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RNG in Turbulence and Modeling of Bypass Transition

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1. Motivation and Objectives

Since I joined CMOTT on July 1990, I have been working on two research projects. The first project concerns the Renormalization Group (RNG) analysis of turbulence and the second project is on the calculation of bypass transition through turbulence modeling. In addition, the preparation of two papers on work performed at was completed.

Application of RNG in turbulence was proposed by Yakhot and Orszag in 1986. RNG is a process which eliminates systematically the small scales, and represents the effect of those eliminated small scales on the uneliminated large scales as the changes in the transport properties. It is because of this property of RNG that Yakhot and Orszag suggested that RNG could be used as a model builder in turbulence modeling. They also presented a $k - \epsilon$ model in their 1986 paper. However, this paper is lengthy, with many unstated assumptions. Our aim is first to understand, and to validate the RNG approach in turbulence through an independent study. We will then study the possibility of constructing RNG based turbulence models, and try to proceed to do the turbulence modeling through RNG in parallel with the classical approach. We will also compare the numerical predictions made by RNG models and by classical models against data from Direct Numerical Simulation and against experimental data from different benchmark cases.

In a quiescent environment, the transition is initiated by the instability of the laminar boundary layer to Tollmien-Schlichting waves. These waves are amplified with streamwise distance and eventually breakdown into turbulent spots, which are precursors of turbulent boundary layer. While in an environment with high freestream turbulence, the transition is found to be a bypass one in which turbulent spots are formed without Tollmien-Schlichting wave amplification. The formation of turbulent spot is a random process, and flow within a turbulent spot is almost fully turbulent. This suggests the possibility of using turbulence modeling to describe and predict the bypass transition. There have been some works in this direction, primarily using different versions of two equation models. Bypass transition is predicted, as the level of the freestream turbulence is increased. However, it is found that the predicted transition is much sharper than that observed in the experiment. In addition, the predicted transition depends on the description of the initial profiles to an certain extent. The works we propose to do are twofold. 1) We will be using a low Reynolds number version of Reynolds stress model rather than the two equation model. This would bring in more physics, and hopefully would fit better the complicated flows such as bypass transition. 2) We will be using an elliptic solver rather than a parabolic solver for this boundary layer transition. This way, we will be able to include the effect of the leading edge. The testing case will be flow passing a flat plate. Both the zero pressure gradient case and the non-zero pressure gradient case will be tested.

2. Work Accomplished

1. Nonlinear dynamics near the stability margin in rotating pipe flow.

The nonlinear evolution of marginally unstable wave packets are studied in rotating pipe flow. These flows depend on two control parameters, which may be taken to be the axial Reynolds number Re and the rotation rate q. Marginal stability is realized on a curve in the (Re, q) plane, and we explore the entire marginal stability boundary. As the flow passes through any point on the marginal stability curve, it undergoes a supercritical Hopf bifurcation and the steady base flow is replaced by a traveling wave. The envelope of the wave system is governed by a complex Ginzburg-Landau equation. The Ginzburg-Landau equation admits Stokes waves, which correspond to standing modulations of the linear traveling wavetrain, as well as traveling wave modulations of the linear wavetrain. Bands of wavenumbers are identified in which the nonlinear modulated waves are subject to a side-band instability.

This work[1] was reported in APS/DFD meeting in November 1990. A paper for this work has been submitted to JFM for consideration of publication. The paper is co-authored with S. Leibovich of Cornell University. This work was supported by AFOSR-89-0346.

2. Unstable viscous wall modes in rotating pipe flow. (AIAA Paper No. 91-1801)

Linear stability of flow in rotating pipe is studied. These flows depends on two parameters, which can be taken as the axial Reynolds number Re and the rotating rate q. In the region of $Re \gg 1$ and $q = O(1)$, the most unstable modes are wall modes. The wall modes are found to satisfy a simpler set of equations containing two parameters rather than four parameters as in the full linear stability problem. The set of equations is solved numerically and asymptotically over a wide range of the parameters. In the limit of $Re \to \infty$, the eigenvalue reaches the inviscid limit and the eigenfunction shows a two layer structure. The eigenfunction reaches the inviscid limit over the main part of the domain, while near the wall of the pipe, the eigenfunction is represented by a viscous solution of the boundary layer type.

This work[2] is to be presented at the AIAA 22nd Fluid Dynamics, Plasma Physics and Lasers Conferences, June 24-26, 1991. The paper is co-authored with S. Leibovich of Cornell University. This work was supported by AFOSR-89-0346.

3. RNG in turbulence modeling.

This work is done in collaboration with Dr. T.H. Shih of CMOTT. In this work, we carry out an independent study of the work done in the paper by Yakhot and Orszag up to their derivation of $k-\epsilon$ equation. Many of their results are repeated. However, we also found some discrepances, and some unclaimed assumptions in their derivations.

3. Future Plans

1. Currently, we are testing and improving the low Reynolds number version of Reynolds stress model proposed by Shih and Mansour (1990) in the simple shear flows, such as channel flow and boundary layer flow. This model is going to be used in the calculation of bypass transition.

2. We will carry an independent derivation of $k-\epsilon$ equation using RNG, and compare it with the one presented by Yakhot and Orszag. We will also compare the prediction of RNG $k-\epsilon$ model with the other $k-\epsilon$ models, in both the high Reynolds number case and the low Reynolds number case.

4. Publications

[1] Yang, Z. and Leibovich, S. 1990 "Nonlinear dynamics near the stability margin in rotating pipe flow", Submitted to *J. Fluid Mech.*

[2] Yang, Z. and Leibovich, S. 1990 "Unstable viscous wall modes in rotating pipe flow", AIAA Paper 91-1801.

5. References

Yakhot, V. and Orszag, S.A. 1986 Renormalization group analysis of turbulence. *J. Sci. Comput.* Vol. 1, No. 1, 3-51.

Shih, T.H. and Mansour, N.N. 1990 Modeling of near wall turbulence. NASA TM-103222, ICOMP-90-0017.