An investigation on airfoil tonal noise generation

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ABSTRACT

The generation of tonal noise by airfoils has been a continuing problem of which the overall mechanism still remains yet to be uncovered. Results of an experimental investigation on tonal noise generation are presented. Quantitative measurements were obtained by use of hotwire and microphone. Furthermore, a flow visualization of the phenomenon was carried out by use of a smoke wire technique. Based on these experiments, a detailed description of the flow close to the trailing edge is obtained. The sound generation process takes place on the pressure side in the near-trailing edge region, where a thin layer of separated flow exists, which is essential to the mechanism. A Kelvin-Helmholtz instability appears to be the cause of the vortex generation. The interaction of shedding eddies with the trailing edge, resulting in the emission of pressure waves, represents the noise source. Events on the suction side are found to be of no significant influence to the sound generation mechanism. The role of TS waves in the sound generation process is re-evaluated and a novel self-excited feedback loop is proposed to explain the occurrence of tonal noise generation.

Key Words: Airfoil tonal noise, trailing edge noise

1. Introduction

The generation of tonal noise by airfoils has been a continuing problem of which the complete mechanism still remains yet to be uncovered. In the 90's numerous large wind turbine parks were erected as to provide an alternative clean power source. In several cases it was found however, that despite no pollutant gas were emitted, now the tonal noise generation by the turbines presented a large hinder to the direct environment. In various other cases tonal noise generation is known to occur: e.g. on airfoils operating at moderate Reynolds number, small aircrafts, rotors and fans. By the present study, it has been attempted to obtain a deeper understanding of the fundamentals of the tonal noise generation process and offer a hypothesis on why tonal noise emission occurs.

2. Experimental Procedure

The experiments were carried out in a closed-loop, closed-test-section, low turbulence wind tunnel facility at the JAXA Aerodynamics Research Group. The wind tunnel is designed to operate at wind tunnel velocities from 1 to 65 m/s and provides a test section of 550 x 650 mm^2. The measurements were carried out using a NACA0015 airfoil with a cord length of 0.4 m. The model was horizontally fitted in the test section, at a fixed angle of attack of 5 degrees, completely spanning the wind tunnel section. Measurements were conducted at a free stream velocity of 14.5 m/s. Acoustic measurements were obtained by a Brüel&Kjær condenser microphone type 4138. The microphone was placed approximately 10cm behind airfoil on the lower wind tunnel wall to avoid flow interference. Velocity measurements were extracted by use of a traverse mounted single wire hotwire. Flow visualization was carried out by use of a smoke wire technique. For this purpose a 50μm diameter, constantan wire was placed in the flow, 1.5 cm upstream the trailing edge at approximately 1 mm distance from the airfoil surface. In order to illuminate the flow a thin laser sheet was used. A Vision Research high speed camera, type Phantom v4.2, enabled image capturing at 2000 Hz, which allowed the detailed recording of the sound generation process

3. Results and Discussion

Prior to quantitative measurements a smoke wire flow visualization was performed in order to acquire a qualitative description of the events occurring on the pressure-side, near-trailing edge region. Smoke wire recordings were made by high speed camera, synchronized with sound measurements. Figure 1 shows a schematic of one cycle of the tonal noise emission process as observed in the smoke wire recordings. It was noted that a separated region exist at the trailing edge, which extends upstream to approximately 10% cord.

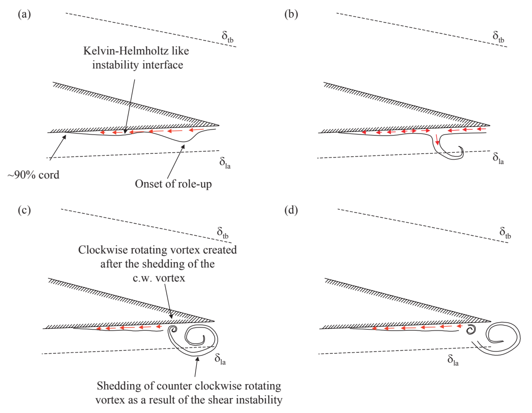

Figure 1: Schematic of the tonal noise generation process

A shear layer instability, as a result of the separated region, causes the rapid amplification of a disturbance wave, which roles up to form a vortex which is shed from the trailing edge. Smoke wire visualization further revealed that no vortex shedding occurs from the suction side and therefore the vortex street behind the airfoil must be a result of wake instabilities.

Hotwire measurements on the pressures-side of the airfoil, presented in Figure 2, show the development of an inflectional velocity profile, most strongly observed at 97% cord. Further downstream, the transfer of high momentum fluid by the shedding vortex, causes the flow to intermittently reattach, which is observed as a weakening of the inflectional property of the velocity profile.

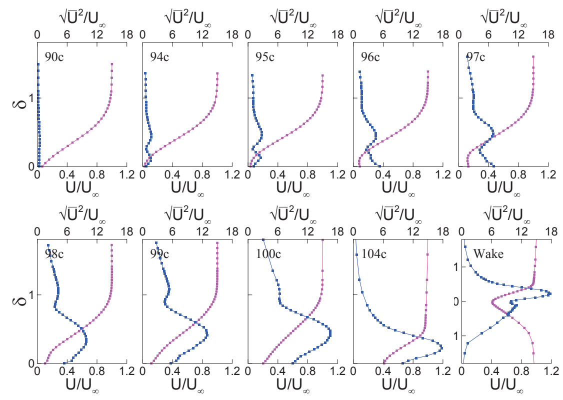

Figure 2: Pressure side velocity and RMS profiles

The RMS profiles show a rapid amplification of the flow fluctuations to 16% of the free stream velocity in a range covering only 10% cord (4 cm). A triple deck structure is observed. The first peak is found closest to the wall, which is associated with separated flow region. A second peak is found at roughly 0.4 δ. A third RMS-peak is found to occur outside the boundary layer at 1.1δ as a result of the vortex extending outside the boundary layer as it sheds from the trailing edge. Phase diagrams also reveal this triple deck structure, showing three regions of correlated fluctuations corresponding with the RMS peaks.

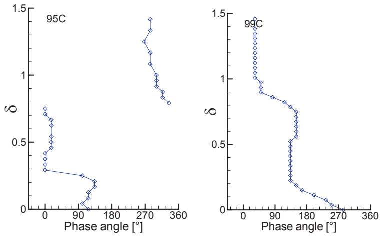

Figure 3: Phase correlation

A new hypothesis on airfoil tonal noise generation is proposed: The sound generation process is confined to the near trailing edge region. Laminar flow separation in this area, provides for a highly unstable flow allowing the rapid amplification of disturbances, which form a vortex which is shed from the trailing edge. A feedback loop is proposed to impose periodicity on the flow. As a vortex is shed, the trailing edge/vortex interaction causes the emission of a pressure wave disturbance. As it propagates upstream it is received at the onset of the instability region, where it initiates the growth of the following vortex.

Realizing the importance of the separation region to the tonal noise generation process a possible explanation of the jumps in the velocity-frequency dependency is deduced. The separation length is found to be in the order of 10% of total cord length. Disturbance wavelength increases with free-stream velocity. When the disturbance-wavelength exceeds that of the separation length it is no longer possible for vortex role-up to occur, resulting in a vorticity imbalance. This enforces the flow disturbances to occur at a shorter wavelength in order to shed excess vorticity. The sudden change in wavelength would be observed as a jump in the velocity-frequency dependency.

4. Summary

An experimental characterization of the flow of the near-trailing edge region by means of by hotwire and smoke wire was successfully carried out. A self-excited feedback loop is proposed in order to explain the periodicity, necessary for tonal noise emission. By considering disturbance wavelength with respect to separation length it is attempted to account for jumps observed in the emitted frequency-velocity dependency.