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Effect of Pressure and Temperature on Shock Wave Propagation in Conducting Gas

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ABSTRACT

This study aims to investigate the effects of pressure and temperature on shock wave propagation in conducting gases, focusing on how these variables influence shock wave amplitude, speed, and structure. A theoretical framework is developed to derive the governing equations for shock wave evolution, discontinuity formation, and disturbance propagation, which facilitates an analysis of the gas's thermodynamic properties and their impact on shock behaviour. The findings reveal that increased pressure steepens the pressure gradient and enhances shock wave strength, while higher temperatures provide gas molecules with additional kinetic energy, altering ionization levels and propagation speeds. The interplay between temperature and pressure significantly affects shock wave dynamics, which is crucial for applications in aerospace, engineering, and astrophysics involving high-energy technologies and propulsion systems. Understanding these dynamics is essential for effectively designing systems that utilize shock waves.

Keywords: Shock wave propagation, Conducting gas, Pressure, Temperature, Fluid dynamics, Thermodynamics.

INTRODUCTION

1.1. Background of Shock Wave Propagation:

The sudden change in temperature, pressure, and density that happens when an object travels through a medium faster than sound is known as shock wave propagation. As a result, a shock wave—a kind of disturbance that moves through a gas, liquid, or solid—forms. Understanding phenomena like explosions, supersonic flight, and cosmic events is made easier by studying shock waves, which is important in many domains, including astrophysics, aerodynamics, and engineering. Shock waves propagate through intricate relationships between thermodynamic parameters, molecular dynamics, and media properties. Comprehending these interplays is crucial for forecasting shock wave conduct in diverse scenarios, such as fluctuations in temperature and pressure, which profoundly impact the shock wave's configuration and dynamics.

1.2. Fundamentals of Conducting Gases:

Gases with free charge carriers, like ions or electrons, are known as conducting gases because they may conduct electricity. Plasma and some ionized gasses are typical examples. The electrical conductivity, thermal conductivity, and behaviour at different pressure and temperature levels are the basic characteristics of conducting gases. The way neutral molecules and charged particles interact with one another is a key factor in defining the thermodynamic behaviour of conducting gases. The behaviour of conducting gases can be explained by the Boltzmann transport equation, highlighting the significance of collision dynamics in shock wave propagation. These gases have special properties, like non-equilibrium particle distributions, which can result in intricate shock wave patterns. Because it sheds light on how variations in temperature and pressure affect shock wave propagation and stability, a grasp of the principles of conducting gases is therefore essential to the study of shock wave dynamics.

1.3. Influence of Pressure on Shock Wave Dynamics:

In conducting gases, pressure significantly affects the dynamics of shock waves. Changes in a gas's density usually correspond with an increase in pressure, which modifies the shock wave's strength and speed. A steeper pressure gradient across the shock front caused by higher pressure can increase the amplitude and velocity of the shock wave. According to the Rankine-Hugoniot relations, which characterize the conditions throughout a shock wave, a shock wave becomes more powerful as pressure rises along with the post-shock temperature and density. The structure of the shock wave may also alter, displaying more abrupt state transitions. This behaviour can have important ramifications for real-world applications, like propulsion system design and high-energy event research, where an understanding of shock wave dynamics under varied pressure circumstances is crucial for efficient engineering and safety precautions.

1.4. Role of Temperature in Shock Wave Behaviour:

In conducting gases, shock wave behaviour is highly dependent on temperature. A change in the speed of sound in a medium is caused by the fact that the kinetic energy of gas molecules increases as the temperature rises. Since shock waves move more quickly in hotter gases, this variation in sound speed affects the speed at which they propagate. Furthermore, a gas's state can change at higher temperatures, which can have an impact on its electrical conductivity and ionization levels. The ideal gas law and other thermodynamic equations can be used to explain the relationship between temperature and shock wave behaviour. These equations show how temperature changes affect the amplitude and structure of the shock wave. Higher temperatures in conducting gases can also alter the ionization of the gas, which creates more intricate interactions within the shock wave. Predicting how shock waves will spread in different contexts requires an understanding of how temperature affects shock wave behaviour, especially in high-temperature applications like combustion and aerospace engineering.

1.5. Interrelation Between Pressure, Temperature, and Shock Waves:

In conducting gases, the relationship among temperature, pressure, and shock waves is a crucial and intricate field of research. The state and behaviour of the gas are greatly influenced by temperature and pressure, which in turn affects the properties of shock waves. The ideal gas law states that an increase in pressure usually results in an increase in temperature. On the other hand, if the volume stays the same, the temperature may climb along with the pressure. The interplay between pressure and temperature can modify the thermodynamic parameters of the gas, hence impacting the shock wave's speed, amplitude, and structure. Furthermore, these correlations play a critical role in defining shock wave stability and behaviour in a variety of settings, especially high-energy systems such as those encountered in aerospace and astrophysical contexts. Comprehending this correlation is crucial for forecasting shock wave actions in diverse scenarios, enabling enhanced designs in shock wave-related applications including propulsion systems and explosion dynamics.

DISTURBANCE PROPAGATION EQUATION :

When studying wave propagation in an ideal gas (i.e., assuming constant tension in the presence of changing temperature and density distributions), we can obtain a one-dimensional wave propagation equation that describes perturbations in the gas whose density is spatially dependent and is denoted by ρ 0(x). When there are no heat sources, we concentrate on weak wave propagation, which occurs in situations with small temperature gradients in the medium. With the premise that the tension doesn't change, this paradigm enables us to examine how temperature changes affect wave behaviour. Here, the non-uniform temperature distribution means that while entropy values may vary between different particle paths, each particle path maintains a constant entropy state. This is an important detail because it suggests that the thermodynamic parameters along a given channel are constant, which offers a steady background for the study of wave propagation. Moreover, we limit our analysis to waves propagating forward, purposefully excluding reflected waves that may originate from medium borders or interfaces. The premise that reflected waves are rare in areas with moderate temperature change justifies this omission, making the study as a whole simpler. Focusing on this one-dimensional framework, we may extract insights into the dynamics of wave propagation under these particular circumstances in gases, which will help us comprehend how thermodynamic factors interact with wave phenomena in non-uniform media. Understanding the behaviour of sound and other disturbances in gases is essential for forecasting system reactions to dynamic changes in temperature and pressure, which makes this subject very pertinent in a number of domains, including atmospheric physics and engineering applications.

The gas density is first irritated in one aspect, with the change from ρ(x, t) to ρ0(x). The improvement of the disturbance is depicted by the progression equation

∂ρ(x, t)/∂t + ∂Q(ρ, x, t)/∂x = 0, where Q(ρ, x, t) stands for the mass motion. As an example of a non-uniform medium, coming up next is the congruity equation:

$$\frac{\partial\rho(x,t)}{\partial t} + v(x,t)\frac{\partial\rho(x,t)}{\partial x} + \frac{\partial Q(\rho,x,t)}{\partial x} = 0, \qquad (2.1)$$

where v(x, t) = ∂Q(ρ, x, t)/∂ρ is the velocity at which the disturbance propagates. Furthermore, the following relations hold when using the conservation principles of momentum and energy and keeping in mind that entropy remains constant along a particular particle route:

$$v(x,t) = a(\rho,x) + u(x,t), \qquad (2.2)$$

$$a(\rho,x) = a_0(x)\left[\frac{\rho(x)}{\rho_0(x)}\right]^{(\gamma-1)/2} + O\left(\frac{\Delta a_0}{a_0}\frac{u}{a_0}\right), \qquad (2.3)$$

In fluid dynamics, the mass velocity of a stream, denoted as u (x, t) = Q(x, t)/ρ(x, t) represents the flow rate of a fluid per unit density at a specific point x and time t. Here, Q(x,t)is the volumetric flow rate and ρ(x,t) is the local density of the fluid, which can vary due to changes in pressure and temperature. The local speed of sound in the fluid, represented as a(ρ,x) is critical for understanding wave propagation within the medium. This is contrasted with a0(ρ, x) which signifies the speed of sound in undisturbed conditions. The term Δa0 quantifies the change in the speed of sound induced by disturbances in the flow, such as compressions or expansions that may arise from pressure waves or other dynamic processes. In the context of equation (2.3), the second term on the right side encapsulates the effects of various factors that have not been explicitly accounted for in the primary equation, indicating that there are additional influences on the flow that require consideration. When the disturbance in the flow is small, as indicated by the condition ua<<1, and when the variation in the speed of sound along the disturbance is minimal, expressed as Δa0<<1 the behaviour of the system simplifies considerably. Under these assumptions, equation (2.3) aligns with the results predicted for isentropic flow, a process characterized by entropy remaining constant, implying that the flow is adiabatic and reversible. This connection to isentropic flow is crucial because it allows for the application of established theoretical frameworks and solutions from classical fluid dynamics, as highlighted in Whitham's work from 1974, which serves as a foundational reference in the study of wave motion and disturbances in fluid systems. Thus, under the stipulated conditions, the mathematical treatment becomes more tractable, enabling engineers and scientists to derive insights into the behaviour of compressible flows in various practical applications.

$$\left(\frac{\Delta a_0}{a_0}\frac{u}{a_0}\right) \approx 0.$$

The density disturbance is likewise negligible for a weak wave, meaning that for any x, (ρ – ρ0)/ρ0<<1. For a minor density perturbation, (2.3) can be linearized to yield using Taylor's expansion.

$$a(\rho, x) = a_0(x)\left[1 + \frac{\gamma-1}{2}\frac{\rho(x)-\rho_0(x)}{\rho_0(x)}\right] + O\left(\left(\frac{\rho-\rho_0}{\rho_0}\right)^2\right).$$

By combining this with Q = ρu, we can determine the mass flux and disturbance propagation velocity as follows:

$$v(x,t) = a_0(x)\left[1 + \frac{\gamma+1}{2}\frac{\rho(x)-\rho_0(x)}{\rho_0(x)}\right] + O\left(\left(\frac{\rho-\rho_0}{\rho_0}\right)^2\right), \qquad (2.4a)$$

$$Q(\rho, x) = a_0(x,t)\left\{\rho(x) - \rho_0(x) + \frac{\gamma+1}{4}\left[\frac{\rho(x)-\rho_0(x)}{\rho_0(x)}\right]^2 + O\left(\left(\frac{\rho-\rho_0}{\rho_0}\right)^3\right)\right\}. \qquad (2.4b)$$

From (2.3), we obtain for the density

$$\rho(x,t) = \rho_0(x)\left\{1 + \frac{2}{\gamma+1}\left[\frac{v(x,t)}{a_0(x)} - 1\right] + O\left(\left(\frac{v(x,t)-a_0}{a_0}\right)^2\right)\right\}. \qquad (2.4c)$$

Moreover, we get the following set of equations by computing the derivatives of each item in (2.1) and expressing them in terms of a0(x), ρ0(x), and v(x, t):

$$\frac{\partial \rho}{\partial t} = \frac{2}{\gamma+1}\frac{\rho_0(x)}{a_0(x)}\frac{\partial v}{\partial t}, \qquad (2.5a)$$

$$\frac{\partial \rho}{\partial x} = \frac{2}{\gamma+1}\frac{\rho_0(x)}{a_0(x)}\frac{\partial v}{\partial x} - \frac{2}{\gamma+1}\frac{\rho_0(x)v}{a_0^2}\frac{\mathrm{d}a_0(x)}{\mathrm{d}x} + \frac{\mathrm{d}\rho_0(x)}{\mathrm{d}x}\left\{1 + \frac{2}{\gamma+1}\left[\frac{v}{a_0(x)} - 1\right]\right\}, \qquad (2.5b)$$

$$\frac{\partial Q(\rho,x,t)}{\partial x} = \frac{\rho_0(x)}{\gamma+1}\frac{\mathrm{d}a_0(x)}{\mathrm{d}x}\left\{\left[\frac{v}{a_0(x)} - 1\right]^2 + 2\left[\frac{v}{a_0(x)} - 1\right]\right\}$$

$$-a_0(x)\frac{\mathrm{d}\rho_0(x)}{\mathrm{d}x}\left\{1 + \left[\frac{v}{a_0(x)} - 1\right] + \frac{1}{\gamma+1}\left[\frac{v}{a_0(x)} - 1\right]^2\right\}. \qquad (2.5c)$$

The linear terms in the expansions remain after all terms of O ((ρ – ρ0)/ρ0) 2) were disregarded in system (2.5). Lastly, stopping (2.5) into (2.1) yields the accompanying equation for the propagation velocity of the disturbance:

$$\frac{\partial v(x,t)}{\partial t} + v(x,t)\frac{\partial v(x,t)}{\partial x} = v(x,t)\frac{\mathrm{d}a_0(x)}{\mathrm{d}x}. \qquad (2.6)$$

Notably, the equation reduces to the form shown in equation (2.6) for a uniform medium when the derivative of $a0(x)$ with respect to x equals zero.

2.1 Shock Velocity and Shock Strength vs Distance :

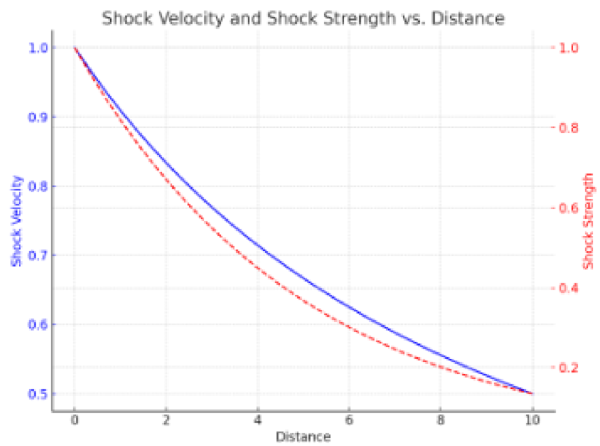

Figure 1: Shock Velocity and Shock Strength vs Distance

The link between shock velocity and shock strength with distance is shown on the graph. Whereas the y-axis displays shock strength and velocity, the x-axis depicts distance. The red line shows how the shock strength changes with distance, while the blue line shows how the shock velocity changes with distance.

Shock strength and velocity both decrease with increasing distance. This suggests that when the shock wave moves through the medium, its energy is lost. Shorter distances show a faster decline in shock velocity and strength, suggesting that the rate of decline is non-linear. This implies that elements like the medium's characteristics and the shock's initial energy have an impact on the shock wave's attenuation.

THE FORMATION OF THE SHOCK WAVE AND THE EVOLUTION OF AN INITIAL DISTURBANCE:

Shock waves are an important phenomenon in fluid dynamics that occur when a compressible fluid's flow characteristics abruptly change. When there is a sharp differential in temperature, density, and pressure caused by the fluid velocity exceeding the local speed of sound, these waves are usually detected. A crucial circumstance is satisfied at the exact spot where a shock wave occurs: the absolute values of the stream rate and the speed of sound's principal derivatives both approach infinity. This suggests that there is a discontinuity in the flow field due to the flow's characteristics changing from supersonic to subsonic. The flow variables, including density ρ (,) and velocity $v\ (x\ ,t\ )$, as well as their first derivatives, show continuity before reaching the shock front, despite this sudden transformation. This indicates that these characteristics follow the governing equations of fluid dynamics, changing smoothly and predictably as the fluid gets closer to the shock wave. But as soon as the fluid crosses the shock wave, its characteristics change significantly and instantly. This is because the fluid is compressed, which causes its density to rise sharply and its velocity to fall. This behaviour, which acts as a border when the fluid experiences major thermodynamic changes, emphasizes the special and intricate character of shock waves. Because these shock wave structures control the interactions between different flow regimes and the resulting physical effects on the surrounding environment, they are essential to understanding a wide range of applications, including supersonic flight, explosion dynamics, and astrophysical phenomena. Thus, research on these shock waves contributes to our understanding of fluid mechanics and influences practical engineering designs as well as safety procedures across a wide range of sectors.

In the domain x ∈ (−∞, ∞), v(x, t) agrees with (2.6). We settle equation (2.6) by generating another dimensionless time τ = ωt and another coordinate ξ = κx. Both ω and κ have aspects of s−1 and m−1, individually, and they are associated through the equation ω/κ = a0, where a0 is the breaking point as x approaches vastness of a0(x). In the event that the disturbance is spatially bounded, κ can be scaled in relation to the disturbance width, XL, so that ω = a0/XL and κ = 1/XL. Afterwards, for a fresh dimensionless disturbance speed.

$$\bar{v}(\tau,\xi) \equiv \frac{v\left(\frac{\tau}{\omega},\frac{\xi}{\kappa}\right)}{a_0} = \bar{a}_0(\xi) + \tfrac{1}{2}(\gamma+1)\frac{u\left(\frac{\tau}{\omega},\frac{\xi}{\kappa}\right)}{a_0},$$

where a¯0(ξ) ≡ a0(ξ/κ)/a0, (2.6) becomes:

$$\frac{\partial \bar{v}}{\partial \tau} + \bar{v}\frac{\partial \bar{v}}{\partial \xi} = \bar{v}\psi(\xi). \tag{3.1}$$

In this case, ψ(ξ) ≡ ∂a·0(ξ)/∂ξ. Assume that a disturbance happens at time τ = 0 such that

$$\bar{v}(\tau,\xi)|_{\tau=0} = \bar{a}_0(\xi) + f(\xi), \tag{3.2}$$

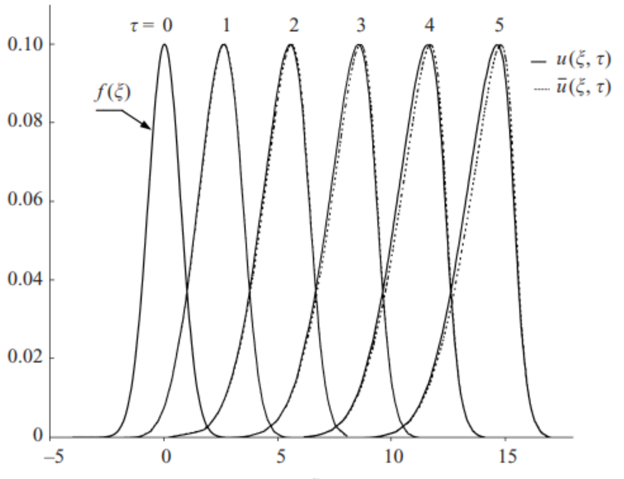

Figure 2: Comparison of - - -, the approximation provided by (3.3), and ——, the numerical solutions of (2.6). The disturbance velocity's initial distribution is represented by f(ξ).

The original form of the disturbance is adequately represented by the function (ξ). Equation (3.1) and the starting condition (3.2) together allow us to explain how the main disturbance changed with time. An analytical solution for equation (3.1) can be obtained, as described in Appendix A,

$$\bar{u}(\xi,\tau) = f(\varphi(\xi,\tau) - \bar{u}\tau), \qquad (3.3)$$

where ϕ (ξ, τ) is stated by a·0(ξ) and τ through ¯u ≡ ¯

$$\tau = \int_{\varphi(\xi,\tau)}^{\xi} \frac{dx}{\bar{a}_0(x)}.$$

The equations ϕ (ξ, τ) = ξ − τ and ¯u = f(ξ − τ − ·uτ) are valid when the temperature circulation of the medium is uniform (a·0(ξ) = 1). An answer for this particular case, provided that the initial disturbance is communicated as f(ξ) ∼ sin ξ. For various conveyances of a¯0(ξ) and f(ξ), we noticed areas of strength for a between the numerical arrangements of (2.6) and the approximate analytical arrangement of (3.3). Figure 1 shows one example of such a comparison. The speed of sound in the temperature gradient zone and the initial disturbance are depicted by the capabilities a¯0(ξ) = 2 + (2/π) arctan ξ and ξ and f(ξ) = u|τ=0 = 0.1 exp (−ξ2), separately. The disturbance gradient will in general look like a shock wave and steepens with time for the two arrangements. To find out when the initial disturbance turns into a brokenness that generates the shock wave, we really want to tackle the accompanying arrangement of equations.

$$\left(\frac{\partial \xi}{\partial \bar{u}}\right)_\tau = 0, \quad \left(\frac{\partial^2 \xi}{\partial \bar{u}^2}\right)_\tau = 0. \qquad (3.4a, b)$$

By using (3.3), it is possible to write (3.4) as:

$$1 + \tau\frac{\partial f}{\partial g} = 0, \quad \frac{\partial^2 f}{\partial g^2} = 0, \qquad (3.5a, b)$$

equation (ϕ(τ, ξ) – ·uτ) represents g. A necessary prerequisite for brokenness, as can be seen from (3.5a), is the presence of a site, ξ, where ∂f/∂ξ < 0. This rule eliminates the probability of a "decompression" wave and infers instead that the wave is a pressure wave.

$$\tau_d = \frac{1}{|df/d\xi|_{max}}. \qquad (3.6a)$$

The discontinuity's location, ξd, is determined by:

$$\xi_m = \varphi(\tau_d, \xi_d) - f(\xi_m)\tau_d. \qquad (3.6b)$$

In this case, the maximum of df/dξ is located at ξm. Whitham's (1974) equation for a disturbance traveling through a uniform medium is the same as this one. Then, we decide the initial disturbance's propagation accelerate to the irregularity's formation. The initial disturbance capability, f(ξ), is assumed to have a solitary maximum fmax at ξ = 0. For a homogeneous medium, the answer for equation (3.5) is zero, where ξ(τ) is the maximum location of the wave at time τ, and τ is not exactly or equal to f maxτ. Another way to get the maximum speed of the disturbance is to utilize the formula Vd = dξ/dτ = 1+ fmax. Along these lines, the maximum disturbance speed for a non-uniform district can be calculated utilizing the accompanying system of equations:

$$\varphi(\xi(\tau),\tau) - f_{max}\tau = 0, \quad \int_{\varphi(\xi(\tau),\tau)}^{\xi(\tau)} \frac{dx}{\bar{a}_0(x)} = \tau, \quad V_d = \frac{d\xi(\tau)}{d\tau}, \qquad (3.7a\text{–}c)$$

which has the solution

$$V_d = \bar{a}_0(\xi) + f_{max}\frac{\bar{a}_0(\xi(\tau))}{\bar{a}_0(f_{max}\tau)}. \qquad (3.8)$$

The solution of equation (3.7b) for ξ(τ) is given by ϕ(ξ(τ), τ) = fmaxτ. Equation (3.6) demonstrates that the time it takes for a mild shock wave to be generated is defined solely by the initial disturbance and is unrelated to the distribution of temperatures in the medium. Then again, a¯0(ξ) figures out where the shock wave is shaped. Assuming the temperature gradient is positive, the shock wave takes longer to arise from the initial disturbance, and that means that the maximum velocity of the disturbance (Vd) increases relative to uniform temperature. The converse is valid for negative temperature gradients.

3.1 Variation of Temperature and Pressure with Distance During Shock Wave Propagation:

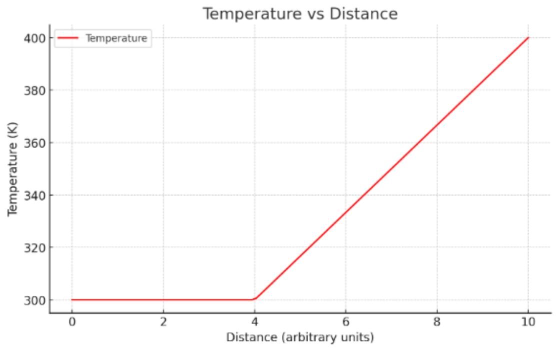

Figure 3: Temperature vs Distance

Figure 4: Pressure vs Distance

When analysing how shock waves travel in a material, changes in important physical characteristics like temperature and pressure are crucial to comprehending how the wave behaves as it advances. As the shock wave develops, the graphs show how temperature and pressure change with distance.

Temperature vs. Distance

A distinctive tendency often seen in shock wave events is seen in the temperature vs distance graph. The temperature stays comparatively constant at a lower value prior to the shock front's arrival, suggesting that the medium is unharmed. The temperature rises abruptly when the shock wave gets closer and travels through a spot in the medium. This surge results from the shock front's compression and quick energy transfer, which pushes the medium's particles to smash more forcefully and produce heat. In order to represent the new equilibrium condition of the medium post-disturbance, the temperature starts to stabilize at a higher value than the original state after the shock front has passed.

Pressure vs. Distance

The pressure versus distance graph shows a similar pattern. The pressure in the medium is fixed at a baseline value before the shock wave arrives. The compression of the medium is represented by the sudden rise in pressure that occurs when the shock front arrives. The shock wave's rapid force, which results in a quick and notable increase in pressure when the shock compresses the gas or fluid, is what produces this fast surge. The pressure stabilizes at a new, higher value once the shock has passed, signifying that the compressed medium has returned to equilibrium.

Overall Trend

At the shock front, temperature and pressure change quickly, indicating that the medium has changed from its undisturbed condition to one that is more compressed and has more energy. The effect of the shock wave is usefully shown by these graphs, where temperature and pressure are two crucial variables that change simultaneously as the wave moves. The traditional behaviour of forward-propagating shock waves is shown by the abrupt increase followed by stability at higher levels; for simplicity, reflected or secondary waves from medium boundaries are purposefully left out of this study.

A WEAK SHOCK WAVE PROPAGATING THROUGH A NON-UNIFORM MEDIUM :

While considering τ>τd, we account for the propagation of the disturbance. Like recently stated, the dispersion of the mass velocity u(ξ, τ) and its most memorable derivative doesn't remain constant all through their arguments for τ > τd.

$$\left.\begin{aligned} \bar{u}_1 = f(\varphi(\xi,\tau) - \bar{u}_1\tau), \quad \int_{\varphi(\xi,\tau)}^{\xi} \frac{\mathrm{d}x}{\bar{a}_0(x)} = \tau \quad (\xi < \xi_d(\tau)), \\ \bar{u}_2 = f(\varphi(\xi,\tau) - \bar{u}_2\tau), \quad \int_{\varphi(\xi,\tau)}^{\xi} \frac{\mathrm{d}x}{\bar{a}_0(x)} = \tau \quad (\xi > \xi_d(\tau)). \end{aligned}\right\} \tag{4.1a}$$

$$\bar{u}_{1d} = f(z_1), \quad \bar{u}_{2d} = f(z_2), \quad \int_{z_1+f(z_1)\tau}^{\xi_d(\tau)} \frac{\mathrm{d}x}{\bar{a}_0(x)} = \tau, \quad \int_{z_2+f(z_2)\tau}^{\xi_d(\tau)} \frac{\mathrm{d}x}{\bar{a}_0(x)} = \tau, \tag{4.1b}$$

where (z1 > z2), z1 = ϕ(ξd(τ), τ) – ·u1dτ, and z2 = -ϕ(ξd(τ), τ) – ·u2dτ. ¯u1d < ¯u2d is the intermittence point through which the mass velocity increases because τ = –(z1 – z2)/(f(z1) – f(z2) and df(ξ)/dξ|ξ=ξd < 0. Conservation standards could be utilized to generate the equations for the irregularity position. The irregularity plane's still up in the air by the accompanying if capability a·0(ξ) and its derivative are persistent:

$$\dot{\xi}_d(\tau) = \bar{a}_0(\xi) + \tfrac{1}{2}[f(z_1) + f(z_2)], \tag{4.2}$$

The equations can be expressed in differential form as follows:

$$\left.\begin{aligned} \dot{\xi}_d(\tau) &= \bar{a}_0(\xi_d) + \tfrac{1}{2}(\dot{z}_1 + \dot{z}_2)[1 + \tau(f'(z_1) + f'(z_2))]\frac{\bar{a}_0(\xi_d)}{\bar{a}_0\left[\frac{1}{2}(z_1 + z_2 + \tau(f(z_1) + f(z_2)))\right]}, \\ \dot{\xi}_d(\tau) &= \bar{a}_0(\xi_d) + \tfrac{1}{2}[f(z_1) + f(z_2)], \\ \tau &= \frac{z_1 - z_2}{f(z_2) - f(z_1)}. \end{aligned}\right\} \tag{4.3a}$$

A derivative over each function's corresponding argument is shown by the prime. System (4.3a) ought to meet prerequisites:

$$\xi_d(\tau)|_{\tau=\tau_d} = \xi_d, \quad \dot{\xi}_d(\tau)|_{\tau=\tau_d} = \bar{a}_0(\xi_d) + f(\xi_m)\frac{\bar{a}_0(\xi_d)}{\bar{a}_0(f(\xi_m)\tau)},$$
$$z_1(\tau)|_{\tau=\tau_d} = z_2(\tau)|_{\tau=\tau_d} = \xi_m \tag{4.3b}$$

where ξm is the point where the maximum of |f0 (ξ)| is located, and ξd is found from (3.6b).

An analytical answer for (4.3a) and (4.3b) couldn't be found for random

f(ξ) and a·0(ξ). At τ → ∞,we instead checked out at the asymptotic behaviour of the intermittence. Picture a scenario where the capability f(ξ) is non-no beyond the interval (0, ξL) yet has a solitary maximum inside that range. An answer for the shock-wave velocity and the wave Mach number not set in stone in this case:

$$\frac{M(\bar{\xi}) - 1}{M_0 - 1} = \frac{\bar{w}(\bar{\xi})}{\bar{a}_0(\bar{\xi})\left[1 + \int_1^{\bar{\xi}} \frac{\mathrm{d}x}{\bar{a}_0(x)}\right]}, \tag{4.4}$$

$$V(\bar{\xi}) = a_0(1)\left\{\bar{a}_0(\bar{\xi}) + (M_0 - 1)\exp\left\{\frac{1}{2}\int_1^{\bar{\xi}} \frac{\mathrm{d}y}{\bar{a}_0^2(y)\left[1 + \int_1^{y} \frac{\mathrm{d}x}{\bar{a}_0(x)}\right]}\right\} \Big/ \left[1 + \int_1^{\bar{\xi}} \frac{\mathrm{d}x}{\bar{a}_0(x)}\right]\right\}. \tag{4.5}$$

Here,

$$\bar{w}(\bar{\xi}) = \exp\left\{\frac{1}{2}\int_1^{\bar{\xi}} \frac{\mathrm{d}y}{\bar{a}_0^2(y)\left[1 + \int_1^{y} \frac{\mathrm{d}x}{\bar{a}_0(x)}\right]}\right\},$$

The equation ¯ξ = ξd/ξd0 depicts the relationship between the initial components of the shock-wave Mach number and the sound speed (upstream of the thermal gradient zone), with ξd0 addressing the starting mark of the irregularity and M0 and a0(1) being the associated initial aspects. The details of the asymptotic arrangement are given in Appendix B.

4.1 Analysis of Density Fluctuations Induced by Weak Shock Waves in Non-Uniform Media:

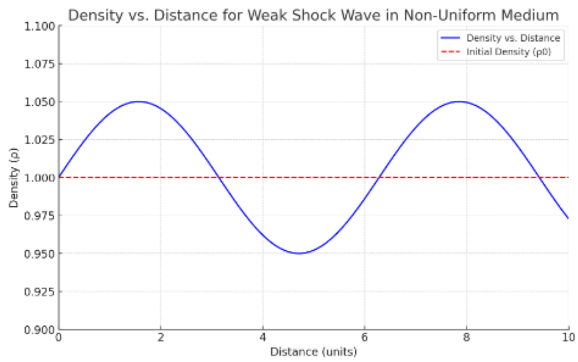

Figure 6: Density vs Distance for weak shock Wave in Non-Uniform Medium

The "Density vs. Distance for Weak Shock Wave in Non-Uniform Medium" graph shows how density (ρ) changes with distance in a medium where a weak shock wave is traveling. The red dashed line shows the medium's starting density (ρ_0), while the blue curve shows the actual density profile.

It is evident from the graph that as the shock wave advances, the medium's density varies around the starting density. Higher and lower density areas are represented by the curve's peaks and troughs, accordingly. This implies that compression and rarefaction waves are being propagated across the medium by the shock wave.

The shock wave is progressively fading as it passes through the non-uniform medium, as seen by the density fluctuations' apparent reduction in magnitude with distance. This dissipation most likely results from the shock wave's contact with the medium's inhomogeneities, which transfers energy from the wave to the medium.

CONCLUSION

The investigation of shock wave propagation in conducting gases provides important new understandings of how temperature and pressure affect these phenomena' dynamics. It is clear that shock wave properties like speed, amplitude, and structure are greatly influenced by temperature and pressure. Because of the greater gas density and steeper pressure gradients, higher pressures increase the intensity and velocity of shock waves. On the other hand, greater temperatures cause gas molecules to have more kinetic energy, which causes complicated interactions and quicker shock wave propagation because of variations in ionization levels.

Shock wave behaviour, temperature, and pressure all interact in complex ways that are important for applications in astronomy and engineering. By better understanding these interactions, shock wave behaviour in a variety of contexts can be predicted, leading to breakthroughs in areas like high-energy event research, combustion processes, and propulsion systems. This information emphasizes the need of taking pressure and temperature changes into account in shock wave research and is essential for efficient engineering designs and safety precautions in high-energy systems.

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