Preliminary investigation of flapping paper inside a file

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Abstract. The present paper is about the flapping mechanism of a paper locked inside a file. The investigation consists of visualization of flapping phenomenon and acoustic measurements resulting from the flapping. The normal ceiling fan is used as a source for the flow. The axial flow is converted to wall jet flow by using a surface perpendicular to the axis of the fan. The file placed with an offset from the fan which produces instabilities and in turn triggers the flapping mechanism. A super slow-motion camera is used to record the phenomenon and a microphone is used for acoustic measurements. The time-series results reveal the intermittent nature of the flow. The acoustic measurements reveal the noise sources and their frequencies via Fast Fourier Transformation.

1. Introduction
The curiosity[1] in human beings is the main source of many scientific inventions. This curiosity is telling humans to think about a phenomenon with questions like how it can happen or what drives it or when it can happen and why it should happen[2]. This curiosity of the author has led to the present manuscript and the history is as follows. The author accompanied his grandfather to the library multiple times during his childhood. He has observed some peculiar noise patterns in that environment. Decades later, the author asked his students to place a set of journal articles in a file for reference purposes. This file was kept on the table with many other stationeries. One fine morning when the author switched on the fan and started his work, flapping noise was annoying him. This led the author to think about how this flapping happens, why flapping and when flapping occurs resulting in this study.

Flapping and bending bodies[3] interacting with fluid flows is an interesting subject for fluid dynamics researchers around the world. The flapping mechanism was studied by many researchers for mimicking insect flapping for thrust and lift production[4,5]. The flapping mechanism studies started with the flapping of rigid plates[6] to understand the fluid dynamics especially the vortex production. Flexible plates[7,8] find more applications and the studies about them are more interesting especially the flutter or fluid-structure interaction phenomenon like the flapping of flag. The flexibility in the flapping material is also studied for its influence on propulsion. All these studies are primarily focussed on the aerodynamic forces thereby leaving a void on flapping paper. Hence, the present study tries to address the flapping of paper kept inside a file in a rudimentary way.

2. Experimental Methodology
The experimental methodology is explained in this section. The object of study, environment where the study was performed with the data acquisition methodologies are described in detail.
2.1. Object of study
The object of study is a lever file containing standard A4 sheets of 75GSM as shown in figure 1. The file dimensions consist of length 350mm, width 270mm, and height or slit 50mm with a circular hole on the side with the label for pulling the file.

![Figure 1. A lever file used in the study.](image)

2.2. Environment for experimentation
The environment for the present experiment consists of a conference room present in the Advanced Computing Lab. The file is placed on the conference table with an offset of 0.5m from the axis towards the right and 1m approximately from the fan longitudinally as seen in figure 2. The distance from fan to table is approximately 1.5m and the room is well lit and completely sealed.

![Figure 2. Conference room in lab revealing file placed on the table with fan in ceiling.](image)

2.3. Data acquisition system
The data acquisition consists of a vane anemometer, a 25MP camera with f/1.7 lens and a microphone. The vane anemometer can acquire velocity data from 0 to 30 m/s. The camera (device - Samsung Galaxy A50 with Exynos processor) is used in photo mode for pictures of experimental setup and in
super slow motion mode with 480 frames per second for recording the flapping phenomenon. The microphone from the previously mentioned device that can record from 20 Hz to 20 kHz was utilized for recording the acoustic pressure fluctuations via OpeNoise application for Fast Fourier transform and Noise Capture application for spectrogram or waterfall graph. The microphone time-varying at a location 300mm from the file on the right side (refer figure 2) for acoustic measurements. The vane anemometer is placed on the front side where the slit is seen such that it can measure the incoming air velocity. The measurements made are post-processed by the software or applications mentioned above and the results are discussed in the following section.

3. Results and Discussion
In this section, the data obtained from the experiments are discussed in detail via sub-sections like spectral characteristics, intermittency, flapping cycle and transition between flapping.

3.1. Spectral characteristics
The flow velocity is 2.1 m/s at the entrance of the file with fluctuations in the order of 0.1 m/s. Figure 3 shows the spectrum of acoustic pressure data resulting from FFT for three cases i.e. a) background noise b) fan noise and c) flapping noise. The background noise is measured while the fan is kept off and the spectrum shows some noise which is due to the sound from the exterior. The fan noise is measured as shown by the spectrum and it reveals low-frequency broadband noise and a peak in the high-frequency region 8 kHz. The flapping noise is revealed by high amplitude and low frequency in the spectrum which is approximately around 5 to 10Hz (calculated from the slow-motion video) and associated noise is seen in the 200–300Hz range. The peak is seen with a higher amplitude at the same frequency at 8 kHz. There is a secondary peak towards the end of the spectrum at 22 kHz and beyond which the microphone is incapable to measure. It is to be noted that the frequency of flapping is varying with the incoming flow which is out of scope for the present work.

3.2. Intermittency
The flapping phenomenon is observed by the author for a long period of time and it is observed that the flapping is intermittent. The flow instabilities influence the flapping cycle and it can be a separate study for knowing the start of flapping. To reveal the intermittency behavior, a spectrogram or
waterfall graph of acquired acoustic data is plotted and shown in figure 4. The acoustic data recorded is for 30 seconds and the cycle continues till it is brought to end. Figure 4 shows flapping sound by vertical streaks which can be grouped easily based on visual observation. The first set of flapping occurs between 0 to 5 seconds followed by a brief gap of 2 seconds. A short second cycle of flapping can be observed from 7th second till 9th second. The intermittency of flapping is observed and it is not constant with respect to the time. This phenomenon can happen due to the usage of a fan as a source of flow. To know more about the intermittency pattern in detail, an experiment can be conducted via wind tunnel at a constant flow velocity.

3.3. A flapping cycle
The flapping cycle is revealed by the super slow-motion video captured at 480 frames per second. The paper is at rest when there is no flow. The flow is enabled and the air molecules penetrate into the layers i.e. in the gap between the top paper and the next paper. The accumulation of air molecules...
between two papers leads to bulging of the paper in the middle. When the momentum of molecules is high enough to push the paper upwards, the paper starts the flapping motion. The middle line of paper hits the top surface of the file during the half of the flapping cycle and looks like a Gaussian profile from the side. Now, the air molecules start moving over the surface of the paper to create stagnation near the top end where paper hits the file. This stagnation pressure pushes the paper from top to the bottom and the flapping cycle continues. This flapping cycle is revealed by the pictures as seen in figure 5. This flapping cycle is consisting of two motions and one resting position. The bulging of paper to hit the top surface is the upstroke and the flattening of paper to touch the bottom is the downstroke. There is a very brief resting position, where the paper stays flat.

3.4. Transition between flapping cycles
The flapping cycle is intermittent and it can be noticed that there is a transition occurring between two cycles of flapping. When the top paper sticks to the bottom bunch of papers, the start of flapping is delayed until molecules penetrate the gap between the papers. Once started, the top paper does not stick to the bottom bunch perfectly. The free end of the paper is always at a height from the bottom bunch as seen in the pictures shown in figure 6. Figure 6 shows the downward pointing tip of top paper which is denoting the end of the flapping cycle. Figure 6 b shows the mid position or the resting position during the flapping motion and whereas figure 6 c shows the tip of the paper pointing upwards for the start of the next cycle. In total, figure 6 shows the transition phenomenon happening during the mid of the flapping cycle.

4. Conclusions
The present study was about the flapping mechanism of a paper bunch kept locked inside a file. The investigation consisted of visualization of flapping phenomena via video recording with super slow motion and acoustic pressure measurements via a microphone. It is found that the file placed with an
offset from the fan containing paper starts flapping due to the flow magnitude and its fluctuations. The time-series results revealed the time-varying intermittent nature of the flapping phenomenon. The acoustic data revealed the noise sources and their frequencies are found in the lower end of the spectrum. This study provides scope for detailed work on the flapping mechanism of paper inside a file.

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5. **References**

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