Practicability of a Statistically Induced Thermal Transport Model Based on TASK3D-a Transport Analyses Database

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The practicability of a statistically induced thermal transport model (fit to the database) by exploiting transport analyses database accumulated by TASK3D-a (integrated transport analysis suite for LHD plasmas) is examined. The promising results, such as reproduction of measured ion temperature profiles and observed tendency, have been obtained through a systematic comparison against LHD plasmas. It encourages to further pursue a statistical approach for transport modelling of fusion plasmas.

Keywords: thermal transport modelling, statistical approach, TASK3D-a, Large Helical Device (LHD)

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The integrated transport analysis suite, TASK3D-a [1], has enhanced thermal transport analyses for the Large Helical Device (LHD) [2] plasmas. Then, the possibility has emerged for attempting the thermal transport modelling based on statistical approach by exploiting accumulated TASK3D-a transport analyses database, taking the radial-profile information into account as well. As the first attempt for this idea, a regression form of the ion heat diffusivity, χ_i (more precisely, normalized by Bohm diffusion coefficient, $T_\mathrm{i}/(eB)$, with T_i being the ion temperature), was obtained as reported in [3],

$$\chi_\mathrm{i}/(T_\mathrm{i}/eB) = 6.08 \times 10^{-9} \nu_\mathrm{i}^{*-0.139} \rho_\mathrm{i}^{*-2.29} (T_\mathrm{e}/T_\mathrm{i})^{0.77}, \tag{1}$$

where ν_i^*, ρ_i^*, and T_e are the normalized ion collisionality, the normalized ion Larmor radius, and the electron temperature, respectively. This regression has the coefficient of determination (conventionally denoted by R^2) of 0.83 (adjusted R^2 as well), which can be considered as a reasonably high value indicating the variation of the original database is statistically well covered by this simple expression.

It should be strongly emphasized here that the induced regression expression, Eq. (1), is not the scaling law, but just the regression fit to the existing database. Thus, it is not valid to try to apply this expression to any other devices (regardless they are existing or under design), or other operation scenario even in the same device, LHD. In other words, Eq. (1), was obtained solely to reproduce existing database of ion heat diffusivity with a few explanatory variables for simplicity. Thus, any arguments for applying this expression beyond the current database or applying design of future devices is not meaningful. Extending the transport analyses database (such as parameter range and operation scenarios based on "learning" experiment) and further improving the statistical analyses may approach this stage step by step. However, it is too early to attempt extrapolations towards future devices based on this newly implemented way of thinking in transport modelling. It is also not valid to compare Eq. (1) with results in previous scaling research, even in the same device, LHD [e.g., [4, 5]], since the employed database for those researches are quite different (with much less ion heating and without ion internal transport barrier formation [6]) from that treated in this Letter.

In this Letter, results of implementation of this regression expression into the predictive transport simulation (TASK3D [7]) as a transport "model" are described to test and measure its practicability. These "validation" calculations have given an encouragement to further pursue the thermal transport modelling based on a statistical approach exploiting the accumulated TASK3D-a transport analyses database.

Systematic calculations to elucidate some tendency would help convince the practicability of this model. In this regard, a systematic comparison was performed for 8 cases with different density and ion temperature (ranging from ~1.5 to ~2.7 × 10^{19} m^{-3} and from ~3 to ~4 keV). In these calculations, the density and electron temperatures are fixed as measured. NBI deposition is calculated for each case by TASK3D. Then, only the transport equation for the ion temperature is solved by implementing Eq. (1) as a heat diffusion coefficient to reach the steady-state T_i profile. The T_i at the plasma edge is assumed to be the same as measured ones.

T_i profiles for 4 out of these 8 cases are shown in Fig. 1 ((a) for measured (with error bars) and (b) for predicted ones). Measured ones indicate the formation of ion transport barrier [6] (in particular, for the case of 109125

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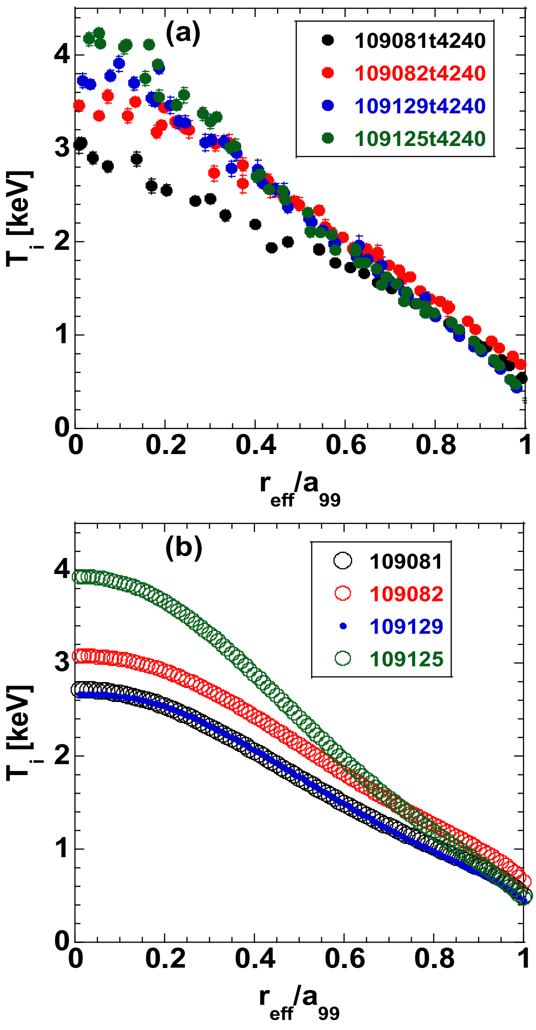

Fig. 1 Ion temperature profiles for (a) measured and (b) predicted by TASK3D, for 4 out of 8 cases of systematic comparison calculations. Data points for 109081 and 109129 are almost the same, since the prediction calculation for a case of 109129 failed to reproduce its measured profile.

and 109129) while keeping almost unchanged T_i profiles at $r_\mathrm{eff}/a_{99} > 0.6$. Here r_eff/a_{99} is the effective minor radius normalized by the radius inside of which 99% of the electron pressure is enclosed. The statistical model fails to reproduce the barrier formation for the case of 109129, but the change of T_i for other 3 cases are reasonably reproduced, of course, with a certain discrepancy for the absolute T_i values. The modelling might be improved, for example, by deriving regression expressions separately according to radial regions, such as considering inside/outside of the transport barrier. Such trials, as a future investigation, would increase physics-relevance of this approach. However, as for the practical prediction of T_i values, this approach tends to provide reasonably practical results.

Figure 2 summarizes the dependence of the central T_i values ($T_\mathrm{i}(0)$) on the central density values ($n_\mathrm{e}(0)$) for

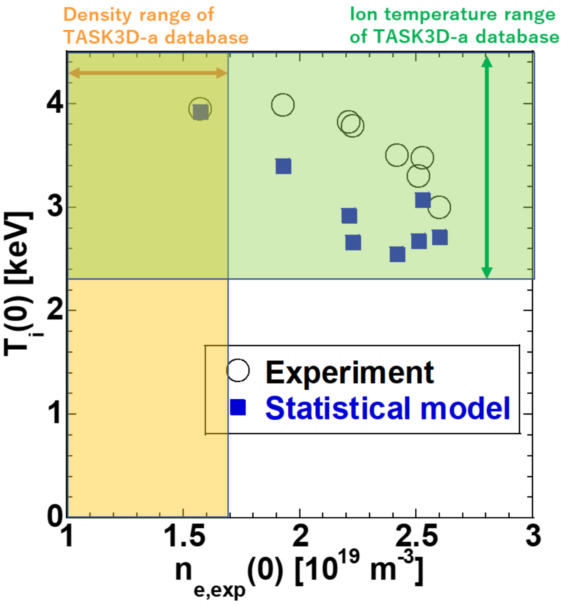

Fig. 2 Dependence of the central T_i values ($T_\mathrm{i}(0)$ on the central density values ($n_\mathrm{e}(0)$). A hatched region corresponds to the density and ion temperature range of TASK3D-a analyses database used to induce Eq. (1). Boundary is obtained from inner-region data of Fig. 1 in Ref. [3].

8 cases of this systematic comparison. It is recognized that there are some discrepancy between measured and predicted values, but the dependence ($T_\mathrm{i}(0)$ on $n_\mathrm{e}(0)$) of measured values is practically reproduced. It should be noted here that the density and ion temperature ranges of TASK3D-a analyses database used to induce Eq. (1) is up to $\sim 1.7 \times 10^{19}\,\mathrm{m}^{-3}$ and above 2.3 keV [3], which correspond to hatched regions in Fig. 2. Thus, most of these 8 cases are beyond such density range but within the ion temperature range. Rigorously speaking in a statistical analysis sense, Eq. (1) is only valid for parameter regime where database covers. Despite of this, Fig. 2 indicates that one could possibly consider the reproduction of ion heat diffusivity (Eq. (1)) can provide practical values for ion temperatures within the regime covered by the TASK3D-a database. This encourages to pursue this statistical approach for transport modelling furthermore.

As emphasized in Ref. [3], this transport "model" does not depend on any physics-based considerations such as neoclassical/turbulent transport, impact of radial electric field and impurities, and others. However, it might be very practical to predict plasma profiles after accumulating transport analyses cases based on "learning" experiments. Although only T_i profile is examined in this Letter, this approach can be similarly extended to density and electron profiles by further extending transport analyses databases (also for deuterium plasmas in LHD). This is possible now after several-years developments and exploitations of TASK3D-a by many collaborators. This extended activity along with upgrading statistical analyses will be reported in the near future.

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[1] M. Yokoyama *et al.*, Nucl. Fusion **57**, 126016 (2017).
[2] Y. Takeiri *et al.*, Nucl. Fusion **57**, 102023 (2017).
[3] M. Yokoyama, Plasma Fusion Res. **9**, 1302137 (2014).
[4] H. Yamada *et al.*, Nucl. Fusion **45**, 1684 (2005).
[5] H. Funaba *et al.*, Plasma Fusion Res. **3**, 022 (2008).
[6] K. Nagaoka *et al.*, Nucl. Fusion **51**, 083022 (2011).
[7] A. Sakai *et al.*, Plasma Fusion Res. **10**, 3403048 (2015).