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Electronic Cooling Simulation Helps Reduce Design Time

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Electronics cooling simulation is helping a major aerospace manufacturer reduce design time while minimizing system weight. Thermal management is important for safe and reliable operation of all electronic equipment, and is especially so for airborne systems. Yet it can take several months and cost on the order of $10,000 to build and test a single prototype for certain equipment. For Hamilton Sundstrand, a maker of power modules for aerospace and marine applications, these obstacles have been overcome by using computational fluid dynamics (CFD) software to evaluate the effectiveness of different designs. By using simulations to better understand the airflow within each proposed device, engineers can determine the best methods for heat removal before the first prototype is built. In this manner, the company can often find novel ways to improve thermal management while reducing component weight.

During the past several years in all sectors of the electronics business, system functionality has been steadily increasing while system size has been steadily decreasing. The combination of these trends has led to a steady increase in the amount of heat generated per unit volume. Removing internally generated heat requires an effective path along which the heat can flow from the heat-dissipating components to the surroundings. To meet this need, a variety of cooling techniques is available to design engineers including, for example, conduction, natural convection, forced-air cooling, radiation cooling, and liquid cooling. Selecting and eventually optimizing thermal management has relied on, traditionally, building a series of physical prototypes using different cooling methods, and measuring the performance of each.

HARDWARE VS. SOFTWARE PROTOTYPING

Unfortunately, the traditional approach is timeconsuming and it is difficult to build physical prototypes during the early stages of the design,performance in terms of minimizing pressure drops

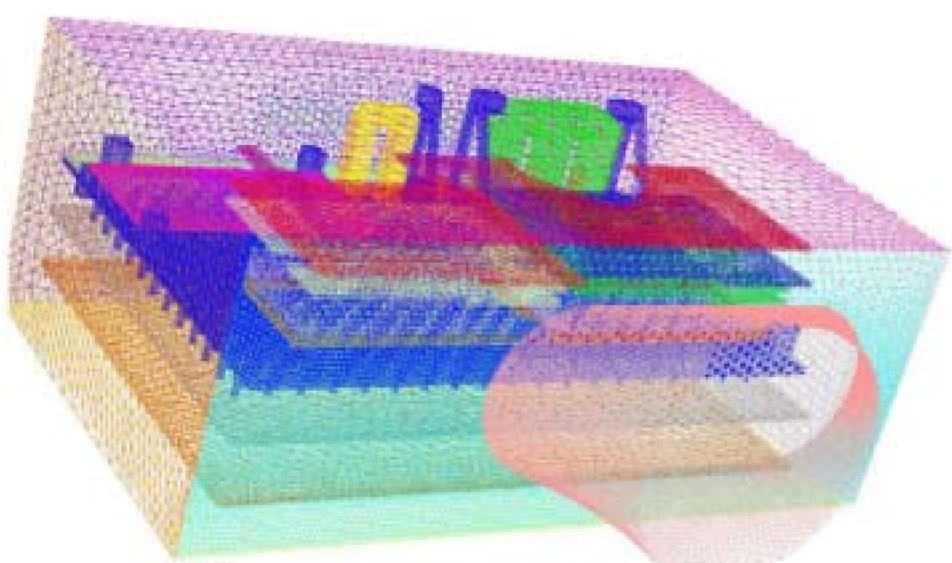

Figure 1: CFD model of motor control module

when other issues are being tackled. The construction and testing of many prototypes is often needed to meet a stringent design requirement. This can turn into an expensive process with the potential to delay the entire development cycle. Another problem is that although building and testing prototypes can yield accurate thermal performance measurements, it sheds little or no light on the internal flow and heat transfer conditions that determine why the design does or does not work. As a result, engineers obtain very little information from each test and have to proceed mainly on instinct.

In order to address these issues, Hamilton Sundstrand engineers have been using computer simulations for a number of years to create virtual prototypes of their concept designs and evaluate thermal management without the time and expense required for physical prototyping. Computational fluid dynamics (CFD) software allows users to build models that simulate the flow conditions within an enclosure, making it possible to evaluate virtual prototypes on a computer. Virtual prototyping can be performed at a much lower cost and in much less time than physical prototyping, and has the additional advantage that engineers can determine important flow variables, such as velocity, pressure, and temperature at any point in the design, making it easier to optimize thermal performance.

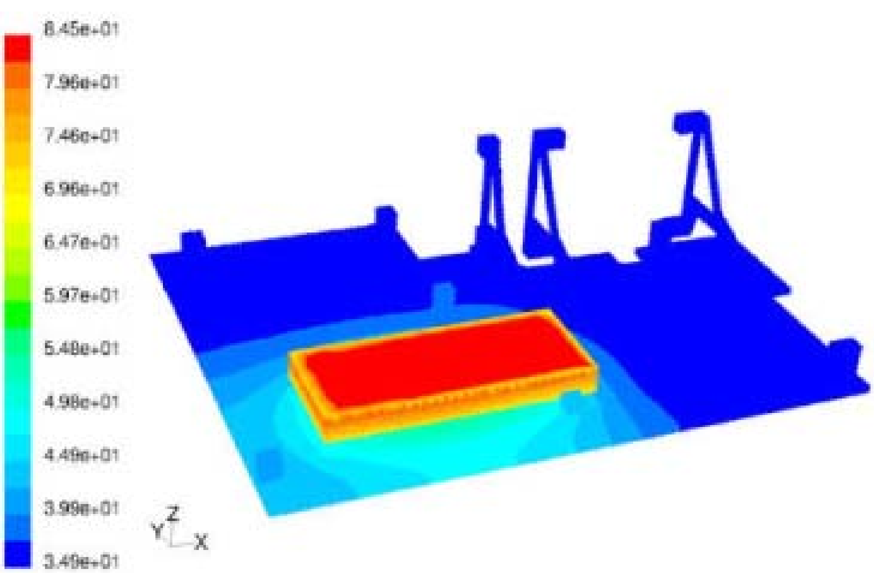

Figure 2: Temperature distribution inside the motor control module

One question facing any engineer who wants to create a virtual prototype is whether to use a general purpose CFD software package, or to use software designed specifically for electronics cooling analysis. The advantage of using software designed specifically for electronics cooling is that it reduces modeling time by providing a library of common electronic components that can be used to streamline the modeling process. The advantage of general purpose CFD software is that it can handle a wider range of geometries and physical models. At Hamilton Sundstrand, engineers use both methods and select the best one for each individual application, based on its operating characteristics.

OPTIMIZING THE THERMAL PERFORMANCE OF A MODULE

In one typical example, the objective was to optimize the thermal performance of a motor drive module for a flap/slat control unit. This product is used to extend the flaps and slats of a commercial aircraft during takeoff and landing, and retract them when they are no longer needed. The module fits inside the wings of the aircraft and includes a powerful motor, with control circuitry that dissipates a large amount of heat. The initial concept design of the module was generated using Pro/ENGINEER computer aided design software. The complexity of the geometry made it desirable to use a general purpose CFD code, so FLUENT, from Fluent Incorporated, Lebanon, New Hampshire, was chosen to construct the virtual prototype. Engineers imported the geometry into GAMBIT, FLUENT's preprocessor, which automatically generated the mesh. Only minor adjustments were required to correct mesh elements with excessive skewness that might impact the accuracy of the results.

The box containing the control module in this example is cooled with forced air driven by a fan. The characteristic fan curve was entered into the CFD model and used as a boundary condition for the analysis, along with the heat sources from the various components. Once completed, the simulation predicted air velocity and temperature distributions within the enclosure. These results were used to select components for the module that are able to withstand the thermal conditions predicted by the analysis. By using CFD, it was possible to select components that were well suited for the application from a thermal standpoint, while it could have taken months and tens of thousands of dollars of hardware prototypes to achieve the same goal using physical testing.

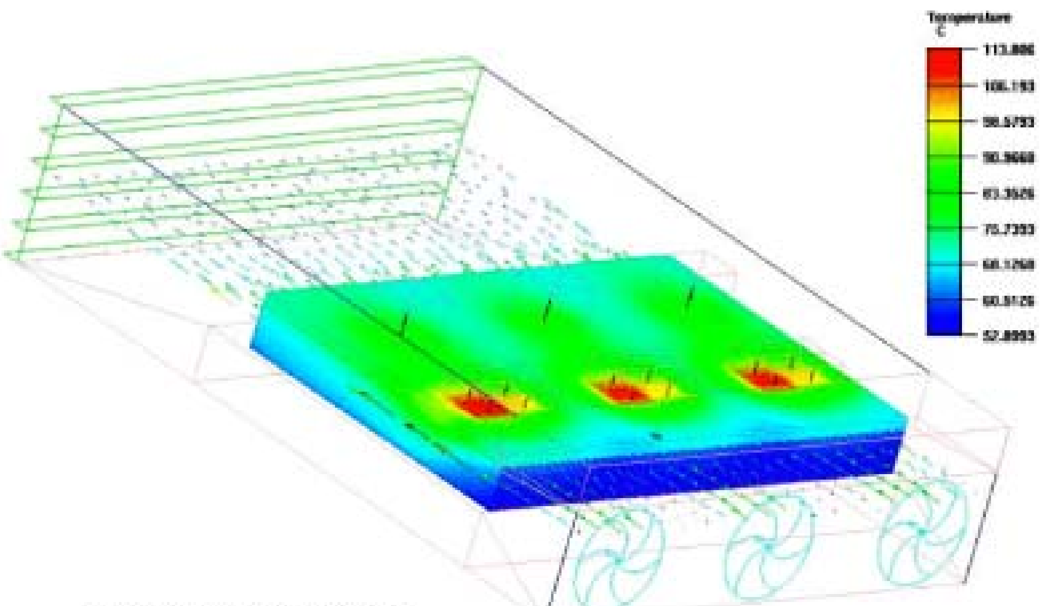

Figure 3: Temperature distribution inside the controller of the EHDU

CFD analysis was also performed on another motor drive module. While similar to the first, the second module uses natural convection as a cooling mechanism rather than forced convection. Because the geometry was again very complex, FLUENT was deemed to be the right thermal analysis tool. Based on the analysis, engineers decided not to reduce the size of the heat sink in the unit, but to utilize the extra mass as heat capacitance to support the natural cooling mechanism.

ELECTROHYDRAULIC DRIVE UNIT THERMAL MANAGEMENT

Hamilton Sundstrand engineers also faced the challenge of designing an electrohydraulic drive unit (EHDU) that includes an integrated 65-kilowatt variable speed permanent magnet electric motor and a 35-gallon per minute (at 3000 psi) hydraulic pump. The highly efficient design of this unit is achieved through a variable speed/variable displacement control strategy, with reliance on design principles adapted from Hamilton Sundstrand's long experience in power systems.

Because the geometry was less complex in this example, engineers used Icepak, another software package from Fluent Incorporated that is specifically designed for electronics cooling analysis. It differs from general-purpose CFD codes in its use of "objects" such as blocks, plates, vents, openings, fans, resistances, and sources. Objects, which are pre-defined 3D solid models, make it easier to generate system-level models. Users simply pick a component and enter its characteristics, such as thermal conductivity or specific heat, rather than modeling it from scratch, as would be done with general-purpose CFD software.

DISSIPATING 3 KILOWATTS WITH FORCED AIR COOLING

The concept design for the EHDU used forced aircooling instead of liquid cooling for a particular application in order to save weight, space, and power. This approach can be challenging from a thermal management standpoint and the initial design showed that a very large heat sink would have been required to maintain junction temperatures at acceptable levels. The Icepak results also showed the existence of recirculation zones that restricted the transfer of heat to the outside of the enclosure. Engineers rearranged the positions of some of the components in order to eliminate these recirculation zones and improve the airflow inside the unit. The changes were so successful that it became possible to use a heat sink only one-third as large as that required by the initial concept design. The CFD analysis also helped engineers select and position the fans. The resulting design was able to dissipate over 3 kilowatts of power without exceeding the maximum temperatures of the electronic components inside the unit.

VIRTUAL EVALUATION OF REPLACING ELECTRONIC COMPONENTS ON A PRINTED BOARD

When it became necessary to replace several components on a printed circuit board of another motor control unit, Icepak was again used to determine the impact of the change on the thermal conditions inside the enclosure. The analysis showed that the additional heat generated by the new components raised temperatures beyond acceptable levels. Several alternative designs were evaluated using CFD, and an effective cooling mechanism was identified and applied to the actual board.

As these examples show, both general-purpose and electronics cooling CFD software can help optimize the design of electronic equipment without the need for prototyping. A key advantage of both software tools is that their postprocessing capabilities make it possible to visualize airflow and heat transfer inside the enclosure. Understanding the behavior of an existing design usually makes it possible to iterate quickly to an optimized design. The net result is a significant reduction in the time and cost required to resolve thermal management issues and bring about performance improvements.

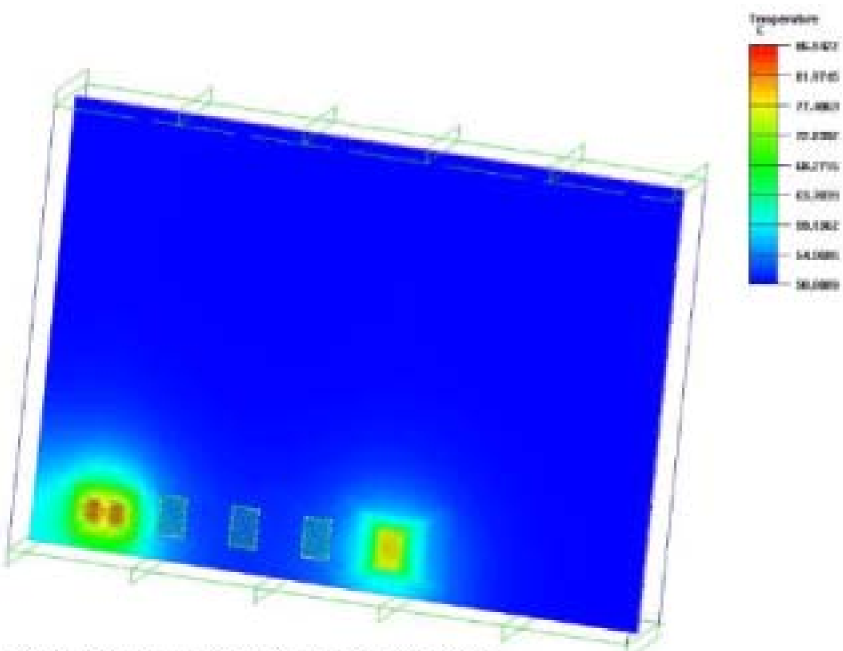

Figure 4: Board temperature distribution in the EHDU