ABOUT TO CRACK

SBIR-SUPPORTED SOFTWARE PREDICTIVELY PREVENTS FRACTURED ENGINE COMPONENTS

On July 19, 1989 in the cornfields over Sioux City, Iowa the tail engine of United Airlines Flight 232 exploded with 296 people on board.

Flying debris cut the lines for all three hydraulic systems on the DC-10, leaving the pilots unable to steer. As the plane looped downward, the desperate pilots idled the left engine and applied full power to the right in a crude attempt to stabilize it.

As the plane came in for a crash landing at Sioux Gateway Airport, the tip of its right wing hit first, spilling fuel and starting a terrible fire. The tail section snapped off at impact and the fuselage rolled and broke into several pieces, some coming to rest upside down. One-hundred and eleven passengers died. Miraculously, 185 survived.

Investigators determined that the cause of the explosion was a fan disc in the engine that had disintegrated from a fatigue crack, which inspectors had missed. Predictively pinpointing the exact locations in engine parts most susceptible to cracks in order to prevent such tragedies became the mission for a company founded in 1988 called Fracture Analysis Consultants, Inc.

"We are still 'small,' but we have a big impact in our field," said company president Anthony R. Ingraffea.

FRANC3D stands for Fracture Analysis Code 3D. Its prototype software began at Cornell University in Ithaca, New York. There, Ingraffea, now a professor emeritus of civil and environmental engineering, created a division called the Cornell Fracture Group. According to its website, the mission of its research is to, "increase the standard of living across the globe by enabling better performing, lower cost, and more sustainable technologies." Its main focus is research on engines.

"Engine components present some of the greatest challenges for modeling crack growth of any engineered structures," Ingraffea said. "Turbine blades and disks are among the most geometrically complex manufactured artifacts."

FRANC3D gives engineers and researchers new ways of seeing the effects of fretting fatigue. Fretting fatigue occurs when two surfaces are clamped together and are then moved in a way that causes sliding contact, such as in the joints where turbine blades meet disks. By simulating the cracks that can develop, FRANC3D allows aircraft operators to better know when critical parts could break down. In the Air Force, such parts are known as "fracture critical components."

"This means that if these components fail in flight, the aircraft could be lost," explained Patrick Golden and Reji John, who work in the research laboratory at Wright-Patterson Air Force Base in Ohio.

In a joint email, they said that FRANC3D allowed aircraft part manufacturers and operators alike to, "better predict the safe service life of these fracture critical components so that the components can be inspected and/or replaced, ensuring safety and planning maintenance schedules."

With the support of Air Force and Navy SBIRS in 2006, FRANC3D has evolved into a newer program known as FRANC3D/NG (for "next generation"). Ingraffea said it has been

made to work in tandem with commercial finite element simulation software, especially the popular ANSYS, from a company based in Pennsylvania. The finite element simulation software makes computer models of structures and it imprints onto them a geometric grid pattern known as a mesh. Also, it then analyzes this mesh and color-codes it to illustrate the areas of highest stress.

FRANC3D takes those models, complete with mesh and color codes, and inserts cracks into them. Using custom algorithms, FRANC3D shows researchers how the cracks behave; the stresses that cause them, the stresses that they cause, the velocity of their growth, and at all different stages.

"FRANC3D uses this information to predict how the crack will evolve," Ingraffea said.

The result is the best, most scientifically-detailed pictures of potential cracks on earth. With its latest SBIR project, another Air Force SBIR begun in 2011, Fracture Analysis Consultants investigated four separate cracking incidents on test engine programs. The investigations were done on the F119 and F135—both military afterburning turbofan engines—plus one commercial engine. Working with actual engine parts is vital to check and calibrate the calculations of FRANC3D, Ingraffea said.

"Our decisions to fund the continued development of the software through the SBIR contracts speaks to our support of the tool," Golden and John said in an email.

Ingraffea said that Fracture Analysis Consultants have been the main contractor or a participating subcontractor on multiple SBIR projects dating back to 1990.

"Early on, each new SBIR allowed us to gain knowledge, follow the trends in software design, languages, and every-growing computer capabilities, while also building a network of contacts throughout the industry and the DOD," he said.

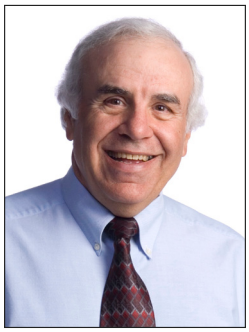
With every incarnation, FRANC3D has improved to show how cracks behave under an array of pressures, vibrations, rotations, fatigue spectra, and temperatures. Ingraffea described FRANC3D as working "in symphony" with existing finite element simulation software, like ANSYS. An advantage of FRANC3D's niche, he said, is it can be put to use with minimal instruction, at the same work station, which makes it a "value added proposition."

"Staff familiar with that software have no difficulty using FRANC3D," he said. "We have, at relatively small additional expense, added substantial additional purpose capability."

> "The SBIR program enabled FAC to develop software that is now being used around the world."

Golden and John added that the ability for FRANC3D to work with existing software "without extensive redevelopment of the component models" is "one of the best things" about it.

FRANC3D is used in more than 70 universities around the world, Ingraffea said, putting it in a position to, "help educate new generations of engineers." In addition, it is used by corporate clients in multiple countries including Pratt and Whitney, NASA Langley, Rolls-Royce, Air Force Institute of Technology, U.S. Naval Academy, Corning, Inc., Cummins, Toyota, Honda Jet, Kawasaki Heavy Industries and Mitsubishi Heavy Industries.



Tony Ingraffea

"The SBIR program enabled FAC to develop the FRANC3D software into an entity that is now being used commercially around the world," he said. "Eventually, over the last decade, it allowed us to transition to what we are today: a state-of-the-art special purpose software vendor and support company."

Fracture Analysis Consultants, Inc. • Ithaca, NY

Modernization Priority: General Warfighting Requirements (GWR)

SBIR contract: N68335-08-C-0011 • Agency: Navy • Topic: N06-126, Fretting Fatigue Modeling and Life Prediction

SBIR contract: FA8650-07-C-5216 • Agency: Air Force • Topic: AF06-095, Three-Dimensional Nonlinear Structural Analysis Methods for Gas Turbine Engine Metallic Components and Component Assemblies

SBIR contract: FA8650-12-C-5111 • Agency: Air Force • Topic: AF103-157, Three-Dimensional (3-D) Crack Growth Life Prediction for Probabilistic Risk Analysis of Turbine Engine Metallic Components