High-Fidelity Simulations of NASA’s Urban Air Mobility Concept Vehicles

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Urban Air Mobility (UAM) is envisioned to be a safe and efficient air transportation system, where everything from small package delivery drones to passenger-carrying air taxis will operate in urban areas. NASA is contributing to this revolution in aeronautics.
NASA’s RVLT UAM Concept Vehicles

- **Side-by-Side** (Intermeshing Rotors) [1]
- **Quiet Single-Main Rotor (QSMR)** (NOTAR, specifically designed for quiet operations) [3]
- **Tilt-Wing** (Airplane mode for efficient cruise flight, helicopter mode for VTOL) [4]
- **Quadcopter** (Vertically-Separated Rotors) [2]

**Reference vehicles contain relevant UAM features and technologies**

- 6 pax VTOL; 2 x 37.5 mile mission with 10 kt headwind; 20 min cruise reserve

Motivation

- Current design tools for UAM vehicles use empirical models that are based on historical data that is biased toward traditional Vertical Take-Off and Landing (VTOL) vehicle configurations.
- This can result in inadequate models since most UAM vehicles have very non-traditional VTOL configurations.

Use high-fidelity CFD and overset structured grids to accurately model the moving rotors, solve the flow and calculate aerodynamic performance, for NASA’s UAM concept vehicles.
Numerical Approach

High-fidelity CFD: OVERFLOW
Overset Grid Generation: Chimera Grid Tools
Comprehensive Analysis: CAMRAD II
Loose Coupling Methodology: CAMRAD II – OVERFLOW
OVERFLOW

• OVERFLOW is a high-order accurate Navier-Stokes solver
  • Solves the unsteady Reynolds-averaged Navier-Stokes (RANS) equations
  • Structured overset grids
  • $5^{th}$ order accurate central differences with scalar dissipation for convective terms
  • $2^{nd}$ order accurate dual time-stepping
  • Hybrid RANS/LES turbulence models
    - Spalart-Allmaras one equation turbulence model
    - DDES length scale
    - $y^+ ≤ 1$
Chimera Grid Tools (CGT)

- CGT is NASA’s overset grid generation software
- Four main steps in overset grid generation:
  - **Geometry processing**: Geometry obtained from CAD or 3D scan techniques
  - **Surface Grid Generation**: feature based domain decomposition, grid point distribution, mesh fill
  - **Volume Grid Generation**:
    - Hyperbolic Near-Body (NB)
    - Cartesian Off-Body (OB)
  - **Domain Connectivity**: grid points blanking, donor stencil search
Comprehensive Analysis

CAMRAD II

- CAMRAD II is an aeromechanics analysis of rotorcraft that incorporates a combination of advanced technologies, including multibody dynamics, nonlinear finite elements, and rotorcraft aerodynamics.
- The trim task finds the equilibrium solution for a steady state operating condition, and produces the solution for performance, loads, and vibration.
- The aerodynamic model for the rotor blade is based on lifting-line theory, using two-dimensional airfoil characteristics and a vortex wake model.
- CAMRAD II has undergone extensive correlation with performance and loads measurements on rotorcraft.

Results
Side-by-side
Quadcopter
QSMR
Tiltwing
CAD file for SbS aircraft (IGES or STEP)

- Imported into CGT using EGADS API from Engineering Sketch Pad
- \textit{egads2srf} tool \textarrow{} Discrete representations are generated from each solid.

Boundary Representation (BRep)

Structured untrimmed patches obtained from the CAD geometry using EGADS
Motivation: Overlapped, side-by-side rotor performance in cruise is better than separate non-overlapped rotors:
- The combined wake system approximates that of a single wing with a large span, which reduces the induced power.

Objectives: Study the aerodynamics and performance of NASA’s side-by-side UAM concept:
- High-fidelity CFD loosely coupled with rotorcraft comprehensive analysis.
- The tools developed can be used to explore the noise and performance for different configurations of multi-rotor UAM vehicles in support of eVTOL air taxi operations.

Quadcopter air taxi

Structured untrimmed patches obtained from the CAD geometry using EGADS

Vertical separation between front and rear rotors to reduce rotor-rotor interactions in cruise, and decrease power required for forward flight [1]

Quiet Single-Main Rotor (QSMR)

• Most UAM vehicles designed with multiple rotors

• Often disregarded configuration is the single-main rotor helicopter
  • Known path for certification
  • NOTAR to remove tail rotor noise
  • Specifically designed for low-noise operations

• Based on the work from Johnson [1].

QSMR in Hover

**Q-criterion vorticity iso-surfaces colored with vorticity magnitude**

- Blade-vortex interactions (BVI).

- The tip droop changes the position of the primary tip vortex and decreases its strength, as seen by the lower vorticity magnitude.

- A secondary weak vortex is formed where the droop starts, due to the change in aerodynamic distribution at that section of the blade.

Two different CAD geometries

Airplane mode

Helicopter mode

“Airplane mode” geometry is used for cruise, no wing/fuselage gap

“Helicopter mode” geometry is used for hover/transition
SUMMARY

• NASA’s air taxi UAM concepts have been analyzed using overset grids, comprehensive tools and high-fidelity CFD.

• The comprehensive code CAMRAD II and the high-fidelity CFD flow solver OVERFLOW have been loosely coupled for accurate rotor flow simulations.

• NASA’s air taxi concepts are designed to focus and guide NASA research activities in support of aircraft development for emerging aviation markets, in particular VTOL activities.

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Questions?