We present new experimental results from the University of Maryland Three Meter Geodynamo experiment. We drive a fully turbulent flow in water and also in sodium at magnetic Reynolds number $Rm = \Delta \Omega (r_o - r_i)^2/\eta$, up to 715 (about half maximum) in a spherical Couette apparatus geometrically similar to Earth’s core. We have not yet observed a dynamo, but we study MHD effects with an externally applied axisymmetric magnetic field. We survey a broad range of Rossby number $-68 < Ro = \Delta \Omega/\Omega_o < 65$ in both purely hydrodynamic water experiments and sodium experiments with weak, nearly passive applied field. A large number of distinct turbulent flows are observed in different ranges of Ro. We characterize angular momentum transport and generation of internal toroidal magnetic field (the $\Omega$-effect) by these different flow states. The angular momentum transport, characterized by the torque on the inner sphere, shows some common features with recent findings in Taylor-Couette flow, but different behavior for Ro > 0 which suggests enhancement of angular momentum transport by system-scale Rossby waves. Internal azimuthal field generation peaks at Ro = 6, and at this Ro we also increase the strength of the applied field and observe a reduction of the $\Omega$-effect, a large increase in angular momentum transport, and the onset of new dynamical states. The state we reach at maximum applied field shows substantial magnetic field gain in the axial dipole moment, enhancing the applied dipole moment. This intermittent dipole enhancement must come from nonaxisymmetric flow and seems to be a geodynamo-style feedback involving differential rotation and large-scale drifting waves.