Hybrid Oxidizer Tank Filling and Dynamics

Team #3

April 25, 2020

Advisor:

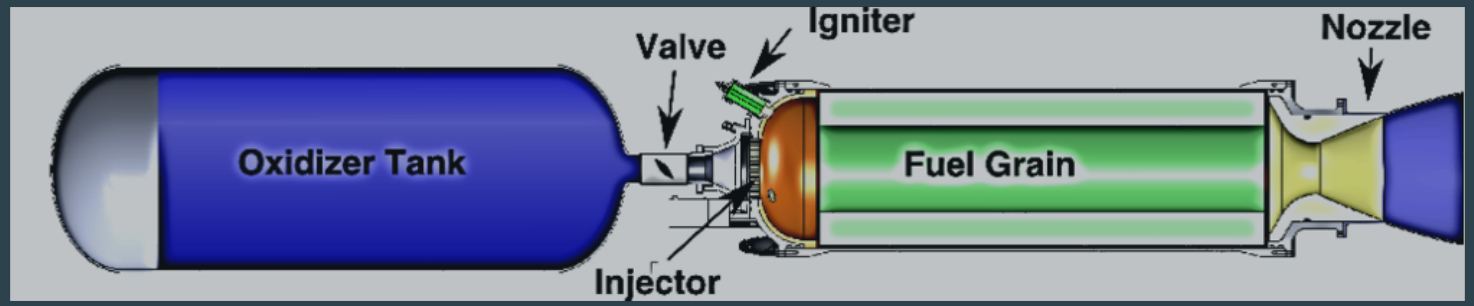
Dr. Jeffrey Santner

Agenda

- Introduction
- Python Simulations
- ANSYS Simulations
- Structural Design & Analysis
- Control Systems
- Conclusion

Introduction

- Sub-unit of the Eagle Rocketry SEDS Club at Cal State LA
  - Aerospace centric club researching rocket engines: Hybrid
  - SEDS: Students for Exploration and Development of Space



Objectives

- Remotely transfer 15kg of nitrous oxide from a commercially purchased vessel
- Create a testing structure for the nitrous oxide pressure vessel which can double as a launch pad
- Predict the time taken for the filling process

Meet the Team



Orifiel Ortiz

- Computational Fluid Analyst

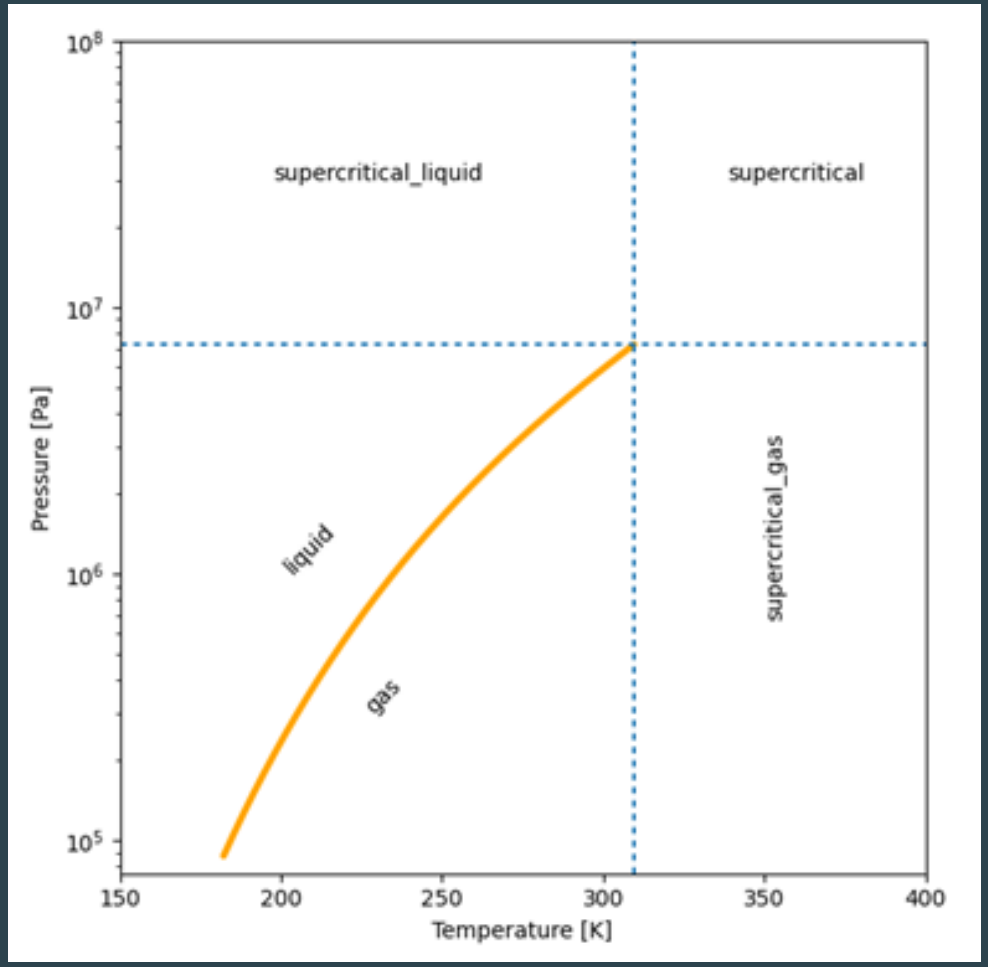
Python Simulations

Model Overview

- Based on a modified Equilibrium Model. [1]

Limitations:

- CoolProp cannot compute thermodynamic properties when the fluid is supercritical
- CoolProp cannot calculate N_2O thermal conductivity or viscosity at any temperature or pressure



Thermal Conductivity and Viscosity

- Supercritical Thermal Conductivity is calculated from tables published by Richter and Sage. [2]

Validity range:

$277.59K - 444.26K$

$101.33kPa - 34.47\ MPa$

- Supercritical Viscosity is calculated from work by Takashi et. al. [3]

Validity range:

$298.15K - 398.15K$

$102.50kPa - 5.50MPa$

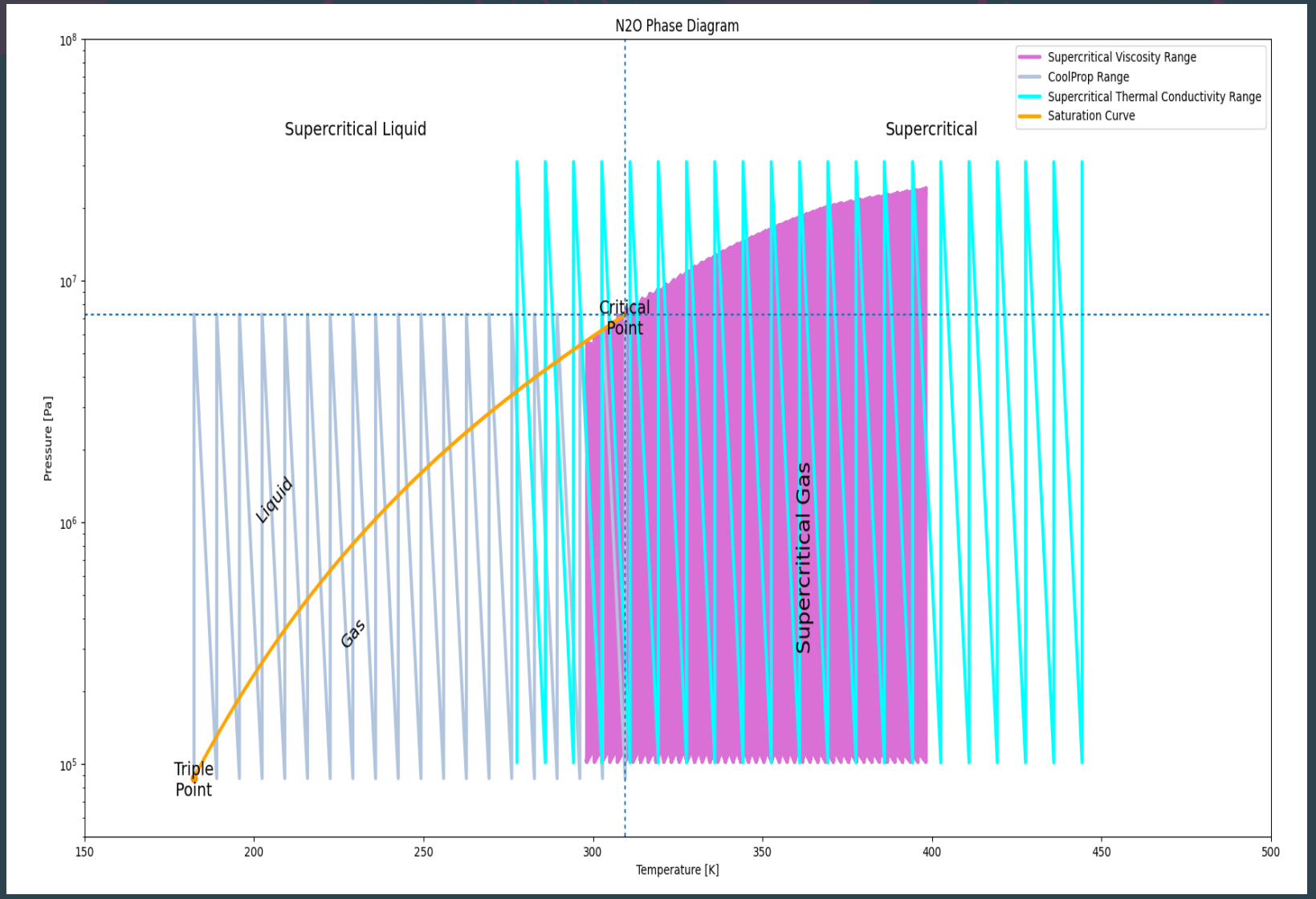
Thermal Conductivity and Viscosity

- Saturation values calculated from equations published by ESDU. [4]

Validity range:

$182.33K - 309.57K$

$87.3kPa - 7.24MPa$



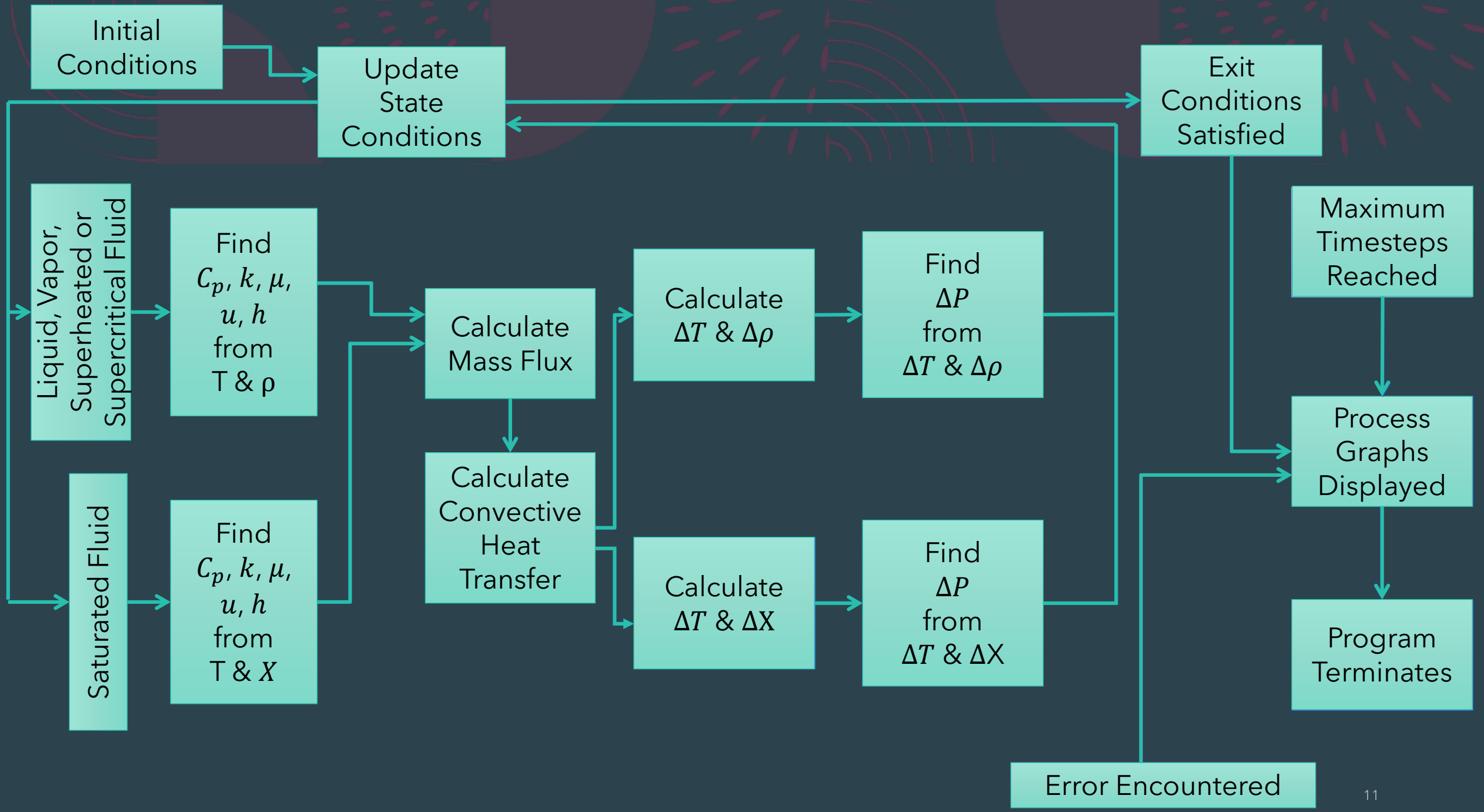
Solution

- Helmholtz Functional Equations using temperature and density as the two known supercritical fluid states. [5]

$$\alpha(\delta,\tau) = \alpha^0(\delta,\tau) + \alpha^r(\delta,\tau)$$

  - $\alpha(\delta,\tau)$ = Helmholtz Energy
  - δ = normalized density
  - τ = normalized temperature

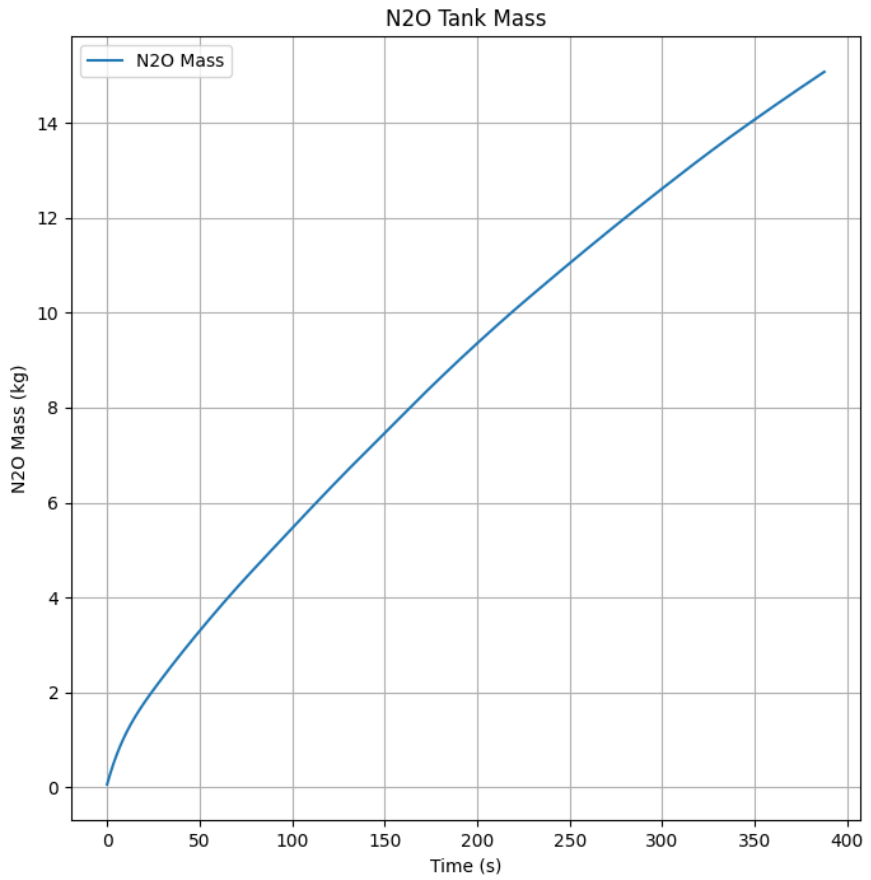
- Other fluid properties can be calculated through the First Law of Thermodynamics, with a known Helmholtz Energy

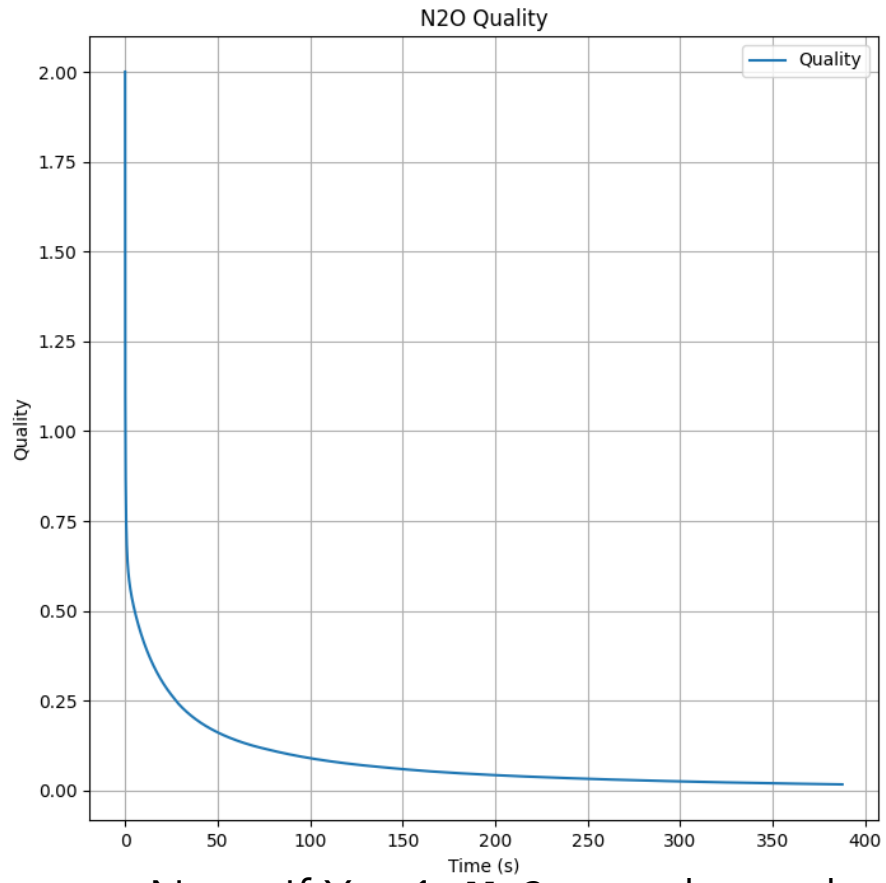

Initial Conditions
Update State Conditions
Exit Conditions Satisfied
Liquid, Vapor, Superheated or Supercritical Fluid
Find C_p, k, μ, u, h from T & ρ
Calculate Mass Flux
Calculate ΔT & $\Delta\rho$
Find ΔP from ΔT & $\Delta\rho$
Maximum Timesteps Reached
Process Graphs Displayed
Saturated Fluid
Find C_p, k, μ, u, h from T & X
Calculate Convective Heat Transfer
Calculate ΔT & ΔX
Find ΔP from ΔT & ΔX
Program Terminates
Error Encountered

Boundary Conditions

- Initial/Atmospheric Temperature: $298K$
- Initial Pressure: air at $101.33\ kPa$
- Tank Length: $1.27\ m$ $(50\ in)$
- Tank Inner Diameter: $152.4\ mm$ $(6\ in)$
- Source Tank Pressure: $689.48\ kPa$ $(1000\ Psi)$
- Total Tank Mass: $15kg$

m & X





Note: If X > 1, N_2O superheated

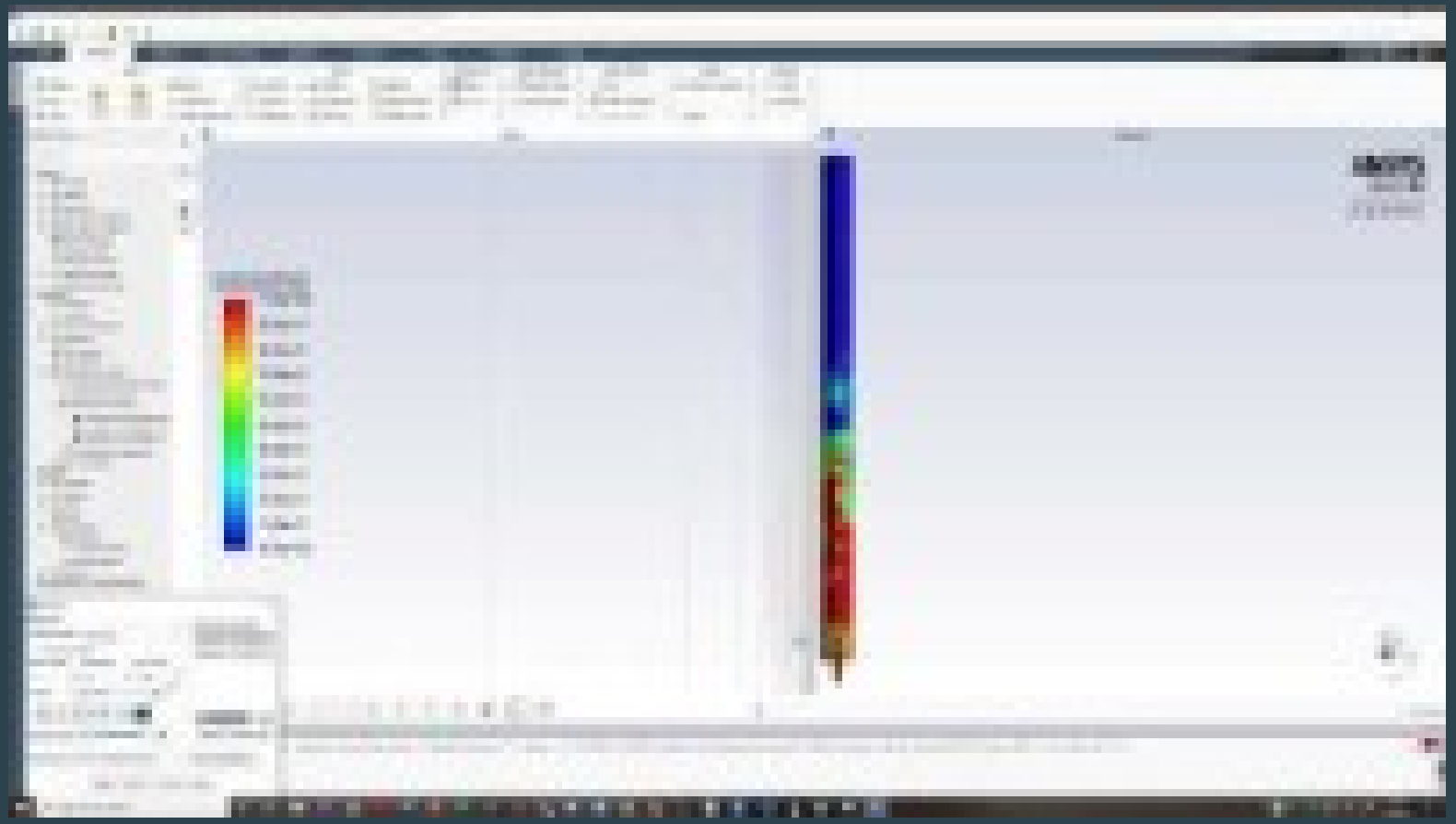


Miguel Romero

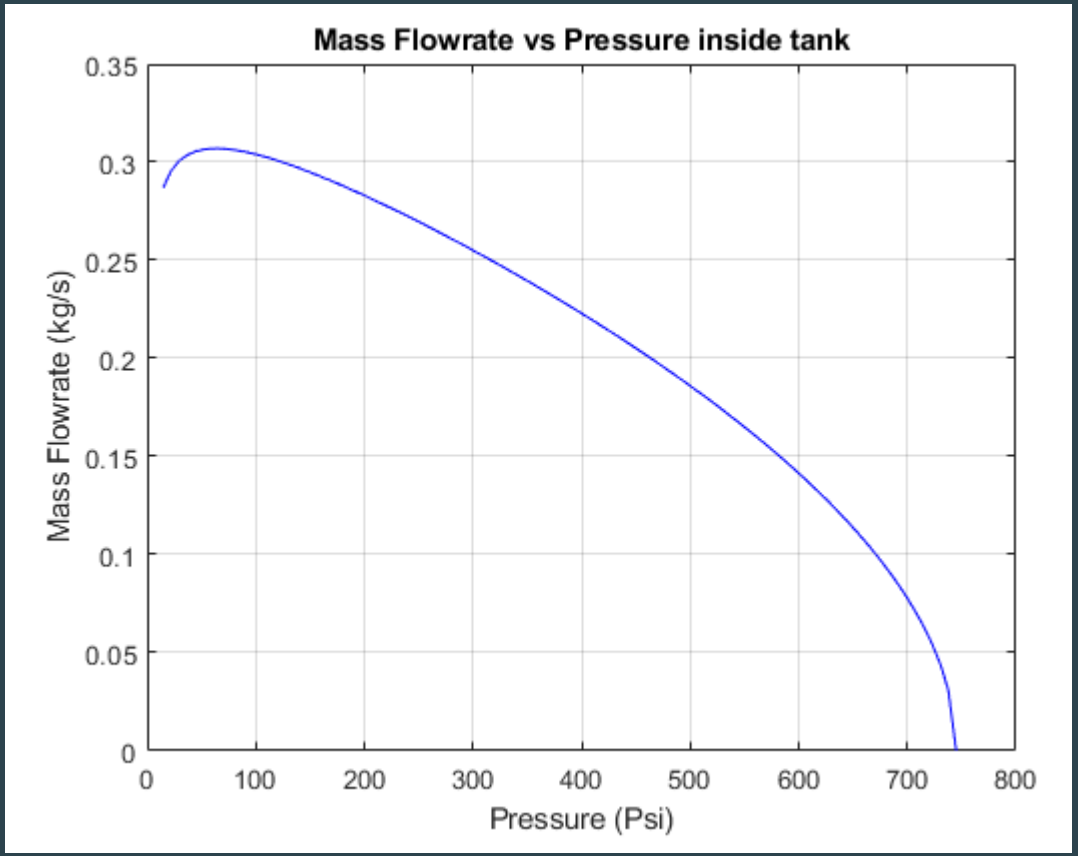
- Pressure Vessel Fluid Analyst

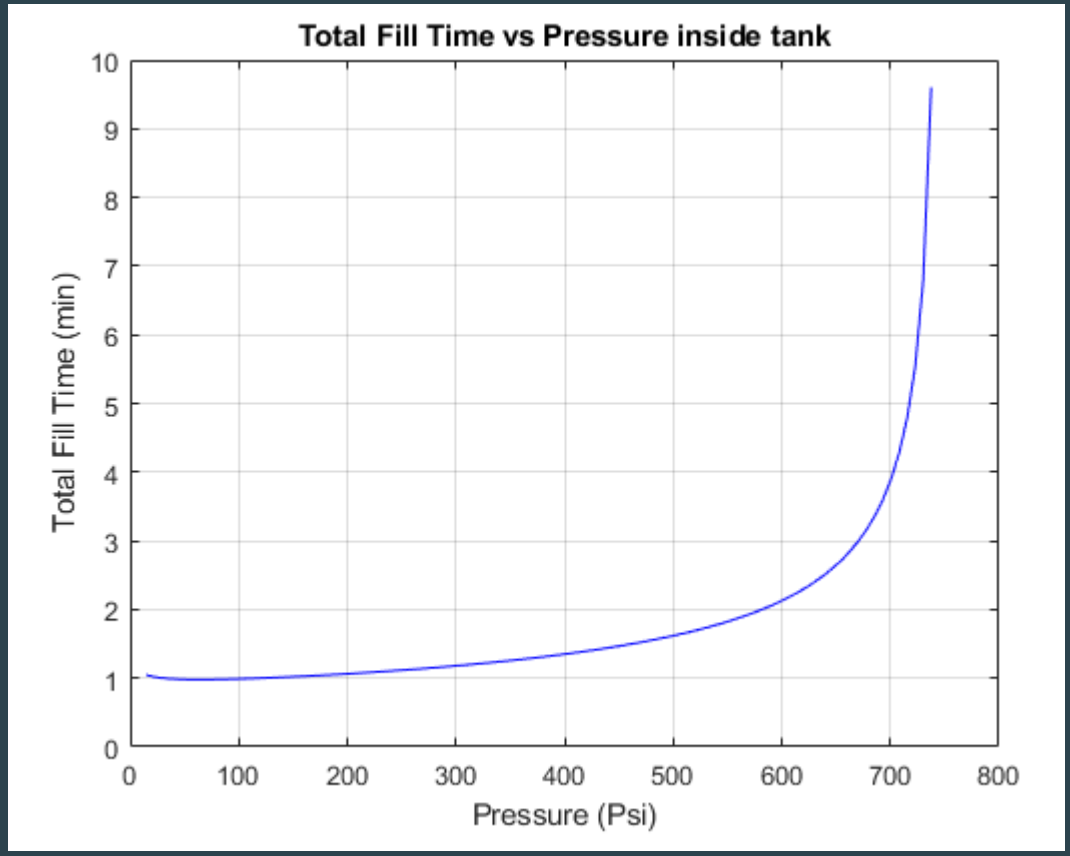
Ansys Pressure Vessel Simulations

Oxidizer Tank Filling



MATLAB

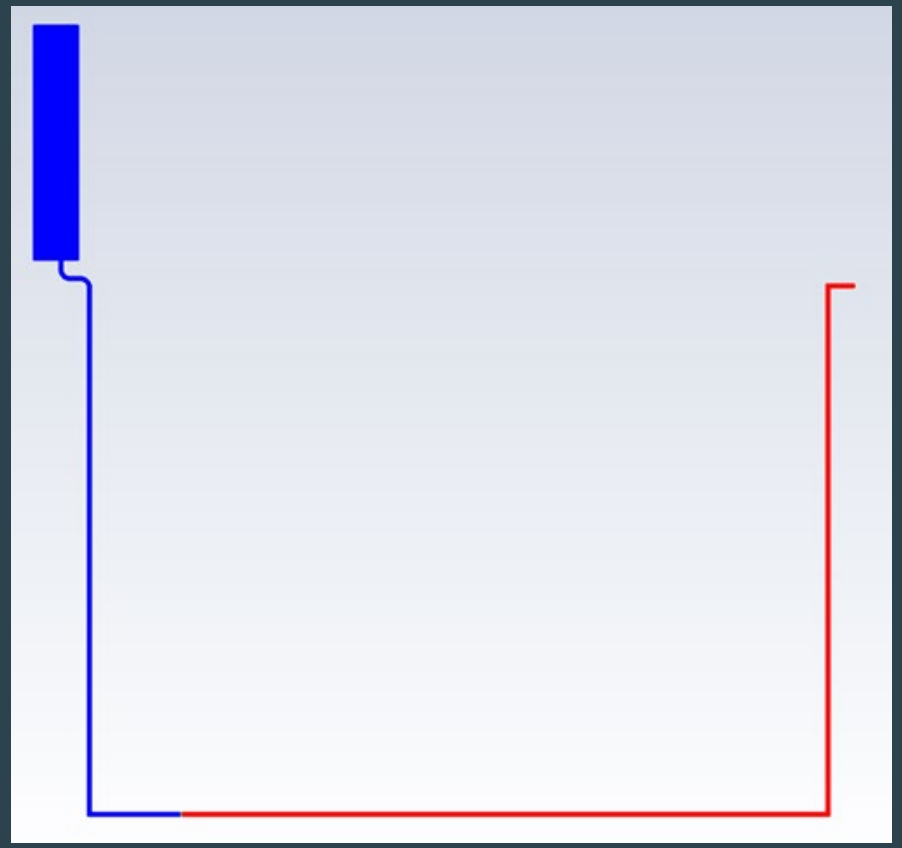

Mass Flowrate vs Pressure inside tank
Mass Flowrate (kg/s)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
100
200
300
400
500
600
700
800
Pressure (Psi)

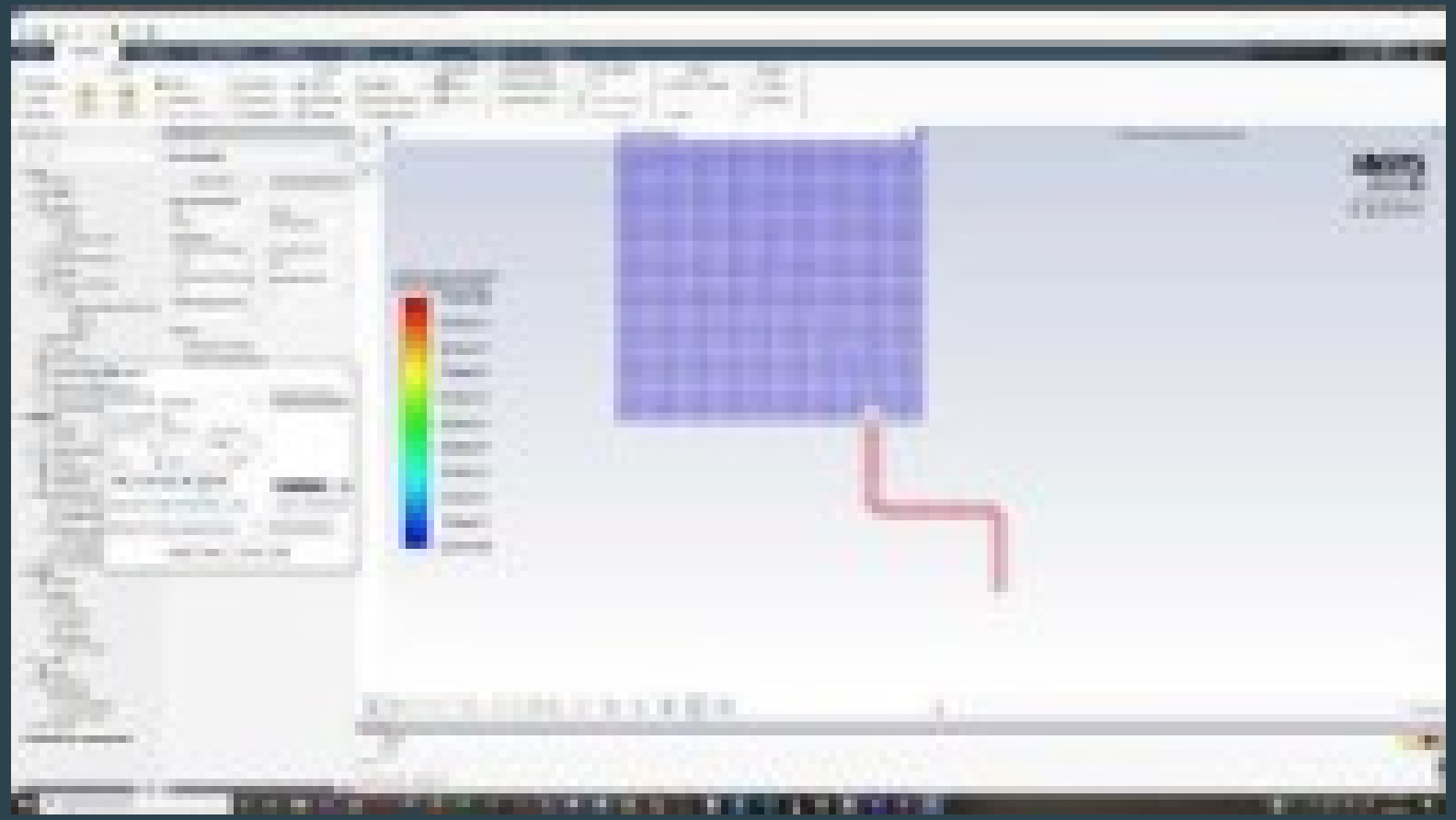

Total Fill Time vs Pressure inside tank
Total Fill Time (min)
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800
Pressure (Psi)

Ground Fill System

- Inlet diameter to Oxidizer Tank: 0.25in
- Inner diameter of piping system is 0.25in
- Going to open the source tank at varying pressures to slow down the filling time

Ground Fill System





Mass Requirements

- Do we have enough N20 to fill the tank and for the ground system piping?
  - N2O mass system = 28kg
  - N2O source tank = 27kg
  - 2 source tanks from vendor

Grade & Gas Specification	Cyl. Size	Product Code◈	Contents Pounds	Cylinder Rental	Cylinder Pressure (psi)	CGA Outlet	Nominal Cylinder Dim. (in.)◈	Shipping Wt. Lbs◈
Nitrous Oxide AA 99.6%	200	**NO AA200**	60	YES	745	326	9 x 55	202
	G	**NO AA56**	56	YES	745	326	8.5 x 55	170
	G	**NO AA50**	50	YES	745	326	8.5 x 55	164

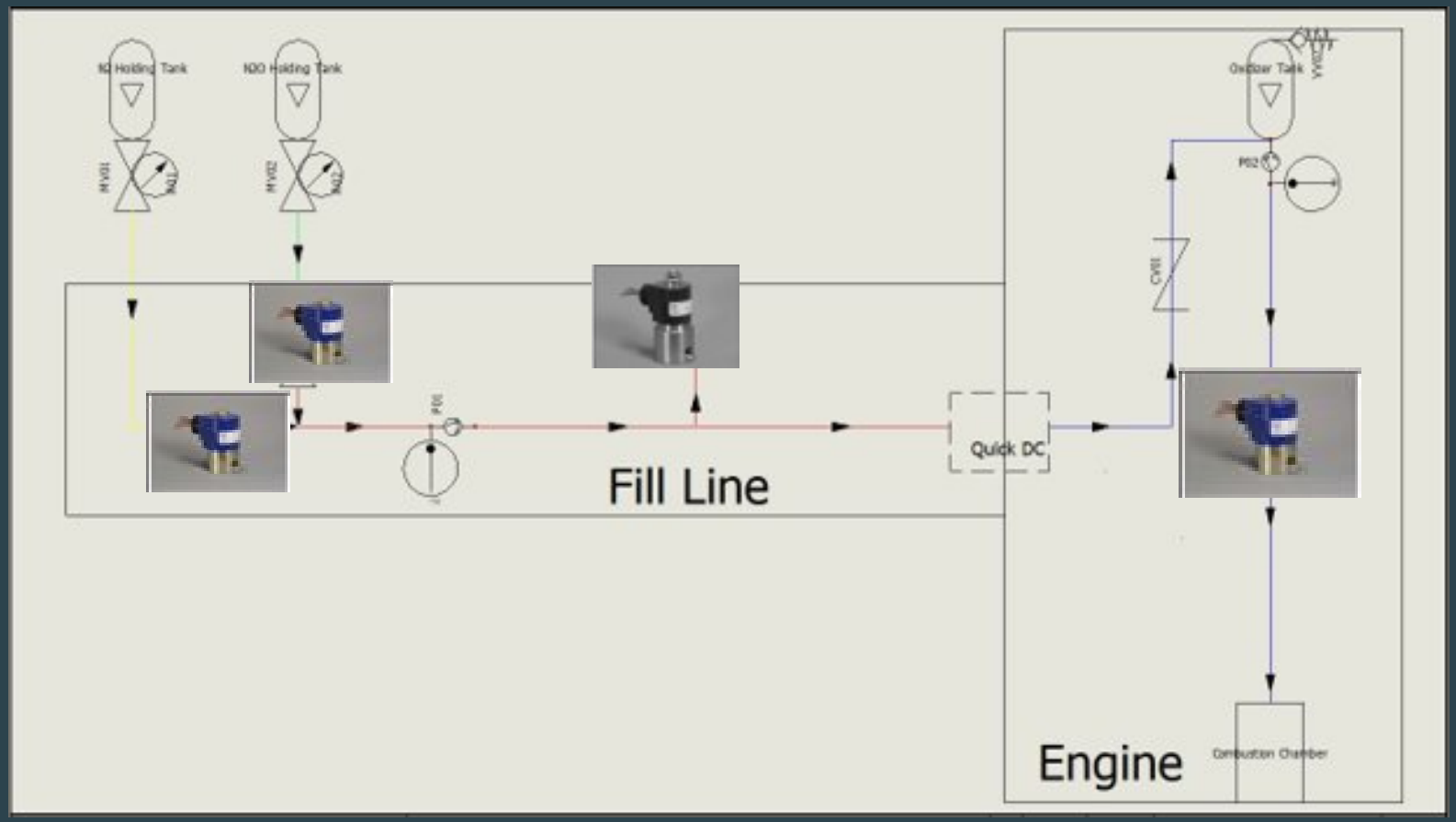
Ansys & Valve Simulations



Amy Moore

- Piping & Valve Fluid Analyst

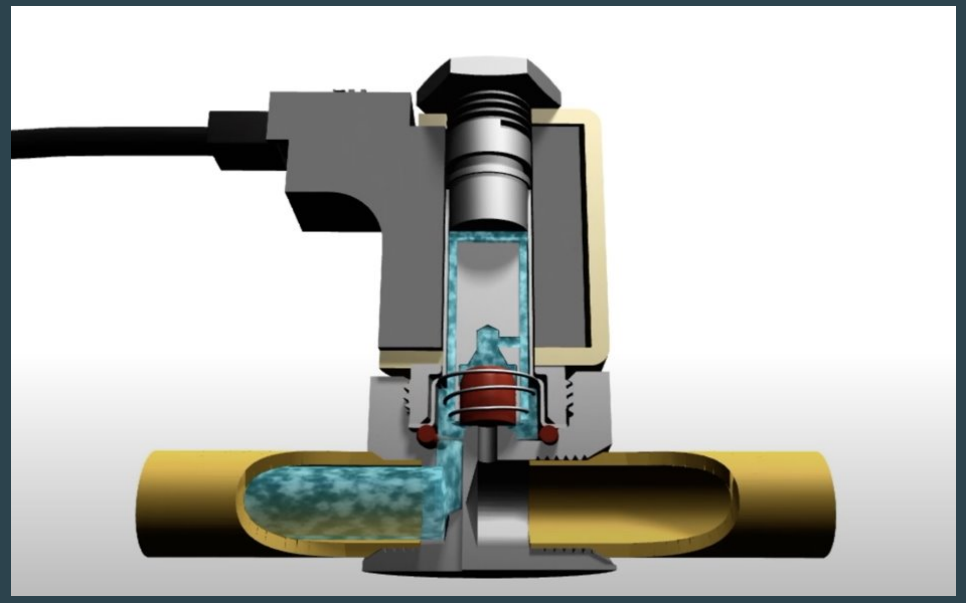
Schematic of Valve Layout

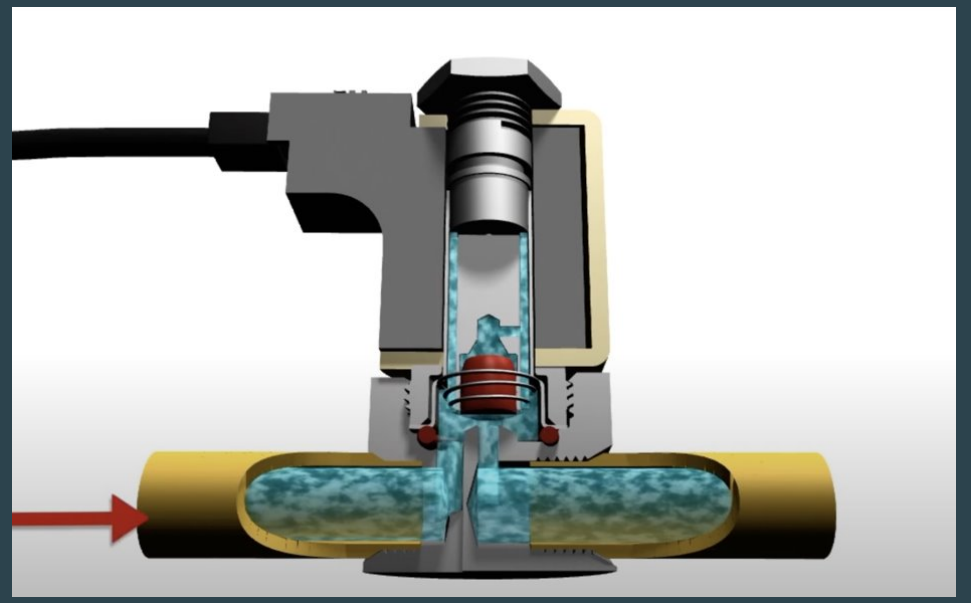


V01-Normally Closed (Blue)
V02-Normally Closed
V03-Normally Open (Gray)
V04-Normally Closed

Valve System Analysis

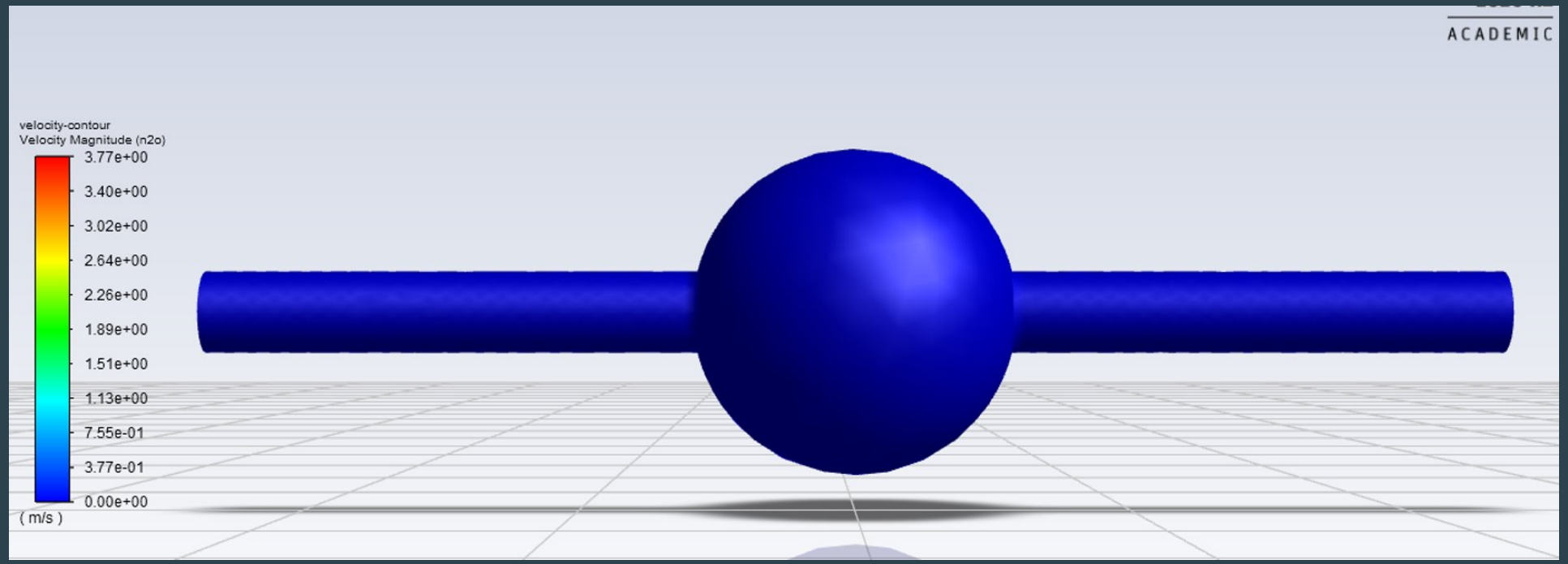
- CFD simulations performed on valves
- ANSYS and SimScale software was implemented
- Valve normally closed tested
- Inner and outer diameter 0.25 in.





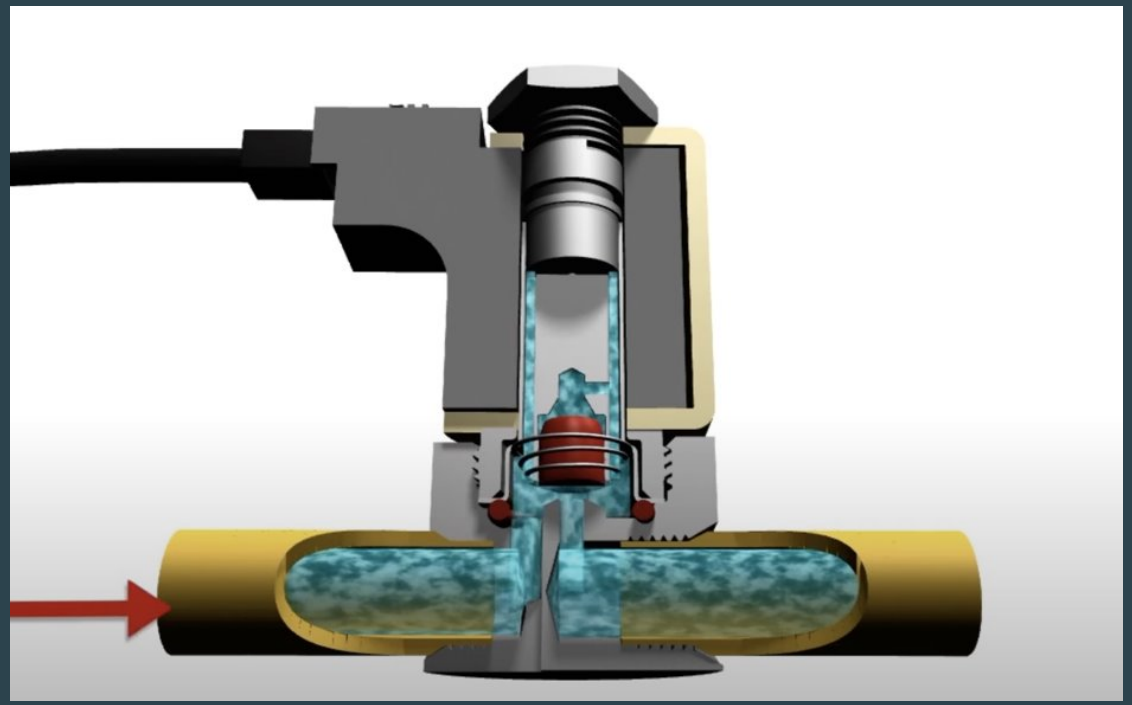
Valve Analysis ANSYS

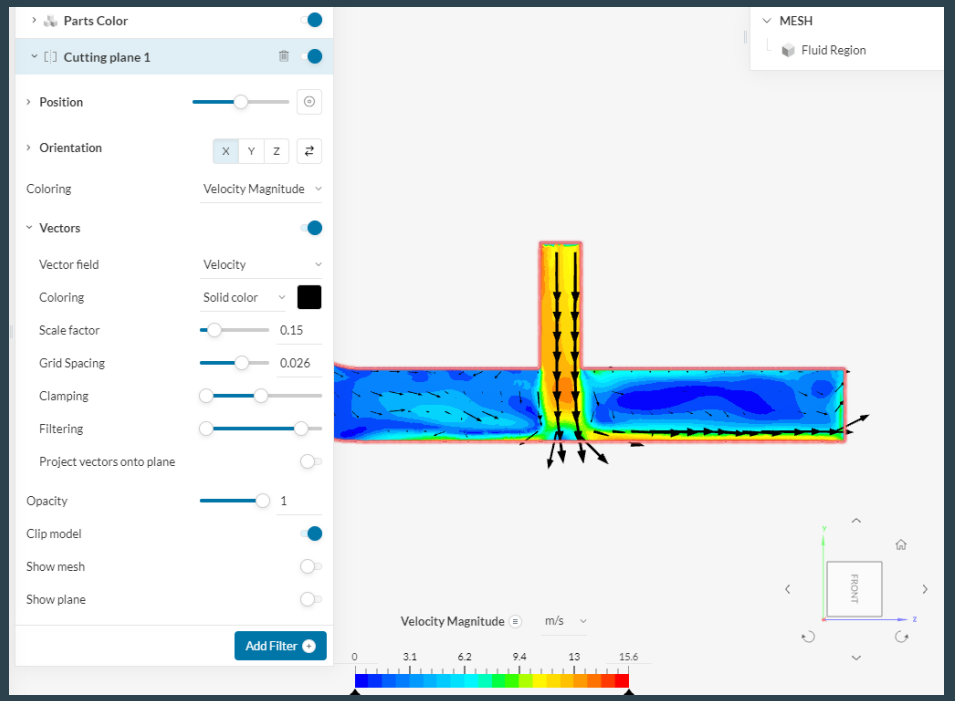
- Velocity entering valve 3.77 m/s
- Mass flow rate entering valve 3 kg/s



Valve Analysis SimScale

- SimScale is a program able to understand CAD models
- Velocity at the stopper region is 9 m/s





Base Structure Analysis

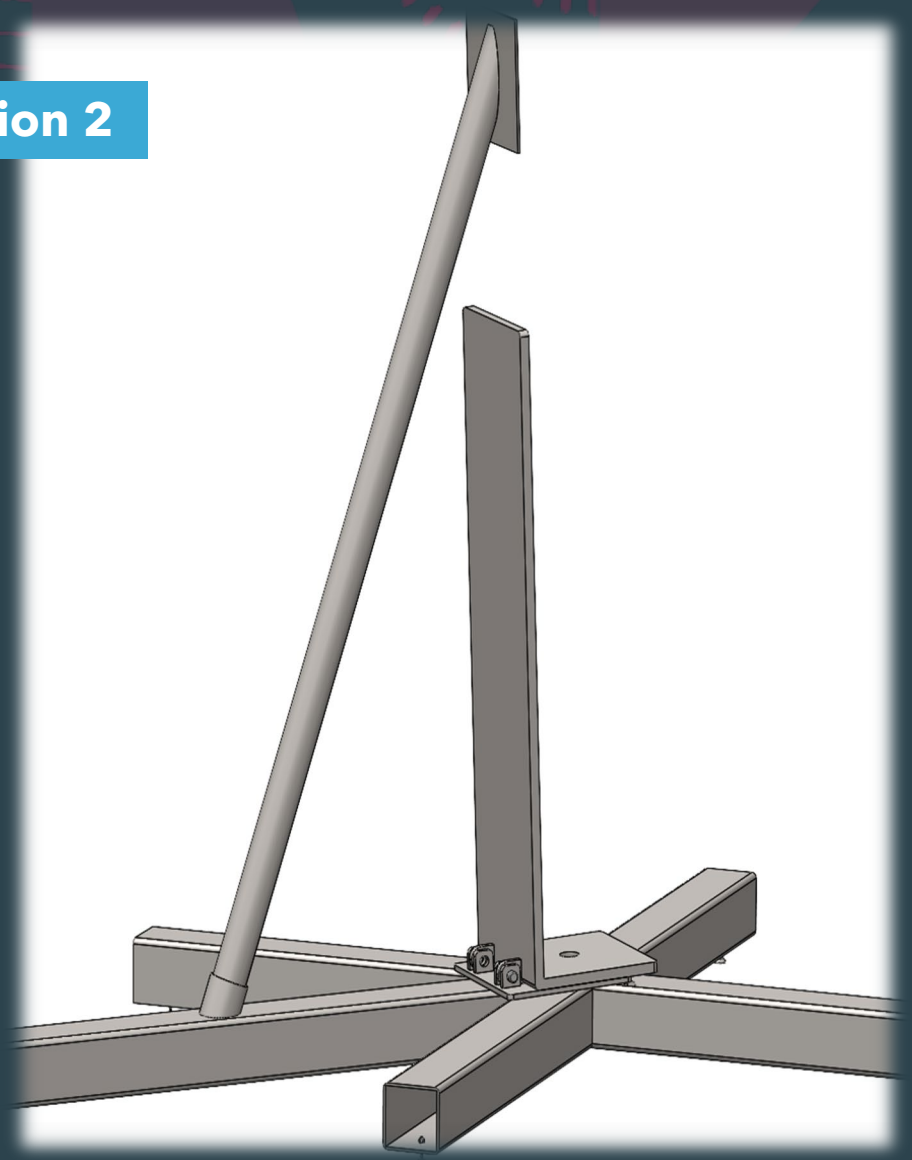


Vicente Estrada

- Structural Designer & Analyst

Base Structure

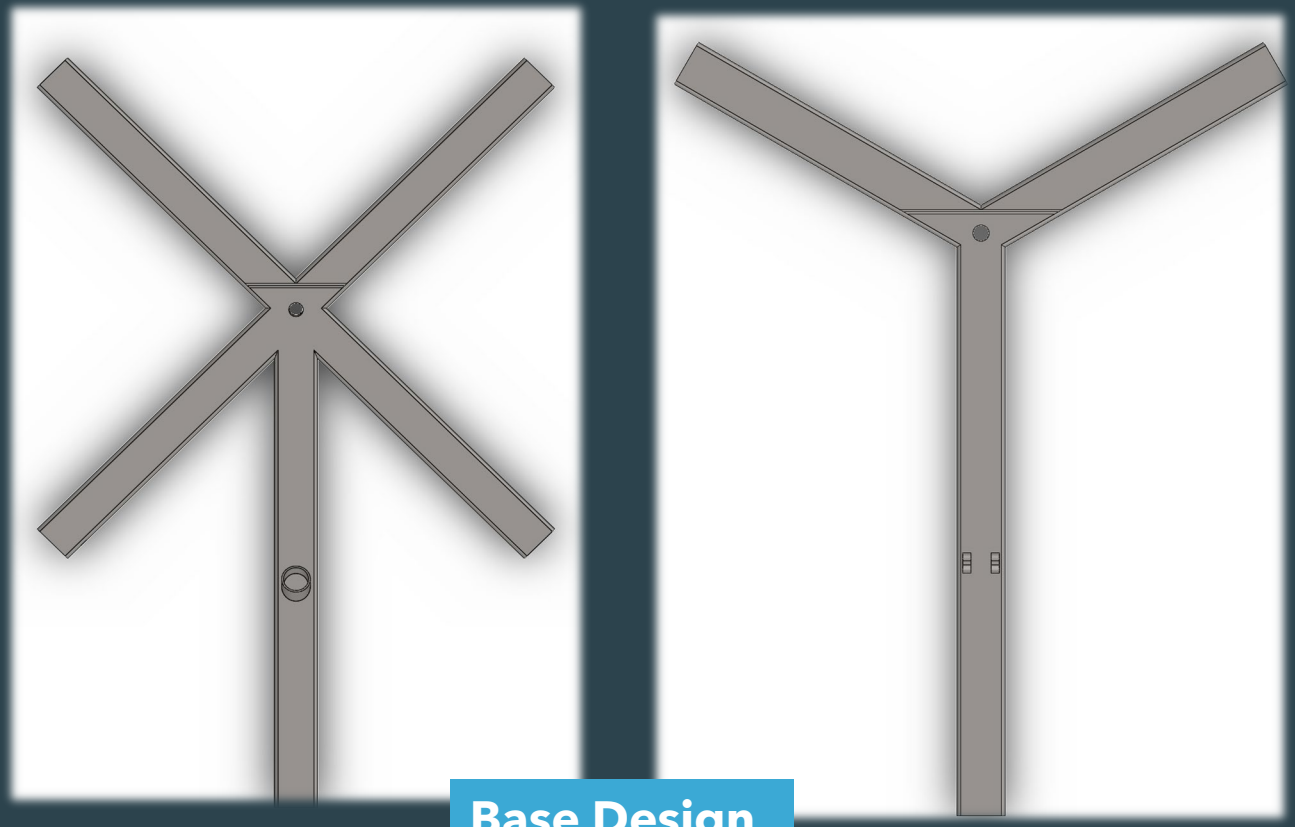
Revision 2



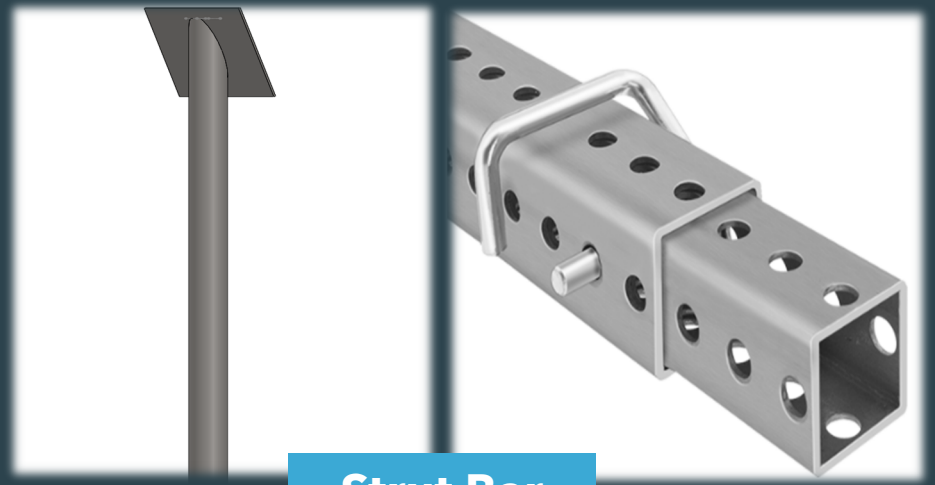
Final Revision



Major Changes

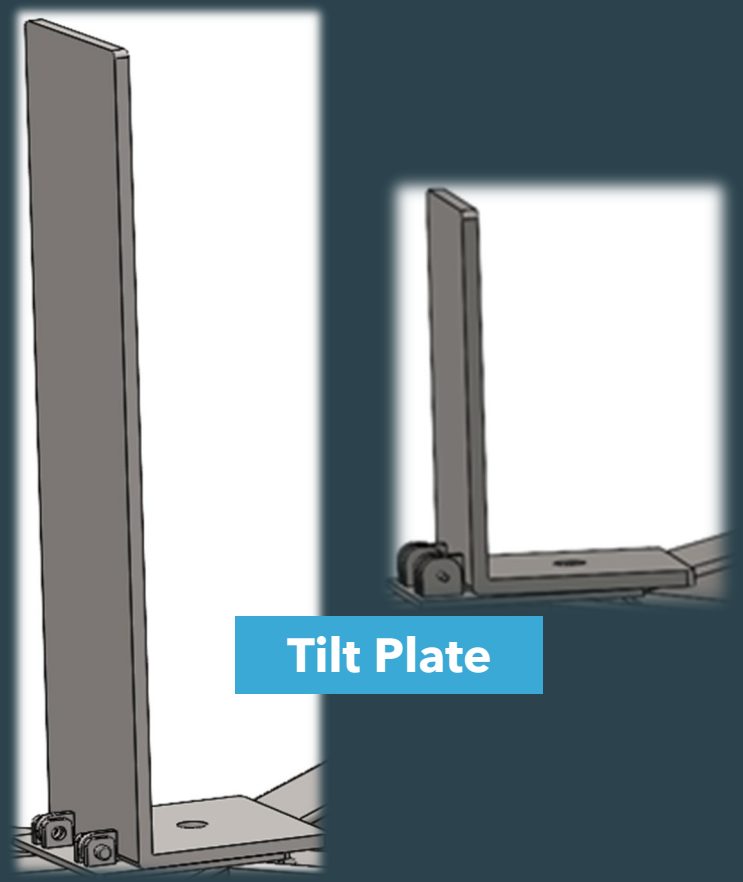


Base Design

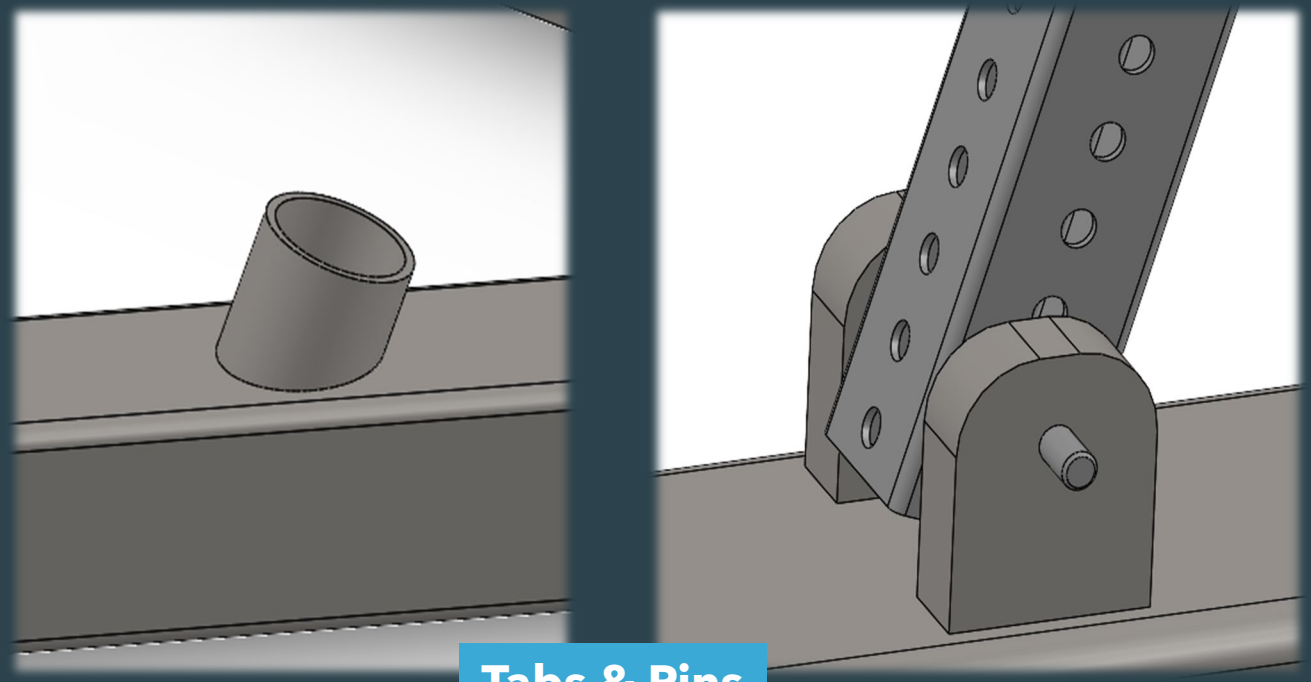


Strut Bar

Major Changes



Tilt Plate



Tabs & Pins

Hand Calculations

$$W_T = 284.78N$$

$$F_T = 2500N$$

$$\Sigma F_y: 0 = R_s Cos(68) + R_y + F_T - W_T$$

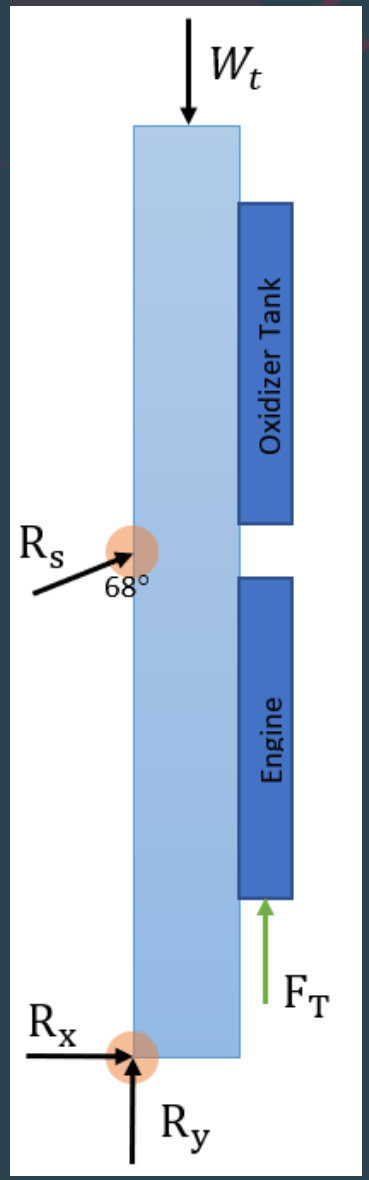
$$\Sigma F_x: 0 = R_s Sin(68) + R_x$$

$$\Sigma M: 0 = (0.3048m)F_T - (2.231m)R_s Sin(68) - 21.7Nm$$

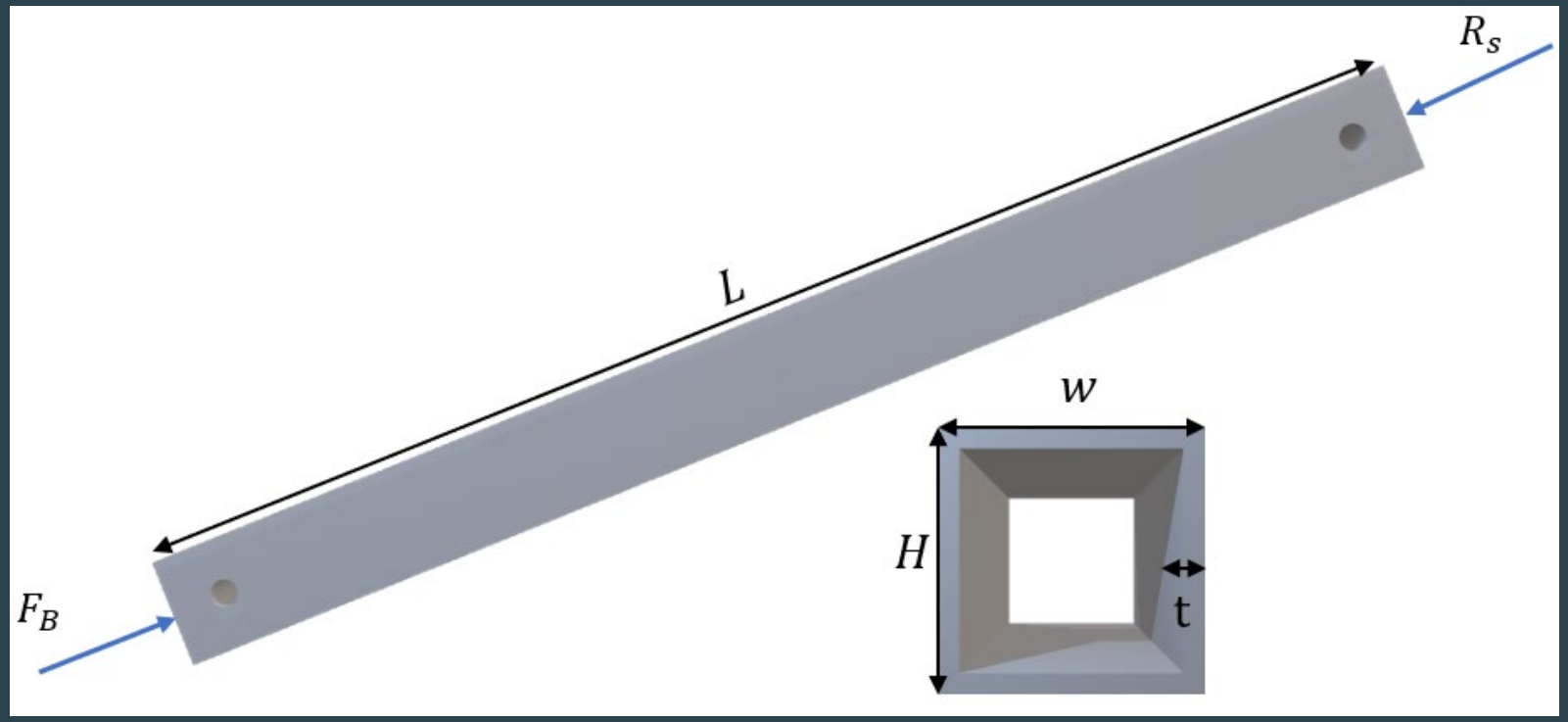
$$R_y = -2349.28N$$

$$R_x = -331.82N$$

$$R_s = 357.88N$$



Hand Calculations



$$L = 2.4384\ m$$

$$H = w = 0.0635m$$

$$t = 2.67X10^{-3}m$$

$$k = 1$$

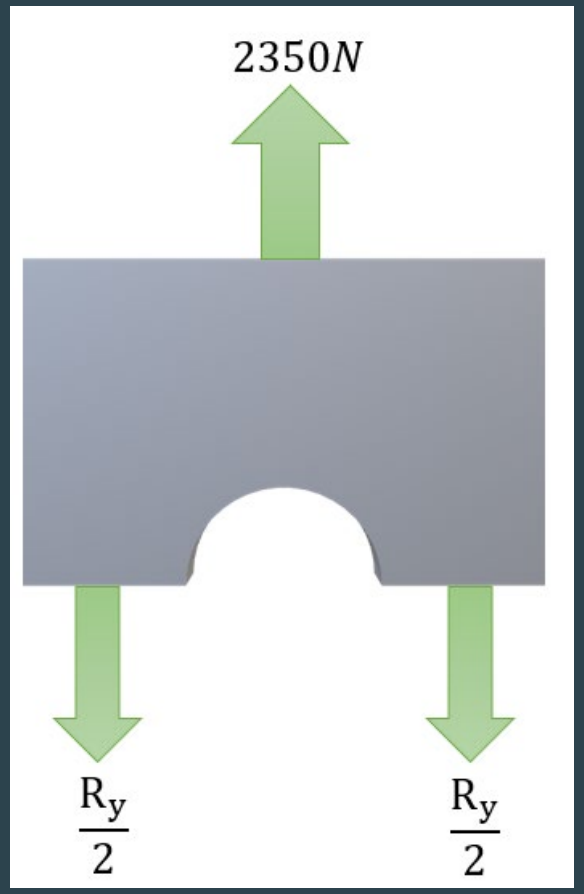
$$E = 200\ GPa$$

$$I = 39.9X10^{-7}m^4$$

$$P_{cr} = 127.83\ kN$$

$$R < P_{cr}$$

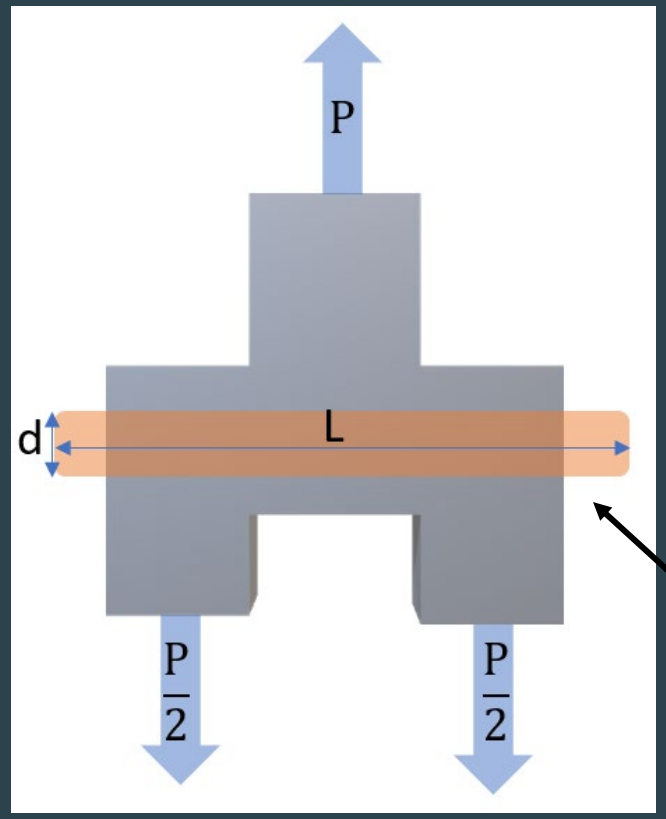
Hand Calculations



$$\sigma_Y = 206\ MPa$$

$$\sigma = 2.33\ MPa$$

$$\sigma_Y > \sigma$$



$$P = R_y$$

$$\tau_U = 66278.5N$$

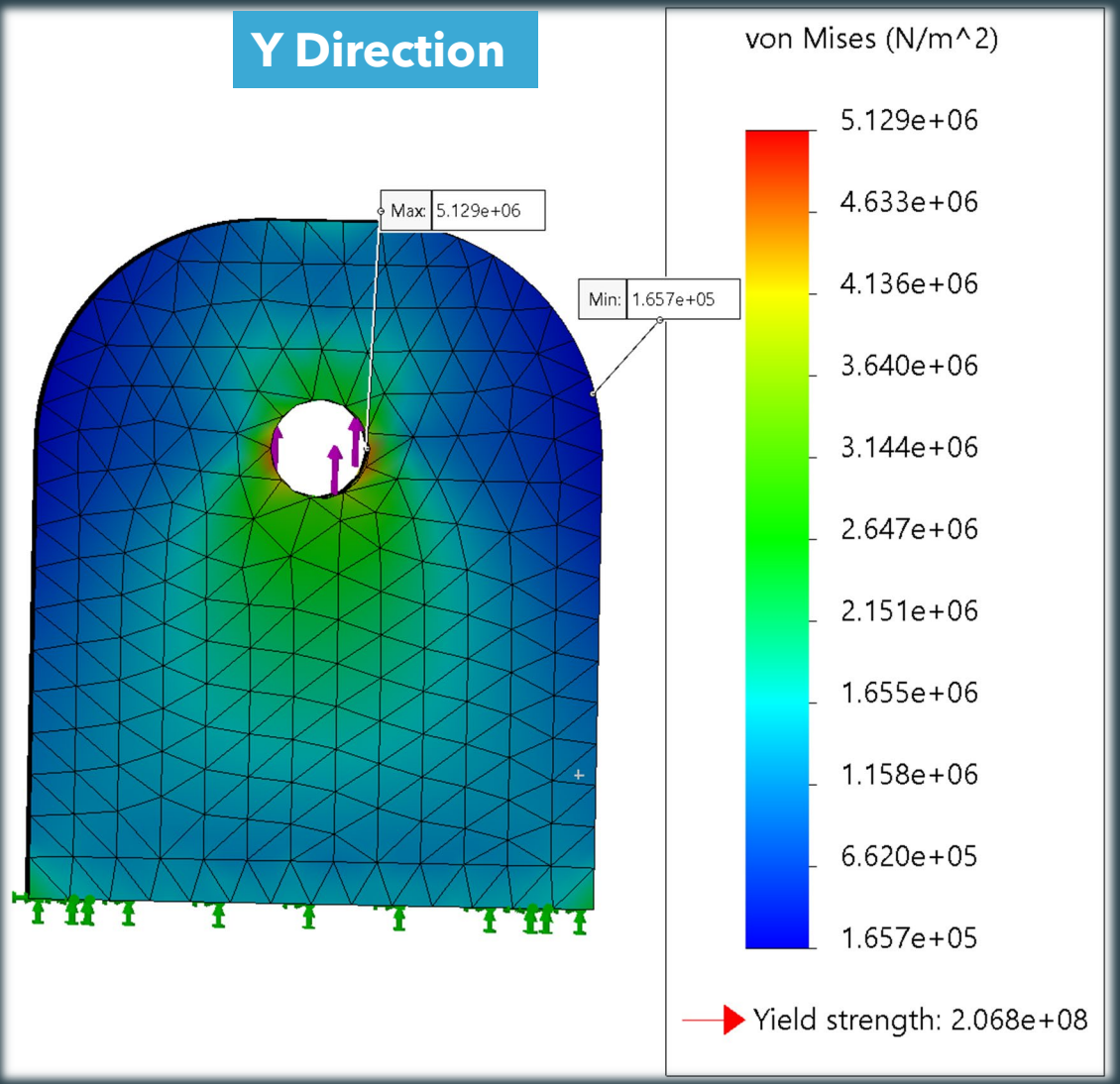
$$L = 0.127m$$

$$d = 0.4375m$$

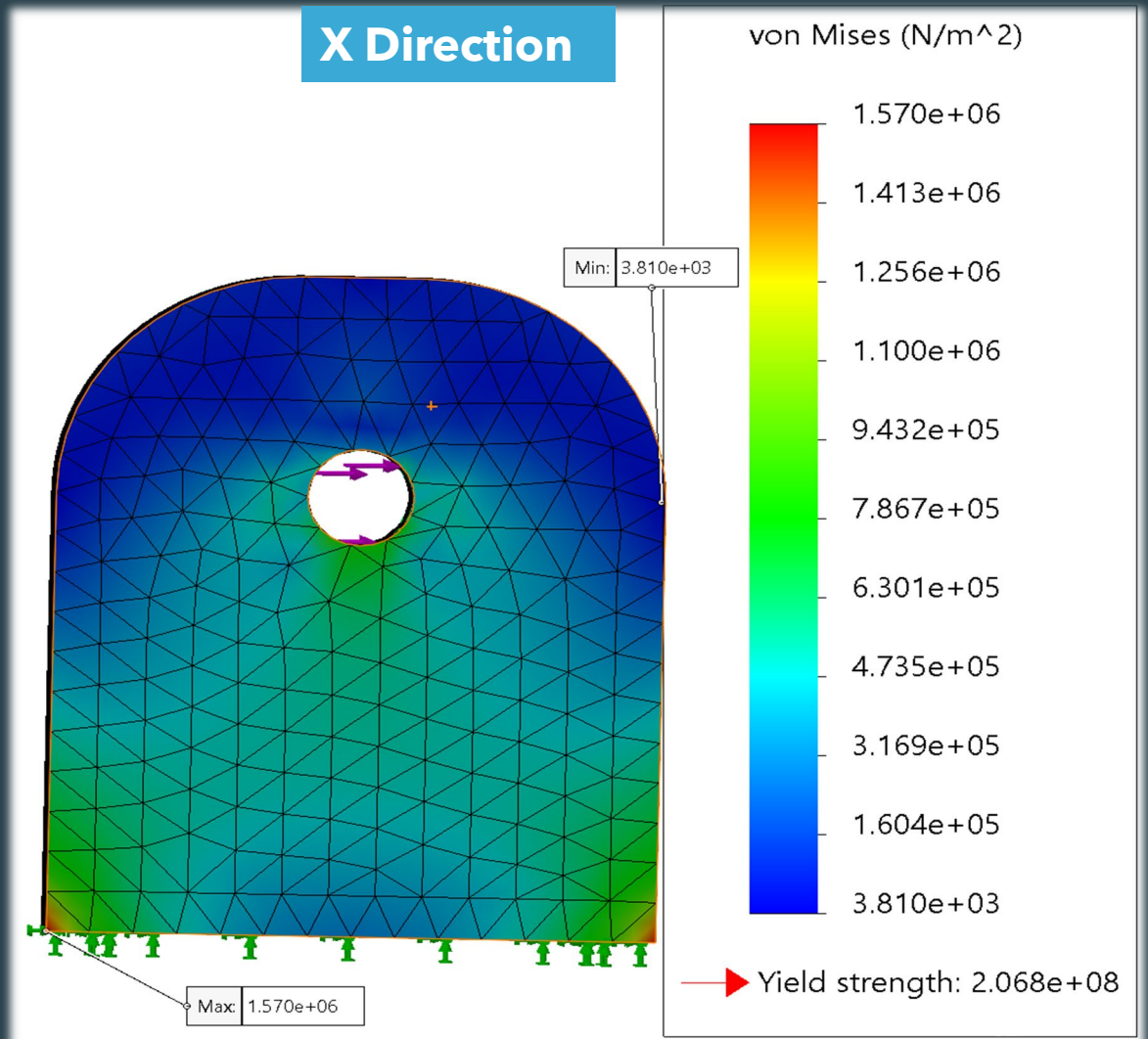
Stainless Steel Pin

FEA

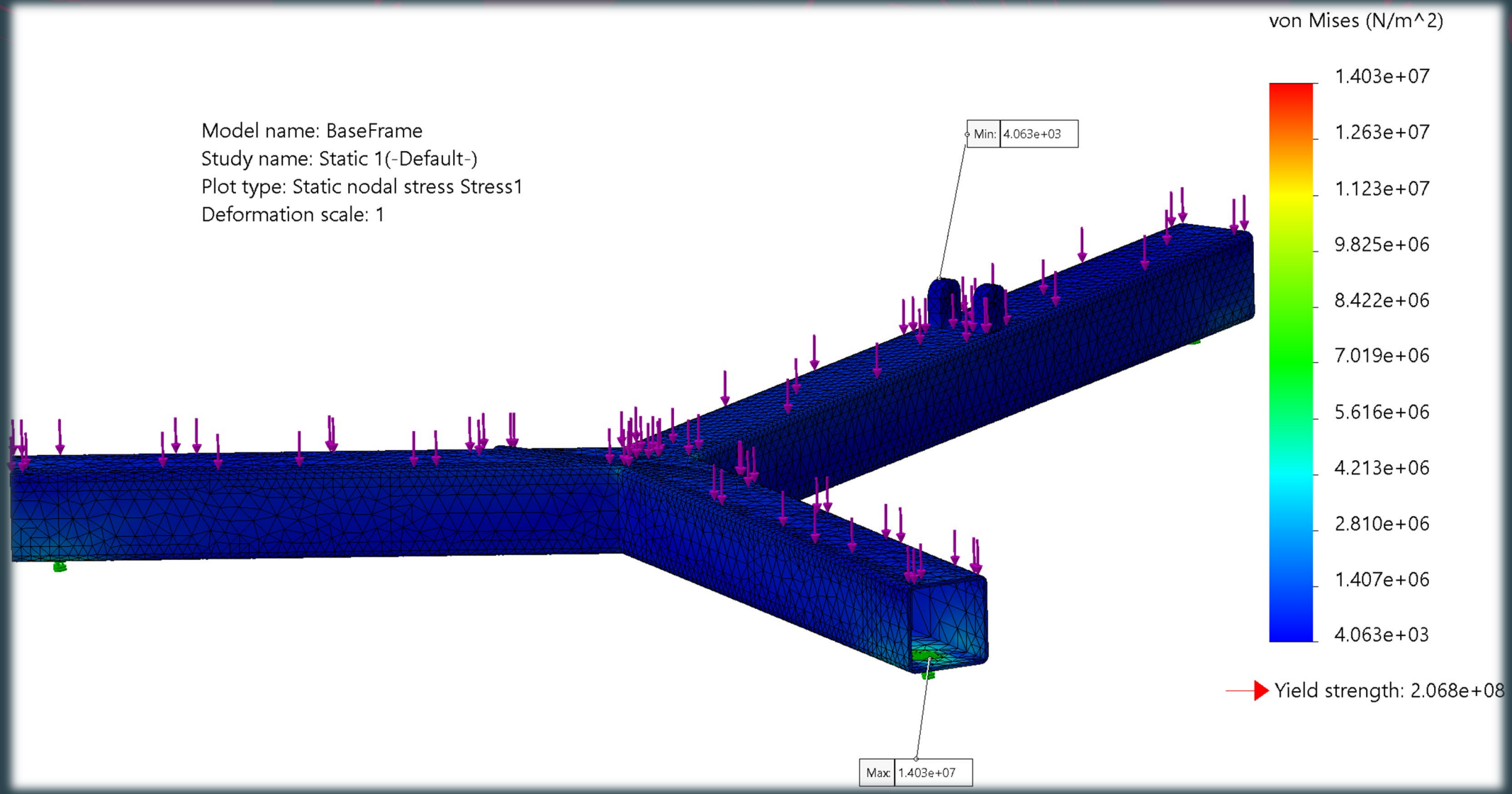
Y Direction



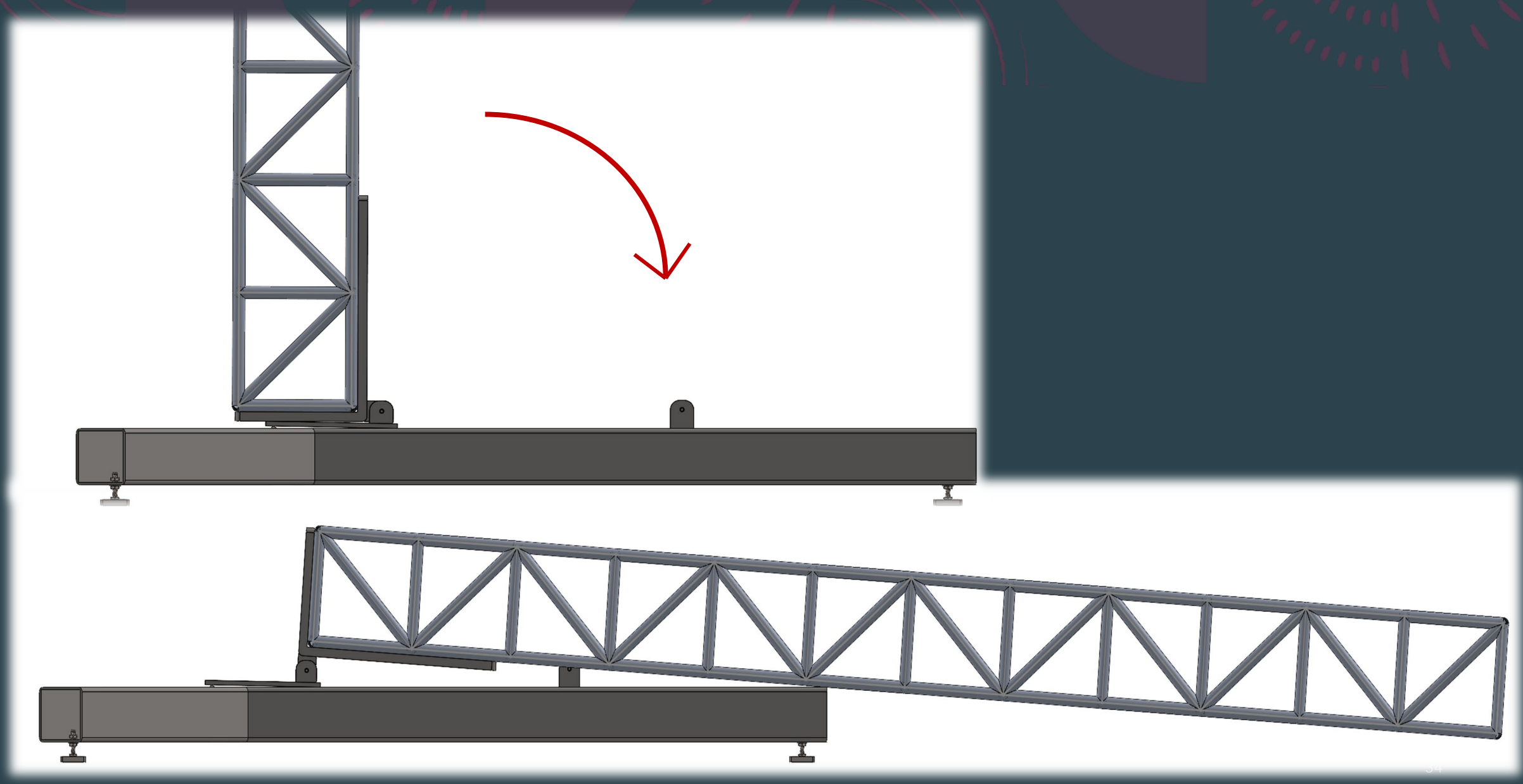
X Direction



FEA


Model name: BaseFrame
Study name: Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 1
Min: 4.063e+03
Max: 1.403e+07
von Mises (N/m^2)
1.403e+07
1.263e+07
1.123e+07
9.825e+06
8.422e+06
7.019e+06
5.616e+06
4.213e+06
2.810e+06
1.407e+06
4.063e+03
Yield strength: 2.068e+08

Transportation/Mounting Assembly



Test Stand Analysis

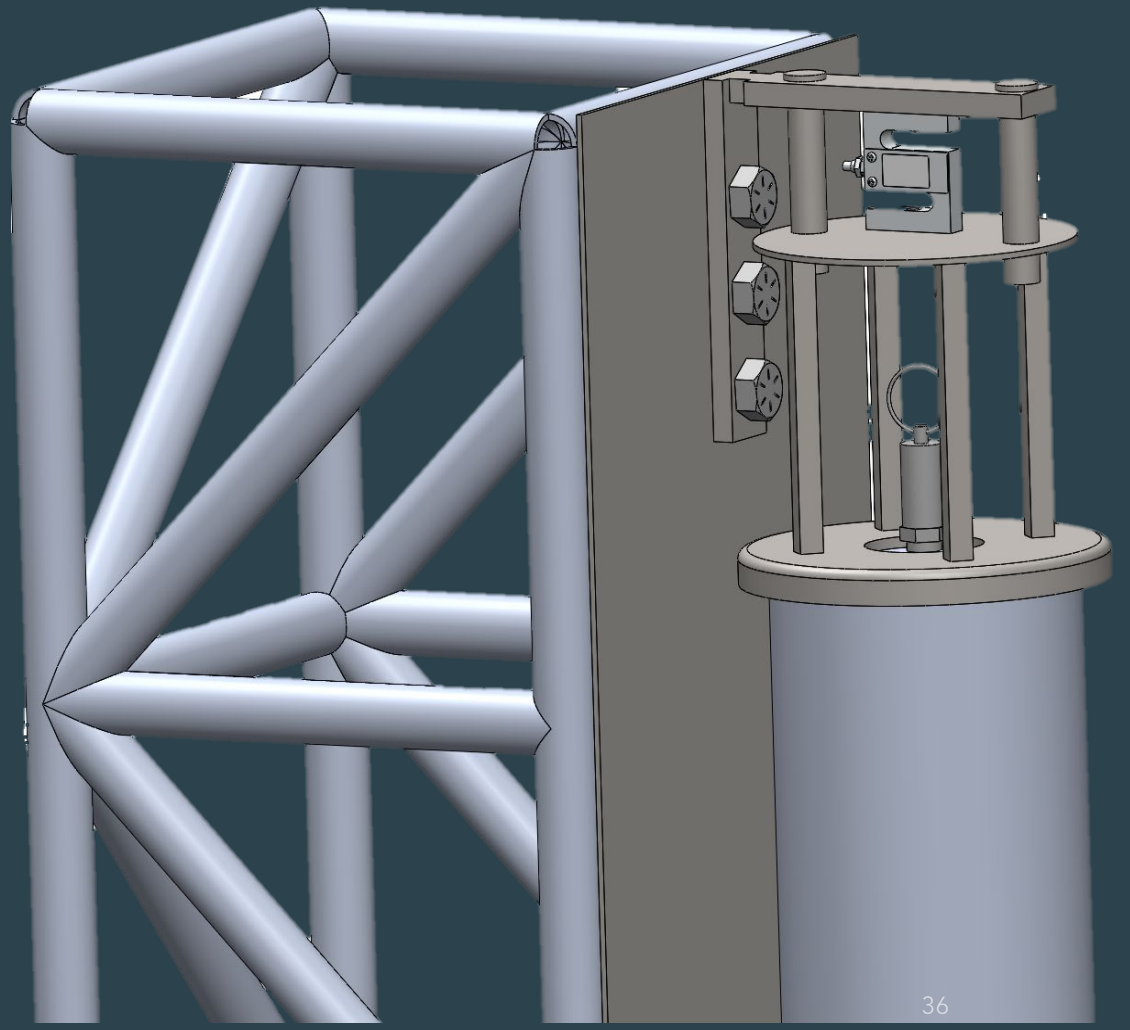


Alex Guilbaud

- Structural Designer & Analyst

Mechanical Force Analysis

- Concern:
  - Original bracket has potential to fail
- Resolve:
  - Calculate bending stresses and conduct FEA; determine if true



Mechanical Force Analysis

Mass Properties

Static fire top bracket v2.SLDPRT

Options...

Override Mass Properties... Recalculate

Include hidden bodies/components

Create Center of Mass feature

Show weld bead mass

Report coordinate values relative to: -- default --

Mass properties of Static fire top bracket v2
Configuration: Default
Coordinate system: -- default --

Density = 0.29 pounds per cubic inch

Mass = 2.76 pounds

Volume = 9.55 cubic inches

Surface area = 60.07 square inches

Center of mass: (inches)
X = 2.07
Y = 0.74
Z = -5.53

Principal axes of inertia and principal moments of inertia: (pounds * square inches)
Taken at the center of mass.

Ix = (-0.71, 0.00, 0.71)	Px = 6.64
Iy = (0.71, 0.00, 0.71)	Py = 24.00
Iz = (0.00, 1.00, 0.00)	Pz = 29.55

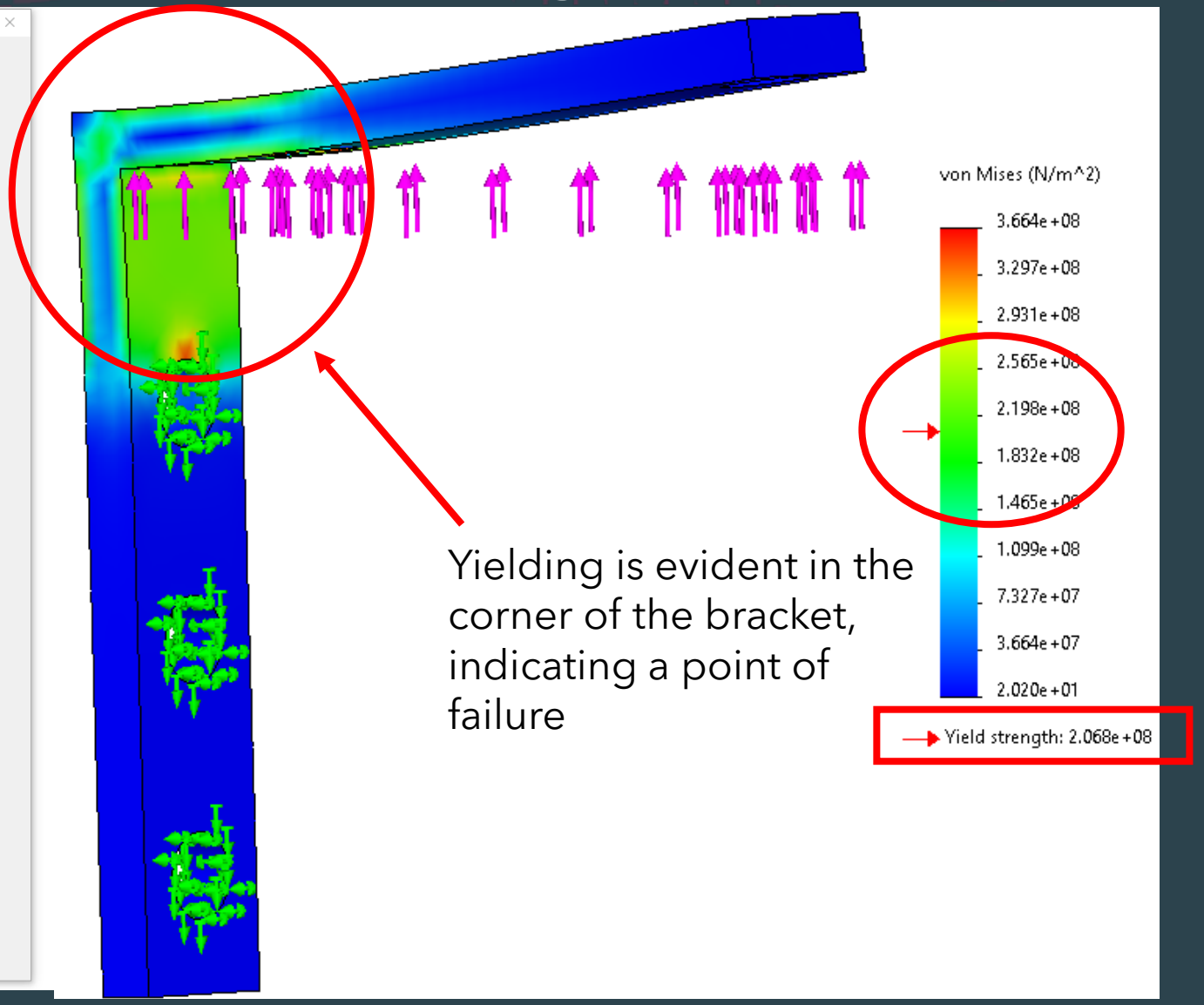
Moments of inertia: (pounds * square inches)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 15.37	Lxy = 0.00	Lxz = -8.68
Lyx = 0.00	Lyy = 29.55	Lyz = 0.00
Lzx = -8.68	Lzy = 0.00	Lzz = 15.27

Moments of inertia: (pounds * square inches)
Taken at the output coordinate system.

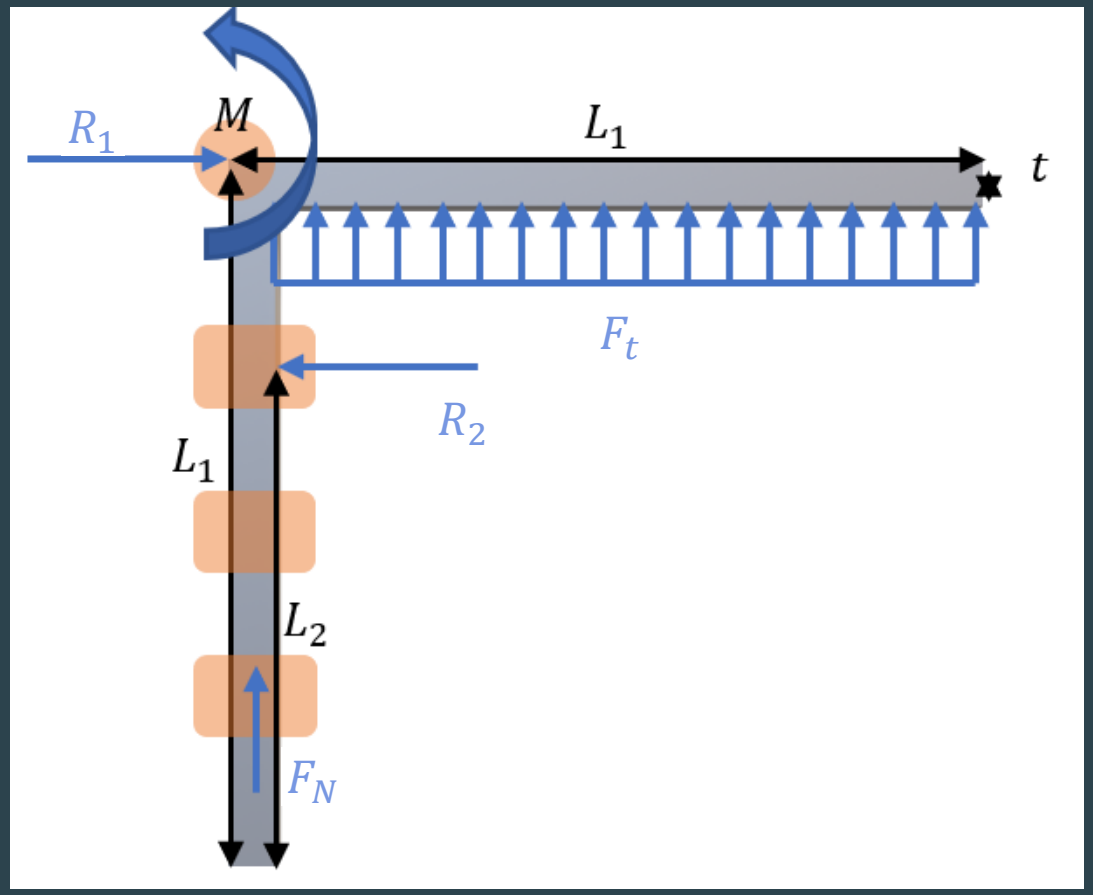
Ixx = 101.14	Ixy = 4.21	Ixz = -40.31
Iyx = 4.21	Iyy = 125.70	Iyz = -11.21
Izx = -40.31	Izy = -11.21	Izz = 28.63

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Yielding is evident in the corner of the bracket, indicating a point of failure

Hand Calculations



$$L_1 = 0.191m$$

$$L_2 = 0.127m$$

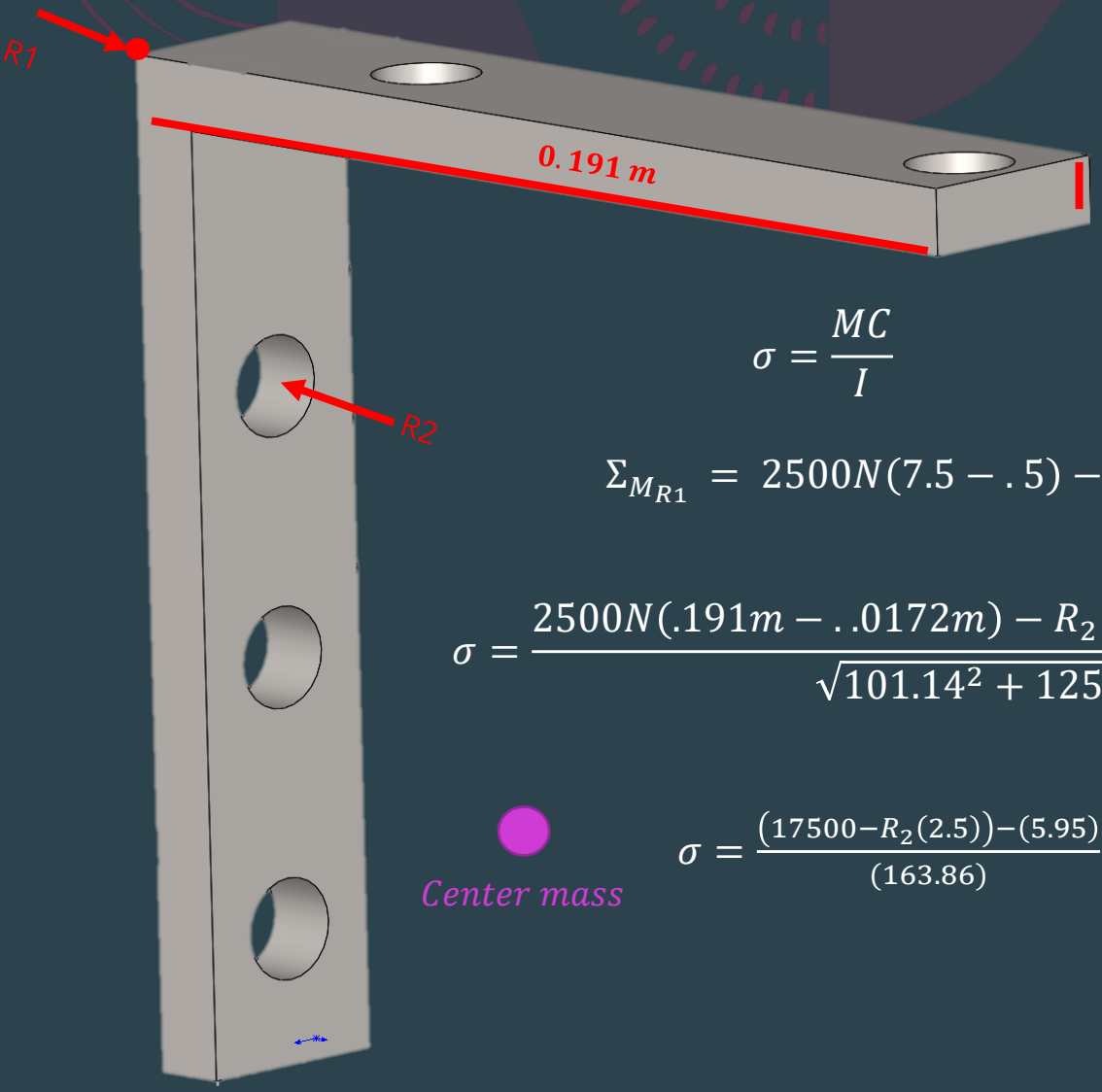
$$t = 0.0127m$$

$$F_T = 2500N$$

$$\Sigma F_x : R_1 = R_2$$

$$\Sigma F_y : F_n = -mg + F_T$$

$$\Sigma M_{R_1} : M = 17500Nm - R_2(L_1 - L_2)$$





$$\sigma = \frac{MC}{I}$$

$$\Sigma_{M_{R1}} = 2500N(7.5 - .5) - R_2(l - l_2)$$

$$\sigma = \frac{2500N(.191m - ..0172m) - R_2(l - l_2)\sqrt{(2.07)^2 + .74^2 + 5.53^2}}{\sqrt{101.14^2 + 125.70^2 + 28.63^2}}$$

Center mass

$$\sigma = \frac{(17500 - R_2(2.5)) - (5.95)}{(163.86)} = \text{inconclusive}$$

$$\sigma = \frac{MC}{I}$$

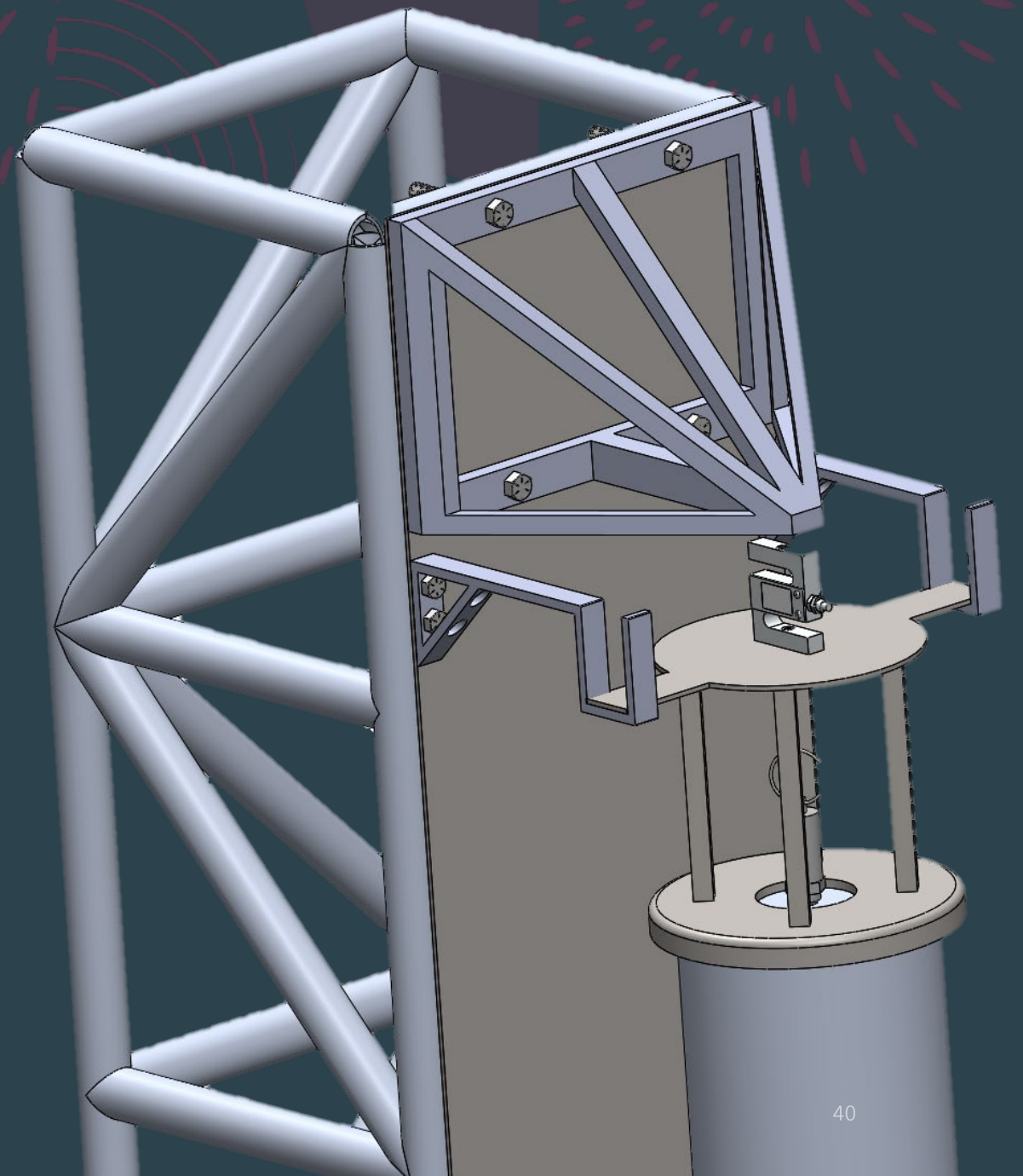
$$I = \frac{B * h^3}{12}$$

$$\sigma = \frac{(477.5\ N * m) * (\frac{.191m}{2})}{\frac{(477.5\ N * m) * (.0172m)^3}{12}}$$

$$\sigma = 5.6245 * 10^8 Pa$$

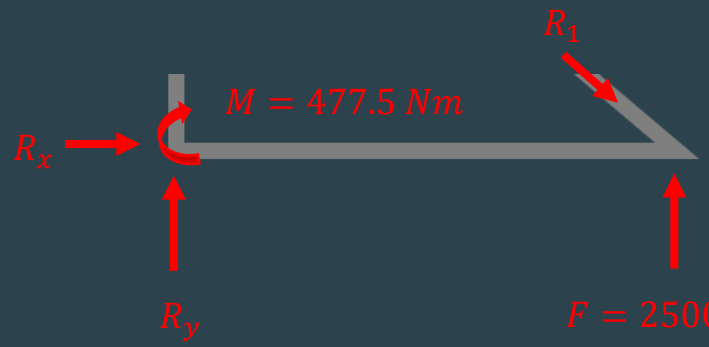
Design Changes

- Evidence of failure present; redesign necessary
- Reinforced truss shape adopted to prevent bending
- Water cut in 4 separate pieces and welded together

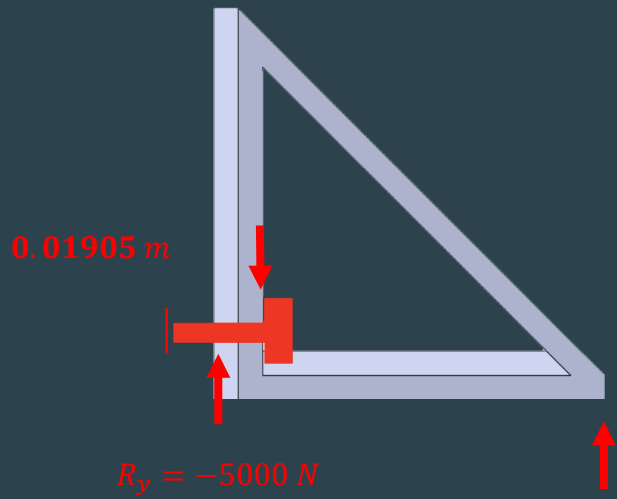


Bracket FEA

- no yielding is evident with new design
- Same mounting hardware can be used

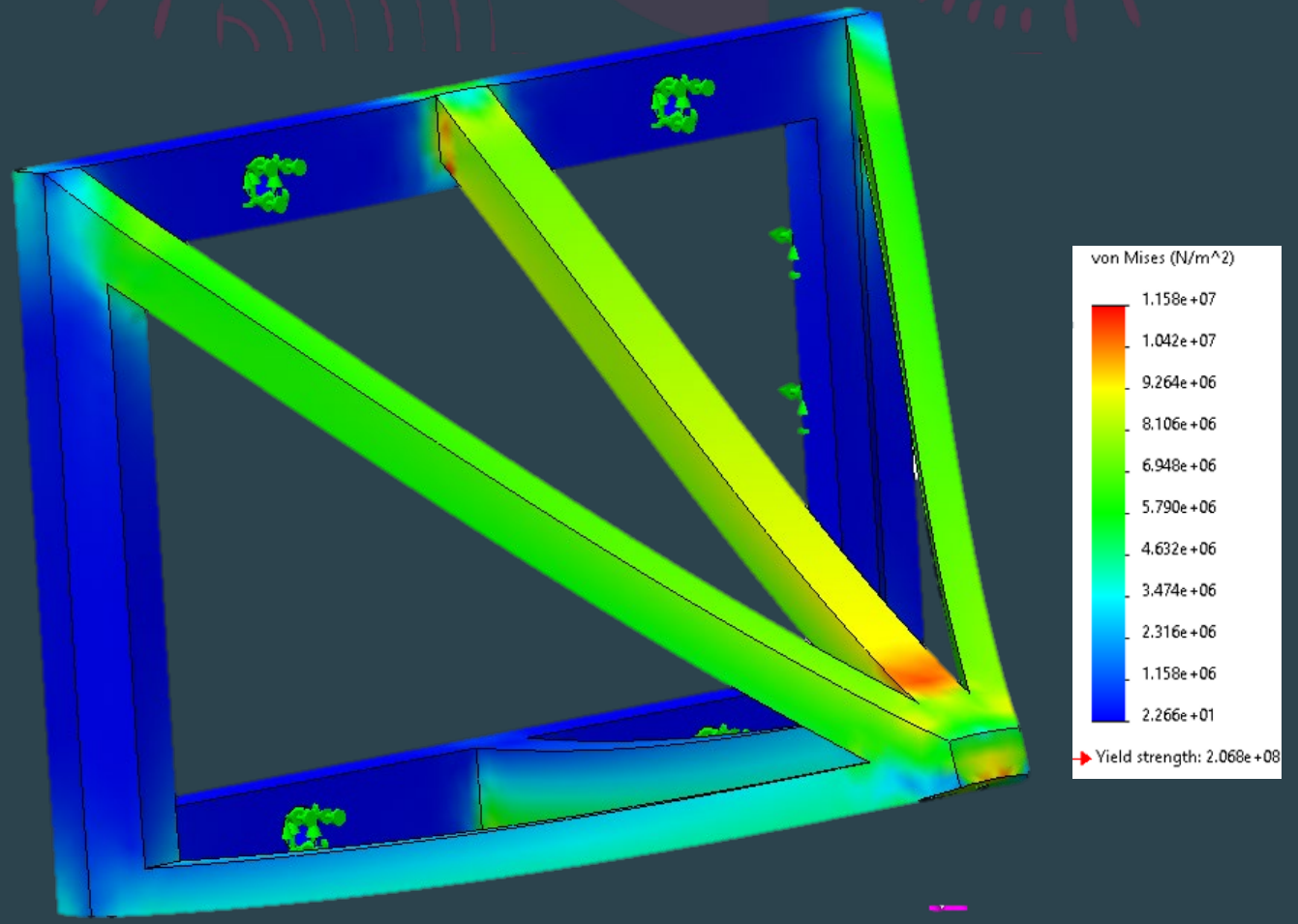


$$R_1 = 3535.53\ N$$
$$R_y = -5000\ N$$
$$R_x = -2500\ N$$
$$\mathrm{M} = -5.61 * 10^{-4}\ N * m$$



$$\mathrm{T} = \frac{4F}{\pi * D^2}$$

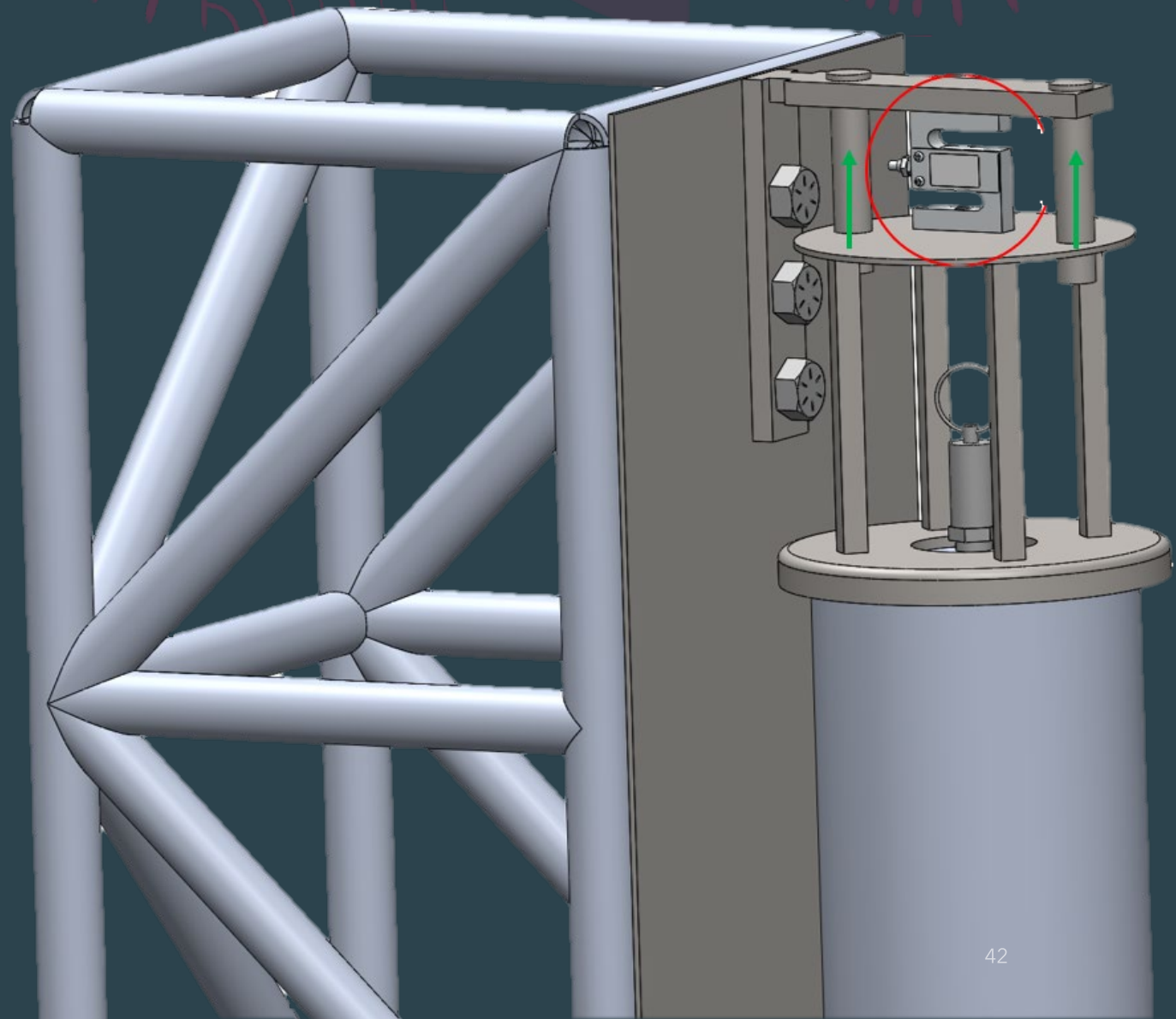
$$\mathrm{T} = 3.34 * 10^5 \frac{N}{m}$$

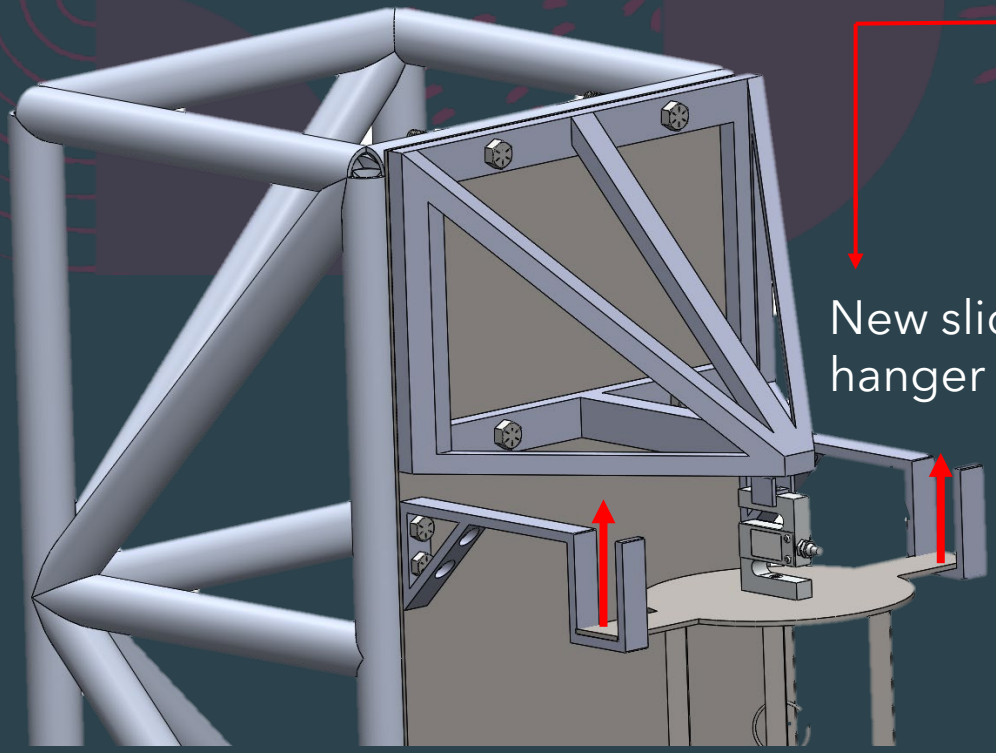


Design changes

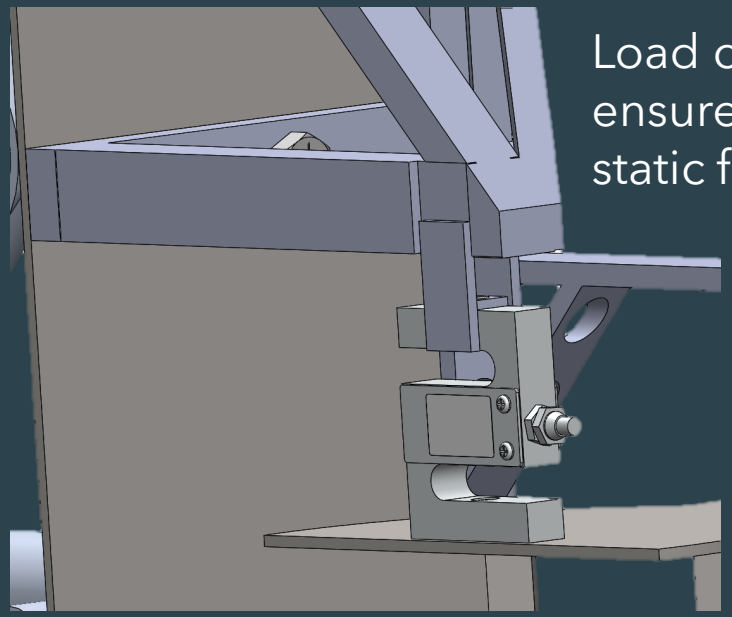
- Original slide system for load cell could bind/stuck during test fire

- Bracket redesign meant redesigning this slide system as well

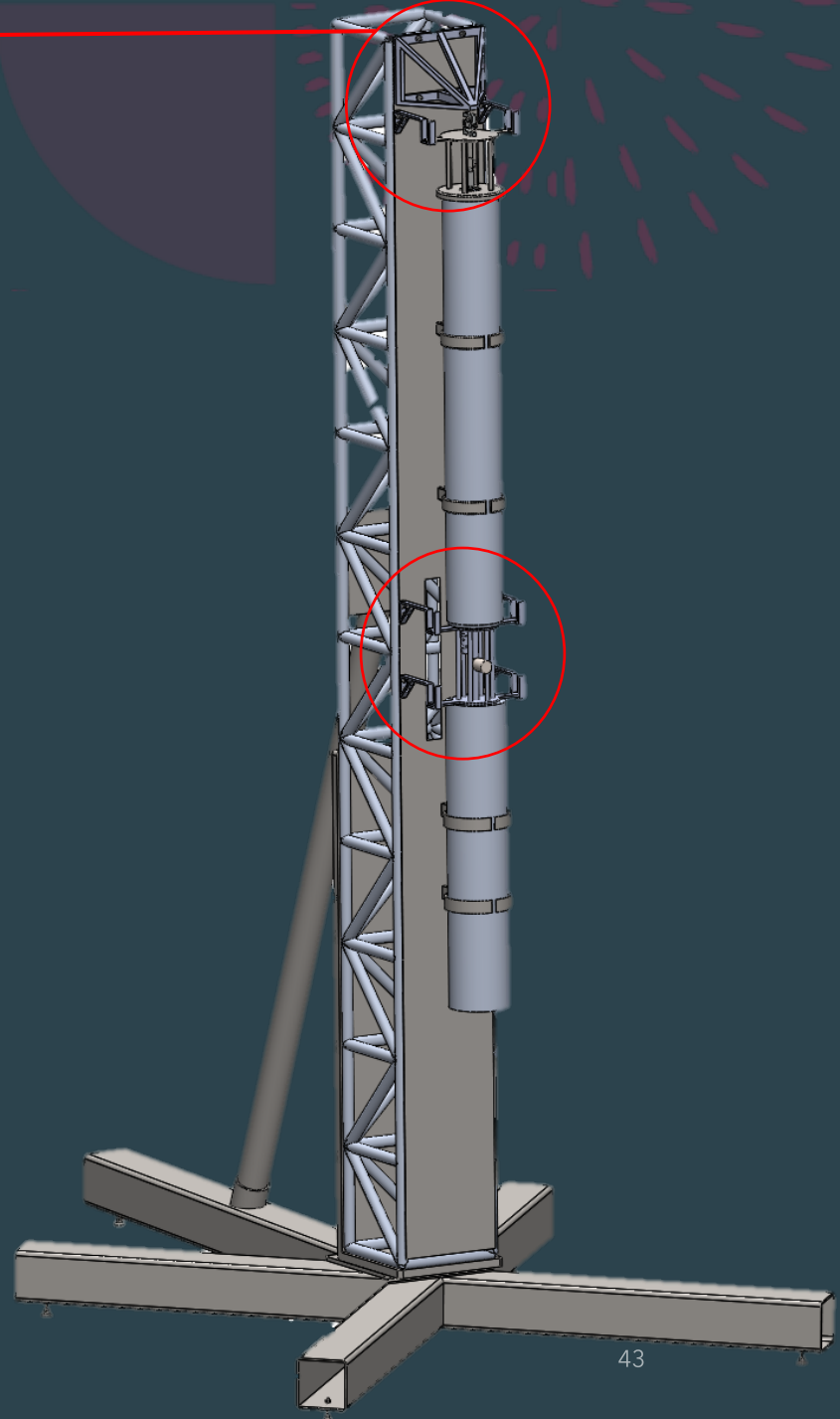




New slide system doubles as a hanger for motor assembly



Load cell is guided with tabs to ensure constant contact with static fire bracket



Controls System



Anthony Urzua

- Controls System Designer

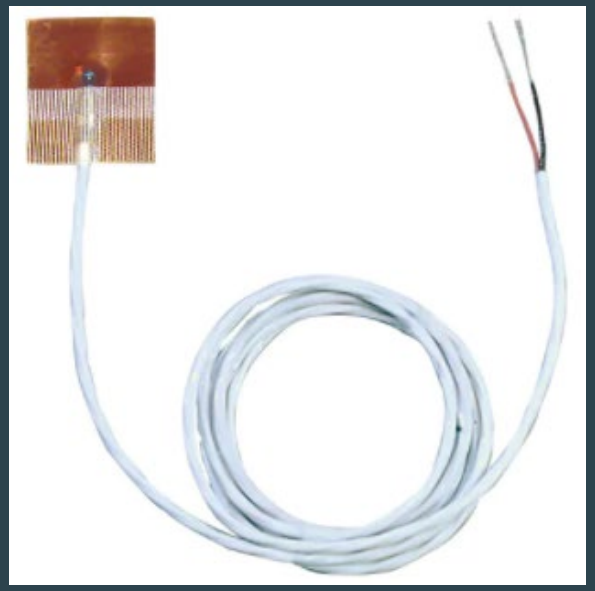
Control System Design

- Design a GUI to allow operators to control the fill, drain, and purging sequencing of the oxidizer tank using LabVIEW and Arduino

Selected Sensors

- Explosion-Proof Industrial Pressure Transducer
- Self-Adhesive Polyimide Fast Response Thermistor Surface Sensor





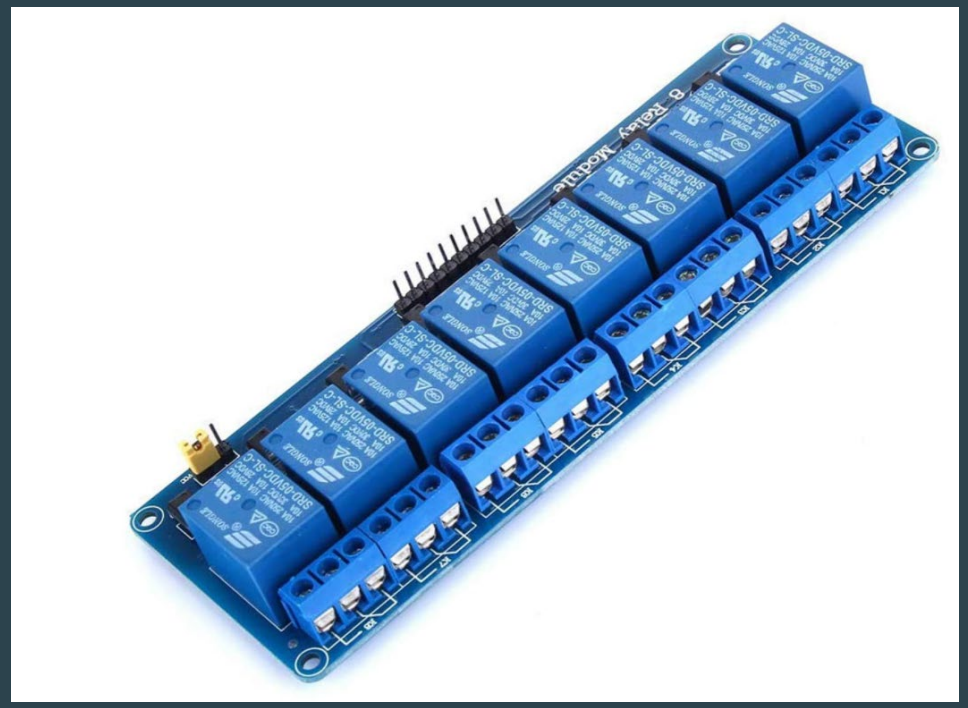
Issues

- Pressure transducer was selected but was not able to be ordered. Could not get a hold of any technical documentation.

Additional Hardware

- 6 V Battery
- 8-Channel 5V DC Relay Module Control Board

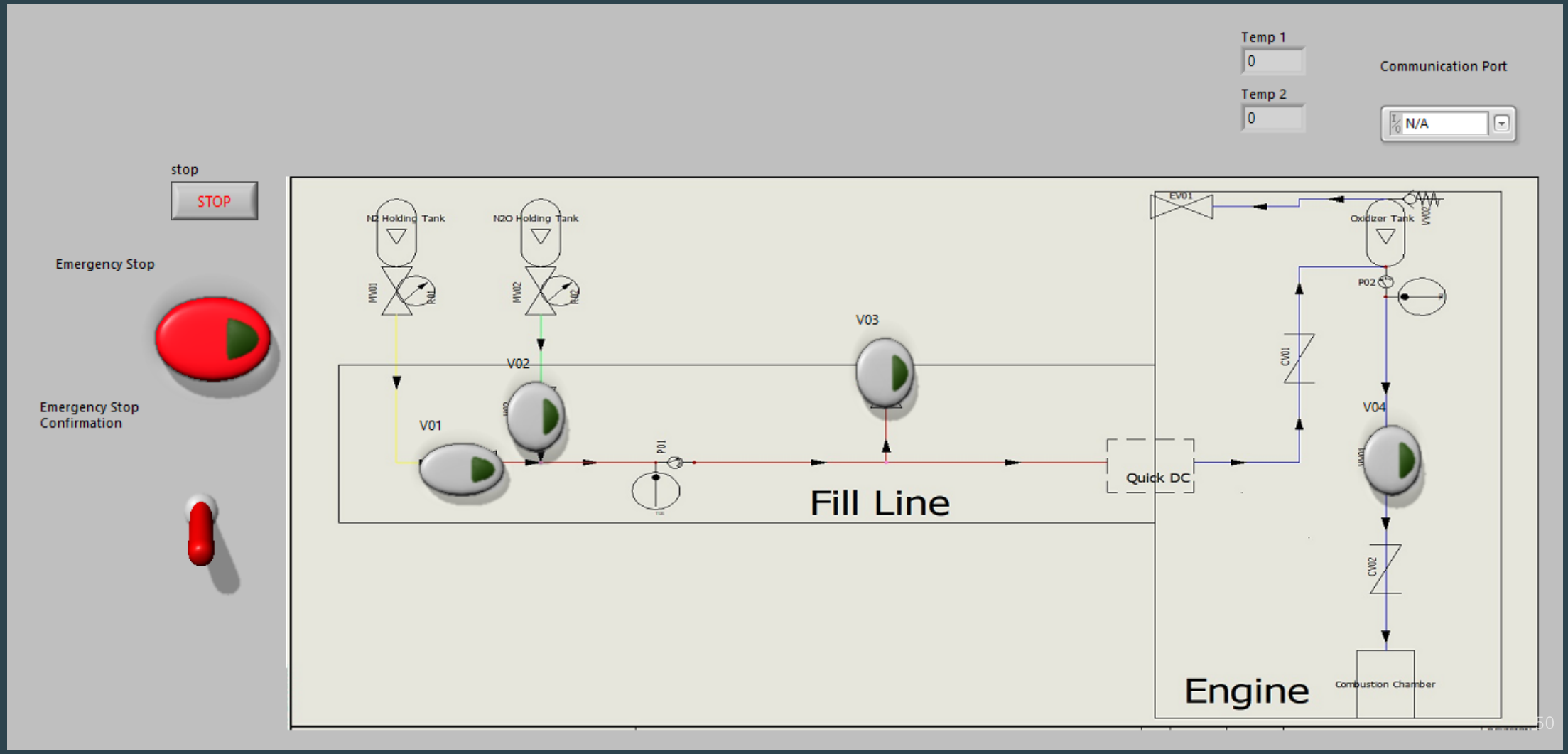




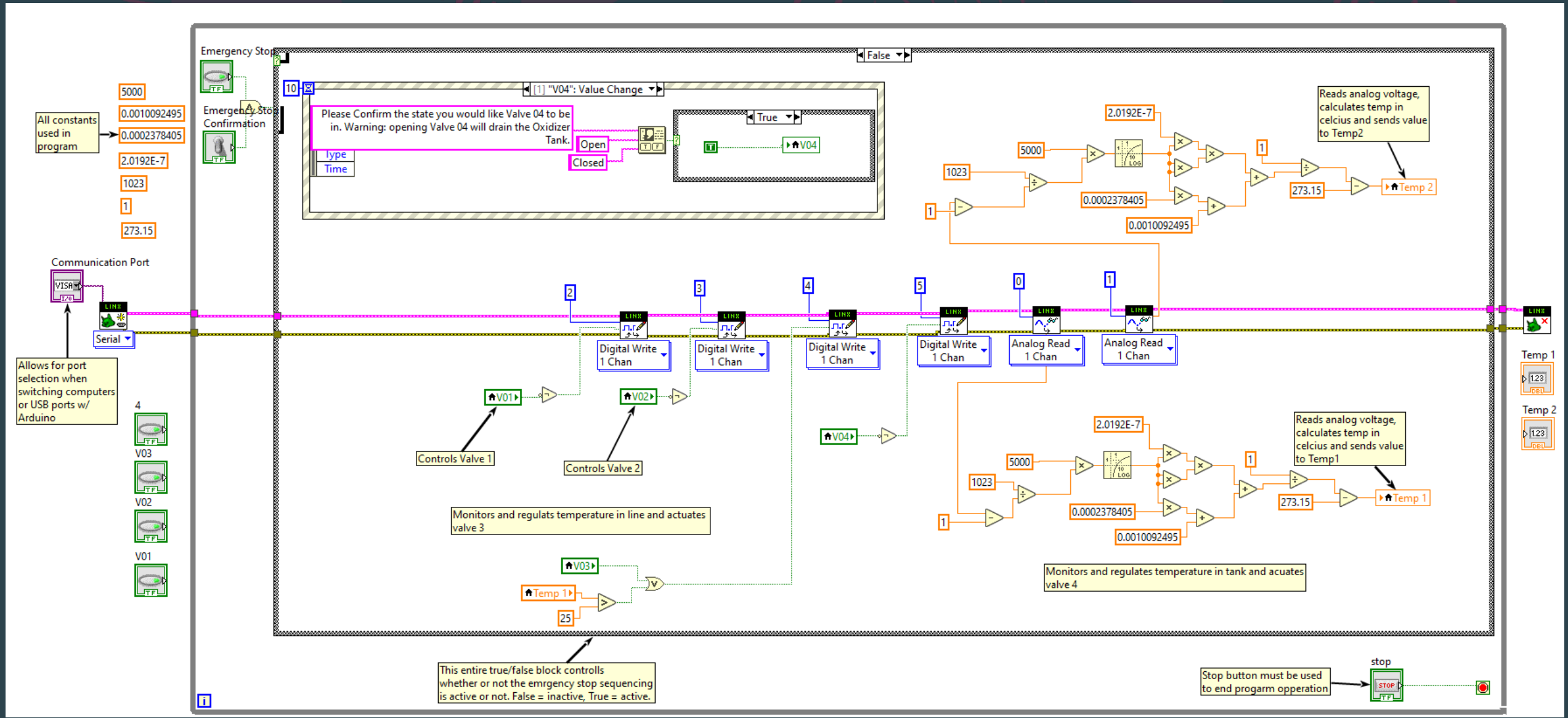
Current Block Diagram



Front Pannel

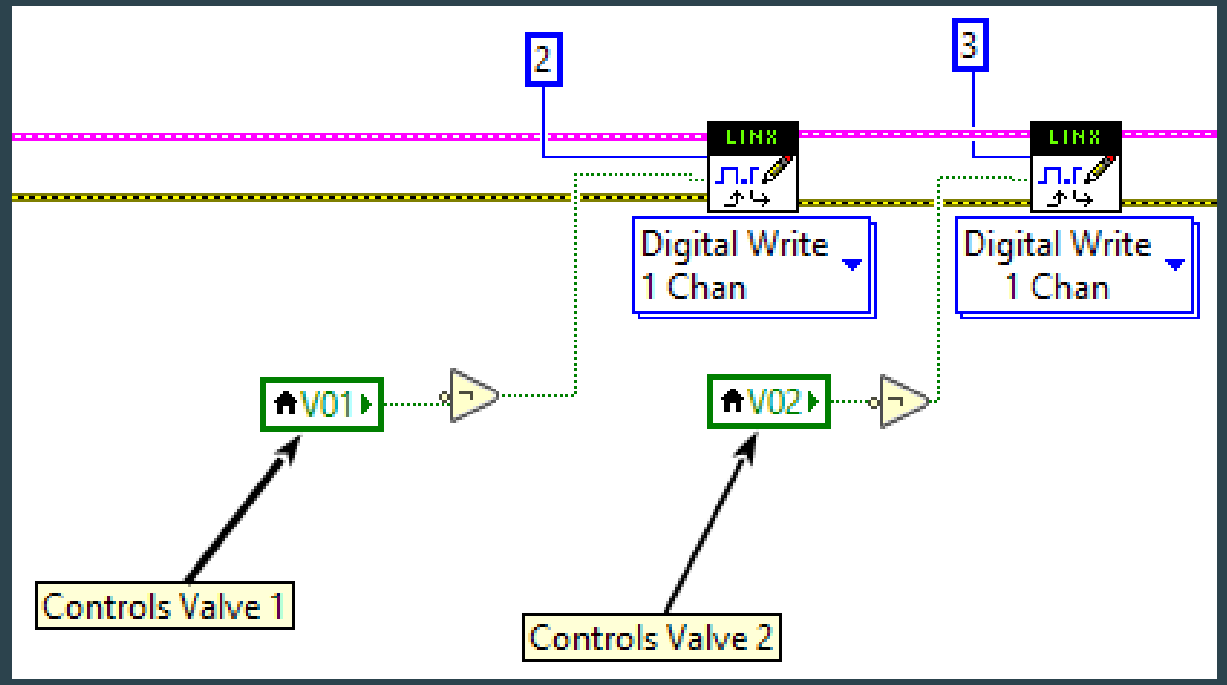


Block Diagram



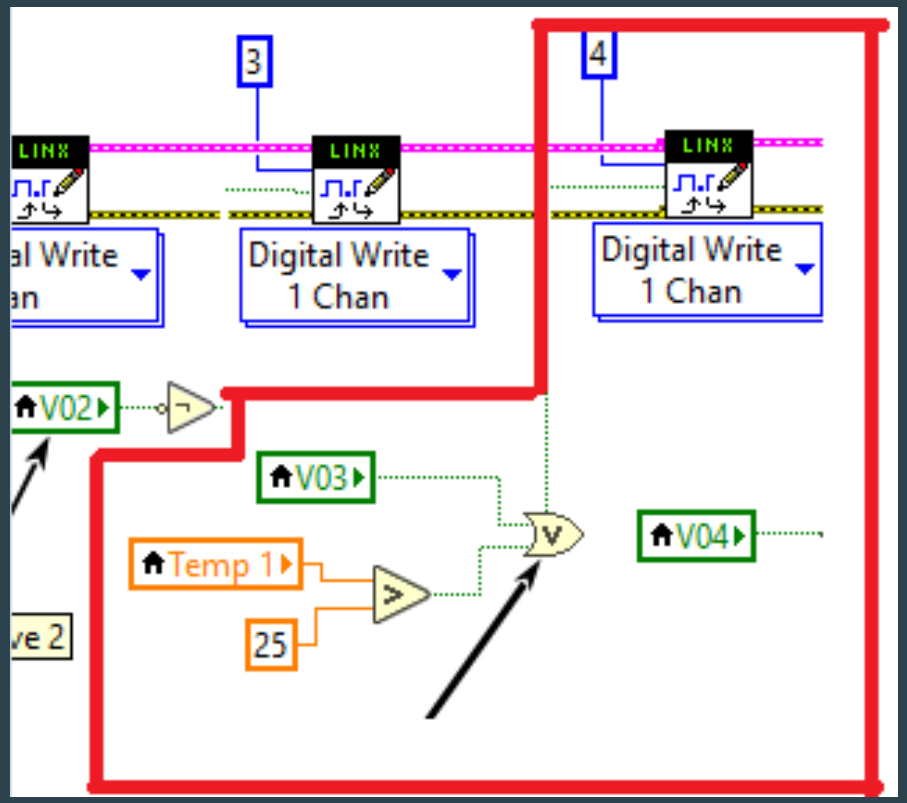
Valve actuation logic

Normally Closed:

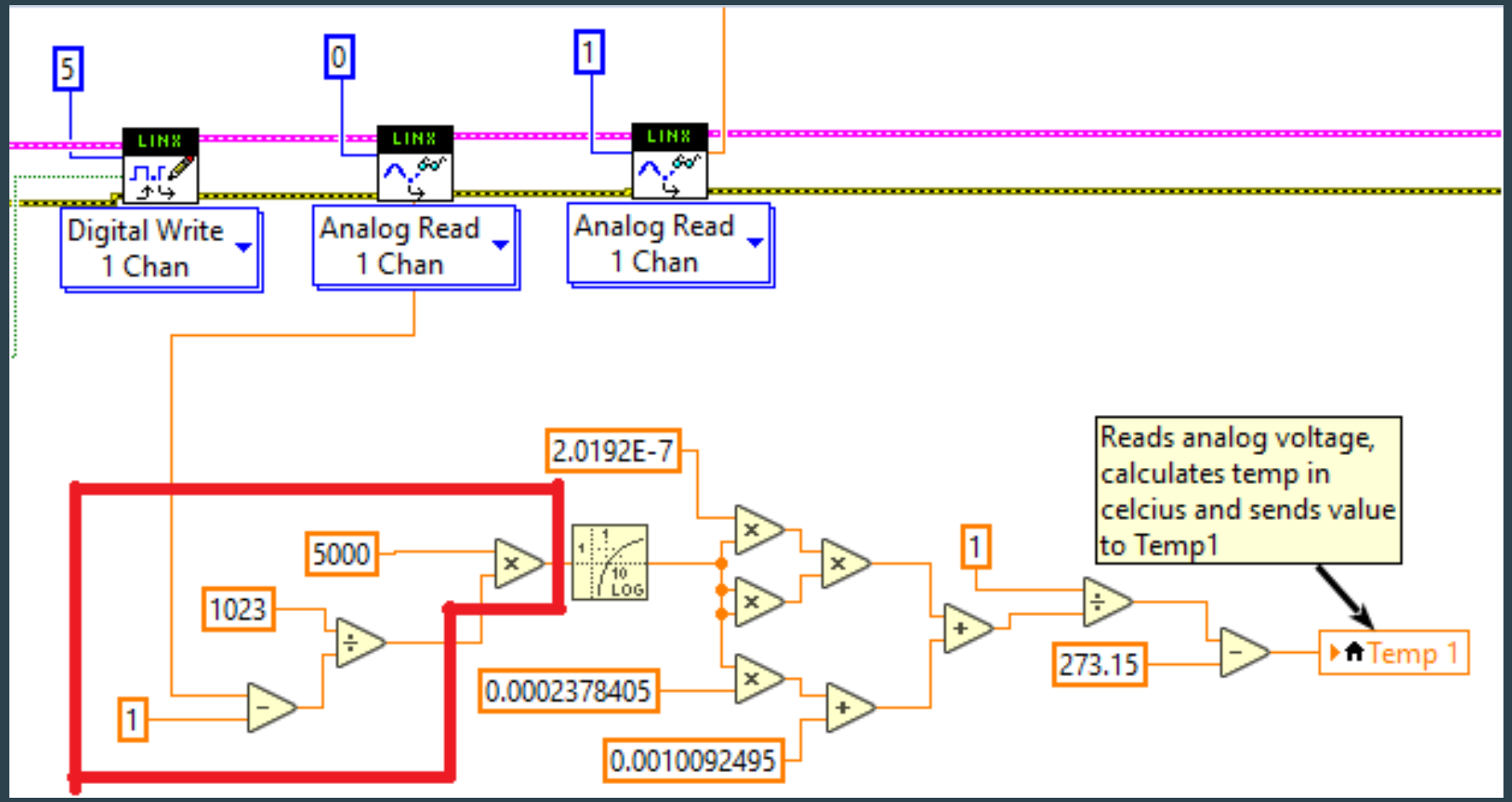


Valve Actuation logic

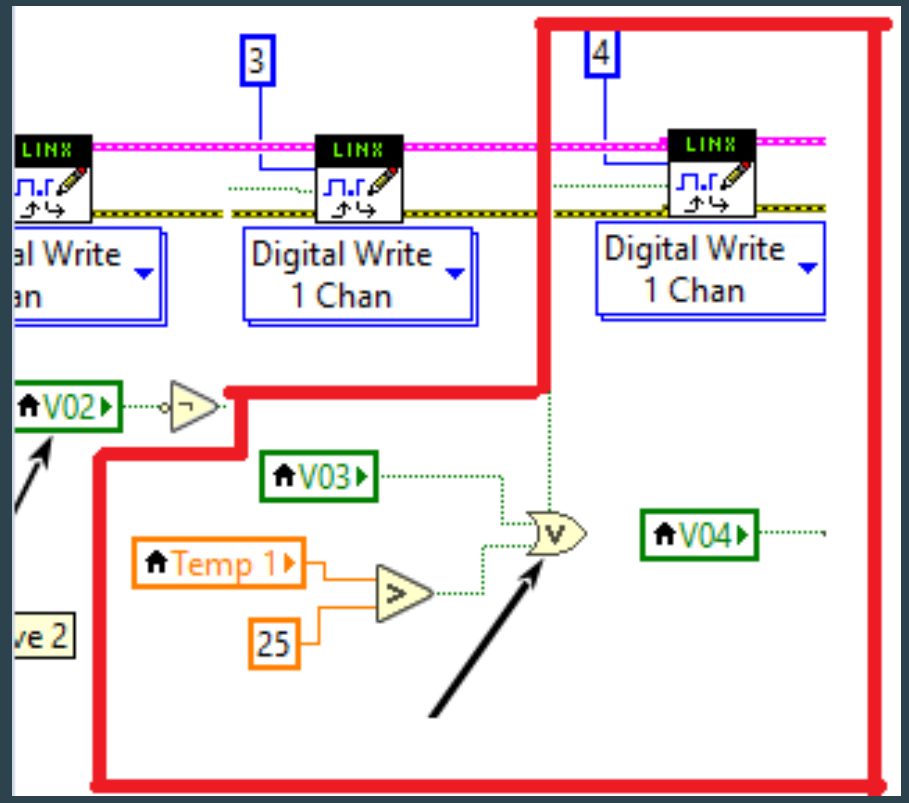
Normally Open:



Temperature Calculation



Temperature Regulation



Truth Table:

Temp	Valve controller	Temp || Valve	Valve Position
0	0	0	Closed
0	1	1	Open
1	0	1	Open
1	1	1	Open

In Conclusion

- Python and ANSYS total times are within 2 minutes of each other.
- Valve losses increase total fill time.
- Structural designs reduce manufacturing complexity.
- Structure can withstand static fire forces.
- Controls system allows process to be done autonomously.

Thank you!

- Dr. Santner
- ERSEDS
- GC Valves
- EMJ Metals
- College of ECST

References

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[2] N. G. Richter and B. H. Sage, "Thermal Conductivity of Fluids. Nitrous Oxide," *Journal of Chemical & Engineering Data,* vol. 8, no. 2, pp. 221-225, 1963.

[3] M. Takahashi, N. Shibasaki-Kitakawa, C. Yokoyama and S. Takahashi, "Viscosity of Gaseous Nitrous Oxide from 298.15 K to 398.15 K at Pressures up to 25 MPa," *Journal of Chemical & Engineering Data,* vol. 41, no. 6, pp. 1495-1498, 1996.

[4] ESDU, "Thermophysical properties of nitrous oxide," *ESDU Series on Physical Data, Chemical Engineering,* September 1991.

[5] E. W. Lemmon and R. Span, "Short Fundamental Equations of State for 20 Industrial Fluids," *Journal of Chemical Engineering Data,* vol. 51, no. 3, pp. 785-850, 2006.