1. Purpose of Experiments
Include immediate goal of the experiments, scientific importance and/or programatic relevance.
Refer to any relevant program milestones.

The proposed experiment will investigate the sensitivity of the locked mode threshold on \( q_{95} \), particularly for \( q_{95} \approx 3 \). The results will help clarify recent observations in the ITER-shape development experiments (MP#362), and contribute to the overall understanding of error-field effects.

2. Background
Discuss Physics basis of the proposed research, Prior results at Alcator or elsewhere, and any related work being carried out separately

Locked mode activity during recent experiments [1,2] in support of MP#362, to develop high normalized current equilibria in the ITER shape, has been difficult to explain in terms of known and inferred intrinsic 2/1 error fields, which were believed to be nearly cancelled in these experiments by use of the non-axisymmetric control coils. One possibility is that our present model of the 2/1 error is incorrect or at least incomplete, such that the magnitude or phase of the A-coil current applied in this experiment was inadequate. Another possibility is that the observed locked mode is dominantly driven by sideband effects of uncompensated error field components with \( m/n = 1/1 \) or \( 3/1 \). The ability of such sidebands to induce locking at the \( q = 2 \) surface, due to toroidal and shaping effects, has been observed experimentally [3,4] and accounted for theoretically [5]. For example, in experiments in Compass-D [4], which has extremely low intrinsic error fields and the capability of providing nearly harmonically pure applied, 2/1 islands were driven by application of 3/1 perturbations alone. Similar results were reported with dominantly 1/1 applied fields.

The intrinsic error field in C-Mod, particularly the 1/1 and 3/1 components, are not very well known. A model which incorporates known (as-built/as-designed) assymetries in the OH windings and TF bus, as well as tilt and shift displacements of the PF ring coils inferred from single coil test pulses has been developed [6], but significant uncertainties
remain. According to the model, the phase of the 1/1 intrinsic error component is approximately opposite to that of the 2/1. Since the standard A-coil configuration has the 2/1 and 1/1 components aligned, compensation of the 2/1 error leads to augmentation of the 1/1 error field. Speculation following the run on 1031126 considered the possibility that the combined intrinsic and applied 1/1 field was responsible for the observed locking. However, evidence from the run on 1040127 indicates that increasing the A-coil current delayed or prevented onset of the locked mode in these discharges, while decreasing the A-coil current resulted in earlier onset of the mode. It therefore seems unlikely that the 1/1 component is the major problem in these experiments.

In JET [3] the stable operating space in $\langle n_e \rangle$ vs $q_\psi$ was characterized by steps at integer q values, at least in limiter discharges. Theoretically, Fitzpatrick and Hender [5] accounted for this behavior in the presence of a multi-mode external perturbation as being due to shielding of the 3/1 component from the $q=2$ surface by an ideal $q=3$ surface when $q=3$ enters the plasma. Similar effects are predicted for higher $m$ and their corresponding q surfaces. Since the ITER-shape experiments were carried out with $q$ just below 3, this effect may be playing a role.

The scaling of the locked mode threshold proposed in the ITER Physics Basis [7], based largely on scaling studies at DIII-D and JET, is $\tilde{B}/B_T \propto q^{-0.05}$. However, recent results [8] from the JET portion of the JET/C-Mod error-field identity experiment (MP#361) have indicated a significant variation, approximately $\propto q^1$ in applied field at constant $B_T$ between $q = 3.2$ and $q = 4.2$.

This proposal aims to investigate the locked mode threshold as a function of q, and particularly near $q=3$, for more standard equilibria, where the vertical stability is not an issue (as it is for the ITER shape) and at lower current where disruptions are more benign. The goals are to test the overall scaling of the locked mode threshold with $q$ and to determine whether there are sharp features in the vicinity of integral edge $q$.

3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

Ideally, the determination of the effect of the presence of a shielding surface at $q=3$ on the onset of a 2/1 locked mode would be done in the presence of a known substantial 3/1 applied field. Unfortunately, the C-Mod non-axisymmetric coils do not produce much 3/1 component in any configuration, and the ratio of 3/1 to 2/1 is never more than about 25% (except in cases with dominant reverse helicity, i.e. -2/1, which have never been shown to result in driven locked modes). Therefore, the most suitable source of error field may be the intrinsic error itself. The drawback of this approach is that the magnitude of the non-axisymmetric perturbation is not measured, and we must rely on a model to justify the condition that it changes only slightly over the range of conditions in the experiment.

The proposed experiment is along the lines depicted in Fig. 5 of reference [3]. The locked mode stability will be mapped out as a function of density at constant current for a
series of q values, obtained by varying $B_T$. According to the calculations in [6], the toroidal field bus does not contribute significant 3/1 error field (typically $B_{TF}^{31}/B_T \approx 10^{-5}$). The calculated variation in the 2/1 and 1/1 components over the proposed range of toroidal fields is 0.8 G and 1.4 G, respectively. Use of the density of locking as a proxy for the threshold non-axisymmetric field is commonly done in cases where the total error-field is not known, and is based on the observation that the threshold field is nearly linearly proportional to density in cases where the applied field is dominant or the intrinsic errors are sufficiently well-known to be subtracted off. The present C-Mod dataset is inadequate to confirm the exact scaling at this time, but the data are at least semi-quantitatively consistent. Better data on this subject is expected from the results of the C-Mod portion of MP#361, the C-Mod/JET identity error-field experiment.

Shots will be modeled after 1030715025, a 1MA, 5.4 T, $q_{95} = 3.9$ lower single null with density ramping down from $n_e = 1.2 \times 10^{20} m^{-3}$ ($nl_{04} = 8 \times 10^{19} m^{-2}$) at 0.45sec to minimum achievable value at the end of the current flattop. The A-coil will be turned off for most shots. Shot 1030715025 had a locked mode onset at a density $\bar{n}_{Lock} \approx 8 \times 10^{19} m^{-3}$; a subsequent shot, #27, demonstrated locked mode suppression with the A-coil down to $\bar{n}_e = 4.5 \times 10^{19} m^{-3}$. We will first repeat 1030715025, and then vary q from 4.2 down to 2.7 while monitoring the locking density. The range of fields to be covered is $6 \geq B_T \geq 3.8$.

Following this main scan, we will repeat a portion of the q-scan by varying current while keeping $B_T$ constant at approximately 4 T, making contact with the well-documented 4 T, 600 kA cases of MP#339, Run 1030618. In this scan, we expect that the intrinsic error field in all components will be varying significantly with the plasma current, as the OH and EF coil currents will be changing. In an effort to better quantify this effect and provide further benchmarking for the intrinsic error model, we will carry out the current scan using shots with and without the A-coil energized in a standard configuration.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field:** -3.8 to -6.0T
- **Plasma Current:** -1.1 MA to -600kA
- **Working gas species:** D$_2$
- **Density:** $nl_{04}$ ramped from 0.8 to $0.2 \times 10^{19} m^{-2}$
- **Equilibrium configuration (if possible, refer to database equilibria):** 1030715025

**Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms:

Current EOF at 1.5sec, density rampdown from 0.45 to 1.5sec
4.2 Auxiliary Systems

RF Power, pulse length, phasing: None
Pellet Injection (species): None
Impurity blow-off injection: None
Diagnostic Neutral Beam: OK, not required
Special gas puffing: Ar for rotation measurement
Other: A-coil (+DTOP -DBOT -JTOP +JBOT) for part 3 of the run plan.

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

Standard magnetic diagnostics

HIREX for rotation (desirable, not essential),

ECE (FRCECE if possible, GPC and GPC2 with gratings adjusted to give coverage over as much as possible of the range of TF requested.)

5. Experimental Plan

Both sections must be filled in.

5.1 Run sequence plan

Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period (10 hours maximum), etc.

One run day.

5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements etc. Include contingency plans, if appropriate.

1. Reproduce shot 1030715025 (1MA, 5.4T, A-coil off, density rampdown [1-2 shots]

2. Scan $B_T$ up to 6T, and down to 3.8T (adjust limits to get $2.7 < q_{95} < 4.2$) in 0.2 T increments. Depending on results, we may adjust the increments to get better statistics around integral q if step-like features are apparent. [12-15 shots]

3. At a field near 4 T (choose $q$ greater or less than 3.0 based on results of $B_T$ scan) scan current to 1.1, 1.0, 0.9, 0.8, 0.7, 0.6 MA, with and without A-coil (configured +DTOP -DBOT -JTOP +JBOT, 2500A). [11 shots]
6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

This experiment should provide additional information on the q scaling of the locked mode threshold, for comparison with established scalings in the Iter Physics Basis as well as theoretical models of mode locking. It may also clarify the results of previous attempts at MP#362 (ITER shape development) and, by adding to the C-Mod locked mode dataset, help constrain the model of intrinsic field errors in C-Mod. The results are likely to contribute to proposed papers at the IAEA and/or APS-DPP Meetings.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.

   http://www.psfc.mit.edu/cmod/online/RunSummaries/run_summary_1031126.txt
   http://www.psfc.mit.edu/cmod/online/RunSummaries/run_summary_1040127.txt
7. ITER Physics Basis Chapter 3, Nucl Fusion (1999)