ANALYSIS OF AIRFLOW GENERATED BY A CEILING-FAN SYSTEM

A MINI-PROJECT REPORT

submitted by

Prasannavenkatesh B. (119009253)

Vignesh V. (119009222)

Sai Anirudh R. (119017034)

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SASTRA Deemed to be University

Thirumalaisamudram, Thanjavur — 613 401, Tamilnadu, INDIA

BONAFIDE CERTIFICATE

This is to certify that the mini-project work titled "**ANALYSIS OF AIRFLOW GENERATED BY A CEILING FAN SYSTEM**" is a bonafide record of the work carried out by

Prasannavenkatesh B. (119009253)

Vignesh V. (119009222)

Sai Anirudh R. (119017034)

students of final year B.Tech Mechanical Engineering and Aerospace Engineering (119017034), in partial fulfilment of the requirements of the degree of B.Tech in Mechanical Engineering and Aerospace Engineering of **SASTRA DEEMED TO BE UNIVERSITY, Thirumalaisamudram, Thanjavur, Tamil Nadu, India – 613401,** during the academic year 2018-19.

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ABSTRACT

KEY WORDS: Ceiling fans, Built environment, Cooling, Thermal comfort, Pitot static tubes, Airflow.

Studying the airflow in a room due a system of ceiling fans gives us insight into how cooling is achieved and how we perceive that cooling. This study was conducted using a set of Pitot static tubes held by a portable mechanical setup. The functioning of a Pitot static tube is validated through a wind-tunnel test. The main experiment is carried out by measuring the velocity of air at different coordinates in a given three dimensional space (room) consisting of a system of ceiling fans. The fundamental outcome of the experiment is the total and static pressure values at the aforementioned coordinates. The total and static pressure values obtained using the Pitot static tubes are further used to calculate the dynamic pressure, and thus the velocity of air at each coordinate in the room. These data are used for further statistical analysis.

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CHAPTER 1

INTRODUCTION

Ceiling fans are an integral part of buildings and their environment aimed at providing humans and even animals comfort. Ceiling fans create airflow which makes the room's occupants feel cool and comfortable. With a ceiling fan running, air conditioners can be set to a temperature higher than what is required and still achieve the same cooling effect. This is a win- win situation as there is better cooling and less power consumption. It is seen that increasing the temperature by 2 to 4 degrees can cut our running costs by 4 to 6 %. To elaborate the efficiency with an example, a typical central air conditioning system uses 3500W of energy while running while a ceiling fan uses just 60 W even under high loads. In addition to electricity costs being cut, there is also the saving of maintenance costs. The maintenance of a ceiling fan costs just a fraction of an air-conditioner's maintenance costs. Adding to this is the maintenance requirement – as we all know, fans running in closed indoor environments rarely require maintenance.

The airflow created by fans speeds up the evaporation of perspiration on human skin, which makes the body's natural cooling mechanism much more efficient. Since the fan works directly on the body, rather than by changing the temperature of the air, during summer it is a waste of electricity to leave a ceiling fan on when no one is in a room unless there's air conditioning, open windows, or anything that can heat up the room.

Fig1. Figure illustrating hot and cool air’s flow

The above picture illustrates the flow of air by a ceiling fan during different seasons. During winters the fan creates airflow such that the hot air is pushed down thereby increasing the temperature and thermal comfort during winters.

In summers the aim is to keep the temperatures as low as possible, so fans during summers are designed to push the cold air down and in turn the hot air goes up and this enhances the thermal comfort required during summer i.e. we feel cooler. These types of ceiling fans are predominantly used in tropical regions where seasons are dominated by hot weather. Nowadays, the use of fans in colder environments (for the purpose of warming) has considerably reduced due to the prevalence of centralised heating systems. Nevertheless, the use of ceiling fans in hotter environments is continuously growing, especially the developing nations in Africa and Asia.

CHAPTER 2

LITERATURE REVIEW

DETAILED EXPERIMENTAL INVESTIGATION OF AIR SPEED FIELD INDUCED BY CEILING FANS

In this paper, the airflow profiles induced by a single fan and multiple fans using high spatial resolutions measurements in a climatic chamber are investigated in detail. This is also the first time the interaction between multiple fans have been recorded meticulously. A quintessential airflow pattern has been developed from the quantification and which were further validated using smoke visualization.

The objectives being to provide a formidable spatial resolution air speed measurements over the whole occupied zone of one and two ceiling fans at varying distance at both of the cases at different speeds too, to develop classic air speed profiles from the observations which are noted and also from the smoke visualizations, to develop which can be used to describe the air speed uniformity in a space and also for the fan interaction effects.

A grid made of 180 locations in the climatic chamber are earmarked as the measurement locations where the points are suitable for measurements for various reasons. In total 5760 measurements were taken for both single-fan and double-fan case respectively. The airspeed in the climatic chambers which aren't generated by ceiling fans did not exceed 0.05m/s.

The core from the fan are observed at about 0.35m-0.4m from the fan center and at low speed, the jet has similar air speeds across it which is about 0.3m/s to 0.5m/s at heights of about 0.4m-1m above the floor. The jet generated by the fan does not spread out of the cylindrical zone under the fan until it passes through the height of 0.8m above the floor.

In double fan case the fans are kept at three different configurations or here center-to-center distances which are 1.3xD, 1.7xD, 2.1xD. When the fans are kept at medium speed regardless of the configuration they are in, more than 40% of the whole room is affected by air speed higher than 0.5m/s. At high speed level 70% of room area had speed higher than 0.5m/s in the first configuration and 80% of the room in the second configuration and a 100% in the third configuration. The interaction between fan jets increases with the decrease of the distance between the fans. If the fans are at different speeds, the jet of the weaker fan is not symmetrical but is skewed in the direction of the dominant fan.

The flow below the fan is highly unsteady and the air speed changes with time which reflects the fact that the flow is highly turbulent. Differences of up to 0.7m/s in the peak values between two sides of the fan at a height of 1.1m. This suggests that the measurements made along the radial direction will underestimate or overestimate the air speed.

The experiments were measured with restricted dimension of the climatic chamber which could affect the results and the fans are also closely located and this work could be greatly improved in the future by introducing measurements in a more general open space with symmetrical fan locations and also the effect of having obstacles on the interaction among multiple fans would be useful as it is common that fans have their interactions blocked by various factors.

EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF INDOOR AIR MOVEMENT DISTRIBUTION WITH AN OFFICE CEILING FAN

In this paper the air movement distribution in an unoccupied office room which is installed with a ceiling fan is investigated systematically which are influenced by fan rotational speed, ceiling height, blade geometry, ceiling to fan depth. The air speeds were both measured and simulated at four heights in the occupied zone according to *ANSI/ASHRAE/IES Standard 55*

(2013) for both seated and standing occupants. CFD predictions were validated by the experimental results.

The results acquired from numerical simulations show that for an unoccupied space the following factors influence the air speed, ceiling to fan depth, blade geometry and ceiling height and these too influence the velocity profiles in a cylindrical zone which is under the ceiling fan with the radius identical to that of the fan. The average speed of air within the zone at different heights are very similar and the change observed for different fan blade shapes is less than 10% so it can be said that fan blade doesn't influence the air speed as intended and the velocity profile in the zone remain similar for various rotational speeds.

The following conclusions were drawn from the experiment conducted, they are

1) On increasing the rpm of ceiling fan the average air speed increases in the occupied zone and also the velocity profile self-similarity exists for different rotational speeds in the zone below the fan.

2) The ceiling fan driven model is well predicted by standard k-epsilon turbulence model when incorporated with multiple reference frame fan model.

3) The rpm and ceiling height have a greater effect on the velocity distribution and air speed in the zone when compared with the effect of blade geometry and the distance between fan and ceiling.

CHAPTER 3

EXPERIMENTAL PROCEDURE

Equipment Calibration:

- The velocities obtained using the existing metal Pitot static tube and the 3D printed Pitot static tube were compared.
- Firstly, the rpm corresponding to the required flow velocities were found using the existing Pitot static tube.

2 trials were taken using the 3D printed Pitot static tube.

- For each trial, the new tube was clamped to the existing tube(which was just used as a support i.e. rotated by 180º to face the opposite end of the tunnel).
- To minimize interference, the 3D tube was pushed to the maximum limit.

Fig.2. A 3-D printed tube clamped inside the wind tunnel

Experimental Area:

The area chosen is a closed, indoor portion of a room with a system of ceiling fans – 2 fans placed equidistant from the nearby walls.

The area chosen was a rectangular portion of 4.09m length and 2.34m breadth. The surface area chosen was 9.57 sq. meters.

This area was equally divided into 40 grid points, every grid point equidistant to one another by 58.5cm. This is the edge length of one tile used in the flooring of the room.

Every common vertex to four tiles (within the considered area) is considered as a grid point. Velocity is measured at every one of the grid points.

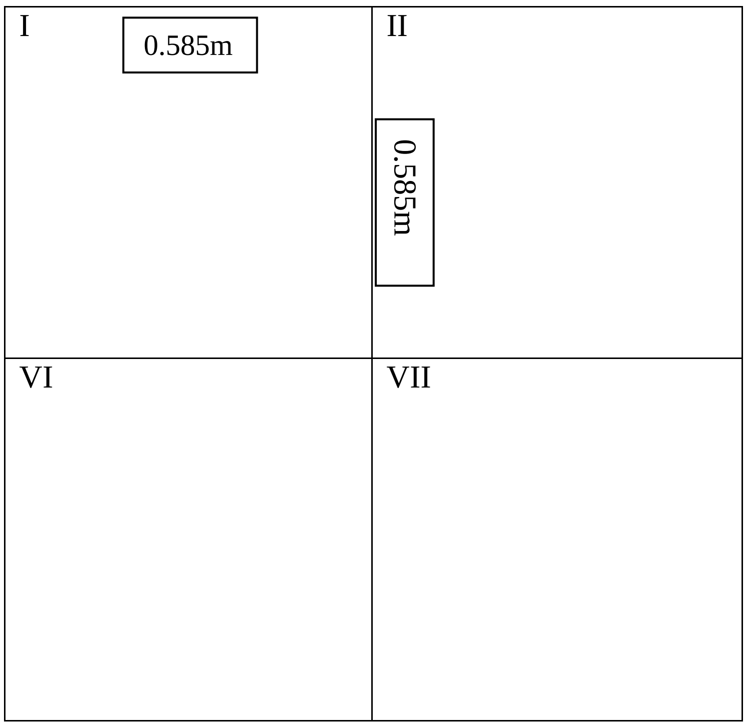


Fig.1. An illustration of how grid points were considered

Fig.4. The room under consideration, with the setup at the right of the room.

Experimental Setup:

The height-adjustable portable mechanical setup to hold the Pitot static tubes was designed by us and fabricated (with assistance from the workshop members) inside SASTRA premises. The setup consists of four parts namely – the base plate, the outer vertical support, the inner adjustable vertical support and the 4 arms which have holes provided in them to hold the Pitot static tubes in a vertical position.

Specifications:

1. Material Used: Standard grade Mild Steel was used to fabricate the setup.
2. Weight: The weight of the setup was 20~30 Kgs.
3. Dimensions: Base Plate = 380*380 mm.

   Outer support height = 914.4 mm (3ft height)

   Inner support height = 914.4 mm (3ft height)

   Arm length = 150mm.
4. Welding Used: Arc welding.
5. Ceiling fan used: Two five speed standard Crompton Greaves fans(always running at maximum speed).
6. Holes: one 8.5mm (the O.D. of the Pitot static tube) was drilled on each arm, 10mm away from the edge.
7. Bolts Used: Standard M12.

Design:

This adjustable design was adopted to facilitate measuring at different heights using the same setup. Using the same setup, 3 different heights could be achieved namely – 3, 4 and 5ft. This was achieved by drilling a hole onto the outer and inner vertical support rods at every 1ft height so that the inner rod could be lifted up and bolted using the corresponding M12 hole.

To achieve heights lower than 3ft, a simple modification of cutting off the vertical rods' bottom end portion and re-welding with the base-plate is required.

The design was initially modelled using SolidWorks, whose rendered image is as follows. A crucial modification to this design was done before fabrication – the four cross-arms were fixed to the top of the inner rod such that the tip of the tubes (the total port) was always exposed to undisturbed airflow. The initial design could not achieve this as at lower heights, the protrusion of the main vertical support above the level of the Pitot static tubes was feared to disturb the flow before it reached the total port of the tubes.

Pressure Measurement:

A 64-channel Scanivalve pressure scanner was used to observe the pressure values at each grid point. The first 4 of the 64 ports were used – the 1st and 3rd being the total pressure ports of the two Pitot static tubes; and the 2nd and 4th being the static pressure ports respectively.

Fig.5. The portable setup with the pressure scanner connections

Experiment:

The experiment was conducted using two Pitot static tubes held on two opposite arms of the setup, at a fixed height. The two tubes were each 140mm (which is the length of one tube) away from the grid points. The mean of the velocities measured using the two tubes were considered, for a more accurate velocity measurement at the grid points.

The height was chosen to be 4ft for the first set of observations. An M12 bolt was used to locate, and bolt the second holes of the inner and outer vertical rods in order to achieve the 4ft height.

The Pitot static tubes were held such that they protruded by 70mm (half the length of a Pitot static tube from the top surface of the arm. This was to:

1. Ensure that the total pressure port did not face any obstruction to the airflow.
2. Ensure that the static pressure port was safely moved up from the drill-hole on the arm.

A small table (whose height was lower than 4ft) was used to bear the laptop using which the observations were recorded.

The frame rate of the pressure scanner was set to 700 readings/second and the number of observations were set to 10000 before each grid point was observed.

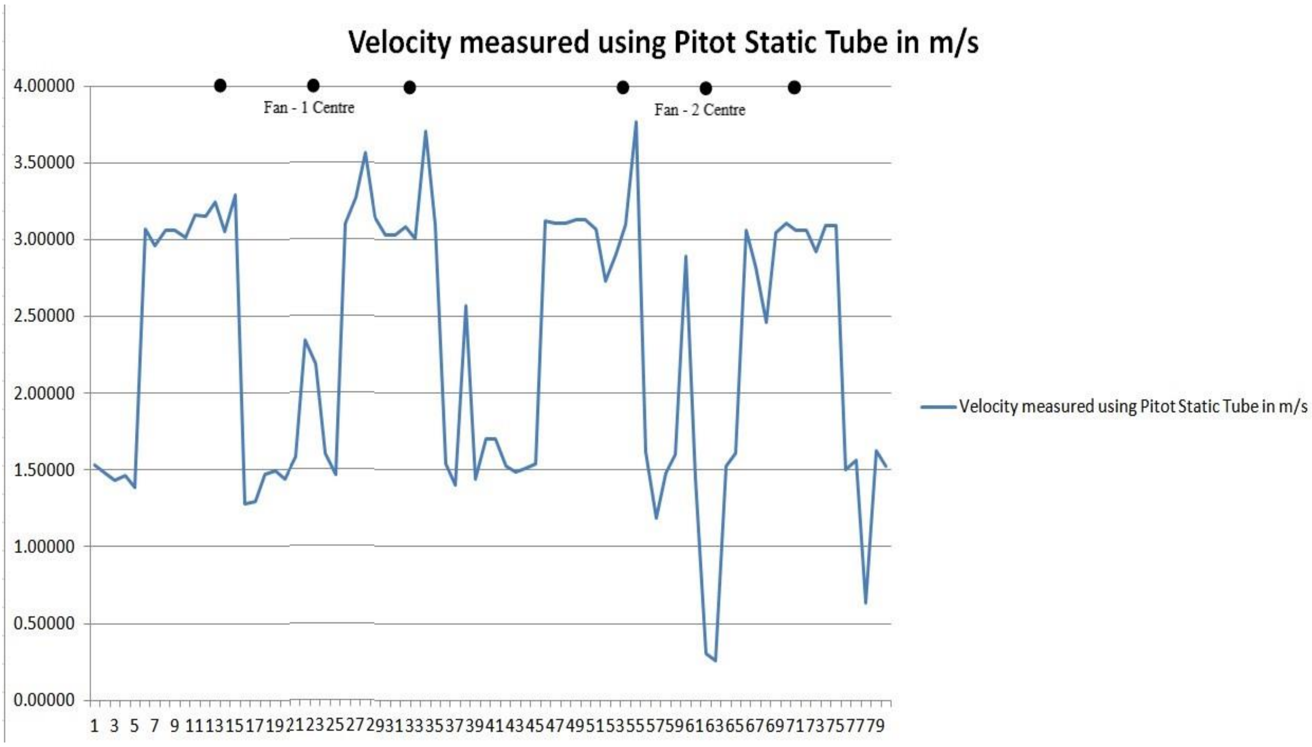
As a precautionary measure, it was ensured that no one and nothing above the 4ft height was in the vicinity of the tubes while the readings were being recorded.

CHAPTER 4

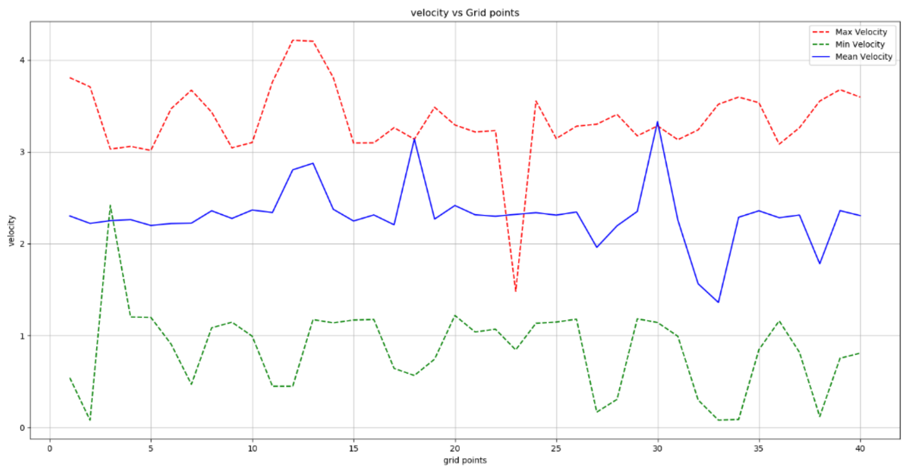
RESULTS AND DISCUSSION

- The Pitot static tube measured the total and static pressure at its position. The average of the 10000 observed values were considered.
- The dynamic pressure was found using the relation $p_0 = p_s + p_d$.
- The velocity was found from the dynamic pressure value, using the relation

  $p_d = 0.5\rho v^2$.
- The maximum velocity was obtained from the maximum dynamic pressure i.e. the maximum difference between the total and static pressures, out of the 10000 readings. Similarly, the minimum velocity was also found.
- The magnitude of airflow corresponds to the position of the fan's blades directly above it. The blades of the fan on the left side(as seen in Fig.4) is located approximately above grid points 8 and 18 (diametrically opposite points on the blade).
- Thus, we obtain the maximum mean velocity at the grid points directly below the blades.
- Similarly, the blades of the fan on the right side of the room (as seen in Fig.4) is located approximately above grid points 28 and 38.
- The first plot is for the 80 locations where the actual Pitot static tubes are placed (140mm apart from the grid points on both sides).
- The second plot is for the 40 grid points (obtaining the mean velocity of the two Pitot static tubes; this plot also includes the maximum and minimum velocities at each grid point).



Plot.1. A linear plot between the 80 locations (2 locations for each grid point) and the velocity measured in m/s



Plot.2. Linear plot for mean, maximum and minimum velocities in m/s at each grid point

CHAPTER 5

CONCLUSION

Through the course of this work, we quantitatively obtained the velocities of air due to a system of ceiling fans using a Pitot static tube setup. We quantitatively determined by how much the airflow increased with a decrease in the distance between the grid point and fan's blades. This data can be further used with data obtained from a multi hole probe, to accurately map the velocity vectors in the considered three dimensional space.

CHAPTER 6

FUTURE SCOPE

A multi-hole probe could be used to find out the direction of the velocity primarily, which could help us in mapping the airflow at every three dimensional coordinate. This would give us insight into which regions receive what amount of airflow and which regions remain devoid of airflow, despite the continuous functioning of two ceiling fans at high speed.

PIV(Particle Image Velocimetry) technique could also be used to measure a velocity on a particle-level(through the introduction of tracer particles in the flow), which would help us in mapping the airflow on a more accurate level.

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