Introduction

- Experiments indicate tokamak turbulence is strongly affected by sheared flows.
- Extensive theoretical work has been undertaken:
  - flow shear can tear apart turbulent eddies, suppressing turbulence
  - not all shear flows are stabilising eg Parallel Velocity Gradient (PVG) instability beyond critical perpendicular shear PVG linearly stabilised: transient perturbations remain.
- Strong toroidal flows of tokamaks have both perpendicular and parallel shear.
- What is the optimum shear flow for confinement – do we want ever more toroidal flow shear?
- Investigate effect of flow shear on Ion Temperature Gradient (ITG) and PVG instabilities in sheared slab via dissipative fluid model: simple system allows clear interpretation.

System Equations

- Analyse sheared slab, magnetic and flow fields: \[ \mathbf{B} = \hat{B}_0 (\hat{z} \times \hat{z}) \] \[ \mathbf{V} = \hat{V}_0 (\hat{z} \times \hat{z}) \]; \[ \mathbf{V} \equiv 0. \]
- Work in "twisting-shearing" representation \[ \mathbf{M} = \frac{\mathbf{v}}{c} \]
- removes problems of shear and time dependence from background flow
- aligns coordinate lines with characteristics of plasma response: sound waves
- normalised: \[ (x, y, z) = (r, \phi, z); \mathbf{v} = \sqrt{E/M};, T = T(z);, \gamma = 5/3; \]
- usual orderings: \[ \alpha = \alpha_{\parallel} - \alpha_{\perp}; \alpha_{\perp} = \alpha_{\perp} \]
- additional collisional orderings: \[ \gamma_{\parallel} \sim \sim \gamma_{\perp} \gamma_{\parallel} \sim \sim \gamma_{\perp} \]
- \[ \mathbf{V} \equiv \mathbf{v} \equiv \mathbf{v} \]
- twisted shear

Parallel Flow Instability

- Take Boltzmann electron response; ions described by collisional fluid equations
- derived from gyro-kinetic equation in doubly sheared coordinates with flow
- normalised: \[ (x, y, z) = (r, \phi, z); \mathbf{v} = \sqrt{E/M};, T = T(z);, \gamma = 5/3; \]
- usual orderings: \[ \alpha = \alpha_{\parallel} - \alpha_{\perp}; \alpha_{\perp} = \alpha_{\perp} \]
- additional collisional orderings: \[ \gamma_{\parallel} \sim \sim \gamma_{\perp} \gamma_{\parallel} \sim \sim \gamma_{\perp} \]
- \[ \mathbf{V} \equiv \mathbf{v} \equiv \mathbf{v} \]
- twisted shear

Impact of Convection

- Investigate effect of varying the magnetic field and flow shear on ITG and PVG instabilities.
- Solutions have form: \[ F(z) = \exp(a_{\parallel} z / 20) \exp(x_{\parallel} z) \]
- simple harmonic oscillator equation:
  - eigenvalue condition: \[ x_{\parallel} = \gamma_{\parallel} \sqrt{2/3} \alpha_{\parallel} \]
  - large \[ x_{\parallel} \] modes dominated by viscosity: FLR effects excluded
- Twisting mode localised where perpendicular gradients are small to minimise collisional dissipation.

Conclusions

- Investigated ITG and PVG instability in a sheared field with parallel and perpendicular flow shear.
- Instabilities are twisting modes, convected along the field by perpendicular shear flow.
- Parallel flow shear drives instability, having complex interaction with ITG drive.
- Sensitivity to angle of flow
- Instabilities with parallel shear flow small, but large M growth can be substantial.
- Mode decay slow; promotes sub-harmonic turbulence?