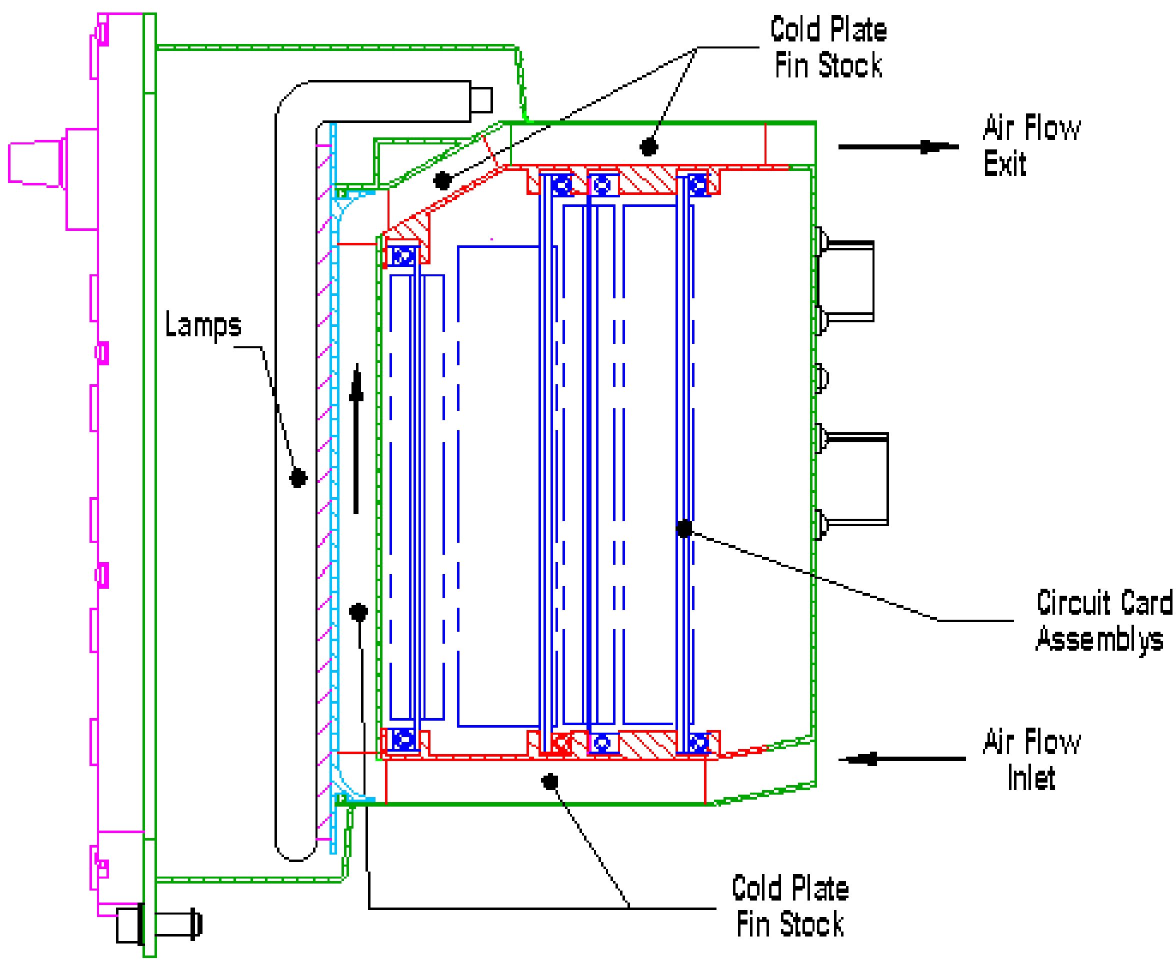

Figure 2

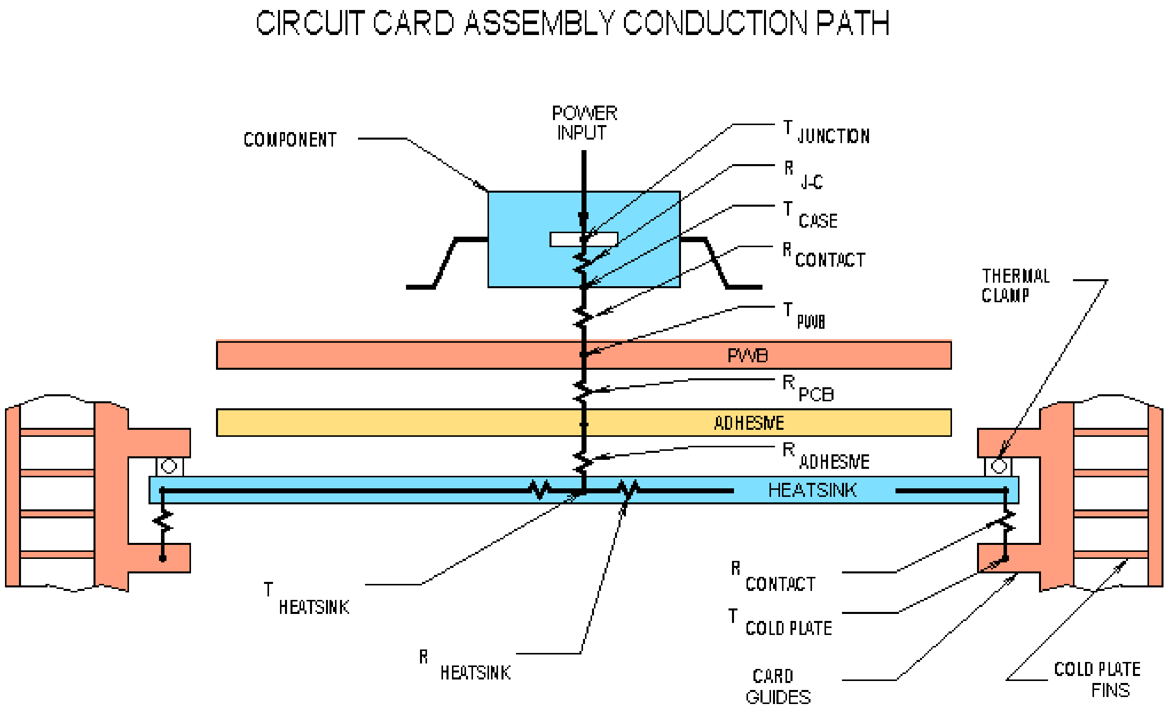
CIRCUIT CARD ASSEMBLY CONDUCTION PATH
COMPONENT
POWER INPUT
T JUNCTION
R J-C
T CASE
R CONTACT
T PWB
THERMAL CLAMP
PWB
R PCB
ADHESIVE
R ADHESIVE
HEATSINK
T HEATSINK
R HEATSINK
R CONTACT
T COLD PLATE
CARD GUIDES
COLD PLATE FINS

Figure 3

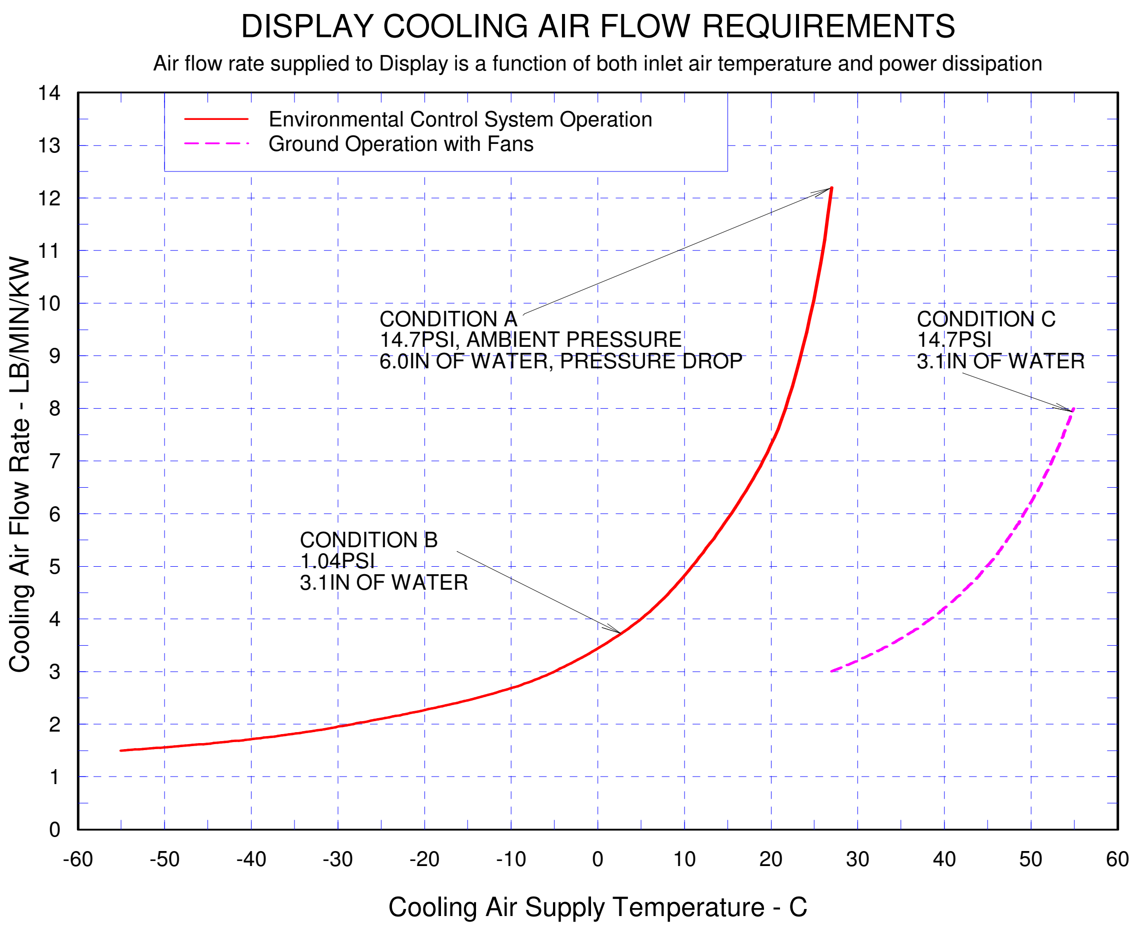
DISPLAY COOLING AIR FLOW REQUIREMENTS
Air flow rate supplied to Display is a function of both inlet air temperature and power dissipation
Environmental Control System Operation
Ground Operation with Fans
CONDITION A
14.7PSI, AMBIENT PRESSURE
6.0IN OF WATER, PRESSURE DROP
CONDITION B
1.04PSI
3.1IN OF WATER
CONDITION C
14.7PSI
3.1IN OF WATER
Cooling Air Flow Rate - LB/MIN/KW
Cooling Air Supply Temperature - C
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60

Figure 4 Design Curves

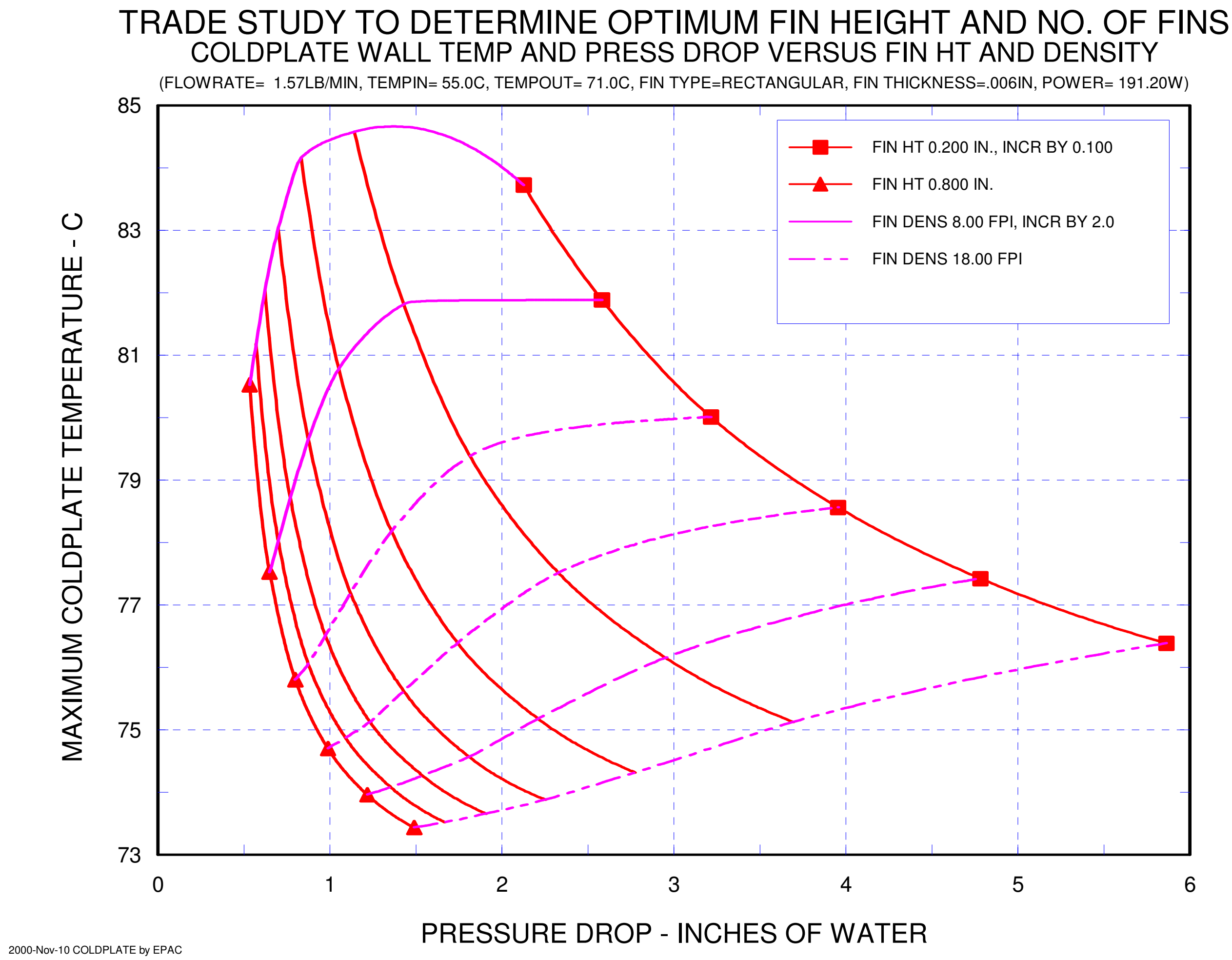

Figure 5 Temperature (C) Contour Plot for Flight Condition A