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Enhancing Fire Safety in Commercial Vehicles: Assessing the Efficacy and Advantages of Exploding Fire Extinguishing Balls

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Abstract

Fire incidents in commercial vehicles pose significant risks to passengers, drivers, and cargo. Traditional fire extinguishing systems, while effective, may have limitations in terms of response time, coverage, and human intervention [1]. This study investigates the efficacy of a novel fire suppression technology—the Exploding Fire Extinguishing Ball (EFEB) —as an alternative and complementary fire safety solution for commercial vehicles. The research employs a multidisciplinary approach, encompassing engineering, materials science, fire safety, and human factors analysis. A systematic literature review establishes a comprehensive understanding of existing fire suppression technologies, including EFEBs. Subsequently, this study analyzes the unique features of EFEBs, such as automatic activation, as well as manual activation upon exposure to fire, and their potential to provide rapid, localized, and autonomous fire suppression. The study presents original experimental investigations to assess the performance and effectiveness of EFEBs in various fire scenarios representative of commercial vehicles. Experiments include controlled fires in confined spaces and dynamic simulations to emulate real-world fire incidents. Data on activation times, extinguishing capability, and coverage area are collected and analyzed to compare the efficacy of EFEBs with traditional fire extinguishing methods. Furthermore, this research shows the practical aspects of implementing EFEBs in commercial vehicles. A feasibility study examines the integration challenges, cost-benefit analysis, and potential regulatory implications. The study also addresses the impact of EFEBs on vehicle weight, stability, and overall safety. Human factors and user acceptance are crucial elements in adopting new safety technologies. Therefore, this research utilizes an experimental design to assess the performance and effectiveness of EFEBs in various fire scenarios representative of commercial vehicles. This dissertation presents original controlled experiments to emulate real-world fire incidents, including controlled fires in confined spaces and dynamic simulations. The experimental approach ensures rigorous evaluation and objective insights into EFEBs' potential as an autonomous fire suppression system for commercial vehicles. This includes the perspectives of drivers, passengers, fleet operators, insurance agencies, and regulatory bodies. Factors influencing trust, perceived safety, and willingness to adopt EFEBs are analyzed to provide insights into the successful integration of this technology. The findings of this research will contribute to the knowledge of fire safety technology and expand the understanding of the applicability of EFEBs in commercial vehicles.

Keywords

Exploding Fire Extinguishing Balls, Commercial Vehicles, Fire Suppression, Fire Safety Technology, Human Factors, Usability Feasibility Study

1. Introduction

Fire safety in commercial vehicles is a critical aspect of transportation safety, particularly given the high annual mileage and cargo value associated with these vehicles [2]. Traditional fire suppression methods often fall short in addressing the unique challenges posed by vehicle fires. This study explores the potential of EFEBs to fill this gap by providing a rapid and autonomous fire suppression solution.

The trucking industry serves as the key component of the supply chain, providing essential goods and services that sustain our daily lives. Safeguarding the well-being of truck drivers, their cargo, and the motoring public is not only a matter of paramount importance for those involved in the industry but also a vital national concern. This research proposal focuses on the critical issue of large vehicle fires and aims to investigate the efficacy of Exploding Fire Extinguishing Balls (EFEB), manufactured by E Fire, USA. In collaboration with PL Weaver & Company, a prominent trucking company based in Lancaster County, Pennsylvania, this study seeks to comprehensively assess the practicality and potential impact of the product within the transportation industry.

The EFEBs under scrutiny comprise a chemical compound known as monoammonium phosphate enclosed within a polystyrene shell. When exposed to fire, a heat-sensitive trigger mechanism degrades, initiating a chemical reaction that forcefully expels the contents outward in all directions. This process creates a cloud of fire-extinguishing powder, (**Figures 1-3**), capable of swiftly depleting the oxygen level feeding the fire and breaking the chain reaction within the fire tetrahedron, composed of oxygen, heat, fuel, and a chemical reaction. Consequently, the theoretical premise suggests that the fire should be extinguished when this innovative extinguishing method disrupts any of the four components of the tetrahedron.

Considering the prevalence of large truck and bus fires, a National Fire Protection

Association (NFPA) study highlights that 59% of such incidents between 2013 and 2017 were attributed to mechanical failures or malfunctions, while 28% of vehicle fires were initially ignited by electrical wires [3]. According to a 2018 report [4], 62 percent of all highway vehicle fires originate in the engine area, running gear, or wheel area of the vehicle (**Figure 4**). Among those, nearly 45 percent were reported as a mechanical failure or malfunction. Collisions are only noted as contributing to 5 percent of highway fires. However, they are responsible for 60 percent of fatal highway fires. This compelling data, along with other relevant sources that will be explored further, indicates the engine bay as a focal point for this investigation.

By undertaking a comprehensive examination of the E Fire, USA, EFEBs and their potential application within the transportation industry, this research endeavors to contribute valuable insights toward enhancing fire safety measures. The collaboration between E Fire, USA, PL Weaver & Company, and Paul Ford, PhD, aims to better understand the EFEB's efficacy and suitability for safeguarding large vehicles against fire-related risks. With the goal of bolstering safety standards in the trucking sector, this study aspires to offer valuable recommendations and advancements for mitigating the incidence and impact of large vehicle fires in the United States.

Figure 1. Photo showing the ignition of the EFEB.

Figure 2. Photo showing the blast of monoammonium phosphate (MAP) powder.

Figure 3. Photo showing the engine on fire with the truck's hood closed at the moment of ignition.

Table 3. Areas of fire origin in highway vehicle fires (2014-2016)	
Areas of fire origin	Percent of highway vehicle fires (unknownsapportioned)
Transportation, vehicle areas	93.1
Engine area, running gear, wheel area	62.2
Operator/Passenger area oftransportation equipment	12.3
Other vehicle areas	8.7
Cargo/Trunk area-all vehicles	4.6
Exterior, exposed surface of vehicle	3.4
Fuel tank, fuel line	1.6
Separate operator/control area of transportation equipment	0.3
All other areas	6.9
Total	100.0

Source: NFIRS 5.0.

Figure 4. A table from a report issued by the Federal Emergency Management Agency, National Fire Data Center, and US Fire Administration in 2018 shows vehicle fire origins.

Every passing hour, emergency personnel respond to a staggering 31 vehicle fires across the United States [5]. Multiple studies conducted by the National Highway Traffic Safety Administration [6] [7] revealed that gross vehicle weight rating (GVWR) class 8 trucks experienced a fire fatality frequency six times greater than that of other motor vehicles. Among the many categories of vehicles, heavy commercial vehicles stand out due to their high annual mileage, averaging between 80,000 to 100,000 miles, which is approximately 650% more than the average American car [8]. This extensive usage not only heightens the risk of accidents but also significantly increases the likelihood of vehicle fires.

Despite these alarming numbers of large truck fires, research on commercial motor vehicle fires remains relatively sparse, necessitating immediate and rigorous academic inquiry to address this critical issue without biases associated with manufacturer-designed testing. This research seeks to explore vehicle fire risks, with a particular focus on heavy commercial vehicles, to unravel the complex factors contributing to this pressing safety concern.

The distinct characteristics and operating conditions of heavy commercial vehicles necessitate specialized attention when assessing the root causes of vehicle fires. Therefore, this research will adopt a multidimensional approach, encompassing technological, operational, and regulatory aspects to gain a comprehensive understanding of the problem. By encompassing a variety of perspectives, this study aspires to provide a holistic and unbiased analysis, shedding light on previously unexplored facets of commercial motor vehicle fires.

The significance of this research lies in its potential to influence policy, improve safety standards, and save lives within the trucking industry. By adopting an objective approach to investigating vehicle fire risks in heavy commercial vehicles, this research aims to provide actionable insights that empower industry stakeholders, regulatory bodies, and emergency responders to proactively address this critical public safety concern.

The engine compartments of large trucks harbor numerous intricate components that distinguish them from typical passenger cars. Among these distinctive elements, the presence of a fuel/water separator plays a vital role in removing moisture from diesel fuel while simultaneously holding a substantial amount of fuel during the filtration process. Unfortunately, if a critical seal is compromised, fuel leakage onto hot engine parts can create a dangerous potential for ignition. Moreover, the engine bay also accommodates a significant electrical junction or fuse box, which, as a large commercial vehicle traverses the road, is subjected to constant vibrations and chassis twisting due to torque. This mechanical stress can cause electrical wires to come loose from their housing or rub against other components, exposing them. In this vulnerable state, exposed wires are susceptible to overheating, melting, and igniting, posing a significant fire risk. Given that most large commercial trucks house 4 to 6 batteries to power various electrical components, the consequences of such fires can be severe.

Compounding these risks, a National Fire Protection Association (NFPA) study [9] revealed that large truck fires accounted for an average of only 33 out of the 355 annual highway vehicle fire deaths between 2013-2017 (9 percent). However, the death rate associated with large truck fires, at 2.7 deaths per 1000 fires, was 36 percent higher than the 2.0 deaths per 1000 highway vehicle fires of all types [10]. This data underscores the urgency of understanding and mitigating the fire hazards specific to heavy trucks, particularly considering that while these vehicles constitute just 5 percent of all registered vehicles in the United States, they accumulate over 700% more miles on average than a passenger vehicle. This significant road time elevates the risk factor exponentially, necessitating a comprehensive investigation into the vulnerabilities of heavy truck engine compartments and the development of effective safety enhancement strategies.

The primary objective of this study is to address the critical issue of mitigating commercial truck fires that pose severe risks of driver injury or fatality. As the topic remains relatively underexplored, conducting a comprehensive case study presents challenges, and unanticipated variables may emerge, potentially altering the study's depth and scope. To tackle these complexities, data collection and simulated designs are essential. However, resource constraints necessitate a strategic approach to maximize quantitative data for accurate qualitative analysis. While recognizing that this study cannot encompass every aspect of the problem, its purpose is to establish a foundation upon which future researchers can build, advancing our comprehension of large commercial vehicle fires and effective measures to prevent, suppress, or extinguish them while minimizing driver risk. Through this investigation, the study aims to pave the way for future researchers to build upon this foundation, ultimately advancing our understanding of fire safety in the transportation industry and safeguarding the lives of drivers.

The proposed conceptual framework for this aims to improve the accuracy of tests conducted on EFEBs in vehicles' engine compartments. To achieve this, identifying potential hotspots or "trouble areas" will help to narrow down the best locations to mount the devices. Thermal imaging technology will assist in this area by highlighting the potential danger zones where the passive fire suppression devices will be most effective (Figure 5, Figure 6). Moreover, precise AutoCAD drawings (Figure 7, Figure 8) will be utilized to depict the available air space in the engine compartments, allowing for the overlaying of the blast radiuses of the dry chemical, monoammonium phosphate, used in the extinguishing balls. By creating both detailed models for vehicles, the study seeks to enhance the precision of physical testing.

Figure 5. Thermal imaging picture on the passenger side of the engine.

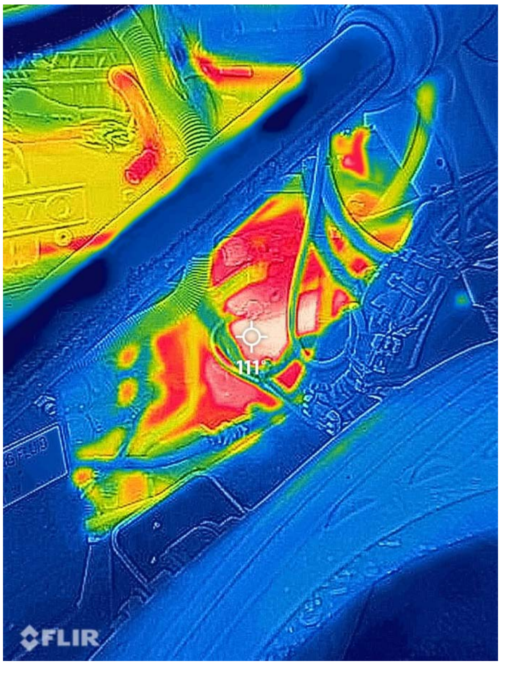

Figure 6. Thermal imaging picture on the driver side of the engine.

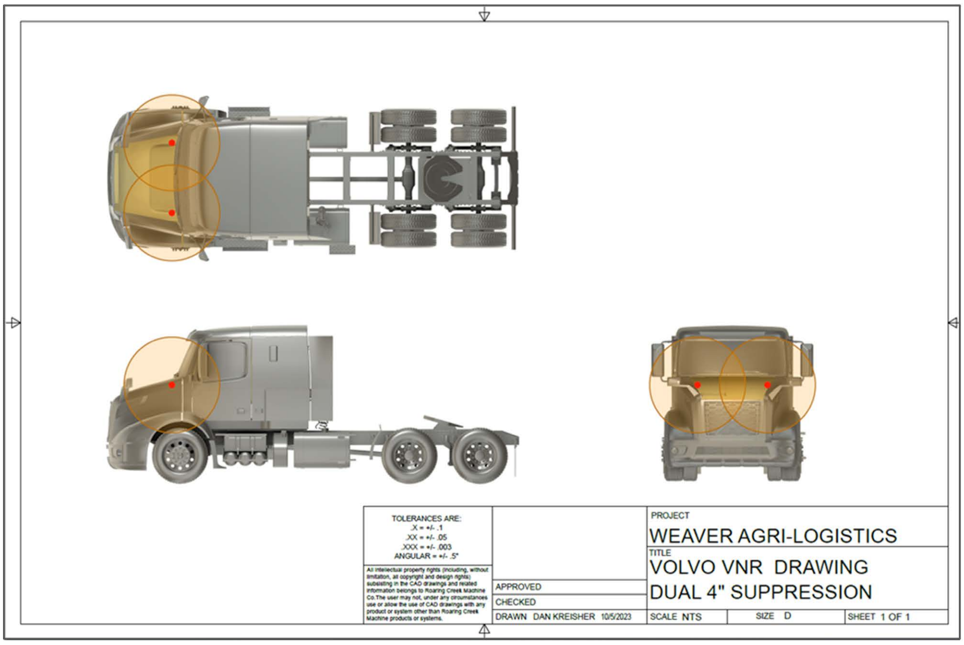

Figure 7. AutoCAD drawing of dual 4-inch EFEB blast radiuses.

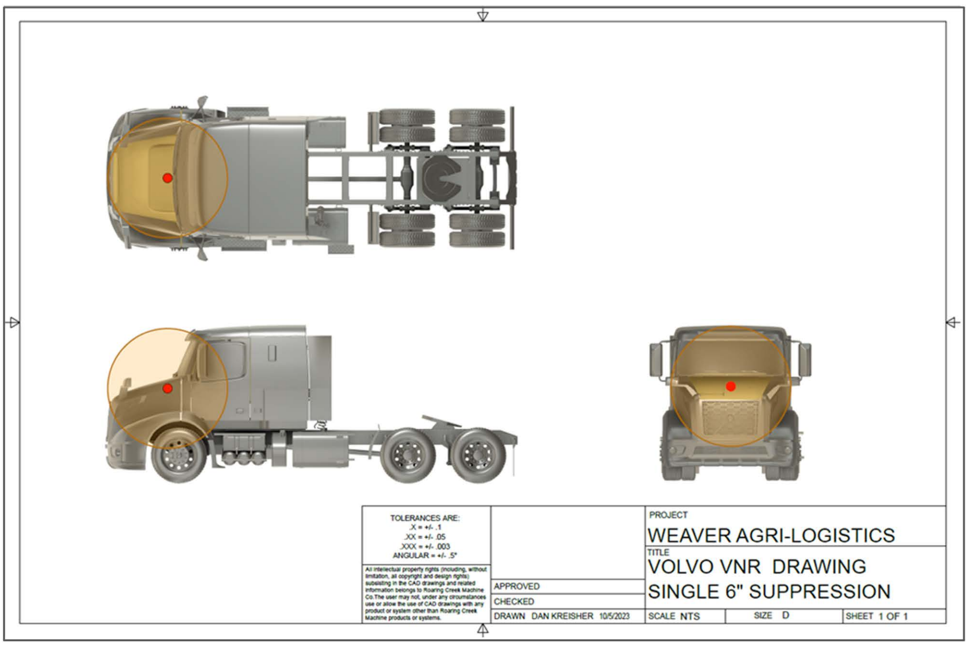

Figure 8. AutoCAD drawing of a single 6-inch EFEB blast radius.

As the effectiveness of the EFEB is influenced by its blast radius, the research will explore the impact of using various sizes and volumes of the blast radius during physical testing. This aspect of the study is deemed crucial to ensure the selection of the most appropriate configurations for practical applications.

To obtain comprehensive data, the investigation will incorporate diverse variables, including the location of fire initiation, the type of accelerant involved, and the prevailing weather conditions during the tests. These factors will be analyzed to determine their influence on the EFEBs' performance and their potential to create a time gap for the driver to evacuate safely.

While considering these essential variables, the primary objective remains to examine whether the EFEBs effectively provide the driver with sufficient time to safely egress. To achieve a thorough analysis, the study will also consider prior testing data and relevant research to support the interpretation of the data collected in this research endeavor.

By integrating these elements within the conceptual framework, the research aspired to contribute valuable insights into the efficacy of fire extinguishing balls within the engine compartments of vehicles. Through precise modeling, physical testing, and data analysis of key variables, the research sought to provide meaningful recommendations for enhancing fire safety measures and driver evacuation protocols in the transportation industry.

The significance of this study lies in its exploration of passive fire suppression devices in commercial vehicles, specifically focusing on establishing a critical window of time for drivers to egress to safety. Remarkably, the research conducted thus far on this topic has been limited, leaving a substantial knowledge gap in the field. By undertaking this study, I aspire to make a profound and positive impact on fire safety within the transportation industry and contribute to the realm of occupational health and safety.

Drawing upon my extensive career experience in the transportation industry, my commitment to enhancing driver safety on the roads fuels this endeavor. It is of utmost importance to ensure that our dedicated truck drivers return home safely, free from the risks posed by vehicle fires. As such, this research holds immense potential to advance our understanding of fire safety measures specifically tailored to commercial vehicles.

The data analysis will reveal that passenger vehicles are involved in a greater number of fires annually, averaging 244,030 incidents, compared to commercial vehicles' average of 23,550 fires [11]. However, the crucial distinction emerges when considering the ratio of commercial vehicles to cars, which stands at approximately 20:1. Remarkably, this means that, per capita, commercial vehicles are twice as likely to catch fire.

This research has the transformative capability to revolutionize the transportation industry's perception and response to the risks associated with vehicle fires, thanks to such data-driven insights. This study's findings and recommendations could pave the way for the adoption and implementation of passive fire suppression devices, effectively reducing fire-related hazards for commercial drivers. Consequently, this research holds immense promise in shaping a safer and more secure environment for truck drivers, instilling confidence, and influencing better practices in the transportation industry.

2. Contribution to the Body of Knowledge

The research and study on the efficacy and benefits of exploding fire extinguishing balls (EFEBs) in Commercial Vehicles will significantly contribute to the existing body of knowledge in fire safety and transportation engineering. Through a detailed examination of EFEBs' efficacy in suppressing engine fires, the study aims to advance fire suppression technology tailored specifically for commercial vehicles. By evaluating factors such as placement, size, and performance of EFEBs, the research will provide valuable insights into optimizing fire safety measures within transportation systems. Empirical evidence obtained from controlled experiments and simulations will inform the development and refinement of vehicle safety standards related to fire suppression systems, potentially influencing regulatory guidelines and industry practices.

By assessing the safety and reliability aspects of EFEB integration, the study will contribute to mitigating fire-related risks in transportation operations, supporting the adoption of proactive measures to prevent fire incidents. Additionally, the comprehensive cost-benefit analysis conducted as part of this research will assist stakeholders in making informed decisions about investing in fire suppression technology, while the examination of regulatory standards and legal implications will facilitate the responsible adoption and usage of EFEB technology within the regulatory framework.

Through educational outreach efforts, the research aims to raise awareness among stakeholders about the benefits of EFEBs in enhancing fire safety in commercial vehicles, fostering a culture of safety consciousness within the transportation industry and among the general public. This research will make a multifaceted contribution to advancing fire safety practices, mitigating risks, and enhancing the overall safety and reliability of commercial vehicle operations.

3. Research Participants

The research participants who contributed to the study played crucial roles in facilitating the testing and evaluation of Exploding Fire Extinguishing Balls (EFEBs) in commercial vehicles. E Fire USA, the manufacturer of the EFEB products under investigation, was actively involved from the inception of the research project. Representatives from E Fire USA, who serve as both product suppliers and sources of valuable information, collaborated closely with the research team to ensure a comprehensive understanding of the EFEB technology and its potential applications in commercial vehicles. Their expertise and support were instrumental in guiding the experimental process and providing essential resources for the study. Due to the manufacturer's interest in their product performing well, a conflict-of-interest management agreement was drafted and signed by both parties to eliminate any appearance of bias as well as to protect the integrity of the independent research.

The researcher's employer, PL Weaver & Company, played a critical role in the study's success. For testing purposes, PL Weaver & Company generously donated two trucks and their property, demonstrating a commitment to advancing fire safety measures in commercial vehicle operations. In addition to providing the necessary infrastructure for the experiments, PL Weaver maintenance employees played an active role in assisting with truck staging and testing setup, ensuring that the experiments were conducted with precision and accuracy.

Overall, the collaborative efforts of E Fire USA, PL Weaver & Company, and their respective representatives significantly contributed to the research project's success. By working together, these stakeholders demonstrated a shared commitment to promoting safety, protecting lives, and mitigating risks in transportation operations.

4. Research Methodology

For this research methodology, a quasi-experimental design is considered the most suitable approach, given the impracticality of randomization. Before conducting physical experiments, a quantitative research phase using AutoCAD technology will be employed to determine the airflow and available space within the engine compartments and underneath the vehicles' hoods. This preliminary step is essential to understanding the blast radius of the EFEBs and overlaying that data with the available air space, thus establishing a theoretical baseline assumption for subsequent tests and eliminating experimental design flaws.

In addition to the AutoCAD drawings, a thermal imaging camera will be used to identify areas of the engine that expel the most heat and are most likely to cause or contribute to a vehicle fire. For these models, a FLIR One Edge Pro camera will be used to establish the ideal location for fire extinguishing devices in a commercial vehicle's engine bay. The engine bay of a commercial vehicle is a dense labyrinth of interconnected components, each producing and dissipating heat at varied rates under normal operation. Conventional observation fails to effectively visualize these heat distributions and gradients. An infrared camera, using thermal imaging technology, registers the temperature variations in the form of color or grayscale heat maps that enhance this visualization. Infrared thermal imaging uses infrared radiation, invisible to the human eye, to create images based on an object's temperature variations. More specifically, the camera's detector elements convert the object's infrared radiation, depending on the temperature and material characteristics, into an electrical signal that is displayed as an image. By allowing users to 'see' temperature variations and hotspots, thermal imaging cameras unlock unprecedented visibility into mechanical and electrical systems.

A comprehensive experimental design was developed once the quantitative data had been collected and evaluated. This phase involved strategically placing appropriately sized fireballs in predetermined locations, as indicated by the numerical data, to optimize the testing process and minimize wastefulness. The case study utilized two decommissioned commercial vehicles, with 1 or 2 fireballs mounted in different sizes and configurations in each vehicle's engine compartment. Including the preliminary testing phase, the approximate number of EFEBs will be 12 - 15. Each truck will be outfitted with a thermocouple temperature probe. The probe wires are 66 feet long and connected to a dual-channel thermometer.

During the tests, each truck will be set ablaze individually, working closely with the local fire department.

During the experiments, the following key data points were recorded and analyzed:

- Time passed until the fireballs exploded.
- The fireballs' effectiveness in extinguishing or suppressing fire.
- The overall fire damage inflicted upon the vehicle.
- Temperature fluctuations in the cab during the tests.

This dataset, along with a comparison of the different fireball sizes and placements used, lead to the identification of the most optimal setup for passive EFEBs in commercial vehicles. The research findings provide valuable insights into the efficacy of these devices, offering evidence-based recommendations for enhancing fire safety in the transportation industry and safeguarding the lives of drivers. By combining theoretical assessments with the physical testing, this research aims to contribute significantly to the development of more effective fire suppression strategies for commercial vehicles, ultimately mitigating fire-related risks and improving overall driver safety.

The chemical used in the EFEB is monoammonium phosphate (MAP). MAP is a dry chemical agent commonly used in fire extinguishers and suppression systems. When applied to fires, MAP functions through two primary mechanisms: chemical flame inhibition and heat absorption [12]. The chemical reaction releases ammonium radicals that interfere with the combustion process, disrupting the fire's chain reaction [13]. Additionally, the powder form of MAP helps smother the fire by forming a barrier that prevents oxygen from reaching the fuel source. This dual-action mechanism makes MAP highly effective in combating Class A (wood, paper, cloth), Class B (flammable liquids), and Class C (electrical fires) fires [14]. According to the United States Department of Agriculture (USDA), monoammonium phosphate (MAP) has no adverse environmental effects that are acute or chronic. The OSHA permissible exposure limit (PEL) is 15 mg/m3 for total dust, and 5 mg/m3 for respiratory fraction. "The need for respiratory protection is not probable during short-term exposure" [15]. Personal protective equipment (PPE) during production or processing should be evaluated on a case-by-case basis. Prolonged exposure to MAP dust may cause eye irritation, respiratory irritation, or distress. In a 2023 article [16], Praatik Trivedy explains, that when exposed to high concentrations of MAP dust, over a prolonged period, without the protection of an appropriate respirator, there are risks of more serious health complications, such as bronchitis or pneumonia. This is true of prolonged physical contact with the chemical as well. Over a prolonged period, in high concentrations, MAP powder can cause more serious skin irritation and even a chemical burn.

5. Preliminary Testing

The scientific endeavor to develop a reliable and effective fire suppression system for the protection of vehicle occupants during a fire incident necessitated a thorough and methodical approach. Recognizing the potential dangers and complexities involved, preliminary testing became an essential phase in the research process. The need for preliminary testing was a vital part of establishing a baseline understanding of the system's functionality, determining optimal parameters, and refining the experimental setup for subsequent testing phases.

In preparation for each testing phase, extensive planning and coordination were undertaken to ensure the highest level of safety. Collaboration with the local fire department, comprehensive safety briefings, the provision of protective gear, and the strategic placement of fire extinguishers were fundamental components of this protocol. However, to truly gauge the efficacy of the fire suppression system, preliminary tests were conducted under carefully controlled conditions, mimicking real-world scenarios.

Infrared thermal imaging, AutoCAD drawings, and insights from expert diesel mechanics provided a foundation for the preliminary testing phase. These elements facilitated the identification of four initial mounting locations for the fire suppression system: both sides of the firewall, the center of the hood, and the driver's side fan shroud. The exploratory nature of preliminary testing allowed for data-driven decisions. The underside of the hood and the 4-inch fireball revealed through these tests, were deemed less effective and subsequently excluded from further experimentation.

Moreover, fine-tuning variables such as fuel and fabric quantities were a crucial outcome of preliminary testing. The determination of the most realistic fire simulations involved the selection of specific materials—an 18" × 18" segment of blended polyester moving blankets—and precise fuel saturation. These adjustments, guided by the insights gained from the preliminary tests, were instrumental in refining the experimental setup for the conclusive testing phases.

The culmination of seven preliminary tests, incorporating variations in fabric amounts, fuel quantities, and fireball placement, provided invaluable insights into the functionality of the fire suppression system. Notably, the preliminary testing phase led to the exclusion of less effective components and the optimization of critical variables. In the subsequent experimental trials, involving the 2015 Volvo VNR truck and the 6-inch fireball device, the effectiveness of the system was strikingly evident. The fireball's activation, accompanied by a potent 170-decibel warning, demonstrated swift suppression of flames, preserving a survivable temperature range within the cabin. In contrast, control tests without the fireball device witnessed a rapid escalation of interior temperatures, highlighting the critical significance of the fire suppression system in life-threatening conditions.

The preliminary testing phase, marked by meticulous planning, iterative adjustments, and data-driven decisions, laid the foundation for a comprehensive evaluation of the fire suppression system. The subsequent sections of this research narrative will delve into the conclusive testing phases, presenting a thorough analysis of the experimental outcomes and their implications for vehicular safety under fire conditions.

The importance of preliminary testing cannot be overstated when evaluating the efficacy of safety technologies, such as the fireball system in commercial vehicles. Preliminary testing serves as a critical phase in the research and development process, acting as a meticulous and methodical approach to narrow margins of error and closely replicate real-life scenarios. This phase is indispensable in ensuring that the subsequent experimental trials are grounded in a solid foundation, providing accurate insights into the technology's performance under diverse conditions.

During the preliminary testing phase described in the study, meticulous planning and coordination were emphasized, particularly with the involvement of the local fire department. This collaborative approach not only enhances safety protocols but also establishes a framework for effective real-time responses during testing. The inclusion of AutoCAD drawings, infrared thermal imaging, and insights from seasoned diesel mechanics add a layer of precision, aligning the preliminary tests with the intricacies of a commercial vehicle's engine and fire dynamics.

The identification of initial mounting locations and subsequent elimination of less effective positions based on the preliminary tests exemplify the attention to detail required in these early stages. Such refinement ensures that the experimental trials focus on the most promising configurations, streamlining the testing process and contributing to more meaningful and reliable results.

Moreover, the fine-tuning of variables like fuel and fabric quantities further highlights the commitment to creating a testing environment that mirrors real-world conditions. This meticulous approach accounts for unique specifications that could impact the technology's performance, such as variations in fuel type and saturation, as well as fabric types. By addressing these variables in the preliminary phase, I was able to reduce uncertainties and enhance the accuracy of subsequent experiments.

Preliminary testing serves as the cornerstone for precision experimental trials. It allows researchers to identify and address potential sources of error, optimize testing parameters, and create a controlled yet realistic environment. By narrowing margins of error during this phase, the subsequent experimental results more closely represent the complexities of real-life scenarios, providing valuable insights that can inform the integration and deployment of safety technologies in commercial vehicles. This emphasis on careful preliminary testing contributes to the overall reliability and effectiveness of the fireball technology in mitigating the risks associated with vehicle fires.

6. Testing Procedures

In preparation for each testing phase, meticulous planning and coordination with the local fire department were imperative. This involved ensuring their presence on-site, conducting a comprehensive safety briefing for all involved parties, providing appropriate protective gear, and strategically placing fire extinguishers within easy reach. This protocol was established to guarantee the utmost safety during the testing process.

To create a testing environment mirroring real-world conditions, a series of preliminary tests were conducted. These sessions were guided by AutoCAD drawings, infrared thermal imaging, as well as guidance from expert diesel mechanics, who offered valuable knowledge regarding critical engine areas. Four initial mounting locations were identified: both sides of the firewall, the center of the hood, and the driver's side fan shroud.

Fine-tuning the fuel and fabric quantities was crucial to achieving the most realistic fire simulations. For the conclusive testing phases, precisely 1 cup of diesel fuel was absorbed by an 18" × 18" segment of recently acquired moving blankets, crafted from a blend of polyester mesh and cotton. This material was selected for its capacity to retain liquid fuel, similar burning attributes in comparison to single-layered cotton or burlap, and ability to replicate the same burning rate as the insulation beneath the hood. Following saturation with diesel fuel, the fabric was positioned approximately 12 - 14 inches beneath and in front of the fireball. The hood was then securely shut, and a propane torch was used to start the fire. Rigorous data collection was carried out using three separate stopwatches, a digital thermometer with a 60-foot thermocouple, quantitative data forms, and assistance from two camera-equipped personnel. In total, the testing encompassed 6 four-inch fireballs, 6 six-inch fireballs, and an additional 2 six-inch fireballs featuring a manual ignition option, providing a failsafe for drivers to manually trigger the suppression system if needed.

7. Results

It is widely accepted that "above 50˚C or 122˚F, heat stroke is almost certain. In this case, most mammals, including human muscles, will get stiff, and then death will eventually occur in the absence of urgent help" [17]. This quote regarding the critical threshold for heat stroke serves as an important contextual backdrop for understanding the significance of the experimental results. It highlights the physiological risks associated with elevated temperatures and underscores the urgent need for effective temperature control measures, particularly in life-threatening situations such as vehicle fires. This sets the stage for interpreting the experimental data in terms of its impact on human safety and survival.

In the first experimental trial involving the 2015 Volvo VNR truck and the 6-inch fireball device, the initial cabin temperature of 70 degrees Fahrenheit provided a baseline for comparison. The activation process of the fireball, marked by its 170-decibel warning, demonstrates the device's ability to alert occupants to impending danger. The subsequent ignition and suppression of the fire within a span of 3 seconds exemplify the fireball's rapid response and effectiveness in safeguarding the cabin's potential occupants. This real-time demonstration of the fireball's performance underscores its potential lifesaving impact in emergency situations.

The subsequent trial with the same 6-inch fireball, initiated at a slightly cooler cabin temperature of 67 degrees Fahrenheit, further validates the device's efficacy.

Despite the lower initial temperature, the fireball's warning and ignition sequence follow a similar pattern, resulting in swift fire suppression and ensuring the safety of the cabin's occupants. This consistent performance across different temperature conditions reinforces the fireball's reliability and versatility as a fire suppression tool.

In contrast, the control test, which omits the use of a fireball device, starkly illustrates the consequences of not having effective fire suppression measures in place. The initial temperature of 68 degrees Fahrenheit provides a reference point for understanding the rapid escalation of heat within the cabin. The alarming temperature spikes observed within the first few minutes show the rapid progression of the fire and the imminent threat it poses to human life. This radical contrast between the experimental trials with and without the fireball device emphasizes the critical significance of employing such technology to maintain a survivable temperature range within the cabin, especially in high-risk environments like vehicle fires.

Overall, these experimental results provide compelling evidence for the effectiveness of fireball technology in mitigating the risks associated with vehicle fires and ensuring the safety of occupants. Analyzing and interpreting such data not only contributes to the advancement of knowledge in the field but also underscores the real-world impact of the research on human safety and well-being

8. Data Analysis

8.1. Correlation Analysis

Pearson or Spearman correlation is employed to examine the degree of association between two continuous variables, revealing both its direction (positive or negative) and magnitude. A positive correlation signifies that as one variable rises, so does the other, while a negative correlation suggests that as one variable increases, the other decreases. To answer some of the questions posed earlier, I used the following to highlight to clarify and find the answers, for example, to answer Question 2: I will use Cabin temperature and fire duration. Two continuous variables so Pearson's r correlation coefficient. Resource:

https://www.statisticshowto.com/probability-and-statistics/correlation-coefficient-formula/

By performing a correlation analysis, the relationship between the cabin temperature and the duration of the fire in each test can be examined.

Test	Cabin Temperature (F)	Fire Duration (seconds)
#1 with a 6-inch fireball	71	23
#2 with a 6-inch fireball	69	33
Control Test (1 minute)	88	60
Control Test (2 minutes)	171	120
Control Test (3 minutes)	201	180

The correlation coefficient, denoted by r, ranges from −1 to 1.

- If r is close to 1, it indicates a strong positive linear relationship.
- If r is close to −1, it indicates a strong negative linear relationship.
- If r is close to 0, it indicates a weak or no linear relationship.

Correlation Coefficient (r): 0.944

The correlation coefficient (r) is 0.944, which indicates a very strong positive linear relationship between Cabin Temperature and Fire Duration. This suggests that as Cabin Temperature increases, Fire Duration tends to increase as well.

8.2. T-Test Analysis

To perform a T-test, I compared two groups and determined if there was a statistically significant difference between their means. In this case, I compared the fire duration for the two groups: the tests with a 6-inch fireball and the control tests.

Group 1 (with 6-inch fireball):
• Test #1: 71˚F, 23 seconds • Test #2: 69˚F, 33 seconds
Group 2 (control tests):
• Control Test (1 minute): 88˚F, 60 seconds • Control Test (2 minutes): 171˚F, 120 seconds • Control Test (3 minutes): 201˚F, 180 seconds

The p-value of 0.1145 indicates the probability of observing the data if the null hypothesis were true. In this case, the null hypothesis is that there is no difference in the mean fire durations between the group with the 6-inch fireball and the control group.

A common significance level (α) used to determine statistical significance is 0.05. If the p-value is less than α (0.05), we reject the null hypothesis, indicating that there is enough evidence to suggest that there is a significant difference between the groups.

However, since the p-value of 0.1145 is greater than 0.05, we fail to reject the null hypothesis. This means that we do not have enough evidence to conclude that there is a significant difference in the mean fire durations between the two groups. In other words, the difference in fire durations between the group with the 6-inch fireball and the control group could be due to random variation rather than a true effect.

Based on the p-value of 0.1145, of this one test, I do not have sufficient evidence to claim that the mean fire durations differ significantly between the two groups. The t-statistic measures the difference between the means of the two groups relative to the variation within the groups. A negative t-statistic indicates that the mean of group 1 (with the 6-inch fireball) is lower than the mean of group 2 (control group). In this case, the t-statistic of approximately −2.63 suggests that there is a difference in the mean fire durations between the two groups. The magnitude of the t-statistic indicates the size of this difference relative to the variability within each group.

To interpret the significance of the t-statistic, I compared it to critical values from the t-distribution corresponding to a chosen significance level. If the absolute value of the t-statistic is greater than the critical value, I will reject the null hypothesis and conclude that there is a significant difference between the groups. In this case, with 2 degrees of freedom, the t-statistic of approximately −2.63 is less than the critical value of 2.92. Therefore, I cannot reject the null hypothesis, indicating that there is not enough evidence to conclude that there is a significant difference in the mean fire durations between the group with the 6-inch fireball and the control group at the 0.05 significance level. I suspect that given the significant time duration differences between the EFEB tests and the control tests, the variable has affected the outcome. We can see a significant relationship between time and temperature between the control tests and device tests.

9. Discussion

Following the initial trials, subsequent experiments were conducted using the 2015 Volvo VNR truck. The 6-inch fireball was once again employed, with the initial cabin temperature at 70 degrees Fahrenheit. The fireball emitted its 170-decibel warning at the 21-second mark, followed by a 4-second delay before it detonated. The flames were promptly suppressed, maintaining a safe cabin temperature for potential occupants.

In the second trial with the 2015 Volvo VNR, the initial cabin temperature was measured to be slightly cooler at 68 degrees Fahrenheit. The fireball emitted its warning at 20 seconds and ignited 5 seconds thereafter. The fire was rapidly extinguished, once again ensuring a safe cabin temperature.

Contrary to the fireball trials, the control test witnessed a rapid escalation of temperatures within the cabin. Starting at an initial temperature of 69 degrees Fahrenheit, the interior heat quickly intensified. After 1 minute, the cabin temperature soared to 121 degrees Fahrenheit, and by the 2-minute mark, it had reached a dangerous 204 degrees Fahrenheit. This stark contrast between the controlled fireball experiments and the control test further emphasizes the critical role of fire suppression technology in maintaining survivable conditions within the cabin.

In summary, the experimental trials demonstrated the remarkable effectiveness of the 6-inch fireball in suppressing fires and preserving safe cabin temperatures. The fireball's rapid activation time and efficient suppression capabilities offer a significant advantage in mitigating the risks associated with vehicle fires. These results provide compelling evidence for the potential lifesaving impact of fireball technology in commercial vehicles.

The experimental trials conducted in this study have yielded valuable insights into the effectiveness of fireball technology in suppressing fires and preserving safe cabin temperatures. The results unequivocally demonstrate the critical role that fire suppression devices, such as the 6-inch fireball, can play in safeguarding the lives of commercial vehicle occupants in the event of a fire.

The experiments' data highlights the fireball's rapid response time and efficient extinguishing capabilities. In all trials, the fireball successfully suppressed the fire, preventing further escalation and maintaining a safe cabin environment. This contrasts starkly with the control tests, where the absence of fire suppression technology led to rapid and dangerous increases in cabin temperatures.

Based on these findings, several recommendations can be made to enhance fire safety in commercial vehicles:

1) Fireball Technology Integration: Commercial vehicle manufacturers should consider incorporating fireball technology as a standard safety feature. This study's effectiveness highlights its potential to significantly reduce the risks associated with vehicle fires.

2) Driver Training and Education: Drivers should receive comprehensive training on the Fireball technology's operation and benefits. This knowledge empowers them to take swift action in the event of a fire, potentially preventing catastrophic outcomes.

3) Regulatory Considerations: Regulatory bodies and safety organizations should evaluate the potential benefits of mandating the use of fire suppression devices in commercial vehicles. This step could contribute to a substantial reduction in fire-related risks.

4) Continued Research and Development: Ongoing research and development efforts should focus on further refining fireball technology, optimizing its performance, and exploring potential adaptations for various types of commercial vehicles.

5) Emergency Response Preparedness: Emergency responders should be trained to recognize and effectively respond to incidents involving fireball technology. This knowledge ensures a coordinated and efficient response in emergency situations.

6) Public Awareness Campaigns: Outreach initiatives should be launched to raise awareness among fleet operators, drivers, and the general public about the benefits of fireball technology in enhancing fire safety.

The findings of this study provide compelling evidence for the efficacy of the E Fire USA fireball technology as a critical component of fire safety measures in commercial vehicles. By integrating this innovative technology, the transportation industry can significantly reduce the risks associated with vehicle fires, ultimately saving lives, and minimizing property damage. This research represents a significant step towards advancing fire safety in the commercial vehicle sector, and we hope that these findings will serve as a catalyst for further research, development, and widespread adoption of fireball technology in the transportation industry.

10. Limitations

In order to address the limitations of the experimental trials, it is imperative to recognize the need for further research that better simulates real-world vehicular fire incidents. While the controlled environment provided valuable insights, it failed to capture the full spectrum of variables encountered in actual scenarios. Factors such as wind direction, variations in fuel types, and the unpredictable nature of fire patterns in different contexts can significantly impact the performance of fire suppression devices like the 6-inch fireball. Therefore, future studies should strive to incorporate these variables into their experimental design to ensure a more accurate assessment of the device's effectiveness across diverse conditions.

Expanding the scope beyond a single truck model is also critical for improving the findings' generalizability. While the trials conducted on the 2015 Volvo VNR truck yielded valuable data, extrapolating these results to other vehicle types with different structural compositions and fire dynamics may not carry over with the same effects. To address this limitation, future research should include a wider range of vehicle models to provide a more comprehensive understanding of how fire suppression devices perform across various platforms.

Furthermore, while the study focused primarily on the immediate effects of the fireball device in suppressing flames and controlling cabin temperatures, it overlooked potential secondary effects such as smoke dispersion and interior damage to the vehicle. Exploring these secondary effects is essential for understanding the full impact of fire suppression technology on vehicular safety. Future research should incorporate comprehensive assessments of both primary and secondary effects to provide a more holistic understanding of the device's performance.

Lastly, addressing the assumption of optimal deployment conditions for the fireball device is crucial for ensuring its effectiveness in real-world scenarios. Factors such as response time, accessibility, and potential human error in activation can significantly influence the device's performance. Therefore, future studies should explore these practical considerations and assess how they impact the device's effectiveness under realistic conditions.

While the experimental trials provided valuable insights into the effectiveness of the 6-inch fireball device, addressing the limitations outlined above is essential for advancing our understanding of fire suppression systems in vehicular contexts. By conducting more comprehensive and representative studies, researchers can improve the overall effectiveness of fire safety measures and enhance the protection of vehicle occupants in the event of a fire.

11. Challenges and Considerations

- Standardization: Balancing customization with the need for standardization in safety features requires careful consideration. Striking the right balance is crucial to ensure widespread adoption.
- Collaboration with Manufacturers: Successful implementation depends on strong collaboration between fire safety experts, engineers, and semi-truck manufacturers. Establishing open lines of communication and collaboration is paramount.

By treating these devices like modern airbags, we can leverage advanced design technologies to customize solutions for each truck model. This research lays the foundation for a new era in fire suppression technology, where adaptability and efficiency converge to create a safer environment for drivers, cargo, and the industry as a whole. As we continue to explore innovative solutions, the potential for reducing the impact of fire incidents in semi-trucks becomes more tangible, paving the way for a safer and more secure future.

Continued research and development are crucial for refining the technology and adapting it to different vehicle types. Additionally, emergency responders should be trained to handle incidents involving fireball technology, ensuring a coordinated response in emergencies.

Overall, the adoption of fireball technology in commercial vehicles represents a significant advancement in fire safety. By prioritizing this technology, the transportation industry can significantly reduce the risks associated with vehicle fires, thereby protecting lives, reducing property damage, and ensuring a safer environment for commercial vehicle operations.

Expanding on the conclusion, it's important to consider the impact of external factors such as weather, vehicle vibrations, and the overall durability of the fireball technology, as well as the legal implications associated with its use.

One of the most concerning aspects of traditional fire extinguishing systems is their susceptibility to failure due to mechanical issues, human error, or environmental factors. In contrast, the Exploding Fire Extinguishing Ball (EFEB) offers a more reliable and consistent approach to fire suppression. By utilizing a self-contained, disposable unit, the EFEB minimizes the risk of equipment malfunction and reduces the potential for human error in the event of a fire. This reliable approach ensures a quicker response time, maximizing the chances of extinguishing a fire before it spreads and causes further damage or injury.

Moreover, the EFEB's high-pressure release mechanism allows for rapid and precise deployment, covering a large area in a short period of time. This extensive coverage ensures that the fire is effectively extinguished throughout the affected area, providing a comprehensive and efficient fire protection solution. Additionally, the EFEB's compact design enables it to be easily stored and transported in various commercial vehicles, offering an accessible and portable fire suppression solution.

The Exploding Fire Extinguishing Ball (EFEB) presents a novel and effective fire suppression technology for commercial vehicles. Its rapid response time, broad coverage, and convenient portability make it a valuable asset for enhancing fire safety measures. By providing an efficient and reliable alternative to traditional fire extinguishing systems, the EFEB has the potential to significantly reduce the risk of life and property loss due to fire incidents in commercial vehicles. To further evaluate and optimize the EFEB for widespread application, further research should be conducted to assess its effectiveness in different types of vehicles, under varying environmental conditions, and in combination with existing fire safety systems. Additionally, cost-benefit analyses should be conducted to determine the realistic feasibility of the product.

The effectiveness of the fireball technology in various weather conditions is a crucial aspect to consider. Commercial vehicles often operate in diverse climatic conditions, ranging from extreme cold to intense heat, along with exposure to rain, snow, and humidity. Fireball technology must maintain its functionality and reliability across these varying conditions. Durability tests should be conducted to ensure that the device's components, such as the triggering mechanism and fire suppression agents, remain effective over time and in different environmental conditions. This durability not only ensures consistent performance, but it also contributes to the overall cost-effectiveness of the technology, as a durable product requires less frequent replacement or maintenance.

Commercial vehicles are subject to significant vibrations and jolts, especially when traversing rough terrain or during long-haul travel. These vibrations could potentially impact the fireball's sensitivity and activation mechanism. Ensuring that the device is robust enough to withstand these conditions without false activations or failure to activate when needed is critical. This requires rigorous testing under simulated conditions that mimic real-world vibrations and shocks. Fireball technology that is resilient to such conditions would be more reliable and safer for use in commercial vehicles.

The integration of fireball technology into commercial vehicles also brings forth legal considerations, particularly regarding liability. Manufacturers and installers of these devices need to ensure compliance with existing safety standards and regulations. This includes obtaining the necessary certifications and conducting thorough testing to meet industry guidelines. From a legal standpoint, the effectiveness and reliability of fireball technology in preventing or controlling fires could potentially reduce liability for transportation companies in the event of a fire-related incident. However, there is also the consideration of liability in the event of a malfunction or if the device fails to activate during a fire, leading to property damage or injury. Therefore, comprehensive insurance policies and clear guidelines on the proper usage, maintenance, and expectations of the technology are vital.

In light of these considerations, it is imperative for manufacturers to continuously monitor and improve the design and functionality of the fireball technology, taking into account weather resilience, and vibration resistance, and ensuring compliance with legal and safety standards. These steps will not only enhance the reliability and effectiveness of the product but also provide a clearer framework for legal and liability issues, thereby reinforcing the trust and confidence of commercial vehicle operators in adopting this lifesaving technology.

One emerging technology that will be crucial to further research and development of the exploding fire suppression balls is artificial intelligence (AI). As the transportation industry continues to prioritize safety measures, the integration of exploding fire extinguishing balls (EFEBs) into commercial vehicles represents a promising advancement. However, ensuring the optimal performance of these devices requires rigorous testing under diverse conditions. By accurately dialing in variables such as ignition source, fire origin, weather conditions, accident scenarios, and device blast radius, AI-driven testing promises to enhance the reliability and effectiveness of EFEBs in mitigating the risks associated with vehicle fires.

The integration of exploding fire extinguishing balls (EFEBs) in commercial vehicles has garnered significant attention as a proactive measure to enhance fire safety. These innovative devices are designed to rapidly suppress fires upon detection, thereby safeguarding vehicle occupants and minimizing property damage. However, ensuring the optimal performance of EFEBs necessitates comprehensive testing methodologies that replicate real-world scenarios with precision and accuracy. In this context, the use of artificial intelligence (AI) offers unprecedented capabilities to fine-tune testing parameters and optimize device performance.

Under the vehicle hood, AI algorithms enable the optimization of EFEB blast radius and air space utilization. By simulating various scenarios, researchers can evaluate the efficacy of EFEBs in different fire conditions. Weather factors such as wind speed, humidity levels, and ambient temperature can significantly impact fire dynamics. AI-driven testing allows for the precise manipulation of these variables, ensuring comprehensive evaluations of EFEB performance under diverse environmental conditions. AI facilitates the simulation of both accident and non-accident scenarios to assess EFEB efficacy in different contexts. By modeling realistic accident scenarios, researchers can evaluate the device's response to collision-induced fires, ensuring robust performance in emergencies. AI algorithms enable optimization of EFEB blast radius and air space utilization under the vehicle hood. By analyzing vehicle geometry and fire dynamics, researchers can determine the optimal placement and quantity of EFEBs for maximum effectiveness.

AI-driven testing ensures precise control over test parameters, resulting in more accurate evaluations of EFEB performance. Automated data collection and analysis streamlines the testing process, allowing for rapid iteration and refinement of device design. Cost-Effectiveness: AI-driven simulations reduce the need for expensive physical testing, resulting in cost savings for manufacturers and researchers.

AI-driven testing relies on large volumes of high-quality data to train algorithms effectively. Access to comprehensive datasets is essential for accurate simulations. Ethical and safety concerns: In AI-driven testing, ensuring the safety of researchers and test subjects is paramount.

The inclusion of artificial intelligence (AI) in testing methodologies for exploding fire extinguishing balls (EFEBs) represents a paradigm shift in the evaluation of fire safety technologies for commercial vehicles. By accurately dialing in variables such as ignition source, fire origin, weather conditions, and accident scenarios, AI-driven testing promises to enhance the reliability and effectiveness of EFEBs in mitigating the risks associated with vehicle fires. As the transportation industry continues to prioritize safety, the adoption of AI-driven testing methodologies will play a pivotal role in advancing fire safety standards and protecting vehicle occupants worldwide.

12. Conclusion and Recommendations

In conclusion, the comprehensive experimental trials conducted to assess the E Fire USA fireball technology in commercial vehicles have demonstrated its remarkable effectiveness in suppressing fires and maintaining safe cabin temperatures. The 6-inch fireball device, in particular, showed rapid activation and efficient fire suppression capabilities, significantly mitigating the risks associated with vehicle fires. This is starkly contrasted with control tests, where the absence of such technology led to dangerous and rapid increases in cabin temperatures, well beyond human survivability thresholds.

This study's results do not predict imminent regulatory action due to the many constraints present in the commercial vehicle industry, especially in the area of vehicle design. The prospects for an automatic fire suppression system performance standard do not appear promising because the simulation results have shown that most fire events are too large to be extinguished by a reasonable number of suppressors. Rather, the expected implementation could be through the motor carrier insurance industry. Currently, insurance rates are based on actuarial tables and do not directly reflect a given motor carrier's actual safety performance. If the insurance industry could feasibly reward carriers that install fire suppression systems with lower premiums, it would provide an economic incentive for carriers to invest in fire safety technology. Another possible mechanism would be to offer insurance discounts for carriers that use vehicles that meet certain fire safety design standards. This would give vehicle manufacturers an added incentive to improve vehicle fire safety. An empirically based fire safety standard could also be considered by motor carrier industry regulators. This is a very speculative idea, but it has the potential to improve the fire safety of commercial vehicles if it were based on ongoing research in vehicle fire dynamics and updated as new technology becomes available.

Outfitting commercial vehicles with exploding fire extinguishing balls (EFEBs) appears to be financially reasonable based on a preliminary cost-benefit analysis. Considering an estimated 13.5 million registered commercial vehicles in the United States, according to the Bureau of Transportation Statistics [18], and assuming each vehicle experiences one fire incident during its operational lifespan, the total cost to implement EFEBs across all vehicles would amount to approximately $1.62 billion, considering each EFEB costs $120 [19]. On the other hand, the potential savings from reduced fatalities due to truck fires are substantial. With an estimated 2.7 fatalities per 1000 fires, the total number of potential fatalities without EFEBs stands at 36,450. Assuming an average insurance payout per fatality of $1,750,000 [20], the total potential savings from reduced fatalities would amount to an impressive $63.8 billion. Since, on average, large trucks only account for 3.7 percent of all vehicles on the roadways, but represent 11.8 percent of all fatal crashes, fireballs are one mathematically certain way to reduce the number of fatalities in the United States.

Comparing the cost of implementation to the potential savings, it is evident that outfitting commercial vehicles with EFEBs could yield significant financial benefits. However, these calculations do not include research and development (R&D) costs associated with EFEB technology, which could affect the overall financial feasibility of implementation. Furthermore, the actual number of fire incidents and fatalities may vary, potentially impacting savings. Therefore, further comprehensive analysis, including detailed cost-benefit studies considering all relevant factors, would be necessary to make a more precise determination of the financial viability of EFEB implementation in commercial vehicles.

The cost-effectiveness and return on investment for transportation companies adopting this technology are evident. The fireball's ability to rapidly control fires not only improves safety for vehicle occupants, but it also minimizes potential property damage, which can translate into significant financial savings over time. Additionally, the integration of this technology could potentially reduce insurance premiums due to improved safety standards.

Given these findings, it is recommended that commercial vehicle manufacturers integrate fireball technology as a standard safety feature. This should be complemented by driver training and public awareness campaigns to ensure effective use and understanding of the technology. In addition, regulatory bodies should consider mandating the use of such fire suppression devices to improve overall vehicle safety standards.

Manufacturers can approach this technology by treating these EFEBs as airbags. Yes, airbags. Like modern airbags, molding these devices to suit the specific layouts of various truck manufacturers enhances their effectiveness and ensures optimal utilization. The paper discusses the potential benefits of this approach, addressing both safety and practical considerations. By integrating this technology seamlessly into different engine bay configurations, we aim to elevate the overall fire safety standards in the trucking industry. Traditional fire suppression systems in semi-trucks often face limitations in terms of adaptability to different engine bay configurations. The idea of exploding fire suppression balls offers a more versatile solution. Similar to airbags, these devices can be strategically molded to fit seamlessly into the unique spaces within each truck model. This not only enhances their efficiency but also ensures a customized approach to fire safety in the trucking industry. Molding exploding fire suppression balls involves a comprehensive understanding of the diverse engine bay layouts across different semi-truck manufacturers. Advanced computer-aided design (CAD) technologies can be employed to create molds that precisely match the contours and dimensions of each engine bay. This section explores the technical aspects of the design process, emphasizing the need for collaboration between fire safety experts and truck manufacturers to create tailor-made solutions. It is, of course, important to factor in the pros and cons of this technology.

Benefits of Molding Exploding Fire Suppression Balls

- Enhanced Efficiency: Tailoring the suppression balls to fit specific engine bays ensures that they cover critical areas prone to fire incidents. This targeted approach maximizes the device's ability to suppress flames rapidly and effectively.
- Reduced Response Time: Customized molding enables the suppression balls to deploy swiftly in the event of a fire, minimizing response time and potentially preventing catastrophic damage.
- Adaptability to Various Truck Models: A molded approach ensures that fire suppression technology can be seamlessly integrated into a wide range of semi-truck models, promoting widespread adoption across the industry.
- Cost-Effectiveness: While the initial investment in molding technology may be significant, the long-term cost benefits of reducing fire-related damages and enhancing overall safety make it a financially prudent choice.

This research aimed to explore the efficacy of exploding fire extinguishing balls (EFEBs) in commercial vehicles through a comprehensive research process. The study began with a thorough review of prior research, highlighting existing knowledge gaps and setting the foundation for further investigation. Subsequently, the research focused on creating a real-world scenario to test EFEBs, emphasizing the importance of accurately replicating fire dynamics and environmental conditions.

Through meticulous planning and coordination, a series of experimental trials were conducted, simulating various ignition sources, fire origins, and fuel types. Data analysis played a crucial role in evaluating EFEB performance, with researchers examining factors such as ignition time, suppression effectiveness, and blast radius. The findings provided valuable insights into the effectiveness of EFEBs in mitigating vehicle fire risks.

However, it is essential to acknowledge the limitations of the study. Despite efforts to replicate real-world scenarios, laboratory testing may not fully capture the complexities of actual fire incidents. Additionally, the study focused primarily on controlled environments, potentially limiting the generalizability of the findings to dynamic, unpredictable situations.

Looking into the future, further research is warranted to address these limitations and expand our understanding of EFEB performance in diverse contexts. Future studies could explore the integration of AI-driven testing methodologies to enhance accuracy and efficiency. Additionally, field trials involving actual commercial vehicles could provide valuable insights into real-world EFEB deployment and effectiveness.

It is with great pride that this dissertation will contribute to the growing body of knowledge on fire safety in commercial vehicles, highlighting the potential of EFEBs as a proactive measure to protect vehicle occupants and minimize property damage. By reviewing prior research, creating realistic testing scenarios, analyzing data, and acknowledging study limitations, the research provides a foundation for future advancements in EFEB technology and fire safety research.

Submission Statement

This manuscript is submitted for exclusive consideration for publication in the Journal of Transportation Technologies. It has not been published previously and is not under consideration for publication elsewhere. The author confirms that all necessary permissions for any third-party content included in the manuscript have been obtained.

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Conflicts of Interest

The author declares no conflicts of interest related to this study. A conflict-of-interest management agreement was signed with E Fire USA to ensure the integrity and independence of the research.

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