An actuator disk array within a turbulent Ekman boundary layer

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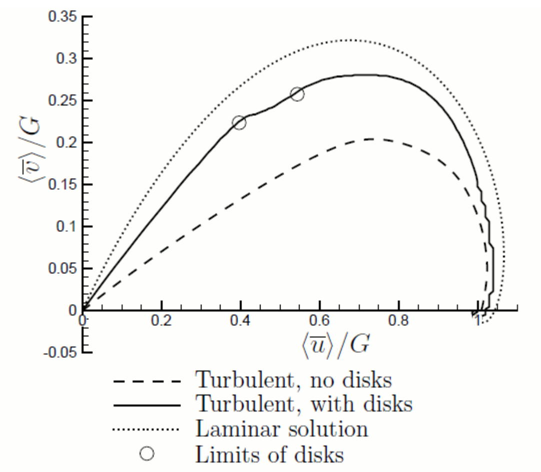
DNS of a neutral turbulent Ekman layer containing an actuator disk array is performed, with a view to improving the understanding of the coupling between the atmospheric boundary layer and large arrays of horizontal-axis wind turbines. An infinite array is simulated using 64 disks in a periodic domain. The disks are represented by body forces and aligned with the time-dependent incoming flow. The same flow is also simulated with disks absent. Relative to the latter simulation, the peak shear stress is doubled and located at the top of the disks, rather than at the wall. With a disk spacing of 5 diameters, the array efficiency is reduced to below 30%, in approximate agreement with the predictions of simple models approximating the turbines as roughness. We observe that the Ekman spiral limits the vertical transport of kinetic energy. The disks increase the boundary-layer depth, and the ratio of the ageostrophic to the geostrophic velocity component within the boundary layer, so that the Ekman spiral becomes more pronounced. These effects are required for the satisfaction of the global kinetic energy balance; the power output of the array is linked to the integral of the ageostrophic velocity over the boundary-layer depth. At disk height, the power extracted by the disks is locally balanced largely by the turbulent transport of mean flow kinetic energy. However, the increased turbulence kinetic energy production attributed to the disks is a large fraction of the power abstracted by them. The results suggest that mixed tower heights might use the available resource more efficiently



Mean velocity hodograph