NPOI Nitrogen Distribution

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Engineering Analysis
Document

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1. Introduction

The U.S. Naval Observatory (USNO) does research for the Naval Research Laboratory in providing position, navigation and timing for the U.S. Department of Defense. Our sponsor, the Navy Precision Optical Interferometer (NPOI), works under the USNO. The NPOI has its site located just East of Flagstaff, AZ in Anderson Mesa. The research done in this facility involves precise observations of the astronomy needed for navigation use.

On behalf of NPOI, our clients Jim Clark and Steve Winchester have requested an improved nitrogen supply system. This nitrogen supply is used to operate pneumatic actuators at several stations and to purge any humidity or debris from the Siderostat mirrors. The nitrogen will be supplied by a 1000L Dewar tank and must travel down three separate 300m long runs. Each run has eleven stations that consist of a manual shutoff valve and five ports that feed separate regulators. The three different components that will be analyzed include the tubing material, distribution style at each location, and valve style.

2. Supply Calculations

Each arm of the NPOI array consists of one astrometric hut, ten imaging stations, and a set of three gate valves. However, there will only be two imaging stations in use on each arm at one time due to the design of the interferometer. There is also another astrometric hut that will be fed by a separate, smaller run from the supply tank. In the future, the staff at NPOI will be installing a set of six more gate valves at a location approximately 50m from the center of the array. All of the previously listed components must be accounted for when calculating the necessary nitrogen flow rate on each arm, as well as the whole system.

The astrometric huts contain several different precision instruments, but the only items that require nitrogen are the siderostat mirrors. Each mirror requires a cover with a nitrogen purge that will keep the mirror clean and dry. Each purge consists of a 0.004in orifice at 9PSI line pressure. Since the purge is releasing into the atmospheric air, the pressure drop across the orifice can be assumed to be the line pressure. However, the drop will actually be lower than this so this calculation will be an underestimate. The flow coefficient, C for a square edged orifice plate is equal to 0.75. The calculation for the flow rate on each purge is shown below [1]:

$$Q = CA_o\sqrt{\frac{2\Delta P}{\rho}} \quad (1)$$

Where:

D_o= 0.004in= 0.1016mm

$A_o = \left(\pi/4\right) \times {D_o}^2 = \left(\pi/4\right) \times (0.1016mm)^2 = 0.008107mm^2 = 8.1073E^{-9}m^2$

C= Flow coefficient= 0.75

$\Delta P = P_{line}$= 9PSI= 62052.6Pa

$\rho = Density\ of\ nitrogen = 1.25\ {kg}/{m^3}$

$$Q = 0.75 \times 8.1073E^{-9} m^2 \sqrt{\frac{2 \times 62052.6 \, {kg}/{m \times s^2}}{1.25 \, {kg}/{m^3}}} = 1.9158E^{-6} \, {m^3}/{s}$$

$$Q = 1.9158E^{-6} \, {m^3}/{s} \times 35.3147 \, {ft^3}/{m^3} \times 3600 \, {s}/{hr} = 0.2436CFH$$

While this value seems logical, the staff at NPOI stated that the flow rate had been calculated as 0.5CFH. This inaccuracy can be due to an underestimate of pressure drop, turbulence through the orifice, and compressibility of nitrogen gas (the above equation assumes the fluid is incompressible).

At each imaging station there are three pneumatic cylinders that are used to open the hoods covering the "lizard head" and there will soon be two pneumatic cylinders at each camera dome. There is also a siderostat mirror inside the lizard head and the dome, with a purge identical to those located in the astrometric huts. These cylinders operate at an ideal gauge pressure of 45PSI. The pneumatic cylinders have a 1in bore with a 5in stroke. The volume calculation for the cylinder is shown below:

$$V = L \times A \tag{2}$$

Where:

$A = \left({\pi}/{4}\right) \times D^2$

D= bore= 1in

L= stroke= 5in

$$V = 5in \times \frac{\pi}{4} \times (1in)^2 = 3.927in^3 \tag{3}$$

Due to the dual actuation of these cylinders, both tubes that are attached to the cylinder must be filled on each actuation. These tubes are ${}^{3}/_{8}$in diameter and approximately 10ft in length. The volume calculation of these tubes is shown below:

$$V = 2 \times 10ft \times \frac{12in}{1ft} \times \left(\frac{\pi}{4}\right) * (0.375in)^2 = 26.507in^3 \tag{4}$$

Now that we have the volume that must be filled to actuate these cylinders, we must convert this to the flow rate that it will be pulling from this system. Since pneumatic cylinders are not 100% efficient, the volume required to extend the rod is not exactly equal to the length times the area, and nitrogen is a compressible fluid, the equation for the flow rate of a pneumatic cylinder is shown below [2].

$$Q = \frac{V \times P_{abs}}{28.8 \times t \times P_{atm}} \left[\frac{in^3}{s}\right] \tag{5}$$

Since the absolute and atmospheric pressures are required, it must be noted that atmospheric pressure at 7000ft is 11.3PSI rather than 14.696PSI like it is at sea level [3]. The time, t is the time required to complete the actuation which is 2 seconds for this application. To convert to the required units of CFH, in^3 must be converted to ft^3 and seconds must be converted to hours:

$$Q\left[\frac{in^3}{s}\right]\times 3600\ \left[\frac{s}{hr}\right]\times\frac{1}{12^3}\left[\frac{ft^3}{in^3}\right]=Q\times\frac{25}{12}\ CFH \tag{6}$$

$V=V_{cylinder}+V_{tubes}=3.927in^3+26.507in^3=30.434in^3$
t= 2s
P_{abs}= 45PSI+11.3PSI= 56.3PSI

$$Q=\frac{30.434in^3\times 56.3PSI}{28.8\times 2s\times 11.3PSI}\times\frac{25}{12}=5.484\rightarrow 6CFH \tag{7}$$

Figure 1 – Pneumatic cylinder [4]

After the sixth imaging station on each run, there are large gate valves installed in the vacuum tubes that carry the beams of light into the processing station. These tubes are 8 inches in diameter and contain a long series of very expensive mirrors that reflect light at precise angles. If one of these tubes gets damaged, dust and abrasive particles will enter the system and wreak havoc on all of these mirrors. This would cause hundreds of thousands of dollars worth of damage if it were not contained. To prevent this catastrophe, the staff at NPOI installed gate valves that will block any flow in the case of emergency. There are 3 gate valves on each location and each one is actuated with a dual actuation pneumatic cylinder with a 3 inch bore, 15 inch stroke, and 5 feet of tubing attached to each port. The volume calculations for the cylinder and tubes are shown below:

$$V_{cylinder}=L\times A=15in\times\frac{\pi}{4}\times(3in)^2=106.03in^3 \tag{8}$$

$$V_{tubes}=2\times 5ft\times\frac{12in}{1ft}\times\left(\frac{\pi}{4}\right)\times(0.375in)^2=13.254in^3 \tag{9}$$

$$V=106.03+13.254=119.282in^3$$

$$Q=\frac{119.282in^3\times 56.3PSI}{28.8\times 2s\times 11.3PSI}\times\frac{25}{12}=21.495\rightarrow 22CFH \tag{10}$$

Figure 3 – VAT 8-inch pneumatic gate valve [5]

While the actuators that open the hoods and actuate the gate valves are used intermittently, the purges must flow constantly. The only time that these purges will not flow is when the covers are removed for the astronomers to perform their nightly image capturing. Due to the design of the system, the gate valves will never actuate at the same time that one of the hoods is being opened or closed. Therefore, the maximum flow rate in each arm is shown below:

$$Q = 22CFH + 6 \times 0.5CFH = 25CFH \text{ for 6 seconds} \quad (11)$$

This flow rate must be followed by a constant flow rate of 3CFH to continue feeding the mirror purges. While 25CFH is the maximum flow rate that will be seen by each arm, the other situations should also be analyzed.

The hoods on each of the active imaging stations will be opened every night and closed every morning, but will sometimes be opened more frequently. As was previously stated, there are three actuators in each lizard head, and there will be two more in the camera domes. The three cylinders in the lizard head will be operated simultaneously and roughly thirty seconds later, the two other cylinders will operate simultaneously. The flow rate as seen by the supply line is equal to three simultaneous cylinders followed by two simultaneous cylinders all while the mirror purges are flowing. There will be several minutes between each imaging station being operated, so there will be plenty of time for the lines to recover before another large amount of nitrogen is pulled from the system.

$$Q_{open} = 3 \times 6CFH + 6 \times 0.5CFH = 21CFH \text{ for 4 seconds} \quad (12)$$

The reason that it is calculated for 4 seconds is because it will take two seconds to open the lizard head, and two seconds to open the camera dome. It is unlikely that these two will be opened consecutively, but since there is a chance that it will happen, it is best to account for it. Since the potential use of storage tanks will affect the tubing size, the calculation for the supply line tubing size will be discussed after the storage tanks.

3. Tank Implementation

In order to reduce the load on the main supply line, storage tanks could be installed in series with the supply line near the gate valves. The use of these tanks would allow a smaller tubing size to be used, because rather than the allowable pressure drop being across the entire length of each arm, it would only be across $^1/_3$ of that for the total flow rate and $^2/_3$ of the length for the flow rate that is required by the imaging stations after the gate valves. Considering the availability and low cost of 5-gallon air tanks, this size is the most likely to be used. A 5-gallon tank is equal to $0.6684ft^3$ so it will allow a large amount of nitrogen to be used without instantly affecting the main supply line.

Figure 4 – 5 gallon air tank with multiple ports [6]

Shown below is the calculation for the length of ½in (0.55in ID) tubing that would be evacuated if a tank were not used:

$$L = \frac{V}{A} = \frac{0.6684ft^3}{\left(\pi/_4 \times \left(0.55in \times \left(^{1ft}/_{12in}\right)\right)^2\right)} = 405.123\text{ft} \qquad (13)$$

The equivalent length of $^5/_8$in tubing (0.68in ID) is shown below:

$$L = \frac{0.6684ft^3}{\left(\pi/_4 \times (0.68in \times (^{1ft}/_{12in})^2\right)} = 265.0277ft$$

The fact that a tank can play the role of more than 1/3 the length of the supply line would be extremely helpful in an emergency situation that requires the gate valves to be closed instantaneously. It would also be helpful when one active imaging station is near the center, and the second one is at or near the end. Rather than nitrogen having to travel down several hundred feet of tubing, it would be readily available in the 5 gallon storage tank.

4. Tubing Size

In order to calculate the required tubing size for this application, the total length of tubing must first be calculated. The total length of each arm must account for the ~985ft length between the center and the final station as well as the ten 180º bends and several smaller 45º bends. The calculation below will account for the lengths and bends, but it is likely that there are slight bends in the cable tray that are not included. For this reason, a small length will be added to reduce the risk of underestimating the pressure drop in the line.

$$L = L_{straight} + N[(\pi \times R) - (R \times 2)] + M(\pi \times R) \tag{14}$$

Where:
$L_{straight}$= Unobstructed cable tray length= 985ft
N= Number of 180º bends= 10
R= Radius of curvature of cable tray= 3ft
M= Number of 45º bends= 10

$$L = 985ft + 10(\pi \times 3ft - 3ft \times 2) + 10(\pi \times 3ft) = 1113.496ft \rightarrow 1120ft \tag{15}$$

If no tank is used, the pressure drop must be calculated across this whole length for a flow rate that can feed two imaging stations, one astrometric hut, and the set of gate valves (25CFH). For cleaned and capped copper tubing, $^5/_8$in tubing has an inner diameter of 0.68in, ½in tubing has an inner diameter of 0.555in, and $^3/_8$in tubing has an inner diameter of 0.436in. Since the fluid must pass by every connection, the equivalent length is affected by 11 line flow tees, and goes through one tee in branch flow.

As was shown in the previous report and presentation, a MATLAB code was created that calculates the pressure drop and equivalent length for a given tube. These calculations are done after accounting for any losses due to tees, valves, bends, or curves. The following equations are at the heart of the MATLAB code to calculate the equivalent length and pressure drop:

$$L_{eq} = \frac{KD}{f} \tag{16}$$

Where:
K= loss coefficient (dependent on fitting style and found in table) [10].
D= Flow diameter
f= Friction factor (Dependent on Reynolds number and relative roughness)

$$Re = \frac{\rho V D}{\mu} \tag{17}$$

Where:
ρ= Density of nitrogen= 1.1651 $^{kg}/_{m^3}$
V= Fluid velocity= $^{Q}/_{A}$
D= Flow diameter
μ= Dynamic viscosity= 1.755E^{-5} $Pa \cdot s$

$$\Delta P = f\frac{L_{eq}}{D}\frac{V^2}{2} \tag{18}$$

The output of the code gives the equivalent length in units of meters, the diameter in inches, and the pressure drop in PSI. The units are all converted to SI units prior to calculation in the MATLAB code, and then converted back to the desired units before being displayed. The pressure drop is calculated for $^3/_8$, ½, and $^5/_8$in tubing:

>> Tubingsizetank

What is diameter?0.436

How many tees?11

How many branch tees?1

How many valves?0

What is line pressure?50

Line length [m]?340

Flowrate [CFH]?25

Include curves of cable tray? 1 for yes 0 for no1

Equivalent length=

349.9311

Total Pressure Drop

9.1315

This pressure drop is very large, considering the goal for allowable pressure drop is 5PSI.

>> Tubingsizetank

What is diameter?0.55

Flowrate [CFH]?25

Equivalent length=

350.0328

Total Pressure Drop

2.9951

>> Tubingsizetank

What is diameter?0.68

Flowrate [CFH]?25

Equivalent length=

350.1281

Total Pressure Drop

1.1760

The pressure drop is within range for either $^1/_2$ or $^5/_8$in tubing. Unfortunately, without storage tank there will be a delayed time response, which makes this design less desirable.

The storage tanks will be located ~100m (330ft) down the line, but all of the 180º bends and half of the small bends are within this length, so the actual length is shown below:

$$L_{before\ tank} = 330ft + 10(\pi \times 3ft - 3 \times 2) + 5(\pi \times 3ft) = 411.372ft$$

The pressure drop for the line prior to the tank is calculated using the length above, line pressure of 50PSI, 7 tees in line flow (6 imaging stations and one astrometric hut), no valves, and a flow rate equal to the maximum possible for the arm (25CFH).

>> **Tubingsizetank**

What is diameter?0.555

Flowrate [CFH]?25

Equivalent length=

159.8500

Total Pressure Drop

1.3678

>> **Tubingsizetank**

What is diameter?0.436

Flowrate [CFH]?25

Equivalent length=

159.7738

Total Pressure Drop

4.1693

The pressure drop after the tank would be along the rest of the length of each arm using the flow rate required by four purges and the actuators for the imaging stations (the gate valves will be pulling from the tank rather than the tubing), which is 20CFH. The flow must pass through 3 tees in line flow and one in branch flow. The pressure drop that occurs after it goes through the last tee will be assessed later. The MATLAB calculation for this pressure drop is shown below:

>> Tubingsizetank

What is diameter?0.555

Flowrate [CFH]? 20

Equivalent length=

215.1254

Total Pressure Drop

1.2872

This pressure drop seems appropriate since the system has an allowable pressure drop of 5PSI.

>> Tubingsizetank

What is diameter? 0.436

Flowrate [CFH]?20

Equivalent length=

215.1084

Total Pressure Drop

3.9095

Coming off of the supply tank there will either be one large tube that will feed all three of the arms and the additional gate valves, or one individual line feeding the west arm and a larger tube feeding the other two arms and gate valves. The client must agree on the choice on this matter, so the calculation will be made for both.

If one large tube feeds all three arms, the maximum flow rate will be equal to six imaging stations, four astrometric huts, and the set of six gate valves (32CFH). This is because of the way that the interferometer is setup, there will be no circumstances where multiple sets of gate valves or imaging station actuators will be used at once. The pressure drop for this section must be quite small, because it will deny the whole system of nitrogen once the tank outlet reaches a pressure equal to the needed line pressure plus the pressure drop (the larger the pressure, the higher the pressure where it becomes unusable). The calculation for this large tubing size is done with a length of 100m.

>> Tubingsizetank

What is diameter?0.68

Flowrate [CFH]?32

Total Pressure Drop

0.4992

>> **Tubingsizetank**

What is diameter?0.555

Flowrate [CFH]?32

Total Pressure Drop

1.2766

For a tube feeding two of the arms and the six gate valves, the flow rate will be equal to four imaging stations, three astrometric huts, and the six gate valves (29CFH).

>> **Tubingsizetank**

What is diameter?0.68

Flowrate [CFH]?29

Total Pressure Drop

0.4260

>> **Tubingsizetank**

What is diameter?0.555

Flowrate [CFH]?29

Total Pressure Drop

1.0878

Table 1- Summary of supply tubing pressure drop.

Location	Tubing ID (in)	ΔP (PSI)	Tubing ID (in)	ΔP (PSI)
Total arm (no tank)	0.555	2.9951	0.68	1.1760
Prior to tank	**0.555**	**1.3678**	0.436	4.1693
After tank	**0.555**	**1.2872**	0.436	3.9095
Main line (if feeding all 3 arms)	**0.555**	**1.2766**	0.68	0.4992
Main line (if feeding 2 arms)	0.555	1.0878	0.68	0.4260

5. Thermal Expansion

Any material that experiences a change in temperature will suffer from thermal expansion. The change in length due to a change in temperature is dependent on the coefficient of thermal expansion, the initial length, and the difference between the installed temperature and the maximum or minimum temperature that is seen by the material.

$\alpha = 9.3 \times 10^{-6}$/°F for copper

$T_{max} = 120$°F

T_{min}= -20°F

$T_{install} = 70$°F

$$\Delta L_{hot} = L_o \alpha (T_{max} - T_{install})$$

$$\Delta L_{cold} = L_o \alpha (T_{install} - T_{min})$$

$$\Delta L_{hot} = 700ft \times 9.3 \times 10^{-6}/°\text{F}(120 - 70) = 0.3255\text{ft} = 3.906\text{in}$$

$$\Delta L_{cold} = 700ft \times 9.3 \times 10^{-6}/°\text{F}(70 - -20) = 0.5859\text{ft} = 7.0308\text{in}$$

The thermal stress on this tubing is also dependent on the coefficient of thermal expansion, as well as the modulus of elasticity, and the change in temperature. The allowable stress for copper tubing is 6KSI. If the stresses are any larger, an expansion loop can be installed to absorb the changes in length.

$$\sigma = \alpha \Delta T E$$

E= 16MPSI

$\sigma = 9.3 \times 10^{-6}/°\text{F}(70 - -20) \times 16MPSI = 13.392$KSI

The expansion loop equation is shown below:

$$L = \frac{1}{12}\left(\frac{3E}{P}\right)^{\frac{1}{2}} (d_o \Delta L)^{\frac{1}{2}}$$

$$L = \frac{1}{12}\left(\frac{3 \times 16E^6 PSI}{6000PSI}\right)^{\frac{1}{2}} (0.625in \times 7.031in)^{\frac{1}{2}}$$

L= 16.098in

The above equations show that an expansion loop with a total length of 16.098in can be used to absorb the changes in length so that the stress does not seriously affect the tubing.

6. Component List

The original plan of keeping the allowable pressure drop below 5PSI was to keep from wasting nitrogen when the tank pressure falls to a pressure near line pressure. The pressure drop that occurs from the supply tank to the end of each arm is equal to **1.2766+1.2872+1.3678= 3.9316PSI,** which leaves 1PSI to be lost between the supply line and the manifold. It is highly unlikely that a pressure drop grater than 1PSI will occur, so it is safe to use ½in tubing from the supply tank to the end of each arm.

The cleaned and capped copper tubing is available in 50ft and 100ft lengths so the tubing must be ordered in these increments. There are three runs each of 1120ft, so a total of 3360ft would fulfill the total amount. Therefore, it would be wise to order 34 100ft lengths to account for any discrepancies or tubing that would be wasted during a poorly soldered joint or improperly bent curve. As was previously discussed, there will also be a length of tubing that feeds into each arm. Regardless of which setup is used, this line will still be a 100m length of ½in tubing. 100m is equal to roughly 328ft, so a total of 3688ft of ½in tubing will be needed in all. Therefore, 37 rolls of 100ft will be ordered. Since each run will be built using multiple rolls, solder couplings will be used to connect the joints. These are inexpensive and will be included in the total cost of materials.

Each manifold in the system will require a tee to be soldered into the supply line. This means 11 tees will be required in each line. Since there are three lines, 33 ½in copper tees are required. The flexible tubing that comes off of the tee will be $^3/_8$ in diameter so the tubing must be converted to a $^3/_8$ in barb fitting. While suppliers carry copper reducer tees that can provide a $^3/_8$ in branch outlet, they are not cost effective when compared to other methods. Several different ways of converting from ½in tubing to a $^3/_8$ in barb fitting were considered. The table below compares the cost of different methods.

Table 2- Cost of different connection methods

First part	Second part	Third part	Total cost ($)
½in to $^3/_8$ in tubing reducer	$^3/_8$ in tube-$^3/_8$ in female NPT	$^3/_8$ in female NPT to $^3/_8$ in barb	7.40
½in to $^3/_8$ in tubing reducer	$/_8$ in tube-$^3/_8$ in male NPT	$^3/_8$ in male NPT to $^3/_8$ in barb	5.85
½in tube to ½in female NPT	**½in male NPT to $^3/_8$ in barb**		**4.69**
½in tube to ½in male NPT	½in female NPT to $^3/_8$ in barb		5.66
½in tube to $^3/_8$ in female NPT	$^3/_8$ in male NPT to $^3/_8$ in barb		5.37
½in tube to $^3/_8$ in male NPT	$^3/_8$ in male NPT to $^3/_8$ in barb		5.31

Since all of these different components are designed to flow well, and the inlet and outlet diameters are the same, there would be very little difference in the pressure drop between the different configurations. This is why cost was the number one priority when choosing which design to use. The cheapest configuration using off-the-shelf parts was found to be a ½in tubing to ½in female national pipe thread fitting attached to a ½in male pipe national pipe thread to $^3/_8$ in barb fitting. However, since a shut off valve is required prior to each manifold, a ½in ball valve will be inserted between the branch outlet of each tee and the tubing to female NPT adapter. The cost breakdown and photos for each section are shown below:

$$Total\ cost\ of\ adapters\ at\ each\ location = \frac{1}{2} in\ tee(\$1.45) + \frac{1}{2} in\ ball\ valve(\$4.33) + \frac{1}{2} in\ \ tube\ to \frac{1}{2} female\ NPT(\$1.79) + \frac{1}{2} in\ female\ NPT\ to \frac{3}{8} in\ barb(\$3.19) = \$10.76$$

Figure 5- ½in tubing copper tee [7]

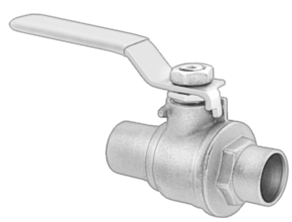

Figure 6- ½in brass solder ball valve [7]

Figure 7- ½in tube to ½in male NPT copper fitting [7]

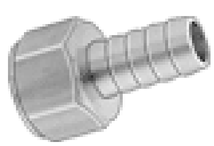

Figure 8- ½in female NPT to $^3/_8$in barb fitting [8]

Figure 9- ½in solder coupling [7]

After converting to a 3/8in barb fitting, several feet of flexible rubber tubing must be ran to the manifold. The tubing that will be used is $^3/_8$in flexible, black, UV resistant, PVC tubing. This tubing was selected after speaking with our clients, because they have used this tubing and the past with great success. When purchased as 100ft rolls, this tubing costs only $0.44 per ft. At the imaging stations, the manifold will be placed approximately 10 feet away from the supply line, and the manifolds for the gate valves will be approximately 5 feet from the supply line and placed inside the large cabinet that houses the valves. Since the astrometric huts are located several feet from the supply line and the siderostats inside are placed opposite of the supply, the manifold will be approximately 25 feet away from the supply line. The total length of 3/8in tubing is shown below:

$$L_{total} = \#\ of\ imaging\ stations \times 10ft + \#\ of\ astrometric\ huts \times 25ft + \#\ of\ gate\ valve\ stations \times 5ft$$

$$L_{total} = 30 \times 10ft + 4 \times 25ft + 4 \times 5ft = 420ft \quad (19)$$

Since 420ft of tubing is required, it would be wise to order 500ft since the price per foot is lower if 100ft rolls are ordered, and so that the staff can have extra tubing on site in case of emergency. Since fluid is flowing through up to 25ft of small diameter tubing, there will be pressure drop between the supply line and manifold. The manifold design that has been selected is essentially a smooth combination of line flow tees with a branch flow tee at the end. This is a poor approximation, but it is better to exaggerate the losses than to underestimate them. Since the largest manifold that will be used consists of 7 ports, the calculation will use six line flow tees and one branch flow. A ball valve is installed on this line and the maximum flow rate is 19CFH (3 simultaneous actuators and 2 constant purges).

```
>> Tubingsizetank

What is diameter?0.375

Flowrate [CFH]? 19

Equivalent length=

   8.2018

Total Pressure Drop

   0.2751
```

The above pressure drop is quite small, which is the goal. Since the ideal pressure for the actuators is 45PSI, it must be ensured that a 50PSI line pressure will still provide 45PSI after the regulator. Therefore, the sum of each pressure drop using a storage tank must be less than 5PSI as previously mentioned:

$$\Delta P_{total} = \Delta P_{main} + \Delta P_{prior\ tank} + \Delta P_{after\ tank} + \Delta P_{manifold}$$

$$\Delta P_{total} = 1.2766\text{PSI} + 1.2872\text{PSI} + 1.3678\text{PSI} + 0.2751\text{PSI} = 4.2067\text{PSI}$$

Table 3- Summary of tubing sizes and lengths

Location	**Size (in)**	**Length (ft)**
Main supply	½	350
Prior to tank (All 3)	½	1250
After tank (All 3)	½	2100
Supply to manifold	$^3/_8$ PVC	500

It was originally believed that every location would use a 5 port manifold to supply the devices. However, the staff at NPOI plans on adding two additional actuators at the imaging stations so 7 port manifolds will be required at the imaging stations. While each gate valve station on the three main arms have only three valves, the station that is separate from the supply lines will use 6. Therefore, it would be wise to use the same 7 port manifolds that the imaging stations use so the parts will be interchangeable. The staff at NPOI obtained several black anodized aluminum 5 port manifolds from Polyconn Fluid Power Products several years ago, so these will be used at the gate valve locations, and the same brand and model will be used for the other sizes.

Table 4- Description, quantity, and cost of manifolds [9].

# of ports	Quantity	Cost ($)	Total Cost ($)
7	31	21.30	660.30
5	3	18.84	56.52
2	4	14.87	59.48
3*	1	26.22	18.84
	39		**795.14**

Every manifold without * uses a 1/4 in male NPT to ¼ in barb fitting. These manifolds use a $^3/_8$in female NPT inlet on both of the ends, so one 3/8in barb to $^3/_8$in male NPT is required for the inlet and the other side will use a $^3/_8$in male NPT plug since no flow will come into, or out of that end. Several 1/4in male NPT plugs are required since several ports will be unused when this system is first installed. The * manifold is used to supply the three arms from the main line and uses ½in NPT inlets and outlets. Male NPT to tube adapter fittings will be used as well as an NPT plug on the unused inlet.

Table 5- Description, quantity, and cost of all components [7,8].

Inlet	Outlet	Quantity	Cost ($)	Total Cost ($)
$^5/_8$in coupling		3	1.27	3.81
½in coupling		32	0.37	11.84
½in tee		37	1.45	53.65
½in ball valve		38	4.33	164.54
$^1/_2$in tube	$^1/_2$in female NPT	37	1.79	66.23

$^{1}/_{2}$in male NPT	$^{3}/_{8}$in barb	37	3.19	118.03
$^{3}/_{8}$in barb	$^{3}/_{8}$in male NPT	38	1.90	72.20
$^{3}/_{8}$in male NPT	Plug	38	1.38	52.44
¼in male NPT	¼in barb	240	1.383	331.92
$^{1}/_{4}$in male NPT	Plug	67	1.23	82.41
$^{1}/_{2}$in male NPT	$^{1}/_{2}$in tube	4	1.79	7.16
$^{1}/_{2}$in male NPT	Plug	1	2.58	2.58
		572		**966.81**

7. Conclusion

While there are hundreds of components that will be soldered or threaded together, the analysis is quite simple if each part of the system is analyzed individually. The initial goal for tubing size was to keep pressure drop throughout the whole system below 5PSI. While there was a short period where it was believed that this was not cost effective (due to having the incorrect density stored in the MATLAB code), this problem was fixed and the goal was achieved. The total pressure drop from the supply tank to the end of each supply line is equal to 4.2067PSI.

After all of the calculations were completed, it was found that 3700ft of ½in copper tubing, 500ft of $^{3}/_{8}$in black PVC tubing, 572 components (tees, valves, adapters, barb fittings, etc.), and 39 manifolds are required. The maximum stress in the copper tubing due to thermal expansion is 13.4KSI. However, utilizing expansion loops with a diameter of 5.12in can offset this large amount of stress. Installing 5-gallon storage tanks will reduce the response time to the important gate valves as well as the imaging stations that are located near the ends. These tanks will also reduce the amount of thermal expansion in each tube, since the supply line on each arm will become two shorter lengths.

There is no way to know with 100% confidence that all of the values obtained in this report are correct since it is still theoretical, but there are several ways to check the validity of them. Any results that are unclear or unreasonable can be discussed with the client as well as the technical advisor that was appointed for this project.

8. References

[1] Flow rate equation through orifice plate pg. 438: Beasley, Donald E., Figliola, Richard S. (2011). *Theory and Design for Mechanical Measurements (5th Edition)*. Danvers, Ma. Wiley & Sons, Inc.

[2] Flow rate equation: http://www.parkermotion.com/pneu/simplify/Sizing_Cylinders.pdf

[3] Pressure measurement: http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html

[4] Pneumatic cylinder: http://www.airoil.com/v6/contents/en-us/d123.html

[5] Pneumatic gate valve: http://www.vatvalve.com/products/catalog/A/481_1_V

[6] 5 gallon air tank: http://www.rakuten.com/prod/5-gallon-air-tank-4-train-horn-air-suspention-more-free-gauge/248387884.html?listingId=279990422

[7] Tee & male adapter: http://www.mcmaster.com/#cleaned-and-bagged-solder-joint-tube-fittings/=pey1n4

[8] Barb fitting: http://www.mcmaster.com/#standard-barbed-hose-fittings/=pey0q4

[9] Manifolds: http://www.polyconn.com/black-anodized-manifolds-p-2626-l-en.html

[10] Loss coefficients for various components pg. 439: Munson, Okiishi et all. (2013). *Fundamentals of Fluid Mechanics (7th edition).* Danvers, Ma. Wiley & Sons, Inc.