An OpenFOAM Implementation of Ice Accretion for Rotorcraft

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Abstract

Ice accretion modeling for rotorcraft remains an issue and is in need for an advanced modeling capability. We are currently investigating such a modeling capability within the OpenFOAM framework. This problem presents issues including a multi-physics nature, combined with long simulation times (4 to 40 minutes), making it a challenge. Our approach couples numerous solvers into a single ice accretion solver. It includes a (1) compressible fluid-flow solver for the aerodynamics, (2) an Eulerian-based droplet solver for water accumulation on surfaces, (3) a surface-film solver on surfaces, (4) ice-evolution of the ice accretion, (5) a blade-element momentum (BEM) solver (outside the OpenFOAM framework) for the rigid-body blade dynamics and trim settings for a helicopter, and (6) conductive-heat-transfer analyses through rotor-blade skin. This presents a wide-range of physics enabled through the OpenFOAM framework along with other software libraries.

One of the challenges in rotorcraft is the ability to handle multi-body dynamics associated with the rotor-blade motions. We incorporate the "foamedOver" library of Boger *et al.* [1], which uses the SUGGAR [2] and DiRTlib [3] overset libraries, to handle complex rotor-blade motions. Directly resulting from the long-simulation times, there is a strong need to develop large-time-stepping solvers. Although the aerodynamic calculations may not be rigorous, it will still provide adequate deposition rates based on the work of Sarofeen *et al.* [4]. In order to extend the time-step size, a dual-time stepping approach is incorporated into a compressible-flow solver (based on the AUSM$^+$-up scheme [5]), a droplet solver, and a surface-film solver. For ice-accretion modeling, we use approaches similar to LEWICE [6] and FENSAP-ICE [7], which include film-model sources, convective-heat transfer, and conductive-heat transfer.

Lastly, we examine an approach to couple these various solvers and an arbitrary number of regions using the overset approach. The long simulation times (10s of minutes) required for rotorcraft icing along with typical rotations rates (300 revolutions/minute) requires time accurate simulation of a huge number of rotor blade rotations. In order to reduce the computational costs we are investigating the application of a zonal approach to simulating these cyclic flows where regions/zones are "frozen"and updated periodically. Coupling between the regions is achieved via stored overlapping mesh information within DiRTlib, enabling specified regions to advance more revolutions than others and considerably decreasing the computational time. The approach also enables a multi-physics capability, by switching equations sets in each region, and relying on overset to handle mesh to mesh information transfer.

This presentation will focus on various aspects of the implementation, with primary emphasis on the multi-region approach and multi-physics coupling. Validation cases will include stationary geometries, and non-stationary, rotorcraft simulations.

Key words: Ice Accretion, multi-physics, rotorcraft, Overset, OpenFOAM

References

[1] Boger, D.A., Noack, R.W., Paterson, E.G., "Dynamic Overset Grid Implementation in OpenFOAM," submitted to the 5th OpenFOAM Workshop, Chalmers, Gothenburg, Sweden, June 21-24, 2010.

[2] Ralph W. Noack, David A. Boger, Robert F. Kunz, and Pablo M. Carrica, Suggar++: An Improved General Overset Grid Assembly Capability, AIAA Paper 2009-3992, 19th AIAA Computational Fluid Dynamics Conference, San Antonio, TX, 22-25 June 2009.

[3] Ralph W. Noack, DiRTlib: A Library to Add an Overset Capability to Your Flow Solver, AIAA Paper 2005-5116,

17th AIAA Computational Fluid Dynamics Conference, Toronto, Ontario, Canada, 6-9 June 2006.

[4] Sarofeen, C., Kinzel, M, Noack, R., Morris,P., Kreeger, R.,"A Numerical Investigation of Droplet/Particle Impingement on Dynamic Airfoils and Rotor Blades," AIAA Paper AIAA-2010-4229, to be presented at the 28th AIAA Applied Aerodynamics Conference, Jun 28th-July 1st , Chicago, IL, USA.

[5] Liou, M.-S., "A Sequel to AUSM, Part II: AUSM+-up" J. Comput. Phys., Vol. 214, 137- 170, 2006.

[6] Bidwell, C.S., and Potapczuk, M.G., "Users Manual for the NASA Lewis Three-Dimensional Ice Accretion Code (LEWICE3D)," NASA TM 105974, December 1993.

[7] Beaugendre, H., Morency, F., and Habashi, W.G, "Development of a Second Generation In-Flight Icing Simulation Code," J. Fluids Eng., 128, 378 (2006), DOI:10.1115/1.2169807.