Toroidal rotation prediction of ITB *H*-mode JET plasmas using CRONOS code

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This work investigates toroidal rotation of ITB *H*-mode JET plasmas and uses an integrated predictive simulation code CRONOS to simulate plasma profiles of JET discharge. The core transport models used in these simulations is a combination of an anomalous transport model semi-empirical Mixed Bohm/ gyro-Bohm (Mixed B/ gB) or the gyro-Landau fluid (GLF23) that includes ITB effects and a neoclassical transport model NCLASS A simple linear pedestal model is used based on an international scaling to estimate the top of pedestal. Time evolution of plasma temperatures and electron density profiles of JET optimized shear discharge 46123 are compared between experimental measurements and simulation results.

Analysis of toroidal rotation

In this part, toroidal velocity data of 10 JET optimized shear discharges (40542, 40847, 46123, 46664, 51599, 51976, 52009, 53521, 53532 and 53537) from the International Profile Database [1] are used for investigation. Previously, B. Chatthong *et al.* found that, in NBI heating discharges, there is a strong correlation between the local ion temperature (T_i) and toroidal velocity (v_{tor}) [2] as shown:

$$v_{tor}[\mathrm{m/s}] = cT_i\left[\mathrm{keV}\right], \tag{1}$$

where the constant c was estimated based on over ten thousand data points from those ten discharges to be around 1.43 x 10^4. However, the same calculation made from each individual discharge yields different constant number as shown in table 1.

Further investigation using empirical fit and statistical method yields that the toroidal velocity is depending on both local ion temperature and NBI heating power, but not on ICRH heating power, plasma current or toroidal magnetic field. As expected, the NBI heating plays important role in driving toroidal momentum. The new relation is in the form:

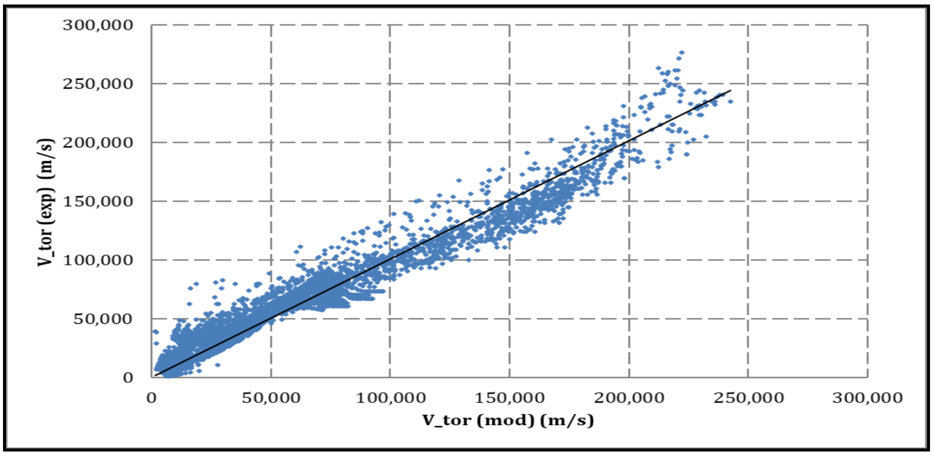
$$v_{tor}[\mathrm{m/s}] = \left(-1239.4P_{NBI}\left[\mathrm{MW}\right] + 29889\right)T_i\left[\mathrm{keV}\right]. \tag{2}$$

The comparison of toroidal velocity from the calculation and from the database can be seen in figure 1. Note that the prediction is much better than what was done in Ref. [2].

Table 1 Proportional constant of each JET discharge as well as its engineering parameters at diagnostic time

Discharge	c	P_{NBI} (MW)	P_{ICRH} (MW)	I_p	B_ϕ
40542	7844	18	2.5	3.22	3.49
40847	7342	18	0	3.05	3.5
46123	5800	13.5	4	2.5	2.54
46664	9744	16	6	2.89	3.51
51599	9650	10.1	4.7	2.2	2.65
51976	9448	17	4	2.45	3.5
52009	15308	12.38	0	2.5	2.7
53521	10894	14.6	4	2.02	3.54
53532	14811	12	0	2.22	2.64
53537	10190	9.6	6	2.22	2.64

Figure 1 Toroidal velocity comparison of all data points from 10 JET discharges



Simulation Setup

CRONOS code: The CRONOS code was written and first proposed by Artaud and groups in 2010 [3]. The model was developed and validated for applying to the various ingredients of a burning plasma discharge, covering the full range of research subjects in fusion plasma theory. It is a numerical code designed to solve the transport equation for various plasma quantities such as current density, electron and ion temperatures, electron density, toroidal momentum, etc. The transport equations are solved in 1D of magnetic flux Coordinate. The magnetic equilibrium, radiation and particle losses, thermal and particle sources are solved in 2D. The code has been used to study plasma behaviour of devices like Tore Supra, JET, ITER and others [4–7].

Mixed Bohm/gyro-Bohm (Mixed B/gB): This model was developed to describe turbulent transport in tokamak plasma. Bohm scaling was appropriate to describe both electron and ion transport only in a large tokamak device like JET [8,9]. Therefore, the gyro-Bohm term was added to model smaller devices [10]. In short, the ion and electrons for thermal and particle transport diffusivities are calculated as linear combination of both Bohm and gyro-Bohm effects.

Gyro-Landau fluid (GLF23): The GLF23 transport model [11] computes the quasilinear energy, particle and toroidal momentum transport fluxes due to ion/ electron temperature gradient (ITG/ ETG) and trapped electron modes (TEM) according to the drift wave linear eigenmodes. The fluxes are normalized to give the same ion thermal energy flux as non-linear gyro-Landau fluid simulations of ITG/TEM modes.

Simulation results and discussion

Figure 2 Spatio-temporal profiles of JET discharge 46123 for ion temperature (left) and electron temperature (right): experimental data (top) and simulation results using Mixed Bohm-gyroBohm (middle) and glf23 (bottom)

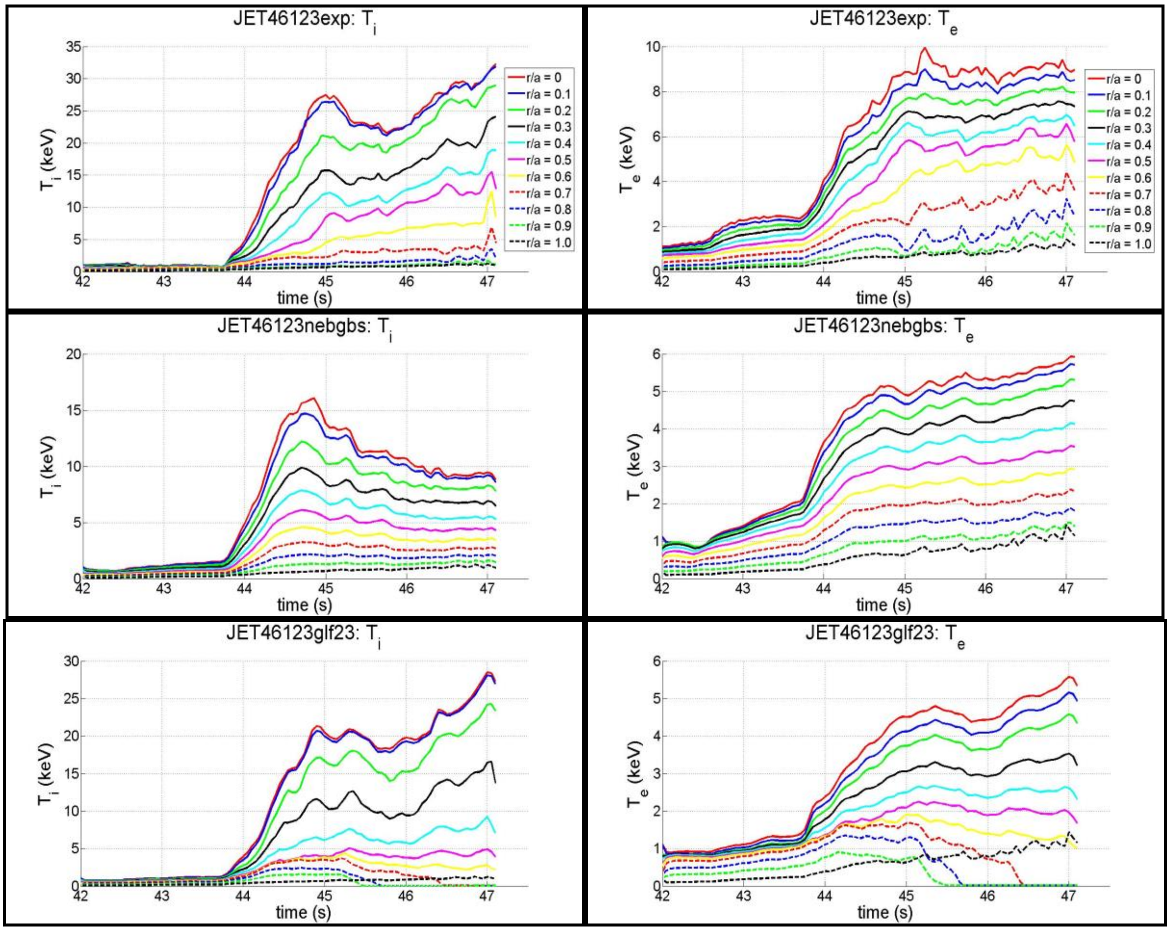


Figure 2 shows the comparison of experimental data of JET discharge 46123 and simulation results using CRONOS with Mixed B/gB and GLF23 transport models. Each line represents different location in the plasma from center to the edge. The x-axis represents the time where the plasma is being discharged (42-47 seconds). It can be seen that simulation using GLF23 yields better ion temperature profiles both qualitatively and quantitatively. Both models under-predict the experimental data. On the other hand, it appears that Mixed B/ gB can predict better electron temperature. Both also under-predict the electron temperature. It also appears that GLF23 can simulate better ITB structure of the plasma. This is presented as the local gradient of temperature profiles. Two ITBs are found, initially at the inner half of plasma core and then later, another is found at the outer half of plasma core.

Conclusion

In this work, toroidal velocity data of 10 ITB *H*-mode JET discharges are analyzed to yield a simple empirical relation. It is found that the toroidal velocity is related to both local ion temperature and NBI heating power. This makes sense because the NBI heating power is the dominant heating scheme for these discharges. Additionally, the heating affects both ion temperature and toroidal velocity because it can provide plasma both thermal source and toroidal momentum. CRONOS simulations of discharge number 46123 is also carried out using either Mixed B/gB or GLF23 transport models for turbulent transport effect. It is found that GLF23 model is better in ion temperature prediction while Mixed B/gB is better in electron temperature prediction. ITB structure can be found only in GLF23 model simulations.

Acknowledgments

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