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Cavitation in Engine Cooling Fluid due to Piston-Cylinder Assembly Forces

Anthony Deku

Subramanya Kompella

Department of Mechanical Engineering
Blekinge Institute of Technology
Karlskrona, Sweden

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Supervisor: Ansel Berghuvud, Ph.D. Mech. Eng.

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DEKU ANTHONY
SUBRAMANYA KOMPELLA

Department of Mechanical Engineering
Blekinge Institute of Technology
Karlskrona, Sweden
2006

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Abstract:

The problem of possible pitting and cavitation in internal combustion engines is receiving considerable attention. Both theoretical and simulation simulation studies are carried out in order to understand the noise and vibration sources, using a force equation. For this work, the main aim is to actually study these vibrations and try to model it. A foundation is also laid to study cavitation and find possible ways of increasing the life of the engine components. A model to calculate pressure variation in the system is carried out using Modeling software, with the help of Finite Element Analysis and Fluid-Structure Interaction Analysis. Some important results have been shown with negative pressures leading to the fact that the developed models predict the presence of cavitation in the cylinder liner surface, stressing the importance of improving the piston and cylinder liner design.

Keywords:

Cavitation, Cooling fluid, Internal Combustion Diesel Engine, Ansys, Vibrations, Acoustics, Fluid-Structure Interaction.

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Karlskrona, November. 2006

SUBRAMANYA KOMPELLA

ANTHONY DEKU

Contents

1 Notation

1.1 List of Symbols

C	Centre of gravity of connecting rod
L	Length of the connecting rod
P	Position of the piston
R	Radius of crankshaft
F_p^{xi}	Force acting on the piston in the X-direction
F_c^{xi}	Force acting on the centre of mass of connecting Rod
F_c^{yi}	Force acting on the piston in the Y-direction
F_{cp}^{y}	Side thrust force
F_G	Force due to gravity
M_c	Centre of mass of piston
M_c	Centre of mass of connecting rod
r	Radius of gyration of connecting rod
γ	Ratio of radius of crankshaft to length of the connecting rod
ω	Angular velocity
ϕ	Angle between connecting rod and horizontal axis
$\ddot{\phi}$	Angular Acceleration
θ	Crank angle
$\dot{\theta}$	Rotational speed as
ψ_s	Dimensionless side thrust force quantity
ψ_G	Ratio of the gas force to centrifugal force
ψ_p	Ratio of the piston inertia force to centrifugal force.

ψ_c Ratio of the connecting rod inertial force to centrifugal force

1.2 Abbreviations

TDC Top dead centre

BDC Bottom dead centre

2 Introduction

Periodic loads on structures may results in severe vibratory motion. Letting the structure interact with a fluid affects the characteristics of the system behaviour. This coupled problem is of interest when designing for example cylinder liners in combustion engines. Neglecting this effect may result in unexpected occurrence of severe pitting and failure due to cavitation. This presentation explores modeling and simulation of the occurrence of cavitation on a liquid cooled cylinder liner surface.

2.1 Background

In the world today, there are more vehicles as compared to other machines. Of the two internal combustion engines, IC Diesel Engines are now replacing the more expensive petrol engines. They are mostly being used as commercial vehicles due to its fuel economy. Diesel Engines do not always have the good news, for beneath its fuel economy, comes the noise factor. They are known to generate a lot of noise as a result of piston slap. They operate at high peak pressure giving rise to greater noise and vibration.

The noise generates a lot of vibration in the cylinder chamber which causes cylinder liners to vibrate, there is also the effect of the piston slap which is the result of the piston side thrust on the cylinder liner as it moves to and fro from TDC to BDC, the net effect of which makes the cooling fluid in the cooling chamber to undergo vibration and then the production of the unwanted cavitation in the cooling chamber. The forces causing the cavities to form and collapse are due to a continuous series of high frequency pressure pulsation in the liquid.

It has been a fact that the effects of cavitation are very worrying. Some of these effects are so damaging that they can even destroy the whole cylinder liner and thus a new one needs to be purchased. Theoretical aspect of this work deals with various types of cavitation, how they affect the cylinder liner, the dynamics of the piston-crankshaft assembly, the piston slap and the vibration forces that comes with it.

2.2 Aim and Scope

The purpose of this work is to model a coupled fluid-structure interaction featuring cavitation at the interfacing domain boundary, applied on the cylinder liner and cooling liquid in an internal combustion diesel engine. Focus is put on representing the varying pressure distribution along the cylinder liner, assuming negative pressure values imply presence of cavitation.

2.3 Method

An overview is given based on a literature survey of general theory for the cavitation phenomenon, and its physics. The studied system is then described. The system is modelled using CAD software to create needed geometry, and finite element software to implement physics and carry out simulations. The coupled problem is described in a single finite element model. Both 2D and 3D models of the system are analyzed.

In the following chapters, we discuss cavitation in brief. Next we go forward with Internal Combustions Engines along with the Cooling Systems in running the engine efficiently. The next chapter would be a force analysis of the piston slap followed by the simulation aspects of the whole set up. Finally we point out at the modern developments in piston design to reduce noise and vibrations in the IC Engines and end with the conclusion that we have reached at the end of this thesis.

3 Cavitation and Sources of Cavitation

An overview of the cavitation phenomenon and its physics based on a literature survey is given here as a support to the modelling approach in the present work.

It is difficult to give a precise definition of cavitation. Cavitation is the formation and activity of bubbles or cavities in a liquid. Formation of bubbles refers to creation and change in existing cavities. These bubbles may be suspended in a liquid or may be trapped in tiny cracks either in the liquid's boundary surface or in solid particles suspended in the liquid.

The expansion of the minute bubbles may be affected by reducing the ambient pressure by static or dynamic means. The bubbles then become large enough to be visible to naked eye. These bubbles may contain a gas or vapour or a mixture of both. If these bubbles contain gas, then the expansion may be due to diffusion of dissolved gases from the liquid to the bubble, or by pressure reduction, or by temperature rise. However the bubbles chiefly contain vapour, reducing the ambient pressure sufficiently at essentially at constant temperature causes an explosive vapourization into the cavities which is the phenomenon that is called cavitation, where as rising the temperature sufficiently causes mainly the vapour bubbles to grow continuously producing boiling. This gives an interesting observation that explosive vapourization or boiling does not occur until a threshold is reached. F. Ronald Young[1].

3.1 Growth of bubble

The start of cavitation is observed with the formation of a bubble. The growth and collapse of a bubble play an important role in the determining the type of cavitation to follow. Following are the ways in which a bubble may grow.

1. For a gas filled bubble, it could be by pressure reduction or increase in temperature. This is called gaseous cavitation.
2. For vapour filled bubble, by pressure reduction. This is called vapourous cavitation.

3. For a gas filled bubble, by diffusion. This is called degassing as gas comes out the liquid.
4. For a vapour filled bubble, by sufficient temperature rise. This is called boiling.

3.2 Features of Cavitation

A critical examination of cavitation reveals the following facts.

1. Cavitation is a liquid phenomenon and does not occur in solid and gases.
2. Cavitation is the result of pressure reduction in the liquid and thus presumably, controlling the amount of the minimum absolute pressure can control it. If the pressure is reduced and maintained for sufficiently long duration of time, it will produce cavitation.
3. Cavitation is a dynamic phenomenon and it is concerned with the growth and collapse of cavities.

3.3 Occurrence of Cavitation

Some significant observations from previous experiments show some interesting characteristics of cavitation, which are listed below.

1. Cavitation occurs in a liquid, which is moving, or at rest.
2. There is no indication that the occurrence of cavitation is either restricted to or excluded from solid boundaries. This goes to show that cavitation may occur either in the body of the liquid or on a solid boundary.
3. The description is concerned with dynamics of cavity behaviour. A distinction is implied between the hydrodynamic phenomenon of cavity behaviour and its effects such a cavitation erosion.

3.4 Stages and Types of Cavitation

Cavitation can be classified in to two types **based on its occurrence.**

Due to **Tension** in the liquid following types of Cavitation may be observed:

1. ***Hydrodynamic cavitation***: This is produced by pressure variation in a flowing liquid due to the geometry of the system.
2. ***Acoustic cavitation***: Sound waves produced by pressure variations in the liquids give rise to Acoustic cavitation.
3. ***Vibratory cavitation***: When the liquid is at rest or flows with a very small velocity, many cycles of cavitation in a given time period can be noticed. This is called Vibratory cavitation.

Due to **local deposition of energy** in the liquid following type of cavitation may be observed:

4. ***Optic cavitation***: photos of high intensity light rupturing a liquid produce this type of cavitation.
5. ***Particle cavitation***: may be observed in when some type of elementary particles, such as proton rupturing a liquid, as in a bubble chamber.

Further descriptions of these five types of cavitation are given below. Vibrations are considered to be of main interest in the present work.

3.4.1 Hydrodynamic Cavitation

The local variation in velocity of a flowing liquid is due to some discontinuities like vibration, surface roughness, geometry etc. Generally low pressures and cavities occur at places where the liquid has the highest velocity.

Hydrodynamic cavitation can be further classified into

1. *Travelling cavitation*: This type of cavitation occurs when a bubble or a cavity formed flows and grows along with liquid and collapses subsequently.
2. *Fixed cavitation*: occurs when a cavity or bobble attached to a rigid boundary of an immersed body or a flow passage forms, and remains fixed in a position in an unsteady state.
3. *Vortex cavitation*: occurs in the cores of vortices, which form in regions of high shear, and often occurs on the blade tips of propellers. So it is also called as tip cavitation.

3.4.2 Acoustic Cavitation

In an acoustic field, a bubble or cavity in the liquid can be created when the liquid pressure momentarily drops below the vapour pressure as a result of pressure oscillation.

The pressure oscillations in acoustic cavitation cause bubbles to contract and expand. Gas from the liquid diffuses into the bubble upon expansion, and leaves the bubble during contraction. When the bubble reaches a size that can no longer be sustained by its surface tension, the bubble will collapse, and the intensity of this collapse on a solid surface is related to the type of acoustic cavitation produced.

There are two types of acoustic cavitation: transient and stable (or controlled).

1. *Transient cavitation:* Transient cavities exist for a few cycles, and are followed by a rapid and violent collapse, or implosion, that produces very high local temperatures. Ultrasonic frequencies, typically between 20 and 350 kHz, transform low-energy/density sound waves into high-energy/density collapsing bubbles, producing transient acoustic cavitation. Transient acoustic cavitation can cause damaging surface erosion.

2. *Stable cavitation*: Mega sonic frequencies, 700 to 1000 Hz, produces stable acoustic cavitation bubbles have less time to grow and are smaller, resulting in a less vigorous collapse than in transient cavitation. And the implosion associated with these smaller, gas-filled bubbles is less likely to produce surface damage.

3.4.3 Vibratory Cavitation

This type of cavitation comes in a class where cavitation is not accompanied by major flow. It means that the flow velocity is either zero or too small. When the velocity is too small or zero the liquid element is exposed to multiple of cycles of cavitation in the cavitation zone in a given a period of time in the order of milli-seconds. Due to continuous series of high amplitude, high frequency pressure pulsations in the liquid, the cavitation forces form and collapse cavities. These pressure pulsations are generated by submerged surface, which vibrates normal to the surface to its face and sets up pressure waves in the liquid. The important aspects of vibratory cavitation to be considered are

1. The characteristics of the vibratory surface that produces the oscillating pressure fields together with the characteristics of the resulting wave pattern and
2. The effects of oscillating pressure field on the liquid and on the cavities formed.

The driving surface that causes vibratory cavitation may be either one of the following two kinds. First case, the surfaces that are caused to vibrate unintentionally as for the example, a secondary effect from the operation of a machine. Second case, surfaces of devices such as transducers, designed for the specific purpose of producing a pressure wave train in the liquid. The shape of the vibrating surface determines the type of wave train produced, i.e., plane diffused, or concentrated. If the wave train is plane or diffused, the maximum amplitudes, and hence minimum pressures, will occur at surfaces. If the wave train is concentrated or focused, the maximum amplitude will be at focal point with in the body of the liquid.

3.4.4 Optic Cavitation

This type of cavitation occurs when a light of high intensity is focused in to a liquid. This intensity ruptures the liquid and initiates the formation of bubbles. These bubbles may propagate due to some source like a fast moving mirror of a camera

3.4.5 Particle Cavitation

This type of cavitation is based on the growth of bubbles in a superheated liquid. If a charged particle is sent through the liquid it leaves an ionization trial for a small amount of time. Some of the energy from these ions goes into a few fast electrons, which can give up to 1000 electron volts of energy in a small volume to produce rapid local heating. If the liquid has been superheated by expansion, boiling will occur along the track, which will appear as a line of tiny bubbles.

Young[1] and Knapp, Daily and Hammitt [2]

4 Internal Combustion Engines

The operation principle, cooling system and resulting piston slap force loads in an internal combustion (IC) diesel engine is presented as a description of the studied system.

4.1 Operation of IC diesel Engine

Most vehicles run on hydrocarbon fuels. Recent technology has also brought in other fuels like the electrical cells and solar cells and other hydrogen cells. On economy grounds IC diesel engine is gaining grounds.

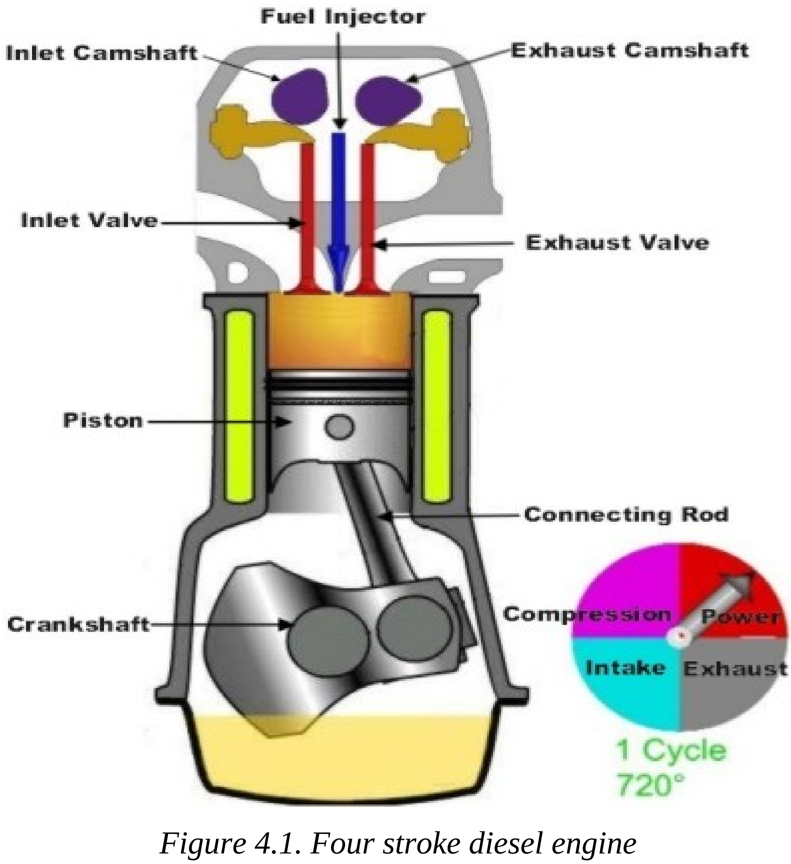

Figure 4.1. Four stroke diesel engine

The Four Stroke in an IC diesel Engine will be considered with reference to figure 4.1.

The four strokes consist of:

1. The intake stroke
2. The compression stroke
3. The power stroke
4. The exhaust stroke.

Intake stroke:

As the piston starts down on the stroke, the intake valve opens and the air is drawn into the cylinder. When the piston reaches the bottom of the bottom dead centre in the intake stroke the intake valve closes trapping the air in the cylinder.

Compression stroke:

The piston moves up and compresses the trapped air that was brought by the intake stroke. The amount that the air is compressed is determined by the compression ratio, which is between 14:1 and 25:1. This means that when the piston reaches the top dead centre the air is squeezed to about one twenty-fifth of its original volume.

Power stroke:

Here a measured quantity of atomized fuel is injected into the chamber. The heat of the compressed air lights up the fuel, which produces a powerful expansion of vapour. The combustion process pushes the piston down the cylinder with great force turning the crankshaft to provide the power to propel the vehicle. Each piston fires at a different time, determined by the engine firing order. By the time the crankshaft completes two revolutions each cylinder in the engine would have gone through one power stroke.

Exhaust Stroke:

When the piston is at the bottom dead centre of the cylinder, the exhaust valve opens to allow the burnt exhaust gas to be expelled to the exhaust system. Since the gas inside the cylinder is at high pressure after the combustion stroke, the gas is expelled out with a violent force from the exhaust port when the exhaust valve opens. This process repeats as it moves to the next stroke.

4.2 Engine Cooling

The engine, in generating mechanical power also generates waste heat energy because they are not perfectly efficient. Cooling is therefore prevalent in order to prevent the engine from cooking in its own heat.

Even though some waste heat goes out with the exhaust in most IC engines, further cooling is required to prevent the engine from material and lubricant failure. For this work we concentrate on liquid coolants.

Most liquid coolants contain a greater amount of water and approximately 30 percent of ethylene glycol. The cooling process starts at the radiator where there is a store of the liquid. The liquid is pumped into the cooling chamber going round the wet side of the cylinder liners. The heat transfer is such that the liner gets cooled and the liquid gets hot. The hot liquid is then returned to the radiator where a fan blows around it to cool it for the process to begin again. For an effective running of the engine the cooling liquid is kept at a temperature between 70 and 75^{o} Centigrade. A low temperature cooling liquid also slows down the efficiency of the engine.

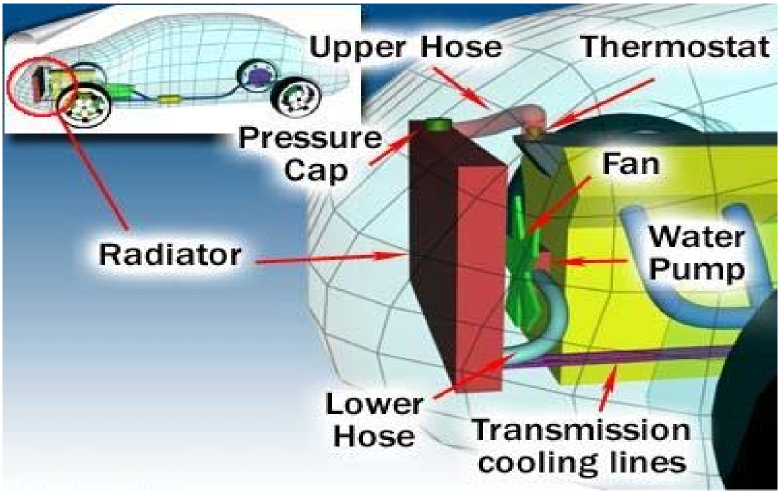

Figure 4.2. Layout of a typical cooling system of IC Diesel Engine

The above diagram shows the cold liquid in the lower hose the hot liquid in the upper hose. The rest of the parts are labeled in the diagram in figure.4.2 above.

The activities in the pistons impinge on the cylinders which on being cooled by the cooling fluid, introduces vibration into the fluid and thereby causing it to cavitate, the effect of which causes pitting on the cylinder liner.

4.3 Piston Forces

The derivation of force equation relating to the piston cylinder assembly is shown below. This is based on the assumptions made below by Cho, Ann and Kim[3],Ungar and Ross[4]

4.3.1 Assumptions

In dealing with this there are some basic assumptions that need to be addressed. Some of these major assumptions that are used to simplify the mathematical equations are as follows:

- All the piston-liner impact forces are instantaneous
- The piston contacts the cylinder bore are the top and or bottom of the piston skirt.
- Piston skirt deformation and linear elasticity is are considered negligible
- The skirt/liner oil film exhibit little effect on the transverse motion of the piston
- The gas forces are assumed to act through the centre line of the piston so that the equations of motion apply no matter where the piston is in the cylinder.
- The major piston impact occurs in close proximity to TDC firing.

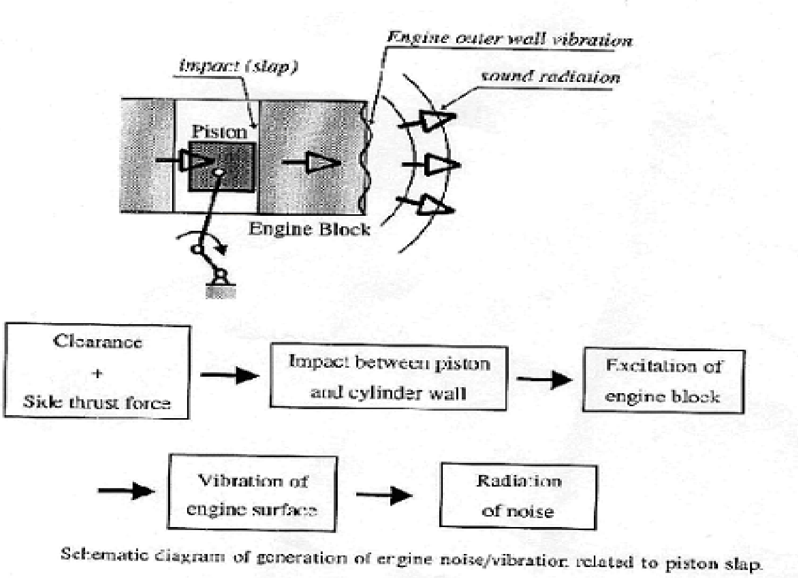

Figure 4.3 Schematic diagram of generation of engine noise/vibration related to piston slap Cho,Ahn and Kim [3]

Figure 4.3 shows a schematic diagram of engine noise generation.

A two dimensional lumped parameter model is shown in figure 4.4. This figure describes the motion in translation along the X and Y-axis. The motion in the Z-axis and angular motion are neglected. This is because they are negligible and can be ignored.

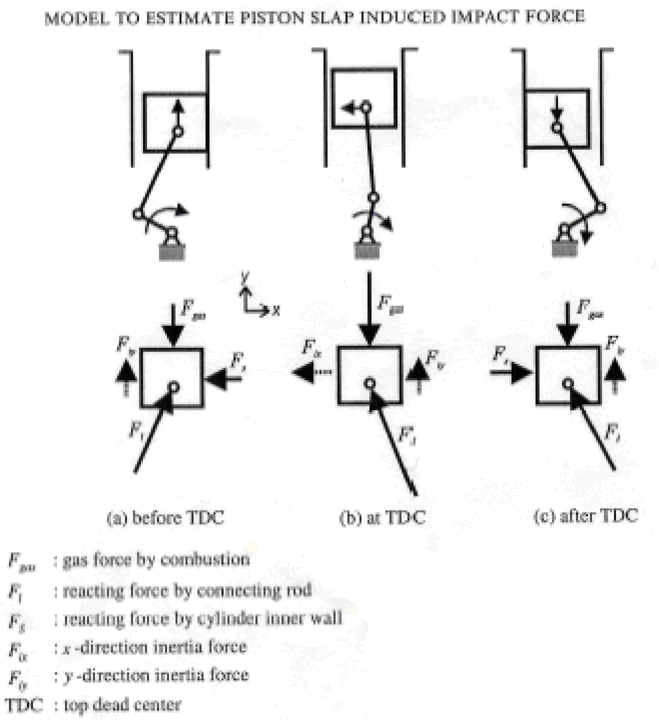

Figure 4.4 Schematic diagram of generation of noise and vibrations related to piston slap Cho, Ann and Kim [3].

4.3.2 Primary Motion and Inertia Forces of Machine Components

The motion of the piston in the cylinder describes a slider crank mechanism, as shown in figure 4.5.

Now if we take the piston as a first approximation to be constrained to move only along its ideal kinematic axis of motion, then we can calculate the co-ordinates of the piston P and of the connecting rod centre of gravity C in terms of the angles θ and ϕ, shown in figure 4.6.

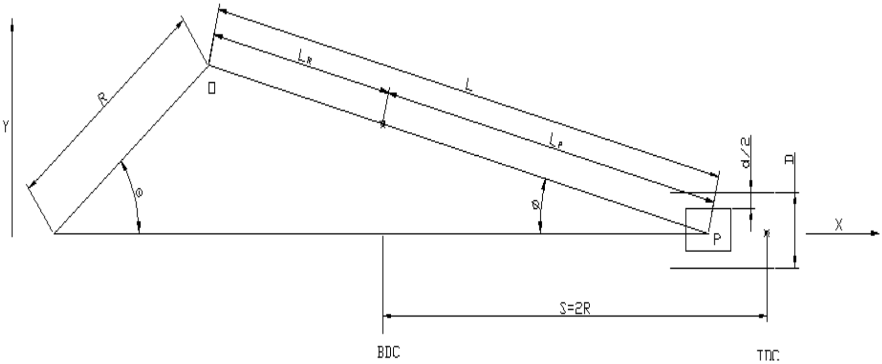

Figure 4.5 The figure above illustrates the component parts and its motion, Ungar and Ross [4]

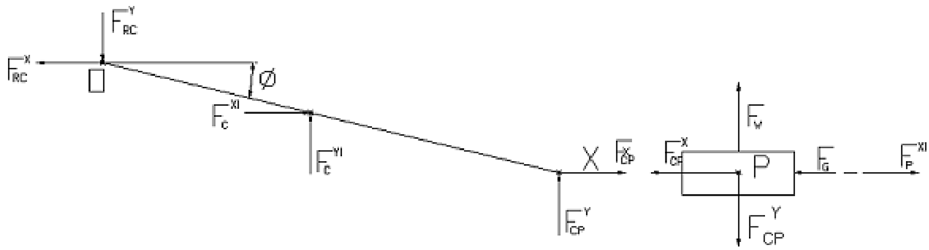

Figure 4.6 Free body diagram: shows the inertia and forces on its mechanism, Ungar and Ross [4]

The corresponding acceleration components may then be obtained by double differentiation with respect to time, using the rotational speed as $\dot{\theta}$ to be constant with the presently considered degree of accuracy.

The angle ϕ is related to the crank angle θ as defined in the figure by

$$\sin\phi = \gamma \sin\theta, \gamma = \frac{R}{L} \qquad (4.1)$$

The length of the connecting rod is L. This is greater than the crank Radius. Therefore $\gamma^2 << 1$. Considering the approximations made this leads to the equation mention below

$$\cos\phi \approx 1 - \left(\frac{\gamma^2}{2}\right)\sin^2\theta$$

$$\tan\phi \approx \gamma\sin\theta\left(1 + \left(\frac{\gamma^2}{2}\right)\sin^2\theta\right),$$

$$\phi \approx \gamma\sin\theta + \frac{1}{2}(\gamma\sin\theta)^3,$$

$$\ddot{\phi} \approx -\gamma\omega^2\cos\phi\sin\theta\left(1 - \gamma^2\cos 2\theta\right).$$

The inertia forces are as shown below

The superscript i denotes inertia, x, y denote co-ordinates, c-Centre of gravity and p- Piston

Thus

$$F_p^{xi} = -M_p\ddot{x}_p = \omega^2 M_p R\left(\cos\theta + \gamma\cos 2\theta\right),$$

$$F_c^{xi} = -M_c\ddot{x}_c = \omega^2 M_c\left(R\cos\theta + L_R\gamma^2\cos 2\theta\right),$$

$$F_c^{yi} = -M_c\ddot{y}_c = \omega^2 M_c\left(L_p\gamma\sin\theta\right),$$

(4.2)

4.3.3 Side thrust action on piston

Now the equations of dynamic equilibrium for the piston in the X-direction and for rotation of the connecting rod about the pin O:

From the set of equations, mentioned above the side thrust force F_{cp}^{y}, that the connecting rod exerts on the piston can be solved. This is as follows:

$$\psi_S = \frac{F_{cp}^{y}}{M_p R\omega^2\gamma} = \left[\psi_G - \left(\psi_p + \psi_c\right)\right]\sin\theta \qquad (4.3)$$

Where

$$\psi_G = \frac{F_G \tan\phi}{M_p R\omega^2 \gamma \sin\theta} = \frac{F_G}{M_p R\omega^2},$$

$$\psi_p = \frac{F_P^{xi} \tan\phi}{M_p R\omega^2 \gamma \sin\theta} = \frac{F_G}{M_p R\omega^2},$$

$$\psi_c = \frac{\left(F_c^{yi} + F_c^{xi} \tan\phi\right)L_R \cos\phi + \left(r^2 + L_R^2\right)\ddot{\phi} M_c}{L\cos\phi . M_p R\omega^2 \gamma \sin\theta} = \mu L(V + \cos\theta)$$

(4.4)

In which r denotes the radius of gyration of the connecting rod about an axis through its centre of gravity (and parallel to the crank shaft), and

$$\mu = \frac{M_c}{M_p}, L = \frac{L_R}{L}, \rho = \frac{r}{l}$$

$$V = \frac{\left(L - 2L^2 - \rho^2\right)}{Lr} \qquad (4.5)$$

ψ_s represents a dimensionless side thrust force quantity. ψ_G, ψ_p and ψ_c are made by the gas force, the piston inertia and the connecting rod inertia respectively.

The appropriate equation in 4.4was obtained using the inertia force equation 4.2 and the small angle approximations of equation 4.1, which holds for the usually applicable inequality $\gamma^2 << 1$. $M_p R\omega^2$ May be used as centrifugal force that the piston would exert if it were a point mass attached to the rotating crankshaft at the crack radius.

$\psi_G(\theta)$ = Ratio of the gas force at the crank angle θ to its centrifugal force and ψ_p = Ratio of the piston inertia force to this centrifugal force.

The lateral piston motion is induced when $\sin\theta = 0$ and also for $\psi_G = \psi_p + \psi_c$.

This piston slap occurs when $\theta = 0$ (top dead centre and bottom dead centre), $\theta = \pi$

The piston slap forces are used as excitation forces in the simulations.

5 Modelling and Simulation

The studied system representing an IC combustion engine is modelled as a piston-crankshaft mechanism interacting with a cylinder and surrounding liquid coolant. The structural flexibility of the cylinder is considered and the dynamic interaction between the vibrating structure and the surrounding fluid is modelled and investigated in two different types of analyses.

Simulation with the finite element software Ansys lends itself to the integration to the piston and cylinder liner dynamic Equations and also its incident effect on the cooling fluid. The relationship between the computer and engineer leads to an easy application of the piston/liner and cooling fluid behaviour to be obtained.

Simulation technique can never be complete replacement for an experimental testing. But they can provide a useful service in that the effect of parameter changes may readily be expressed without resource cutting metal, leaving experiment to confirmatory role.

Experiment must also provide the evidence needed to validate the mathematical model in first instance.

Since it was difficult to perform experiments within the present project to get the point load that impact on the side of the cylinder, data was taken from journals, which were used to run the program.

5.1 Geometry modelling

The geometry of the parts in the studied system was created using the Autodesk Inventor CAD software. The figures 5.1 and 5.2 below show the piston cylinder liner geometry and assembly. Shigley and Uicker [5].

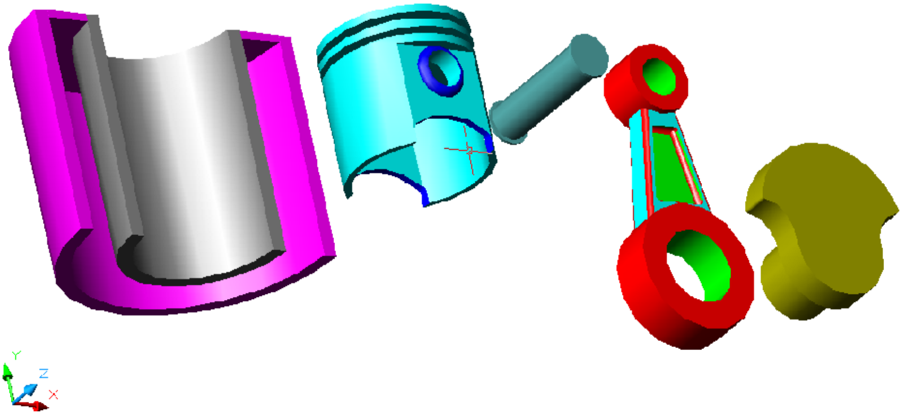

Figure 5.1. The parts in the studied system.

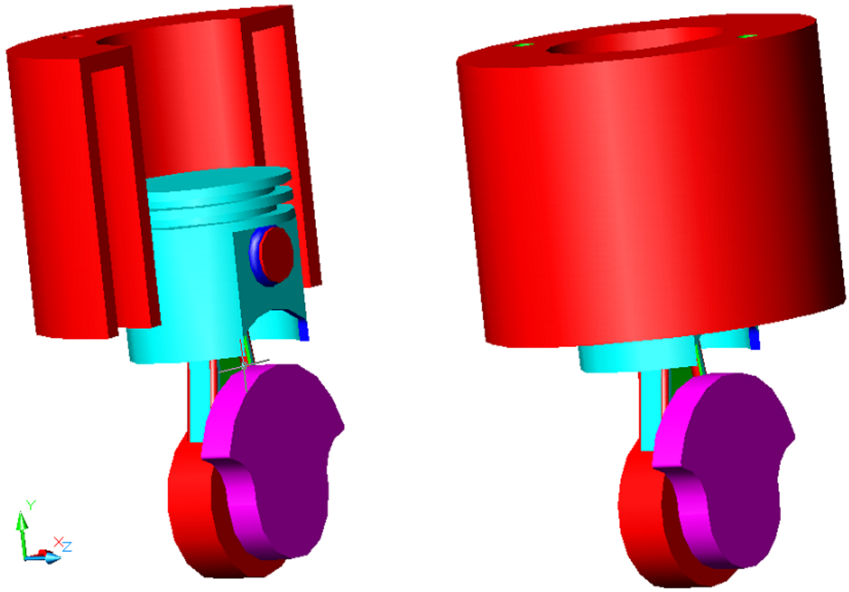

Figure 5.2. Total Assembly.

5.2 Finite Element Analysis

Finite element models were created based on the geometry of the system assembly. The modelling and simulation was carried out using the finite element software Ansys.

For the problem use was made of a two dimensional beam and a three dimensional beam.

A job was created with its attendant job name. I the pre-processor domain, modelling was picked and then area selected to create the job dimensions. Areas one and two were created, one lying on the other, signifying the region for the grey cast iron (cylinder liner) and the cooling fluid (liquid).

5.2.1 Steady State Analysis

A steady state analysis deals with the effect of a steady load applied on a system or component. This helps establish initial conditions, as loads varying over a period of time can be ignored.

In the element type region, still in the pre-processor we selected the element type as solid for (plane 42 and solid 45) and Ansys fluid (fluid 29, fluid 30).

The type of material and its properties were also chosen in the material properties –material models for both the fluid and solid.

An element size edge of 0.001 was used to mesh the first material (the solid). This was done specifying the default attribute and the plane 42 with the material model 1.

The same thing was done to the fluid, this time using fluid 29 and material model 2 as default attributes. This is as shown below.

For elements in plane 42 and 45

Plane 42 is selected to mesh a plane in two dimension and solid 45 is used to mesh a three dimensional object.

For the fluids:

Fluid 29 is used to mesh a 2D fluid and fluid 30 for a 3D fluid

An element size edge shows the size of a division in a mesh. ANSYS[6]. These values are explained in the appendix B.

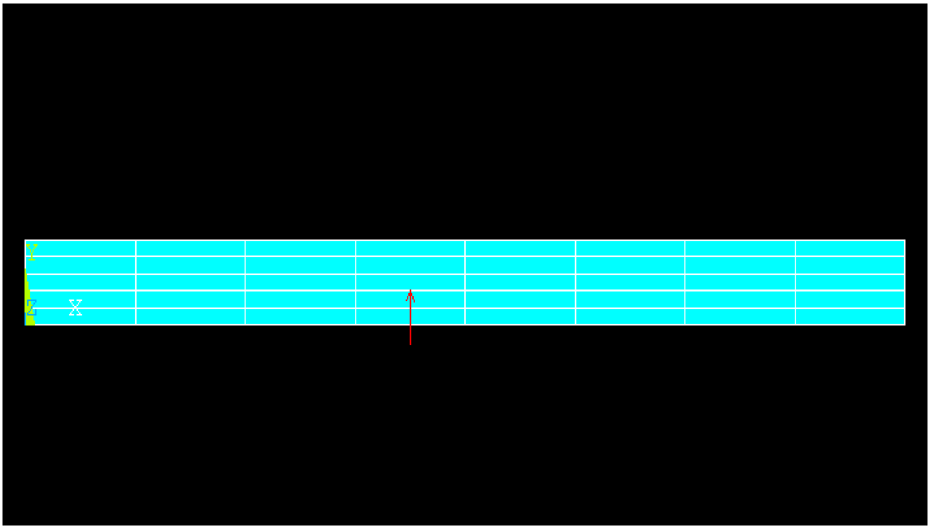

Figure 5.3. A 2D Meshed area of the fluid and solid. The red arrow in the meshed 2D object above shows the fluid solid interaction interface.

The fluid structure interaction is governed by the equation as below. ANSYS [6]

$$[M_s]\{\ddot{U}\}+[K_s]\{U\}=\{F_s\}+[R]\{P\} \tag{5.1}$$

$$[M_f]\{\ddot{P}\}+[K_f]\{P\}=\{F_f\}-\rho_0[R]^T\{\ddot{U}\} \tag{5.2}$$

Where M_s, M_f, U, P and F denote mass of solid, mass of fluid, translation, pressure and force.

R is the coupling matrix, which denotes the effective surface area associated with each node on the fluid-structure interface

$$\begin{bmatrix} M_s & 0 \\ \rho_0 R^T & M_f \end{bmatrix} \begin{pmatrix} \ddot{U} \\ \ddot{P} \end{pmatrix} + \begin{bmatrix} K_s & -R \\ 0 & K_f \end{bmatrix} \begin{pmatrix} U \\ P \end{pmatrix} = \begin{pmatrix} F_s \\ F_f \end{pmatrix} \qquad (5.3)$$

Equation (5.3) implies that nodes on a fluid-structure interface have both displacement and pressure degrees of freedom.

The solid/fluid regions were coupled using either coupling adjacent regions or coupling coincident nodes.

The fluid and solid interface was accounted for using the field surface on lines or an area depending on weather the system is 2D or 3D.

A load of magnitude 65N and 45N was applied at points A and B of the solid part of the beam. Pressure in the fluid entrance was kept at 2 bars. These values were gotten from experiment carried out on the cylinder by Cho, Ahn and Kim [8].

For the solid model loads of magnitude 65N and 45N were applied at points A and B, point A taken close to top dead centre and the point B taken close to the bottom dead centre of the piston travel. The temperature from the heating surface was kept at 200^0C. One end of it was clamped and the other end left to vibrate freely. These boundary conditions were taken from the work of Cho, Ahn and Kim [8].

For the fluid, an entry liquid pressure and temperature of 3 bars and 75^0C respectively were used with an exit pressure of 1.86bars. The flow was also taken into consideration.

In the solution menu we select the type of analysis. Here we could choose from static, modal, harmonic etc. the problem is then solved.

In the general post processing, we first of all check the result summary and then we read the rest taking the last set.

The results are then plotted and the contour plot is used to achieve this. The deformed shape with the undeformed edge can be viewed and analysis drawn from it.

The effects of pressure, flow and temperature stress strain can be observed from this solution.

This process is also used for the 3D models too but in this case we have to extrude the 2D to get the 3D shape. Here too the solid 45 and the fluid 30 are used to specify the extrusion since they are 3D solid and fluids respectively

The other processes are just as it is with the 2D model

5.2.2 Output

Figure 5.4 shows a 2D beam acted upon by point loads of 65N and 45N, pressure and flow. Figure 5.5 shows a meshed volume of the fluid and the solid, fluid coloured blue and the solid green. Fluid structure interaction shown in red is seen in figure 5.6. In figure 5.7 we have the final model in 3D showing the application of load pressure and flow.

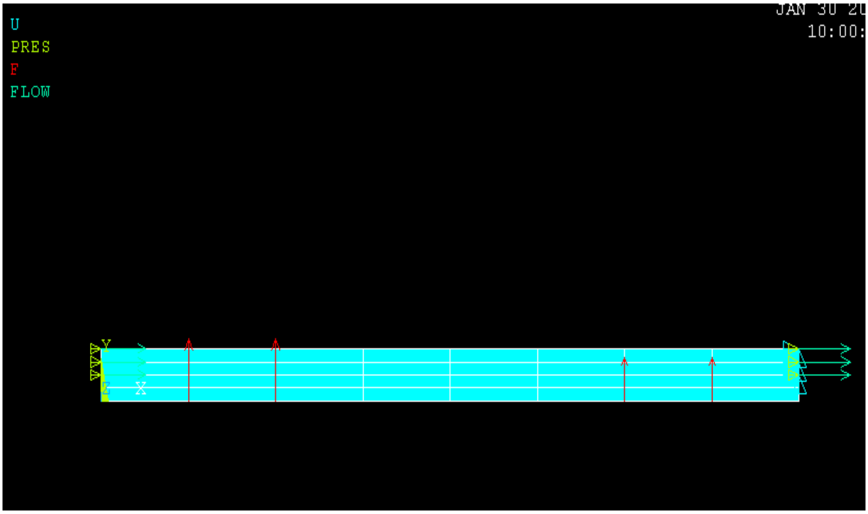

Figure 5.4 The diagram shows the solution to a 2D representation of the problem.

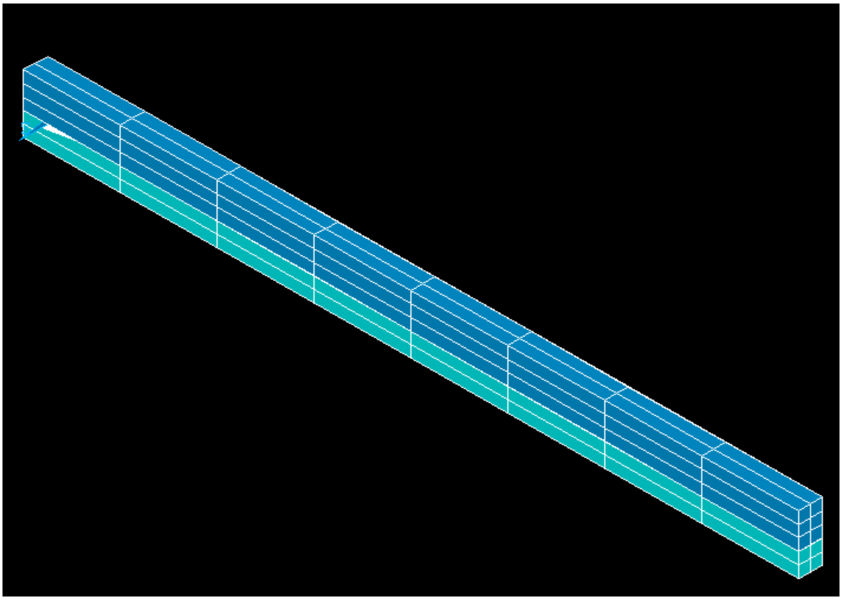

Figure 5.5 A 3D meshed volume the fluid is coloured blue and the solid is green

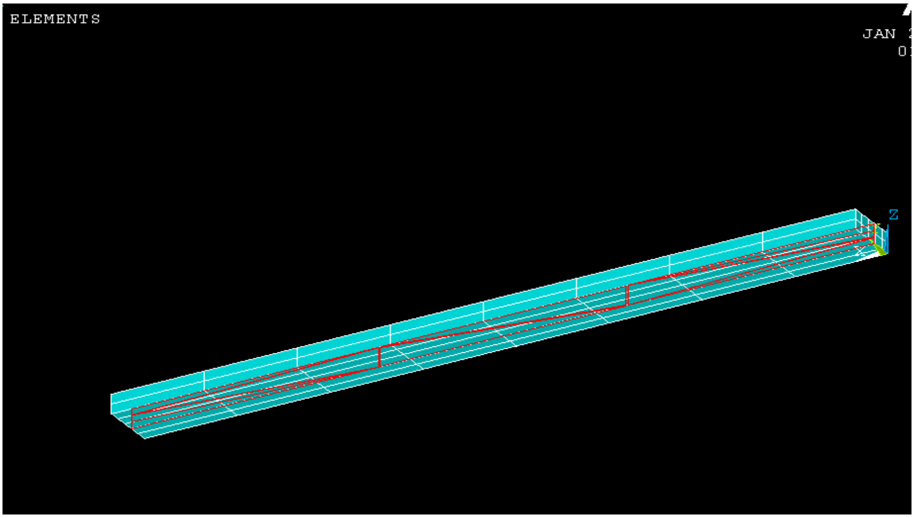

Figure 5.6 The red lines in the meshed 3D object above shows the fluid solid interaction interface.

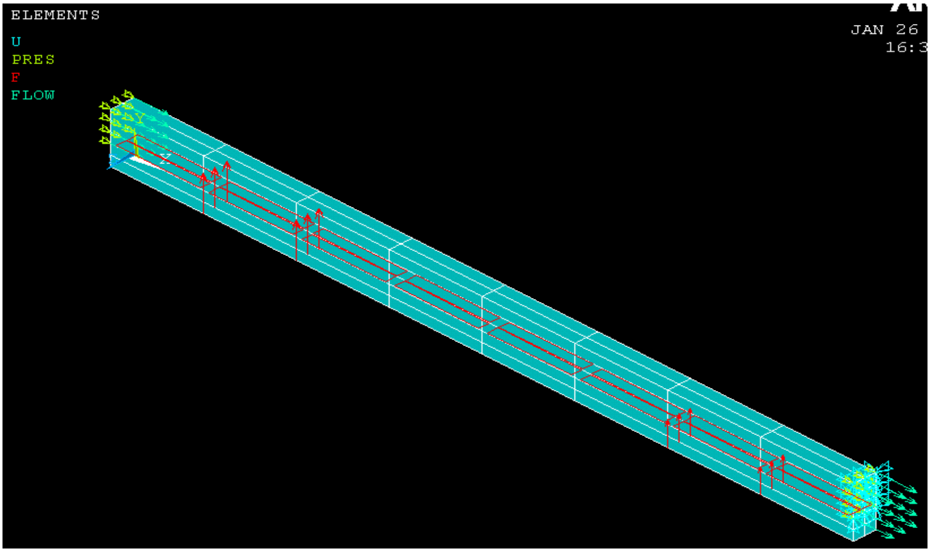

Figure 5.7 *The final model is as shown (3D model) below, showing the application of the load pressure and flow.*

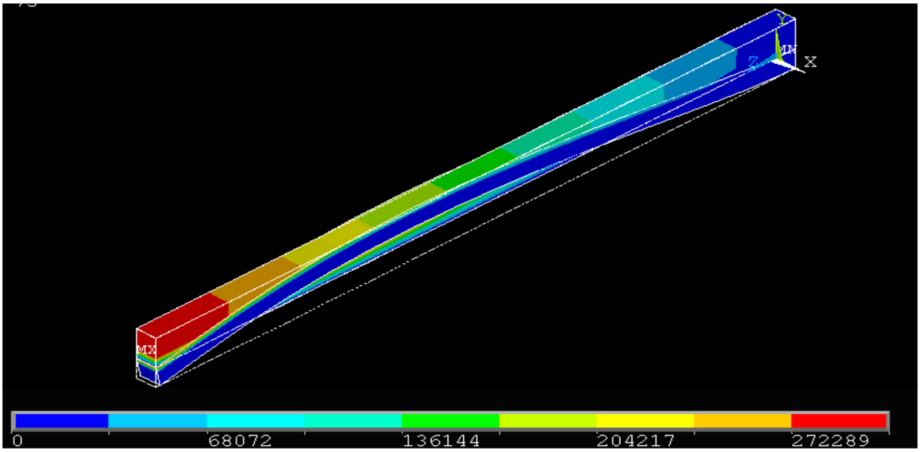

Figure 5.8 *Figure showing pressure variation for the 3D steady model*

5.2.3 Results interpretation

Cavitation will occur at areas on the solid fluid boundary where there are zero or negative pressures.

The solution above shows 2D and a 3D pressure variation on the setup.

It can be observed that pressures closest to the solid structure are either low or negative ones.

It is evident that there can be cavitation on the fluid solid interface.

The pressure readings were the average readings shown with the colour codes below the solution diagrams.

Specific values of the fluid pressure taken close to the solid surface was as follows

- 0.6bar
- 0.75bar
- 0.9bar
- 0

5.2.4 Harmonic Analysis with Fluid-Structure Interaction

Harmonic analysis deals with the response of a structure to harmonically time varying loads. It gives the ability to predict the sustained dynamic behaviour of structures.

Whilst the steady state deals with point loads the harmonic analysis deals with varying loads with frequency.

5.2.5 Thermal Analysis

Thermal analysis is used since the structure is also under the effect of heat from the combustion chamber.

The results provided above were prepared based on **steady state analysis**. Here are results from the **Harmonic Analysis** with the frequency limits taken as 0 and 100. The effect of **Temperature** is significant which lays foundation to **Thermal analysis** of the present system. Thermal analysis has been coupled with **Acoustic analysis & Structural analysis**. Thermal analysis is performed first, taking thermal element **'Quad4node 55'**.While performing the acoustic analysis '**Quad4node 42'** and '**3d acoustic 30'** for solid and fluid were used respectively. The latter are performed together and the thermal analysis results are inserted while declaring the boundary conditions for the coupled analysis. The analysis below also takes into consideration the thermal effect on Cavitation (as shown in the 3-D figures). To understand the effect of temperature, a comparison is shown between 2-D (without thermal analysis) and 3-D (with thermal analysis) in figures 5.9 to 5.17. Here, thermal analysis has been coupled with acoustic analysis & structural analysis, which are performed together.

The Thermal Element "Quad4node 55" was chosen to perform thermal analysis. The following is the meshing of the area as shown below with 3*20 elements using ANSYS. The cylinder liner is made of grey cast iron, the material under test. Use was thus made of the material properties of grey cast iron in ANSYS, SI units of which are 20W/mK for thermal conductivity, 547J/kgK for specific heat and emissivity of 0.60. ANSYS [6]

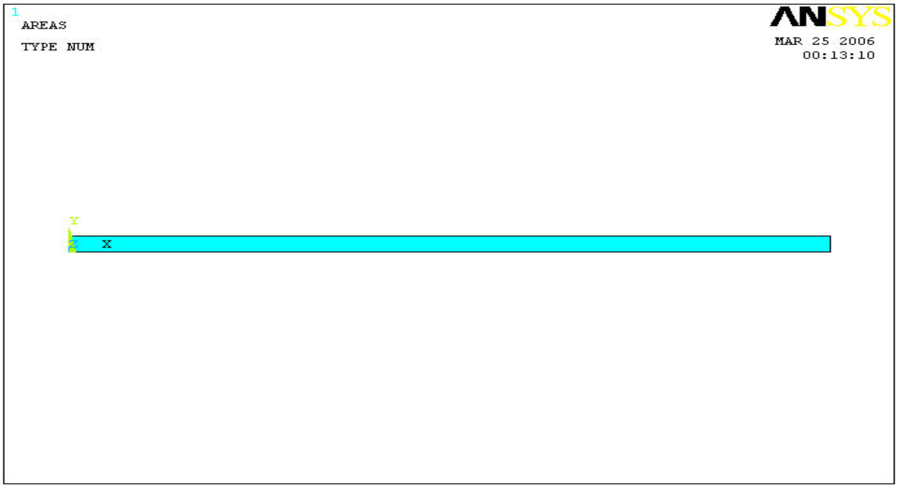

Figure 5.9 a solid structure with required dimensions is taken as shown above.

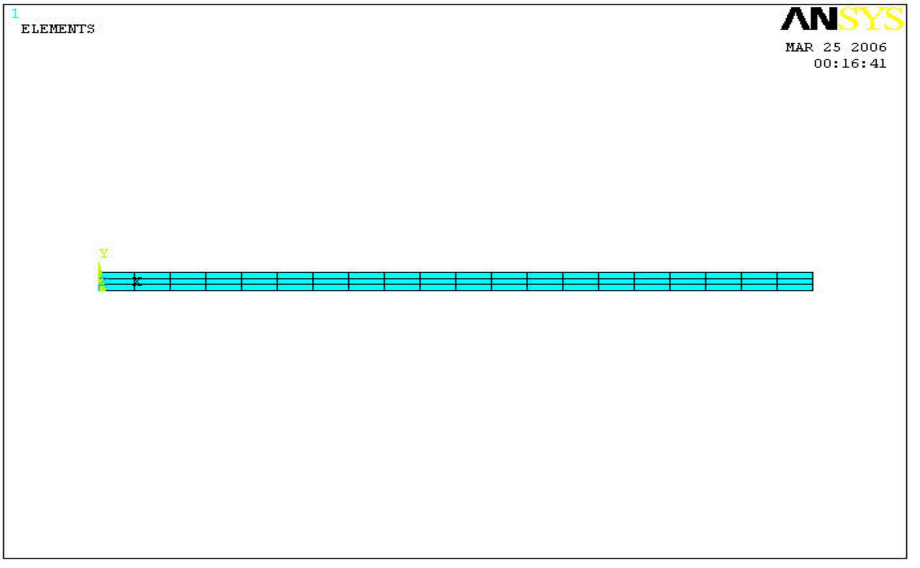

Figure 5.10The above figure is the meshing of the solid element

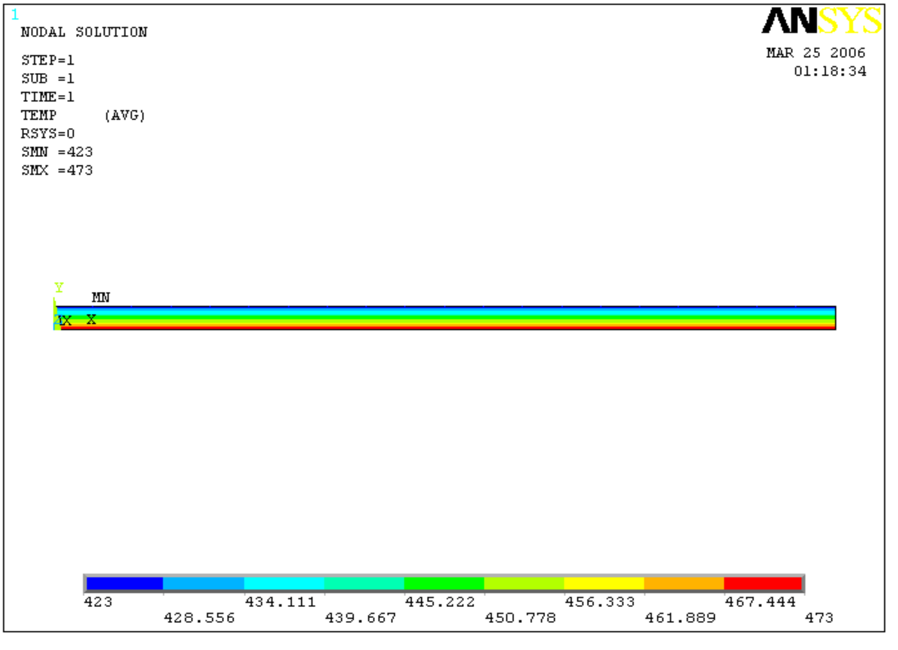

Figure 5.11 Figure above is the temperature distribution along the solid structure. The temperatures range from 423K to 473K.

*Note: Before we move to Analysis using **FLUID-STRUCTURE Interaction** we replace the thermal element Quad4node 55 with structural element Quad4node 42 with the same dimensions and similar mesh. The material properties are also changed as per the structural requirements of the acoustic analysis, because the fluid structure interaction cannot work with Quad4node 55. A further explanation is found in the ANSYS appendix B.*

5.2.6 Acoustic Analysis

An acoustic analysis, available in the ANSYS Multiphysics and ANSYS Mechanical programs only, usually involves modeling the fluid medium and the surrounding structure. Typical quantities of interest are the pressure distribution in the fluid at different frequencies, pressure gradient, particle velocity, the sound pressure level, as well as, scattering, diffraction, transmission, radiation, attenuation, and dispersion of acoustic waves.

A coupled acoustic analysis takes the fluid-structure interaction into account.

The ANSYS program assumes that the fluid is compressible, but allows only relatively small pressure changes with respect to the mean pressure. Also, the fluid is assumed to be non-flowing. Uniform mean density and mean pressure are assumed, with the pressure solution being the deviation from the mean pressure, not the absolute pressure.

The material models include the properties of the fluid, solid and also elements at the interface. The finite Element model is shown below with elements of the fluid on top, elements of the Interface at the center and solid at the bottom. It is important to create similar mesh for both solid and fluid so that they could be merged accurately as shown above. After merging the fluid and solid elements, an interface is created by merging lines 3 and 5 in the mesh.

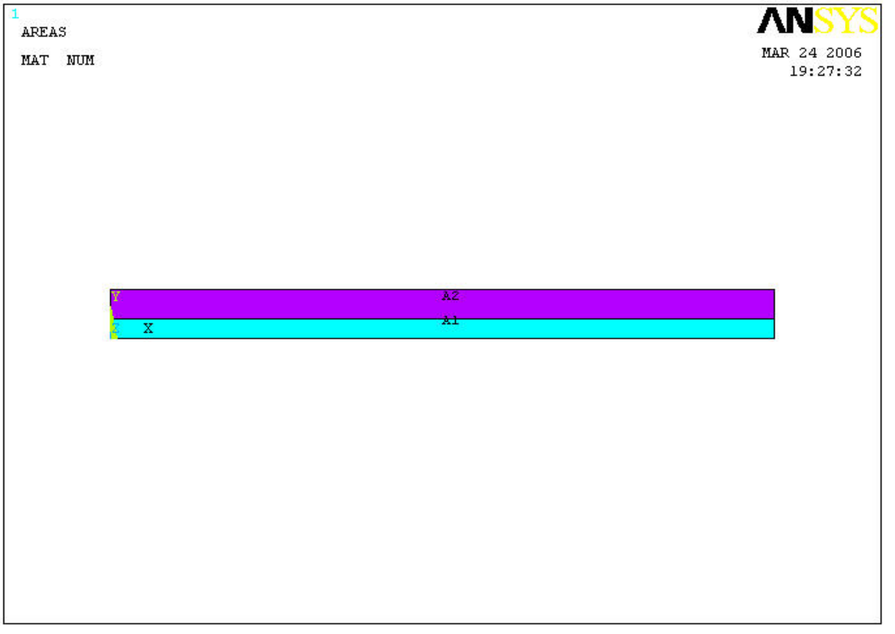

Figure 5.12 The above figure demonstrates the Geometric Model with areas corresponding to fluid (on top A2) and solid (at the bottom A1)

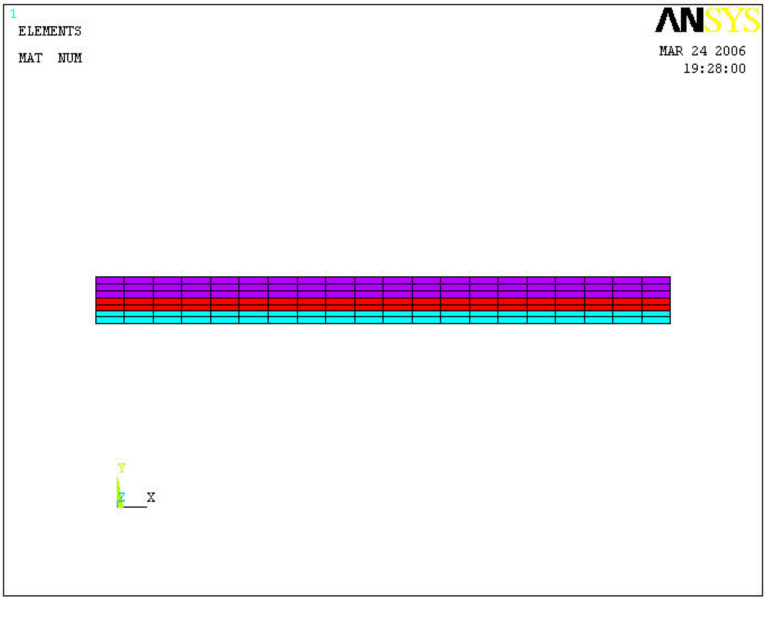

Figure 5.13 The 2D mesh of the geometric model

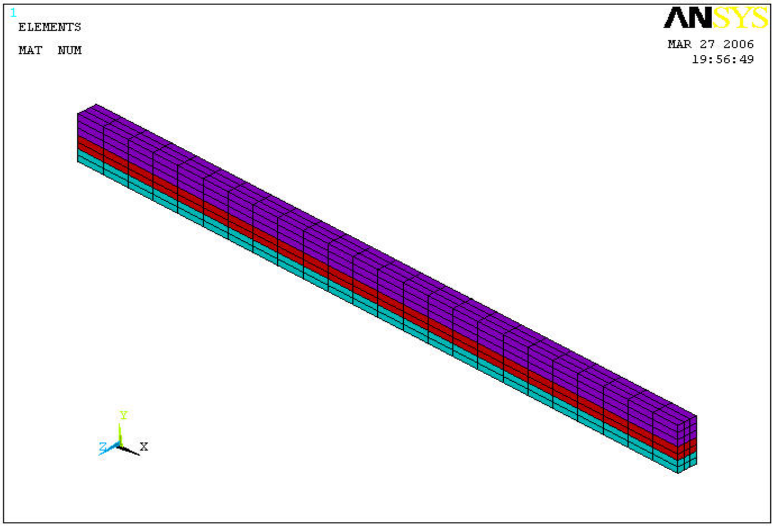

Figure 5.14 The 3D mesh of the geometric model

After creation of the mesh the boundary conditions for both the fluid and the solid are specified. Then we associate the line at the center and the nodes attached to it with the properties of the third material as declared along with the impedance. *The effect of temperature is taken from the thermal analysis file with extension .rth, which cannot be seen in the figure.*

Figures 5.15, 5.16 and 5.17 demonstrate the various boundary conditions.

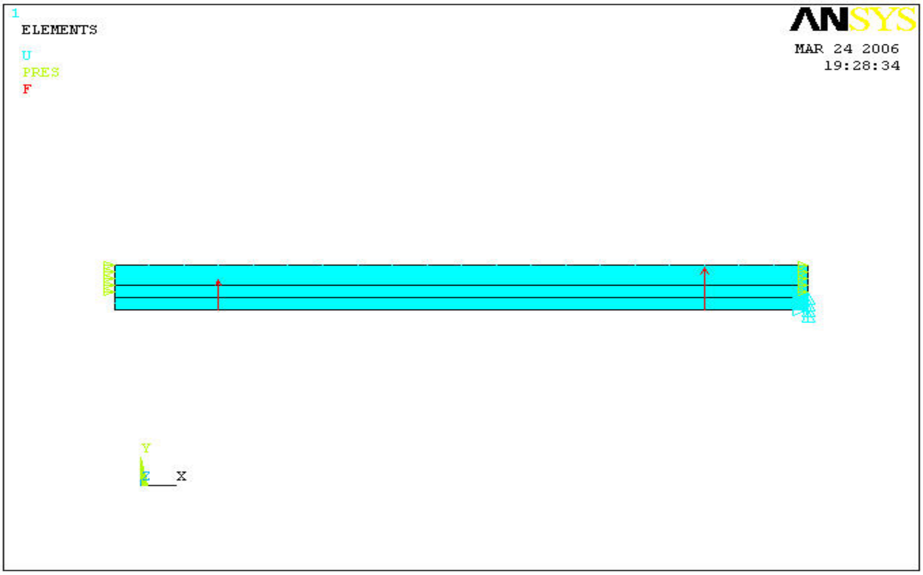

Figure 5.15 The above figure demonstrates the various boundary conditions in the 2D.the hatch lines at the top shows acoustic properties, the two red arrows shows the applied loads. The three divisions from below shows the solid the next is the solid fluid interaction and the top is the fluid.

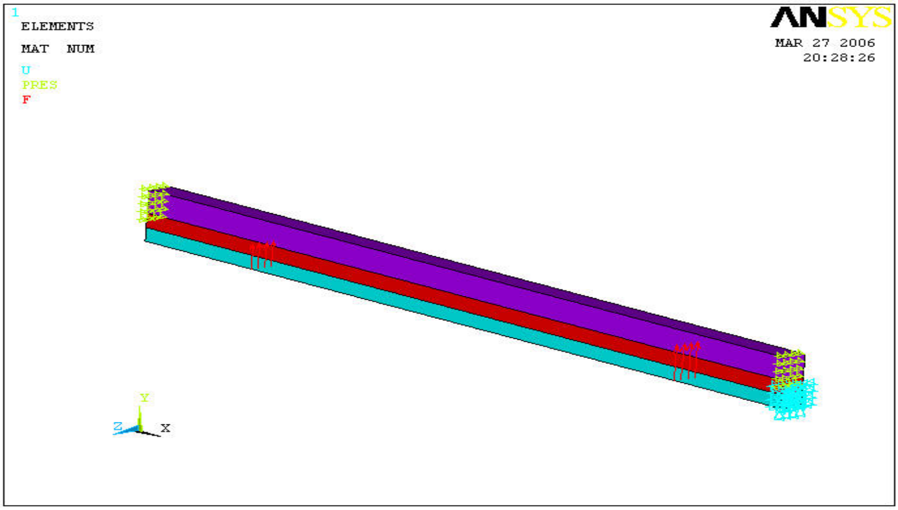

Figure 5.16. The above figure demonstrates the various boundary conditions in the 3D

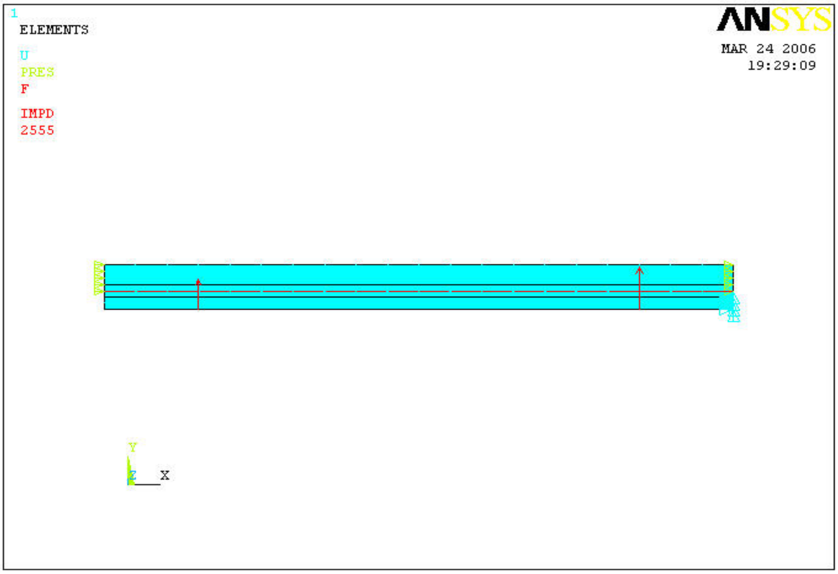

Figure 5.17 The above figure with all the boundary conditions and impedance shown in particular in the 2D.

Note: Before we move to solution options we consider the frequency interval for harmonic analysis between 0 and 100 with load step of 20.

5.2.7 Output

The output results of the harmonic analysis are created using ANSYS on both the 2D and the 3D model they are shown from the figures 5.18 to 5.34 below.

Following are results of the harmonic analysis performed starting with the displacement in the fluid due to the vibration in the solid structure on account of the loads applied at the bottom.

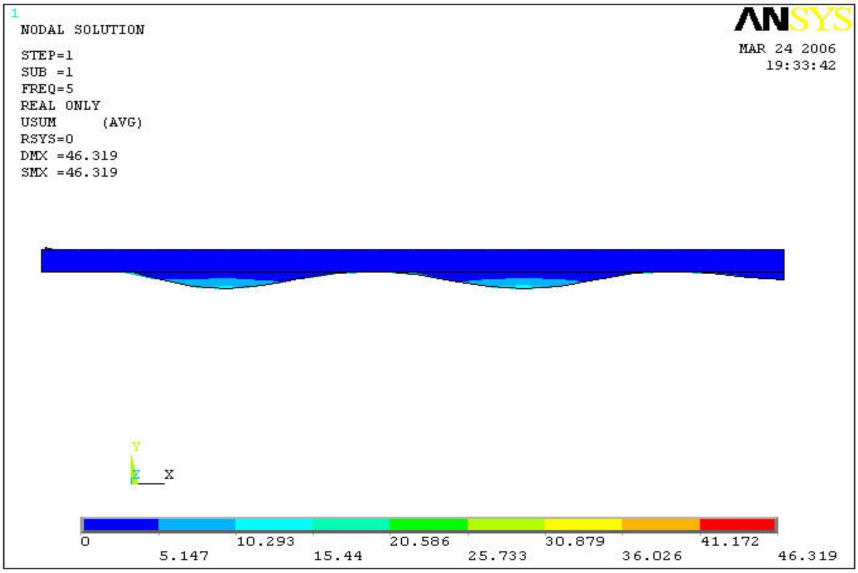

Figure 5.18 Figure showing the displacement in the fluid in the 2D

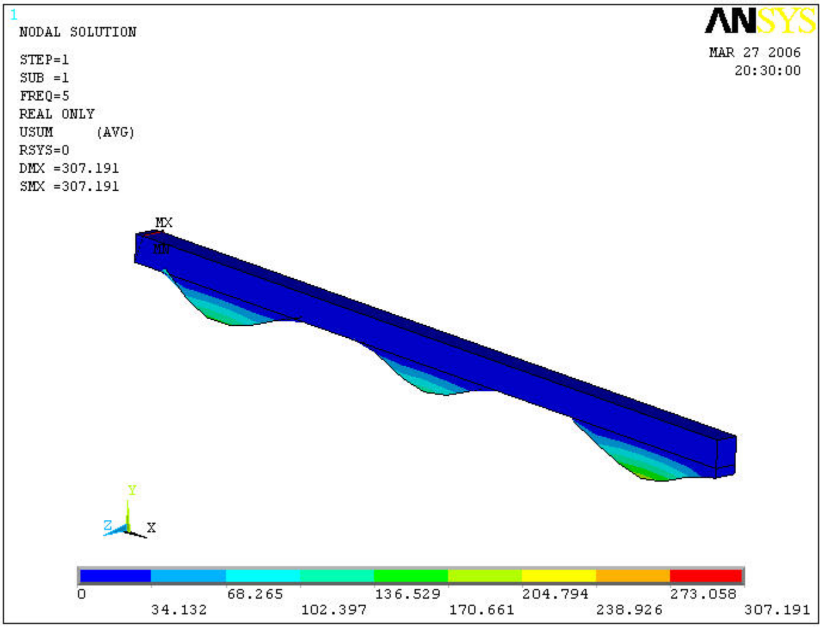

Figure 5.19 Figure showing the displacement in the fluid in the 3D

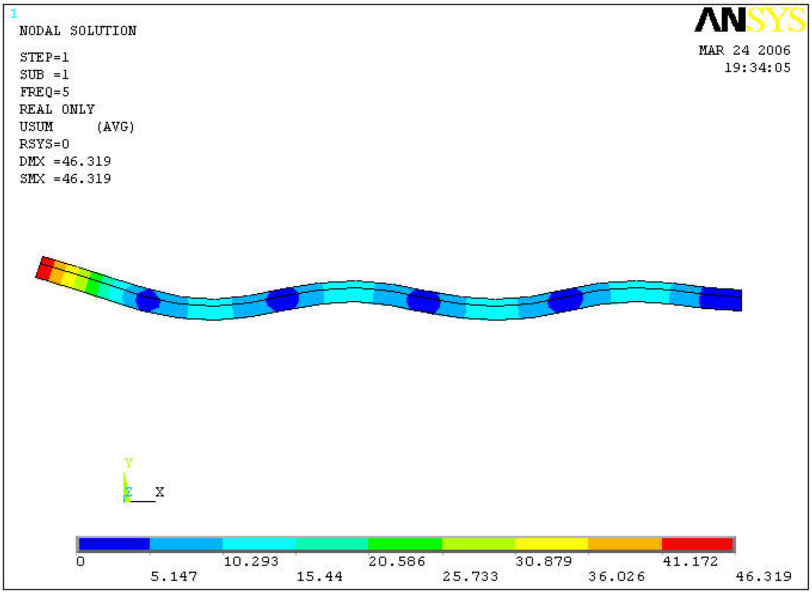

Figure 5.20 Figure demonstrating the displacement in the solid in 2D

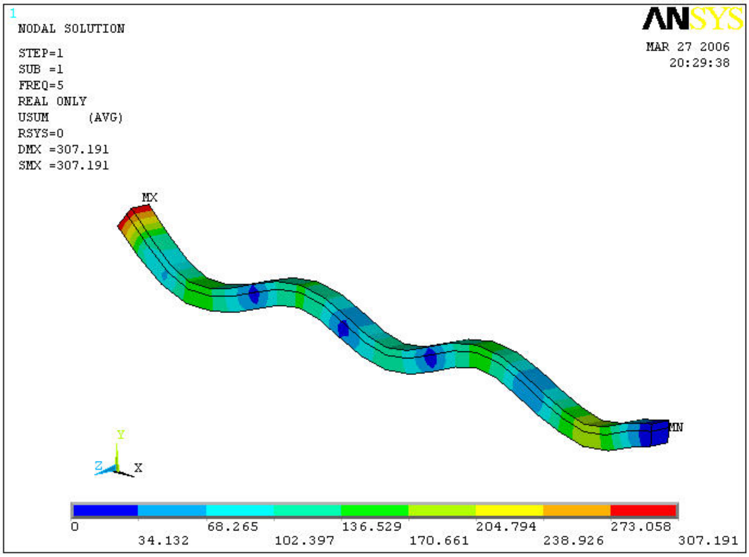

Figure 5.21 Figure demonstrating the displacement in the solid in 3D

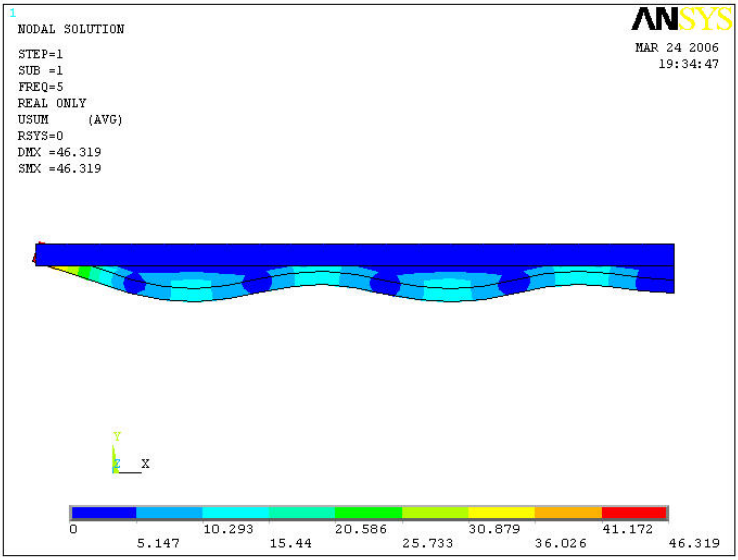

Figure 5.22. The displacement of the coupled structure in 2D

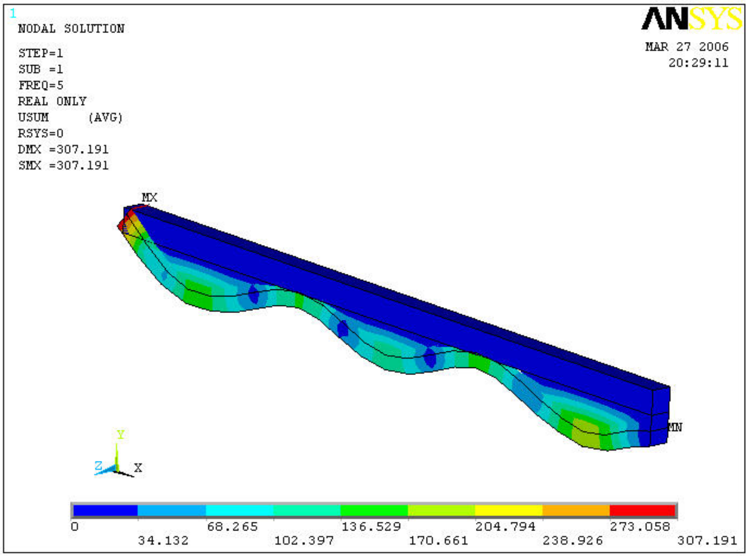

Figure 5.23 The displacement of the coupled structure in 3D

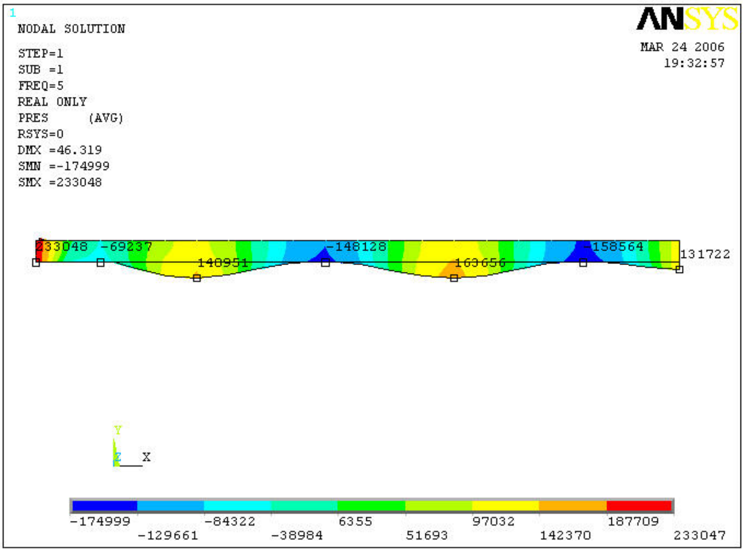

Figure 5.24. Figure demonstrating the changes in pressure in the fluid after the total analysis in 2D

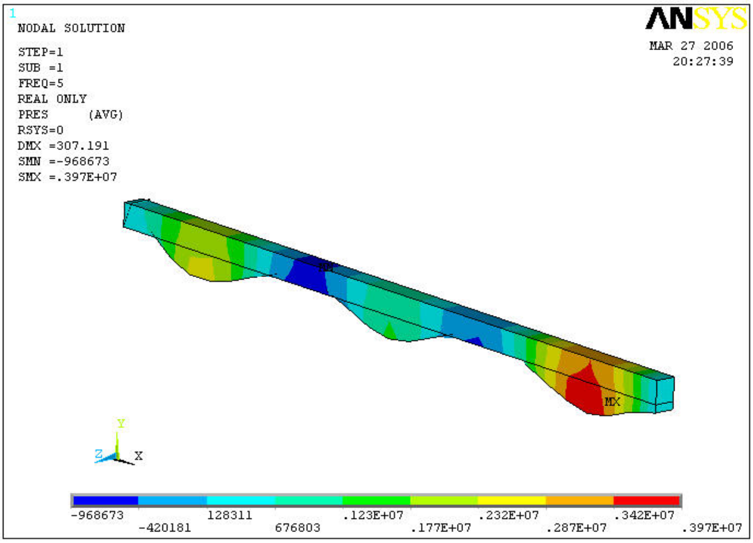

Figure 5.25 Figure demonstrating the changes in pressure in the fluid after the total analysis in 3D

Figures 5.24 and 5.25 above show the pressure drop below zero in the fluid, which is an evidence of presence of cavitation.

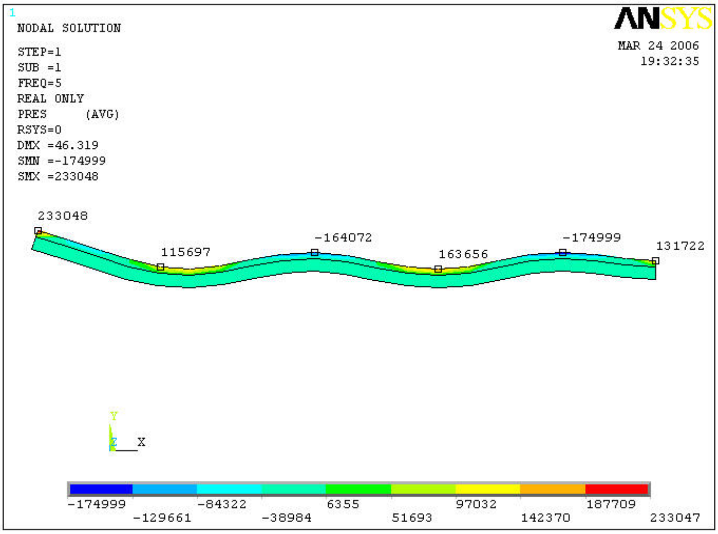

Figure 5.26 The above figure shows the pressure drop below zero in the solid, where there is a chance for development of a cavity in 2D

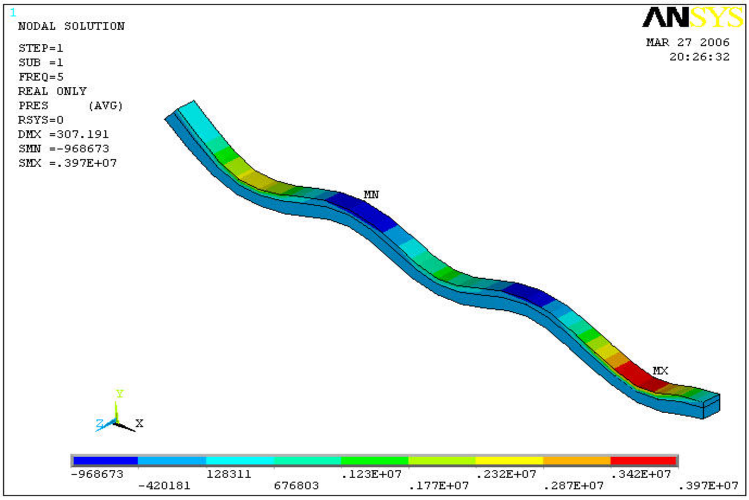

Figure 5.27 The above figure shows the pressure drop below zero in the solid, where there is a chance for development of a cavity in 3D

Following is the total assembly of the fluid and the solid for a clear indication of the cavities location and pressure drop.

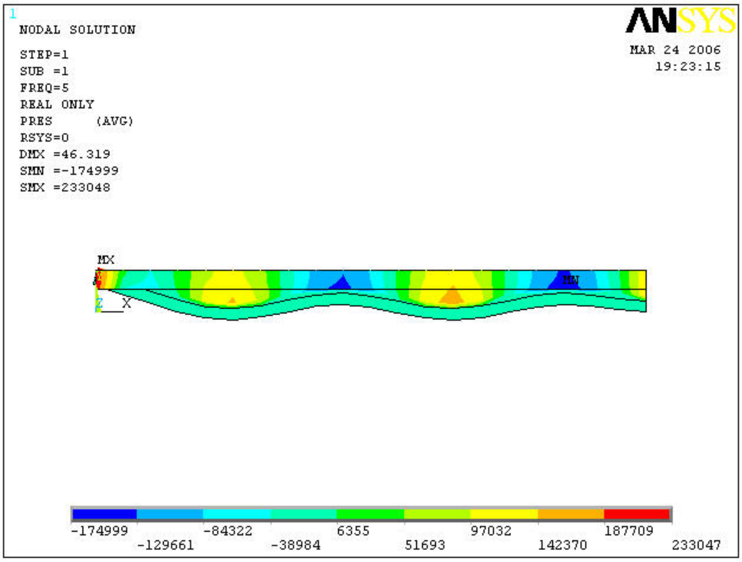

Figure 5.28 Pressure drop in the whole system in 2D

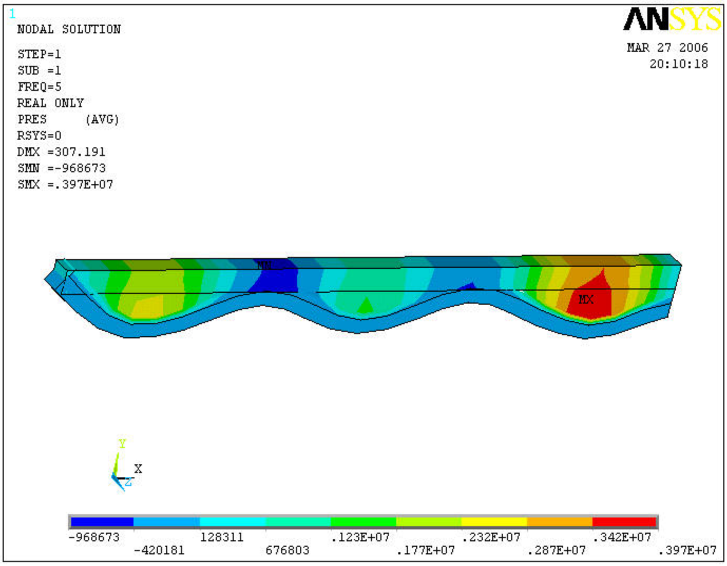

Figure 5.29 Pressure drop in the whole system in 3D

The Following is the FE Model of the assembly for an elemental indication of the cavitation location on the solid structure

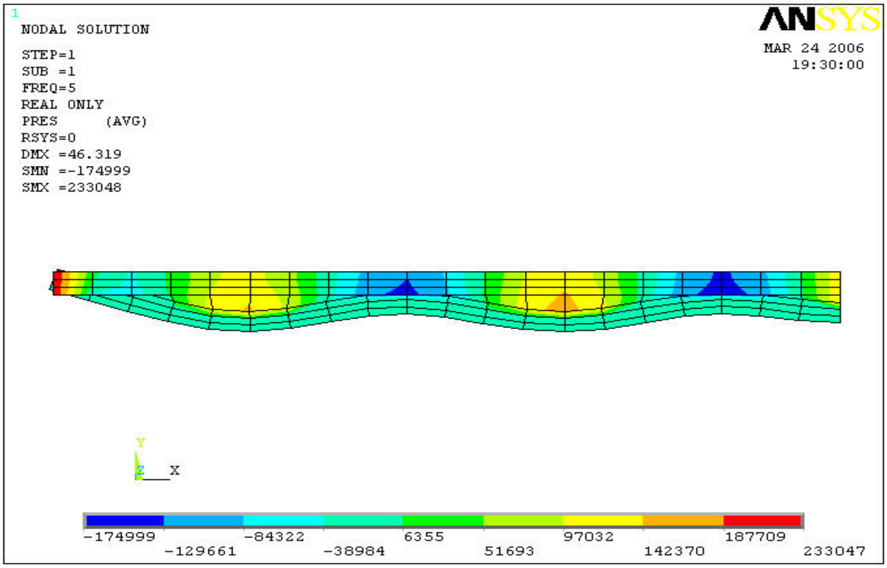

Figure 5.30 Pressure drop in the whole system in with elemental description

Figure 5.31 is a graphical representation of pressure variation along the solid surface from the 2D analysis (The negative pressures indicate the presence of cavitation).

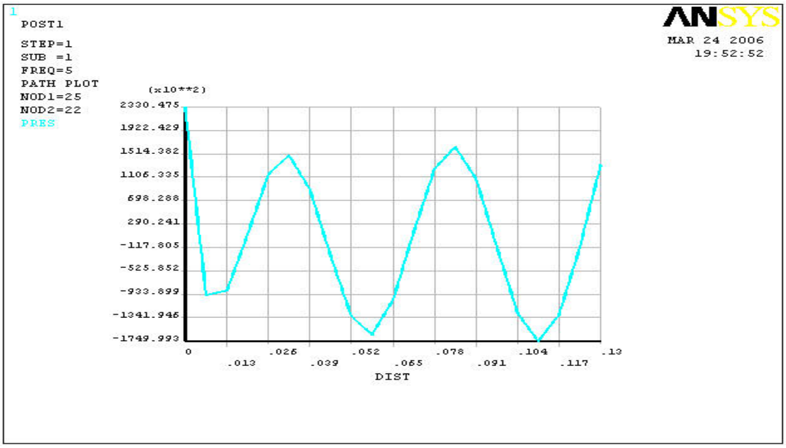

Figure 5.31 Distance Vs pressure curve from 2D analysis

Observations: from the 2D model of the harmonic analysis, with reference to figure 5.30 and figure 5.31, it can be seen that there were area along the solid fluid regions where there were negative pressures. Below is a list of some nodes with negative pressures in the FE model at the interface from the 2D. The whole data is shown in the Appendix A, giving the values of all the nodes at the fluid structure region.

LOAD STEP= 1

SUBSTEP= 1
FREQ= 5.0000

LOAD CASE= 0

NODE	PRES
29	51071.
30	-54281.
31	-0.12873E+06
32	-0.13240E+06
33	-59792.
38	-50498.
39	-0.17839E+06
40	-0.22010E+06
41	-0.13251E+06
15	-39712.
116	-0.10011E+06
117	-0.10385E+06
118	-47063.
123	-39408.
124	-0.13962E+06
125	-0.17196E+06
126	-0.10285E+06

Note: We are keen in pointing out the nodes where the pressure is negative (mentioned in red) and where we can predict the presence of cavitation. A graph is also plotted below for more precision.

Pressure drop curve along the length of the beam for the 3D Model is shown in figure 5.32.

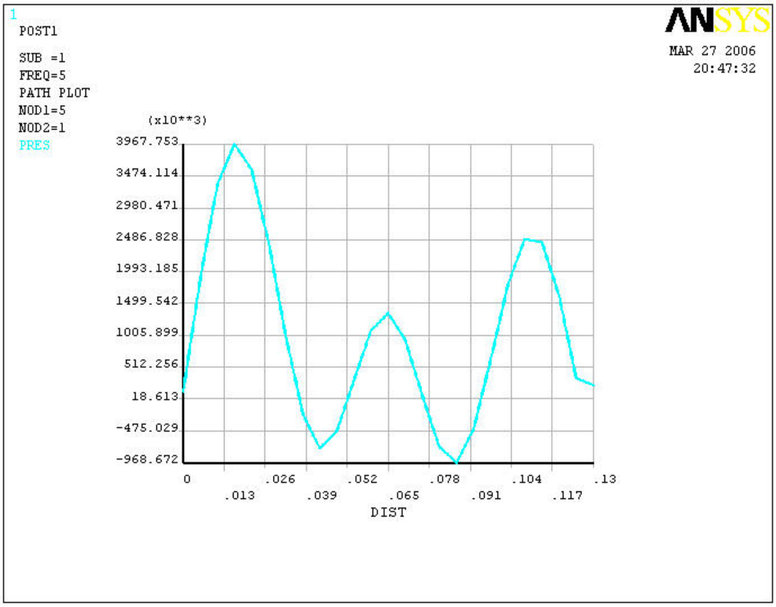

Figure 5.32 Distance Vs pressure curve from 3D analysis

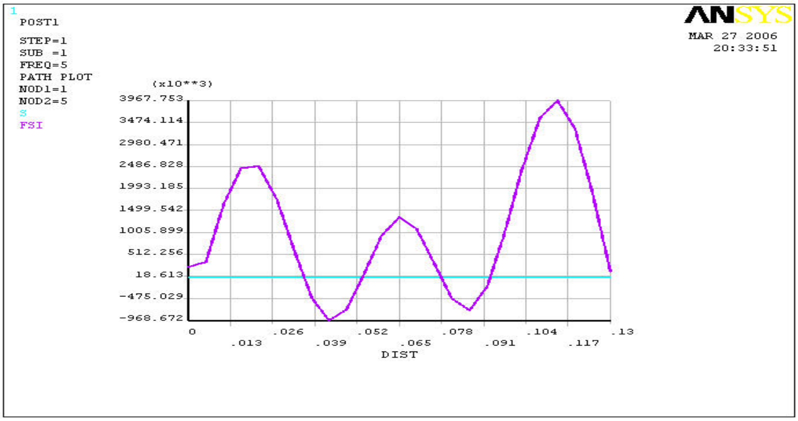

Figure 5.33 Distance Vs pressure curve from 3D analysis. This shows pressure variation along the fluid-structure interface caused by the vibration in cylinder. The green line being the mean pressure

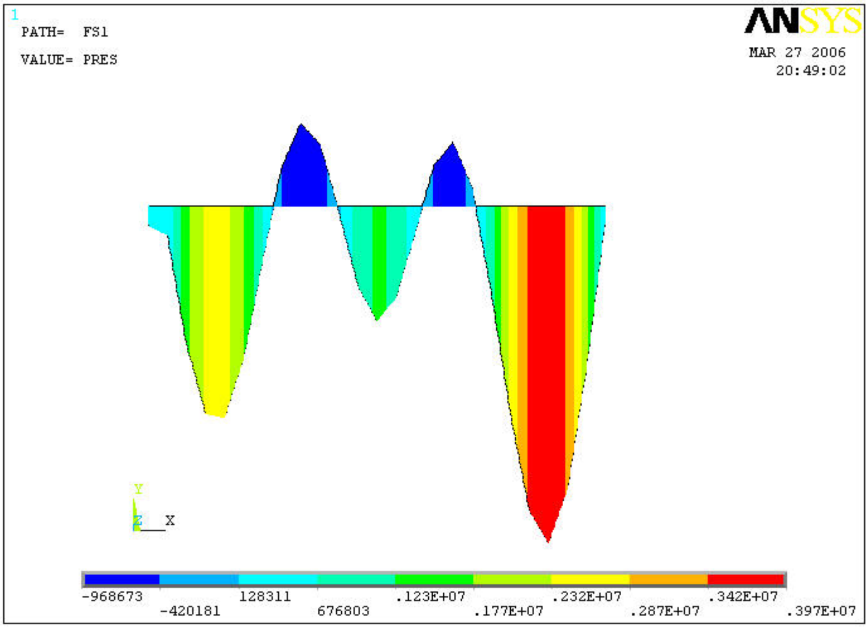

Figure 5.34 The figure below shows the proportion of area under different pressures.

6 Discussion and Conclusions

The presence of cavitation in IC Diesel engines is real and cannot be overlooked. Its damaging effect leads to economic and material constrain on its owners.

In this study much was done on the literature review of cavitation, force equations on the piston cylinder/assembly of an IC diesel engine and geometrical model of the piston and the cylinder.

The data gathered were used as boundary conditions to generate a model using the software ANSYS.

A steady state analysis and a harmonic analysis were considered for both a 2D and a 3D model. Use was also made of a thermal and acoustic properties pertaining to grey cast iron and fluid, the materials in question. The effect of thermal properties led to results of higher values of pressure variations in magnitude.

From the results gathered it was shown that there were areas along the fluid/solid boundary that experienced negative pressures, the purpose of the work, negative pressure predicts that cavitation can occur.

This work was done using ANSYS. In furtherance to this work can be done using other software like IDEAS to get the mode shapes and other quantise that were not done here.

6.1 Towards the future

An effort has been made to analyse the sources and types of cavitation. Piston slap is a source of Vibratory cavitation and Acoustic cavitation as well.

So to reduce the cavitation the piston motion has to be studied and the following are some of the ways of reducing the vibrations and noise coming from the piston-slap [7]

1. Reducing the clearance between piston and cylinder liner, this is based on the assumption that the impacting energy increases with increasing the lateral travel distance of the piston. Although this technique is simple and easy to understand, there are a few

drawbacks, it is difficult to achieve such a small clearance on the production line and maintain it during the whole operating life of the engine. If the clearance is too small then it’s a source of a wear and tear in the engine.

2. Wrapping the piston skirt with leather, this is an attempt to add a cushioning or a compliant material on the piston side. This method is not directly applicable due to its durability. But a similar technique has been developed with Teflon pad on the thrust side.

Following are some of the modern developments in the piston design in reducing the vibrations and noise:

1. Thermal strut piston
2. Articulated piston
3. Piston pin offset

A *Thermal strut piston* contains a steel strut inside the piston skirt. This strut controls the clearance between the piston and the cylinder wall during all operating conditions by controlling thermal expansion.

An *Articulated piston* is a combination of two pistons which perform the two main functions of a piston separately, that of a slider and vertical load carrier. The piston is divided into two parts connected to each other by a piston pin. The upper part (mainly ring land) carries the combustion force and can rock back and forth. The lower part (skirt) slides up and down in the cylinder. With this design it is easier to control the oil film thickness than when using a solid piston.

Piston pin offset is commonly used and the idea is to shift the impact timing by setting the piston off the centre line of the piston and thus centre in the cylinder. The amount of offset might differ from cylinder to cylinder.

Studies of the performance of the above mentioned and other designs are left as suggestions for future work.

7 References

1. F.Ronald Young,(1989), Wartford college, Hertfordshire, Cavitation McGraw-Hill Publishing company.
2. R. T. Knapp, J.W.Daily, F.G.Hammitt, (1970), Cavitation, McGraw-Hill Publishing company.
3. S.-H Cho, S.-T.Ahn and Y.-H. Kim, (2001), A Simple Model to Estimate the Impact Force Induced by Piston Slap, Journal of Sound and Vibration vol.255 (229-242).
4. E.E. Ungar,D.Ross,(1965), Vibration and Noise Due to Piston-Slap in reciprocating Machinery, Journal of Sound and Vibration 2, Bolt Beranek and Newman Incorporated (132-146).
5. J.E.Shigley,J.J.Uicker,Jr,(1980),Theory of Machines and Mechanisms, McGraw- Hill Publishing company.
6. ANSYS Release 9 Documentation
7. www.answers.com
8. Sam D.Hadad, (1992), Theoretical Treatment of Piston Motion in I.C. Piston engine for the prediction of piston slap excitation, Mechanism and Machine Theory vol.30 (253-269)
9. W.J. Griffiths and J. Skorecki, (1964). Some Aspects of Vibration of a Single Cylinder Diesel Engine, Journal of Sound and Vibration vol. 1 (345-364)
10. S. D.Hadad and P.W Fortscue,(1976), Simulating Piston Slap by Analogue Computer, Journal of Sound and Vibration vol. 52 (79-80)

Appendix A, Nodal pressure

Following is the pressure at all the nodes in the interface of the solid and the fluid for the 2 dimensional simulations.

(Thermal properties were also included)

LOAD STEP=1

SUBSTEP=1
FREQ= 5.0000

LOADCASE=0

NODE	PRES
26	0.16228E+06
27	0.17357E+06
28	0.13750E+06
29	51071.
30	-54281.
31	-0.12873E+06
32	-0.13240E+06
33	-59792.
34	53369.
35	0.14609E+06
36	0.16338E+06
37	87077.
38	-50498.
39	-0.17839E+06
40	-0.22010E+06
41	-0.13251E+06
42	68719.
43	0.30552E+06
44	0.46866E+06
106	0.13172E+06
107	0.13172E+06
108	0.13172E+06
109	0.13172E+06
110	0.23305E+06

111	0.15354E+06
112	0.15555E+06
113	0.11987E+06
114	46505.
115	-39712.
116	-0.10011E+06
117	-0.10385E+06
118	-47063.
119	41873.
120	0.11483E+06
121	0.12849E+06
122	68584.
123	-39408.
124	-0.13962E+06
125	-0.17196E+06
126	-0.10285E+06
127	54009.
128	0.23590E+06
129	0.34258E+06
130	0.23305E+06
131	0.23305E+06
132	0.23305E+06
133	0.40988E+06
134	0.37143E+06
135	0.34964E+06
136	0.27502E+06
137	0.25323E+06
138	0.24022E+06
139	62055.
140	57531.
141	54883.
142	-0.11916E+06
143	-0.10999E+06
144	-0.10462E+06
145	-0.19854E+06
146	-0.18361E+06
147	-0.17485E+06
148	-0.16102E+06
149	-0.14901E+06
150	-0.14195E+06
151	-45533.
152	-42094.
153	-40074.

154	78790.
155	73059.
156	69693.
157	0.14775E+06
158	0.13694E+06
159	0.13058E+06
160	0.13208E+06
161	0.12239E+06
162	0.11670E+06
163	48217.
164	44654.
165	42562.
166	-54095.
167	-50148.
168	-47828.
169	-0.11962E+06
170	-0.11077E+06
171	-0.10556E+06
172	-0.11593E+06
173	-0.10705E+06
174	-0.10183E+06
175	-47789.
176	-43265.
177	-40595.
178	48976.
179	47573.
180	46767.
181	0.12955E+06
182	0.12410E+06
183	0.12092E+06
184	0.16548E+06
185	0.15990E+06
186	0.15663E+06
187	0.15850E+06
188	0.15575E+06

MAXIMUM ABSOLUTE VALUES
NODE 44
VALUE 0.46866E+06

Appendix B, Some ANSYS documentation

This information was taken from the ANSYS release 9 documentation.

Overview Of Harmonic Response Analysis

Definition Of Harmonic Response Analysis:

Harmonic response analysis is a technique to predict the sustained dynamic behavior of structures. A sustained cyclic load will produce a sustained cyclic response (a harmonic response) in a structural system. Thus it enables a study on sustainability of overcoming resonance, fatigue, and other harmful effects of forced vibrations in various structural designs.

Application of Harmonic Response Analysis

Harmonic response analysis is a technique used to determine the steady-state response of a linear structure to loads that vary sinusoidally (harmonically) with time. The idea is to calculate the structure's response at several frequencies and obtain some response quantity (usually displacements) versus frequency. "Peak" responses are then identified on the graph and stresses reviewed at those peak frequencies.

This analysis technique calculates only the steady-state, forced vibrations of a structure. The transient vibrations, which occur at the beginning of the excitation, are not accounted for in a harmonic response analysis.

Harmonic Response Systems

It is important to note that Harmonic response analysis is a linear analysis. Some nonlinearities, such as plasticity will be ignored, even if they are defined in Ansys. However, unsymmetric system matrices such as those encountered in a fluid-structure interaction problem Harmonic analysis can also be performed on a prestressed structure.

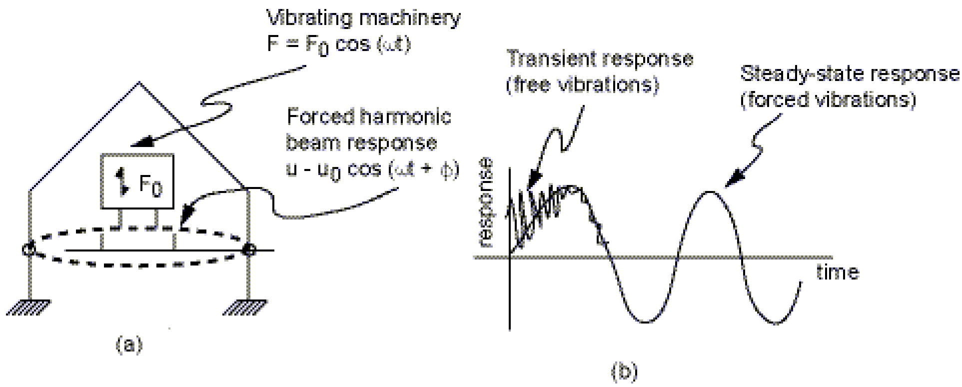

Figure Demonstrating a Typical Harmonic Response System used to model the Dynamic behavior of structures. F_0 *and* ω *are known,* u_0 *and* ϕ *are unknown (a). Transient and steady-state dynamic response of a structural system (b).*

Harmonic Acoustic Analysis

For a harmonic acoustic analysis, following points are to be considered:

Element Types used

- These element types are used to model the fluid portion. FLUID29 and FLUID30 are used to model the fluid portion of 2-D and 3-D models respectively.
- FLUID129 and FLUID130, companion elements to FLUID29 and FLUID30, are used to model an infinite envelope around the FLUID29 and FLUID30 elements.
- These element types are used to model the structural element (PLANE42, SOLID45, etc.) for the solid.

Following is a brief note of the Element types, their shape and application

PLANE42 ELEMENT DESCRIPTION:

PLANE42 is used for 2-D modeling of solid structures. The element can be used either as a plane element (plane stress or plane strain) or as an axisymmetric element.

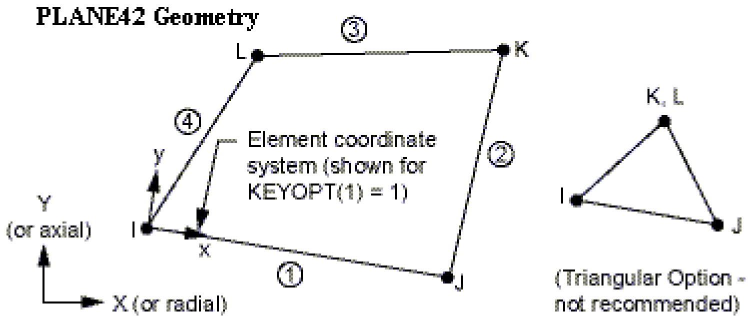

Figure demonstrating PLANE42 Geometry used to model the solid surface in the 2D model study.

The element is defined by four nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

SOLID45 ELEMENT DESCRIPTION:

SOLID45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

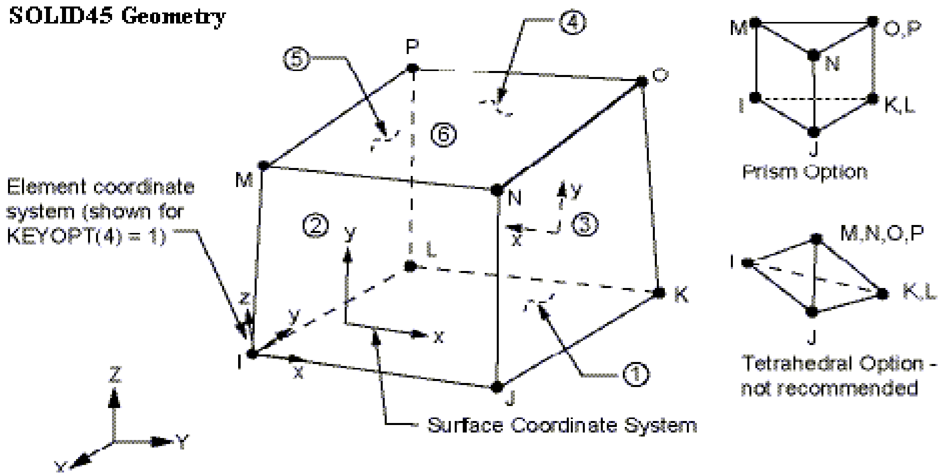

Figure demonstrating SOLID45 Geometry used to model the solid surface in the 3D model study.

The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. A reduced integration option with hourglass control is available.

PLANE55 ELEMENT DESCRIPTION:

PLANE55 can be used as a plane element or as an axisymmetric ring element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node.

The element is applicable to a 2-D, steady-state or transient thermal analysis. The element can also compensate for mass transport heat flow from a constant velocity field. If the model containing the temperature element is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as PLANE42).

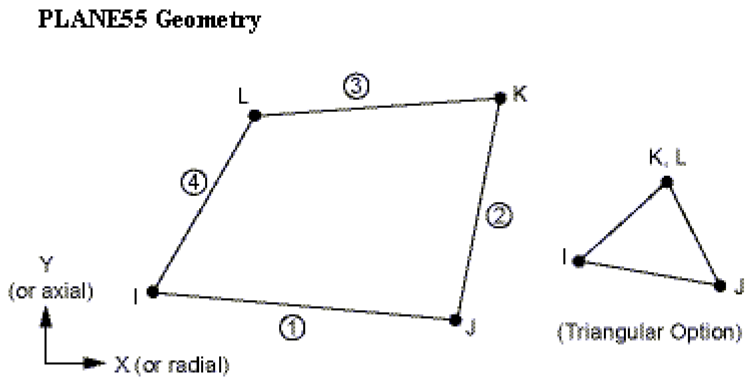

Figure demonstrating Plane55 Geometry used to model the solid surface in Thermal Analysis in the 2D model study.

An option exists that allows the element to model nonlinear steady-state fluid flow through a porous medium. With this option the thermal parameters are interpreted as analogous fluid flow parameters.

SOLID70 ELEMENT DESCRIPTION:

SOLID70 has a 3-D thermal conduction capability. The element has eight nodes with a single degree of freedom, temperature, at each node.

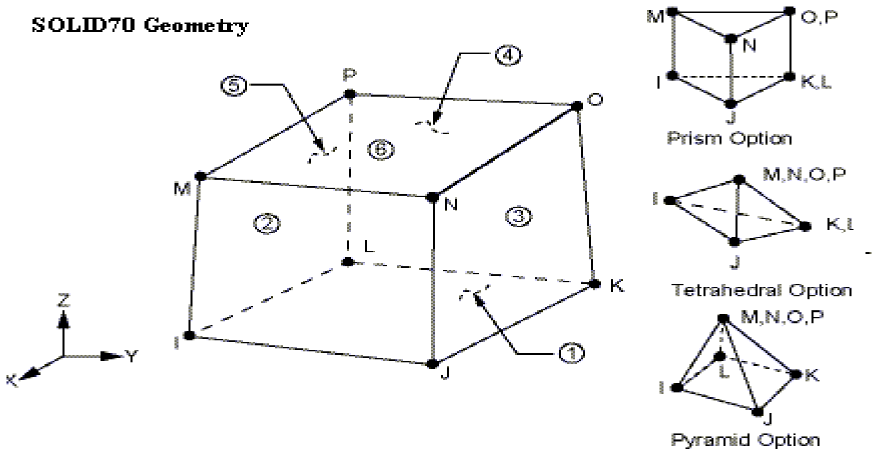

Figure demonstrating Solid70 Geometry used to model the solid surface in Thermal Analysis in the 3D model study.

The element is applicable to a 3-D, steady state or transient thermal analysis. The element also can compensate for mass transport heat flow from a constant velocity field. If the model containing the conducting solid element is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SOLID45).

FLUID29 ELEMENT DESCRIPTION:

FLUID29 is used for modeling the fluid medium and the interface in fluid/structure interaction problems. Typical applications include sound wave propagation and submerged structure dynamics. The governing equation for acoustics, namely the 2-D wave equation, has been discretized taking into account the coupling of acoustic pressure and structural motion at the interface. The element has four corner nodes with three degrees of freedom per node: translations in the nodal x and y directions and pressure. The translations, however, are applicable only at nodes that are on the interface.

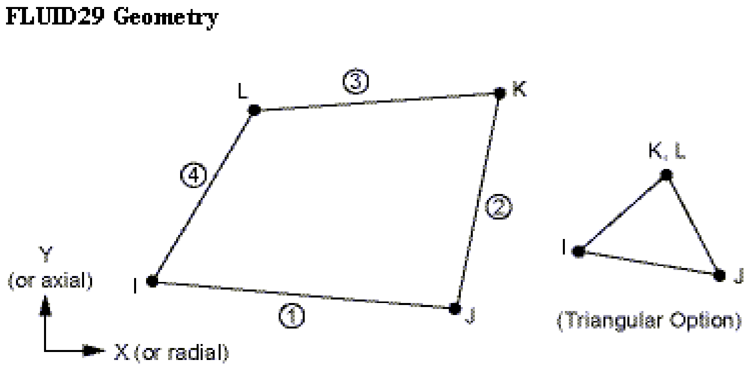

Figure demonstrating Fluid29 Geometry used to model the Fluid surface in Fluid/Structure interaction in the 2D model study

The element has the capability to include damping of sound absorbing material at the interface. The element can be used with other 2-D structural elements to perform unsymmetric or damped modal, full harmonic response and full transient method analyses. When there is no structural motion, the element is also applicable to static, modal and reduced harmonic response analyses.

FLUID30 ELEMENT DESCRIPTION:

FLUID30 is used for modeling the fluid medium and the interface in fluid/structure interaction problems. Typical applications include sound wave propagation and submerged structure dynamics. The governing equation for acoustics, namely the 3-D wave equation, has been discretized taking into account the coupling of acoustic pressure and structural motion at the interface. The element has eight corner nodes with four degrees of freedom per node: translations in the nodal x, y and z directions and pressure. The translations, however, are applicable only at nodes that are on the interface.

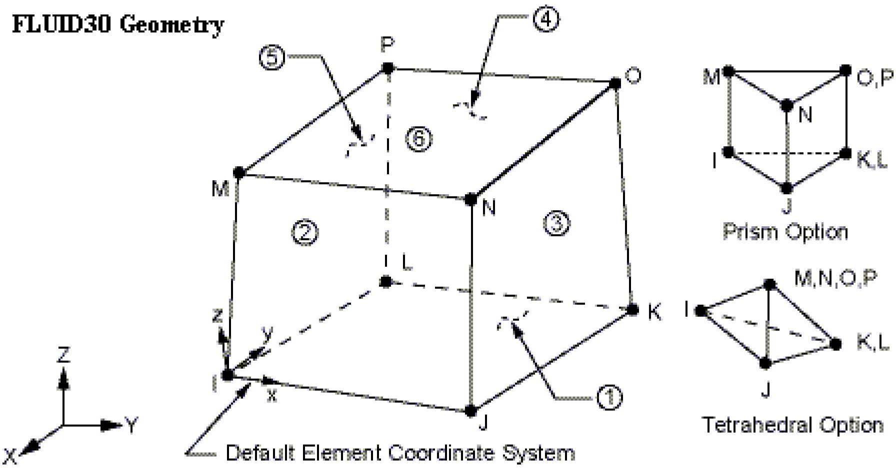

Figure demonstrating Fluid30 Geometry used to model the Fluid surface in Fluid/Structure Interaction in the 3D model study

The element has the capability to include damping of sound absorbing material at the interface. The element can be used with other 3-D structural elements to perform unsymmetric or damped modal, full harmonic response and full transient method analyses. When there is no structural motion, the element is also applicable to static, modal and reduced harmonic response analyses.

FLUID129 ELEMENT DESCRIPTION:

FLUID129 has been developed as a companion element to FLUID29. It is intended to be used as an envelope to a model made of FLUID29 finite elements. It simulates the absorbing effects of a fluid domain that extends to infinity beyond the boundary of FLUID29 finite element domain.

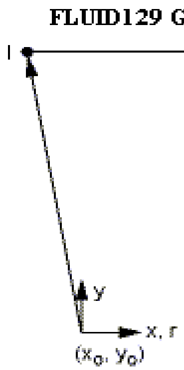

Figure demonstrating Fluid129 Geometry used to model the Envelope over the Fluid surface in Fluid/Structure Interaction in the 2D model study.

FLUID129 realizes a second-order absorbing boundary condition so that an outgoing pressure wave reaching the boundary of the model is “absorbed” with minimal reflections back into the fluid domain. The element can be used to model the boundary of 2-D (planar or axisymmetric) fluid regions and as such, it is a line element; it has two nodes with one pressure degree of freedom per node. FLUID129 may be used in transient, harmonic, and modal analyses. Typical applications include structural acoustics, noise control, underwater acoustics, etc.

FLUID130 ELEMENT DESCRIPTION:

FLUID130 has been developed as a companion element to FLUID30. It is intended to be used as an envelope to a model made of FLUID30 finite elements. It simulates the absorbing effects of a fluid domain that extends to infinity beyond the boundary of the finite element domain that is made of FLUID30 elements.

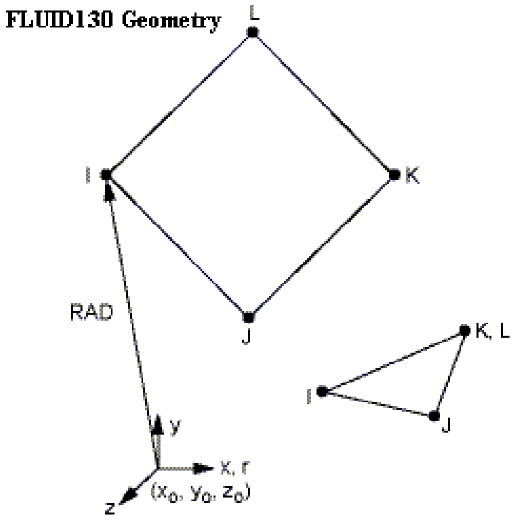

Figure demonstrating Fluid130 Geometry used to model the Envelope over the Fluid surface in Fluid/Structure Interaction in the 3D model study

FLUID130 realizes a second-order absorbing boundary condition so that an outgoing pressure wave reaching the boundary of the model is “absorbed” with minimal reflections back into the fluid domain. The element can be used to model the boundary of 3-D fluid regions and as such, it is a plane surface element; it has four nodes with one-pressure degrees of freedom per node. FLUID130 may be used in transient, harmonic, and modal analyses. Typical applications include structural acoustics, noise control, underwater acoustics, etc.

Important Steps to be followed during Preprocessing:

For acoustic elements that are in contact with the solid, it should be made sure to use KEYOPT(2) = 0, the default setting that allows for fluid-structure interaction. This results in unsymmetric element matrices with UX, UY, UZ, and PRES as the degrees of freedom. For all other acoustic elements, set KEYOPT(2) = 1, which results in symmetric element matrices with the PRES degree of freedom.

These infinite acoustic elements absorb the pressure waves, simulating the outgoing effects of a domain that extends to infinity beyond the FLUID29 and FLUID30 elements. FLUID129 and FLUID130 provide a second-order absorbing boundary condition so that an outgoing pressure wave reaching the boundary of the model is absorbed with minimal reflections back into the fluid domain.

FLUID129 is used to model the boundary of 2-D fluid regions and as such is a line element. FLUID130 is used to model the boundary of 3-D fluid regions and as such is a plane surface element.

Material Properties - The acoustic elements require density (DENS) and speed of sound (SONC) as material properties (FLUID129 and FLUID130 require only SONC). If sound absorption at the fluid-structure interface exists, use the label MU to specify boundary admittance β (absorption coefficient). Values of β are usually determined from experimental measurements. For the structural elements, specify the Young's modulus (EX), density (DENS), and Poisson's ratio (PRXY or NUXY).

Real Constants - When using FLUID129 and FLUID130, the boundary of the underlying finite element mesh must be circular (2-D and axisymmetric) or spherical (3-D), and the radius of the circular or spherical boundary of the finite domain must be specified as real constant RAD. The center of the circle or sphere is also specified using real constants:

R,3,RAD,X0,Y0!REAL set 3 for FLUID129

R,3,RAD,X0,Y0,Z0!REAL set 3 for FLUID130

If the coordinates (X0, Y0) for the 2-D and axisymmetric cases or (X0, Y0, Z0) for the 3-D case of the center of the circle or sphere are not specified via real constants, ANSYS assumes the center to be the origin of the global coordinate system. ANSYS[6]

Department of Mechanical Engineering, Master's Degree Programme
Blekinge Institute of Technology, Campus Gräsvik
SE-371 79 Karlskrona, SWEDEN

Telephone: +46 455-38 55 10
Fax: +46 455-38 55 07
E-mail: ansel.berghuvud@bth.se