Effect of Turbulence Modeling on Rotor Performance Prediction for NASA's Tiltwing Air Taxi Concept

D. Garcia Perez*, P. Ventura Diaz*, and S. Yoon*

Urban air mobility (UAM) is driving innovation in the aerospace industry with novel aircraft designs to accommodate for the need of efficient and quiet operation in urban environments. Most of these concepts, such as the tiltwing, quadrotor, or side-by-side vehicles are based on multi-rotor configurations. An inaccurate modeling of the rotor wakes, unsteady flow patterns, and complex aerodynamic interactions can significantly impact aircraft's stability and performance.

High-fidelity computational fluid dynamics (CFD) is therefore the preferred method to obtain a detailed representation of the flow and capture rotor-wake-airframe interactions. NASA's OVERFLOW[1] CFD code is a finite-difference, body-fitted structured overset grid, high-order accurate Navier-Stokes solver that has been used to perform high-fidelity simulations of NASA's fleet of UAM air taxis[2] in a wide range of flight conditions. Of particular interest are hover, and vertical take-off and landing, as these phases involve low-speed axial flight. The vortex wake will remain for an appreciable length of time in close proximity to the rotor and will have a significant influence on the aerodynamics. In such cases, previous research studies[3] have acknowledged turbulence modeling as a critical factor in accurately predicting rotor performance. Standard Reynolds-averaged Navier-Stokes (RANS) models, such as the Spalart-Allmaras (SA) or Baldwin-Barth one-equation models, exhibit a tendency to generate excessive turbulent eddy viscosity deep within the rotor wake due to the turbulence length scale used. Over time, these large viscosities can migrate up the vortex wake, infiltrate the boundary layer, and locally increase drag. Hence, the performance will be severely underpredicted. Subsequent modifications to the original SA model addressed the issue of artificially large eddy viscosities and introduced the detached eddy simulation (DES). This formulation is generally utilized for the computation of rotor flows with OVERFLOW.

The overset grid approach is accommodative on the turbulence model specification, allowing the user to choose different models for near- and off-body grids. Past research[4] has focused on studying the effect of wake turbulence model characteristics on the accuracy of solutions for isolated rotor flows in hover. In the present work, we aim to extend that research to multi-rotor configurations. The geometry studied is NASA's tiltwing[5] air taxi concept. Various turbulence models —RANS/SA, RANS/SST, DDES/SA, DDES/SST— are used for the near- and off-body grid-zones to assess their impact on the prediction of rotor airloads and performance in hover.

*Computational Physics Branch, NASA Advanced Supercomputing Division, NASA Ames Research Center, Moffett Field, CA 94035, United States

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[4] Yoon et al., *AIAA Paper 2015-2766*, (2015).

[5] Garcia Perez et al. *AIAA Paper 2023-2282*, (2023)