Plane Digits

Bringing computer technology to wind tunnel testing

By IVARS PETERSON

Sporting enormous twin engines, each one wide enough to engulf a tractor trailer, the giant Boeing 777 is now in the midst of a year of intensive, rigorous testing before going into service as a commercial jetliner.

Computers played a significant role in the design and construction of this new aircraft. For example, Boeing's introduction of an innovative digital design system meant that blueprints, drafting tables, large mockups, and bulky plaster models practically disappeared from the plant floor.

Boeing engineers used their elaborate computer system to visualize in detail exactly what the plane would look like and how its components would fit together before workers cut the first sheet of metal. They even identified a number of situations in which maintenance mechanics would have difficulty making repairs. Basing their decisions on these digital auditions, they made the necessary design changes before it became too costly to modify the plane.

***A**n engineer makes a measurement on a model of an experimental supersonic transport. The model is coated with pressure-sensitive paint, giving its surface a pink color.*

At an earlier stage, extensive computer simulations of air flows over the aircraft's surface helped shape its fuselage and wings. Using the results, engineers fine-tuned the plane's shape to improve its flight characteristics.

However, despite dramatic progress in computational fluid dynamics over the last few years, Boeing could not rely on computer simulations alone. Models of the aircraft still had to be tested in wind tunnels.

A decade ago, some supercomputer proponents had predicted that high-speed number crunchers would eventually make the wind tunnel obsolete (SN: 9/29/84, p.200). Today, although computational aerodynamics has greatly expanded its role in aircraft design, wind tunnels show no sign of disappearing.

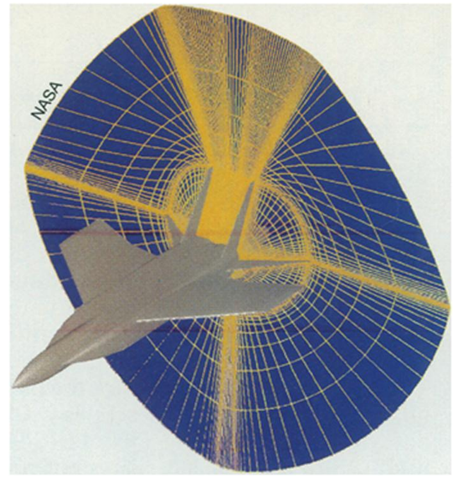
"Neither computational fluid dynamics nor the wind tunnel by itself gives the right answers," says Michael W. George, chief of the design cycle technologies branch of NASA's Ames Research Center in Mountain View, Calif. Aircraft designers need both, he asserts.

This realization has prompted a new effort to integrate the computational side of aircraft design and wind tunnel testing. "The emphasis is on saving time — developing an aircraft as quickly as possible," George says. This means using wind tunnels more efficiently and effectively.

"There is a definite need for a revolution in wind tunnel testing," agrees Robert M. Kulfan of the Boeing Co. in Seattle.

The IofNEWT (Integration of Numerical and Experimental Wind Tunnels) project at NASA Ames incorporates several innovations. They include the use of a special paint that senses pressure on wind tunnel models, new techniques for data management and visualization (SN: 1/4/92, p.8), and remote communications to enable users anywhere in the country to monitor wind tunnel tests.

"We need to bring the numerical and experimental aspects together," says Dennis J. Koga, head of the IofNEWT program.



***C**omputational study of drag on a twin-engine fighter.*

NASA Ames operates a wide range of wind tunnels, including the largest in the world. This behemoth can accommodate a full-sized 737 aircraft. But it's expensive to run, drawing enough electric power to supply a small city.

Other, smaller wind tunnels at NASA Ames, some equipped for supersonic wind velocities, are heavily used for testing aircraft components or scaled-down models. Over the last 30 years, nearly every major commercial and military aircraft produced in the United States has gone through one or more of these installations.

At the same time, NASA Ames has maintained a strong program in computational fluid dynamics, developing computer software for calculating aerodynamic flows and visualizing data. Its National Aerodynamic Simulation facility serves as a center for research on the use of supercomputers to solve aircraft design problems.

Traditionally, the computational and experimental teams have operated somewhat independently, with relatively little direct interaction between those running wind tunnel tests and those computing aerodynamic flows. Although both approaches are vital to modern aircraft design, each has inherent disadvantages.

Wind tunnel tests are time-consuming and expensive. It can take up to a year to construct a scale model and incorporate the instrumentation necessary for measuring pressure and other parameters affecting performance.

Moreover, a wind tunnel's walls affect air flow, as does the model's scale. It's difficult for a wind tunnel to match precisely the conditions a full-scale aircraft would encounter flying through the air.

In the case of computational fluid dynamics, researchers have greatly improved their simulations in the last few years to achieve reliable results. However, they still have great difficulty handling turbulence and providing detailed simulations of three-dimensional air flows around complicated shapes.

"Computers are still not big enough or fast enough to do the complete job," says Bobby L. Berrier of NASA's Langley Research Center in Hampton, Va.

"We've had some people pushing computation and others pushing wind tunnels," Koga says. In IofNEWT, "we wanted to see if we could use the tools that we have more effectively by really working to combine them."

In this way, computation could be used in conjunction with experimental results to correct for wall effects, unnaturally stiff aircraft wings, and other deficiencies skewing wind tunnel tests, and test data could be used to calibrate and improve computational models.

The trick is to collect more data than previously possible during wind tunnel tests, use computers to analyze these measurements while the tests are still running, provide comparisons with numerical models to pinpoint the physics underlying the behavior observed in the wind tunnel, and promptly transmit the information to off-site engineers.

To gather more complete data about aircraft performance from wind tunnel tests, researchers have turned to a new type of paint that responds to pressure. By evenly coating the model's surface with this material, they can map the pressure exerted by air on all parts of the aircraft.

In the past, engineers had to rely on a fixed number of pressure sensors installed at various points on a model's surface. Because the coverage was necessarily incomplete, they found it hard to compare these point measurements with the pressure contours that come out of aerodynamic calculations.

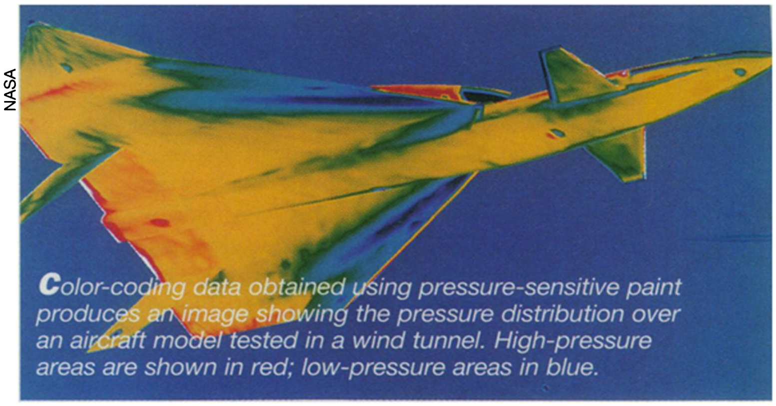
"It's also very expensive to put these pressure taps in a model, and it takes a lot longer to build the model," Berrier says. "Pressure-sensitive paint gives you lots more information at a lower cost."

Several groups throughout the world have experimented with a variety of materials to serve as pressure indicators. The IofNEWT project uses a paint developed at NASA Ames and the University of Washington in Seattle.

This proprietary paint consists of molecules sensitive to the pressure of oxygen. Sprayed on a model's surface and illuminated by ultraviolet light, it fluoresces a pink color. Because the intensity of the color depends on the pressure, measuring variations in intensity provides a pressure map of the model's surface.

"A lot of people are looking toward the day when they can compare an experimental picture made using pressure-sensitive paint with the [computational fluid dynamics] picture generated by computer codes," Berrier says. "The paint works, but the question is whether you can make it accurate enough to be acceptable."

In general, paints that respond to pressure are also somewhat sensitive to temperature, which can alter the results. Moreover, the quality of the results often depends on how carefully the paint is applied. "All these issues need to be worked out before it's going to be accepted as a real tool," Berrier contends.



NASA

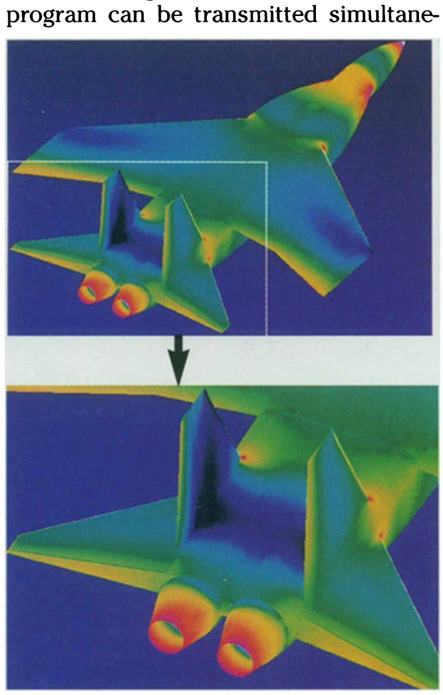
Color-coding data obtained using pressure-sensitive paint produces an image showing the pressure distribution over an aircraft model tested in a wind tunnel. High-pressure areas are shown in red; low-pressure areas in blue.

Researchers at NASA Ames and elsewhere are also experimenting with techniques such as infrared thermography to map temperature variations and particle tracking to monitor air flows. "The different techniques give us different types of information," says Pieter G. Buning of NASA Ames.

All of these techniques generate huge quantities of data. Researchers are developing ways of rapidly storing, retrieving, visualizing, and analyzing these data to convert them into usable knowledge for aircraft designers.

The Remote Access Wind Tunnel (RAWT) represents one piece of this evolving information infrastructure. This capability, now in testing, enables users in various parts of the country to monitor wind tunnel tests as they happen. Users also gain access to the supercomputers at NASA Ames.

Thus, experimental results and other information generated in the IofNEWT program can be transmitted simultaneously and shared by wind tunnel personnel and off-site customers. One recent test of the system involved NASA Ames, Boeing in Seattle, and McDonnell-Douglas in Long Beach, Calif., and it proved quite successful.



NASA

NASA

Computed pressure contours for a twin-engine fighter.

"The idea has really caught fire now," Koga says. "Companies are saying that [the RAWT] can really revolutionize the way they conduct [wind tunnel] tests."

For example, aircraft manufacturers would no longer have to send a full team of engineers to the facility at Ames for test runs. "They can quite easily eliminate two-thirds of the staff that comes down here," Koga says.

However, several issues — such as data security — await resolution. "We have to find a way to get information through efficiently without compromising a company's computer security system," Koga says.

Initiated in late 1993, the IofNEWT approach is having some success. Boeing participated in about 10 system tests last year and may run as many as 25 tests, involving several aircraft design projects, this year.

"The IofNEWT program is an exploratory one just to see if it can be done," Berrier comments. "If the Ames effort is successful, I'm sure you are going to see it expanded to a lot of different places, not only in NASA but also in industry."

Koga and his team are already looking toward the next generation of IofNEWT. "We are starting to build the framework for incorporating computational and experimental innovations as they get developed down the road," he says.

In other words, it's no longer just a matter of making more efficient use of wind tunnel time. The new effort aims at increasing the use of computational fluid dynamics and other tools in the early stages of an aircraft's design to cut down the number of wind tunnel tests necessary to validate a design.

"It's important to make the right decisions early," Boeing's Kulfan says. "You need to be able to rapidly explore options to see what is best."

Yet despite all these advances, one truism still holds.

Computation and wind tunnel tests set the stage and, if all goes well, increase a new design's chance of success. But the actual flight test determines the ultimate outcome. □