# NPOI Vacuum Manifold

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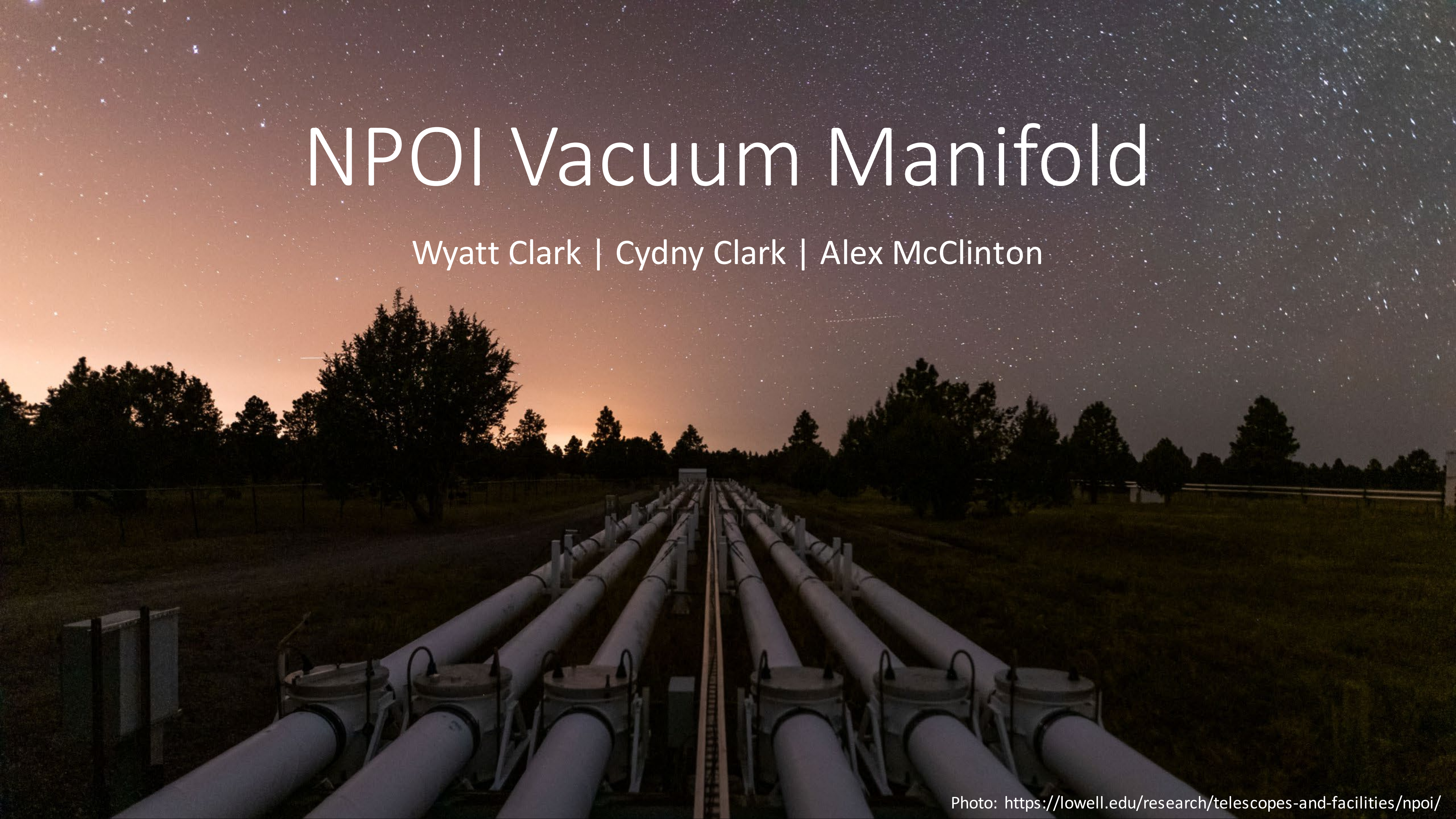


Photo: https://lowell.edu/research/telescopes-and-facilities/npoi/

# Presentation Outline

- Project Description
  - Background information
  - Who is the client
- Benchmarking
  - Current in use system
  - Overview how we fit in
    - Why it's important
  - Other industry systems
- Literature Review
  - Technical resources
- Project Requirements
  - Customer and Engineering
- Schedule and Budget
  - Project timeline | budget

# Project Description (Background Information)

- The Navy Precision Optical Interferometer (NPOI) is the world's largest optical interferometer with a 430-meter footprint [1]
- It is a collection of up to 6 small telescopes that work together to synthesize a much larger telescope
- Star light collected by the small telescopes travels through a large vacuum array to a detector
- Parts of the vacuum system need a redesign to increase safety and relatability

https://www.google.com/maps/@35.0965761,-111.5337258,600m/data=!3m1!1e3

# Project Description (Client)

U.S. NAVAL RESEARCH LABORATORY

UNITED STATES NAVAL OBSERVATORY

Lowell OBSERVATORY

NPOI is a Navy instrument in collaboration with long term contractor Lowell Observatory. Jim Clark is the primary client representing all three organizations. He is also the current director of NPOI.

# Benchmarking (Current system)

Image: The six fast delay line vacuum tubes

- NPOI utilizes two types of light path delay lines. The image features the “Fast Delay Lines” (FDLs) which are held under vacuum
- This Capstone will mechanically interface with all six FDLs
- The Capstone team will develop a new vacuum manifold between the vacuum pump(s) and the delay lines

# Benchmarking (Current system)

- A rotary-vain vacuum pump is mounted to the wall (out of frame)
- Copper pipe is used to connect the vacuum pump to each of the delay lines
- Each delay line is isolated by a vacuum valve
- The manifold attaches to the delay line via the “snoots”


Image: Connection of FDL to current vacuum manifold

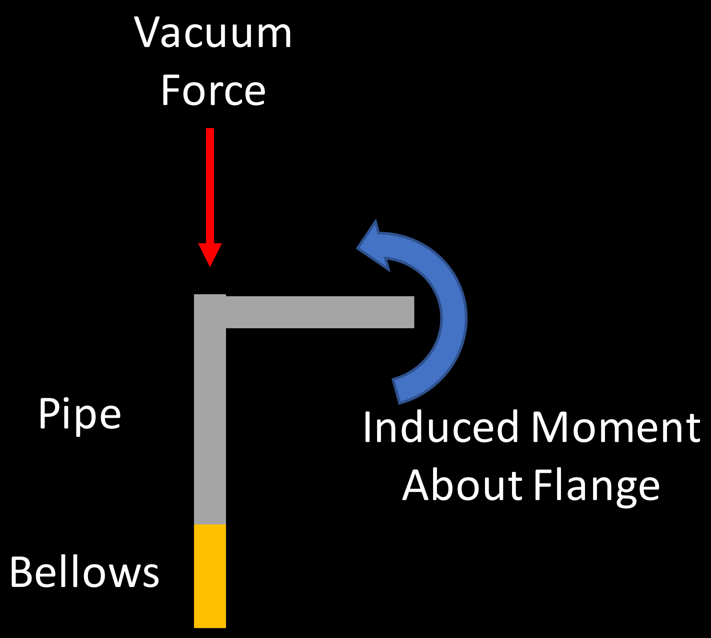
# Benchmarking (Current system)


Image: Inner optics room

- The snoots extend into the “inner optics room”
- The snoots hold expensive optics and are held in precision alignment
- Any time work needs to be performed on the delay lines the manifold and snoots must be disassembled

# Benchmarking (Current system)


Image: Pump and current vacuum lines



# Benchmarking (Current system)

Image: Connection of snoots to manifold

- The off-axis force induces a moment about the vacuum pump flange
- The combined moment is approximately 277 ft*lbf
- The system is not stable and is rotating over time
- Bellows are used to compensate for the positional uncertainty
- Note the variation in manifold connection angles

# Benchmarking (Overview How We Fit In)

## Why it's Important

- Current system is failing
- Current system is dangerous
- Current system is hard to use

Image: different angle of connection to manifold (line 6 removed)

## What we are doing

The Capstone team has been tasked to design, manufacture, install, and validate a new FDL vacuum manifold

# Benchmarking (Other Industry Systems)

- Laser Interferometer Gravitational-Wave Observatory (LIGO)
  - World's third-largest vacuum chambers: Two L-shaped detectors with 4 km long vacuum chambers [2]
  - The pressure inside LIGO's vacuum tubes is one-trillionth of an atmosphere ($10^{-9}$ torr) [2]

Outside View Of LIGO’s Arms [3]

# Literature Review (Wyatt)

1. *"VACUUM EQUIPMENT FOR RESEARCH AND DEVELOPMENT" by* Edwards Vacuum [4]
   - Covers a verity of industry standard vacuum hardware and best use cases
   - Covers the Importance of proper vacuum hardware selection and methods for making selections
2. *"Flange Systems Overview"* by Kurt J. Lester Company [5]
   - NPOI utilizes KJLC hardware and the KF system for most "off the shelf" compensates
   - Discusses the types of vacuum flange connections and in what situations they should be used
3. *"Valves Technical Notes"* by Kurt J. Lester Company [6]
   - Discusses types of vacuum system valves and how to select the best style for your application
   - Argues a valve is equally important as a vacuum pump

Images from KJLC

# Literature Review (Alex)

1. "Metal Expansion Joints and Metal Bellows" by MACOGA Engineered Expansion Joint [7]
    - Details the various types of expansion joints and metal bellows that can be manufactured and how to best utilize them
2. "Vacuum Technology of the LIGO Interferometers" by LIGO [8]
    - Covers the basics of how LIGO achieves its $10^{-9}$ torr vacuum
    - Details the challenges in maintaining this low pressure
3. "Vacuum Physics and Technology" Chapter 8 by Y. Shapira and D. Lichtman [9]
    - Covers how various materials react to vacuum pressure
    - Uses these considerations to showcase the best materials for building vacuum pipes

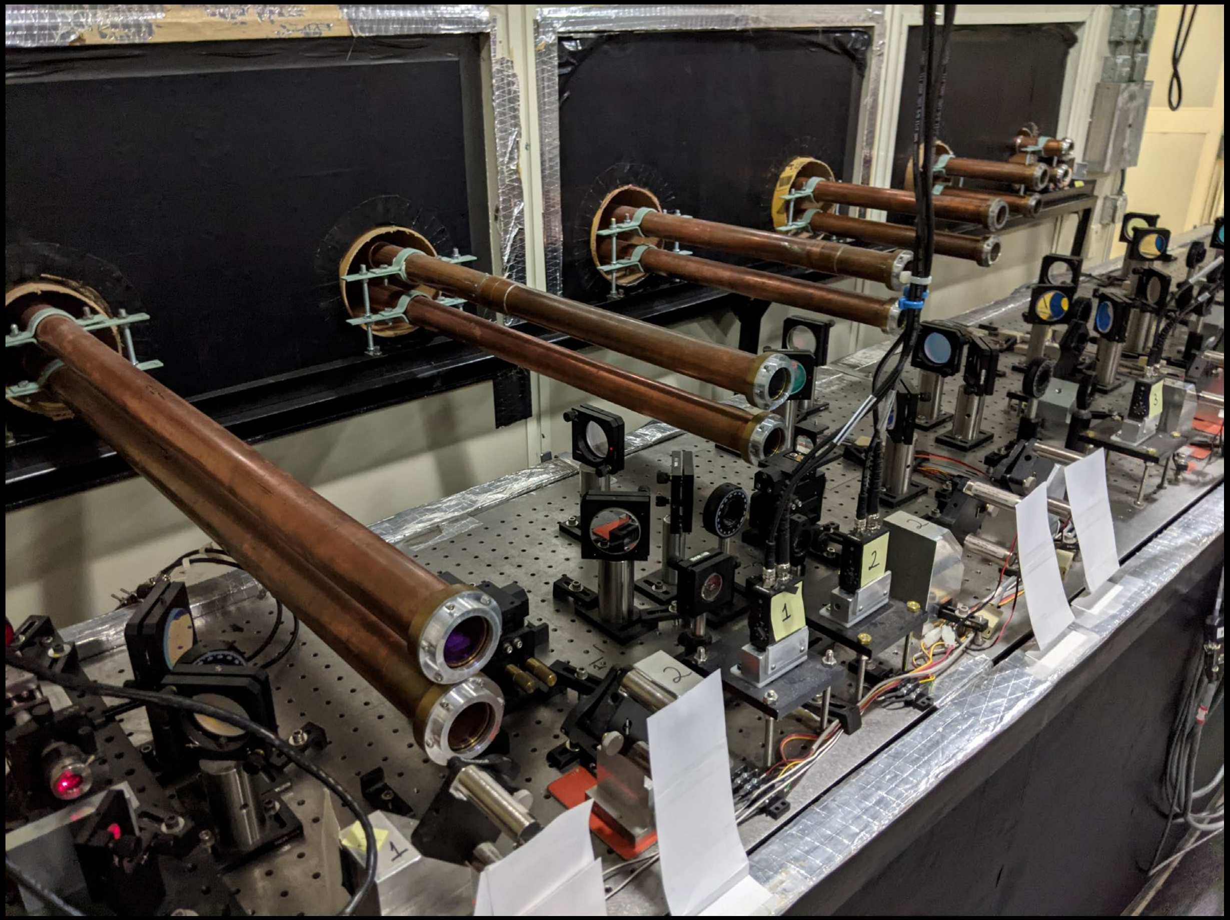
# Literature Review (Cydny):

1. “FORMAL METHODOLOGY FOR SAFETY-CRITICAL SYSTEMS ENGINEERING AT CERN ” by F. Valentini [10]
   - Describes that for the unction and operation of the CERN LHC one major aspect of the safety plan is to use safety function modeling.
2. “LIGO Caltech 40 Meter Laboratory Laser Safety Plan” by Alan Weinstein [11]
   - Outlines the overall safety goal as well as the safety procedures for the use of the lab facilities.
   - This is a document given to any person entering the lab and is to be signed off on, stating that each person understands the contents of the documents and the outlined safety precautions.
3. “Observer Troubleshooting- Vacuum” by NPOI
   - This document serves as a list of instruction of what to do and what not to do when working with the vacuum.
   - There are also question and answer sections that describe how instruments should be functioning.

# Project Requirements (Customer)

- Develop a new FDL vacuum manifold
- Must be safe and reliable
- Must include high vacuum pressure sensors
- Must reduce mechanical transfer of vibration
- Must be an improvement to downtime work
- Cannot connect to the snoots
- Should consider future NPOI work/programs/modifications

# Project Requirements (Engineering)



- Created by putting a quantifiable numerical value on customer needs
- Optimize material for:
  - Cost
  - Manufacturing
  - Strength
  - Vacuum degradation / contamination

- Optimize design for:
  - Supporting external loads
  - System factors of safety
  - Cycles to failure
  - Flexibility of design (accommodate future needs)

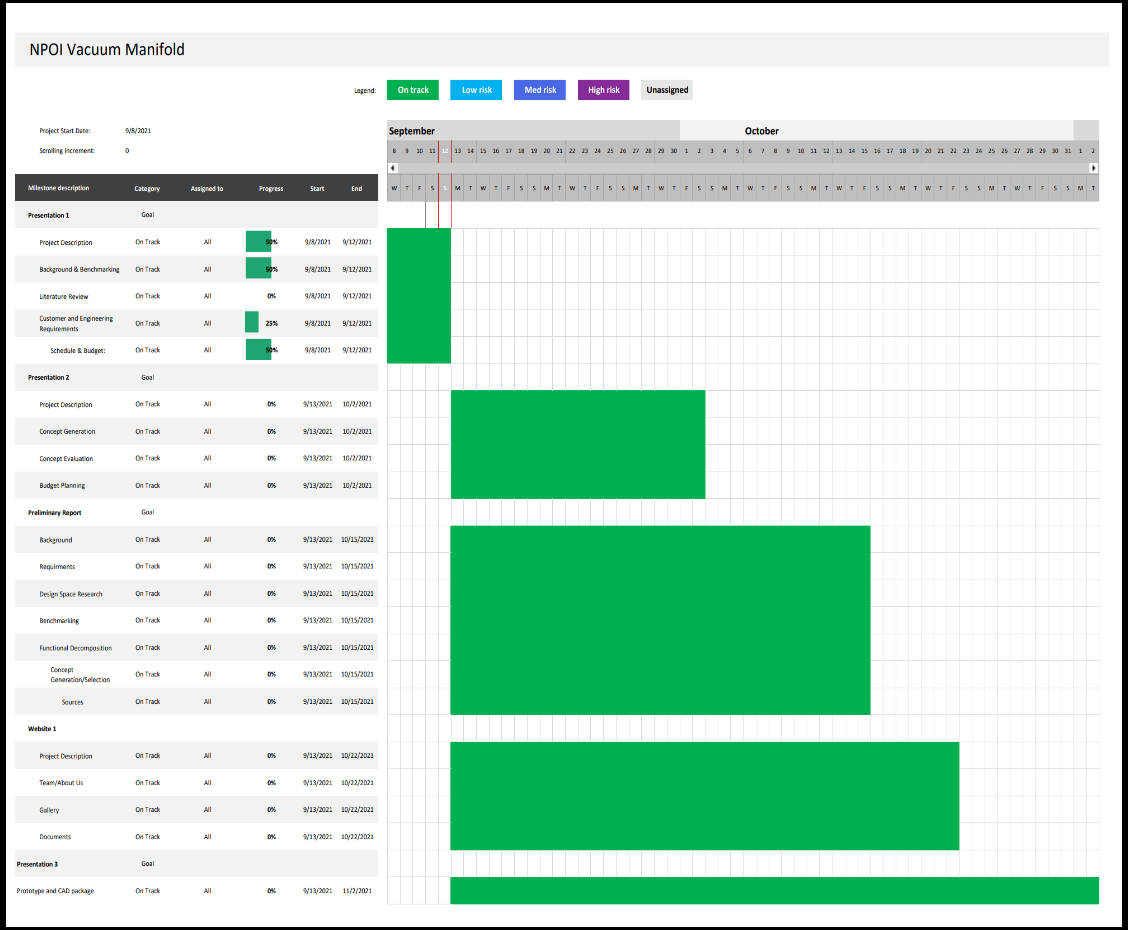
# Project Requirements (QFD)

| House Of Quality | | * | ↓ | ↓ | * | * | ↑ | ↑ | Improvement Direction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Design Requirements / Customer Requirements | Importance | Factors of Saftey | Manufactureing Lead Time | Project Cost | Smaller Pump Flow Rate | Main Pump Flow Rate | Minimize downtime | Youngs Modulus | Customer Competitive Assessment: 1 Worst | 2 | 3 | 4 | 5 Best |
| Safty | 9 | 9 | 1 | 9 | | | | | A | | | | BC |
| Cost | 3 | 9 | 9 | 9 | | | 1 | | B | C | A | | |
| Ease of use | 3 | | | 1 | 1 | 9 | 3 | | | BC | A | | |
| Relyability | 9 | 9 | | 3 | | | 3 | 3 | | A | | BC | |
| Repairability | 9 | 1 | 1 | 3 | | | 9 | 1 | | A | BC | | |
| Longjevity | 3 | 9 | 1 | 3 | 1 | | | 3 | | A | BC | | |
| Furture project intagration | 1 | | 1 | 3 | | 1 | 1 | | | ABC | | | |
| **Technical Importance: Absolute** | | 147 | 34 | 102 | 10 | 81 | 84 | 33 | | | | | |
| **Technical Importance: Relative** | | 35% | 8% | 27% | 1% | 4% | 19% | 7% | | | | | |
| **Target Value** | | 2.5 | 4 | 10000 | 2.1 | 350 | 4 | 190 | | | | | |
| **Units** | | N/A | Weeks | US$ | Torr/min | $m^3$/Hr | Hr | GPa | | | | | |
| **Design Competitive Assessment** | Worst: 1 | | | | | | A | | | | | | |
| | 2 | | A | C | | | | | | | | | |
| | 3 | | BC | AB | | | BC | A | | | | | |
| | 4 | A | | | A | ABC | | BC | | | | | |
| | Best: 5 | BC | | | BC | | | | | | | | |

| Key | |
|---|---|
| Current Sys | A |
| CERN | B |
| LIGO | C |

# Schedule

- Deliverables and Due dates
  - Presentation 1: 9/12/21
  - Concept Generation: 9/22/21
  - Concept Evaluation: 9/28/21
  - Start CAD and eval. By client: 9/29/21
  - Presentation 2: 10/2/21
  - Start making/ordering some parts: 10/3/2021
  - All Literature review sources: 10/8/21
  - Preliminary Report: 10/15/21
  - Website basics: 10/22/21



NPOI Vacuum Manifold

Legend: On track | Low risk | Med risk | High risk | Unassigned

Project Start Date: 9/8/2021

Scrolling Increment: 0

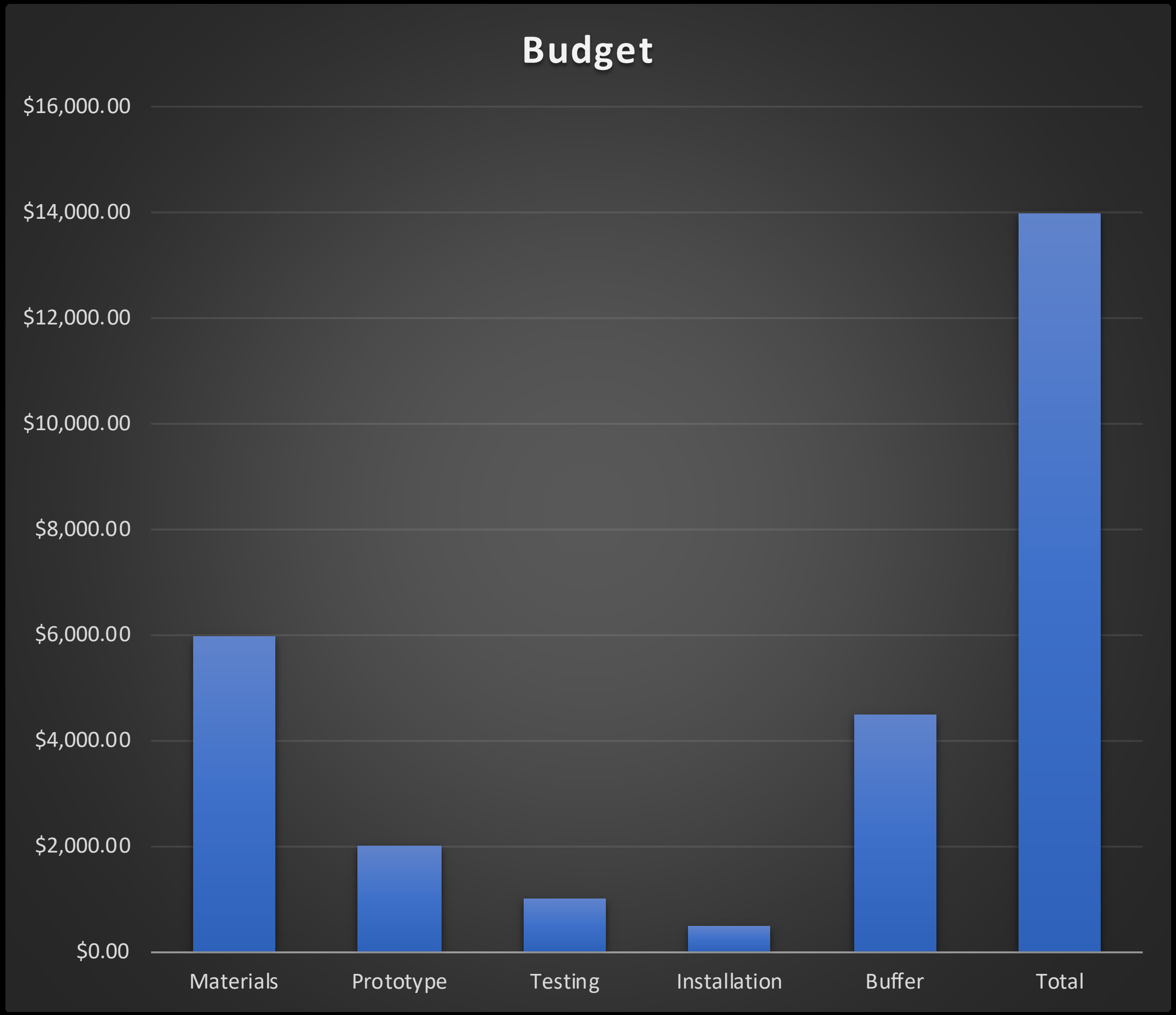
| Milestone description | Category | Assigned to | Progress | Start | End |
|---|---|---|---|---|---|
| **Presentation 1** | Goal | | | | |
| Project Description | On Track | All | 50% | 9/8/2021 | 9/12/2021 |
| Background & Benchmarking | On Track | All | 50% | 9/8/2021 | 9/12/2021 |
| Literature Review | On Track | All | 0% | 9/8/2021 | 9/12/2021 |
| Customer and Engineering Requirements | On Track | All | 25% | 9/8/2021 | 9/12/2021 |
| Schedule & Budget: | On Track | All | 50% | 9/8/2021 | 9/12/2021 |
| **Presentation 2** | Goal | | | | |
| Project Description | On Track | All | 0% | 9/13/2021 | 10/2/2021 |
| Concept Generation | On Track | All | 0% | 9/13/2021 | 10/2/2021 |
| Concept Evaluation | On Track | All | 0% | 9/13/2021 | 10/2/2021 |
| Budget Planning | On Track | All | 0% | 9/13/2021 | 10/2/2021 |
| **Preliminary Report** | Goal | | | | |
| Background | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| Requirments | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| Design Space Research | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| Benchmarking | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| Functional Decomposition | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| Concept Generation/Selection | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| Sources | On Track | All | 0% | 9/13/2021 | 10/15/2021 |
| **Website 1** | | | | | |
| Project Description | On Track | All | 0% | 9/13/2021 | 10/22/2021 |
| Team/About Us | On Track | All | 0% | 9/13/2021 | 10/22/2021 |
| Gallery | On Track | All | 0% | 9/13/2021 | 10/22/2021 |
| Documents | On Track | All | 0% | 9/13/2021 | 10/22/2021 |
| **Presentation 3** | Goal | | | | |
| Prototype and CAD package | On Track | All | 0% | 9/13/2021 | 11/2/2021 |

# Schedule (Continued)

- Deliverables and Due dates
  - Prototype and CAD: 10/26/21
  - Built at least one tanks worth of headwear: 11/2/21
  - Presentation 3: 11/2/21
  - Final Report: 11/14/21
  - Finished CAD Model: 11/15/21
  - Final BOM (and CAD): 11/19/21
  - Final Prototype: 12/3/21
  - Integration with NPOI: 12/2/21
  - Website 2: 12/7/21

# Budget

- Total Budget: 14,000$
- Expected Expenditures:
  - Materials: pressure sensors, tubing, readers, valves ~6000$
  - Prototype cost: ~2000$
  - Testing: ~1000$
  - Installation: ~500$
  - Buffer: ~4500$
- Expenditures to Date: 0$



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[2] “Facts | LIGO Lab | Caltech.” https://www.ligo.caltech.edu/page/facts (accessed Sep. 11, 2021).

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# Questions?

# Appendix: Moment on manifold

$$A = \frac{\pi D^2}{4}$$

$$A_{manifold} = \frac{\pi(2[in])^2}{4} = 3.14\ [in^2]$$

$$F = A * P$$

$$F_{manifold} = (3.14[in^2])\left(14.7\left[\frac{lbf}{in^2}\right]\right) = 46.16[lbf]$$

$$M = F * s$$

$$M_{manifold} = (47.16[lbf])(1[ft]) = 46.16[ft * lbf]$$

$$M_{total} = M_{manifold} * 6_{tanks} = 277\ [ft * lbf]$$