Driven and intrinsic rotation, rotation sinks and momentum transport

Rotation and velocity shear are important for their role in the H-mode transition, ITB formation and RWM suppression. The magnitude, direction and velocity profile shape are determined by a combination of rotation sources, momentum transport and any sink mechanisms that are present.

Rotation can be driven by external momentum sources, or can be self-generated (intrinsic or spontaneous rotation). The most common method of direct external momentum input is via neutral beam injection. Flow drive by mode conversion of the ICRF fast wave has recently been demonstrated, which is directed co-current, and has a higher efficiency than NBI. Counter-current rotation has been observed with LHCD, but since the mechanism is not currently understood, this may not be considered as external flow drive. Complex profile shapes, co- or counter-current in the core while co-current at the plasma edge, have been observed with ECH and ECCD, but since the mechanism is similarly not well understood, this also might not be considered as external flow drive. Large co-current velocities (up to 150 km/s, ion thermal Mach number ~0.3) have been observed in ICRF discharges, but this is most likely not due to wave or fast ion orbit effects. The rotation speed is most closely correlated with the pedestal pressure gradient and is not externally driven. Very similar spontaneous rotation has been observed in Ohmic H-mode plasmas, which is certainly not externally driven. One area of controversy is the apparent discrepancy between observed poloidal rotation and neo-classical calculations, which depend mainly on the temperature gradient.

Momentum transport is usually characterized as anomalous, with observed momentum diffusivities frequently more than an order of magnitude larger than neo-classical values. Momentum transport is closely related to ion thermal transport, and Prandtl numbers are generally found to be in the neighborhood of unity. Turbulent momentum transport is relatively well understood, and recent observations of an inward momentum pinch are in good agreement with theory. Currently there is a lot of theoretical effort in understanding off-diagonal momentum transport coefficients, the residual stress.

The most common sinks of rotation are due to magnetic perturbations that break toroidal axisymmetry. Resonant magnetic perturbations due to error fields can lead to strong toroidal rotation damping, sometimes followed by mode locking or disruption. Non-resonant perturbations can manifest themselves as neo-classical toroidal viscosity, which can lead to a large counter-current offset in the toroidal rotation velocity.

Looking ahead to reactor-grade plasmas, momentum input in the core from NBI is likely to be minimal due to the large machine sizes, high densities and high beam energies. The two alternatives are intrinsic rotation or some variety of RF drive. While extrapolation of intrinsic rotation from an inter-machine database appears favorable (for example, intrinsic rotation of several 100s of km/s is predicted for ITER), relying on a mechanism without a strong theoretical underpinning is risky. Recent observations of ICRF MCFD look promising, although verification on a variety of devices, along with a more stringent comparison with theory, should be undertaken. Further work with ECH, ECCD and LHCD should also be pursued as potential profile control tools.

Momentum transport is comparatively well understood, but off-diagonal terms should attract further study.

A potential problem area pertains to momentum sinks. Care must be taken to minimize error fields, and a system to cancel error fields with a coil set would be prudent. RMP coils for suppressing ELMs look very promising for that purpose, but further study on possible unwanted toroidal rotation damping is warranted. The counter-current offset to rotation from NTV could potentially cancel out externally driven rotation and needs to be documented in order to extrapolate to future devices.

Action items:

MCFD- document on a variety of devices, refine theory for comparison.

LHCD, ECH, ECCD- document on a variety of devices, develop theory for explanation.

Spontaneous rotation- more theoretical work needed for explanation of mechanism.

Poloidal rotation- further documentation and comparison with neo-classical theory.

Momentum transport- continue experiments, develop database, further comparison with theory, expand theory of residual stress.

Sinks- continue studies of resonant and non-resonant magnetic perturbations.