CLIMATE CONTROL GETS ELEVATED

Extreme temperature and pressure differences outside the aircraft while in flight and on the ground must be accommodated to keep passengers comfortable and safe. Systems-level simulation and detailed thermal analysis are combined to meet industry standards.

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Reliably comfortable and safe commercial air travel requires creating a cabin that is a hospitable in-flight environment throughout a wide range of extreme external climatic conditions. To successfully design a cabin for passenger comfort, a system of aircraft components must work in concert within industry standards for cabin climate control to maintain suitable pressure and temperature inside the plane.

An airliner's environmental control system (ECS) consists of several key parts, including heat exchangers, pipelines, compressors, fans, turbines and a water separator. At a cruising altitude of 30,000 to 40,000 feet, the outside air temperature is around –50 C to –60 C (–58 F to –76 F) and the pressure is 0.3 atm to 0.2 atm (4.2 psi to 2.9 psi). These conditions are much too low for traveler safety and comfort, and must be raised inside the cabin. To do this, several systems must effectively work together. For example, in a two-wheel ECS system, hot high-pressure air bled from the engine is cooled by ram air in a heat exchanger. A compressor then further pressurizes the air to reach the desirable pressure but at a high temperature. The hot air is cooled again in the main heat exchanger and, after passing through a turbine, the air temperature is cooled to the required cooling temperature and a suitable pressure. The cooling process leads to water vapor condensation so the condensed water is removed by a water separator. Finally the cool air mixes with the filtered return air from the cabin to deliver a suitable temperature and pressure. The ECS then distributes air from the mixing manifold to the cabin to remove heat in cabin air produced by passengers, crew and equipment, and to maintain a pressure in the cabin similar to that at around 6,000 feet above sea level.

SYSTEMS SIMULATION

For the benefit of ECS designers, it is important to understand the interaction of these components before testing them during an actual flight. Researchers at Tianjin University in China and Purdue

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▲ The MD-82 aircraft and GAC system used to heat or cool the cabin on the ground

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University in the U.S. have been investigating the behavior of an ECS using both systems-level and computational fluid dynamics (CFD) simulation tools from ANSYS. The two universities work together using ANSYS software to study the problems related to human health, safety and comfort in the field of transportation. Aircraft manufacturers such as Boeing and the Commercial Aircraft Corporation of China (COMAC) are members of the Cabin Air Reformative Environment (CARE) consortium, as is ANSYS. The universities' work supports CARE goals.

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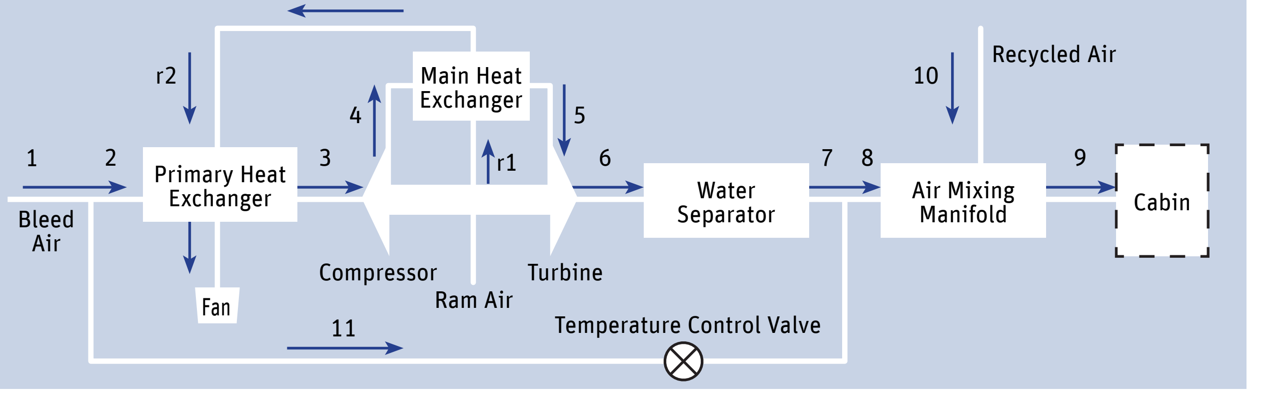
At the overall system level, the cabin thermal environment is regulated by a temperature controller, in which feedback signals from the cabin are used to modify the flow rate of the supplied engine bleed air. The controller contains proportional–integral–derivative (PID) logic, which the research team implemented into a systems-level model using the built-in PID module in ANSYS Simplorer. At the detailed level, the team created a 3-D model of the first-class cabin of an MD-82 jet in ANSYS Academic Research CFD (ANSYS Fluent) software using geometry obtained from a laser tracking system and employing a mesh with 6.4 million cells.

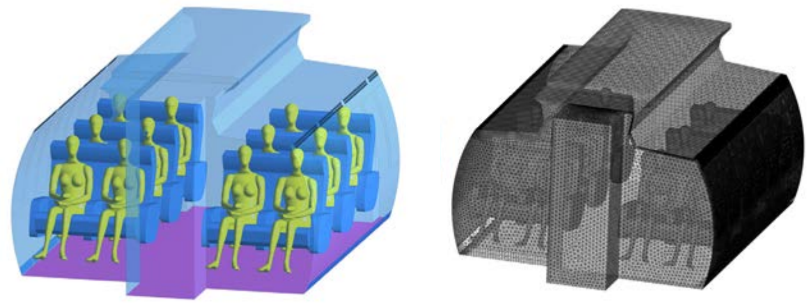
Researchers then coupled the Simplorer and Fluent models to analyze the transient impact of the ECS on the cabin thermal environment. During the coupled simulation, Simplorer predictions of the air temperature supplied to the cabin provided boundary conditions to the detailed CFD cabin model. CFD predictions of temperature at various cabin locations were compared to the desired temperature set point, and any deviations directed the temperature controller to adjust the flow rate of engine bleed air. This flow rate was a new boundary condition for the Simplorer ECS model, and iteration proceeded to completion.

GROUND-BASED CLIMATE CONTROL

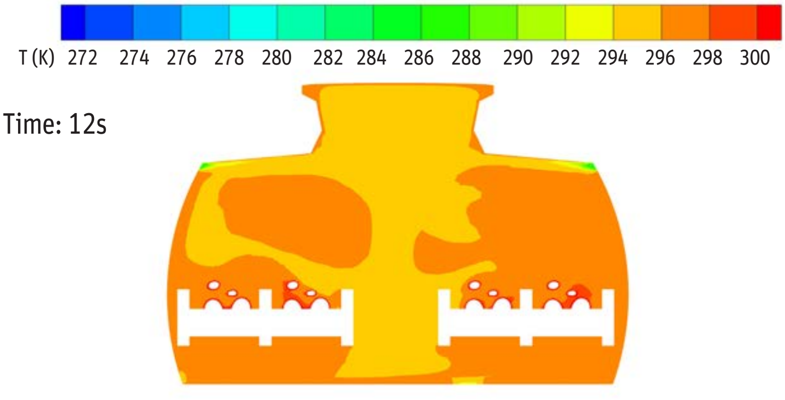
Prior to modeling the ECS, however, the team needed to evaluate the effectiveness of simulation on a climate-control system that did not require them to physically conduct in-flight testing. The first step was to analyze the ground air-conditioning cart (GAC) system, in which a mobile vehicle pipes outside air into the plane while it is idle at the airport. The GAC contains a heating coil, a cooling coil and a centrifugal fan that can heat the cabin in cold months and cool the cabin during warmer months. The team followed a similar process to build a systems-level model of the GAC in Simplorer, and then coupled it to the CFD model of the MD-82 cabin.



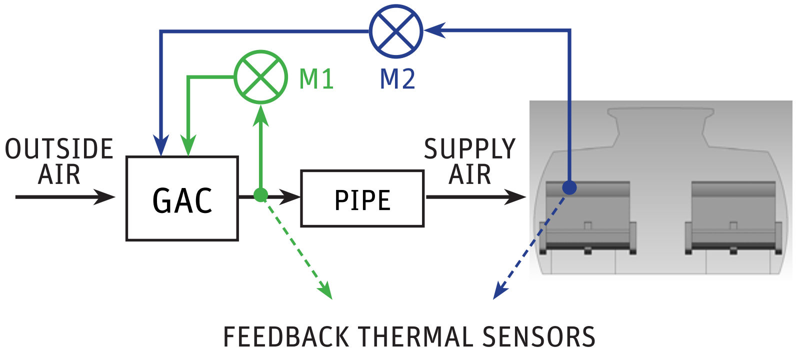
▲ Process diagram of airflow from the engine into the cabin through the components of the ECS



Geometry (left) and mesh (right) for the CFD model of MD-82 first-class cabin



Detailed ANSYS CFD predictions of temperature within the cabin during the initial taxiing stage of a simulated flight on a hot day



Process diagram of airflow from the external environment into the cabin through the GAC system. M1 and M2 represent the locations of two different temperature controllers being studied.

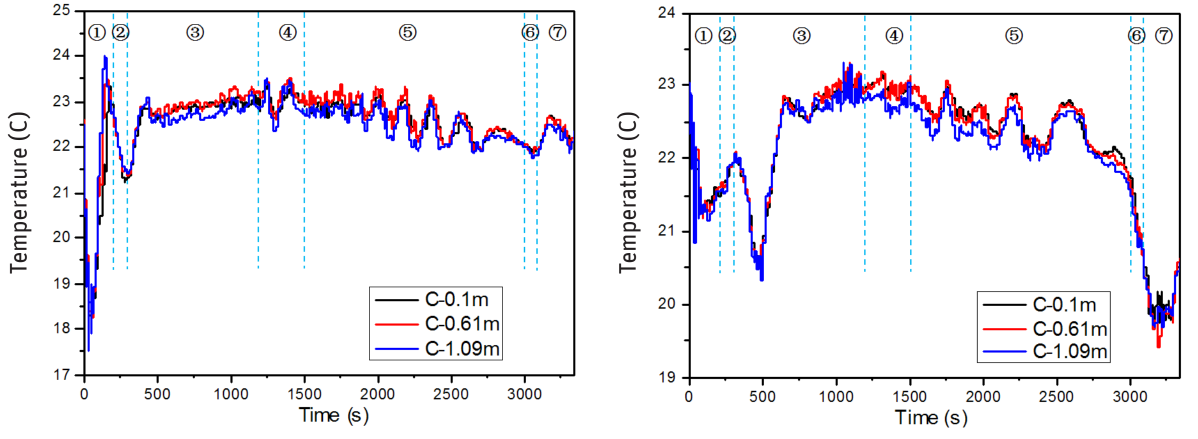
Researchers evaluated the impact of different locations for the sensors sending data to the PID modules controlling flow. The first temperature feedback location studied was at the GAC outlet pipe sending air into the plane, while the second location was inside the cabin at passenger breathing height. Air temperature and velocity test data measured from an MD-82 cabin in Tianjin during January and June — with respective outside temperatures of about –5 C (23 F) and 35 C (95 F) — agreed closely with predictions made by the Simplorer GAC system model and the detailed CFD cabin model. The results helped the team learn that locating temperature feedback sensors closer to passenger seats provided more uniform temperature distribution at different heights within the cabin.

IN-FLIGHT CLIMATE CONTROL

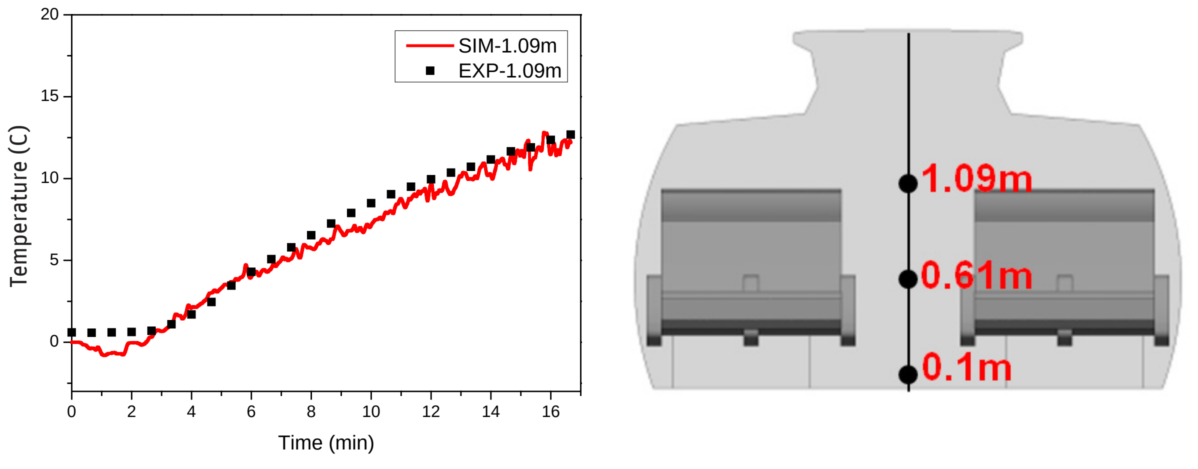
Having developed and validated this simulation procedure, the research team then used the coupled Simplorer–Fluent analysis to simulate ECS behavior for conditions that a commercial aircraft would encounter during the typical seven stages of a short flight. These conditions included a four-minute taxi on the runway, one minute for takeoff, 15 minutes of climbing, five minutes of cruising, 20 minutes descending, 40 seconds for landing, and five minutes to taxi back to the gate. Simplorer predicted the changing mass flow rate of engine bleed air required to keep the cabin at the desired temperature set point of 23 C (73 F) during all seven flight stages. As expected, CFD simulations predicted that the in-flight cabin air velocity and temperature would fluctuate more when it is hot at ground level because of the larger temperature difference between the ground and the flight altitude.

Over the course of seven different coupled simulations of GAC and ECS cases, the team typically completed model setup in Simplorer and Fluent

The researchers coupled ANSYS Simplorer and ANSYS Fluent models to analyze the transient impact of the ECS on the cabin thermal environment.



▲ ANSYS Simplorer predictions for air temperature in the cabin for the seven simulated flight stages on cold (left) and hot (right) days. These results indicate that the control strategy should produce reasonably uniform temperatures at different heights within the cabin over the flight duration.



▲ ANSYS Simplorer predictions for air temperature in the cabin being heated by the GAC system in January compared well to experimental results measured at different heights inside the cabin.

in about four hours. Simplorer models ran very quickly, while a typical highly detailed transient CFD analysis of cabin airflow during simulated flight conditions required about 60 hours running on 32 processors. Work is continuing to implement a reduced-order model (ROM) representation of the ANSYS Fluent CFD model of the cabin so that overall system simulation time can be drastically reduced without sacrificing the accuracy of the simulation output.

The Tianjin and Purdue team shared its findings with researchers at Boeing and COMAC through the CARE consortium. Early indications are that these manufacturers will be setting up their own virtual platforms for simulation of future ECS designs. Future experimental validation of the team's ECS predictions done in collaboration with CARE industry partners is also on the horizon to help further elevate the performance of such aircraft systems.

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