17th AIAA Computational Fluid Dynamics Conference
6 - 9 June 2005, Toronto, Ontario Canada

AIAA 2005-5124

A CFD Framework for Analysis of Helicopter Rotors

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A CFD method suitable for the analysis of hovering and forward-flying rotors has been developed and validated against experimental data. The Caradonna and Tung as well as the ONERA 7A/7AD1 rotors have been simulated and results were found to be in excellent agreement with wind tunnel measurements. As a second step the method was coupled with a trimming algorithm devised using rotor blade element theory. The coupled algorithm demonstrates the rapid convergence to prescribed thrust coefficient values and no deterioration of the convergence rates relative to simulations of untrimmed rotors.

I. Introduction

During the last decades, CFD methods for the numerical simulation of the flow around fixed-wing aircraft have improved significantly.[1] Modern CFD methods can with relative ease, at design conditions, predict with good accuracy wing lift and with fair accuracy total wing drag. For rotary-wing aircraft, however, the situation appears to be more complicated and the application of CFD in the rotorcraft industry has not reached the same level of maturity. It appears that CFD analysis of flows around rotary-wing aircraft is significantly harder in comparison to the fixed-wing case.[2–10] There are several reasons contributing to this situation: i) Rotor flows are complicated and rich in fluid mechanics phenomena.[11] CFD methods have to cope with strong interacting vortices, the formation of a vortex wake that spirals down below the rotor disk, transition to turbulence and a wide variation of the Mach and Reynolds numbers in the radial direction and around the azimuth. ii) There is a strong link between the aerodynamics and aeromechanics for rotor flows. This includes both the 'rigid blade' motions of the rotor blades about hinges in the rotor hub and the elastic deformation of the rotor blades. In level forward flight, the rotor blade motions form part of the problem, as are the control setting of the rotor to achieve the required flight state. This is known as the rotor trimming problem which further complicates the numerical simulations of the flow field created by a rotor in forward flight.

Figure 1 introduces the frame of reference used here, i.e. the rotor shaft axis is the z-axis and the rotor revolves in anti-clockwise direction. The angle ψ defines the azimuthal position. The coordinate system $\underline{x}$ corresponds to the helicopter-fixed frame of reference. In this system, the rotor moves in the negative x-direction. For a typical helicopter rotor, the rotor blades are attached to the rotor head by a set of three hinges: the flap hinge allowing the blade to flap up and down, the lead-lag hinge allowing the blade an in-plane forward or backward motion and the feathering hinge, required to change the blade pitch. In a number of modern helicopters one or more of these hinges is replaced by a flexible connecting beam. The degrees of freedom about the hinges are necessary for achieving a balance of forces and moment on the helicopter. The construction of rotor heads is fully explained in many text books.[12–14] A rotor with these degrees of freedom for the blades is called *fully articulated.* Figure 1 shows the linear transformations from the helicopter-fixed frame of reference to a blade-fixed frame of reference. The control input consists of a 'collective' pitch, i.e. a revolution averaged pitch that is identical for all blades, and a 'cyclic' pitch, i.e. a periodic pitch change in the azimuthal direction. The deflections in flapping and lead-lag result from balances of inertial and aerodynamic forces. In the case of hover, the blade encounters a constant blade normal velocity, and as a result, no cyclic pitch change is needed to balance the helicopter. In this case, a cyclic pitch is set

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