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Software Design Strategies for Multidisciplinary Computational Fluid Dynamics

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As Figure 1 shows, helicopter flight involves many multidisciplinary physics problems that are difficult to predict with today's engineering modeling and simulation tools. Aerodynamic rotor wake systems, which involve complex interactions among the rotor blades, rotor wakes, and fuselage, create challenges such as

- simultaneous modeling of rotating and nonrotating components;
- retreating-blade low-speed aerodynamic stall;
- advancing-blade transonic flow;
- rotor "trim" requirements to balance aerodynamic and dynamic forces for particular control settings; and
- a strong coupling between rotor-blade aerodynamics and rotor blade dynamics (both rigid and elastic blade motion).

A successful rotorcraft aeromechanics simulation must accurately represent all these physical phenomena. These software models typically require substantial engineering expertise, powerful computer systems, and must often couple computational fluid dynamics (CFD), computational structural dynamics (CSD), and vehicle flight controls.

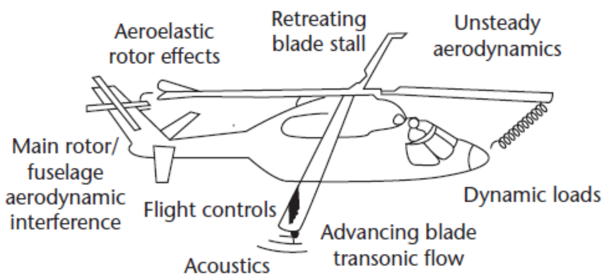

Figure 1: Rotary-wing vehicles present a number of challenges for multidisciplinary fluid and structural dynamics modeling.

Rotary-wing aeromechanics' multidisciplinary nature poses a daunting task for designing practical modeling and simulation software that's accurate, efficient, and maintainable. Traditional rotary-wing modeling and simulation software tends to be monolithic, combining all of the multidisciplinary physics models into a single code infrastructure. Experience has shown that such monolithic software is fraught with problems, both in the software development cycle and in later maintenance and support phases. Errors abound when there are too many "cooks" developing the same piece of monolithic computer code. Also, to implement code changes in future software upgrades requires an intimate knowledge of the entire package, which limits upgrades to only a few highly qualified personnel.

With an aim to solving these problems, the US Army Aeroflightdynamics Directorate has developed a software product called, "Helios" for multi-disciplinary rotary-wing aeromechanics modeling. The

Helios infrastructure links both new and existing software modules with little need for extensive code modifications. Data exchanges between software modules occur through a Python-based integration framework that is shown in Figure 2. This Python software framework is both object-oriented and scalable on large parallel computer systems.

The Python-language-based approach treats each software module as an object, providing a convenient way to assemble complex multidisciplinary simulations in an object-oriented fashion. This ability to effectively combine both new and legacy software modules reduces development time and software maintenance; it also provides flexibility by allowing for multiple, interchangeable software modules. As a result, it Helios software developers can readily extend their own software and leverage the work of others by allowing new components to “plug in” in place of others.

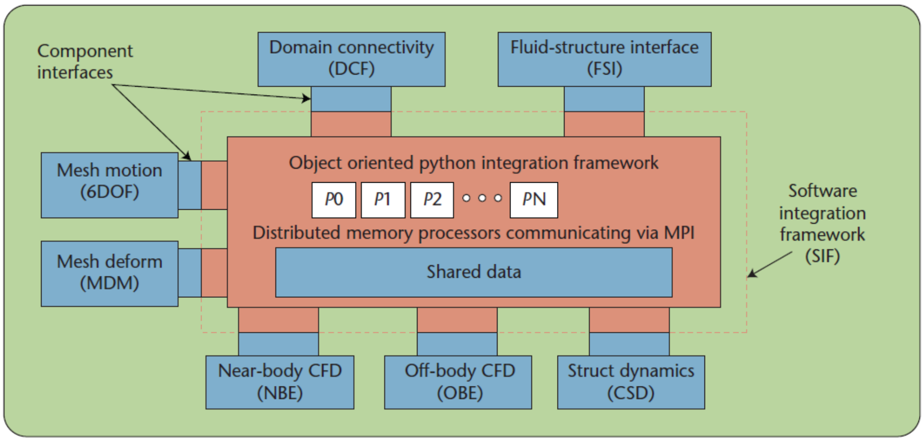

Figure 2: The Helios software integration framework for multidisciplinary analysis of rotary-wing flowfields. The multicode Python infrastructure consists of an execution interface that controls each module and a set of module-specific interfaces.

This Python infrastructure enables Helios to use a combination of a number of novel features to analyze the multidisciplinary rotary-wing aeromechanics problem.

- Unstructured near-body viscous grid systems to facilitate grid generation on complex geometries
- Cartesian grid systems away from the solid surfaces with high-order solution algorithms for high accuracy and computational efficiency.
- Fully-automated mesh connectivity for interpolation of flow field solutions across overlapping unstructured and Cartesian CFD mesh systems.
- Automated solution-adaptive mesh refinement to capture concentrated flow features in the Cartesian off-body meshes
- Strong coupling between the computed aerodynamics solution and dynamics responses for moving rotor blades.
- “On the fly” extraction of flow field solution data for visualization on local computer workstations
- Scalability to billions of CFD mesh points computed across thousands of parallel processors.
- Software version control and automated regression testing for both the overall Helios flow solver and for the individual component software modules.

This paper will describe these new Helios software features and present several examples of how these techniques are used to model complex problems in rotary-wing aerodynamics and dynamics. In addition to highlighting new Helios modeling capabilities, these applications problems also point to a number of shortcomings in the current multidisciplinary CFD approach. This paper will identify and prioritize these shortcomings and also provide suggestions for new strategies to improve both the technical approach and the overall software design.