Rotating turbulent flows and modeling

The motivation for the group effort in this section stems from the fact that it can be shown that all one point closure models currently used in RANS (Reynolds-averaged Navier-Stokes) codes fail to correctly model the effects of strong rotation on turbulence. Yet, turbulent flows that are subjected to system rotation are found in many situations, examples are turbomachines, the wing tip vortex, geophysical flows, and many others. A prime objective of the CTR is to foster a climate where new ideas on understanding and modeling of turbulent flows will generate innovations that become part of the foundation of the turbulence knowledge base. The five papers in this section form a good example where innovations in modeling and new insights into the effects of rotation on turbulence are achieved through the use of a combination of both theory and simulations (direct and large-eddy).

Blaisdell and Shariff performed direct numerical simulations of homogeneous turbulence in elliptic streamline flow. This is a new flow in a series of building block flows where particular issues about turbulence modeling and physics are addressed. In this flow, the effects of both rotation and strain combine to provide an instability mechanism that has been proposed as a universal mechanism for energy transfer from large scales to small scales. Four cases were simulated to investigate the effects of Rossby number and ellipticity. A fifth case at high resolution was carried out to test resolution and sampling issues. Statistics of interest to turbulence modeling are presented. The simulations lead to the discovery of a homogeneous flow where the non-linear cascade is periodically suppressed and re-established.

Mahalov derived and analyzed the evolution equations for long-time averaged rotating shallow-water equations. He then used the same approach to derive equations for homogeneous flows subjected to background rotation. In this case, he decomposed the flow field into two-dimensional modes that are unaffected by rotation and three-dimensional disturbances. He showed a connection between his physical space formalism and the helical wave space formalism. The derived equations may prove useful in explaining the effects of rotation on the turbulent transfer between the scales.

Squires, Chasnov and Mansour used large-eddy simulations to investigate the asymptotic similarity of rotating homogeneous turbulence. They build on their previous investigations where, in the limit of high Reynolds number and small Rossby number, power laws for the turbulent stresses and length scales were derived based on dimensional analysis and simulation results. In the present study, a search for similarity laws for the spectra was carried out. They defined four independent energy spectra and found scalings that would collapse three out of the four spectra. The spectrum which does not collapse corresponds to two component motions in the plane normal to the rotation axis. A strong reverse cascade of the energy from small-to-large scales is found. These results hint at the tendency of the flow to become two-dimensional.

Cambon, Mansour and Squires used the same large-eddy simulations as above to investigate the development of anisotropies and the tendency of the flow to become two-dimensional. This tendency is often used as a confirmation of the Taylor-Proudman theorem. However, it can be shown that a key assumption in the derivation of the theorem does not hold for homogeneous flows. Cambon has long argued that the observed two-dimensionalization in rotating flows is a non-linear phenomenon. In the present work, results from low-Reynolds number direct numerical simulations and from high-Reynolds number large-eddy simulation are unified by arguing for the existence of two transitions in rotating turbulence that can be identified by two key Rossby numbers. During the first transition, anisotropies develop when a macro Rossby number drops below unity. During the second transition, the nonlinear transfer is shut off when a micro Rossby number drops below unity. The large-eddy simulation fields were also analyzed for alignment between vorticity fluctuations and the rotation axis. The results confirm the dominance of corrotative vorticity in the long-time high-Reynolds number limit.

Hadid, Mansour and Zeman tested a new one-point closure model that incorporates the effects of rotation on the power-law decay exponent of the turbulent kinetic energy. This modification to the ϵ-equation was proposed by Zeman based on the large-eddy simulation results. During the summer program the model was successfully tested against experimental data of isotropic turbulence that was subjected to uniform rotation. A new definition of the mean rotation was proposed based on critical point theory to generalize the effects of rotation on turbulence to arbitrary mean deformations. The model was then incorporated in a code used at Rocketdyne and tested for a backward-facing step and a dump combustor. Preliminary results show promise. Further collaborations on modeling rotating flows will continue between CTR, NASA/Ames, and Rocketdyne.

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