Experimental investigation of turbulence inside a confined chamber using non intrusive methods

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The main objective includes finding appropriate motor to drive fans inside a closed chamber to generate turbulence inside it.BlDC motor with required power rating was selected and was ran and synchronised using feedback algorithm in arduino.Olive oil seeding particles were used to visualize the flow field.Particle Image Velocimetry was used to measure the velocity flow field inside the chamber.

NOMENCLATURE

$U^{'}$ Fluctuation component of instantaneous velocity m/s
$u^{'}$ Fluctuation component of velocity in x direction, m/s
Υ Longitudinal correlation coefficient, dimensionless
u^{*} Normalised instantaneous x velocity, dimensionless
$v^{'}$ Fluctuation component of velocity in y direction, m/s
K_I Integral gain constant revolution1
K_p Proportional gain constant, RPM1
Subscript
rms Root mean squared value
x Value for x direction
y Value for y direction
Acronyms/Abbreviations
PIV Particle Image Velocimetry
PWM Pulse Width Modulation

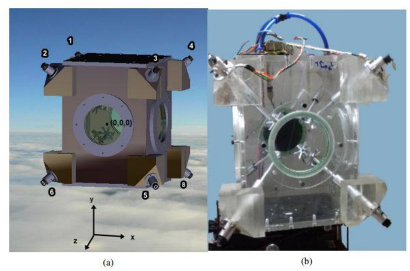

FIG. 1. Left: CAD model of the chamber showing co-ordinate system and the numbering of fans. Right:Chamber after fabrication.

I. INTRODUCTION

This study is part of a project that aims at getting a better understanding in turbulence premixed flame interaction. In this work, experiments are carried out in a fan-stirred vessel. The flame speed is the speed of a mean flame surface with respect to the mean flow, while the burning velocity is the burning rate per unit area of a mean flame surface normalized with unburned gas density[1]. Need for studing turbulence effect on flames was necessary because flame speed was dependent on characterization of flow . Fan stirred vessels constitute a special class of experimental setups with near zero mean flow and hence most of the conventional velocity measurement techniques can not be used for investigation of HIT. For this reason, the studies on HIT inside fan stirred vessel have mainly relied on PIV and LDV techniques. Majority of the present literature of turbulent combustion centres around the study of statistically stationary homogeneous isotropic turbulence(HIT)[1]. Statistically stationary means that all the average quantities do not change with time while the instantaneous parameters can. Statistical homogeneity implies at the translation invariance of the mean quantities. Statistical isotropy is the invariance of the average quantities under rotation or reflection .Thus for a statistically stationary HIT, the average quantities do not vary with time, location or direction. Thus each parameter of interest has a single value for the entire field of interest. Moreover, in HIT, the small-scale properties like Taylor and Kolmogorov scales, which are difficult to calculate experimentally, are functions of the large scale properties like RMS velocity and the integral length scale.

II. EXPERIMENTAL SETUP

Experiments were carried out in acrylic chamber of dimensions of 215×215×315 mm . Eight fans, placed symmetrically along the corners of chamber, were used to generate turbulence. The fans were driven by high precision quad encoder DC motors placed outside the chamber, whose speeds were synchronised and could be varied to control the turbulence intensity inside the chamber .The fan to fan distance was 133mm , and it directs the flow towards the centre .The speed of the fan was adjusted accurately to 5000 rpm .

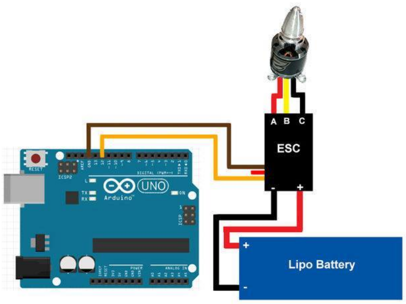

FIG. 2. Connection Of ESC with motor

II.1. Motor Selection

For creating turbulence in given chamber, the existing motor faced some problems. These include

1. Encoders stops working after it gets heated up when ran for long time.
2. No proper alignment of the motor shaft and propeller shaft leading to create vibrations ,and changes in load which leads to changes in fan speed .
3. Failure of shaft due to stress concentration because of length constraint.

It was decided to use BLDC Brushless DC motor for driving the fans so as to create turbulence.

II.1.1. Brushless DC Motor

Brushless DC motor may be described as electronically commuted motor which do not have brushes. These types of motors are highly efficient in producing large amount of torque over a vast speed range. In brushless motors, permanent magnets rotate around a fixed armature and overcome the problem of connecting current to the armature. Commutation with electronics has large scope of capabilities and flexibility. They are known for smooth operation, and holding torque when stationary.

BLDC motor requires additional unit to run that is ESC . An electronic speed control or ESC is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. It converts PWM sent by the Arduino to required voltage.

Pulse Width Modulation is a method of getting analogue like results using digital means. A PWM signal from an Arduino board is a square wave that switches between high (5 V) and low, at a high frequency. By varying the fraction of time that the signal remains high during each cycle, called as duty cycle, a resultant signal equivalent to any value between 0 and 5 V can be produced. A PWM signal of 100 % duty cycle (corresponding to 5 V), makes the motor utilise the full voltage , while a signal of 50% dutycycle (corresponding to 2.5V) make it utilize just half of the supply voltage (VSS), thereby enabling to control the motor speed.

II.1.2. Feedback control

The feedback system designed was PID controller . A PID (proportionate- differentiate- integral) controller is a control loop feedback mechanism (controller) widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value as the difference between a desired setpoint and a measured process variable and applies a correction based on proportional, integral, and derivative terms (sometimes denoted P, I, and D respectively) which give their name to the controller type. The controller tries to minimize the error over time by adjusting error . This is done by the equation below

$$m_n = k_p * e_n + \frac{k_e * T}{T_{reset}} \sum_{i=0}^{n} e_i + k_d \frac{e_n - e_{n-1}}{\delta t} + m_R$$

where m_n is the output of the controller at the nth sampling instant, m_R is the reference value at which the control action is initialized, e_n is the value of the error at the nth sampling instant, T_{reset} is the reset or integral time, kp and kd are the proportional and derivate gains respectively.

For motor, calculation of constants ki ,kd, kp was tough job which requires motor specifications such as inductance , flux , moment of inertia . Gathering all these information was not possible . Another method for calculation of these constants was trial and error . Motor behaved unusually when any arbitrary values of these constants were set . Unusual behavior include starting running at very much high speed and then suddenly stopping . To counter attack this problem a new method using matlab to claculate the control parameters was used.

II.1.3. Calculation of control parameters

PID Tuner provides a fast and widely applicable single-loop PID tuning method for the Simulink PID Controller blocks. Transfer function maybe defined as mathematical representation of interrelation between input and output in linear time uninterrupted systems. Calculation of transfer function was done with help of Matlab PID tuner.PID tuning is the process of finding the values of proportional, integral, and derivative gains of a PID controller to achieve desired performance and meet design requirements. PID controller tuning appears easy, but finding the set of gains that ensures the best performance of your control system is a complex task .Initially response with no feedback system was fetched to Matlab .

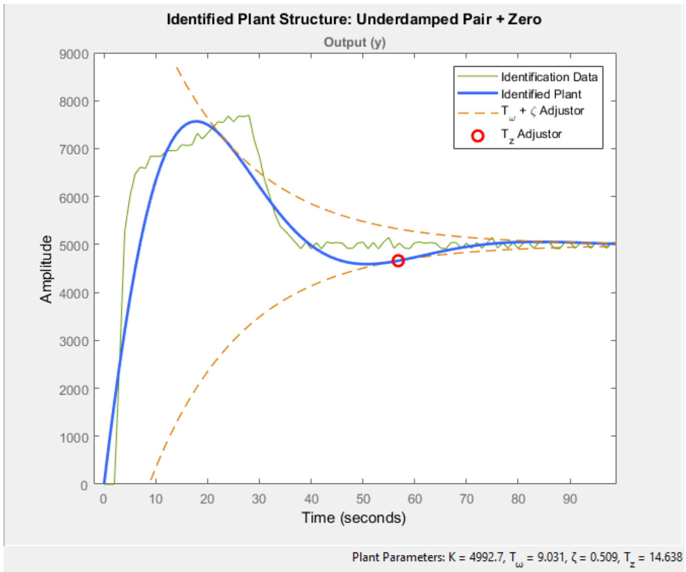

FIG. 3. PID tuner to calculate control parameters

Initial response include speed of the running motor wrt to time. This graph was tuned with the help of tools given in software and most appropriate transfer function was calculated from tuned graph . The kp , ki and kd values got from the graph reduced the overshoot ,rise time and settling time . The following kp = 0.00457 , ki = 0.0048 , kd = 0.00054 . These values were taken for feedback algorithm and following motor was maintained at same speed all the time .

III. PARTICLE IMAGE VELOCIMETRY

PIV is the abbreviation for Particle Image Velocimetry, one of the most widely used non intrusive velocity measurement technique of modern times. The basic idea behind PIV is simple: seeding the flow with some particles and then studying their motion to get an idea about the flow field.

III.1. PIV setup

The basic configuration of any PIV system consists of the following: A laser source, optics to create laser sheet, a camera, a seeding system and a computer system for post processing. The laser source produces high energy laser beams to illuminate the seeding particles. The laser beam is converted into a sheet of laser after which it is shone onto the seeding particles dispersed in the flow. At least two laser pulses are sent at close intervals, with a gap of δt seconds. These two illuminations of the seeding particles are either recorded in the same frame or two different frames by a camera which is synchronised with the laser light source. The time gapδt between the laser illuminations is small enough so that the particles in the flow would have moved only a few pixels in the image. Since it is impossible to track each of the seeding particles individually, post-processing algorithms have been developed which divide the frame into many sub areas called interrogation windows. These windows are so small that all the particles within each interrogation window can be assumed to move homogeneously between two laser illuminations. Hence the post processing algorithms compute the displacement for each interrogation window.
A Nikkon lens with 35 cm focal length was used for focussing the image on the camera. Imager Pro 4X camera with a resolution of 2048×2048 pixels and a maximum acquisition frequency of 7 Hz in double frame mode was used for acquiring the images. However, after synchronising the laser with the camera, maximum acquisition frequency of only 5.5 image pairs per second could be achieved. To achieve this, the trigger rate was set as 11 Hz and recording rate was set as 5.5 Hz. Only the sensors focussing on the area of interest,40mm×40mm square centred about origin were enabled during recording.

III.2. PIV Post Processing

Post processing of PIV images is done through auto correlation or cross correlation depending on whether the two exposures have been recorded on the same frame or different frames respectively. For the present work, two different frames have been used for recording, and hence only cross correlation technique will be discussed in detail here.

The parameters required to calculate of quality of HIT include velocity of points obtained in PIV measurements , its mean and rms velocity . The given set of data was provided which includes 150 frames taken by camera with each frame containing 27000 points . For a given particular frame points ranges from -20 - +20 in both x and y directions . In a turbulent flow, the velocity of any point shows random fluctuations with time. The term instantaneous velocity refers to the velocity of any point, measured at a particular instant. The average velocity of a point is the average value of the instantaneous velocities of that point . The fluctuations velocity is calculated by subtracting instantaneous velocity from mean velocity . So the calculated fluctuation velocity will be matrix of 27360×150 rows and columns.

$$U_{mean} = \frac{\Sigma_{i=1}^{n} U_i(X)}{n} \tag{1}$$

$$U'_{RMS} = \sqrt{\frac{\Sigma_{i=1}^{n} U_i(X)^2}{n}} [1] \tag{2}$$

$$\Upsilon_x(X, \delta x) = \frac{\sum_{i=1}^{n} U_i(X) U_i(X + \delta x)/n}{U_{RMS}(X) U_{RMS}(X + \delta x)/n}$$

$$\Upsilon_y(X, \delta y) = \frac{[\sum_{i=1}^{n} v_i(X) v_i(X + \delta x)]/n}{v_{RMS}(X) v_{RMS}(X + \delta x)/n} \tag{3}$$

Similarly lateral correlation coefficients are defined as[2]

$$\zeta_x(y, \delta x) = \frac{[\sum_{i=1}^{n} u_i(X) u_i(X + \delta y)]/n}{u_{RMS}(X) u_{RMS}(X + \delta y)/n} \tag{4}$$

$$\zeta_y(X, \delta y) = \frac{[\sum_{i=1}^{n} v_i(X) v_i(X + \delta x)]/n}{v_{RMS}(X) v_{RMS}(X + \delta x)/n} \tag{5}$$

Integral length scale can be obtained from the longitudinal correlation coefficient as per the formula [2]

$$L(X) = \int_0^{\inf} \Upsilon(X, \delta x) dx \tag{6}$$

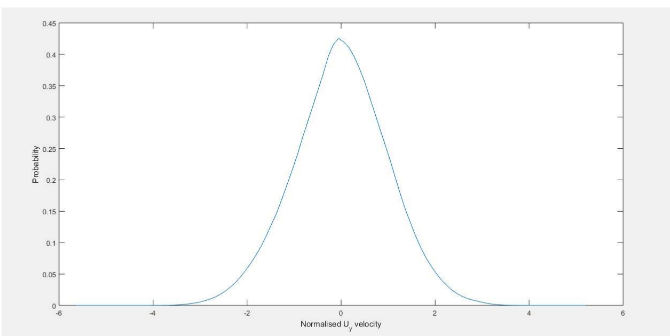

FIG. 4. Normalized Instantaneous y-Velocity in m/s

Probability distribution function for normalised instantaneous x and y velocities, averaged over all points in the 20 mm × 20 mm region. The standard normal (Gaussian distribution with mean =0 and standard deviation = 1) PDF is also given for comparison.

IV. RESULTS

Synchronisation of motor was done successfully by tuning the speed-time curve of motor.kp,ki,kd value of the following system was calculated .Transfer function was also calculated and found out to be

$$Transferfunction = K \frac{T_z s + 1}{T\omega^2 s^2 + 2\varsigma T\omega s + 1} \tag{7}$$

.Accuracy was maintained within 1% of input speed. Calculation of correlation coefficient was done , this was done to calculate integral length scales which was property of turbulence. HIT ratios was calculated for understanding the turbulence generated in vessel .Variations for velocity component fluctations has also been plotted .The cold flow conditions experiments done in fan stirred vessel for turbulence characterization is important for calculating flame speed in spherically expanding flames .

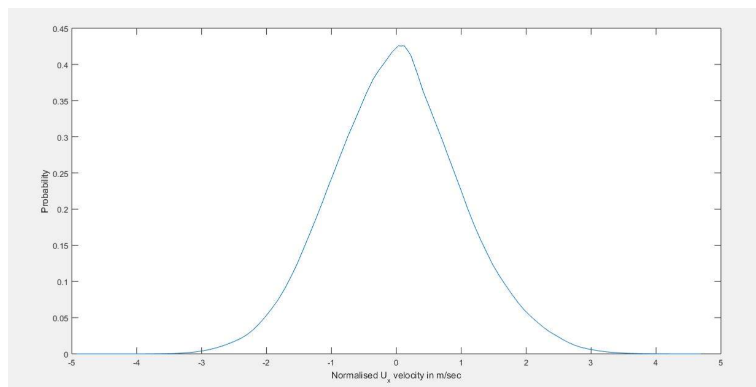

FIG. 5. Normalized Instantaneous x-Velocity in m/s

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