Wave Extinguisher

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Project Summary:

The goal of this project was to use acoustic sound waves to extinguish and/or suppress a flame. Traditional fire extinguishers, such as chemical foam or water, are used successfully but pose the threat of severely damaging indoor equipment, whereas an acoustic wave fire extinguisher would protect them from further damage caused by the fire. The extinguishing device developed is intended for typical residential and commercial use. However, it can have non-typical applications such as use in a spacecraft and aircraft.

This project utilized the scientific principle of physics and the engineering aspects of electronics to successfully suppress a flame. Based on the physical aspects of acoustic waves, it is important to understand that acoustic wave patterns are referred to as longitudinal pressure waves – meaning that the waves move in a back-and-forth vibrating motion in which they are able to agitate air molecules away from the fuel of the flame. Secondly, we hypothesized that the physical aspect of The Ideal Gas Law has an effect on suppressing a flame. The Ideal Gas Law states that Pressure times Volume is equal to the constants \( n \), the substance of gas and \( R \), the universal gas constant multiplied by temperature (\( PV=nRT \)). Therefore, when the pressure waves are being directed at the source of a flame, it will decrease the pressure at the source, which in turn will decrease the temperature of the flame.

The idea of fire being affected by sound was discovered as far back as 1857 when an Irish scientist, John Tyndall [1], recognized that sound waves could extinguish flames. Tyndall’s work has brought on new waves of research on sound waves and their effects on fire. The most recent research was carried out by West Georgia University's Prometheus Project [2] and DARPA's (Defense Advanced Research Projects Agency) experiments. DARPA’s research [3] concluded that, "a threshold acoustic velocity must be applied to the flame in order to achieve extinction, rather than a specific frequency or acoustic pressure." However, we found that this is not always the case. There were specific frequencies where the flames were extinguished. Frequencies between 0Hz and 10Hz
did not effectively extinguish a fire; but frequencies between 30Hz and 60Hz showed promising signs of suppressing a fire. Following this discovery, our proposed design intends to address the need for a new, efficient, light-weight, and innovative approach toward fire suppression.

Fire is heat and light from rapid combination of oxygen and other materials. A flame is composed of glowing particles of burning material and luminous gases. For fire to exist, a combustible substance must be present, the temperature must be high enough to cause combustion, and enough oxygen must be present to sustain rapid combustion.

Combustion is a chemical process in which a substance reacts rapidly with oxygen and gives off heat. The original substance is called the fuel and the source of oxygen is called the oxidizer. The reaction releases the energy as heat and light. In one of our designs, we targeted the suppression of combustion and found that acoustic fields have a significant effect on the process of combustion. This is due to the acoustic oscillations of the heat released from the flame. When acoustic oscillations are combined with the vibrations of heat released from the flame, it alters the transportation process of combustion [4]. It has been studied that frequencies in the 0 Hz to 60Hz range have significant effect on the activity of the flame [5].

As research has shown, some types of fires contain plasma. The existence of plasma in a flame is dependent on the material that is being burned and the temperature the flame reaches. Temperature of the flame varies depending on the region of the flame. In a cooler gas flame, atoms are found to be electrically neutral. The number of electrons are balanced with the positive charge in the nucleus. However, in higher temperature flames, particle collisions occur and remove electrons from neighboring atoms. This increases a number of freely moving electrons and leaves some of the atoms to be positively charged ions. These positively charged atoms and the gas itself are now "ionized" [6]. Plasma is a type of ionized gas, but not all ionized gases are plasmas. For an ionized area of a flame to be categorized as a plasma, it must contain enough charged particles to portray certain electrical characteristics of a plasma.

Acoustic waves naturally interact with each other. This interaction can be expressed in two different categories: constructive and destructive interference. When waves are superimposed on each other, the sound pressure or particle displacement at any point of interaction is the sum of the amplitudes of both of the waves. The phase of the wave also combine to either cancel or amplify points along the wave. Sound waves consist of a repeating pattern of high-pressure and low-pressure regions moving through a medium; thus sometimes referred to as a pressure wave. The compressions are regions of high air pressure while the rarefactions are regions of low air pressure. Figure 1 depicts a sound wave created by a tuning fork and propagated through the air in an open tube. The compressions and rarefactions are labeled.

![Figure 1: Behavior of pressure waves](image-url)
Our wave extinguisher takes its design from the phenomenon of center core. This toroid shape carries the particles further than a jet of particles [8]. Similar to the rotating wheels of a car, the poloidal flow of the vortex lessens the friction between the core and the surrounding stationary particles. This allows the vortex ring to travel far with little loss of mass and kinetic energy while retaining its size and shape (Figure 2).

Light, or in this case, fire has both properties of waves and particles. Our device capitalizes on light acting as both a wave as well as light acting as a particle. The wave-particle duality of light ties together two major solutions of this device. First, the pressure waves emitted from the wave extinguisher affect the air particles by pushing and pulling them away from the source of the flame. Secondly, at the proper frequencies, the acoustic waves produced by the wave extinguisher are going through a process of destructive interference to interrupt the natural behavior of the flame.

Based on theoretical knowledge, we targeted different physical phenomena and developed several versions of the wave extinguisher and progressed from extinguishing a small fire (flame from a lighter) to a larger one of 12" diameter (kitchen pan). The final design was tuned based on experimental data and effectiveness of intermediate prototype (Figure 3).

The final experimental system was tested for different frequency range, wave patterns and effectiveness in extinguishing flames. Flame extinguishing testing was conducted for a 9" cooking pan filled with 6oz of rubbing alcohol to simulate a grease fire. The summary of this test is shown in Figure 4. The results show that for frequencies between 20Hz and 40Hz, we were able to extinguish fire at a distance of 10 to 14in, while frequencies outside this range did not.
References