MAR06-2005-001125

Abstract for an Invited Paper
for the MAR06 Meeting of
the American Physical Society

Transient growth and subcritical transition in shear flows

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The possibility for disturbance growth in shear flows which are linearly stable is discussed, and it is shown that a necessary condition is that the underlying linear operator is non-normal, i.e. that it is associated with non-orthogonal eigenfunctions. Since the non-linear terms are conservative it is only by utilizing linear growth mechanisms associated with the non-normal linearized operator that energy growth is possible also for subcritical finite amplitude disturbances. The non-normal effects are manifested in the possibility for large transient growth of the disturbance energy, large response to forcing and large sensitivity of the eigenvalues. The optimal transient growth and response to forcing are calculated as the norm of the matrix exponential and resolvent, respectively. The optimal disturbances are streamwise vortices and the optimal responses are streaks of high and low velocity in the streamwise direction. These flow structures are prevalent in all subcritical transitional shear flows, including pipes and channels. It is shown by direct numerical simulations that transition scenarios initiated by the optimal disturbances have low transition thresholds. The dependence of the thresholds on the Reynolds number is also presented. Finally, extensions of the transient growth concept to more complex flows are discussed and examples of its use given.