NPOI Nitrogen Distribution

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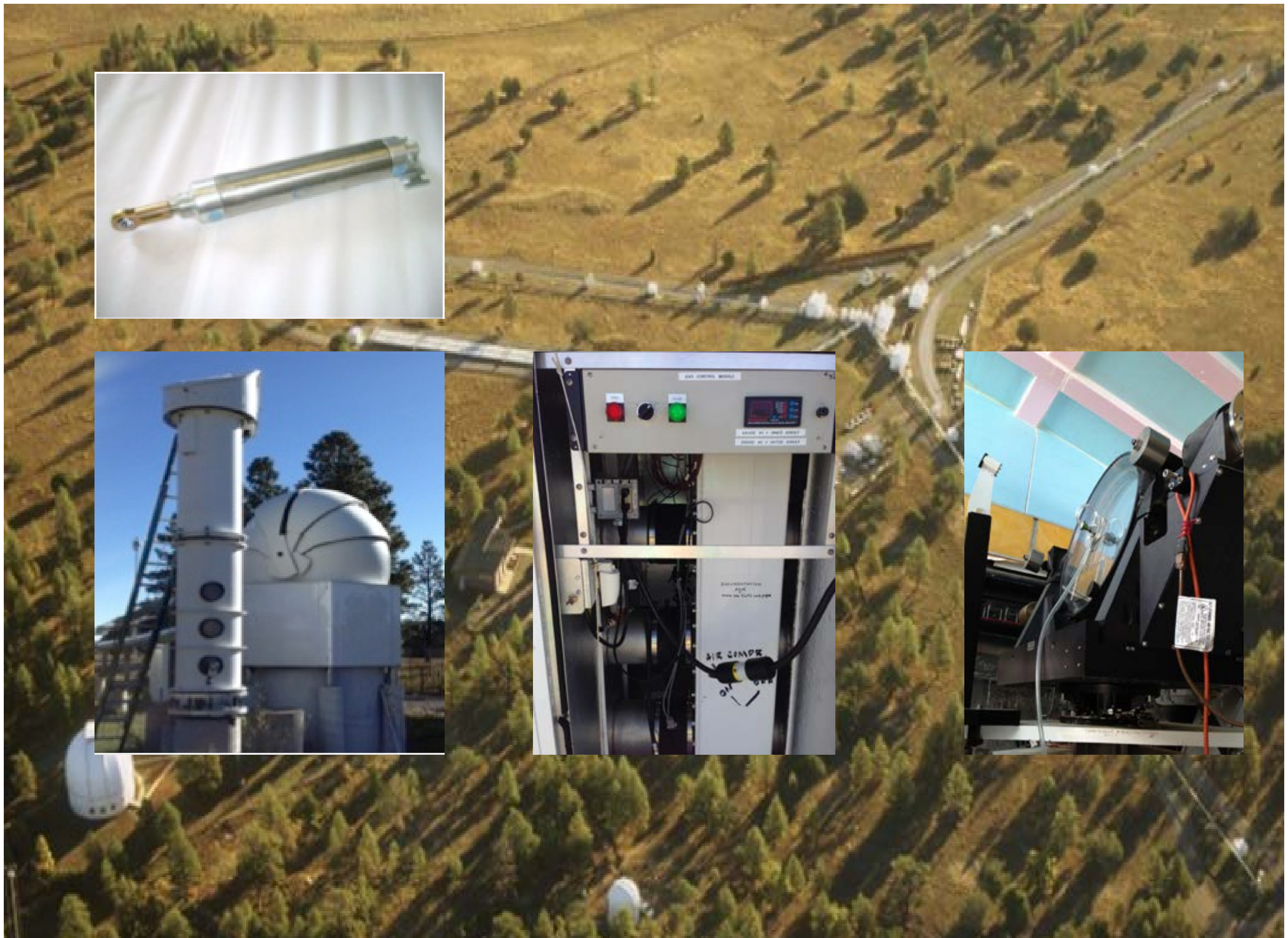
Overview

- Introduction
- Problem formulation
- Proposed design
- Prototype fabrication
- Testing and results
- Cost analysis
- Conclusion

Navy Precision Optical Interferometer

- Map astrometric position for navigation and satellites
- Array telescope
  - 250m arms
  - Stations along arms utilize nitrogen
- Nitrogen is more reliable than compressed air

Navy Precision Optical Interferometer



Project Goals and Needs

- Nitrogen distribution system that requires less maintenance at a lower cost than the current system.
- Provide proper flow rate and pressure to each device.
- Supply nitrogen to all devices on site:
  - 10 imaging stations per arm
  - 1 astrometric hut per arm & 1 in center
  - 1 gate valve station per arm
- Utilize 1000L liquid nitrogen Dewar tank

Constraints

	Pressure [PSI]	Volumetric flow rate [CFH]
Astrometric hut	9	0.5
Gate valves	40	22
Imaging station actuators	40	18

Operating Environment

- Operate between temperatures of -20°F to 120°F

- Nitrogen supply lines must be able to handle vibrations and contact with cable tray.

- System is exposed to wind, rain, snow, ice, and UV light.

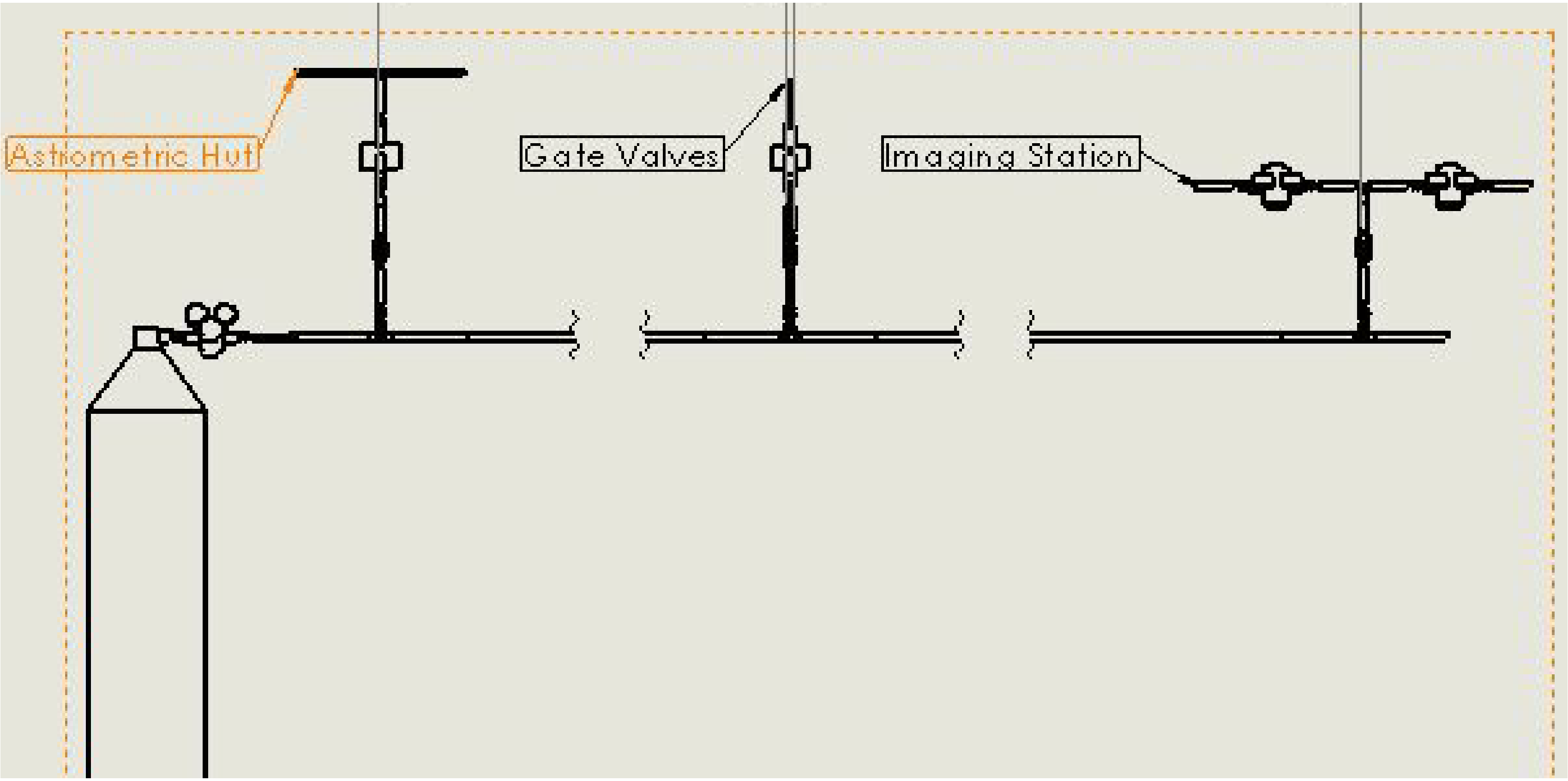
Proposed Design

- Cleaned and capped copper tubing
  - ½in tubing size
  - Easily bent into shape due to soft temper
  - Solder fittings at all joints
- Brass fittings to convert branch flow to ¼in barb
- ¼in polyvinyl hose from supply line to device

Proposed Design continued

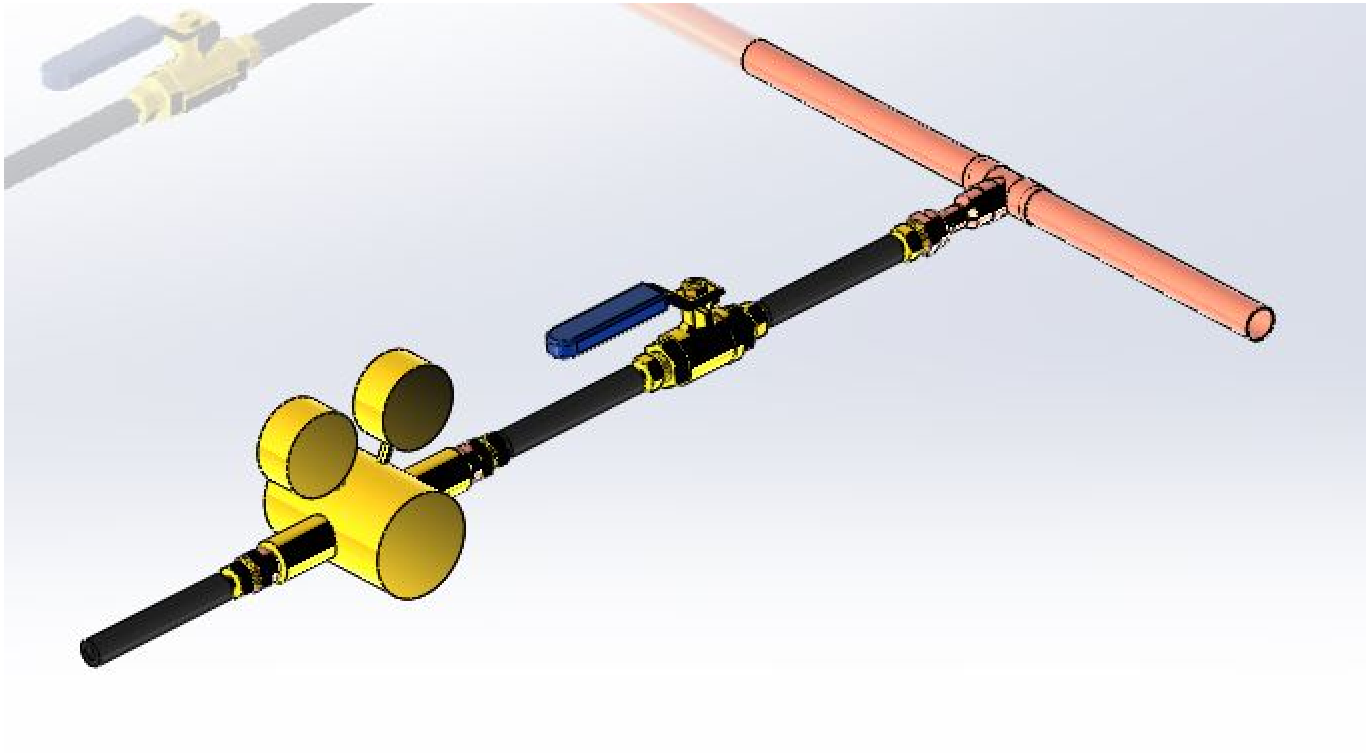
- In-line regulator for each device
- ¼in ball valve
  - Most efficient manual valve
  - Smallest pressure drop
- 5-gallon reservoir tank prior to gate valves
  - Same volume as 405ft of ½in tubing

Design Drawing

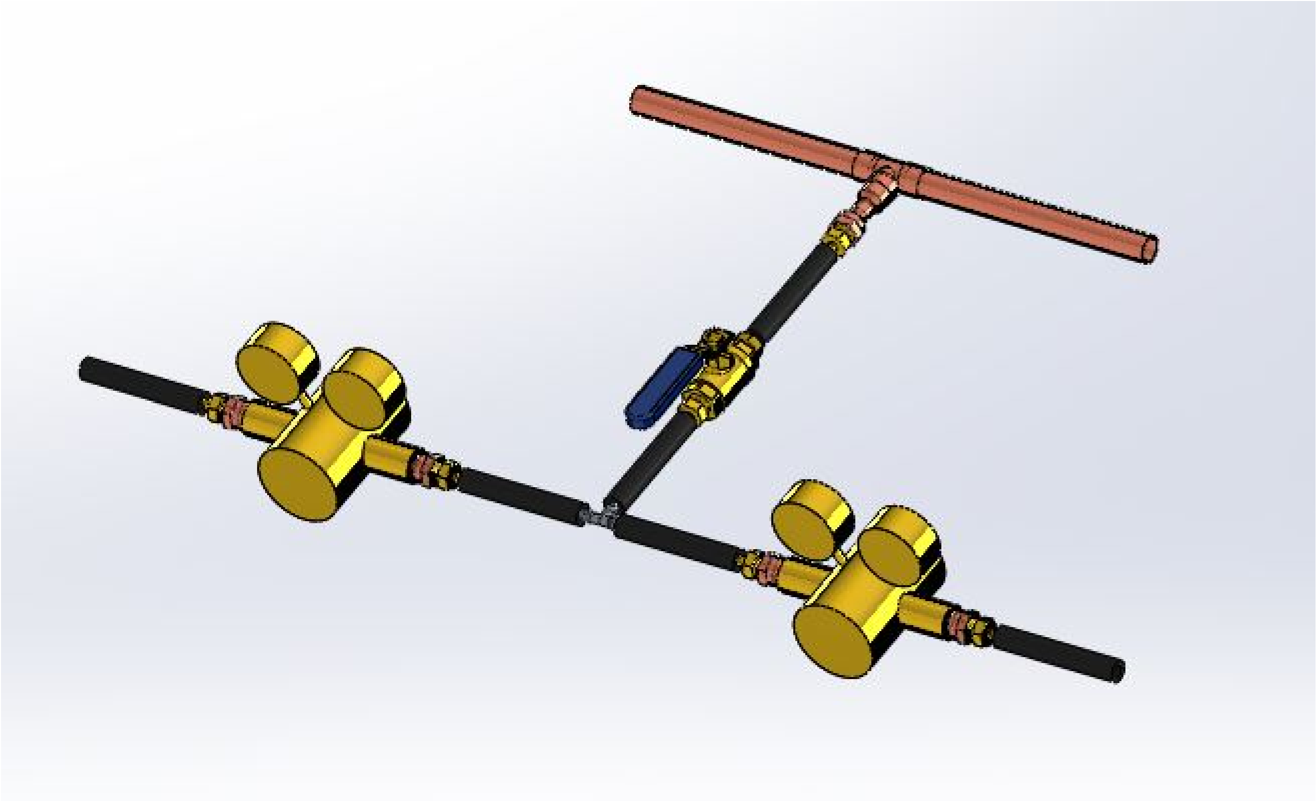


Astrometric Hut

Gate Valve



Imaging Station



Engineering Analysis

- $Q = \frac{V \times P_{abs}}{28.8 \times t \times P_{atm}} \left[\frac{in^3}{s}\right]$
- P_{atm}= 11.3PSI at 7000ft
- Gate valves require 22CFH
- Imaging station actuators require 18CFH
- Max flow rate= 21CFH at 300m

Numerical Analysis

- Several aspects of array affect pressure drop:
  – Tubing length
  – Flow rate
  – Loss coefficient of valves and tees
  – Curves in cable tray
- MATLAB code built around Darcy-Weisbach equation

MATLAB Code

- $\Delta P = \ f_d \frac{L}{d}\frac{\rho V^2}{2}$
- $f_d =$ Friction factor from Colebrook equation
- $\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\in}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$
- $Re = \frac{\rho V D}{\mu}$
- $V = \frac{Q}{\pi r^2}$
- ∈= Relative roughness

Material Selection

- Maximum pressure drop in 300m tube:
  - 0.436in→ 5.97PSI
  - 0.555in→ **1.95PSI**
  - 0.680in→ 0.77PSI

Thermal Expansion

- Change in length due to change in temperature
- $\Delta L = L_o \alpha (T_{install} - T_{min})$
- Coefficient of thermal expansion for copper $\alpha = 9.3x10^6/°F$
- $\Delta L = 7.03in$

Expansion Loops

- Absorbs the change in length to reduce stress
- $L = \frac{1}{12}\left(\frac{3E}{\sigma_{max}}\right)^{\frac{1}{2}}(d_o \Delta L)^{\frac{1}{2}}$
- L= 16.1in=πD→ D= 5.12in

Prototype Description

- 100 ft. section of west arm
- Contains one of each:
  - Astrometric hut
  - Gate valves
  - Imaging station
- Coil to simulate entire arm
- Reservoir tank for gate valves

Prototype Fabrication

- Copper tubing was installed in cable tray
- Majority of soldering was performed indoors to prevent cold joints
- 3-gallon tank was used due to availability
  - Affected pressure drop when actuating gate valves
- Angle valves were used instead of ball valves
  - Loss coefficient for angle valve= 2
  - Loss coefficient for ball valve= 0.2

Prototype Testing

- The prototype successfully performed all necessary tasks
- Gate valves had slight delay due to 3-gallon tank
- Imaging station actuators responded quickly

Prototype Results

- Pressure drop was calculating while operating pneumatic actuators
- Predicted pressure drop= 0.37PSI
- Actual pressure drop= 0.50PSI
- Error= 36%
- Adjusted final pressure drop= 2.65PSI

Cost Analysis of Operation

- 1000L Dewar has gaseous equivalent volume equal to 86 tanks
- Total cost to refill tanks: $35.00x30= $1050.00
- Cost to refill Dewar tank= $1000.00
- Nitrogen cost is projected to be ~1/3 of current system

Cost of Prototype

- Prototype had budget of $500.00
- The cost of materials came just under this $500.00
- All materials were already located on site, no expense for the NPOI staff

Final Design Bill of Materials

Item	Quantity	Cost ($)	Total Cost
100ft copper roll	35	202.80	7098.00
50ft polyvinyl hose	5	44	220.00
½in tee	37	1.45	53.65
½in coupling	35	0.37	12.95
¼in ball valve	37	8.27	314.26
½in tube- $^{1}/_{8}$in female NPT	37	2.62	96.94
$^{1}/_{8}$in male NPT-¼in barb	37	1.20	44.40
Hose clamps	140	0.72	100.80
Mounting clamps	320	0.42	135.17
¼-20 SS316 Bolt	320	0.29	92.80
¼-20 SS316 Washer	320	0.08	26.40
5-gallon reservoir tank	3	84.99	254.97
Harris regulator	13	85.09	1106.17
¼-20 Nylock nut	320	0.19	59.26
Total cost			**9556.51**

Conclusion

- The Navy Precision Optical Interferometer is in need of an updated nitrogen supply system.
- New designs must operate with the same parameters as the current system (i.e. same pressures and flow rates).
- Copper and polyvinyl were chosen based on cost, resilience, efficiency and effectiveness.
- Engineering analysis shows 2.65PSI drop over 300m length with proper flow rates on the final design.

Conclusion Continued

- A smaller scaled prototype, built on site, has given successful results on operation of all devices 200ft away from source.
- With the prototype proven, the cost of all materials for the final design is $9556.51.

References

- *Navy Precision Optical Interferometer. http://ast.noao.edu/facilities/other/npoi*
- *Fundamentals of Fluid Mechanics (7th edition).* Munson, Okiishi et all. (2013). Danvers, Ma. Wiley & Sons, Inc.

Questions?