Study pushes the design limits on rotary blades in quest for quieter copters/drones

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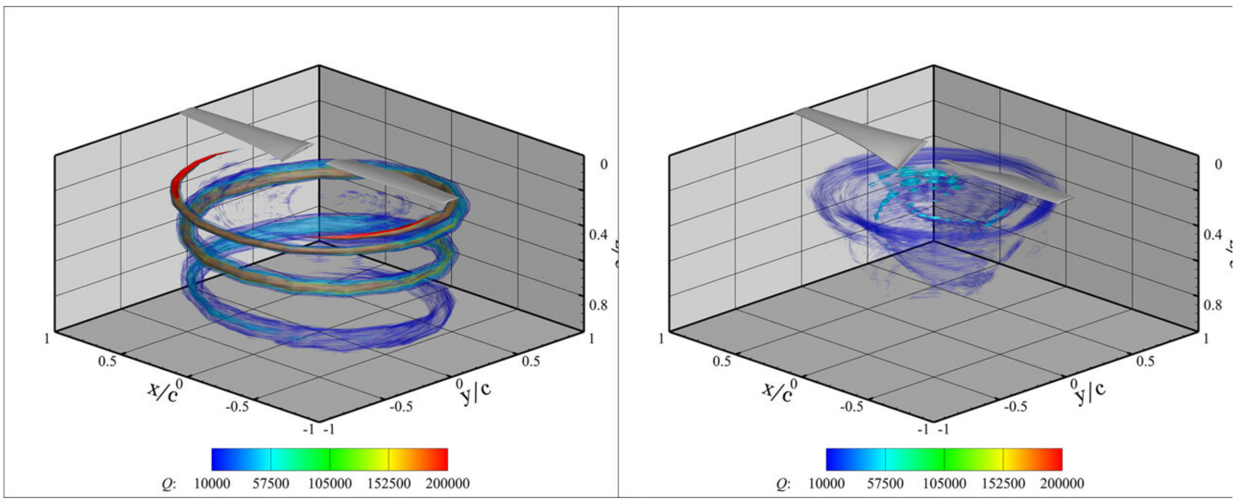

Wake structures produced by rotary wings: left, helical shape imposed by strong tip vortices of traditional rotor; right, conical shape by weak vortex strength of quiet rotor. Credit: University of Illinois Dept. of Aerospace Engineering

When a helicopter flies overhead, that familiar whup-whup-whup-whup low-frequency sound created by the rotary blade interaction with the wake drowns out everything else. That sound could be even more deafening as drone delivery and urban air mobility vehicles gain popularity. Researchers at the University of Illinois Urbana-Champaign tested the limits of rotary blade design to find an efficient but quieter option.

"Just like a fixed wing, a rotor blade typically leaves a very strong and coherent tip vortex that has a high concentration of angular momentum within it. The presence of that vortex in the axial wake of a propeller or rotor can cause all sorts of operational implications—ones that affect the rest of the vehicle," said Phillip Ansell, a professor in the Department of Aerospace Engineering. "After the vortex is released into the wake by one blade, another blade can come by, hit it, and boom—all this acoustic energy is released."

In this research, Ansell said he and his graduate student Daniel Yu looked at the fundamental framework of aerodynamics differently and altered the entire rotary wing, rejecting the assumption that a coherent vortex must form in the wake.

"Rotor systems and blade elements are typically designed for peak efficiency. Under these conditions the lift is distributed across the rotor blade to require the least amount of power to operate at a fixed thrust," he said. "The strong tip vortex is a consequence of the lift distribution, however. Vortices will form whenever there are sharp changes in the distribution of lift along the span of the wing, which commonly occurs at wingtips.

"We developed an optimization framework to determine the lift distribution that results in the same thrust as a conventional rotary wing, but without the dramatic decreases in lift these configurations typically produce. Instead of producing a strong tip vortex, a thin sheet of weak vorticity is produced with the same integrated strength as a conventional vortex, but without forming into a tightly knit vortex structure. Because the lift distribution is altered from what you would typically see on a rotary wing, however, it does come with a penalty of increasing power requirements of the rotor system."

Ansell said this experimental work is highly controversial because it pushes the limits and challenges fundamental perspectives of aerodynamics—namely that a wing flies through the air, produces lift, and leaves a tip vortex or a pair of tip vortices in its wake.

"There are many other devices and strategies out there that do an excellent job at attenuating tip vortex structures produced by wings, though these approaches will often focus on the physical design characteristics local to the wingtip only. The beauty of our approach is that we considered what fundamental mechanisms that result in the production of coherent vortex structures by a wing and looked holistically at how to design a wing that mitigates this process.

"It turns out, there are many other ways to make rotary wing systems quieter relative to some baseline as well—some of which are more efficient and some less. If we lower the tip speed, the rpm goes down and so does the noise. But you may need a larger, heavier wing or a more aggressive pitch of the of the blades which may put the system at a greater risk of stalling," he said.

Ansell said noise is one of the key bottlenecks for the urban air mobility market for obvious reasons. Community acceptance won't come if UAM vehicles are operating with the same acoustic signature of a helicopter.

"Altering the blade-vortex interaction changes the efficiency, but there will need to be tradeoffs between noise and efficiency if we want to greatly increase urban drone delivery. Otherwise, we can expect the future will hold vehicles that produce a cacophony reminiscent of swarms of angry bees. We need to identify ways to design rotary wing systems that meet operational needs."

Ansell said this kind of research is important because it challenges conventional thinking, and it allows us to understand things that are broadly applicable to the science of flight vehicles, rather than assuming we've learned all we can about aerodynamics.

"In these experiments, we looked at the far limit of how much attenuation you could have in the tip vortex, but there is much more to be done—trading some of these novel wake roll up/wake formation types of physics with highly efficient operation—in which we could potentially find a middle ground that doesn't sacrifice performance. In this way, the design of rotors for minimum power and minimum vortex roll-up behavior is kind of like a spectrum, and by understanding far can we push the system to either end, the better we can determine anything in between."

The study, titled "Design of Rotary Wings with Passive Mitigation of Coherent Tip Vortex Roll-Up," was published as part of the *AIAA SCITECH 2022 Forum*.

More information: Daniel Yu et al, Design of Rotary Wings with Passive Mitigation of Coherent Tip Vortex Roll-Up, *AIAA SCITECH 2022 Forum* (2022). DOI: 10.2514/6.2022-1677

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