AERO-OPTICAL PREDICTIONS OF HIGH-REYNOLNDS NUMBER FLOWS USING WALL-MODELED LARGE-EDDY SIMULATION

Abstract

by

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Reliable prediction of optical wavefront distortions induced by compressible turbulent flow surrounding an aperture is crucial to the development of airborne laser systems. Large-eddy simulation (LES) with a wall model provides a promising high-fidelity simulation method for high-Reynolds-number aero-optical flows by avoiding the severe near-wall resolution requirement. In this study, wall-modeled LES is employed to predict and analyze aero-optical distortions of subsonic and supersonic turbulent boundary layers, and subsonic and transonic flows over cylindrical turrets at high Reynolds numbers. The results are compared to experimental measurements and previous results from wall-resolved LES at reduced Reynolds numbers.

For turbulent boundary layers at Mach numbers from 0.5 to 4.3 and Reynolds numbers up to $Re_\theta = 6.9 \times 10^4$, reasonable agreement is obtained between numerical predictions and experimental data in terms of the magnitude and structures of optical distortions. The optical statistics are dominated by large-scale flow structures in the outer layer. The density correlations and pre-multiplied power spectra capture the large-scale motions represented by hairpin vortices whose length scales are comparable to the boundary layer thickness.

Subsonic and transonic flows over a cylindrical turret are simulated under experimental conditions. The subsonic flow aero-optical results show agreement with the experimental data of Gordeyev et al. (AIAA Paper 2005-4657) and previous wall-resolved LES results. For the transonic flow, the simulation accurately predicts the fundamental frequency of the shock-induced pressure fluctuations and harmonics (Vorobiev et al., AIAA Paper 2014-2357). It is found that the piston and tilt components of the optical distortions are highly correlated with the shock-induced pressure oscillations, and the shock motion is clearly identified in the unsteady wavefront, which gives valuable input for the design of adaptive-optics systems synchronized with surface-pressure sensors. The LES data is also employed to provide a better understanding of the underlying physics of the shock-separation interaction.