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An Overset Dual-Mesh Solver for Computational Fluid Dynamics

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Although fixed-wing aircraft often fly in relatively steady clean air, rotary-wing vehicles regularly fly inside their own unsteady wakes. They experience both tail buffet from vortices shed from the hub as well as blade-tip vortex interaction that greatly effect handling qualities, vibration, and noise. In the worst case, vortex flows can lead to catastrophic flight conditions like vortex ring state where the rotor experiences a sudden loss of lift when it becomes enveloped in its own vortex wake. Wake effects can also play an important role in certain fixed-wing applications, such as when the tip vortices emanating from the nose and swept wing of high angle-of-attack fighter jets create tail buffet and loss of control during maneuvers. CFD simulation of these phenomena require both accurate simulation of the aerodynamic loads as well as accurate simulation of the unsteady wake.

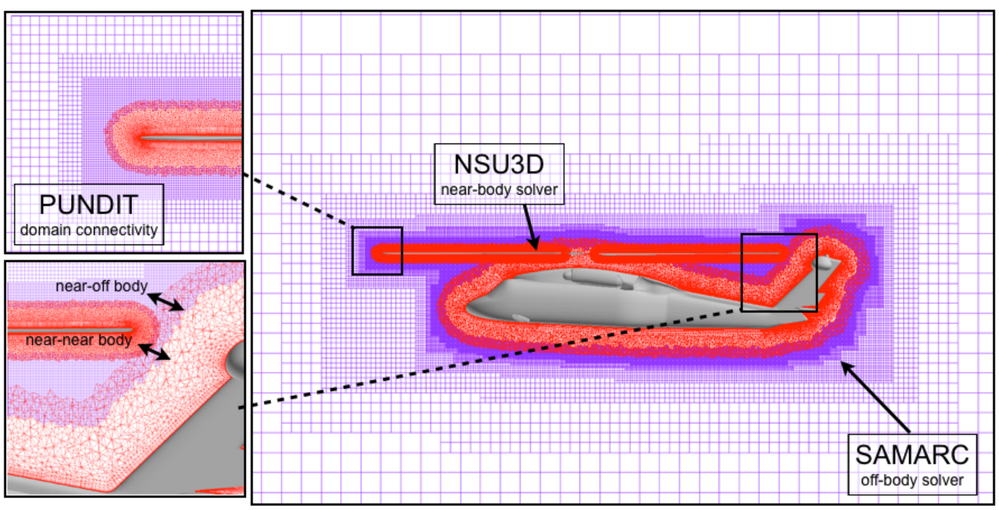
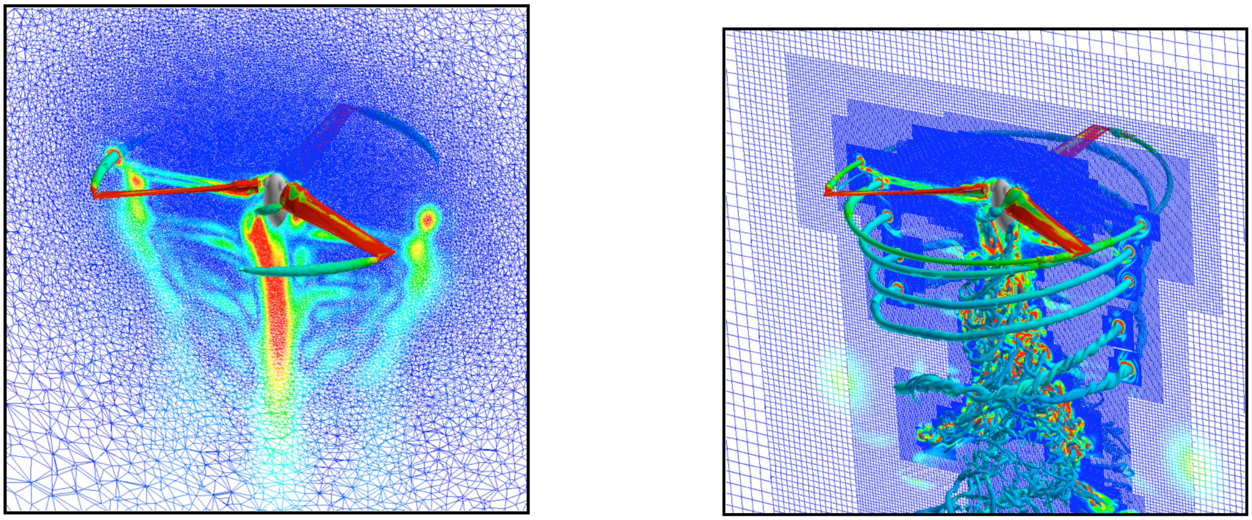


Figure 1: Overset near/off-body gridding paradigm used in Helios. Unstructured grids capture geometric features and boundary layer near body surface, adaptive block-structured Cartesian grids to capture far-field flow features.

Viscous flow around the rotor and fuselage surfaces plays an important role in achieving the correct prediction of lift and drag as well as other important phenomenon like separation. Rotary-wing aircraft also tend to be quite geometrically complex. For these reasons, unstructured RANS or DES solvers traditionally used by the fixed-wing community are equally applicable to rotorcraft. For predicting the wake, however, dissipation in these schemes often becomes problemmatic.

The Helios software [1, 2] adopts a dual-mesh paradigm which couples the unstructured RANS or DES solver in the near-body with a block structured Cartesian solver in the off-body to resolve the wake through a combination of high-order algorithms and adaptive mesh refinement (AMR). An overset procedure facilitates data exchange between the two mesh types as well as enables relative motion between the mesh systems



(a) RANS-alone

(b) RANS-Cartesian

Figure 2: Isolated TRAM rotor calculations. Iso-surface of Q-criterion shown, colored by vorticity magnitude (red indicates high vorticity, blue low). (a) fully unstructured; (b) unstructured near-body with adaptive Cartesian off-body.

- i.e. the near-body unstructured rotor meshes rotate and deform inside the stationary adaptive Cartesian off-body grids system. Rotor motion, deformation, flight controls and trim operations are provided by an external comprehensive analysis package. Coordination of the different codes is managed through a lightweight and flexible Python-based infrastructure.

The spatial discretization scheme used by Helios employs an overset near-body/off-body approach, using unstructured body-fitted grids near the body surface and adaptive Cartesian grids away from the surface (Fig 1). The mixed-element unstructured near-body mesh is cut a certain distance from the wall. The RANS/DES solver NSU3D is applied to this subsetted unstructured near-body mesh, the block structured adaptive Cartesian code SAMARC is used as the off-body solver, and the PUNDIT software manages the chimera grid hole cutting and overset interpolation. For cases with structural deformations, a patch force based fluid structure interface RFSI exchanges force and deformation information with the RCAS rotorcraft comprehensive analysis which performs structural dynamic analysis and trim. The coupling of all these components is accomplished through a Python-based infrastructure with emphasis on preserving the modularity of the participating solvers.

Figure 2 shows the computed wake for the Helios RANS-Cartesian and RANS alone calculations of the TRAM rotor. Fig. 2(a) is clearly much better resolved than the RANS alone solution shown in Fig. 2(b). The RANS-Cartesian solution benefits from the use of high-order algorithms and refinement of the mesh to vortex structures. Vortex structures are maintained at nearly full-strength for four rotor revolutions. On the other hand, the RANS alone solution causes the wake structures to dissipate quickly because the solution is lower (2nd) order and the grid is not clustered to capture the vortices.

References

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