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PLANNING A HOSE AND NOZZLE SYSTEM FOR EFFECTIVE OPERATIONS

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BY JAY COMELLA

The Oakland (CA) Fire Department (OFD) convened a Board of Inquiry to investigate the line-of-duty-death of Firefighter Tracy Toomey, who died on January 10, 1999. The fire building at 3052 Broadway was a two-story, balloon-frame building of mixed occupancy, with a residential area over the commercial premises. It was not an unusual building for Oakland.

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On arrival, the first-alarm companies encountered a heavy fire condition on the first floor with extension up the stairway. They made an aggressive interior attack using multiple 1 1/2-inch handlines. Fire was not extinguished in time to prevent the loss of structural integrity. The resulting collapse of the second floor into the first floor killed one OFD member and left two others with career-ending injuries. One of the three direct causes the Board of Inquiry report cited for the line-of-duty death was the inability of 1 1/2-inch hose to flow sufficient water to extinguish the heavy volume of fire encountered.



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(1) Left to right: automatic nozzle (50-350 gpm), adjustable-gallonage nozzle (30-60-90-125 gpm @ 100 psi), constant-gallonage nozzle (150 gpm @ 50 psi), and 1 5/16-inch smooth-bore nozzle (180 gpm @ 50 psi). (Photos by Daryl Liggins.)

The report further recommended using 1 3/4-inch hose to remedy insufficient fire flow volume of the 1 1/2-inch hose. By simply upgrading from 1 1/2-inch to 1 3/4-inch hose, the OFD could eliminate fully one-third of the direct causes cited by the Board of Inquiry. The Board of Inquiry report included findings, recommendations, and OFD responses. It was published in September 2000.

The Board of Inquiry's findings were based on the assumption that the departmental target flow rate of 125 gallons per minute (gpm) through 1 1/2-inch hose was met. This, however, is unlikely for the following reasons:

1. Age, condition, and kinds of nozzles
2. Age and condition of hose.
3. Inaccurate pump chart that states friction loss (FL) to be 15 pounds per square inch (psi) per 100 feet to flow 125 gpm through 1 1/2-inch hose. This underestimates friction loss by 23 psi per 100 feet. Actual FL in 100 feet of 1 1/2-inch hose while flowing 125 gpm is 38 psi.
4. The pump chart underestimates accurate nozzle pressure (NP) by 20 psi. The only combination (fog) nozzles that the OFD currently employs are designed to operate at 100 psi NP. The pump chart states nozzle pressure to be 80 psi.
5. Theoretical flow at 15 psi FL per 100 feet of 1 1/2-inch hose is 79 gpm.
6. Recent flow tests performed with various engine companies showed flows ranging from 60 to 105 gpm. The average was about 85 gpm.

The Board of Inquiry report raises grave concerns about inadequate fire flow volumes. The fact that the actual flows were even less than the assumed 125 gpm compounds these concerns.

Today's fireground is a much more volatile environment than that of the past. The flow rate of 125 gpm was deemed to be adequate at a time when fuel loads were lighter and comprised of so-called ordinary combustibles, such as wood, paper, and cloth (cellulosic materials). Most likely, the OFD's current target flow rate was based on 1918 testing that established the standard fire time/temperature curve.

Fuel loads today are heavier and largely hydrocarbon-based (plastics). Plastics are petrochemical products that behave like solid gasoline and generate large quantities of thermal energy. One pound of cellulosic materials gives off 8,000 British thermal units (Btus) when burned, whereas plastics generate 16,000 Btus per pound of fuel. Not only do plastics produce twice the Btus, but they do so at a heat-release rate that is much faster than that of traditional fuels. Couple these factors with tighter and better insulated buildings that inhibit fire from self-venting (tight building syndrome), and the millennium engine company most definitely faces a much more dangerous enemy than it had in the past.

Since the enemy has become much more dangerous, the weapon used to combat the enemy must be upgraded accordingly. Akin to the police evolving from the 38-caliber revolver to the 40-caliber automatic, the fire department also must make a more intelligent weapon selection. The hose and nozzle system is the engine company's weapon for attacking the fire. The vast majority of the American fire service considers 150 gpm to be the minimum acceptable flow rate for interior structural fire attack. Many fire departments use a target flow rate of 180 gpm to ensure an added margin of safety.

In his brilliant treatise on the art and science of applying water on fire ("Little Drops of Water: 50 Years Later," Parts 1 and 2, Fire Engineering, February and March 2000), Andrew Fredericks, the foremost expert on engine company operations, further states that in addition to 150 gpm being the minimum acceptable flow for residential fires, 250 gpm is the minimum acceptable handline flow for operations in commercial occupancies. OFD's target flow rate of 125 gpm is well below the nationally accepted fire service standard, and its actual flow rate of 85 gpm simply is inadequate for modern fire conditions.

The outcome of fireground operations depends on the outcome of the battle between the water the engine company delivers (gpm) and the heat (Btus) the fire generates. The flow at which the engine company can win the battle and kill the fire is defined as the critical flow rate. If the critical flow rate is not met, the battle will be lost. This dictates that the single most important characteristic of a hose and nozzle system is water flow capability. The water the engine company delivers must be sufficient to expediently kill the fire. Maneuverability of the hose and nozzle are important factors, but to sacrifice flow for ease of use has proved to be suicidal.

Although an adequate flow rate cannot be sacrificed for ease of use, handling characteristics cannot be completely overlooked either. The amount of effort required from the nozzle operator is that which is necessary to resist the nozzle reaction. Nozzle reaction is measured in pounds of force and is a function of two factors—flow rate and nozzle pressure. An increase in one or both of these factors will result in an increase in nozzle reaction force (RF). The higher the nozzle RF, the more difficult the nozzle is to control. Since adequate flow rate is the ultimate goal of a well-conceived hose and nozzle system, the logical way to keep nozzle RF within the manageable range is to keep nozzle pressures low and avoid sacrificing flow. More than 75 pounds RF is considered to be too much reaction force for a handline. However, RF less than 45 pounds is considered to be a sign of an ineffective stream.

Hoseline handling characteristics are a function of the following factors:

1. Flow rate.
2. Hose size.
3. Friction loss.
4. Pump discharge pressure.

Handline maneuverability is determined by the pressure at which a given size line must be pumped to attain a desired flow rate. If hose size remains constant and flow is increased, pump discharge pressure must be increased to account for greater friction loss. This reduces maneuverability as the line approaches the stiffness of a pipe. Conversely, if hose size increases while flow remains constant, pump discharge pressure may be reduced due to lower friction loss requirements. This results in improved maneuverability because the line becomes more bendable.

The aforementioned parameters lead to certain conclusions about what constitutes a well-planned hose and nozzle system for residential fires. The hose should be capable of flowing between 150 and 180 gpm with relatively low friction loss. The nozzle should have similar flow capability at a nozzle pressure that will maintain reaction force in the range of between 45 and 75 pounds.

Because of the pressures required to account for friction loss, the practical flow limit for 1 1/2-inch hose is 125 gpm, whereas the practical flow limit for 1 3/4-inch hose is 200 gpm (see Figure 1).

Figure 1. Friction Loss and Reaction Force

FRICITION LOSS

1½-inch hose:

15 psi per 100 feet to flow 79 gpm ☼
 38 psi per 100 feet to flow 125 gpm ☼
 55 psi per 100 feet to flow 150 gpm ☼
 60 psi per 100 feet to flow 160 gpm ☼
 86 psi per 100 feet to flow 180 gpm ☼

1¼-inch hose:

30 psi per 100 feet to flow 150 gpm
 35 psi per 100 feet to flow 160 gpm
 40 psi per 100 feet to flow 180 gpm

REACTION FORCE

Fog Tips:

150 gpm @ 100 psi = 76 lbs. ☼☼
 150 gpm @ 75 psi = 66 lbs.
 150 gpm @ 50 psi = 54 lbs.
 125 gpm @ 100 psi = 63 lbs. ☼☼
 79 gpm @ 80 psi = 36 lbs. ☼☼

Smooth-Bore Tips:

¾-inch
 160 gpm = 57 lbs.
1-inch
 180 gpm = 66 lbs.

1. Below minimum acceptable flow of 150 gpm.
2. Beyond acceptable nozzle reaction force of 75 lbs.
3. Less than 45 lbs. nozzle reaction is a sign of an ineffective stream.
4. Not practical, since pump discharge pressures that exceed department hose test pressures are easily reached.

The tool at the very heart of the entire fireground operation is the nozzle. It is the weapon with which members enter into close-quarter combat with the enemy. If the nozzle malfunctions or is not used properly, all other tools and tactics on the fireground are likely to become quite limited in their effectiveness in saving life and protecting property. All kinds of nozzles perform their all-important mission by providing some rather simple, uncomplicated, albeit incredibly necessary, functions. They control flow, create shape, and provide reach. Since the functional requirements for a nozzle are relatively simple and yet immensely important, intuitively it makes sense to select the kind of nozzle with the least complicated design and the fewest moving parts. The low-tech choice in nozzle selection ensures the greatest degree of durability and reliability. Simple, durable, and low-tech are all qualities that contribute to low initial and long-term costs. More importantly, these qualities lead to reliability, which, in turn, leads to increased safety. There is an inverse relationship between nozzle cost and suitability for interior structural firefighting. Unlike so many things in modern-day, high-tech society, the best kind of nozzle actually costs substantially less than the other kinds.

NOZZLE CHARACTERISTICS

The kinds of nozzles available today, in descending order of simplicity and durability, are smooth-bore, constant-gallorage (single gallonage) fog, adjustable gallonage fog, and constant pressure (automatic) fog.

Smooth-Bore Nozzle. The smooth bore is the most low-tech of all nozzle designs. It consists of a ball valve shutoff device onto which is threaded the smooth-bore tip, which is basically a piece of tapered pipe. Together, the shutoff and tip present a very compact (7¾-inch) and lightweight (21½ lbs.) package. Genius lies in the simplicity of its design. It has only one moving part—the ball valve.

To emphasize how difficult it is to clog a smooth-bore nozzle, Fredericks held a 15/16-inch tip up to his eye and, looking through it, he exclaimed to his lecture audience, "This is all the water sees on its way to the fire." It is the most durable and reliable of all nozzles. It requires the least maintenance of any nozzle type and has the longest service life.

Smooth-bore nozzles are by far the least expensive kind to purchase and maintain. Of all nozzles, the smooth-bore requires the least amount of training for pump and nozzle operators to become proficient. The incredible reliability of the smooth-bore nozzle is a significant safety feature. Since you can produce only a solid stream with the smooth-bore nozzle, its use ensures that members and victims will not be exposed to the potentially debilitating or lethal effects associated with introducing a fog stream into the fire area.

Emphasizing the need for durability, reliability, and low maintenance in nozzles, OFD Captain Ted Aff in *Fire Stream Management Handbook* by David P. Fornell (Fire Engineering, 1991) says, "If you give a fireman a 2-inch stainless steel ball bearing and put him in a bare, windowless room for an hour, when you open the door and ask about the ball bearing, he will have either bent it, broken it, or lost it." The smooth-bore nozzle is the safest and most efficient weapon for combating interior structural fires. Therefore, it is the only kind of nozzle that should be taken into the most hostile work environment on the face of the earth—the interior of a burning building. Fog nozzles should be kept in the inventory for other uses, such as flammable-liquid fires.

Constant-Gallonage Fog Nozzle. The constant-gallonage nozzle is the simplest, most reliable, least maintenance-intensive and, hence, safest member of the fog nozzle family. Of all fog nozzles, this type requires the least training. It does, however, require somewhat more training than the smooth-bore nozzle. Constant gallonage or single gallonage indicates that this nozzle is designed to flow a specific gallonage when operated at the specific pressure for which it is designed, such as 150 gpm at 100 psi NP.



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(2) Oakland (CA) Fire Department (OFD) members operate a 2 1/2-inch hoseline with a 1 1/8-inch smooth-bore nozzle (266 gpm @ 50 psi) during testing and evaluation.

In addition to the 100-psi model, constant-gallonage nozzles also come in 75-psi and 50-psi models. The nozzle is 12 1/4 inches long and weighs 6.1 pounds. As the name suggests, there is the distinct possibility of a fog stream being introduced into the fire area. This has the potential to, in short order, turn a still-tenable environment into one that is untenable. As with all fog nozzles, when the water flows from the hose—through the shutoff, into the tip, to be broken into a spray stream—a clog point exists. The constant-gallonage nozzle is the only kind of fog nozzle that should be in an engine company's inventory.

Adjustable-Gallonage Fog Nozzle. The adjustable gallonage takes fog nozzle technology to the next level of complexity. It has more moving parts and is more maintenance-intensive than the constant-gallonage nozzle and, hence, has an increased potential for nozzle failure or malfunction. Using a flow-selection ring, the nozzle operator can choose a desired flow. This operation requires an increased level of training for nozzle and pump operators. If the

nozzle operator changes the flow setting, the pump operator must be informed so he can adjust pump discharge pressure to the appropriate level for the selected flow. It is possible to put the flow-selection ring on the wrong setting, resulting in the nozzle's flowing less than the desired amount of water. So, in addition to the possibility of introducing a dangerous fog stream into the fire environment, there is a great potential to produce a flow that is less than the acceptable minimum. The adjustable-gallage nozzle is 12 1/4 inches long and weighs 5.6 pounds. The adjust-able-gallage nozzle should not be part of an engine company's nozzle inventory.



(3) The 1 3/4-inch hose allows significantly higher flow than the 1 1/2-inch line, yet size and weight differences are nominal.

Automatic Fog Nozzle. Automatic nozzles originally were de-signed in the late 1960s by Chief Clyde McMillan of the Gary Fire Task Force, an auxiliary unit of the Gary (IN) Fire Department. One of the roles of the task force was to respond to large fires and put master streams into operation. Often, initial water supply was inadequate when transitioning to defensive operations. McMillan set about de-signing a master stream appliance nozzle that would produce a stream with good reach, even at the low flows available during the transitional phases of operations. He also wanted that same nozzle to be appropriate for the high flows achievable after augmentation of the water supply.

The automatic nozzle is also called the constant-pressure nozzle. Constant pressure refers to the fact that the nozzle produces a stream of reach and appearance consistent with 100-psi tip pressure regardless of the pressure actually coming into the base of the nozzle. This is accomplished by a baffle and spring arrangement. As a given amount of water enters the nozzle base, it puts the spring under a given amount of tension. This, in turn, moves a baffle that changes the nozzle's orifice size. As the amount of water flow fluctuates, so does the orifice size. The orifice is maintained at a size that, for the given amount of water, provides approximately 100 psi NP. This creates a visually attractive stream with good reach over an extremely wide range of flows. This has prompted nozzle sales representatives to state, "The automatic nozzle will produce an effective stream no matter what the flow." Though stream quality and reach are important, stream effectiveness is determined by whether it meets the critical flow rate. Often, the stream produced by the automatic nozzle is good-looking but doesn't have much water in it.

The automatic fog nozzle is bulky (length—13 3/4 inches, weight— 6.5 pounds) and costly. It is at the high-tech end of the spectrum of fire service nozzles. To be used properly, it requires more training for both nozzle and pump operators than any other nozzle type. It has the most complicated design of any nozzle and the most moving parts. It is the most maintenance-intensive and the most susceptible to failure.

To use a suitable military analogy, the automatic nozzle is to the smooth bore as the early M-16 was to the AK-47. The simple, low-tech, battle-proved AK-47 with its simple design and

loose operating tolerances could handle an incredible amount of abuse in the field and still remain a very functional and effective weapon. On the other hand, the early model M-16, with its complex design, superior machining, and fine tolerances, was very susceptible to malfunction in the harsh environment of the battlefield.

Because of its design intricacy, the automatic nozzle has a high susceptibility to malfunction. It also has a propensity to mask insufficient flow by presenting an attractive stream over a wide range of flows.

THE 2 1/2-INCH HANDLINE

The first step in planning a hose and nozzle system is to establish the needed flow for the occupancy type in question. The flow requirement is derived by determining the flow at which the engine company most often will overwhelm the heat generated by the encountered fuel load. To deliver the desired volume of water, parameters for hose selection are based on flow and friction loss characteristics. Parameters for selecting a nozzle to couple to the business end of that hose are based on flow and reaction force characteristics. This holds true for residential occupancies and for fires in commercial buildings.

As mentioned earlier, when paraphrasing Fredericks, the minimum acceptable handline flow for operations in commercial occupancies is 250 gpm. For this type of flow, 2 1/2-inch hose is the line of choice. Friction loss at 250 gpm is 12 psi per 100 feet of 2 1/2-inch line. For the same flow in two-inch hose, the friction loss is 50 psi per 100 feet. Though a 2 1/2-inch line is a very substantial piece of equipment, it is not too heavy to aggressively advance as a handline, as would be the case with three-inch hose.

The key to using a 2 1/2-inch line efficiently is proper nozzle selection. The 100-psi combination nozzle effectively has removed the 2 1/2-inch line from the department's arsenal of offensive weaponry because of the astronomical nozzle reaction force of 126 pounds while flowing 250 gpm at 100-psi nozzle pressure. When pumped according to the department pump chart at 80-psi tip pressure, flow drops to 220 gpm with a still relatively high reaction force of 113 pounds. Low-pressure nozzles (50-psi tip pressure) that impart significantly less reaction force will return the venerable 2 1/2-inch line to its former status as a very aggressive, very offensive weapon.

Many departments successfully employ a 1 1/4-inch tip. Its 324-gpm flow technically classes it as a large-caliber stream, making this size tip possibly better suited for use with master stream devices. A far greater number of departments use the 1 1/8-inch tip. With a flow of 266 gpm at 50-psi nozzle pressure, it has a reaction force of 95 pounds. Although it is still very important to keep nozzle reaction force low, it would be impractical to try to apply the previously cited 75-pound cap to flows from large-caliber handlines.

Paired together, the 2 1/2-inch line and the 1 1/8-inch tip create a user-friendly, offensive, large-caliber weapon. As Fredericks states in his article "The 2 1/2-Inch Handline" (Fire Engineering, December 1996), "No combination of smaller handlines can duplicate the volume, reach, and pure knockdown power of a single, well-placed 2 1/2-inch line. In addition to its high-volume flows (between 250 and 320 gpm) and long stream reach, 2 1/2-inch hose provides the following benefits when used with a 1 1/8-inch solid stream tip:

- low friction loss per 50-foot length (only about six to eight psi at 262 gpm),
- exceptional penetrating power due to hydraulic force of the stream,
- little premature water vaporization in highly heated fire areas,
- easy reduction to smaller handline(s) after knockdown, and
- much better maneuverability than three-inch hose (sometimes used as a handline) or portable master-stream devices."



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(4) An OFD member using a pitot gauge during testing and evaluation.

Using a 2 1/2-inch line is indicated in situations in which fire conditions are likely to overwhelm smaller handlines. Fredericks cites the oft-used mnemonic device "ADULTS," which refers to scenarios requiring the use of 2 1/2-inch line:

Advanced fire on arrival
Defensive operations
Unable to determine extent (size) of fire area
Large, uncompartmented areas
Tons of water
Standpipe system operations

The ADULTS acronym is reminiscent of an anecdote related by retired Chicago (IL) Fire Department Battalion Chief Ray Hoff regarding proper handline selection. On seeing an engine company stretching a 1 3/4-inch line toward a commercial occupancy exhibiting a heavy fire condition, Hoff requested, "Would you please put that down and bring me an adult-size line?"

When the engine company encounters advanced fire on arrival, the high flow available from 2 1/2-inch hose is needed for rapid control. Even a private dwelling may exhibit a fire condition heavy enough to warrant the quick knockdown power of the 2 1/2-inch line. This is especially true of extensive involvement of the first floor or front porch.



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(5) OFD members comparing a 1 3/4-inch hose with a 1 5/16-inch smooth-bore nozzle flowing 180 gpm vs. a 1 1/2-inch hose with 125 gpm @ 100 psi adjustable-gallonage nozzle flowing 79 gpm (pump discharge pressure as per OFD SOPs).

Although using master stream appliances is not recommended for occupied residential

buildings, the same cannot be said of 2 1/2-inch hose. The 2 1/2-inch line with 1 1/8-inch smooth-bore nozzle is a large-caliber weapon that is aggressive, mobile, and offensive. It can rapidly darken down a very heavy fire condition to allow an interior attack. This permits three tactical options: The 2 1/2-inch handline can be advanced into and through the structure; the attack can transition to the use of a smaller line with the big line left where it is; or the 2 1/2-inch line can be reduced down to a smaller line to press the interior attack for final extinguishment.

Whether operations are defensive initially or transition from offensive to defensive, smaller-caliber handlines should not be used. The 2 1/2-inch line is a much safer and more efficient alternative. The reach afforded by the larger line allows it to be operated from outside the collapse zone. Once its high-volume stream penetrates into the fire area, it has a much greater effect on conditions than does a stream from a smaller line. The 2 1/2-inch handlines are much more mobile and easier to deploy than master stream devices. This allows streams to be brought to bear from a greater variety of locations.

If the engine company officer is unable to determine the extent (size) of the fire area, a 2 1/2-inch line should be used. The high-flow stream allows for unforeseen contingencies. During the course of operations, it may be determined that the amount of fire encountered can be handled with smaller hose. As with the above-mentioned private dwelling scenario, the 2 1/2-inch hose can be reduced to, or replaced by, a smaller line.

Fires in large, unpartitioned areas require levels of reach, penetration, and volume that are beyond the capabilities of smaller handlines. In addition to wide-open floor plans, occupancies such as supermarkets, bowling alleys, warehouses, theaters, houses of worship, and the like often have very high ceilings. High ceilings allow massive amounts of heated fire gases to accumulate. Once these flammable vapors ignite, they may prove to be too formidable for streams from smaller lines. The reach and tremendous cooling power of the 2 1/2-inch line with 1 1/8-inch tip allows for operation from an entranceway into the rolling flame front of combustible gases beneath the ceiling. Once the hazard in the fuel-laden overhead area has been dealt with, the attack can be pressed farther into the interior of the structure.

At some fires, extinguishment simply requires tons of water. This is often the case for fires in piles of tires, junkyards, garbage dumps, and lumberyards, to name a few. A 2 1/2-inch line with 1 1/8-inch tip operating at 50 psi NP discharges more than a ton of water a minute. The use of smaller lines in this kind of situation would be an exercise in futility.

Proper consideration for members' safety demands the use of 2 1/2-inch hose and smooth-bore nozzles for standpipe operations. NFPA 14, Standard for Standpipe Systems, was developed based on the use of 150 feet of 2 1/2-inch hose equipped with a 1 1/8-inch smooth-bore nozzle. Depending on which of the two versions of the standard a given standpipe system was de-signed under, outlet pressures can be either 65 psi (old criteria) or 100 psi (new criteria). Outlet pressures such as these simply will not meet the friction loss requirements for smaller-diameter hose, especially in conjunction with 75-psi or 100-psi nozzles.

Many standpipe systems have pressure-reducing valves that are not field-adjust-able. This means that no matter what pressure fire department pumpers pump into the system, outlet pressure will not rise above a given outlet's rated pressure. As Fire Department of New York Battalion Chief John Norman states in *Fire Officer's Handbook of Tactics* (Fire Engineering, 1998), to use anything other than 2 1/2-inch hose and smooth-bore nozzles for standpipe operations is to use the standpipe system in a manner other than that for which it was designed. Prior to becoming a member of the professional fire service, Norman was a fire protection engineer and made his living designing sprinkler and standpipe systems.

Because of design configurations and conditions of standpipe systems, pressure problems chronically plague operations. Though certainly not an ideal situation, even at a very low outlet pressure, the combination of 2 1/2-inch hose and a 1 1/8-inch smooth-bore tip still can develop a usable fire stream.

In February 1991, the Philadelphia (PA) Fire Department had a disastrous experience dealing with a fire in the One Meridian Plaza building. At the time, the Philadelphia Fire Department

used 1 3/4-inch hose and automatic fog nozzles for standpipe operations. At numerous sessions of the Fire Department Instructors Conference (FDIC) Engine Company Operations Class, Denver (CO) Fire Department Battalion Chief David McGrail replicated the outlet pressures (40-45 psi) that existed at the One Meridian Plaza fire. Consistently, 1 3/4-inch hose with an automatic tip flows less than 50 gpm while 2 1/2-inch line with a 1 1/8-inch tip achieves flows in the range of 200 to 210 gpm. This concurs with information found in Fornell's Fire Stream Management Handbook. The building eventually was demolished. The loss of the building, however, is inconsequential when compared with the loss of three members of the Philadelphia Fire Department. The tragic loss of these members was caused in no small part by poor weapons selection. The Philadelphia Fire Department now uses 2 1/2-inch hose and 1 1/8-inch smooth-bore nozzles for standpipe operations. Hopefully, it will not take more tragedies of this nature for other departments to rethink their weapons selection for standpipe operations.

SOLID STREAMS

Increased handline flows through hose and nozzle configurations that maintain maneuverability and impart manageable reaction forces will lead to more effective, more efficient, faster, and safer extinguishment operations. More expedient extinguishment, in turn, makes all other fireground operations proceed more safely and efficiently.

The solid streams produced by smooth-bore nozzles will further serve to increase the safety and efficiency of fireground operations. Solid streams are less susceptible to premature vaporization than fog streams. That is the reason solid streams are superior to fog streams in so many aspects of the fire extinguishment process. Solid streams are better able to penetrate superheated atmospheres. This, combined with the fact that their physical properties give them far superior reach, means that solid streams are much more apt to reach the seat of the fire.

With a smaller percentage of the stream vaporizing, the excess steam generation inherent in fog stream application is not present. Less steam generation means less disruption of the thermal balance of the fire compartment. Maintaining the thermal balance relatively intact preserves a condition of differentiated heat strata. Most of the heat remains in the upper levels of the fire compartment while the floor area remains relatively tenable. Visibility is less negatively affected, and the solid stream does not push products of combustion toward victims, members, or uninvolved areas of the structure.

This is in direct opposition to the conditions created by introducing a fog stream into the fire compartment. As the fog stream readily vaporizes, voluminous amounts of deadly, superheated steam are driven down to the floor. This severely increases the hostility of the environment in which members are operating, and incapacitated victims lie helplessly awaiting salvation. The use of smooth-bore nozzles will lead to safer and more efficient fireground operations for department members. This, in turn, will lead to an increased window of survivability for victims.

The key to using a solid stream is rapid, vigorous nozzle movement to splatter the stream off the ceiling and upper walls. This method will break the stream up into large, heavy drops of water that will rain down onto the burning solid fuels. This creates conditions that Fredericks likened to "an August thunderstorm." As these large chunks of water begin their journey downward toward the seat of the fire, they simultaneously cool the upper area of the fire compartment. The upper level of the fire compartment is the birthplace of rapid fire progress phenomena, such as backdraft and flashover. The large, heavy drops of water created by smooth-bore nozzle movement have a much lower surface-to-mass ratio than the fine droplets produced by a fog nozzle. Thus, they are much less prone to premature vaporization. This makes the solid stream more efficient for extinguishment because its large drops of water cool the upper area of the fire compartment and then still are able to pass down through superheated strata to the seat of the fire—the burning solid fuels where the fuel-flame interface is located. Thus, the superheated upper portion of the fire compartment, containing massive quantities of unburned fuels, is quenched and the further distillation of flammable vapors and particulates at the fuel-flame interface is quelled in the lower level of the fire compartment. In Fire Stream Management Handbook, Fornell likens this manner of preventing further production of gaseous and particulate fuel—applying water to the seat of

the fire—to turning off the valve of a leaking propane cylinder.

OPTIONS FOR IMPROVEMENT

It is incumbent on the OFD to react to the findings of the Board of Inquiry in some manner. The existing body of knowledge concerning engine company operations, coupled with the facts that have been brought to light surrounding the line-of-duty death, indicate that the status quo is simply unacceptable.

There are a number of options the OFD can employ to improve the extinguishment capabilities of its engine companies and, hence, increase the safety of all department members and the civilians whom they are sworn to protect. The following options are listed in ascending order of acceptability:

Option 1. Do nothing other than change the OFD pump chart to accurately reflect the current flow rate from 1 1/2-inch hose. This will ensure that members are informed regarding how much water flow (79 gpm) is at their disposal while conducting interior structural firefighting operations. This is the least acceptable option.

Option 2. Issue a standard operating procedure (SOP) stating the proper pump discharge pressures necessary to attain the flow volumes the department has long stated to be its target flows. The pump chart would need to be corrected to show true FL and NP; 40 psi (rounded up from 38 psi to make calculations easier at 02:00) FL per 100 feet of 1 1/2-inch hose and 100 psi NP to flow 125 gpm, and 12 psi FL per 100 feet of 2 1/2-inch line and 100 psi NP to flow 250 gpm. Nozzle RF would be 63 pounds and 126 pounds, respectively. Theoretically, this would meet the department target flow rate. The practicality of meeting the target flows is questionable because a major portion of the nozzle inventory is of types and conditions that will affect flow rate negatively. There is no implementation cost. However, 1 1/2-inch flow still will not meet the 150-gpm minimum acceptable flow rate for interior operations in residential occupancies, and the unwieldy RF of the 2 1/2-inch line will cause it to be considered a static defensive weapon.

Option 3. Implement Option 2. Additionally, purchase the needed quantity of 1 1/2-inch and 2 1/2-inch 100-psi fog nozzles. Purchase the constant-gallonage kind. Results would be the same as Option 2. However, the practicality of meeting target flows will be greatly improved because of the nozzle inventory.

Option 4. Replace existing 1 1/2-inch fog nozzles with 150-gpm @ 100 psi constant-gallonage fog nozzles, which generate 76 pounds RF. Update the pump chart to show 55 psi FL per 100 feet of 1 1/2-inch hose to flow 150 gpm. Ensure that all 2 1/2-inch fog nozzles are constant gallonage. Flow, NP, and RF numbers for 2 1/2-inch would be the same as in Option 2. This option would allow engine companies to achieve the minimum acceptable handline flow for interior structural firefighting, 150 gpm. This improved flow, however, would come at an excessive RF.

Option 5. In addition to new nozzles, purchase 1 3/4-inch hose. To flow 150 gpm, 1 3/4-inch hose is a much more practical choice than 1 1/2-inch. FL would be 30 psi per 100 feet of line.

Option 6. With 1 3/4-inch and 2 1/2-inch hose, use 75-psi constant-gallonage fog nozzles. 150 gpm @ 75 psi NP results in 66 pounds RF. 250 gpm @ 75 psi generates 109 pounds RF. This would allow engine companies to flow 150 gpm at an RF that is in the spectrum appropriate for smaller handlines, between 45 and 70 pounds.

Option 7. With 1 3/4-inch and 2 1/2-inch hose, use 50-psi constant-gallonage fog nozzles. 150 gpm @ 50 psi NP results in 54 pounds RF. 250 gpm @ 50 psi generates 89 pounds RF.

Option 8. Implement one of Options 2 through 7. Additionally, issue an SOP stating that only the narrowest pattern (straight stream) on a fog nozzle shall be used for interior firefighting. Direct the Training Division staff to stop training the recruits to use a 30° fog pattern for interior fire attack. Enough members have received steam burns to question the validity of this tactic. Options 2 through 7 address safety through addressing flow. Option 8 goes a step further toward improving safety by attempting to ensure proper stream selection. However, there is the possibility that the nozzle may be left on the wrong pattern setting or the setting may be inadvertently switched as the nozzle gets bumped around during stretching and advancing.

Option 9. With 1 3/4-inch and 2 1/2-inch hose, use 7/8-inch and 1 1/8-inch smooth-bore nozzles, respectively. A 7/8-inch smooth-bore tip will flow 160 gpm @ 50 psi NP with 57 pounds of RF. A flow of 160 gpm through 1 3/4-inch requires a FL of 35 psi per 100 feet

When reviewing the above-listed options, consider several factors, including how each option affects the following issues: initial and long-term costs, maintenance needs, durability, reliability, service life, effectiveness, efficiency, safety of members, and safety of victims. In view of these considerations, the implementation of Option 10 is the best method by which to improve the arsenal of weapons at the disposal of the engine company. As was mentioned previously, effective, efficient, and safe engine company operations equal expedient extinguishment. Expedient extinguishment allows every other tactic (entry, ventilation, search, etc.) taking place on the fireground to become safer and more efficient. The tactics members implement during the fire stand between victims and mortality. More efficient fireground operations lead to a higher victim survival rate.

Hopefully, the information contained in this article will help the fire service move forward toward the goal of safer, more effective, and more efficient engine company operations.

This article is dedicated to Oakland Fire Department Hoseman Tracy Toomey, Engine Co. 6 (working in Engine Co. 12), who made the supreme sacrifice on January 10, 1999, while operating at a fire at 3052 Broadway. It is also dedicated to Firefighter (promoted posthumously to Lieutenant) Andrew Fredericks, Squad Co. 18, FDNY, who made the supreme sacrifice on September 11, 2001, while operating at the World Trade Center. Fredericks' life's work was dedicated to the betterment of the fire service and improving the safety of its members.

Thanks to the following for their assistance in preparing this article: Battalion Chief James Edwards, Battalion 2, OFD; Battalion Chief Ted Corporandy, Battalion 2, San Francisco (CA) Fire Department; District Chief David McGrail, Denver (CO) Fire Department; Lieutenant Anthony DiStefano, Engine Co. 5, OFD; Lieutenant (Ret.) Kenneth Van Gorder, Engine Co. 8, OFD; Lieutenant Richard Patterson, Division 6, FDNY; Fire-fighter Daryl Liggins, Engine Co. 16, OFD; Firefighter Mark Wesseldine, Ladder Co. 58, FDNY; and Janet Kimmerly, editor, WNYF.

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