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Mathematical Investigation on the Physiological Effects of Road Traffic Noise: A Reference to Varying Frequency

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Abstract: *In this paper mathematical modeling to assess physiological effects of noise has been studied. Effects of prolonged noise exposure from human beings leading to increase in the diastolic blood pressure up to 8.8 mm Hg (threshold shift) cause the variation on the pulse rate, the total peripheral resistance, the narrowing of the arteries (mild stenosis). Analytical solutions of Bessel's functions have been solved using series solution method. Measurements of blood pressure and heart rate for the noise exposed people have been recorded for systolic and diastolic blood pressures. Noise related data have been recorded at the selected noisy locations [L-1, L-2, and L-3] with 5m, 10m, 15m distance from the center of the road in and around Davangere city (Karnataka, India). TES-1351 the noise investigator is used to measure sound pressure level (SPL) and equivalent sound level (L_{eq}). Results show the temporary threshold shift (TTS) in the hearing process. Model predicts the increase in mean systolic and diastolic pressure with 5-8 mm Hg.*

Key Words: *noise, blood, pressure, artery.*

1. INTRODUCTION:

Noise can act as a distracting stimulus and may also affect the psychological health of the individual. This leads to extra strain on the body induced by noise. It may cause the development of fatigue either directly or indirectly through interference with sleep, indeed, all performances can be adversely affected by noise. It has been observed that certain types of noise especially those of an impulsive nature may cause a startle reflex even at low levels. Numerical clinical symptoms and signs like changes in blood pressure, heart beat have also been attributed many a time to noise exposure. Nausea, headache, insomania and loss of appetite are also said to be caused by excessive noise exposure. Continuous noise exposure has been found to cause constriction of blood vessels in humans which may eventually lead to heart ailments. This potential of noise is indicated by higher incidence of atherosclerosis and coronary heart diseases among humans exposed to noise and comparatively higher incidence of hypertension and bradycardia cases among workers in more noisy work places. The above type of ambiguities observed in the physiological and psychological effects present difficulties in the actual assessment of casual relationship between noise exposure and non-specific health effects. The problem is that increase in blood pressure, heart diseases, gastric ulcers and other stress related syndromes have a multi-factorial origin including social class, personel habits and personality characteristics besides noise. Noise induced hearing loss and presbycusis are basically similar that both occur in the inner ear, both have their initial effect on hearing at the higher frequencies, both develop slowly in the individual and they are additive. However, the two effects also have their differences in Noise Induced Hearing Loss (NIHL) shows a maximum at around 4KHz while presbycusis continues to increase towards higher audio frequencies also.

Ruth F. Curtan[1] illustrated by taking the example of stochastic partial differential equations. Les Frair [2] incorporates population distribution considerations around an airport and the annoyance caused by aircraft noise. Roland Leduc et. al. [3] showed the best prediction capabilities while the next best is the stochastic initial condition model. G. Naadimuthuet. al. [4] applied the quasilinearisation method to the modeling of the air pollution. P. C. Chatwin. et. al. [5] summarized recent theoretical work on turbulent diffusion that is based on a simple extension of exact results for the ideal case when there is no molecular diffusion.Campbell Steele [6] assumed a line source and constant speed traffic, and in Britain is thesole instrument for the assessment of road traffic environmental impacts by roadauthorities.Sheng-TunLiet. al. [7] proposed two-level self-organization map neural network that demonstrates its ability in identifying clusters on the highdimensionalwavelet-transformed space.Zaheeruddinet. al. [8] developed a fuzzy expert system for predicting the effect of sleep disturbance by noise on humans as a function of noise level. Dennis Guignet [9] suggested that people are capable of interpreting pollution concentrations and in turn expressing how they think property values are impacted. Heather Mcmullen, et. al. [10] provided evidence that individuals adjust their signals during vocal interactions to change the acoustic environment therefore. C. Brehmet. al. [11] provided an overview of the numerical solver and the computational setup used to perform LES of the FJID. An evaluation of the mean flow and its unsteady flow features is provided.Chao Lu et al.[12] studied the hybrid flowship scheduling problem widely and compare the results with other research works, these results show accurate findings.

In the present study, the flow parameters velocity, wall shear stress and pressure gradient are employed. These parameters show that the varying frequency will induces the effect on the physiological flow.

2. FORMULATION:

For the human artery, the narrowing (constriction) phenomena have been considered for the aortic valve. The flow has been taken as pulsatile to predict the present model as the problem of noise induced heart rate and aorta valve vibration. The fluid (blood) is incompressible, Newtonian fluid and the aorta is taken as axisymmetric tube.

Boundary of the axisymmetric aorta is given by,

$$R = R_0 + \left(\frac{R_0 f_i}{c}\right)\sin\left(\frac{2\,\pi\, f_i\, z}{c}\right) \tag{1}$$

where z - axial distance, f_i - frequency, c – wave speed, R_0 - radius of unconstricted aorta.

Governing equations in cylindrical polar co-ordinate system for the axisymmetric case is given by,

$$\frac{\partial u_r}{\partial t} + u_r\frac{\partial u_r}{\partial r} + u_z\frac{\partial u_r}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial r} + \nu\left[\frac{\partial^2 u_r}{\partial r^2} + \frac{\partial^2 u_r}{\partial z^2} - \frac{u_r}{r^2} + \frac{1}{r}\frac{\partial u_r}{\partial r}\right] \tag{2}$$

$$\frac{\partial u_z}{\partial t} + u_r\frac{\partial u_z}{\partial r} + u_z\frac{\partial u_z}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + \nu\left[\frac{\partial^2 u_z}{\partial r^2} + \frac{\partial^2 u_z}{\partial z^2} + \frac{1}{r}\frac{\partial u_z}{\partial r}\right] \tag{3}$$

$$\frac{\partial u_r}{\partial r} + \frac{\partial u_z}{\partial z} + \frac{u_r}{r} = 0 \tag{4}$$

Eliminating pressure gradient term from (2) and (3) and introducing the values of stream functions as,

$$u_z = -\frac{1}{r}\frac{\partial \psi}{\partial r} \tag{5}$$

$$u_r = \frac{1}{r}\frac{\partial \psi}{\partial z} \tag{6}$$

We obtain,

$$\left[\frac{\partial}{\partial t} + \frac{1}{r}\frac{\partial \psi}{\partial z}\frac{\partial}{\partial r} - \frac{1}{r}\frac{\partial \psi}{\partial r}\frac{\partial}{\partial z} - \frac{2}{r^2}\frac{\partial \psi}{\partial z}\right]\left[\frac{\partial^2 \psi}{\partial z^2} + \frac{\partial^2 \psi}{\partial r^2} - \frac{1}{r}\frac{\partial \psi}{\partial r}\right] = \nu\nabla^2\left[\frac{\partial^2 \psi}{\partial z^2} + \frac{\partial^2 \psi}{\partial r} - \frac{1}{r}\frac{\partial \psi}{\partial r}\right] \tag{7}$$

Introduce

$$\nabla^2 = \frac{\partial^2}{\partial z^2} + \frac{\partial^2}{\partial r^2} - \frac{1}{r}\frac{\partial}{\partial r} \tag{8}$$

$$\nabla^4\psi = \nabla^2(\nabla^2\psi) \tag{9}$$

We obtain from equation (7) as,

$$\left[\frac{\partial}{\partial t} + \frac{1}{r}\frac{\partial \psi}{\partial z}\frac{\partial}{\partial r} - \frac{1}{r}\frac{\partial \psi}{\partial r}\frac{\partial}{\partial z} - \frac{2}{r^2}\frac{\partial \psi}{\partial z}\right]\nabla^2\psi = \nu\nabla^4\psi \tag{10}$$

Boundary conditions are,

$$\left.\begin{aligned} \frac{1}{r}\frac{\partial \psi}{\partial r} &= 0 \text{ and} \\ \frac{1}{r}\frac{\partial \psi}{\partial z} &= 0 \end{aligned}\right\} \tag{11}$$

$$\psi = \text{constant at } r = R \tag{12}$$

Setting dimensionless quantities,

$$z' = \frac{z}{\lambda},\ r' = \frac{r}{R_0},\ \psi' = \frac{\psi}{R_0},\ t' = \frac{\nu t}{\lambda R_0},\ R' = \frac{R}{R_0} \tag{13}$$

Then equations (7) to (13) becomes,

$$\left(\frac{R_0 f_i}{c}\right)\left[\frac{\partial}{\partial t} + \frac{1}{r}\frac{\partial \Psi}{\partial z}\frac{\partial}{\partial r} - \frac{1}{r}\frac{\partial \Psi}{\partial r}\frac{\partial}{\partial z} - \frac{2}{r^2}\frac{\partial \Psi}{\partial z}\right]E^2\Psi = E^4\Psi \tag{14}$$

where

$$E^2 = \left(\frac{R_0 f_i}{c}\right)^2 \frac{\partial^2}{\partial z^2} + \frac{\partial^2}{\partial r^2} - \frac{1}{r}\frac{\partial}{\partial r} \tag{15}$$

$$h = \left(\frac{R_0 f_i}{c}\right) < 1 \tag{16}$$

Then

At $r = \pm R$

$$\left.\begin{aligned} \frac{\partial \psi}{\partial r} &= 0 \text{ and} \\ \frac{\partial \psi}{\partial z} &= 0 \end{aligned}\right\} \tag{17}$$

$$\psi = \text{constant at } r = R \tag{18}$$

3. ANALYSIS:

The noise produced vibrations show the variations on the arterial pressure. As a result, the characteristics of the fluid conveying vessels well associated with the flow system are stressful one. Such characteristics stimulate the sympathetic nerve fibers in blood flow through the vessels. Then the stream function ψ can be written as an asymptotic power series in $\left(\frac{R_0 f_i}{c}\right)$ as,

$$\Psi = \Psi_0 + \left(\frac{R_0 f_i}{c}\right)\Psi_1 + \left(\frac{R_0 f_i}{c}\right)^2 \Psi_2 + \cdots \tag{19}$$

Substituting equation (19) in equations (14) – (18) and collecting the zero and first order terms on both sides, then substituting,

$$\psi_0 = \psi_{00}\, e^{i\omega t},$$

$$\psi_1 = \psi_{10} + \psi_{11}\, e^{i\omega t} + \psi_{12}\, e^{2i\omega t}, \tag{20}$$

Further solving for stream function, we obtain,

$$\Psi = R_1{}^2\left(2 - R_1{}^2\right) + \left(\frac{R_0 f_i}{c}\right)\begin{Bmatrix} \frac{4i\omega R^2}{192}\left(1 - 3R_1{}^2 + 2R_1{}^6\right)e^{i\omega t} + \\ \frac{1}{36}\frac{1}{R}\frac{\partial R}{\partial z}\left(-5 + 16R_1{}^2 - 12R_1{}^6 + R_1{}^8\right)e^{2i\omega t} \end{Bmatrix} \tag{21}$$

For various values of sound pressure levels, the constriction of the vessel wall varies because the adrenal medulla in response of the activated sympathetic nerve stimulation causes the nerve fibers to dilate. Then we find h as the function of sound pressure value at the increased levels $\left(\frac{R_0 f_i}{c}\right) = f(S_k) = h_k$ where S is the sound pressure level, k takes for repeated series of calculation). Analyzing $f(S_k)$ by Gompertz equation for noise values 5m, 10m, and 15m distances from the centre of the road (i.e.20 ft to the 40 ft width),

$$h = [a]\,[b^c]^{S}$$

Gompertz method is employed to estimate the values of the summations M_1, M_2 and M_3 from the noise table.

Where S_i = 58, 78, 90

For bumped data

$$y = a + bx + \left[\frac{\alpha}{e^{n(X-x)} + e^{n(x-X)}}\right]$$

$$y - \delta^1 = \delta$$

We obtained the axial velocity as,

$$u_z = \begin{Bmatrix} \left(\frac{4}{R^4}\right)\left[6.25 - R^4\right]\cos(\omega t) + \\ + \left(\frac{1.5}{R^2}\right) h_k \omega \left(\frac{6.3}{R^2} - 1\right)\sin(\omega t) - \\ - \left(\frac{25P_G}{R^5} - \frac{(240.8)P_G h_k}{R^7}\right)\cos(2\omega t) \end{Bmatrix} \tag{22}$$

Wall shear stress(WSS) is obtained as,

$$\tau_\omega = \left(\frac{8}{R^3}\right)\cos\omega t + \left(\frac{\omega}{2R}\right) h_k \sin\omega t + \left(\frac{4.4}{R^4}\right) h_k \left(\frac{\partial R}{\partial Z}\right)\cos 2\omega t \tag{23}$$

Axial pressure gradient is computed as,

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$$\frac{\partial p}{\partial z} = \left(\frac{16}{R^4}\right)\cos\omega t + \left(\frac{\omega}{R^2}\right)h_k \sin\omega t + \left(\frac{12.4}{R^5}\right)h_k\left(\frac{\partial R}{\partial Z}\right)\cos 2\omega t \qquad (24)$$

with $R = 1 + \varepsilon \sin\left(\frac{2\pi z}{\lambda}\right), \quad \varepsilon = \frac{h}{R_0}, \quad R_1 = \frac{r}{R_0}$

4. RESULTS AND DISCUSSION:

Model predicts the variation of velocity profiles corresponding to variation of road distances and road heights (table: 1). It indicates the simulation with the behavior of heart rates and blood pressure values of adopted individuals chosen at the selected noisy locations (NH - 4) at Davangere, Karnataka, India. Exposure to the noise by the individuals at 5 meter distance from the center of the road with 10 feet height outside the road gives the insight of the study to predict the first stage evidence of variation of blood flow temporary shift in diastolic values to 3 mm Hg, at 10 meters distance, 7 feet height we noticed less than 2 mm Hg and at 15 meters distance with 5 feet height we noticed less than 1 mm Hg rise in diastolic blood pressure. When these exposures are prolonged then there exists the onset of the effect leads to permanent threshold shift of diastolic blood pressure.

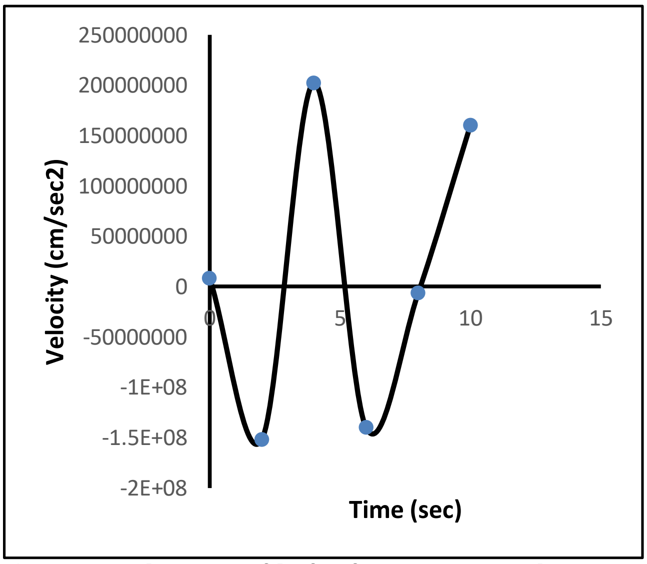

Figure 1: velocity profile for frequency 4000 kHz

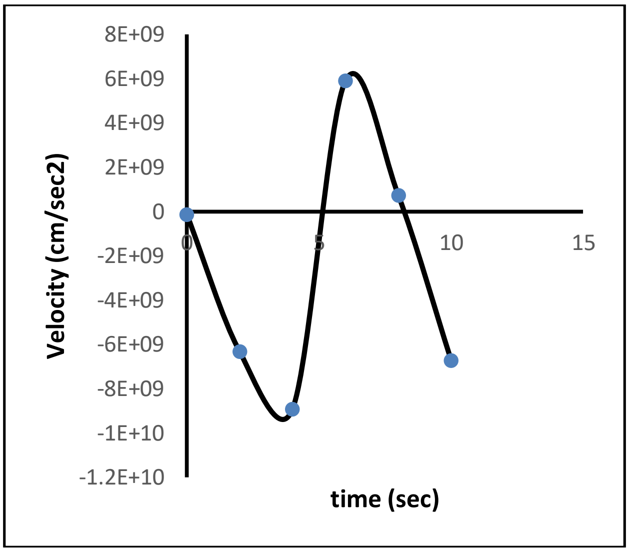

Figure 2: velocity profile for frequency 5000 kHz

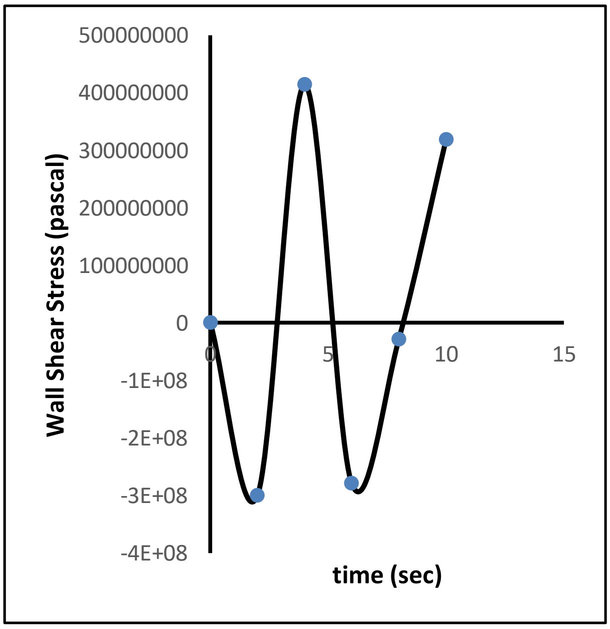

Figure 3: wall shear stress for frequency 4000 kHz

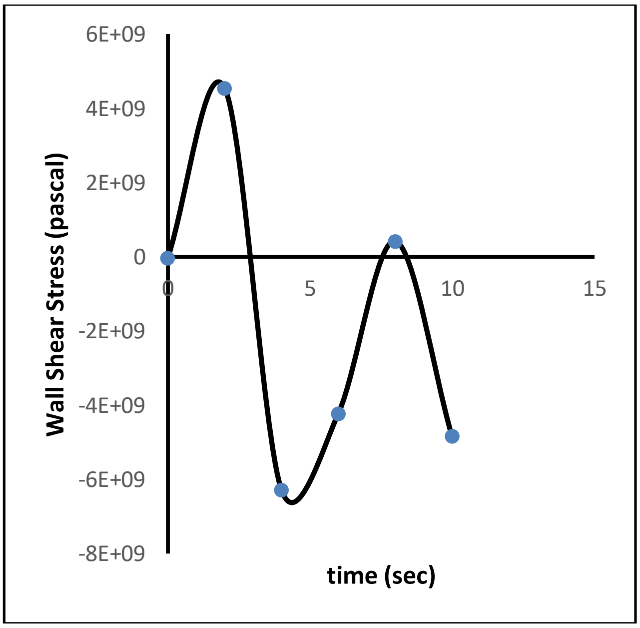

Figure 4: wall shear stress for frequency 5000 kHz

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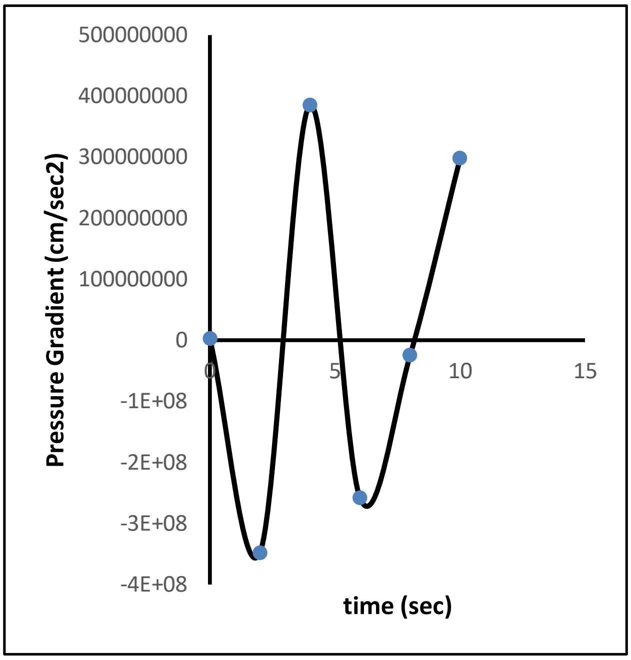

Figure 5: pressure gradient for frequency 4000kHz

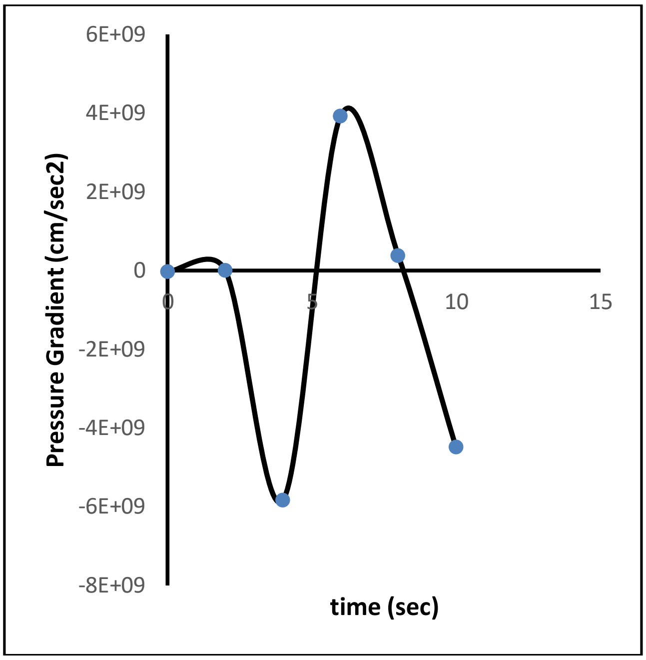

Figure 6: pressure gradient for frequency 5000 kHz

Table 1: Noise measurements at F(L-1), Bada cross

Heights	L_{max}	L_{min}	LF (dB)
h_1	112.8	68.4	117.6
	111.9	68.9	117
	111.2	69.6	116.2
	110.2	69.9	116.4
	110.8	70.8	116.2
h_2	111.8	70.6	116.8
	111.2	70.3	116.2
	110.8	71.8	116.1
	110.2	69.8	115.8
	110	71	116.1
h_3	112.8	71.4	116.2
	110.9	72.3	116.1
	110.1	72.1	116
	110	70.4	115.8
	109.2	70.6	115.1

Table 1: Measurements of blood pressure and heart rate of the noise exposed person on National Highway (NH-4) Pune-Bangaluru road, Davangere, Karnataka, India

Name	**Age**	**Systolic blood pressure mm Hg**			**Diastolic blood pressure mm Hg**			**Heart rate Beats/min**		
		M	**A**	**E**	**M**	**A**	**E**	**M**	**A**	**E**
Manjunath	45	135	143	161	121	126	130	71	79	90
Sathisha	39	111	125	140	70	79	92	94	101	125
Shivaraju	47	127	135	160	111	96	90	87	73	85
Ravi Kamath	38	138	139	145	88	95	100	78	90	105
Preethi	35	114	130	150	70	92	95	77	85	98
Ibhrahim	46	150	123	149	79	73	88	78	81	70
Irshad	48	150	134	145	125	107	112	95	94	98
Ashok	50	107	132	148	69	78	90	106	100	85
Semi Ulla	45	153	132	146	90	87	80	94	94	100
Shobha	39	119	116	135	76	66	95	77	80	91
Shiakumar	37	150	139	153	104	94	100	91	81	85

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