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Direct numerical simulations of supersonic turbulent channel flows of dense gases. (English)

Zbl 1383.76293
J. Fluid Mech. 821, 153-199 (2017).

Summary: The influence of dense-gas effects on compressible wall-bounded turbulence is investigated by means of direct numerical simulations of supersonic turbulent channel flows. Results are obtained for PP11, a heavy fluorocarbon representative of dense gases, the thermophysics properties of which are described by using a fifth-order virial equation of state and advanced models for the transport properties. In the dense-gas regime, the speed of sound varies non-monotonically in small perturbations and the dependency of the transport properties on the fluid density (in addition to the temperature) is no longer negligible. A parametric study is carried out by varying the bulk Mach and Reynolds numbers, and results are compared to those obtained for a perfect gas, namely air. Dense-gas flow exhibits almost negligible friction heating effects, since the high specific heat of the fluids leads to a loose coupling between thermal and kinetic fields, even at high Mach numbers. Despite negligible temperature variations across the channel, the mean viscosity tends to decrease from the channel walls to the centreline (liquid-like behaviour), due to its complex dependency on fluid density. On the other hand, strong density fluctuations are present, but due to the non-standard sound speed variation (opposite to the mean density evolution across the channel), the amplitude is maximal close to the channel wall, i.e. in the viscous sublayer instead of the buffer layer like in perfect gases. As a consequence, these fluctuations do not alter the turbulence structure significantly, and Morkovin's hypothesis is well respected at any Mach number considered in the study. The preceding features make high Mach wall-bounded flows of dense gases similar to incompressible flows with variable properties, despite the significant fluctuations of density and speed of sound. Indeed, the semi-local scaling of *A. Patel* et al. ["Semi-local scaling and turbulence modulation in variable property turbulent channel flows", Phys. Fluids 27, No. 9, Article No. 095101, 24 p. (2015; doi:10.1063/1.4929813)] or *A. Trettel* and *J. Larsson* ["Mean velocity scaling for compressible wall turbulence with heat transfer", ibid. 28, No. 2, Article No. 026102, 18 p. (2016; doi:10.1063/1.4942022)] is shown to be well adapted to compare results from existing surveys and with the well-documented incompressible limit. Additionally, for a dense gas the isothermal channel flow is also almost adiabatic, and the Van Driest transformation also performs reasonably well. The present observations open the way to the development of suitable models for dense-gas turbulent flows.

MSC:

76F65 Direct numerical and large eddy simulation of turbulence
76N15 Gas dynamics, general
76J20 Supersonic flows

Keywords:

compressible turbulence; turbulence simulation; turbulent flows

Full Text: DOI

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