APEX Task V Summary for FY01

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1. Task V: Conducting Shell Deployment for Liquid Wall Concept

1.1 Introduction

A major goal of APEX Task V in FY01 was to assess rapidly flowing liquid metal walls relative to simple conformal shells for stabilizing MHD modes. Studies of wall concepts provide insight into the nature and control of plasma instabilities. The severe effects of neoclassical tearing modes on plasma confinement are a major concern.

One option is to have a conformal shell. In this case, a liquid metal wall installed for other purposes may be used. This requires an active feedback system. A second option is a rapidly flowing liquid metal wall. A rapid flow is required for mode stabilization, and no active feedback is required.

1.2 MHD Stabilization with a Conformal Shell

To investigate the first option, the ideal MHD stability analysis of candidate plasma equilibria used codes including PEST from Princeton and GATO from General Atomics. These programs are “community standards” that are well benchmarked against many experimental results.

For resistive MHD analysis, a novel program called WALLCODE was developed at the Institute of Fusion Studies at the University of Texas. This code treats finite resistance walls, and includes active feedback from external voltage sources in coils and antenna loops. It was benchmarked against analytical results and calculations for ARIES reactor design cases and DIII-D plasmas.

The WALLCODE program was used to evaluate the elongation limits for axisymmetric

MHD stability. The calculations demonstrated that a conformal shell has advantage over a "TCV-like" rectangular conducting shell, as shown in Fig. 1.2-1. A conformal shell also has an advantage over a shell with a "DIII-D-like" vacuum vessel shape. The code successfully predicted the elongation limit for DIII-D, as indicated in Fig. 1.2-2. With a conformal shell, however, the elongation limit is ≈5.

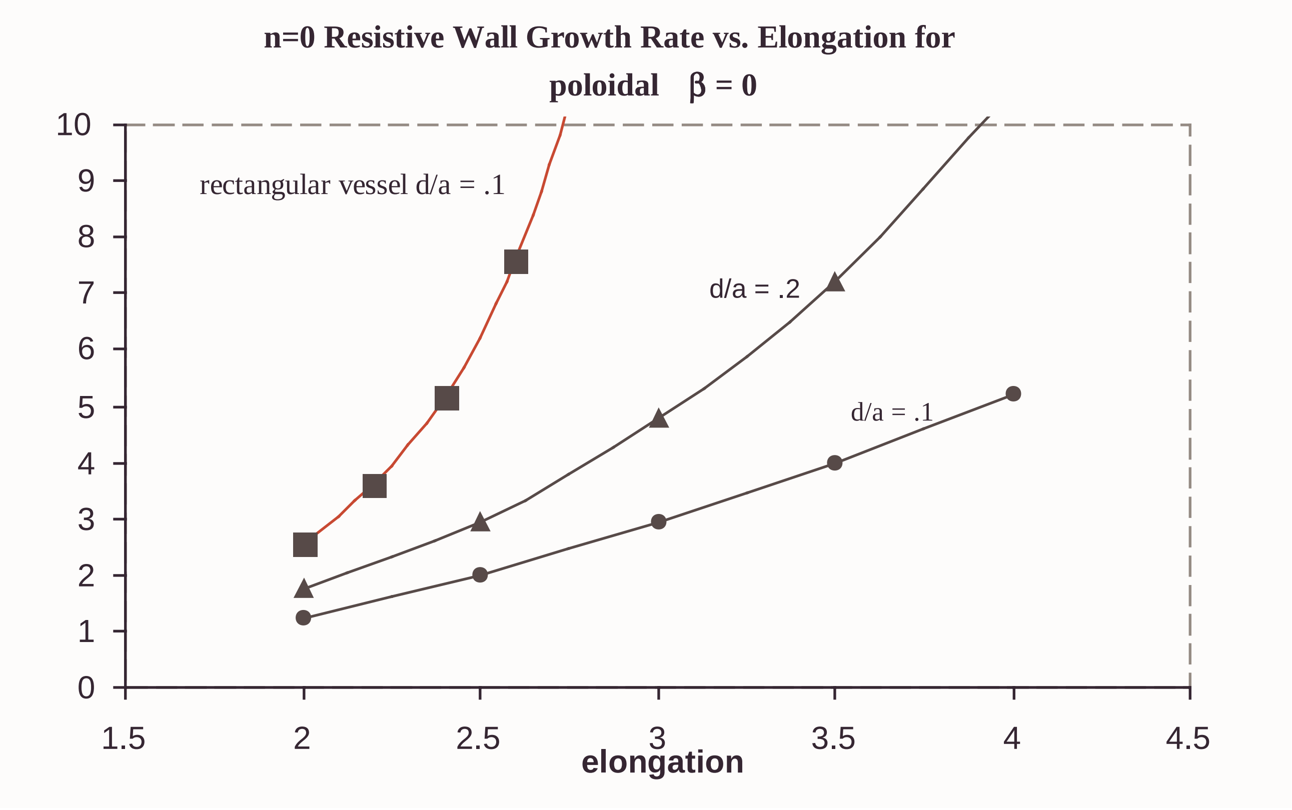

Fig. 1.2-1. Resistive wall growth rate shown to depend on degree by which stabilizing shell conforms to the plasma.

The feedback stabilization requirements with coils ≈1.3 m from the plasma were also investigated with WALLCODE. If κ is the elongation, a single sensor and active loop were needed for κ≈3. At κ≈4-5, several sensors and active loops were required. With κ≈5, the requirements rose to10-20 single sensors and active loops

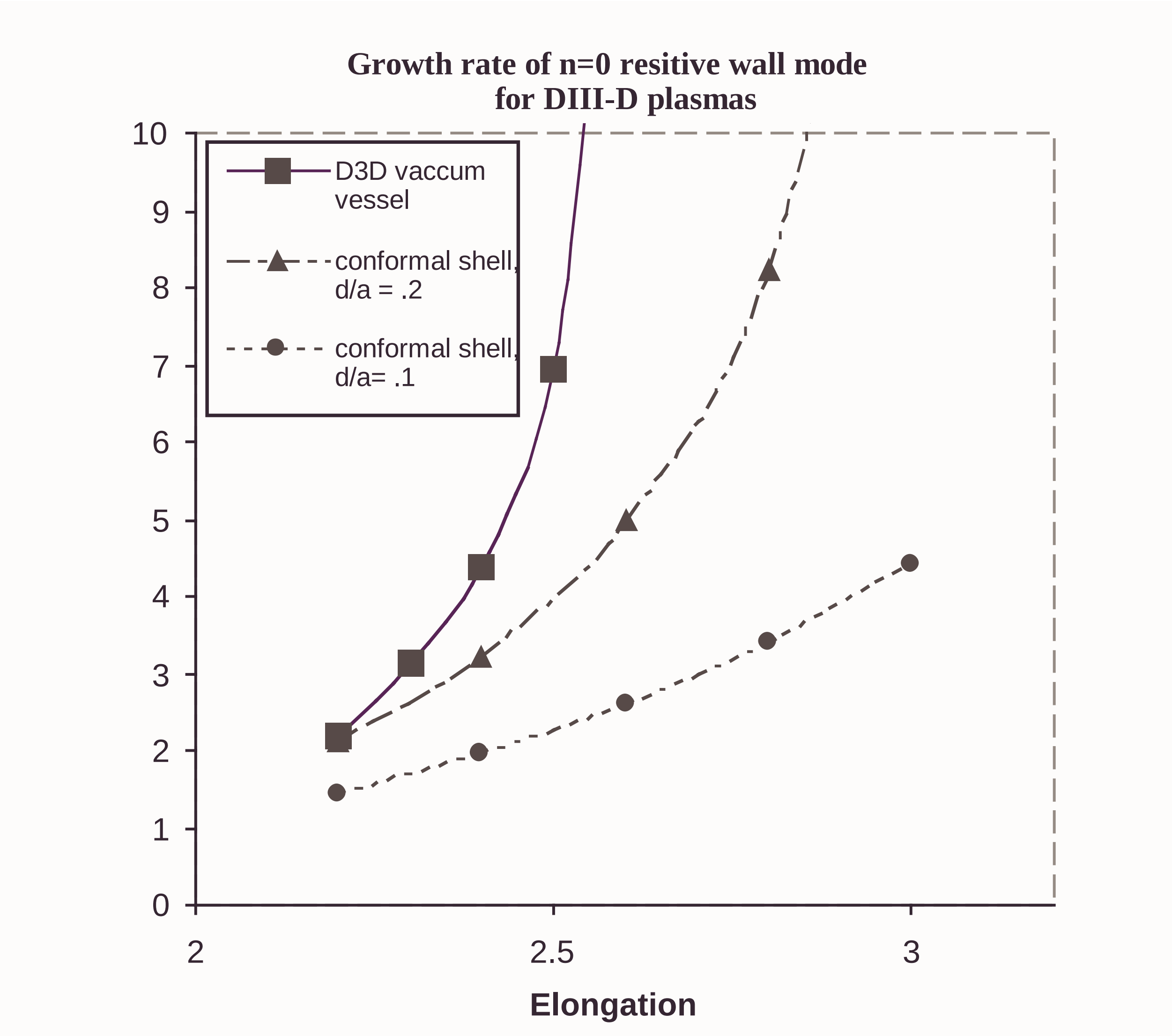

Fig. 1.2-2. WALLCODE predicts that elongation limit is reached at κ≈2.5 for DIII-D vessel shape. Highest value reached by DIII-D is κ≈2.5

1.3 MHD Stabilization with a Flowing Metal Wall

To examine the effects of a rapidly flowing liquid metal wall, a cylindrical current driven model of kink modes was used for the resistive wall mode calculation. Guided by the theory of resistive wall modes, the parameters of the cylindrical model were adjusted to match the stability characteristics of realistic, full geometry ideal MHD code calculations with GATO and PEST. A case with an aspect ratio of 4 and an elongation of 3 was chosen.

A “split” geometry, as found in the “CLIFF” concept or the half-shells considered for magnetic propulsion, was chosen for the study of stabilization by a fast liquid metal flow. The results are summarized in Fig. 1.3-1. Surprisingly, a fast flow appears to be more effective in stabilizing high-n modes than low-n modes.

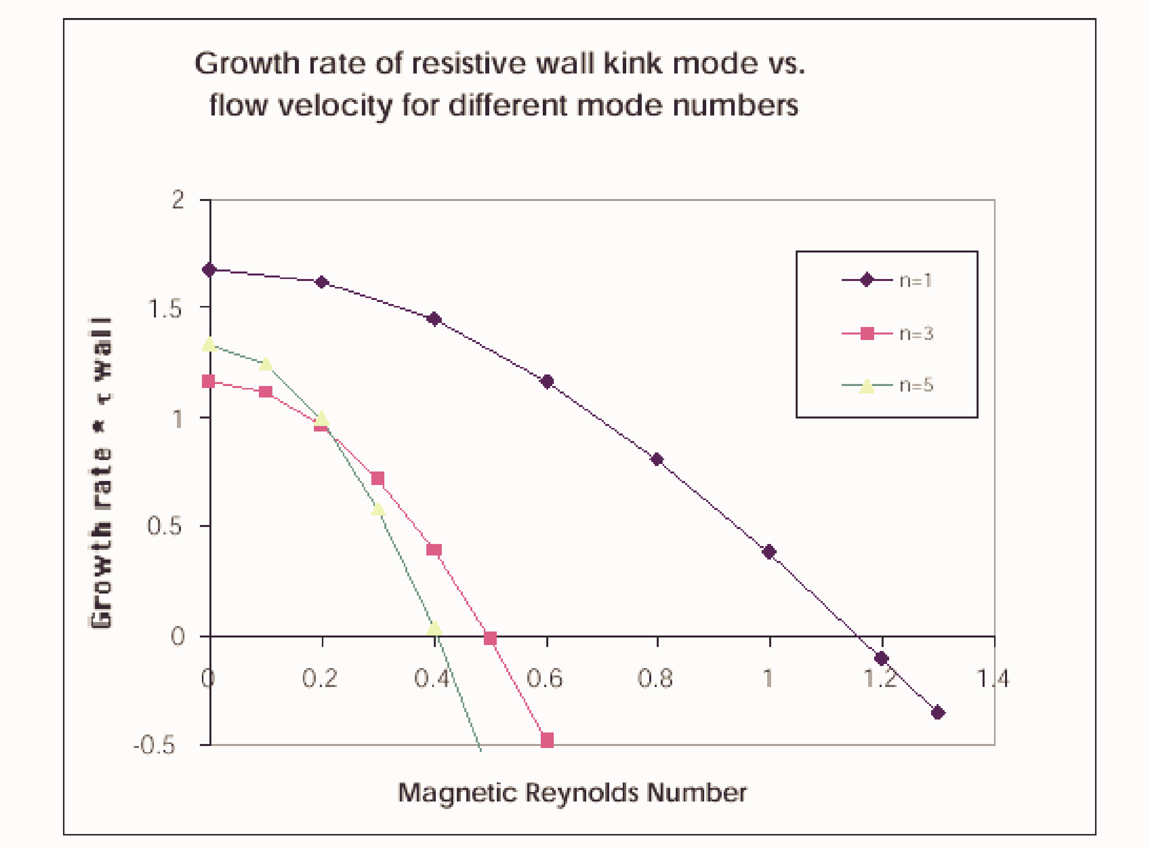

Fig. 1.3-1. Stabilization of resistive wall kink mode with flowing wall at a distance from the plasma of 5% of the minor radius.

There are several points to note about different flowing wall materials. Tin, for example, is to be operated within the recommended erosion limit at a flow < 10 m/s. For a 2 cm thickness, it has a magnetic Reynolds number R = .7. In that case, the stabilization of n = 1 modes is not achieved. However, this is sufficient to stabilize high-n modes. Lithium at 10 m/s with a 2 cm thickness has R =1.4, and it barely stabilizes the n =1 mode. Since lithium can attain twice the magnetic Reynolds number as tin, it is much better for kink mode stabilization.

It should also be noted that feedback has roughly complementary characteristics. For active coils significantly far from the plasma, it is easier to stabilize low-n modes. Thus, a system for stabilizing the lowest n modes with feedback and higher n modes with wall rotation may provide the best combination.

Another possibility for stabilization is with plasma rotation. This scheme is least effective with the conducting wall close to the plasma, which is the opposite of both wall flow and feedback stabilization. For parameters roughly characteristic of a modest subsonic plasma flow, e. g., a Mach number M ~ .3, the results are shown in Fig. 1.3-2 for the n = 1 mode. Stabilization of n=1 modes with a close fitting metallic shell present, e. g., d/a ~ .05, is very difficult using plasma rotation. This is because unrealistic plasma rotation speeds are required. The calculations for the n = 3 mode are summarized in Fig. 1.3-3. It shows that plasma rotation is much more effective at stabilizing higher n modes.

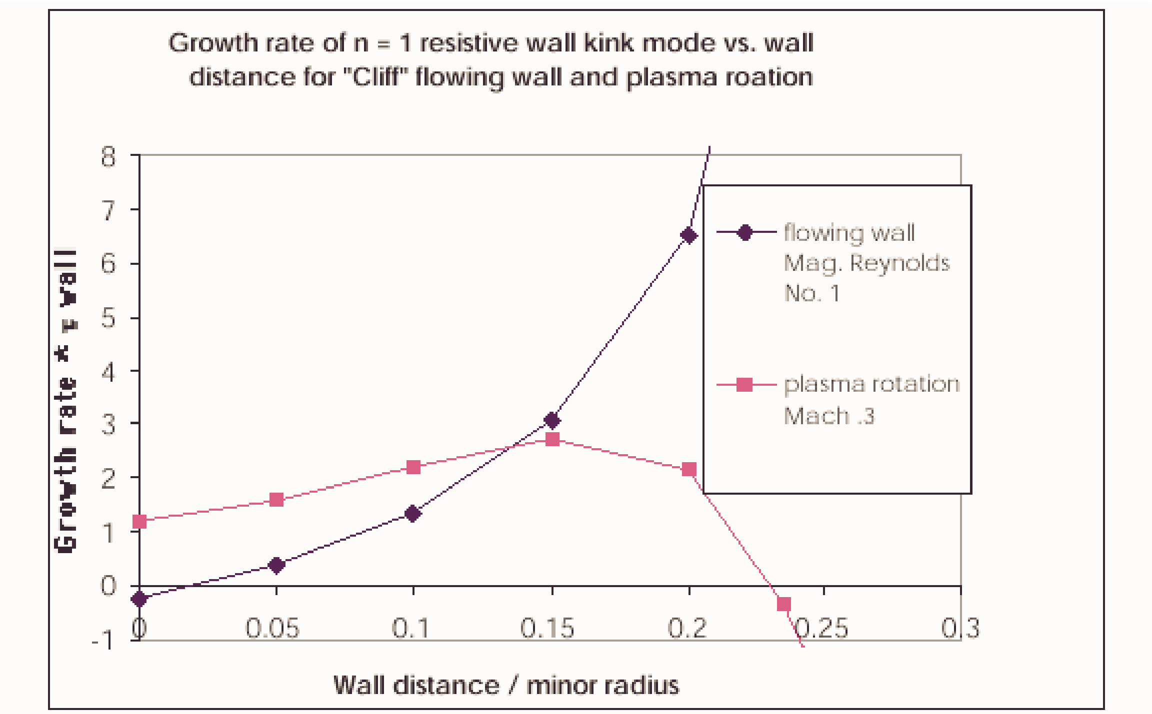

Fig. 1.3-2. Comparison of stabilization of n = 1 resistive wall kink mode with flowing wall

and plasma rotation.

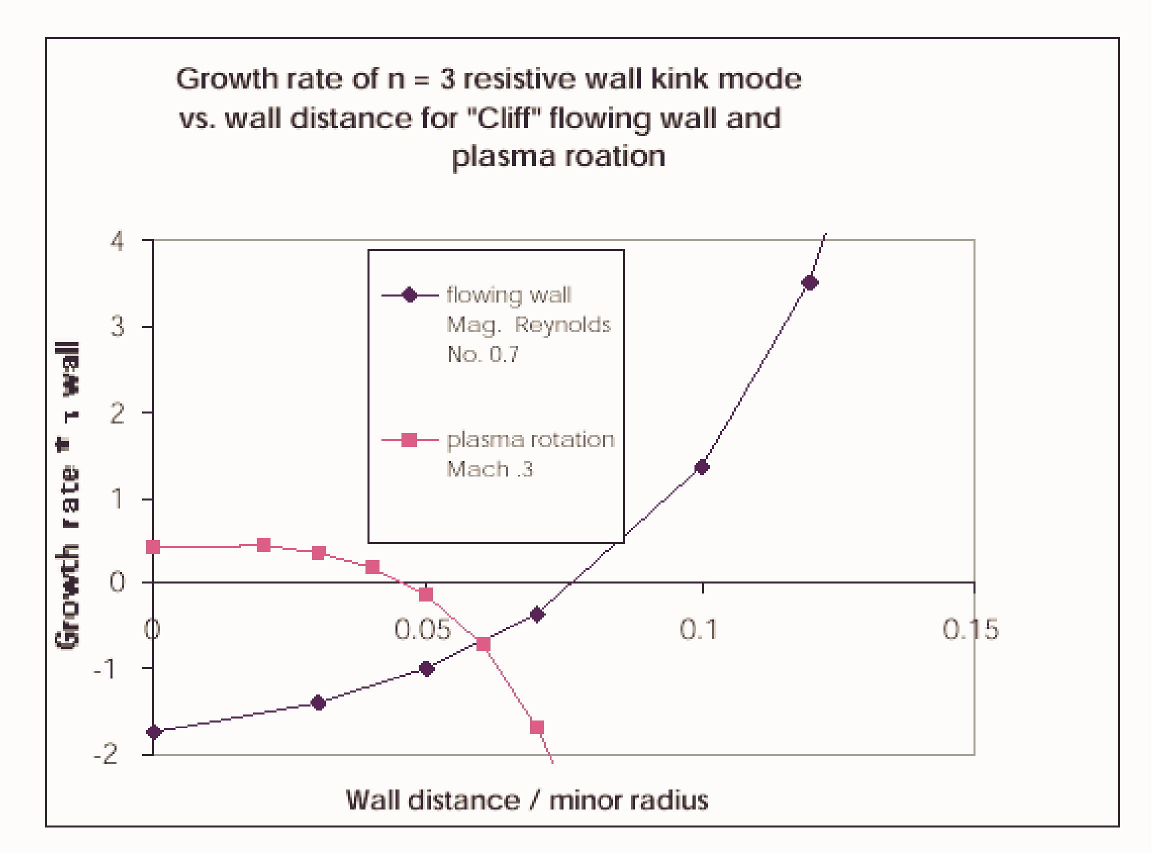

Fig. 1.3-3. Comparison of stabilization of n = 3 resistive wall kink mode with flowing wall and plasma rotation.

1.4 Summary

The FY01 conformal shell studies showed that the stabilizing MHD effects overcome destabilizing “bootstrap” pressure related effects for neoclassical tearing modes with κ plus mild indentation. The implications for future reactors are that higher κ permits higher βand current (I/aB) limits, and higher power density and wall loading. A Q=10 FIRE ignition device, for example, becomes possible by decreasing the major radius from 2 m to 0.7 or 0.8 m, while still permitting a plasma current of about 5.8 MA for a corresponding κ of 5 or 4.

The FY01 investigations of flowing liquid walls demonstrated that several strategies for stabilizing resistive wall kink modes are possible. Feedback may be needed for the n = 1 mode, whereas either plasma rotation or flowing metal walls can stabilize higher n modes. The choice of wall materials is also important, as flowing tin is significantly less stabilizing than flowing lithium.