Large-eddy simulation using a cut-cell method of the flow over a ducted axial fan

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Long Abstract

Introduction

Due to extremely complex geometries and highly unsteady turbulent structures, the flow field in turbomachines has always been a big challenge in research. Flow phenomena near the tip-gap region of axially rotating blades are a significant source of inefficiency and therefore, one of the major problems in turbomachinery research. Aerodynamic losses, rotating instabilities, and blockage induced by the tip-leakage flow strongly affect the performance of turbomachines. Another important aspect is the contribution of the tip-gap flow to the broadband noise emission. For these reasons, the tip-gap flow will be focused on in this study.

1. Methods

The turbulent low Mach number flow through an axial fan at a Reynolds number of 9:36 x 10^5 based on the outer casing diameter is investigated by large-eddy simulation (LES). A finite-volume flow solver in an unstructured hierarchical Cartesian setup for the compressible Navier-Stokes equations is used. To account for sharp edges, a fully conservative cut-cell approach is applied [1], [2]. Using a new periodic boundary condition for Cartesian meshes the simulations are performed just for a 72° segment, i.e., the flow field over one out of five axial blades is resolved. A detailed grid convergence study is performed on four computational grids with 50 million, 250 million, 1 billion, and 1.6 billion cells focusing on the development of the vortical structures in the tip-gap region and being shed from the blade tip. Results of the instantaneous and the mean fan flow field are thoroughly analyzed based on the solution with 1 billion cells. High levels of turbulent kinetic energy and pressure fluctuations are generated by a tip-gap vortex upstream of the blade, the separating vortices inside the tip gap, and a counter-rotating vortex on the outer casing wall. An intermittent interaction of the turbulent wake, generated by the tip-gap vortex, with the downstream blade, leads to a cyclic transition with high pressure fluctuations on the suction side of the blade and a decay of the tip-gap vortex. The disturbance of the tip-gap vortex results in an unsteady behavior of the turbulent wake causing the intermittent interaction. For this interaction and the cyclic transition two dominant frequencies are identified which perfectly match with the characteristic frequencies in the experimentally determined sound power level.

References

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[2] L. Schneiders, D. Hartmann, M. Meinke, and W. Schröder, "An accurate moving boundary formulation in cut-cell methdods," Journal of Computational Physics **235**, 786-809, 2013.