Summary of thesis: Spatially localized self-sustaining mechanism induced by inhomogeneity in turbulence

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1 General Introduction

Turbulence ubiquitously appears in nature, and we try to understand turbulence based on coherent structures. The term coherent structure has several meanings according to contexts. Roughly speaking, coherent structures are minimal autonomous components of dynamic and vortex structures embedded in turbulence. We have introduced four categories about turbulence:

- Minimal Turbulence, which denotes a temporally chaotic flow in a small periodic region. This flow contains a coherent structure.
- Weak Turbulence, which denotes flows in spatially extended systems at relatively low Reynolds number. Such flows contain many coherent structure, and these coherent structures are similar to that appearing in minimal turbulence.
- Developed Turbulence, which denotes flows with multiple scale coherent structures. Coherent structures of different scales coexist, and interscale interaction is important.
- Mature Turbulence, which denotes flows with spontaneous spatial inhomogeneity. Different types of coherent structures coexist, and they create spatial inhomogeneity.

The development of the dynamical systems approach [1] for minimal and weak turbulence has been summarized, and the objective of this thesis, to extend the dynamical systems approach to developed and mature turbulence, is discussed.

2 Damping filter method

We have introduced the damping filter method for obtaining spatially localized solutions. The damping term works on a filtered region Ω, and vanishes out of Ω (unfiltered region). An exact solution of this filtered equation is connected to a solution of original equation by executing a continuation. The damping filter term enables us to extract local dynamics as a localized solution. This method has been applied to Swift-Hohenberg equation and Kuramoto-Sivashinsky equation. Technical issues in the continuation process have been successfully resolved.

3 Ejection-Jet cycle: self-sustaining interface

We have investigated the novel self-sustaining mechanism, we call ejection-jet cycle (EJC). EJC is realized in two-dimensional channel flows at relatively high Reynolds number $Re = 6000$ to 10000. This self-sustaining mechanism describes a synchronized interscale collective dynamics: This cycle consists of the meandering jet corresponding to outer-wall dynamics of the outer scale and the vortex pairs corresponding to the inner-wall dynamics of the wall scale. While Waleffe's self-sustaining process [2] utilizes an absolute instability, the EJC model does a convective instability, which needs sufficient space to grow up. That is, the convective instability makes it possible for the structures of the two different scales to interact with each other. This two-scale interaction mechanism may be applied for the large-scale motion in three-dimensional wall-turbulence [3], although the chaotic nature of the chaotic interface is far weaker than that of three-dimensional wall-turbulence.

4 General Conclusion

We introduce "functional" coherent structure (FCS) to denote the chaotic interface. Since the chaotic interface has the "role" in addition to the unclosed dynamics as noted above and the role represents some "function", we adopt these properties as the definition of FCS. In general, we use a functional coherent structure to describe a locally self-sustaining coherent structure of which local dynamics is unclosed due to its additional function. In this sense, the FCS-based dynamical systems approach can be called role-based approach. While the turbulence-laminar interface in two-dimensional channel flow is a single FCS system, we can consider multiple FCS systems where FCSs work cooperatively. We expect that multi-FCS picture helps us understand developed and mature turbulence.

References

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[3] Sadayoshi Toh and Tomoaki Itano. Interaction between a large-scale structure and near-wall structures in channel flow. *Journal of Fluid Mechanics*, 524:249–262, feb 2005.