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RECOGNIZE THE COLD FLOW PERTURBATION SOURCES IN A DUMP COMBUSTOR WITH TAPER EXIT

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ABSTRACT

This paper reports on experimental investigation of the flow field inside a low aspect ratio dump combustor with tapered exit. The length of the combustor studied was less than the reattachment length for the separated flow. The flow field behavior in the combustor is evaluated from pressure and velocity measurement at varying flow Reynolds number. The pressure measurement inside the combustor at different locations was performed by the piezo-resistive pressure sensors. The velocity measurement inside the combustor was carried out by a hot wire probe. The rms (root mean square) velocity and turbulence intensity distributions are found to be axisymmetric due to the geometry of the combustor. The variation in pressure and velocity with locations and Reynolds number was studied. The velocity variation near the surface of the combustor (r/R=0.66) was showing the opposite behaviour upto x/h=4.837 than the radial locations (r/R=0.0, 0.33) due to presence of recirculation and high separation of shear layer by deceased in the strength of the potential core. The pressure and velocity measurement studies support that the presence of the strong recirculation and high turbulence inside the combustor. The power spectral studies of the pressure and velocity fluctuations also suggested the presence of strong recirculation, acoustic modes and turbulence behaviour inside the combustor. The velocity distributions were corroborated by comparing the frequency spectrum with the wall pressure distributions and the results were found to be in very good qualitative agreement with each other.

Keywords: Dump, combustor, perturbation, turbulence, recirculation

INTRODUCTION

Combustion stability, intensity and efficiency all depend on the fluid flow and turbulence distribution within the combustor and so does the heat transfer to the chamber walls. For these reasons much combustor development has focused on internal flow patterns. In typical combustors, liquid reactant is introduced into a re-circulating environment of the gaseous reactant, which improves the rate of evaporation of the liquid droplets. The presence of the re-circulating eddies also improve the mixing of the reactants which improves the combustion process, providing complete combustion and higher heat release. The turbulence characteristics of confined jets with re-circulating flow are of particular relevance to the flows in combustion chambers, coal gasification furnaces and other chemical reactors. Precise understanding of nature of re-circulating turbulent flow is needed to determine the characteristics of such chemical equipment. However, sufficient knowledge of three-dimensional unsteady turbulent flows with recirculation has not been obtained either theoretically or experimentally.

A significant amount of research have been performed on re-circulating flow field in a suddenly enlarged combustion chamber and the role of shear layer's large scale structures in mixing processes and jet noise generation. Recent attention has been given to a structure's potential as a driver of combustion-induced pressure oscillation. In this context, the interaction between the large scale coherent turbulent structures and acoustic wave excited in the combustor cavity is of special interest. Coherent structures represent large, rather well-organized lumps of fluid and display their own dynamic behavior in turbulent flows [1]. Their large size implies a long lifetime. Coherent structures arise in various types of turbulent flows, such as boundary layers, jets, wakes, and mixing layers. In contrast with our usual understanding of turbulent flows as involving the cascading of large eddies into smaller ones, we must realize that some coherent structures may increase in size as they move downstream. In some cases, the merging of two smaller structures into a single large one causes the increase, in other cases, the sizes of coherent structures may remain fairly constant. One obvious manifestation of coherence is intermittency. Presently, there has been substantial interest in the study of coherent structure. The coherent structures cannot be ignored, since the large-scale orderly structures contribute more than half of the Reynolds-stress term, as evidenced by experiments results. Schadow et al. [2] showed the re-circulating eddies provide low velocity regions inside the combustor, thus improving the stability of the flame. The dynamics of re-circulating flow field inside a dump combustor has been studied extensively. One category of study of re-circulating flow inside a dump combustor has focused on the re-circulation generated by swirling flow from a swirler. Sarpkaya [3] has studied the vortex breakdown in a swirling conical flow and has reported spiral, double-helix and axisymmetric breakdown of vortices depending on two basic mechanisms of vortex breakdown, namely, hydrodynamic instability and finite-transition to a sequent state. Rhode et al. [4] has provided artistic impressions of flow fields of swirling flows from a collection of flow visualization photographs and illustrated the existence of a central potential core. Escudier and Keller [5] have reported that in the absence of combustion, entire flow field is strongly affected by the exit geometry, but in the presence of combustion, in contrast, backflow do not occur. Thus, the combustion process has been shown to govern the flow field and decouple the flow from the downstream variations. The second category of re-circulating flow research inside dump combustors focuses on influence of acoustic oscillations on the flow dynamics and uses active control techniques for suppression of combustion instabilities created by the flow and acoustic coupling. Joos and Vortmeyer [6] have studied self-excited oscillations of premixed flames behind a step. They have shown that when more than one frequency was excited, an unsteady sound field forms. As a result, the phase position of the sound pressure and the sound particle velocity at the flame continually changes. Schadow and his group in their several studies ([2], [7] – [9]) have characterized the large scale structures in acoustically forced ducted flows in dump combustors and have shown control over the combustion instabilities in gaseous combustion using acoustic driver. They have also extended this study to liquid fuel systems by using pulsating fuel injection. In all their studies, they have shown a strong influence of acoustics on the flow dynamics inside a combustor.

Pressure fluctuations in a turbulent boundary layer are a source of excitation. They may generate acoustic noise and also excite the wall vibration, which can affect the performance of the device concerned. Flow situations involving flow separation through flow restrictions and adverse pressure gradients are more prone to induce noise and vibration problems. Drewry [10] has discussed the flow in a dump combustor and suggested four distinct regions in the flow field, namely, imbedded vortices, flow reattachment, recirculation region and a fully developed flow inside the combustor. Viets and Drewry [11] have observed the strong influence of the inlet velocity profile on the pressure distribution in a dump combustor flow fields. The larger pressure rise is caused by uniform velocity distribution, while the down stream pressure reduced by more fully developed boundary layer. Teyssandier and Wilson [12] have analyzed the problem of a sudden enlargement in pipe and have concluded that the full pressure recovery occurs if the length of the combustor is larger than the reattachment length. Yang and Yu [13] have studied the flow field behaviour in the sudden enlargement combustor in which the reattachment length was shorter than the combustor length. The maximum velocity fluctuation along the centerline occurred immedietly after the racctachment. The shear layer, where the high gradient of mean velocity occurs, is assocoated with high energy level. This high turbulence kinetic energy is transported by both diffusion and convection in and out of the recirculation reagion. Usui et al. [14] have discussed the turbulence level in the sudden expansion spray chamber. The turbulence level in this chamber was higher than the turbulence level of free jet or tube flow and suggested that the large fluctuation in the chamber was caused by the unsteady or intermittent nature of the downward jet. For adverse pressure gradient and three dimensional turbulent boundary layers and other complex flows also having practical applications, the structure of the surface pressure fluctuations and its relationship with the turbulent flow field are needed for use in the noise calculation methods, as well as for better understanding of these flows. Farabee et al. [15] studied the frequency spectra and frequency cross-spectra of the wall pressure fluctuations beneath a turbulent boundary layer in a low-noise flow facility. They obtained results over an extended range of frequencies and sensor spacing. The central issue examined in their investigation was the identification of the turbulent source regions within the boundary layer that contribute to the low, mid and high-frequency ranges of the wall pressure field. They had drawn a preliminary comparison of simulated channel flow. The experimental boundary layer data was made for the root mean square of pressure, wall pressure spectra and convection velocities to examine this issue. They also studied the variations in root mean square of wall pressure as a function of Reynolds number, which was also cited in the works of Simpson et al. [16] and Bull [17]. In the present study this variation has also been studied to get an insight of it. Measurements of these surface pressure fluctuations in a turbulent boundary layer are complicated since the propagating acoustic pressure fluctuations generated by the flow facility are superimposed on the pressure fluctuations produced by the turbulence. In addition, the pressure transducer signal is also contaminated by the vibration of the chamber wall to which the pressure transducer is attached. Simpson et al. [16] proposed a technique for the cancellation of the acoustic noise contribution to the microphone signal in a wind tunnel with two-dimensional mean flow. The wind tunnel test section acted as a waveguide for the disturbances, so that any stream wise location and the stream wise acoustic waves are the same across the test section at any instant of time. Since the turbulence signal is due to the locally produced velocity field, the acoustic and turbulence signals are uncorrelated at any stream wise location. Simpson et al. [16] also pointed out that the two microphones must be spaced far apart span wise across the test section to avoid canceling part of the turbulence-produced signal. This technique has been utilized with two pressure sensors subtracting signal of one from another without delaying any signal to true turbulence level inside the chamber. Usui and Sano [18] have used the space time correlation method to determine the recirculation velocity of the large eddy. In their experimental result they observed the large recirculation eddies near the wall of the test chamber. Menon and Wen [19] have studied the interaction between the vorticity and the acoustic component of the flow field in a combustor. The low frequency pressure fluctuation at the base of the step perturbed the separated shear layer at the step. The shear layer instability and large scale vertical structure amplified perturbation in the downstream and finally generated the secondary vortices and large fluctuation at the throat of the nozzle exit. Mcmanus et al. [20] have discussed the vortex passage frequencies of the large scale structures in the unforced shear layer. These frequencies of the structures were different from those in the separated boundary layer. Schadow et al. [21] have discussed the interaction between the acoustic waves and the different stages of the shear layer development. They have identified the large scale coherent structures related to the instability frequencies and the forcing the flow at the preferred mode frequency improved the mixing in the shear layer and pipe flow regimes. Gutmark and Ho [22] have discussed that if the frequency of the specially coherent perturbations is closed the most amplified frequency, the initial instability waves will form at this frequency. The perturbations extended the formation and the merging of the vortices from the trailing edge to the downstream location.

In most of the literature, the measurement of velocity field was done using either Laser Doppler Velocimetry (LDV) or particle image velocimetry (PIV). These methods have problem of light scattering and wall effects in confined spaces. Secondly, one has to provide orthogonal and optically flat optical accesses for the laser beams to pass. Apart from that, seeding creates a major problem in re-circulating combustor flows due to accumulation of seeding particles/smoke in re-circulating zones creating very dense regions, thus, reducing the accuracy of the measurements. The most important drawback of laser based techniques is the poor temporal resolution of the data, preventing the use of frequency domain analysis to identify the sources of unsteadiness in the flow. Even though hotwire anemometry is an intrusive measurement technique, the measurement by the hot wire is simple and more economical and provides very good temporal resolution. Due to their superior temporal sensitivity, quite high frequency flow oscillations (up to the Kolmogorov scale [23]) can be resolved by hot wire anemometry and hence, hot wire anemometry has been used extensively over the years to characterize highly turbulent and complex flow fields [24, 25, 26] and even the spectral studies of turbulent flows carried out using PIV and LDV were correlated against hotwire measurements [27].

In this paper we present the result of a set of experiments at varying flow conditions under non-reacting environment using pressure sensors and single probe hotwire anemometry in a dump combustor with tapered exit. The velocity measured by the hot wire is the resultant velocity because the heat loss by the probe sensor is equivalent to the effective velocity of the flow passing normal to the probe sensor wire from different directions. Since the velocity measured by the probe is the effective velocity, the root mean square of velocity fluctuations and mean velocity were estimated to represent the turbulence. The turbulence stresses were not estimated because they required cross momentum terms, which could not be measured by a single probe without rotation. Detailed velocity and power spectral density of velocity fluctuations measurements were carried out to understand the cold flow perturbation in the combustor. The pressure measurement study was carried out at same conditions to support the velocity measurement studies. This study is based on developing an understanding of the hydrodynamics and re-circulating flow generated within a sudden expansion followed by a tapered contraction as employed in a numbers of chemical reactors e.g. combustion chambers and in the area of mixing around the feed to a reactor vessel. This knowledge will enable the design of more efficient mixing systems. The upstream flow separates at the entrance forming a turbulent free shear layer. This shear layer grows by entraining fluid from both the main stream and from the region of recirculation formed adjacent to the walls. The corresponding lateral spread of this layer results in flow reattachment at some location downstream of the expansion. Reattachment is a relatively gradual process, the shear layer approaching the wall at a glancing angle. At reattachment some fluid from the shear layer returns upstream to the re-circulating flow region, replacing that originally entrained, while the remainder joins the bulk flow. The confined volume produces intense recirculation and high energy dissipation rates within the separated flow region, hence its importance in determining the overall combustor performance. The re-circulating flow observed for the geometry of the present study is much stronger than those observed for simple expansion flow, because the reattachment point is located in the conical section. Thus the experimental results obtained for unsteady and strong re-circulating flow may be useful as fundamental data to be compared in the future with more sophisticated turbulence predictions

NOMENCLATURE

h	Step height (m)
I	Turbulence intensity
Lpm	Liter per minute
Pin	Mean pressure in pipe (Pa)
Prms	Root mean square of the pressure
Pw	Mean pressure (Pa)

r	Radial distance from the center of the combustor (m)
rms	Root mean square
R	Radius of the combustor (m)
Re	Reynolds number
RSE	Referenced single- ended mode
SPL	Sound pressure level
u'	Velocity perturbation (m/s)
u'_{rms}	Root mean square of the velocity perturbation (m/s)
U	flow velocity (m/s)
$\overline{U}$	Mean of flow velocity (m/s)
Vrms	Root mean square of the velocity
x	Axial distance from the inlet of the combustor (m)

EXPERIMENTAL SETUP

The schematic of the dump combustor geometry used in this study is shown in the Fig. 1. The combustor chamber diameter is 120 mm and incoming pipe diameter is 40 mm, therefore step height of the combustor is 40mm. Combustor exit is tapered and make an angle of 35^0 with combustor exit plane. The flow field behavior of this combustor was different from that presented by Drewry [10] and Yang et al. [13] because the separated flow reattachment length for this combustor was higher than the length of the combustor. Figure 2 presents a view of the test section and equipment used for studies the pressure and velocity flow field of the non-reacting flow. Compressed air at known and regulated pressure gauge (accuracy ±1% of full scale) was supplied into the combustor through a calibrated rotameter (accuracy ± 2% and repeatability ± 0.25% of full scale) that measured the flow rate.

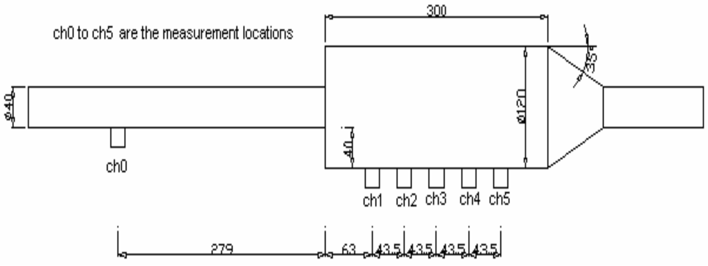


Figure 1. Geometry of the Dump Combustor [dimensions are in mm]

Data Acquisition and Data Reduction

The pressure measurement inside the combustor was performed by the calibrated (maximum calibration error = 4%) pressure sensors (Sensym19C, pressure range of 0-100psi, output voltage 100 ± 2 mV full scale span, max nonlinearity ± 0.25% and repeatability ± 0.03% of full scale span) 0.1 ms of response time. These sensors are located at different positions (ch0-ch5), one at inlet pipe (ch0) and five at combustor surface along axial locations (ch1-ch5 or x/h=1.575-5.925, Δx/h=1.087) at equal space as shown in the Fig. 1. The schematic of the experimental setup used for pressure measurement is shown in the Fig. 2a. The sensors are connected to a SC-2043-SG signal conditioner (gain error ± 0.15% of reading max and nonlinearity ± 0.01% of full scale). This signal conditioner has an inbuilt low pass filter having cutoff frequency of 1600 Hz and power by external power supply of 10 V dc. The output from the signal conditioner was acquired to a personal computer using National Instruments® PCI 6036E 16 bit data acquisition card in NRSE mode. The data (2^{16}) were acquired at a rate of 3200 samples per second in continuous acquisition mode for 10.24 second using an acquisition code in Lab VIEW 8.2.1® at varying air flow rate of 50-100 Lpm at a pressure of 4.14 bar with corresponding flow Reynolds number of 4095-8189 based on inlet pipe diameter. The chamber pressure is directly measured by a calibrated digital pressure transmitter (pressure range 0.0 to 20.0 bar and the full scale accuracy ± 0.5%) just before the exit valve.

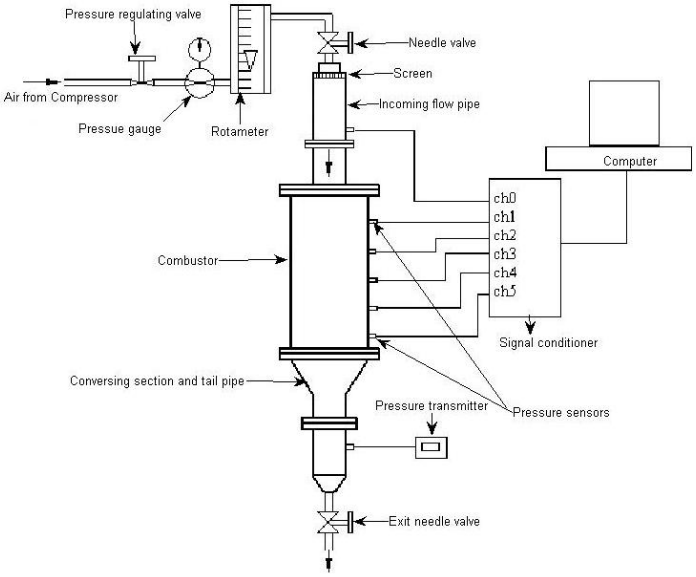


Figure 2a. Schematic of experimental setup for pressure measurement

The velocity measurement inside the combustor was carried out by calibrated (maximum calibration error =0.4% and standard deviation =1.4%) one-dimensional hot wire probes (Miniature wire-55P11, Dantec Dynamics®) for the same flow conditions mentioned above. The schematic of the experimental setup used for velocity measurement is shown in the Fig. 2b. One probe was located at the inlet pipe and second one was used to measure the velocity at different axial (x/h = 1.575-5.925, Δx/h=1.087) and radial (r/R=0.0 to ± 1.0, Δr/R=0.08) locations inside the combustor. These hot wire probes were connected to the Dantec Dynamic's® multichannel CTA-54N81 system. The hot wire output signal was acquired to a personal computer using National Instruments® PCI 6036E 16 bit data acquisition card in RSE mode. The data (2^{17}) were acquired at a rate of 25000 samples per second in continuous acquisition mode for 5.24 second using an acquisition code in Lab VIEW 8.2.1®. The data were analyzed using a MATLAB® 7.0.1.

The hotwire probe was oriented perpendicular to the combustor axis and was inserted radialy into the combustor as shown in Fig. 2c. The velocity (U) measured by the hot wire is the resultant of u_x and u_r as shown in Fig. 2c. Since this hotwire uses a single probe and works on convective heat transfer mode, the total heat loss is equivalent to the heat loss by the effective velocity [28]. As the measured velocities are resultant velocities, the turbulent stresses could not estimated by this method.

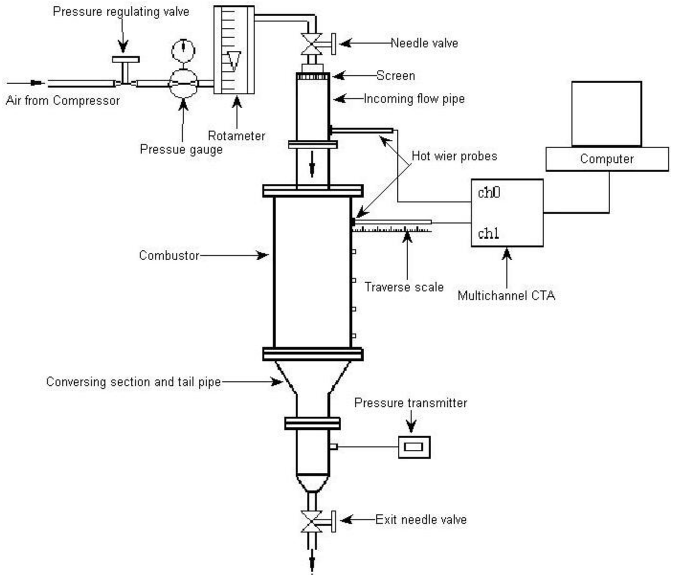


Figure 2b. Schematic of experimental setup for velocity measurement

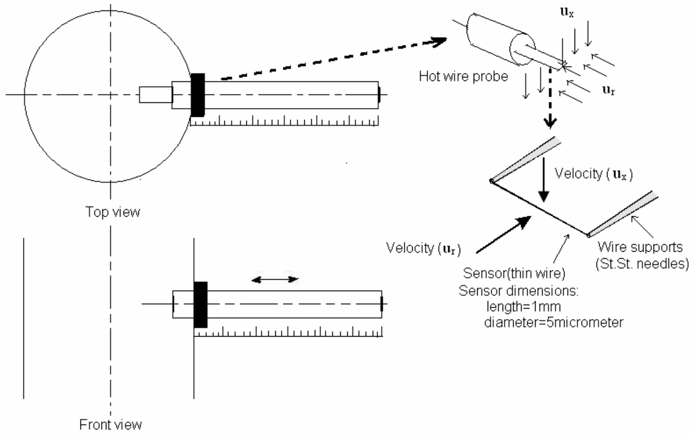


Figure 2c. Schematic for velocity measurement by hotwire probe [28]

The uncertainty analysis associated with the experimental measurement employed the method of Moffat [29]. By assuming those errors are independent of each other, the overall error in pressure and velocity measurement are less than 2% and 2.3% respectively, calculated by the root sum square method [29-30].

The turbulence parameters were estimated at a point using following equations [31]:

$$U = \overline{U} + u' \qquad (1)$$

$$u'_{rms} = \sqrt{\overline{u'^2}} \qquad (2)$$

Turbulence intensity

$$I = \frac{u'_{rms}}{\overline{U}} \qquad (3)$$

RESULT AND DISCUSSIONS

The mean pressure (Pw) inside the combustor is non-dimensionalzed by the inlet pressure in the pipe (Pin). The variation of the mean and rms pressure inside the combustor at different axial locations with Re are given in Fig. 3a and Fig. 3b respectively. The mean pressure inside the combustor is increased in axial direction from x/h=1.575 to 4.837 shown in Fig. 3a. Beyond x/h=4.837, pressure variation is smaller for Re=4095 to 5733 while for Re=7370 to 8189 pressure is decreased with Re. This was happened due to fully developed boundary layer and formation of smaller eddies by the flow reversal from the taper exit. The change of slope of pressure variation from x/h=2.66 to 4.83 are higher due to uniform velocity distribution [11]. The pressure fluctuation is increased

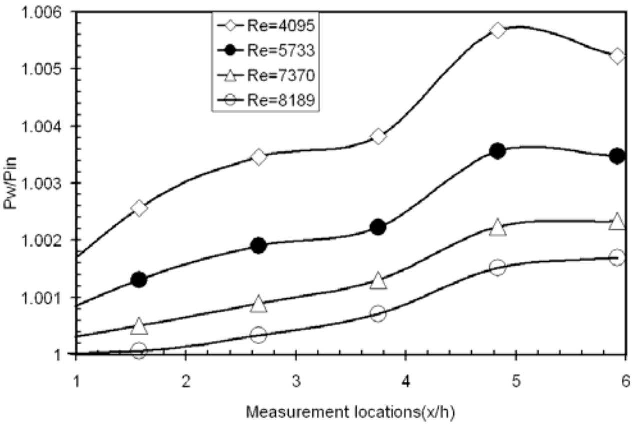


Figure 3a. Variation of mean pressure inside the combustor in axial direction (x/h) with Re

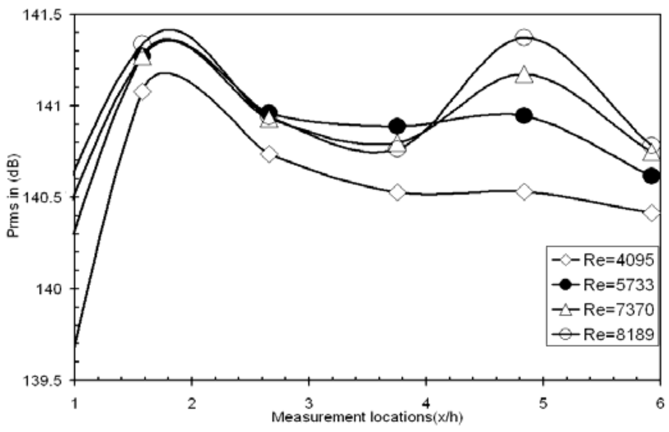


Figure 3b. Variation of rms pressure of the combustor in axial direction (x/h) with Re

from inlet pipe to inside the combustor upto x/h=1.575 and it decreased upto x/h=3.57 as shown in the Fig. 3b. Further pressure fluctuation is increased with axial location (x/h) and beyond x/h=4.837 sudden decreased. The pressure fluctuation inside the combustor followed the same pattern with Re. At high Re from 5733 to 8189 the variation in the pressure fluctuation is very small at all location except x/h=4.837. This was happened due to reversal of the flow from the taper exit of the combustor and development of the flow boundary layer [10-12].

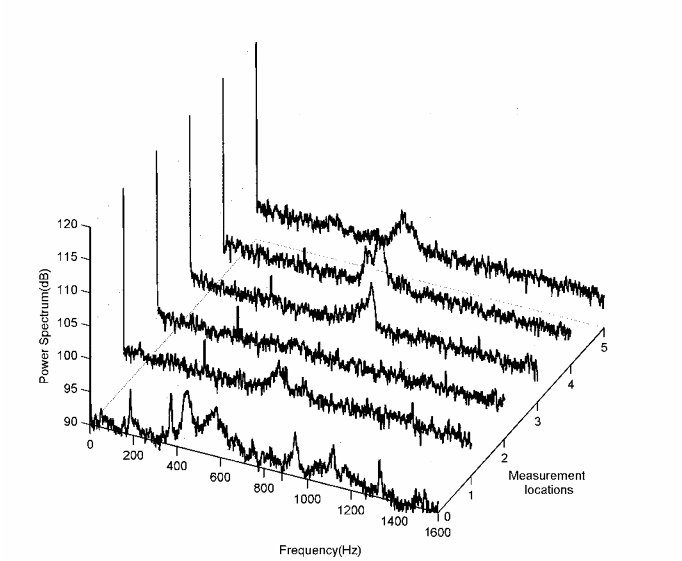
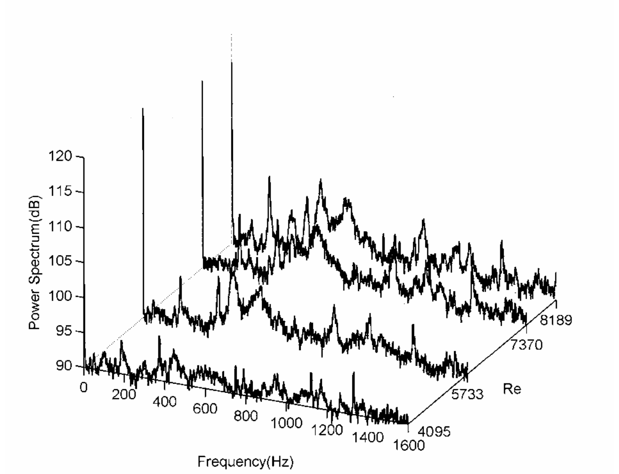
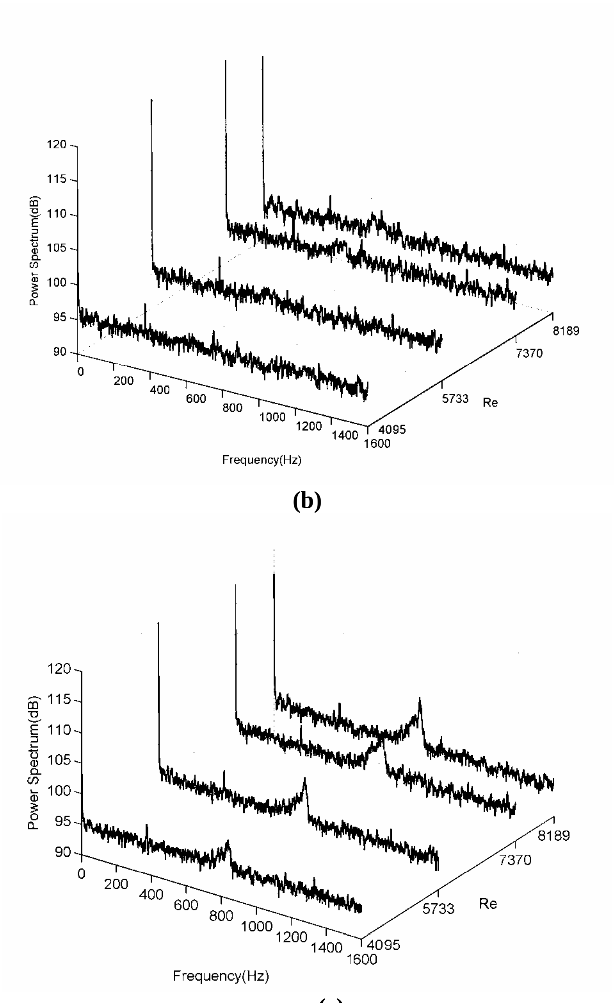


Figure 4. Variation of power spectrum with frequency for different measurement locations at Re=5733

The variation of the power spectrum with frequency at different measurement locations inlet pipe and inside the combustors are given in the Fig. 4. The frequencies 186, 374, 451, 584, 749, 945, 1120, 1332 Hz peaks are visible in the inlet pipe (location ch0). All the frequencies are the harmonic modes of frequency 186 except 451 Hz. The dominant peaks 451 Hz are exit due to turbulence behaviour in the pipe. The acoustic frequencies 374, 1120, 1332 are also observed at all locations (x/h=1.575 to 5.925). The frequency 77 and 717 Hz are present inside the combustor at location x/h=1.575. This low frequency existence occurred due to the recirculation at the dump plane while high frequency is caused due to turbulence inside the combustor. At location x/h=2.66, frequency 750 Hz is observed which was also a harmonic mode of the frequency 186 Hz that was observed in the inlet pipe. The dominant frequency 374 Hz at this location is also a harmonic of the 186 Hz. The dominant frequency 835 Hz at axial location x/h=3.75 are observed due to turbulence behaviour. This behaviour developed due to formation of the coherent structures (recirculation) by the collision of the small eddies. Because the axial location x/h=4.837 and 5.925 also shows the dominant frequency 716 and 684 Hz respectively and these are not the harmonic mode of 186 Hz. The change in the magnitude of the frequency occurred due to flow reversal from the taper exit of the combustor. The acoustic behavior was found at location x/h=2.66 due to transition zone between the dump plane recirculation and secondary recirculation at location x/h=3.75 reported by Yadav and Kushari [32]



(a)



(b)

(c)

Figure 5. Variation of power spectrum with frequency for different Re at measurement locations (a) inlet of the combustor (b) x/h=2.66 (c) x/h=3.75

The power spectrum variation with frequency in the inlet pipe for different Re is given in the Fig. 5a. The frequency peaks in the Fig. 4 at the inlet pipe are also seen in Fig. 5a as Re increased from 4095 to 8189, while the magnitude of the power spectrum of these frequency peaks are increased with Re. Figure 5b. shows the frequency spectrum at location x/h=2.66 for different Re. The acoustic frequencies are leading at this location but due to high Re the frequency peaks 658 Hz are clearly visible at Re=8189 and it was the second highest peak at this location hence due to high Re the fluid dynamic behaviour and strong flow reversal dominant the acoustic nature. This was showing the presence of strong recirculation inside the combustor. The effect of Re on the frequency spectrum at location x/h=3.75 are given in the Fig. 5c. The same frequency peaks are observed as discussed in the Fig. 4. But due to increase in the Re from 4095 to 8189 the power spectrum of harmonic mode frequency peaks are decreased while the frequency peak 835 Hz is increased up to 3dB. Therefore the increased the fluid dynamic effect at location x/h=2.66 and increased in the frequency peaks at location x/h=3.75 are caused by strong recirculation due to flow reversal from the taper exit of the combustor.

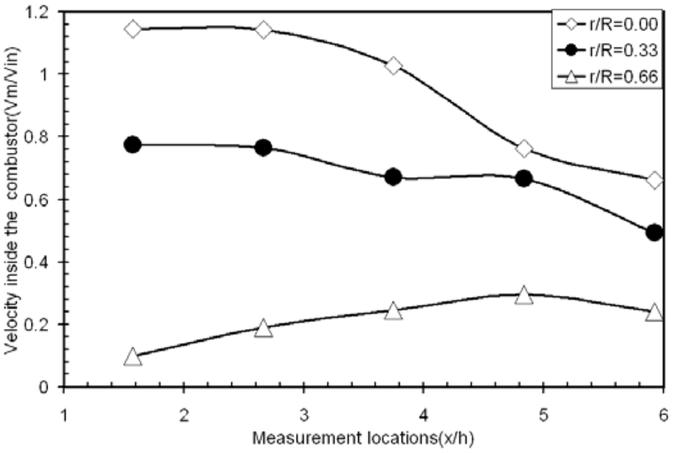


Figure 6. Mean velocity inside the combustor in axial direction (x/h) for different radial location (r/R=0.00-0.66) at Re=5733

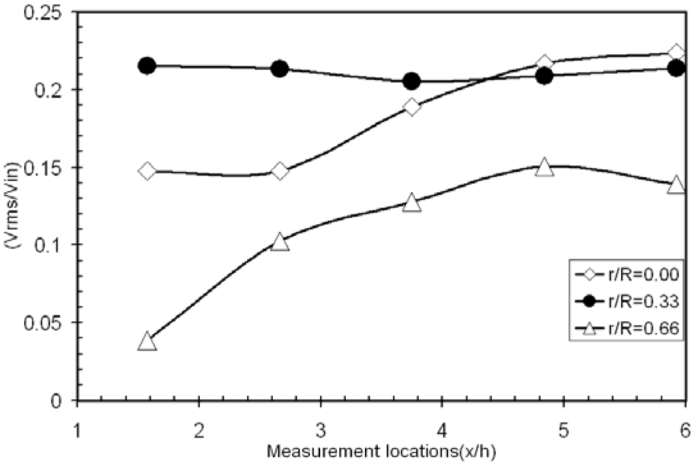


Figure 7a. Variation of rms velocity inside the combustor in axial direction (x/h) for different radial location (r/R=0.00-0.66) at Re=5733

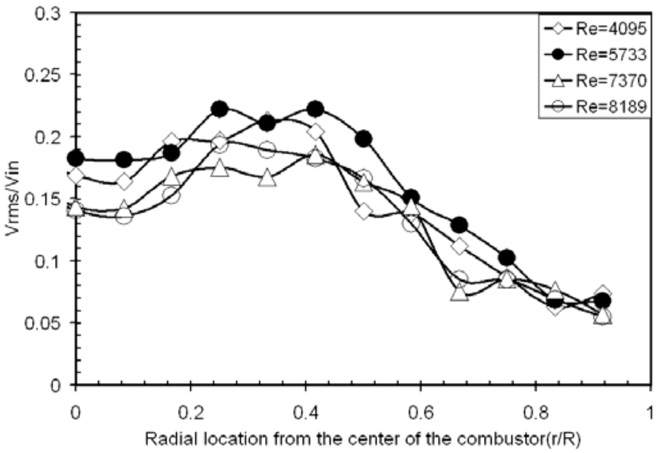


Figure 7b. Variation of rms velocity inside the combustor in radial direction (r/R) with Re at axial direction (x/h=3.75)

The velocity measurement studies are done for the same inlet condition as discussed in the pressure measurement studies. The mean and rms velocity along different axial locations (x/h=1.575 to 5.925) at constant radial locations (r/R=0.00 to 0.66) and Re=5733 are non-dimensionalized by the inlet velocity of the combustor. The mean velocity at the center of the combustor (r/R=0.00) is decreased along the axis of the combustor shown in Fig. 6. The mean velocity variation upto x/h=2.66 is approximately constant because of presence of strong potential core. Beyond x/h=2.66, slope of velocity variation along axial location decreased due to development of the boundary layer in presence of recirculation. The variation of the velocity from x/h=4.837 to 5.925 are small due to flow reversal from the taper exit of the combustor. The velocity at radial location r/R=0.33 is followed same patterned as discussed at r/R=0.00. The velocity at location x/h=4.837 is higher than the location x/h=3.75. This is occurred due to presence of recirculation. The velocity variation near the surface of the combustor (r/R=0.66) was showing the opposite behaviour upto x/h=4.837 than the radial locations (r/R=0.00, 0.33). This was happened due to presence of recirculation and high separation of shear layer and deceased in the strength of the potential core. Beyond x/h=4.837 velocity is decreased at all radial locations due to flow reversal from the taper exit of the combustor. The rms velocity at the center of the combustor varied in axial direction is given in the Fig. 7a. The fluctuation level is approximately constant upto x/h=2.662 at r/R=0.00 due to potential flow in the center of the combustor. Beyond x/h=2.662 rms velocity is increased due to fast decay in the potential flow and separation of the flow due to taper exit of the combustor and development of the boundary layer. The variation of the rms velocity was small in axial direction at r/R=0.33 while it was higher than the rms velocity at r/R=0.0, 0.66. This was happened due to the presence of recirculating flow. The rms velocity beyond x/h=3.75 is lower than the r/R=0.00. This was happened due to reversal of the flow from the exit of the combustor. The rms velocity at r/R=0.66 is lower than r/R=0.0, 0.33 but the variation in the velocity is high. The rms velocity is increased upto x/h= 4.837 and beyond it decreased. The rms velocity variation in radial direction from r/R=0.0 to 0.916 for different Re (4095 to 5733) at axial location x/h=3.75 shown in Fig. 7b. The rms velocity was high between r/R=0.2 to 0.6 because of high turbulence due to presence of recirculation by the collision of smaller eddies. At high flow Reynolds number rms value of velocity decreased but the difference in the lower and higher limit of the rms velocity is also deceased. This is happened due to strong effect of flow reversal from the tapper exit by increased in the Re. Therefore the pressure and velocity measurement studies support that the presence of the strong recirculation and high turbulence. These are presence due to higher reattachment length and tapper exit of the combustor. The effect of turbulence on the turbulence intensity along the radial direction at axial location x/h=3.75 is shown in Fig. 8. The low turbulence level less than 20% with small variation is observed from r/R=0.0 to 0.2 because potential core approached upto x/h=3.75.The turbulence intensity increased upto 54% for r/R=0.2 to 0.6. In this region high turbulence intensity occurred due to presence of shear layer.

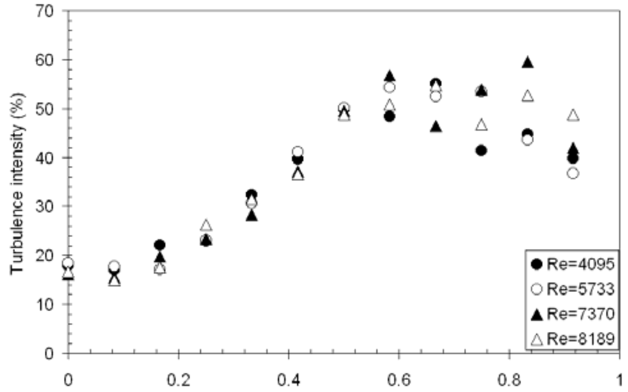
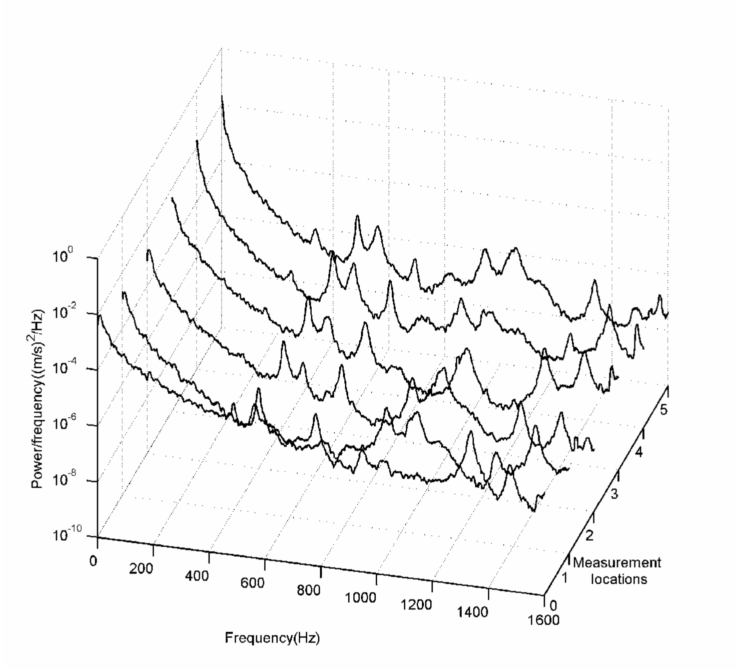
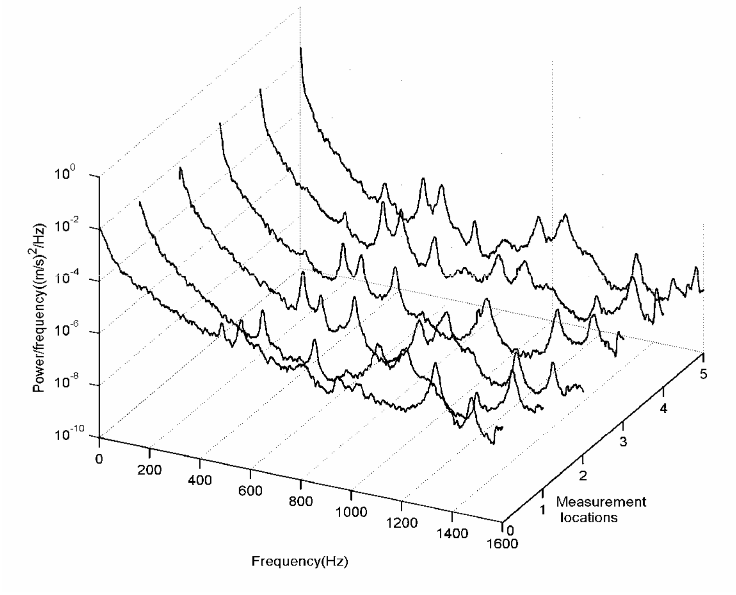


Figure 8. Radial variation of turbulence intensity at x/h=3.75

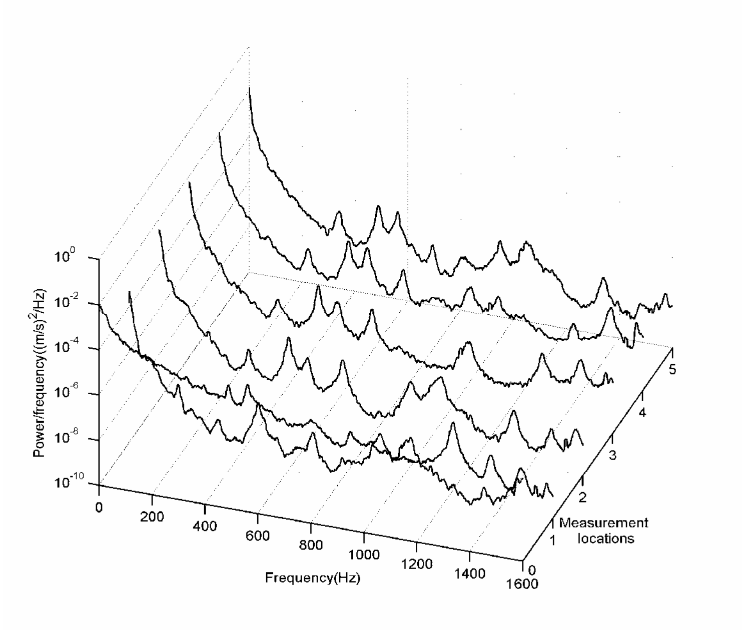
The power spectrum at different axial locations at Re=5733 for radial locations (r/R=0.00, 0.33 and 0.66) is given in the Fig. 9. The frequency peaks 192, 409, 569, 1342



(a)



(b)

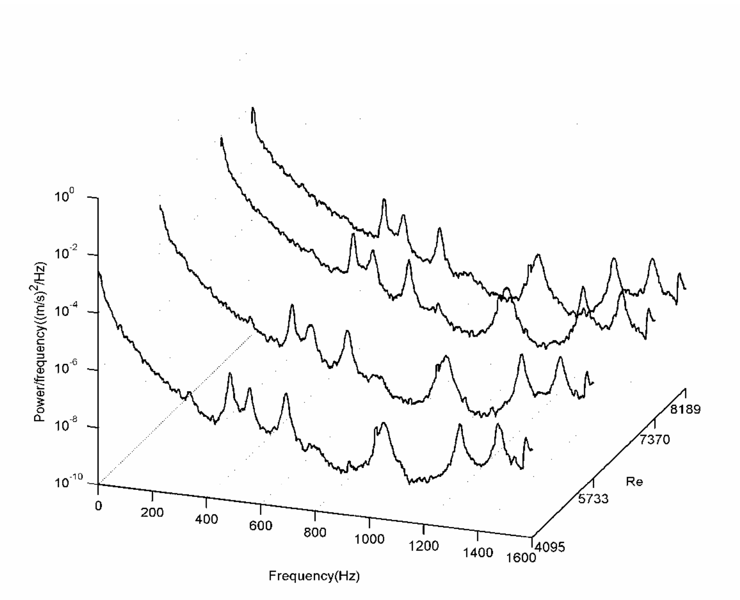


(c)

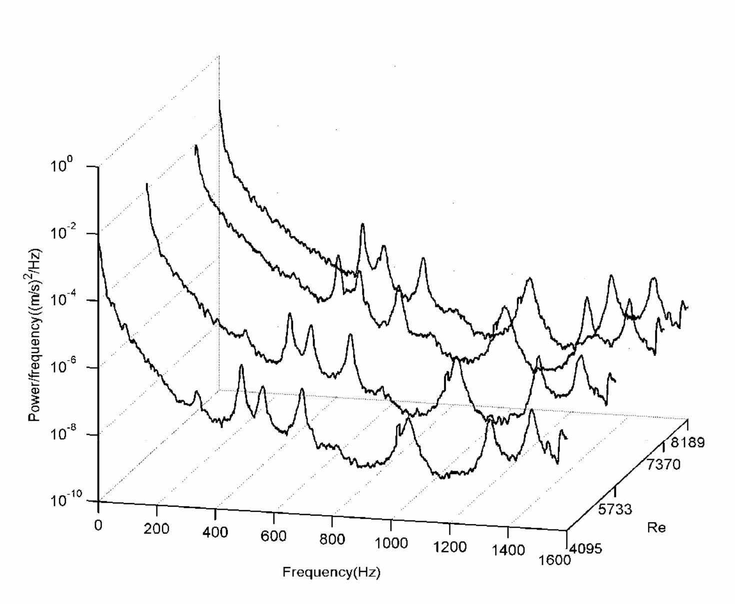
Figure 9. Variation of power spectrum with frequency for different measurement locations (inlet pipe and inside the combustor at Re=5733 for (a) r/R=0.0 (b) r/R=0.33 (c) r/R=0.66

and 1484 Hz are visible in the inlet pipe (location ch0) given in the Fig. 9a. The frequency peaks 1342 Hz dominant peaks in the inlet pipe. The frequency peaks 494, 569, 1342 and 1484 Hz are also visibled at axial locations (x/h=1.575 to 5.925) inside the combustor while 343, 698, 950 and 1056 Hz are not visibled in the inlet pipe. At axial location x/h=3.75 frequency 950 Hz are not observed. The power spectrum at radial location r/R=0.33 shown in Fig. 9b followed similar pattern as discussed in Fig. 9a. The frequency variation with power spectrum at different axial locations for Re=5733 and r/R=0.66 are given in Fig. 9c. The frequency peaks at locations are found similar as discussed in Figs. 9a and 9b. But lower frequency 200 Hz found at location x/h=1.575. The frequency 565 Hz is not present at this location. Therefore the power spectrum level of the lower frequency is increased by variation of radial location from r/R=0.00 to 0.66. The frequency peaks are shifted by ± 5Hz due to variation in axial and radial locations.

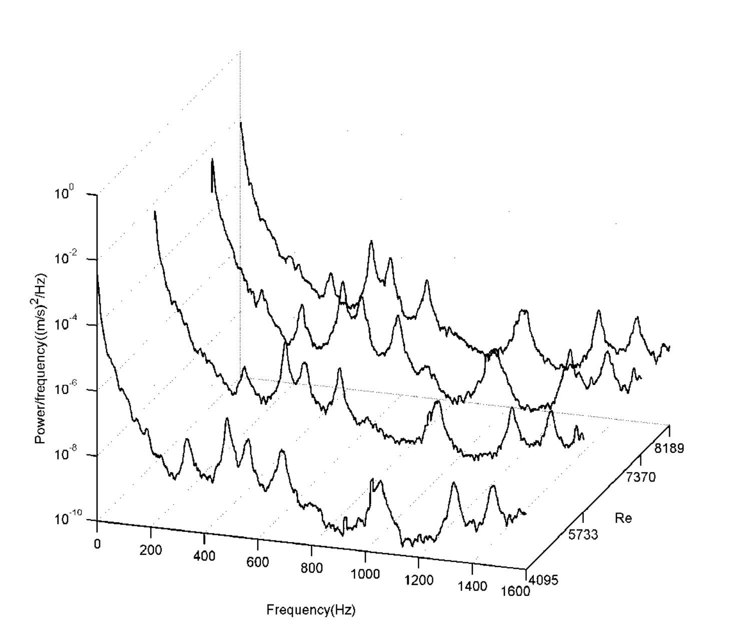
The power spectrum of the velocity for different Re and radial locations (r/R=0.00, 0.33 and 0.66) at axial location x/h=3.75 are given in the Fig. 10. The frequency peaks 493 Hz is the dominant frequency at r/R=0.0. The magnitude of the high frequency is increased by increased the Re from 4095 to 8189 while the frequency 343 Hz is not visibled at high Re as shown in Fig. 10a. The effect of Re at radial location r/R=0.33 also increased the magnitude of the frequency. The low frequency peak is affected by Re (greater than 5733) as in Fig. 10b. The similar effect of the Re was found at radial location r/R=0.66 but frequency 343 Hz magnitude is also increased with Re given in the Fig. 10c



(a)



(b)



(c)

Figure 10. Variation of power spectrum with frequency for different Re at measurement location x/h=3.75 for (a) r/R=0.0 (b) r/R=0.33 (c) r/R=0.66

The source of the frequency peaks that was observed during velocity and pressure measurements are estimated theoretical by calculating the acoustics frequencies inside the combustor and inlet pipe. The frequency peaks 186, 340, 567 Hz are the longitudinal acoustics mode while 709 and 1062 are the first transient acoustics mode frequencies. Therefore, the frequency peaks 185, 340, 564, 700, 1060 Hz in velocity measurement study were present inside the combustor or inlet pipe due to acoustic behaviour of the combustor. In the pressure measurement study 187, 372, 579, 715, 1120, 1123 Hz are also acoustic frequencies. The small differences in these frequencies were observed compared to the velocity measurement because the pressure measurements were done at surface of the combustor. Therefore the velocity and pressure measurement studies support the similar behaviour.

CONCLUSIONS

The study of the cold flow perturbation inside a low aspect ratio tapered exit dump combustor was done by pressure and velocity measurements inside the combustor. These studies shown that the mean pressure inside the combustor decreased with increased in flow Reynolds number while the pressure fluctuations at x/h=4.837 increased due to strong flow reversal from taper exit of the combustor. The low turbulence intensity was observed in the potential core. In the shear layer region high turbulence intensity was seen. Furthermore, the taper exit of the combustor strengthened the recirculation and increased the number of strong eddies inside the combustor. The power spectral studies of pressure and velocity fluctuations measurement did also support the presence of recirculation and effect of flow reversal on fluid dynamic behaviour of the combustor. The acoustic behaviour is also seen inside the combustor. The same dominant frequency peaks were observed in both the measurements. Therefore, the pressure measurement studies support the velocity measurement.

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