Biomimetic Rotor Optimization for Passive Autorotation: Development of an Innovative Rotor Configuration for High-Precision, Controlled Descents During Aerial Delivery and Airdrop Operations

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In payload delivery and humanitarian aid, parachutes often suffer due to instability and drift. Autorotation offers potential solutions, yet it's treated as an emergency condition rather than a primary descent mechanism. However, stable autorotation naturally occurs in Samara seeds due to their asymmetrical geometry and leading-edge vortices (LEV's). Through biomimicry, this project reframes autorotation as a novel design-first objective by translating Samara geometry and LEV stabilization into rotors for aerial descent. To select an efficient airfoil, XFOIL evaluated Samara-shaped airfoils against NACA 2412 under low Reynolds-number conditions. The S1221 airfoil exhibited enhanced aerodynamics and reduced destabilizing moments. Two baseline rotors were then constructed from NACA 2412 and S1221 to isolate airfoil effects and quantify efficiency through Blade Element Momentum Theory. Utilizing the S1221, Samara-shaped rotors were CAD modeled. Parameters like camber and planform were iteratively refined through transient Computational Fluid Dynamics (CFD). This resulted in the finalized prototype increasing lift/thrust by 22.8% and L/D ratio by 22%. Additionally, flow visualizations showed stable vorticity. To enhance dynamic stability during descent, a MATLAB PID controller, tuned via Zeigler-Nichols Method, adjusted blade pitch in response to wind variations, reducing yaw instability by 71.43%. The biomimetic rotor's descent was physically validated in a UAV model through tethered descent rigs. Compared to the parachutes tested, which descended slower but had greater variability, the rotor exhibited consistent behavior. ANOVA and t-test confirmed this. By reframing autorotation through biomimicry, its potential as an efficient aerial descent system is demonstrated.

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