Strategy and Tactics for Fog Nozzles

By John D. Wiseman

Introduction

The NFPA has recently published a Second Edition of STRUCTURAL FIREFIGHTING with the subtitle of Strategy and Tactics. In the chapter on "Offensive Operations", the authors make the following statement.

> "The reality is that there is little need for fog streams during offensive structural firefighting."

The authors define "offensive fire attack" as an interior attack. A "defensive fire attack" is defined as an exterior attack.

These two simple definitions do not work out in reality   As an example I want to use the first structural fire call that my fire department answered. The structure was a country style with the longest dimension extending from the front to the rear An enclosed porch had been added to the rear with windows on three sides. There was a single door connecting to the rest of the house.

The fire was burning out all the windows, and was also burning through the roof of the porch. Our fire truck stopped alongside the house, and the two preconnects were pulled. The fire was controlled with firefighters moving around the outside using TFT automatic fog nozzles. Fire had begun to spread through a louvre into the attic space above the main part of the house. An extension ladder and a roof ladder were used to access the peak to extinguish the fire there.

While all this was going on, a mutual aid department sent an attack crew into the front door. They had to go through several rooms to reach the back door to the porch. This was a nighttime fire and there were no lights on in the house. They never did find this door.

Is the exterior attack made on the porch not an offensive attack because it was made from the outside? How about the attack through the front door? The authors of STRUCTURAL FIREFIGHTING classify this attack as offensive because it was made from the inside, or from the unburned side of the structure. Its purpose was to put out the fire, but it failed to do this.

In fact, the purpose of the exterior attack was to put out the fire. Since the purposes of the two attacks are the same, they should be classified as the same type of attack. In other words, both attacks are offensive in nature with the same purpose. In reality the purpose of a given attack should be used to determine whether an attack is offensive or defensive in nature. Using purpose gives another simple way to classify methods of attack. Is the purpose to put out the fire? Or is the purpose to stop the spread of the fire and protect exposures?

Credit for first stating this means of classifying methods of attack goes to Bill Nelson, Chief Instructor at the Fire Service Institute, Iowa State University. .He said:

> "Each officer and nozzleman must understand fire behavior, and must determine the purpose of their attack on a given day and then choose the method of attack which will best fit that purpose."

Now let's return to the main idea of the offensive operation chapter. The authors state that the essential question to be answered is:

> "How many gallons per minute (liters per minute) are required to extinguish a given fire?."

On the same page (194) on which this question is stated, there appears a little box divided into two parts: - a fallacy and a fact.

The fallacy:

"Rate-of-flow calculations are used to determine the exact amount of water needed."

The fact:

> "Rate-of-flow calculations yield a rough approximation of the flow."

The authors do not offer a quantification of "exact amount" or "rough approximation". Presumably "exact amount" means 100%. How far off is a "rough approximation" The authors don't say.

On the same page the authors do make a statement that is helpful It is:

> "it is not possible to take into account every single variable that will be encountered at a fire scene."

The variables that the authors are talking about are the different kinds of fuels encountered in different structure fires. Ii is true that all the r-o-f formulas are based upon the amount of oxygen in a confined space In reality the variation in fuels is accounted for in a way that the authors could not imagine. The formulas are accurate and dependable in answering the essential question of how much water is needed to extinguish a given fire.

To make further progress, two new definitions must be introduced, a confined structure fire and an open structure fire. A confined structure fire is defined as:

> A confined structure fire is one in which a fire is burning in a room(s) in which the ceiling or roof is intact.

An open structure fire is defined as:

> An open structure fire is one in which fire is burning in a room(s) in which the ceiling and roof is not intact.

A fire burning out a window or door is still a confined fire.. The percentage of ventilation for a confined space is calculated by adding the areas of all the walls and ceiling. The area of the floor is excluded since there is little interaction between the fire area and the area below. For example, a room with a total surface area of walls and ceiling of 500 ft^2 and one window open of 12 ft^2 has a ventilation factor of 2.5%.A much higher percentage of ventilation is required (say 25%) before a confined fire becomes an open fire.

There is a very important reason why we must separate confined structure fires from open structure fires. In a confined fire any steam created in that confined space will stay there for as much as two minutes. This means that the steam will smother the fire by steam expansion and deprive the fire of oxygen needed for combustion. This does not happen in open fires as steam moves up and out of the structure without anything to stop it. Thus defensive operations require a different r.o.f. formula and different tactics.

The NFPA reports that 75% of all structure fires in the U.S. occur in one or two family detached dwellings. In about the same percentage of structure fires such fires are confined to the room of origin with a single attack line. So let's move on to consider the r.o.f. formulas in STRUCTURAL FIREFIGHTING as applied to confined structure fires

Thornton's Rule

Thornton's Rule was discovered more than 50 years ago. However, it has not been used until recently in fire engineering research. It appears in the 17th Edition of the NFPA Handbook 1991, Appendix A. Appendix A was revised by Dr. Vytenis Brabauskas, Head of the National Institute of Standards and Technology. Dr. Brabauskas makes the following observation about Thornton's Rule

> "Recently, however, increasing engineering use is made of the observation that the heat of combustion per kg of oxygen consumed is nearly constant for most organic fuels. It can be shown that
>
> $$\Delta h^1_c / r_o = 13.1 \text{ Mj/kg for } O_2$$
>
> is near constant."

Now the question needs to be answered whether Thornton's Rule applies to confined structure fires where the rate of heat release is controlled by the limited amount of oxygen available to the fire

Dr. Clayton Huggett of the National Bureau of Standards, Washington D.C., considered this question in an article appearing in 1980 in FIRE AND MATERIALS magazine. Since confined structure fires involve incomplete combustion, the question narrows down to what effect incomplete combustion has on Thornton's Rule.

After examining this question in detail for various fuels and products of combustion, Dr. Huggett reached the following conclusions.

> "1. The rate of heat release in a fire can be estimated with good accuracy from two simple measurements, the flow of air through the fire system and the concentration of oxygen in the exhaust stream.
> 2. The heat release from a fire involving conventional organic fuels is 13.1kj/gram of oxygen consumed with an accuracy of + or – 5%.or better.
> 3. Incomplete combustion and variation in fuel have only a minor effect on this result. Appropriate corrections can be made if necessary.
> 4. The oxygen consumption technique of heat release measurement is adaptable to a wide range of applications ranging from small scale laboratory experiments to very large scale fire system tests.

Please note the suitability of Thornton's Rule to fire engineering experiments.. Thornton's Rule is widely used today because it provides a simple means of calculating the rate of heat release in a confined fire.

A second question that can be asked about Thornton's Rule is this:

Are confined fires limited by the amount of oxygen in the confined space?

All scientists or engineers agree that the rate of heat release in a structure fire is limited by either:

(1) the fuel surface areas available to a fire, or
(2) the oxygen available to the fire.

It is a scientific fact that the rate of heat release in confined structure fires is oxygen limited, or ventilation controlled during most of their fire development. John A. Campbell, writing in the 17th Edition of the NFPA Handbook in his article "Confinement of Fire in Buildings:, states that:

> "Considerable ventilation is required for a fully developed fire to burn at a fuel-surface controlled rate…Many, if not most, building fires will be ventilation controlled at least during the period of time in which containment is a

> consideration…The maximum intensity of post-flashover fires occur when ventilation is just sufficient to permit fuel surface controlled combustion.”

Thus, except for the very beginning at ignition, a confined structure fire is ventilation controlled up to the time of maximum, or peak intensity. Also note that Dr.Huggett states that incomplete combustion and variation in fuels have only a minor effect on the result This is the reason why we do not have to take into account fuel variation in the r –o-f formulas. Thornton’s Rule is all that is needed for confined structure fires in which the amount of oxygen available to the fire limits the rate of heat release. Thus whether it is possible, or not, to account for fuel variations is not needed to make the r –o-of formulas accurate. Thornton’s Rule is all that is needed. In spite of the author’s statement, it is possible to account for variation in fuels. In an oxygen limited confined fire a single number, 13.1 Mj, accounts for all the hydrocarbon fuels. That is truly amazing, but that is the impact of Thornton’s Rule for fire behavior in confined structure fires.

The Iowa Rate-of-Flow Formula

The authors of STRUCTURAL FIREFIGHTING begin their discussion of rate of flow formulas by stating that all r-o- f formulas have “imprecision built into them” thus changing the essential question to the following.

> The question is how much water is needed to overwhelm the fire.

The implication here is that by trial and error methods you will start applying water and keep on increasing the flow until you can overwhelm the fire. The more the better! However, for confined structure fires this strategy does not work. It is a common myth throughout the United States that you should try to overwhelm the fire Enough research has been done by the Fire Service Institute at Iowa State University and the U.S. Navy’s Research Laboratory to prove that too much water on confined fires creates thermal imbalance. Thermal imbalance has bad consequences for fire fighting

The essential question for confined structure fire fighting has been stated by Floyd (Bill) Nelson of Iowa State University as follows.

> In principle fire fighting is very simple. All one needs to do is put the right amount of water in the right place and the fire is controlled.

This is quite a different statement of strategy from that of the authors of STRUCTURAL FIREFIGHTING. This strategy requires that we have formulas that are accurate and dependable. That we have.

The authors begin their discussion of formulas with “Indirect Application Theory” that centers around Chief Lloyd Layman of the Parkersburg, W.V. during World War II. Chief Layman was Director of the Coast Guard Fire School at Ft. McHenry, Baltimore

Maryland. Chief Layman experimented with extinguishing fuel oil fires below the deck plates of the engine room of a liberty ship. He is credited with creating a new method of fire attack besides the direct attack with a smooth bore nozzle, called “the indirect attack with atmospheric displacement.” The authors failed to mention that Chief Layman spent 3 years with his fire department adapting this new method of attack to structural firefighting in Parkersburg.. He was quite successful in this, and the NFPA published 2 books by Chief Layman, one describing how he used industrial type fog nozzles to fight fires in Parkersburg. In 1950 Chief Layman’s speech to the FDIC conference was the single most important event that resulted in most fire departments switching to fog nozzles.

So Chief Layman has his place in the history of the fire service in the United States. Remember that at that time (1950) very little was known about fire behavior, and fog nozzles. I think that Chief Layman realized that the tactics he was using in structural firefighting in Parkersburg were not truly an indirect attack. He did not describe exactly how he instructed his firefighters to distribute water in the fire area. At any rate, Chief Layman said that the problem of how much water is needed had not been solved, and he did not produce a r.o.f. formula even though the numbers needed for the formula were incorporated into his data.

The first formula discussed by the authors is the Royer/Nelson formula. The authors on page 196 state that no r – o – f formula calculation is completely accurate. I am curious as to whether the authors know how the Iowa Rate of Flow formula was created and especially why the constant “100 “ appeared

The first formula created by Royer and Nelson is what they called the “Gallonage Formula”. It is:

$$\text{GPM} \times t - \frac{\text{Vol}}{200}$$

Where “GPM” = gallons per minute, t – time in minutes or a fraction of a minute, Vol = volume of a confined space in cubic feet, and “200” is the constant that is explained next.

The constant “200” is based solidly on two scientific facts.

1. One gallon of water at 212°F expands instantly to 227 cubic feet of steam. This number is rounded down to “200” to allow for a 90% rate of conversion to steam.
2. One gallon of water with a margin of safety absorbs all the heat produced by the oxygen in 200 cubic feet of normal air.

It is quite remarkable that both of these facts converge on the same number, 200.

Notice that both of these facts allow for an accuracy of 10%, that is, allowing for a 90% conversion of liquid water to steam. This formula is the one that can be used for actual fire fighting. For example, let’s find out how much water is needed to fill a confined space full of steam. Suppose the space is a room with a volume of 2,000 ft^3.

$$\text{GPM} \times t -= \frac{2{,}000}{200}$$

Division of 2,000/200 yields 10, the number of gallons needed to expand as steam to 2,000 ft^3.

The authors of STRUCTURAL FIREFIGHTING do not mention this formula. In fact I do not know whether they are aware of its existence. However, it is easy enough to derive the ratio V/100 from the Royer-Nelson formula. First, substitute 0.5 (30 seconds) for “t”. Dividing both sides of equation by 0.5 gives the equation used by the authors.

$$\text{GPM} = \frac{V}{100} \qquad t = 0.5$$

Where “V” = “Vol;” The fact that time equals 30 seconds should be stated somewhere or somehow. Adding this statement after the equation is one way to accomplish this.

Bill Nelson and Keith Royer discovered during their research that almost all structure fires could be extinguished within30 seconds. Keith Royer has recommended that this fact be used in preplanning a fire department’s capability for handling fires in its district. This is the formula that has been known as the Iowa Rate of Flow formula. The authors have used this formula as recommended by Keith Royer. Also they have used the largest open area of a structure, not the entire structure, as recommended by Royer. The authors are the first that I am aware of who have used the Iowa Rate of Flow formula correctly.

There is “No Magic Pill”

I have heard Keith Royer say on numerous occasions that “there is no magic pill.” By this he meant that there is no one tool, or tactic, that will solve all of your fire fighting problems. Thus we must agree with the authors of STRUCTURAL FIREFIGHTING when they say that the Royer-Nelson (Iowa) formula may understate the needs in well ventilated, large fires. This means open fires in which steam does not smother the fire as in a confined space. The Iowa r-o-f formulas should not be used to calculate the needed fire flow (NFF).

The second formula discussed by the authors is the formula created at the National Fire academy. It is:

$$\text{GPM} = \frac{\text{Area}}{3}$$

and “Area” equals the square feet area of the structure.

The authors state that this formula has not come from data provided by any research, so the authors conclude that the validity of this formula has not been proved. Hence we don't really know whether the formula is valid for confined structure fires, or for open structure fires. There is "no magic pill" here for sure. They also note that considerable research was done to create the Iowa formula.

The authors also talk about sprinkler systems, and especially that some sprinkler calculations involve fuel load.. They do give information as to how to access these calculations. Again, keeping in mind the "no magic pill" principle such calculations may, or may not, be helpful in determining the NFF for structure fires extinguished by hand lines. The big difference here is that sprinklers operate in the early stage of fire development that requires much less water than a fire development that occurs when the fire department response occurs some minutes later. At any rate the authors do not mention residential sprinklers or the calculations for them

There is one more r-o-f formula in existence that the authors apparently are not aware of. This formula first appeared on the internet at the web site "firetactics.com". The creator of this formula is Paul Grimwood, retired London Fire Brigade, London, England. He called his formula one for " minimum fire ground requirements." It is:

$$\text{Lpm} = A \times 2$$

Where "Lpm" = liters per minute, A = Area of the fire, and 2 is a constant. This formula, of course uses the metric system.

We must make two changes to this formula. First, we must include "t" time as a factor since we do not want to be restricted to a time of one minute. Second, we must change "A" area to volume. This is easy to do by multiplying area by ceiling height.
of 3 meters (10 ft).

$$\text{Lpm} \times t = \frac{3 \times A \times 2}{3}$$

Since "3 x A" = Vol, we make the change to Vol in cubic meters. Multiplying the numerator and denominator by 0.5 gives us the final form of the formula.

$$\text{Lpm} \times t = \frac{\text{Vol}}{1.5}$$

This equation is identical to the Royer-Nelson formula in the metric system, with 1.7 rounded down to 1.5 to account for 90% conversion of liquid water to steam.

What is the significance of this finding? First these two formulas were created 36 years apart and in difference countries. Second both formulas are the result of careful research. Since both formulas are actually one, the research done on fog nozzles converges on the same set of facts and principles. It is safe to say that the Royer, Nelson, Grimwood formula is the only valid formula that the fire service will have to work with for confined fires. Further, the formula is accurate within 10%, and together with Thornton's Rule provides a firm foundation for fighting confined structure fires with fog nozzles.

Defensive operations

This chapter does not add anything to the r-o-f formulas discussed in the offensive operations chapter. The authors are concerned that defensive operations with master streams require much less manpower than offensive operations, in fact they say that defensive operations are easier to handle. They seem to prefer smooth bore nozzles based upon the myth that solid streams penetrate better than straight streams from fog nozzles. They are perpetuating a myth since penetration force depends upon the following physics. Penetrating force is calculated by multiplying mass times velocity. Thus if the mass projected by two nozzles are the same, and the velocity is the same, then the penetrating force is the same.

There is a r-o-f formula for larger fires in larger buildings that was created by Warren Y. Kimball in the 1960s. He was at that time Manager of the NFPA Fire Service Department. He wrote two books published in 1966 and 1968 titled: FIRE ATTACK, Command Decisions and Company Operations, FIRE ATTACK, Planning, Assigning, Operating. He considered the question of how much water is needed (NFF) in the second volume

Warren Kimball looked at data supplied by various fire departments throughout the United States that reported actual fire flows at its largest structure fires. He did not include any of this data in his book. The data revealed that the NFF necessary and sufficient to control and extinguish such fires averaged around

$$4 \text{ gpm per } 100 \text{ ft}^3$$

This r-o-f is the same as (0.04 gpm) per 1 ft^3, The equation for this formula is:

$$GPM = 0.04 \times V$$

with V – volume of a structure in cubic feet. This formula increases the NFF by a factor of four times compared to the NFF for offensive operations with hand lines where the NFF is 0.01 per cubic foot.

One reason for the dramatic increase in inefficiency is that a master stream that remains stationary and directs its water to one spot in the open fire does little good in extinguishing the fire by a direct attack. A direct attack requires that the water be distributed to all the fire area with sufficient velocity to vaporize the water throughout the fire area. This requires a continuous motion of the nozzle to directly attack all of the fire. It may require more manpower to make this direct attack than the authors realize.

The Efficiency and Effectiveness of Fog Nozzles

How can we evaluate the performance or capabilities of nozzles? There are two standards that should be used. They are:

- Efficiency - This standard relates to how much water is needed or used.
- Effectiveness - This standard relates to how much time is needed or used.

A fire attack is more efficient than any other method if it uses less water to control or extinguish a given fire. The way that water becomes highly efficient in fighting fires is when liquid water is converted to steam (a gas). A look at the numbers tells you why. Raising the temperature of one gallon water from 62° F to 212° F requires 1,250 btus. In other words, that amount of heat is absorbed (1,250 btus) by raising the temperature of that gallon to 212° F. When one gallon of liquid water is vaporized at 212° F, this change of state requires 8,080 btus. This number is more than six times greater than the number of btus absorbed by simply heating the liquid water to 212° F.

Truly you cannot be efficient in fighting fires if you cannot change all, or almost all, of the water applied to steam. Any liquid water left over after fire control is water that is wasted, and that water can cause a lot of damage to the structure besides the damage caused by the fire itself. So a highly efficient method of attack should convert at least 90% of the liquid water applied to steam.

This standard leads to the principle that a highly efficient method of attack should use the right amount of water, that is, the amount that is necessary and sufficient to control the fire. Too little, or too much, water does not work as efficiently as applying the right amount, or close to it.

The second standard, effectiveness, relates to how much time is required to execute a given method of attack. One might say that it doesn't matter how long it takes to control a fire, so long as you can get the fire out. It is also true that a fire will eventually burn out when it no longer has any fuel available. So what's the hurry?

There is a good reason to hurry when you are fighting a confined structure fire. Engineers are agreed that most such fires may be described as "t^2" fires. That means that if at the end of one minute the rate-of-heat release is a certain number, $r_1 = 1$ (1^2), then at the end of the second minute, $r_2 = 2^2$ (or 4), $r_3 = 3^2$ (or 9), and so on. Thus the fire becomes much greater as time goes on. As an example, a fire starting a clothes dryer can spread to half a house in 15 minutes. So there is a good reason not to waste time in fighting confined structure fires.

Also, I think that these two standards work together, hand in hand. If your attack is efficient, then the attack will also be highly effective. If you can accomplish an attack with less water, then you can undoubtedly save time as well. Of course you can be highly effective at times, and still not be so efficient. In this case you might consider yourself to be lucky. Now let's apply the two standards of efficiency and effectiveness to fog nozzles and to smooth bore nozzles to determine how they rank

First, for fog nozzles there is a formula that tells you how much water is needed to control or extinguish <u>confined</u> structure fires. A confined structure fire is defined to be one in which the ceiling or roof is intact. This enables any steam that is created to remain in the structure for up to 2 minutes, and hence this steam smothers the fire by removing the oxygen supply. The formula is the Royer-Nelson r-o-f formula.

$$\text{NFF} \times t = \frac{\text{Vol}}{200}$$

The symbols are: NFF = r-o-f in Gpm, T = time in minutes, or fraction of a minute, Vol = volume of a confined space in cubic feet, and 200 is the Royer Nelson constant that is explained next.

1. One gallon of water at 212° F expands instantly to 227 cubic feet of steam. This number is rounded down to 200 to allow for 90% rate of conversion to steam..
2. One gallon of water with a margin of safety absorbs all the heat produced by the oxygen in 200 cubic feet of normal air.

It quite remarkable that both of these scientific facts converge on the same number, 200.

Let's use the Royer-Nelson formula to calculate how much water is needed to attack a confined structure fire. Let's take an average size room of 2,000 cubic feet.

$$\text{NFF} \times t = \frac{2{,}000}{200}$$

$$\text{NFF} \times t = 10$$

Thus 10 gallons of water expands to 2,000 cubic feet of steam to fill the room full of steam. If NFF = 60 gpm, then

$$60 \times t = 10$$

$$t = \frac{10}{60}$$

Thus 10/60 of a minute equals 10 seconds. Our data is that a flow of 60 gpm for 10 seconds produces 10 gallons of water that expands to 2,000 cubic feet of steam. This, of course, fills the room full of steam and instantly extinguishes the fire. This is a full fog attack that achieves 90% efficiency and effectiveness

Now how about smooth bore nozzles? I have never seen any research that establishes any level of efficiency or effectiveness. Chief Lloyd Layman said in his book published by the NFPA that a smooth bore nozzle is “grossly inefficient” and thus is destined to be of secondary use in fighting fires. I can/t recall any other statement by anyone dealing with this subject.

So why are fog nozzles so much more efficient and effective than smooth bore nozzles? There are two reasons. First, liquid water must be projected with sufficient velocity near burning fuels to be vaporized. This is extremely difficult to do with a smooth bore nozzle that projects a solid slug of water with a stream whose reach is much too great for average size rooms. Water will travel through the fire at high velocity, hit a wall or ceiling, and splatter back. This creates a lot of turbulence (thermal imbalance) with a mix of hot and cold areas in the room. The water is completely out of control.

The fog nozzle, on the other hand, is highly efficient in distribution. The reach of the fog stream can be adjusted to the width of the room (no splattering). Moving the nozzle in a systematic way (clockwise rotation) distributes the water throughout the room evenly. The result is that all the water is turned to steam in a few seconds. The sudden appearance of white condensing steam expanding out of the room signals a cooling below 212° F. The fire is under control. Efficient distribution is the first key to the superiority of fog nozzles.

The second key is the little drops of water. The ability of water to absorb heat is directly related to the surface area of the water applied to the fire. The correct math term is “directly correlated”. This means that if the surface area is doubled, then the ability of water to absorb heat is doubled. The smallest drops of water produced by a fog nozzle are 0.01 inches in diameter. If the drops were all 0.01 inches in diameter, then the surface area of the little drops from a fog nozzle would be 1,400 times greater than the surface area of the solid slug of water from a smooth bore nozzle! That is truly amazing.

The diameter of some of the drops is somewhat bigger, but they are still little drops of water .Lets take an average to account for the bigger drops, say 1,000 to one. This ratio is still difficult to comprehend, but it is true!. About all you can say is that the little drops of water from a fog nozzle far exceed the ability of a solid slug of water from a smooth bore nozzle in fighting a fire.

In view of this fact, it is difficult for me to understand why the use of fog nozzles should not be preferred over the use of smooth bore nozzles for confined structure fire fighting .Remember the 1,000/1 ratio. That fact alone should be sufficient to make a choice.

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