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Design of a Special-Effects Wrist-Mounted Flamethrower

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Abstract: *This paper presents the design of a special-effects wrist-mounted flamethrower. The device facilitates the illusion of the user holding a flame in the palm. It is intended as a cost-effective special effects device to be used in the local entertainment industry. This paper covers the main issues that were considered during the development of the flamethrower from inception to the development of the final design concept. With initial tests of the prototype, the potential utility and usability of the device are demonstrated. The potential of the flamethrower as an enabling tool in the Special Effects sector will also be discussed.*

Keywords: *Product design, special-effects, flame thrower, entertainment*

1. Introduction

Computer animation of natural phenomena often poses great challenges for visual effects teams. It is often very difficult to realistically recreate the fluid-like motions of water, wind and, in particular, fire. Fire is one of the elements that is most used in the entertainment industry, and while there have been significant advances in computational simulation, the visual reproduction of the elements has yet to be captured in a realistic form. Additionally, the cost of creating these effects can be very expensive. Given this, filmmakers sometimes opt to have their special effects teams build devices that actually generate fire from controlled explosions and pyrotechnics. This paper shares the design of a flamethrower that can be worn and be triggered with the press of a button.

2. Background

Fire effects are some of the most desirable effects in modern films. However they often pose a challenge: filmmakers and visual effects teams still have difficulty in producing realistic looking animation effects. Nguyen et al. (2003) state that the complexity of the motion exhibited by natural phenomena defies the ability of animators to produce realistic animations by hand. In the era where unrealistic visual effects are being harshly reviewed by the audience and critics alike, there is need for a realistic and safe alternative.

The aim of this project was to design, build and test a wrist mounted flamethrower for use in the entertainment industry. It is intended to add to the special effects industry by creating a flamethrower that is capable of being mounted in such a way that the flamethrower can be worn close to the body and be triggered with the press of a button.

To pursue our objective, it was imperative to examine different types of flamethrowers to get a holistic view of the existing mechanisms and how these could be successfully adapted for use in the special effects industry. The majority of the flamethrower designs outlined are the classic models that are often used in the military or for agricultural purposes. It is extremely difficult to obtain information on flamethrowers that are used for special effects purposes in movies as the creators most often do not make designs available to the general public. One such example is Filmmaker Evan Glodell who built three flamethrowers for his film *Bellflower* (2011), one of which was a regular special effects flamethrower while the other two were fuel-injected exhaust flamethrowers adapted and attached to the back of a muscle car.

Gartrell (1965) describes the ideal portable flamethrower as a weapon that is light, compact, requires little training to operate, has a range of 100 meters or more, and has self-contained pressurisation. Benson (1990, 24-26) describes a simple flamethrower that can be built with everyday materials for a cost of less than 1,000 USD. This includes:

1) A pump to propel the petroleum or other fuel out of the nozzle.
2) An engine, pressure tank or similar to power the pump.
3) A spray nozzle or spray gun to propel and disperse the fuel over a target and away from the body.

4) A lighting mechanism to set alight the fuel as it leaves the spray nozzle.
5) High pressure hoses to circulate the fuel from the storage tank to the pump and then to the spray nozzle.
6) A pressure valve to relieve pressures within the recirculation system. This involves returning the unused fuel to the storage tank.
7) The fuel storage tank.
8) A clutch or engine/pump coupling. This is used as a safety mechanism to engage the clutch only when the spray nozzle trigger is pulled.

A portable flamethrower, developed by Graham (1947) boasts of an improved gas ignition system and a safety trigger that controls the ignition. Graham (1947) decomposes his flamethrower into two main sections: the fuel unit (comprised of the pressure system, part of the fuel system and the carrying pack) and the flame gun (which is comprised of the rest of the fuel system, the electrical ignition system and the ignition gas system).

The operation of this flamethrower starts by opening one of the valves to allow pressured gas from a cylinder to pass through the pressure diffuser to the fuel tanks. From there a second valve is then opened (this is known as the fuel discharge valve) which propels the opening of a third valve. This third valve leads to the emission of the ignition gas from the ignition gas cylinder to the ignition trigger valve that is controlled by a push button. The flame gun is then gripped and the fuel discharge lever is disengaged by sliding the locking lever into a position where the catch disengages and the generation of sparks begins. The operation trigger valve is then released to permit flow of the ignition gas into the pilot vent, where the pilot gas is ignited followed by the ignition of the combustible mixture in the gas burner. Release of the lever then results in the termination of the flame by stopping the flow of the gas.

This flamethrower boasts of improved performance due to the introduction of the pressure diffuser system. The nozzle design is critical as it improves the distance achieved by the flamethrower. Finally, the use of the electrical ignition system is vital as it improves the safety and the reliability of the system. Figure 1 shows the two main parts described for the first section comprised of the fuel unit and the second section with the flame gun. Figure 2 shows a detailed design drawing of the ignition gas cylinder inclusive of the sparking generator housing.

Hayner and Loew (1949) developed the fluid projector to produce a flamethrower that was lightweight and easier to use in tactical situations, where it would be impractical and even cumbersome to use a traditional flamethrower that would be carried on one's back. The fluid projector works on the principle of pressurising a gas within the barrel of the system, thus forcing the fluid out of the container. The pressurised system can use either a solid material to manually force the liquid out or a highly compressed gas or propellant that forces the liquid out. The fluid projector may be operated automatically with the use of a remote or an automatic delay device. This then leads to the ignition of the incendiary agent. Figure 3 shows the main sections of the Fluid Projector developed by Hayner and Loew.

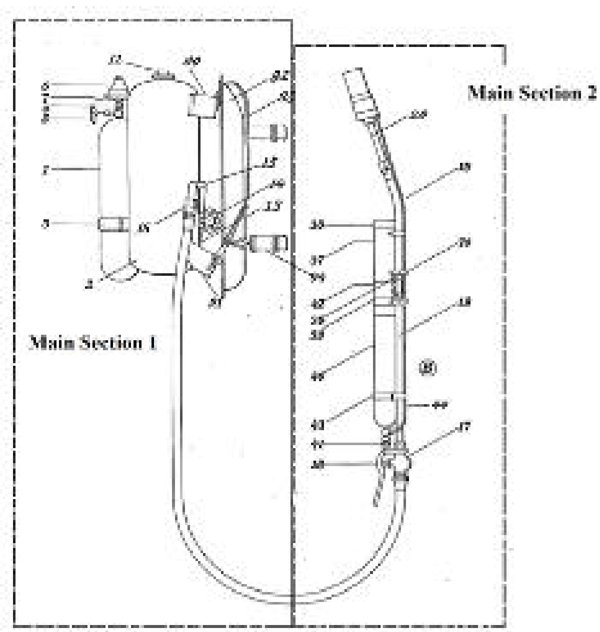

Figure 1. Two Main Sections of the Flamethrower
Source: Adapted from Graham (1947)

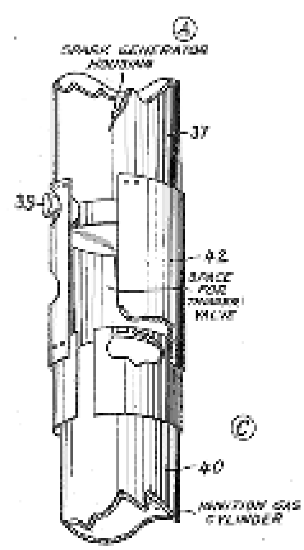

Figure 2. Sparking Generator Housing and the Ignition Gas Cylinder. Source: Adapted from Graham (1947)

Figure 4 shows the flamethrower created by Benson (1990). The system works by first setting up the pump and engine in order to start the circulation system at the storage tank. The pump, engine and storage tank are all double connected using high pressure hoses. As the fuel

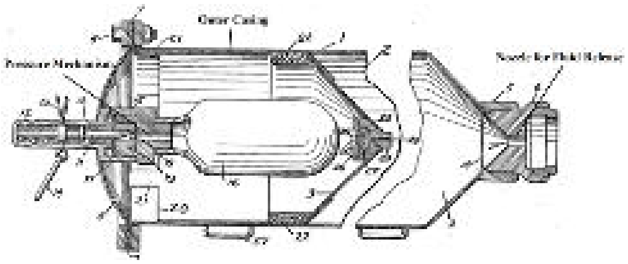

Figure 3. Main Parts of the Fluid Projector: The Pressure Mechanism, Outer Casing and Nozzle. Adapted from Hayner and Loew (1949)

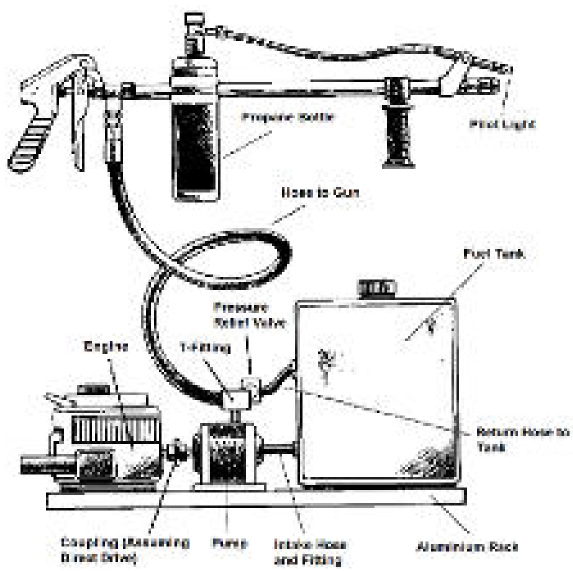

Figure 4. Design of a typical Flamethrower
Source: Adapted from Benson (1990, 26)

is pumped along the system, the trigger is then pulled in order to disperse the fuel. As this is engaged, the lighting mechanism is triggered thus igniting the fuel leaving the spray nozzle. When the trigger is released, the lighting mechanism is disengaged and the pump sends the excess fuel through a pressure valve for depressurisation and then back into the storage tank. The notable features of this design are a separate propane bottle which is used for the lighting and an aluminium rack at the bottom for bolting on the pump, engine and storage tank. The entire system of pump, engine and storage tank can be configured in such a way that it can be either carried on the back or left on the ground depending on how large a flamethrower is needed.

One of the most important aspects of this project was the attention to safety due to potential risk. The safety considerations have been divided into two main categories: 1) The materials and design against fire and 2) safety precautions for flammable or potentially explosive materials. One of the main design concerns is the fuel storage tank. Cooke et al. (1997) extensively discuss the consequences of a vessel containing pressurised liquid gasses being consumed by fire.

Cooke et al. (1997) conducted four liquid propane jet fire impingement trials. There was tank failure when the tanks were unprotected. Jet fire, as defined by the Health and Safety Executive (HSE), "is a turbulent diffusion flame resulting from the combustion of a fuel continuously released with some significant momentum in a particular direction or directions". This is useful information as propane is often used in modern flamethrowers especially of smaller scaled design. In Cooke et al.'s testing, a standard two tonne tank was consumed by fire and failed within 5 minutes of the jet fire impingement with pressures ranging from 16.5 to 24.4 bar/g and temperatures ranging from 704^{o}C to 870^{o}C. There was longitudinal splitting of the tank, leading to fireballs (the rapid release of the contents after the tank splits) and noise. The test also examined the use of passive fire protection (PFP) materials. PFP materials prevent or slow the spread of fire through protective coating. The two materials tested were a cementitious coating and epoxy intumescent coating with the cementitious coating being the superior material for containing the effects of jet fire impingement.

While the Occupational Safety and Health Administration Act (OSHA 2004) does not expressly provide guidelines for the production and handling of a potentially flammable device, there are general safety guidelines that should be applied when dealing with anything potentially flammable. This is detailed in part 5 section 29 of the act: "In every industrial establishment there shall be provided, maintained and kept readily available for use appropriate fire equipment approved by the fire authority for fighting fire and the occupier shall ensure that a sufficient number of persons trained in using such equipment are available during the working hours and a record of the number of persons trained and the frequency of lectures and fire drills shall be kept and presented on demand for inspection by the fire authority". Therefore when handling the testing of the device all fire safety precautions should be taken into consideration inclusive of both personal protective equipment and fire safety procedures.

Standard safety procedures include the prompt extinguishing of a fire by removing either the fuel source (disconnecting the fuel valve) or the exclusion of oxygen by the use of a blanketing agent such as foam, carbon dioxide, dry chemical or vaporizing liquids. Guidelines for handling of flammable liquids and open flames and sparks include:

1) Using less flammable liquids when possible
2) Storing flammable liquids in closed containers
3) Limiting the amount of flammable liquid in the work area to only the amount that is required at a given time
4) Providing safe disposal of flammable waste

5) Prohibiting smoking, open flames or spark producing devices or equipment in the vicinity of flammable liquids
6) Providing adequate ventilation for all operations involving the use or storage of flammable liquids
7) Encouraging housekeeping to prevent the accumulation of fuels and combustibles in the vicinity of open flames
8) Providing fire extinguishers where open flames are unavoidable
9) Providing adequate clearance between combustibles and open flame
10) Using certified equipment - Personal Protective Equipment inclusive of fire resistant clothing, eye and face protection and safety shoes)

These safety guidelines informed the building, testing, and use of this device.

3. Design Process and Final Design

The design process was customised for the specific problem being considered (Otto and Wood, 2000, Clarkson and Ekert, 2005, Eppinger and Ulrich, 2007). After identification of the need and setting design requirements, an extensive conceptual design process was executed to generate many design alternatives. These alternatives were evaluated and a final conceptual design was produced. A functional prototype was constructed, and various tests were carried out to ensure the device functions as intended. In addition, various safety tests were carried out based on safety guidelines for such equipment.

Given that the success of the flamethrower depends on its usability and safety (Rubin and Chisnell, 2008), these aspects were the focus of user testing in order to demonstrate that the design will work as intended and would be of value to potential users (Otto and Wood, 2000, Eppinger and Ulrich, 2007). The testing methodology and results are presented in the user testing section of the paper. This combination of both functional and user testing provided comprehensive evidence that the new flamethrower design can be a viable competitor in a largely untapped local market.

3.1 Flamethrower Design

The device developed was named The Prometheus after the figure in Greek Mythology best known for his theft of fire for the benefit of mankind. Figure 5 shows detailed drawings of the final concept of the Prometheus. Like many conventional flamethrowers the Prometheus consists of three major working systems. These are: 1) the storage area and propellant system, 2) the spraying mechanism to distribute the fuel and 3) the lighting mechanism. Figure 6 provides a closer look at the Flame Pack. This is used as the storage area for pressurised butane. Figure 7 shows the flame glove system inclusive of the piezoelectric spark generator (the lighting mechanism) and the mounted nozzle (the distribution system).

In order to use the Prometheus, after strapping the system onto the user, the butane tanks are loaded into the flame pack housing and the cover is used to depress the top of the canister before locking it into that position. Two valves located along the tubing are then opened to allow the flow of gas out of the nozzle that is mounted onto the palm of the glove. The piezoelectric spark generator is then used to ignite the gas flowing out of the nozzle thus producing the flame stream. There are then the methods of disengaging the system; these are shown in Figure 8. This is further elaborated on in Section 4.2.1.

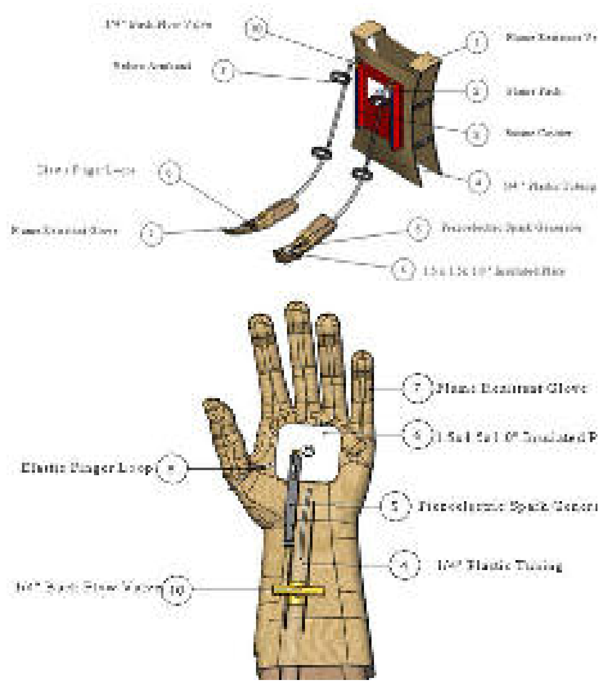

Figure 5. Isometric View (top) and the Flame Glove Control (bottom) for Final Concept

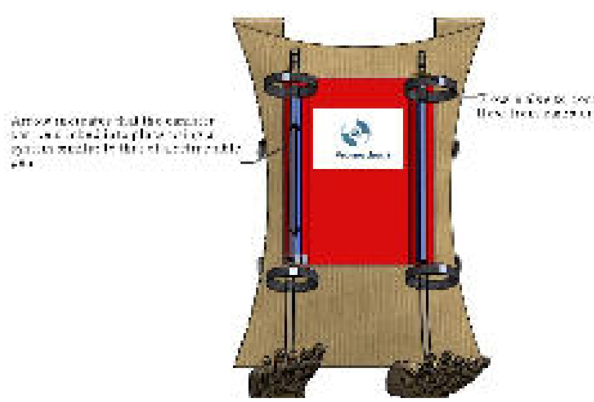

Figure 6. Operation of the System

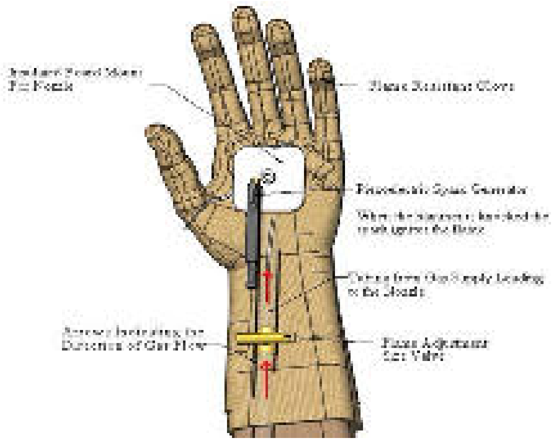

Figure 7. The Flame Glove System Major Components and Operation

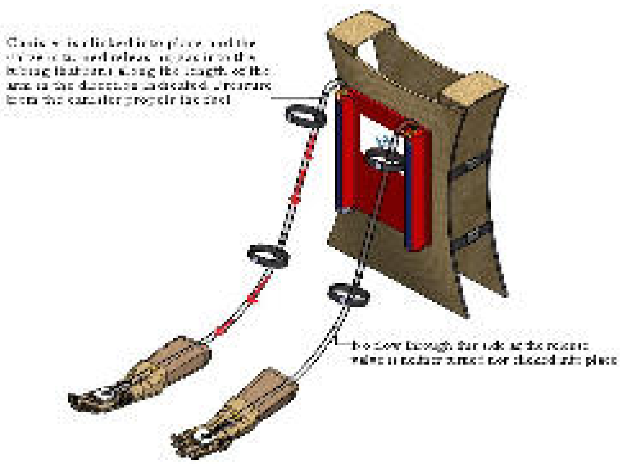

Figure 8. Operation of the Gas Flow System

3.2 Sub-Assemblies within the Prometheus

3.2.1 The Cap for the Canister Holster

The cap for the canister holster doubles as a safety mechanism as well as a method for depressing the top of the butane canister. Figure 9A shows the exploded view of all the components that comprise the canister cap. The canister cap has spring-loaded triggers that when compressed can fit inside of the cap as shown in Figure 9B. This allows the cap to slide along the inside of the canister holster before locking into place and depressing the butane tank top.

When the fuel supply is to be stopped, the triggers are pressed and the spring on the top of the cap cover is released and pushes the cap upward. Figure 10A and 10B are section views of the cap exposing the mechanism working on the inside of the cap.

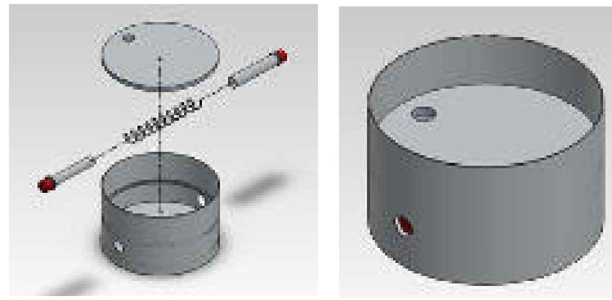

Figure 9. A) Exploded View of Canister Cap (left) B) Collapsed View of the Canister Cap (right)

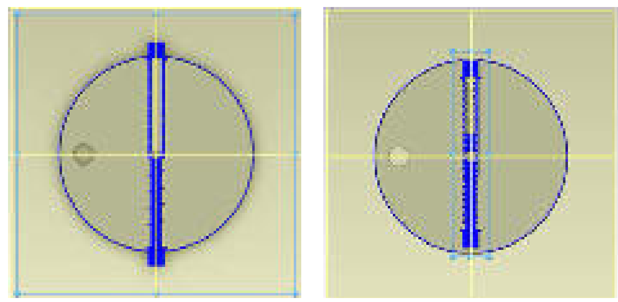

Figure 10. A) Rest State of the Canister Holster Cap (left) B) Canister Cap when Triggers are compressed (right)

3.2.2 Canister Holster Triggering Mechanism on Flame Pack

The flame pack requires safety precautions as this is where the top of the butane canister is depressed thus releasing the gas in the first place. It is therefore the first point for safety mechanisms. It is imperative that the design not only caters for depressing the button at the top, but also for quickly releasing to stop the flow of gas. This is achieved with the use of the specially designed cap for the canister holster. Figure 11 shows the collapsed view of the flame pack as well as the exploded view showing all the components that comprise the flame pack triggering mechanism. Figure 12 shows a cross sectional view of the flame pack, revealing the workings of the flame pack in more detail.

Figure 11. The Major Sub-Components of the Flame Pack in both the Collapsed and Exploded States

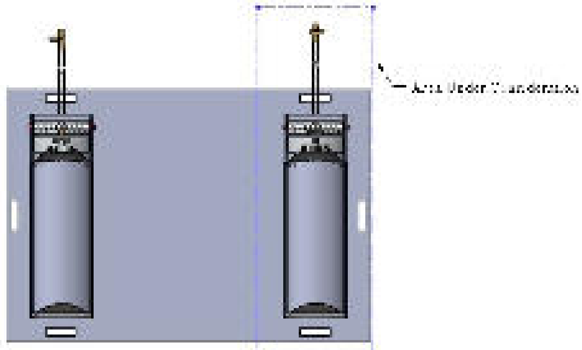

Figure 12. Cross Sectional View of the Flame Pack

When the cap is disengaged, the cap triggers are on top of the canister and the spring is uncompressed (the cap cannot go any higher than the locking collar that is indicated). When it is engaged, the bottom of the cap presses down on both the spring and the trigger of the canister thus allowing the gas to flow into the tubes of the system. This can be seen in the engaged state. Figure 13 shows the inner workings of the flame canister triggering mechanism.

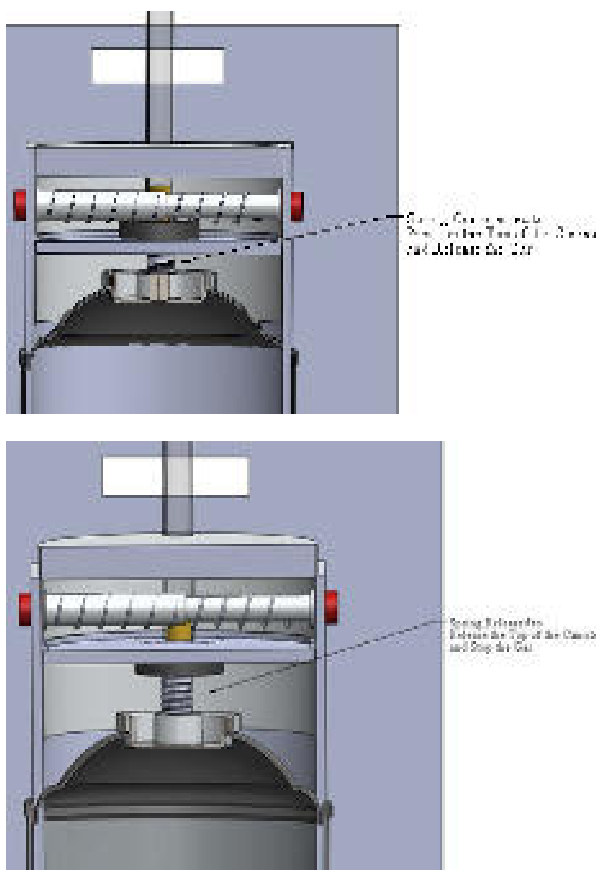

Figure 13. The Inner Workings of the Flame Canister Triggering Mechanism in the Disengaged State and the Engaged State

3.2.3 The Flame Glove Controls

Figure 14 shows the controls of the flame glove. The configuration is simple: it is the nozzle mounted onto a 1.50'' x 1.50''x 0.016'' plastic plate. The piezoelectric spark generator is connected onto the top of the plastic board so that the sparking wires sit just above the top of the nozzle. When the fuel flows through the top of the nozzle, the piezoelectric generator is knocked, creating a spark that ignites the fuel. The back flow valve must be turned on to allow the gas to flow through the system and out of the top of the nozzle. When the valve is turned off, the flow of gas stops and thus the flame stream will stop.

Figure 14. The Flame Glove

3.2.4 Material Selection

The maximum pressure inside the tubing was assumed to be a worst-case pressure of the canister containing the fluid, which was 28 psi. The maximum working pressure of the vinyl tubing selected was 55 psi (The Home Depot, 2015). Therefore the tubing size was safe for this application.

A 26 gauge sheet of aluminium was used to construct the flame pack itself. This material was chosen for its flexibility and lightweight properties. Aluminium is the best material for the flame pack as it allows for the device to be light enough to carry while still being strong enough to support the butane canisters. The flame pack contributes to the bulk weight of the device. Brass release turn valves were used as the main method for releasing or stopping gas flow through the system, in addition to being one of the safety features of the device. This allows the user to easily control gas flow by simply turning the valve on and off like a tap. These were selected as the preferred fixtures as they are most commonly used when dealing with gases which must be cut-off without leaking.

4. Experimental Testing of Prototype

4.1 Safety Testing

4.1.1 Pre-Operation Phase

Due to the nature of the project and its use of highly flammable materials, it was imperative that all precautions necessary be taken to ensure that no physical harm may come to people either testing the device or a casual observer. Therefore several safety experiments were conducted before testing with the butane and spark generator. This ensured the structural and design integrity of the device. Liquid Penetrant Dye Testing and Visual Inspection were conducted.

4.1.2 System Connection and Leak Testing

The System Connection and Leak Testing experiment is a non-destructive testing method, testing for leaks during the operation of the device, while submerged in a tank of water. The presence of air bubbles is noted. Method of testing involved the following steps:

1) The system is set-up for use with the butane canisters replaced by compressed air canisters.
2) The system, shown in the Figure 15, is placed in a small tank filled with water. These are the main areas that must be airtight and thus the essential areas to be tested.
3) While submerged, the hand controls are engaged (it should be noted that the piezoelectric spark generator is not present at this point) and the system is allowed to run as normal.
4) The system is run for a period of 3 minutes with observations made at every 30 seconds.
5) After the 3 minute period, the system is disengaged and removed from the tank.

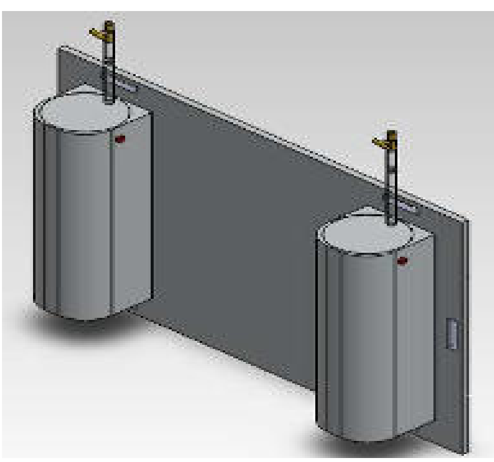

Figure 15. System undergoing the System Connection and Leak Test

Although this test is a good one for checking for leaks there are a few limitations. Though the presence of the air bubbles will indicate the general location of the defect, it is difficult to locate exactly the defect. Additionally it may be difficult to pinpoint the exact location if the air bubbles obscure the tubes from view. These limitations were compensated for, however, by the use of the multiple testing methods such as Visual Inspection and Liquid Penetrant Dye Testing.

4.2 Operational Testing

4.2.1 Safety Mechanism Test

The safety mechanism test is a simple way of checking whether the valves and the trigger can shut off the system independently. The system is engaged and is disengaged using the various mechanisms along the system. The three methods of shutting off the system are:

1) Shut off the wrist-valve
2) Shut off the valve above the flame pack
3) Disengage the canister by releasing the housing trigger.

If the system can be disengaged by any one of the methods, it is awarded a pass and if it requires more than one method to disengage the system is awarded a fail. This is done to ensure that at least 3 safety features are available at all times and are able to work independently to shut off the system.

4.2.2 Flame Height Test

The flame height test is a simple test to determine the highest distance the flame can attain when the canister is fully depressed and all the valves are opened fully. This is accomplished by gradating a board and placing it in the background and filming the tests. This is a crude method used to get the approximate maximum height (a high speed camera is the preferred method for taking this reading), but it gives a fair enough approximation to determine if the objective was achieved. Figure 16 shows an image of the Flame Height Test with a maximum flame height of 3 feet.

Figure 16. Flame Height Test

4.2.3 Sound Test

The sound test is a simple test used during operation to determine whether or not the system is leaking. This is achieved by listening to the system while it is engaged and determining if there is a hissing sound, indicating that there may be gas leaks. If this is the case, the system is to be disengaged immediately and either the soap bubble test is conducted or the pre-operation testing phase is repeated. This is the most common test used to determine the leaks in the system.

4.2.4 Soap Bubble Test

The soap bubble test determines the location of a leak if sound testing indicates a possible gas leak. This is done by pasting soapy water along the region where the leak is assumed to be and looking for the formation of the bubbles in the soap. This would indicate the position of the leak.

4.3 User Testing

A short demonstration was held in an open park. This demonstration included eight people involved in the entertainment industry, mainly in film and photography. The demonstration was done to show the functionality of the flamethrower in addition to the visual effects it is able to produce. After several screen tests and still shots (see Figure 17), participants were allowed to try on the device and operate it for themselves. The footage and stills that were obtained from the demonstration were further distributed to another four individuals involved in The University of the West Indies, St. Augustine Film Programme for their review. After the demonstration was completed, questionnaires were distributed and feedback was recorded (Rubin and Chisnell, 2008).

Figure 17. Still from the Prometheus Flamethrower Demonstration

Of the twelve participants involved in the validation study, 8 were female (67%) and 4 were male (33%). In terms of the age distribution, 8 participants were in the 18-25 age group, 2 participants were in the 26-35 age group, and 2 participants were over 56 years of age. Participants were involved in various activities (with some being involved in multiple activities): 8 working in film and television (66.66%), 3 in photography (25%), 2 in theatre (16.67%) and 1 in musical concerts and performance (8.33%). 3 participants use mechanical effects (25%) in their work, 9 participants use digital effects (75%), 6 participants use live action (50%) and 3 participants use matte painting and stills (25%). Table 1 shows their responses to the more general questions with respect to the device.

From the evaluation of the questionnaires all twelve respondents found the device to be safe to use and easy to incorporate into their respective fields of the industry (filmmaking and photography) with a very short set-up time (inclusive of stunt training required for the operation). Additionally seventy-five percent of the users have indicated that the device was ergonomic. After the demonstration eighty-three percent of the users intimated they would consider using the device in their work for the future. The device received positive reviews overall with one respondent stating, “Excellent minimal/compact design approach to a normally bulky and dangerous device. Can be utilised as expected in a multitude of operations in many operating conditions.” and another stating, “It is light, effective and completely autonomous which gives the user complete control. The flame size can be controlled which is a plus as it takes into account all kinds of performances and visual effects”. These free responses are seen documented in their unedited form in Table 2.

5. Discussion

There are many benefits to a wrist-mounted flamethrower, especially in the entertainment industry. At the start of this project, the device has sparked great interest mainly due to the lack of innovation in this area in general, and particularly in the local context of Trinidad and Tobago. The intention is that such a project will hopefully encourage more innovators to see the opportunities for design and innovation in the local environment.

There are many avenues for future development of the flamethrower. Since this prototype achieved its objectives, in terms of usability, safety and ergonomics, further development can be pursued. Areas for improvement include:

1) The development of the hand-control system in order to achieve independent ignition.
2) Further work on the mechanisms for choking the flame and thus turning off the flame through the use of hand independent controls.
3) Development of the flame pack to further reduce the size of the device (although this is directly proportional to the amount of fuel the device can store as well as the maximum flame height that may be achieved).
4) Experimentation with different gases to achieve different flame colours.

Table 1. Results from Questionnaire

Question	Response	
	Yes	**No**
Do you apply the use of Visual Effects or Special Effects in your work?	66.7%(8/12)	33.3%(4/12)
From the Demonstration do you consider the Prometheus Flamethrower safe to use?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower as one that is easy to use?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower a Special Effects Device that would be easy to incorporate into your area of the entertainment industry?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower as one that is easy to set-up with little time consumption?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower as one that is ergonomic? *(n=8 responders for this question as the remaining four would not be able to discern this from video footage and stills alone).*	75%(6/8)	25%(2/8)
Would you consider using the Prometheus Flamethrower in your future projects?	83.3%(10/12)	16.7%(2/12)

Table 2. Responses to free-response questions

Q: In your own words, describe your initial thoughts and feelings with regards to the Prometheus Special Effects Flamethrower Demonstration.	"Operates as desired, safety hazards have been well reduced to within reason. The model is robust and will not require costly approaches when modifying or adjusting." "I would definitely like to use this in my next project!" "Amazing" "It was easy to use and I felt safe and comfortable." "I especially liked that it was very small, simple to setup, manoeuvrable and could be operated by one person. This can potentially lead to a more efficient workflow on the set (saving on crew and time). To be able to achieve that level of efficiency while still being able to deliver realistic special effects will be the driving points behind this tool." "Having tried it myself, I didn't feel unsafe and felt that it was very simple and got the job done."
Q: Overall, what are your final thoughts on the Prometheus Wrist-Mounted Special Effects Flamethrower?	"Excellent minimal/compact design approach to a normally bulky and dangerous device. Can be utilised as expected in a multitude of operations in many operating conditions." "It's perfect for like stage plays and even carnival events. And if there is someone who wants to play the Human Torch or Pyro or any fictional character with flaming powers the Prometheus Wrist-Mounted Flamethrower can do the job." "It is light, effective and completely autonomous which gives the user complete control. The flame size can be controlled which is a plus as it takes into account all kinds of performances and visual effects." "I think it's something that can definitely enhance the local film industry and the quality of productions that are currently being put out. Hopefully this will also spark more innovations for local filmmakers and the film industry." "It is an easy to use, affordable device."

6. Conclusion

The design for a special effects, wrist-mounted flamethrower was presented. From the results obtained both via the simulation study and the practical prototype test, the device can project flames from the palm of the hand in a manner that is safe for the user while at the same time being visually appealing. Further work on the device involves optimisation, rigorous performance testing, and a more extensive user testing study in an actual stage or carnival performance. It is hoped that the device presented in this paper would contribute to the special effects sector of the entertainment industry.

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