5 FIREGROUND HYDRAULICS

5.1 BACKGROUND

5.1.1 Hydraulics is a science that, in its broadest terms, deals with water and other fluids while at rest and in motion. In the fire service, the scope of this definition is usually limited to the study of water for firefighting purposes.

5.1.2 Often, the most practical method of fire extinguishment involves the application of water in a form that will quickly reduce the temperature of the burning material to a point where combustion no longer takes place.

5.1.3 Due to its availability and low cost, water has always been our most practical and commonly used extinguishing agent.

5.1.4 To produce an effective fire stream, a comprehensive knowledge of hydraulics is essential. Using water to its fullest potential requires the firefighter to be aware of the advantages, as well as the limitations, associated with water.

5.2 PURPOSE AND SCOPE

5.2.1 The purpose of this section is to explain a practical method of determining the pump discharge pressure (PDP) necessary to produce an effective fire stream. The information presented in this document was prepared with the understanding that there are several methods used by firefighters to solve fireground hydraulics problems. It must be understood that, because of various factors encountered at each fire scene and the necessity of being able to quickly compute the correct pump discharge pressure for each situation, a practical approach to hydraulics is necessary. The information contained in this section is satisfactory for most fireground situations.

5.2.2 The scope of this section is limited to essential hydraulic principles a firefighter must know to be an efficient pump operator. The International Fire Service Training Association (IFSTA) manuals have been adopted by our departments as the basic training guides. Several IFSTA Manuals were utilized in the development of this section. *Engine Company Fireground Operations* by Harold Richman, *E-One Training and Operations Manual, Fire Officers' Handbook of Tactics* by John Norman, and the *National Foam Manual* were also consulted in updating material. Members who wish to increase their knowledge and comprehension of hydraulics are encouraged to consult these and other references for additional information.

5.3 ABBREVIATIONS AND SYMBOLS

5.3.1 Custom has developed certain symbols and abbreviations that are used in formulas necessary to calculate hydraulic problems. The following is a list of abbreviations and mathematical symbols that are used in this book and in the fire service:

- AL — appliance loss
- D — nozzle diameter
- EL — elevation loss or gain
- FL — friction loss
- GPM — gallons per minute
- lb — pound(s)
- NP — nozzle pressure
- NR — nozzle reaction
- PDP — pump discharge pressure
- PSI — pounds per square inch
- Q — quantity of water flowing divided by 100
- RP — residual pressure
- + — Plus (addition)
- - — Minus (subtraction)
- x — Times (multiplication)
- / or ÷ — Divided by (division)
- √ — Square root
- " — Inch
- ' — Foot or feet

MATHEMATICAL HINT: You will find as you proceed through this section of the book that your greatest chance of error will be in performing your mathematical calculations. In order to help reduce the possibility of error, there are some steps that can be utilized to assist you. You will notice that you will be squaring a lot of half numbers, such as $(2.5)^2$, $(4.5)^2$, $(7.5)^2$, etc. To help simplify this process, the following is suggested:

- Identify the two whole numbers that the half number is between. (2.5 is between 2 and 3)
- Multiply those two numbers together (2 x 3 = 6)
- Add .25 to that total (6 + .25 = 6.25)
- That is your answer. This procedure will work when squaring any number that ends in .5.

5.4 DEFINITION OF TERMS

5.4.1 Firefighters must have a complete understanding of fire department hydraulics in addition to a solid working knowledge of the pump they are operating. Therefore, every operator must know and understand the following definitions of hydraulic terms:

5.4.1.1 Appliance – a device, other than a hand-held nozzle, where the direction of water flow is interrupted or changed.

5.4.1.2 Attack engine -- any pumper that is supplying water directly to attack lines.

5.4.1.3 Back pressure – the same as "head pressure." Pressure generated by the weight of a column of water. This pressure is exerted at .434 psi per foot of elevation. On the fireground, this number is rounded to .5 psi.

5.4.1.4 Discharge – the quantity of water issuing from an opening and is expressed in gpm.

5.4.1.5 Supply engine – any pumper that is supplying water from a source, such as a hydrant or pond, to an attack engine.

5.4.1.6 Flow pressure – the forward velocity pressure of water issuing from a discharge opening. Flow pressure is usually measured by using a pitot gauge.

5.4.1.7 Friction loss – the loss in energy (pressure) due to friction. This results from the turbulence in the water and the water molecules rubbing on the interior surfaces of the hose and appliances.

5.4.1.8 Head pressure – see back pressure.

5.4.1.9 Ladder pipe – a master stream device that is attached to the rungs or rails of an aerial ladder. These may be pre-piped and permanently mounted or they may be appliances that must be attached to the aerial when needed.

5.4.1.10 Master stream – any fire stream that is too large to be controlled without mechanical aid. A master stream delivers more than 350 gpm. These devices may be fixed or portable. (Deck gun / Deluge gun)

5.4.1.11 Normal operating pressure – pressure on a water system during regular domestic consumption.

5.4.1.12 Nozzle pressure – the flow pressure of water as it leaves a nozzle.

5.4.1.13 Nozzle reaction – the backward force created by a stream of water as it is discharged from a nozzle.

5.4.1.14 Pressure – a measure of the energy contained in water, and measured and stated as psi.

5.4.1.15 Residual pressure – the pressure *remaining* in a water system when water is flowing.

5.4.1.16 Siamese – an appliance that combines two or more hose lines into one.

5.4.1.17 Static pressure – the pressure exerted by water when at rest.

5.4.1.18 Velocity – the speed at which water passes a given point, usually measured in feet per second. (FPS).

5.4.1.19 Water hammer – the concussion effect of a moving stream of water against the sides and ends of pipes, pumps, or hose lines when its movement is suddenly stopped.

5.4.1.20 Wye – an appliance that breaks one hose line into two or more hose lines.

5.5 STANDARDS AND MEASUREMENTS

5.5.1 Because water is the most practical extinguishing agent, a comprehensive knowledge of its physical properties is essential. In addition, there are certain standards and measurements that are associated with fireground hydraulics that must be understood. These include:

5.5.1.1 One cubic foot contains 1728 cubic inches.

5.5.1.2 One cubic foot contains 7.5 gallons.

5.5.1.3 One gallon contains 231 cubic inches.

5.5.1.4 One cubic foot of fresh water weighs 62.5 pounds.

5.5.1.5 One gallon of fresh water weighs 8.33 pounds (use 8.3 in formulas).

5.5.1.6 A column of water one foot high exerts a pressure of .434 psi at its base.

5.5.1.7 A column of water 2.31 feet high exerts a pressure of 1 psi at its base.

5.5.1.8 One inch of mercury equals 13.546 inches of water in the pressure it exerts downward. For drafting purposes, use 1 inch of mercury to indicate one foot of lift.

5.5.1.9 One length (50 feet) of 1 ¾-inch hose contains 6.24 gallons of water.

5.5.1.10 One length (50 feet) of 2 ½-inch hose contains 12.75 gallons.

5.5.1.11 One length (50 feet) of 3-inch hose contains 18.3 gallons.

5.5.2 One length (100 feet) of 4-inch hose contains about 125 gallons. Sizes and types of fire streams

5.5.2.1 A small stream is 40 gpm or less.

5.5.2.2 A 1 ¾-inch hand line ranges from 100 to 210 gpm.

5.5.2.3 A 2 ½-inch hand line flows up to 325 gpm.

5.5.2.4 A master stream is considered to be 350 gpm and greater.

5.5.3 Nozzle pressure

5.5.3.1 Nozzle pressure for hand lines with smooth bore nozzles is 50 psi. The pressure can be increased to 65 psi to achieve a higher flow.

5.5.3.2 Nozzle pressure for master streams with smooth bore nozzles is 80 psi but can be increased to 100 to achieve higher flow rates.

5.5.3.3 Nozzle pressure for fog nozzles is 100 psi unless otherwise indicated.

5.5.3.4 Low-pressure fog nozzles are designed for 75-psi nozzle pressure. Knowledge of what nozzles you have on your apparatus is essential to ensure that the correct pressure is applied to achieve a good fire stream.

5.6 PRINCIPLES OF HYDRAULICS

5.6.1 There are six principles that cover the characteristics of pressure in fluids. They are:

5.6.1.1 Fluid pressure is perpendicular to any surface on which it rests.

5.6.1.2 Fluid pressure at a point in a fluid at rest is of the same intensity in all directions.

5.6.1.3 Pressure applies to a confined fluid from an outside source is transmitted equally in all directions.

5.6.1.4 The downward pressure of a liquid in an open vessel is proportional to its depth.

5.6.1.5 The downward pressure of a liquid in an open vessel is proportional to the density of the liquid.

5.6.1.6 The downward pressure of a liquid on the bottom of a vessel is independent of the shape of the vessel itself.

5.7 COMPUTING VOLUME

5.7.1 In order to determine the amount or weight of water contained in a vessel or container, the volume of the container, must first be determined.

5.7.1.1 The formula for determining volume for a rectangular or square shaped container is:

VOLUME = LENGTH x WIDTH x HEIGHT (L x W x H)

Example 1: What is the volume of a swimming pool that is 40 feet long, 20 feet wide, and 10 feet deep?

40 x 20 x 10 = 8000 cubic ft (ft^3)

How many gallons of water can this pool hold?

Since 1 cubic foot of water contains 7.5 gallons, and the pool has a volume of 800 cubic feet, by multiplying 8000 by 7.5 it can be determined that the pool can hold 60,000 gallons of water.

8000 x 7.5 = 60,000

Example 2: What is the weight of water on a flat roof of a townhouse that is 30 feet long, 25 feet wide and 1 ½ feet deep? (Hint: Keep all measurements in feet. As you will see later, you cannot combine feet and inches).

30 x 25 x 1½ = 1125 cubic feet

One cubic foot of water weights 62.5 pounds; therefore by multiplying 1125 by 62.5, it can be determined that there is 70,312 pounds of water on the roof.

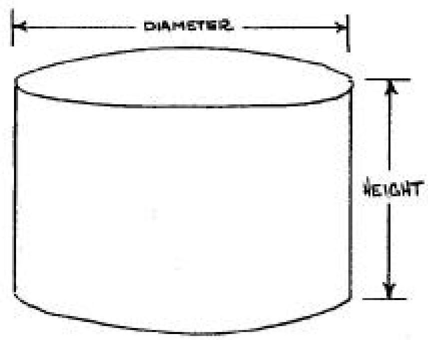
1125 x 62.5 = 70,312.5

5.7.1.2 To determine the volume of a cylinder, the formula is:

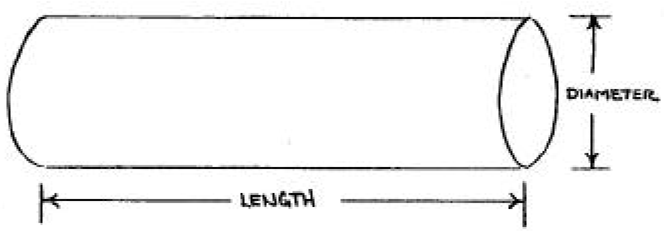
$$.7854 \times D^2 \text{ (diameter squared) } \times H \text{ or}$$

$$.7854 \times D^2 \times L$$

(In the above equation, H means height and L means length)



.7854 x D^2 x H



.7854 x D^2 x L

Example 3: What is the volume of a cylinder that is 6 feet in diameter and 20 feet high?

$$.7854 \times 6^2 \times 20 =$$

.7854 x 36 x 20 = 565.488 cubic feet (round to 565)

By multiplying 565 by 7.5 (gallons in a cubic foot) it can be determined that there can be 4237.5 gallons of water in this cylinder.

565 x 7.5 = 4237.5 (round to 4238)

Example 4: How much water is in a length or section (50 feet) of 3" hose?

$$.7854 \times D^2 \times 50$$

The diameter of the hose is in inches. As mentioned earlier, inches and feet cannot be combined. You must convert to either all inches or all feet. In this case, it is best to convert the inches to feet. 3 inches is ¼ or 25% of a foot. The formula then works out as:

$$.7854 \times (.25)^2 \times 50 =$$

$$.7854 \times .0625 \times 50 = 2.45$$

The 2.45 here is in cubic feet. Multiply is now by 7.5 to find out how many gallons are contained.

$$2.45 \times 7.5 = 18.3$$

If the problem was done by converting to inches, the formula would then a work out as follows:

$$.7854 \times (3)^2 \times 600 \text{ (50 feet = 600 inches)}$$

$$.7854 \times 9 \times 600 =$$

$$.7854 \times 5400 = 4241$$

Since one gallon contains 231 cubic inches, divide 4241 by 231.

$$4241 \div 231 = 18.3$$

One length of 3" hose contains 18.3 gallons of water.

5.8 COMPUTING DISCHARGE

5.8.1 In this section, we are concerned with obtaining adequate flow for an effective fire stream. A thorough knowledge of basic hydraulic formulas will enable us to understand and visualize all factors concerned with fire stream development. On the fireground, determining the proper pump pressure is mandatory. An important step in reaching this objective is the ability to compute the amount of water that is being discharged through hose lines and nozzles.

5.8.2 Smooth bore nozzle discharge

5.8.2.1 Determining the flow from a smooth bore nozzle can be computed by using a formula for gallons per minute when the nozzle pressure is known. The formula is stated: **$GPM = (29.7D^2)\sqrt{NP}$**

> 29.7 is a mathematical constant derived from the natural law of physics for a round opening. To simplify calculations, the factor **30** should be substituted in place of **29.7**.

NOTE: When utilizing the 15/16" smooth bore tip on 200’ of 1 ¾” hose, your pump pressure should be 160 psi, which would give you 185 GPM at 50 psi nozzle pressure. These figures are easily obtained by using the GPM, Friction Loss, and Engine Pressure formulas found in this manual. This shortcut is a known pressure to be utilized with 200' of 1 ¾" hose.

Example 5: A 1 ¼" smooth bore tip at 80 psi will discharge how much?

$$GPM = 30\ (1.25^2)\ \sqrt{80} =$$

$$30 \times 1.5625 \times 9 = 421$$

Note that 1.5625 is rounded to 1.56 and 9 is actually the square root of 81. Rounded numbers are used simply because precisely correct hydraulic calculations on the fireground are not practical or necessary. The difficulty is applying the above formula on the fireground is self-evident. On the fireground the exact number of gallons per minute is not important. We are approximating the flow with rounded numbers. For use on the fireground, the following list of standard flow rates may be used.

15/16"	=	185 gpm @ 50 psi and 210 gpm @ 65 psi	
1"	=	200 gpm	**Hand lines @ 50 psi**
1 1/8"	=	250 gpm	
1 ¼"	=	325 gpm	

1 ¼"	=	400 gpm	**Master Streams @ 80 psi**
1 3/8"	=	500 gpm	
1 ½ "	=	600 gpm	
1 ¾"	=	800 gpm	
2"	=	1000 gpm	

5.8.3 Fog nozzle discharge

5.8.3.1 The Akron Turbojet nozzle is a constant flow, adjustable gallonage nozzle. That is, it is designed to deliver a particular amount of water at a given nozzle pressure. It is also equipped with a selector ring that allows the operator to select the flow desired. The standard setting for the Akron Turbojet nozzle is 150 gpm. The Turbojet is the nozzle used by Fairfax County on the 1 ¾ pre-connected attack lines. These nozzles should be operated at **100 psi** at the nozzle.

5.8.3.2 Arlington County and the Cities of Fairfax and Alexandria use the Elkhart Chief nozzle which is a low pressure, constant flow nozzle. Arlington County Fire Department uses a 150 GPM nozzle, Alexandria uses a 175 GPM nozzle, and the City of Fairfax uses a 200 GPM nozzle. All these nozzles are designed to operate at a nozzle pressure of **75 psi**.

5.8.3.3 The Airport Authority Fire Department uses Task Force Automatic Nozzles.

5.8.3.4 The Elkhart “Chief” nozzle is a constant flow nozzle that is used as part of Fairfax County standpipe packs. This nozzle is designed to deliver 150, 175, or 200 gpm at a nozzle pressure of 75 psi. The specific nozzles and hose loads used by each department are found in section 4.12.

5.8.3.5 The fog nozzle available for use on 2 ½-inch lines is also typically a Turbojet. This nozzle should be set to deliver 250 gpm at a nozzle pressure of 100 psi.

5.9 FRICTION LOSS

5.9.1 Factors affecting friction loss in hose lines.

5.9.2 All things being equal, friction loss will vary directly with the length of hose. For example, if there is 20 pounds of friction loss in 100 feet of hose, there will be 40 pounds of loss in 200 feet of hose, provided the flow remains the same.

5.9.3 For the same size hose, the friction loss will increase exponentially as the quantity of the water flowing increases. What that means to the pump operator is simply that if the officer asks for an increase in the amount of water, you cannot assume the friction loss will increase by the same amount.

5.9.3.1 If the quantity of water flowing in a hose is doubled, the friction loss will be four times greater.

5.9.3.2 If the quantity in a hose is tripled, the friction loss will be 9 times greater.

Example: Assume a hose line is delivering 100 gpm through 200 feet of hose and the friction loss is 20 pounds. If the flow rate is increased to 200 gpm, the friction loss would increase to 80 psi.

5.9.4 For the same discharge, friction loss varies inversely as the fifth power of the diameter of the hose. This principle proves the advantage of using larger hose to reduce friction loss.

Example 6: One hose line 1" in diameter, flowing the same quantity as another hose line 3" in diameter. Friction loss in the 3" hose is:

$$({}^{1}/_{3})^{5} =$$

$${}^{1}/_{3} \times {}^{1}/_{3} \times {}^{1}/_{3} \times {}^{1}/_{3} \times {}^{1}/_{3} =$$

1/243rd that of 1" hose.

5.9.5 At a given quantity of flow, friction loss (FL) is nearly independent of pressure. The velocity of water through a hose line, **not pressure**, causes friction loss.

5.9.6 Other factors affecting friction loss in hose lines include:

- Rough linings in the hose
- Sharp bends or kinks
- Improperly seated gaskets
- Appliances
- Partially closed valves

5.10 CALCULATING FRICTION LOSS IN HOSE LINES

5.10.1 Fireground activities often prohibit the use of complex formulas to calculate the exact pump pressure. Because of existing conditions and lack of available time, it is necessary to utilize condensed formulas and rules of thumb for determining friction loss calculations at the fire scene.

5.10.2 Friction loss coefficients for the hose sizes used in Northern Virginia are as follows:

1 3/4-inch hose	= 15.5
2-inch	= 8
2 1/2-inch	= 2
3-inch	= 1 (rounded up from .8)
3 1/2-inch	= 0.34
4-inch	= 0.2

NOTE: Some manufacturers of hose used in Northern Virginia have made claims that friction loss coefficients are different in their hose. Tests of hose that has been in service have shown that these claims have not always held true.

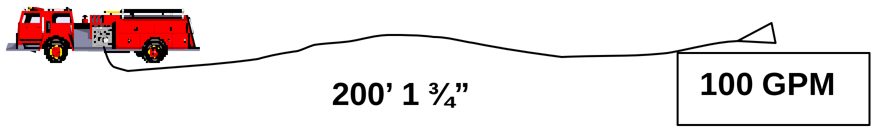
5.10.3 The standard formula for calculating friction loss is:

$FL = C \times Q^2$ per 100’ where “C” = coefficient

5.10.3.1 Friction loss in 1 ¾" hose

FL = 15.5 x Q^2 per 100 feet of hose (Q = gpm ÷ 100)

Example 7:



FL = 15.5 x Q^2 per 100'

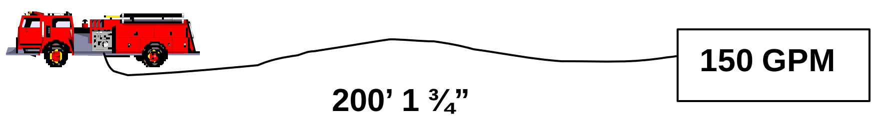
= 15.5 x (1 x 1)

= 15.5 x 1

= 15.5 x 2 (200' feet of hose)

= 31 psi

Example 8:



FL = 15.5 x Q^2 per 100'

=15.5 x (1.5 x 1.5)

= 15.5 x 2.25

= 34.87

= 34.9 x 2 (200' of hose)

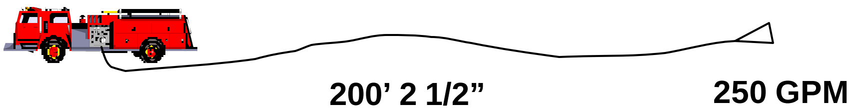
= 69.8 psi

This is rounded to 70 psi

5.10.3.2 Friction loss in 2 ½ " hose

FL **= $2Q^2$ per 100 feet of hose (**Q = gpm ÷ 100)

Example 9



F.L. = $2Q^2$ per 100'

= 2 x (2.5 x 2.5)

= 2 x 6.25

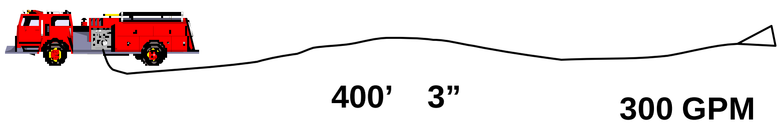
= 12.5 x 2 (200’ of hose)

= 25 PSI

5.10.3.3 Friction loss in 3" hose

FL **= Q^2 per 100 feet of hose**

Example 10:



F.L. = Q^2 per 100'

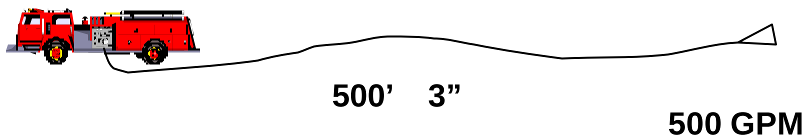
= 3^2 or (3 x 3)

= 9

= 9 x 4 (400' of hose)

= 36 PSI

Example 11:



F.L. $= Q^2$ per 100'

$= 5^2$ or (5×5)

$= 25 \times 5$ (500' of hose)

$= 125$ PSI

5.11 Multiple supply lines

5.11.1 The friction loss in multiple supply lines is determined as follows:

5.11.2 When two lines are of equal size (diameter) and length, the procedure is to divide the total flow in half and figure the friction loss for one line. Pump both lines at that PDP.

5.11.3 When three lines of equal diameter and length, the procedure is to divide the total flow by three and figure the friction loss for one line. Pump all three lines at that PDP.

5.12 Friction loss in appliances

5.12.2 The appliance itself also causes additional resistance to the flow of water, which increases friction loss. Experience has shown that the following pressures will overcome friction loss in appliances:

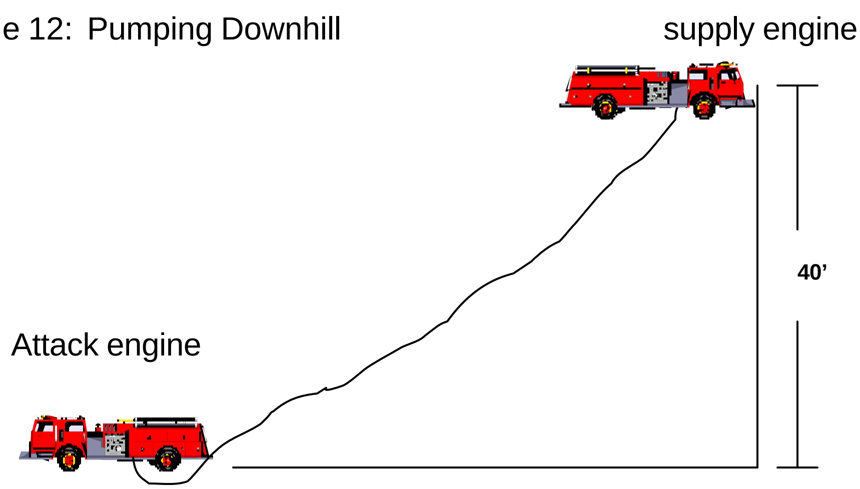
- **5 psi loss** – small appliances such as gated wyes and siameses. For flows greater than 350 gpm add 10 psi.
- **10 psi loss** – ladder pipes
- **15 psi loss** – deluge guns unless otherwise indicated

5.13 ELEVATION LOSS AND GAIN

5.13.2 When hose lines are laid to a location that is higher or lower than the pump, an additional factor must be considered. This factor is “back pressure” or “head pressure,” which is the amount of pressure that is exerted against the pump.

5.13.3 In the section on standards and measurements (5.5), we learned that a column of water one foot high and one inch square exerts a pressure of **.434 psi** at its base. Therefore, the same column of water at a height of 10 feet will exert a pressure of 4.34 psi. **For our purposes in fireground operations, round off 4.34 to 5 psi for every 10 feet of elevation above or below the pumper.** When you are pumping downhill or to a location below the pump, subtract rather than add the 5 psi for every 10 feet of elevation.

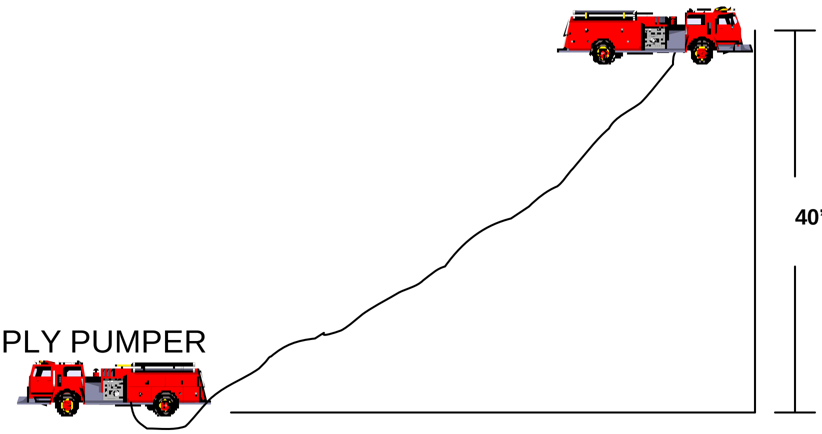
Example 12: Pumping Downhill



40 ft. = 20 psi

EL = <u>SUBTRACT</u> 20 psi.

Example 13: PUMPING UP HILL



40 ft. = 20 psi

EL = ADD 20 psi.

5.14 PUMP OPERATIONS

5.14.1 For our purposes, the **function** an engine performs on the fireground determines whether it is an attack engine or a supply engine.

5.14.2 Attack Engine

5.14.3 Pumping operations are concerned with 5 basic items in obtaining correct PDP.

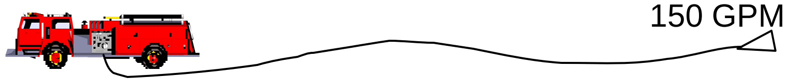
- Nozzle pressure (NP)
- Friction loss in the hose (FL)
- Elevation loss or Gain (EL)
- Friction loss in appliances (AL)
- Maximum safe PDP **250 psi**

5.14.4 Basic Engine Operator's Formula

PDP = NP + FL + /- EL + AL

Example 14:

150 GPM 100 psi



200' 1 ¾"

PDP = NP + FL +/- EL + AL

FL = 15.5 $(Q)^2$ per 100'

= 15.5 x (1.5 x 1.5)

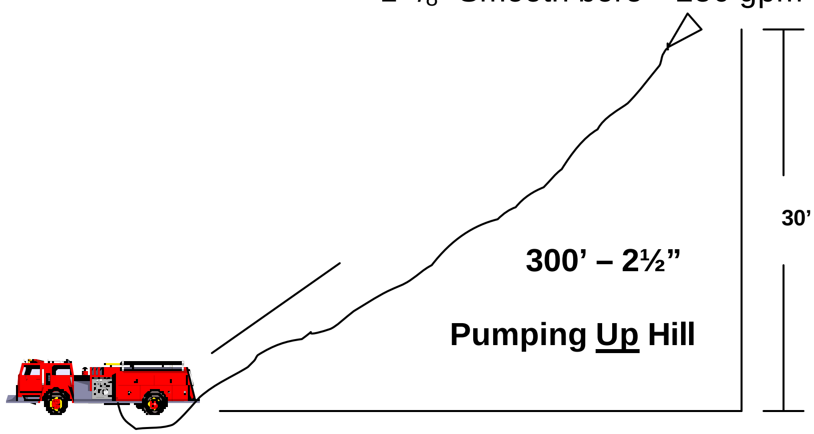
= 15.5 x 2.25

= 35 x 2 (200')

FL = 70 psi

PDP = 100 + 70 + 0 + 0 = 170

Example 15:



PDP = NP + FL +/- EL + AL

FL = 2 $(Q)^2$ per 100'

= 2 x (2.5 x 2.5)

= 2 x 6.25

= 12.5 x 3 (300' of hose)

FL = 37.5

PDP = 50 + 37.5 + 15 + 0

= 102.5 psi (Round to 105 for pumping)

5.14.5 Supply Engine Operations

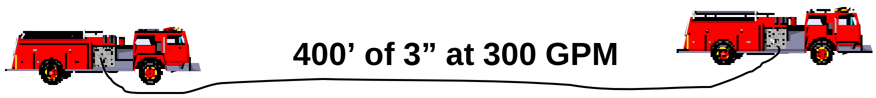
5.14.5.1 The 5 items that regulate the PDP that a supply engine should pump are:

- Residual pressure of no less than 20 psi is desired.
- Friction loss in hose lines between the attack and supply engines (FL)
- Elevation loss or gain (EL)
- Appliance loss (AL)
- **Maximum safe PDP is 250 psi.**

5.14.5.2 The basic pump operator’s formula is slightly modified to reflect the fact that in this case there is no nozzle pressure to use, rather it is residual pressure. The formula, then, is:

PDP = RP + FL +/- EL + AL

Example 16:



PDP = RP + FL +/- EL + AL

= 20 + FL + 0 + 0

FL = Q^2 per 100'

= $(3)^2$

= 9

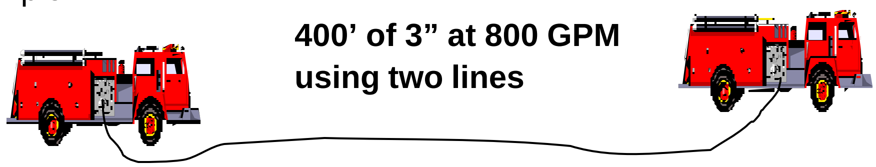
= 9 x 4 (400')

= 36 psi

= 20 + 36

= 56 psi PDP (round to 55 psi for pumping)

Example 17:



Dual Lines, Equal Diameter **800 ÷ 2 = 400 GPM each line**

PDP = RP + FL +/- EL + AL

FL = $(Q)^2$ per 100'

= 4 x 4

= 16 x 4 (400')

= 64 psi

= 20 + 64 + 0 + 0

= 84 psi (Round to 85 psi for pumping)

5.15 STANDARD OPERATING PRESSURES AND STARTING PRESSURES

5.15.1 Standpipe operations

5.15.1.1 Standpipe operations involve an extra factor in addition to the ones previously studied, which is friction loss in the standpipe. In layouts involving hose lines and building systems, the PDP must be sufficient to:

- Overcome friction loss in the attack line
- Provide the proper nozzle pressure
- Overcome the elevation loss in the standpipe
- Overcome the friction loss in hose lines to the siamese
- Overcome the friction loss in the siamese, standpipe, and riser valve.

5.15.1.2 **In Fairfax County and the City of Fairfax:**

- **Start water into a standpipe system immediately upon arrival on the scene and without orders to 150 psi PDP**. One line should be connected to the siamese and charged. Then **every additional siamese shall be supplied**.

- Maximum PDP is 250 psi.
- Once water is flowing, refer to the High-Rise Standpipe Operations PDP chart in section. The pump operator can follow this chart and adequate volume and pressure will be delivered to the siamese outlets.

5.15.1.3 The following chart is provided as a reference for engine operators for Fairfax County and Fairfax City pumping standpipe operations. Note that it is assumed that each hand line off of the standpipe connections is 200 feet long.

REQUIRED ENGINE PRESSURES FOR STANDPIPE OPERATIONS

100 feet of 2 ½ and 100 feet of 1 ¾ " Hose			**200 feet of 2 ½ "Hose**	
FLOOR #	**PSI**		**FLOOR #**	**PSI**
1-5	**160-170**		**1-5**	**100**
6-10	**200**		**6-10**	**125**
11-15	**225**		**11-15**	**150**
16 & UP	**250**		**16-20**	**175**
			21-25	**200**
			26-30	**225**
			30 & UP	**250**

All pressures were calculated to the siamese.
NOTE: For fires above the 20th floor, pump at 250 psi and utilize the smooth bore nozzle.

5.15.1.4 **In Alexandria:**

- **Start water into a standpipe system immediately upon arrival on the scene and without orders to 170 psi PDP**. One line should be connected to the siamese and charged. Once the siamese is charged, calculate the elevation loss and add 5 psi for every floor above grade level. . Then **every additional siamese shall be supplied**.
- The friction loss in the hoseline being used then needs to be added to this total.

5.15.1.5 **In Arlington:**

- **Start water into a standpipe system immediately upon arrival on the scene and without orders to 150 psi PDP**. One line should be connected to the siamese and charged. Once the siamese is charged, calculate the elevation loss and add 5 psi for every floor above grade level. . Then **every additional siamese shall be supplied**.
- The friction loss in the hoseline being used then needs to be added to this total.

Example 18: Fire Reported on the 9th Floor

150 + 40 (8 floors above siamese x 5) = 190 PSI Pump Pressure

EXAMPLE 19: Fire Reported on the 15th Floor

150 + 70 (14 floors above the siamese x 5) = 220 Pump Pressure

NOTE: For fires located above the 20th floor the $^{15}/_{16}$" smooth bore nozzle should be utilized to provide a sufficient fire stream at or near 185 GPM. This procedure will ensure proper NP for the various standpipe packs used.

5.15.1.6 **If an inline gauge is available control of the outlet discharge pressure can be accurately controlled to match the configuration of the attack line.**

5.15.2 Sprinkler systems

5.15.2.1 Sprinkler systems present a complex array of considerations when attempting to determine the exact PDP. Due to the necessity of adequately supplying a sprinkler system early in a fire situation, a standard operating pressure has been assigned.

5.15.2.2 **Standard starting PDP for sprinkler systems is 150 psi**. This pressure is capable of providing adequate supply to the system without the danger of over pressurizing the system and causing damage to the piping.

5.15.2.3 **<u>Charge sprinkler systems when there is smoke or fire showing or upon confirmation of a working fire.</u>** As with a standpipe system, one line should be connected to the siamese and charged. All other siamese intakes must then be supplied.

5.15.3 Combination systems

5.15.3.1 Combination systems are those fire protection systems that use the same supply piping for both the standpipe and the sprinkler systems. **<u>These systems should be considered a standpipe and supplied and charged immediately upon arrival on the scene and without orders</u>**. Starting pressure for combination systems is also **150 psi**. **<u>In Alexandria, the starting pressure is 170 psi.</u>**

5.15.3.2 In all cases, once the siamese is charged to the starting pressures, the procedures for supplying standpipes as described previously shall be followed.

5.16 Relay operations

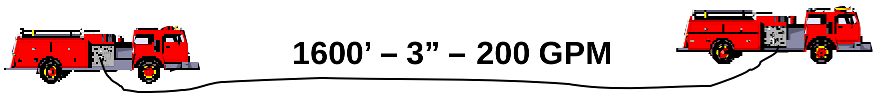
5.16.1 Relays are defined as 2 or more engines that are in line between the water source and the nozzle. Attack engine and supply engine evolutions are the most commonly encountered relay operations. As previously stated, to calculate the proper PDP for the supply engine, there are 5 necessary factors to be considered:

- RP (**minimum of 20 psi**)
- FL
- EL
- AL
- Maximum PDP of 250 psi

5.16.2 This information is often unknown during the early stages of fireground operations. Due to the importance of getting water flowing early in such operations, a starting pressure has been established until proper operating pressures can be calculated. It is important, however, for the attack engine's operator to advise the supply engine of the amount of water being discharged. Equally important is for the supply engine's operator to know the length of the supply line(s) being pumped.

5.16.3 **The starting PDP for a relay operation is 100 psi.** The friction loss in 3" hose allows a wide margin of flow and hose length combinations and still is within the starting pressure limits. This does not eliminate the need for engine operator's to calculate PDP and adjust accordingly.

Example 22:



EP = RP + FL +/- EL + AL

FL = $(Q)^2$ per 100'

= $(2)^2$ x 16 (1600 feet of hose)

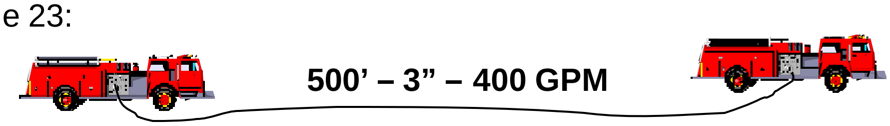
= 4 x 16

= 64 psi

PDP = 20 + 64 + 0 + 0

= 84 PSI (Round to 85 psi for pumping

Example 23:



EP = RP + FL +/- EL + AL

FL = $(Q)^2$ per 100'

= $(4)^2$ x 5 (500 feet of hose)

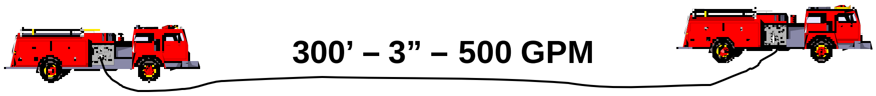
= 16 X 5

= 80 psi

PDP = 20 + 80 + 0 + 0

= 100 PSI

Example 24:



EP = RP + FL +/- EL + AL

FL = $(Q)^2$ per 100'

= $(5)^2$ x 3

= 25 X 3 (300 feet of hose)

= 75 psi

PDP = 20 + 75 + 0 + 0

= 95 psi

5.17 ELEVATED MASTER STREAMS (Ladder pipes and tower ladders)

5.17.1 One of the most important uses of an aerial unit is to provide an elevated stream for fire attack and exposure protection. Elevated streams can be effectively directed into or onto the upper portions of tall buildings, which are beyond the reach of ground mounted devices. These ground or apparatus mounted devices are usually only effective to about the third floor. Heavy streams from aerial devices (especially tower ladders) can also be very effective in controlling volume fires on the lower or ground floors.

5.17.2 When setting up aerial devices, consideration must be given to wind direction and exposure protection. Officers should anticipate the need for elevated master streams during escalating fires. Consideration should be given to initial truck placement for rescue, ventilation, access and the potential need to relocate for ladder pipe operations. If possible, spot the apparatus for current tactical assignments and future needs. Building collapse may be a possibility, so the truck and personnel should be placed outsider the potential collapse zone.

5.17.3 Aerial units should be provided with their own supply engine with not more than 250 feet between the engine and the truck. If a hydrant is not available within that distance, another engine should be used to relay water to the unit supplying the aerial. When requesting a truck for master stream operations, consideration should be given to requesting an additional engine to be dedicated to the truck for water supply. At least two 3" supply lines should be used to supply the aerial device.

5.17.4 There are 5 factors that will determine the correct PDP when supplying a ladder pipe:

- NP
- FL in hose between the siamese and the ladder pipe OR if you are supplying a pre-piped ladder pipe, do not calculate any friction loss.
- FL in appliances (ladder pipe and the siamese)
- EL (ladder height)
- FL in hoses between the siamese the engine.

5.17.5 Clamp-on ladder pipes use 3 or 3 ½-inch hose. When supplying one of these appliances, use 150 psi PDP as a starting pressure and confer with the truck operator for more specific pumping information. If needed, the formula for calculating FL in 3 ½" hose is **$^{1}/_{3}$ (Q^2) per 100 feet of hose**. A constant that can be used is to figure 40 psi of FL in the 3 ½" hose when flowing 1000 gpm.

5.17.6 For fireground operations, use 150 psi as the starting pressure for supplying any ladder pipe or tower ladder. Once water has been started, the correct PDP should be calculated after conferring with the truck operator.

5.17.7 If the engine is supplying a tower ladder (TL), once the pressure calculations have been completed, the engine operator should confirm with the tower ladder operator that the bucket crew is receiving the necessary pressure. Tower ladders have a gauge at the nozzle in the platform. The driver of the TL should be positioned at the turntable. If at all possible, check with that member face to face. The TL crew can communicate over their intercom, thus keeping this communication off of the radio.

Example 25: You are supplying a ladder pipe that is using a 1 ½" tip and the ladder is raised 40 feet. There are two 3-inch lines between the engine and the siamese. The formula for this situation is:

EP = NP + FL (3 ½ hose) + AL (siamese and ladder pipe) + EL + FL (dual 3" lines)

NP = 80

FL = 12 $(^1/_3 (Q^2) = {}^1/_3 (6)^2 = 12$

AL = 15 10 psi for the ladder pipe and 5 psi for the siamese

EL = 20

FL = 9 Split the flow and calculate for one line

EP = 136 (Round to 135 psi for pumping)

5.17.8 The tip sizes that are carried on ladder pipes and tower ladders include sizes 1 $^{3}/_{8}$", 1 ½ ", 1 ¾ ", and 2". The fog nozzles have an operating range of 350 to 1500 gpm.

5.17.9 The following is a list of procedures that are common to all ladder pipe operations, regardless of the type of aerial device.

- The engine should be within 250 feet of the siamese for supply.
- Use a minimum of 2 supply lines for aerials, 3 for tower ladders.
- Charge lines slowly and gradually increase pressure.
- Charge lines on orders of the truck OIC.
- Shut down lines gradually, not abruptly.

5.18 PENETRATION AND EFFECTIVE STREAMS

5.18.1 Penetration refers to an effective hose stream reaching a predetermined and desired distance into a building. When using the term “effective fire stream” there are several “text book” definitions. However, **an effective fire stream of water is defined as a stream of water that consists of the correct amount of water, in the proper configuration, with adequate reach that will safely extinguish the fire.**

5.18.2 To find out the amount of penetration the stream is producing or to determine where you must place the nozzle for proper penetration, use the following quick method:

- Divide the horizontal distance between the nozzle and the building by the story into which the stream is to be directed. When the nozzle is elevated into an upper story by an aerial or tower ladder or other means, the story that is horizontally on a line with the nozzle shall be considered “ground level” and all calculations made from that point. <u>Remember to count the ground floor as number one. This contradicts the procedures for standpipe pressure calculations and elevation loss calculations when pumping to handlines on floors above ground level. This is where most mistakes are made in this problem.</u>

5.18.3 In order to achieve maximum penetration into a structure, the stream must enter a window or other opening at the lowest point in that opening at about a 30^{o} angle.

5.19 CALCULATING ADDITIONAL WATER AVAILABLE FROM HYDRANTS

5.19.1 The ability for the pump operator to calculate the available flow from a hydrant is an essential part of the overall role of the pump operator. Regardless of the size of the fire, pump operators should know the amount of water available from a particular hydrant when pumping during an incident. A minimum of 10 psi residual pressure should be maintained when pumping from a hydrant.

5.19.2 The following methods can be used to calculate additional water from a hydrant.

5.19.2.1 When a pumper is connected to a hydrant and not discharging water, the pressure on the intake gauge is the static pressure. This pressure reading alone tells nothing about the capacity of the hydrant! After the pumper begins discharging water, the intake gauge reading becomes the flow pressure. The difference between the static and flow pressure is known as residual pressure.

5.19.2.2 To determine how much water is available from a hydrant, the percent decrease in pressure must be calculated. This can be done by using the formula:

$$\text{\% decrease in pressure} = \frac{(\text{static} - \text{flow}) \times 100}{\text{static}}$$

After determining the percent of decrease of pressure, apply the following table:

% Decrease of pressure	Additional water available
0 – 10%	3 times the original amount
11-15%	2 times
16-25%	1 time
> 25%	More water may be available but less than an equal amount of the original gpm.

Example 26: A pumper is supplying on line with 250 gpm. The static pressure was 80 psi and the flow pressure is 75 psi. How much more water can this hydrant deliver?

$$\% \text{ Decrease of pressure (psi)} = \frac{(80 - 75) \times 100}{80}$$

$$= \frac{5 \times 100}{80}$$

$$= \frac{500}{80}$$

$$= 6.25\%$$

Since 6.25% falls between 0 and 10%, this hydrant can be expected to deliver at least 3 more time the original amount flowing. In this case, the original amount was 250 gpm. Therefore, the hydrant can be expected to flow an additional 750 gpm for a total of 1000 gpm.

5.20 NOZZLE REACTION

5.20.1 Nozzle reaction is based upon the principle: “For every action, there is an equal and opposite reaction.” As water leaves a nozzle under pressure, it causes a force in the opposite direction. The amount of this reaction depends upon the size of the nozzle tip and the pressure, and is due to acceleration of water in the nozzle. The maximum recommended nozzle reaction for a ladder pipe mounted on the fly section is 400 psi. In order to find out what this pressure is, the formula when utilizing a smooth bore tip is:

$$NR = 1.5 \times D^2 \times NP$$

NR means “nozzle reaction” measured in psi.

NOTE: It is recognized that pump operators are not likely to have the need to calculate nozzle reaction on the fireground. However, this information is provided in order for pump operators to have an understanding of nozzle reaction and to appreciate the forces developed by the flow of water. Pump operators must be cognizant of nozzle reaction, particularly when supplying heavy caliber streams and take extreme care to calculate PDP properly. Over pressurizing hand lines and master streams can lead to dangerous reaction pressures and injuries to firefighters.

Example 29: 1 ½" tip operating at 80 psi

NR = 1.5 x (1.5^2) x 80

= 1.5 x 2.25 x 80

= 270 psi.

5.20.2 Nozzle reaction is less severe with fog nozzles because the water leaves the nozzle at an angle, which tends to cancel out some of the reactionary forces. The reaction will be greatest at the straight stream setting. The formula for nozzle reaction for fog nozzles is:

NR = .0505 x Q x vNP

Example 27: Fog nozzle flowing 750 gpm at 100 psi

NR = .0505 x 750 x v100

= .0505 x 750 x 10

= 378 psi

5.20.3 An easy rule of thumb for estimating the nozzle reaction from a fog nozzle is to use NR = ½ (gpm). Using example 27, ½ of 750 is 375.