Final Report

Center for Momentum Transport and Flow Organization (CMTFO)

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ABSTRACT:
The Center for Momentum Transport and Flow Organization (CMTFO) was established in 2009 as a multi-institutional U.S. DOE Plasma Science Center, with a focus on the fundamental physics mechanisms that lead to the transport of momentum within fusion and astrophysical plasma systems, and the subsequent formation of ordered behavior in such systems. It was funded in two tranches; this report covers the activities supported by the second period of funding which ran from May 2012 through May 2016.

Project Summary:

The Center has focused effort on basic laboratory measurements of collisional viscosity in plasmas, nonlinear MHD simulations of the solar tachocline region, experimental studies of momentum transport in accretion disk-like hydrodynamic flows, and the theory and experimental studies of spontaneous toroidal and poloidal flow formation in magnetic fusion devices. Collaborating groups are located at UC San Diego, UC Santa Cruz, PPPL, UW-Madison, and CU-Boulder.

Work at UC San Diego focused on studies of the formation of ordered zonal flows out of randomized turbulent fluctuations driven by the plasma pressure gradient. These studies were both theoretical and experimental in nature, with experiments occurring on a small scale laboratory plasma device (the CSDX device) at UC San Diego. This group also used the techniques and physics insights developed from this work to study the physics origin of the low-confinement mode (L-mode) to high confinement mode (H-mode) regime in tokamak devices. These experiments were carried out on the HL2A and EAST tokamaks located in China, along with the ALCATOR C-Mod and DIII-D tokamaks located in the USA. The results showed that the L-H transition is triggered by the turbulent Reynolds stress, which acts to concentrate turbulent flow into a narrow sheared jet at the boundary of the plasma. This coherent flow is powered by a nonlinear transfer of kinetic energy from the small-scaled randomized turbulence found at the boundary. This transfer process has to conserve total energy and momentum, and thus as the jet amplitude grows the turbulent amplitude must die away. As a result, the turbulent transport of particles and heat is largely eliminated in a thin layer at the plasma boundary. This then allows a strong ion pressure gradient to develop at the boundary; this gradient then “locks in” the strong sheared flow, resulting in a new stationary high confinement regime. These results helped explain at 30+ year old mystery in fusion research. References [1-17] below provide the key papers that document this work on a number of tokamak devices, together with related theory and modeling papers.

Work at UC Santa Cruz focused on using 3D nonlinear MHD simulations to study the formation of ordered sheared zonal flows within the solar tachocline, which is a thin zone lying between the solar radiative zone located deep within the sun, and the convective zone, which lies in the outer region of the sun. This zone is thought to play a key role in generating strong upwelling of stellar material and magnetic fields which erupt at the sun’s surface, and forming coronal mass ejections and prominences at the surface, which the basis for space weather that effects the Earth. The work also showed the important of conducting boundary conditions on the self-generation of a magnetic field from a turbulent flow (the so-called turbulent dynamo) in recently published experiment. These results are documents in references [18-20].

Work at UW-Madison was focused on the first experimental measurement of classical collisional viscosity in a plasma. This work used a novel plasma-based Couette flow device to apply rotation to the outer layers of an unmagnetized cylindrical plasma. The gradual inward propagation of this flow layer then permitted the viscosity to be determined. The results showed that collisional theory is in fact correct, and that the observed collisional viscosity is consistent with theory. This work is documented in references [21, 22].

Work at CU-Boulder was focused on the use of optical diagnostics to characterize the development of drift waves and drift turbulence in a magnetized plasma, and to compare these results against probe-based measurements. In addition, CU-Boulder researchers also developed optical-flow velocimetry as a technique to infer turbulent flow fields in magnetized fusion plasmas. The results provided confirmation of the formation of coherent drift wave instabilities at conditions near the theoretical threshold for instability, and provided new techniques to infer turbulent flows at the boundary layer region of tokamak devices. This work also was used to study the development of turbulence in a linear plasma device driven by multiple free energy sources (i.e. electron and ion pressure gradients), and to show that this turbulence could be modeled as a series on interacting monopole vortices. These results can be found in references [23-26].

Work at PPPL focused on experimental studies of hydrodynamic stability of non-Keplerian sheared flows. In particular, these workers carried out an experiment to see if such flows become unstable when a large amplitude velocity perturbation is applied to them. This search for a so-called sub-critical instability showed that, in fact, no such instability occurs up to very high Reynolds numbers. The results imply that the rapid accretion found to occur in the accretion disks found around newly formed stars and compact objects cannot be explained by purely hydrodynamic processes and that, in fact, other physics associated with ionized gases must therefore be at work. This work is documented in references [27-30].

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