MARS-Q MODELING OF KINK-PEELING INSTABILITIES IN DIII-D QH-MODE PLASMA

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ABSTRACT

- The plasma resistivity is found to strongly modify the mode growth rate. The computed mode growth rate scales as $S^{-1/3}$ with S being the Lundquist number.
- Drift kinetic effects all have a destabilization effect on these modes. The drift kinetic effects associated with thermal particle species push the peak location of the eigenmode radially inward but still in the pedestal region.
- The combined effect of the damping of the flow amplitude and change of the edge flow shear is found to be the stabilizing factor for the kink-peeling mode, leading to the mode saturation and thus EHOs.

BACKGROUND

- The detailed triggering and saturation mechanisms of EHOs have not been fully understood. All the previous studies were carried out within the MHD model, without taking into account the possible drift kinetic effects from plasma particles. Direct interaction between the plasma flow and the kink-peeling mode was not emphasized in these studies either.

COMPUTATION MODEL AND PLASMA EQUILIBRIUM

Computation model

MARS-F/Q solves the single fluid perturbed MHD equations. The drift kinetic effects are incorporated via a non-perturbative MHD-kinetic hybrid formulation (MARS-K), i.e. the perturbed scalar pressure from MHD equations being replaced by a perturbed pressure tensor **p**

$$\mathbf{p} = p_{\|}\mathbf{bb} + p_{\perp}(\mathbf{I} - \mathbf{bb}),$$

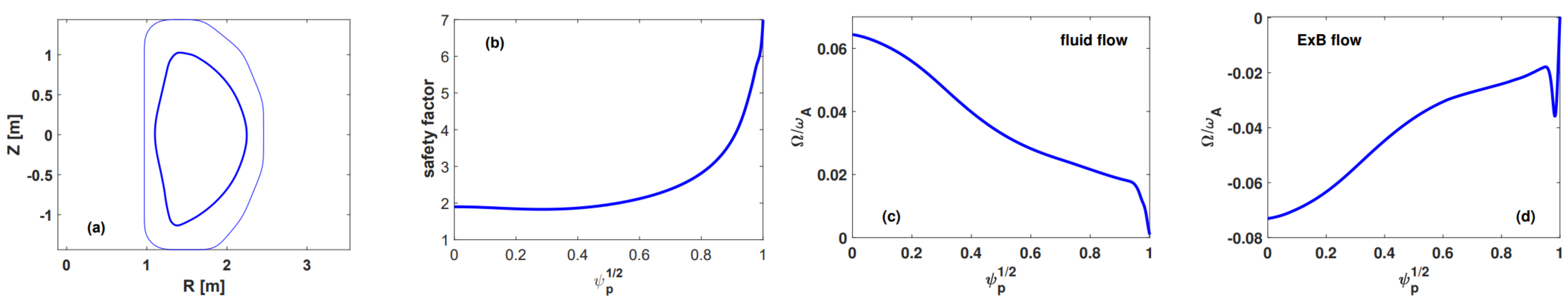
$$p_g = p_g^{\mathrm{a}} + \alpha_{\mathrm{D}} p_g^{\mathrm{D}} + \alpha_{\mathrm{B}} p_g^{\mathrm{B}} + \alpha_{\mathrm{C}} p_g^{\mathrm{C}}, \quad g = \| \text{ or } \perp,$$

To study the non-linear interplay between MHD perturbations and the plasma flow, MARS-Q also solves the n = 0 toroidal momentum balance equation

$$\frac{\partial L}{\partial t} = D(L) + T_{\mathrm{NTV}} + T_{j\times b} + T_{\mathrm{rey}} \qquad D(L) = \frac{\partial}{\partial s}\chi_{\mathrm{M}}\langle|\nabla s|^2\rangle\frac{\partial L}{\partial s}$$

Equilibrium

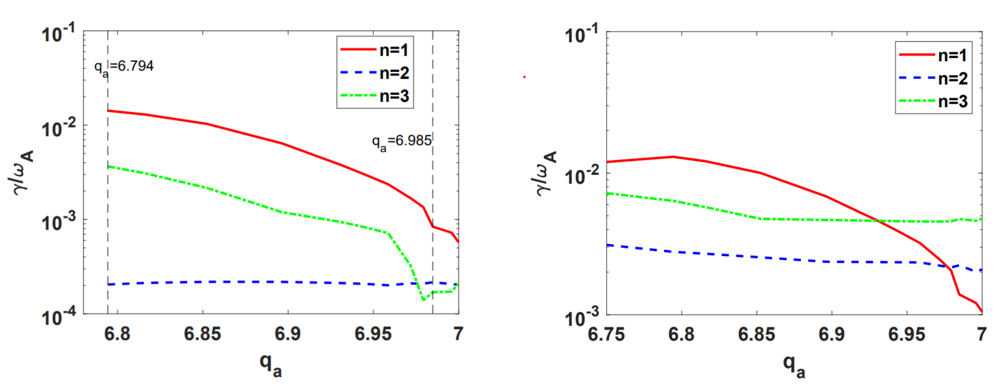
This equilibrium is reconstructed from the DIII-D discharge 157102 at 2420 ms.



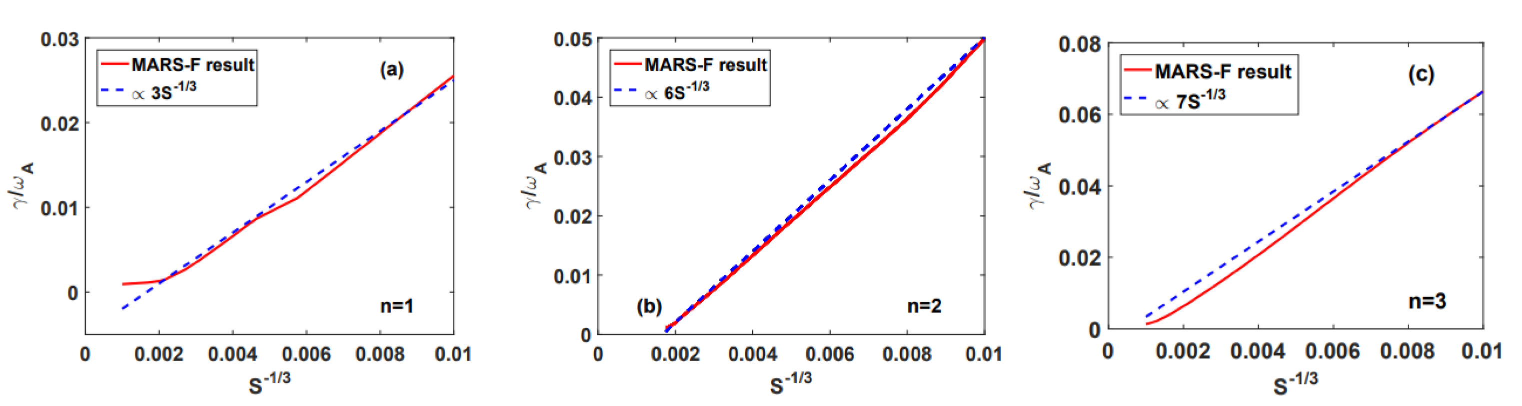
(a) the plasma boundary shape and the resistive wall shape, and (b-d) the radial profiles of various equilibrium quantities reconstructed from DIII-D discharge 157102 at 2420 ms.

Linear stability analysis

No plasma equilibrium flow nor the presence of a resistive wall is assumed in (a), while (b) both these two effects are included.

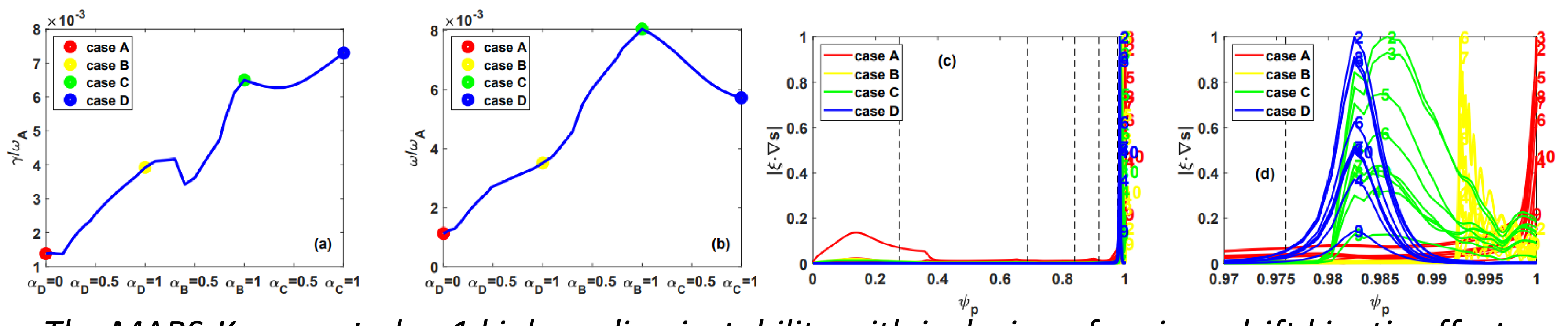


The MARS-F computed growth rates of n = 1, 2, 3 ideal instabilities while slightly smoothing plasma boundary shape, resulting in variation of edge safety factor q_a with q_{95} being nearly unchanged.

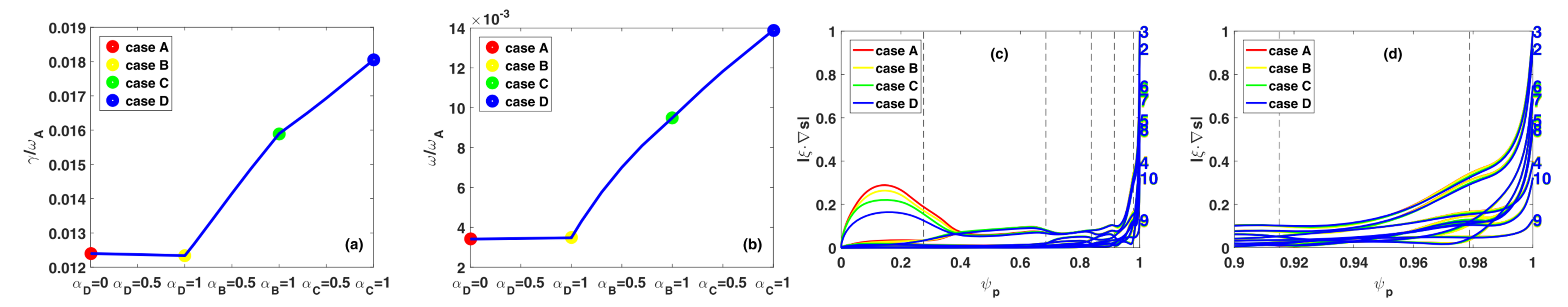


The MARS-F computed growth rates while scanning the Lundquist number S.

Linear stability analysis

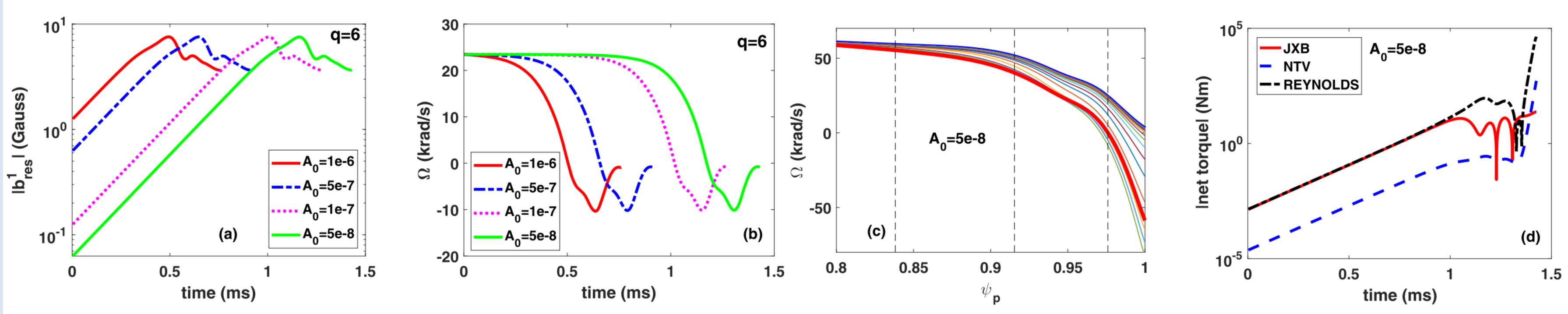


The MARS-K computed n=1 kink-peeling instability with inclusion of various drift kinetic effects. Assumed are $\tau_w/\tau_A=10^4$, the equilibrium with the edge safety factor q_a=6.985 and Spitzer resistivity.

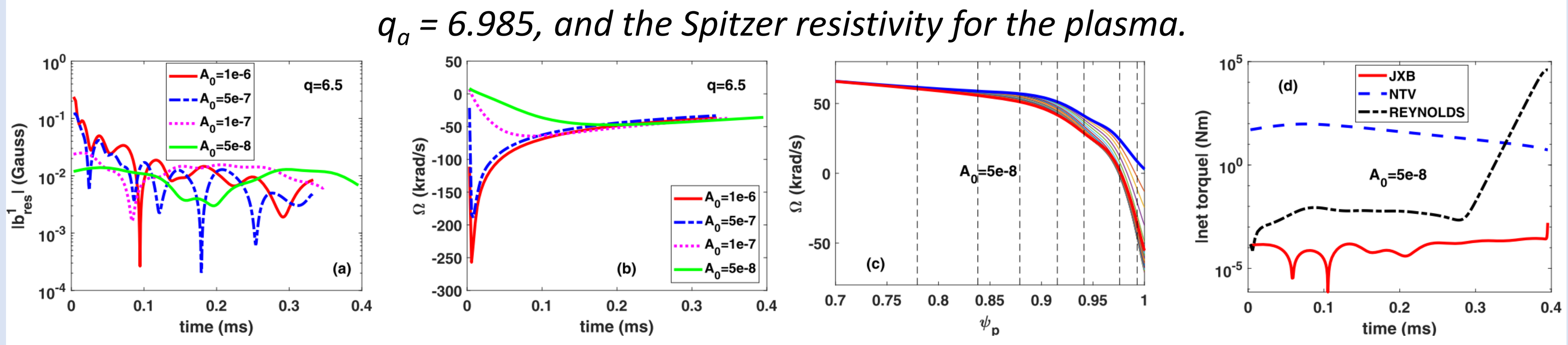


The MARS-K computed n=1 kink-peeling instability with inclusion of various drift kinetic effects. Assumed are $\tau_w/\tau_A=10^4$, the equilibrium with the edge safety factor q_a=6.794 and Spitzer resistivity.

Non-linear interaction between plasma flow and instability



The MARS-Q simulated time traces of the initially unstable n=1 resistive kink-peeling mode: (a) and (b) the perturbed m/n=6/1 resonant radial field component and the toroidal rotation frequency, respectively, at the q=6 rational surface, with different choices for the amplitude A_0 of the initial perturbation; (c) and (d) evolution of the rotation profile and the time traces of three toroidal net torques, respectively, assuming the initial perturbation amplitude of $A_0=5\times10^{-8}$. The thick blue (red) curve in (c) indicates the initial (final) rotation profile. The vertical dashed lines in (c) indicate locations of the rational surfaces associated with the n=1 perturbation. The initial rotation profile is assumed to be the fluid rotation as shown in figure 1(c). Assumed are χ_M = 0.1 $m^2 s^{-1}$, $\tau_w/\tau_A= 10^4$, q_a = 6.985, and the Spitzer resistivity for the plasma.



The corresponding MARS-Q simulated time traces of the initially unstable n=2 mode.

CONCLUSION

- The edge safety factor q_a sensitively affects growth rate of the instability.
- The resistive wall has minor effect on the mode instability, due to the fact that the associated magnetic perturbation decays fast outside the plasma.
- The plasma resistivity, however, has a strong destabilizing effect on these kink-peeling modes. The numerically computed mode growth rate is found to scale approximately as $S^{-1/3}$.
- The plasma toroidal flow, either assuming fluid flow model or E × B flow model, or their linear combination, has relatively weak (stabilizing) effect.
- All three types of kinetic resonances play significant roles in mode destabilization.
- From MARS-Q simulation, The kink-peeling mode changes both the flow amplitude and flow shear near the plasma edge. The Reynolds stress torque is found to generally play a major role in the flow damping.

ACKNOWLEDGEMENTS

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