The successful implementation of controlled magnetic confinement fusion would advance humanity’s transition towards renewable energy. The largest obstacle in the way of achieving controlled fusion is turbulence in the plasma fuel. To reduce the deleterious impacts of this turbulence, new tokamak geometries are analyzed by first running a ballooning stability code to assess stability in the MHD regime across the parameter space in which the pressure gradient and magnetic shear are varied. To assess the stability of the plasma at shorter wavelengths, the gyrokinetics code GS2 is run. Points in the parameter space that are MHD stable are found to be unstable in the gyrokinetic regime. The predicted impact of these instabilities will be assessed in future work.

**The Future of Energy**

- Three plausible long-term energy solutions:
  1. Solar with improved storage
  2. Reconsideration of Fission Power
  3. Development of Deuterium-Tritium Fusion Power

**Fusion in Principle**

- Deuterium easily processed from ocean water (1 in 6000 hydrogen atoms)
- Tritium created from lithium and DT neutrons:
  \[ \frac{1}{3}L + n \rightarrow \frac{1}{3}He + \frac{2}{3}T \]
- Fusion reaction releases 17.6 MeV via:
  \[ \frac{2}{3}D + \frac{2}{3}T \rightarrow \frac{4}{3}He + n^0 + 17.6 \text{ MeV} \]

- Turbulence has thus far prevented a successful implementation of the Tokamak design
- Chaotic fluctuations in pressure lead to rapid energy loss, has prevented energy output from exceeding energy input to heat the plasma to temperatures necessary for fusion
- Specifically, we are looking at ballooning instabilities

Unstable Ballooning
- Radially elongated jets of “hot” and “cold” plasma along projected flux surface

Stable Ballooning
- No such jets visible along projected flux surface

**Results**

- While points in stable region are MHD stable, they can experience instabilities in gyrokinetic regime
- Blue points are evaluated further with gyrokinetic code

**Methodology**

- Use alternate Tokamak geometries to prevent turbulence from destroying necessary temperature gradient for fusion
- Run Magnetohydrodynamics (MHD) code to determine ballooning stability boundary for short wavelengths for given tokamak geometry
- For a specified flux surface (related to radius), where is the stability boundary in terms of \( \beta' \) and \( \delta \)?
- \( \beta = \frac{2p}{\mu} \) is comparable to \( \tilde{\mu} \)
- \( \delta \) is the component of \( \tilde{J} \) in direction of increasing rho
- Run Gyrokinetic code to determine extremely short wavelength instabilities

**Abstract**

The Tokamak

Equilibria and Stability in Magnetic Confinement Fusion

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Magnetic Confinement Fusion

- Ions need to be at such a high temperature (200 million degrees Celsius) that confinement by a magnetic field is necessary
- By Lorentz Force Law:
  \[ F = ze\left( E + \frac{1}{c} v \times B \right) \]
- Ions are “locked” to magnetic field lines, even after collisions with other ions

The Tokamak

- Turbulence has thus far prevented a successful implementation of the Tokamak design
- Chaotic fluctuations in pressure lead to rapid energy loss, has prevented energy output from exceeding energy input to heat the plasma to temperatures necessary for fusion
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Unstable Ballooning
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**Conclusion**

Determining ballooning stability is only the first step in determining stable configurations of tokamak control parameters. While certain regions of the parameter space can be ruled out as MHD unstable, the gyrokinetic analysis reveals that even MHD stable points can be unstable at shorter wavelengths. More calculations will be performed over a larger parameter space and with different tokamak geometries to determine regions of both MHD and gyrokinetic stability.

**References**

J. Ball. Up-down asymmetric tokamaks. 2016.