# Asymmetric wall force and thermal quench in JET disruptions


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# Contents

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** See the Author list of X. Litaudon et al., Nuclear Fusion 57, 100201 (2017)*

***Asymmetric wall force in JET depends on CQ time and resistive wall time***
- ***Simulations with M3D-C1 and M3D***
- ***Compare well with JET data***
- ***Mechanism: VDE causes q = 1***
- ***Mitigating in ITER***

***Thermal quench time can depend on resistive wall time***
- ***Simulations with M3D show resistive wall tearing mode (RWTM)***
- ***Might be mitigating in ITER***

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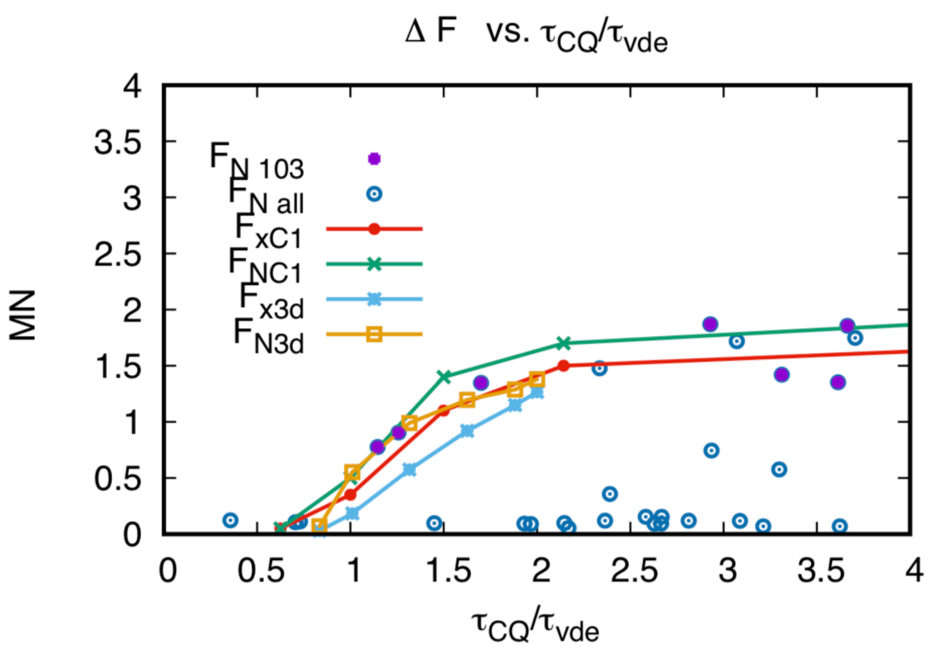
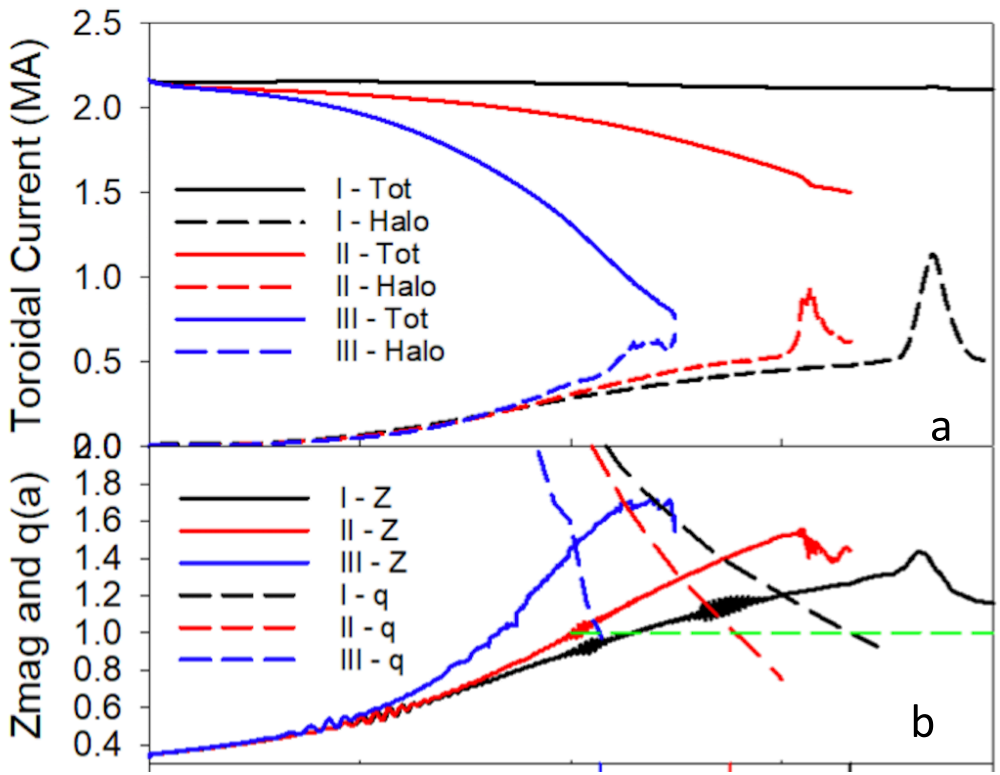
# JET sideways force

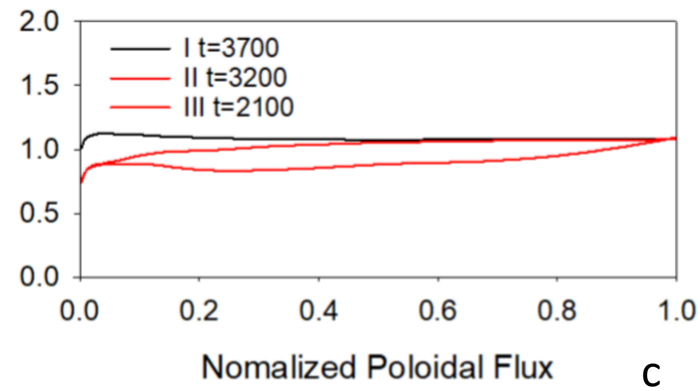
M3DC1 and M3D runs were initialized with a reconstruction of JET shot 71985. The current quench time $\tau_{CQ}$ was controlled by applied electric field, and resistive wall time $\tau_{wall}$ was held fixed. Asymmetric or sideways wall force $\Delta F$ was calculated as a function of time, and peak value of $\Delta F$ shown as a function of $\tau_{CQ}/\tau_{wall}$. JET ILW 2011-2016 database was used to obtain force $\Delta F_x \approx \pi B \Delta(IZ)$, where $\Delta$ is the amplitude of the asymmetric perturbation.

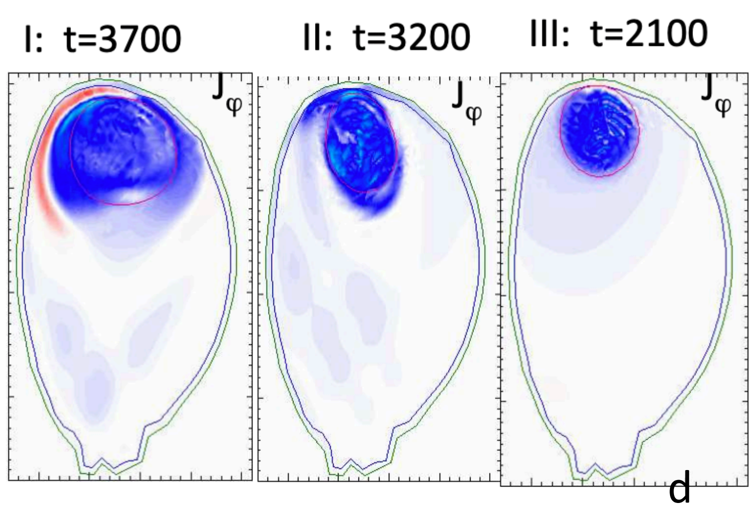



$\Delta F_x$ as a function of $\tau_{CQ}/\tau_{wall}$, Dots are JET Noll force. $F_{N103}$ are VDE shots, $F_{Nall}$ are from all shots. Simulation data is given for M3D-C1 wall force labelled $F_{xC1}$ and Noll force $F_{NC1}$, as well as M3D runs $F_{x3d}$ and $F_{N3d}$ [Strauss *et al.* PoP 2017, PoP 2020]

# (1,1) mode




(a) toroidal current and halo current vs. time

(b) Vertical displacement and q vs. time

(c) q profile when q = 1

(d) Current density depends on CQ.

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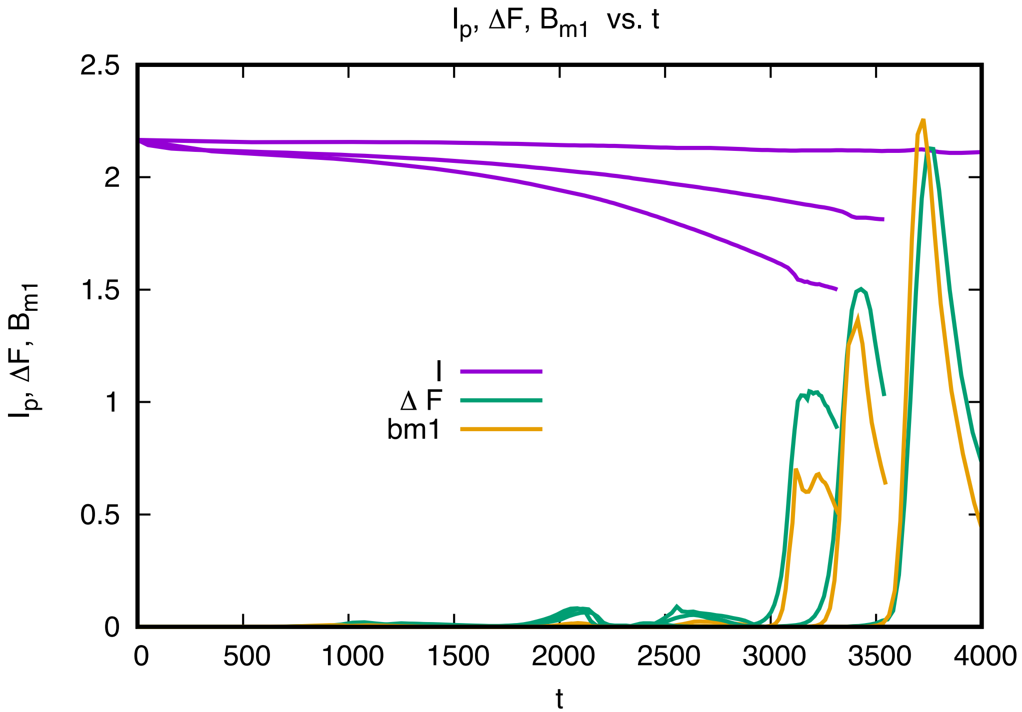
# Increase of wall force with CQ time

VDE causes plasma to scrape off at the wall until edge $q = 1$, destabilizing $(1, 1)$ mode. Wall force coincides with large $n = 1$ magnetic energy $B_{m1}$. $\Delta F_N \propto (B_{m1})^{1/2} I_p$. Both $B_{m1}$ and $I_p$ increase with $\tau_{CQ}$.

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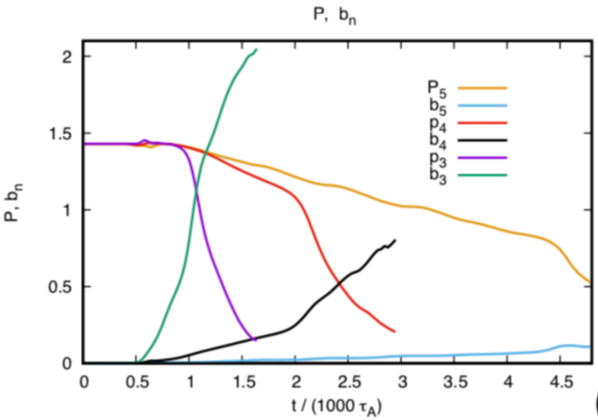
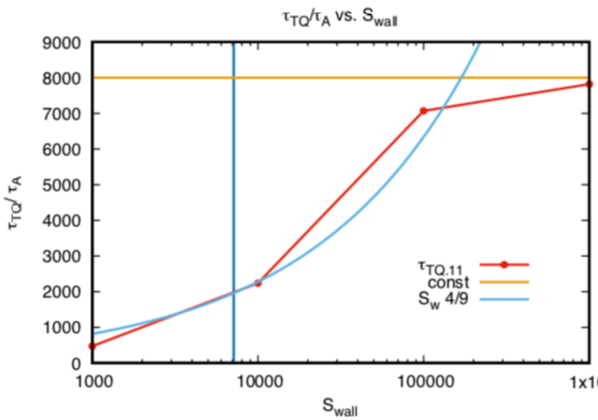
# Thermal quench

M3D simulations initialized with JET shot 81540. The TQ time depends on $S_{wall} = \tau_{wall}/\tau_A$. Thermal transport depends on advection by RWTMs and parallel thermal conduction, which in turn depends on the magnetic field perturbations $b_n$ at the wall. In the simulations $S = 10^6, \chi_{\|} = 10Rv_A$.




(a)




(b)

(a) History of total pressure $P$ and wall normal magnetic field perturbation $b_n$ as a function of time. As $b_n$ increases in time, $P$ falls more rapidly. Three cases are shown, with $S = 10^6$, and $S_{wall} = 10^3, 10^4, 10^5$. The subscript in the label refers to $S_{wall}$ such that $P_a, b_a$ correspond to $S_{wall} = 10^a$. (b) $\tau_{TQ}/\tau_A$ vs. $S_{wall}$, The fits are to $S_{wall}^{4/9}$ and constant. Linear simulations confirm growth rate

$$\gamma = c_0 S_{wall}^{-4/9} S^{-1/3}.$$

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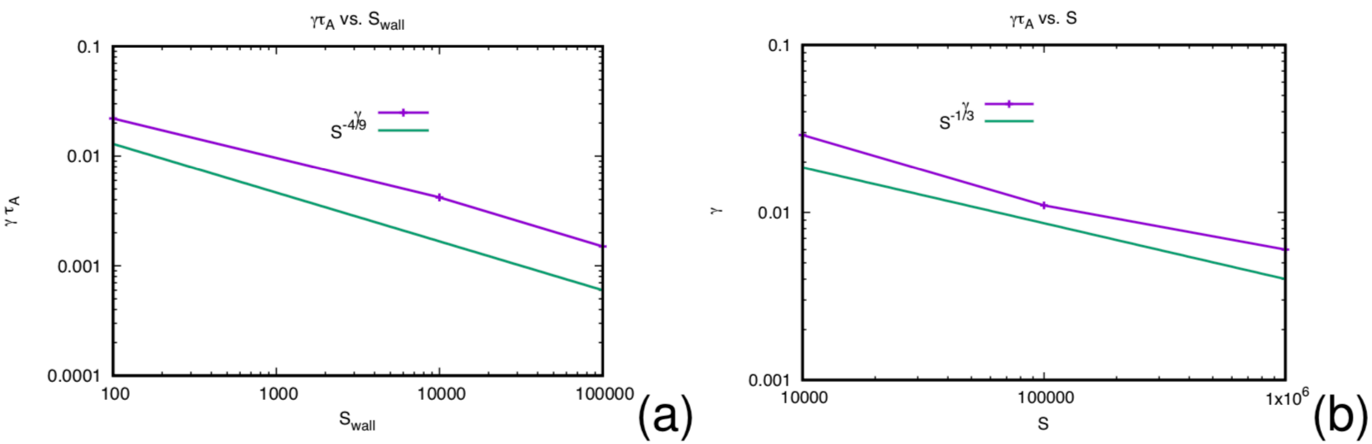
# Linear simulations

Linear stability calculations indicate the presence of the resistive wall tearing mode. The RWTM growth rate [Finn, 1995] is

$$\gamma \tau_A = c_0 S^{-1/3} S_{wall}^{-4/9} \tag{1}$$




(a) Linear growth rate $\gamma$ as a function of $S_{wall}$, from simulations of JET shot 81540 . The growth rate is consistent with $S_{wall}^{-4/9}$. (b) Growth rate as a function of $S$, consistent with $S^{-1/3}$ scaling. Combining, $\gamma = c_0 S_{wall}^{-4/9} S^{-1/3}$. with $c_0 \approx 9$. ($q > 1$ to eliminate $(1, 1)$ mode.)

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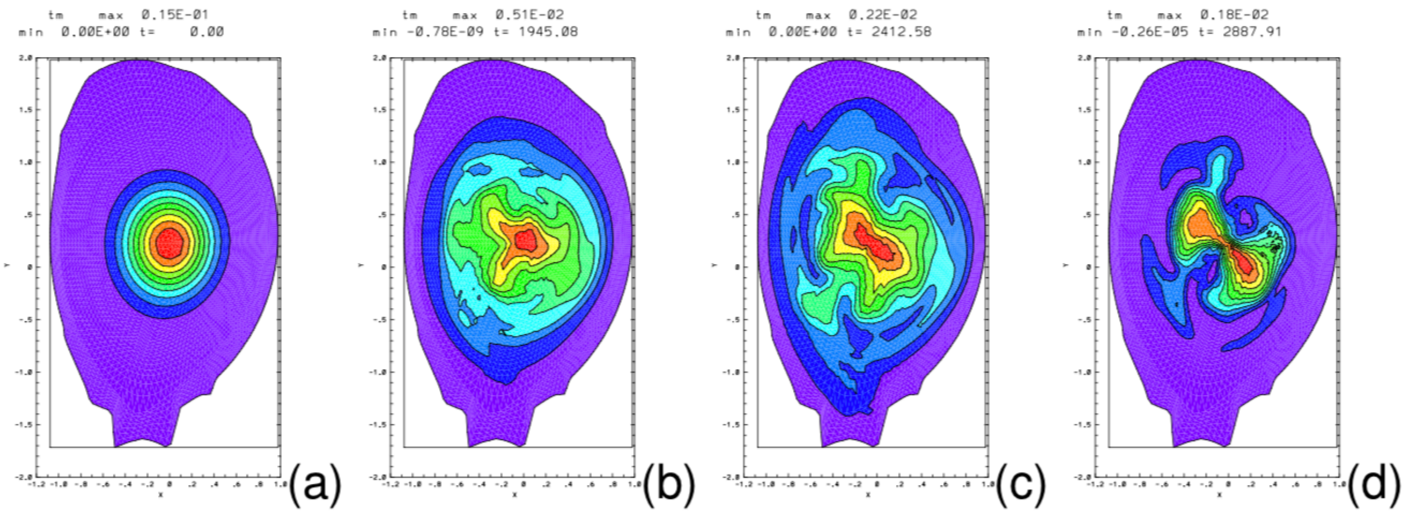
# Nonlinear TQ simulations




(a) initial temperature $T$. (b) temperature $T$ at $t = 1945\tau_A$, showing $(2,1)$ and $(3,2)$ magnetic perturbations. At this time $P \approx 70\%$ of its initial value. (c) $T$ at $t = 2428\tau_A$. At this time $P \approx 30\%$ of its initial value. (d) $T$ at $t = 2888\tau_A$, at the end of the simulation.

# Theory of TQ

$$\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r} r\chi_{\|} b_r^2 \frac{\partial T}{\partial r} \quad (2)$$

where $b_r$ is the normalized asymmetric radial magnetic field, assuming circular flux surfaces for simplicity, and neglecting $\chi_\perp$.

Integrating, the total temperature is given by

$$\frac{\partial < T >}{\partial t} = a\chi_{\|} b_n^2 T' \quad (3)$$

where $< T >= \int T r dr$, and $T' = \partial T/\partial r$ at $r = a$, $a^3 T'/ < T >\approx 1$. The normal magnetic field at the wall grows during the TQ as $b_n = b_0 \exp(\gamma t)$. Then substituting for $b_n$ in (3) and integrating in time, can obtain the approximate *ad hoc* formula

$$\tau_{TQ} \approx \frac{1}{2\gamma + \chi_{\|} b_n^2/a^2} \quad (4)$$

**Convection dominates thermal conduction when** $T_e < 200eV$ near the wall, which was observed in shot 81540. The ratio $\gamma/\chi_{\|} \propto T^{-3}$.

**magnetic perturbations -** From the simulations, $b_n \approx 1 \times 10^{-3}$. Consistent with JET data [DeVries *et al.* 2016].

**TQ time** $t_{TQ} \approx 1ms$.

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# Summary

- asymmetric wall force $\Delta F_x$ calculated in M3DC1 simulations.
  - plasma scrape off to $q = 1$ causing $(1,1)$ mode.
  - $\Delta F_x$ decreases as $\tau_{CQ}/\tau_{wall}$ decreases.
  - can mitigate wall force in ITER

- TQ time can vary as $S_{wall}^{-4/9}$ due to RWTMs.
  - RWTM dominates parallel thermal conduction when $T \lesssim 200eV$.
  - In ITER, if RWTM is suppressed, might mitigate wall heat load and RE formation.

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