GA–C26082
Rev. 1

FES JOULE MILESTONE 2008

by
DIII-D, C-Mod, and NSTX Research Teams

MAY 2008

GENERAL ATOMICS

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Annual Target

Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY08, FES will evaluate the generation of plasma rotation and momentum transport, and assess the impact of plasma rotation on stability and confinement. Alcator C-Mod will investigate rotation without external momentum input, NSTX will examine very high rotation speeds, and DIII-D will vary rotation speeds with neutral beams. *The results achieved at the major facilities will provide important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas.*

QUARTER 2 MILESTONE

Begin conducting planned experiments on at least one of the three facilities.

COMPLETION OF 2ND QUARTER MILESTONE

All three facilities have initiated a significant number of the experiments listed on the FY08 plan submitted at the end of the 1st Quarter. The spreadsheet listing of experiments appended below has been updated. The added column lists experiments that have received run time in the 2nd quarter, using the identification scheme unique to each facility, XP# (experimental proposal) for NSTX, MP# (mini-proposal) for C-Mod, and FY08 experimental designation numbers for DIII-D, e.g. 02-01. The website for each facility gives further information about each experiment as identified by these designations. These websites are listed at the end of this report.

The data from these experiments must be analyzed further before any firm conclusions will be forthcoming. As seen in the spreadsheet, all facilities have devoted some experimental time to the addition of resonant, or non-resonant magnetic error fields to investigate the effect upon rotation. This focus is aimed at obtaining improved understanding of what to expect for ITER, given the proposed magnetic perturbation coils now under discussion there, and an assumed level of random magnetic error fields.

C-Mod has initiated a unique experiment on intrinsic rotation utilizing their new lower hybrid (LH) system. There appears to be a signature in the intrinsic rotation profile with co-directed (to the plasma current) LH current drive. This should provide further insight into what could be a local rearrangement of toroidal angular momentum. Figure 1 shows data versus time from the LH current drive (CD) experiment (MP523) on C-Mod this quarter. The average density, n_e, and central electron temperature, $T_e(0)$, traces in Fig. 1(a) and 1(b) show relatively small changes with the application of LHCD power, shown in Fig 1(c). The CD is in the toroidal direction of the plasma current. The central plasma toroidal velocity, $V_{Tor}(0)$, Fig. 1(e), is in the direction counter to the plasma current, indicated by being negative, and this velocity accelerates in the counter direction with the application of LHCD. Figure 1(d) shows the plasma internal inductance, l_i, which is reduced with LHCD, indicating a broadening of the plasma toroidal current profile. This toroidal acceleration with LH electron current drive is a novel, and potentially useful effect. The LHCD wave applies no significant torque to the plasma, so this is an intrinsic rotation effect.

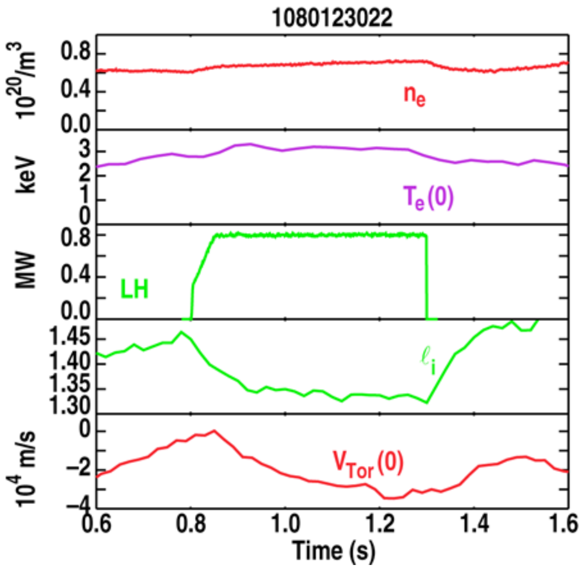

Fig. 1. CMOD data from FY08 experiment on the effect of LHCD upon the toroidal rotation velocity of the plasma. (a) averaged electron density (b) central electron temperature (c) Lower Hybrid wave power (d) plasma internal inductance, (e) central toroidal velocity showing acceleration in the negative (counter-Ip) direction with LH power.

In Fig. 2 we show data from the DIII-D experiment (53-01) conducted this quarter to investigate the rotation effect upon the power required to make the transition from low confinement, L-mode, to the high confinement regime, H-mode. This power is designated by P_{thres} and plotted on the vertical axis. The horizontal axis is plotted as the net torque delivered by the neutral beams, which is used to vary the toroidal rotation at the time of the L-H transition. A positive torque is in the direction of the toroidal plasma current. The blue and red points are from an experiment in 2007. The green symbols add data from this year, with electron cyclotron heating (ECH) into the power mix this year in order to add heating with no torque. Some points on the torque = 0 line are with ECH only in order to get a comparison with balanced neutral beams. The direction of ∇B toward or away from the X-point is known to vary P_{thres}, with more power required for “away”. The lower P_{thres} for low rotation, that is low torque, is an important result that projects favorably to ITER. This experiment and follow on work seeks to understand what causes the variation with rotation.

In Figs. 3 and 4 we show data from two NSTX experiments that are utilizing different methods for modifying the toroidal velocity of the plasma in order to study toroidal momentum transport. Time traces from an experiment adding an $n = 3$ toroidal mode magnetic perturbation field are shown in Fig. 3. The top frame shows that three different values of plasma current are being used in a parameter scan. The middle frame shows the timing of the added magnetic perturbation current and the bottom frame shows the reduction of the toroidal velocity at one location for each plasma current case, due to the drag from the perturbation. The decay in the overall velocity profile and the recovery will be used for momentum transport analyses. In Fig 4 two full radial velocity profiles are shown for two different values of the neutral beam power, and thus different levels of the torque driving the rotation. This provides another way to perturb the velocity profile for transport experiments.

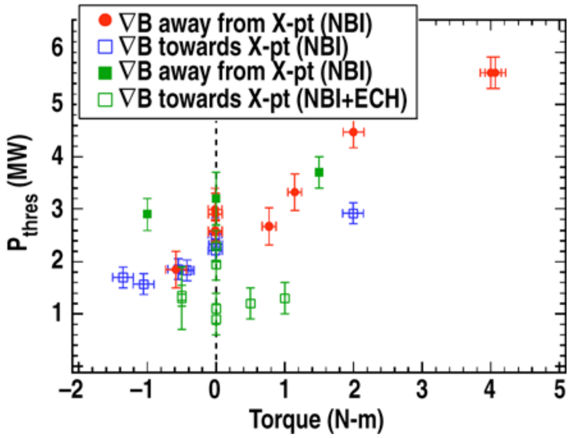

Fig. 2. DIII-D FY08 experiment on the effect of toroidal rotation on the power required for transition from the L to H mode, P_{thres}. The green symbols represent new data from this year, and include points for electron cyclotron heating (ECH) only, plotted at the Torque = 0 location.

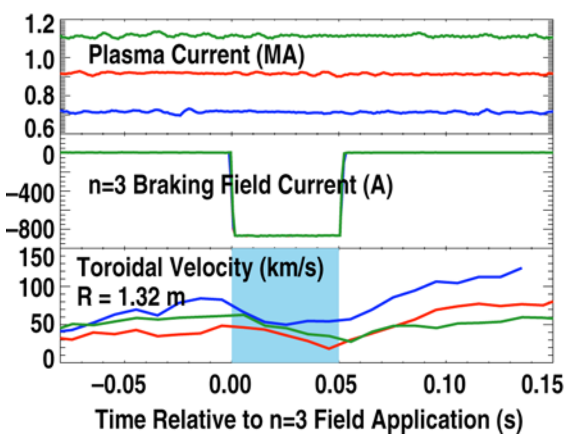

Fig. 3. Time traces from an NSTX experiment on the effect of $n = 3$ magnetic perturbations on plasma toroidal velocity. a) Traces of plasma toroidal current, showing three values tested. b) Current pulse in coils producing the $n = 3$ perturbation. c) The reduction in toroidal velocity during application of the perturbation, at a location roughly 2/3 out from the plasma magnetic axis.

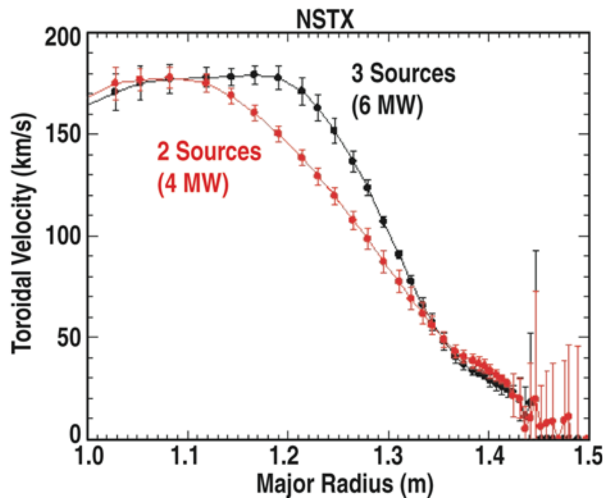

Fig. 4. Two radial profiles of the toroidal velocity in NSTX, showing the ability to vary the profile with different neutral beam powers, and torques. This experiment investigates toroidal momentum transport by the time history of profile relaxation.

Two additional emergent experiments relevant to the JOULE milestone have been added to the list. In DIII-D an experiment was added (#41) to investigate any coupling between the main plasma rotation and flows in the scrape-off-layer, outside the contained plasma. In C-Mod one was added to the list (#42) which will use a fast change in the plasma shaping to induce a change in the intrinsic rotation profile. The subsequent relaxation will be used to investigate intrinsic momentum transport.

Websites for further information on the experiments are found at:

CMOD: List of experimental mini proposals (MPs) and links to run date where applicable.
https://www.psfc.mit.edu/research/alcator/program/cmod_runs.php?miniproposals&sort=date_filed&dir=desc

NSTX: List of experimental plans (XPs) with files that describe the XPs listed here.
http://nstx.pppl.gov/DragNDrop/XP_Folder/Approved_XPs/FY08/

DIII-D: List of experiments by date with a link to the mini proposals describing the experiments. The experimental number used in the attached spreadsheet is comprised of the numbers in columns 4 and 5.
https://diii-d.gat.com/diii-d/Expsched08

Apendix A

Not in priority order

FY2008 Joule Milestone 2nd Quarter Progress
C=C-Mod N=NSTX D=DIII-D

Numbers for linkages to others

Area		exp	Title	links	exp	Experiments started in 2nd Quarter
IA Sources: Intrinsic	C	1	Intrinsic rotation database continuation	5,6	1	Multiple exps
	C	2	Intrinsic rotation profile evolution	5,13,14	2	Multiple exps
	C	3	Rotation in LHCD plasmas, (and possibly MCEH plasmas)	6	3	MP523
	C	4	Rotation inversion vs ne, Ip - in limiter/divertor plasmas		4	
	D	5	Intrinsic rotation at high normalized pressure using balanced NBI	1,2	5	02-03
	D	6	Expand DIII-D intrinsic rotation database, especially shape effects, SOL flows	1,3	6	
	D	7	Measure edge turbulent momentum transport (relates to boundary condition)	8	7	
	N	8	Mean and oscillating turbulent flows using Doppler reflectometry	7	8	
IB Sources: Driven	D	9	Measure off-axis NBCD and validate NBCD physics		9	55-02
	D	10	Affect of Alfven Eigenmodes on NBCD and fast ion profileÜ		10	
II Momentum Transport	N	11	Perturbative modulation of core rotation using beam blips; diffusion and pinch.	14,2	11	XP820
	N	12	Non-core perturbative modulation of rotation using n=1 magnetic braking blips	19,20	12	XP813
	C	13	Momentum transport, locked/unlocked	2,20,22,12	13	
	C	2	Intrinsic rotation profile evolution	11,14	2	
	D	14	NBI modulated transport at low rotation with balanced NBI (piggybacks)	2	14	
	C	42	Momentum impulse due to rapid shape change (SSEP)	2,20,22	42	MP537
IIIA Sinks:	N	15	Comparison of NTV among tokamaks	18	15	XP804
non-resonant b	N	16	Island-induced NTV		16	
	D	17	Test Two vs. One row ELM-suppression coils for ITER, n=3		17	03-01
	D	18	Test NTV offset rotation, and collisionality effect, with applied n=3	15,21	18	02-01 02-02 02-07
IIIB Sinks:	C	19	Intrinsic rotation with n=1 braking	12	19	MP478
resonant b	D	20	Resonant n=1 braking and error field thresholds	12,13	20	02-05
IV b Penetration	D	21	RMP screening or amplification dependence upon rotation	18	21	
	C	22	Rotation in H-modes and locked modes	13	22	
V Boundary Condition	C	23	Er well spatial structure and parameter scaling		23	MP538
	D	7	Measure edge turbulent momentum transport	8	7	
	D	5-7	included in these experiments		5-7	
VI Main ion rotation/	C	24	Edge ion rotation in helium plasmas (related to boundar condition)	25	24	MP519

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Apendix A

FY2008 Joule Milestone 2nd Quarter Progress
C=C-Mod N=NSTX D=DIII-D

Not in priority order

Numbers for linkages to others

Neoclassical theory	D	25	Main ion rotation studies (helium)	24,26	25	
	N	26	Poloidal rotation studies; relation to neoclassical theory	25	26	
VIIA Rotation and Stability - RWM	D	27	Measure RWM damping by plasma rotation	29	27	
	D	28	Demonstrate RWM feedback stabilization at low rotation		28	14-01
	N	29	RWM stabilization and damping	27	29	XP805
	N	30	Active RWM feedback stabilization optimization		30	
VIIB Rotation and Stability - NTM	N	31	Rotation dependence of 2/1 NTM thresholds	33	31	XP801 XP810
	N	32	Studies of the 3/2 NTM; rotation and rampdown	34	32	
	D	33	Effect of rotation on NTM beta limits	31	33	
	D	34	NTM 3/2 mode stability at low rotation	32	34	
VIII Impact of Rotation on Confinement	N	35	Dependence of energy and impurity transport upon rotation (n=3 modification)		35	XP812
	D	36	Changes in confinement with rotation		36	
	C	37	Rotation during sawteeth	33	37	MP520
IX Other Rotation Effects that impact ITER	D	38	Dependence of the L->H power threshold upon rotation		38	53-01
	D	39	QH mode at low small plasma rotation		39	03-02
	N	40	Dependence of the L->H power threshold upon rotation through n=3 braking		40	
	C	1	Intrinsic rotation database continuation		1	
	D	41	Effect of Core Rotation on SOL flows		41	56-01