Determining Flow Through Nozzle Reaction

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Signed: ____

Abstract

The problem was the Mississippi State Fire Academy had never determined whether or not a firefighter could identify a reduction in their target flow using nozzle reaction. The purpose of this Applied Research Project (ARP) was to determine if firefighters currently enrolled in the Mississippi State Fire Academy National Fire Protection Association (NFPA) 1001-I-II course were able to identify reduced target flow through the use of nozzle reaction. This ARP utilized the descriptive research method in order to identify the current status of the Mississippi State Fire Academy's curriculum as it pertains to a firefighters understanding and use of nozzle reaction to identify reductions in their target flow. The research questions answered in this ARP were. A) Why is nozzle reaction a valid way of determining water flowing through a nozzle? B) Given a structural fire, how do firefighters determine the critical flow needed for interior fire attack operations? C) Will the operating pressure of the nozzle effect the firefighter's ability to identify target flow using nozzle reaction? Students enrolled in the NFPA 1001-I-II course were given three different nozzles operating at 50 psi, 75 psi and 100psi. They were asked to determine if the nozzles were operating correctly, over pressurized or under pressurized. At the conclusion of the test 46% of the firefighters tested were unable to detect a critical reduction in their target flow. The recommendation of this ARP was to identify training programs and curriculum which will improve the firefighter's ability to identify a critical reduction in their target flow.

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Structural firefighting represents the majority of fire related firefighter injuries across the United States. Utilizing data provided by the National Fire Incident Reporting System (NFIRS) an estimated 29,425 firefighter injuries occurred annually on the fire ground between 2012 and 2014 with 87% of these injuries occurring in structure fires (National Fire Incident Reporting System, 2016). Although strains and sprains represent the largest number of injuries by nature, burns represent a staggering 12.8% of injuries between 2012 and 2014.

Identifying the actions and decisions which contributed to firefighter burn injuries while conducting interior fire attack operations is very difficult. Firefighters often turn to the National Institute of Occupational Safety and Health (NIOSH) and the United States Fire Administration (USFA) for detailed reports of firefighter injuries and fatalities. Two of the most notable reports related to nozzle operations while conducting interior fire attack are the 1991 One Meridian Plaza fire which killed 3 firefighters and injured 24 others (Routley, Jennings, & Chubb, 1991) and a 2014 fire in Boston, Massachusetts which killed two firefighters conducting interior fire attack operations in a basement (National Institute of Occupational Safety and Health, 2016). Each of the above incidents included critical failures in the firefighter's water delivery system after the water left the apparatus pump. During fire attack operations many critical failures may occur downstream of the pump including: kinks, hose line ruptures, hose line burn through, and debris inside of a nozzle. During these situations no method of communication to the pump operator will correct the problem because the problems occur downstream of the pump. The problem was the Mississippi State Fire Academy (MSFA) had never determined whether or not a firefighter could identify a reduction in their target flow using nozzle reaction. Having the ability to identify a reduction in target flow from the nozzle may increase the survivability of firefighters operating on the nozzle by identifying critical failures which need to be corrected.

The purpose of this ARP was to determine if firefighters currently enrolled in the MSFA NFPA 1001-I-II course had the ability to identify a reduction in their target flow after receiving training in hose line and nozzle operations. This ARP utilized descriptive methodology to determine the current status of the MSFA's curriculum. Personal communications with many instructors provided information regarding the current curriculum and the skills being presented. Direct observations of firefighters operating various nozzles were used to determine if firefighters enrolled in the MSFA 1001-I-II course had the ability to identify critical reductions in their target flow using nozzle reaction.

The research questions answered in this ARP were. A) Why is nozzle reaction a valid way of determining water flowing through a nozzle? B) Given a structural fire, how do firefighters determine the critical flow needed for interior fire attack operations? C) Will the operating pressure of the nozzle effect the firefighter's ability to identify target flow using nozzle reaction?

Background and Significance

The MSFA trains approximately 15,000 firefighters across the entire state of Mississippi each year (Mississippi State Fire Academy, 2015). The MSFA has 30 full time staff instructors assigned to 4 different bureaus and 44 adjunct instructors assigned to the Extension Services Bureau. The MSFA is organized into 4 instructional bureaus which are responsible for a number of courses assigned to them. The Extension Services Bureau is primarily responsible for courses managed off of the central campus which includes 164 regional training courses delivered in 82 counties across the state of Mississippi. The Certification Bureau is primarily responsible for courses delivered on and off campus which are accredited and directly associated with the career advancement of firefighters, officers and other support personnel. The Certification Bureau is solely responsible for the delivery of the NFPA 1001-I-II basic training course. The NFPA 1001-I-II course is required by MS Code Annotated Section 45-11-203 for all firefighters operating as a career firefighter. The Special Industrial bureau is primarily responsible for providing all technical rescue training and hazardous materials training. The Special Industrial Bureau also provides rescue, hazardous materials and firefighter training for industrial firefighters. The Curriculum Bureau is primarily responsible for all testing and accreditation for the MSFA. The Curriculum Bureau provides assistance to all other bureaus with correlations to applicable standards, testing processes and test bank security and administration.

In 2015 the MSFA trained 180 firefighters in the 1001-I-II course. During the NFPA 1001-I-II course firefighters learn the basic and fundamental skills in order to work as career firefighters in the state of Mississippi. The NFPA 1001-I-II course is both International Fire Service Accreditation Congress (IFSAC) and Pro Board® Fire Service Professional Qualifications System accredited. The NFPA 1001-I-II course references the NFPA 1001 standard for fire fighter professional qualifications (National Fire Protection Association, 2012).

Through direct observations the researcher witnessed students in many courses at the MSFA lacking a clear understanding of hose line and nozzle selection. Frequent questions arose involving the use of a particular hose line, nozzle and application method. The researcher also noticed an increase in personal communications with fellow instructors regarding the same topic. Many of these questions and concerns arose from research conducted by the Underwriter's Laboratories (UL) and the National Institute of Standards and Technology (NIST). In particular many students and instructors approached the researcher with regard to the Governor's Island research conducted in New York, New York (Underwriters Labarotories, 2013).

The researcher also had direct observations on many occasions where firefighters improperly operated their nozzle during interior fire attacks. The researcher witnessed firefighters flowing water through their nozzles with flow restricted by multiple kinks, students operating the nozzle on improper nozzle patterns during ventilation limited conditions and students operating nozzles without the bail being fully opened. When students were asked about their nozzle characteristics, flow and application methods many had no available answers.

Prior to 2016 the MSFA regularly operated interior attack hand lines at 125gpm. Following recommendations set forth in NFPA 1710, the Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, the MSFA met the minimum recommendations for initial attack line operations (National Fire Protection Association, 2015). NFPA 1710 recommended an initial water application rate of 300gpm provided by the first two hand lines. NFPA 1710 also recommends that a minimum application rate of 100gpm be provided by each line and that each hose line be operated with a minimum of two firefighters. If a firefighter follows NFPA 1710's recommendations and places the first two hose lines in operations with one hose line flowing 100gpm than the other hose line must flow 200gpm to comply with the recommendations. The MSFA followed these recommendations but failed to identify external influences which may contribute to a reduction in target flow and in turn would cause the flow of a hand line to drop below the recommendation provided in NFPA 1710.

In 2010 Jason N. Vestal and Eric A. Bridge produced an outstanding document titled "A Quantitative Approach to Selecting Nozzle Flow Rate and Stream, Part 1" which provided clarity on the topic of NFPA 1710's recommended initial attack line flow requirements (Vestal & Bridge, 2010). In Vestal and Bridge's article they discuss the implications of the first attack line operating at 100gpm and the second operating at 200gpm. Their article discussed the problems with only flowing 100gpm from the first attack line including the increase in nozzle reaction for the second hose line. Specifically, the second hose line's nozzle reaction flowing 200gpm would range from 71-101 pounds, depending on the nozzle's operating pressure, which potentially exceeds the ability of a firefighter or team of firefighters to operate. In November of 1992 Paul Grimwood conducted a research project that evaluated the operational capabilities of firefighting hand line streams for the London Fire Brigade (Grimwood, 2006). During his research Paul Grimwood observed firefighters operating hand lines and determined the maximum flow from a hand line that each firefighter could effectively manage using nozzle reaction. His research provided the fire service with bench mark numbers which can be used to determine staffing requirements for hand lines based on their maximum flow. Grimwood discovered that a single firefighter could operate a hose line with 60 pounds of nozzle reaction, two firefighters could operate a hose line with 75 pounds of nozzle reaction, and three firefighters could operate a hose line with 95 pounds of nozzle reaction.

Using the recommendations for water application from NFPA 1710 and Grimwood's nozzle reaction results firefighters will have a very difficult time effectively using a 200gpm hose line as the second hose line for initial attack operations. Vestal and Bridge also noted the increase in friction loss to maintain proper nozzle pressure for a 200gpm attack line and the increase in hose pressure which would decrease the hose's flexibility making it more difficult to advance.

A significant factor when determining initial attack line operations includes the flow rate requirement needed for interior fire attack. The MSFA utilizes two different formulas to instruct students on how to properly calculate the flow required for a given structure fire. The first formula used is the Iowa Rate of Flow calculation (Hartin, Estimating Required Fire Flow: The Iowa Formula, n.d.). The Iowa Rate of Flow formula is:

Required Volume 30 seconds = (Length X Width X Height) ÷ 100

The second formula used at the MSFA is the National Fire Academy's (NFA) Fire Flow Formula (Hartin, Estimating Required Fire Flow: The National Fire Academy Formula, n.d.). The NFA Fire Flow Formula is:

Needed Fire Flow = ((Length X Width) ÷ 3) * Percentage of Involvement

Each of the above formulas give firefighters a tool to determine the flow needed on a fire ground. However, delivering that calculated flow on a fire ground with many external influences may result in a reduction in the flow needed. In 2007 an article was produced by Fire Engineering Magazine showing the effects of kinks within a hose line and their ability to reduce a firefighter's target flow (Pillsworth, Knapp, Flatley, & Leihbacher, 2007). In the article the researchers concluded that even a single 180-degree kink could reduce the flow by 25%. If a firefighter utilizing a 125gpm nozzle encountered a 180-degree kink their hose line this would effectively drop their flow below the recommendations provided by NFPA 1710.

Utilizing the information provided the researcher identified a significant threat to firefighter safety when performing interior fire attack operations. The MSFA's nozzle selection at the time did not provide a margin of safety for firefighters encountering reductions in flow from problems such as kinks in a hose line. The researcher also determined that the solution to this problem was not only technical in nature but provided an adaptive challenge to the MSFA.

The MSFA instructional staff must be provided with information in order to create a change in the instructional delivery methods. This information must also be communicated to students throughout all courses which are delivered by three different instructional bureaus. Consistency in the delivery of all interior fire attack courses represents an adaptive challenge which must place instructor buy in as the number one priority. Identifying this problem would also provide the MSFA with justification to revise current curriculum which will effectively meet goal number 3 of the United States Fire Administration operational objective which states “Enhance the Fire and Emergency Services’ Capability for Response to and Recovery From All Hazards” (US Fire Administration, 2014).

Literature Review

On February 23, 1991 three firefighters were killed in the line of duty while operating at the One Meridian Plaza fire in Philadelphia, Pennsylvania (Routley, Jennings, & Chubb, 1991). During the initial operations of this high rise fire firefighters made an attempt to establish a 1.75” attack hose line off of the standpipe system on the 21st floor. The standpipe system was outfitted with pressure reducing valves which provided an outlet pressure of less than 60psi. The firefighters were utilizing an automatic nozzle with an operating pressure of 100psi. This reduction in target flow led to confusion on the fire ground and delays getting water on the fire. Firefighters operating the initial attack line were operating in dark smoky conditions and were unable to correct the actions caused by the PRV. The outlet pressure of less than 60psi would not deliver an effective fire stream in order to control the fire. The Philadelphia Fire Department followed their Standard Operating Procedures (SOPs) but no one was prepared for the external factors which would influence their ability to effectively control the fire.

This event triggered many fire departments to evaluate their high rise hose and nozzle selections. During the incident firefighters using 100psi nozzles were receiving dramatically less pressure than is required to operate effectively. Identification of this reduction in flow from the firefighter operating on the nozzle is critical in order to correct the problem causing the reduction in target flow.

Another well documented fatal fire occurred in Boston, Massachusetts on March 26, 2014. On this day firefighters from Engine Company 33 responded to a 4 story structure with smoke showing from the first floor (National Institute of Occupational Safety and Health, 2016). Engine 33 stretched an uncharged hose line into the structure when during the initial attack operations, the Lieutenant of Engine 33 was advised there may be potential victims in the basement. At that time the Lieutenant and Firefighter from Engine 33 went down the stairs into the basement to search for the potential victim. As Engine 33 made their way to the basement Engine 7 stretched a 2.5" hand line to back up Engine 33. Engine 33 then called for water which was received by the pump operator at which time he charged the line. Within three minutes the hose line was in operation but the Lieutenant of Engine 33 was unaware of a critical failure in the hose line. Due to the rapidly changing conditions Engine 33's hose line had burned through reducing the pressure in the hose line. For approximately 5 minutes the crews fought to get water to Engine 33's crew operating inside the structure. The Lieutenant and Firefighter of Engine 33 became trapped in the basement and later succumbed to their injuries.

When selecting attack hose lines firefighters must take into account the nozzle reaction of the attack line. When flowing the same amount of water, nozzles which operate at 100psi will have higher nozzle reactions than nozzles operating at 50psi. Theoretical nozzle reaction is a fundamental component of the MSFA NFPA 1002 Driver Operator Course. Students in the

NFPA 1002 course learn to calculate theoretical nozzle reaction for both smoothbore nozzles and fog or combination nozzles. The following formulas are used during the NFPA 1002 course delivered at the MSFA (IFSTA, 2015):

Nozzle Reaction for a Smoothbore Nozzle, $NR = 1.57 \times d^2 \times NP$

Nozzle Reaction for a Fog Nozzle, $NR = .0505 \times Q \times \sqrt{NP}$

Using the above calculations, a firefighter can determine the nozzle reaction generated by a particular nozzle provided that the firefighter knows the nozzle pressure and flow.

In 1990 Paul Grimwood completed a research project to determine the nozzle reaction a firefighter can effectively manage (Grimwood, 2006). He observed firefighters operating hand lines individually, as a team of two and as a team of three. He determined that a single firefighter was capable of effectively managing a nozzle with a reaction force of 60 pounds. Using the formulas provided above a firefighter can calculate the nozzle reaction for a range of nozzles to determine which nozzle can be effectively managed by a single firefighter. A 7/8" smoothbore nozzle with 50psi of nozzle pressure will generate a nozzle reaction of 60 pounds which would allow a single firefighter to operate the hose line effectively by him or herself. A fog nozzle flowing 150gpm at 75psi nozzle pressure will generate a nozzle reaction of 65 pounds. A fog nozzle flowing 125gpm at 100psi nozzle pressure will generate a nozzle reaction of 63 pounds. These three nozzles will all provide a firefighter with a nozzle reaction of around 60 pounds which is the recommended nozzle reaction for a single firefighter to manage. Firefighters must decide to use higher pressure nozzles with lower flow rates or lower pressure nozzles with higher flow rates.

Along with nozzle reaction, target flow must be taken into consideration when establishing initial attack hose lines. The National Fire Academy has provided firefighters with a formula to use for determining the required flow for initial attack hose lines. This formula states to multiply the length and width of the structure and then multiply that number by the percent of involvement (Hartin, Estimating Required Fire Flow: The National Fire Academy Formula, n.d.). This formula was a result of an analysis performed after the Iowa Formula was produced. The Iowa Formula utilizes volume calculations by including the height of the structure and not just the square footage of the structure involved (Hartin, Estimating Required Fire Flow: The Iowa Formula, n.d.). The Iowa Formula establishes that when using an application rate of 30 seconds a firefighter can determine the required flow rate by multiplying the structure's length, width and height together and then dividing that number by 100.

Firefighters often have predetermined target flows based on SOPs or pre-plans of their territories. NFPA 1710 provides firefighter with a recommended initial attack line flow requirement. This document recommends a flow rate of 300gpm delivered by the first two hose lines in operation, with no less than 100gpm flowing on either hose line (National Fire Protection Association, 2015). The NFPA 1710 recommendation has been scrutinized by many firefighters including Vestal and Bridge who provided an article clarifying the document in 2010 (Vestal & Bridge, 2010) .

Vestal and Bridge took into consideration the nozzle reaction and friction loss which would be associated with the recommended flow rates provided by NFPA 1710. In their article they explain the problems associated with a hand line configuration of 100gpm and 200gpm used together to meet the recommended flow rate. If a firefighter selects a nozzle with a flow of 100gpm for their first attack line than the second attack line must flow 200gpm in order to meet the recommendation. However, a hand line flowing 200gpm would generate a nozzle reaction force of 71 to 101 pounds which exceeds the manageable nozzle reaction a firefighter can effectively control by him or herself. These flows would generate a nozzle reaction that even a two or three firefighter team may have trouble operating.

Another consideration originally discussed by Pillsworth, Knapp, Flatley and Leihbacher is the flow reduction caused by a kink in the hose line (Pillsworth, Knapp, Flatley, & Leihbacher, 2007). There is an enormous difference between a hose line operating in a controlled testing environment and one which is being used on an active fire ground. Fire hoses are subjected to many conditions which may cause reductions in target flow. In the article "How Kinks Effect Your Fire Attack System" researchers discovered a hose line with a 180-degree kink could reduce the flow of the hose line by 25%. This type of kink could cause a 125gpm nozzle to reduce its flow below the recommended flow rate in NFPA 1710.

Following the line of duty death of Tracey Toomey, Jay Comella conducted research on determining effective flow rates on the fire ground. A Board of Inquiry investigated the line of duty death and at the conclusion of the investigation a recommendation was made for initial attack line flow rates in the range of 150 to 185gpm (Comella, 2003). In Comella's article he also discusses the importance of keeping nozzle reaction force low in order to provide effective hose line operations with maximum flow rates.

When performing a literature review related to fire attack operations, hose line selection and nozzle selection one would be remised if Andy Fredericks writings were not included. Andy Fredericks was an FDNY firefighter who passed away on September 11, 2001. Andy contributed many articles to the fire service and paved the way for future subject matter experts. In his article titled "Little Drops of Water: 50 Years Later, Part 2" Andy discussed the modern fire environment and the hostility and unpredictability of the fires modern firefighters face. Andy recommended a minimum of 150gpm be used for residential fires (Fredericks, 2000).

This literature review provided clarity in the selection of nozzles and flow rates. The information gathered revealed significant gaps in the MSFA curriculum currently being used in the NFPA 1001-I-II course. The literature review also provided information for determining the nozzle selection used during this ARP. Nozzle selection was determined by providing a single firefighter with a manageable hose line with a nozzle reaction around 60 pounds. The literature review also provided information in regards to the reduction in flow to be used during the testing of firefighter nozzle operations.

Procedures

This ARP is a direct result of discussions with firefighters Brian Brush and Aaron Fields. Each of these firefighters have impacted the fire service by providing skills and techniques to promote more efficient engine company operations and specifically hose line and nozzle operations. The researcher discussed with Brian Brush and Aaron Fields the significance of nozzle reaction and its ability to be used as a tool to identify critical reductions in target flow of a hand line. Observations at the MSFA for several years revealed a lack of clear understanding regarding hose line selection, performance and handling characteristics. This sentiment was shared with firefighters Brian Brush and Aaron Fields.

Brian Brush suggested to approach this ARP from the view point of the MSFA. The MSFA trains firefighters across the entire state of Mississippi which created a very large sample size and could make the procedures of this ARP very difficult. Using the MSFA as the central theme allowed the researcher to clearly identify the problem and purpose of this ARP.

Aaron Fields shared ideas of common fire ground issues which would lead to critical reductions in a firefighter’s target flow. His initial suggestions included building a prop which would physically kink a hose line but would not allow the firefighter operating the nozzle to see the kink. This would provide firefighters with a hidden problem which would inhibit the firefighter's ability to see any influence in the hose line which could cause a reduction in flow.

After discussing the procedures of this ARP the researcher decided to provided a range of nozzles each with the ability to adjust the nozzle's operating pressure. This would allow each nozzle to be adjusted individually and would provide the same reduction in flow as a problem such as a kink in the hose line.

Three nozzle operating pressures were chosen to represent multiple regions of the state of Mississippi. The first nozzle utilized was an Akron Turbojet model number 1715 which is a 1.5" 100 psi selectable gallonage nozzle with the ability to adjust the gallons per minute (gpm) in the following settings: 30gpm, 60gpm, 95gpm and 125gpm. The Akron Turbojet model number 1715 is the current nozzle utilized on all exterior fires at the MSFA. The second nozzle utilized was the Akron Assault model number 4815 which is a 1.5" 75psi fixed gallonage nozzle delivering 150gpm. The Akron Assault model number 4815 is a nozzle currently available to students at the MSFA during interior fire attack operations. The third nozzle utilized was an Akron 1.5" smoothbore nozzle using a 7/8" tip which delivers 160gpm at 50psi nozzle pressure. The Akron 7/8" smoothbore nozzle is currently available to students at the MSFA during interior fire attack operations. All three nozzles utilized did not have pistol grips attached. The current hose handling techniques at the MSFA do not require a pistol grip nozzle.

Hose line selection was very important during this ARP. Hose line manufacturers each have their own performance characteristics which may change throughout the various models they manufacture. The researcher selected a hose line which would provide the closest internal diameter to 1.75". The hose line which meets this requirement at the MSFA is the Key Big 10 1.75" attack hose manufactured by Key Fire Hose Corporation. Each attack line used during this

ARP consisted of 100’ of 1.75” Key Big 10 hose and one of the three nozzles provided. Every hose line used during this ARP was manufactured in June of 2015.

The water delivery system used during this ARP was the MSFA’s campus water system. This system consists of a pump house which drafts water from a well which is over 20’ deep. This well is connected by two 36” pipes which travel underground to a lake which provides the water source for the system. The pump used in this system is a 1,500gpm electric pump which generates 130psi of system pressure. The water is then distributed across the entire campus through underground and above ground water mains. Every outlet on the MSFA campus will deliver between 120 and 130psi depending on the location. The location selected for all nozzle operation tests was located at the nearest available outlet and maintained an outlet pressure of 128psi during the testing process.

The three attack hose lines were connected to (2) 2.5” outlets using Task Force Tips gated wyes, part number AYNJ-NF. Initial testing utilized an Akron 2.5” gate valve which was later determined to be unnecessary due to the achievement of target nozzle pressures for each nozzle without having to gate any hose line. The three hose lines were placed on the ground and operated on a level asphalt surface. Each of the three hose lines were terminated with one of the three nozzles available.

Calibration of each nozzle was achieved by using Task Force Tips Sho Flo meters, an Akron 1.5” inline analog pressure gauge and an Akron pitot gauge. The 1.5” inline pressure gauge was connected directly behind each nozzle one at a time. This was conducted while all three hose lines were actively flowing water to insure pressure readings were accurate during testing. The pitot gauge was used to calculate the 7/8” smoothbore nozzle operating pressure. Collectively all three of these measurement tools were used to validate the nozzle’s operating pressures. Once each nozzle was measured for flow in gpm and nozzle pressure all measurement tools were removed from the hose lines and nozzles. Each nozzle was placed at a distance of 10' onto the asphalt with the remaining hose line laid in the grass to the connection at the outlet.

Firefighters from the MSFA 1001-I-II course were provided with a briefing about the test they were about to receive. Each firefighter was told the operating pressure of each nozzle and the flow of each nozzle when pressurized correctly. The firefighters were then asked to flow each nozzle for no more than 1 minute to determine if the nozzle was operating at the proper nozzle pressure, under-pressurized or over-pressurized. Each participant was instructed to operate the nozzle from a position on the ground to simulate interior fire attack conditions. The participants were allowed to visually observe the nozzles while operating and were allowed to manipulate the fog nozzles through all pattern adjustments. During the test all three hose lines were operated at the same time beginning with a count down from the researcher. At the end of 1 minute the researcher again provided a count down to shut down the nozzle. At the conclusion of flowing the nozzle each participant was told to rotate to another nozzle. The participants flowed all three nozzles before providing their observations. Once complete all three participants recorded their name, years of experience and whether or not they believed each nozzle was operating at the correct nozzle pressure, under-pressurized, or over-pressurized. After three participants provided their observations three more participants were brought into the testing area to begin another round of testing.

Only one of the 3 nozzles used had their flow reduced to a critical level. This level was determined by referencing the initial attack line flow recommendations set forth in the NFPA 1710 standard. The 7/8" nozzle and the 75psi nozzle were each pressurized to the proper nozzle pressure. The 7/8" nozzle delivered 160gpm at a nozzle pressure of 50psi. The 150gpm nozzle delivered 150gpm at a nozzle pressure of 75psi. The 100psi nozzle's flow was reduced by 25% brining the flow below the recommended flow rate for initial attack lines referenced by NFPA 1710.

Limitations of the procedures used for this ARP included varying levels of firefighter physical and mental stress. The firefighters were tested in the last week of their 1001-I-II course at the end of the day. Due to a wide range of firefighter physical fitness amongst the participants the physical act of operating each nozzle might have been challenging for certain participants. The order of testing also created limitations due to the participants randomly selecting the hose line and nozzle they would operate and in what order they would operate each hose line and nozzle. The participants were all enrolled in the 1001-I-II course and had limited experience in the fire service prior to attending the course. Each participant's years of experience were documented during the testing process.

Results

The results of the nozzle operations test proved to be the most valuable component of this ARP. During the nozzle operations test MSFA students enrolled in the 1001-I-II course had already received skills instruction and had all passed their skills testing portion of the course which met the minimum standards set forth in NFPA 1001-I-II. The nozzle operations test revealed that 46% of the participants were unable to identify a critical loss in flow from the nozzle. This demonstrates the need for an evaluation of curriculum currently being delivered during the NFPA 1001-I-II course.

In Table 1 provided below shows the data retrieved from the participants of the nozzle operations test. Each participant provided their observations by noting if the nozzle was low, good or high. Participants noting a nozzle was low determined the nozzle was under-pressurized and lacked the characteristics needed to determine proper flow and nozzle reaction. Participants noting a nozzle was good determined the nozzle was being operated at the proper nozzle pressure and thus flowing an adequate amount of water. Participants noting a nozzle was high determined the nozzle was over-pressurized and had characteristics of a nozzle operating above it's designed operating pressure.

Years of Service	7/8" Nozzle	75psi Nozzle	100psi Nozzle
0	Good	High	Low
1	High	Low	Good
0	Good	High	Low
0	High	High	Good
0	Good	High	Low
0	Good	High	Low
0	Good	High	Low
0	High	High	Good
0	High	Good	Low
0	Good	High	Good
0	High	High	Good
2	High	Good	Low
4	Good	High	Good
0	Good	High	Good
0	Good	High	Low
1	Good	Good	Low
0	Good	Good	Low
1	High	High	Good
1	High	High	Good
0	High	High	Low
0	Good	High	Low
1	High	Good	Low
1	Good	High	Good
0	Good	High	Good

Table 1. Participant Responses from Nozzle Operations Test

The nozzle operations test provided information related to each nozzle and the firefighters perceived nozzle reaction force as it related to each nozzle tested. The 100psi fog nozzle revealed a staggering 46% of participants were unable to detect a critical reduction in target flow.

Figure 1.1

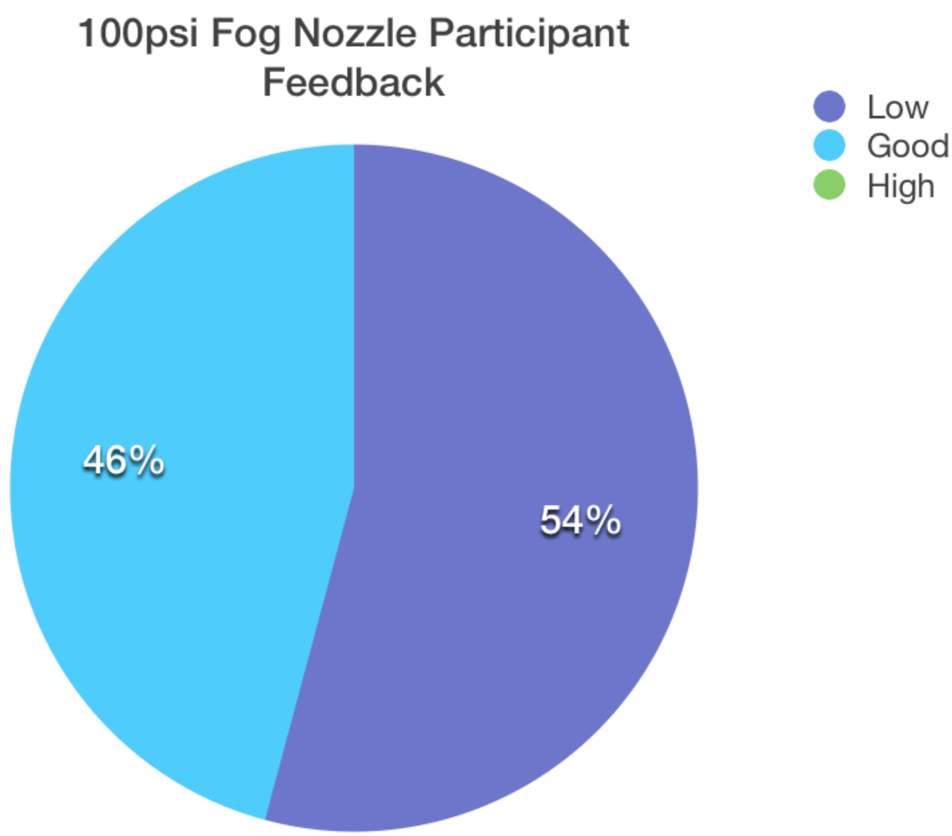

Figure 1.1. Participant feedback of the 100psi nozzle during operation testing.

The 75psi fog nozzle revealed that 75% of participants believed the nozzle was over-pressurized. This may be in part that it generated the highest nozzle reaction force of the three nozzles tested.

Figure 1.2

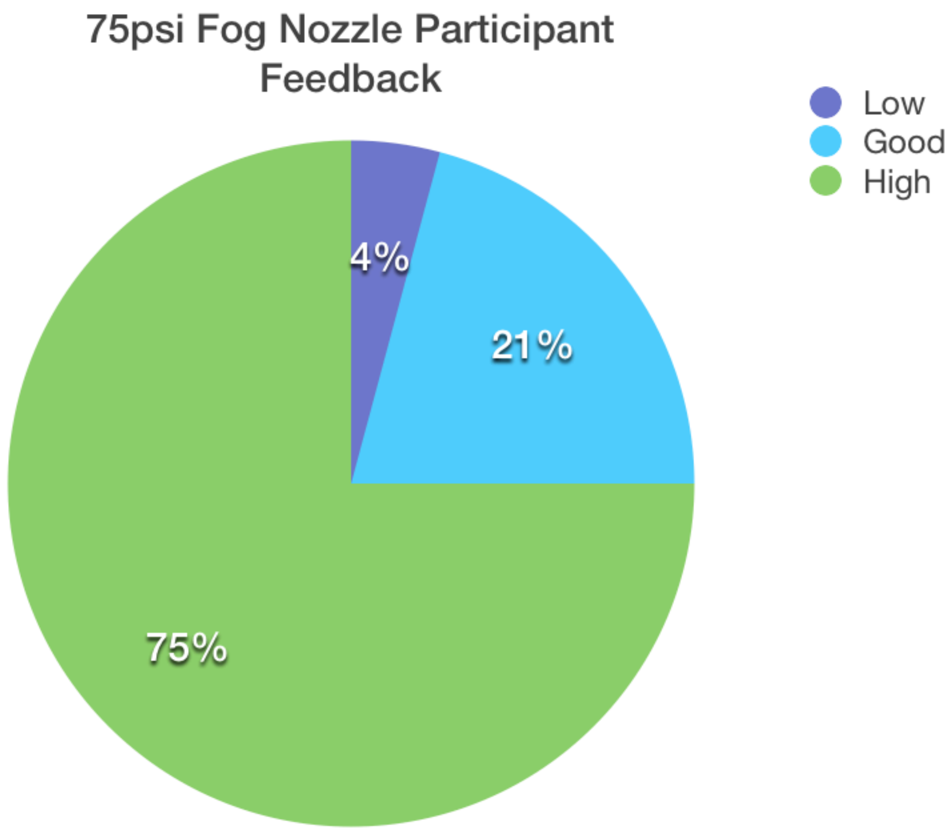

Figure 1.2. Participant feedback of the 75psi nozzle during operations testing.

The 50psi smoothbore nozzle had the most consistent results from the participant's feedback. The majority, 58%, of the group tested identified the smoothbore nozzle as properly pressurized and delivering the target flow required.

Figure 1.3

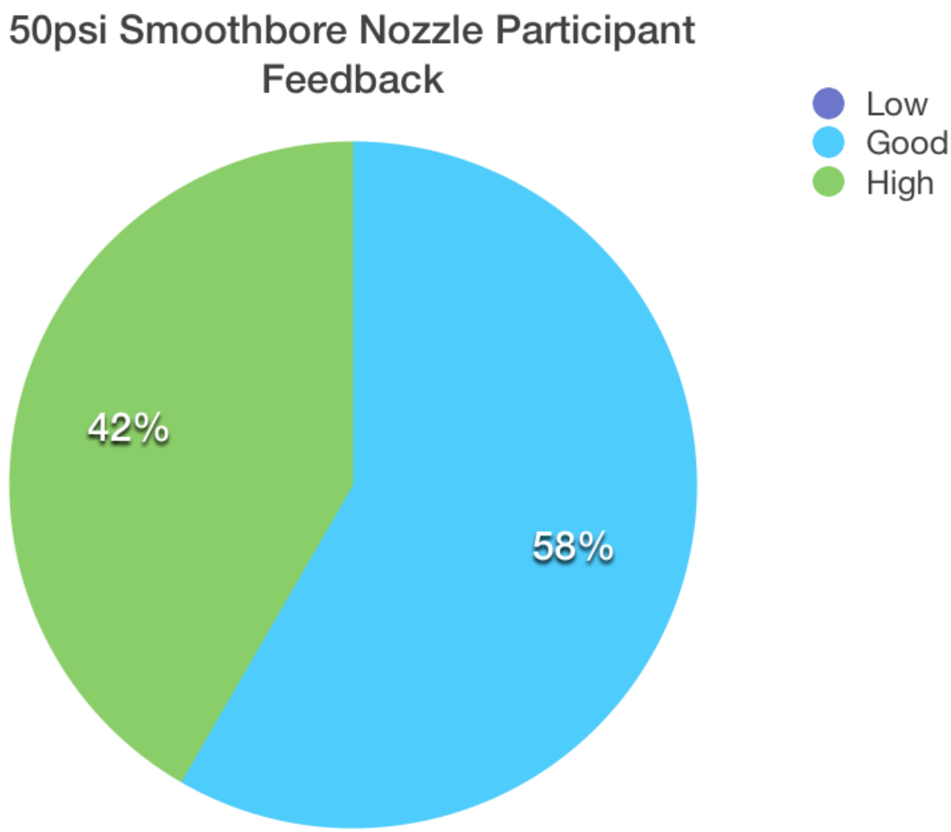

Figure 1.3. Participant feedback of the 50psi smoothbore nozzle during operations testing.

The years of service data was collected from each firefighter participating in the nozzle operation test. This information may be used for future testing of veteran firefighters to see if there is a correlation through the years of service.

Figure 1.4

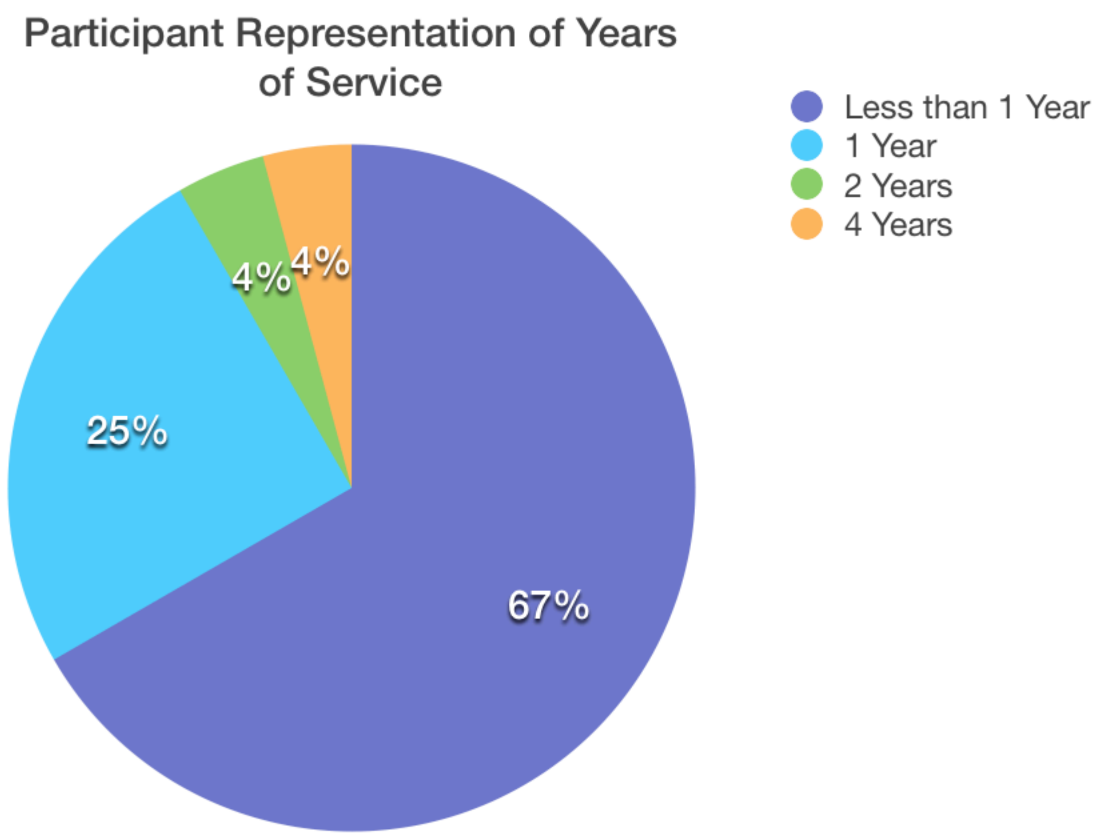

Figure 1.4. A representation of the years of service provided by the 1001-I-II students.

The first questions asked during this ARP was: why is nozzle reaction a valid way of determining water flowing through a nozzle? During the literature review is was determined that theoretical nozzle reaction calculations are directly correlated to the MSFA's hand line and nozzle selections. Using an observation method during live field testing nozzle reaction was also observed decreasing during all critical failures reducing the flow through the nozzle.

The second question of this ARP was: given a structural fire, how do firefighters determine the critical flow needed for interior fire attack operations? The literature review provided much needed information regarding the selection of initial attack hand lines, nozzle selection and target flow needed to extinguish structural fires. Initial attack line selection at the MSFA follows the recommendations set forth in NFPA 1710. Exterior fires at the MSFA are attacked with 1.75" hose lines providing a flow of 125gpm. Interior fires are attacked using two different nozzles, the first being a 7/8" smoothbore nozzle providing a flow of 160gpm and the second being a 75psi fog nozzle providing a flow of 150gpm.

The third questions of this ARP was: Will the operating pressure of the nozzle effect the firefighter's ability to identify target flow using nozzle reaction? This question needs more information at the conclusion of testing. The only nozzle each participant operated with reduced flow was the 100psi fog nozzle. Future tests will need to incorporate the 7/8" smoothbore nozzle with a critical reduction in flow and the 75psi fog nozzle will need to be operated with a critical reduction in flow. The 7/8" smoothbore nozzle showed the most consistent participant observations with 58% of the participants identifying the nozzle as operating at the correct nozzle pressure. A staggering 75% of participants believed the 75psi nozzle was over-pressurized when in fact is pressurized at the correct nozzle pressure.

Discussion

The nozzle operations testing proved a significant percentage of firefighters did not have the skills or ability to recognize a critical reduction in target flow. Nozzles were selected based on their flow and nozzle reaction which could be effectively managed by a single firefighter. The target nozzle reaction force used was 60 pounds based on the research provided by Paul Grimwood's observations of firefighter nozzle operations (Grimwood, 2006). During the testing process firefighters had a 100psi nozzle which had its' flow reduced by 25%, replicating the effects of having a 180-degree kink in the hose line (Pillsworth, Knapp, Flatley, & Leihbacher, 2007). This significant loss in flow would place firefighters in a dangerous situation flowing water below the recommended flow rate in NFPA 1710 (National Fire Protection Association, 2015).

The nozzle testing process also remained consistent with the findings of Paul Grimwood on the subject of nozzle reaction effectively managed by a single firefighter. During testing, the 75psi nozzle was delivering 150gpm which generated a nozzle reaction of 65 pounds which exceeded the nozzle reaction force manageable by a single firefighter. The 75psi nozzle also generated the highest nozzle reaction force of all three nozzles used which could explain the high percentage of firefighters who believed the 75psi nozzle was over pressurized.

Firefighters at the MSFA receive hose line and nozzle handling instructions in a standing position with multiple firefighters backing up the nozzle operator. The reality of an interior fire attack is such that a single firefighter will often be required to operate the nozzle by him or herself from a position on the ground. Firefighters also receive their initial hand line and nozzle handling instruction in daylight with unobstructed vision. Firefighters may visually see a significant obstruction in a nozzle if it disrupts the nozzles pattern but in a smoke filled or dark environment the firefighter will be unable to see this disruption. Firefighters must rely on nozzle reaction and hose line characteristics to recognize critical reductions in target flow.

This ARP provided the researcher with justification to evaluate current curriculum pertaining to hose line and nozzle operations. This ARP will also provide a discussion frame work with instructors at the MSFA to seek recommendations and suggestions on improving the outcomes of firefighter detection of critically reduced target flow.

The first question answered by this ARP was: Why is nozzle reaction a valid way of determining water flowing through a nozzle? This question was answered using primarily theoretical nozzle reaction calculations. When a nozzle has a reduction in its' operating pressure you will notice a reduction in nozzle reaction directly proportional to the reduction in flow (IFSTA, 2015). Nozzle reaction was also evaluated by determining how much reaction force a single firefighter could operate effectively. This information was discovered by the literature review of Paul Grimwood's article "Firefighting Nozzle Reaction" (Grimwood, 2006).

The second question answered in this ARP was: Given a structural fire, how do firefighters determine the critical flow needed for interior fire attack operations? This question was answered in the literature review by referencing multiple resources. The first method of determining critical flow was provided by two different formula methods. The Iowa formula and the National Fire Academy formula. The Iowa formula calculates the needed flow by considering the volume of the structure involved which includes the height of the building (Hartin, Estimating Required Fire Flow: The Iowa Formula, n.d.). The National Fire Academy formula for determining flow requirements utilizes square footage multiplied by the percentage of involvement (Hartin, Estimating Required Fire Flow: The National Fire Academy Formula, n.d.). Other documents were reviewed such as "Planning a Hose and Nozzle System for Effective Operations" written by Jay Comella. Jay's article references a line of duty death which became the subject of an investigation. The investigation provided recommendations of initial flow rates in a range of 150 to 180gpm for interior fire attack operations (Comella, 2003). The literature review also incorporated an article by Andy Fredericks which provided his recommendations on initial attack line flow requirements for residential structures. In his article Andy recommended a flow rate of at least 150gpm for residential structure fires in today's modern environment (Fredericks, 2000).

The third question answered in this ARP was: Will the operating pressure of the nozzle effect the firefighter's ability to identify target flow using nozzle reaction? This question was the hardest question to answer due to the limited sample size of the testing group. In order to provide consistent results an entirely new group of firefighters would be needed to test a reduction in flow of the two nozzle which were operating at the proper nozzle pressure. During the testing process it became evident that a 100psi nozzle proved difficult for students enrolled in the 1001-I-II course to recognize a critical reduction in target flow. A staggering 46% of the firefighters tested failed to identify the reduction in flow. However, the firefighters tested also identified the 75psi nozzle as being over-pressurized when in fact it was operating at the correct pressure. The most consistent results came from the 7/8" smoothbore nozzle with 58% of the firefighters tested identifying the nozzle as being properly pressurized.

This research created a discussion on the MSFA campus which will improve the understanding of nozzle reaction and the relationship it has on identifying reductions in target flow. The MSFA will analyze the data provided by this research and will evaluate the curriculum currently being used in the 1001-I-II course.

Recommendations

Identifying a critical reduction in target flow using nozzle reaction has been identified as a problem which needs improvement. This ARP provided information about the current status of the MSFA curriculum and the student's abilities to recognize critical reductions in target flow. The following recommendations are provided to the MSFA in order to improve the outcomes of identifying critical reductions in target flow.

Instructors working at the MSFA should receive information regarding hose line and nozzle selection and the importance of delivering the proper flow required for interior fire attack operations. Instructors should receive training on hose line and nozzle handling techniques which may improve the ability of a firefighter to recognize a critical reduction in target flow. Instructors at the MSFA should familiarize themselves with the different types of fire hose provided on the campus and how their construction may change hose handling characteristics which may confuse students due to inconsistent hose handling performance.

An evaluation of curriculum for interior fire attack operations should be conducted. During this evaluation the MSFA should identify the best methods of determining critical application rates and nozzle selection. A discussion should be started in regards to suggestions and techniques available for instructing hose line and nozzle handling.

Steps should be taken to reduce the likelihood of critical reductions in target flow during live fire evolutions. This steps should include removal of all kinks or obstructions which may interfere with the operation of the hand line. The MSFA should evaluate its' current methodology for checking the nozzle prior to performing an interior fire attack.

Further research should be conducted on the various nozzle operating pressures available. The MSFA should identify the nozzle which provides the best methods of identifying critical flow reductions. The MSFA should also evaluate veteran firefighters to determine if the results are consistent throughout a firefighter's career in Mississippi.

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