An Analysis on the Helicopter Rotor Aerodynamics in Hover and Forward Flight using CFD/Time-Marching-Free-Wake Coupling Method

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In this study, a helicopter rotor is simulated by tightly coupled CFD/Free-wake method to describe wake characteristics. Rotor blade and flow field aerodynamics are calculated by CFD, and wake motions are simulated by Time-Marching-Free-Wake(TMFW) method. This tightly coupled CFD/Free-wake method can describe wake characteristics as well as rotor aerodynamic properties. Using this coupling analysis, hovering is analyzed for accurate aerodynamics. In forward flight, rotor blade has pitching and flapping motions. To simulate moving blades, moving overset grid technique is applied to the coupling method. For validation, all of numerical results are compared with experimental results.

1 Introduction

Helicopter rotor wake is more complex than fixed wing's wake because wake generated by rotating blades has a spiral motion. Particularly tip vortices generated from blade tip have very strong circulation strength. These rotor wakes and tip vortices make characteristics of inflow which decides rotor performance. For that reason, description of rotor wake is most important thing to simulate rotor aerodynamic characteristics. Conventional rotor CFD has a difficulty to simulate rotor wake due to numerical dissipation. This dissipation causes diminishing flow vorticity. The numerically diminished flow can't sufficient induced velocity and inflow deciding rotor aerodynamic performance. To overcome this problem, vortex capturing method, grid adaptation and vortex model have been studied.

In this paper, Time-Marching-Free-Wake(TMFW) method is used to describe wake effects. TMFW can compute rotor wake without numerical dissipation because free-wake is lagrangian approach method. And it is faster than conventional CFD because TMFW not use grid system.[1] But TMFW is difficult to simulate transonic and viscous effects such as shock and dynamics stall. These problems can be overcome by coupling with Rotor CFD. In this paper, Rotor CFD is tightly coupled TMFW at each computational time step. The TMFW coupled with CFD can describe inboard vortices as well as tip vortices. Therefore, detailed geometry of the wake can be predicted. The wake characteristics obtained TMFW can provide induced velocity required rotor CFD calculaton.

The CFD/TMFW coupling method is applied to predict hover, forward flight. In forward flight, blades move with pitching and flapping motion. To consider blade motion, moving overset technique is used. And parallel computation technique is used to accelerate computational speed.

2 Methodology

2.1 Numerical Method

3dimensional unsteady Euler equation is govering equation. Finite Volume method (FVM) is used to discritize governing equation. In this FVM, cell centered method is used. Roe's FDS(Flux Difference Splitting) and van Leer's MUSCL(Monotone Upstream Scheme for Conservation) is used for inviscid flow calculation, and van Alada's limiter is used for stability. For time marching, DADI(Diagonalized Alternating Direction Implicit) is used. To improve time accuracy, dual time stepping is applied. And multigrid method and local time stepping are used to accelerate convergence. To consider blade motion, moving overset grid technique is applied.

Time-Marching-Free-Wake

Wake is described by vortex filaments. Generally, induced velocity of vortex filaments is obtained from Biot-Savart law. Generally, vortex filaments are described to the straight filaments. But vortex filaments have curved shape because rotor tip vortices and wake have a spiral motion. In addition, curved vortex filament can generate self-induced velocity which is required for description of wake movement. In this study, parabolic blending function is applied to the curved line interpolation. This parabolic blending interpolation can describe the circular line and give clear curved line without non-intuitive tangential vector to the line. Induced velocity of curved vortex line can be obtained from Moore-Rosenhead equation,

$$\mathbf{V}_{ind} = \int_C \frac{\mathbf{r}}{(|\mathbf{r}|^2 + \mu_s^2)} \times \Gamma \frac{\partial y(\xi, t)}{\partial \xi} d\xi \tag{1}$$

y is position on the curved line coordinate. And μ_s is Rosenhead's cut-off variable for singularity removal. In the present work, cut-off variable is set to be 0.1 of the chord length. This interpolation technique is only applied to the trailing vortex filaments which is perpendicular to the trailing edge.

Tightly coupling method

CFD/TMFW can consider wake description as well as compressible and viscous effects. Specially, inflow variation induced by wake is described with azimuth. This coupling method uses lifting line and boundary correction approach. Trailed vortex information of TMFW comes from lifting line which represents aero-load of CFD. This trailed vortex strength is deference between sectional aerodynamic forces. Wake represented by vortex filament bundles can decide induced velocity of arbitrary space position. For that reason, diminished inflow in CFD calculation is corrected by adding induced velocity of TMFW. Induced velocity is imposed at the boundary of CFD domain at each time. Fig.1 indicates schematics of coupling process. Fig.2 shows wake of TMFW in CFD domain.

3 Numerical results

Using coupling method, hover and forward flight simulation are performed. In hover flight calculation, Caradonna and Tung's rotor model[2] is used. And AH-1G rotor model[3] is used in forward flight. These numerical results are compared with experimental data.

Hover flight

Rotor blade pitch angle is 8degree. And tip Mach number is 0.439. Total computation revolution is 10. Grid system shown Fig.3 It is composed of 5 blocks. 5 block grids organize 3 bodies. 2 bodies describe 1 blade. 1 body represent background. The number of One Blade grid nodes is $2\times19\times67\times105$. And Background grid node number is $71\times89\times89$. Fig.4 shows rotor wake geometry in the CFD domain. In fig.5, pressure coefficients are compared with experimental data. And table.1 is total thrust coefficient of present and experimental data.

Table 1. Thrust coefficient

Present	Experiment
0.00467	0.00459

Forward flight

Tip Mach number of AH-1G is 0.65. Advance ratio is 0.19. And thrust coefficient is 0.00464. This rotor blade has a pitching and flapping motion with azimuth(ψ). Pitch angle is $\theta = \theta_0 + \theta_{1c}\cos(\psi) + \theta_{1s}\sin(\psi)$. Flapping angle is $\beta = \beta_0 + \beta_{1c}\cos(\psi) + \beta_{1s}\sin(\psi)$. Blade motion is determined by rotor trimming. Table.2 is control angle of blade.

Table 2. Pitch and flapping angle

degree	θ_0	θ_{1c}	θ_{1s}	β_0	β_{1c}	β_{1s}
Present	6.2	1.38	-5.19	0	2.13	-0.15
Exp.	6	1.7	-5.5	0	2.13	-0.15

4 Conclusion

In this study, CFD/TMFW coupling method was deveploed to simulate unsteady rotor aerodynamics efficiently. Using this method, hover and forward rotor was simulated. And this numerical results was vailidated through the comparision with experimental data. It is suitable for predicting unsteady rotor aerodynimics and noise, because CFD/TMFW coupling method is more efficient and accurate than conventional rotor CFD.

Acknowledgement

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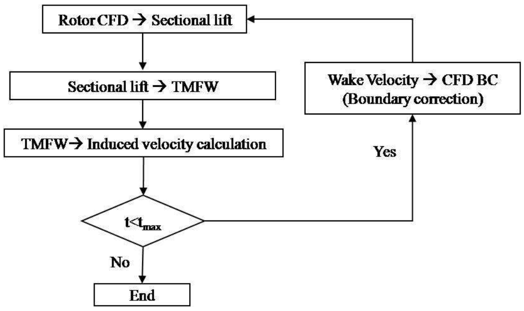

Fig. 1. Procedure of CFD/TMFW Coupling Method

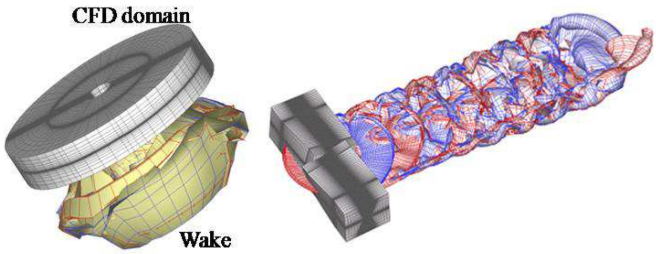

Fig. 2. Wake description in CFD domain

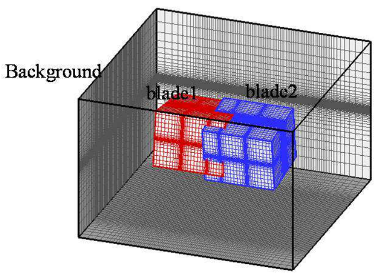

Fig. 3. Grid system

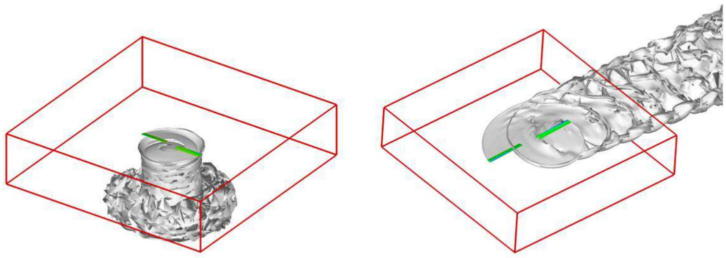

Fig. 4. Wake geometry in hover and forward flight

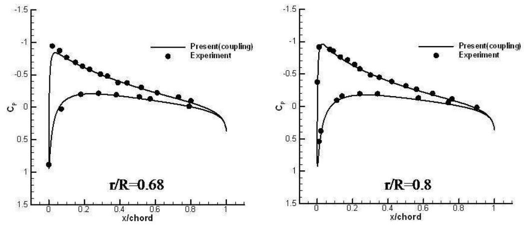

Fig. 5. Pressure coefficient in hover flight

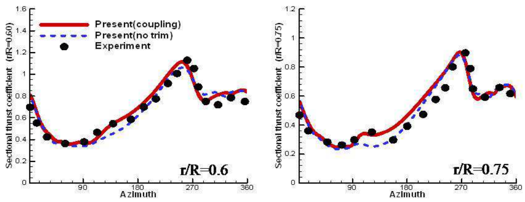

Fig. 6. Sectional lift coefficient

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