EFFECTS OF STREAKS ON SECOND-INSTABILITY IN BOUNDARY-LAYER TRANSITION

Hui Guo[*, ** a)], Yulong Feng[*,**], Haiwen Wang[*,**] & Ziteng Liu[*,**]
[*]*School of Aeronautic Science and Engineering, Beihang University, Beijing, 100191, China*
[**] *Key Laboratory of Fluid Mechanics (Beihang University), Ministry of Education, Beijing, 100191, China*

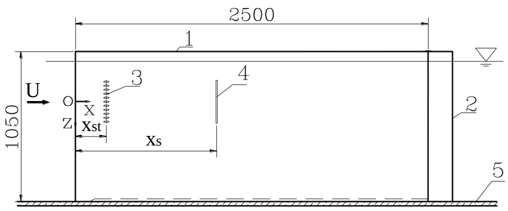
Summary This paper presented a novel method to study the effects of streaks on second-instability development in transitional boundary layer, by exciting transition under a specific condition near the second branch of neutral instability curve. Streaks are generated by suction through discrete oblique holes aligned spanwisely. The hydrogen bubble visualization results show that the narrow-spacing streaks of 14mm depress the second-instability development, while the wide-spacing ones of 28mm promote it.

INTRODUCTION

Introducing steady streaks upstream to delay boundary layer transition is an unique idea first proposed by Cossu et al.[1]. Subsequent experiments demonstrated that the streaks definitely depress T-S wave propagation[2], and may delay transition[3]. However, whether streaks delay or promote transition also depends on their effects on the second-instability, which is another important stage of transition. Some direct numerical simulation and Floquet analysis results indicated that narrow-spacing streaks delay transition, and wide-spacing ones promote transition[4,5], but they remain uncertain due to the lack of experimental evidence. That's the very objective of this paper. Unfortunately, there exists a big obstacle to study the effect of streaks on the second-instability. For a regular transition, second-instability is the result of preceding T-S wave development, thus before streaks affect second-instability, interaction between streaks and the T-S waves has occurred, which will interfere the effects of streaks on the second-instability. Such interference is generally hard to eliminate. This paper tackled the problem by selecting a unique condition of transition excitation, which ensured that the effects of streaks on second instability were studied independent of this interference.

EXPERIMENTAL SETUP

The experiments were conducted in the low-speed water tunnel in Beihang University with test section of 1m×1.2m×16m (width×height×length). The test speed is 0.15m/s with turbulence level 0.5%. The test plate is made of Plexiglas, with size of 2.5m×1.05m×0.02m (length×width×thickness). It is mounted vertically in the test section, as shown in Fig.1. An elliptic leading edge and an adjustable trailing flap ensure the flow attached to the test plate without separation. Boundary layer transition is excited by a weak 'zero-net-mass flux jet' introduced through the spanwise slot at x_s=1m downstream of the leading edge, which excites a T-S wave locally in the boundary layer. The excitation comes from a sine wave signal generated by a signal generator with adjustable frequency and amplitude. Steady streaks were introduced by suction through a discrete holes aligned spanwisely with spacing of 14mm, 4mm diameter and 15 degree oblique to the flow direction at x_{st}=218mm. Streaks are formed by the induction of counter-rotating vortex pairs generated by the suction holes through a mechanism called 'lift-up effect'. Fig.2 presents the typical streaks flow pattern visualized by hydrogen bubble timelines, with high-speed and low-speed region alternating spanwisely.



1. test flat plate, 2. trailing flap, 3. oblique suction holes, 4. slot, 5. bottom of water tunnel

Fig.1 Sketch of experimental setup

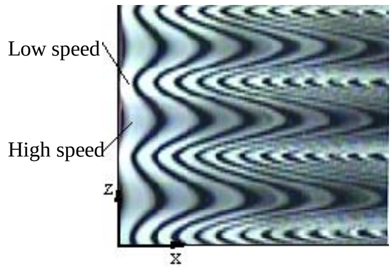


Fig.2 Typical streaks flow pattern

EXPERIMENTAL RESULTS

Basic flow and transition excitation

Without the perturbation of steaks and transition, the basic flow on the plate was confirmed to be that of Blasius laminar boundary layer by the measurements of velocity profile and displacement thickness at 5 streamwise positions. Transition excitation perturbation at the slot, marked '*' in Fig.3, is near the second branch of neutral instability curve, which is quite different from the conventional transition excitation introduced near the first branch. The subsequent solid line indicates the test region. The two non-dimensional parameters are defined as $F=2\pi f\nu/U^2$ and $R=(Re_x)^{1/2}$, where f, ν, U and Re are excitation frequency, kinematic viscosity, freestream velocity and Reynolds number at x downstream the flat plate leading edge. The value of signal amplitude is set to 3.5V in order to excite T-S waves with enough amplitude for direct excitation of second-instability and transition, skipping the T-S wave development. Thus, the effects of streaks on

a) Corresponding author. Email: guohui@buaa.edu.cn

the second instability can be studied independent of the effects of streaks on the T-S wave development.The hydrogen-bubble pictures in Fig.4 demonstrate typical T-S waves (Fig.4a), Λ structures(Fig.4b), typical flow structure appearance of second-instability, and flow breakdown(Fig.4c) with platinum wire(hydrogen bubble wire) at $x\text{-}x_s$=200mm, 400mm and 800mm downstream the slot respectively.

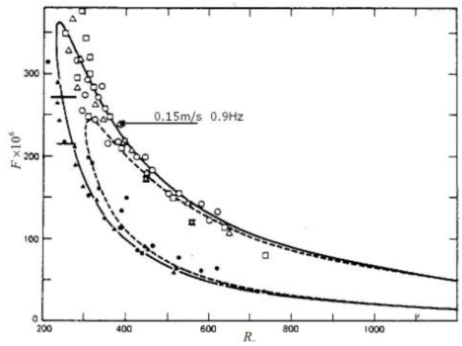
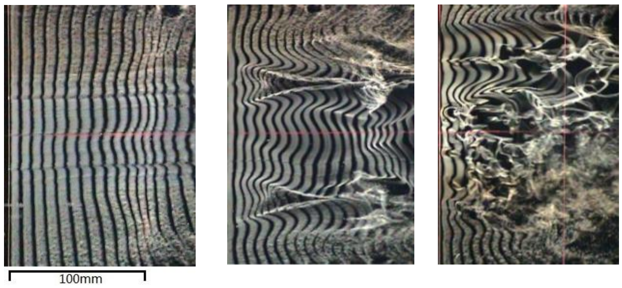


Fig.3 condition of transition excitation

Effects of streaks on second-instability and transition

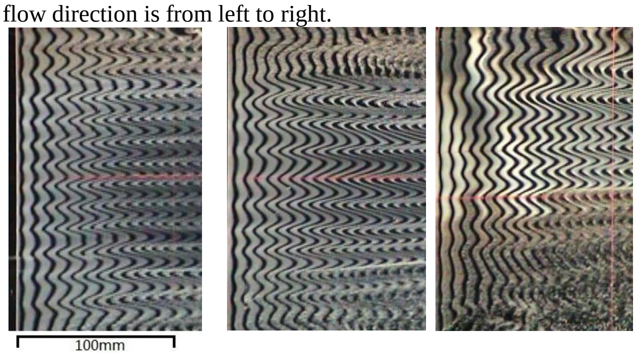
Streaks with spanwise spacing of Δz=14mm and 28mm were introduced respectively in the transitional boundary layer mentioned above. The visualization results are presented in Fig.5 and Fig.6 respectively，with the platinum wire at $x\text{-}x_s$=200mm, 400mm and 800mm. For the narrow-spacing streaks of Δz=14mm, the transition is delayed by the fact that the flow randomness at $x\text{-}x_s$=800mm in case without streaks (Fig.4c) is obviously suppressed (Fig.5c). At upstream $x\text{-}x_s$=200mm and 400mm, flow structures like T-S wave and Λ structure can not be observed any longer. While when Δz=28mm, transition is promoted by the evidence that the degree of flow randomness at $x\text{-}x_s$=800mm is much stronger (Fig.6c), compared to that without streaks (Fig.4c). Moreover, the flow breakdown takes place upstream, which can be evidently observed even at $x\text{-}x_s$=200mm in the visualization picture of Fig.6a, and appears as the result of the sinuous instability of the low speed streaks.

Considering the influence of the streak amplitude, streak amplitude at the slot A_{st}=3.2%, 7.6% and 8.5% for Δz=14mm, A_{st}=11.7%, 15.3% and 21.2% for Δz=28, were tested . The flow pattern at $x\text{-}x_s$=800mm indicates that for the narrow-spacing streaks, a larger streak amplitude will bring stronger suppression to second-instability development and flow breakdown, while for the wide-spacing streaks, the amplitude increase will enhance their ability to promote the second-instability and cause stronger flow breakdown.



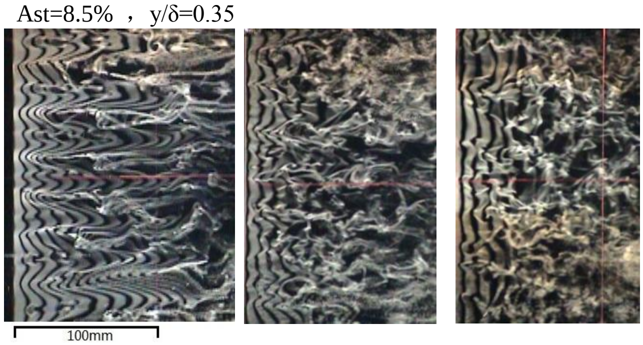
a. $x\text{-}x_s$=200mm b. $x\text{-}x_s$=400mm c. $x\text{-}x_s$=800mm

Fig.4 Flow pattern visualized by plan-view of hydeogen bubble timelines at different stage of transition at height of y/δ=0.35. flow direction is from left to right.



a. $x\text{-}x_s$=200mm b. $x\text{-}x_s$=400mm c. $x\text{-}x_s$=800mm

Fig.5 the flow pattern after the narrow-spacing streaks of Δz=14mm introduced, with streak amplitude at the slot Ast=8.5% ，y/δ=0.35



a. $x\text{-}x_s$=200mm b. $x\text{-}x_s$=400mm c. $x\text{-}x_s$=800mm

Fig.6 the flow pattern after the wide-spacing streaks of Δz=28mm introduced, with streak amplitude at the slot Ast=21.2%，y/δ=0.35

CONCLUSIONS

The effect of streaks on second-instability may be definitely different. The narrow-spacing streaks of Δz=14mm can depress the development of second-instability, thus delay the flow breakdown. Their higher amplitude will enhance this ability. While the wide-spacing streaks of Δz=28mm promote the second-instability development, thus make the transition take place earlier. The higher the amplitude, the stronger the promoting effect can be observed.

Acknowledgements

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