Precursor of Separation

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The change in surface pressure during a pitching-up motion of an airfoil was measured, and was analyzed to obtain a precursor of separation. A pitching airfoil was adopted to produce a predictable separation, because it is necessary to know a precise time to start separation to distinguish the precursor from other signals. The sinusoidal wave amplified exponentially in time was found to appear just before separation. This fluctuation is regarded as an instability wave of boundary layer based on the velocity profile with an inflection point.

Key Words: *Separation, Precursor, Instability, Boundary layer, Pressure, Velocity profile, Pitching airfoil, Unsteadiness*

1. Introduction

Many studies has been done in past few decades in establishing an active and feedback control of separation. Most of them were motivated by understanding response of the separated shear layer to artificial excitations. The most effective frequency and magnitude of the excitation was found to suppress separation. The control energy had to be added continuously to keep suppression of separation in the previous studies, because it was important to understand availability of the control method. The continuous control is not realistic to expect a modification of the performance of turbomachines in practical use. The turbomachines are designed ideally so that the separation does not occur in usual use. Therefore, it is not necessary to suppress separation always in general; the control of separation is necessary when the separation occurs. How do we know the onset of separation? The changes in flow rate or in pressure of the turbomachines and the change in angle of attack of an airfoil may give us an information about the premonitory symptoms of separation, when the performances are well known[(1)(2)]. However, the best signal to detect the onset of separation should be searched in flow properties around an object required the suppression of separation in more extensive applications. The purpose of this study is to search the onset of separation.

2. Experimental setup and procedure

To investigate the signal of the premonitory symptoms of separation, namely a precursor of separation, it is necessary to determine the time of separation first. The dynamic stall of the airfoil in pitching-up motion was adopted to obtain a predictable certain separation. The experimental setup is shown in Fig. 1. The airfoil was an NACA0015 airfoil with a chord length of c=120 mm and a span of 120 mm. The airfoil pitched up from 0 to 30 degrees about its 1/4c pivot with a constant pitch rate, ω. The free stream velocity U was 6 m/s. The Reynolds number based on c and U was 4 x 10^4. The non-dimensional pitch rate, S $\{=3c\omega/(4U)\}$, was 0.018. The surface pressure was measured by a condenser microphone mounted in the airfoil at x/c=0.08, 0.25. 0.42, and 0.59. Here, x is a distance measured in the direction from the leading edge to trailing edge. The velocity was measured by a hot-wire probe installed on the surface of the airfoil.

3. Results and discussions

Figure 2 shows the velocity signature during the pitching-up motion measured at a position from the wall where the ratio of a local velocity to the free stream velocity was 0.8 in each x section. The fluctuation in velocity with a large amplitude appears at a particular t^* (= tU/c, t is the time measured from the beginning of the pitching-up motion) for each signature, indicated by a triangular mark in the figure. The start of the sudden fluctuation shows the front of the separation region. The position moved toward the leading edge with increasing the angle of attack.

The surface pressure fluctuation measured at x/c=0.42 and a result of its wavelet analysis are shown in Fig. 3. The periodic fluctuation amplified with increasing time during t^*~3 to 5 is recognized just before separation (t^*=5.2). Here, the time of separation was defined as a time when the pattern of the contour changed remarkably. The result of the wavelet analysis applied to the pressure fluctuation presented in this figure is also shown in Fig. 3. It is clear that the property of the signal changes abruptly at the time of separation. The averaged frequency of the periodic fluctuation before separation is about 500Hz. The change in amplitude during t^* ~3 to 5 shows an exponential increase to t^*. This means that the growth of the surface pressure fluctuation relates to that of the velocity fluctuation due to the shear layer instability.

The velocity profile at x/c=0.42 may change in time according to the approach of the front of the separation region. The velocity profile at different time at x/c=0.42 is shown in Fig. 4. The velocity profile at t^*=0 presents that the boundary layer is laminar without separation. On the other hand, the profile at t^*=4.4 shows that the profile is a type of separation. Therefore, the observed frequency is considered as the frequency due to the instability of the shear layer with inflection point in the velocity profile. The instability frequency of the velocity profile given by the profile obtained at t^*=4.4 shown in Fig. 4 was calculated as 350Hz according to Michalke (1990)[3]. This value agrees well with our experimental result.

4. Conclusion

The precursor of separation was found in the surface pressure fluctuations as a result of an instability wave due to the inflection point of velocity profile.

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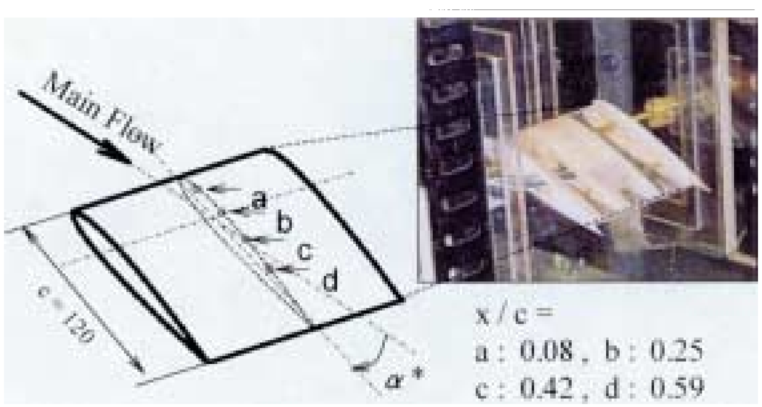

Fig. 1 NACA0015 airfoil and symbols.

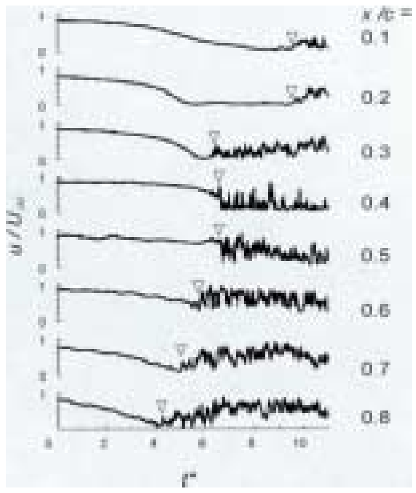

Fig. 2 Velocity signature measured in boundary layer at which u/U=0.8 for each x/c.

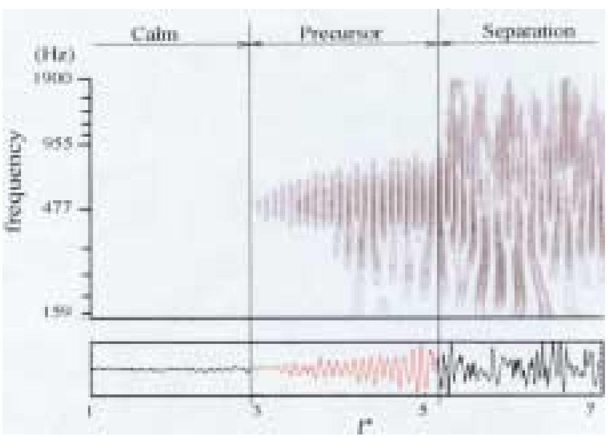

Fig. 3 Wavelet analysis of surface pressure signal measured at x/c=042.

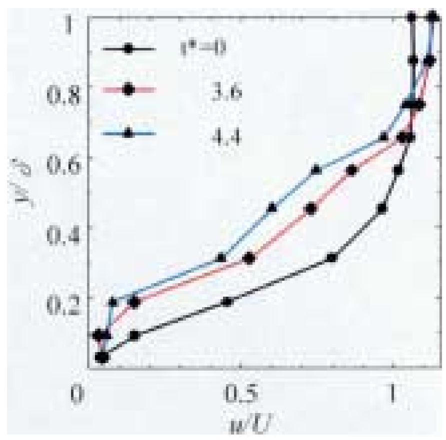

Fig. 4 Instantaneous velocity distribution at different time at x/c=0.42.