Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Navy Precision Optical Interferometer
To: Jim Clark & Steve Winchester
From: Amelia Fuller, Wyatt Huling, & Scott Ryan
Date: 12/11/2013
Re: Nitrogen Supply Distribution Project Proposal and Prototype

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As of December 11, 2013, a final design has been produced and analyzed in regards to the nitrogen supply system at the Navy Precision Optical Interferometer in Flagstaff. With help from the operators at the NPOI we have devised a system that is supplied by a 1000L Dewar tank located at the center of the facility. The nitrogen will pass through a regulator and be supplied to the full length of each arm of the interferometer through 1⁄2inch clean and capped copper tubing. Located at each of the imaging stations and valve stations a T-fitting will be soldered into the main supply tubing. This will allow implementation of an appropriate sized manifold for each application. In order to attach the manifold to the main supply tubing, 3/8 inch PVC tubing was chosen due to its flexibility and resistance to the environment. In order to install these sections of tubing, soldering will be necessary on all copper/copper connections and a variety of fittings will be required to attach the manifolds, regulators, and valves. This system is also designed to implement the use of pressurized nitrogen tanks located on each arm, to avoid drastic pressure drops in the system. These will be installed in-line with the main supply tubing. Stainless steel mounting hardware will be used to mount the tubing inside the cable tray.

As it was already discussed, a prototype will be installed on a small section of the facility near the supply tank. This includes one imaging station, one set of gate valves, and an astrometric hut. Since the imaging stations currently only use three pneumatic cylinders, a 5-port manifold will be used. Since the staff at NPOI is already in possession of several of these 5-port manifolds, this size can be used at all three locations by simply installing ¼in NPT plugs on the excess ports. Exact measurements have not been made, but it is believed that only one 100ft roll of ½in copper tubing, and one 100ft roll of $^{3}/_{8}$in PVC tubing can be used. This creates a tubing cost of $248.80. The total cost of all fittings and valves is equal to $46.11. To perform the installation, the tubing must be cut, bent, and soldered together. Tools required for this job include Stay-Brite #8 solder (6% silver content), an Acetylene torch kit, tubing cutter, and a tubing bender for a total of $393.72. Assuming all of these tools must be purchased and combing with the material costs of $294.91, the prototype cost will equal $688.63. Fortunately, obtaining these tools for the prototype means that they can be reused for the final install.

NPOI Nitrogen Distribution

By
Amelia Fuller, Wyatt Huling, Scott Ryan
Team 16

Project Proposal

Document

Submitted towards partial fulfillment of the requirements for
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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Table of Contents

Nomenclature

Q= Volumetric flow rate [m^3/s] or [CFH]

C= Flow coefficient through orifice

ρ= Density [kg/m^3]

ΔP= Pressure drop [Pa]

V= Volume [m^3]

A= Area [m^2]

L= Length [m]

t= Time [s]

K= Loss coefficient in pipe component

D= Diameter [m] or [in]

f= Friction factor

v= Velocity [m/s^2]

α= Coefficient of thermal expansion [$^{o}F^{-1}$]

ΔL = Change in length [ft.]

T = Temperature [ºF] or [ºC]

List of Figures

List of Tables

Abstract

The Navy Precision Optical Interferometer (NPOI), under the U.S. Naval Observatory, has requested an improved nitrogen supply system. The NPOI is located 16 miles southeast of Flagstaff, AZ on Anderson Mesa. Research at this facility involves astronomy observations needed for navigation and is an integrated research for the Naval Research Laboratory. Our clients Jim Clark and Steve Winchester, of the NPOI, have presented a need of improved nitrogen supply that is used to operate pneumatic cylinders and purge nitrogen over siderostat mirrors to prevent debris and contamination. The supply line consists of three separate 300 meter long runs fed by a large 1000l Dewar tank of liquid nitrogen. Along each run there are 10 imaging stations, 1 astrometric hut, and a set of 3 gate valves. Another astrometric hut is located near the center of the array, and a set of 6 gate valves is located roughly 50m away from the array and these will also require nitrogen. The gate valves are operated using a large pneumatic actuator, and there are 5 smaller pneumatic actuators at each imaging station. For each location there must be a manual shut off valve and a distribution system that will feed into a regulator for each item.

This report will cover the concept generation of what types of materials were decided on and what was more efficient to our clients' needs and the environmental constraints they are working under. The material and supply include tubing selection, distribution style, and valve selection. From the materials selected, a design analysis will be presented. The design analysis includes the supply calculations for the volumetric flow rates through each pneumatic cylinder and siderostat purge. The volumetric flow rate and line pressure will be used to calculate the required tubing size as a function of pressure drop and the length of each run. A thermal expansion analysis will also be given for the material of tubing used to take into account the operating environment and pressure being supplied.

From the engineering analysis of material constraints and distribution needed, a list of material parts and cost analysis will be covered. The large size of the interferometer creates a tubing system much larger than is commonly seen with nitrogen supplies. However, these parts easily attainable from an industrial supplier so the parts quantity and cost will be summarized in this report. To conclude, our client is in need of an improved nitrogen supply system that is easy for them to maintain under extreme weather conditions. Our team has designed an improved supply system that is cost efficient and far easier to maintain than the current nitrogen supply system that is in effect at the NPOI site.

Chapter 1. Introduction

1.1 NPOI Description

The U.S. Naval Observatory (USNO) does research for the Naval Research Laboratory in providing astrometric positioning which is used for navigation and timing for the U.S. Department of Defense. Most military and GPS navigation is still based on the position of the stars and the process of orienteering. Stars are always moving relative to the earth and the other stars, so the U.S Navy is required to continuously map the location of these stars. The Navy accomplishes this by the use of the Navy Precision Optical Interferometer (NPOI). Our sponsor, the operators of the NPOI, work under the USNO. The NPOI is located 16 miles southeast of Flagstaff, AZ on Anderson Mesa. The research done in this facility involves precise observations of the astronomy needed for navigation use.

The NPOI is considered an array telescope. It consists of three 300meter arms that have observatory like mirrors along each arm. By utilizing an array, the optical surface being studied is effectively the diameter of the whole facility. Using the mirrors at the ends of the array has an equivalent effect of employing the use of a 600meter diameter solid mirror. These mirrors are used to direct optical light, the visible light spectrum, into a lab facility that further studies the image.

To operate and manage this system of mirrors, each station is equipped with a gaseous nitrogen supply. This consists of a 150lb rented nitrogen tank at each of the 11 stations on each of the three arms, as well as the fourth astrometric hut that is near the center of the array. The gaseous nitrogen is used to accomplish two tasks. The first is to purge the mirrors of any moisture buildup that may ruin the mirrors. Nitrogen is pumped directly onto the mirror surface whenever the array is not in use, which keeps water from accumulating on the very delicate reflective surface. Aside from this, the nitrogen is also employed for a series of pneumatic actuators. Surrounding the very expensive mirrors are housings and flaps for protection. In order to open these flaps to let light through for observation, nitrogen is sent to a pneumatic system that opens the coverings with no vibration due to water in the line or any debris. Pneumatic actuators are also used to operate gate valves that are placed inside the vacuum tubes that direct light into the facility. If one of these vacuum tubes were to be punctured in any way, the sudden pressurization to atmospheric pressure would cause stirring of dust that would ruin all of the mirrors in the system. Gate valves are installed in each arm to prevent the damage from spreading to all of the arms in the array,

On behalf of NPOI, our clients Jim Clark and Steve Winchester have requested an improved Nitrogen Supply system.

1.2 Needs Identification

Navy Precision Optical Interferometer (NPOI) has approached the NAU mechanical engineering program with this project in pursuit of improving their nitrogen supply system. It is currently a cumbersome system that involves more work than intended for our client. In order to provide an improvement, our client gave us some specific requirements to meet their needs. These requests include:

- One single supply station
- Flow time to stay within time constraint to prevent a waste in nitrogen
- Intermittent high flow rate at 60PSI for a short time period
- Continuous flow at a flow rate of 3CFH at 10PSI in each arm
- Nitrogen compatible tubing that is corrosion resistant
- Tubing that handles potential temperature drops within cable trays where thermal expansion can occur
- Tubing strong enough to prevent failure from vibrations within cable tray

Based on these needs, we have concluded that our client needs an easily operable nitrogen supply system that is not labor intensive without spending an excessive amount of money.

1.3 Project Goal

The goal of this project is to design the nitrogen distribution with one supply station to replace the several smaller tanks that are currently in use and to have a system that prevents a waste in nitrogen gas. In order to prevent any further waste, the improved design must have the supply to the mirror purges shut off when not in use. There are currently 11 supply stations along each of the three 300 meter length arrays, and another supply station at the fourth astrometric hut. Within each station there are supply tanks that are routinely refilled to maintain nitrogen levels.

Our client has emphasized that the waste in nitrogen affects the cost of supply and renting of the supply tanks itself. Site operators themselves refill each station with nitrogen tanks manually, which is labor intensive.

1.4 Objectives

When creating this system, three runs of nitrogen compatible tubing are connected to a large supply tank. This tubing must be of a diameter that is large enough to handle the necessary flow rate, but small enough to fit inside the cable tray. Since the system will undergo a large change in temperature, the tubing must have a small enough thermal expansion coefficient that it does not induce a large amount of stress on the tubing or brackets. Any vibrations that affect the tubing must be of a low enough amplitude that an infinite amount of cycles will not reduce the life of the system. Although there is no budget for the finalized system, it is also important that cost be kept as low as possible.

Table 1.1: Table of Quantifiable Objectives

Objective	Measurement Basis	Units
Inexpensive	Cost	$
Tubing size	Diameter	m
No significant change in size (Thermal expansion)	Length	m
Vibration resistant	Cycle life	# of cycles

1.5 Operating Environment

The NOPI site is located in a high elevation environment. It is located in this area for the advancement of their research. However, the effects of the environment place constraints of what material and how it can be supplied efficiently throughout the site. The location of the facility must take into account the exposed system to rain, snow, ice, UV light and potential wildlife interfering with its operating environment. There is a temperature gradient that creates a concerning factor for moisture and thermal expansion. The supply system must be able to operate between the temperatures of -20^{O}F to 120^{O}F.

The supply of nitrogen is dispersed to each station by means of nitrogen tubing along cable trays. The cable trays are run along the stations and are exposed to the atmosphere as well as with other machine operating cables. These cable trays vibrate and therefore require that the nitrogen lines have a life cycle high enough to prevent fatigue and damage in their line.

1.6 Constraints

To meet the needs of the clients, each of the three runs must be 300m long with 11 supply stations on each. These supply stations will provide nitrogen to one regulator per item, since each device requires a different line pressure. The regulators will be used to ensure that the mirror cover purge receives 9psi, the lizard head actuator receives a minimum of 30psi, and the gate valve (only on one manifold per run) receives a minimum of 40psi. Rather than allowing the nitrogen to flow all night when the mirror cover is removed, a solenoid will be put in place to stop flow if the cover is not in place. The client also requested that a valve be put in place before each manifold to allow the flow to be manually shutoff. Since the instrumentation at NPOI is extremely delicate, the employees do not want to add another fragile item to the workplace. Therefore, the nitrogen system should be tough enough that the employees do not have to go out of their way to ensure that they are extremely careful with all of the lines, fittings, regulators, etc.

Chapter 2. Concept Generation and Selection

2.1 Tubing Selection

To reach each station along the 300-meter length arrays, a main supply tubing system needed to be chosen. For this choice, many different materials of tubing were considered. Options such as rubbers, plastics and metals were all considered. Tubing made of plastics included polypropylene and polyethylene. The latter of these two comes very cheap but is not rated for extended outdoor use. Polypropylene boasts a high UV rating but proved to be very expensive and not practical for long lengths. A vinyl option was considered and is very popular in other applications. This would consist of a UV rated polyvinyl chloride, or PVC. Unfortunately under the pressures of the system and the temperatures experienced by the supply line this option is not practical. In the end there were only three viable materials that, would at the very least, cooperate with our constraints. They are as listed and explained below.

The client suggested our first seriously considered material, clean and capped copper tubing. Because this material is used in many commercial refrigeration situations it is relatively cheap and comes pre-cleaned and capped. Installation occurs straight out of the box. Copper is also a fairly soft material, which makes it easier to install through the curved channels of the cable trays where they will be placed. Connections are done using female fittings that fit snugly over the tube and is soldered in place. This makes for very simple installation and maintenance. Unfortunately, because the copper is so soft and easy to work with it is also susceptible to wearing due to mechanical vibrations and general abrasions. However, with special care this can be compensated for.

The next considered material is very similar to the copper tubing. Rather than copper, it is 316 Stainless Steel. Much like the copper, this material can be ordered to come cleaned and capped. Unfortunately this adds considerable cost. Uncapped stainless tubing is still slightly more expensive than the copper, but is much stronger and more resistant to its surroundings. This is definitely something to consider for long-term purposes. This ability also makes the stainless steel a little harder to work with. Although it can still be bent and cut with the same tools as copper, it requires much more effort.

Our last consideration can be found in any automotive vehicle. The door gaskets in most cars are manufactured from ethylene propylene diene monomers (EPDM). This is a very versatile material, as it is used in gaskets, tubing, sheeting and many more applications. The tubing cost of the same diameter is very comparable to the copper tubing. It is considered the easiest to work with and requires the least amount of tools to manipulate. The only drawback experienced with this tubing is much less resistance to its surroundings. Although it is rated for UV and will handle vibrations really well, it will not perform as well for extended periods of time. As to the scale of this project and the time length, EPDM does not perform as well as for smaller applications.

Here is a table that describes how the weighting criteria was done (Table 2.1) as well as the weighting of each material (Table 2.2). The weighting of the different criteria has been chosen based on how important each standard is compared to the others. Table 2.2 is developed with a scale of one to five, with five being the most favorable outcome. Based on this table, it was concluded that the cleaned and capped copper was the best option. It was cheap, easy to work with, and exceptional resilient to the surroundings. Stainless steel was about equally resilient, but the cost and stiffness of the material counted against it. EPDM was considered too susceptible to climate changes and sun damage.

Table 2.1- Weighting criteria for the decision matrices

	Current Supply	**Cost**	**Ease of Installation**	**Maintenance**	**Resistance to Surrounding**		**Final Weight (%)**
Current Supply		0	0	0	0	0	0
Cost	1		0	0	0	1	10
Ease of Installation	1	1		0	0	2	20
Maintenance	1	1	1		0	3	30
Environmental Constraints	1	1	1	1		4	40

Table 2.2- Decision matrix for tubing selection

	Cost	**Ease of Installation**	**Maintenance**	**Resistance to Surrounding**	
Copper	4	3	5	4	**4.1**
316 Stainless Steel	1	2	4	5	3.7
EPDM	3	5	3	3	3.4
	10%	20%	30%	40%	

2.2 Distribution Selection

Three different manifold systems were selected to compare for the supply system distribution. The three systems we narrowed down are a tee to manifold, individual tee, and flow through manifold. For each of these manifold systems there will be a valve at each manifold, as requested by our client. From each port, there is a regulator that will be connected to each line. Therefore, a number of parts are included for each manifold assembly, taking into account the 11 stations at the observatory site.

The tee to manifold includes a tee from the main line connected to a multi-port manifold. There are 11 stations for this supply assembly. Total manifold parts includes:

-11 valves
-11 tees

- -11 tubes from tee to manifold
- -11 conversions from tubing to barb fittings
- -11 manifolds

Figures 2.1 and 2.2 below show the manifold fixture and assembly, respectively.

Figure 2.1: 6 port manifold [10].

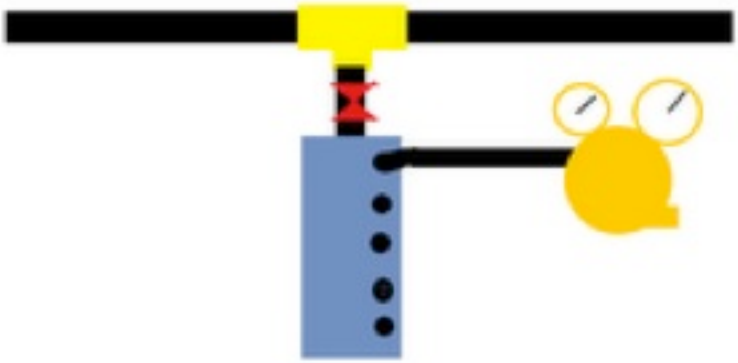

Figure 2.2: Tee to manifold design

Our second design selection uses five individual tees connected into the supply line. For the 11 stations, this design assembly includes:

- -55 valves
- -55 tees
- -55 tubes from valve to regulator

-55 male NPT to barb fitting

The assembly of the individual tee assembly is shown in Figure 2.3 below. As shown in the picture, the tee flows into a valve and then converted to a barb fitting for flexible tubing.

Figure 2.3: Individual tee assembly [19].

The last design choice for our manifold assembly is a flow through manifold system. For the 11 stations, this assembly includes:

-11 valves
-11 manifolds
-22 tube to male NPT fittings (one for each end)
-55 valves
-55 male NPT to barb fittings

Figure 2.4 below shows a flow through manifold with barb fittings on all ends. However, a flow through manifold in this system would use an NPT to tube fitting on all ports, with a valve attached to each outlet.

Figure 2.4: Flow through manifold [19].

Based on our weighted scale and comparing each manifold design, the tee to manifold design out was the best choice. The tee to manifold design had lower cost, installation and is efficient with the surrounding environment. This final design chosen leaves small room for a pressure drop and friction within the tubing system

Table 2.3- Decision matrix for distribution system

	Cost	Ease of Installation	Maintenance	Resistance to Surroundings	
Tee to Manifold	3	3	5	5	**4.4**
Individual Tees	2	1	2	2	1.8
Flow Through	2	2	3	3	2.7
	10%	20%	30%	40%	

2.3 Valve Selection

The final component of this system is the manual shutoff valve that is located prior to each manifold. An effective valve will be easy to operate, have a small flow restriction (low equivalent length), and be low cost. The three different valves that were analyzed include ball, gate, and angle valves.

A ball valve is a simple type of valve that utilizes a sphere with a hole through the middle. If the hole is set parallel to line flow, the valve will allow flow to occur with very little restriction. A simple 90º rotation of the handle on top of the valve will stop the flow because incoming fluid will encounter the side of the sphere with nowhere to go. This style of valve is very easy to use, low cost, and durable.

Figure 2.6 - Brass ball valve [19].

A gate valve operates by pulling a rectangular “gate” out of the path to allow flow, and lowers it to the bottom surface to prevent flow. This design allows for reliable flow rate changes, but is quite restrictive even when fully open. Regulators will be located in each line, so there is no need to use a valve that can alter flow rate. Gate valves have a flow coefficient of 0.15, which is three times higher than that of a ball valve.

Figure 2.7 - Brass gate valve [19].

Angle valves are based off of gate valves, but with a 90º elbow built into the valve assembly. If a sharp bend must be placed in the line near the valve, having a 90º bend in the valve would eliminate the need to purchase an elbow. Since angle valves have a built-in elbow, the flow coefficient is higher than that of a gate valve. The flow coefficient is 2.0 which is forty times higher than a ball valve, and more than thirteen times higher than a gate valve. The equivalent length is directly proportional to the flow coefficient, so if it is forty times higher, the equivalent length will also be forty times higher.

Figure 2.8 - Brass angle valve [19].

Table 2.4- Decision matrix for valve selection

	Cost	**Ease of Operation**	**Maintenance**	**Flow Restriction**	
Ball Valve	4	5	3	5	**4.3**
Gate Valve	3	3	2	4	3.1
Angle Valve	3	3	2	3	2.7
	10%	20%	30%	40%	

The decision matrix shows that ball valves are the best choice in every aspect of our comparison. Ball valves have the lowest flow coefficient, cost, and time needed to go from open to close. Due to its simple design, it is safe to assume that ball valves are also more reliable than the other options.

Chapter 3. Engineering Analysis

3.1 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 pneumatic gate valves to replace the current manually actuated ones 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]:

$$Q = CA_o\sqrt{\frac{2\Delta P}{\rho}}$$

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 the 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:

$$V = L \times A$$

Where:
$A = \left({\pi}/{4}\right) \times D^2$
D= bore= 1in
L= stroke= 5in

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

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:

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

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 [3].

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

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 [4].

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:

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

$V = V_{cylinder} + V_{tubes} = 3.927in^3 + 26.507in^3 = 30.434in^3$

t= 2s

P_{abs}= 45PSI+11.3PSI= 56.3PSI

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

Figure 3.1 – Pneumatic cylinder [5]

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:

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

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

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

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

Figure 3.2 – VAT 8-inch pneumatic gate valve [6]

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:

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

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.

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

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.

3.2 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 3.3 – 5 gallon air tank with multiple ports [7]

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

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

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.

3.3 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.

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

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

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

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.

In order to calculate the pressure drop and equivalent length for a given tube, a MATLAB code was created. These calculations are done after accounting for any losses due to tees, valves, bends, or curves. To ensure that the tank is usable under the largest operating range, the goal is to keep total pressure drop in the system below 5PSI. The following equations are at the heart of the MATLAB code to calculate the equivalent length and pressure drop:

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

Where:
K= loss coefficient (dependent on fitting style and found in table) [2].
D= Flow diameter
f= Friction factor (Dependent on Reynolds number and relative roughness)

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

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

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

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. While using a single line to feed all three arms would require more tubing, the simplicity of the system and the fact that it will provide equal flow to all three arms at all times makes it a more viable option.

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 drop, 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
```

Since the difference in pressure drop between the two main supply line options is minimal, the use of a single line that will run to the center of the array and feed each of the arms through a manifold will be used.

Table 3.1- 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

3.4 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.

$\alpha = 9.3\times10^{-6}/°\mathrm{F}$ for copper

$T_{max} = 120°\mathrm{F}$

T_{min}= -20°F

$T_{install} = 70°\mathrm{F}$

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

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

$$\Delta L_{hot} = 700ft\times9.3\times10^{-6}/°\mathrm{F}(120 - 70) = 0.3255\mathrm{ft} = 3.906\mathrm{in}$$

$$\Delta L_{cold} = 700ft\times9.3\times10^{-6}/°\mathrm{F}(70 - -20) = 0.5859\mathrm{ft} = 7.0308\mathrm{in}$$

3.5 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. Since one piece of tubing will run from the

Dewar tank to the center of the array, this line will be a 100m (328ft) length of ½in tubing. Another 50m (164ft) run will feed the fourth set of gate valves, and the final outlet from the center will run 20m (65ft) to the fourth astrometric hut. Therefore, an additional 557ft of ½in tubing will be needed, bringing the total to 3917ft. To account for every length of ½in tubing, 40 rolls of 100ft each 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 3.2- Cost of different connection methods

First Fitting	**Second Fitting**	**Third Fitting**	**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 3.4- ½in tubing copper tee [8]

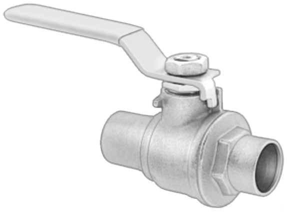

Figure 3.5- ½in brass solder ball valve [8]

Figure 3.6- ½in tube to ½in male NPT copper fitting [8]

Figure 3.7- ½in female NPT to $^3/_8$in barb fitting [9]

Figure 3.8- ½in solder coupling [8]

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:

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

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

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:

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

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

Chapter 4. Cost Analysis

4.1 Parts Total

As was previously discussed, ½in cleaned and capped copper tubing will be used from the tank to the center of the array and from the center to the end of each arm. After each tee, $^3/_8$in PVC tubing will be used to provide nitrogen to each manifold. Shown below are tables showing the length and cost of all tubing used in the system.

Table 4.1- 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
Fourth astrometric hut	½	65
External gate valves	½	164
Supply to manifold	$^3/_8$ PVC	500

Table 4.2- Cost of all tubing

Description	**Size**	**Length (ft)**	**Quantity**	**Cost $**	**Total Cost $**
Copper	½in	100ft	40	202.80	8112.00
Black PVC	$^3/_8$in	100ft	5	44.00	220.00
					8332.00

As was previously stated, NPOI plans on adding two additional actuators at the imaging stations so 7 port manifolds will be required at all 30 imaging stations. The gate valves that will be added separate of the array will utilize 6 gate valves. Therefore, it would be wise to use a 7 port with an NPT plug on one outlet, 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 valves in the three arms, and the same brand and model will be used for the other sizes.

Table 4.3- Description, quantity, and cost of manifolds [10].

# of ports	**Quantity**	**Cost ($)**	**Total Cost ($)**
7	31	21.30	660.30
5	3	18.84	56.52
2	4	14.87	59.48
5*	1	26.22	21.85
	39		**798.15**

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 4.4- Description, quantity, and cost of all fitting components [8] [9].

Inlet	Outlet	Quantity	Cost ($)	Total Cost ($)
½in coupling		35	0.37	12.95
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		**964.11**

There are several different uses and needs for a simple 5-gallon air tank. This allows for a large variety of shapes to be readily available. One tank is needed for each arm, so three 5-gallon, round, 6 port air tanks will be used. While four of the ports will be unused, it is actually cheaper to purchase a tank with 6 ports vs. 2. To attach the supply line to the tanks, a ½in tubing to ½in male NPT fitting must be used on each end. To cap off the unneeded ports, ½in NPT plugs will be used.

Table 4.5- Storage tank supplies [7] [8]

Description	Quantity	Cost ($)	Total Cost ($)
5-gallon tank	3	84.99	254.97
½in tube to ½in male NPT	6	1.07	6.42
½in NPT plug	12	2.58	30.96
			292.35

There will be thermal expansion, vibrations, wind, rain, and snow affecting the cable tray that houses the copper tubing. For this reason, the tubing must be restrained at several locations with a vibration damping rubber isolator. These mounts will be placed on both sides of each tee, and every 10m between each station. This will require 96 of these on each of the three arms, and 32 between the tank and center. While using self-tapping screws would be cheaper and easier, everything at NPOI has been built with the finest quality and detail so it would be wise to follow suit. Jim Clark has stated that he uses stainless steel for the mounting hardware of every object on the site. Therefore, ¼-20 SS316 bolts that are 1-inch long will be used with a nylon-insert locknut. Each bracket uses two ¼in mounting holes so every bracket will require two bolts, two washers, and two locknuts.

Table 4.6- Mounting hardware [14] [15]

Description	Quantity	Package Qty.	Cost ($)	Qty. of packages	Total Cost ($)
¼-20 SS316 bolt	320	25	7.22	13	93.86
¼in SS316 washer	320	100	8.25	4	33.00
¼-20 nylon-insert locknut	320	50	9.26	13	120.38
TPR Vibration-damping clamp	320	25	10.56	13	137.28
	1280			46	**384.52**

4.2 Installation Costs

The labor involved in the installation of this system is relatively simple. Installation will require bending of the copper tubing, cutting and soldering of the connections, securing the tubing in the cable tray, drilling holes in the side of the cable tray at each exit, and routing all tubing to the appropriate locations. The staff at NPOI has a workshop with a relatively large amount of tools, so few tools will need to be purchased. Considering the vast amount of knowledge and hands-on experience that both Jim Clark and Steve Winchester contain, it is likely that these two will perform the installation. However, if they wish to hire an outside source to complete the installation, the cost of this can vary greatly. Labor rates by companies are constantly changing, and there is no way to properly account for the time it would take to install such a customized system.

When cleaned and capped copper tubing is ordered in 100ft rolls, the material has a soft temper that makes it easy to bend without kinking. Lever type tubing benders with a die specific to the outer diameter of the tubing allows the tubing to be bent easily and accurately due to the precise bend angle markings on the tool. A $^5/_8$in (0.625in) die will be used to match the outside of the ½in copper tubing [17]. After the tubing is bent, it must be cut smoothly and normal to the tube so the fittings will fit properly. To perform these cuts, a plumbing metal tube cutter will be used. Both the tube bender and tube cutter are available from McMaster-Carr [18]. The holes that need to be drilled in the cable tray can be performed using a cordless drill and a bi-metal hole-saw or step bit. It is safe to assume that these items are already available to the NPOI staff.

All copper fittings that are used in the system will be soldered using an air-acetylene torch and solder with 6% silver content. This method is much easier to perform than using brazing rod, and since all joints will be soldered in a horizontal configuration, the risk of introducing excess solder into the tubing is very minimal. An 8oz roll of $^1/_8$in diameter Stay-Brite solder is ~$50 and will be enough to solder every joint in the system [11]. An air-acetylene torch setup such as a Victor Turbo Torch® [12] is a common tool for HVAC technicians and plumbers, or a torch kit can be purchased from McMaster-Carr® and an acetylene tank can be rented or purchased from Praxair, Inc. which is the same company that is providing the large nitrogen tank [13].

Table 4.7- Installation items

Description	**Size**	**Cost**
Tubing Bender	$^5/_8$in OD	148.33
Tube Cutter	$^1/_8$in to $^3/_4$in OD	15.50
Stay-Brite #8 Solder	$^1/_8$in diameter, 8oz	50.26
Prest-O-Lite Torch Kit	N/A	179.63
Acetylene Tank	10ft^3	N/A (Industrial pricing)
		393.72

4.3 Bill of Materials

The total values for the materials and installation supplies are shown below in the bill of materials.

Table 4.8- Total bill of materials

Description	**Quantity**	**Cost**
Tubing	45	8332.00
Manifolds	39	798.15
Fittings	572	964.11
Installation		393.72
Mounting hardware	1280	384.52
Tank Supplies	21	292.35
		11164.85

Chapter 5. Conclusion

Today's military still bases its navigation and global positioning systems on the positions of the stars relative to the earth. However, because of the nature of the technique, constant remapping of the stars is required. In order to do this, the U.S. Naval Observatory employs the Naval Precision Optical Interferometer (NPOI) just outside of Flagstaff Arizona to do just this.

The NPOI is an array telescope that consists of three arms each equaling 300 meters long. Along each of these arms are several imagines stations that all require devices powered by pressurized nitrogen. Currently, the facility is designed to utilize a nitrogen tank deployed at each of the many stations along the arms that require refilling and changing regularly. It is because of this that the operators of the NPOI have requested an alternative nitrogen supply distribution system that requires less hassle and more reliability.

In order to fulfill the requirements of the supply system, many factors had to be taken into account. These include: a single supply station, operating environment, nominal consistent flow rates, and of course low cost. Along each of the three arms are three manifolds that have five ports. Each of these manifolds has to be able to sustain 0.5[ft^3/hr.] of nitrogen consistently at 9psi for a purge system and a 30psi burst to operate pneumatic cylinders. These are to be operated with minimal maintenance over the lifetime of the system.

While designing, the system was broken up into three distinct sections. These were as followed, tubing material, nitrogen distribution style and shutoff valve layout. The tubing material mainly consisted of the main supply line that runs the entire length of the arms of the array. Three materials were finally considered. Of copper, stainless steel and EPDM, clean and capped copper was chosen for the main supply line. This was because of its low cost and exemplary ability to withstand the elements.

At each imaging station a distribution style was needed. In order to achieve this, three types of styles were considered. The first was a flow through manifold. This included a manifold soldered directly into the main supply line at each station. Very similar to this was the T-fitting to manifold, which had a T-fitting soldered into the main supply line with an external tube leading to a manifold. The final system was series of T-fittings at each station directly leading to each device. Decisions for this system were made primarily on ease of installation and use. Because of this, the T-fitting to manifold design was chosen.

The last part of the nitrogen supply system to design was the manual shutoff valves at each of the stations. Manually shutting off each station only involves the use of one valve at each manifold, as decided earlier. In other words, only the type of valve had to be chosen for this part. A ball valve proved to be much cheaper and easier to use than the gate valve or the angle valve. Deciding this did not take long.

While fully analyzing and designing this nitrogen supply system the major factors being taken into account were the required flow rates and pressure drops along the whole system. In order to reduce the pressure drops while still maintaining the designated flow rates to operate the devices along the array, a specific copper tubing size was selected to be 0.55inch inner diameter. Leading to this right off the main supply tank would be a copper tubing section of a larger diameter. In order to further reduce the risk of pressure drop and system failure the implementation of pressurized nitrogen tanks were also taken into consideration along the array arms. This included analysis of the pressure prior and after the tanks. Along with this main calculation thermal expansion also had to be calculated.

Implementing this whole supply system requires a variety of tubing types and sizes along with many tubing fittings and mounting hardware. Including but not limited to T-fittings, ball valves, male NPT copper fittings, barbed fittings and soldering couplings all of various sizes. Both copper tubing and black PVC tubing was selected along with a variety of manifolds with different quantities of ports. The cost of all of these materials alone is just over $10,000.00. However, when considering the cost of installation tools this price increases to an estimated $11,164.85 when ordering the majority of the supplies from McMaster Carr®.

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

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

[10] Black Anodized Aluminum Manifolds. http://www.polyconn.com/black-anodized-manifolds-p-2626-l-en.html

[11] Lincoln Electric Stay-Brite Solder. http://www.homedepot.com/p/Lincoln-Electric-Stay-Brite-1-8-in-x-8-oz-Spool-Solder-SB61-2POP/100672841?cm_mmc=shopping-_-googleads-_-pla-_-100672841&skwcid&kwd=&ci_sku=100672841&ci_kw=&ci_gpa=pla&ci_src=17588969 #.UqP0T6X3BFI

[12] Prest-O-Lite Torch Kit. http://www.mcmaster.com/#gas-welding-torches/=ppp7u7

[13] Praxair Acetylene tank information. http://www.praxair.com/gases/buy-acetylene-gas-or-chemical-acetylene/?tab=supply-options

[14] Stainless steel mounting hardware http://www.mcmaster.com/#stainless-steel-products/=pqik42

[15] Rubber isolators http://www.mcmaster.com/#pipe-routing-clamps/=pqikn8

[16] Copper tube http://www.mcmaster.com/#standard-metal-tubing/=pqiltp

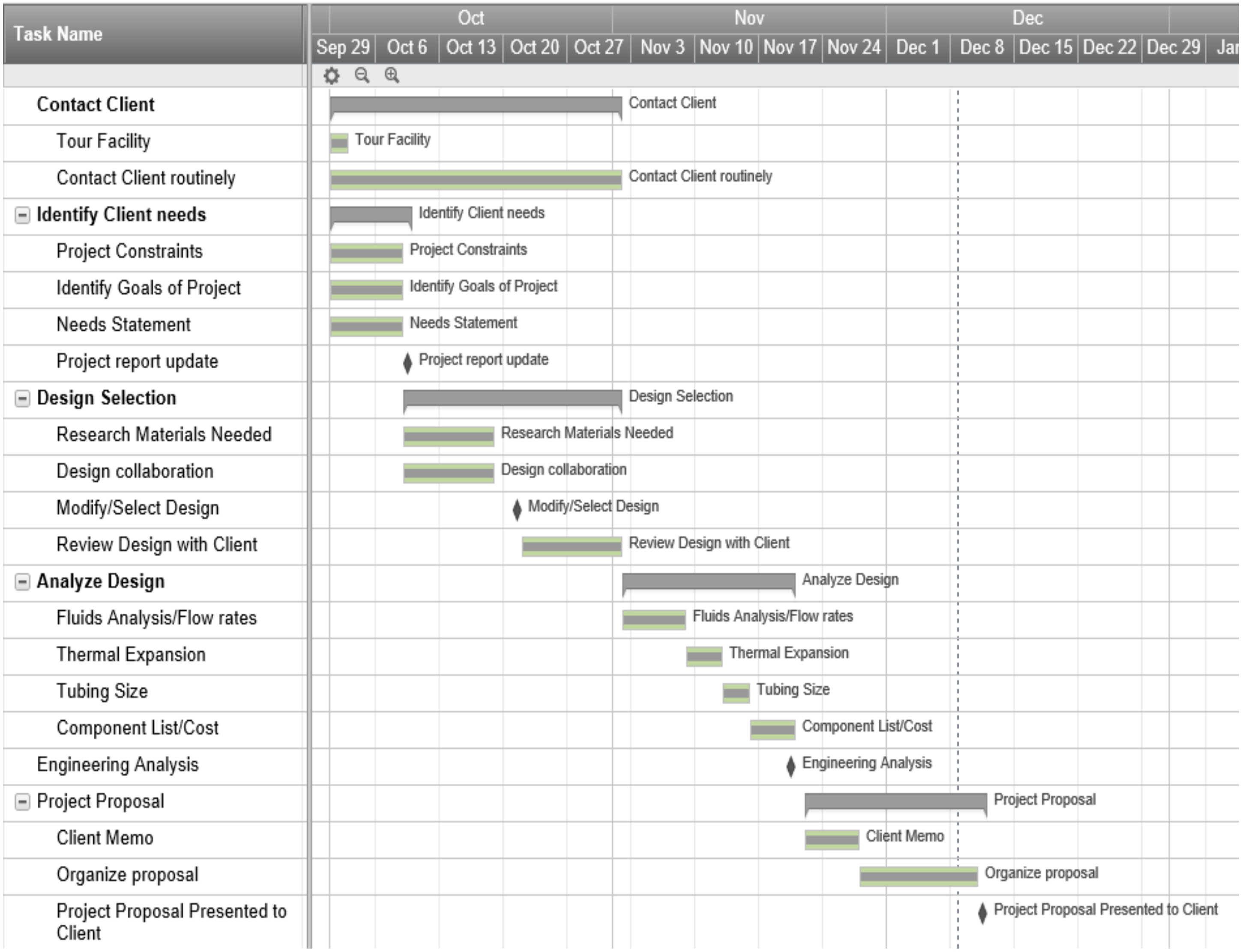
[17] Tubing bender http://www.mcmaster.com/#tube-benders/=pqko7r

[18] Tube cutter http://www.mcmaster.com/#tube-cutters/=pqkmls

[19] Component Pictures http://www.mcmaster.com

Appendix A

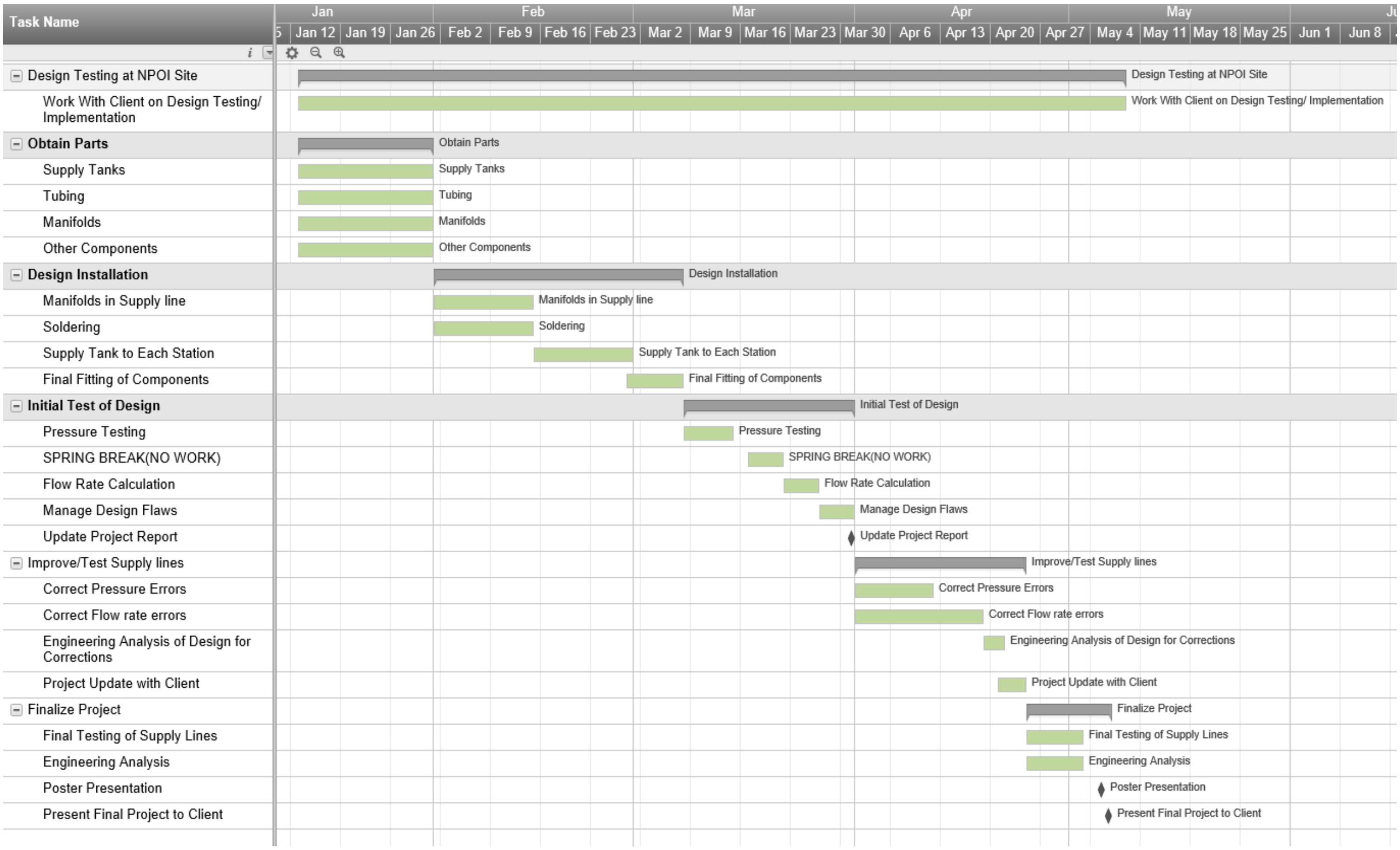
Fall 2013 Project Schedule



Task Name

- **Contact Client**
  - Tour Facility
  - Contact Client routinely
- **Identify Client needs**
  - Project Constraints
  - Identify Goals of Project
  - Needs Statement
  - Project report update
- **Design Selection**
  - Research Materials Needed
  - Design collaboration
  - Modify/Select Design
  - Review Design with Client
- **Analyze Design**
  - Fluids Analysis/Flow rates
  - Thermal Expansion
  - Tubing Size
  - Component List/Cost
- Engineering Analysis
- Project Proposal
  - Client Memo
  - Organize proposal
  - Project Proposal Presented to Client

Spring 2014 Project Schedule



Task Name

- Design Testing at NPOI Site
  - Work With Client on Design Testing/ Implementation
- **Obtain Parts**
  - Supply Tanks
  - Tubing
  - Manifolds
  - Other Components
- **Design Installation**
  - Manifolds in Supply line
  - Soldering
  - Supply Tank to Each Station
  - Final Fitting of Components
- **Initial Test of Design**
  - Pressure Testing
  - SPRING BREAK(NO WORK)
  - Flow Rate Calculation
  - Manage Design Flaws
  - Update Project Report
- Improve/Test Supply lines
  - Correct Pressure Errors
  - Correct Flow rate errors
  - Engineering Analysis of Design for Corrections
  - Project Update with Client
- Finalize Project
  - Final Testing of Supply Lines
  - Engineering Analysis
  - Poster Presentation
  - Present Final Project to Client

Appendix C: Pressure Drop Matlab Code

```
%%% Tubing diameter Calculation for NPOI %%%
%%%         Wyatt Huling                 %%%
%%%          October 2013                %%%

prompt= 'What is diameter?';
Dinch= input(prompt);
promptone= 'How many tees?';
N= input(promptone);            %Number of tees
promptbranch= 'How many branch tees?';
O= input(promptbranch);
prompttwo= 'How many valves?';
M= input(prompttwo);
promptthree= 'What is line pressure?';
Pressure= input(promptthree);
promptfour= 'Line length [m]?';
L= input(promptfour);                         %Length, m
promptfive= 'Flowrate [CFH]?';
Qcfh= input(promptfive);


Kvalve= 0.05;                   %Flow coefficient for ball valve
Ktee= 0.2;                      %Flow coefficient for line flow in
flanged tee
Kbranch= 1.0;
D= Dinch*0.0254;                %Diameter in meters
e= 0.015*10^-6;                 %Equivalent roughness


Qcfm= Qcfh/60;
Q= Qcfm*0.00047;                %Volumetric flow rate, m^3/s
v= Q/((pi/4)*D.^2);             %Velocity

Lcurves= 10*(pi/2)*2;           %10 curves of 180degrees with 1m radius
Leqcurves= (28/304.8)*Lcurves;
Lcurve= Lcurves+Leqcurves;
rho= 1.1651;                    %Density, kg/m^3
mu= 17.164*10^-6;               %Dynamic Viscosity, Pa s

Re= (rho*v*D)/mu;               %Reynold's number

f= 0.25/((log10((e/(3.7*D))+5.74/(Re.^0.9))).^2);   %Friction factor


Leqtee= (Ktee*D)/f;             %Equivalent length of each tee
Leqvalve= (Kvalve*D)/f;         %Equivalent length of each valve
Leqbranch= (Kbranch*D)/f;

%When flow reaches the end, it will havegone through all of the tees
%but only one of the valves
promptsix= 'Include curves of cable tray? 1 for yes 0 for no';
question= input(promptsix);
if question== 1
```

```
    Ltotal=L+Lcurve+(N*Leqtee)+(M*Leqvalve)+(O*Leqbranch);
%Total equivalent length
else
    Ltotal= L+(N*Leqtee)+(M*Leqvalve);
end

disp('Equivalent length=')
disp(Ltotal)

Pdrop= f*((Ltotal/D)*((rho*v.^2)/2));   %Pressure drop in line

Patm= Pdrop*0.000145;

Pressuredrop= Patm*14.696;                %Pressure drop in PSI

disp('Total Pressure Drop')
disp(Pressuredrop)
```