



Design and Fabrication of Sound Wave Fire Extinguisher

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Abstract - Conventional fire suppression agents, water, foam, dry chemical powder, and gaseous agents can be unsuitable around sensitive electronic equipment because of short-circuit risk, residue, or cleanup requirements [1]-[5]. This paper reviews acoustic flame suppression and presents a demonstration-scale sound-wave fire extinguisher built around an Arduino Nano signal generator, a Class-D audio amplifier, and a horn-loaded subwoofer driver. Recent literature shows that acoustic flame response depends strongly on frequency, sound pressure, source geometry, flame type, and the airflow generated by the speaker itself [2], [9]-[23]. The work therefore treats acoustic suppression as an experimental non-contact mechanism for small localized flames rather than a certified for conventional extinguishers. The paper retains the original sub-system design, indicative bill of materials, cost estimate, photographs, tables, safety framework, and staged bench-test protocol, while extending the literature review and reference list to include recent peer-reviewed research.

Keywords - Acoustic fire suppression, sound wave extinguisher, low-frequency acoustics, flame suppression, Class-D amplifier, embedded systems

I. INTRODUCTION

Conventional fire suppression relies on water, foam, dry chemical powder, or gaseous agents such as CO₂. While effective for many fire classes, these agents can be unsuitable for sensitive electrical and electronic equipment because water and foam can create electrical damage and chemical agents can leave residue. This motivates interest in non-contact alternatives for small, localized flames [1], [5], [24], [25].

A flame is a reacting region sustained by fuel and oxidizer transport to a thin reaction zone. A sufficiently strong oscillatory flow can deform and destabilize this zone, modify flame stretch, and alter the local supply of reactants. Experimental studies have demonstrated acoustic response and extinction in line flames, jet flames, pool fires, dripping flames, and firebrand flames, although the governing mechanism and practical operating envelope vary by configuration [9]-[23].

The present work focuses on a buildable student-scale system. It combines a signal generator, power amplifier, high-excursion low-frequency driver, and directional enclosure. The objective is to provide a reproducible platform for bench experiments, not to claim certification or general-purpose firefighting performance. The organization follows the original manuscript: Section II reviews related work; Section III develops the working principle; Section IV gives a simplified theoretical model; Sections V-VII describe architecture, sub-system design, and cost; Section VIII compares methods; Section IX sets safety limits; Section X gives the test methodology; Section XI discusses applications and limitations; and Section XII concludes with future scope.

II. LITERATURE REVIEW

Acoustic fire suppression has progressed from demonstration experiments to systematic studies of flame dynamics and extinction. A recent review by Shiet al. summarizes "low-frequency" acoustic suppression as being strongly associated with airflow disturbance, while also noting that sound pressure, waveform, and experimental configuration affect suppression efficiency [2].



Su Ying, and Liu provide a broader 2026 review of acoustic-flame coupling and distinguish transverse and longitudinal acoustic excitation, emphasizing that the flame response depends on the direction and structure of the acoustic field [9].

Controlled experiments clarify why a single frequency or sound-pressure value should not be treated as universal. Friedman and Stoliarov investigated laminar line flames at 30-50Hz and related extinction to acoustic perturbation and flame-response parameters [16].

Niegodajew et al. also studied gas-burner flame quenching at 30-50Hz and varied burner power and source distance [15]. Zong et al. investigated methane jet diffusion flames over 60-100 Hz, showing that low-frequency acoustic excitation can alter flame height and extinction behavior [19].

Shi et al. examined ethanol pool fires over 20-100 Hz and found changes in flame shape, instability, and fuel consumption under acoustic excitation [20].

Several studies further demonstrate that the physical cause of extinction may be aerodynamic rather than the acoustic pressure wave alone. Xiong et al. found that speaker-diaphragm motion and its induced wind can generate airflow much larger than the particle displacement associated with the transmitted sound wave [11]. Their later study explicitly examined whether extinction is caused by the sound wave or speaker-induced wind and concluded that the induced airflow can dominate the observed blowoff in their test configuration [14]. These findings are important for prototype interpretation measured SPL should be accompanied by measurements or estimates of airflow and source-to-flame geometry.

The literature also covers more complex targets. Xiong et al. reported extinction of a flame attached to a moving firebrand, with the extinction condition depending on firebrand velocity, sound pressure, and frequency [12].

Their study of dripping flames showed that acoustic extinction became more effective for early-stage drips and that extinction could be described using a Damkohler-number-based criterion [13]. Sim, Vargas, Ahn, and Karagozian studied methane microjet flames under transverse acoustic excitation and observed several flame-response modes preceding extinction [21]. Beisner et al. investigated acoustic suppression in microgravity [18], while Friedman et al. demonstrated that acoustics can enhance water-mist suppression of heptane flames, illustrating the potential of hybrid rather than acoustic-only suppression [17].

More recently, Cliftmann and Anderson demonstrated remote flame extinction using time-reversal focusing of sound. Their work showed that transient acoustic focusing can generate acoustic streaming at the flame, and the authors attributed extinction to the induced streaming flow rather than simple acoustic particle displacement [10].

Wilk-Jakubowski et al. reviewed modulated and unmodulated low-frequency wave experiments and discussed automatic detection as a complementary technology [23]. Ghosalkar et al. Presented a portable acoustic-wave fire suppression system, providing a directly

and together, the literature supports the feasibility of acoustic flame disturbance at small scale. But it also shows that the effect is highly configuration-dependent. The present paper therefore contributes primarily a practical subsystem design, photographs of the fabricated hardware, a simplified sizing model, a cost estimate, and a staged experimental protocol rather than a new extinction mechanism.

III. THE WORKING PRINCIPLE

Low-frequency sound waves are alternating regions of compressed and rarefied air. When a driver moves sufficient air at a suitable frequency and amplitude, the resulting oscillatory flow can deform and destabilize the flame.

Reported mechanisms include flame stretching, displacement of the reaction zone, modification of the near-flame airflow, and speaker-induced wind [2],[9],[11],[14],[16].

Frequency selection is therefore an experimental variable rather than a universal constant. Studies have reported extinction in different frequency ranges, including approximately 30-50Hz for line and gas-burner flames [15],[16], 50-70Hz for propane diffusion flames [11], 60-100 Hz for methane jet flames [19], and 90-110Hz for moving/dripping flame configurations [12],[13]. The 80-110Hz region retained in the original project is consequently best interpreted as a design/test region for this particular prototype, not as a general extinction band for all the flames. A further consideration is flame stretch. Oscillating acoustic flow imposes a periodic strain on the reaction sheet; when the local strain becomes sufficiently large relative to the flame's extinction limit, the reaction cannot be sustained locally [11],[12],[16]. The practical interpretation is that the prototype must be characterized empirically using the actual driver, enclosure, flame, fuel, and airflow conditions.

IV. THE THEORETICAL MODEL

A simplified acoustic-pressure model is useful for first-pass sizing of the amplifier and driver so that a target sound pressure level is available at the intended standoff distance. The model is not intended to replace empirical characterization, particularly because a low-frequency driver operates in a near field and because speaker-induced airflow can dominate the flame response [11],[14].

$$SPL = 20 \log_{10}(p_{rms} / p_0), \quad p_0 = 20 \mu Pa$$

$$SPL(r) = SPL(r_0) - 20 \log_{10}(r/r_0)$$

For a point-source approximation, doubling the distance reduces SPL by approximately 6dB. This illustrates why a compact acoustic suppressor has a short effective range compared with a conventional extinguisher. Fundamentals of Acoustics provides the basic relationships between pressure, particle velocity, and acoustic propagation [3], while instrumentation references provide the measurement context needed for SPL and sensor characterization [4].

relevant engineering precedent for compact implementation [22].

$$u = p_{rms} / (\rho_0 c)$$

where $\rho_0 \approx 1.2 \text{ kg/m}^3$ is air density and $c \approx 343 \text{ m/s}$ is the approximate speed of sound in air. For the prototype, the plane-wave relation is only a first-order estimate because the driver operates at close range and low frequency.

$$P_{el} = 10^{[(SPL_r - S + 20 \log_{10} r)/10]}$$

where S is the driver sensitivity in dB SPL at 1W/1m. The equation provides a first-pass electrical-power estimate for selecting an amplifier with suitable headroom. Class-D amplifier design guidance is relevant to efficiency and switching-loss considerations [6].

Fire-dynamics and combustion texts provide the broader context for flame behavior and extinction [24]-[27].

V. SYSTEM ARCHITECTURE

The system consists of three functional stages arranged in series: a signal generator that produces the drive waveform, an amplifier that raises the electrical power, and a speaker/driver that converts the amplified signal into acoustic pressure and airflow. A regulated power supply and a directional enclosure support these core stages. Signal flow is one-directional-the Nano output feeds the amplifier input and the amplifier output drives the speaker-so each stage can be tested independently with an oscilloscope, multimeter, or suitable acoustic measurement instrument.

TABLE I. CORE SUBSYSTEMS

Component	Role	Key Spec.
Signal generator	Produces drive waveform	Arduino Nano; 30–60 Hz sweep
Amplifier	Boosts signal to drive the speaker cone	Class-D, ~200 W
Speaker/driver	Converts signal to air movement	Subwoofer; high Xmax
Power supply	Powers amplifier and control electronics	Sized to peak draw
Enclosure/mount	Directs acoustic output at target	Horn or reflector

VI. SUBSYSTEM DESIGN

A. Signal Generator

An arduino nano generates a sine or square wave in the 30-60 Hz range, ideally swept rather than fixed, because the response depends on flame size and driver characteristics. A square wave is simple to generate but contains harmonics; a sine wave produced by direct digital synthesis (DDS) and filtered before the amplifier provides cleaner fundamental excitation. The output should be buffered to avoid loading the microcontroller pin. Embedded fire-detection work [7] and automatic acoustic-suppression research [23]. Also suggest a future extension in which flame or smoke sensing triggers the acoustic stage.

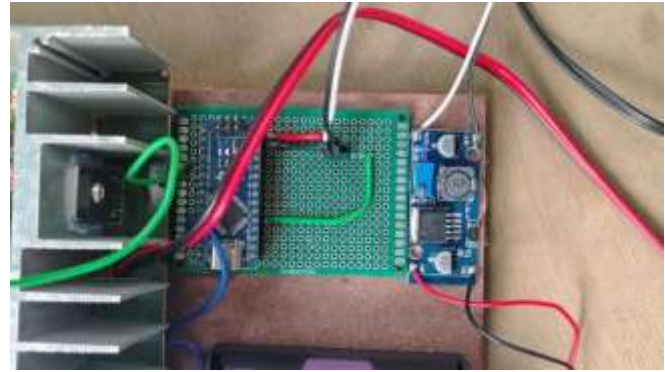


Fig. 1. Control and power electronics used in the prototype

A Class-D audio amplifier is used for efficient high-duty cycle "low-frequency" operation. The original design target is approximately 200W. Class-D operation reduces conduction losses relative to a linear amplifier at comparable output power, but the high-current stage still requires appropriate fusing, thermal management, wiring, and power-supply headroom [6].



Fig. 2. Class-D amplifier/power stage used in the prototype

C. Speaker / Driver

Driver selection prioritizes cone excursion (X_{max}) and cone area over mid/high-frequency SPL rating. X_{max} determines how far the cone moves and therefore influences the volume of air displaced per cycle. This is particularly relevant because several experimental studies indicate that the flow generated by the source is central to flame disturbance [11], [14].



Fig. 3. Horn-loaded low-frequency driver used in the prototype



D. Enclosure And Directional Coupling

Because acoustic pressure decreases with distance, a horn or reflector can concentrate the driver's output toward the target. Enclosure geometry should be treated as an experimental parameter because the near-field acoustic and flow conditions are not fully represented by the point-source model. The fabricated enclosure shown below is part of the original project hardware.



Fig. 4. Fabricated directional acoustic enclosure

E. Thermal and Power Budget

The original design estimates 80-90% amplifier efficiency. At 200W and 85% efficiency, the approximate dissipated loss is 35W. The regulated DC supply should be sized for peak rather than average current demand, with adequate heatsinking and ventilation.

VII. BILL OF MATERIALS AND COST ESTIMATE

Exact part numbers depend on approx cost and target build cost. The following tables are for student-project budgeting.

TABLE II. INDICATIVE BILL OF MATERIALS

Item	Notes
Arduino Nano	Or equivalent PWM/DDS-capable MCU
Class-D amplifier, ~200 W	Matched to driver impedance
Subwoofer/driver, 4–8 Ω	Prioritize X_{max} over SPL
Regulated DC supply	Sized to amplifier peak draw
Horn/reflector enclosure	3D-printed or fabricated
Mounting hardware, wiring, fuse, heatsink	Fuse the high-current stage

TABLE III. INDICATIVE COST ESTIMATE

Item	Cost (₹)	Cost (US\$)
Arduino Nano	450–700	5–9
Class-D amplifier (~200 W)	1,500–2,500	18–30
Subwoofer driver	2,000–5,000	24–60
Power supply	1,000–2,000	12–24
Enclosure materials	500–1,500	6–18
Wiring/fuse/heatsink/misc.	500–1,000	6–12
Total (indicative)	5,950–12,700	71–153

VIII. COMPARISON WITH CONVENTIONAL METHOD

The comparison below is qualitative and retained from the real manuscript NFPA-10 is used as benchmark method for conventional portable-extinguisher requirements; the acoustic prototype is not presented as a certified replacement [5]. Hybrid suppression research also indicates that acoustics may be useful as an enhancement to other suppression methods rather than as a stand-alone solution in larger or more complex fires [17].

TABLE IV. QUALITATIVE COMPARISON OF SUPPRESSION METHODS

Method	Residue	Equip. Risk	Certified
Water	None	High	Yes
Foam	Yes	High	Yes
Dry chemical	Yes	Medium	Yes
CO ₂ gas	None	Low	Yes
Acoustic (proposed)	None	None	No*

Not currently certified under fire-safety codes such as "NFPA 10" [5], positioned as a supplementary, non-contact first-response mechanism for small, early-stage flame rather than a replacement for certified equipment.

IX. SAFETY AND OPERATIONAL LIMITATIONS

This technique is demonstrated and studied at small scale (candle to small pan fire) it is not a substitute for a rated fire extinguisher and should not be relied on as a primary safety device [2], [5]. The literature further shows that high amplitude acoustic systems can generate substantial airflow and sound pressure [10], [11], [14]. Because the acoustic mechanism does not remove fuel or the ignition source, reignition remains possible.

- Effective range is "short-typically" centimeters to a few tens of centimeters for compact "prototypes" because acoustic pressure and useful airflow decrease with distance.
- Sustained high-SPL output at close range can create hearing risk, suitable hearing protection and exposure controls are required during testing.
- The method does not cool fuel or remove ignition sources, so reignition is possible every trial needs a plan for post-suppression fuel or ignition removal.
- High-current amplifier stages must be fused and adequately heatsinked to avoid electrical or thermal failure during extended sweeps.
- Live-fire testing must be conducted with conventional extinguishing equipment on hand as backup and never by a single person working alone.

X. TEST METHODOLOGY AND EXPECTED

PERFORMANCE

Table V summarizes the original design targets. These are design specifications rather than measured results. Published



experiments show that extinction thresholds vary with fuel, flame size, frequency, acoustic pressure, source distance, and airflow, so the values below must be experimentally validated for this prototype [11]-[20].

TABLE V. DESIGN PARAMETER TARGETS

Parameter	Symbol	Design Target
Drive frequency range	f	30–60 Hz (sweep)
Target SPL at 0.3 m	SPL_o	≥ 115 dB
Approx. extinguishing threshold*	SPL_{th}	≈ 100 dB
Design standoff distance	r_{max}	≤ 1.0 m
Amplifier electrical power	P_{el}	150–250 W

Approximate value informed by the literature reviewed in [2].

Exact thresholds depend on flame size, fuel type, and airflow conditions and should be refined through bench testing. A staged testing approach reduces risk and produces more useful data than an immediate full-power live-fire test.

1. Bench-test the signal generator alone, verifying a clean 30–60 Hz sweep at the buffered output before connecting the amplifier.
2. Bench-test the amplifier and driver at low volume without the horn attached, checking stable operation and heatsink temperature over several minutes of continuous drive.
3. Assemble the full chain and characterize sound pressure and airflow at the driver face at several sweep frequencies, without a flame present.
4. Introduce a candle flame at a fixed, generous distance and reduce distance while sweeping frequency, recording on video which combination first achieves suppression.
5. Repeat with a small, controlled pan fire only once candle-scale results are consistent, with backup extinguishing equipment and a second person present.
6. Iterate on enclosure geometry using the candle-scale setup as a fast, lower-risk feedback loop.

Throughout testing, frequency, measured or estimated SPL, distance, airflow where possible, flame-size, fuel type, and outcome should be logged for each trial. Repeated trials are necessary because ambient airflow, flame size, and wick condition vary. Success rate across repeated trials is more informative than a single binary pass/fail result [4],[20],[21].

XI. APPLICATIONS AND LIMITATIONS

Potential applications include experimental suppression around electrical panels, server racks, and small laboratory setups where residue-free interaction is desirable. educational demonstrations of acoustics and combustion, and low-cost laboratory studies of flame response. However, the literature indicates that acoustic suppression remains sensitive to source geometry, airflow, flame type, and acoustic amplitude [2],[9]-[23].

The system's effectiveness is bounded by acoustic power. Reliable flame disturbance generally requires high local sound pressure and/or airflow at close range, which constrains portability and standoff distance. The prototype is

therefore not intended as a certified replacement for standardized fire-safety equipment under "NFPA 10" [5]. Extending useful range substantially remains an engineering challenge because acoustic attenuation and required electrical power increase unfavorably with distance.

The simplified model and empirical test protocol are intentionally complementary. The model gives a first-pass sizing estimate, while experiments determine whether a particular driver, enclosure, and frequency actually suppress the target flame. This is especially important because speaker-induced wind and near-field effects can differ substantially from ideal plane-or point-source assumptions [11], [14].

XII. CONCLUSION AND FUTURE SCOPE

This paper reviewed the physical basis for acoustic fire suppression and integrated the original prototype design with an expanded research literature covering flame dynamics, line flames, jet flames, pool fires, dripping flames, moving firebrands, microgravity, water-mist enhancement, and remote time-reversal focusing [2],[9]-[23]. The demonstrated system uses an Arduino-driven low-frequency signal, a Class-D amplifier, a high-excursion driver, and a directional enclosure. The original photographs, table, cost estimate, safety framework, and staged test methodology have been retained.

The literature also indicates that the phrase “sound-wave extinguishing” should be interpreted carefully in several experimental configurations, extinction is strongly influenced by airflow generated by the speaker diaphragm or by acoustic streaming [10],[11],[14]. Future work should therefore measure both acoustic pressure and local airflow, establish repeatable extinction maps versus frequency and distance, optimize enclosure geometry, and investigate flame/smoke sensing for automatic triggering. These steps would allow the current design targets to be replaced by measured performance data.

APPENDIX

A. Frequency Sweep Reference Table

TABLE VI. FREQUENCY-RESPONSE REFERENCE (30–150 Hz)

Freq. Range	Typical Flame Response	Suitability
< 30 Hz	Sways/flickers; minimal boundary-layer disruption	Poor
30–50 Hz	Visible displacement; often re-stabilizes	Marginal
50–80 Hz	Flattening increases; suppression begins	Good
80–110 Hz	Most reliable suppression reported	Optimal
110–150 Hz	Coupling weakens with shorter wavelength	Marginal
> 150 Hz	Acoustic pressure decouples from boundary	Poor



B. Glossary of Terms

TABLE VII. GLOSSARY OF TERMS

Term	Definition
Xmax	Maximum linear cone excursion of a driver from its rest position.
SPL	Sound pressure level, a logarithmic measure of acoustic pressure referenced to 20 μ Pa.
Reaction zone	The thin region of a flame where fuel vapor and oxidizer actively combine and react.
Boundary layer	The thin layer of air adjacent to the fuel surface feeding the reaction zone.
Flame stretch	The rate of change of flame surface area under an imposed strain field, e.g. from acoustic flow.
DDS	Direct digital synthesis—generating an analog waveform by stepping through a stored lookup table.

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