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Title

Shell models of turbulence in aero-optics

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Abstract
The effects of turbulence have been studied for a long period of time and much progress has been made, but many phenomena associated with turbulence are still difficult to predict, especially for large Reynolds numbers. One such phenomenon is the laser beam propagation through turbulence. This paper presents a shell model approach that provides a rapid, computationally inexpensive analysis of the strength of turbulence and corresponding optical distortions, which relate to the turbulent fluctuations of the temperature, pressure and humidity. The approach is based on the combination of the shell model of turbulence for the case of the buoyancy driven turbulence, turbulence in the vibrationally non-equilibrium flow and aero-optics after transition to the Fourier space and introducing a spectrum of the refractive index. Using the developed model an analysis of the second order structure functions, spectrum of the turbulent kinetic energy and temperature, the refractive index spectrum and the refractive index structure parameter has been performed for the various temperature gradient. It is shown that the refractive index spectrum generated using the shell model reflects experimentally observed structure functions of temperature and behavior of the refractive structure parameter associated with the changeable temperature gradient. These changes correlate well with the behavior of the dissipation rate of the temperature variance in the shell model, and dependence of the structure function parameter on the temperature gradient follows the same tendency as the dissipation rate of the temperature variance, thus the enhancement of the temperature dissipation rate at the high temperature gradient causes the increase of the structure function parameter. The dissipation rate of the temperature variance is controlled by the initial conditions in the first shell, assuming classical scaling for the fluctuation spectrum of temperature. The proposed approach agrees well with the experimental observations of the refractive structure parameter and structure functions behavior, showing classical scaling in the inertial and dissipative subranges, and changes associated with the temperature gradient. Thus, the shell model can be used for the preliminary evaluation of the strength of turbulence and its changes with height assuming thermal forcing. Additionally, analysis of the effect of the vibrational non-equilibrium on the turbulent cascade has been performed on the basis of the developed shell model. It was also shown that changes in the structure function parameter are controlled by the rate of dissipation of the temperature variance, which depends on the level of the vibrational non-equilibrium. The more energy is in the vibrational mode the less is the local maximum of the energy dissipation rate. As a result, with the increase of the vibrational non-equilibrium formation of the similarity regime is postponed, and for the high level of vibrational non-equilibrium deviations from Kolmogorov scaling for the refractive index spectrum are observed.

References

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