Bearing heavy loads

Flying a helicopter with thousands of pounds of equipment slung beneath it can be a white knuckle experience. Erik Schechter explains how computational fluid dynamics is being applied to predict how helicopters will react under various load and weather conditions.

Department of Defense

CONEX: A pallet of medical supplies dangles from a UH-60 Black Hawk helicopter. Buffeting in bad weather can cause a CONEX — a container express — to twirl and rock.

A quick resupply by helicopter is sometimes the only thing that can stave off disaster for survivors of a hurricane or for troops pinned down by the enemy with ammunition running low. But the crew of the helicopter must fly cautiously, especially if the supplies are slung beneath their aircraft in the typical fashion — dangled from a gimbal and tether and stored inside a large, non-aerodynamic metal box called a CONEX, short for container express. Depending on weather conditions and the helicopter's forward speed, it can be buffeted by the wind and bad weather, and the aircraft's forward speed can produce a turbulent wake similar to the one experienced by motorists stuck behind an 18-wheeler on the highway.

At minimum, such buffeting can cause drag. But it can also play havoc with the sling load, causing it to twirl around on itself, tangling its cables, or sending it rocking back and forth — an instability that can be relayed back to the helicopter with dangerous consequences. "You're asking the poor pilot to fly this helicopter with this horrible swinging back and forth and spinning going on beneath it," says Marilyn Smith, a professor of aerospace engineering at the Georgia Institute of Technology.

It's not uncommon for pilots facing such situations to feel forced to jettison their sling loads.

Aerospace engineers try to keep that from happening by testing assorted cargo configurations in flight to advise pilots how fast they can go before complications develop. That can get expensive, given that it can cost $4,000 an hour to fly a UH-60 Black Hawk. Computational fluid dynamics (CFD) software models could, in theory, be a more affordable alternative, but they have reputations for being slow, computer hogs.

Enter Smith and her team at Georgia Tech. While attempting to study loads with traditional computation, the team encountered a computation roadblock that left them no choice but to find a CFD shortcut — a bit of serendipity that is beginning to pay off with quicker modeling of complex load dynamics.

"This is not a CFD code," Smith explains. "It's what's called a reduced-order modeling code." Reduced-order models attempt to accurately depict a phenomenon without employing high-fidelity CFD modeling, and Smith says that the one her team developed does just that for sling loads. "Basically, we are taking information from tests — wind tunnel tests and flight tests — and from CFD computations. And we are combining it with what we know about physics of these configurations" — to produce a quick and versatile software model that goes beyond its source material.

U.S. Army Aviation officials have been sponsoring Smith's research through the Vertical Lift Research Center of Excellence based at Georgia Tech. These officials do not expect the new model to completely eliminate test flights, but they are very excited about the prospect of its significantly reducing the number of future tests. "If we have to test only one-tenth of our configurations, it's a huge money savings," says Bill Lewis, director for aviation development at the Army's Aviation and Missile Research, Development & Engineering Center.

Finding the limits of CFD models

In 2010, the Georgia Tech team began looking at the air flow effects on non-streamlined "bluff" bodies, rectangles in particular. Researchers reviewed the scientific literature on previous experiments and noticed that the aerodynamic side force on a static box varies with changes in the angle of attack and the ratio of the box's dimensions. Though this observation would have no bearing on the CFD model the researchers first developed, it would later prove useful in the reduced-order model, says Daniel Prosser, a doctoral student working with Smith.

Smith and her team moved on to high-fidelity software simulations in late 2012-early 2013. Using a NASA CFD code called FUN3D, they broke down the air flow field around the bluff body into millions of grid cells and calculated the fluid properties — velocity, pressure and density — for each one. This data was then passed on to a library, or set of computer subroutines, used to simulate the six-degrees-of-freedom motion of a tethered load.

The Georgia Tech researchers expected their model to predict the behavior of a tethered object in flight. However, they found serious discrepancies once they compared their results against experiments conducted in 2010-2011 by Georgia Tech's Experimental Aerodynamics Group in the university's John J. Harper Low Speed Wind Tunnel. The software model predicted that, at certain speeds, the sling load's cable would spin, twisting on itself. Yet that didn't happen at all in the wind tunnel.

It took a while to figure out what went wrong, but the team concluded that their CFD model did not take into consideration friction acting upon the gimbal holding the tethered load in the tunnel. "What we hypothesized is that the model of our tether that we're using in our simulation had some assumptions built in, and one of those was that there wasn't any friction in the gimbal which attached to the tethers," Prosser says.

At that point, the team could have "de-bugged" their model and run it all over again, but doing so was simply not feasible. Solving for millions of grid cells, high-fidelity CFD models are, computationally speaking, very expensive: it can take a supercomputer weeks to process just 15 seconds of data. "If we had tried adding in some friction to the gimbal model, we would have had to run a whole new simulation, and then maybe that value wouldn't have worked," Prosser explains.

What the team needed was a short cut. So in September 2013, they began work on a reduced-order model that could solve their problem in a matter of minutes instead of weeks.

Devising a quick and accurate model

Looking back at the published work of others in Israel, the U.K. and the Army's Aeroflightdynamics Directorate, Georgia Tech researchers developed a reduced-order model that takes the real-life experimental results of a non-streamlined bluff body both in wind tunnels and flight tests, and combines them with a physics model of how air flows over an aerodynamic form in motion. Together, those two data sets — and a bit of extrapolation — provide a model of sling load behavior at a given speed, crosswind and scale.

"We started putting all this stuff together so that we could try to reverse-engineer to find the gimbal friction, and what came out of it was something that was extremely fast, orders of magnitude faster than CFD," Smith says.

What would take a CFD model an hour to calculate, the reduced-order model can do in .04 seconds — and do so reliably. According to Smith, the new stripped-down approach gets nearly the same results as the CFD model and wind tunnel tests. Finally, besides being fast and accurate, the reduced-order model, because it relies in part on physics, can be reliably applied to different speeds and different sized objects, she says.

Others have tried to develop a reduced-order model, but the approach taken at Georgia Tech takes into account variables not addressed before. The team looked at the random influence of turbulence and the phase lag, the delayed reaction of air flow to a body changing its angle of attack. The model also allows researchers to solve second-order differential equations that address the influences of velocities and acceleration, helping aerospace engineers to predict things like load autorotation, which is when the cargo load spins and twists its cables.

Smith sees the reduced-order model ultimately included in the comprehensive codes used by aerospace engineers for the rapid prototyping of new helicopters.

"By adding a module that allows them to take into effect accurately the behavior of these sling loads, then they can do a better design of the actual vehicle before it ever gets to the point of being operational," she says.

Georgia Tech Research Institute

RMAX: Research on a Yamaha RMAX unmanned helicopter at Georgia Tech benefits from a new technique that provides accurate and far faster modeling of dynamic loads.

"Unless you actually include these dynamic interactions correctly, you're not going to be able to model it, and that's where we are going beyond what people have done before," Smith says.

Besides being able to determine how fast a helicopter can safely fly with a particular sling load, the reduced-order model is now being used by other Georgia Tech faculty to develop guidance and navigation control systems for vertical takeoff and lift drones. Eric Johnson, a professor of avionics integration and director of the UAV Research Facility at Georgia Tech, has been working with a Yamaha RMAX helicopter, but his Georgia Tech UAV Simulation Tool lacked a way of modeling aerodynamics of sling loads. Now he can incorporate a reduced-order model into the simulator.

"That's a huge deal," Johnson says.

Future improvements

The next step for the Georgia Tech team is to extend the reduced-order model beyond rectangles to cylinders, flat plates and other shapes. To do so, researchers will have to conduct new wind tunnel tests on or apply CFD software models to these new shapes. But once they have completed this preliminary stage, they will have the raw material for future applications of the reduced-order model, Prosser notes.

Smith adds that the model can also be augmented in other ways: It could be sped up and made more comprehensive. "This is not as fast as it can go. We haven't tried to optimize the speed yet," she says. "We are also looking at what happens when we get higher-order fidelity…in other words, when we add more corrections or states."

Erik Schechter
erik.schechter@gmail.com