Study of Sound Wave as a Flame Extinguisher

by

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16036

Dissertation submitted in partial fulfilment of

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Mechanical

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CERTIFICATION OF APPROVAL

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MECHANICAL

Approved by,

________________________ ________________________

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Supervisor	Co-Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ALAN ARULANDOM ALEXANDER

ABSTRACT

The current fire extinguishing comes with various drawbacks. The need for new fire extinguishing techniques is vital as fire accidents cause deaths and injuries. Sound wave could be one of the potential alternative in putting off flames. The acoustic pressure and air velocity produced from a speaker is the main theory used to explain how sound waves put off flames. This research aims study and analyze the effect of different frequency of sound wave on flames. A simulation of sound wave was carried out to study behavior acoustic wave propagation in the collimator and surrounding environment. Experiments were then conducted to study suitable sound wave frequency range to extinguish flame and to analyze the acoustic-flame interaction through observations from camera. Three different sources of flames were used to with three different state of fuel (solid, liquid and gas). From the first part of results, using an ordinary collimator, it was found that sound wave can only extinguish gas fuel type flames at 91 Hz. However, in the second part of the experiment, the sound wave manage to extinguish all flames of different fuel types, with the converged collimator design. This mainly is due to the converged collimator gives a higher air velocity output as compared to an ordinary collimator design, which was verified through simulation result. The combination of varying high and low pressure and coupled with high flow air velocity, which in then causes disturbances in air-fuel ratio at the flame boundary (leading to thinning of flame boundary), is one of the possible explanation leading to flame extinction. In both experiment, the frequency range needed suppress the flames was found to be, between 90 to 94 Hz. However, in both experiments the flame boundary used was relatively small as compared real fire accidents due to safety consideration. Nevertheless, this sound wave based fire suppression technology could be used to combat early stages of fire accidents

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My completion of Final Year Project will not be a success without the help and guidance from my supervisor and colleagues. Hereby, I would like to acknowledge my heartfelt gratitude to those I honor.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fire extinguishers are trying to eradicate one of the elements in the pyramid (a flame tetrahedron) in order to eliminate the flame. Firefighting in an enclosed space has always been a problem, other than the accessibility for the fire fighter to access the place, accessing the water, carbon dioxide (CO_2) or other fire extinguisher technology to the closed space is a major challenge. A compact, independent and reliable fire extinguisher is required in order to overcome this problem. Space station and submarine are the main examples of the application that highly required new fire extinguisher technology that will be able to be used in a confined and very limited space.

Fire manipulation using sound was not a new technique. The interactions between sound and flames was first reported by John Leconte in 1858, who noted flames within an orchestral respond to beats within music. A German physicist, Heinrich Rubens in the 1900s, showed the technique using a section of pipe with holes perforated along the top. One end was sealed off with a sound speaker connected; the other sealed off and attached with a gas supply. Subsequently, igniting the gas leaking from one of the openings and varying the sound frequency being emitted, the height of the flames could be manipulated, this effect is called Rubens tube.

1.2 Objectives

1. To identify the frequency range that will be able to suppress an open flame.
2. To analyze the physics of sound-flame interactions.

1.3 Problem Statement

Current method of firefighting using has significant drawbacks such as toxic to humans and leaves residue (for dry chemical base fire extinguisher) while water base fire extinguishing techniques freezes in cold climates and conduct electricity. Using sound wave with certain frequency as a fire extinguisher will have significant advantages such as leaving no residues and non-toxic.

1.4 Scope of Study

Acoustic simulation will be performed prior to experiment to study the acoustic pressure and acoustic velocity profile in the collimator.

The suitable sound wave frequency between 0 Hz to 200 Hz put out the flames is determined.

The experiment is conducted with three different sources of flames: wooden fire (solid), gasoline (liquid) and butane gas (gas).

The permissible distance between the collimator and flame to cause fire extinction is also investigated.

CHAPTER 2

LITERATURE REVIEW

2.1 Fire

Fire is the fast oxidation of a material in the exothermic chemical process of combustion, releasing light, heat, and different reaction products. Flame is the observable portion of the fire. Fires start when a flammable and/or a combustible material, in combination with an adequate quantity of an oxidizer for instance, oxygen gas is exposed to a source of heat or ambient temperature above the flash stage for the fuel/oxidizer mix, and is able to withstand a rate of rapid oxidation that produces a chain reaction. This is normally called the fire tetrahedron (Figure 2.1). Fire cannot exist if deprived of all of these elements in place and in the right proportions.

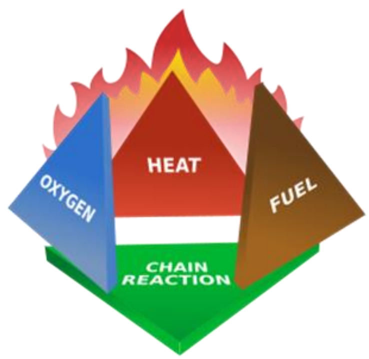

Figure 2.1: A flame tetrahedron

There are four main classes of fire: Class A, B, C and D. Class A fires are those fueled by materials that, when they burn, leave a residue in the form of ash, such as cloth paper, rubber, wood, and certain plastics. Class B fires involve flammable liquids and gasses, such as gasoline, kitchen grease, propane, and acetylene. Fires that involve energized electrical wiring or equipment (motors, computers, panel boxes) are Class C fires. Flames in exotic metals, such as magnesium, sodium, titanium, and certain organometallic compounds are in Class D fires.

2.2 Conventional fire extinguishing techniques

There are four common techniques used in extinguishing fires. Cooling down the burning material is the most common practice used to extinguish fire. Water is usually available and the best cooling agent to use particularly in fires involving solid materials. By vaporizing in contact with fire, water also mantles the fire, cutting off the oxygen supply. However, water should never be applied to fires involving hot cooking oil or fat because it can cause the fire to spread. Secondly, is thru excluding oxygen from the fire. Asphyxiating agents are substances used to extinguish a fire by cutting off the oxygen supply. Foam, which is the content of some fire extinguishers, can help to cool down and isolate the fuel surface from the air, reducing combustion and being able to resist wind and draught disruption. Nevertheless, foam should never be used on energized electrical equipment, because it is an electrical conductor. Other smothering agents include carbon dioxide, which is found in some fire extinguishers and is ideally used in electric equipment and sand, which is effective only on small burning areas.

Another method of extinguishing a fire is to remove the fuel supply by switching off the electrical power, isolating the flow of flammable liquids or removing the solid fuel, such as wood or textiles. In woodland fires, a firebreak cut around the fire helps to isolated further fuel. In the case of gas fire, closing the main valve and cutting off the gas supply is the best way of extinguishing the fire. Flame inhibitors are substances that chemically react with the burning material, thus extinguishing the flames. Dry-chemical fire extinguishers work in this way, and can contain monoammonium phosphate, sodium and potassium bicarbonate and potassium chloride. Vaporizing liquids, also have a flame inhibiting action. Conversely, most of these substances have been phased out due to high levels of toxicity.

2.3 Sound wave

Sound is a vibration that propagates as a perceptible mechanical wave of pressure and displacement, through a medium such as air or water. Sound propagates through compressible media such as air, water and solids as longitudinal waves and also as a transverse waves (in solids). The sound waves are generated by a sound source, such as the vibrating diaphragm of a speaker. The sound source creates vibrations in the surrounding medium. As the source continues to vibrate the medium, the vibrations propagate away from the source at the speed of sound, thus forming the sound wave. At a fixed distance from the source, the pressure, velocity, and displacement of the medium vary in time. At an instant in time, the pressure, velocity, and displacement vary in space. The particles of the medium do not travel with the sound wave, the vibrations of particles in the liquid or gas transfer the vibrations, while the mean location of the particles over time does not change. During propagation, waves can be reflected, refracted, or decreased by the medium.

The matter that carries the sound is called the medium and sound cannot travel through a vacuum. Sound is transmitted through gases, plasma, and liquids as longitudinal waves. Longitudinal sound waves are waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction, while transverse waves (in solids) are waves of alternating shear stress at right angle to the direction of propagation. Additionally, sound waves may be viewed simply by parabolic mirrors and objects that produce sound.

Sound waves are regularly streamlined to a description in terms of sinusoidal plane waves, which are characterized by these common properties: frequency, wavelength, wave number, amplitude, sound pressure, sound intensity, speed of sound, and direction. Sound that is perceptible by humans has frequencies from about 20 Hz to 20,000 Hz. In air at standard temperature and pressure, the corresponding wavelengths of sound waves range from 17 m to 17 mm.

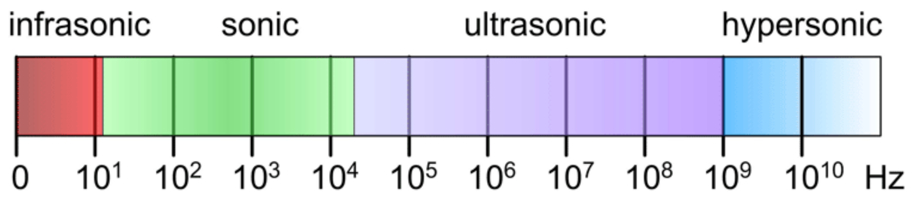

Figure 2.2: Frequency range of sound wave [7]

2.4 Sound-Flame interactions & using sound wave as flame extinguisher

Sound wave was found to be one of the alternatives in creating new method in flame extinguishing technology. There are some aspects of the combustion that can be affected by sound wave. The flame Air-Fuel Ratio at the boundaries which is at the lowest lean limit of the combustion of fuels can be affected by sound wave by changing the velocity of its medium (air). Furthermore, the changes in air velocity changes will also be able to affect the flow rate of the fuel around the heat source as well as increasing the convective heat transfer of the heat source and reducing the average temperature of the flame. These effects are similar to flame blow-off characteristics.

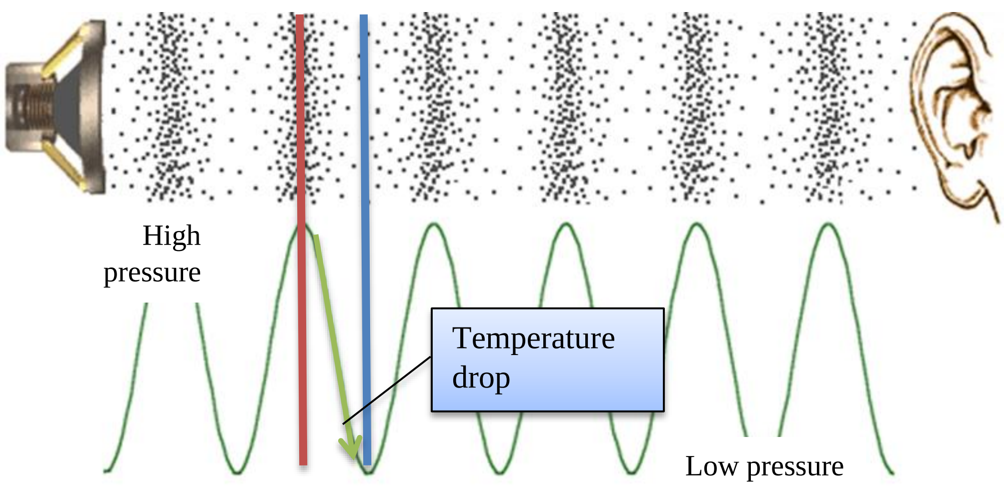

Figure 2.3: The physiology of sound

The main stream analysis for the sound wave effect on the flame is depicted in Figure 2.3. The pressure fluctuations due to the sound wave propagation will cause a significant change in temperature profile near the flame. High pressure to low pressure and vice versa will cause immediate change on the temperature according to the first law of thermodynamic. The combination actions of fluctuating temperature, pressure and air-fuel ratio to the flame will affect the flame behavior under the regulated sound wave environment. Pressure perturbations is known to have influence on the burning rate of a material and cause combustion instabilities, which could eventually lead to flame extinction (Hood and Frendi) [11].

Contrariwise, ultrasonic frequency proven to have an effect in chemical kinetics of a reactions (Ultrasound in Organic Chemistry). High frequency excitation on a reaction will be able to enhance the combustion as well as delaying and perturbing the chemical reaction which depends on the affected bonding for every specific chemical compound on certain frequencies. However, ultrasonic application for flame suppressor has not been investigated due to the results of previous experiment that shows the optimum frequency was at 60 Hz [1].

2.4 Acoustics Fundamentals and Governing Equation

Acoustics is the interdisciplinary field that deals with the study of all mechanical waves in gases, liquids, and solids as well as subjects such as vibration, sound, ultrasound and infrasound. The study of acoustics encompasses around the propagation, generation, and reception of vibrations and mechanical waves. There is one fundamental equation that describes sound wave propagation, the acoustic wave equation, but the phenomena that emerge form it are varied and often complex.

The fluid momentum (Navier-Stokes) equation and continuity equations are abridged to get the acoustic wave equation via the following assumptions, i.e.

- the fluid is compressible (density changes due to pressure variations) and,
- there is no mean flow of the fluid.

The acoustic wave equation is given by:

$$\nabla \cdot \left(\frac{1}{\rho_0}\nabla p\right) - \frac{1}{\rho_0 c^2}\frac{\partial^2 p}{\partial t^2} + \nabla \cdot \left[\frac{4\mu}{3\rho_0}\nabla\left(\frac{1}{\rho_0 c^2}\frac{\partial p}{\partial t}\right)\right] = -\frac{\partial}{\partial t}\left(\frac{Q}{\rho_0}\right) + \nabla \cdot \left[\frac{4\mu}{3\rho_0}\nabla\left(\frac{Q}{\rho_0}\right)\right] \qquad (1)$$

Where:

c = speed of sound $\left(\sqrt{K/\rho_o}\right)$ in fluid medium

ρ_o = mean fluid density

K = bulk modulus of fluid

μ = dynamic viscosity

p = acoustic pressure (= p(x, y, z, t))

Q = mass source in the continuity equation

t = time

Equation 1 can be reduced to the following inhomogeneous Helmholtz equation (to reduce the complexity of analysis)

$$\nabla \cdot \left(\frac{1}{\rho_0}\nabla p\right) - \frac{\omega^2}{\rho_0 c^2} p + j\omega\nabla \cdot \left[\frac{4\mu}{3\rho_0}\nabla\left(\frac{1}{\rho_0 c^2} p\right)\right] = -j\omega\left(\frac{Q}{\rho_0}\right) + \nabla \cdot \left[\frac{4\mu}{3\rho_0}\nabla\left(\frac{Q}{\rho_0}\right)\right] \qquad (2)$$

Where:

$\omega = 2\pi f$

$j = \sqrt{-1}$

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The experiment will be carried out in two stages, the first one is the results confirmation on the previous experiment done by previous researchers from DARPA. It was stated that the optimum sound frequency for fire extinction is 60 Hz. This experiment will be focusing on the observation in the frequency range of 35 – 200 Hz (human hearing frequency) in order to confirm the results from previous research.

There are three types of flame that is going to be tested, solid, gas, and liquid fuels, of which each is a single representatives for each thermodynamic state of a material. The fuels are: wood, methane and gasoline. A Schlieren imaging device will be used to compare the heat convection pattern of the three sources of fuels. A collimator will be used to modify the intensity and direction of the sound wave in the experiments. Collimator will increase the intensity of the sound wave to a single point which will provide better results in suppressing the flame. An acoustic simulation will be executed prior to experimental setup to study the propagation of sound wave (acoustic wave), specifically to study the acoustic pressure and acoustic velocity profiles in the collimator.

The experimental setup is shown as Figure 3.1. A collimator and fire source is placed on the test bench as designed in Appendix 1. The speaker is connect to an amplifier. The amplifier is used to amplify signals coming from the frequency generator software.

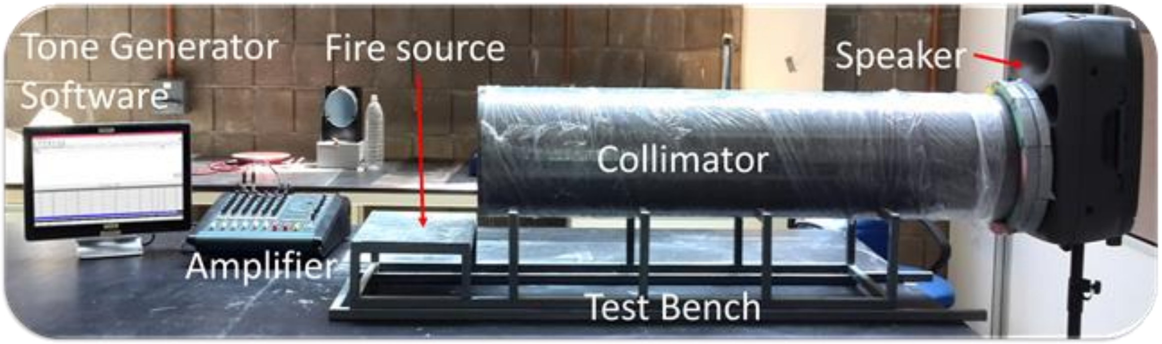

Figure 3.1: Experimental setup

3.2 Hardware & Software Required

3.2.1 Hardware

- 300 Watt Speakers
- 250 Watt Amplifier
- Collimator (12 inch, 1.7 meters length PVC pipe)
- Power supply unit
- High speed camera

3.2.2 Software

- ANSYS® Multiphysics Mechanical
- NCH® Tone Generator software (version 3.12)

3.3 Flow Chart

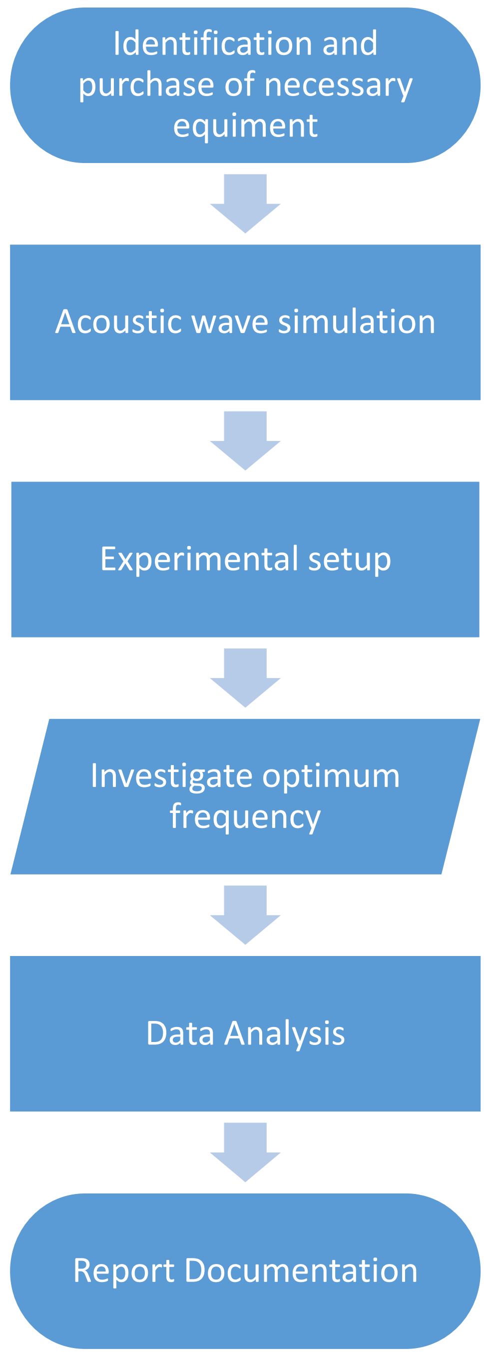

Figure 3.2: Experimental procedure

3.4 Gantt Chart & Key Milestone

Table 3.3.1: Gantt chart & Key milestone for FYP 1

Final Year Project 1															
No	**Item/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project title selection		●												
2	Project background study and literature review														
3	Extended proposal submission						●								
4	Proposal defense														
5	Identifying & Purchase of necessary hardware														
6	Simulation of acoustic wave propagation														
7	Arrival of hardware														
8	Submission of interim report														●

● = Key milestone

Table 3.3.2: Gantt chart & Key milestone for FYP 2

Final Year Project 2																
No	**Item/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Fabrication of test bench	■	■	■	■	■	●									
2	Conducting experiment							■	■	■	■	■	■			
3	Progress report submission							●								
4	Poster presentation										●					
5	Documentation									■	■	■	■	■		
6	Submission of technical paper													■		
7	Submission of dissertation														■	
8	Oral presentation															●
9	Submission of Thesis															■

● = Key milestone

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Acoustic wave simulation

The propagation of sound wave in the collimator is simulated using ANSYS Multiphysics Mechanical. Figure 4.1 below shows geometry used and boundary conditions used in the simulation (in 2D view).

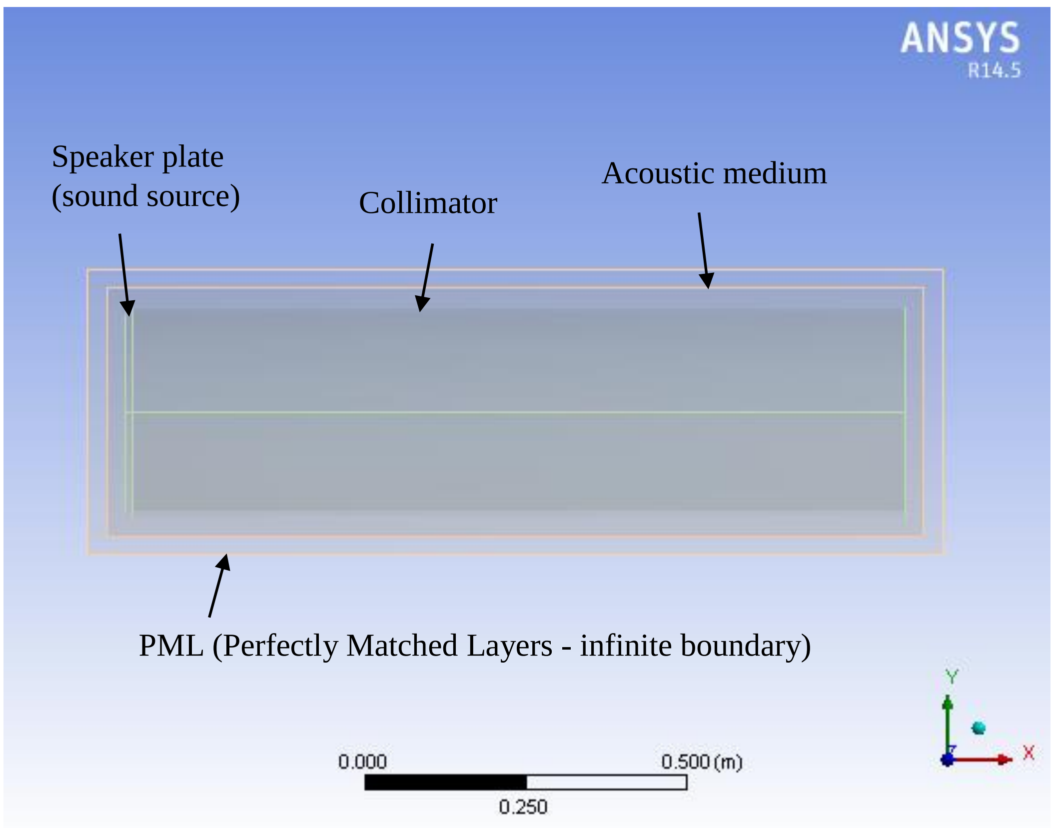

Figure 4.1: Simulation setup and geometry

Harmonic analysis is used, whereby frequency varies sinusoidal between 0 Hz to 1000 Hz. A mass source rate with amplitude of 0.01 kg m^{-2} s^{-1} is applied at the speaker plate.

Figure 4.2 and 4.3 below shows the acoustic pressure and acoustic velocity profile after post processing of simulation. It can be seen that for the acoustic pressure profile there's alternating pattern of red and dark which corresponds to the alternating compression (red) and decompression (blue) of pressure in the air as depicted in Figure 2.3 in theory of sound waves.

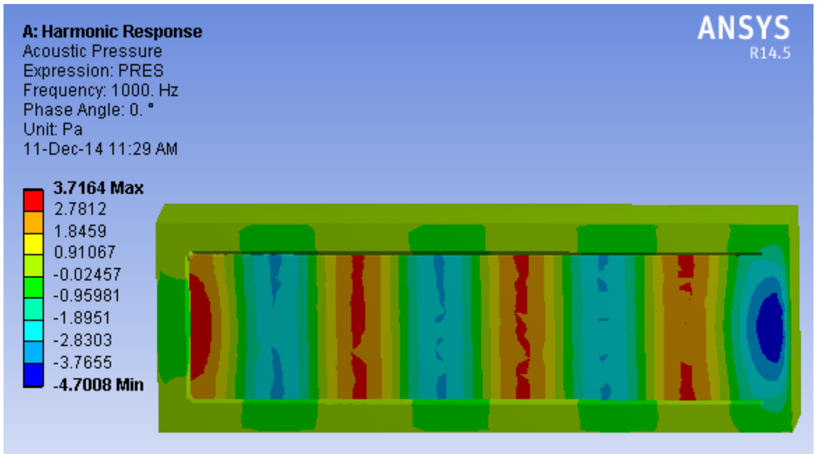

Figure 4.2: Acoustic pressure contours

The acoustic velocity does not show a smooth constant profile of air flow as shown in Figure 4.3 (as in a typical flow of air in a pipe). This could be due to the fact as the acoustic pressure wave undergoes alternating changes, this to affects the acoustic velocity profile, almost similar pattern to the acoustic wave profile, whereby yellow region shows higher velocity than the blue region. This pattern also interchanges inside the collimator.

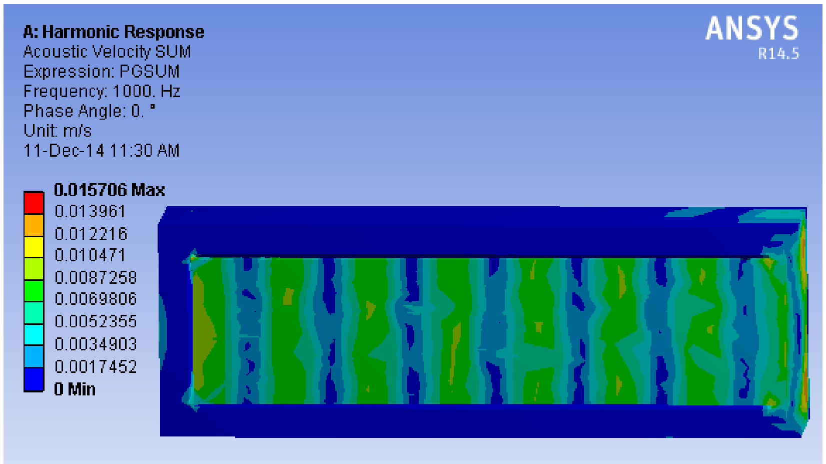

Figure 4.3: Acoustic velocity contours

4.2 Converged collimator design

A converged design collimator design theoretically would give higher velocity output as compared ordinary collimator design. The feasibility of fabricating a converged is first investigated, prior to considering the use of this concept.

4.2.1 Fabrication of converged collimator

The converged collimator design, which is basically a cylindrical-cone geometry, is first converted into 2-D shape, using mathematics equation, according to figure attached in Appendix 2. It is then, cut on a sheet metal and rolled into a conical shape using a plate rolling machine. Finally, the two height ends of the conical shape is welded together.

4.2.2 Simulation of converged collimator design

Two sets of converged collimator design is used for this simulation, whereby the diameter of other end of the collimator is reduced by 25% and 50%. The results is shown in the Figure 4.4, 4.5, 4.6, & 4.7 in page 17.

It can be seen, that the exit acoustic velocity of the collimator increases with smaller diameter while the acoustic pressure decreases with smaller exit diameter of the collimator. As the exit diameter is decreased by 25 % (Figure 4.4 & 4.5), the acoustic pressure decreases down to 14% while the acoustic velocity increases up to 97 %. Likewise, as the exit diameter reduced to 50% (Figure 4.6 & 4.7), the acoustic pressure lowers down to 40%, while the acoustic velocity rises up to 155%. Both comparison is made with original non-converged design at the exit. This phenomenon, is quite similar to a laminar flow of fluid (air) in a converged pipe, whereby, the velocity of flow in the converging part increases due to continuity and the pressure decreases in the direction of flow accordingly in compliance with the Bernoulli's theorem.

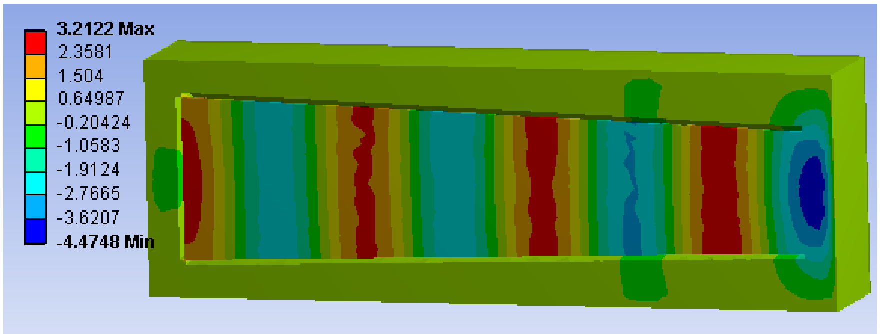

Figure 4.4: Acoustic pressure profile of 25% smaller exit diameter of collimator

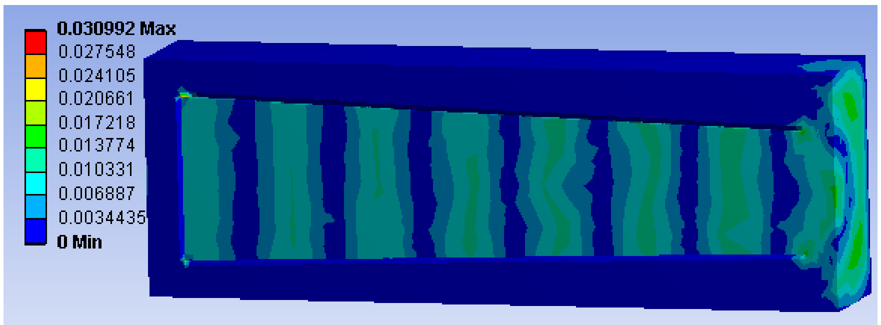

Figure 4.5: Acoustic velocity profile of 25% smaller exit diameter of collimator

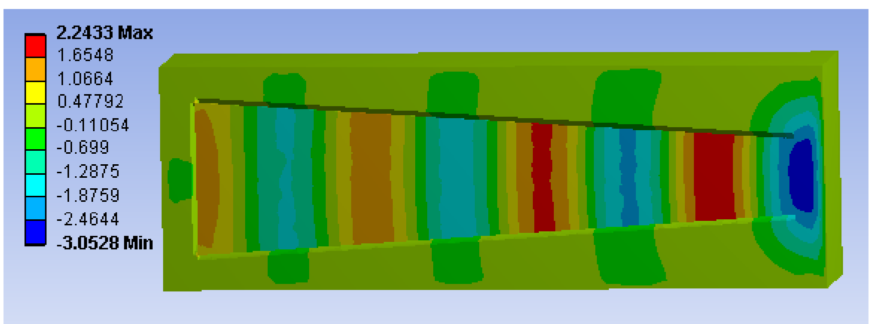

Figure 4.6: Acoustic pressure profile of 50% smaller exit diameter of collimator

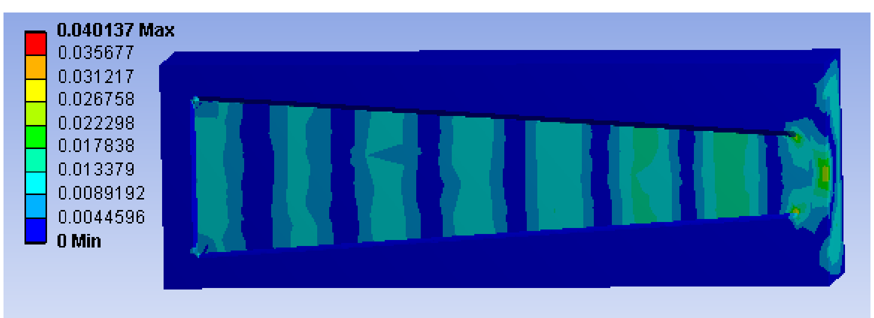

Figure 4.7: Acoustic velocity profile of 50% smaller exit diameter of collimator

4.3 Flame extinction by acoustics will collimator

Before conducting the actual experiment, a candle flame was first tested to initiate the experiment. The sound wave was able to extinguish the candle at 91 Hz within 1.3s.

The figure below shows sequence of high speed images of candle flame leading to flame extinction

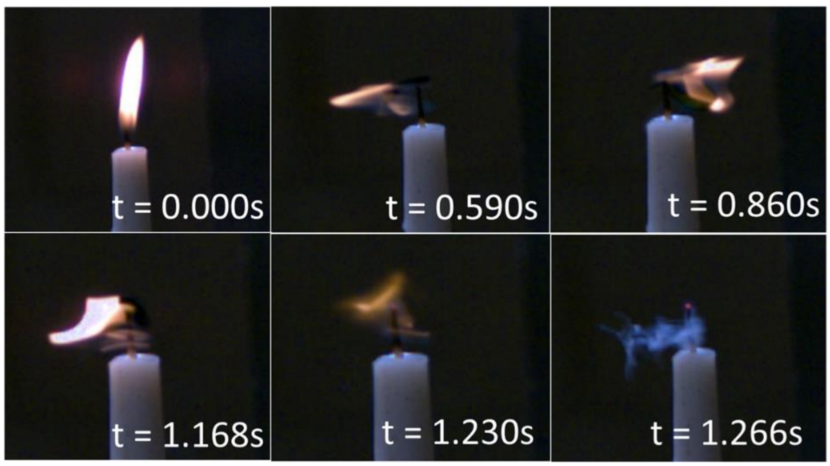

Figure 4.8: Hi speed images of candle flame extinguishing

It can be seen that the flame boundary resonates (back and forth) with sound wave. After certain period of time, the flame boundary slowly thins due varying high and low pressure, which induces air velocity and causes toward flame extinction.

The table below shows summary of results obtained after acoustic excitation was performed on three different fuel sources.

Table 4.1: Summary of experimental results

Fuel type	Time taken	Frequency
Wood	~ 3 minutes	92 Hz
Petrol	Not available	92 Hz
Gas	1 seconds	91 Hz

4.3.1 Solid fuel based fire

For solid fuel (wood) based fire, the flame doesn't extinguish quickly, however the flame boundary diminishes gradually over time (approximately three minutes). The Figure 4.9 below shows sequence of images of solid fire leading to extinction. The flame size was about 7 cm × 7 cm.

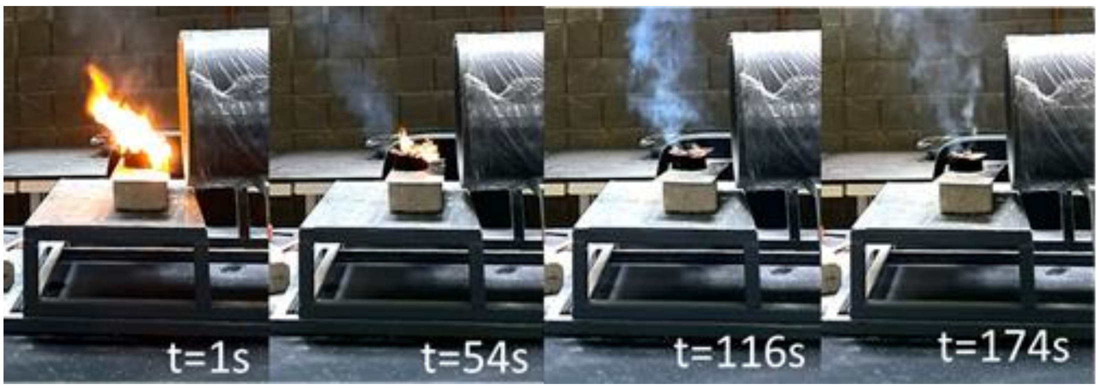

Figure 4.9: Solid based fuel flame extinguishing

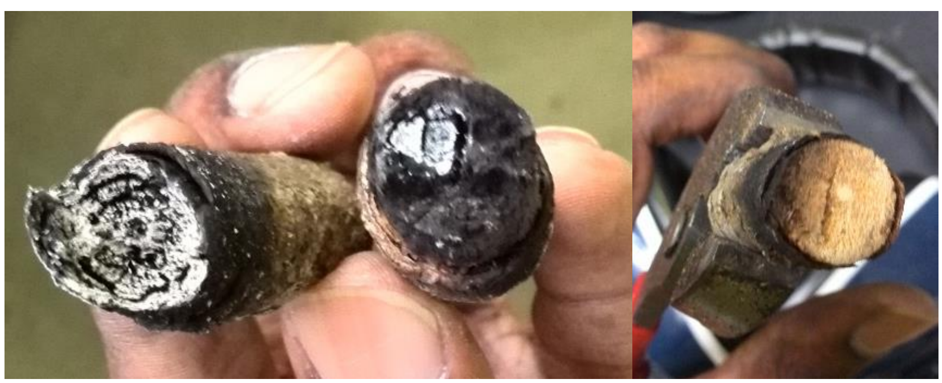

Figure 4.10: Penetration of fire in wood

Figure 4.10 shows images of wood and cross section (right) after extinguished to show that depth of fire penetration.

4.3.2 Liquid fuel based fire

In liquid based fuels (petrol), the flame doesn't extinguish however it causes the fuel to burn faster with observable, enlarging flame boundary. Figure 4.11 below shows the images of the flame. The flame size was about 7cm (W) × 9.5cm (H).

Figure 4.11: Sound wave interaction with liquid fuel based

4.3.3 Gas fuel based fire

In gas based fuel flames, the flame extinguishes instantly within 1 seconds. Figure 4.12 below sequence of hi speed images of gas stove flame leading to extinction. The flame size was about 5 cm (W) × 1.5 cm (H).

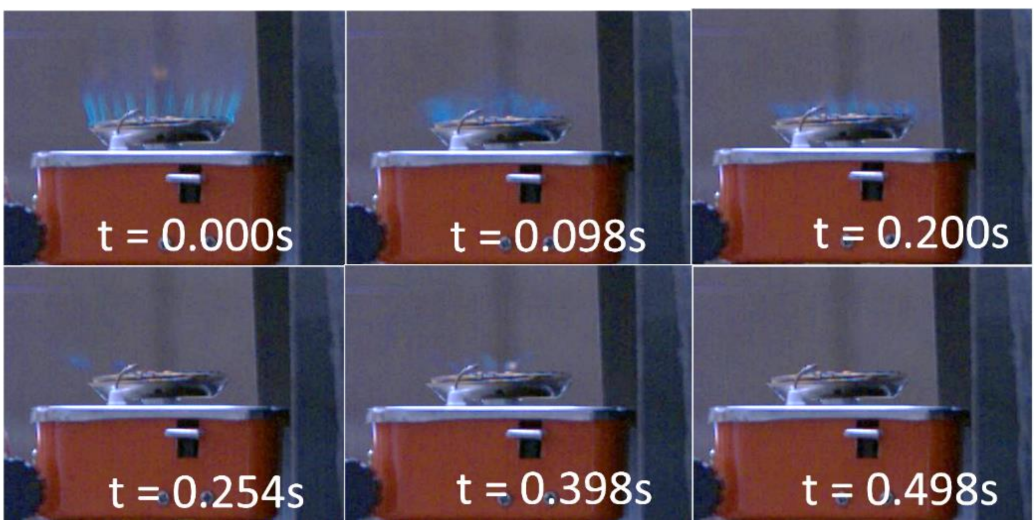

Figure 4.12: Hi speed images of gas stove

4.4 Discussion on first part of experiment

Sound wave generates acoustic wave that increases the air velocity and produces fluctuating pressure. This causes vibration and local air displacement at the body of the flame, which can be observed using high speed camera. The sinusoidal varying of high and low pressure, also might lead decrease in temperature of air (as accordance to ideal gas law). The combination of varying high and low acoustic pressure and flow of air velocity, causes the disturbances in air-fuel ratio at the flame boundary (leading to thinning of flame boundary), is one of the possible explanation for the flame extinction.

The permissible distance between flame boundary and the collimator was found to be within less than five centimeters, in order to achieve significant vibration at the flame boundary. At this range, the sound level is around 128 dB (decibels), and it drops every four dB, for every 10 centimeter moving away from the sound source since the sound travels radially.

As this phenomenon is similar to blow-off mechanism, this might explain the inability of the sound wave to extinguish solid & liquid fuel sources. The acoustic field leads to higher fuel vaporization, which causes the fuel to speed up the burning process rather than leading to extinction of the flame.

4.5 Second experiment with converged collimator

4.5.1 Converged collimator details

The second part of this experiment uses a converged collimator, as the converged collimator will higher output of air velocity. Due to the difficulty to fabricate the converged collimator, an ordinary orange safety cone made from high-density polyethylene (HDPE) was bought. The image below shows the dimension of the collimator. The inlet diameter of the cone is 305mm while the outlet is 25mm, with reduction of 92%.

Figure 4.13: Converged collimator used

4.5.2 Results with converged collimator

The experimental results shows with converged collimator is much better (in terms of time taken) in putting of flame as compared ordinary collimator. Apart from that, the flame boundary size is relativity bigger as compared with experiment using normal collimator, size the converged collimator puts off flame much faster.

The table below shows summary of results obtained with converged collimator.

Table 4.2: Summary of results with converged collimator

Fuel type	Time taken	Frequency used
Solid (wood)	4 seconds	92 Hz
Liquid (petrol)	2 seconds	
Gas (butane gas stove)	5 seconds	

4.5.3 Solid fuel (wood) based fire with converged collimator

The flame boundary size of the wood fire is similar to the one used in first experiment. It can be seen that from the images the flame is extinguished within 4 seconds.

Figure 4.14: Sequence of images of solid fuel fire extinguishing

4.5.4 Liquid fuel (petrol) based fire with converged collimator

A larger flame boundary was created for petrol fuel flame on a flat metal plate. The images below shows liquid fuel based flame leading to extinction. The flame width is about approximately 17 centimeters.

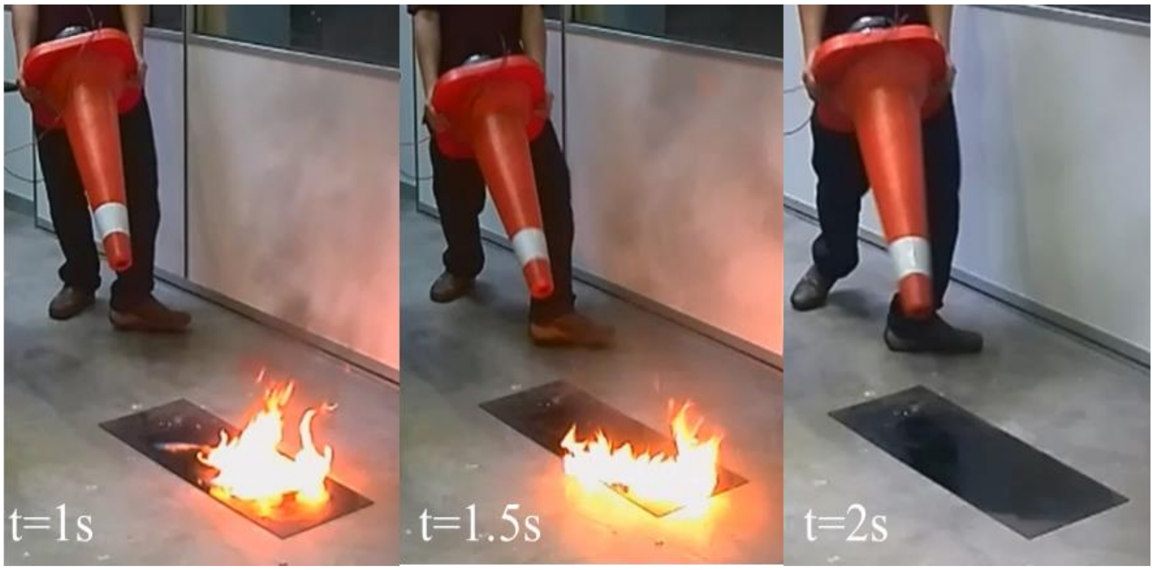

Figure 4.15: Liquid fuel flame extinguishing

4.5.5 Gas fuel based fire with converged collimator

A gas stove was also used in this experiment with butane gas as fuel. The flame extinguishes quickly with the same flame size as first experiment. Therefore it was decided to use larger flame size by turning gas flow rate to maximum. With that, a higher flame size was achieved measuring approximately, 5.5 cm (W) × 37.5 cm (H). The image below show gas fuel based flame leading to extinction with the cone.

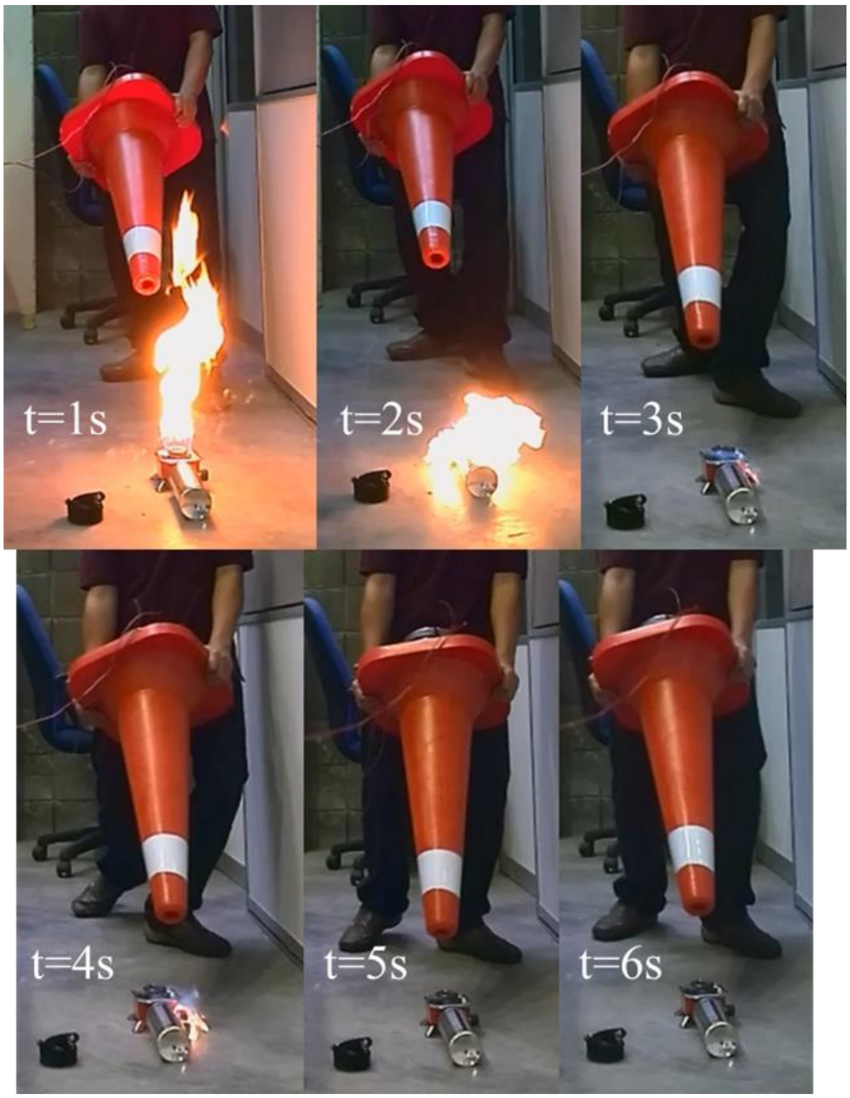

Figure 4.16: Gas fuel flame extinguishing

4.6 Discussion on second part of experiment

Since a converged collimator gives a high output of air velocity (based simulation results and basics of fluid mechanics), that explains the instant extinction observed on three different sources. The gush of high velocity stream of air onto the flame causes widening of flame boundary, which disperses the heat of the flame and fuel (for gas fuel fire). This is also eliminates one of the components of fire in fire tetrahedron.

In this second experiment there was flexibility of directing sound wave toward the fire source (angle of inclination and distance between sound and fire source), using the lightweight converged collimator (safety cone). That could be one of the possible explanation in achieving a better result in this experiment.

Other mechanism could also be present in assisting sound waves to extinguish flames. In the section where gas fuel flame extinguish by sound wave, it was observed (by playing the video at 0.25x slower) that the flame gets withdrawn into the converged collimator. The figure below sequence of images of that phenomena.

Figure 4.17: Vacuum effect of collimator by sound wave

The sound wave produces high air velocity and low air pressure with converged collimator. Lowering the size of exit diameter of collimator, increases the air velocity but lowers the air pressure. At the flame boundary, the pressure is higher due to high temperature of flame (as accordance to gas law, high temperature leads to high pressure). Due to presence of lower pressure in the collimator as compare to higher pressure at the flame boundary (also coupled with atmospheric pressure from the surrounding), this causes a vacuum to be created at exit of the converged collimator, which forces the fluid to flow towards the sound source. Since the sound wave produces varying high and low pressure, the vacuum effect is not present all the time, it might be achieved at a certain distance between the sound source and the flame.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

With the simulation performed, it can observed how the sound wave propagates inside the collimator based on the acoustic pressure and velocity profile. The pattern of the profile resembles according to the sound wave theory. Next, the design of the exit end of the collimator was varied to study effect on the exit acoustic velocity and pressure. Correspondingly, it can be seen that the exit acoustic velocity of the collimator increases with smaller diameter, while the acoustic pressure decreases with smaller exit diameter of the collimator. This phenomenon is similar to a flow of fluid in a converged pipe.

Based on the experiment result obtained it can be seen that the sound wave can extinguish flames. The frequency range that was able sound wave suppresses the flame is at 92 Hz averagely. Various theories could be used to explain how sound wave interacts with flame. In this first part of experiment, it was assumed that varying acoustic pressure and air velocity, which leads to disturbances at the flame boundary, could be the explanation on extinction of flame. However, based on the second part of the experiment, it was observed that, the velocity of air primarily, is the main contribution leading to extinction of the flame. However, for both experiments, the flame boundary created was relativity small as compared size or sound intensity of the speaker and does represent a real fire related accident. This is mainly due to concern of safety issues as larger flame could lead to uncontrollable accidents. Nevertheless, this sound wave based fire extinguishing could be used to extinguish initial stage fires.

5.2 Recommendation

As for the sound wave propagation simulation, it is recommended that the simulation in other Multiphysics software such as COMSOL, to further verify the simulation results. Apart from that, another simulation could be performed, coupled with fluid dynamics of fire and acoustics to study how the fire is being extinguished with sound (acoustic) interaction.

In the experimental part, different parameters could be used to further explore is study such as using different intensity of sound (by using different speaker power rating), positioning of sound towards the fire source and size of flame (or flame intensity) & varying design of collimator. Apart from that, measuring the output sound pressure (and also along the collimator), exit air velocity and temperature could also be taken into account. Smoke generator could also be used by pumping smokes into the collimator to study how the fluid propagates out from collimator.

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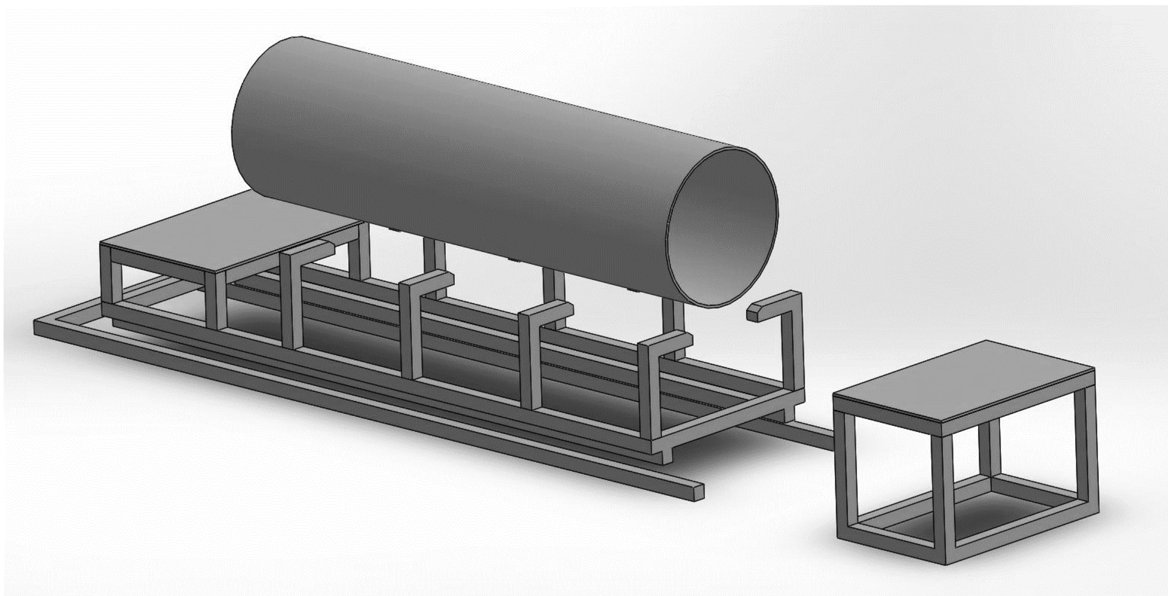
APPENDICES

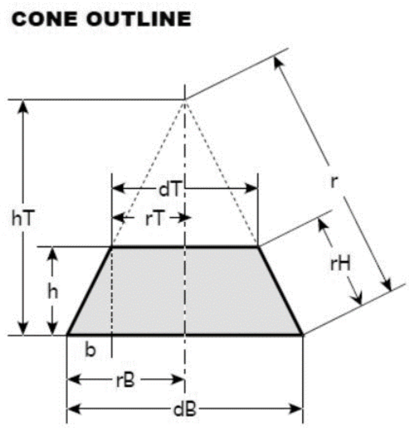
Appendix 1: Overall test bench design

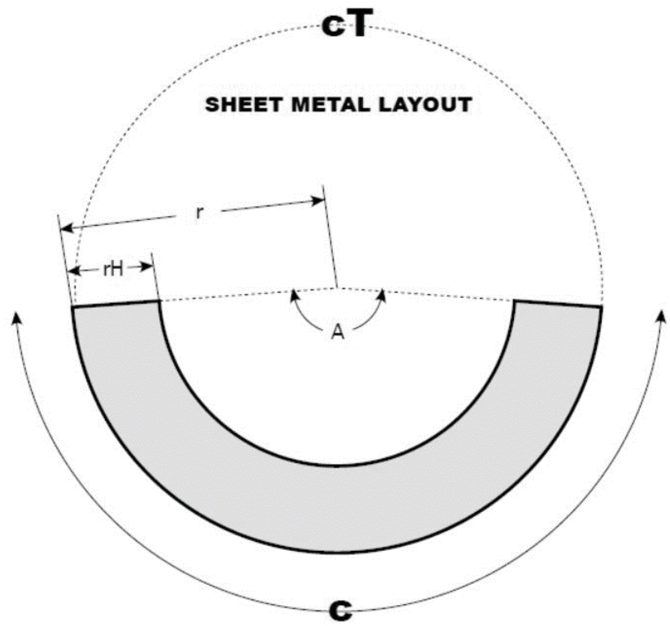


Appendix 2: Sheet metal layout equations for converged collimator

Inputs

dB = Cone bottom diameter
dT = Cone top diameter
h = Cone height





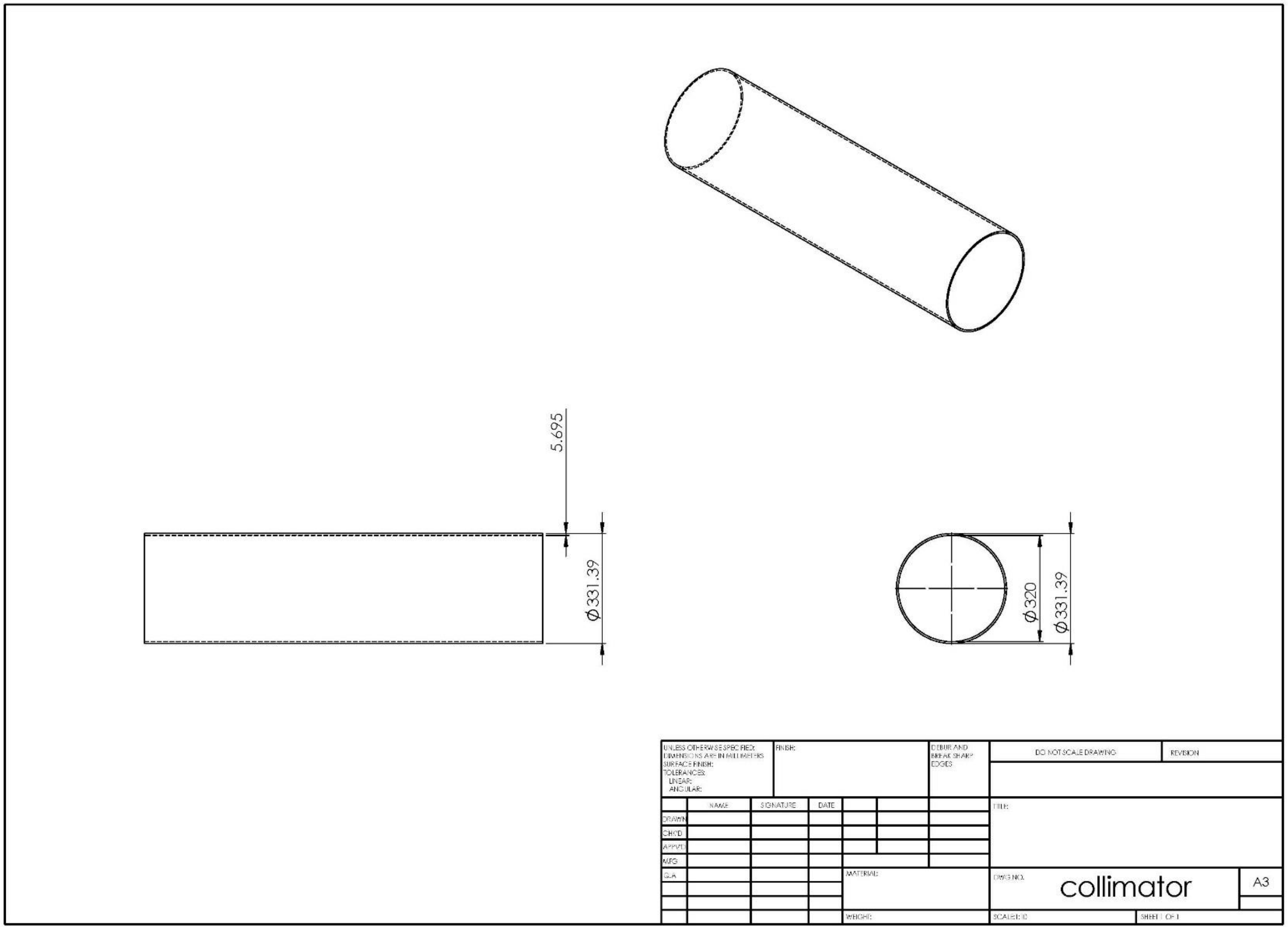
Calculated Values

hT = Triangle height
rH = Radius for cone height
r = Pattern outer radius
c = Cone circumference
cT = Total pattern circumference
A = Arc angle

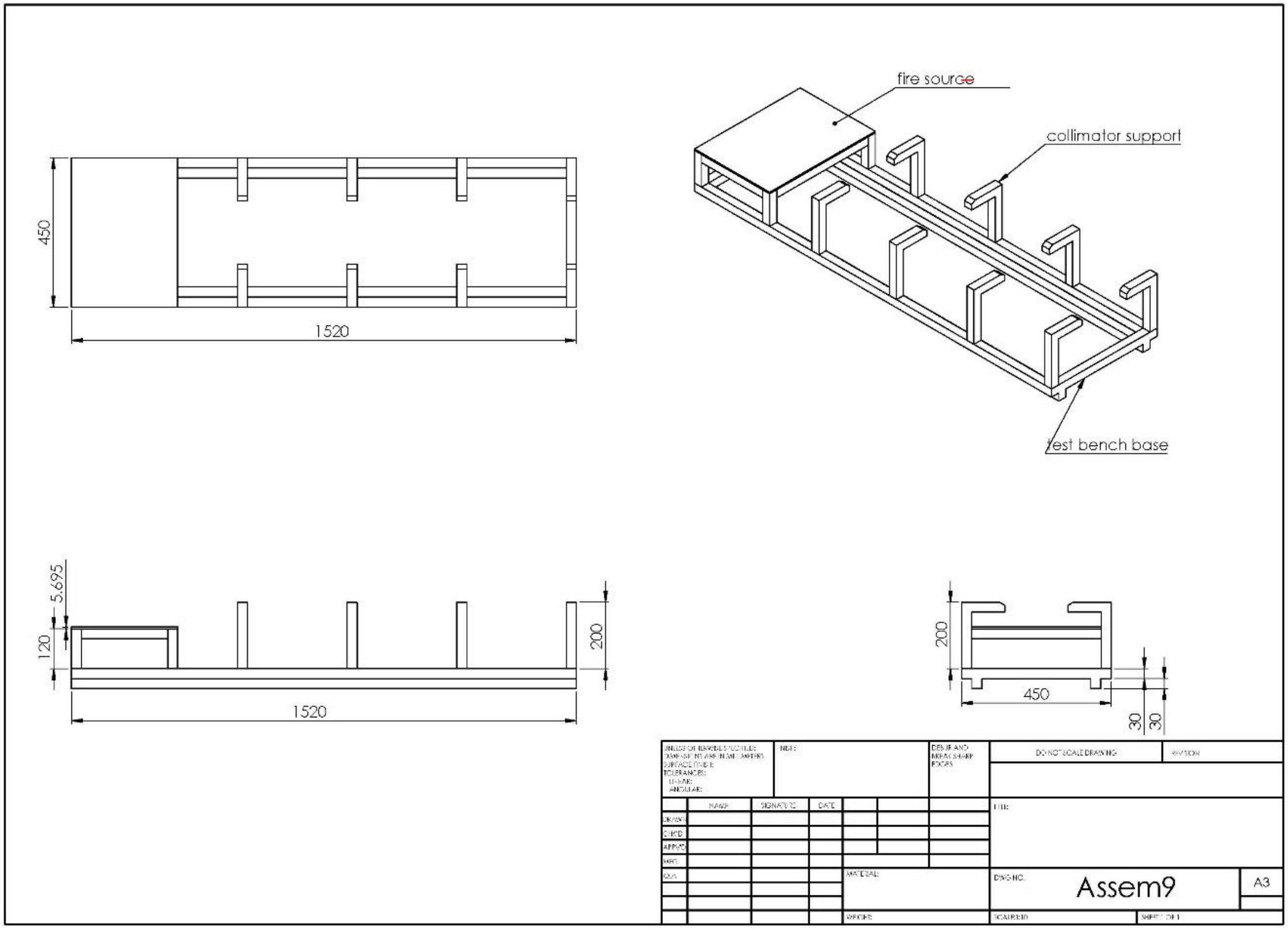
Formulas

```
rB = dB / 2     rT = dT / 2     b = rB - rT
hT = h * dB / (dB - dT)
rH = pythagorean(h, b)    r = pythagorean(hT, rB)
c  = PI * db              cT = PI * 2 * r
A  = 360 * c / cT
```

Appendix 3: Collimator design drawing



Appendix 4: Test bench design drawing



Appendix 5: Converged collimator design drawing