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Summary

Accurately modeling the aerodynamic impact of moving control surfaces on aircraft performance is a challenging yet essential task. It not only aids in understanding the effects of these devices on the surrounding flow but also contributes to the design of more efficient and quieter aircraft. In this thesis we develop methodologies and numerical methods aimed at simplifying the simulation of moving control surfaces, as well as enhancing the accuracy of predicting wall-bounded flows.

To model moving control surfaces effectively, separate meshes are necessary for each aerodynamic component. For instance, in a wing and aileron configuration, distinct grids must be created for the wing and the aileron. Initially, this research concentrates on simplifying the grid generation process for overset component grids. We propose a methodology to automatically generate overlapping regions between component grids, thereby reducing the time required for generating valid meshes. Subsequently, recognizing that the requirement for overlapping regions not only introduces mesh generation complexities but also computational overhead, we propose a new sliding interface method. This method effectively balances the fluxes between component grids without requiring overlapping regions, thereby enhancing overall efficiency.

The proposed methods are validated, and the sliding interface algorithm is employed in the simulations of the benchmark active controls technology (BACT) configuration, which encompasses a wing with upper and lower spoilers, as well as a trailing edge control surface. Here, we only consider the trailing edge device with respective spanwise gaps. Both Reynolds-averaged Navier–Stokes (RANS) and hybrid RANS-large-eddy-simulation (LES) turbulence models are considered for the static deployment of the trailing edge control surface, whereas only RANS models are used to compute the harmonically oscillating control surface. Comparative analyses reveal that while RANS simulations adequately predict overall flow trends for small control surface deflection angles, hybrid RANS-LES simulations offer deeper insights into flow characteristics within spanwise gaps.

In an effort to advance the capabilities of hybrid RANS-LES models for resolving wall-bounded flows in the future, we propose two new LES models: the single-layer and the two-layer anisotropic minimum dissipation (AMD)-Bardina models. These models combine the dissipative nature of the AMD model with the capacity to capture turbulent structure interactions, including backscatter, provided by the Bardina model. Notably, the two-layer
AMD-Bardina model exhibits significant promise in addressing wall-bounded flows, as it is able to almost perfectly match the first-order statistics from direct numerical simulations of turbulent channel flows at different Reynolds numbers.
Samenvatting

Het accuraat modelleren van de aerodynamische invloed van bewegende stuurvlakken op de prestaties van vliegtuigen is een uitdagende, maar essentiële taak. Het helpt niet alleen bij het begrijpen van de effecten van deze onderdelen op de omringende stroming, maar draagt ook bij aan het ontwerp van efficiëntere en stillere vliegtuigen. In dit proefschrift ontwikkelen we methodologieën en numerieke methoden die gericht zijn op het vereenvoudigen van de simulatie van bewegende stuurvlakken en het verbeteren van de accuraatheid van voorspellingen van wandgebonden stromingen.

Om bewegende stuurvlakken effectief te modelleren zijn aparte roosters nodig voor elk van de aerodynamische componenten. Bijvoorbeeld, in een vleugel en rolroer configuratie, moeten verschillende roosters gemaakt worden voor de vleugel en het rolroer. In eerste instantie concentreert dit onderzoek zich op het vereenvoudigen van het roostergeneratieproces voor overlappende roosters per component. We stellen een methodologie voor om automatisch overlappende gebieden tussen component roosters te genereren, waardoor de tijd die nodig is voor het genereren van toepasbare roosters gereduceerd wordt. Vervolgens stellen we een nieuwe glijdende interface methode voor, omdat overlappende gebieden niet alleen complexiteit van de rooster generatie met zich meebrengt, maar ook computatiele kosten. Deze methode balanceert in feite de fluxen tussen component roosters zonder dat overlappende gebieden nodig zijn, waardoor de algehele efficiëntie toeneemt.

De voorgestelde methoden zijn gevalideerd en het glijdende interface-algoritme is toegepast in simulaties van de benchmark active controls technology (BACT)-configuratie, die een vleugel met boven- en onderspoilers en een achterrand controle oppervlak omvat. Hier beschouwen we alleen de achterrand regelaar met spletten in de spanwijdte. Zowel Reynolds-averaged Navier-Stokes (RANS) als hybride RANS-large-eddy-simulatie (LES) turbulentiemodellen worden beschouwd voor de statische inzet van het achterrand controle oppervlak, terwijl alleen RANS-modellen worden gebruikt om het harmonisch oscillerende controle oppervlak te berekenen. Vergelijkende analyses laten zien dat terwijl RANS-simulaties de algemene stromingseigenschappen voor kleine afbuighoeken van het controle oppervlak adequaat voorspellen, hybride RANS-LES-simulaties diepere inzichten bieden in de stromingseigenschappen binnen de spletten in de spanwijdte.

Om de mogelijkheden van hybride RANS-LES modellen voor het oplossen van wandgebonden stromingen in de toekomst te verbeteren, stellen we twee nieuwe LES-modellen voor:
de enkellaags en tweelaags anisotroop minimum dissipatie (AMD)-Bardina modellen. Deze modellen combineren de dissipatieve aard van het AMD-model met de capaciteit van het Bardina-model om interacties van turbulente structuren, inclusief backscatter, vast te leggen. Met name het tweelaags AMD-Bardina-model is veelbelovend voor wandgebonden stromingen, omdat de eerste-orde-statistieken bijna perfect overeenkomen met die van directe numerieke simulaties van turbulente kanaalstromingen bij verschillende Reynoldsgetallen.
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