1. Purpose of Experiments

The purposes of this experiment are to understand the consequences of requiring that the current profile and the pressure profile be tightly coupled via the condition of high bootstrap current fraction in the collisionless regime and to study the behavior of fully noninductive plasmas when the total current is not constrained by pre-programming. Two cases will be examined: EDA H-mode and density Internal Transport Barrier (ITB) plasmas.

2. Background

Steady-state discharges in ITER and following reactors must, of necessity, be fully noninductive and dominantly of bootstrap origin. For example, it takes 30 MW of gyrotron waves (150 MW of fusion thermal power) to drive 1 MA of plasma current via ECCD in the core of ITER. For efficient operation the bootstrap fraction should be 90%. In these discharges, the current and pressure profiles as well as transport and stability are closely coupled. The objectives of this experiment are threefold: To begin to explore the self-consistent profiles of current and pressure reached by a fully noninductive, high-bootstrap-fraction, collisionless discharge; Second, to examine whether this state is dynamically stable; And third, to ascertain whether it has good confinement and high stability limits. Operationally, the present experiment is designed to produce fully noninductive, essentially 100% bootstrap current discharges and to determine what initial conditions lead to a stationary final state (and what conditions lead to collapse of the plasma), under what conditions the current and pressure profiles in this state are stable, against both MHD instability and steady decay, whether the final state is unique (for given particle and energy sources), and what is the maximum stable beta in the self-consistent stationary state. Previous experiments with transformerless operation on DIII-D have shown a marked sensitivity to small MHD perturbations. It will be important to understand the extent to which this affects the achievable beta.
3. Approach

Alcator C-Mod is well-suited to achieve these objectives as its dominant heating method, minority ICRF, does not directly drive current and thereby mask the bootstrap current. Its small size accelerates L/R decay of unwanted inductive currents while the strong magnetic field maintains good confinement. The experimental approach will be to produce, with inductive current control and the maximum available RF power, a target plasma with the highest bootstrap fraction possible. This leads one to low-current discharges - 200-500 kA. The location of the ICRF resonance will be varied so that either EDA H-mode or ITB discharges will be available for investigations. Both on- and off-axis heating will be necessary to control ITB plasmas. One must remark that the high electron-density gradients of ITB plasmas are very favorable for increasing bootstrap current.

Planning estimates indicate that high bootstrap fraction discharges in C-Mod will occur at quite low plasma currents 200 - 300 kA. The scenario to achieve high bootstrap fraction proceeds as follows: An initial transformer current ramp will be establish observes the plasma evolution. As the total current decays, theory predicts that the bootstrap fraction will increase. Hopefully the discharge will eventually settle into a self-consistent, self-organized, steady-state plasma with or without an internal transport barrier. The plasma current will be almost entirely of bootstrap origin driven by the pressure gradients which in turn are maintained by the ICRF heating. Since the discharge is by now steady-state, there will be no loop voltages in the system. Control of density peaking, with pellets or spontaneously via an ITB, will be very useful in increasing the bootstrap current. Scaling of anticipated results will be documented in a separate memo. Currents in the range 200-400kA are expected based on scaling from existing discharges.

If high-bootstrap discharges are found, then scans of density, heating power, rf frequency and plasma size and shape will be needed to support projections to reactor-scale devices.

A concern is that the heating - 4 MW for 5s - is too weak and thus the plasma will be on the fringes of the collisionless region.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

**Toroidal Field:** 4.0-7.0 T

**Plasma Current:** 200-400 kA

**Working gas species** = D

**Density:** \((1.0-2.0)*n_{20}\) (H-mode phase)
Equilibrium configuration $SN, \kappa = 1.7$

pulse length = 5sec

4.2 Auxiliary Systems

RF Power 4 MW @ 80MHz, at least 1 MW @ 70 MHz, pulse length = 5s, phasing = dipole

Pellet Injection: D

Diagnostic Neutral Beam:

4.3 Diagnostics

full magnetics, $[n_e]> , T_e ,$

5. Experimental Plan

Both sections must be filled in.

5.1 Run sequence plan

Up to three half-day sessions to develop initial discharges. $T_e(0) = 1.5$ keV is expected. Provided a successful plasma formation technique can be found, full-day scans to determine the maximum stable heating power and density as well as an optimized shape and bootstrap fraction will be carried out for both H-mode and ITB plasmas.

5.2 Shot sequence plan

develop low current (500kA), peaked density & pressure target discharge. Vary ICRF resonance location to choose H-mode vs. ITB plasmas.

after target plasma is established, release transformer current control (or equivalent) and allow current to evolve

adjust initial current so that minimum evolution occurs

raise beta (at fixed poloidal beta for 100% bootstrap) by increasing power in quasi-steady discharge and document profile changes and stability limits

establish existence of of 100% bootstrap with a density ITB (which should greatly increases the bootstrap current. This is implemented by moving the ICRF resonance to the high-field-side.
6. Anticipated Results

The objective is to provide an experimental basis for steady-state plasma operation with 100% bootstrap current. This is the key operational mode foreseen for a steady-state fusion reactor and has yet to be demonstrated experimentally. To date, steady-state plasmas have had a current drive fraction of 10% or higher. This experiment can also be carried out in JET or TORE-SUPRA and an early start on this research is recommended to avoid being scooped. The results of this experiment will also define rf power requirements to test toroidal beta limit. (A 100% bootstrap plasma has fixed poloidal beta)

7. References