Transport Modelling with a Combined Core and Edge Code

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INTRODUCTION

Transport of energy and particles in Tokamaks is usually studied separately for the region inside the last closed flux surface (separatrix) and for the edge region. This implies that modelling of the plasma core is replaced by boundary conditions in edge transport codes and modelling of the plasma edge is replaced by boundary conditions in core transport codes.

However there are problems where such a splitting can be inadequate and it would be desirable to study transport in a global way, from the centre to the divertor targets. Examples of such problems are the L-H transition, ELMs, and other phenomena that appear to imply sudden modifications of transport coefficients over a wide plasma region correlated to modifications of the plasma edge [1].

On a longer time scale, of the order of the energy or particle confinement time, or even in steady state, transport studies in the plasma core can benefit from a global approach. This happens each time that particle and energy source or sink terms cannot be accurately measured or simulated without properly simulating the plasma edge. Examples are transport of hydrogen isotopes in all regimes and evaluation of charge exchange losses in the hot ion regime[2].

NUMERICAL APPROACH

In developing the JET code for global transport studies we aimed to include all features routinely used in $1^1/_2$D core transport codes and 2D edge transport codes, such as sophisticated transport models for the plasma core, proper evaluation of power input terms, connection to existing data bases and well developed post-processors for the analysis of results and quantitative comparison with experiments. Another important requirement was the possibility to simulate transients on any time scale of interest without a big overhead in computer time.

Such considerations led us to couple the $1^1/_2$D core transport code JETTO to the EDGE2D/NIMBUS plasma/neutrals 2D transport code for the edge, by means of an adaptation of the so called fractional steps technique.

In essence the method reduces to enforcing continuity of density and temperatures (n, T_e and T_i), and of the corresponding total particle and energy fluxes (Φ, Q_e and Q_i) at a chosen interface, by imposing proper boundary conditions to each code at each time step. Namely, in JETTO:

$$n_J{}^n = n_E{}^{n-1} , \quad T_{e,J}{}^n = T_{e,E}{}^{n-1} , \quad T_{i,J}{}^n = T_{i,E}{}^{n-1}.$$

In EDGE2D/NIMBUS:

$$\Phi_E{}^n = \Phi_J{}^{n-1} , \quad Q_{e,E}{}^n = Q_{e,J}{}^{n-1} , \quad Q_{i,E}{}^n = Q_{i,J}{}^{n-1}.$$

Here the superscript n indicates the time step, while the subscripts E and J refer to the codes and poloidal averages of the quantities are used at the interface in EDGE2D/NIMBUS.

Continuity of neutral profiles and fluxes is also enforced in order to have a consistent evaluation of particle sources.

Other combinations of boundary conditions are possible and have been tested. The important point is that at the interface one code receives a variable or flux from the other and gives back the corresponding flux or variable. This procedure ensures continuity of all relevant quantities with sufficient accuracy by simply running both codes with time steps typical of EDGE2D/NIMBUS, avoiding extra iterations at each time step. As a result the coupled code is very robust and requires less than 10% additional computer time with respect to the stand alone EDGE2D/NIMBUS.

A series of tests showed that transients related to initial conditions not properly matching at the interface are washed out on a time scale shorter than the typical time τ_{sol} required by the Scrape Off Layer (SOL) to reach steady state in EDGE2D/NIMBUS runs ($\tau_{sol} \approx 30$ ms for typical JET discharges). The time evolution following these transients is consistent with the time scales expected from SOL and core physics. Moreover, large differences in the initial conditions of the SOL, which correspond to small differences in the initial conditions of the global problem, result in small differences at the interface and in the global solution after a time $\approx \tau_{sol}$. This is consistent with the overall problem being well posed and numerically stable. Therefore transients with a fast evolution (time scale $\leq \tau_{sol}$) require a pre-run of the coupled codes to obtain properly matching steady state or quasi-steady state (i.e. changing on a time scale of the order of the global confinement times) initial conditions. On the other hand transients on a time scale > τ_{sol} can be studied starting from initial conditions not accurately matching at the interface.

Very slow plasma evolution, on the time scale of the core energy or particle confinement time, and steady state situations can be studied assuming that the edge region follows a series of quasi steady states. These are obtained by running the coupled codes for relatively short time intervals ($\approx\tau_{sol}$) at chosen times during the evolution of the plasma core.

EXAMPLE OF MODELLING WITH THE COMBINED CODE

As an example of the application of the combined code in a non stationary situation we present results of a simulation of the ohmic phase immediately following the X-point separatrix formation and preceding neutral beam injection in the JET shot 32919.

During this phase, lasting about half a second and normally preceding JET hot ion H-modes, the average plasma density $<n_e>$ strongly decreases (fig. 1) supposedly due to particle absorption by the divertor targets.

In our simulation the particle absorption has been modelled by imposing a difference between the outgoing plasma flux and the influx of neutrals at the targets approximately equal to the rate of change dN/dt of the core plasma particle content N. The corresponding absorption rate $\approx$ 1.4 10^{21} s^{-1} (out of $\approx$3.5 10^{22} s^{-1} ions reaching the divertor targets) is about ten times larger than the flux of neutrals to the divertor pump, as computed by NIMBUS.

This very crude model, which does not take into account the actual dynamics of the particle absorption nevertheless gives a reasonable simulation of the $<n_e>$ evolution (Fig. 1).

For the energy transport model in the core plasma (from the centre to the interface with the boundary region less than 5 mm inside the separatrix) we used a combined Bohm-gyro-Bohm model [1] including a 'non local' dependence of the Bohm-like term on $L_{T_{ea}}=<\nabla T_e/T_e>_{\rho>0.8}$. Results of this model are particularly sensitive to the electron temperature T_{ea} at the interface. This temperature is computed, not prescribed from experimental traces.

We also assumed an empirical effective particle diffusion coefficient D^{eff} which is of the order of the heat diffusivity χ in the central part of the discharge. However the ratio D^{eff}/χ needs to be decreased as the normalised minor radius ρ increases, in order to provide a reasonable simulation of the slope of the experimental density profile with the flux of neutrals across the interface computed by EDGE2D/NIMBUS ($\Phi_0\approx$4 10^{21} s^{-1}). This result could possibly be an indication of an inward particle flux term strongly increasing towards the plasma boundary.

The core boundary values resulting from the model have been used as constant transport coefficients in the region beyond the separatrix. However an explicit inward pinch velocity such that $V/D=15m^{-1}$ had to be added in this region for a proper simulation of the probe measurements reported in [3].

Simulated and experimental values of temperature and density profiles in the plasma core are given in Fig 2. Figs 3 and 4 show computed and experimental values of parallel ion saturation current and electron temperature at the external divertor target.

The power fluxes into the SOL are a result of the simulation (P_e $\approx$0.8MW and P_i $\approx$1.1MW) and slowly diminish with time as $<n_e>$ decreases and the electron temperature increases. The density at the interface n_{ea} is also a result of the simulation and it appears to decrease with time together with $<n_e>$. However this implies a decreasing ion saturation current at the targets, which does not seem to be supported by probe measurements. This result might indicate that in this case D^{eff} should become larger as $<n_e>$ diminishes.

We conclude from the results obtained so far that the combined JETTO/EDGE2D/NIMBUS code is a powerful tool to simulate tokamak discharges in steady state and time dependent situations over the entire plasma cross section, from the centre to the divertor targets.

By eliminating ad hoc (and sometimes ‘convenient’) assumptions at the interface between core and boundary regions this code provides a very tough and complete test for transport models, including the effect on the boundary of transport assumptions in the core and viceversa.

REFERENCES

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[3] G.K.McCormick et al., 12th PSI Conference, St. Raphael, France, 20-24 May 1996.

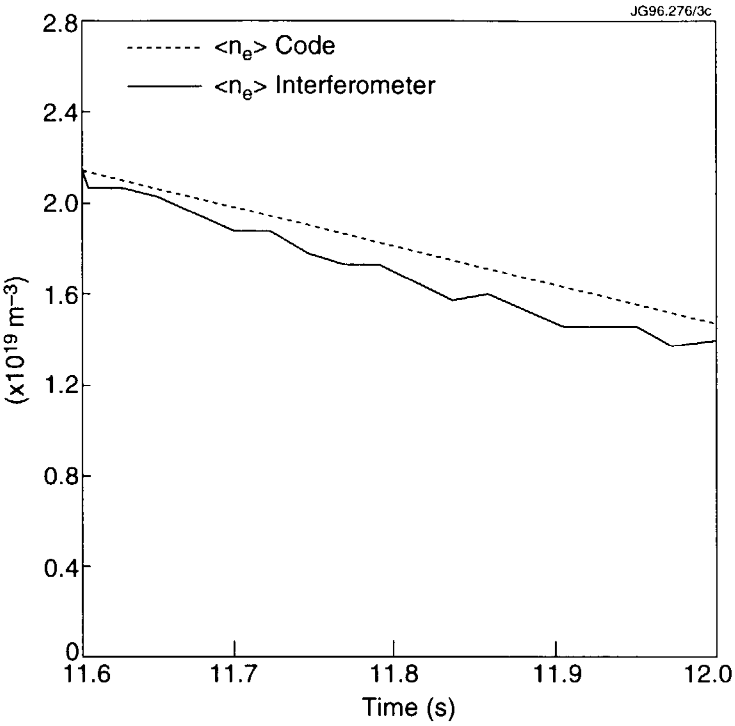

Fig. 1 Experimental and computed time evolution of the average density in JET pulse 32919 before NBI heating.

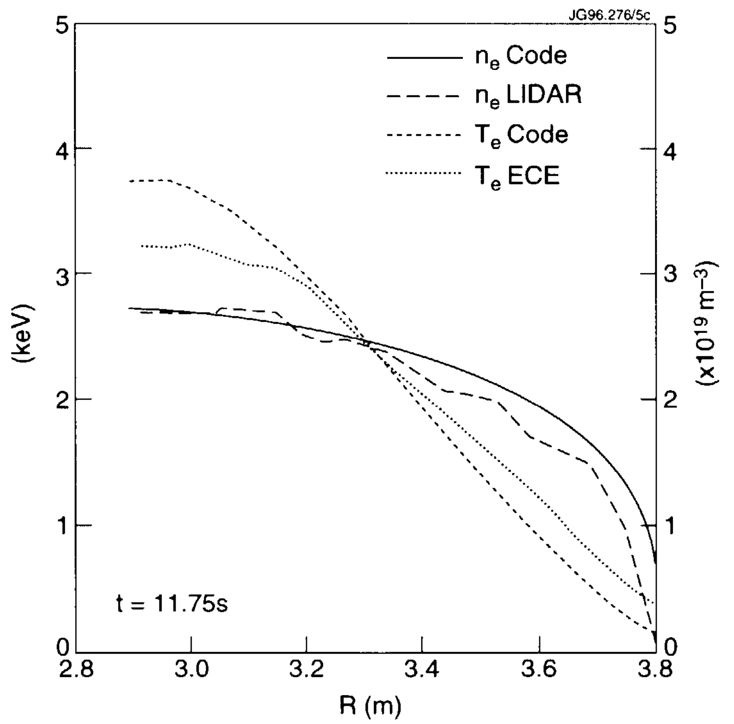

Fig. 2 Experimental and computed electron density and temperature profiles in the plasma core at t=11.75 s.

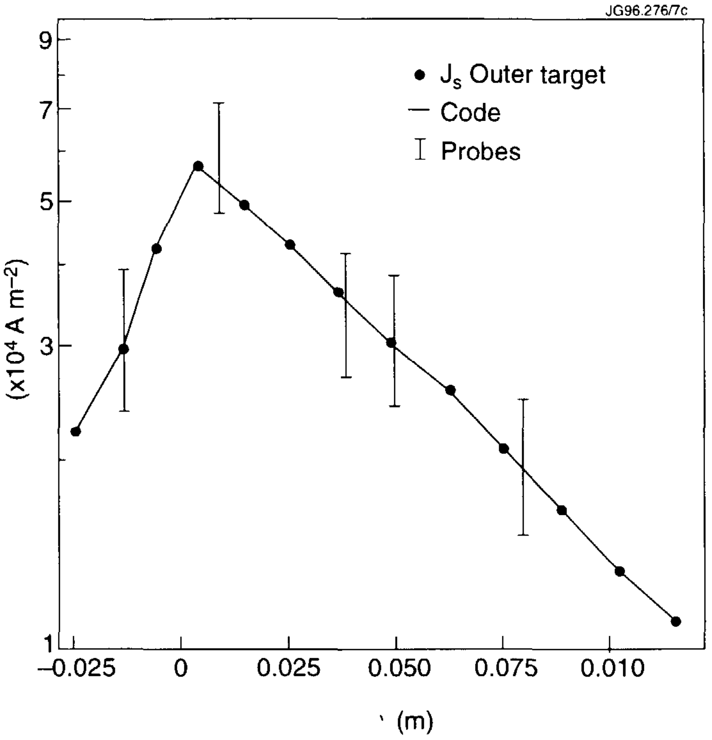

Fig. 3 Experimental and computed ion saturation current at the outer divertor target at t=11.75 s.

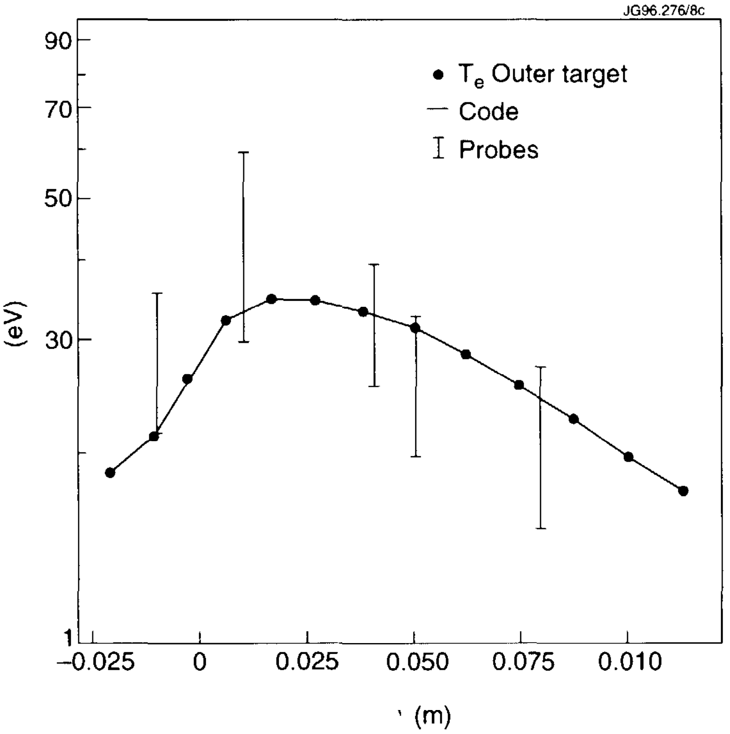

Fig. 4 Experimental and computed electron temperature at the outer divertor target at t=11.75 s.