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SAVING AMERICA'S AGING AIRLINE FLEET: COMPUTER-AIDED TECHNIQUES HELP UNDERSTAND DAMAGE; NEW ALLOYS MAY PREVENT FLAWS

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As airlines prepare to spend millions of dollars to remedy potential structural problems in their aging aircraft, researchers are developing new computer-aided techniques for understanding structural damage mechanisms -- and new aluminum alloys that are lighter and less susceptible to failure.

At the Georgia Institute of Technology, materials engineers are using computer-aided tomography (CAT) -- developed to help doctors peer inside the human body -- to look inside aircraft component materials. Other Georgia Tech researchers are developing improved aluminum alloys and better fabrication procedures which may reduce the problems of fatigue and corrosion failure in future aircraft.

FINDING HIDDEN FLAWS

Most failures in aircraft structures result from fatigue caused by cycles of use: repeated pressurization and de-pressurization of an airliner's cabin or the constant flexing of its wings in flight. That fatigue initiates development of tiny cracks, which can grow in size to jeopardize the strength of key components.

Corrosion also affects aluminum alloys, causing surface pitting which can also initiate fatigue cracks. Fatigue problems worsen with the number of use cycles, while corrosion is a factor of time and the environment in which the aircraft is used. Both can work together to weaken an aircraft's structure.

"There is a negative synergism," said Dr. Stephen Antolovich, director of Georgia Tech's School of Materials Engineering. "When a little bit of corrosion forms, you will have created conditions for fatigue to take place more easily. What happens when you have interactions between fatigue and corrosion is that cracks propagate faster."

To help detect and understand those processes, Antolovich, Dr. Stuart Stock and other researchers in Georgia Tech's Mechanical Properties Research Laboratory have been using computer-aided tomography (CAT) to look at the internal structure of materials used in aircraft components. They believe the non-destructive technique will give them a better understanding of the complex processes which induce failure -- and lead to strategies for preventing it.

"You can actually get a physical picture of what is happening internally," Antolovich explained. "Conventional inspection techniques rely on surface examination and conventional X-ray techniques rely upon interpretation of a signal, but we really get a visual picture of the three-dimensional defect structure."

The technique, which can use synchrotron radiation, is applicable to all types of materials, including metals, ceramics, polymers and composite materials.

"The physical picture we get in a direct way is excellent for revealing damage, and it also greatly aids our understanding of the mechanisms of damage -- and helps in predicting how it will evolve in time or cycles," he added.

The technique produces resolution a hundred times better than medical scanning techniques, Stock said, though it can view only millimeter-sized samples. Data gathered by passing X-rays through the sample is analyzed section by section on a large computer. The resulting images can be further manipulated by a Pixar animation computer to show the damage defects in three dimensions.

The research is being conducted in collaboration with Dr. John Kinney at Lawrence Livermore Laboratories and a research team at the University of Dortmund in West Germany. Results were presented to the annual meeting of the American Metallurgical Society in February in Las Vegas, NV.

Aluminum alloys in use today resist cracking, and the cracks that eventually develop grow at a predictable rate. Airlines now rely on periodic inspection to find early-stage cracks before they grow to a critical size that might endanger the aircraft.

But with two recent structural failures, the U.S. Air Transport Association recently recommended repairs and replacement for crack-prone components in nearly all popular airliners.

EACH AIRCRAFT HAS ITS OWN NEEDS

But Antolovich cautions that because of the cyclical nature of fatigue and importance of environment in corrosion, each aircraft should be considered independently in prescribing remedies.

"Every aircraft is a different animal, because it flies under different conditions," he explained. "Some fly in different environments such as over salt water. Some carriers fly long distances, but with relatively few cycles. All of these factors must be taken into account."

With proper maintenance and inspection, however, he believes older aircraft can safely remain in service well beyond the time originally envisioned by their designers.

"The airlines themselves need to be monitoring their fleets very carefully," he cautioned. "They need to have in-house experts in the areas of damage analysis, life prediction and nondestructive inspection."

In addition to corrosion and fatigue, structural problems can also result from improper maintenance techniques, Antolovich warned. In 1982, cracks caused by improper maintenance allowed an engine to break off a DC-10, causing a crash that killed all aboard. Military crashes have resulted from unauthorized changes in engine air flow which led to vibration and failure in engine components, he noted.

Because they operate at high temperatures and in corrosive environments, aircraft jet engines have been subjected to stringent inspection for years. Antolovich believes airframes now need to receive similar scrutiny.

NEW ALLOYS WILL BE STRONGER, LIGHTER

For years, aircraft designers have worked with the same basic set of aluminum alloys. Because of their long experience with them, designers know the materials' strengths and how resistant they are to damage.

Metallurgists are now developing a new generation of alloys that will be stronger, lighter and more damage resistant than current materials. And through better understanding and control of the manufacturing processes, these new materials will better retain their attributes.

"It's not that the alloys used on commercial airplanes are inferior, it is simply that we can produce better materials," said Dr. Thomas Sanders, professor in Georgia Tech's School of Materials Engineering.

During the 1970s, the OPEC oil embargo and rising fuel costs prompted a search for lighter materials to reduce fuel consumption. Among the results were alloys of aluminum and lithium which promise significant fuel savings.

"With the addition of alloying elements such as lithium, you can see a ten percent reduction in weight. That's pretty substantial over the life of an airplane," Sanders noted.

New alloys will also help improve the performance and damage tolerance designers can build into aircraft. Those are particularly important to U.S. military agencies, whose pilots must push their aircraft to the limits of their capabilities.

"For the military, there are issues of density and high temperature stability, because these aircraft move at fairly high velocities," he explained. "The military is really pushing for performance."

Regardless of their other characteristics, however, any new alloys must prove themselves through years of testing -- and retain their resistance to damage.

TAILORING MATERIALS TO THEIR USES

Sanders believes aircraft may eventually be constructed of a large variety of aluminum alloys, as well as new composite materials. The material characteristics could be carefully chosen to meet the needs of the individual components.

Moving a promising new alloy from the laboratory to manufacturing facilities can be difficult, however.

"You can't control things in production nearly as well as you can control them in a lab," Sanders noted. "In a lab, you test perhaps 200 pounds of material, but in production you are manufacturing several thousand pounds every day. Because everything is much larger, things like heat transfer become a problem."

The final properties of aluminum depend on such factors as the crystalline structure and the porosity of the metal, which depend largely on the manufacturing process. Sanders is attempting to optimize manufacturing through precise control of factors such as temperature, solidification rate and processing speed.

But for aluminum-lithium alloys, one important stumbling block remains. Lithium cannot be used in beverage cans, so the aluminum industry will have to keep the alloy out of aluminum scrap being recycled for that purpose.

The work on aluminum alloys has been sponsored by the U.S. Navy and Alcoa Aluminum. Data on Sanders' research was presented in March at a conference on aluminum-lithium alloys in Williamsburg, VA.