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Insights into a negative triangularity reactor from EUROfusion's TSVV 2

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Experimental observations show that Negative Triangularity (NT) plasma shaping can significantly improve the energy confinement time of tokamaks. Moreover, relative to the standard Positive Triangularity (PT) shape, NT plasmas have much *more* difficulty accessing H-mode. Together these two facts may enable an attractive power plant design – the plasma can be heated to reactor conditions while remaining in L-mode (avoiding the material survivability concerns associated with ELMs), yet still achieve sufficiently good confinement for high fusion gain. This potential has motivated EUROfusion's Theory, Simulation, Verification, and Validation (TSVV) project on NT, which is investigating the most important issues for the feasibility of a NT power plant. In this talk, we will summarize the results obtained thus far.

Local and global gyrokinetic simulations generally find NT has improved energy confinement relative to PT, though this typically requires a kinetic treatment of electrons. Such simulations are quantitatively consistent with TCV experiments and reproduce significant trends. They show the heat flux reduction in NT is primarily due to an increase in the critical gradient, while the stiffness remains similar.

Interestingly, simulations show that NT is more beneficial at large aspect ratio, while it can degrade confinement in spherical tokamaks (for trapped electron mode turbulence) [1]. This indicates that the standard physical picture for why NT decreases transport, which is based on trapped electron stability [2], is incomplete. Further investigation motivated an expanded physical picture based on FLR damping as well as a resonance between the magnetic drift velocity and the ion (or electron) diamagnetic velocity. This physical picture holds well at conventional and large aspect ratio and can be used to explain previously observed trends [3].

Global gyrokinetic simulations and novel flux tube simulations with profile shearing [4] both indicate that the scaling of transport with device size is similar in NT and PT. Additionally, finite plasma β simulations at conventional aspect ratio indicate that electromagnetic turbulence is similar or weaker in NT, as compared to PT. These facts suggest that the confinement benefits of NT will persist in reactor-scale devices. However, electromagnetic turbulence does appear significantly stronger for NT (relative to PT) in spherical tokamaks [1,5].

Reduced modeling of NT has been performed using ASTRA-TGLF with SAT2, displaying good agreement with nonlinear gyrokinetics [6]. Profile predictions sometimes display a weak improvement from NT, but more often see no effect from triangularity. This observation, as well as analysis of TCV experiments, suggests that most of the confinement improvement is coming from $\rho_{tor} > 0.9$, which is largely outside the simulation domain and is challenging to model.

Theoretical and numerical investigations into tearing stability suggest little distinction between PT and NT. Modeling of Alfven eigenmode stability and the resulting fast ion transport indicate that both are modestly improved in NT [7], which is consistent with TCV experiments. Predictive [8] and interpretive [9] simulations of the Scrape-Off Layer (SOL) suggest that NT will have an SOL width that is between that of a PT L-mode and a PT H-mode [10]. This indicates that NT should be beneficial for power exhaust.

References

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