Survey of Experimental Data on Shear Flow-Induced Decorrelation and Suppression of Turbulence

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TTF Meeting '99

Goals of this talk:

- Survey available experimental data
- Evaluate shear flow stabilization model

Outline:

- Criteria for checking shear flow stabilization model
- Survey of turbulence data from various machines
- Evaluation of criteria using turbulence data
- Fluctuation diagnostic concerns
- Additional Physics issues
- Suggestions
- Conclusions

Criteria for Evaluating Turbulence Data in Terms of Models of Shear Flow Stabilization of Turbulence

- Decrease in radial correlation length of turbulence L_r
- Relationship between magnitude of shear flow rate and magnitude of turbulence suppression
- Causal relationship between increased shear flow rate and turbulence suppression
- Correlation of ExB shear flow with transport reduction
- Agreement with BDT criterion (approximate)
- Agreement with a specific first-principles model of turbulence generation, saturation, and shear suppression (e.g. based on ITG modes)

  (apparently no published examples of this one)

Possible Definitions of "Shear Suppression of Turbulence"

1) Fluctuation levels (e.g. ñ) go down with shear

2) Relative fluctuations (e.g. ñ/n) go down with shear

3) Fluctuations are unchanged (either ñ or ñ/n) but local fluctuation "drive" increases (e.g. ∇p)

4) Fluctuations levels themselves are meaningless, only their relative changes when compared with changes in local plasma gradients (e.g. ∇p)

5) The effect of ExB shear on the fluctuations levels can not be interpreted unless there is a specific model for the saturated state of the fluctuations with and without ExB shear (including changes in
local drive and damping/coupling mechanisms)

Evaluation of the evidence for "shear suppression of turbulence" depends on which definition is used

We use (1) / (2) to represent "strongest" definitions

Note that transport can not be directly related to density fluctuations alone (without φ fluctuations)

Evaluation of Data on L_r

- Slight reduction in L_r seen using probes in TEXT shear layer at outer midplane in OH

  - might be due to other factors besides shear, e.g. presence of LCFS very near shear layer

- Decrease in L_r seen using probes in CCT during biased H-mode, but increase in L_r seen at inner midplane

  - maybe different local shearing rate in/out

- Decrease in L_r seen in edge L->H with PCI in DIII-D, but only for $k_{pol} \approx 0$ with no poloidal resolution

  - interpretation appears highly model-dependent

=> Little evidence for shear induced radial decorrelation of turbulence

Evaluation of Data on ñ vs. Shear

(some examples from DIII-D)

- Decrease in FIR scattering from core during H-, VH- and NCS (Rettig '93, Rettig '97)
- Increase in FIR scattering from core during H-mode in DIII-D (Rettig NF '93, Moyer '99)
- Equal ñ/n as measured by probes in edge for L-mode and ELM-free H-mode in DIII-D (Moyer '97)
- Strong sustained decrease in reflectometer signal from edge shear in H-mode edge of DIII-D (Doyle '91)
- Slight increase in probe fluctuations from edge shear layer after very slow L-H transition (Moyer '99)
- Clear decrease in probe fluctuations in SOL in H-mode without any local flow shear (Moyer '95)

=> Lack of consistent evidence for "shear suppression" by definitions (1) or (2)

=> Possible qualitative consistency with "shear suppression" by definition (4)

Evaluation of Data on Causality

- TEXT EML (Ritz '90) - little significant change in edge turbulence with large change in edge flow shear
- CCT bias (Tynan '92) - reduction in turbulence levels and flux with bias, but also in SOL without shear
- DIII-D brake (Rettig '93) - reduced turbulence and sometimes transport with increased flow shear
- TFTR NBI (Synakowski '97) - E_r shear changes prior to ERS back-transition
- TEXTOR bias (Weyants '98) - E_r shear changes prior to bias-induced edge density increases

=> some evidence for externally changed E_r causing transition to improved confinement

Evaluation of Data on ñ vs.Transport

- Clear reduction of turbulence-induced particle transport through outer edge during H-modes (Tynan '92, '94, Moyer '95, '99)

- Correlation between reduced turbulence and reduced heat transport in core (Rettig '93, Rettig '94)

- Reduction in level of bursting fluctuations in core with NCS/ERS transition (Rettig '97, Synakowski '97)

=> Good connection between reduced ñ and reduced particle flux in L-H transition

=> Probable correlation between reduced turbulence and reduced transport in core

Evaluation of Data on BDT Model

- BDT satisfied without much reduction in turbulence or transport barrier in edge (Ritz '90, Tynan '94)
- BDT correlated with edge fluctuation amplitudes in edge inside LCFS (Moyer '95, Coda '97)
- BDT satisfied with small changes in turbulence and transport in SOL (Toyama '94)
- No direct evaluations of BDT made using measured turbulence properties in core
- Approximate agreement with theoretical criterion $\omega_s > \gamma_{lin}$ for onset of transport barriers in core

=> Transport and turbulence is either very sensitive to shear, or shear is the wrong parameter to look at

Fluctuation Diagnostic Issues

- Langmuir probes:

  - effect of electron temperature fluctuations
  - effect of probe bias on radial plasma potential

- Reflectometry:

  - need clear evaluation of k_r or k_{pol} resolution
  - effect of density fluctuation level on k resolutions
  - effect of non-linearity of response to local ñ

- FIR scattering:

  - lack of absolute calibration of ñ
  - lack of direct spatial localization

- PCI:

  - unclear k_{pol} resolution
  - lack of spatial resolution

=> need better turbulence measurements !

Additional Physics Issues

- Evaluation and effects of 2π poloidal asymmetries in turbulence, such as seen in TEXT and CCT
- Effect of open-field lines on edge turbulence, e.g. resistive sheath instabilities (Endler '95)
- Direct effect of electric fields on ion orbits, leading to transport changes without turbulence changes
- Possible effect of large scale stationary convective cells on transport, e.g. edge of CCT or stellarators
- Effect of magnetic separatrix and plasma shape on H-mode physics not in standard theories
- Nature of MTE events and bursts of fluctuations associated with them (VH, NCS, ERS)
- Possible effect of neutrals on L-H transition

=> Additional physics may be needed for quantitative explanation of transport barriers

Specific Suggestions

1) Radial decorrelation:

   evaluate L_r in a wide variety of conditions to isolate effects due to E_r shear from effects due to variations in gradients and other plasma parameters

2) Fluctuations vs. shear:

   plot database of local ñ vs. local E_r shear for various regimes and machines, while also keeping track of local gradients and other plasma parameters

3) Fluctuations vs. transport:

   plot local transport vs. local E_r shear for various regimes and machines, while also keeping track of local gradients and other plasma parameters

4) Causality:

   the "cause" of transport barriers can be clear only when there is a quantitative understanding of the mechanisms of turbulence, with and without shear

5) BDT criterion:

   use measured turbulence parameters (L_r, L_{pol}, ω_c) to evaluate BDT and/or check theory of core barriers

Conclusions

- A considerable body of evidence has been obtained on the relationship of ExB shear to turbulence

- There is not yet an accurate quantitative model that explains this relationship (accurate = better than "factor of 2" !)

- Further quantitative connections are needed of between turbulence measurements and models, e.g.:

  - scaling of local ñ vs. transport vs. shear
  - 2-D spatial structure of turbulence vs. shear
  - measurement of turbulent Reynold's stress
  - variation with geometry, e.g. linear , NSTX