Unsteady Numerical Simulations of Multi-Element Airfoil

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Project Term
2019 - 2020

Clusters
Lichtenberg Cluster Darmstadt

Software
OpenFOAM

Additional Software
ParaView

Institute
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University
Technische Universität Darmstadt

Introduction

As high-lift configurations, multi-element airfoils have shown satisfactory aerodynamic performance at high Reynolds number. The application of this kind of design to low-Reynoldsnumber cases could potentially benefit the development of small aerial vehicles. This potential benefit introduces the demanding for understanding the flow physics of low-Reynolds-number flows over multi-element airfoils. The experimental investigations in Beihang University have revealed novel flow structures and their complex interactions in the low-Reynolds-number flows over a two-dimensional 30P30N multi-element airfoil. However, further understanding on this kind of flow is limited by the two-dimensional experimental measurements, which can not resolve every detail of the three-dimensional flows over such a complex geometry. The current project hopes to obtain three-dimensional databases by numerical simulation, which could further promote the understanding of low-Reynolds-number flows over multi-element airfoils. However, all the simulations in the current project have large meshes (cell number larger than 7 million), which makes the using of High Performance Computer (HPC) necessary.

Methods

The eddy-resolving simulation tool, developed in the Institute for Fluid Mechanics and Aerodynamics (German name: Strömungslehre und Aerodynamik, SLA), is employed in the current project. To save the computational resources, a time-average is applied to the Navier-Stokes equations to avoid resolving the complex fluctuations. Due to the time-averaged process, a new unknown Reynolds stress tensor appears in the equations. As a result, turbulent models are needed to build the connections between the resolved mean flow and the unknown Reynolds stress tensor, which finally closures the governing equations. This is the basic idea of conventional RANS and URANS. However, limited by the fixed turbulence length scale, conventional RANS and URANS can not resolve fluctuations with different length scales, which are important for correctly predicting complex flows. Following the Scale-Adaptive Simulation concept of Mentor & Egorov, an eddy-resolving Reynolds stress model is developed from the conventional Reynolds stress model by SLA. An additional source term is added to the transport equation of specific rate of dissipation, which determines the turbulence length scale. This term could increase the production of specific rate of dissipation and then decrease the turbulent viscosity. Finally, the modelled part of turbulence is decreased and the resolved part, which could contain turbulent fluctuations, is increased. This tool has been well validated and shows good performance for several canonical cases.

Results

During the project period, several important results have been obtained:

- After persistent improvements, several good meshes, which could replicate the “waketriggered double-secondary vortices” case, have been generated. All the experiences behind this mesh improvement will be a big contribution to the academic community. Especially, the parameterized study of the effects of mesh density in the spanwise direction on the flows qualitatively reveals suitable mesh density for resolving reasonable flow patterns.
- With suitable numerical setups, the eddy-resolving simulation tool performs well for replicating the “wake-triggered double-secondary vortices” case. Several important flow patterns from the experiments (the wake-triggered double-secondary vortices, the threedimensional instability of double-secondary vortices and the regeneration and selforganization of hairpin vortices after the instability of double-secondary vortices) could be qualitatively revealed by the eddy-resolving simulation.
- The negative results for replicating “Görtler vortices” case intensify the challenge behind this case and help the researchers to find the correct direction.

Discussion

- The low-Reynolds-number flow over such a complex geometry is the state-of-the-art topic for both experiments and numerical simulations. The eddy-resolving simulation tool developed by SLA shows attractive performances for this topic. The three-dimensional databases from the eddy-resolving simulation shed light on the deep understanding of the flow physics.
- Though the “Görtler vortices” case has negative results now, positive results of this case should be expected in the next

period because of the attractive performances of our tool.

- Limited by the short project period, no quantitative result has been obtained yet. Running the simulation for longer time will be the main task of next period.

Reference

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