Fan tone generation in an isolated rotor due to unstable secondary flow structures

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FAN TONE GENERATION IN AN ISOLATED ROTOR DUE TO UNSTABLE SECONDARY FLOW STRUCTURES

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Both centrifugal and axial fans are used in many applications like ventilation systems or cooling units and thus being subject of our everyday life. Due to official restrictions and the increasing consideration of comfort factors the acoustic performance of that kind of machines becomes more and more important. A typical acoustic spectrum of a fan consists of both broadband and tonal components, see figure 1. Often, the overall acoustic level is dominated by the tonal part, especially the tone at blade passing frequency (BPF) and higher harmonics. The source mechanism for the BPF noise of centrifugal fans typically refers to the interaction between the blade channel flow and guide vanes or the volute-cutoff. In case of an axial fan the rotor-stator interaction is often the source of BPF noise. For both types of fans an isolated rotor should not exhibit tonal noise at the blade passing frequency. However, measurements show the opposite. As shown by many authors [1, 2], the steady loading of the blades as well as the volume displacement by the moving blades can not be the source of the BPF noise for fans with a low characteristic circumferential Mach number. Thus, the detailed noise generating mechanism of the BPF noise of an isolated fan rotor is still unknown.

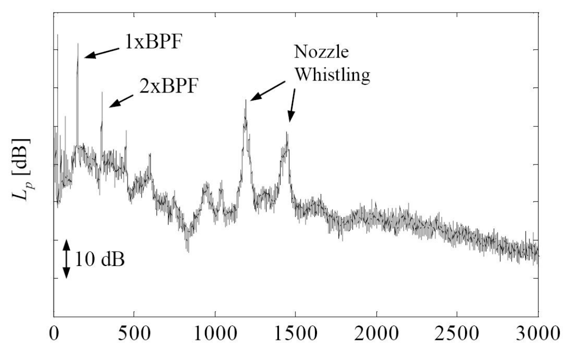

Figure 1: Noise spectrum of an isolated centrifugal impeller near design point, BPF tones and whistling tones are not related to each other [3]

The objective of this study is to characterize the BPF noise of a centrifugal fan in a controlled laboratory environment and eventually to shed some light on the source mechanism. For that purpose an isolated centrifugal fan in a large semi-anechoic room has been investigated with one-dimensional hot wire anemometry, flush mounted pressure transducers and microphones to measure the acoustic sound pressure. The acoustic mea-

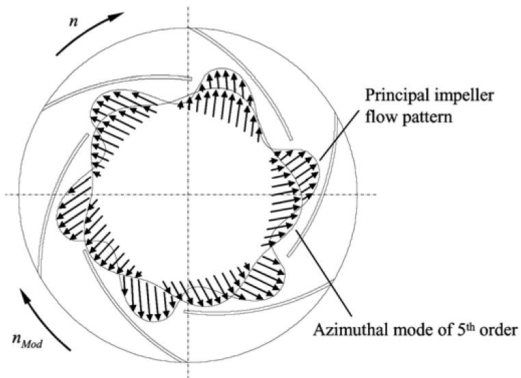

Figure 2: Example of a 5th order mode interfering with a 6th order principal flow pattern at the inflow (schematically)

surements show that the amplitude of the BPF tone varies more or less with time and hence indicate a slight unsteady source mechanism. A spectral decomposition reveals that the BPF noise is exclusively flow-induced. With the aid of a modal analysis azimuthal modes, i.e. highly coherent flow structures, have been detected, which are steady or at least quasi-stationary in respect to the laboratory system. These modes are believed to interact with the rotating blades and cause periodic blade force fluctuations at the BPF frequency, see figure 2.

However, the modal analysis is not able to identify any causality. Although the measurements indicate that the modes originate in the intake and are convected through the blade channels to the discharge of the impeller, a 3D unsteady numerical simulation using the hybrid SAS method has been performed to gain an insight into the detailed flow field. The simulation shows that the blades of the impeller and the friction of the rotating hub gradually impose a pre-swirl on the inflow and cause the formation of an unstable inlet vortex, see figure 3. This vortex takes a helical form with the vortex core varying slowly its position with respect to the impeller center. Compared to the blade speed the movement of the vortex is so slow that it can be considered to be quasi stationary, but simultaneously it explains the time varying BPF noise mentioned above. The dominated frequencies of the predicted blade pressure fluctuations at a monitored point on the blade agree well with the analyzed measured time signals. Seemingly, the simulation supports the hypothesis that came up with the measurements, figure 2. With the results of both the measurements and the numerical investigations the BPF noise of a centrifugal impeller can be traced back to the formation of an unstable inlet vortex that leads to quasi stationary secondary flow structures which interacts with the rotating impeller blades.

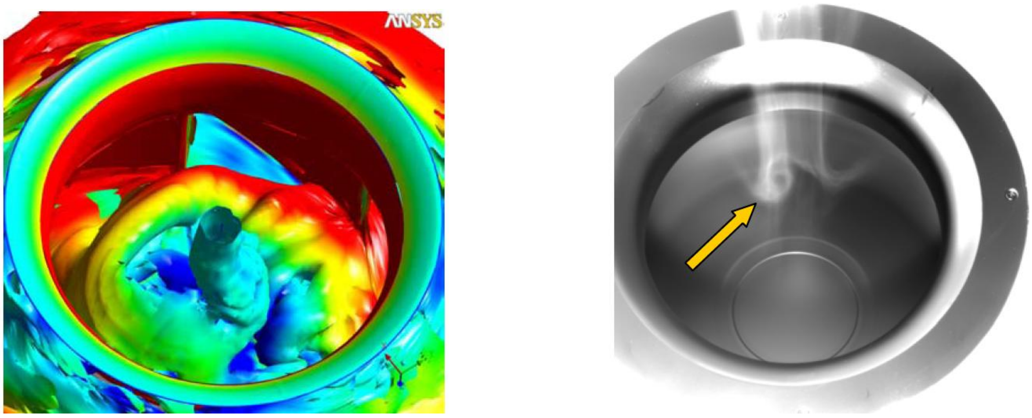

Figure 3: Vortex formation at impeller intake at arbitrary instances of time: CFD (left) and snapshot of a smoke filament (right)

In future the vortex generation mechanism should be investigated in more detail considering the relevant literature, e.g. [4]. A further research topic is related to the inflow structure of axial fans. It is of interest whether a similar phenomenon is responsible for blade tone harmonics observed in these machines.

References

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