CFD Helps Decrease Ambient Air Entrainment in Ice Cream Freezer by 30%

Researchers at the von Karman Institute used computational fluid dynamics (CFD) analysis to decrease ambient air entrainment in an ice cream freezer by 30 percent, improving the operation of the freezer in hot, humid climates. Previously, the freezer had a problem with frost buildup in these environments. One option for solving the problem was to build and test alternative freezer designs, but the manufacturer ruled that out because of the time and expense involved. Researchers at the von Karman Institute used CFD for this project because it provided a faster method of evaluating multiple designs. Once a CFD model of the problem was created, researchers could quickly change freezer geometry and operating parameters and see how the new design affected airflow and temperature. A series of CFD analyses led to design changes that redirected the flow field to prevent ambient air from entering the freezer compartment.

The von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, is a non-profit international educational and scientific organization, hosting three departments: aeronautics and aerospace, environmental and applied fluid dynamics, and turbomachinery. The institute provides post-graduate education in fluid dynamics and encourages "training in research through research." Created in 1956 following Theodore von Kármán's proposal, it is currently supported with subsidies from most of the member countries of NATO and with additional income derived from contract research. The Environmental and Applied Fluid Dynamics Department, created in 1974, is the youngest department at the Institute. Its activities are related to a wide range of domains such as biological flows, multiphase flows, wind effects on buildings and structures, gas dispersion in the atmosphere, heat transfer, rocket engine fuel supply, for example. Some of the industrial fields in which this department has already been active include: coating processes, continuous casting of steel, pneumatic transport, spray and jet cooling, galvanization of strips and wires, cyclone separators, synthetic fibers, micronization of solid materials, and gas/droplets separation.

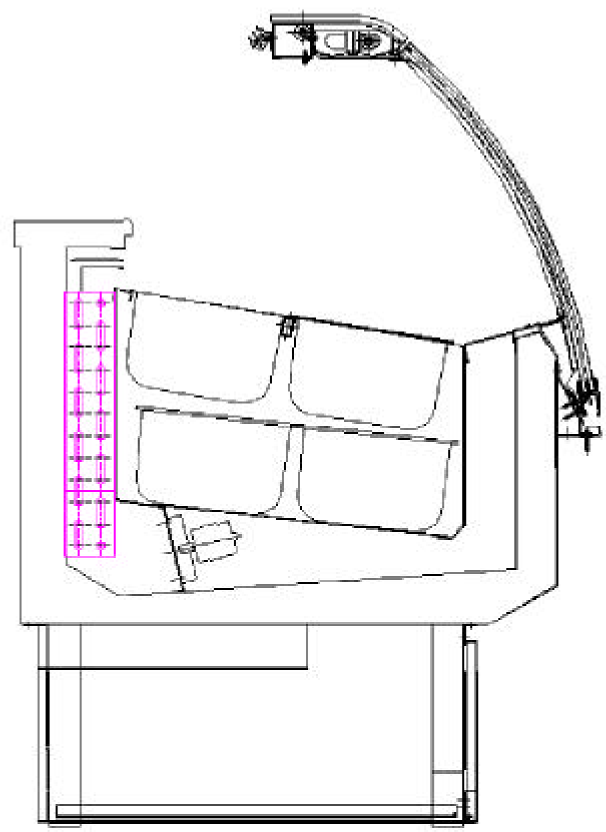

Figure 1: Diagram showing the geometry of the freezer

Problems with frost

Although the ice cream freezer mentioned above performed well in dry, cool climates, the manufacturer contacted the von Karman Institute because they were having problems with the machines in hot, humid environments such as those found in Asian countries. There, when the freezer lid was opened to remove or add ice cream, warm moist air from outside entered the cabinet and formed ice on the heat exchanger. This increased power usage and ultimately required the freezer to be shut down and defrosted. Three different freezer models from the manufacturer were in use at the time and each was having the same problem. The manufacturer asked the von Karman Institute to find ways to alter the design to reduce frost buildup.

The researchers knew that to understand why air entrainment was occurring, they needed to study the flow field within the freezer. "The performance of this type of freezer is deeply linked to the air flow characteristics inside it," says Phillippe Planquart, Research Engineer of the von Karman Institute. "We needed a technique that would allow us to visualize that flow field." Laser Doppler Anemometry (LDA) offered one possibility, since all of the freezer models had transparent walls to allow the customer to see the containers of ice cream inside. LDA uses a two-component differential system with backscattering receiving optics. The flow is seeded by means of a fog generator designed for LDA applications. Although this method would provide the necessary view of the flow field, set up time would be lengthy. LDA requires the installation of a moving optical probe either within or outside the freezer. It also requires making small openings in the metal wall of the freezer for positioning recording devices. The other, more serious limitation is that LDA does not facilitate the evaluation of multiple design options since the freezer must be physically altered for each iteration.

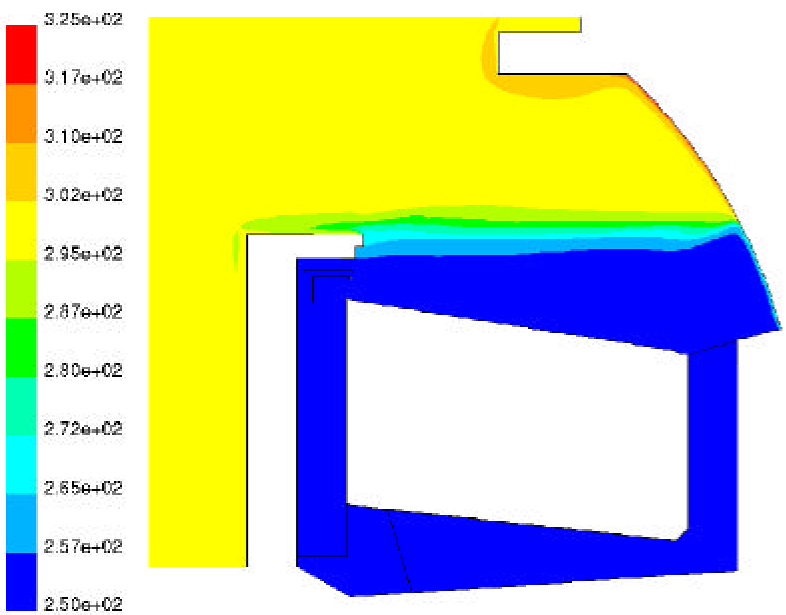

Figure 2: CFD image showing temperature contours in the freezer

The need for a faster and easier way of evaluating multiple designs led the researchers to CFD. "This technology can simulate the performance of different freezer configurations in software, eliminating the need to modify the actual machine," says Planquart. A CFD simulation provides fluid velocity, pressure, and temperature values (and more variables, depending on the simulation requirements) throughout the solution domain for problems with complex geometries and boundary conditions. As part of the analysis, a researcher may change the geometry of the system or the boundary conditions, such as inlet velocity or temperature, and view the effect on the flow field. CFD also can provide detailed parametric studies that can significantly reduce the amount of experimentation necessary to develop a device and thus reduce design cycle times and costs.

The research team chose the FLUENT CFD program from Fluent Incorporated, Lebanon, New Hampshire. "We have used this program for many years and knew it had the capabilities we needed for this project. Furthermore, the vendor provides excellent technical support," says Planquart. "FLUENT has numerous physical models and a robust solver available. It includes a preprocessor that automatically creates the analysis mesh. It also provides several built-in turbulence models to choose from, which appealed to us because of the turbulent nature of the flow field."

Creating the analysis model

Planquart began the CFD analysis by importing the manufacturer's 2D AutoCAD drawings of the three freezers into GAMBIT, Fluent's preprocessor. Planquart defined the computational domain as the interior of the freezer and the ambient air outside it, then instructed GAMBIT to create an unstructured mesh of the geometry. The software scaled the mesh to account for differences in the size of the components being analyzed. For example, it automatically created a very fine mesh around small, critical areas and made the mesh progressively coarser as components grew larger. The mesh had approximately 20,000 cells.

Planquart modeled the freezer's blower using FLUENT's fan model and by means of a polynomial regression of the nominal data for the real freezer fan. The heat exchangers were modeled using the software's radiator model and a porous media. The real freezer had an electrically heated front window to prevent fogging. Since Planquart knew the value of the power supplied to the window, he used a heat flux boundary condition to represent it. Boundary conditions used for the air flow were specified as either pressure inlets or pressure outlets.

Planquart performed a CFD analysis on each of the three existing freezer designs. The results clearly showed the expected cold air stream passing slowly over the containers of ice cream parallel to the shelves. Velocity ranged from just above 0 to 0.3 meters/second. Some cold air rose in the back half of the compartment, allowing ambient air to enter in the front half. The results showed some natural convection resulting from the heated front window. The natural convection propelled air out of the cabinet while simultaneously allowing ambient air to come in.

The CFD results also showed areas of recirculation near the evaporator. "Recirculation there was not good because it increased the velocity close to the front window, pulling in ambient air," Planquart explains.

By studying velocity plots, turbulence diagrams and temperature maps for the three existing freezer designs, Planquart was able to determine which aspects of the freezer could be modified to minimize the entrainment of ambient air. For each new design change he considered, he simply modified the freezer geometry in the preprocessor, had the software regenerate the analysis mesh, and repeated the analysis, using modified operating parameters, if necessary.

After evaluating six different designs, Planquart arrived at a configuration that reduced entrainment by 30 percent. In this design, the size of

Figure 3: A photo of the actual freezer.

the evaporator was increased. That reduced the velocity at the front window and almost completely eliminated the recirculation that occurred there in the existing freezer designs. The shape of the deflectors above the evaporator was changed to keep the cold air flowing parallel to the shelves rather than flowing upward as it had in the previous models. After experimenting with flat and curved front windows, Planquart determined that a curved window was better because it reduced the velocity due to the natural convection caused by the heated window. He also reduced the temperature of the heating element for the window, further reducing the natural convection.

For the manufacturer, the value of having the von Karman Institute do this research was that it gave them a quantitative and qualitative assessment of the existing freezers as well as a new design that would reduce the frost buildup problem. Planquart's design suggestions are now being incorporated into a new freezer model. "Each of their existing freezers was supposed to be an improvement on the previous model, but they had no way of knowing that for sure," says Planquart. "With CFD, we were able to see exactly how the air flowed in the existing models and why entrainment of ambient air was occurring. With that understanding, we were able to come up with a new design that minimized the problem. CFD was the ideal technology for this application because it was easy to try different design ideas."