

S.J.P. Pamela, G.T.A. Huysmans, M.N.A. Beurskens, G. Arnoux, A. Kirk, T. Eich,
S. Devaux, S. Benkadda, L. Frassinetti and JET EFDA contributors

Simulation of ELMs in JET

“This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts or references may not be published prior to publication of the original when applicable, or without the consent of the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

“Enquiries about Copyright and reproduction should be addressed to the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

The contents of this preprint and all other JET EFDA Preprints and Conference Papers are available to view online free at www.iop.org/Jet. This site has full search facilities and e-mail alert options. The diagrams contained within the PDFs on this site are hyperlinked from the year 1996 onwards.

Simulation of ELMs in JET

S.J.P. Pamela¹, G.T.A. Huysmans¹, M.N.A. Beurskens², G. Arnoux²,
A. Kirk², T. Eich³, S. Devaux³, S. Benkadda⁴, L. Frassinetti⁵
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

¹*Association EURATOM-CEA, F-13108 Saint-Paul-lez-Durance, France*

¹*EURATOM/CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*

³*Max-Planck Institut für Plasmaphysik, EURATOM Association, Garching, Germany*

⁴*PIIM, CNRS - Univ. Provence, Centre St.Jérôme, Case321, 13397 Marseille Cedex20, France*

⁵*Association EURATOM-VR, Department of Physics, SCI, KTH, SE-10691 Stockholm, Sweden*

** See annex of F. Romanelli et al, "Overview of JET Results",
(Proc. 22nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

Preprint of Paper to be submitted for publication in Proceedings of the
37th EPS Conference on Plasma Physics, Dublin, Ireland.

(21st June 2010 - 25th June 2010)

1. INTRODUCTION

The future tokamak ITER is expected to run routinely in type-I ELMy H-mode confinement regime. In fact, the ELMs are necessary in order to rid the plasma of its impurities. However, it is expected that ELMs in ITER could release up to 20MJ, which is not bearable for the presently designed tungsten divertor [1,2]. Hence, some techniques have been developed to control ELMs (RMPs, pellets, kicks), but there is at present poor understanding of how these tools provoke or mitigate the ELMs. In fact, the ELMs themselves are not fully understood. The linear stability of ELMs has been well established in the last two decades [3], but the understanding of the nonlinear properties of ELMs still requires some effort.

The nonlinear simulation of ELMs is already in reasonable qualitative agreement with experimental observation [4,5]. In particular, simulations show a filamentation of the plasma edge into the Scrape-Off Layer, and large amounts of energy arriving on the divertor in the form of small heat-flux structures near the strike point. In sight of using the simulations to obtain some predictions of ELMs in ITER, the MHD code JOREK [4,5] should first undergo a quantitative validation against experimental data. This paper aims at a first step towards this validation, by presenting simulations of ELMs for a given plasma pulse from JET. The long term goal being to extend the simulations to multiple shots analysis, both for JET and for other tokamaks.

2. FROM EXPERIMENTAL DATA TO NUMERICAL SIMULATIONS

The JET Pulse No: 73569 has been chosen as a first simulation basis because it was a regular type-I ELMy H-mode with good HRTS profiles (High-Resolution Thomson Scattering diagnostic [6]), and a good view of the Infra-Red camera on the outer divertor. For this pulse, the field was 2T, the density $n_e = 6 \times 10^{19}$ at the magnetic axis and the temperature $T_e = 3\text{keV}$. In order to produce a JOREK simulation, one needs to solve the Grad-Shafranov equilibrium, so that three ingredients are needed: the pressure profile p , the current profile j , and the poloidal flux ψ on a closed boundary W around the plasma.

The pressure profile is obtained from HRTS, which gives the electron density and temperature. Since JOREK solves the two-fluidMHD equations with separate variables ρ , T_i and T_e , the ion temperature profile is assumed to be identical to the electron temperature profile. The HRTS profiles are all taken before the ELMs (80-99% of the ELM-period), and a fit is done over the profiles. This way, using multiple profiles ensures a good resolution in the pedestal, so that the pressure profile is reliable (see the superimposed profiles in Fig.1(b)).

The global current profile is obtained from the EFIT equilibrium reconstruction, with an additional bootstrap current calculated from HELENA, according to the pressure profile, following the Sauter method [7].

The flux ψ at the boundary is taken from the EFIT reconstruction. Since there yet no resistive wall boundary conditions in JOREK, this contour has been taken just outside the vacuum vessel wall, and close to the divertor. The resulting ψ from JOREK is shown in Fig.1(a) next to the EFIT flux. Also shown in Fig.1(b) are the temperature and density profiles from JOREK, compared to the HRTS profiles.

3. JET SIMULATIONS

The resulting JET equilibrium has a pressure profile very close to ideal ballooning stability limit, which is highly unstable with respect to resistive ballooning. Hence the perturbation of toroidal mode numbers results in a pedestal crash, which may be compared to an ELM. The simulations have been run for different mode numbers, varying the main plasma parameters (resistivity η , parallel thermal conductivity κ_{\parallel} etc...).

One first observes the distinction between T_i and T_e during the ballooning crash. The theoretical κ_{\parallel} for each species (implemented in the code) depends on the corresponding temperature and has a coefficient which depends on the species' mass, resulting in a faster conductivity for T_e . Namely $\kappa_{e,\parallel}/\kappa_{i,\parallel} \approx 40$. As a consequence, and as can be seen on Fig.2a, T_e is rapidly conducted to the divertor, where distinct stripes are observed near the strike point. This is not the case for T_i , which is convected into filaments like the density. T_e filaments are also observed, but less distinctively than T_i filaments.

These T_e stripes are important, because they are responsible for most of the energy arriving on the divertor. Similar stripes are observed in JET during ELMs. The common procedure to determine the dominant mode number of an ELM in JET relies partly on the signals from Mirnov Coils, but also on the number of stripes observed on the outer divertor tile. Simulations clearly show a relation between the mode number and the number of stripes, as seen from Fig.2(b). Thus, simulations could be used in return to reinforce the interpretation of IR diagnostics in order to determine the mode number of an ELM in JET.

As another example of comparisons between simulations and experiments, Fig.3 shows the HRTS profiles before and after ELMs from Pulse No: 73569, and the profiles taken from simulation at the same position as HRTS, before and after a crash. The main interest of such a comparison is to look at the convective/conductive ELM losses, and the ELM-affected area, which gives the penetration of the ELM into the pedestal.

4. COLLISIONALITY SCAN

In the multi-machine collisionality scan done by Loarte [1], the ELMs size is shown to increase with decreasing collisionality. This result is most important for ITER, which should run at even lower collisionality than JET. It is therefore of great interest to produce a collisionality scan with simulations, in order to check if simulated ELMs have the same particularity. Furthermore, such a scan could help understand why the ELMs size is increasing at lower ν^* .

To get such a scan with simulations, density and temperatures are varied together such that the total pressure profile does not change. This way, the ideal MHD stability properties of the plasma remain identical, but collisionality changes. The principal parameters that are affected by this scan are the resistivity η and the parallel thermal conductivity κ_{\parallel} , which vary as $\eta \sim \nu^{*1/6}$ and $\kappa_{\parallel} \sim \nu^{*-1}$. It is yet not possible to use the proper experimental values for η and κ_{\parallel} , due to limited numerical resolution, but it is important to understand whether this results in simulations which are far from reality or not.

A first scan has been done with collisionality varying from 1.4×10^{-2} to 0.9, with a resistivity varying from 4×10^{-8} to 10^{-7} . The result was that the ELMs size was decreasing with decreasing

collisionality, which is mainly due to the fact the resistivity has a strong influence on the growth rates of the ballooning modes. Hence, in this resistive regime, the resistivity dominates the collisionality scan, and the result is opposite to that expected.

A second collisionality scan was then run with lower (a factor 10) resistivity. However, at lower resistivity, the ballooning modes are stable to the pressure profile, so the pedestal width was reduced from 2.8cm to 1.5cm. The results of this second scan were closer to experiments, and ELMs size is seen to increase with decreasing collisionality. Furthermore, the growth rates show that resistivity does not have such a strong effect anymore, so that the parameter of merit becomes $k\lambda$, which evacuates more temperature from the pedestal at low collisionality.

CONCLUSIONS

Simulations of ELMs were obtained for the JET Pulse No: 73569. The transition from experimental data to numerical simulations was presented, and basic features of ELMs simulations were analyzed. The stripes observed on the targets in simulations are similar to those seen in experiments. As an example of comparisons with experiments stood the fact that the number of stripes on the divertor increases with increasing ballooning mode number. The second part of this paper presented a collisionality scan for ELMs for the base case of Pulse No: 73569. The aim of this scan was to answer a key question for ELMs simulations, namely, what type of ELMs are simulated. The fact that this scan was done for a specific JET pulse gives further consolidation to the answer to the question: Two scans were run for different resistivity regimes. At relatively high resistivity ($\eta \sim 10^{-8} - 10^{-7}$) the ELMs size decreases with decreasing collisionality, which is opposite to what is observed in experiments, at least for standard type-I ELMs. At lower resistivity ($\eta \sim 10^{-8} - 10^{-7}$), the regime is more ideal, so that the ballooning modes are really destabilized by the pressure gradient, not by resistivity. In this case, the ELMs size does increase with decreasing collisionality. It should be noted that a resistive regime is not necessarily an artifact from simulations, and that the ELMs simulated for high resistivity could correspond to ELMs other than type-I.

REFERENCES

- [1]. A. Loarte et al., Plasma Physics and Controlled Fusion **45** 1549-1569 (2003)
- [2]. B. Bazylev et al., Phys. Scr. T128 229-233 (2007)
- [3]. J.P. Freidberg, 'Ideal Magneto-Hydro-Dynamics' ISBN-13: 978-0306425127
- [4]. G.T.A. Huysmans and O. Czarny, Nuclear Fusion **47** 659-666 (2007)
- [5]. G.T.A. Huysmans et al., Plasma Physics Controlled Fusion **51** 124012 (2009)
- [6]. M.N.A. Beurskens et al., Nuclear Fusion **49** 125006 (2009)
- [7]. O. Sauter et al., Physics of Plasmas **6** 2834 (1999)

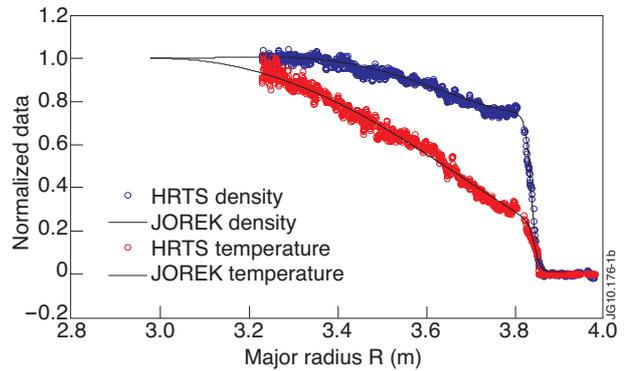
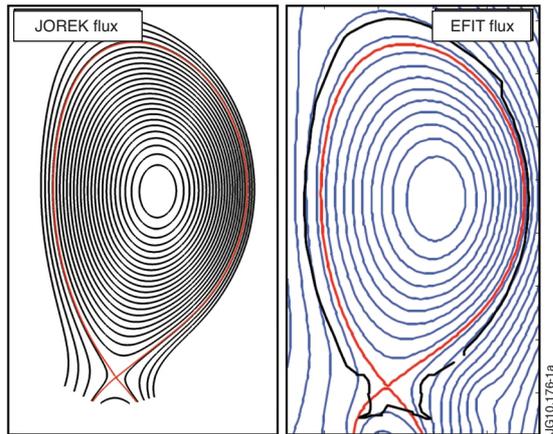


Figure 1: (a) compares the initial EFIT flux (right) with the JOREK equilibrium calculated using HRTS profiles and EFIT current (left). (b) shows the density and temperature profiles from HRTS (circles) together with the JOREK profiles (lines).

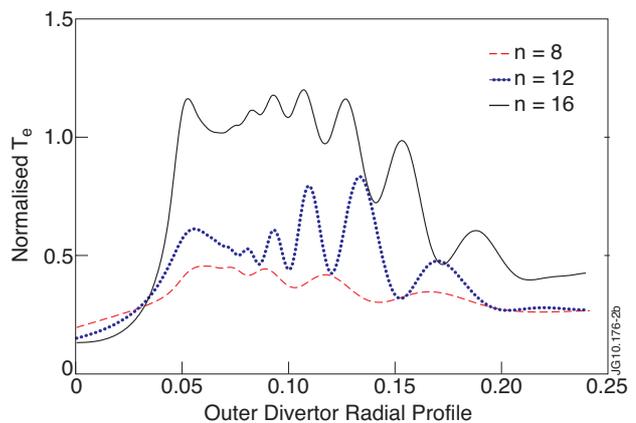
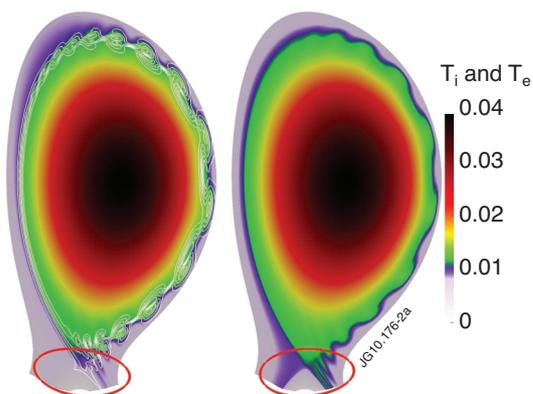


Figure 2: (a) shows T_i filaments together with density contours (white) on the left, and T_e on the right. The red circles show the stripes of T_e on the divertor, which are less distinct for T_i . (b) shows profiles of T_e on the divertor for different mode numbers. As the mode number increases, the number of stripes increases too.

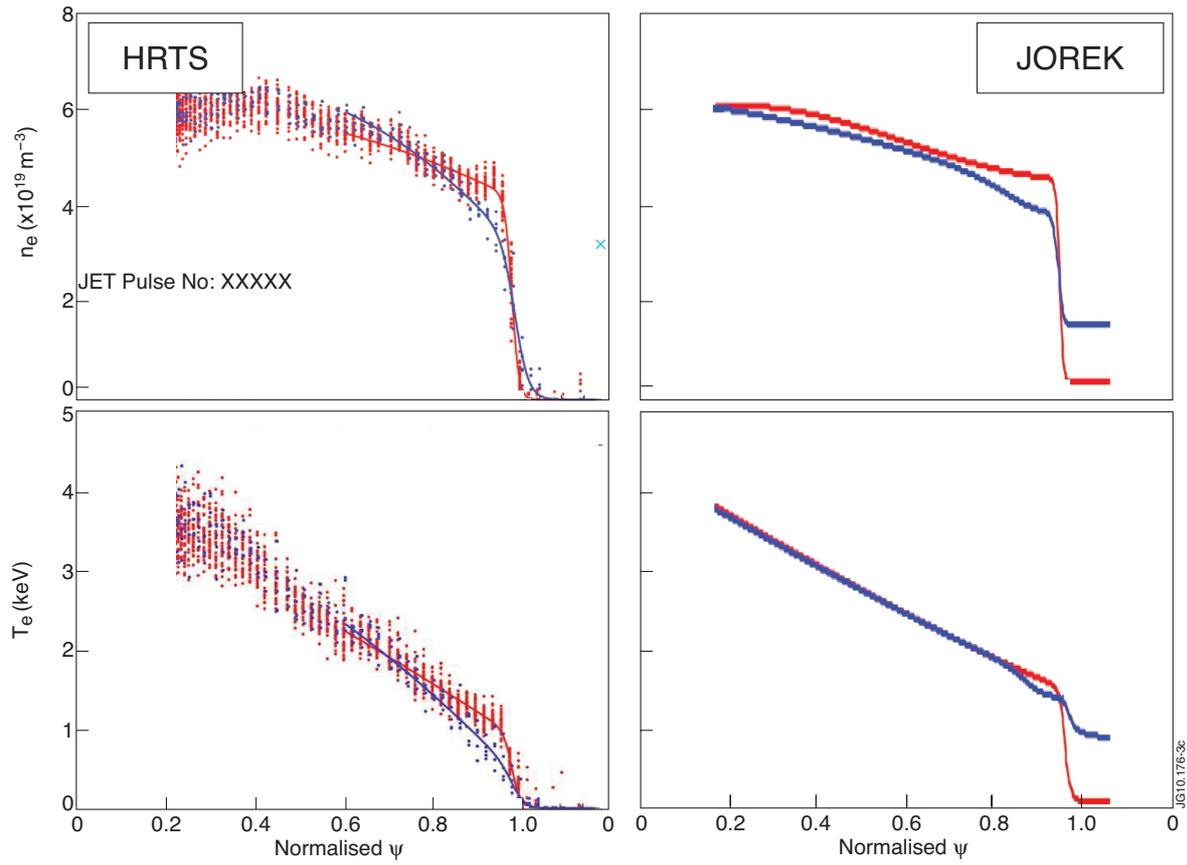


Figure 3: The density and temperature profiles from the HRTS diagnostic (left) can be compared to simulation results (right) for Pulse No: 73569.

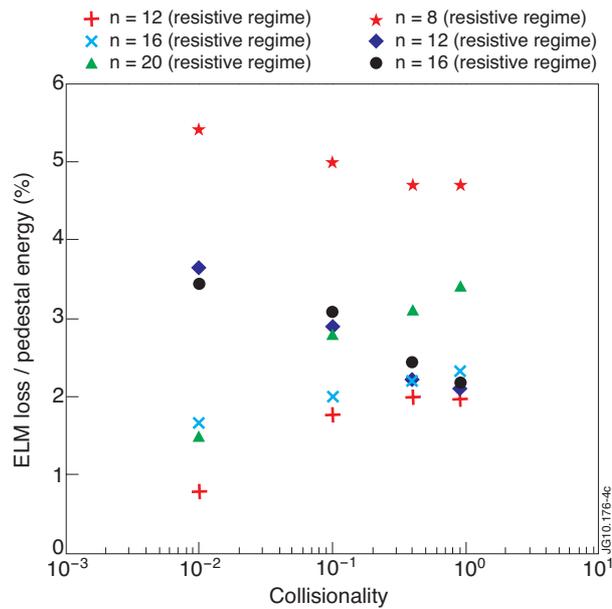


Figure 4: A collisionality scan done for two different regimes. A resistive regime (blue) and a more ideal regime (red) with lower resistivity. The different signs stand for different mode numbers.