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TRAVELLING DISTURBANCE APPEARING IN A YAWED CYLINDER BOUNDARY LAYER TRANSITION

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Abstract

Boundary Layer developing over existing fluid machineries are most of the cases in three-dimensional state owing to spin, yaw, or surface curvature of bodies. Therefore, three-dimentional(3-D) boundary layer transition study is essential to work with as long as practical aerodynamics is concerned.

Present investigation is specialized in a yawed body problem among those general 3-D boundary-layer transition problems. Using a yawed cylinder model, which represents leading edge portion of a swept wing, crossflow instability mechanism was investigated using hot wire velocimeter and flow visualization technique in detail. As a result, travelling disturbance with two different frequencies f_1, f_2, which are different in frequency about one order, are detected in the transition region. Phase velocities and travelling directions of those disturbance are measured. The results for the low frequency disturbance f_1 showed qualitative coincidence with numerically predicted results. Namely, f_1 travels nearly in spanwise direction of a yawed cylinder. The results for the high frequency disturbance f_2 showed good agreement with previous experimental results. f_2 disturbance is found to be the high frequency inflexional secondary instability in 3-D boundary layer trandition. Two stage transition process, where stationary crassflow vortices appear as primary instability and travelling inflextional disturbance is generated as secondary instability, was absorved. Secondary instability seems to play major task for turbulent transition.

Introduction

Gray(1952) discovered that wing sweep has a strong destabilizing effect to the wing boundary layer for the first time in his flight test. Since then, crossflow instability is recognized as important 3-D boundary layer transition problem. Gregory et al.(1955) started systematic investigation on crossflow instability problem using rotating disk flow both theoretically and experimentally. It is difficult to measure the boundary layer on a swept wing leading edge regions where the boundary layer thickness is thin, and velocity is high. Moreover, the surface is curved and yawed. Mainly for such reasons, investigation has been made using different flow models such as a rotating disk, yawed flat plate with upper body, or a yawed cylinder.

This paper deals with a yawed cylinder together with hot wire velocimeter and effective flow visualization. Main interest is focused on finding the nature of the travelling disturbance which might be acting major task on turbulent transition process in the case of crossflow instability.

Experimental equippments and conditions

Experiment has been carried out using a low turbulebce wind tunnel equipped at Institute of Fluid Science, Tohoku University. Test condition is depicted in Fig. 1. 300mm diameter hollow cylinder is placed in an open jet working section of the tunnel. In order to prevent attachmentline contamination from the turbulent boundary layer developd in the tunnel nozzle wall, suction slot was equipped to the lower part of the cylinder as shown in the figure. Yaw angle of the cylinder was kept constant to $\lambda = 45$ degree. Wind speed ranges from 30 m/s to 50 m/s. Single and parallel hot wire probes are used together with high accuracy 3-D traverse system.

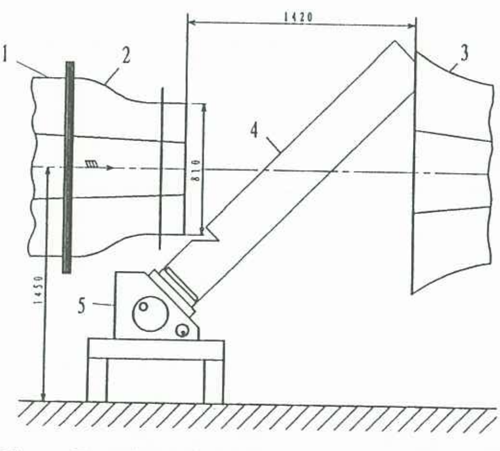


Fig.1 Experimental apparatus
1. nozzle 2. second nozzle 3. collector
4. cylinder 5. tilting table

Results and discussion

Figure 2 shows frequency spectrum of hot wire signal obtained at $\phi = 84°$, $z = 0.7$mm. Where ϕ is azimuthal angle measured from attachimentline, and z is the dislance measured vertical to the surface. Two peaks $f_1 = 1$ kHz and $f_2 = 12$ kHz are existing in the profile indicating that two different travelling disturbances are appearing in the transition region. Similar disturbances were measured in the same flow field by Poll(1985). However, f_2 was 17.5 kHz in his case instead of 12 kHz, and no further detailed explanation have been done. Recently, Kohama et al.(1991) measured crossflow dominant transition region on a swept wing, and detected similar travelling disturbances. In their case $f_1 = 350$ Hz and $f_2 = 3.5$ kHz. It seems to be quite possible that in crossflow dominant transition region, always f_1 and f_2 exists. Figure 3 shows low frequency disturbance with respect to uniform flow velocity U_∞. Figure 4 shows high frequency disturbance with respect to U_∞. f_2 stays constant in the flow range $U_\infty = 40\text{m/s} \sim 47\text{m/s}$.

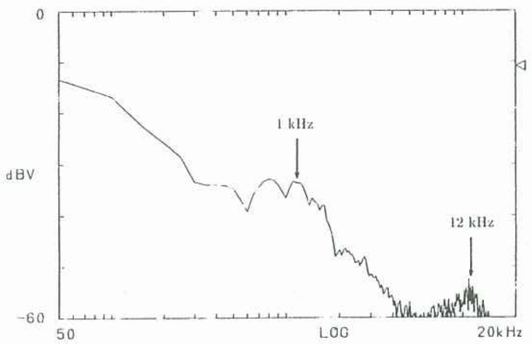


Fig.2 Frequency spectrum of the velocity signal
$U_\infty = 44\text{m/s}$, $\Lambda = 45°$, $\phi = 84°$, $z = 0.7$mm

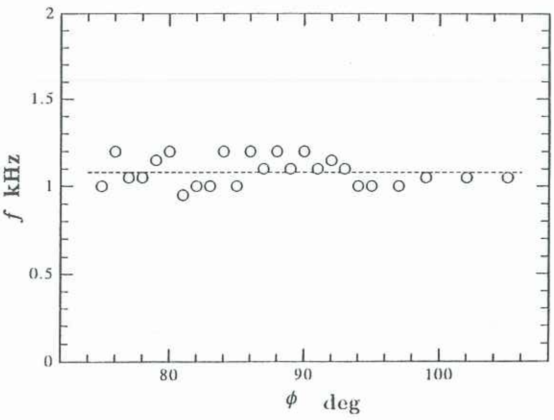


Fig.3 Low frequency disturbance f_1 with respect to U_∞

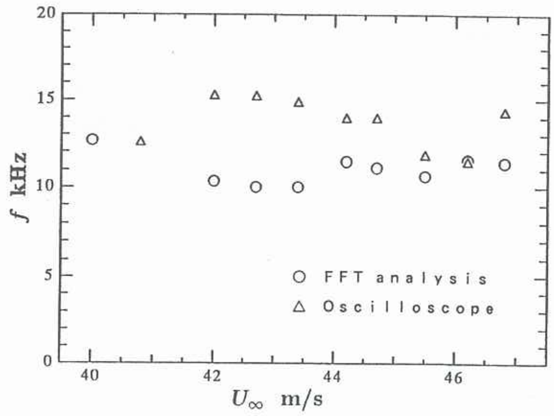


Fig.4 High frequency disturbance f_2 with respect to U_∞

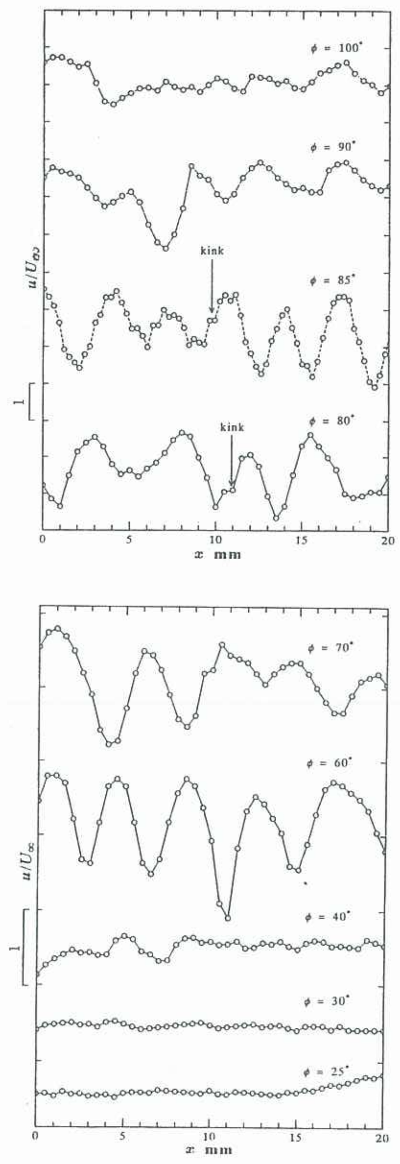


Fig.5 Velocity profile $u(x)/U_\infty$
$U_\infty = 40\text{m/s}$, $\phi = 25° \sim 100°$, $z = 0.7$mm

Velocity distribution $u(x)/Ue$ is plotted in Fig. 5. Here, x is spanwise distance and Ue is the velocity at outer edge of boundary layer. Existence of stationary crossflow vortices are clear if we observe the figure at $\phi = 60° \sim 85°$. Sinusoidal regular variation in the profile is clear and most obvious at $\phi = 60°$. Wave length λ of the stationary crossflow is about 5mm.

Since the flow structure seems very complicated, velocity profiles $u(z)/Ue$ are measured at five diferent positions, (a) to (e) in the span as shown in Fig. 6, and plotted in Fig. 7. From this, high velocity position (a) in $u(x)/Ue$ profile has full profile in $u(z)/Ue$ profile, and low velocity position (b) has inflexional profile. Futher, at kink like profile (d) in the high velocity region in $u(x)/Ue$ profile, double inflexional profile exists. Such structure well fit to the results obtained by Kohama et al.(1991) measured in a swept wing flow. Detailed measurement by two different band pass filter conditions showed that origin for f_1 disturbance exists at each low velocity positions in $u(x)/Ue$ profile and near the wall, while origin for f_2 disturbance exists also at each low velocity positions, but near to the edge of boundary layer.

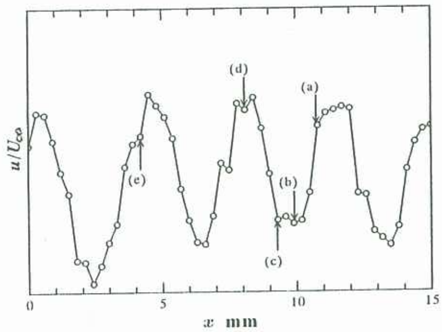


Fig.6 Velocity profile $u(x)/U_\infty$
$U_\infty = 46$m/s, $\phi = 85°$

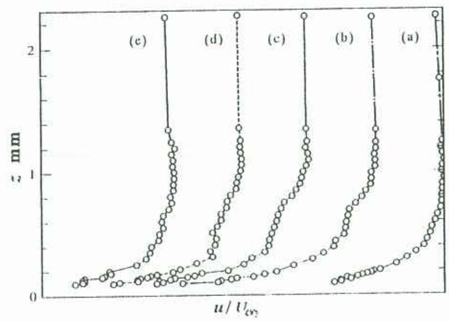
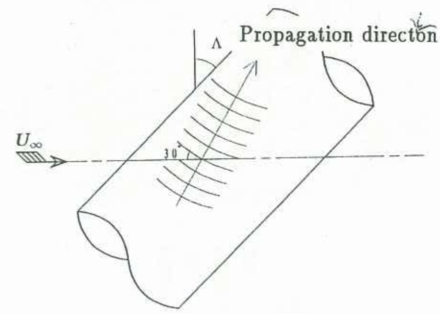
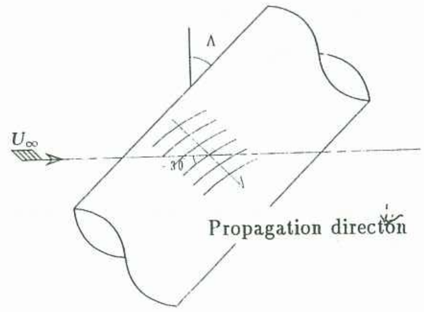


Fig.7 Velocity profile $u(z)/U_\infty$
$U_\infty = 46$m/s, $\phi = 85°$

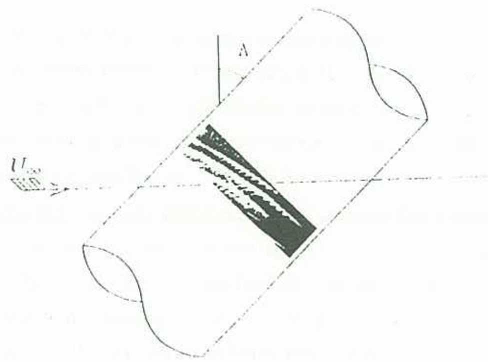
Parallel probe measurement showed the propagation directions of f_1, f_2 disturbances as shown in Fig.8 (a) and (b). Phase velocities of these disturbances are also measured as $Up_1 = 0.24$m/s and $Up_2 = 18$m/s when $U_\infty = 34.5$m/s and 43.6m/s respectively. Since the nature of f_2 is quite similar to the high frequency secondary instability visualyized by Kohama, et al.(1987a) and shown in Fig.8(c), it is quite possible that the travelling disturbance f_2 is the secondary instability which is same as the one obtained by Poll(1985), and in a swept wing flow (Kohama, et al., 1991).



a) $U_\infty = 34.5$m/s, low frequency disturbance f_1



b) $U_\infty = 43.6$m/s, high frequency disturbance f_2



c) Flow visualization picture of f_2 disturbance refered from Kohama(1987b)

Fig.8 Propagation directon of f_1, f_2 disturbances

Considering from obtained all the results, and comparing the results with other investigations in similar crossflow fields, the transition structure can be sketched as shown in Fig.9. The figure is quoted from Kohama (1987b).

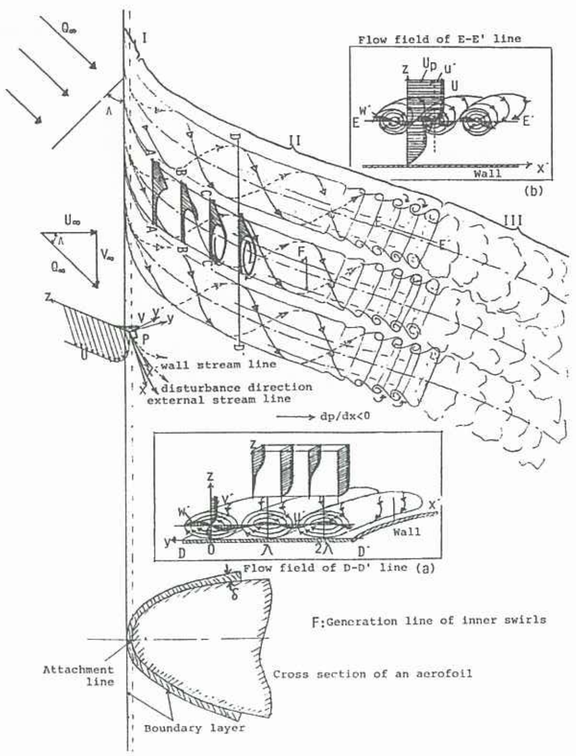


Fig.9 Transition structure on a swept wing refered from Kohama(1987b)

Conclusions

Through detailed measurement on a yawed cylinder transition field, randomization process in crossflow transition field was well clarified. Namely, advancing to T-S wave instability, at $\phi \approx 30°$, stationary crossflow vortices will appear as primary instability. Then at around $\phi = 65°$, travelling low frequency diaturbance will appear which is possibly the crossflow primary unsteady disturbance. Then further downstream, at around $\phi \approx 80°$, high frequency disturbance f_2 will be generated as secondary instability which is locally appeared inflexional instability. Considering from rapid growth rate of f_2, this high frequency disturbance seems to drive the boundary layer directly to full turbulent state.

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