While many believe that smooth-bore nozzles offer better penetration and knock-down ability than combination nozzles, scientific analysis suggests otherwise.

Unconventional Wisdom

BY RON EILKEN

A debate has ensued for years in the fire service concerning the comparative advantages and benefits of smooth-bore and combination nozzles. In this article, we will modernize some outdated information and interject genuine facts into this age-old debate, first by comparing both streams via visual observation, and then by examining in greater depth the reach, impact force, nozzle reaction, air movement and extinguishment capabilities of each, as well as the effects of pressure and turbulence on the streams.

It seems that more and more articles are appearing that state the smooth-bore nozzle must be the "nozzle of choice" for interior operations because it perceivably offers greater penetration and knockdown abilities. Historically, much of the information concerning these nozzles came from sources — such as the IFSTA and the NFPA — that provided excellent information — indeed, information that was the best available at the time of publication — but which could benefit from an update, especially concerning currently available equipment. For instance, it wasn't until the late 1990s that the NFPA changed standard 1964 to recognize the option of low-pressure combination nozzles, compared with the previous standards that dictated a pressure of 100 psi. Further, much of the information that has been passed on through the years concerning nozzles is subjective in nature and has little or no scientific evidence to support it.

Some departments test by setting their pumps at a fixed pressure and placing a variety of nozzles on the end of the hose. This practice does not take into account friction loss in plumbing, the designed flows and nozzle pressures, or the corresponding hose-friction losses.

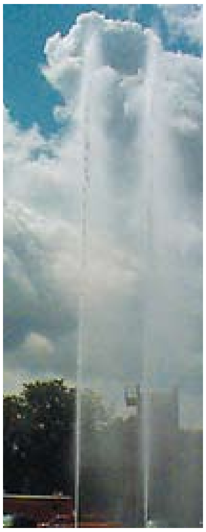
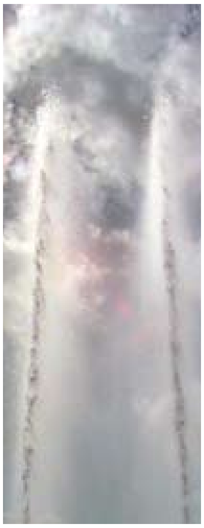
Indeed, many departments are unfamiliar with the newer, low-pressure combination nozzles and lack experience regarding valid test methods. Some departments test by setting their pumps at a fixed pressure and placing a variety of nozzles on the end of the hose. This practice does not take into account friction loss in plumbing, the designed flows and nozzle pressures, or the corresponding hose-friction losses. All of these variables can result in both confusion and misleading conclusions.

Accurate testing requires the use of calibrated flow meters, line gauges and pitot tubes, as well as a basic understanding of physical science. To accurately assess the similarities or differences of a smooth-bore nozzle compared with a combination nozzle, one must first start with nozzles that have the same flow at equal nozzle pressures, i.e., apples to apples.

Fixed Gallonage

With the advent of today's low-pressure nozzles, there are a variety of combination nozzles that are capable of producing the same flows at the same pressures as those provided by a smooth-bore tip. This article will examine a "fixed-gallonage" nozzle, as it operates most like a smooth-bore — flow increases as pressure increases; conversely, flow decreases as pressure decreases. Nozzle manufacturers offer a variety of different flow rates on their low-pressure nozzles that often can be modified simply by replacing the stem or a disk.

The first requirement is to decide upon a minimum flow. NFPA 1410 outlines a minimum flow requirement of 300 gpm; 100 gpm on the initial attack

The first shows both streams side by side, while the second provides a closer view of the tops of the streams. Both streams are flowing equal gallons at equal inlet pressures. Which one is from the smooth-bore?

line and 200 gpm on the back up. With today's increased fire loads, the consensus among firefighters in the field tends toward boosting the minimum flow on the initial attack line to 150 gpm. The closest nozzle to this would be a 7/8-inch smooth-bore with a flow of about 160 gpm.

With that in mind, let us examine a fixed-gallonage, 200 gpm (at 75 psi) nozzle and a 7/8-inch smooth-bore tip. Both will deliver approximately 160 gpm when pumped to 50 psi at the tip and about 200 gpm when pumped to 75 psi at the tip. The tip pressures are only manufacturer's recommendations. You can under pump or over pump a nozzle to meet your needs, as long as the nozzle is tested to ensure that the stream quality, range and the desired gallonage is achieved.

Most combination nozzles will produce effective streams at well below the manufacturer's rated operating pressure. In this case, we under pumped the 75 psi, low-pressure nozzle to 50 psi. This resulted in the same operating pressure as the smooth-bore. At this pressure, the flows are equal, at about 160 gpm. When we pump the low-pressure nozzle at its rated pressure of 75 psi and over pump the smooth-bore to 75 psi, we find that both produce flows of about 200 gpm. If the gallonage available at 50 psi is not doing the job, the firefighters can request the higher pressure, which also will increase the flow.

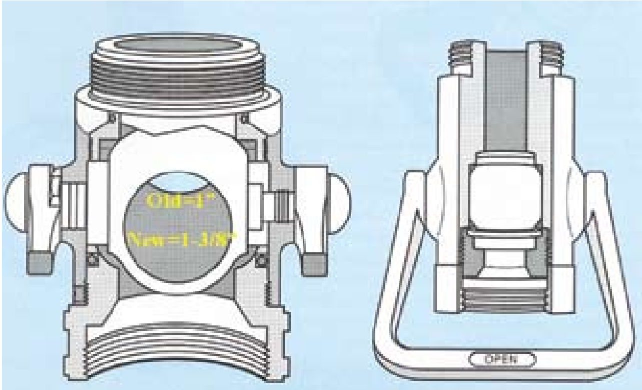
Fluid dynamics are said to be empirical in nature, which means that much of the knowledge is gained by observation. Look at the pictures on the left. The first shows both streams side by side, while the second provides a closer view of the tops of the streams. Both streams are flowing equal gallons at equal inlet pressures. Which one is from the smooth-bore? (If you are not sure, that's OK; many firefighters who saw these in person guessed incorrectly.)

For the tests, deluge gun bases were used to ensure equal angles when comparing the streams vertically — roughly 32° for optimum reach. The second image shows vertical streams that were done for comparison purposes. Both streams had the same height and nearly identical stream quality and appearance. The stream on the left is from the combination nozzle.

The stream on the left is from the combination nozzle.

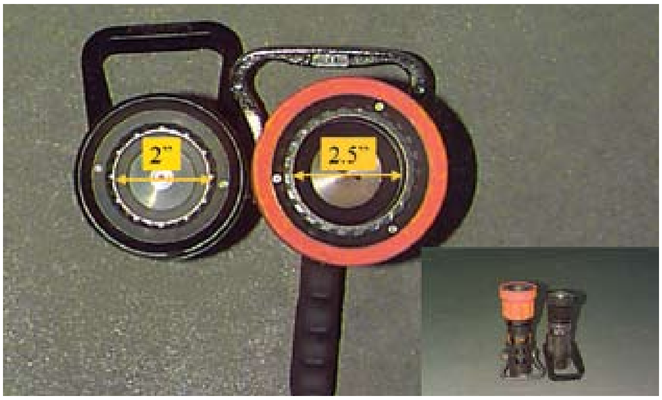
Fogging the Issue

One of the ongoing debates within our industry concerns the notion that the fog nozzle produces water in small drops. However, it is somewhat misleading to call them "fog" nozzles, because that is only one setting on a combination nozzle. The fact of the matter is that both combination and smooth-bore nozzles deliver water in droplet form. A true solid stream, which is termed a "laminar flow", would be glass-like and only is attainable at very low pressures (less than 5 psi). This would produce a stream that has no practical reach. In addition, such a stream would not have the surface area to absorb heat and convert water to steam. You often see streams of this nature at places like the Bellagio in Las Vegas or the Crystal Gardens at Navy Pier in Chicago. While they are interesting to look at, the stream would not provide much in terms of surface area, would not quench much fire, and thus would be ineffective for firefighting purposes. Water absorbs the greatest amount of heat when actually converted to steam (Over 8,000 BTUs per gallon). While the stream from a smooth-bore nozzle looks solid to the naked eye, high-speed photography reveals that it actually consists of water droplets, as is the stream from a combination nozzle when used in the straight-stream setting.



Courtesy of *Fire Stream Practices*, 7th ed, IFSTA

Ball valve size have increased from 1 inch on older fog nozzles to 1 3/8 inches on today's low-pressure models.



Ron Eiklen

Bumpers are larger on the waterways of modern nozzles, as well, increasing from 2 to 2 1/2 inches.

The pressure in a flowing hose line is directly related to velocity. When nozzle pressure is increased in a flowing stream from a fixed-gallonage nozzle, water velocity is increased as well. And, as water velocity increases, so too does turbulence. Firefighting streams are classified as "turbulent." In fluid dynamics, the degree of turbulence is identified via a "Reynolds" number. A Reynolds number greater than 3,000 indicates a turbulent stream, while a Reynolds number greater than 5,000 guarantees a stream that entrains air. Generally, firefighting streams have a Reynolds that is greater than 5,000. The molecules at the center of the hose are moving at one speed and the molecules near the edge are being forced to slow down, a phenomenon known as friction loss. In simple terms, the

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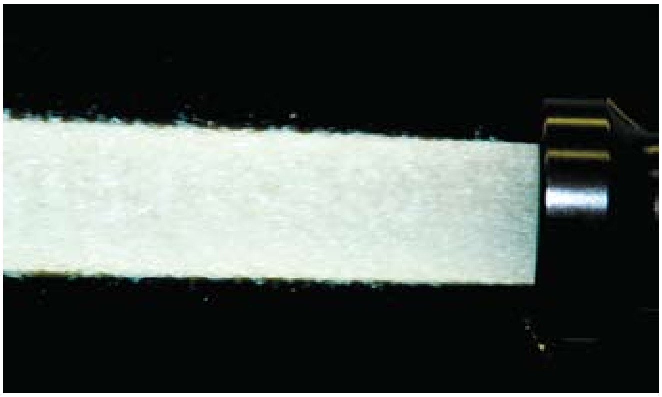
A true solid stream, or Laminar flow, can only be attained at pressures lower than 5 psi, which would not produce enough surface area to absorb heat nand convert water to steam.



Alex Yavanovich

While the stream from a smooth-bore nozzle looks smooth to the naked eye, it actually is made up of droplets of water. This 15/16-inch tip is flowing water at 50 psi

turbulence forces the molecules of water to begin moving in many different directions.

As the molecules that already are moving in many different trajectories leave the nozzle, they are further agitated by friction with the air. This friction — both at the edges of the stream and in front — further break the stream into smaller droplets until it finally loses the battle and falls to the ground in a shower of droplets. So, the higher the hose-line pressure and water velocity, the greater the water turbulence and, consequently, the smaller the droplet size exiting the nozzle. This, along with lower-volume flows compared with traditional smooth bores, gave the old 100-psi combination nozzles smaller droplets with less firefighting knockdown power. The smaller the droplet size, the

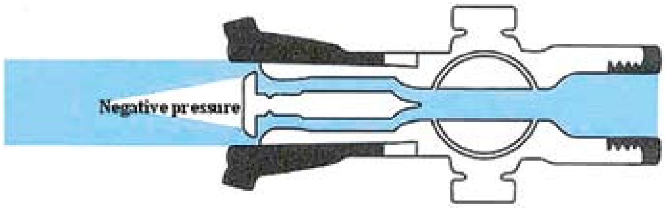
To a certain degree, the nozzle type has less to do with the formation and size of the droplets than the nozzle pressure and resulting velocities. So, Regardless of whether a smooth-bore or combination nozzle is used, if the nozzle pressures and flows are equal, the stream quality tends to be equal as well.

greater the effects of air on the stream and the less its reach will be.

The truth of the matter is that to a certain degree, the nozzle type has less to do with the formation and size of the droplets than the nozzle pressure and resulting velocities. So, regardless of whether a smooth-bore or combination nozzle is used, if the nozzle pressures and flows are equal, the stream quality tends to be equal as well. In other words, at equal nozzle pressures and flows, the stream from a smooth-bore and the stream from a combination nozzle set to straight stream, consist of equally sized droplets and neither is a truly solid stream. Water drop-off tests, where containers are placed at intervals below the streams in order to measure any water that may drop off, have shown that at equal flows and pressures, the containers captured equal amounts of water. This indicates, assuming that reach is equal, that both streams are of fairly equal droplet size and are equally disrupted by air.

Angles and Exits

Some engineers feel that the change in direction that a combination nozzle must make, along with the straight forward thrust from the barrel, helps re-focus the stream and its water molecules. This may explain why some had a slightly greater reach at equal pressure and flows. Now we also can understand why a stream straightener (which is nothing more than some thin veins) helps the reach of a smooth-bore nozzle by re-focusing some of the agitated water molecules. Conversely, the stream straightener does not appear to affect the combination nozzles significantly



Courtesy of *Fire Stream Practices*, 7th ed, IFSTA

The stream from a combination nozzle in a straight stream setting exits the nozzle in an annular pattern, like a donut, and the result is a hollow stream as the water works its way past the baffle. However, this is only for a few feet and acts as an advantage in that the negative pressure in the center of the stream draws the water back together.

because the nozzle design is already performing that task.

If we compare streams, we see more coning or expansion of the stream as it exits the tip of a smooth-bore nozzle. This is due to the molecules being agitated by turbulence, which in turn causes them to travel in many different trajectories. Some are traveling at angles away from the center axis of the stream; as a result, the instant they exit the smooth-bore tip they travel in an outward direction. In addition, as the water molecules are forced through the tapered opening of the smooth-bore tip, the molecules at the center of the stream are traveling at a greater velocity than those at the sides, which further contributes to a separation of the water molecules as they exit the nozzle. In comparison, water from the combination nozzle exits at a uniform velocity. In either case, both nozzles demonstrate a reach that is pretty similar. Moreover, with a reach well in excess of 100 feet, how important is this for interior firefighting?

As we examine the combination nozzle set to a fog pattern, the water movement takes on a trajectory that is away from the center axis, and more droplets become visible to the naked eye. In addition, the water begins to engage the nozzle teeth, which further impacts the droplets by adding rotation to the water molecules, which further fractures the stream. This can be a benefit in situations where the firefighter is facing possible electrical hazards or flammable liquid fires, when he needs hydraulic ventilation, or needs to achieve a greater rate of conversion and/or increased aeration during a foam application.

Ron Eilken

Pitot readings on both streams were equal a few feet from the tip.

Ron Eilken

But there is tighter focus on the combination nozzle, whereas the smooth-bore begins to expand as soon as it exits the tip.

Is it Hollow?

Some might argue that the stream from the combination nozzle set to a straight stream is not a solid stream but rather a hollow stream. This is where physics come into play. As noted above, both streams are in droplet form due to the turbulence formed by the pressures needed for firefighting purposes. The stream from a combination nozzle in a straight stream setting exits the nozzle in an annular pattern, like a donut, and the result is a hollow stream as the water works its way past the baffle. However, this is only for a few feet and acts as an advantage in that the negative pressure in the center of the stream draws the water back together.

Water exhibits a property called "cohesion," which means that the molecules are highly attracted to each other, so they come together or combine to form a stream. However, due to turbulence and forces of the air, the droplets do not come together to form a truly laminar stream but rather, just as occurs with the smooth-bore nozzle, a stream of larger droplets is formed. What we see is that the combination stream is tighter and more focused than the smooth-bore stream for the first three to four feet, but after that they flow in an equal fashion. In fact, a pitot reading taken a few feet out from the tip of either nozzle produced similar readings in both streams.

Next: *Part two of this article will discuss reach, impact force, nozzle reaction and the knockdown ability of a smooth-bore compared to a straight stream.*

Ron Eilken is a 29-year veteran of the fire service and is a deputy chief with the Des Plaines (Ill.) Fire Department. His past duties included service in the department's training division and engineering program. He has been an instructor at the fire academy, FDIC and various fire colleges and fire departments across the country.

The Straight Scoop

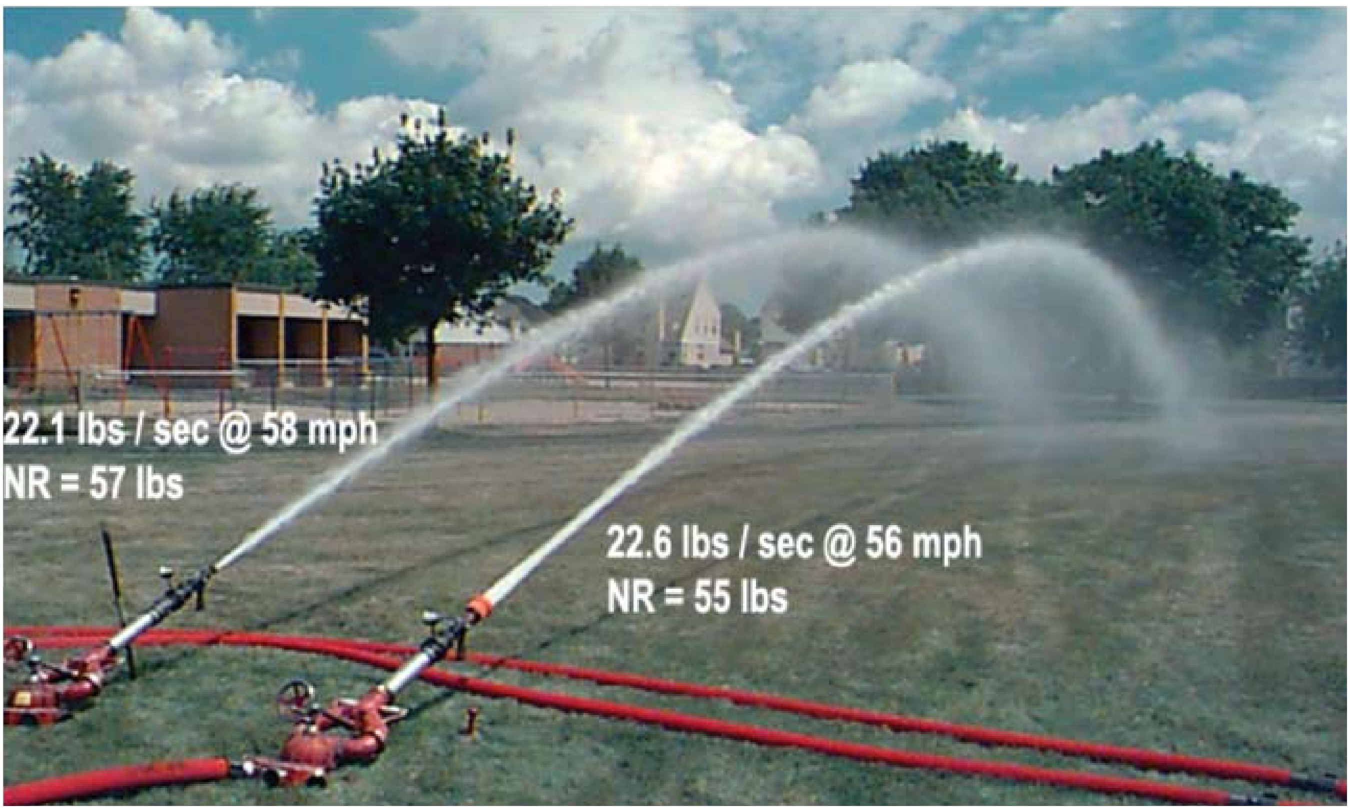
Scientific analysis shows that, at equal flows and pressures, there's not much difference between straight-bore and combination nozzles.

BY RON EILKEN

In the August edition, we looked at visual stream comparisons and test methods related to current nozzle designs, i.e., smooth-bore and combination nozzles. We also examined the effects of turbulence on such nozzles at the same flow and pressure. In this article we will discuss reach, impact force, nozzle reaction and the comparative knockdown ability of streams flowing from smooth-bore and combination nozzles.

Let's start with reach and impact force, which are related somewhat. Again, we turn to science in addition to what we can visualize. Reach is a result of pressure that is converted to velocity as the water leaves the nozzle. The impact force (striking power) is determined by the weight of the water (mass) multiplied by its velocity (speed). Both reach and impact forces are related to the speed at which the water exits the nozzle. The higher the pressure, the higher the speed; thus, the reach is greater and the stream hits harder, provided that the flows (mass) are equal.

It has been said repeatedly that a smooth-bore



NR = Nozzle reaction force
Photo by the author

nozzle hits harder with greater knockdown power than a combination nozzle. The truth is that many conclusions have been drawn by looking at the large flow smooth-bores operating at a lower nozzle pressure, compared to 100 psi combination nozzles, which flowed less volume. This is not a fair comparison. Doing so would be like comparing a .22-caliber rifle with a .44 Magnum.

It is important when comparing streams to ensure that the nozzles being evaluated are producing equal flows at equal pressures. Over-pumping from 50 to 75 psi increased the flow rate, reach and the impact force

Photo: Both streams are of equal quality. Notice the combination nozzle on the right is tighter for the first few feet until the stream comes back together; then it resembles the smooth-bore stream.

of the stream, with no adverse effect on its performance. As the pressure on either nozzle is increased, a little more water drop-off will occur near the edge of the stream due to friction with the surrounding air, which is not moving. When compared properly, both nozzles still delivered a good stream with good characteristics until the break-over point, where they both fell equally into showers of heavy rain.

The eventual break-up of the streams is caused by a "piling up" of air in front of the stream as well as by the displacement of the surrounding air. Both nozzles were affected equally by winds, which cut down the reach of the streams. Even a very slight cross breeze will cut the reach of either stream by 20 to 30 feet. Most nozzles performed equally well at lower pressures down to about 40-psi tip pressure. Keep in mind however, if one maintains the flow rate but operates at lower pressures (50 psi or less), hose kinking will be much greater than at the higher pressures (75 or 100 psi). Crews must be diligent in correcting any kinks should they occur.

Photo by the author

Examine the photo above. Note that both streams appear to have the same reach. In fact, at equal flows and inlet pressures, the stream from the combination nozzle went further than the smooth-bore stream by about 10 feet, unless a stream straightener was placed on the latter. Then, the smooth-bore gained a slight advantage. Regardless, both nozzles had a reach of more than 100 feet. The bottom line is that they both performed in a very similar manner and delivered a nicely shaped stream that landed in a relatively tight area.

Under Pressure

Some argue that the smooth-bore stream hits harder. To determine whether this is true, we can use formulas to convert the gallons into pounds per second (lbs/sec) and the pressure into miles per hour (mph). In the photo on page 28, it is evident that the impact force of the streams at the same flows and pressures are, for all practical purposes, equal.

This has been confirmed by impact testing. One such test used plates that transferred force to a compression load cell at 12½-foot, 25-foot and 50-foot distances, and then compared a combination nozzle to a ⅞-inch smooth-bore nozzle. Both nozzles were flowing 160 gpm at 50 psi. The impact was equal, with the combination nozzle hitting slightly harder at the 50-foot distance.

A pitot tube normally is used to ensure that a smooth-bore nozzle is operating at the proper pressure and thus delivering the proper gallonage. A pitot also can be used on a combination nozzle to determine the exit pressure. It is placed at the edge of the stream — recall that the stream exits the nozzle in the form of a donut — but this is difficult to do and requires a fine-tipped pitot gauge. Instead, manufacturers recommend using a line gauge placed at the base of the nozzle to ensure proper pressures on combination nozzles.

Overall, we found that nozzle reactions almost are identical, with the exception being that there is a slight drop between the base pressure and the exit pressure on the combination nozzle, a disparity that increases as the flows increase. In other words, the combination nozzle loses a slight amount of pressure and thus nozzle reaction due to the water pushing forward on the baffle, as well as the water changing direction as it exits the nozzle, and as flow rates increase, the difference increases. At 250 gpm, the difference was about 10 pounds, resulting in a slightly easier nozzle to handle — though most firefighters would not notice the difference.

At 250 gpm, the difference in pressure was about 10 pounds, resulting in a slightly easier nozzle to handle — though most firefighters would not notice the difference.

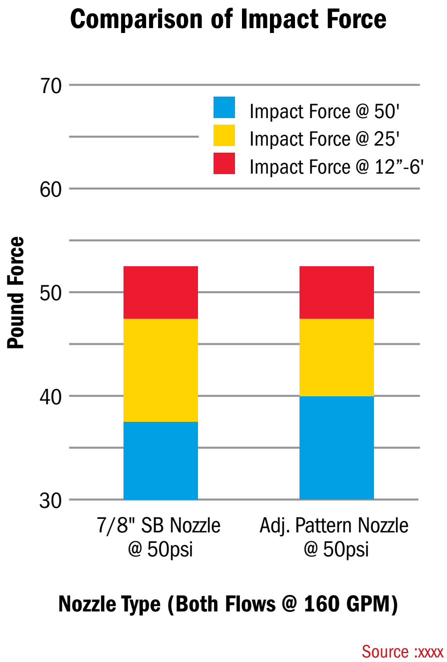
Another test employed scales to check nozzle reactions and confirmed that nozzle reaction formulas are very accurate and that at equal flows and pressures, the reactions almost are identical for both smooth-bore and combination nozzles.

We have now demonstrated that at equal flows and pressures, the streams from both the smooth-bore and low-pressure combination nozzles:

- Look alike
- Have the same reach and reactions
- Strike with equal impact force
- Are equally turbulent
- Are of a similar droplet size

But what about their capabilities to extinguish fire, i.e., their knockdown ability? Some experts believe that both nozzles will deliver water to the seat of the fire in a similar fashion. As demonstrated above, both streams are identical once they are a few feet from the nozzle. Both are equal in quality, reach and impact force, and are affected equally by wind. Moreover, neither stream is solid; instead, both are composed of large droplets.

So, the real determining factor in differentiating between a smooth-bore and combination nozzle is the amount of water that each can be apply to the fire. This is an important consideration, as the volume of water (gpm) determines the amount of BTUs it can absorb and thus the amount of fire that can be extinguished. According to Andy O'Donnell, retired district chief for the



Chicago Fire Department, there is very little difference, if any. "In the real world of interior structural firefighting, the difference between a smooth-bore and straight stream in terms of direct attack effectiveness is negligible," he said.

However, the combination nozzle can absorb greater amounts of heat if set to a fog pattern, where the water begins to break up offering a greater surface area for heat absorption, and those who attended fire school in the early 1980s were taught to use this indirect method of fire attack. But this method has lost support for interior attacks due to the amount of steam generated and the resulting thermal upset, though a high-pressure variation of this method, dubbed "3D," is being used successfully in Europe.

Push Over

Another highly debatable topic concerns whether the combination nozzle will "push" fire. Indeed, while it might be possible to push fire in the fog setting due to the massive air movement it develops, generally neither the straight-stream nor the smooth-bore pushed fire any more or less than the other, provided that the flow rate is adequate for the amount of fire. This is not to say that neither nozzle will push the products of combustion when an overabundance of steam is created. Remember, for every gallon of water required to extinguish the fire, about 200 cubic feet of steam is produced. In situations where stream production is more of a concern — such as when victims are inside the structure — using short, intermittent bursts will minimize this effect.

Here's a simple test to demonstrate this phenomenon: Set a garden-hose nozzle to the straight setting and shoot the stream through the flame of a small campfire or bonfire. The stream will travel through the flames and emerge on the other side with virtually no impact on the flame. Then change the stream to a fog pattern or move the nozzle in a circular pattern — you will begin to see the flames dance in response to the air movement. The same test can be duplicated using a pump-can or pressurized extinguisher with its solid-stream.

The purpose of this article was not to discuss attack methods but rather establish that low-pressure nozzles will perform equal to a smooth-bore tip when used in the straight-stream setting at the same flow and nozzle pressure. But while the smooth-bore nozzle is not a bad nozzle, in the majority of fires the

Testing exit pressure on a combination nozzle using a pitot tube. (Notice the smaller droplet size on this older style 100-psi nozzle)
Photo by the author

combination nozzle will be used in a straight stream setting in the same way as the smooth-bore nozzle. This leads to an important question: Why, if both nozzles provide an equally effective straight-stream pattern, would firefighters not want to use the nozzle that offers the greatest versatility? This answer is obvious, according to O'Donnell, who was one of the early pioneers of the low-pressure combination nozzle, and who in the early '80s pushed manufacturers to produce a lower-pressure combination nozzle that would still offer versatility but operate at pressures more consistent with the smooth-bore streams.

"If the situation changes and we find ourselves fighting a flammable liquids fire in a structure, or if a window in a high-rise breaks and we have to deal with a wind-pushed fire, it's nice to know that I have the option to change my nozzle pattern right at my fingertips," O'Donnell said.

In our department, we have set up our crosslays to offer the same flows and pressures, one with a smooth-bore nozzle and the other using a combination nozzle. The decision is now up to the officer as to which nozzle to choose. If your department is still using the older-style 100 psi nozzles, it may be time to do some testing at different flows

> **Most often, firefighters are relaying experiences from years ago that compared a 100-psi combination nozzle to a smooth-bore nozzle that had a greater flow and certainly less nozzle pressure.**

and pressures to see how the design of your nozzle adapts, or upgrade to a newer-style low-pressure nozzle. Whatever flow that you decide on, there are a variety of options to achieve similar results, and most manufacturers have charts in their catalogs that list the gallons delivered at various pressures from their nozzles. For example, at 185 gpm a 15/16-inch tip compares to a 250@100 psi combination pumped at 50-psi tip pressure. At 250 gpm, a 1 1/8-inch tip compares to a 250@50 psi combination. On rapid attacks the 500-gpm, low-pressure combination tip performs similar to the 1⅜-inch smooth-bore nozzle pumped at 75-psi tip pressure. If your department does not have the equipment needed to conduct nozzle testing, manufacturers usually are willing to come out with their equipment and assist.

The next time someone tells you that the smooth–bore nozzle must be the nozzle of choice or that it is a better nozzle, question them as to what they are basing their conclusions upon. Are they talking about the old 100-psi nozzles? Have they tested the newer low-pressure combination nozzles at equal flows and pressures compared with the smoothbore? And, more importantly, have they done live side-by-side comparisons using valid testing equipment and methodology? Most often, firefighters are relaying experiences from years ago that compared a 100-psi combination nozzle to a smooth-bore nozzle that had a greater flow and certainly less nozzle pressure. As this article has demonstrated, pressure and the resulting turbulence directly affect nozzle performance. But at equal flows and nozzle pressures, which are obtainable with today's nozzles, we see almost identical stream patterns and firefighting effectiveness. Employing physical science to this age-old debate reveals indisputable facts that clearly can assist in understanding how combination and smooth-bore nozzle streams truly compare. ■

Ron Eilken is a 29-year veteran of the fire service and currently serves as a deputy chief for the Des Plaines (Ill.) Fire Department. His past duties have included service in the department's training division as well as its engineering program. He has been an instructor at the fire academy, at FDIC and at various fire colleges and fire departments across the country.