Forge Burner

Caleb DesJardins

Introduction

Description

Propane forge burners are often made by professional and hobbyist blacksmiths to step into an alternative to coal forges. A common theme among them is that they are built out of black iron pipe fittings. Making the burner out of pipe fittings makes it easy, however it results in a lack of efficiency due to the lack of precision in adjusting air/fuel ratio. High efficiency can be obtained by allowing excess air, but this puts more oxygen into the forge, making the metal inside oxidize too much. Burners are also usually attached with set screws holding them in a hole, which makes it difficult to remove the burner and allows the exhaust gas to get into the intake and make them run poorly.

Motivation

The motivation behind this project is a need for easy operation of a forge and efficient use of fuel. Blacksmithing requires proper timing to avoid overheating the material and working the material before it gets cold, so a burner that is easy to operate mitigates distraction from the heat cycles.

Function Statement

The Forge Burner is meant to burn propane more efficiently and with less excess oxygen than black iron pipe alternative.

Requirements

- Intake must be detachable within seconds.
- Intake must be adjustable with specific settings optimized for different propane pressures from 10 to 40 psi.
- Brings forge up to 1500°F 20% faster than existing black iron pipe design.
- Forge exhaust must not be able to flow directly into the intake.

Engineering Merit

The merit behind engineering the burner is obtaining a specific efficiency. Fluid mechanics calculations are required to find the flow rates of the air and propane in order to optimize air-fuel ratio. The flow rate of air will have to be calculated for different intake settings to correspond with different propane pressures.

Scope of Effort

The scope of the project is limited to the geometry of the burner, the intake adjustment and the attachment system to the forge. The forge itself is not designed as it is a control between the designed burner tests and benchmark burner tests.

Success Criteria

At a given propane pressure, the burner would have to bring a forge up to temperature faster than a black iron pipe burner and reach a higher ultimate temperature. For a successful test, the burner will reach temperature 20% faster than the benchmark burner.

Design and Analysis

Approach (RADD)

The burner is required to heat a forge to 1500°F 20% faster than the benchmark burner. This is done by analyzing the flow rates of air and propane and varying geometry to match stoichiometric ratio. Analyses are shown in appendix A. The design parameters are a flange on the body to block exhaust gasses and an adjustable intake with graduations to show the required valve setting for optimized air/fuel mixture for the current propane setting. The burner body with the flange is shown in appendix B 20-0001. Adjustable intake assembly is shown in appendix B 20-0002 through 20-0005.

Design Description

The burner consists of three main parts/assemblies. The intake assembly is mounted at the top of the burner and has a propane injector suspended above a conical air intake where the flow of propane entrains the air for combustion. The air and propane enters the burner body, where turbulence causes them to mix along the length of the mixing tube. At the end of the mixing tube is a nozzle for the gas to expand into and combust. Basic design is based off of the benchmark burner, however it has the following additions to improve efficiency: To block the flow of exhaust gas, the burner body has a flange that covers the burner hole. To adjust the airflow, the intake has a disc that is threaded onto the propane injector, so it can be raised up, or lowered down by spinning it to adjust intake area. The side of the injector bracket is graduated to show the height needed for each propane pressure. Drawings of all parts are shown in appendix B.

Benchmark

The benchmark is a black iron pipe burner and set screw attachment. The benchmark burner is based off a common design used by professional and hobbyist blacksmiths. There is no intake adjustment on the benchmark and attaching it to a forge with set screws allows for exhaust gasses to reach the intake.

Performance Predictions

The improved efficiency of the burner will result in a more even burn of the propane and a less oxidising flame. Uneven burning of propane in the benchmark burner is apparent based on the sound of the burner, and the sound of the designed burner's flame will be an even roar. Optimal air/fuel ratios will be achieved at any propane pressure setting within 10 psi increments as shown in appendix A10-A13. The exhaust gasses from the burner will not be aloud to recirculate back into the intake as the burner port does not allow the gas to flow directly up. Air/fuel mixture is unknown for the benchmark burner, so exact improvement is unknown.

Descriptions of Analyses

The flow analysis of air and propane was done with Bernoulli approximations based on the geometry of the burner intake. The flow rate of propane out of the injector is calculated at every 5 psi of propane pressure between 5 and 40 psi gage with Bernoulli energy balance as shown in appendix A1-A8. Intake area is calculated based on the assumption that the air velocity is equal to the propane velocity in the mixing tube. Velocity through the intake valve is then calculated based on intake geometry. Required intake area is then calculated as shown in appendix A10-A13.

Scope of Testing And Evaluation

Testing will be limited to the resulting performance of the burner to bring a forge up to working temperature and to limit oxidation of the workpiece.

Analyses

Analyses showed that the intake valve must be able to be adjusted to a maximum height of 0.2 inches to give optimal airflow when propane is set to 40 psi. The actual design allows for a maximum height of 1 inch to allow for oxidizing flame when heavy oxidation is desired. Individual areas for each propane setting are shown in appendix A9-A13. Required areas are only analyzed in increments of 10 psi because the difference in area for 5 psi increments were very small. All analyses are shown in appendix A.

Device: Parts, Shapes and Conformation

The general shape of the internal geometry of the burner tapers to a small area in the intake to accelerate it into the mixing tube, and then tapers out in the nozzle for the gas to expand for combustion. The burner body has a flange with holes for press fitting pins to locate it on the Forge coupler.

Device Assembly, Attachments

All parts will be threaded and bolted together in the configuration shown in appendix B 10-0001. The opening of the injector will be where the propane line and regulator will be attached.

Tolerances

All tolerances are given in ANSI Y14.5 drawings shown in appendix B 20-00001 through 20-00005. Most parts are given standard tolerance so parts fit together without interference. Holes in the flange of the burner body are given tighter tolerance as they will be reamed for a pin to be press fit into.

Methods and Construction

Methods

The components are constructed using the CWU machine lab.The burner body will be bored and turned on a lathe, and then holes will be drilled and reamed on a mill.

- Burner body drawing is shown in appendix B 20-0001.
- Internal geometry of the nozzle was bored out on a lathe.
- The general shape of the intake was turned on a lathe, flats and holes were machined and tapped on a mill as shown in appendix B 20-0004.
- The inside of the injector was drilled out of threaded rod. Outer features were then turned on a lathe and the end was threaded to attach to the injector bracket and accept the propane line. Injector dimensions are shown in appendix B 20-0005.
- The intake valve was knurled on the outside and drilled and tapped in the center to be threaded onto the injector.
- The injector bracket was rough-cut on the bandsaw, and final dimensions were machined on the mill out of a flat plate with appropriate holes drilled and tapped shown in appendix B 20-0003. Graduations were stamped on the side of the brackets showing the corresponding intake setting for a certain propane pressure setting.
- The forge couple was not be fully machined as it will be easier to buy a pipe coupler and drill two holes in it to accept locating pins on the burner body flange.

Construction

The burner body is threaded at both ends with a pipe threader for the intake and nozzle to be threaded at both ends. Locating pins are press-fit into the holes in the burner body flange. The injector bracket was then attached to the intake with fasteners. The injector and intake valves are then threaded together, and the propane lines can then be attached to the injector. Propane fitting requires a 45 degree coupler attached to the injector, a brass pipe nipple to attach to a ball valve, and an adapter to connect the ball valve to the propane line The propane line comes from a regulator at the propane tank. The drawing tree in appendix B shows all parts as they connect to each other. Full assembly is shown in appendix B 10-0001 and 10-0002.

Testing Methods

The desired outcomes of the burner are higher efficiency to heat up a forge more quickly without a lean burn causing the workpiece to oxidize too much. The burner is tested against the benchmark black iron pipe burner. The sound of the burner is also a component of the test, as a smoother sounding burn is an indication of a more efficient burn. The forge will start cold in the testing and both burners will be timed to reach 1500 °F. Oxidation test will be done by maintaining 1500 °F chamber pressure and placing a piece of steel in for a given amount of time.

Budget

All raw materials and fittings are bought from Mcmaster-Carr. Total cost comes out to $137.53. Itemized budget is shown in appendix D. Mainly round stock is required for the majority of the parts to be machined out of. All parts that show in the parts list in appendix C that are not shown in the budget are already owned. Labor is valued at $100 per hour with no outsourced labor. Tentative schedule as shown in appendix E predicts 150.4 hours of labor is required, making the total labor cost equal $15,040. Although labor is valued at $100 per hour, it will be completed by a willing engineer accepting $0 per hour, putting total project cost at $137.53. Funding may be sourced from CWU, however if CWU does not accept request, it will have to be funded by the engineer (regardless of his/her) poor financial status.

Schedule

The main deliverables for the project are the proposal with an initial design for the burner, parts that need machining, full assembly of device assembled with purchased parts, and a full test of the device with a testing report. The proposal for the project with the design is to be completed before December 6th, and all changes to design must be completed before the following January 7th. A fully assembled device must be completed before March 13th with various milestones for machined part completion in between. Testing will begin on March 31st and a full report of the test will be completed before June 5th. All individual tasks are scheduled in appendix E with predicted time constraints for each task.

Project Management

The project is overseen by Professor Charles Pringle, Dr. Craig Johnson, and Dr. John Choi. The success of the project will be facilitated by the guidance and expertise of the overseeing professors and machine lab support techs. Physical resources required are accessible in the CWU machine lab. Solidworks and AutoCAD are available on all CAD lab computers for designing the burner. Funding can be supported by the engineer, and funding from CWU will be requested. The project will be designed, built, and tested by the principal engineer. The engineer’s resume is shown in appendix J.

Discussion

Design Evolution / Performance Creep

The burner was originally going to be designed with an electric blower to give forced induction. This design was later overlooked as it would not give adjustability in the air flow. The burner body was originally two inches shorter, however in order for the nozzle to sit in the right position in the forge with the length of the forge coupler and the thickness of the forge insulation, the extra length was added. The first design of the injector bracket was 3 inches tall, however analyses showed that it could be shortened and still give desired adjustability.

Project Risk Analysis

Significant risk is involved in the machining of parts and operation of the device. The engineer must receive required safety training for operation of the equipment being used to machine the parts for the device. Proper safety precautions must be taken when operating the device during use and testing. Specific risks and required precautions are shown in the job hazard analysis in appendix J.

Successful

The final design of the burner is successful as it has the required geometry to achieve the requirements. However, most of the analyses may not be a success as different approaches will be analyzed for solving the flow rates and will be compared to the current approach. Changes in flow rate analyses will not affect the overall design, however it will affect the graduations that will be stamped into the side of the injector bracket.

Next Phase

Because of the complexity of the question being analyzed for the project, the analysis of the flow rates in the burner required various assumptions to make the variables solvable. In the future, different approaches will be made for solving for the flow rates with different sets of assumptions. The different analytical approaches will be compared and the approach with the least assumptions will be used.

Conclusion

The Forge Burner is at a completed design stage and is ready to begin the manufacturing process of a prototype. The analyses show that the geometry is optimized to facilitate the perfect air/fuel mixture for a variety of propane pressure settings. Optimal air/fuel ratios will be achieved at any propane pressure setting within 10 psi increments between 10 and 40 psi. Unlike the benchmark burner, the intake air will not be contaminated with exhaust gas. With this predictability, the designed burner will be on its way to bringing a forge up to temperature 20% faster than the benchmark burner.

Acknowledgment

Professor Charles Pringle, Dr. Craig Johnson, and Dr. John Choi are to be acknowledged for facilitating the project and giving guidance for the engineer in completing the design. Dr. John Choi is especially responsible for helping with analyses with his expertise in fluid mechanics. Dr. John Choi contributed the most guidance for the proposal from weekly milestone checks.

References

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Lawn, C J. "A Simple Method for the Design of Gas Burner Injectors." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol. 217, no. 2, 2003, pp. 237–246., doi:10.1243/095440603762826558.

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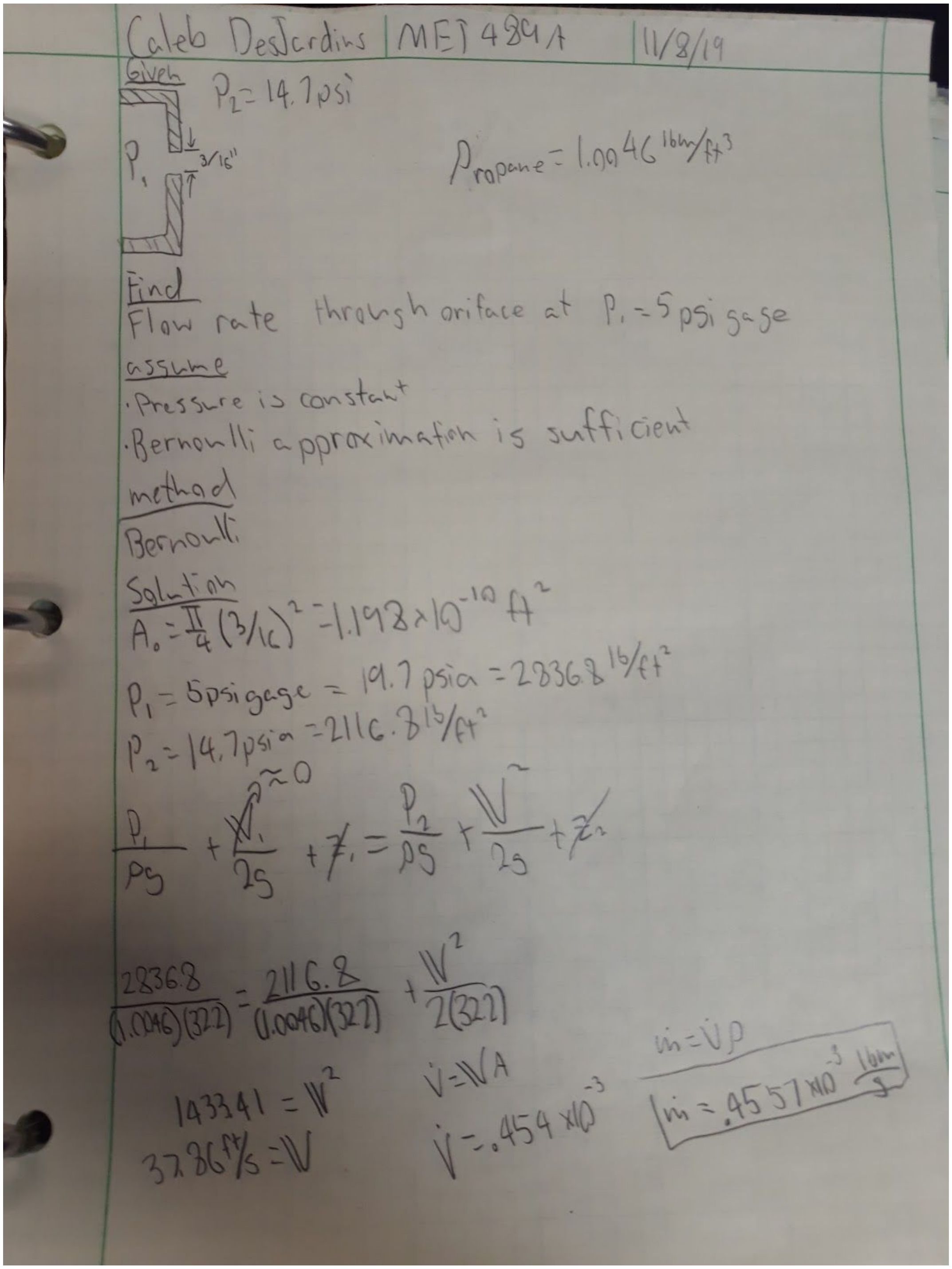
Appendix A



Caleb DesJardins | MET 484A | 11/8/19

Given

$P_2 = 14.7\,psi$

P_1, 3/16"

$\rho_{propane} = 1.0046\ lbm/ft^3$

Find

Flow rate through oriface at $P_1 = 5$ psi gage

assume

- Pressure is constant
- Bernoulli approximation is sufficient

method

Bernoulli

Solution

$A_o = \frac{\pi}{4}(3/16)^2 = 1.198\times10^{-10}\ ft^2$

$P_1 = 5\,psi\,gage = 19.7\,psia = 2836.8\ lb/ft^2$

$P_2 = 14.7\,psia = 2116.8\ lb/ft^2$

$$\frac{P_1}{\rho g} + \underbrace{\frac{V_1^2}{2g}}_{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V^2}{2g} + \cancel{z_2}$$

$$\frac{2836.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$1433.41 = V^2$

$37.86\ ft/s = V$

$\dot{V} = VA$

$\dot{V} = .454\times10^{-3}$

$\dot{m} = \dot{V}\rho$

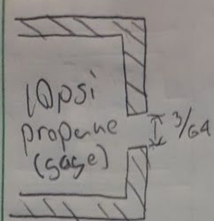
$\boxed{\dot{m} = .4557\times10^{-3}\ lbm/s}$

A1: Flow rate of propane at 5psi gage.

Caleb DesJardins MET 489A 10/17/19

Given

$P_1 = 24.7\,psi = 3556.8\,lb/ft^2$ $P_2 = 14.7\,psi = 2116.8\,lb/ft^2$



$\rho_{Propane} = 1.0046\,lbm/ft^3$

$A_o = 1.198 \times 10^{-5}\,ft^2$

Find

Flow rate through orifice

Assume

- Pressure is constant
- Bernoulli approximation is sufficient

method

Bernoulli

Solution

$$\frac{P_1}{\rho g} + \frac{\cancel{V_1^2}^{\approx 0}}{2g} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + \cancel{z_2}$$

$$\frac{3556.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$53.54\,ft/s = V$

$\dot{V} = VA$

$\dot{V} = 6.414 \times 10^{-4}\,ft^3/s$

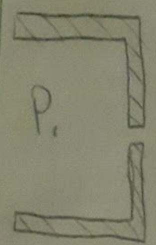
$\dot{m} = \dot{V}\rho$

$\boxed{\dot{m} = 6.444 \times 10^{-4}\,\frac{lbm}{s}}$

A2: Flow rate of propane at 10psi gage.

Caleb DesJardins | MET 489A | 11/1/19

Given



$P_2 = 14.7\,psi$ $\rho_{propane} = 1.0046\ lb/ft^3$

$A_0 = \frac{\pi}{4}\left(\frac{3}{64}in\right)^2$

$A_0 = 1.198 \times 10^{-5}\ ft^2$

Find

Flow rate through oriface at $P_1 = 15$ psi gage

assume

- Pressure is constant
- Bernoulli approximation is sufficient

method

Beroulli

Solution

$P_1 = 15$ psi gage $= 29.7$ psia $= 4276.8\ lb/ft^2$

$P_2 = 14.7$ psia $= 2116.8\ lb/ft^2$

$$\frac{P_1}{\rho g} + \cancel{\frac{V^2}{2g}}^{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V^2}{2g} + \cancel{z_2}$$

$$\frac{4276.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$430022 = V^2$

$65.58\ ft/s = V$

$\dot{V} = VA$

$\dot{V} = .786 \times 10^{-3}\ \frac{ft^3}{s}$

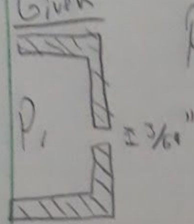
$\dot{m} = \dot{V}\rho$

$\dot{m} = .789 \times 10^{-3}$

A3: Flow rate of propane at 15psi gage.

Caleb DesJardins | MET 489A | 10/25/2019

Given



$P_2 = 14.7\,psi$ $\qquad \rho_{propane} = 1.0046\ lbm/ft^3$

$$A_o = \frac{\pi}{4}\left(\frac{3}{64}\,in\right)^2$$
$$A_o = 1.198\times10^{-5}\ ft^2$$

Find

Flow rate through oriface at $P_1 = 20\,psi$ gage

assume

Pressure is constant

· Bernoulli approximation is sufficient

method

Bernoulli equation

Solution

$P_1 = 20\,psi\ gage = 34.7\,psi = 4996.8\ lb/ft^2$

$P_2 = 14.7\,psi = 2116.8\ lb/ft^2$

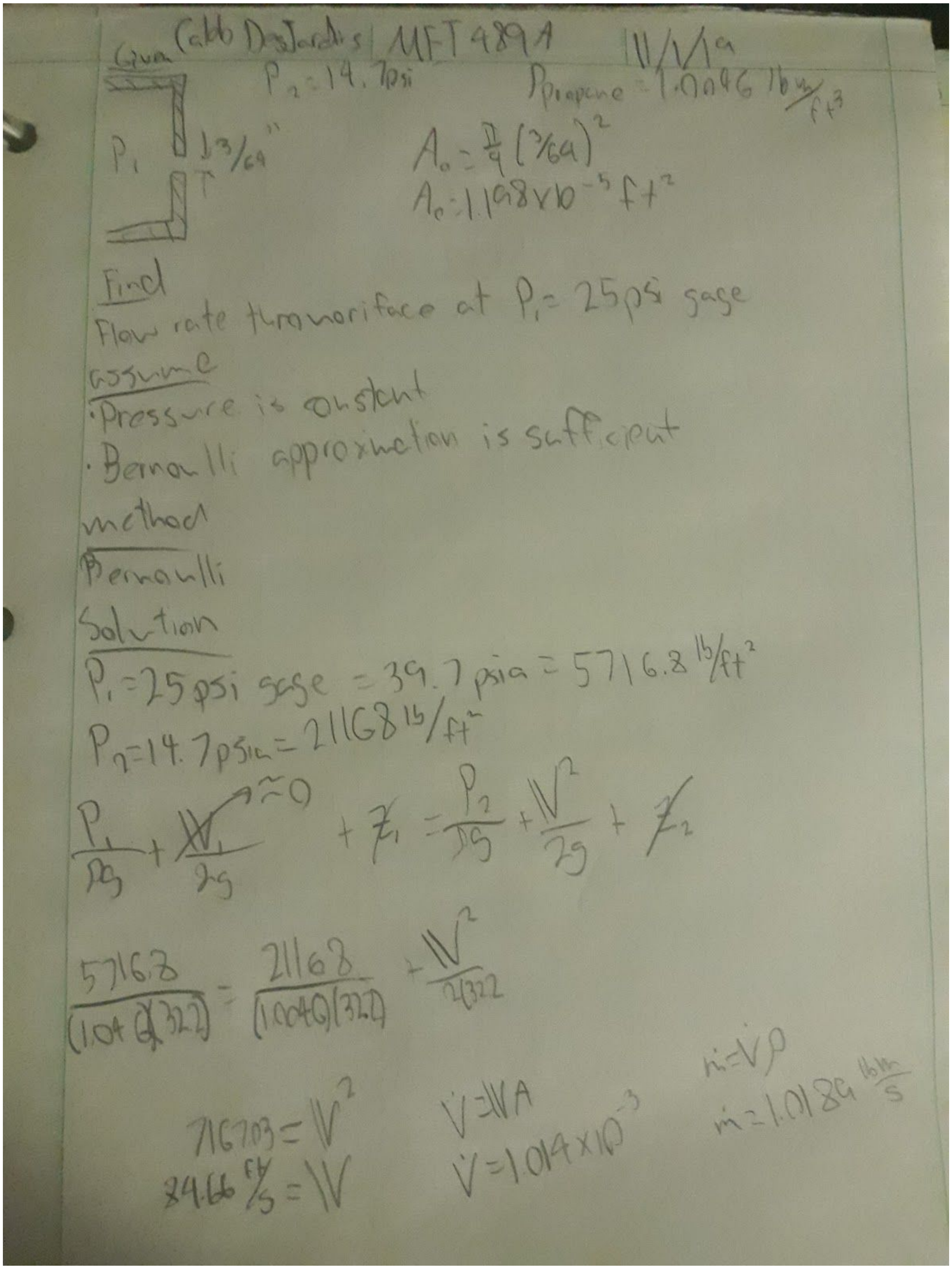
$$\frac{P_1}{\rho g} + \cancel{\frac{V_1^2}{2g}}^{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V^2}{2g} + \cancel{z_2}$$

$$\frac{4996.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$5733.63 = V^2$ $\qquad \dot{V} = VA$ $\qquad \dot{m} = \dot{V}\rho$

$75.72\ ft/s = V$ $\qquad \dot{V} = .907\times10^{-3}\ ft^3/s$ $\qquad \dot{m} = .911\times10^{-3}$

A4: Flow rate of propane at 20psi gage.



Caleb DesJardins | MFT 489A | 11/1/19

Given

$P_2 = 14.7 psi$ $\rho_{propane} = 1.0046 \, lbm/ft^3$

P_1 $13/64''$

$A_o = \frac{\pi}{4}(3/64)^2$

$A_o = 1.198 \times 10^{-5} \, ft^2$

Find

Flow rate thru orifice at $P_1 = 25 psi$ gage

assume

· Pressure is constant

· Bernoulli approximation is sufficient

method

Bernoulli

Solution

$P_1 = 25 psi \text{ gage} = 39.7 psia = 5716.8 \, lb/ft^2$

$P_2 = 14.7 psia = 2116.8 \, lb/ft^2$

$$\frac{P_1}{\rho g} + \cancel{\frac{V_1^2}{2g}}^{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V^2}{2g} + \cancel{z_2}$$

$$\frac{5716.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$716703 = V^2$ $\quad \dot{V} = VA$ $\quad \dot{m} = \dot{V}\rho$

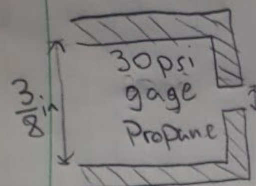
$84.66 \, ft/s = V$ $\quad \dot{V} = 1.014 \times 10^{-3}$ $\quad \dot{m} = 1.0189 \, lbm/s$

A5: Flow rate of propane at 25psi gage.

Caleb DesJardins | ME 489A | 10/16/2019

Given $P_1 = 44.7\,psi$ $\quad P_2 = 14.7\,psi$

$= 6436.8\,lb/ft^2 \quad = 2116.8\,lb/ft^2$



Propane: $\rho = 1.0046\,lbm/ft^3$

$$A_o = \frac{\pi}{4}\left(\frac{3}{64}in\right)^2$$

$$A_o = 1.198 \times 10^{-5}\,ft^2$$

Find

Flow rate through orifice.

Assume

- pressure is constant
- Bernoulli approximation is sufficient

method

Bernoulli

Solution

$$\frac{P_1}{\rho g} + \underbrace{\cancel{\frac{V_1^2}{2g}}}_{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + \cancel{z_2}$$

$$\frac{6436.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$$8600.44 = V^2$$

$$92.74\,ft/s = V$$

$$\dot{V} = V A_o$$

$$\dot{V} = 1.111 \times 10^{-3}\,\frac{ft^3}{s}$$

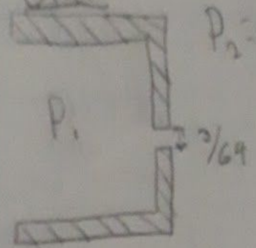
$$\dot{m} = \dot{V}\rho$$

$$\boxed{\dot{m} = 1.117 \times 10^{-3}\,\frac{lbm}{s}}$$

A6: Flow rate of propane at 30psi gage.

Caleb DesJardins | MET 429A | 10/25/2022

Given



$P_2 = 14.7\,psi$

$\rho_{Propane} = 1.0046\ lbm/ft^3$

$A_o = \frac{\pi}{4}\left(\frac{3}{64}in\right)^2$

$A = 1.198 \times 10^{-5} ft^2$

Find

Flow rate through orifice at $P_1 = 35\,psi$ gage

assume

- Bernoulli approximation is sufficient.
- Pressure is constant

Method

Bernoulli equation

Solution

$P_1 = 35\,psi\ gage = 49.7\,psi = 7156.8\ lb/ft^2$

$P_2 = 14.7\,psi = 2116.8\ lb/ft^2$

$$\frac{P_1}{\rho g} + \cancel{\frac{V_1^2}{2g}}^{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V^2}{2g} + \cancel{z_2}$$

$$\frac{7156.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$10032.25 = V^2$

$100.16\ \frac{ft}{s} = V$

$\dot{V} = VA$

$\dot{V} = 1.200 \times 10^{-3}\ \frac{ft^3}{s}$

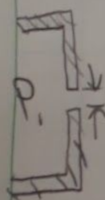
$\dot{m} = \dot{V}\rho$

$\boxed{\dot{m} = 1.205\ \frac{lbm}{s}}$

A7: Flow rate of propane at 35psi gage.

Caleb DesJardins | MET 489A | 11/8/19

Given



$P_2 = 14.7\,psi$ $\quad \rho_{propane} = 1.0046\ lbm/ft^3$

P_1

Find

Flow rate through oriface at $P_1 = 40$ psi gage

assume

- Pressure is constant
- Bernoulli approximation is sufficient

method

Benoulli

Solution

$$A_o = \frac{\pi}{4}\left(\frac{3}{64}\right)^2 = 1.198\times10^{-5}\ ft^2$$

$$P_1 = 40\ psi\ gage = 54.7\ psia = 7876.8\ lb/ft^2$$

$$P_2 = 14.7\ psia = 2116.8\ lb/ft^2$$

$$\frac{P_1}{\rho g} + \frac{\cancel{V_1^2}}{2g}^{\approx 0} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{V^2}{2g} + \cancel{z_2}$$

$$\frac{7876.8}{(1.0046)(32.2)} = \frac{2116.8}{(1.0046)(32.2)} + \frac{V^2}{2(32.2)}$$

$$11396.03 = V^2 \qquad \dot{V} = VA \qquad \dot{m} = \dot{V}\rho$$

$$106.75\ ft/s = V \qquad \dot{V} = 1.279\times10^{-3} \qquad \dot{m} = 1.285\times10^{-3}\ \frac{lbm}{s}$$

A8: Flow rate of propane at 40 psi gage.

Caleb DesJardins | MET489 | 11/22/19

Given

Burner intake geometry: Appendix B 20-0002
20-0003
20-0004

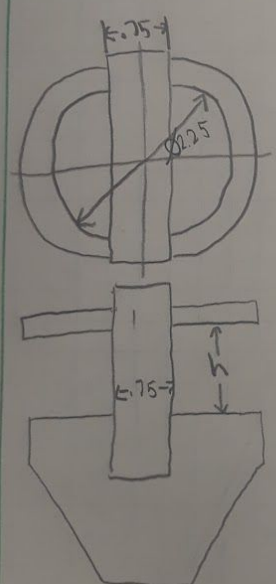
Find

Intake Area as a function of Intake Valve height.

Assume

knurling on intake valve is negligible

Soln.



A = Cylendrical area − Exposed bracket

$$A = 2.25\pi h - 2(.75h)$$

$$\boxed{A = (2.25\pi - 1.5)h}$$

A9: Intake area as a function of valve height

Given

$\dot{m}_{propane} = 6.444 \times 10^{-4} \frac{lbm}{s}$ $\quad$ $V_{propane} = 53.54 \ ft/s$

$R = 15.67$ $\quad$ Area ratio of intake cone $= .222$

$\rho_{air} = .0765 \ lb/ft^3$

Find

required intake area when propane is set to 10psig

Assume/method

Bernoulli approx. is sufficient

$V_{propane} = V_{air}$ at mixture tube

Soln

$\dot{m}_{air} = R \dot{m}_{propane} = .010098$

$$A = \frac{\dot{m}_{air}}{V_{propane}(\text{Area ratio})\rho_{air}}$$

$$\boxed{A = .01105 \ ft^2 = 1.5992 \ in^2}$$

A10: Required intake area for 10psi

Given

$\dot{m}_{propane} = .911 \times 10^{-3} \frac{lbm}{s}$ $V_{propane} = 75.72 \frac{ft}{s}$

$R = 15.67$ Area ratio at intake inlet $= .202$

$\rho_{air} = .0765 \ lb/ft^3$

Find

Required intake area when propane is at 20psig

Assume/method

Bernoulli approx. is sufficient

$V_{propane} = V_{air}$ at mixture tube

Soln.

$\dot{m}_{air} = R \, \dot{m}_{propane}$

$\dot{m}_{air} = .01427 \frac{lbm}{s}$

$$A = \frac{\dot{m}_{air}}{V_{propane}(\text{Area ratio})\rho_{air}}$$

$A = .01111 ft^2 = 1.5998 in^2$

A11: Required intake area for 20psi

Given

$\dot{m}_{propane} = 1.117 \times 10^{-3} \frac{lbm}{s}$ $V_{propane} = 97.74 \, ft/s$

$R = 15.67$ Area ratio of intake cone $= .222$

$\rho_{air} = .0765 \, lb/ft^3$

Find

Required intake area when propane is at 30psig

Assume/method

Bernoulli approx. is sufficient

$V_{propane} = V_{air}$ at mixture tube

Soln

$\dot{m}_{air} = R \, \dot{m}_{propane}$

$= .0175 \frac{lbm}{s}$

$A = \frac{\dot{m}_{air}}{V_{propane} (\text{Area ratio}) \rho_{air}}$

$A = .0112 \, ft^2 = 1.601 \, in^2$

A12: Required intake area for 30psi

Given

$\dot{m}_{propane} = 1.225 \times 10^{-3} \frac{lbm}{s}$ $V_{propane} = 108.75 \frac{ft}{s}$

$R = 15.67$ Air ratio of intake conc = .222

$\rho_{air} = .0765$

Find

Req. intake area when propane is at 40psig

Assume/Method

Bernoulli approx. is sufficient

$V_{propane} = V_{air}$ at mixture tube

Soln

$$\dot{m}_{air} = R\, \dot{m}_{propane}$$

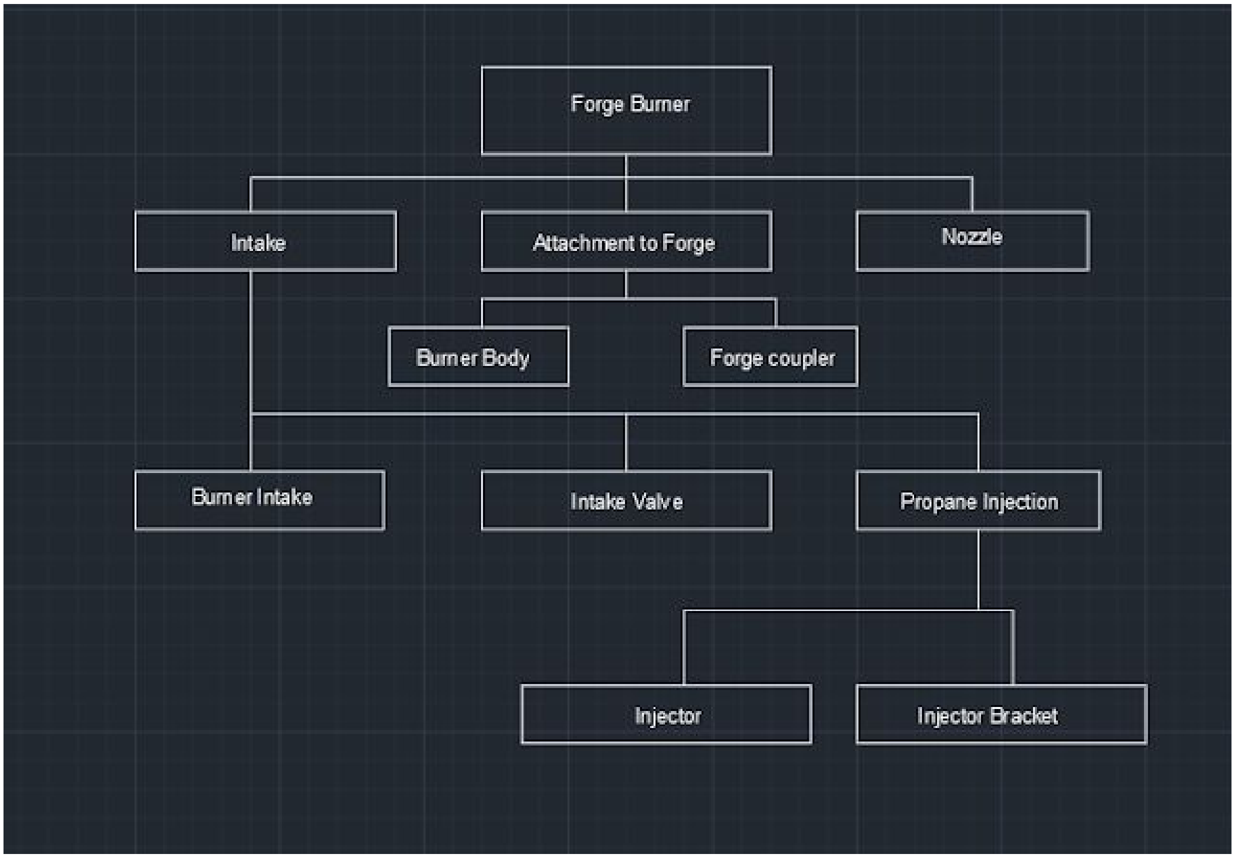
$$= .020199 \text{ lbm/s}$$

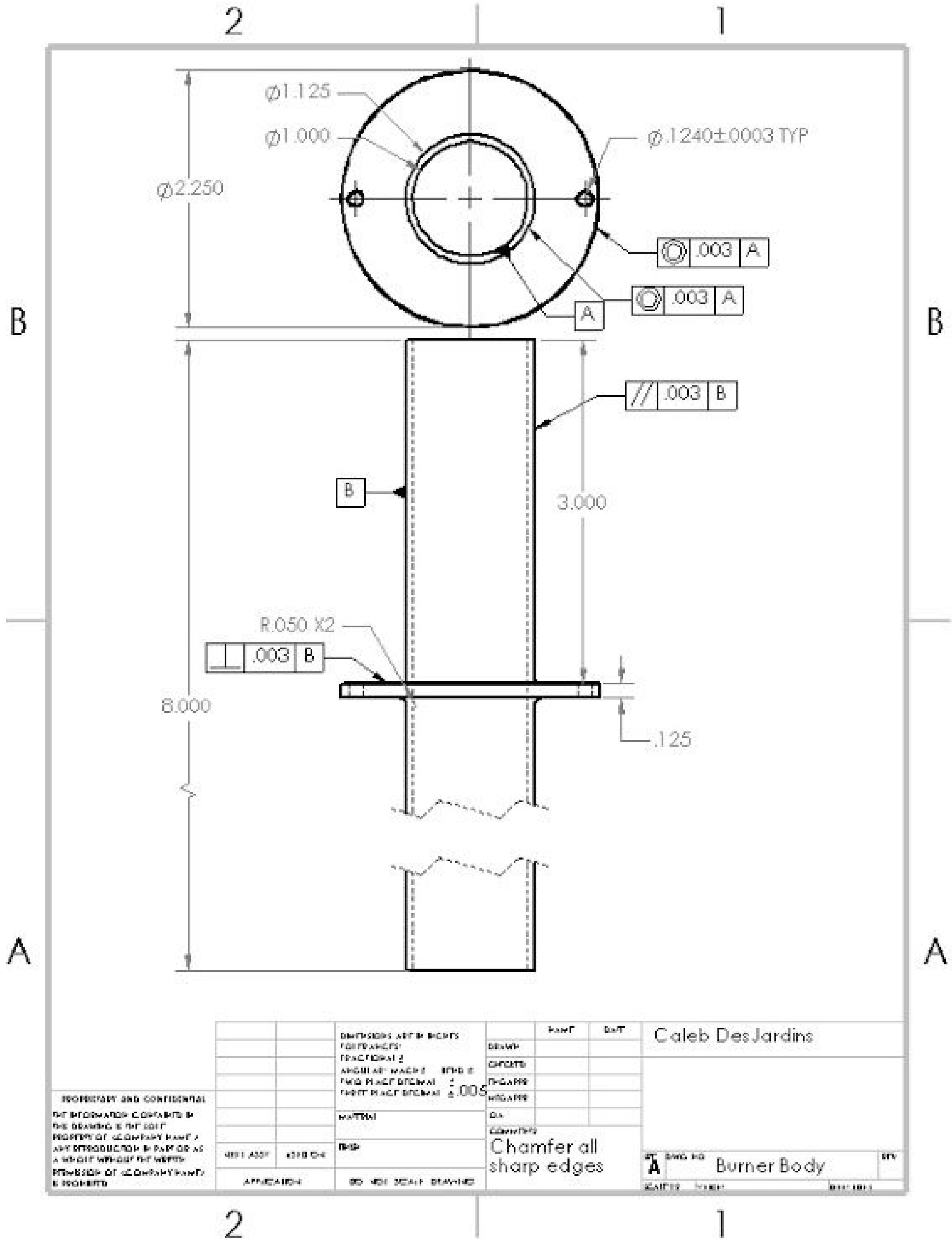
$$A = \frac{\dot{m}_{air}}{V_{propane} (\text{Aria ratio}) \rho_{air}}$$

$$\boxed{A = .01114 \text{ ft}^2 = 1.6036 \text{ in}^2}$$

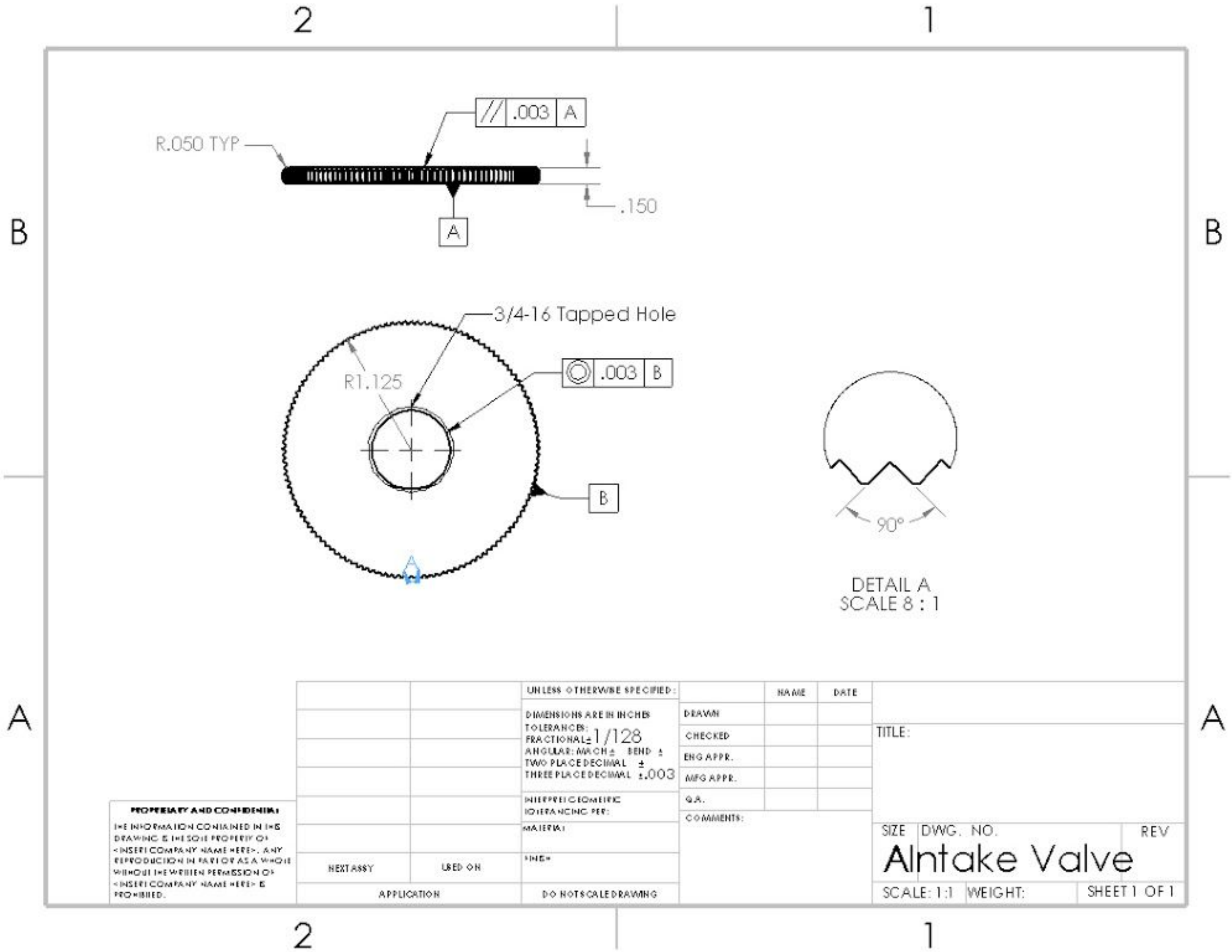
A13: Required intake area for 40psi

Appendix B

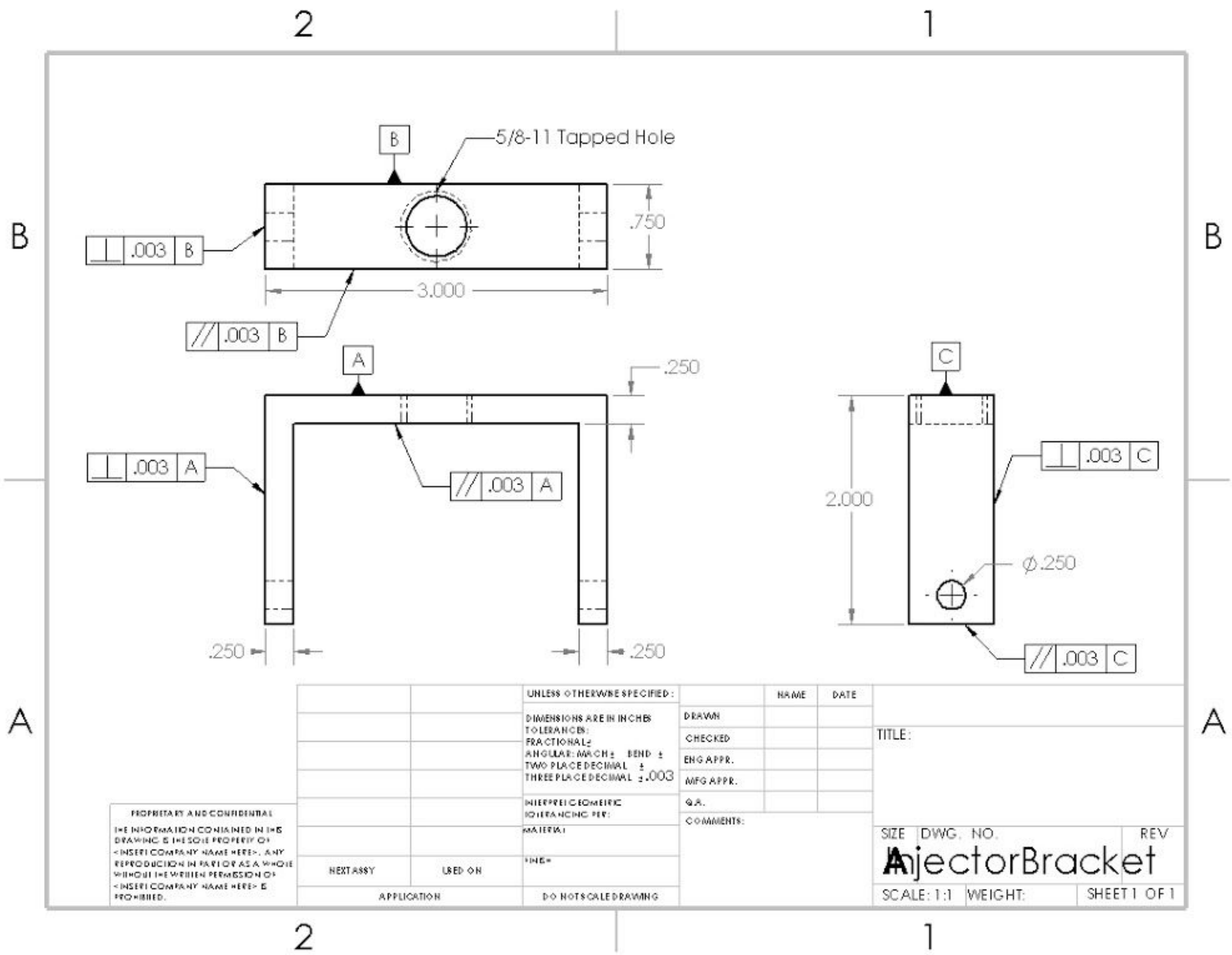

Forge Burner
Intake
Attachment to Forge
Nozzle
Burner Body
Forge coupler
Burner Intake
Intake Valve
Propane Injection
Injector
Injector Bracket



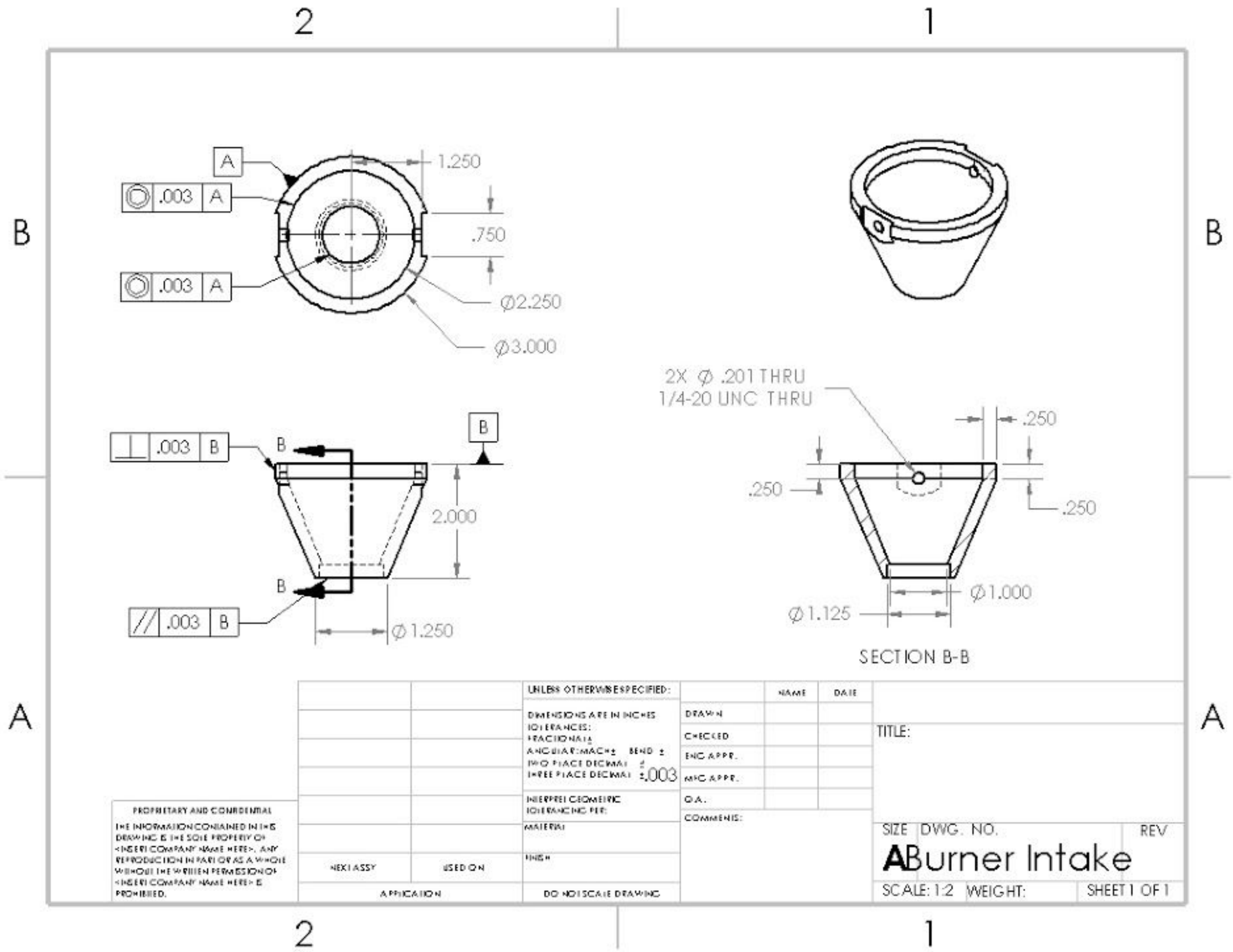
20-0001 Burner Body



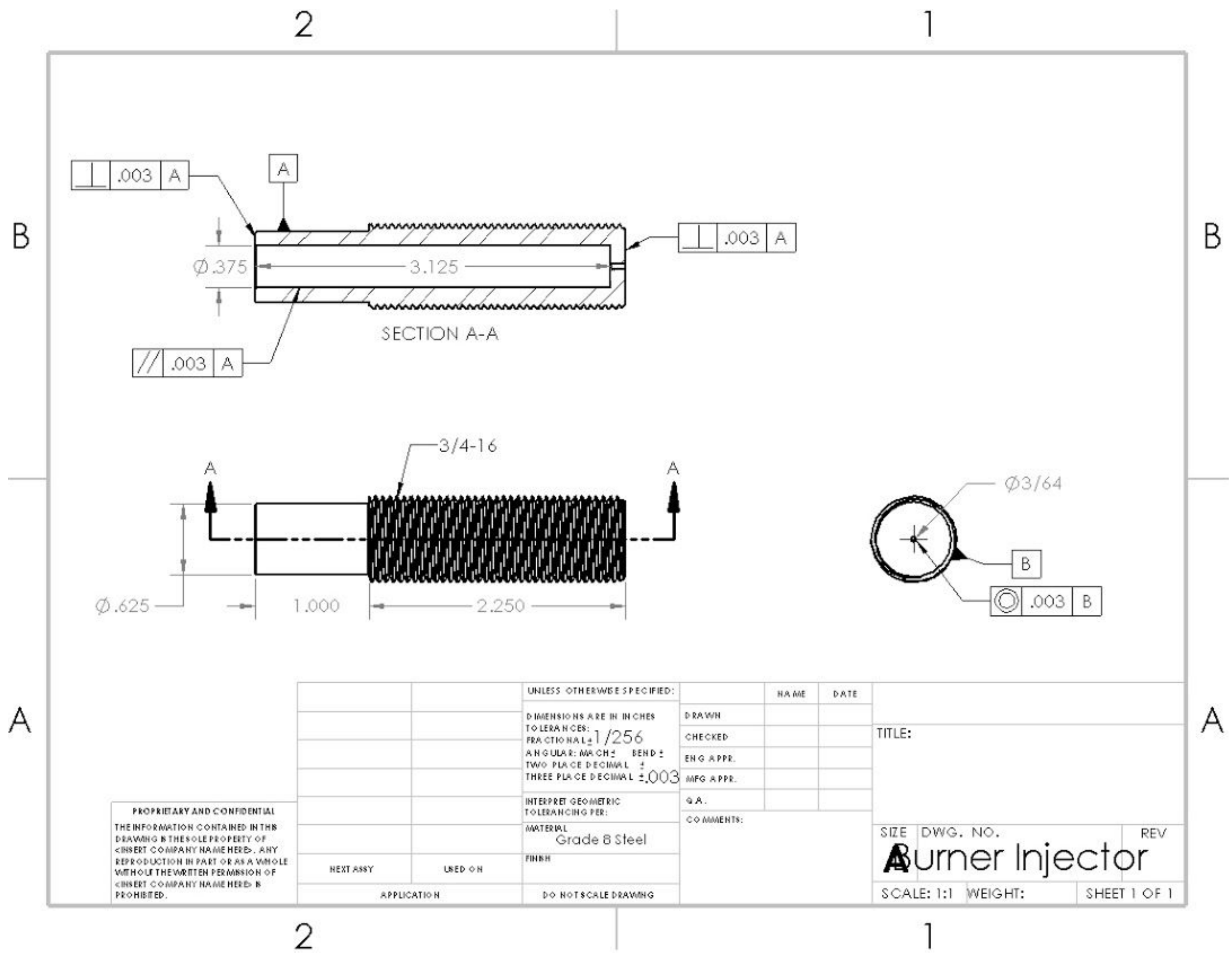
20-0002 Intake Valve



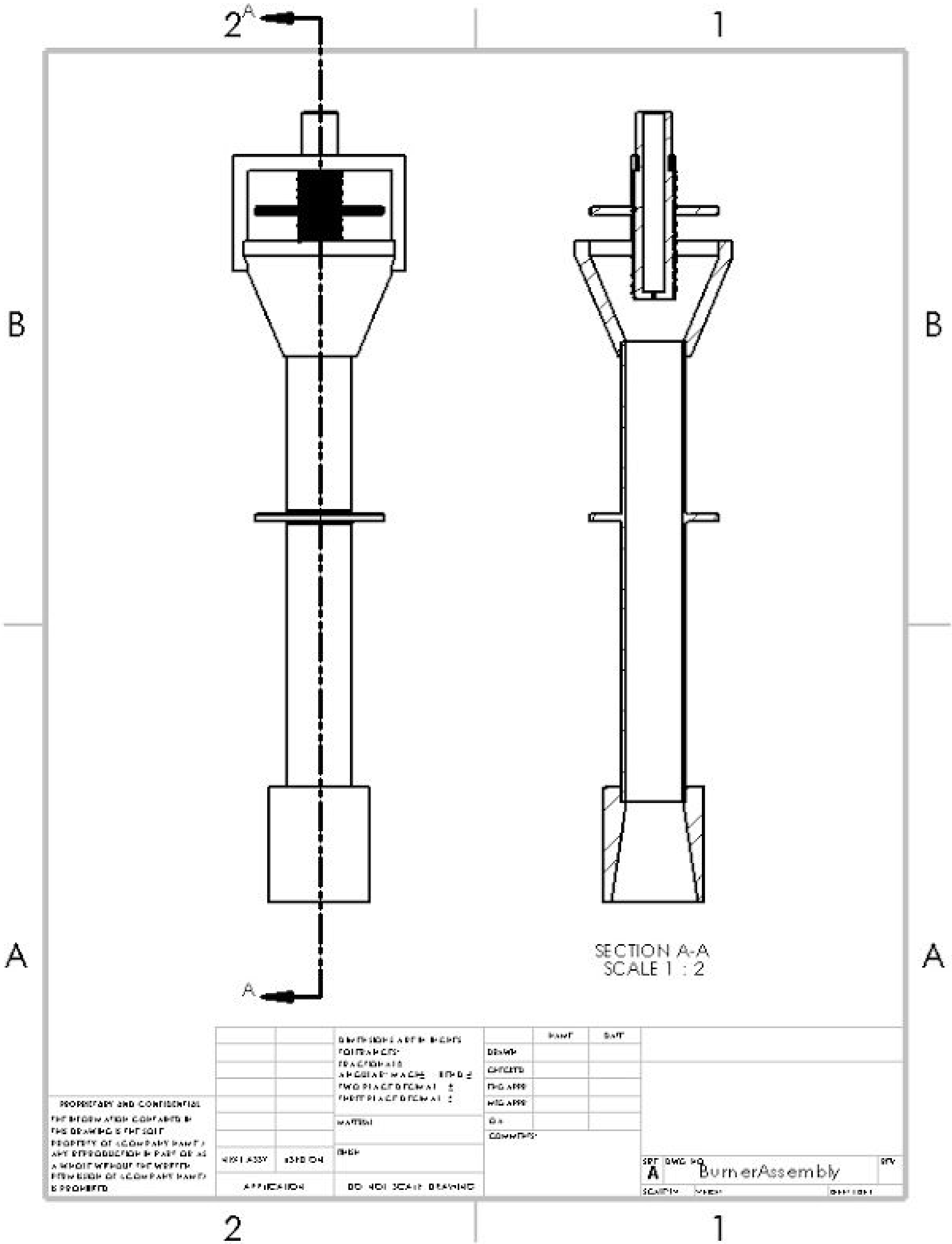
20-0003 Injector Bracket



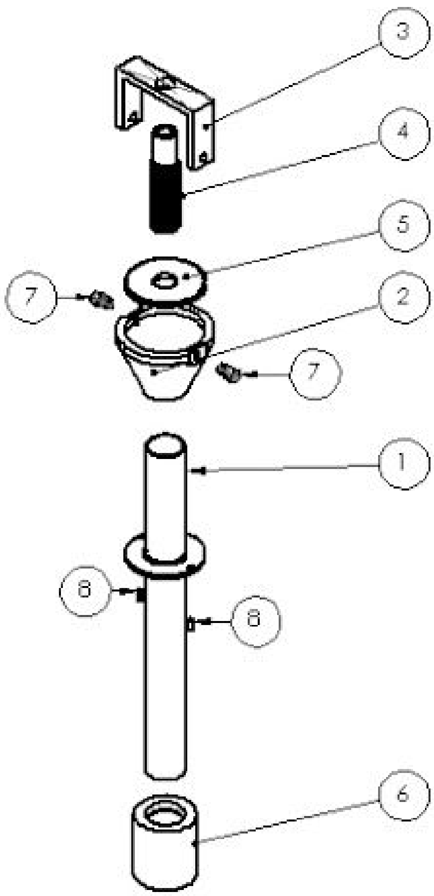
20-0004 Burner Intake



20-0005 Burner Injector



10-0001 Burner Assembly



ITEM NO.	PART NUMBER	QTY.
1	Burner Body	1
2	Burner Intake	1
3	InjectorBracket	1
4	Injector	1
5	Intake Valve	1
6	Burner Nozzle	1
7	1/8 Dowel Pin	2
8	1/4-20 x 3/8 Screw	2

Cale DesJardins

SIZE A DWG. NO. BurnerAssemblyExp

PROPRIETARY AND CONFIDENTIAL

APPLICATION

DO NOT SCALE DRAWING

10-0002 Burner Assembly Exploded View

Appendix C

Parts List:

- Burner body (Machined from material from McMaster-Carr)
- Burner Intake (Machined from material from McMaster-Carr)
- Injector (Machined from material from McMaster-Carr)
- Injector Bracket (Machined from material from McMaster-Carr)
- Intake valve (Machined from material from McMaster-Carr)
- Pipe coupler (owned)
- Pins (owned)
- Brass pipe nipple (Part number 568K153 from McMaster-Carr)
- Brass ball valve (Part number 5754T31 from McMaster-Carr)
- Brass pipe adapter (owned)
- Propane line (owned)
- Propane regulator (owned)
- Propane tank (owned)

Appendix D

Budget:

Item	Source	Price	Quantity	Subtotal	Cost
Steel Cyl. Stock	McMaster-Carr	60.00	1	60.00	64.80
Steel Pipe	McMaster-Carr	4.17	1	4.17	4.50
Steel Plate Stock	McMaster-Carr	1.71	1	1.71	1.85
Steel Injector Stock	McMaster-Carr	26.75	1	26.75	28.89
Brass Pipe Nipple	McMaster-Carr	2.47	1	2.47	2.67
Valve	McMaster-Carr	16.04	1	16.04	17.32
Pipe Adapter	McMaster-Carr	16.20	1	16.20	17.50
				Total:	137.53

Appendix E

Schedule:

DEFINE HOW THE STUDENTS SHOULD INDICATE STARTING EARLY/LATE AND FINISHING EARLY/LATE
X to indicate work

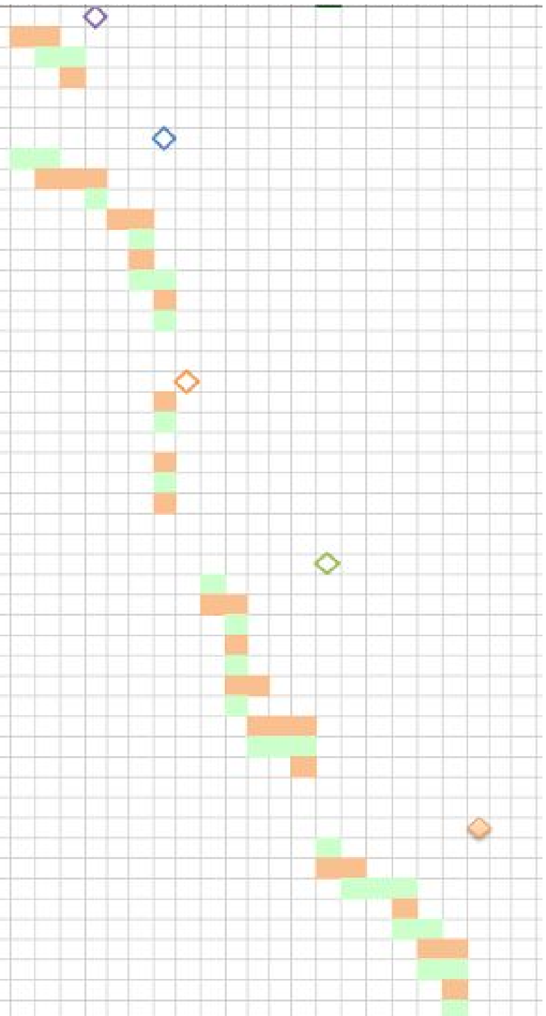
EXAMPLE SCHEDULE FOR SENIOR PROJECT:
NOTE: STUDENTS MUST MAKE THEIR OWN SCHEDULE!!!!!!!!!!!!
PROJECT TITLE: Forge Burner
Principal Investigator.: Caleb DesJardins

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

TASK ID	Description	Duration Est. (hrs)	Actual (hrs)	%Com	S	October				November				Dec		January	February	March	April	May	June
1	Proposal*																				
1a	Outline	3	3							X											
1b	Intro	1	1								X	X									
1c	Methods	1	1								X	X									
1d	Analysis	7	7								X	X	X	X							
1e	Discussion	5	5									X									
1f	Parts and Budget	3	3									X	X								
1g	Drawings	10	10							X	X	X	X								
1h	Schedule	3	3										X	X							
1i	Summary & Appx	4	4										X	X							
	subtotal:	37	37																		
2	Analyses																				
2a	Fluid Mech.=>Geo	10	20							X	X	X	X	X							
2b	Stress Anal=>Geo																				
2c	Power Anal=>Geo																				
2d	Kinematic => Geo																				
2e	Tolerance => Geo	5																			
	subtotal:	15	20																		
3	Documentation																				
3a	Part 1 Burner Body	2	2			X	X														
3b	Part 2 Coupler	1																			
3c	Subassembly Attatchment	0.5	0.5																		
3d	Part 3 Intake valve	1	1					X													
3e	Part 4 Intake	3	2						X												
3f	Part 5 Injector	2	1								X										
3g	Part 6 Injector Bracket	1	1							X											
3h	Subassembly Intake	1	1																		
3i	Part 7 Nozzle	2																			
3j																					
3k																					
3l	ANSIY14.5 Compl	5	4					X	X	X	X	X	X	X							
3m	Make Object Files	2	2					X	X	X	X	X	X	X							
	subtotal:	20.5	14.5																		

4	Proposal Mods		
4a	Project Schedule	5	
4b	Project Part Inv.	6	
4c	Crit Des Review*	5	
	subtotal:	16	0
7	Part Construction		
7a	Make Part Burner Body	2	
7b	Make Part Intake	5	
7c	Make Part Intake Bracket	1	
7d	Make Part Injector	2	
7e	Make Part Intake Valve	2	
7f	Buy Part Ball Valve	0.5	
7g	Make Part Nozzle	4	
7h	Make Part Coupler	2	
7i	Update Website	1	
	subtotal:	19.5	0
9	Device Construct		
9a	Assemble Sub Attatchment	0.2	
9b	Assemble Sub Intake	0.5	
9c			
9d	Assemble Burner	0.5	
9e	Take Dev Pictures	1	
9f	Update Website	0.2	
	subtotal:	2.4	0
10	Device Evaluation		
10a	List Parameters	1	
10b	Design Test&Scope	1	
10c	Obtain resources	1	
10d	Make test sheets	2	
10e	Plan analyses	3	
10f	Instrument Forge	3	
10g	Test Plan*	1	
10h	Perform Evaluation	5	
10i	Take Testing Pics	1	
10h	Update Website	0.5	
	subtotal:	18.5	0
11	495 Deliverables		
11a	Get Report Guide	1	
11b	Make Rep Outline	3	
11c	Write Report	5	
11d	Make Slide Outline	3	
11e	Create Presentation	3	
11f	Make CD Deliv. List	2	
11e	Write 495 CD parts	2	
11f	Update Website	0.5	
11g	Project CD*	2	
	subtotal:	21.5	0
	Total Est. Hours=	150.4	71.5
Labor$	100	15040	

=Total Actual Hrs



Appendix G

Testing Report:

Appendix H

Caleb DesJardins

805 E 5th Ave #5B
Ellensburg, WA
(425) 286-5028
Caleb.Desjardins@cwu.edu

Experience

December 2014 - August 2017
Village Eatery and Tea Company
- Serving/Hosting

August 2017 - September 2018
Starbucks
- High volume customer service

Summer 2019
NorthStar Casteel
- Internship
- Quality control on casting project
- Lead project to organize shipment of casting patterns

Education

2013 - 2018
Cascadia College
- Running Start
- Mechanical Engineering focus
- Associate degree of Science Transfer Track
- Associate degree of Integrated Studies

2018-Present
Central Washington University
- Bachelor's in Mechanical Engineering Technology, June 2020
- Dean's list student
- ASME club member
- Designed and built a propane burner for senior project

Accomplishments

- Running Start student in high school
- Built computers
- Made tutorials on fixing a laptop for iFixit.com
- Designed and built multiple blacksmithing forges, propane burners, and other blacksmithing equipment
- Certified SolidWorks associate

Hobbies

- Blacksmithing/Metal art
- Fixing/building cars
- Strength training

Skills

- Autodidactic in many disciplines.
- Motivated and hardworking individual. Frequently sought out by employers and co-workers for shift coverage because of reputation for good work ethic.
- Can complete tasks in a timely manner. Able to solve problems logically under pressure.
- Experienced and skilled in solving practical/mechanical problems.

Summary

Talented in understanding mechanical things and solving mechanical problems from a young age. Ability to self-teach in any skill to pursue interests and hobbies. History of being a reliable employee with exceptional work ethic.

Appendix J

Engineering Technologies, Safety, and Construction Department

JOB HAZARD ANALYSIS
{Insert description of work task here}

Prepared by: Caleb DesJardins	Reviewed by: Approved by:

Location of Task:	CWU Machine lab
Required Equipment / Training for Task:	Manual lathe, manual milling machine, band saw, and PPE/ ETSC safety training
Reference Materials as appropriate:	https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic https://ehs.unc.edu/workplace-safety/jsa/

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☒	☐	☒	☒	☐
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Turning features on the Injector, Intake, Burner Body, and nozzle.	• Entanglement in unguarded moving parts • Injury due to improper machine operations • Tools and objects can fall and be propelled at the operator. • Hand/finger contusion due to tool slippage from securing chuck or collet • Bodily injury and/or damage to workpiece from incorrect feed rate • Dull tools and improper height lead to bad surface finishes, out of tolerance parts and potentially a hazardous situation. • Hand/finger contusion due to tool slippage from tightening chuck jaws or collet • Injury to exposed body parts at points of operation	• Inspect guards prior to work. • Locate and ensure you are familiar with all machine operations and controls. • Remove unsecured tools and objects from the lathe. • Use correct tool to secure chuck or collet • Refer to operations manual and set proper lathe speed • Use correct and properly sharpened tool • Use correct tool to secure chuck jaws and collet to workpiece • Keep body parts and clothes away from the point of operation

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Revision Date: February 2018 Revised MET489 October 2018

		• Eye injury from debris	• Wear PPE during operation
	Milling Injector bracket and flats on the Injector	• Injury to hands from milling blades • Hearing damage from machine noise • Possible eye injury from wire stitches thrown out by milling blade • Crushing finger hazard from book clamp	• Never disconnect safety shields from milling blades • Wear hearing protection, such as ear plugs, if operating machine for periods extending more than 10 minutes. • Wear safety glasses during operation. • Do not hold book at spine when activating book clamp. Hold book at the face.
	Cutting material to size on bandsaw before machining	• Cut/Puncture/Scrape Hazard • Pinch Hazards	• Keep hands away from pinch points and blade