# THE KEY ROLE PLAYED BY THE SWIFT CHANGE OF THE STABILITY CHARACTERISTIC OF MEAN FLOW IN BYPASS TRANSITION

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*Summary* The scenario of bypass transition is generally described as follows: the low-frequency disturbances in the free-stream may generate long stream-wise streaks in the boundary layer, which later may trigger secondary instability, leading to rapid increase of high-frequency disturbances. Then possibly turbulent spots emerge, and through their merging, lead to fully developed turbulence. This description, however, is insufficient in the sense that it does not provide the inherent mechanism of transition that during the transition, a large number of waves with different frequencies and wave numbers appear almost simultaneously, producing sufficiently large Reynolds stress, so the mean flow profile can change rapidly from laminar to turbulent. In this paper, such a mechanism is found through DNS. And another interesting finding is that, during the transition, the unstable disturbance mode starts from an inviscid mode, but later changes to a viscous mode.

## INTRODUCTION

The location of laminar-turbulent transition of a boundary layer depends heavily on the free stream turbulence (FST). At very low FST, e.g. less than 0.1%, natural transition is observed, in which it takes a long distance for the small amplitude T-S waves to evolve until the final breakdown; while at high FST levels, bypass transition is observed, in which one does not see the slow evolution process of the T-S waves.

So far, the whole scenario of bypass transition is described as consists of the generation of streaks by FST, the evolution of streaks, the secondary instability and the growing and merging of turbulent spots. However, there is no explanation in regard with how secondary instability leads to turbulent spot, and how turbulent spots merge, etc. In a word, there is no clear description about the inherent mechanism of breakdown. The aim of the present paper is to build this missing link in the process of bypass transition.

Some previous studies for natural transition showed that the inherent mechanism of the breakdown in laminar-turbulent transitions was the quick change of the stability characteristics of the mean flow profile, induced by the existing disturbances (T-S waves)[1]. However, in bypass transition, there is no process of slow evolution of T-S waves, so one would wonder if its breakdown mechanism be different in comparison with the natural transition. Notice that no matter which breakdown process it may be, the mean flow profile always changes rapidly during the breakdown process, so our first goal is to verify if the same mechanism works for bypass transition, i.e. if the stability characteristics of the mean flow profile also changes significantly during the by-pass transition..And we also intend to find the details of the breakdown process in bypass transition.

## NUMERICAL METHOD

First, direct numerical simulation (DNS) is done for a by-pass transition. The simulation starts from somewhere that stream-wise streaks have already been triggered by disturbances outside the boundary layer, and ends up until turbulent flow appears in the computational domain. The inflow condition of DNS consists of a basic flow and some high-frequency T-S waves. The basic flow is selected as a Blasius profile, modified by longitudinal streaks, as well as stream-wise vortex, as obtained by Ricco et al.[2], which are triggered by FST, just before the breakdown of laminar flow.

The Reynolds number based on the displacement thickness of the Blasius profile at the inflow boundary is 634.6, and the computational domain is $650\delta^*\times40\delta^*\times7.66\delta^*$, and the number of grids is $1301\times111\times256$. In order to maintain the streaks in the boundary layer, a body force term, representing the effect of the Reynolds stress, is introduced in a short section, from x=0 to 50, downstream of the inlet.

## NUMERICAL RESULTS

Through DNS, the whole process of bypass transition, up to the turbulent state, is computed, and the stream-wise distribution of wall friction coefficient (Cf curve) is shown in Fig. 1. As we can see, the Cf curve rises sharply from about x=175 to x=225, implying the breakdown of the laminar flow occurs. And the length of the laminar stage is only three wave-lengths (about 150) of the basic T-S wave introduced, which is greatly different from the evolution of the T-S waves in natural transition cases.

The mean flow profiles at different locations are shown in Fig. 2, and their stability characteristics are shown in Fig. 3. At the earlier laminar stage, there is an obvious inflexion point at each profile, where the mean stream-wise velocity

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is about 0.9, leading to the phase speed of the unstable waves to be also about 0.9. It is a kind of inviscid mode of instability, whose neutral curves, as well as the phase speed of certain 2-D T-S waves are shown in Fig. 3-a. As it can be seen, the unstable zones of the neutral curves are becoming smaller as the location of the profile is further downstream, and finally vanish at the place of about x=100, at which the mean flow profile is also shown in Fig. 2.

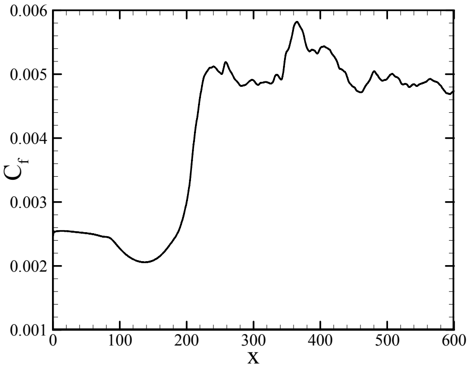


Fig. 1 Cf curve

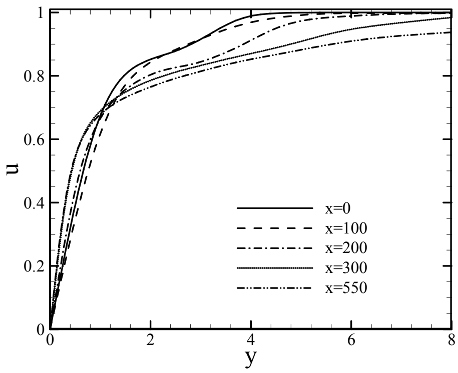
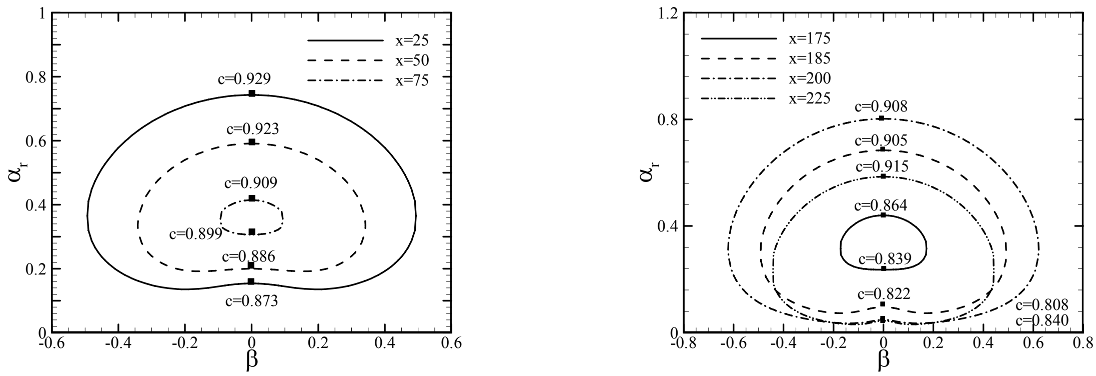



Fig. 2 Mean flow profiles at different locations

However, in the later stage, when breakdown takes place, for example at x=200, another inflexion point appears, but its normal location is lower than that for x=0, bringing about another group of unstable waves with the phase speed of about 0.85. This branch of disturbances, being a viscous mode of instability, are stable under the original laminar profiles. However, at such a short distance, the unstable zones of the neutral curve enlarges amazingly, and the growth rates of the most unstable wave, although not shown here, are increasing rapidly as well. It enables a huge number of waves with the frequencies and wave numbers in the unstable zones to be amplified rapidly, which in turn leads to further rapid modification of the mean flow profile, causing the laminar profile changes swiftly to the turbulent profile..

At x=300 and 550 in Fig.2, the flow is already turbulent, with no inflexion or unstable zone for its mean flow profile.




a) the 1st branch disturbances b) the 2nd branch disturbances

Fig. 3 Neutral curves of the mean flow profiles

## CONCLUSION

In this paper, a bypass transition is simulated via DNS, and the results indicated that the inherent mechanism of bypass transition is similar to natural transition, that is, the quick change of the stability characteristics of the mean flow profiles plays the key role. The change manifests itself in that the unstable zone in the frequency-wave number space enlarges rapidly, as well as the maximum amplification rate of the unstable waves, leading to rapid increase of different disturbances, producing much bigger Reyonlds stress, which in turn further modifies the mean flow profile.

However, the bypass transition process is more complex than the natural transition in that, the unstable disturbances have two different modes. At the earlier laminar stage, there is a branch of so-called inviscid mode disturbances, corresponding to the inflexion in its mean flow profile, caused by the streaks. While at the breakdown stage, the inviscid mode disappears, instead of this, a branch of viscous mode disturbances emerge, which is essential to the breakdown of laminar flow.

## References

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