FIRE DEPARTMENT HYDRAULICS

BASIC CONCEPTS & FORMULAS

WATER MEASUREMENTS

1 Cubic foot of water weighs	62.5 pounds
1 Cubic foot of water contains	1,728 cubic inches
1 Cubic foot of water contains	7.5 gallons
1 Gallon of water contains	8.35 pounds
1 Gallon of water contains	231 cubic inches

HEAD AND ATMOSPHERIC PRESSURE

1 foot of water exerts a back pressure of 0.434psi

EXAMPLE: When working from a standpipe at a point 100 feet above the street, the engineer must provide 43.4psi to overcome the back pressure from the elevation. In addition, the engineer must provide pressure necessary to overcome friction loss and provide nozzle pressure.

1psi will elevate water 2,304 feet

Atmospheric pressure at sea level is 14.7psi

Theoretically, the maximum lift for drafting would be 34 feet

This is determined by taking the atmospheric pressure (14.7psi) multiplied by the number of feet each psi lifts water (2,304 feet) to give 33.87 (34 feet). Practically speaking, lifts over 20 feet should not be attempted.

1" mercury (inches of vacuum) = 1.13 feet of lift

ESTIMATING AVAILABLE WATER FROM A HYDRANT

A recommended minimum of 10psi* should be maintained on the compound gauge when taking water from a hydrant.

*This varies from recommendations in *IFSTA Pumping Apparatus, Driver/Operator Handbook*, *1st Edition*

The terms "static pressure" and "residual pressure" are familiar to every firefighter. However, the difference between them is all too often not properly understood. Static pressure, we say, is the pressure that exists on a given hydrant when no water is flowing. This pressure is the same pressure that is available at the water source. Whether the source be a gravity tank or a pumping station is not important.

Once the hydrant is open and a flow of water is present, a drop in pressure will occur. This drop in pressure is due to the friction loss that is now occurring in the water main system between the water source and the pump. The larger the water main between the source of supply and the hydrant equals less friction loss. The remaining pressure on the main is that which we term residual pressure.

Since we have friction loss on the suction side also, we again must consider the same factors as we considered on the discharge side.

The farther the pumper in use is from the hydrant, the less usable pressure due to increased friction loss. The faster the water is moving (velocity), the greater the loss. If the flow from the hydrant is doubled, the friction loss will be 4 times as great.

It is this factor that will enable the pump operator to tell how many lines the available water pressure will enable him/her to handle.

EXAMPLE: The intake compound gauge showed 70psi before any lines are charged (static pressure) and a 2½" line with a 250 GPM fog nozzle is then charged and the intake pressure drops to 67psi. This indicates the friction loss between the source of supply and the pump intake is 3psi with 250 GPM flowing. By applying the factor – friction loss varies as the $(\text{flow})^2$ – it is simple to calculate the number of lines of the same size the hydrant can supply.

LINE²	GPM	CALCULATION FOR PSI LOSS
1	250	3
2	500	Flow is twice the original – $(2)^2$ = 4 x 3psi drop = 12
3	750	Flow is triple the original – $(3)^2$ = 9 x 3psi drop = 27
4	1000	Flow is 4 times the original – $(4)^2$ = 16 x 3psi drop = 48
5	1250	Flow is 5 times the original – $(5)^2$ = 25 x 3psi drop = 75
		The pressure required for 5 lines is greater than the available pressure and cannot be supplied.

Thus by noting the static pressure reading and applying the numbers 4, 9, 16 or 25 to the pressure drop of the first line, a Fire Apparatus Engineer can determine how many more lines of the same flow he/she can apply.

As can be seen from the example, the Fire Apparatus Engineer could supply 3 additional or more 250 GPM lines for a total of 4 – 250 GPM lines with a residual pressure of approximately 22psi.

In estimating available water, two things must be considered:

1. Quality/quantity of the water supply system
2. Fire department connections to the system

Although the following method can give inference to both, the primary concern is the water available for firefighting, as the fire engineer has connected to the system.

The method employed uses the **Second Friction Loss Rule**, which states:

"In the same size hose, friction loss varies approximately as the square* of the velocity of flow."

Therefore, if the velocity is doubled, friction loss is quadrupled.

EXAMPLE 1

VELOCITY	**VELOCITY SQUARED**	**#1 DROP**	**TOTAL DROP**
Doubled = 2	4	3psi	12psi
Quadrupled = 4	16	3psi	3psi
Quintupled = 5	25	3psi	75psi

EXAMPLE 2

VELOCITY	**VELOCITY SQUARED**	**#1 DROP**	**TOTAL DROP**
Doubled = 2	4	6psi	24psi
Tripled = 3	9	6psi	54psi
Quadrupled = 4	16	6psi	96psi
Quintupled = 5	25	6psi	150psi

**To square a number, multiply the number times itself*

To Estimate Available Water:

1. Note the static reading
2. Note the drop after discharging the first line
3. Multiply the drop from the first line by the square of the velocity to see if the original flow may be doubled, tripled, etc.
    a. Multiply by 4 if doubling the flow
    b. Multiply by 9 if tripling the flow
    c. Multiply by 16 if quadrupling the flow
    d. Multiply by 25 if quintupling the flow

4. Subtract the total drop from the original static pressure, but do not take the Compound Gauge lower than 10psi
5. Product from #3 and your original flow rate will determine the total flow

COMPONENTS OF A MOBILE WATER SUPPLY OPERATION

A. Apparatus
    a. Tanker/tender
        i. NFPA minimum
            1. 1000 gallon capacity
            2. 750 GPM
        ii. Construction features
            1. Tank capacity and size
            2. Chassis and axle loading
            3. Engine and drive train type and size
            4. Dump and vent size
            5. Pump location and size
            6. Tank type or style
        iii. Use
            1. Combination
                a. Attack
                b. Supply
            2. Shuttle
                a. Dump considerations
                b. Loading considerations
                c. Additional considerations depending on local conditions
            3. Nurse (connected to pumper)

    b. Pumpers
        i. Pump capacity
        ii. Hose carried
        iii. Fittings and adapters
        iv. Use
            1. Pump at water source
            2. Unload tankers (power unload or nurse)
            3. Relay (open or closed)
            4. Fire attack

B. Portable tanks
    a. Function
        i. Reservoir
        ii. Dumping site for tanks
    b. Size
        i. 500-6,000 gallons
        ii. Circular or square
    c. Construction
        i. Folding synthetic
        ii. Floating collar
    d. Use
        i. Position and spotting for dumping and drafting
        ii. Level surface
        iii. Access and turn around

C. Auxiliary equipment
    a. Portable pumps
        i. Light-weight
            1. Easily carried to water source
            2. Minimum manpower required
        ii. High volume at low pressure
    b. Loading and unloading dumps
        i. Special hoses or chutes
        ii. Jet drafts
        iii. Siphons or transfer devices
        iv. Low level strainers
        v. Fill devices
        vi. Cam-lock or quick connect couplings

<u>PUMP TESTS</u>

1. Pre-service tests
    a. Certification test
        i. 2 hour – 100% @ 150psi
        ii. ½ hour – 70% @ 200psi
        iii. ½ hour – 50% @ 250psi
        iv. 10 minutes – 100% @ 165psi (overload or spurt test)
    b. Service test
        i. 20 minutes – 100% @ 150psi
        ii. 10 minutes – 70% @ 200psi
        iii. 10 minutes – 50% @ 250psi

iv. 10 minutes – 100% @ 165psi *(optional)* (overload or spurt test)

A minimum of 10psi should be maintained on the compound gauge when taking water from a hydrant.

- 100% capacity @ 150psi net pump pressure
- 70% capacity @ 200psi net pump pressure
- 50% capacity @ 250psi net pump pressure

COMPUTING NET ENGINE PRESSURE

1. Net Engine Pressure (NEP) is the measurement of the total work performed by the pump
    a. To lift water into the pump
    b. To discharge water from the pump
2. Allowances are made for
    a. Friction loss in intake hose
    b. Height of lift
3. Friction loss factors in hard suction hose and strainer (measured in psi):

RATED CAPACITY OF PUMPER	DIAMETER OF SUCTION HOSE	FOR 10 FEET OF SUCTION HOSE	FOR EACH ADDITIONAL 10 FEET OF SUCTION HOSE
500 GPM	4”	6	Plus 1
	4.5 ”	3.5	Plus 0.5
750 GPM	4.5”	7	Plus 1.5
	5”	4.5	Plus 1
1000 GPM	4.5”	12	Plus 2.5
	5”	8	Plus 1.5
	6”	4	Plus 0.5
1250 GPM	5”	12.5	Plus 2
	6”	6.5	Plus 0.5
1500 GPM	6”	9	Plus 1
	2 – 5”	7	Plus 1
	2 – 6”	2	Plus 0.5
1750 GPM	6”	12.5	Plus 1.5
	2 – 5”	6.5	Plus 1
	2 – 6”	3	Plus 0.5
2000 GPM	2 – 5”	8	Plus 1.5
	2 – 6”	4	Plus 0.5

COMPUTING NET ENGINE PRESSURE WHEN DRAFTING

NEP = Suction Side Work + Discharge Side Work

- Work performed on the discharge side of the pump is indicated on the pump's discharge gauge
- Work performed on the suction side of the pump is determined by computing the following formula:

$$\textbf{Work (psi)} = \frac{\textbf{Lift (in feet) + Intake Hose Friction Loss (psi)}}{\textbf{2.3 feet}}$$

Steps:

1. Determine the lift *(in feet)*
2. Determine the friction loss in the intake hose used
3. Add lift and friction loss together
4. Divide by 2.3 (2.3 is the amount of lift *(in feet)* that 1psi of water pressure will support)

EXAMPLE: A pumper is discharging 1000 GPM at a pressure of 142psi. The pumper is drafting water with a lift of 10 feet through 20 feet of 5" hard suction hose and strainer. What is the NEP?

NEP = Suction Side Work + Discharge Side Work

$$\text{SS Work} = \frac{\text{10 feet + 9.5psi}}{\text{2.3 ft.}} = \frac{\text{19.5 ft. psi}}{\text{2.3 ft.}} = \text{8.47psi}$$

Discharge Side Work = 142psi

NEP = 8.47psi + 142psi

NEP = 150psi

DETERMINING THE PUMP DISCHARGE PRESSURES FOR THE SERVICE TEST

NEP = Suction Side Work + Discharge Side Work

To determine the pump discharge pressures for a service test, the Suction Side Work must be subtracted from the NEP.

Pump Discharge Pressure (PDP) = NEP – Suction Side Work

EXAMPLE: A 1000 GPM pumper is to perform an Annual Service Test. What are the desired readings on the pump discharge gauge for the following tests?

1. 100% capacity test @ 150psi NEP
2. 70% capacity test @ 200psi NEP
3. 50% capacity test @ 250psi NEP

The pumper is using 2 – 10 foot sections of 5” hard suction hose. The pump has been primed. The compound gauge reading is approximately 10” Hg.

Steps:

1. Find the lift (10” Hg x 1.13 feet = 11.3 feet)
2. Find the friction loss in the hard suction hose (5” = 9.5psi)
3. Compute Suction Side Work

$$\text{SS Work} = \frac{\text{Lift + Fiction Loss}}{\text{2.3 ft.}} = \frac{\text{11.3 feet + 9.5psi}}{\text{2.3 ft.}} = \frac{\text{20.8 ft. psi}}{\text{2.3psi}} = \text{9psi}$$

4. Solve for Pump Discharge Pressure (PDP)

	NEP	**SS WORK**	**PDP**
1	150psi	9psi	141psi
2	200psi	9psi	191psi
3	250psi	9psi	241psi

COMPUTING NET ENGINE PRESSURE WHEN THE PUMP IS BEING SUPPLIED BY A POSITIVE PRESSURE WATER SOURCE (HYDRANT)

1. No work is being performed on the suction side of the pump
2. The incoming pressure added to the discharge pressure, produced by the pump, produces the total discharge pressure
3. NEP – the total work performed by the pump. Therefore, the incoming pressure must be subtracted for the discharge pressure (found on the discharge pressure gauge) to find the NEP of the pump

NEP = Pump Discharge Pressure (PDP) – Intake Pressure (IP)

EXAMPLE: A pumper is being supplied by a hydrant. The compound gauge shows a residual pressure of 25psi and the discharge pressure is 175psi. What is the NEP?

NEP = PDP – IP
= 175psi – 25psi
= 150psi

NOTES FOR VARIOUS NOZZLE PRESSURES ON FOG NOZZLES

GPM from fog nozzles at various pressure = Rated GPM x √ Desired Nozzle Pressure x 0.1

EXAMPLES:

250 GPM @ 80psi	120 GPM @ 80psi	120GPM @ 50psi
x 9	x 9	x 9
2250	1080	840
x 0.1	x 0.1	x 0.1
225 GPM	108 GPM	84 GPM

GPM's FROM CIRCULAR OPENINGS

Computing GPM's from circular openings shall use the following formula:

GPM's = $29.7d^2 \sqrt{P}$ Pressure

d= diameter of orifice
P= flow pressure (psi) of discharge stream

HAND LINES & MASTER STREAMS

FAE will consider all flows up to 350 GPM to be considered HAND LINES. All flows over 350 GPM will be considered MASTER STREAMS.

Nozzle Pressures

- Smooth Bore
  - Hand-held = 50psi
  - Master = 80psi
- Fogs *(including fogs on master stream devices)*
  - Most fogs = 100psi

NOZZLE REACTION

Newton's Third Law of Motion, *"For every action there is an equal and opposite reaction."* As water leaves a nozzle under pressure, it causes a reactionary force in the opposite direction. The formula used for calculation of nozzle reaction is $NR = 1.57D^2P$.

Relating to fog nozzles and master stream smooth bore tips, fireground nozzle reaction calculations can be computed at approximately ½ the flow (measured in pounds).

ANGLE OF DEFLECTION AND EFFECTIVE REACH

The reach of fire streams is affected by two variables:

1. Air resistance
2. Gravity

The air resistance increases at an accelerated rate as the pressure is raised with the same tip.

- The greatest horizontal reach occurs at elevations of 30-40 degrees
- Maximum effective vertical reach of a fire stream occurs at 60-75 degrees
- The third floor may be said to be the highest floor to which streams may be thrown effectively from street level. (Casey, pg. 329)

Moderate head and tail winds decrease reach 10-15%.

SOLID STREAM NOZZLES

HAND LINES	50PSI NOZZLE PRESSURE (GPM)	MASTER STREAMS	80PSI NOZZLE PRESSURE (GPM)
1”	200	1 ¼”	400
1 ⅛”	250	1 ⅜”	500
1 ¼”	300	1 ½”	600
		1 ⅝”	700
		1 ¾”	800
		1 ⅞”	900
		2”	1000

ONE-EIGHTH (⅛”) RULE

⅛” change in nozzle diameter at 50psi nozzle pressure changes the flow by approximately 50 GPM.

⅛” change in nozzle diameter at 80psi nozzle pressure changes the flow by approximately 100 GPM, up to and including 2” tips.

FRICTION LOSS FORMULAS FOR 100 FEET OF HOSE

HOSE DIAMETER	FRICTION LOSS FORMULA
1 ½”	The FL in 2 ½” hose at 4 times the stated GPM
1 ¾”	$(10 Q^2) + 10$
2”	$(2 Q^2 + Q) \times 3$
2 ½”	$(2 Q^2 + Q)$
3”	$(2 Q^2 + Q) \times 4$
3 ½”	$(2 Q^2 + Q) \times 0.17$
4”	$(2 Q^2 + Q) \times 0.1$
4 ½”	$(2 Q^2 + Q) \times 0.05$
5”	$(2 Q^2 + Q) \times 0.03$

**Q = GPM divided by 100*

EXAMPLE:

1 ½” hose flowing 100 GPM
x 4
2 ½” hose = 36psi =400 GPM

FRICTION LOSS – 1 ½" HOSE

To help simplify the computing of the friction loss in 1 ½" hose, the FAE Committee has accepted a standard GPM and friction loss commonly used in the fire service (200 GPM and 30psi per 100 feet of hose). This standard will be used when teaching this course and for any testing requiring the computing of FL in 1 ½" hose. The instructor may teach additional methods for computing FL in 1 ½" hose, but all FAE testing will only reflect the use of the above standard.

FRICTION LOSS – 1 ¾" HOSE

To help simplify the computing of the friction loss in 1 ¾" hose, the FAE Committee has accepted a standard GPM and friction loss commonly used in the fire service (150 GPM and 32psi per 100 feet of hose). This standard will be used when teaching this course and for any testing requiring the computing of FL in 1 ¾" hose. The instructor may teach additional methods for computing FL in 1 ¾" hose, but all FAE testing will only reflect the use of the above standard.

FIELD HYDRAULICS

- 250 GPM fog nozzle on a 2 ½" line = 15 pounds per 100-feet of friction loss
- 100 GPM fog nozzle on a 1 ½" line = 30 pounds per 100-feet of friction loss
- 150 GPM fog nozzle on a 1 ¾" line = 32 pounds per 100-feet of friction loss

ELEVATION

- Add 5psi for each floor of elevation (exclude one floor)
- Subtract 5psi for each floor below grade

APPLIANCES

- Add 25psi for standpipe system and siamese
- Add 10psi for gated wyes and siamese
- Add 20psi for all master stream devices
- Add 20psi for in-line operations

SPRINKLER SYSTEMS

- Sprinkler systems shall be maintained at 150psi pump discharge pressure
- Calculate the flow from sprinkler heads by using the following formula:
    - Flow (GPM) = ½ pressure (at the sprinkler) + 15

HYDRANT RESIDUAL PRESSURE

- A recommended minimum of 10psi should be maintained on the compound gauge when taking water from a hydrant

FIELD HYDRAULICS

- Pump in CAPACITY when you are going to discharge over 50% of your pumper's capacity
- Pump in PRESSURE when you are going to have to develop a net pump pressure over 200psi

FRICTION LOSS

2 ½" RUBBER-LINED HOSE – POUNDS OF FRICTION LOSS PER 100 FEET

200 GPM	200/100 = 2	2 x (2 x 2) + 2 =	10 pounds
300 GPM	300/100 = 3	2 x (3 x 3) + 2 =	21 pounds
400 GPM	400/100 = 4	2 x (4 x 4) + 2 =	36 pounds – RED LINE
500 GPM	500/100 = 5	2 x (5 x 5) + 2 =	55 pounds
600 GPM	600/100 = 6	2 x (6 x 6) + 2 =	78 pounds
700 GPM	700/100 = 7	2 x (7 x 7) + 2 =	105 pounds
800 GPM	800/100 = 8	2 x (8 x 8) + 2 =	136 pounds
900 GPM	900/100 = 9	2 x (9 x 9) + 2 =	171 pounds
1000 GPM	1000/100 = 10	2 x (10 x 10) + 2 =	210 pounds

3" HOSE – POUNDS OF FRICTION LOSS PER 100 FEET

200 GPM	200/100 = 2	2 x 2 x 2 + (2 x 0.4) =	4.0 pounds
300 GPM	300/100 = 3	3 x 3 x 2 + (3 x 0.4) =	8.4 pounds
400 GPM	400/100 = 4	4 x 4 x 2 + (4 x 0.4) =	14.4 pounds
500 GPM	500/100 = 5	5 x 5 x 2 + (5 x 0.4) =	22.0 pounds
600 GPM	600/100 = 6	6 x 6 x 2 + (6 x 0.4) =	31.2 pounds – RED LINE
700 GPM	700/100 = 7	7 x 7 x 2 + (7 x 0.4) =	42.0 pounds
800 GPM	800/100 = 8	8 x 8 x 2 + (8 x 0.4) =	54.4 pounds
900 GPM	900/100 = 9	9 x 9 x 2 + (9 x 0.4) =	68.4 pounds
1000 GPM	1000/100 = 10	10 x 10 x 2 + (10 x 0.4) =	84.0 pounds

FRICTION LOSS

Red line friction loss = 36 pounds. If friction loss goes over 36 pounds, a second line or larger diameter hose should be used.

	3 ½" HOSE	**4" HOSE**
	$2Q^2 + Q \times 0.17 = FL$	$2Q^2 + Q \times 0.10 = FL$
200 GPM	1.70	1.0
300 GPM	3.50	2.10
400 GPM	6.10	3.60
500 GPM	9.30	5.50
600 GPM	13.20	7.80
700 GPM	17.80	10.50
800 GPM	23.10	13.60
900 GPM	29.0	17.10
1000 GPM	35.70	21.0

	4 ½" HOSE	**5" HOSE**
	$2Q^2 + Q \times 0.05 = FL$	$2Q^2 + Q \times 0.03 = FL$
200 GPM	0.50	0.30
300 GPM	1.05	0.60
400 GPM	1.80	1.0
500 GPM	2.70	1.60
600 GPM	3.90	2.30
700 GPM	5.20	3.10
800 GPM	6.80	4.0
900 GPM	8.50	5.10
1000 GPM	10.50	6.30

COURSE STANDARDS FOR CALCULATING ENGINE DISCHARGE PRESSURES

NOZZLE OR TIP	FLOW	PRESSURE NOZZLE	FRICTION LOSS PER 100 FEET OF HOSE			
			1 ½”	**1 ¾”**	**2 ½”**	**3”**
1 ½”	100 GPM	100psi	30			
1 ¾”	150 GPM	100psi		32		
2 ½”	250GPM	100psi			15	6
1”	200 GPM	50psi			10	4.0
1 ⅛”	250 GPM	50psi			15	6.0
1 ¼”	300 GPM	50psi			21	8.4
1 ¼”	400 GPM	80psi			*36*	14.4
1 ⅜”	500 GPM	80psi			55	22.0
1 ½”	600 GPM	80psi			78	*31.2*
1 ⅝”	700 GPM	80psi			105	42.0
1 ¾”	800 GPM	80psi			136	54.4
1 ⅞”	900 GPM	80psi			171	68.4
2”	1000 GPM	80psi			210	84.0

**RED LINE*

FORMULA FOR ENGINE PRESSURE CALCULATIONS

DP = NP + FL + AFL + E

Pump Discharge Pressure (DP) = Nozzle Pressure (NP) + Friction Loss (FL) + Appliance Friction Loss (APL) + Elevation (E)

- Relays – maintain 20psi for receiving pumper
- Hydrant Residual – maintain 10psi from hydrant
- Wyes/Siamese – 10psi loss
- Standpipe Systems – 25psi loss
- Master Stream Devices – 20psi loss
- Elevation – 5psi per floor (exclude one floor) or ½ psi per foot

SUPPLY & SUPPORT OF SPRINKLERS & STANDPIPE SYSTEMS

The following are suggested methods to indicate if you're not getting into a sprinkler or standpipe system with a supply line.

A. In warm, humid weather, the lack of condensation on the hose coupling attached to the discharge port supplying this line
B. The discharge port and hose butt supplying this line is or becomes warm
C. Lack of a drop in the residual pressure as read on the compound gauge as this line is charged
    a. Once the supply line is full, there is no further movement of water
D. The inability to gate and feather various pressures on the discharge port to which this line is attached
    a. The third principle of fluid pressure, "Pressure applied to a confined fluid from without is transmitted in all directions without diminution."

NOTE: Methods A and B may not be readily apparent or the best indication, especially if the pumper is supplying additional lines which are already flowing.

SUPPLYING A STANDPIPE SYSTEM WHEN THE FIRE DEPARTMENT CONNECTION IS NOT USABLE

When the fire department connection (siamese) supporting a standpipe system is not usable; and the check valve below the fire department connection (siamese) is inoperative, the following procedure should be followed:

1. Stretch a line from the pumper to a gated outlet on the first floor
2. Remove any house lines, reducer connections and/or pressure reducers
3. Connect the pumper supply line to the discharge outlet using a double female adapter
4. When the water is started in the supply line, the outlet valve is opened fully to allow water to flow into the riser
5. Where the hose outlet extends at a right angle from the riser, the weight of the hose and fittings should be supported by a short length of rope
6. If necessary, additional lines can be similarly stretched to hose outlets on other floors

When the fire department connection (siamese) has a frozen swivel, placing a double male and double female adapter on the connection can overcome this difficulty.

SIAMESE OPERATIONS

When it becomes necessary for a pumper to deliver large quantities of water, a siamese operation will be needed. Siamesing lines is one way of reducing the excessive friction loss created by large volume flows. Though it may look difficult to compute, it is actually no harder than a single line.

When it becomes necessary to siamese, divide the GPM by the number of lines that pump is supplying. Next, compute the friction loss for one line at the reduced GPM flow and disregard the other lines. All that remains is to add either the Nozzle Pressure if supplying a deluge gun or 20psi for residual pressure if supplying another engine.

EXAMPLE: It is necessary to supply a deluge set with a 1¾" tip from 400 feet away. This lay would require 800 GPM which would create 55 pounds FL per 100 feet in 3" hose; therefore, siamesing is necessary.

EQUAL SIZE LINES

1. Divide the total GPM by two lines. This will five 400 GPM through each line.
2. Compute the friction loss for one line of 3" hose delivering 400 GPM
    a. 4 x 4 x 2 + 4 = 36 x 0.4 = 14.4 or 15 pounds of FL per 100 feet of hose
3. Multiply the FL for 100 feet by the length of the lay in hundreds of feet
    a. 15 x 4 = 60psi FL for the total lay
4. Add 80 pounds NP to the 60 pounds FL = 20 pounds approximate loss for the deluge set and this will be the engine discharge pressure
    a. 60 + 80 + 20 = 160 pounds engine pressure

EXAMPLE: If, in the above lay, it was necessary to use a 2½" and a 3" line, FL would be computed just a bit differently.

UNEQUAL SIZE LINES

1. Divide the total GPM by two lines; this will give 400 GPM through each line
2. Compute the friction loss for one line of 2½" hose delivering 400 GPM
    a. 4 x 4 x 2 + 4 = 36 pounds FL per 100 feet
3. Compute the friction loss for one line of 3" hose delivering 400 GPM
    a. 4 x 4 x 2 + 4 = 36 x 0.4 = 14.4 or 15 pounds FL per 100 feet of hose
4. Add the two FL answers together and divide by two
    a. 36 + 15 = 51/2 = 14.4 or 15 pounds FL per 100 feet of hose
5. Multiply the FL for 100 feet by the length of the lay in hundreds of feet
    a. 25 x 4 = 100 pounds FL for the total lay
6. Add 80 pounds NP to the 100 pounds FL + 20 pounds approximate FL in the deluge set
    a. 100 + 80 + 20 = 200 pounds engine pressure

"RULE OF THUMB" for siamese of unequal size, but of equal length (2½"-3")

1"-2 ½" & 1"-3" SIAMESE LINES	
TOTAL GPM	**FL PER 100 FEET**
500	10
600	15
700	20
800	24
900	30
1000	40

WYE OPERATIONS

Wye operations are very common and are used in one way or another on just about any fire of consequence. Sometimes they are used to get 1½" hand lines to the fire where the reach is too long for a pre-connect. On most large fires, they are used for overhaul from 2½" lines rather than laying longer and/or additional lines of 1½". Another use would be to get two 2½" lines on a fire from one 3" supply line.

Wye operations, like siamese operations are used to reduce friction loss. By the use of a wye, one may have one large supply line feeding two or more smaller hand lines.

EXAMPLE: 400 feet of 2½" hose wyed to two 200 foot lines of 1½" hose.

1. Total the GPM from both 1½" lines. This is the amount of water for which the supply line must be computed
   a. 100 GPM + 100 GPM = 200 GPM for both 1½" lines
   b. Therefore, the 2½" supply line is flowing 200 GPM
2. Compute the friction loss for the supply line
   a. 2 x 2 x 2 + 2 = 10 pounds FL for 100 feet of hose
3. Compute the friction loss for the supply line
   a. 30 pounds FL per 100 feet = 60 pounds total (disregard the second line)
4. 40 pounds FL for the 2½" supply line
   60 pounds FL for the 1½" hand line
   100 pounds NP
   \+ 10 pounds for the wye
   ___
   210 pounds Engine Discharge Pressure

The lay would give 200 GPM through two 1½” lines 600 feet from the engine. The engine would be running at a discharge pressure of 210 pounds.

If there were two 1½” lines each 600 feet in length, the discharge pressure would be 280psi and the engine would be running at excessive RPM for the job.

FRICTION LOSS CALCULATIONS FOR ELEVATED STREAMS FROM PRE-PIPED WATERWAYS

When it is necessary to supply a pre-piped waterway, there are some basic facts the FAE will have to know:

1. It is necessary to supply the water to the pump inlets or aerial intake when by-passing the pump and supplying the total operation
2. It is necessary to know the size tip that is intended for use in order to calculate pressure, determine the number of lines required and their diameter

Since the waterways on pre-piped aerials are made of pipe, the following constants are used to determine the friction loss in the piping, master stream at different gallon flows.

The friction loss factor for pre-piped waterways will include the friction loss in the:

1. Piping
2. Turret gun
3. Intake at the GMP flow provided

For course and testing purposes, the Fire Apparatus Engineer Committee has accepted a standard flow for pre-piped waterway of 1000 GPM. When supplying a pre-piped waterway flowing 1000 GPM, a friction loss of 60psi will be used; which includes the intake, piping and master stream device. When pumping directly to the waterway, an additional 20psi will be added for the friction loss in the direct piping. Departments are encouraged to flow test their own apparatus to determine the actual friction loss.

There are four ways to supply a pre-piped waterway:

1. Ladder truck pumps through internal piping to the ladder
2. Ladder truck pumps through hose into the ladder intake
3. Engine company pumps into the ladder intake
4. Relay to ladder truck pump operator (refer to relay operations)

EXAMPLE 1: It is necessary to supply a pre-piped aerial ladder. The aerial is elevated 50 feet above grade on a 100 foot aerial with a 2" tip (1000 GPM). The FAE decides to use two 100 foot lengths of 3" hose as feeder lines to supply the aerial's siamese in the rear of the aerial. Each of the lines will carry 500 GPM and the friction loss in the feeder lines will be about 22 pounds for the 100 foot lay. The constant is 60psi friction loss on a 100 foot pre-piped aerial ladder intake connection and master stream device. Obtain the engine pressure and add as follows:

22psi loss for two 100 foot lengths of 3" feeder line
60psi loss for 100 foot pre-piped aerial, intake and master stream
25psi loss for elevation
\+ 80psi loss for nozzle pressure

187psi will be the Engine Discharge Pressure

EXAMPLE 2: Using the same pre-piped aerial ladder as Example 1, except this time the FAE will use the piping form the pump to the aerial:

60psi loss for 100 foot pre-piped aerial, intake and master stream
20psi loss for piping from the pump to the base of the aerial ladder
25psi loss for elevation
\+ 80psi loss for nozzle pressure

185psi will be the Engine Discharge Pressure

The examples given above have been figured with 60psi friction loss in the piping of a 100 foot aerial ladder flowing 1000 GPM as a standard.

All students having aerial devices shall utilize the manufacturer's specified friction loss in their department's pre-piped aerials.

ELEVATED STREAM MISCELANEOUS NOTES

The following are some recommended procedures for obtaining good elevated streams:

1. Try to keep supply lines under 300 feet
2. Nozzle pressure should be 80psi for solid streams and 100psi for fog streams

For each foot of elevation, the weight of water produces a pressure of 0.434 pounds per square inch. This may be rounded off to 0.5 pounds per foot of elevation for fire ground calculations.

Consider the simple basics, good elevated streams are possible if:

1. The proper size tip or fog nozzle is used for the available water supply and pumping capacity
2. Sufficient lines of sufficient diameter are run from the pumper to the base of the elevated apparatus
3. Sufficient pressure is maintained

The modern aerial ladder is a valuable piece of equipment of the department that uses it well. Yet, if used incorrectly, firefighters can be seriously endangered; maintenance costs needlessly high; and fire losses increased. Careful study, supervised training and constant practice are needed to bring the engineer's skill to the highest point of efficiency.

GENERAL OPERATING SUGGESTIONS FOR CENTRIFUGAL FIRE PUMPS

A centrifugal pump is designed for a specific duty and ordinarily will perform this duty satisfactorily over a long period of time. On occasion however, trouble will show up in one form or another and even an experienced operator may have difficulty in locating and correcting it. The suggestions listed below should be helpful.

IF THE PUMP WILL NOT PRIME OR LOSES PRIME

1. Air leaks
    a. Faulty connection
        i. Suction hose or gasket
        ii. Discharge valves or gaskets
        iii. Booster tank
        iv. Drain valves
        v. Gauge
    b. Faulty pump packing
    c. Leaky pump gaskets

All suction hose gaskets should be wiped clean of sand, pebbles and any other foreign matter before hose is attached to the pump. Hose couplings should be tightened snugly enough to make air-tight connections. Main pump packing should always be kept adjusted tightly enough to prevent excessive leakage (see manufacturer's operating instructions for proper packing adjustment procedure).

2. Detecting air leaks
    a. Connect suction hose to the pump with a cap on the opposite end of the hose
    b. Close all pump openings
    c. Open the priming valve and operate the primer until vacuum of 20-22 inches of mercury is shown on the vacuum gauge
        i. If it is impossible to draw this much vacuum, the primer may be defective
    d. Close the priming valve and shut off the primer
    e. Shut off the engine
        i. If leaks are present:
            1. The vacuum will promptly decrease as shown by the vacuum gauge
            2. If the vacuum drops more than 10 inches of mercury in five minutes

3. Locating air leaks

Air leaks may frequently be detected by ear if the engine is stopped. Applying water or oil to the suspected points may aid in detecting leaks. Leaks may be found by applying water pressure to the pump and suction hose by means of an auxiliary pump or hydrant. Pressures should be approximately 50psi and should not exceed that recommended for the suction hose or pump.

a. Dirt in the suction screens
    i. Dirt-clogged suction screens may make it difficult to prime the pump, as well as cause the pump to lose its prime after it is started
    ii. When operating from a draft, be sure suction screens are kept clean
        1. Be sure to keep the end of the suction hose off the lake or river bottom
        2. For this purpose, a special box or basket, which fits around the suction strainer or is threaded to the end of the hose, is frequently fabricated
b. Engine speed too low
    i. Follow the manufacturer's recommendation for priming
    ii. Speeds higher than those recommended do not accelerate priming
c. Primer not operated long enough
    i. Follow the manufacturer's recommendation
    ii. The maximum time for priming for lifts of 10 to 15 feet should not exceed 30 seconds for 1250 GPM pumps or below; or 45 seconds for 1500 GPM pumps or above
d. Lack of oil in the primer reservoir
    i. Where a mechanically driven or electrically driven rotary primer is in use, an adequate supply of oil should always be kept in the reservoir to lubricate and "seal" the priming pump
e. Improper clearance in rotary primer
    i. Due to wear, the clearance between the priming pump rotors and head may become so large as to cause poor priming characteristics
        1. In this case, the proper clearance should be restored by the method outlined by the manufacturer in the priming pump operating instructions
f. Excess carbon on exhaust primer valve seats
    i. See exhaust primer manufacturer's operating instructions to remove carbon
g. Defective priming valve
    i. A broken or deteriorated priming valve spring may cause the valve to leak and the pump to lose its prime.
    ii. Worn parts in the priming valve may also allow air leakage
h. High point in suction line
    i. High points in the suction line (caused, for example, by running suction hose over a bridge railing) create air pockets which may case loss of prime
    ii. In some cases, it may be impossible to rearrange the suction hose to eliminate the high point
        1. In this case, prime may be obtained by closing the discharge valve immediately when the pressure drops and then re-priming
        2. This procedure usually eliminates the air pocket which was drawn into the impellers when the pump was started after first priming; however, it may have to be repeated in some situations

i. Suction lift too high
    i. Lifts of more than 20 feet should not be attempted, even at low altitudes, unless there are practically no air leaks and the equipment is in new condition
        1. In this case, higher lifts may be obtained

j. End of suction hose not under water
    i. The end of the hose may be submerged enough for priming, but when a large volume of water is pumped, a whirlpool is sometimes formed which uncovers the end of the hose

<u>IF PUMP WILL NOT DELIVER CAPACITY</u>

The following may prevent the pump from delivering its rated capacity:

1. Relief valve improperly set
    a. If a relief valve is set at a pressure below the desired operating pressure it will bypass water and lower the capacity (see manufacturer's relief valve operating instructions)
2. Badly worn wear rings
    a. Failure of the pump to deliver its rated capacity at a given pressure may be an indication that the impeller war rings are badly worn, allowing excessive quantities of water to leak around them
3. Suction screen and impeller vanes fouled with debris
    a. Backwash of water from the pump through the impellers when the pump is stopped usually cleans the impeller vanes
        i. Debris on the pump suction screen however, usually remains in the suction hose and is immediately caught by the screen when pumping is resumed
        ii. Therefore, the suction hose should be removed and cleaned
4. Chassis transmission in wrong gear
    a. See operating instructions
5. Suction hose has collapsed
    a. On defective or old suction hoses, the inner liner often collapses when drafting water, thus restricting the flow of water to the pump
    b. Collapse of the inner liner is often hard to detect even when the inside of the hose is examined with a light
        i. This is due to the fact that the inner liner often goes back in place when the suction vacuum is removed
        ii. If the pump will deliver capacity with a different suction hose, it is reasonable to assume the liner on the former hose has become loosened
6. Suction hose not submerged deeply enough
    a. The lower end of the suction hose should be submerged at least two feet below the surface of the water to avoid taking in air

7. Suction hose too small
    a. When higher than normal lifts are involved or at high altitudes, larger hose is needed
8. Insufficient engine power
    a. Although the engine had sufficient power originally, there are several reasons why the power can decrease to the point at which it will not handle the pump at the rated capacity and pressure
    b. Things to suspect are:
        i. Incorrect timing
        ii. Fouled spark plugs
        iii. Burned distributor points
        iv. Weak condenser or coil
        v. Sticking valves
        vi. Worn piston rings
        vii. Worn fuel pump poor carbonation
    c. Also, if the engine is operated at higher than normal altitudes, the power may be too low
        i. The power of an engine decreases about 3-4% for every 1000 feet of increase in altitude
    d. Excessive engine temperatures, which frequently occur in hot weather and during long periods of operation reduce the power
        i. This can be caused by:
            1. Clogged radiator or heat exchanger
            2. Insufficient coolant
            3. Worn water pump
            4. Loose fan belt
            5. Deteriorated crank case oil
    e. Transfer valve improperly set
        i. Does not apply to single stage pumps
        ii. The valve should be in a "parallel" (volume) position when pumping more than one half of the rated capacity
        iii. When changing the position of the valve, make sure it is moved completely into the new position; if not, the pump performance may be seriously affected

IF PUMP WILL NOT DEVELOP SUFFICIENT PRESSURE

In general, conditions which prevent the pump from delivering the rated capacity will also affect the pressure adversely. The following may prevent the pump from developing sufficient pressure:

1. Relief valve improperly set
    a. A relief valve properly set will prevent the pump pressure from rising much above that at which it is set
        i. Consequently, too low a setting causes too low a pressure
        ii. See manufacturer's relief valve operating instructions
2. Insufficient pump speed
    a. May be due to one or more of the following:
        i. Impeller wear rings or other pump parts binding
        ii. Clutch slippage
        iii. Chassis transmission in wrong gear
        iv. Governor limiting engine speed
        v. Insufficient engine power
3. Transfer valve improperly set
    a. Does not apply to singe stage pumps
    b. The transfer valve should be in "series" (pressure) when pumping at high pressures
4. Capacity limiting pressure
    a. Care should be taken not to attempt to take more water from the pump than it can handle at the desired pressure (see instructions on operation of pump)
    b. If the pump is operating at draft under normal suction conditions and the maximum rated capacity is exceeded the pressure will be low due to the characteristic of a centrifugal pump even if the engine has plenty of power and speed
    c. Excess capacity may raise the suction vacuum to a point above that which the pump was designed and lowered pressures will result
    d. On pumping units having engines with low surplus power, the pressure will be limited by engine power if surplus capacity is being pumped

AUTOMATIC PUMP PRESSURE CONTROLLER

The automatic pump pressure controller is a device which regulates the engine speed of a pumper to preclude surges or drops in the pressure of operating discharge lines as other lines are closed or opened.

The basic method by which the device works is to compare the pump discharge pressure to a reference pressure stored, when the pump is set into operation, in a device called an accumulator. As pump discharge pressure varies in response to changing discharge volumes, the reference pressure in the accumulator acts on a hydraulic cylinder which in turn actuates a rod connected to the throttle linkage thereby adjusting the engine speed.

The operating range of most automatic pump pressure controllers is between 75-500 pounds. If the pump pressure drops below 30 pounds per square inch, the unit automatically disengages, thus protecting the engine as in the case of loss of prime. This device is equally effective with gasoline or diesel engines.