Linear Instability of Streamwise Corner Flow

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A streamwise corner is obtained when two flat plates meet at an angle to form a corner parallel to the free-stream flow direction. The interaction of the two boundary layers creates a secondary flow that makes the flow susceptible to separation and early laminar-turbulent transition, which is unwanted. Despite its simplicity, there are not many studies of this flow and current understanding of instability, laminar-turbulent transition, and turbulence is very incomplete. As such, existing computations cannot yet describe premature transition or separation observed in experiments.

The present work is intended to fill an obvious gap in predicting, understanding, and controlling laminar-turbulent transition in streamwise corners. The laminar base flow for a 90^o right-angled corner is considered. Linear stability computations have been performed using a two-dimensional local linear stability theory to compute temporal growth rates and a parabolized stability equations approach for spatial growth. These methods have been developed out of previous work by Alizard & Robinet for two-dimensional flows [1].

Typical eigenvalue spectra for both approaches are compared in Fig. 1. The temporal amplification is for $Re = 707$ ($Re_x = 2.5 \times 10^5$) and $\alpha = 0.2$ for comparison with Parker & Balachandar [2]. The spatial case is for the frequency $\Omega = 0.08$ at $Re = 450$ based on the initial position $x_0 = 225$. Both cases show a branch of eigenvalues which can be attributed to Tollmien-Schlichting (TS-) modes with different transverse wave lengths, i.e., different obliqueness angles with respect to the free-stream flow. The most unstable one of these corresponds to the the classical (two-dimensional) TS-instability mode of the flat-plate boundary layer. Aside of this branch we get an isolated mode whose eigenfunction maxima ride on the inflection point of the base-flow velocity profile in the corner bisector. This is the so-called corner mode. Because of the inflection point it is supposed to be related to an inviscid instability. Here all these eigenvalues are stable and the local theory cannot explain why experimentalists observe a premature laminar-turbulent transition of the corner flow compared to the flat-plate boundary layer.

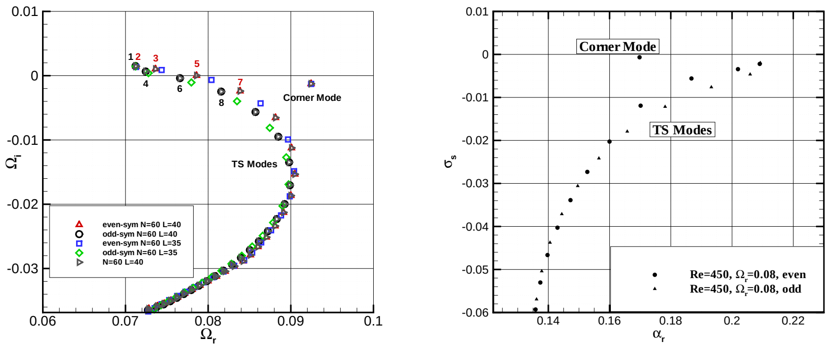

Fig. 1. Comparison of temporal (left) and spatial spectra (right)

However, extending our computations to a full PSE that follows a given frequency in downstream direction such that non-parallel growth of the flow is no longer neglected, we made an unexpected observation, shown in fig. 2. Non-parallel effects are irrelevant for the TS modes as in the case of the Blasius boundary layer, but the corner mode which was stable before now becomes unstable as well. Different non-parallel criteria will be studied in order to determine precisely the critical Reynolds number associated with the corner mode. This analysis could help to explain the experimental results.

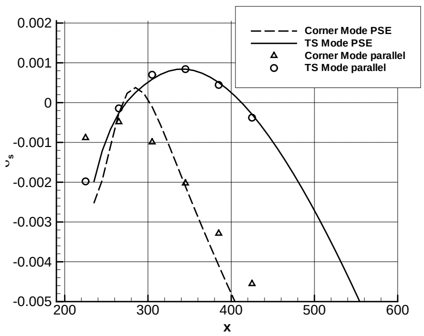

Fig. 2. Comparison of parallel theory with PSE analysis for $\Omega = 0.08$

References

1. F. Alizard, J.-C. Robinet, Spatially convective global modes in a boundary layer, *Phys. Fluids.*, **19**: 114105, 2007.
2. S.J. Parker and S. Balachandar, Viscous and Inviscid Instabilities of Flow Along a Streamwise Corner, *Theoret. Comput. Fluid Dynamics*, **13**, 231–270, 1999.