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COMPUTATIONAL SIMULATION OF TRANSITION TO TURBULENCE THROUGH INVERSE MODELING

by

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The phenomenon of flow transition to turbulence has been intensely studied for several decades owing to its important influences on many practical systems in addition to the intrinsic scientific interest in the subject. Progress in the understanding of this difficult topic during the past decade has been achieved primarily through dramatic advances in computer technology on the one hand, and through refined experimental techniques (such as the LDV) on the other hand. Important applications of transition prediction range from the design of flow conditions upstream of the NASP scramjet inlet to the computation of heating environments influencing turbine blade performance and lifespan. The present investigation has focused on a computational methodology for the fundamental case of *transition in channel flow*, in which recently published experimental data are utilized both as a stimulus and as a measure of merit of the method.

The research has proceeded along three avenues in parallel. The first task has consisted of the development and verification of a computer code which calculates the mean evolution of flow in a channel similar to the one employed experimentally by Blair and Anderson [1]. For simplicity, but without loss of essentials, the channel is restricted to have planar sloping walls, such that the mean flow is symmetrical about the centerline. The appropriate incompressible boundary layer equations are recast into dimensionless form in terms of a mean streamfunction, in which an invariant mean Reynolds number and the wall slope comprise two external parameters. One advantage to this streamfunction formulation lies in the imposition of an additional boundary condition, which represents the conserved total mass flux in the channel. This additional boundary condition provides an unusual means for calculating the varying local pressure gradient, which normally must be externally prescribed in a boundary layer analysis. As part of this task, an analytical test case has been created for the dual purposes of code verification and of highlighting the interactions between the Reynolds stress and the mean velocity profile. This test case generates a Reynolds stress by the residue in the momentum equation which is produced by a typical analytical velocity profile. By a substitution of this Reynolds stress into the appropriate code module, the correctness of the code may be verified, along with the accuracy of the computational method. For ease of quick implementation, the chosen method has consisted of an iterative integral scheme which is coupled with an upwind differencing algorithm in the streamwise direction.

The second task pursued during this research period has involved the development of a triple layer model for the Reynolds stress profile, which has been suggested and derived from experimental velocity profiles. It is demonstrated that the innermost length scale is based on the local friction velocity, the intermediate layer corresponds to the usual logarithmic "law of the wall" region in which the normalized Reynolds stress is approximately unity, and the outermost layer is represented by a closed mathematical form depending explicitly on the velocity profile in the wake region. Further development and implementation of this model will continue to the end of this research period and further pursuit will be proposed.

The third task has been comprised of scrutiny of the excellent database developed by Blair and others, and the planning of its incorporation into the transition analysis. These extensive measurements indicate that turbulent statistics in the transition regime may be considered to alternate between laminar and fully turbulent types, the proportions of which are quantified by a measured intermittency function. The downstream part of this intermittent description appears to fall in good agreement with the commonly quoted Gaussian form, whereas certain deviations are noted in the initial stages of transition. The strategy for transition modeling suggested in the present study involves the application of the triple layer Reynolds stress as factored by the intermittency function. Although this procedure is clearly semi-empirical, and it will rely on further information concerning transition onset, it is believed to comprise an effective computational characterization of the transition regime.

Recommendations for continued investigation fall into two categories. First, through the rapidly developing avenue of direct simulation by spectral methods, a reliable criterion should be sought for initial transition onset, which could be implemented in the present methodology. Direct simulation computations are currently adding insights to the transition phenomenon, which have not been possible in the past. However, these computations become excessively consuming in the last stage of transition even with current capabilities. Second, the study of the triple layer formulation ought to be pursued to a more mature completion. The initial results of the present study show promise of producing a practical engineering tool. Results of the methodology have yet to be compared sufficiently with the available data.

References

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