Uncommon thoughts about commonly used suppression equipment:

“The Missing Tip” and Optimum Handline Flow in 2 ½-inch Hose

Author: Dennis J LeGear, Capt. Ret. Oakland Fire, CA

(Part I) The Need to Address Maximum Deployable Handline Flow in 2 ½-inch Hose

There has been a flood of information over the last two decades in the fire service in regards to nozzles and flow rates. This has mainly focused on initial flows in 1¾-inch attack handlines. The significance of flow rate has been overlooked in 2½-inch handlines. Many interrelated factors indicate the need to address optimum 2½-inch handline flow rate. Several are: modern hydrocarbon fuel loads, rapid fire development, energy efficient building construction, reduced staffing, and longer fire development before initial extinguishment efforts. Taken together, these factors push the fire service to address the need to deliver more water through the initial attack handline. This situation begs the question, has a potentially very useful nozzle and flow rate been overlooked in the 2½-inch handline. **To simplify the discussion, smooth bore tips are used as template examples with an ideal nozzle pressure of 50psi.** The argument has been scientifically made and proven for water application in either a straight stream from a fog nozzle or, preferably, a solid stream, and that this represents today’s best practice for stream selection for structural fire extinguishment. **The goal of this discussion is to address optimum flow rate. To be sidetracked into a debate regarding 30 degree fog vs. solid or straight stream would hinder this purpose.**

“A Quantitative Approach to Selecting Nozzle Flow Rate and Stream” parts one and two by Jason N. Vestal and Eric A. Bridge (Oct 2010, Jan 2011; Fire Engineering) illustrates just how many influences there are in nozzle/stream selection and flow rate. Vestal and Bridge cite National Fire Protection Association (NFPA) 1710 recommendations that the sum of the flow of the first two handlines placed into operation at a structure fire be a minimum of 300 gpm, and that the first handline flow a minimum of 100 gpm. They discuss, at length, several National Institute of Standards and Technology (NIST) studies regarding flashover research, heat release rate, and the heat absorbing capacity of streams. This article represents the most detail-oriented and exhaustive look at effective initial handline flows and stream selection that I know of to date.

Vestal and Bridge also discuss nozzle reaction, stream quality, reach, penetration, type of stream, and unintentional reduction of gpm flow with an emphasis on kinks in the line. Heavily touched upon is the ability of crews to effectively manage and deploy handlines, focusing on nozzle pressure and nozzle reaction. Vestal and Bridge also make a strong case, citing a litany of research and data, that most first-due urban engine companies are arriving at the time of greatest concern in fire development: slightly before, at, or just after flash over. Reading both parts one and two is strongly recommended; for they represent a definitive scientific examination of what first arriving companies are facing today at most common residential structure fires.

Vestal and Bridge conclude that a minimum initial fire flow of 160 gpm is needed in 1 ¾-inch hose and based on kinks that reduce attained nozzle pressure on the fire ground they recommend a 15/16-inch smooth bore tip. This is a logical choice even though the 15/16-inch smooth bore tip is rated at 185 gpm at 50 psi, as a few kinks and or poor line management can reduce flow to around 160 gpm. Most of the discussion regarding handlines in the modern fire service has been centered on 1¾-inch hose because that is the size of line used most often. Logically, if there has been such a need for greater flow in the 1¾-inch attack handline, one must also examine the flow rate of the 2½-inch attack handline.

The two common smooth bore tip sizes used on 2½-inch attack handlines are $1^{1}/_{8}$-inch and 1¼-inch. Their respective flows at 50psi nozzle pressure are 266gpm and 328gpm. **For reasons stated below, this article shall propose the consideration of a 1 $^{3}/_{16}$-inch smooth bore tip, which provides a flow of essential 300 gpm at 50 psi**. (This flow and nozzle reaction could be achived by a fog nozzle designed to flow 300 gpm at 50 psi)

In the author's fire service career, three things have dictated the choice of initial attack handlines. If a handline could not properly suppress a fire, based on the below principles, then the engine company would start an aggressive master stream attack with the goal of moving towards an interior operation, if viable, after initial knock down. The three guiding principles in decision-making are as follows:

1) **Critical flow rate**. William E. Clark's principle of "critical flow rate", described as the minimum flow in gpm needed to extinguish a given fire, is discussed in detail in his book <u>Firefighting Principles and Practices</u> (34). One must make sure the handline will, at the minimum, meet the "critical flow rate". **Optimally, the actual flow rate will far exceed the "critical flow rate". This will lead to rapid knock down, thereby having the most life saving and property conserving potential.** He went on to say, "When a fire continues to burn after water has been applied, it is for one of two reasons. Either the water is not reaching the burning material, or it is not being applied at a sufficient flow rate"

2) **Hydraulics**. Is the handline pumped properly? Is the flow attainable with the length of the stretch and the size of the hose? Is there adequate reach and penetration? David P. Fornell, in his <u>Fire Stream Management Handbook,</u> addresses these issues.

3) **Deployability**. Once the two above criteria have been met, does the handline have a nozzle reaction manageable by a reasonable number of personnel? Can it be advanced while flowing and maneuvered through a structure with inherit obstacles such as furniture, doors, staircases, etc. Fornell described, at length, the advantages of having the lowest possible nozzle reaction while still maintaining an effective stream. Retired FDNY Chief Vincent Dunn also expressed the strong opinion that flows in excess 300 gpm were of large caliber and considered master streams, in which mechanical aid should be provided to maintain adequate control and safety. (Dunn 102)

In this article the color scheme in most tables dictates that red highlighting represents negative consequences. The green highlights represent positive consequences. The yellow highlighting represents the limits of flow and nozzle reaction for handline operations. **Below is Table #1. It includes five commonly used smooth bore tip**

sizes and the proposed $1^{3}/_{16}$-inch smooth bore tip. The two most commonly deployed smooth bore tips are the $^{7}/_{8}$-inch tip and the $^{15}/_{16}$-inch tip. Both are used on 1¾-inch attack handlines. Both meet the NFPA 1710 recommendation of 300gpm combined flow if two lines are pulled, pumped properly, and devoid of significant kinks. Respectively, they produce flows of 161gpm and 185gpm at 50psi nozzle pressure. Nozzle reaction and flow for the chart were calculated by the equations given at the bottom. In addition, those flows have been reproduced via flow test, plus or minus 5gpm by hand-held pitot gauge.

Hose	Nozzle	40 PSI		50 PSI		60 PSI	
		GPM	NR LBS	GPM	NR LBS	GPM	NR LBS
1 ¾”	7/8”	144	48	161	60	176	72
1 ¾”	15/16”	165	55	185	69	202	83
	1”	188	63	210	79	230	94
2 ½”	1 1/8”	238	79	266	99	291	119
2 ½”	*1 3/16”*	265	89	296	111	325	133
2 ½”	1 1/4"	294	98	328	123	360	147

Table#1 RF = 1.57 x (D)sq x NP GPM = 29.7 (D)sq √NP (Fornell)

*** Note the 40 to 60psi spread in Table #1 for nozzle pressure**. Vestal and Bridge in their article noted that fire ground flows based on pump pressure commonly did not produce the rated flow of nozzles, mainly due to kinks and poor line management. This will be referred to as a soft nozzle (low pressure). This is usually due to human error. However, they did not discuss the opposite occurrence, the hot nozzle (high pressure). This is a condition that is at least as common as the soft nozzle. Chief David McGrail, Denver Fire Department (DFD), in his firenuggets.com article, “Keys to Success with the Big Line”, brings out the specter of an over-pumped handline. Many factors can lead to a hot nozzle. Several are: rounding up on pump charts, securing a pressurized water source like a hydrant with throttling back, over estimating the dead load stretch, pumps that idle at a high pressure, errors in pressure gauges, relief valves and governors that have trouble maintaining pressures below 130psi when a hydrant is secured, pump operators with the attitude that it is better to err toward more pressure rather than less, attempting to knock out minor kinks with pump pressure, pump operators not used to pumping large handlines with low friction loss requirements, low lighting, stressful conditions, and poor ability to gate lines down which leads to gate creep if no gate locking mechanism is provided. Based on these facts a good pump operator will, at best, produce a nozzle pressure within a range of plus or minus 10psi of the rated 50psi nozzle pressure. In departments the author has been involved with, both as an instructor and an operating member, a hot nozzle is a more common occurrence on the fire ground than a soft nozzle. Soft nozzles get immediately reports via urgent radio traffic, hot nozzles are uncomfortable lived with and are unfortunately gated down to reduce nozzle reaction. These hot and soft nozzle conditions are hazardous and should minimized with frequent appropriate hose and nozzle wet drills.

(Part II) Nozzle Reaction as it Relates to Nozzle Pressure

Along with adequate residential suppression flow, the nozzle reaction developed by the 7/8-inch smooth bore tip and the 15/16-inch smooth bore tip of 60 lbs and 69 lbs, respectively, are within the ability of an initial hose team of two firefighters to handle when utilizing 1 ¾ -inch hose. **This is mainly attributable to the 50 psi nozzle pressure, which produces a low nozzle reaction.** Low nozzle reaction is a critical component to producing a more maneuverable attack hoseline package. The other components related to deployability of an attack handline package are primarily equipment related such as hoseline size/weight, charged and uncharged, and nozzle-bail type and shape. A large 2 ½-inch handline, although more difficult to maneuver due to increased charged weight, also acts to absorb more of the nozzle reaction based on its inherit increased mass.

For the following discussion please use Table #2 as a reference. If the flow rate in a hoseline were to remain constant, while nozzle pressure was doubled, one would expect a significant rise in nozzle reaction. This rise in nozzle reaction would be due to the increased force and velocity of the stream. A flow of 170gpm will be used as an example. A ¾-inch smooth bore tip pumped at 100psi would generate a flow of around 167gpm, but a nozzle reaction of 88 lbs would also be developed. A similar 170gpm flow in a 7/8-inch smooth bore tip would require a 55psi nozzle pressure, but only produces a 66 lbs nozzle reaction. **Now look at the advantage of enlarging the nozzle diameter to 1 1/8-inch tip (normally deployed on 2 ½-inch hose); this would develop a flow of 252gpm at 45psi and produce a reasonable 89 lbs nozzle reaction.** This represents a significant increase in flow with roughly the same nozzle reaction as the ¾-inch smooth bore tip pumped at 100psi nozzle pressure.

At this point, one might ask about horizontal reach and penetration. Does a drastic nozzle pressure change, above 40psi and yet below 100psi, significantly affect the horizontal nozzle reach of the common handline smooth bore tip sizes ranging from ¾-inch through 1¼-inch? Not as much as one would think. The maximum horizontal range difference between these three tips cited in the preceding paragraph is about 15 feet. These distance figures were calculated using a proven horizontal reach formula, HR = 1/2NP+26 (Purington 279). However, the volume difference is about 85gpm. **Note that when stepping up to the 1 1/8-inch smooth bore tip the horizontal range difference is about 10 feet, but also note the vast increase in flow for the same nozzle reaction.** The reason that 50psi is a good operating nozzle pressure for handline smooth bore tips (and fog nozzles) is that it gives the firefighter an effective reach of around 60 feet for 7/8-inch and 15/16-inch tips, and 70 feet for 1 1/8-inch and 1¼-inch tips, while maintaining acceptable nozzle reaction and flow rate. Although it attains the required 160gpm for safe residential fire suppression, the ¾-inch smooth bore tip, pumped at 100psi, has an unacceptably high nozzle reaction of 88 lbs for an initial 1¾-inch attack handline package supported by a nozzle team of one or two firefighters

Hose	Nozzle	Nozzle Pressure	GPM	NR LBS	Reach Feet
1 ¾”	3/4”	100	167	88	76
1 ¾”	7/8”	55	169	66	59
2 ½”	1 1/8”	45	252	89	64

Table #2 HR = 1/2NP+26

@32 degree / + 5 feet for every 1/8-inch increase over ¾-inch tip diameter (Purington 279)

So, what is acceptable handline nozzle reaction? The **nozzle reaction force must not exceed that force which can be overcome by a hose team assigned to the attack handline without excessive nozzle control issues.** A suitable handline nozzle reaction is one that will allow development of effective flow and reach yet will not quickly exhaust the hose team due to excessive exertion. This ideal handline nozzle reaction must be manageable, within reason, throughout the incident. "Some instructors use a rule of thumb which states that a firefighter can safely handle one-half of his or her body weight in nozzle reaction force" (Fornell 195). At the time of publication for Fornell's book, a fair estimate for average body weight without equipment was around 200 lbs, putting acceptable nozzle reaction at 100 lbs. This rule of thumb produces what the author considers a high acceptable nozzle reaction number for a single firefighter handline, and was most likely developed in the era of heavily staffed 2 1/2-inch hose lines pre 1970.

Andrew Fredericks, a hose and nozzle instructor of national repute, commonly put the safe maximum nozzle reaction for a single firefighter at around 69 lbs. The author found a tolerable nozzle reaction, through experience as a hose and nozzle instructor, to be right in line with about 70 pounds for a "single firefighter" line. Single firefighter is in quotes because a minimum of two firefighters should be assigned to a 1¾-inch attack handline. This second firefighter is more of a door/kink firefighter on a 1¾-inch attack handline and acts only occasionally as true back-up to the nozzle position. **Many fire departments staff up the initially pulled handline line as additional companies arrive on scene. This is to ensure the greatest likelihood of the initial attack handline making it to the seat of the fire.** Proper staffing and placement are paramount for the initial attack handline. This improves mobility to the point where it can be driven to the seat of the fire, rapidly achieving extinguishment. This will lead to a safer fire environment where the bulk of the fire has been rapidly knocked all the way to the seat of the fire. The more rapid the extinguishment, the greater the levels of safety, efficiency, and effectiveness for all other operations that must occur on the fireground. Most fire departments with four or more personnel on engines routinely deploy 1¾-inch attack handline packages with a true hose team of a nozzle firefighter, back-up firefighter, and a door/kink firefighter at the outset of operations.

The high reaction force associated with the $^{15}/_{16}$-inch smooth bore tip at 50psi nozzle pressure requires a greater need for good nozzle technique and constant vigilance in operation, as it is unforgiving to the pump operator. Pump operator error of just 10psi too high produces a nozzle reaction of 83 pounds and a flow of 202gpm in the $^{15}/_{16}$-inch smooth bore tip. **A hot nozzle situation with a $^{15}/_{16}$-inch tip can rapidly create an unsafe condition that can easily lead to a loss of nozzle control and failure to advance the line to the seat of the fire**. The $^{7}/_{8}$-inch smooth bore tip is more forgiving of a hot nozzle condition. At 60psi nozzle pressure the $^{7}/_{8}$-inch smooth bore tip creates 72 pounds nozzle reaction and a flow of 176gpm. Both nozzles are routinely used in fire suppression. However, the $^{15}/_{16}$-inch smooth bore tip requires more vigilance, ideal pump operation, and, ultimately, reasonable staffing for an adequate flowing advance and maneuverability inside a structure. **To argue with the physical universe is to tilt at windmills.** Knowledge of actual nozzle reaction force and its consequences will lead to better deployed and understood attack handline packages, and ultimately more success in combating fire conditions.

(Part III) 2 ½-inch Hose Deployability and Optimum Flow

Now, to delve into the new and unknown world of the **1 3/16-inch smooth bore tip**. An argument based on the physics and facts surrounding deployability and effectiveness on the fire ground shall now be presented as to why this nozzle should be considered the highest flow handline nozzle (300gpm). Again, several factors are now leveraging the fire service into addressing the need to examine optimum flow rate for 2½-inch hose. Predominating amongst these are modern hydrocarbon-heavy fuel loads, rapid fire development, energy efficient building construction, reduced staffing, and longer fire development before initial extinguishment efforts. **It is the intent of this treatise to ensure that the fire service does not overlook a potentially very useful tip size and flow rate for 2½-inch handline operations.**

Before we can address why the new nozzle size is needed, we should look at why the big guns of handlines, the 2½-inch attack packages, are so under utilized. There have been many theories advanced. (McGrail, "Keys to Success Big Line"). Two of those carrying the most credence shall now be addressed. Firstly, use of the 1¾-inch attack handline has become institutionalized. In effect, the fire service has become a victim of its own success. **As the routine stretching of 1¾-inch attack lines successfully combats the vast majority of residential and other smaller scale fires, the line has come to be seen as a panacea for all fire conditions.** This often results in a conditioned response on the part of engine companies to stretch 1¾-inch hose regardless of size-up indicators. Secondly, the fear of difficulty in deploying 2½-inch line often leads to the selection of 1¾-inch hose even though its flow rate is insufficient for the given fire ground scenario. This leads to multiple 1¾-inch attack lines being stretched where a lesser number of well staffed 2½-inch attack lines would more safely, efficiently and effectively combat the given fire conditions. Why so many officers fail to recognize when a larger handline is appropriate and fail to take proper action is not a focus of this presentation. The ADULTS Acronym, popularized by Andy Fredericks, and many others, covers the time and place to pull a larger flow attack handline package as follows:

A — Advanced Fire Upon Arrival

D — Defensive Operating Mode (Defensive Operations)

U — Unable to Determine the Extent (Size) or Location of the Fire

L — Large, Uncompartmented Areas

T — Tons of Water (One ton of water per minute with a 1-1/8" tip)

S — Standpipe Operations

However, that being said, **the fear of failure as it relates to deployability, will be addressed as the key factor, in this article, affecting under-utilization of 2½-inch attack handlines**. Many personnel have had negative experiences, with large handlines, related to deployability, controllability, and maneuverability. These experiences led to judgments that the high flow attack handline is ineffective because it cannot be effortlessly advanced to the seat of the fire. Lack of familiarity and training lead to the inability to move the line forward in an efficient manner. Essentially, many crews view the 2½-inch handline as a defensive line anchored to one spot. This is regardless of the fact that an ADULTS fire requires the greater flow rate based on heat release rate and other factors dictating the need for the increased extinguishing capacity of 2½-inch hose. **An examination of the history and physics behind many negative experiences with 2½-inch handlines is a necessary step on the road toward achieving greater utilization of this very important weapon in the fire service arsenal.**

What is acceptable nozzle reaction for a 2½-inch attack handline package, which today typically flows between 250 and 325gpm? There is not as much material on this subject matter, as compared to that which is available regarding nozzle reaction for 1¾-inch lines. However, it is well understood that to have the best chance of properly deploying a 2½-inch attack handline package a back-up firefighter is required immediately. It is also necessary to have a door/kink firefighter to feed hose and facilitate forward movement of the hoseline. This means that if an engine company is going to deploy a 2½-inch attack handline package flowing 250 to 325gpm it must immediately have three firefighters assigned to the line. **A 2½-inch attack handline package can be deployed in a static aggressive defensive action, using the reach and penetration of the high flow stream, with only one firefighter and then transition to a mobile attack as staffing is augmented**.

Table #4 contains a very common nozzle used to develop large handline flows, the 1 1/8-inch smooth bore tip. It produces a flow of 266gpm with a nozzle reaction of 99 lbs. This nozzle is well known to produce a functional, easily deployable, high flow hoseline when staffed with a nozzle firefighter and back up firefighter with a door/ kink man to help push the line forward. The high flow rate and great extinguishing capacity characteristics coupled with low nozzle reaction force cause it to be a true force multiplier. These qualities lead Chief David McGrail, and many others, to make it a mission to have this line put into routine service. Other notable hose and nozzle instructors that consider this a very functional line are Daryl Liggins, Jay Comella, Aaron Fields, Jason Blake and Curt Isakson to name just a few. The 1 1/8-inch smooth bore tip is also the 2 ½-inch handline nozzle choice for the FDNY, the largest fire department in the United States. This should speak volumes as to the true effectiveness of the 1 1/18-inch smooth bore tip and 2 ½-inch hose attack package.

The author's initial negative experiences with 2½-inch hose are typical for many in the fire service from 1980 to 2000. 100psi combination nozzles became commonplace on the fire ground. A common target flow rate of the time was 125gpm for small handlines (often 1½-inch). This flow at 100psi nozzle pressure only produced a reaction force of around 65 pounds. This is well below the 75 pound nozzle reaction limit to be considered a controllable small attack handline. **The story was quite different as 100psi combination nozzles encroached into the realm of the 2½-inch handline and displaced the old brass play pipes and smooth bore nozzles that operated at 50psi nozzle pressure.**

Two very common 100psi large handline combination nozzles of the time were the adjustable gallonage 200/225/250gpm and the fixed gallonage 250gpm nozzles. The salesmanship and fog stream theory of the time conspired to create a huge influx into the fire service of these 100psi large handline nozzles. The adjustable larger flow 100psi combination nozzles in most departments were usually set at 250gpm, because the logical stance was if one were to pull a 2½-inch handline one would want to flow at least 250gpm. **Table #3 demonstrates the high nozzle reaction forces many fire service professionals dealt with as they learned to operate 2½-inch handlines with 100psi combination nozzles.** High nozzle reaction force associated with this nozzle inevitably led to monumentally bad experiences. Many are left with negative impressions ingrained in their memories of entangled hose straps, slipping feet, twisted knees, wrenched backs and shoulders. All of which led to slow forward progress of the line, even with large commitments of staffing. In an effort to avoid the inordinate reaction force, the member on the nozzle would often gate down the shut-off and/or select a fog stream. These efforts to reduce physical strain have the unfortunate effects of reducing water flow and stream reach.

Those collective bad experiences both on the drill ground and at fire scenes, directly contributes to the bad habit of pulling multiple 1 ¾-inch handlines. This habit really takes root and becomes common place as flows start reaching 180 gpm at 50 psi nozzle pressure in small handline attack packages. Most companies make the easy rationalization of pulling two 1 ¾- inch handline when faced one 2 ½ - inch handline attached to a 250gpm@100psi nozzle system. **The bad habit is forged into acceptable behavior all the way to the command staff level based on the fear of failure founded in the truth of high nozzle reaction generated by 100 psi nozzle pressure in larger attack line packages which lead to nonfunctional large handlines.**

Hose	Nozzle	75 PSI		100 PSI		125 PSI	
	Akron Assault model # 4825	GPM	NR LBS	GPM	NR LBS	GPM	NR LBS
2 ½"	250 Fog @ 100 psi	217	94	250	126	280	158

Table #3 RF = GPM x √NP x .0505 (Fornell 223) GPM for 250@75/100/125 psi (Akron 153)

Whether or not a handline is controllable boils down to one thing, and one thing only, the level of nozzle reaction force. The red highlighting again represents negative consequences. The green highlights again represent positive consequences. The yellow highlights represent the limits of flow and nozzle reaction. Table #3 represents the exorbitantly high price in nozzle reaction for a given water flow when operating a 100psi nozzle. **There is no variance of these characteristics depending on nozzle manufacturer. It is based on physics**. The same would even hold true for a smooth bore nozzle. For example a $^{15}/_{16}$-inch smooth bore tip at 100psi nozzle pressure produces a flow of 261gpm and a nozzle reaction of 138 pounds (Fornell 225). **100psi nozzle pressure, when used to generate flows of 250 to 300gpm, produces a harsh, unforgiving, and unacceptability high nozzle reaction.** These qualities were not of great consequence with the low, 60 to 125gpm, flow from small handline combination nozzles of the 1950's, 60's, and 70's. Due to the low volume of water being moved, excessively high nozzle reaction forces were not generated. However, the high flow 100psi nozzle pressure, 200 to 300gpm, large handline nozzles of the 1970's, 80's, and 90's generated very high levels of nozzle reaction. The drive toward the increased use of combination nozzles was based on the misperception that there was a need to introduce a stream pattern of fine water droplets into the fire compartment. This is a theory that has been thoroughly disproven. See Bridge and Vestel, <u>A Quantitative Approach to Selecting Nozzle Flow Rate and Stream</u>, for a detailed examination of stream selection.

Hose	Nozzle	40 PSI		50 PSI		60 PSI	
		GPM	NR LBS	GPM	NR LBS	GPM	NR LBS
2 ½”	1 1/8	238	79	266	99	291	119
2 ½”	*1 3/16*	265	89	296	111	325	133
2 ½”	1 1/4	294	98	328	123	360	147

Table#4 RF = 1.57 x (D)sq x NP GPM = 29.7 (D)sq √NP (Fornell)

2½-inch hose with an 1 1/8-inch smooth bore tip operating at 50psi nozzle pressure generates a reaction force of 99 pounds. With training, this is considered to be a manageable line to deploy. It has good controllability while flowing and advancing. **1¼-inch is the other currently accepted smooth bore tip size for use with 2½-inch hose. Even with a low nozzle pressure of 50psi, the sheer massive volume of water flowing through the 1¼-inch tip causes a high level of reaction force**. At 50psi nozzle pressure, the 1¼-inch smooth bore tip produces a flow of 328gpm and a nozzle reaction of 123 pounds. The high reaction force causes severely limited controllability, deployability, manageability, and maneuverability. Most hose and nozzle instructors will confirm that, even with three very proficient, physically fit, firefighters (filling the nozzle, back-up, door/kink positions), it is a very difficult endeavor to aggressively advance a 2½-inch line with a 1¼-inch smooth bore tip.

Based on the author’s experience as a hose and nozzle instructor, as well as consultation with other noted instructors such as, Comella, Liggins, and Isakson, the 123 pound reaction force associated with the 1¼-inch smooth bore tip is not practicably manageable while flowing and advancing. Vincent Dunn states that flows above 300gpm are master streams mainly based on reaction force (Dunn 102). “At high rates of delivery, a handheld nozzle would be too difficult to control, so mechanical, electrical, or hydraulic assists are required” (Dunn 102). **It is the author’s belief that a maximum nozzle reaction of 115 pounds lends itself to a functional, mobile, effective 2½-inch attack handline. This nozzle reaction is below what a 1¼-inch smooth bore tip develops at 50psi nozzle pressure.**

A large county fire department, with roughly 600,000 citizens under its protection, is in the process of moving to a more controllable 2½-inch attack handline with which to combat ADULTS fires. They currently use a 300gpm at 100psi combination nozzle on their 2½-inch handlines. With a reaction force of roughly 150 pounds it is rarely used. The members of the department have chosen, based on research and testing, to move to a 1 1/8-inch smooth bore tip at 50psi nozzle pressure in order to reduce reaction force. This makes for a much more deployable 2½-inch handline. After initial training they were able to efficiently deploy the new 2½-inch attack handline package with a three firefighter company. They have used this line successfully at several ADULTS fires. Initial staffing on the line is two firefighters and the hose team is augmented as additional companies arrive. Members’ assessments of the line’s performance bear out that its prompt deployment is more effective than stretching multiple 1¾-inch lines.

.

A 2½-inch handline proves more effective, in many ways, than do multiple 1¾-inch lines. Foremost is flow. **A good goal for a department's handline compliment is that a minimum of a 100gpm flow difference exists between its small and large attack handlines**. 100gpm is a significant increase, which will lead to distinctly accelerated extinguishment when the larger line is chosen over the smaller. Unlike two or more 1¾-inch handlines, the impact of a 2½-inch line is highly concentrated, thus magnifying its effect, as the stream is worked about the fire compartment leading to a higher percentage of water impacting both the superheated overhead and the burning solid fuels. Physics dictates that it produces a stream that is much harder hitting. This is due to the mass of such a high volume of water concentrated in a single stream. Hence, the heavier stream has more power to knock out windows, penetrate compromised drywall, push aside drop-ceiling panels, and effectively coat the interior of the fire compartment with water. **The same qualities that allow the 2½-inch hose stream to more effectively overcome physical obstacles also allow it to more effectively penetrate superheated gasses and create a higher droplet fall out rate, thus absorbing more heat.** There is also a reach advantage of around 10 feet causing the stream to reach further out into large spaces than can multiple 1¾-inch handlines.

(Part IV) Attack Handline Package Soltions and the 1 3/16-inch Tip (or 300 gpm @50 psi Fog)

Based on the logic laid out above and the contributions many fire service professionals whom have come before in the fields of fire stream development, hydraulics, and basic hose deployment Table #5 was developed. **This table represents the three key factors whose interrelation dictates the degree of effectiveness of attack handline fire streams. These factors are flow rate or gallonage, nozzle reaction force, and horizontal reach**. The table is broken down into two nozzle systems. Each system is based on a given department's choice of complimentary sizes of the smooth bore tips for its small and large attack handlines. One system is based on the choice of $^{7}/_{8}$-inch and $1^{1}/_{8}$-inch tips. The other is based on the selection of $^{15}/_{16}$-inch and $1^{3}/_{16}$-inch tips. **This shall be referred to as the rule of eighths and sixteenths.**

Hose	Nozzle	40 PSI			50 PSI			60 PSI		
		GPM	NR	Reach	GPM	NR	Reach	GPM	NR	Reach
1 ¾"	7/8"	144	48#	51'	161	60#	56'	176	72#	61'
2 ½"	1 1/8"	238	79#	61'	266	99#	66'	291	119#	71'
		GPM	RF	Reach	GPM	RF	Reach	GPM	RF	Reach
1 ¾"	15/16"	165	55#	54'	185	69#	59'	202	83#	64'

2 ½"	*1 3/16"*	265	89#	64'	296	111#	69'	325	133#	74'

Table #5 The rule of 1/8ths and 1/16ths is a simple two nozzle system for fire service handlines

This two choice nozzle system is based on simplicity, physics, and community fire load. As of now, 1¾-inch and 2½-inch are the two most commonly used attack hose line sizes in the United States. There are strong arguments for a minimum flow difference of 100gpm between a fire department's handline attack packages. A key component of a handline attack package is that it must be deployable as a true interior attack handline. Two options are presented as possibilities to increase simplification and functionality of handline attack packages.

- **Option one should function well based on most communities' fire loads**. The lines are deployable with company staffing as low as three firefighters. The $^{7}/_{8}$-inch smooth bore tip on 1¾-inch hose generates a controllable nozzle reaction force across a range of 40 to 60psi nozzle pressure. It also provides a stream of sufficient flow for most residential fires. The $1^{1}/_{8}$-inch smooth bore tip generates controllable nozzle reaction across a range of 40 to 55psi nozzle pressure. It provides a 100gpm increase in flow over the $^{7}/_{8}$-inch smooth bore tip. The $1^{1}/_{8}$-inch smooth bore flow of 266gpm makes for an effective line for those fires which fall within the parameters of ADULTS.

- **Option two operates at the acceptable limits of flow and nozzle reaction**. This system is well suited for communities with high fire loads, significant exposure issues, and high occupancy density. Departments choosing this option need company staffing of four or more firefighters per unit. The $^{15}/_{16}$-inch (185gpm) and $1^{3}/_{16}$-inch (296gpm) smooth bore tips represent the limits of controllable reaction force across a range of 40 to 50psi nozzle pressure. There is a minimum of 100gpm difference in flow between the two lines. At 50psi nozzle pressure, the $1^{3}/_{16}$-inch smooth bore tip generates a nozzle reaction force of about 111 pounds. This is below the 115 pounds nozzle reaction force that represents the maximum that is practicably sustainable for personnel.

The venerable 1¼-inch tip has held pride of place, as the largest smooth bore tip to develop a handline stream, for over 100 years. However, it is basically not very functional or deployable in common practice. The 328gpm flow rate comes at the exorbitantly high price of 123 pounds nozzle reaction force. This is well above that reaction force which is practicable for sustained control by personnel on an attack handline.

Looking through older hydraulic texts one cannot help but notice the lack of a $^{15}/_{16}$ -inch smooth bore tip. Lore has it that the Fire Department of New York developed it. FDNY engine companies felt that on 1¾-inch attack line they could handle more than the 60 pounds nozzle reaction force associated with the 161gpm stream developed by a $^{7}/_{8}$-inch tip at 50psi nozzle pressure. Yet many desired a reaction force less than the 79 pounds generated by the 210gpm stream of the 1-inch smooth bore tip (known by various names such as a Bronx blaster and Harlem blaster). Through necessity and ingenuity, the $^{15}/_{16}$-inch smooth bore tip came into being. At 50psi nozzle pressure it flows 185gpm at 69 pounds reaction force. Word has it that some companies still use their "blasters", 1-inch smooth bore tips. However, the $^{15}/_{16}$-inch smooth bore tip was rapidly well received based on both deployability and extinguishing capability. It was adopted as the 1¾-inch handline nozzle of choice, not only in New York City, but also, in many fire departments throughout the country.

Many departments could benefit from the use of the $1^{3}/_{16}$-inch smooth bore tip. Some examples are:

- **Los Angeles City Fire Department** has a static bed of 2½-inch hose with a 1¼-inch smooth bore tip. It is not routinely deployed due to difficulty in controlling high nozzle reaction produced by the 1¼-inch tip causing over-reliance on small handlines.

- **Chicago** also uses the 1¼-inch tip with all of its above-stated high nozzle reaction disadvantages.

- **FDNY** with a less than 100gpm difference in flow between their 1¾-inch hose with $^{15}/_{16}$-inch tip and their 2½-inch hose with $1^{1}/_{8}$-inch tip would likely see benefits by moving up to a $1^{3}/_{16}$-inch smooth bore tip.

- **Redwood City Fire Department** is the only department in the San Francisco Bay Area that routinely deploys a 1¼-inch smooth bore tip and pumps it at a 40psi nozzle pressure to reduce nozzle reaction. They, too, could benefit from the $1^{3}/_{16}$-inch smooth bore tip.

Some, who are well-versed in standpipe operations, may question how a $1^{3}/_{16}$-inch smooth bore tip could be successfully deployed from a 65psi standpipe outlet. At 40psi nozzle pressure, the $1^{3}/_{16}$-inch tip will basically replicate the 266gpm flow of a $1^{1}/_{8}$-inch smooth bore tip at 50psi nozzle pressure. The main differences are a few feet shorter reach and a reduction of 10 lbs of nozzle reaction. It may end up being easier to deploy off a 65psi standpipe outlet based on less nozzle reaction. In addition, many standpipe systems deliver more than the minimum required 65psi outlet pressure. Hence, routinely, greater heat absorbing 300gpm streams can be achieved. This issue, as well as others surrounding standpipe operations, needs to be addressed through testing and expert opinions. Hopefully David McGrail, and others possessing high degrees of experience and knowledge regarding standpipe operations, will find merit in addressing these issues.

Part V Moving Forward the 1 3/16-inch Tip (or 300 gpm @50 psi Fog)

In conclusion, the same logic behind the successful acceptance and implementation of the $^{15}/_{16}$-inch smooth bore tip may also end up to be the impetus behind the successful acceptance and implementation of the $1^{3}/_{16}$-inch smooth bore tip. **For small attack handlines, the flow and reaction force characteristics of the $^{15}/_{16}$-inch tip make it the happy median between the $^{7}/_{8}$-inch and 1-inch smooth bore tips. For large attack handlines, the same concepts dictate that the $1^{3}/_{16}$-inch tip is the happy median between the $1^{1}/_{8}$-inch and 1¼-inch smooth bore tips. The evidence is too great to continue to ignore the potential of the $1^{3}/_{16}$-inch smooth bore tip any longer.** Time and experience will bear out the need for the $1^{3}/_{16}$-inch smooth bore tip. Some prototype $1^{3}/_{16}$-inch smooth bore tips are now being produced for research, testing, and training purposes. Flow testing will be performed. Some of the most experienced hose and nozzle instructors will evaluate the $1^{3}/_{16}$-inch tip. Perhaps in the near future it will no longer be considered, “the missing tip”.

In regards to what will become of all those 1¼-inch smooth bore tips currently being used in the fire service, the following is offered. The 1¼-inch smooth bore tip, at 50psi nozzle pressure, has a reaction force to great for handline operations. However, it may still be useful. The 1¼-inch smooth bore tip, at 80psi nozzle pressure, flows 415gpm with a reach of 86 feet. It would be best deployed on a rapid attack monitor. This flow could be supported by a single 2½-inch line and, as David McGrail might put it, becoming the first step from rifle to artillery.

Works Cited

(Per Modern Language Association Style)

Akron Brass Company. *Akron Brass 2008 Product Catalog.* Wooster: Akron Brass Company 2008

Bridge, Eric A. and Vestal Jason N. "A Quantitative Approach to Selecting Nozzle Flow Rate and Stream, Part1". New Jersey: *Fire Engineering 1 October 2010*

Bridge, Eric A. and Vestal Jason N. "A Quantitative Approach to Selecting Nozzle Flow Rate and Stream, Part 2". New Jersey: *Fire Engineering 1 January 2011*

Dunn, Vincent. *Command and Control of Fires and Emergencies.* New Jersey: Penn Well / Fire Engineering. 1999

Clark, William E. *Firefighting Priniciples and Practices*. 2nd Edition. New Jersey: Penn Well / Fire Engineering. 1990

Fornell, David P. *Fire Stream Management Handbook*. New Jersey: Fire Engineering. 1991

McGrail, Daivd. "Keys to Success with the "Big Line": Proper Weapons Selections" California: Fire Nuggets Website. http://www.firenuggets.com/mcgrail.htm

Noted Contributors

Jay Comella (Capt. Oakland Fire, ret.)	for editing, adjustment to prose, conceptual consultation.
Geoffrey Hunter (Capt. Oakland Fire)	for grammatical editing.
Curt Isakson (BC Escambia Fire)	for motivation and consultation.
Veronica Wunderlich (ES, Dept. Water Res., CA)	for grammatical editing.