Aerodynamic Performance Analysis of a Shrouded Rotor Using an Unstructured Mesh Flow Solver

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Abstract

The aerodynamic performance of a shrouded tail rotor in hover has been studied by using a compressible inviscid flow solver on unstructured meshes. The numerical method is based on a cell-centered finite-volume discretization and an implicit Gauss-Seidel time integration. The results show that the performance of an isolated rotor without shroud compares well with experiment. In the case of a shrouded rotor, correction of the collective pitch angle is made such that the overall performance matches with experiment to account for the uncertainties of the experimental model configuration. Details of the flow field compare well with the experiment confirming the validity of the present method.

Keyword: *Shrouded Tail Rotor, Computational Aerodynamics, Unstructured Meshes*

1. Introduction

A conventional helicopter with a single main rotor requires a tail rotor to compensate the torque reaction of the main rotor and to obtain yaw stability and directional control. Generally, there are three types of tail rotor, that is, conventional tail rotor, shrouded tail rotor which has the shroud covering the blades, and NOTAR(NO TAil Rotor) using Coanda effects.

The first shrouded tail rotor named as Fenestron^{TM}[1] was developed by French Aerospatiale and adopted to Gazelle in 1968. The Russian helicopter, Ka-60, had the fan-in-fin[2] as a tail rotor. In USA, RAH-66 Comanche developed by Boeing-Sikorsky was equipped with Fantail^{TM}[3], and in Japan a similar shrouded tail rotor was developed and adopted to XOH-1 helicopter[4].

The shroud naturally protects the rotor against external aggressions and originally, the concept has been developed for the safety purpose. The shrouded tail rotor has less three dimensional effects by shroud than conventional tail rotor, additional shroud thrust, and more induced downwash which may reduce the possibility of vortex ring state. Helicopters equipped with a shrouded tail rotor have improved aerodynamic characteristics, smooth handling, and excellent yaw maneuverability. The noise attenuation with distance is normally stronger than for conventional tail rotor, as the noise fundamental frequencies are higher by an order of magnitude approximately[5].

There are some aerodynamic analyses[2-5] of various shrouded tail rotors based on wind tunnel tests, classical numerical calculations with test data, or axisymmetric viscous calculations.

In the present study, numerical analysis has been performed for the shrouded tail rotor of Ka-60[2] using a three dimensional, inviscid, compressible flow solver on unstructured meshes. In contrast with former studies, the three dimensional blades were modeled and the results were compared with experiment.

2. Numerical Method

2.1 Governing Equations

The three dimensional, inviscid, compressible Euler equations can be written for absolute flow variables on a rotational frame of reference in an integral form.

$$\frac{\partial}{\partial t}\int_V Q dV + \int_{\partial V} F(Q,n) dS = \int_V S(Q) dV \quad (1)$$

where, S(Q) represents the centrifugal forces.

The invisicd flux across each cell face is computed using Roe's flux-difference splitting formula. An implicit time integration algorithm based on the linearized Euler backward differencing is used. The linear system of equation is solved at each iteration by using point Gauss-Seidel method.

2.2 Boundary Conditions

At the solid wall, the slip boundary condition is used for inviscid flows. To apply boundary condition at far-field boundaries, source-sink boundary condition suggested by Srinivasan[6] which was developed for a single isolated rotor is modified for a shrouded tail rotor. In this method, one dimensional momentum theory modified for shrouded tail rotor is used to approximate the inflow/outflow boundary conditions by introducing a three-dimensional point sink concept to satisfy the conservation of mass.

Because of the periodic nature of the flow for hovering rotors, calculations are performed for a single blade of the rotor, and the periodic boundary condition is applied between the blades[7].

3. Result and Discussion

Three dimensional, inviscid, incompressible analysis is performed for TsAGI test model[2] of Ka-60 shrouded tail rotor. In ref. [2], there are a few unknown values for test model. In present study, therefore, the configuration of test model is simplified and assumed to remove vertical fine and to have equal shroud radial thickness. Fig. 1 is TsAGI test model for Ka-60 shrouded tail rotor, and Fig. 2 is simplified configuration. In Fig. 2, the values in parentheses are assumed.

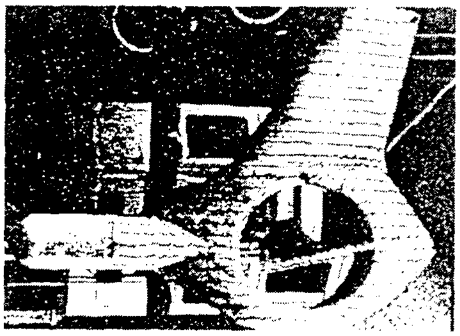

Fig. 1. TsAGI test model

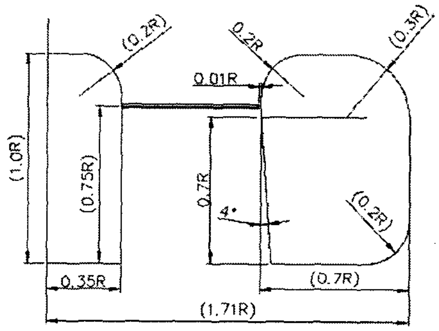

Fig. 2. Simplified configuration

Unstructured meshes are generated for one blade and meshes at two periodic boundaries match each other to use periodic boundary condition. The number of total tetrahedral cells is about 300,000 and the number of total nodal points is about 60,000. The distance of far boundary from solid surface is 5 times of radius. Fig. 3 and Fig. 4 show the triangulations of solid surface and periodic boundaries respectively.

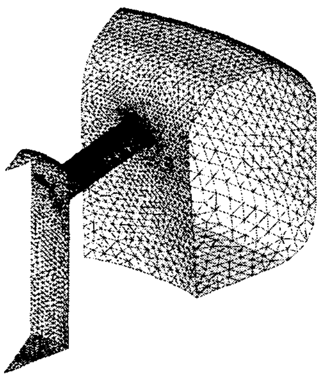

Fig. 3. Solid surface triangulation

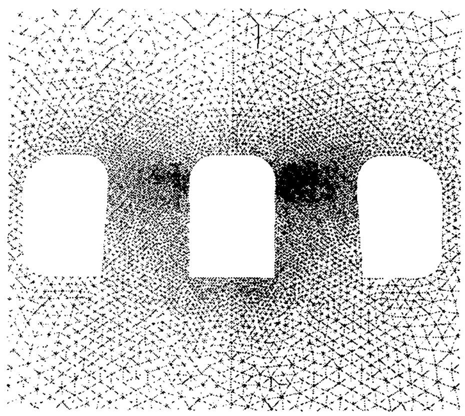

Fig. 4. Periodic boundary triangulation

To verify the present numerical method, inviscid compressible analysis for an isolated rotor without shroud in hover has been performed for the case that tip mach number is 0.22 and collective pitch angle at blade root is 45 deg. The computed thrust of the isolated rotor in the present study is overpredicted by 6 %. This overprediction is due to inviscid assumption of governing equations.

For the shrouded tail rotor, the calculated total thrust is overpredicted by 60% roughly. This is caused by assumptions and simplifications of the tail rotor configuration due to insufficient information of geometry. Simplified configuration has no vertical fin and equal shroud thickness. It can change the mass flow into the rotor plane and have an effect on the effective angle of attack.

Therefore, the correction of the collective pitch angle has to be made such that the overall performance matches with experiment to account for the uncertainties of the experimental model configuration.

In the final paper, it will be shown the detailed flows of the shrouded tail rotor with corrected corrective pitch angle such as spanwise indueced downwash and induced angle of attack distributions.

Acknowledgements

This work was supported by Korea Aerospace Research Institute via "Technology Development of the Helocopter Anti-torque System".

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