Stanford engineers put a damper on 'aeroelastic flutter'

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(PhysOrg.com) -- Anyone who has ever flown knows the feeling: an otherwise smooth flight gets a little choppy. If you are lucky, the plane skips a few times like a rock across a pond and then settles. For the not-so-lucky, the captain has turned on that seatbelt sign for a reason, but even the worst turbulence usually fades.

In certain rare situations, however, those vibrations don't settle and the consequences turn dire. The twisting, up-and-down movement in the wing builds upon itself, each wave compounding the next, until the vibration worsens and the wing is ripped from the plane. In an instant, a simple bit of turbulence becomes a matter of life and death.

Aeronautical engineers know it as "aeroelastic flutter." Pilots call it "buzz."

Complicated stuff

Aeronautical engineers have puzzled over the phenomenon as long as there have been planes. They made their planes better. They built them of new materials. They used supercomputers to predict when it might occur. But, try as they might, they could not absolutely eliminate aeroelastic flutter.

Professor Charbel Farhat, chair of the Aeronautics and Astronautics Department at Stanford's School of Engineering, and David Amsallem, a postdoctoral scholar who worked on his PhD thesis with Farhat, have been studying and trying to solve aeroelastic flutter for years. Computers help, but only to a point.

Listening to Farhat is a bit like flying. He talks quickly with great expression, piloting the listener through his world, swooping from idea to idea in great arcs like a stunt plane, always on the edge of control. He is a barnstormer. Amsallem, the mild-mannered mathematical whiz behind it all, smiles gently, tossing in a French-accented word of clarification here and there.

"This is complicated stuff. It takes today's fastest computer an hour to calculate the aeronautical effect of even a small change in a single variable," said Farhat, his voice rising to deliver the word "today's" as if to reinforce that we are not talking about some mid-century mainframe here. "Imagine a plane in flight and you'll quickly grasp that there are hundreds of variables. Now, imagine the rate of change in those variables for an F-16 at full throttle."

Each incremental shift in pitch of the wing, every inch of altitude, every variation in speed, each milliliter of fuel added or burned sloshing back and forth in the tank are equally at play – alter one, you alter the entire system. And each time you alter the system, the supercomputer starts back at go, computing anew – that is, if you can get time on the supercomputer.

"Now you begin to understand. This is complicated stuff," Farhat said. At this point in the conversation, the professor leaned in. His eyes narrowed and his tone grew serious. "We can now predict flutter in real time … on an iPhone." Someday, he predicted, airplanes will have chips on board that will sense and counteract flutter in real time.

The work has caused a sensation in the aeronautics field. When Farhat and Amsallem presented their paper at the Army Science Conference recently, the crowd of aeronautical old hands sat stunned as the two did a live demo of their work on an iPad.

Farhat chose the iPad over a smaller device, he said, not for processor speed – their innovation works fine on an iPhone, he assured – but for pure visual impact: It looks better on an iPad.

The seat of your pants

Over time, aeronautical engineers have been able to "engineer" flutter to a point of virtual oblivion – emphasis on virtual. It is now only a remote risk.

"But, there are instances when even the smallest of risks is too great a risk," Farhat said.

For instance, when you are a fighter pilot in the saddle of a $60 million F-16, one of the fastest, most agile fighter planes ever developed. F-16 pilots – and their planes – regularly endure forces many times that of gravity. A little turbulence can be a big deal. Each time the wing starts to bounce, no matter how slight the bounce, a little voice nags in the pilot's mind, "Is this the one?" If the vibration fails to fade, the pilot must contemplate the "eject" button. At this point, it is life or plane. Call it flying by the seat of your $60 million pants.

How have Farhat and Amsallem succeeded where others have come up short? The answer sounds suitably complex: interpolation on manifolds. What it means, in essence, is approximating unknowns based on known information. The two engineers devised a system of mathematical approximations that break down complex, computationally demanding equations into smaller, more manageable parts. In mathematics, this is known as "reducing." Reducing allows them to make some very educated guesses, very quickly.

Starting with a mostly random, but carefully selected, sample of a few flight conditions – the variables such as air speed, wing angle and altitude – they "pre-computed" a series of reduced-order models using the very supercomputers they aimed to beat. These models are called "snapshots" – mathematical pictures of the fluid dynamics at play at each flight point. Farhat and Amsallem stored these snapshots in a database, which their computer algorithms can later pluck as needed to make more complex calculations, quite literally, on the fly.

That is the easy part.

Next, using a cleverly designed and painstakingly tested methodology, Farhat and Amsallem segmented data into small groups centered on the pre-calculated points in the databases. In essence, Farhat and Amsallem drew circles around the things they knew – those pre-computed flight conditions – and crafted a system to interpolate the value of any point within each circle.

On a graph, these "cells," as they are described, look like living cells with the known data serving as the nucleus. The rest of the cell is considered of similar enough aeronautical characteristic to the nucleus as to allow the engineers to make very educated guesses as to the behavior of the entire cell – allowing them to determine how the wing will respond at any given moment.

What's more, each time they make a new set of calculations, the new numbers are added to the database, bolstering future results and making their interpolations all the more accurate. The mathematicians call this "training," as if they are teaching the numbers and not the other way around – as if they are telling the numbers what they can and can't do.

Thus, the smartphone beat the supercomputer.

A field aflutter

So, what took so long?

"It sounds simple," said Amsallem, explaining his work, "but the mathematics are exceptionally complex and the stakes of being wrong are great. There's no room for error."

Farhat and Amsallem are able to accurately predict – in real time and where no one had before – whether a plane will experience flutter. Soon, they hope, all planes will have active control mechanisms that continually monitor multiple flight and mechanical data and steer the planes clear of flutter.

While this is good news for pilots and passengers, the implications of the work run far beyond the relatively rare, albeit deadly, phenomenon of flutter.

"Our interpolation method is general enough to work, in principle, on many complex engineering problems," said Farhat, hinting at future possibilities.

And this is what has the field aflutter. Everyone from the Air Force to the Navy to airplane manufacturers to Formula 1 racing teams are lining up – as they once did for time on the supercomputers – to apply the Stanford aeronautical algorithm to their problems.

Provided by Stanford University