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COLD FLOW ANALYSIS OF DUMP ROCKET COMBUSTION CHAMBER

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ABSTRACT

The cold flow simulation has been conducted to evaluate the frequencies and amplitudes of pressure oscillations in solid rocket motor cavity. Axisymmetric model of solid rocket combustor has been modelled and simulated using Fluent. The numerical simulations performed for laminar and turbulent calculation to observe the oscillation frequency and amplitude in combustor. The results for oscillation amplitude have been compared for laminar and turbulent flow and it was observed that a vortex produced from the shear layer has large amplitude with varying the flow rate of working cold fluid. It has been found that the vortex shedding frequency is more oscillating at initial stage and then the oscillation gradually dies out.

Key words: Combustion instability, cold flow, vortex shedding, combustion.

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1. INTRODUCTION

One of them was the exploration of space with a viable mode of transportation technologies, subsequently generalized in name of ‘Space Propulsion Technology’. With time, these devices were developed, tried and mobilized with specific goal and assignment [1]. It is worthy to take notice of the development of chemical propulsion systems that have established themselves as the most superior mode of space propulsion taking into consideration the rate of success till date. The simplistic design and significant level of storable energy for propulsion requirements have attracted the attention of space designers to accommodate the solid rocket propulsion system into every area of rocket based transportation like space missions, missile technology etc. [1]. A solid rocket motor consists of the following elements: the solid propellant, called grain, a case, thermal protections, a nozzle, and an igniter. The PTF rings are, in the authors’ opinion, the most important source of vortex shedding in the Ariane 5 P230 booster rocket [2]. The interaction between aerodynamics and acoustics that is at the heart of self-sustained pressure oscillations in the SRM combustion chamber is essentially a feedback loop. When the vortex shedding frequency is close to the natural frequency of the chamber, pressure oscillations grow and reach a maximum.

The common use of Aluminium has alleviated the instability problems somewhat, because Aluminium tends to suppress some types of combustion instability. Experimental aspects of combustion instabilities are classified under acoustic and non-acoustic instabilities, and linear and nonlinear instabilities. Irregular burning produced by a mechanism involving sound vibration is termed as acoustic instability [3]. On other hand, any occurrence of irregular burning that does not involve interaction between combustion process and a sound field essentially, can be termed as non-acoustic instability. Low frequency or chugging occurs in frequency range between 10 to 400 Hz. Instability may occur in either acoustic or non-acoustic modes. Low frequency is more prevalent at low pressure and is often confined to a narrow frequency range. Screaming occurs in the frequency range above 1000 Hz [4, 5].

Only a few theoretical concepts exist concerning possible mechanisms for nonlinear or non-acoustic instabilities. Fuel and oxidiser mixtures will generally combust if reaction is fast enough to prevail until all the mixture is burned into by products [6].

Combustion of solid rocket propellants can occur in two regimes, which are characterized by widely different propagation velocities for the flame i.e. deflagration and detonation. Velocity of burned gases is the one of the important parameters which influences the combustion instability. Velocity of the burned gases refers to the erosive burning and it increases the propellant burning rate [1]. The high velocity near the burning surface and turbulent mixing in the boundary layer have been found to increase the heat transfer to the solid propellant and thus increase the burning rate. Erosive burning increases the mass flow and thus also chamber pressure and thrust during the early portion of the burning. The effect of environmental variables such as pressure on the burning rate of a propellant is a matter of primary concern in selecting the propellant for specific application. Pressure oscillations are a well-known problem of large SRM. Interaction between aerodynamics and acoustics that cause self-sustained pressure oscillation in SRM is a feedback loop. Using a composite propellant with constant energy content, but with varying oxidizer particle size distribution, indicates a tendency towards irregular or oscillatory combustion. Irregular reaction increases as the particle size becomes finer and the burning rate increases. Experimental results show that the transverse modes are likely to occur with propellant grain having more complicated symmetries such as star perforation.

Star perforations with 5 to 7 points are more stable than perforations having 4 to 6 points. During combustion the material undergoes an exothermic chemical reaction associated with heat loss by conduction through the material to its boundary. Also, it occurs if the energy liberated during the reaction is greater than that lost through the surfaces. The violence of high frequency of instability is in many cases due to shape of the convergent part of the nozzle [7]. The pressure wave propagated in the chamber are not absorbed by the nozzle but reflected in their entirely by the convergent. Generally, acoustic boundary layers develop above a burning propellant. These layers are responsible for the so-called burning losses and govern the local unsteady flow condition. It is essential to understand such acoustics boundary layers for improvement of solid rocket stability. Their analysis was based on mean flow field in 2-D rocket chamber and they transformed all results using FFT for comparison with available experimental acoustics data [8, 9].

In the present paper, the computational study was performed to explore the combustion instability in dump combustor configuration. The Inlet condition was considered with a cold flow condition of 700 to 1000 lpm. The vortex shedding instability was recorded in fluent.

2. MATERIAL AND METHODS

Computational fluid dynamic is being used as an important tool for design and development, not only for steady predictions but also for predictions of unsteady phenomena such as pressure fluctuations, study of oscillation behaviour and transient combustion phenomena in solid rocket engines. Improvement in the accuracy and versatility of devices to measure the response function are used for studying the complexity of the phenomena and greatly reduced cost per test. It also has to systematic evaluation of effect of propellant variable. Combustion of reaction in a confined volume has been accompanied by development of significant pressure oscillations. This oscillations, if appeared to unsteady heat release are usually called as combustion instability. In combustion system, for instance, ramjet engine, afterburner, and solid rocket motor, where vortex shedding has been taken place, combustion instabilities are common problem.

It became possible to incorporate combustion and chamber acoustic into computational fluid dynamics (CFD) codes, and to generate the computational model of combustion vortex acoustic interaction by the available computational software. The nozzle inlet plane was not choked, thus allowing acoustic open –open boundary conditions for the rocket motor scale model. The nozzle inlet plane was choked, resulting in an acoustic open-closed boundary condition. The model used in the current study is shown in Fig.1 and the dimension of the model is represented in Table 1. The Boundary conditions considered as shown in Fig1 are Velocity inlet, casing of chamber as wall and outlet as flow outlet at exit.

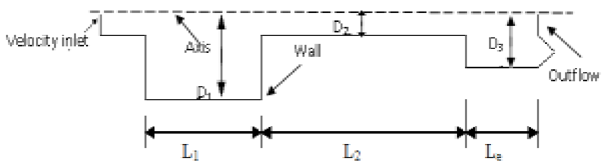


Figure 1 Computational model of SRM cavity

Table 1 Dimension for model geometry in X-Y direction

Pre-combustor Step Dimensions		Combustor Dimensions		Post combustor step Dimensions	
L1 in mm	D1 in mm	L2 in mm	D2 in mm	Le in mm	D3 in mm
150	95	400	15	50	25

A cold flow such as air has been considered as working for the present investigation and observation are carried out under ambient condition (300K) of air. Two different computational analyses such as laminar and turbulent analysis have been selected for present case. The model with two different numbers of cells (50000, 700000) has been considered for present observation. The $k-\varepsilon$ model with turbulent intensity of turbulence based on the empirical relationship { $I = 0.16(\mathrm{Re}_D)^{-0.125}$ } have been considered.

3. RESULTS AND DISCUSSIONS

3.1. Laminar Flow Calculation

The outcomes from laminar stream figuring for low stream rates have been exhibited at first taken after by tempestuous computation for higher stream rates. The laminar count has been considered for the stream rates of 700 and 1000 lpm in light of the fact that the speeds saw in the district of intrigue are very low. Likewise the vortex detailing, development, and shedding has been disseminated if disturbance display considered. The laminar estimation for 700 lpm stream rates have been completed more than 50000 cells on previously mentioned show. The shape of vorticity extent, and stream capacity and recurrence bend for the stream rate 700 lpm at downstream length 50 mm with 50000 cells have been seen. Correspondingly, the laminar figuring with 1000 lpm for 50000 cells with 50 mm downstream length has been completed and countor of vorticity and stream capacity and recurrence observed because of the weight variety. The vortex shedding recurrence came about because of calculation. The uncommon intrigue has been taken to decide the recurrence of vortex shedding at the area of intrigue acquired by various volume stream rate.

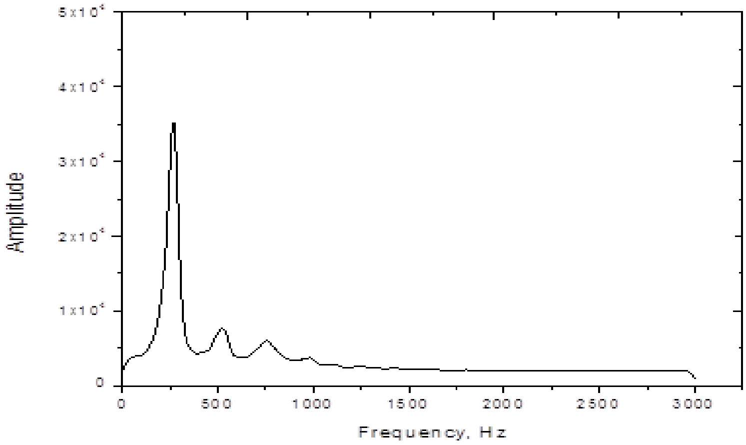


Figure 2 fast Fourier transform (FFT) plot for laminar flow at 700 lpm flow rate

A stream is one where the impact of thickness, warm conduction and mass dissemination are essential. Mass dispersion is critical in a gas with angles in its concoction species. Warm conductivity is critical where it is connected with the difference in the temperature. Here, in this work the mass dispersion and warm conduction are not considered. Just the stream is dealt with as gooey stream where just consistency is predominant. At the point when the liquid streams over a surface, the impact of rubbing exists between the surface and liquid contiguous surface. No-slip condition i.e. speed at the surface zero dominants thick stream. Stream over the surface creates an expanding weight appropriation in the stream course. Such a district of expanding weight is known as the unfavorable weight slope and takes after the liquid component as it moves downstream. The flimsy weight information is gathered at a few checking focuses in the computational area. Fast Fourier Transform of these weight time information has been performed to extricate the prevailing frequencies of the swaying. Power spectra comparing to a similar geometry have, for the stream rates 700lpm and 1000lpm these demonstrates a very much characterized predominant pinnacle

In this present work fierce counts have been done utilizing the 'feasible ' show. Since determination of legitimate network is critical for getting sensibly great answer for any issue, the outcomes may changes with various matrices. Right off the bat, locale based adaption has been done to catch the vortices precisely. Besides, refinement close to all the no-slip surfaces for accomplishing divider Y in addition to values under 30 to determine the limit layers.

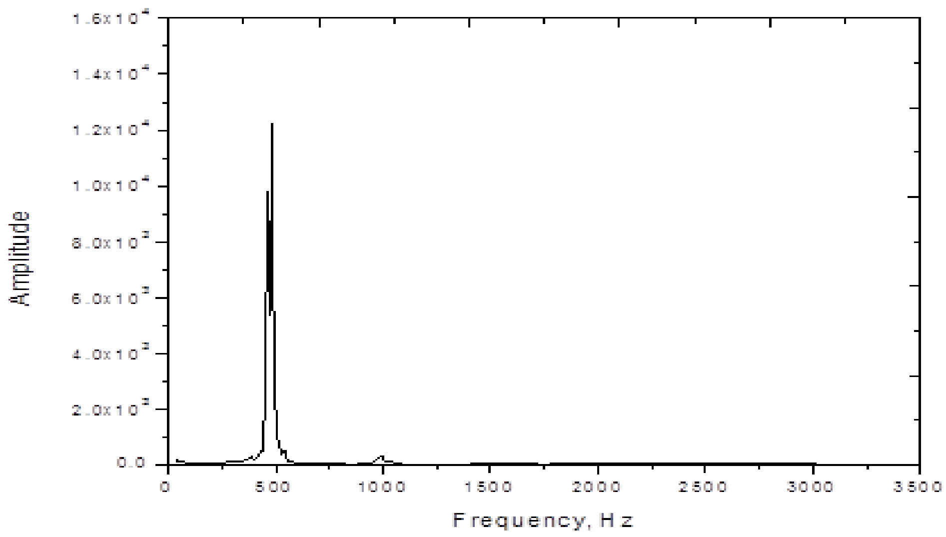


Figure 2 Turbulent Flow Calculation

The calculations have been completed for different stream rates from 1600 lpm to 1900 lpm. Like the laminar calculations, the Fast Fourier change of flimsy weight information have been watched. The unique intrigue has been taken to decide the recurrence of vortex shedding at the locale of intrigue acquired by various volume stream rate. Every one of the outcomes acquired by violent estimation are dissected.

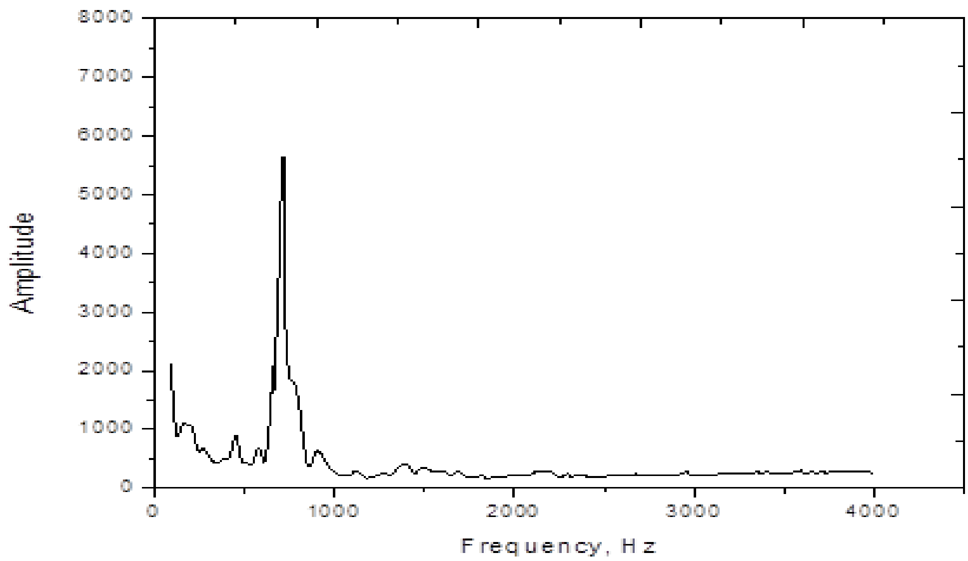


Figure 3 Fast Fourier transform (FFT) plot for turbulent flow at 1700 lpm flow rate

Correspondingly, utilizing 50000 cells and 70000 cells, and volume stream rate of 1800 lpm, the got result have been appeared in Fig 3. Again embracing similar cells esteem and changing the volume stream rate into 1900 lpm the outcomes have been appeared. The outcomes have been investigated in premise of the weight proportion versus time and recurrence versus abundancy diagram. It has been seen from the weight versus time diagram that variance is more with coarse framework contrast with the fine lattice and the quantity of noticeable matrix is more in coarse network than the fine frameworks.

The investigation is completed with unfaltering stream and solver is weight based. The thick model is chosen as k-epsilon with two conditions. The Reynolds number of the stream is around 105. In this way, the stream is tempestuous and the high-Re k-epsilon display is reasonable. The species is considered as non-premixed burning model.

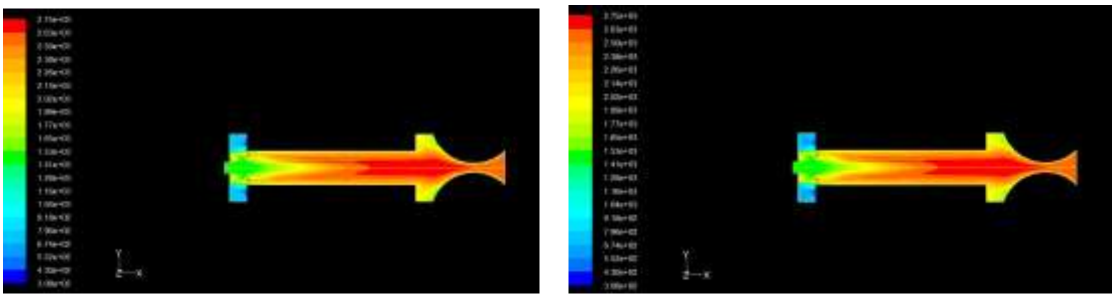
The radiation of the model is expected as P1 radiation on the grounds that the P-1 show is one of the radiation models that can represent the trading of radiation amongst gas and particulates. The material is chosen as liquid for PDF blend which is combusting molecule for nonstop stage and the divider is considered as strong which is considered as Aluminum. The PDF blend is taken as ethylene-Oxygen (C2H4-O2) blend. The outcome is figured from the speed channel with the speed of 50 m/s. also, the temperature for the channel is 1500 K. The divider is allocated as steadfast. The heater divider will be dealt with as an isothermal limit with a temperature of 1200 K. The outlet is doled out as outpouring and the temperature of the outlet is 2000 K. The arrangement is instated from the speed gulf. The kinematic vitality K=0.0001 m2s2 and the dispersal epsilon=1000 m2s3.

In this model the gulf speed is given as 50 m/s. The divider has a consistent temperature of 1200 K the gulf temperature is accepted as 1500 K and the outlet temperature is 2000 K. The Reynolds number in view of the gulf measurement and the normal bay speed is around 100,000. In this manner, the stream is violent. Just 50% of the space width is demonstrated in view of symmetry. At first the relentless stream is considered. The non-adiabatic framework is considered.

The mean temperature accomplishes a pinnacle estimation of 2750 K at MMF of 0.05 and abatements step by step and achieves the 500 K stamp at the MMF of significant worth 1. the mean thickness increments bit by bit with the expansion of MMF. The mean thickness winds up 1.6 at the MMF of 1.

CO2 is framed after ignition and winds up most extreme of 0.201 after the consuming of all the fuel and oxygen and is spoken to in the shapes. In the figure 6.19, the temperature at the channel is given as 1500 K and the divider temperature is 1200 K and after the burning, the temperature achieves the most noteworthy pinnacle estimation of 2750 K in the ignition zone and at the spout leave the temperature is 2630 K. In the figure 6.20, the temperature at the gulf is given as 1500 K and the divider temperature is 1200 K and after the ignition, the temperature achieves the most noteworthy pinnacle estimation of 2750 K in the burning territory and at the spout leave the temperature is 2630 K as appeared in Fig.4.

In the accompanying figures the temperature variety is same up to 140 m/s yet the variety happens in the 170 m/s in light of the fact that at high speed, the burning has the danger of smothered which can diminish the temperature. the high temperature is accomplished at leave region and the retrogressive confronting step. The pinnacle temperature is 2760 K. The variety of temperature in the symmetrical area for the speed of 50 m/s. The pinnacle estimation of temperature is 2750K.



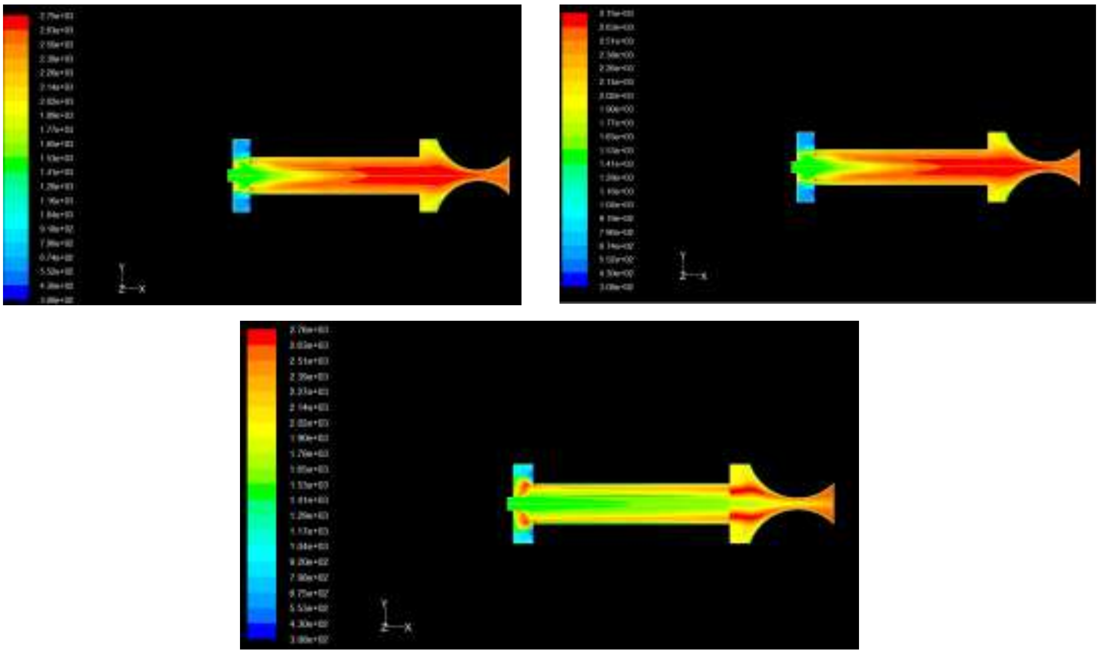


Figure 4 Contours of static temperature for 50,80,110,140 and 170m/s

The XY plots denoting the pressure variations of 50 m/s and 80 m/s is plotted in the same graph and is compared. The pressure variation is very high while using the solid rocket motor. This instability plays some major roles in the structural damages of the combustion chamber. They can be identified using the CFD and can be verified instead of using experimental setup which is time and economy consumable.

4. SUMMARY

The burning precariousness is excessively unpredictable and differing, making it impossible to got thorough quantitative forecast ability inside sensible assets. So in the present examination, an exertion has been made to break down the stream conduct through numerical reproduction and explore the vortex shedding recurrence wavering. Numerical reenactments of insecure, non-responding stream in a scale model of strong rocket engine have been done utilizing familiar. The laminar count have been completed for low stream rates (700-1000lpm) and tempestuous estimation utilizing feasible model, have been performed for stream rates at 1700 to 1900 lpm. It has been discovered that the vortex shedding recurrence is all the more wavering at beginning stage and afterward the swaying bit by bit ceases to exist. Vortex shedding recurrence has been observed to be subject to the stream rate.

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