Final Project Report

SENIOR CAPSTONE DESIGN

Justin Davenport, James Davis, Blake Merritt, Zaeem Siddiqui, William Urwiller
Faculty Advisor: Dr. Alwathiqbellah Ibrahim
VISIONARY ENGINEERING | UNIVERSITY OF TEXAS AT TYLER

Acknowledgements

We would like to thank the staff at the University of Texas at Tyler for their intellectual contribution to our design project. We would also like to thank the sponsors and support from those who work at Trane.

Specific individuals that we would like to personally thank are:

Mr. John Baily – Trane Furnace Team Manager

Mr. Trent Clark – Trane Test Engineer

Dr. Alwathiqbellah Ibrahim – Faculty Advisor

Dr. Nael Barakat – Mechanical Engineering Department Chair

Dr. Nelson Fumo – Faculty Design Consultant

Thank you to all of those who have been involved for your support and advice during the development of this senior design project.

Executive Summary

The content of this report covers the design and development of automated inlet, outlet, and iris shutter for furnace testing in Trane's Gas Lab. The automated systems would be used to replace the current manual testing operations with the objective of reducing test cycle time and increasing test data quality. This report includes documents such as design details programming logic, design simulations, testing results, project budget, and production schematics. The control methods and general functions for each of the furnace shutters were determined through coordination with Trane engineers after which software programs including SolidWorks, LabVIEW, and MATLAB Simulink were used to model, simulate, and validate the designs. Detailed schematics and programming documentation can be found in the appendices.

This report shows that the prototyped shutters work successfully as proof-of-concept devices that only lack additional calibration and tuning to be viable for regular use. Due to the unforeseen interference resulting from the COVID-19 pandemic, testing and refinement was not able to be completed the degree originally anticipated. The design team recommends that each of the shutters have their respective programs further refined for practical implementation in furnace testing.

Table of Contents

Background…… 1

Requirements and Specifications…… 2

Constraints……. 4

Applicable Standards…… 5

Final Design…… 6

Final System Diagrams…….……. 9

Programming Design…….…….. 11

Final Design Calculations……... 16

Risks and Failure Mode Analysis…… 17

Testing Results…… 18

Simulation Results…… 21

Furnace Simulation…….. 21

Finite Element Analysis…… 23

Budget and Bill of Materials…….. 27

Economic Feasibility…….. 28

Programming Flow Charts…… 29

Final Acceptance Criteria…….. 32

Discussion…….. 34

Recommendation……... 37

Conclusion……. 38

References……. 40

Appendices

Appendix A……...A1

Appendix B……...A2

Appendix C……...A4

Appendix D……...A8

Appendix E…….A12

Appendix F…… A15

Appendix G…… A39

Appendix H…… A48

Appendix I……..A49

Appendix J……..A50

Background

During a design project spanning two semesters, the senior design team “Visionary Engineering” worked with the gas lab at Trane, a leading manufacturer of high end HVAC products, in Tyler, TX to produce prototypes of automated shutters to assist in furnace testing. After the development phase of a gas furnace, the furnace goes through extensive testing procedures to prove safety and reliability. In relation to these procedures, Trane commissioned the senior design team to automate two of the testing procedures that are conducted.

The first test is the ANSI 5.26.1 “Allowable Air” test. During the allowable air test, the furnace must maintain a rise of one-degree Fahrenheit per one minute of time by closing the inlet shutter incrementally. This process is currently manual, which requires a technician to read the outlet air temperature and adjust the shutter solely based on personal intuition and experience. This method is inefficient since it is not uncommon for an operator’s error to require the test to be run again, with the result of these mistakes being unnecessary downtime and decreased productivity. An automated process would increase efficiency and data quality by completing the test accurately every time.

The second test performed is the ANSI 5.20 “Blocked Vent Shutoff” test. During the blocked vent shutoff test, an iris shutter restricts gas flow in the flue pipe incrementally over time. Restricting gas flow increases backpressure within the furnace, causing a safety switch to trip and shut down the furnace. Like the Allowable Air test, this process is also manual. A technician performs the test by closing the iris by arbitrarily timed sequences, using handwritten marks as a guide to determine the percent closure of the iris. An automated process would increase accuracy of the percentage closed yielding more accurate test data.

Requirements and Specifications

Below are tables that list the requirements and specifications for each shutter.

Inlet Shutter

Table 1. Inlet Shutter Requirements and Specifications.

Inlet Shutter		
Requirement	Validation Method	Metric
Slotted holes must comply with ASNI Standard 5.26.1	Use of a caliper to verify correct dimensions are met.	(in/mm)
Overall dimensions must be 28" x 28"	Use of tape measure to verify dimensions met.	(in)
Automate opening and closing such that the exiting air temperature rises no more than 1 °F per minute.	Test a mockup of system and log data to confirm proper temperature control.	(°F, min, in)
Weigh less than 10 lbs.	Weigh apparatus.	(lbs.)
Neutral color	Visual inspection	N/A
Low noise	Auditory inspection	(dB)

Outlet Shutter

Table 2. Outlet Shutter Requirements and Specifications.

Outlet Shutter		
Requirement	Validation Method	Metric
Automation of horizontal movement to adjust static pressure.	Must move doors to obtain desired static pressure during testing.	(in. w.c.)
Default horizontal opening is adjustable to start at positions from 14 to 24 in.	Opening will be measured with a tape.	(in)
Vertical movement is adjustable to fit duct ranging 6 to 18 in. heights.	Movement will be manually inspected.	(in)
Weigh less than 10 lbs.	Weigh apparatus.	(lbs.)
Neutral color	Visual inspection	N/A
Low noise	Auditory inspection	(dB)

Iris Shutter

Table 3. Iris Shutter Requirements and Specifications

Iris Shutter		
Requirement	Validation Method	Metric
Maintain a symmetrical, circular shape while closing.	Visually inspect and measure iris shutter as it closes.	(in)
Must decrease the orifice area by a time and position schedule.	Measure the open area of the shutter and time in between adjustments.	(in, min)
Must tolerate temperatures between 300 - 500 °F.	Verify materials can withstand temperatures.	(°F)
Weigh less than 10 lbs.	Weigh apparatus.	(lbs.)
Neutral color	Visual inspection	N/A
Low noise	Auditory inspection	(dB)

Constraints

Below is a table that list the various constraints that the team has experienced in the designing of the automation systems.

Table 4. Project Development Constraints.

Constraints	
Type	Details
Time	The three shutters must be completed by April 2020.
Coordination	The development must work around restrictions imposed by COVID-19.
Funding	The project is limited to a budget of $4,000.
Production	Structural components will be fabricated by the Trane Model Shop and Tool Room.
Material	The shutters must be made from metal for durability and heat resistance.
Weight	The shutters must remain below weight limits for safety and mobility.
Power	All shutters must run from 24-volt DC power supplies.
Software	Control software will require communication from LabVIEW to Arduino.

Applicable Standards

Inlet Shutter

ANSI 5.26 – Allowable Air Temperatures

The furnace air inlet shall be progressively blocked with an air restrictor (inlet shutter), air restrictor for allowable air temperature tests, at a rate that shall produce a warm air outlet temperature rise not in excess of 5°F (3 °C) per minute and at a rate of 1°F (0.5 °C) per minute for the final 10°F (5.5 °C) temperature rise.

Outlet Shutter

ANSI 4.26.10 – Operation Markings

The external (outlet) static pressure of furnaces in testing operation should reside between the minimum and maximum allowed for the given furnace setting.

Iris Shutter

ANSI 5.21 – Burner Blocked Inlet

This test references ANSI 4.14.2 which states that each furnace having a draft hood shall be equipped with a blocked vent shutoff system designed to shut off main burner gas in the event the venting system is totally blocked. The blocked vent shutoff system shall be of the single use or manual reset type.

Final Design

The following figures show the final designs of the inlet, outlet, and iris shutters, respectively.

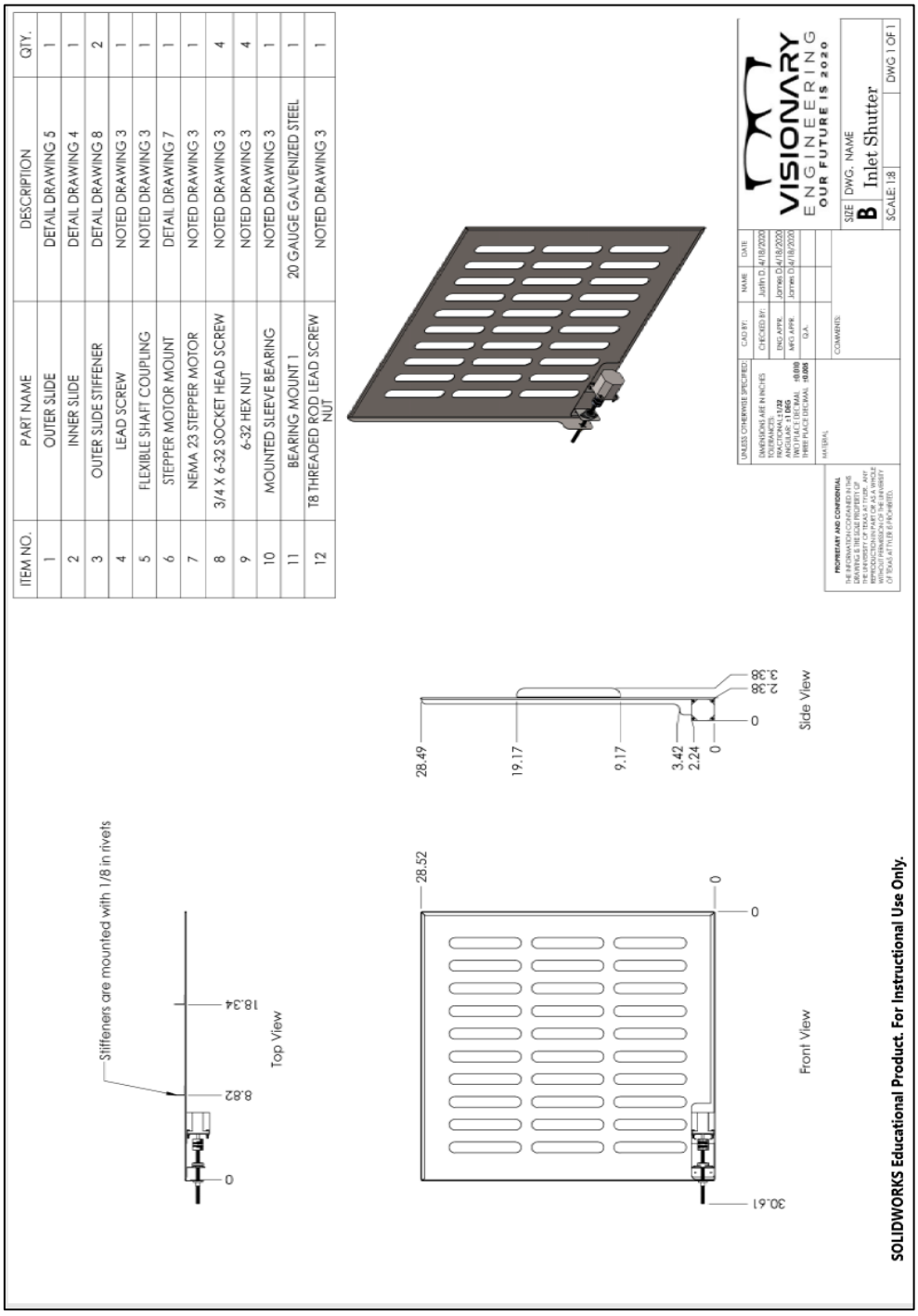


Figure 1. Final Design of the Inlet Shutter.

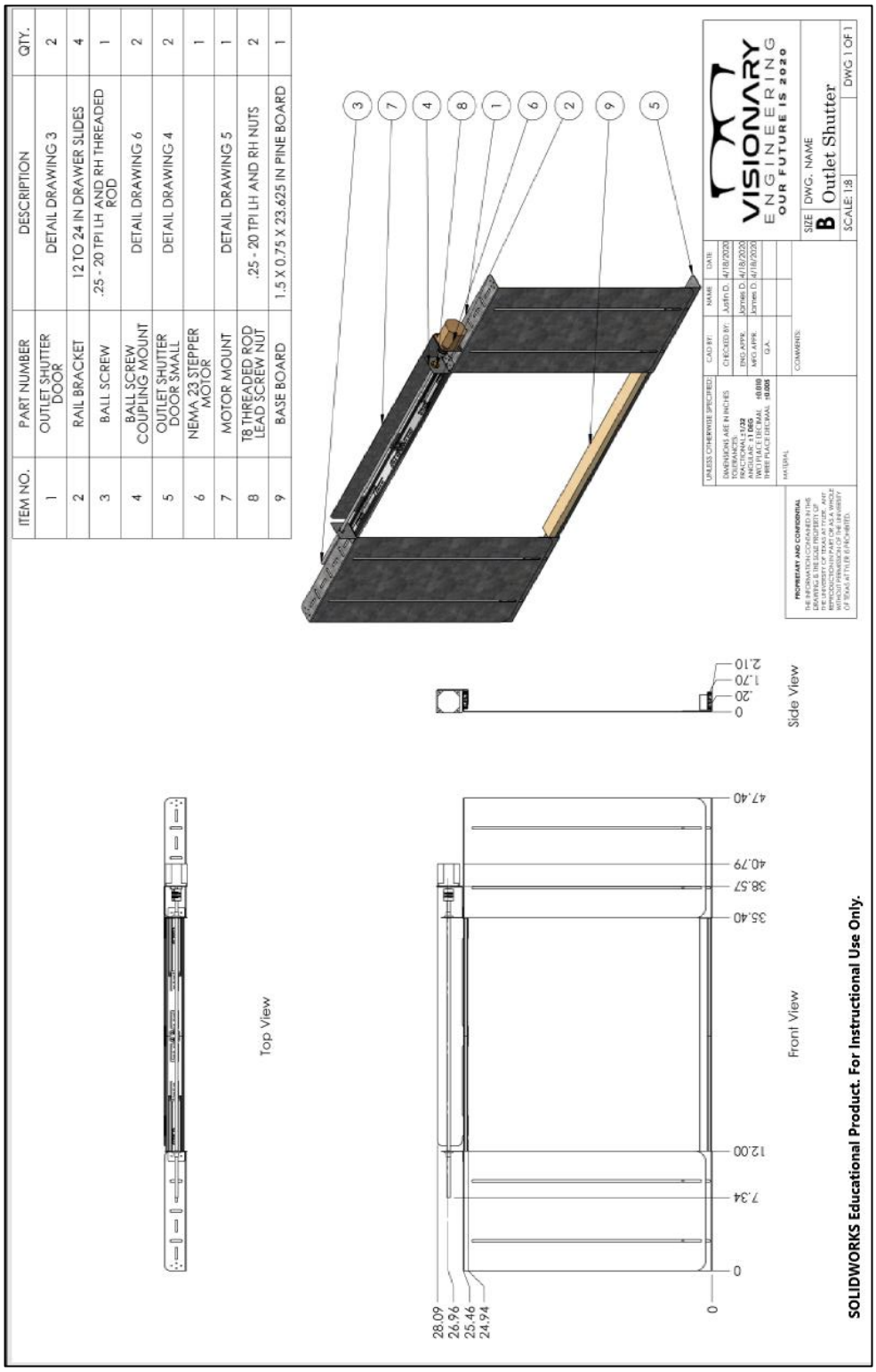


Figure 2. Final Design of the Outlet Shutter.

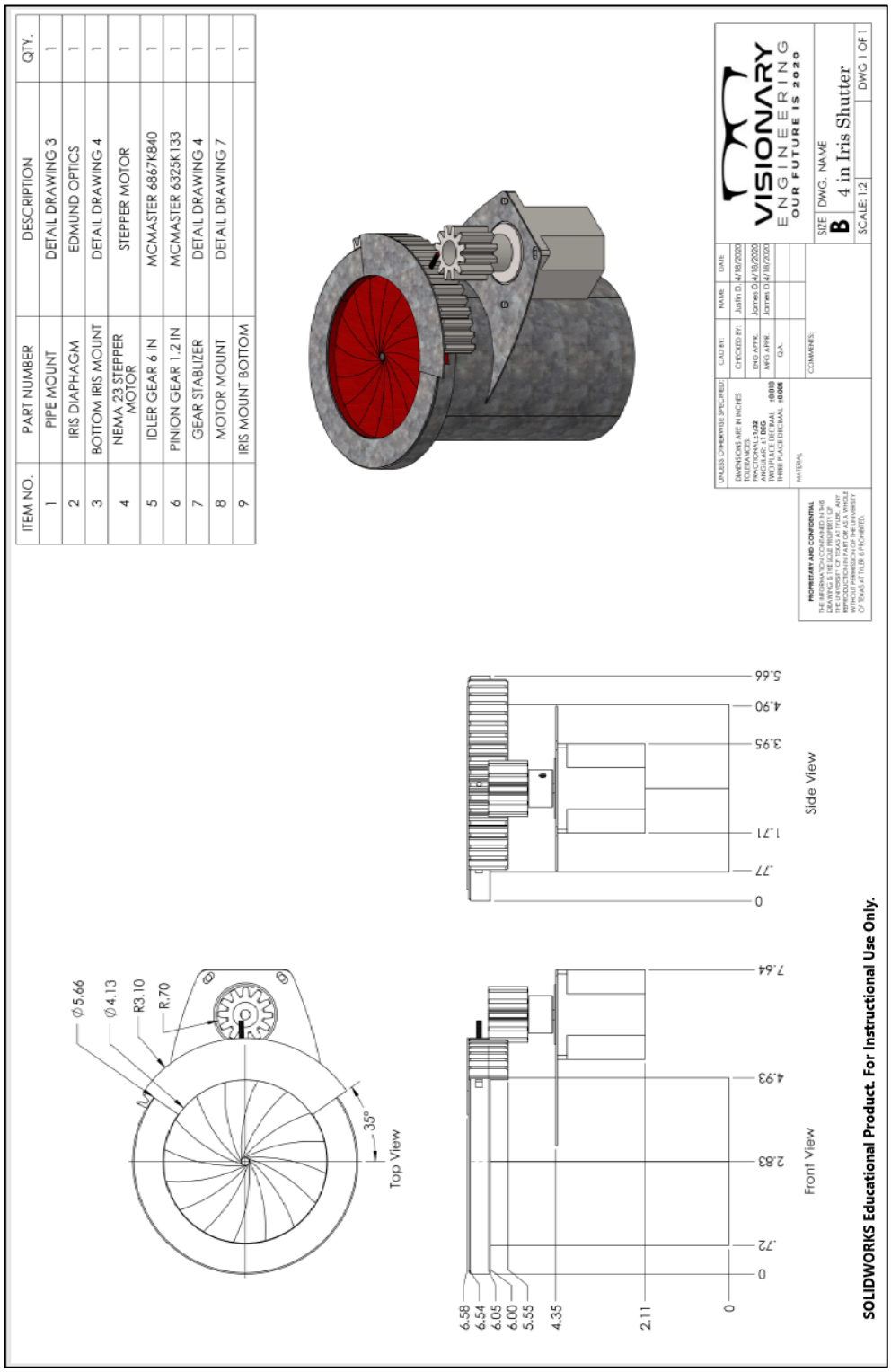


Figure 3. Final Design for 4-in. Iris Shutter.

Final System Diagrams

The following two figures below show the finished shutters mounted onto the furnace in their respective locations.

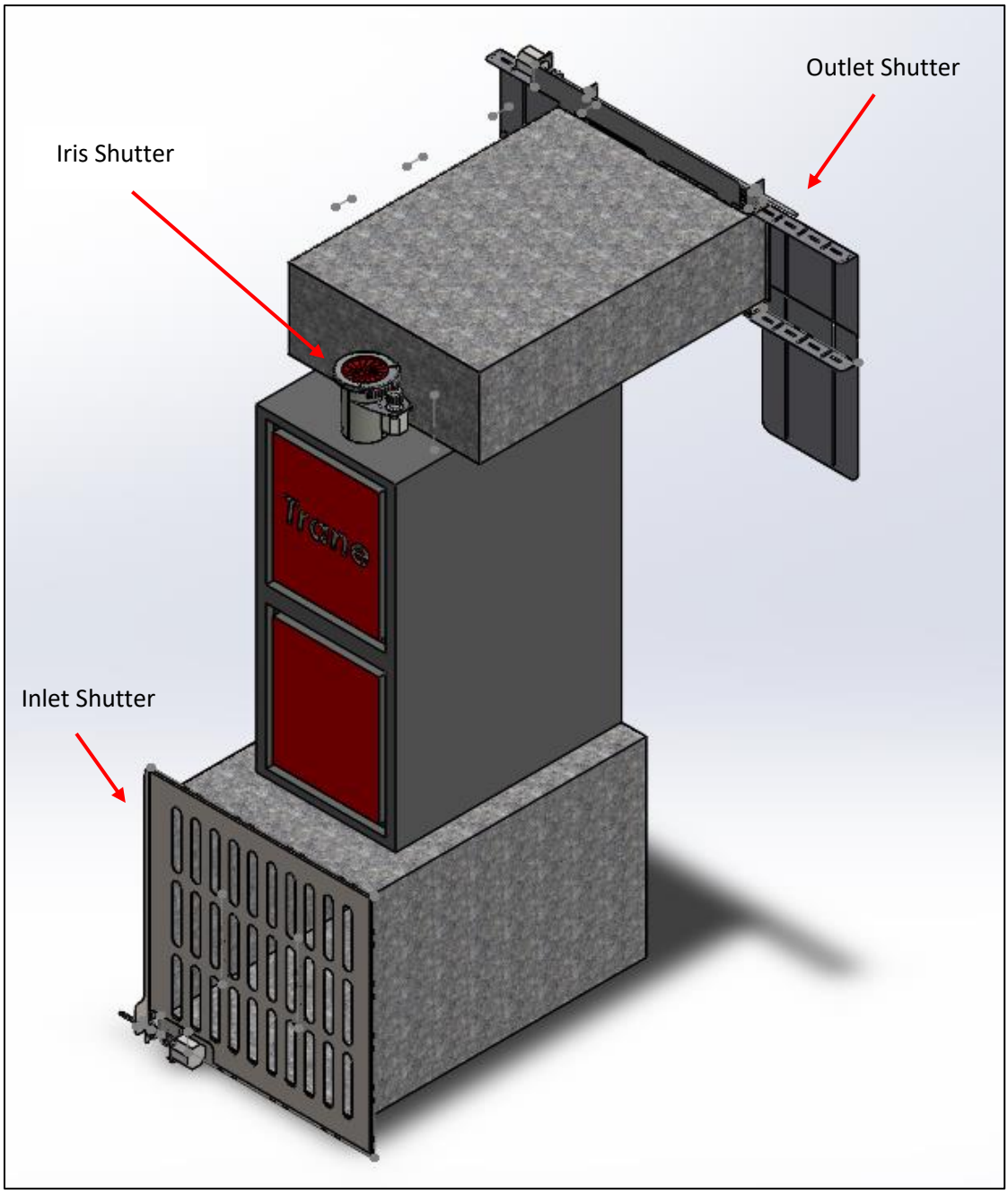


Figure 4. Location of Shutters on Furnace Test Stand.

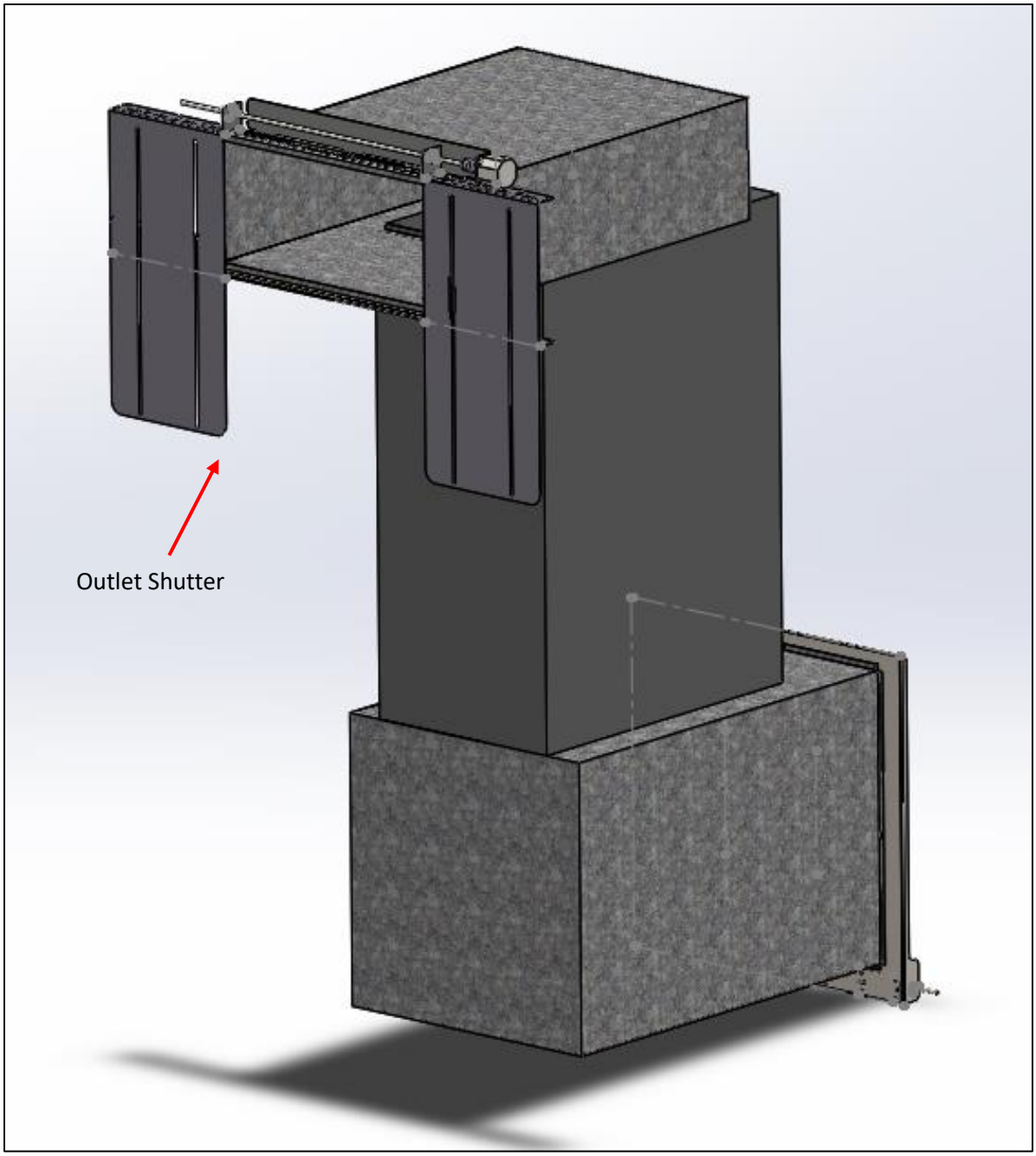


Figure 5. Rear View of Test Stand.

Programming Design

The LabVIEW control software interfaces with the Arduino control board using serial communication through USB. The standard operation of this communication is the same for each shutter with only minor alterations depending on the design variant. In general, a string of data values separated by commas is first compiled in LabVIEW. This string is then sent to the Arduino board where the program parses the string, saving the data points to their appropriate variables for use in the program. The method used for reading this string format was modified from code examples given in an Arduino forum post while the LabVIEW compilation methods and code alterations were developed solely by the design team [1].

LabVIEW

As mentioned earlier, the software platform used for gathering and sorting data and controlling each shutter is LabVIEW. Once the command is made within the Virtual Instrument (VI), LabVIEW must compile the information it has gathered and transmit it to Arduino in a format that the control board can decipher to appropriately adjust the motor. The VIs for all three types of shutter utilize the same basic string format, which is as follows:

<INTEGER,FLOAT(1),FLOAT(2), … ,FLOAT(N-1),FLOAT(N)>

The first character in the string is always a less-than symbol (<) which is used to signal the start of the string. Similarly, the greater-than symbol (>) serves as the termination character, signaling the string's conclusion. The string then contains an integer value followed by a varying number of float values (numbers with decimals), each separated by commas. The integer serves

an identifier for the float's data type. For example, a string sent to Arduino from the inlet shutter VI could be "<1,122.56>." In this case, the integer value 1 indicates that following float value of 122.56 is the measured temperature at the furnace's outlet.

To create the string that is read by Arduino, several different string elements are combined with the measured data into one string using the Concatenate Strings Function, circled in red in Figure 6 below. The Concatenate Strings function allows for as many elements as required to be parsed together into one string, reading from top to bottom.

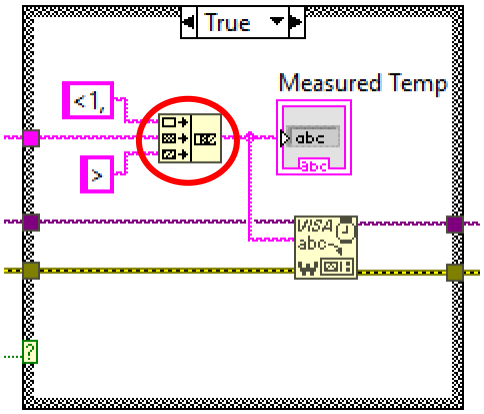


Figure 6. String assembly with the Concatenate Strings Function circled.

In the example shown in Figure 1, the constant "<1," forms the beginning of the string. The second segment of data input in this case is the float value being measured or assigned. As in the previous example, this would be "122.56". Finally, the constant ">" forms the end of the string. When the Boolean operator controlling this event (such as a button within the VI) signals true, the string "<1,122.56>" will be transmitted to Arduino via serial communication.

Arduino

Arduino is used as the platform for each shutter's motor control software. As such, it breaks apart the string sent to it by LabVIEW as that it may then interpret the data gathered. Like the LabVIEW VIs, the Arduino communication programming for all three shutters follow a similar structure. In general, once a string is received its float values are assigned to their proper Arduino variables based on the string's integer identifier.

First, serial communication is initiated within the Arduino program. Then, once it receives a string from LabVIEW it recognizes its start character and begins to break it into its different components. The first value after the start character would be assigned to the variable titled "integerFromPC." Then, reading the comma following the first value, the program would move to the second value and assign it to the variable entitled "floatFromPC." Finally, upon reading the termination character the program would cease parsing and wait for the next string.

Using the previous string example of "<1,122.56>", the variables would be as is listed below:

integerFromPC = 1 floatFromPC = 122.56

These variables are then used in if statements to store them for use by the program logic. For example, "if integerFromPC == 1, measuredTemp = floatFromPC" would be used to store the current temperature of the furnace while "if integerFromPC == 2, startTemp = floatFromPC" would be used to store the temperature of the furnace at the start of the test. Specific details for each shutter are also outlined in their respective sections below.

Inlet Shutter

There are three different integer identifiers, 1, 2, and 3, that are used in the LabVIEW VI for the inlet shutter. These integers correspond to the measured temperature, the starting temperature, and the cancel command, respectively. The measured temperature is the exiting air temperature of the furnace measured by the Data Acquisition (DAQ) system and the starting temperature is the initial temperature used for Blocked Vent testing. The Arduino will use the starting temperature as the baseline for increasing the target temperature over time, as dictated by the test. The cancel command is an integer identifier used to signal the Arduino to halt testing. Each command is tied to its own respective button within the VI. Figures for the LabVIEW VI and the Arduino code controlling the inlet shutter are listed in Appendix H.

Outlet Shutter

There are three different integer identifiers, 1, 2, and 3, that are used in the LabVIEW VI for the outlet shutter. Like the inlet shutter, these integers correspond to the measured static pressure, the desired static pressure, and the cancel command, respectively. Each command is tied to its own respective button within the VI. Figures for the LabVIEW VI and the Arduino code controlling the outlet shutter are also listed in Appendix H.

Iris Shutter

The iris shutter has two different commands: a start command, which sends the time and percent closure schedule to Arduino, and the cancel command. The start command uses two

integer identifiers to send the testing schedule from the table in LabVIEW to Arduino. These consist of a string containing all of the time data points labeled “1” and, after a one second delay, a string containing all of the percent closure values, designated “2.” Using the integer identifiers, Arduino stores these points in their respective variables and proceeds to run the timed sequence that was ordered. Like the inlet and outlet shutters, integer identifier “3” is used to signal the Arduino to immediately halt the test sequence and return to the home position. These two commands are controlled by their respective buttons within the VI. Figures for the iris shutter’s LabVIEW VI and the Arduino code are listed in Appendix H.

Final Design Calculations

The main concern for calculable components was the motor strength. In initial measurements it was determined that the amount of linear force required was 10 lbs. while the amount of torque needed was 96 oz-in. Equation 1 was used to calculate the linear force the motor could output using the threaded rod, where F_l is linear force, T is the torque of the motor, and L is the pitch of the thread, as seen below.

$$F_l = \frac{2\pi(T)}{L} \quad (1)$$

Using Equation 1, it was found that the selected motor was capable of outputting 891 lbs. of linear force, meeting the 10 lbs. requirement.

It was also known that the amount of torque required of the motor would be 96 oz-in. Thus Equation 2 was used to calculate the amount of torque that could be supplied, with T_m being the torque of the motor, F_p being the tangential force of the motor, and R_p being the radius of the pinion gear, as shown below.

$$T_m = F_p(R_p) \quad (2)$$

Using this equation, it was found that the selected motor would be capable of providing 178.5 oz-in. of torque, much more than the necessary 96 oz-in.

Risk and Failure Mode Analysis

Risk and failure mode analysis was completed on all three shutters and the electrical components associated with their operations. A project risk register was used to run the analysis and compare the risks to the shutter's operation. The project risk register can be found in Appendix E.

The register employs the interaction of the impact score and the probability that the risk could happen. It then multiplies these two parts to get an overall score. This overall score is used to understand the risk that has the potential to cause the most harm to the shutters. The impact score is rated from zero to one, and this represents how much damage the risk will cause to the shutters. This number is generated from a consensus of the group. Similarly, probability is generated from zero to one based on a consensus about the probability the risk can happen.

After the analysis, the inlet shutters highest risk was the threaded rod brackets breaking that mount to the inner slide and the bearing. Similarly, the outlet shutter's highest risk was the mounting brackets for the threaded rods and bearings. The iris shutter's highest risk was the deflection of the motor mount. The deflection may result in loss of gear contact. Lastly, the electrical components were assessed. Wire disconnections were the highest risk to the shutter.

Testing Results

Inlet Shutter

Setup:

- DAQ system to read outlet temperature.
- LabView setup to simulate Trane facilities by reading data and sending outputs.
- Completed inlet Shutter with controls.

Proposed Test: Induce a temperature change to the thermocouple and compare the shutter movement to data that the team gathered earlier in the project.

Satisfactory Result: The system makes shutter adjustments that match earlier data found by the team.

Inlet Shutter Test Results

Testing of the inlet shutter was able to be conducted on two separate occasions before restrictions imposed to combat the COVID-19 pandemic forced testing to halt. An allowable Air test conducted by an experienced lab technician was used as the control by which to compare the shutter's results in outlet temperature regulation. It was found in these beginning experiments that the shutter could raise the outlet temperature in the appropriate fashion. However, the temperature was prone to large oscillations as it trended upwards. For more detailed information regarding the design and execution of these experiments, please refer to Appendix J.

Outlet Shutter

Setup:

- DAQ system to read analog voltage change associated with static pressure change.
- LabView setup to simulate Trane facilities by reading data and sending outputs.
- Completed shutter with controls.

Proposed Test: Test the device on a furnace set to blow only room temperature air through the outlet duct and have system change shutter position to control the static pressure.

Satisfactory Result: The outlet shutter maneuvers itself into position to maintain the desired outlet static pressure.

Outlet Shutter Test Results

Because of restrictions enforced due to the COVID-19 pandemic, a prototype of the outlet shutter was not able to be tested. The physical prototype and its software were completed, however.

Iris Shutter

Setup:

- DAQ system to read analog voltage change associated with pressure change.
- LabView setup to simulate Trane facilities by reading data and sending outputs.
- Completed shutter with controls.

Proposed Test: From LabView input desired closing percentage at desired time. Test to see if the shutter makes movements that reflects the inputs. Measure each position and time how long it takes to reach desired position.

Satisfactory Result: The iris shutter will have measured/timed movements that line up precisely with desired values.

Iris Shutter Test Results

Because of restrictions enforced due to the COVID-19 pandemic, a prototype of the iris shutter was not able to be tested. The physical prototype and its software were completed, however.

Simulation Results

Furnace Simulations

The simulations performed focused on the inlet shutter because it has a continuous feedback model operating throughout the allowable air (AA) test as opposed to the outlet or iris shutter, which do not. Figure 7 incorporates two graphs side by side which were both generated in MATLAB and modeled after data captured during experimental testing in the Trane Gas Lab. Graph 1 simulates a constant temperature rise of 1 degree F a minute (which is the goal of an automated AA test) and Graph 2 shows the inlet shutter position over time. The shutter position changes in order to maintain a temperature rise of 1 degree per minute. For example, if the temperature is rising too slowly compared to the ramp function, the shutter closes to decrease convection cooling. Likewise, if the temperature is rising faster than 1 degree per minute, the shutter opens to increase convection cooling.

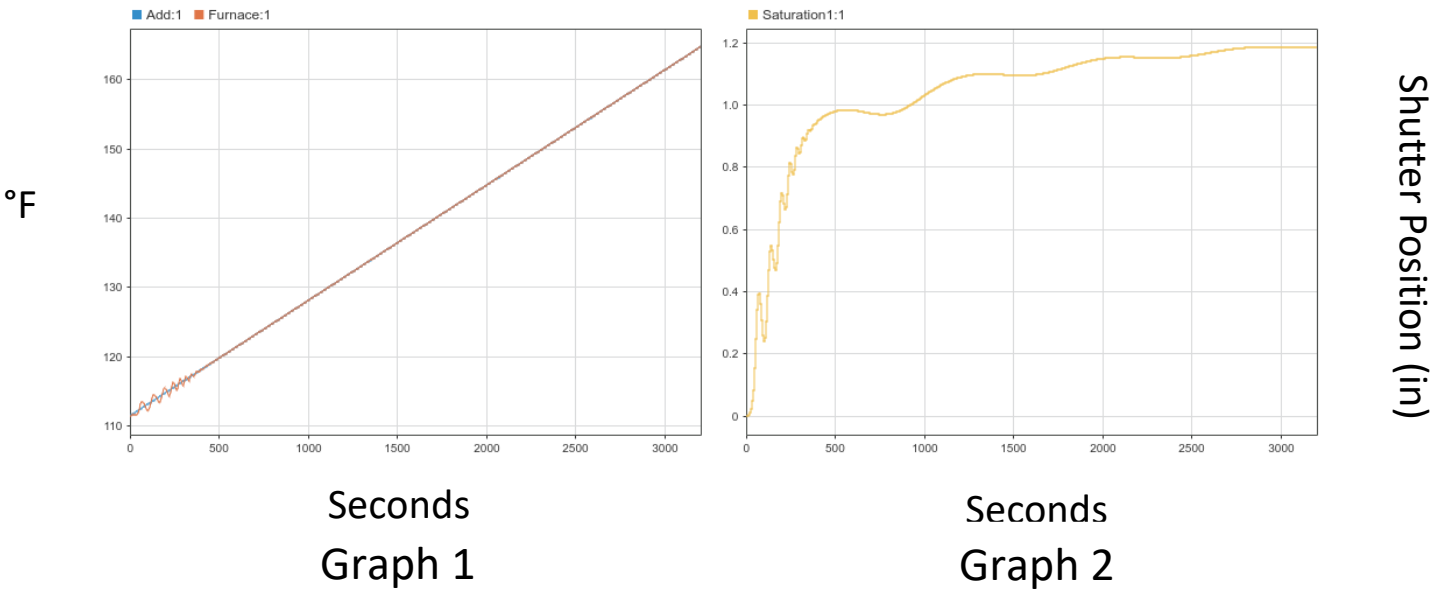


Figure 7. MATLAB Furnace Simulations.

The verification of the simulation was done by running data similar to a test conducted early in the project. Figures 8 and 9 show the data collected on a furnace in the lab and the data generated by the simulation, respectively.

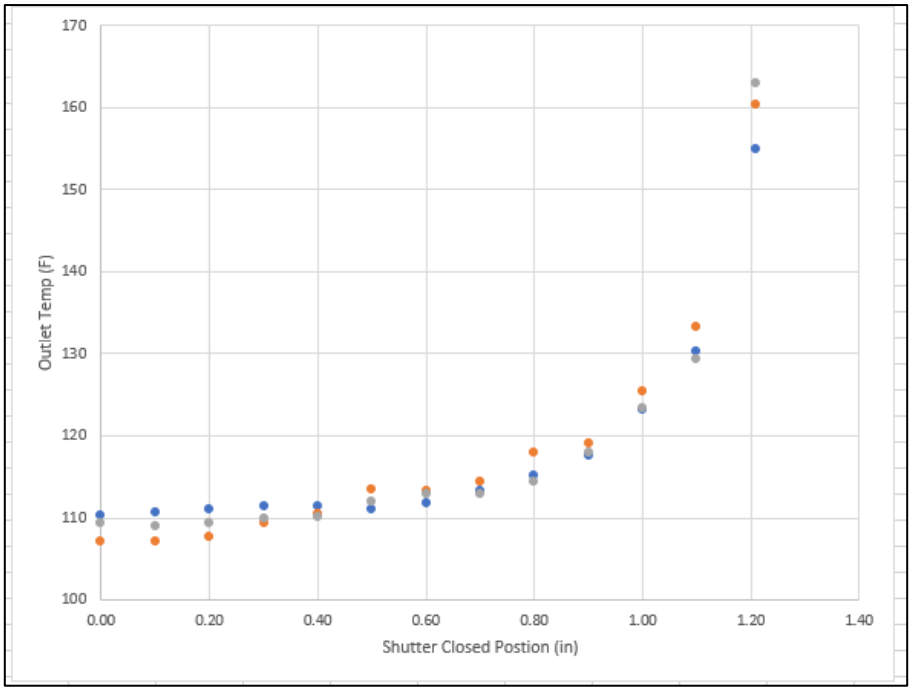


Figure 8. Data Collected on Furnace.

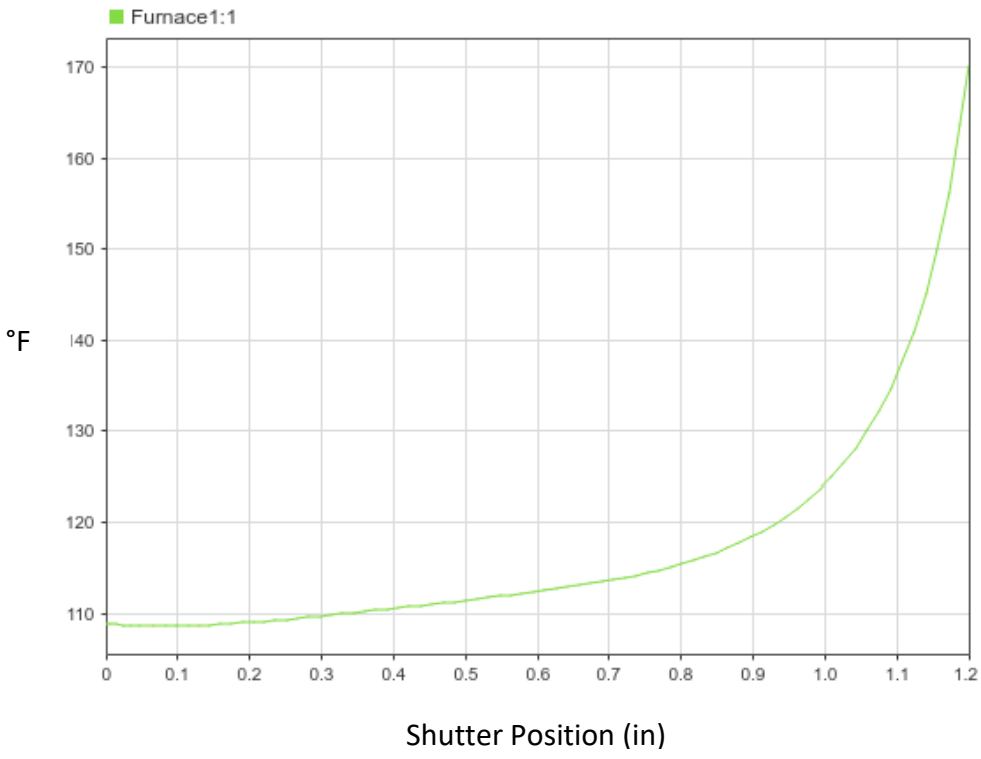


Figure 9. Data Generated by Simulation.

Finite Element Analysis

A finite element analysis simulation was performed in ANSYS Mechanical to determine the validity of the stiffeners applied to the back of the inlet shutter. During initial demonstrations of the furnace testing with the inlet shutter it was noticed that the shutter would deform. This deformation was cause by the pressure difference from the moving air as the shutter closed restricting air flow. Stiffeners were added to the design to reduce the deformation since it would cause error in the test by allowing excess air to get through the shutter. Another reason the stiffeners were added was to facilitate the reduction of the overall thickness of the material used to construct the inlet shutter. This was done because the added weight of the mechanical components was to great.

The figures below show the deformation flow of the inlet shutter's outer slide as it experiences the maximum pressure during testing.

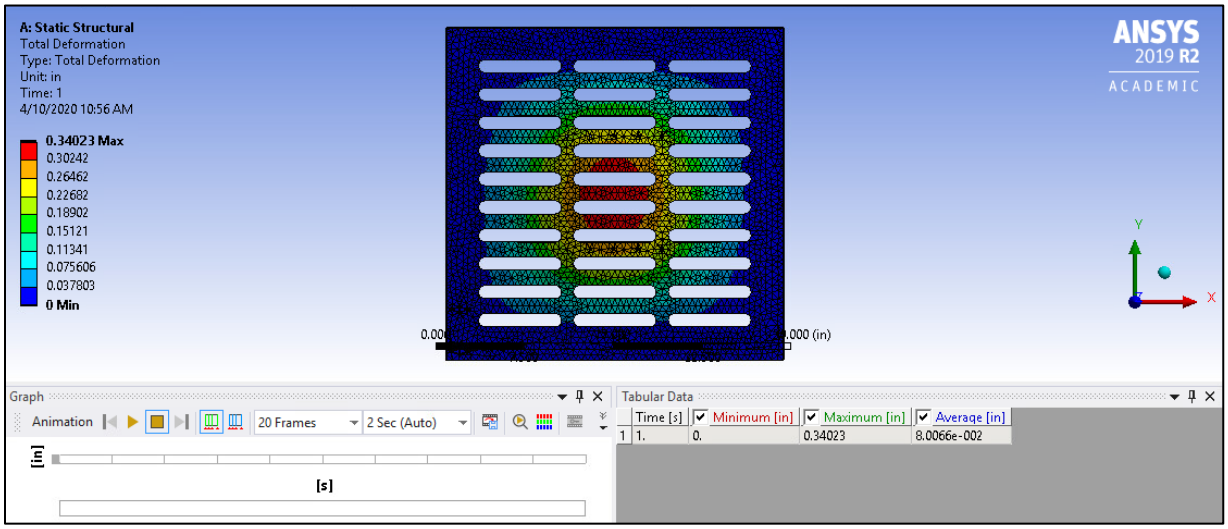


Figure 10. Front View of Shutter ANSYS Analysis.

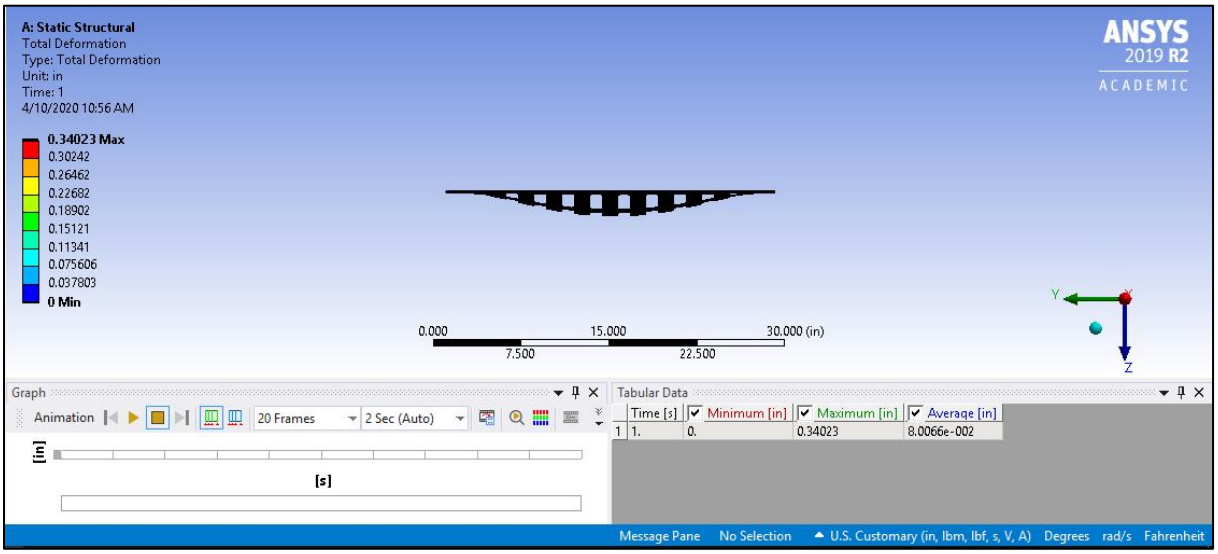


Figure 11. Side View of Shutter ANSYS Analysis.

The next figures below show the deformation flow with the stiffeners mounted to the outer slide of the inlet shutter.

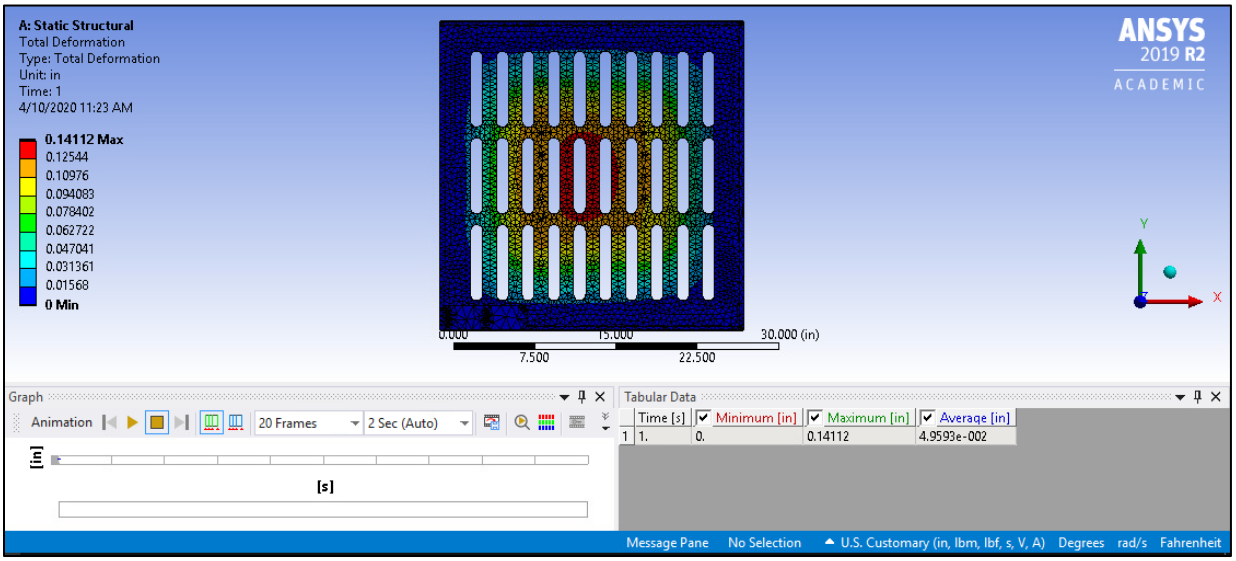


Figure 12. Front View of Shutter with Stiffeners

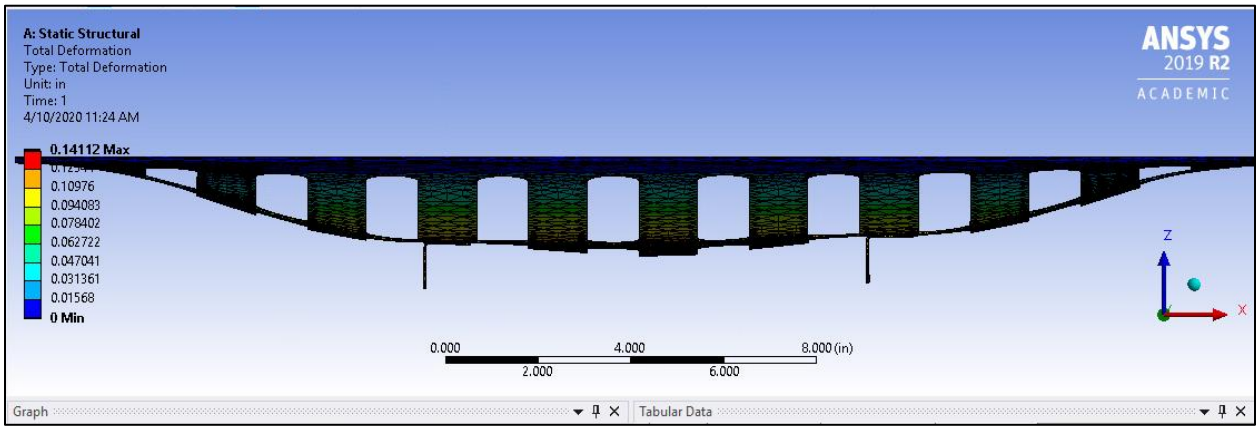


Figure 13. Side View of Shutter with Stiffeners

The result of the analysis showed that the added stiffeners reduced the total deformation by half. This is significant because the reduced air gap can ultimately lead to more accurate tests.

It should be noted that the figures presented show an exaggerated deformation and is not scale to the true deformation.

Budget and Bill of Materials

At the beginning of the project the set budget was $4000. This was to be used to produce four inlet shutters, 12 outlet shutters, two 4-in. iris shutters, one 3-in. iris shutter, and one 2-in. iris shutter. However, it was discovered during the design process that this budget would not be sufficient to build the original quantities commissioned. It was discussed and then decided in the final design review that the team would use the $4000 budget to build one inlet shutter, one outlet shutter, and one 4-in. iris shutter. Table 5 shows the final bill of material purchases for the finished prototypes.

Table 5. Bill of Materials - Purchased Items

Product	Qty	Price	Shipping Per Order	Tax Per Order
Metal Gear - 12 Teeth	1	$ 44.48		
Metal Gear - 60 Teeth	2	$ 87.52	N/A	N/A
Clamping Handle w/ Threaded Stud	4	$ 14.02		
Steel Drawer Slides	2	$ 16.93	$ 10.10	$ 8.25
L-Handed, Grade 5 Steel Hex Nut	1	$ 8.57		
M-strength Steel Hex Nut	1	$ 4.88		
L to R hand Female Hex Adapter	2	$ 8.16	N/A	N/A
24V AC to 12V DC	3	$ 12.99		
Nema 23 Motor	3	$ 23.99		
120pcd Jumper Wires	3	$ 5.79		
Elegoo UNO R3 Boards	3	$ 10.99		
Stepper Motor Drivers	3	$ 38.99		
DC Voltage Reducers 24V to 12V	3	$ 16.09	N/A	$ 26.91
T8 600mm S-Steel Lead Screw, w/ mounted ball	2	$ 25.35	N/A	$ 4.18
T8 400mm Lead Screw +copper nut	2	$ 11.99	N/A	$ 1.98
Roller Micro Switches	1	$ 7.99	$ 9.99	$ 1.48
Iris Diaphram 140mm	1	$ 327.50		
Iris Diaphram 100mm	1	$ 225.00	$ 9.99	$ 46.41
Grand Total	**$**	**1,420.21**		

Economic Feasibility

The table below show the breakdown of the economic feasibility of the different shutters. This was based on the labor rate saved with the automation.

Table 6. Economic Feasibility Study

Economic Feasibility Study				
Shutter	Cost Saving Strategy	Material Investment Cost	Avg. Time Saved Per Run	Pay-Back Time
Inlet Shutter	Automation	$ 283.00	2 Hour	1 Week
Outlet Shutter	Automation	$ 312.00	.25 Hour	9 Weeks
Iris Shutter	Automation	$ 513.00	.25 Hour	15 Weeks
		Total Cost	Total Time Saved Per Run	Overall Payback Time
		$ 1,108.00	2.5 Hours	3.5 Weeks

Programming Flow Charts

Inlet Shutter

These are the general variables used in the inlet shutter's programming logic:

- $Outlet\ Tempeerature\ (T_a)$
- $Initial\ Temperature\ (T_i) = T_a(time = 0)$
- $Desired\ Temperature\ (T_d) = T_i + \frac{1F}{1min}$

Shown below, Figure 14 illustrates the programming logic of the inlet shutter.

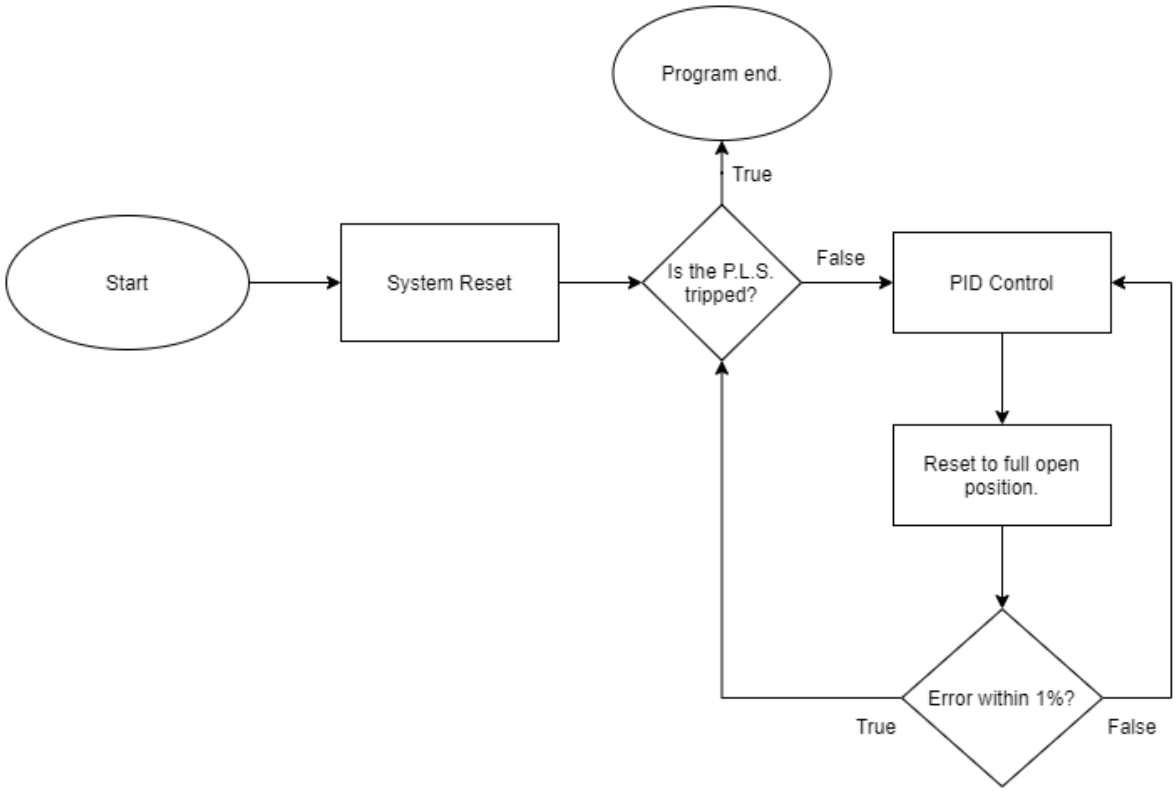


Figure 14. Inlet Shutter Control Logic.

Outlet Shutter

These are the general variables used in the inlet shutter's programming logic:

- S.P. = Static Pressure
- V desired = Voltage Desired based on S.P. / Voltage Graph
- V actual = Actual voltage being read from senor (correlates to current pressure)

Figure 15 describes the general programming logic governing the outlet shutter.

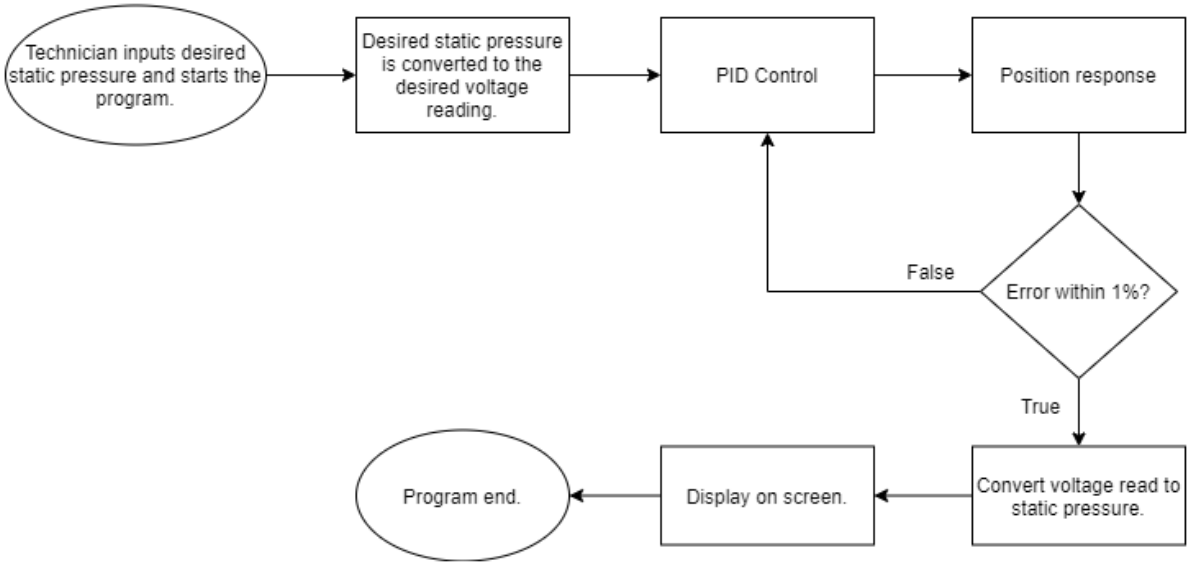


Figure 15. Outlet Shutter Control Logic.

Iris Shutter

Figure 16 outlines the flow of programming logic for the iris shutter.

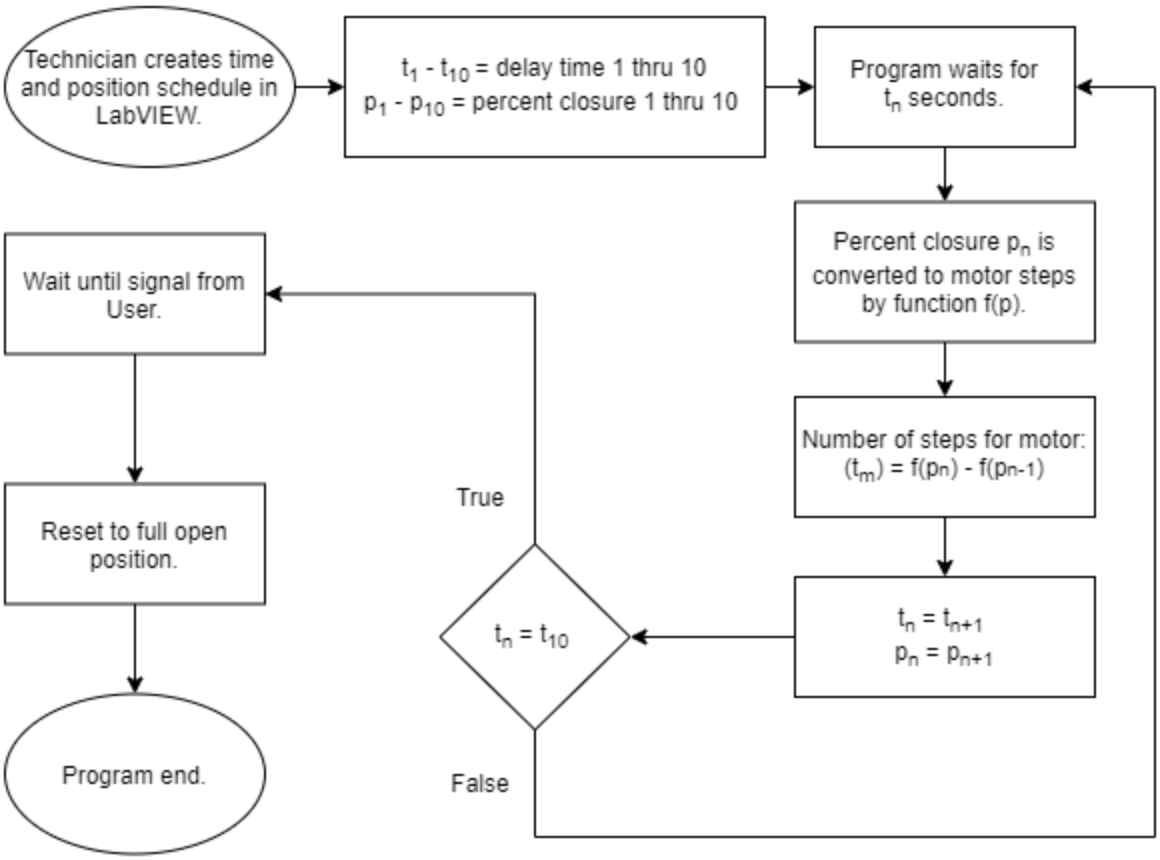


Figure 16. Iris Logic Flow Chart.

Final Acceptance Criteria

The project will be deemed complete and be accepted by Trane when design criteria specific to each shutter has been met. For the inlet shutter, the design must first comply with ASNI 5.26.1. This testing standard dictates the proper sizing and arrangement of the shutter's holes as well as the testing procedure of raising the temperature at a rate no greater than one-degree Fahrenheit per minute. As such, the shutter must operate autonomously in compliance with this standard. The inlet shutter's dimensions must measure 28 by 28 inches to the largest inlet duct size used in furnace testing. Finally, the shutter must weigh less than 10 lbs. for ease of transport and safety. Meeting these criteria is necessary for a successful inlet shutter design. The shutter that has been produced meets these specifications, although additional testing and tuning is required.

For the outlet shutter to be accepted, the final product must primarily be able to autonomously adjust its doors to produce the static pressure desired by the technician. It also needs to be able to fit all ductwork sizes used in furnace testing. To this point, the shutter will need to be able to fit heights ranging from 6 to 18 inches and widths ranging from 14 to 24 inches. Lastly, the outlet shutter must also weigh less than 10 lbs. for lifting and safety reasons. The created outlet shutter meets these criteria. However, as was previously noted, the device was unable to be completely programmed and tested.

The iris shutter must close in such that it is always symmetrical, hence the use of a mechanical iris. Secondly, the programming of the shutter must allow for the operator to input a schedule of closure positions and wait times to customize for testing. The produced shutter must also be able to withstand the temperatures of the flue gas, which can range from 300 to 500 °F.

Finally, to meet the criteria outlined by Trane the iris shutter must weigh less than 10 lbs., like the other shutters. The iris shutter that the team produced meets all of the mechanical criteria, all that is lacking is testing and tuning of the code.

Discussion

Current Progress

To date the team has completed all that was necessary for developing the three automated shutters during the first half of the project term. Including design selection, part sourcing/pricing and sponsor approval to proceed. The team has also developed test plans to be undertaken as the project progresses through winter break and the spring semester.

Forward movement

Moving forward with this project will require the team to build and test prototypes from each of the shutter apparatuses. For the inlet shutter the primary focus of testing will be refining the PID controller that controls the position of the shutter. Since there can be variation in needed shutter position to produce a certain outlet temperature between different furnace models many test will need to be conducted to produce the correct P, I and D constants to work as a general control for all furnace types. Additionally, one feature that is common across all furnaces using the inlet shutter is that smaller and smaller shutter movements will be required as the test progresses. So, the controller will need to account for this and make incrementally smaller adjustments to the shutter as it goes. For the outlet shutter the primary focus of testing will be similar to that of the inlets – optimizing the PID controller. The process here will require the system to understand where its starting shutter position is in relation to the static pressure it produces. If the system starts from a more closed off position it will immediately produce a higher than desired static pressure and will need to automatically open to reduce said pressure. Another aspect of testing for this shutter will be for it to accurately hit the desired target static pressure set by the technician. Testing the iris shutter will seek to make a seamless interface

between the device and the technician's computer (where he will input the desired percent close at time values).

After testing has been completed the team will seek to produce four inlet and iris shutters and twelve outlet shutters to be used by Trane's gas lab. After completion of major production goals, a full and final report will be completed along with a presentation to highlight achievements and setbacks experienced by the team.

Challenges

Major challenges standing in the way of successfully completing this project are two things; number one, the integration of Trane's facilities and the developed shutters, and number two, the budget that the team has been allotted to spend on this project. The first issue presents itself because the shutters depend completely on the data (such as pressure and temperature) they receive from Trane's facilities. If there is any trouble between these connections the shutters will not be able to operate as designed and will be rendered ineffective. What makes this particularly challenging is that the team is not allowed to tamper with any of Trane's software or testing hardware. To mitigate this problem Trane's own software engineer, James Coleman and test engineer, Trent Clark have contacted to assist with this element of the project. The second issue, regarding the budget, comes primarily from the expensive cost of the electrical components and prebuilt iris shutters. Since these parts are critical to the success of the project the team cannot simply discard their use. However, possible mitigation arises from the fact that Trane already owns two of the more expensive iris components that the team could retrofit with the automation portion to save money. Another mitigation will come through purchasing electrical components

in bulk, thus reducing the cost accounted to purchasing individual electrical components further reducing the proposed expenditure.

Recommendations

Based on the results that have been outlined in this report, it is recommended that the team be given permission to order parts and fabricate components for the assembly of prototypes for each of the three shutters. The designs for the inlet, outlet, and iris shutters are only paper designs at this point and to make any more significant progress in their development, the assembly and testing of prototypes and models will be required. In terms of the mechanical development, problems with the structure and mechanisms of each shutter will be more quickly discovered and solved with a physical prototype. In addition to this, with actual electronic controls built for testing, programs can be written, ran, and revised with real-world results that are easier to study. The paper designs for the inlet, outlet, and iris shutters have been thoroughly explored and evaluated within this report. Thus, it is self-evident that allowing the purchasing and fabrication of parts and models for testing is the next step in this project's design development.

Conclusion

University of Texas at Tyler's Visionary Engineering team will be automating test apparatuses for the Trane Technologies Gas Lab located in Tyler, TX. The goal of this automation is to reduce cycle time to conduct Allowable Air and Blocked Vent testing. This will provide significant convenience in testing because currently a technician must be present and involved for the entirety of each test. They can take hours to complete, results can be inconsistent, and re-tests commonly occur because of human error.

Visionary Engineering will be automating tests for all three shutters: inlet, iris, and outlet. The inlet and outlet shutter tests are used for the Allowable Air testing, while the iris shutter test is used for the Blocked Vent testing. For the inlet shutter, the system will be closing off airflow incrementally to maintain a 1ºF temperature increase per minute by controlling the shutter movement. Similarly, the outlet shutter will be maintaining outlet duct static pressure by closing the shutter incrementally. In this test, the technician will put in a single input for the desired pressure and the system will then adjust the shutter position to reach that given pressure. Lastly, the iris shutter test will be used for the measurement of the backpressure which is increased by the gradual closing of the iris. This test will simply take a single set of inputs for the time and position schedule by the technician and implement it. For all three tests, key operations will be tested individually with a stand-alone setup which will then be tuned at Trane on a gas stand system.

The shutter movements will be implemented by a NEMA 23 stepper motor through a DM542T stepper driver which is going to be controlled by an Arduino microcontroller. It will be programmed as a PID controller for accurate and precise results through a feedback system to

minimize error. Also, the micro stepping feature on the driver will also be useful to obtain accuracy.

The Arduino microcontroller will be executing its stepper motor operator based on the instructions it receives from LabVIEW, which is the also the software Trane uses for acquisition. As also explained in prior sections, the data is first compiled in string data type in LabVIEW which is then sent over to Arduino through USB serial communication. The program in Arduino then parses it and assigns it to the relevant variables. Lastly, the operation is executed through the programmed PID controller for each shutter. All three shutters follow the same overall procedure, though there can be slight modifications based on each component's purpose.

References

[1] Arduino Serial Communication Code - https://forum.arduino.cc/index.php?topic=396450.0

TYL 1: Visionary Engineering

Electrical & Mechanical Engineering

Trane Gas Lab Equipment Automation

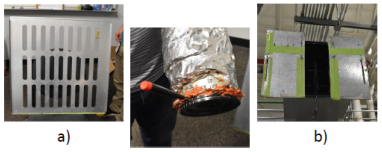
Team Members: Blake Merritt, James Davis, Justin Davenport, William Urwiller, Zaeem Siddiqui
Sponsor: Trane Technologies
Advisor: Dr. Alwathiqbellah Ibrahim

Abstract

Mechatronic automation can eliminate many of the errors induced by manual, technician-operated controls, improving experiment quality. As such, automation of the Trane Gas Lab's furnace testing devices will improve the quality of experiment data and reduce the time needed to complete a test, increasing productivity. To achieve this, the existing air shutters used in furnace testing were retrofitted using mechatronic equipment and computer controls to increase the efficiency of testing operations and remove the error introduced by human technicians. Compared to technician operated tests, the control devices developed have reduced the time required to perform the tests while significantly increasing data quality.

Objective

The furnace testing equipment consists of Inlet Shutter (Fig.1a), Outlet Shutter (Fig.1b), and Iris Shutter (Fig.1c).



a) c) b)

Fig.1 Furnace test equipment parts: a) Inlet Shutter, b) Outlet Shutter, and c) Iris Shutter

Our main objective from this project is to automate the furnace test equipment for the Trane Gas Lab located in Tyler, TX, with a goal of reducing cycle time to conduct allowable air and blocked vent testing.

Design

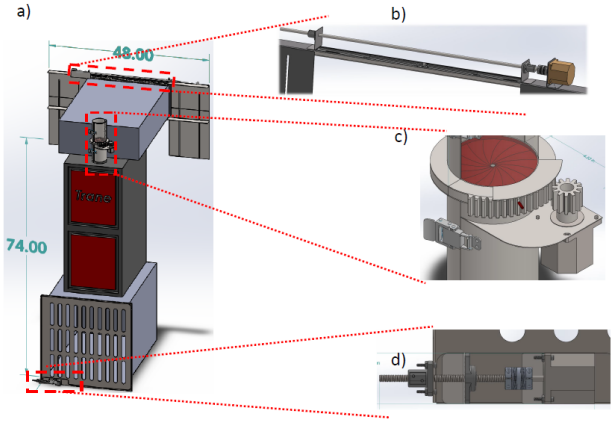


Fig.2 a) Automated furnace test equipment design: b) Inlet Shutter, c) Outlet Shutter, and d) Iris Shutter.

Inlet Shutter:

Automated by using stepper motor and feedback control to closes incrementally to restrict the flow of air coming into the furnace, thus increasing the temperature of the air leaving it. The feedback control will consist of a proportional controller that intakes the position error of the system and outputs the right position.

Outlet Shutter:

A similar mechanism will be used to incrementally closes and restrict the airflow of conditioned air leaving the furnace to maintain a given static pressure. To give the outlet shutter its motion a dual threaded lead screw system will be used in conjunction with a stepper.

Iris Shutter:

A direct connection will be used between the stepper motor and Trane facilities to control the shutter which operates by closing the opening of the flue exhaust port incrementally to build back pressure in the system.

Testing Results

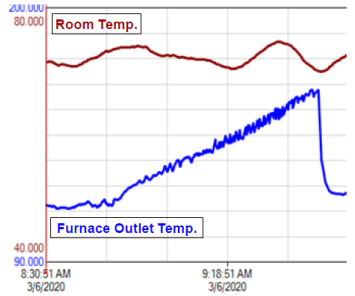


Fig.3. Results from testing inlet shutter taken from Trane's WonderWare® application; Test conducted: Allowable Air.

The results shown in Fig. 3 display the best of 8 test runs conducted by the team at Trane's Gas Lab on the Inlet Shutter. This image shows the achievement of one of the main operating goals for this shutter, namely, the linear nature of the furnace outlet temperature.

Conclusions

As shown Visionary Engineering (TYL 1) has validated the automation of test apparatuses for the Trane Gas Lab located in Tyler, TX. Further testing would seek to refine current results to eliminate variation in results. Additionally, team would seek to test the two remaining apparatuses.

Acknowledgments

UT Tyler - College of Engineering
Mr. John Bailey - Trane
Mr. Trent Clark - Trane

Appendix B

Sign-off Sheet

Senior Design Project II

MENG 4216 / EENG 4315

Project Trane Gas Lab Equipment Automation Delivery and Acceptance

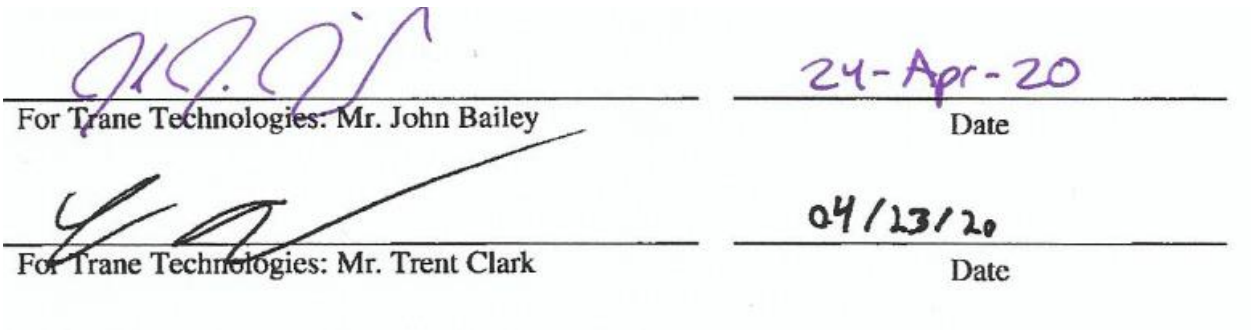
Senior design team Visionary Engineering, from UT-Tyler College of Engineering, has worked with a sponsor: Trane Technologies design, build and deliver three gas lab testing apparatuses as part of the senior students' academic work during the academic year of 2019-2020. This document includes the sign-off list and Trane Technologies final approval of the outcome of Trane Gas Lab Equipment Automation delivered by Visionary Engineering, based on the previously set and mutually-approved scope and specifications of the project. An authorized signature indicates this approval.

Table 1: Sponsor Sign OFF list for Deliverables of the Senior Project Trane Gas Lab Equipment Automation.

Item No.	Description of Deliverable	Comments:	Sponsor Sign Off: Authorized Initials
Inlet Shutter Apparatus	28"x28" - 20Ga, Galvanized Carbon Steel		
Motor	NEMA 23 (3x)	Each apparatus gets one of each	
Microcontroller	Arduino (3x)	Each apparatus gets one of each	
Driver	DM542T Stepper Motor Driver (3x)	Each apparatus gets one of each	
Transform	24V DC to 10V DC (3x)	Each apparatus gets one of each	
Outlet Shutter Apparatus	Dual Slide - 20Ga, Galvanized Carbon Steel		
Iris Shutter Apparatus	20 Ga, Galvanized Carbon Steel		

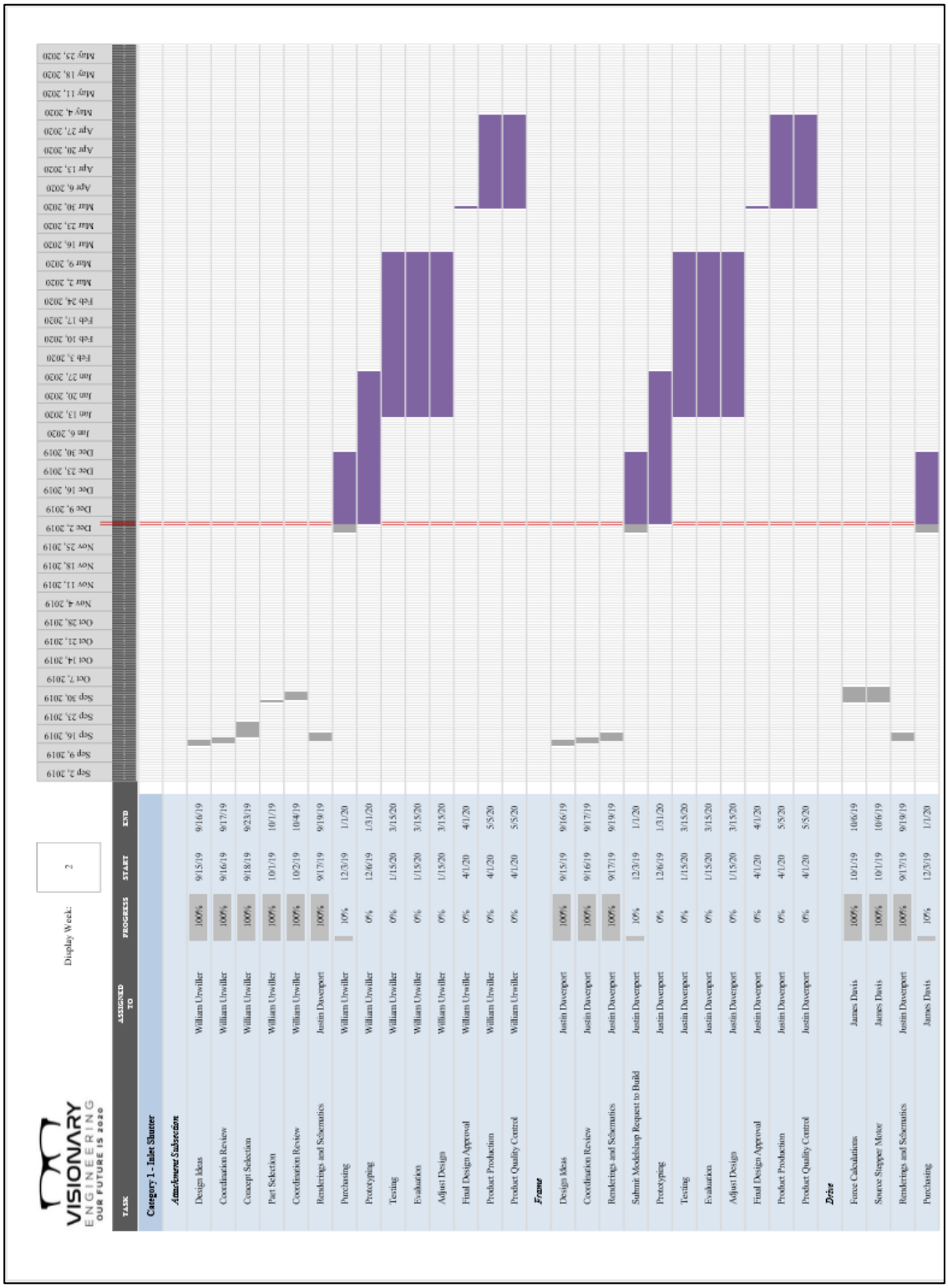
Mechanical Aperture	4” Diameter
Production Model Documentation	Technical Documentation
B.O.M.	Bill of Materials
I.O.M.	Installation and Operations Manual
Technical Drawings	Details of physical features and prints for reproduction
Testing	Testing of system
Inlet Shutter Validation/Refinement	Operation proven. Control parameters adjusted to improve apparatus performance

The following signatures indicate that Trane Technologies approves of the completion of this project and deliverables stated above which included all sponsor changes from original design and any consequent changes in the project, as mutually approved by all signing parties. Also indicated is the acknowledgement by Trane Technologies of reception of the final product of the project.



Appendix C

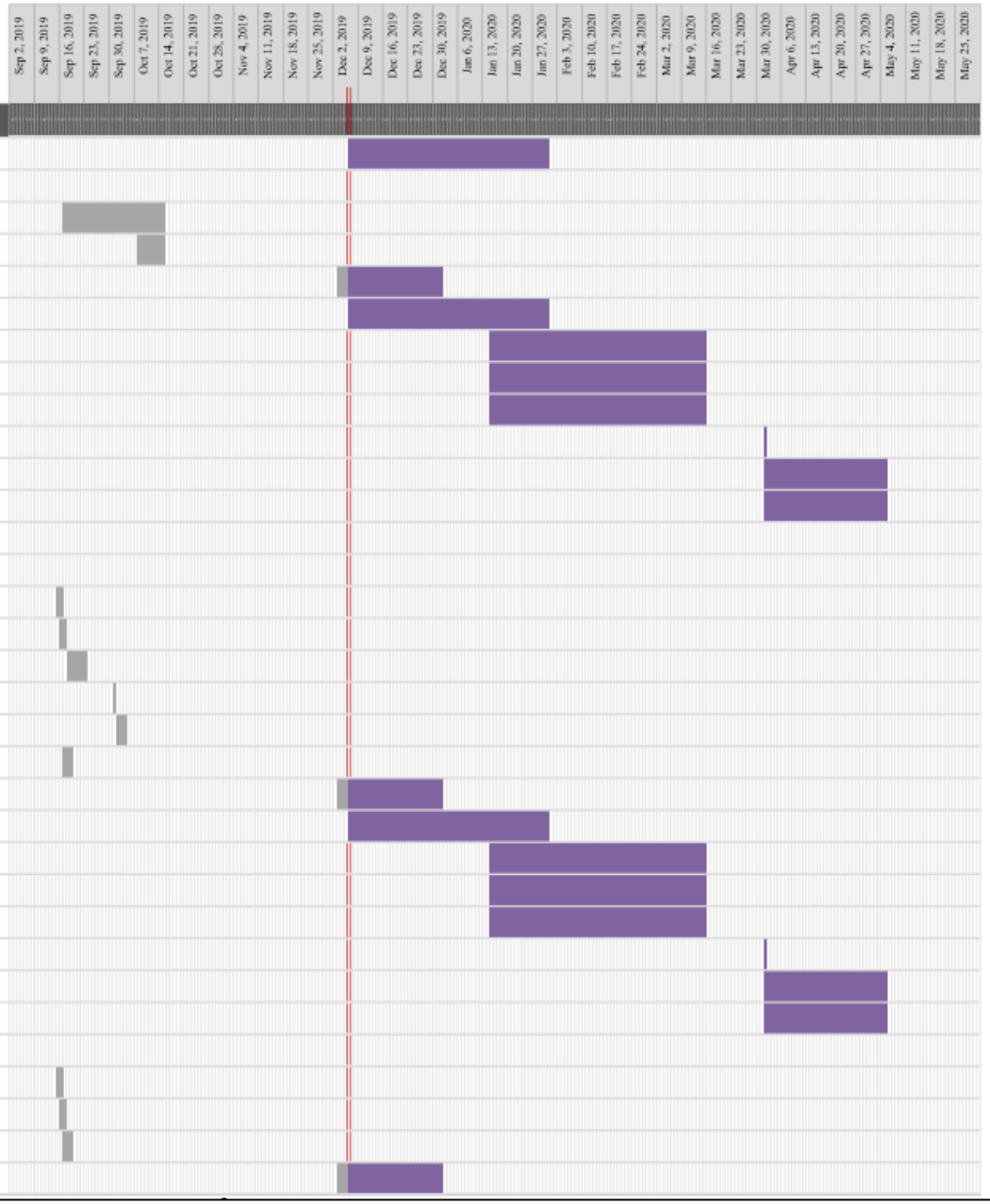
Timelines and Milestones



VISIONARY ENGINEERING
OUR FUTURE IS 2020

Display Week: 2

TASK	ASSIGNED TO	PROGRESS	START	END
Integrating into Whole Assembly	James Davis	0%	12/6/19	1/31/20
Controls				
Generate Control Logic	Blake Merritt/Zaeem Siddiqui	100%	9/17/19	10/15/19
Decide on Microcontroller	Blake Merritt/Zaeem Siddiqui	100%	10/8/19	10/15/19
Purchase Parts	Blake Merritt/Zaeem Siddiqui	10%	12/3/19	1/1/20
Integrate into Assembly	Blake Merritt/Zaeem Siddiqui	0%	12/6/19	1/31/20
Testing/Calibrate	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Evaluation	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Adjust Design	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Final Design Approval	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	4/1/20
Product Production	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	5/5/20
Product Quality Control	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	5/5/20
Category 2 - Outlet Shutter				
Attachment Subsection				
Design Ideas	William Urwiller	100%	9/15/19	9/16/19
Coordination Review	William Urwiller	100%	9/16/19	9/17/19
Concept Selection	William Urwiller	100%	9/18/19	9/23/19
Part Selection	William Urwiller	100%	10/1/19	10/1/19
Coordination Review	William Urwiller	100%	10/2/19	10/4/19
Renderings and Schematics	Justin Davenport	100%	9/17/19	9/19/19
Purchasing	William Urwiller	10%	12/3/19	1/1/20
Prototyping	William Urwiller	0%	12/6/19	1/31/20
Testing	William Urwiller	0%	1/15/20	3/15/20
Evaluation	William Urwiller	0%	1/15/20	3/15/20
Adjust Design	William Urwiller	0%	1/15/20	3/15/20
Final Design Approval	William Urwiller	0%	4/1/20	4/1/20
Product Production	William Urwiller	0%	4/1/20	5/5/20
Product Quality Control	William Urwiller	0%	4/1/20	5/5/20
Frame				
Design Ideas	Justin Davenport	100%	9/15/19	9/16/19
Coordination Review	Justin Davenport	100%	9/16/19	9/17/19
Renderings and Schematics	Justin Davenport	100%	9/17/19	9/19/19
Submit Modelshop Request to Build	Justin Davenport	10%	12/3/19	1/1/20



VISIONARY ENGINEERING
OUR FUTURE IS 2020

Display Week: 2

TASK	ASSIGNED TO	PROGRESS	START	END
Prototyping	Justin Davenport	0%	12/6/19	1/31/20
Testing	Justin Davenport	0%	1/15/20	3/15/20
Evaluation	Justin Davenport	0%	1/15/20	3/15/20
Adjust Design	Justin Davenport	0%	1/15/20	3/15/20
Final Design Approval	Justin Davenport	0%	4/1/20	4/1/20
Product Production	Justin Davenport	0%	4/1/20	5/5/20
Product Quality Control	Justin Davenport	0%	4/1/20	5/5/20
Drive				
Force Calculations	James Davis	100%	10/1/19	10/6/19
Source Stepper Motor	James Davis	100%	10/1/19	10/6/19
Source Lead Screw Mechanism	James Davis	100%	10/1/19	10/6/19
Purchasing	James Davis	10%	12/3/19	1/1/20
Renderings and Schematics	Justin Davenport	100%	9/17/19	9/19/19
Integrating into Whole Assembly	James Davis	0%	12/6/19	1/31/20
Controls				
Generate Control Logic	Blake Merritt/Zaeem Siddiqui	100%	9/17/19	10/15/19
Decide on Microcontroller	Blake Merritt/Zaeem Siddiqui	100%	10/8/19	10/15/19
Purchase Parts	Blake Merritt/Zaeem Siddiqui	12%	12/3/19	1/1/20
Integrate into Assembly	Blake Merritt/Zaeem Siddiqui	0%	12/6/19	1/31/20
Testing/Calibrate	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Evaluation	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Adjust Design	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Final Design Approval	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	4/1/20
Product Production	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	5/5/20
Product Quality Control	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	5/5/20
Category 3 - Iris Shutter				
Attachment Subsection				
Design Ideas	William Urwiller	100%	9/15/19	9/16/19
Coordination Review	William Urwiller	100%	9/16/19	9/17/19
Concept Selection	William Urwiller	100%	9/18/19	9/23/19
Part Selection	William Urwiller	100%	10/1/19	10/1/19
Coordination Review	William Urwiller	100%	10/2/19	10/4/19
Renderings and Schematics	Justin Davenport	100%	9/17/19	9/19/19



VISIONARY ENGINEERING
OUR FUTURE IS 2020

Display Week: 2

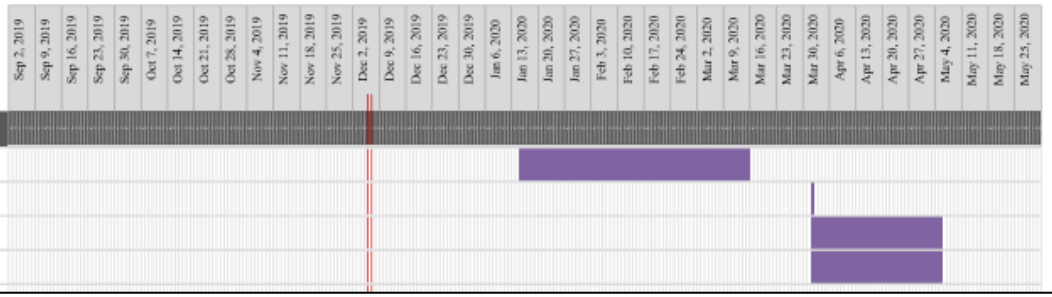
TASK	ASSIGNED TO	PROGRESS	START	END
Purchasing	William Urwiller	10%	12/3/19	1/1/20
Prototyping	William Urwiller	0%	12/6/19	1/31/20
Testing	William Urwiller	0%	1/15/20	3/15/20
Evaluation	William Urwiller	0%	1/15/20	3/15/20
Adjust Design	William Urwiller	0%	1/15/20	3/15/20
Final Design Approval	William Urwiller	0%	4/1/20	4/1/20
Product Production	William Urwiller	0%	4/1/20	5/5/20
Product Quality Control	William Urwiller	0%	4/1/20	5/5/20
Frame				
Design Ideas	Justin Davenport	100%	9/15/19	9/16/19
Coordination Review	Justin Davenport	100%	9/16/19	9/17/19
Renderings and Schematics	Justin Davenport	100%	9/17/19	9/19/19
Submit Modelshop Request to Build	Justin Davenport	10%	12/3/19	1/1/20
Prototyping	Justin Davenport	0%	12/6/19	1/31/20
Testing	Justin Davenport	0%	1/15/20	3/15/20
Evaluation	Justin Davenport	0%	1/15/20	3/15/20
Adjust Design	Justin Davenport	0%	1/15/20	3/15/20
Final Design Approval	Justin Davenport	0%	4/1/20	4/1/20
Product Production	Justin Davenport	0%	4/1/20	5/5/20
Product Quality Control	Justin Davenport	0%	4/1/20	5/5/20
Drive				
Force Calculations	James Davis	100%	10/1/19	10/6/19
Source Approvied Stepper Motor	James Davis	100%	10/1/19	10/6/19
Source Stepper Motor	James Davis	100%	10/1/19	10/6/19
Renderings and Schematics	Justin Davenport	100%	9/17/19	9/19/19
Integrating into Whole Assembly	James Davis	0%	12/6/19	1/31/20
Controls				
Generate Control Logic	Blake Merritt/Zaeem Siddiqui	100%	9/17/19	10/15/19
Decide on Microcontroller	Blake Merritt/Zaeem Siddiqui	100%	10/8/19	10/15/19
Purchase Parts	Blake Merritt/Zaeem Siddiqui	10%	12/3/19	1/1/20
Integrate into Assembly	Blake Merritt/Zaeem Siddiqui	0%	12/6/19	1/31/20
Testing/Calibrate	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Evaluation	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20



VISIONARY
ENGINEERING
OUR FUTURE IS 2020

Display Week: 2

TASK	ASSIGNED TO	PROGRESS	START	END
Adjust Design	Blake Merritt/Zaeem Siddiqui	0%	1/15/20	3/15/20
Final Design Approval	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	4/1/20
Product Production	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	5/5/20
Product Quality Control	Blake Merritt/Zaeem Siddiqui	0%	4/1/20	5/5/20



A8

Appendix D

ARCI Chart

This ARCI Chart was developed as a responsibility matrix to show who is responsible, accountable, consulted, and informed for each component of the project.

Table 13.1 ARCI Chart

Project: *Trane Gas Testing Automation* Company: *Visionary Engineering* ARCI Matrix		**Justin Davenport**	**Zaaem Siddiqui**	**James Davis**	**William Urwiller**	**Blake Merritt**
Task #	**Category 1 - Inlet Shutter**					
	Attachment Subsection					
1	Design Ideas	C	C	C	R	A
2	Coordination Review	I	A	I	R	C
3	Concept Selection	I	I	C	R	A
4	Part Selection	I	I	A	R	C
5	Coordination Review	I	I	I	R	A
6	Renderings and Schematics	R	I	A	I	I
7	Purchasing	I	I	C	R	A
8	Prototyping	A	C	C	R	C
9	Testing	I	A	I	R	A
10	Evaluation	I	A	I	R	A
11	Adjust Design	A	I	I	R	C
12	Final Design Approval	C	C	C	R	A
13	Product Production	I	A	I	R	I
14	Product Quality Control	I	A	I	R	I
	Frame					
15	Design Ideas	R	C	C	C	A
16	Coordination Review	R	A	I	I	C
17	Renderings and Schematics	R	I	A	I	I
18	Submit Modelshop Request to Build	R	I	A	I	I

A - Accountable
R - Responsible
C - Consulted
I - Informed

19	Prototyping	R	C	C	I	C
			A	I	I	A

Table 13.2 ARCI Chart

21	Evaluation	R	A	I	I	A
22	Adjust Design	R	I	C	I	C
23	Final Design Approval	R	C	C	C	A
24	Product Production	R	A	I	C	I
25	Product Quality Control	R	C	I	A	I
	Drive					
27	Force Calculations	A	I	R	C	I
28	Source Linear Actuator	A	C	R	I	I
29	Renderings and Schematics	R	I	A	I	I
30	Purchasing	I	C	R	I	A
31	Integrating into Whole Assembly	A	A	R	I	C
	Controls					
32	Generate Control Logic	I	A	I	C	R
33	Decide on Microcontroller	I	R	C	I	A
34	Purchase Parts	I	A	I	I	R
35	Integrate into Assembly	C	R	I	I	A
36	Testing/Calibrate	I	R	I	C	A
37	Evaluation	I	A	I	I	R
38	Adjust Design	I	A	C	I	R
39	Final Design Approval	C	A	I	I	R
40	Product Production	I	R	C	I	A
41	Product Quality Control	I	R	I	C	A
	Category 2 - Outlet Shutter					
	Attachment Subsection					
42	Design Ideas	C	C	C	R	A
43	Coordination Review	I	A	I	R	C
44	Concept Selection	I	I	C	R	A
45	Part Selection	I	I	A	R	C
46	Coordination Review	I	I	I	R	A
47	Renderings and Schematics	R	I	A	I	I
48	Purchasing	I	I	C	R	A
49	Prototyping	A	C	C	R	C
50	Testing	I	A	I	R	A
51	Evaluation	I	A	I	R	A
52	Adjust Design	A	I	I	R	C

53	Final Design Approval	C	C	C	R	A
54	Product Production	I	A	I	R	I
55	Product Quality Control	I	A	I	R	I

Table 13.3 ARCI Chart

56	Design Ideas	R	C	C	C	A
57	Coordination Review	R	A	I	I	C
58	Renderings and Schematics	R	I	A	I	I
59	Submit Modelshop Request to Build	R	I	A	I	I
60	Prototyping	R	C	C	I	C
61	Testing	R	A	I	I	A
62	Evaluation	R	A	I	I	A
63	Adjust Design	R	I	C	I	C
64	Final Design Approval	R	C	C	C	A
65	Product Production	R	A	I	C	I
66	Product Quality Control	R	C	I	A	I
	Drive					
67	Force Calculations	A	I	R	C	I
68	Source Stepper Motor	A	C	R	I	I
69	Source Ball Screw Mechanism	A	I	R	I	I
70	Purchasing	I	C	R	I	A
71	Renderings and Schematics	R	I	A	I	I
72	Integrating into Whole Assembly	A	A	R	I	C
	Controls					
73	Generate Control Logic	I	A	I	C	R
74	Decide on Microcontroller	I	R	C	I	A
75	Purchase Parts	I	A	I	I	R
76	Integrate into Assembly	C	R	I	I	A
77	Testing/Calibrate	I	R	I	C	A
78	Evaluation	I	A	I	I	R
79	Adjust Design	I	A	C	I	R
80	Final Design Approval	C	A	I	I	R
81	Product Production	I	R	C	I	A
82	Product Quality Control	I	R	I	C	A
	Category 3 - Iris Shutter					
	Attachment Subsection					
83	Design Ideas	C	C	C	R	A

84	Coordination Review	I	A	I	R	C
85	Concept Selection	I	I	C	R	A
86	Part Selection	I	I	A	R	C
87	Coordination Review	I	I	I	R	A
88	Renderings and Schematics	R	I	A	I	I
89	Purchasing	I	I	C	R	A
90	Prototyping	A	C	C	R	C
91	Testing	I	A	I	R	A
92	Evaluation	I	A	I	R	A
93	Adjust Design	A	I	I	R	C
94	Final Design Approval	C	C	C	R	A
95	Product Production	I	A	I	R	I
96	Product Quality Control	I	A	I	R	I
97	***Frame***					
98	Design Ideas	R	C	C	C	A
99	Coordination Review	R	A	I	I	C
100	Renderings and Schematics	R	I	A	I	I
101	Submit Modelshop Request to Build	R	I	A	I	I
102	Prototyping	R	C	C	I	C
103	Testing	R	A	I	I	A
104	Evaluation	R	A	I	I	A
105	Adjust Design	R	I	C	I	C
106	Final Design Approval	R	C	C	C	A
107	Product Production	R	A	I	C	I
108	Product Quality Control	R	C	I	A	I
	Drive					
109	Force Calculations	A	I	R	C	I
110	Source Approvied Linear Actuator	A	C	R	I	I
111	Source Stepper Motor	R	I	A	I	I
112	Renderings and Schematics	R	C	A	I	A
113	Integrating into Whole Assembly	A	A	R	I	C
	Controls					
114	Generate Control Logic	I	A	I	C	R
115	Decide on Microcontroller	I	R	C	I	A
116	Purchase Parts	I	A	I	I	R

117	Integrate into Assembly	C	R	I	I	A
118	Testing/Calibrate	I	R	I	C	A
119	Evaluation	I	A	I	I	R
120	Adjust Design	I	A	C	I	R
121	Final Design Approval	C	A	I	I	R
122	Product Production	I	R	C	I	A
123	Product Quality Control	I	R	I	C	A

Appendix E

Project Risk Register

Project Risk Register						
No.	**Risk title**	Description	Impact score	Probability	Overall risk score	Mitigation
Inlet						
1	Threaded rod brackets breaking	Sheet metal bracket pieces connected to bearings brake from rivets	1	0.15	0.15	Ensure no repeated over extension of brackets
2	Contact with hem	Inner slide contact hemmed edge	0.4	0.3	0.12	Visually inspect hem bracket prior to use
3	Shaft Coupling	Shaft coupling breaking	0.85	0.05	0.0425	Visually inspect system and monitor for over extension
4	Bearing failure	Bearing wears out and fails	0.5	0.01	0.005	Visually inspect prior to use
Outlet						
5	Dropping from top of furnace	Dropping causing large deformation	1	0.05	0.05	Use caution when mounting and unmounting from furnace
6	Threaded rod brackets breaking	Sheet metal bracket pieces connected to bearings break from rivets	1	0.15	0.15	Ensure no repeated over extension of brackets
7	Shaft Coupling	Shaft coupling breaking	0.85	0.05	0.0425	Visually inspect system and monitor for over extension

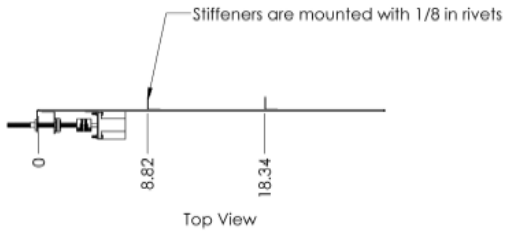
8	Coupling	LH and RH coupling loosening	0.3	0.07	0.021	Visually inspect system and monitor in operation
9	Bracket nuts	Welded nuts break from weld	0.8	0.001	0.0008	Visually inspect prior to each use
10	Mounting rivets	Rivets loosening or breaking	0.2	0.1	0.02	Visually inspect after several uses
11	Bearing slides	Slides become stuck or no longer open	0.6	0.005	0.003	If noticeable friction add oil based lubricant
12	Cam locks	Stop nut loosening	0.07	0.15	0.0105	Visually inspect and tighten if needed
13	Bottom door connection	The connection coming loose from screws	0.09	0.15	0.0135	Visually inspect and handle with care and replace if necessary
Iris						
14	Motor mounting plate	Deflection may result in loss of gear contact	1	0.25	0.25	Visually inspect prior to use
15	Rack	Rack comes off pin	1	0.01	0.01	Visually inspect prior to use
16	Aperture	Aperture fins damaged	0.3	0.09	0.027	Visually inspect and clean if necessary
17	Set Screw failure	Set screw loosening on spur gear	0.45	0.04	0.018	Visually inspect and tighten if needed
18	Aperture pin failure	Aperture pin breaks or becomes damaged	0.5	0.001	0.0005	Visually inspect and remanufacture part if necessary
Electrical						
19	Arduino Failure	Board failure/malfunction	1	0.009	0.009	Handle board with care
20	Wire Disconnections	A wire disconnects from any component	0.6	0.1	0.06	Visually inspect connections and handle with care

21	Motor Failure	Motor does not function	0.9	0.003	0.0027	Ensure proper electrical connections and check driver function
22	Driver Failure	Driver fails to drive stepper motors	0.9	0.003	0.0027	ensure proper electrical connections
23	Arduino USB failure	USB fails to interface with computer or with Arduino	0.5	0.09	0.045	Ensure connection and handle with care

Appendix F

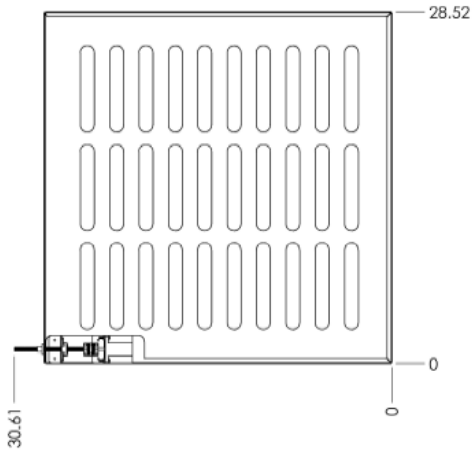
Mechanical Drawings

Inlet Shutter

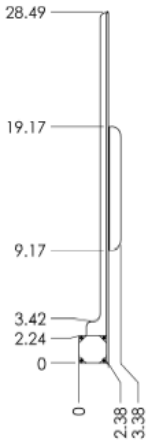


Top View

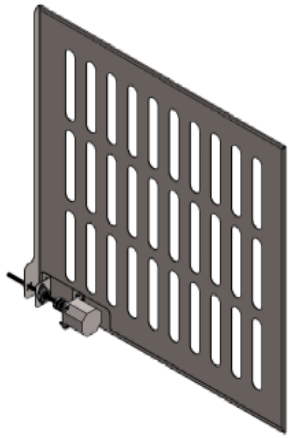
ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	OUTER SLIDE	DETAIL DRAWING 5	1
2	INNER SLIDE	DETAIL DRAWING 4	1
3	OUTER SLIDE STIFFENER	DETAIL DRAWING 8	2
4	LEAD SCREW	NOTED DRAWING 3	1
5	FLEXIBLE SHAFT COUPLING	NOTED DRAWING 3	1
6	STEPPER MOTOR MOUNT	DETAIL DRAWING 7	1
7	NEMA 23 STEPPER MOTOR	NOTED DRAWING 3	1
8	3/4 X 6-32 SOCKET HEAD SCREW	NOTED DRAWING 3	4
9	6-32 HEX NUT	NOTED DRAWING 3	4
10	MOUNTED SLEEVE BEARING	NOTED DRAWING 3	1
11	BEARING MOUNT 1	20 GAUGE GALVENIZED STEEL	1
12	T8 THREADED ROD LEAD SCREW NUT	NOTED DRAWING 3	1



Front View



Side View



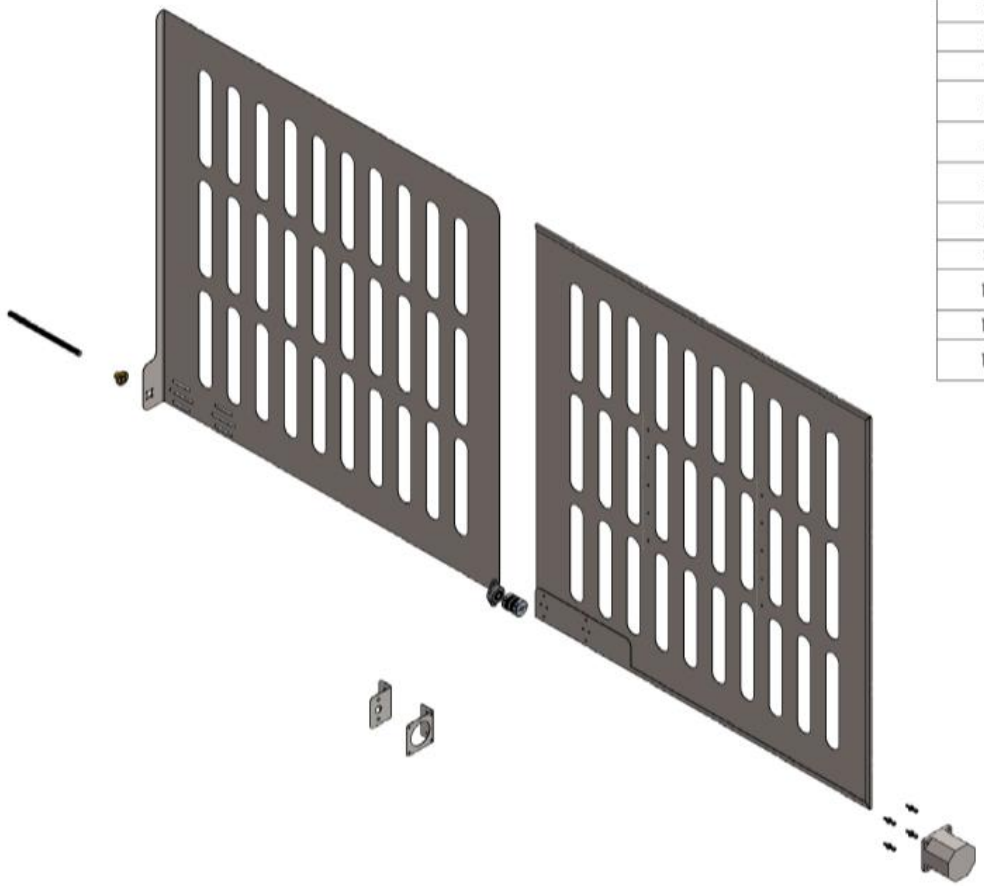
UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL			
	COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME	
B	Inlet Shutter	
SCALE: 1:8		DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	OUTER SLIDE	20 GAUGE GALVENIZED STEEL	1
2	INNER SLIDE	20 GAUGE GALVENIZED STEEL	1
3	OUTER SLIDE STIFFENER	20 GAUGE GALVENIZED STEEL	2
4	LEAD SCREW		1
5	FLEXIBLE SHAFT COUPLING		1
6	STEPPER MOTOR MOUNT	20 GAUGE GALVENIZED STEEL	1
7	NEMA 23 STEPPER MOTOR		1
8	3/4 X 6-32 SOCKET HEAD SCREW		4
9	6-32 HEX NUT		4
10	MOUNTED SLEEVE BEARING	NOTED DRAWING 2	1
11	BEARING MOUNT 1	20 GAUGE GALVENIZED STEEL	1
12	T8 THREADED ROD LEAD SCREW NUT	NOTED DRAWING 2	1

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL	COMMENTS:		

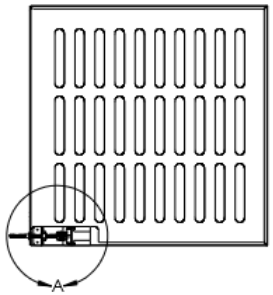
PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

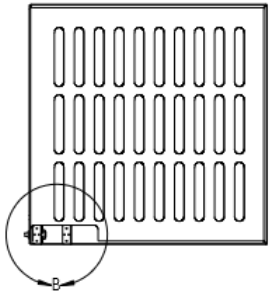
VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Exploded View
SCALE: 1:6	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

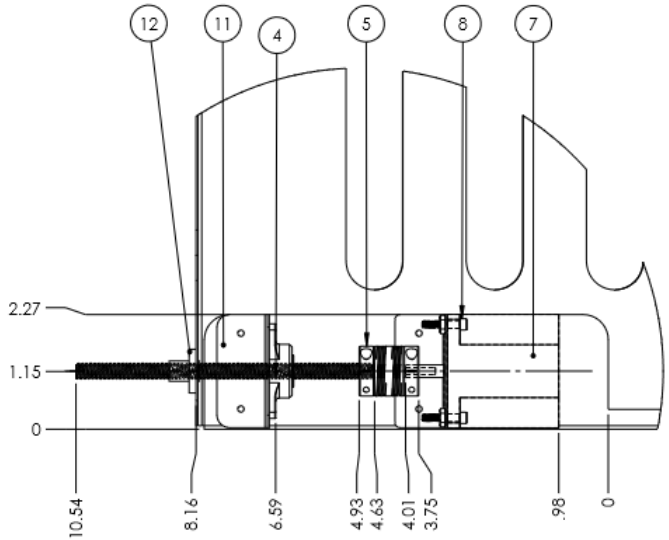


Detail Mechanical Components

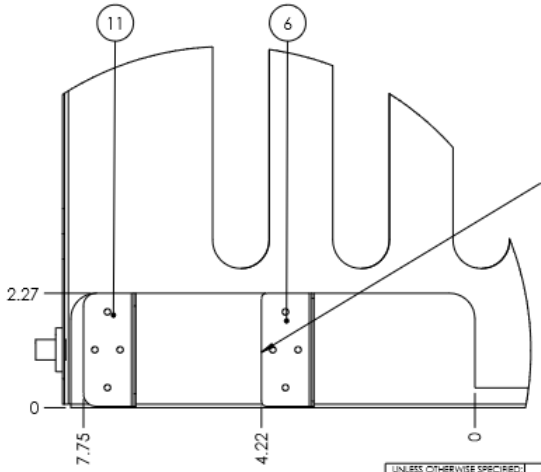


Detail Mounting Components

ITEM NO.	PART NAME	DESCRIPTION	QTY.
4	LEAD SCREW	SEE ORDERED PARTS SPECIFICATIONS SHEET	1
5	FLEXIBLE SHAFT COUPLING	SEE ORDERED PARTS SPECIFICATIONS SHEET	1
6	STEPPER MOTOR MOUNT		1
7	NEMA 23 STEPPER MOTOR	SEE ORDERED PARTS SPECIFICATIONS SHEET	1
8	3/4 X 6-32 SOCKET HEAD SCREW		4
9	6-32 HEX NUT		4
10	MOUNTED SLEEVE BEARING	NOTED DRAWING 2	1
11	BEARING MOUNT 1	20 GAUGE GALVENIZED STEEL	1
12	T8 THREADED ROD LEAD SCREW NUT	NOTED DRAWING 2	1



DETAIL A
SCALE 1 : 2



DETAIL B
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL			
	COMMENTS:		

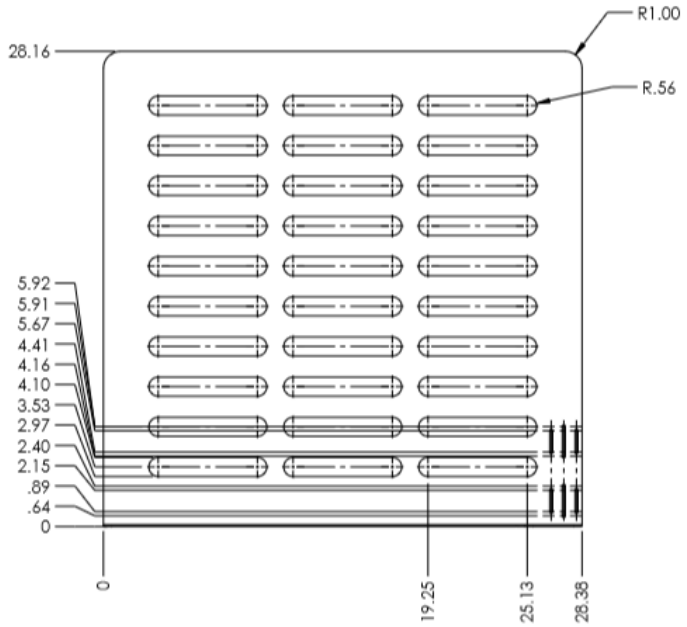
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Location Details
SCALE: 1:2	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

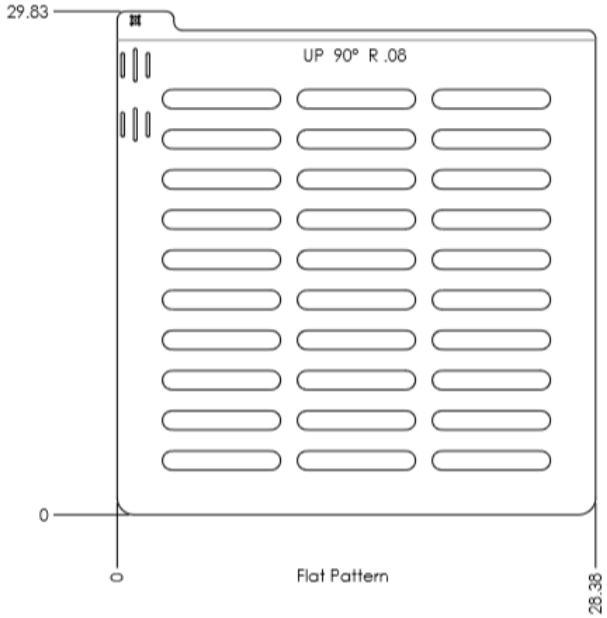
ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	INNER SLIDE	20 GAUGE GALVENIZED STEEL	1



Front View



Side View



Flat Pattern

SOLIDWORKS Educational Product. For Instructional Use Only.

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES	CHECKED BY:	Justin D.	4/18/2020
TOLERANCES:	ENG APPR.	James D.	4/18/2020
FRACTIONAL ±1/32	MFG APPR.	James D.	4/18/2020
ANGULAR: ±1 DEG	Q.A.		
TWO PLACE DECIMAL ±0.010			
THREE PLACE DECIMAL ±0.005			
MATERIAL			

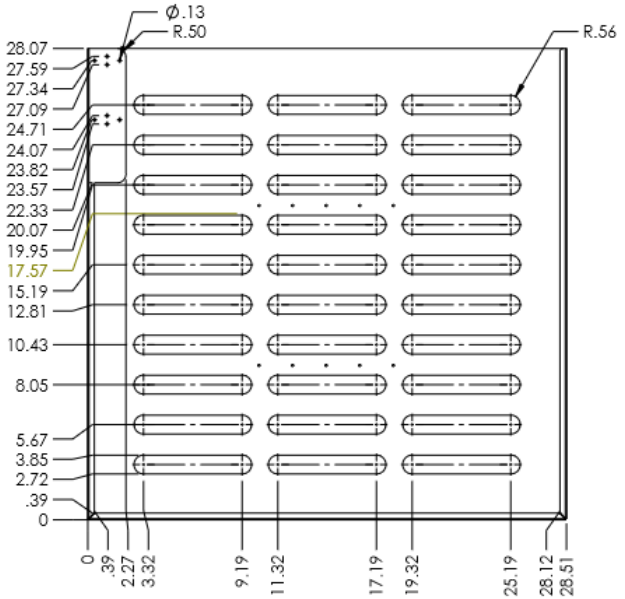
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

COMMENTS:
DXF'S Attached

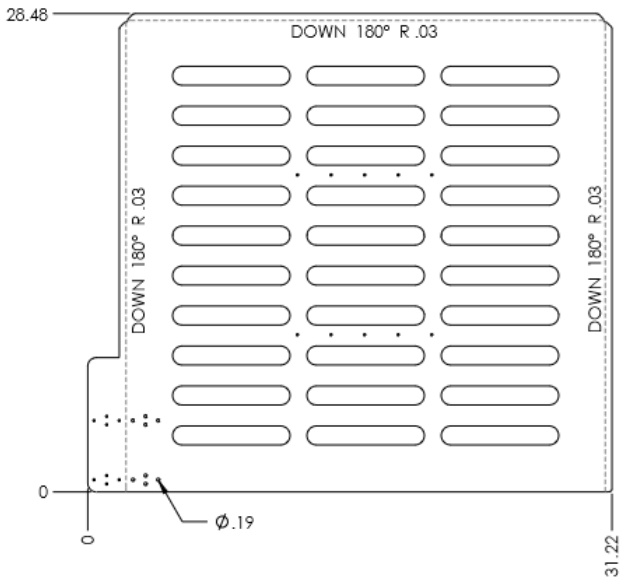
VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Inner Slide Detail
SCALE: 1:8	DWG 1 OF 1

ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	OUTER SLIDE	20 GAUGE GALVENIZED STEEL	1



Front View



Flat Pattern



Side View

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL			
	COMMENTS: DXF'S Attached		

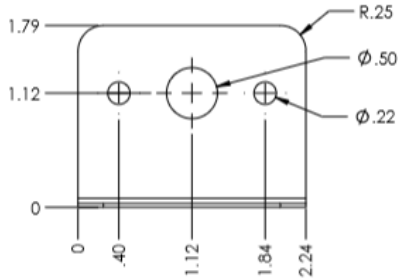
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

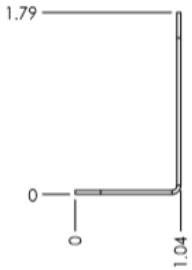
SIZE	DWG. NAME
B	Outer Slide Detail
SCALE: 1:6	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

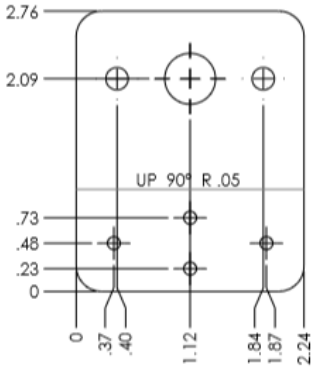
ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	BEARING MOUNT 1	20 GAUGE GALVENIZED STEEL	1



Front View



Top View



Flat Pattern

SOLIDWORKS Educational Product. For Instructional Use Only.

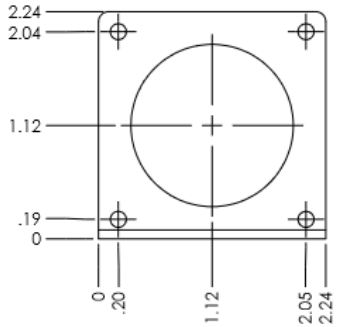
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CAD BY:		
	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL 20 Gauge Galvenized Steel	COMMENTS: DXF Attached		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

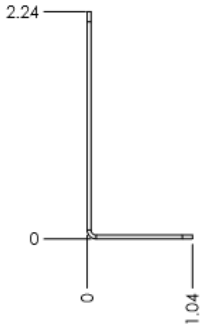
VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME	
B	Bearing Mount Detail	
SCALE: 1:1		DWG 1 OF 1

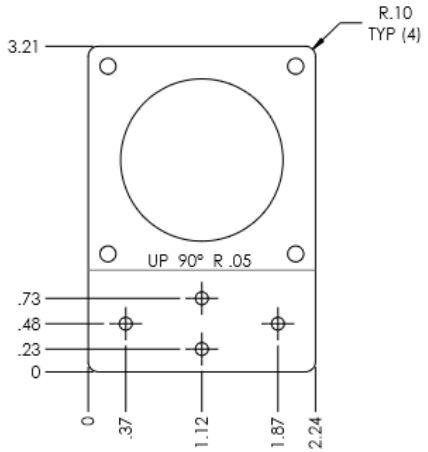
ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	STEPPER MOTOR MOUNT	20 GAUGE GALVENIZED STEEL	1



Front View



Side View



Flat Pattern

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CAD BY:		
	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D	4/18/2020
	MFG APPR.	James D	4/18/2020
	Q.A.		
MATERIAL 20 Gauge Galvenized Steel	COMMENTS: DXF'S Attached		

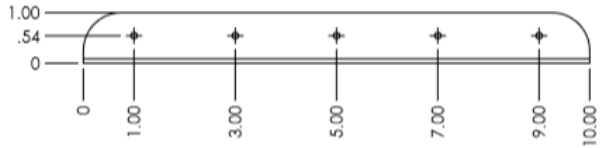
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Motor Mount Detail
SCALE: 1:1	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

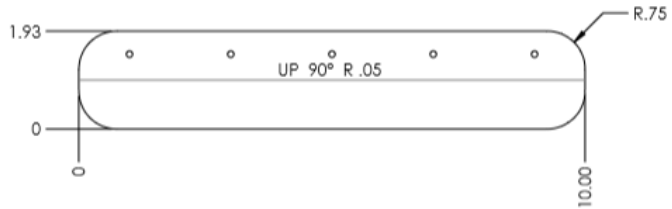
ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	OUTER SLIDE STIFFENER	20 GAUGE GALVENIZED STEEL	2



Front View



Side View



Flat Pattern

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL: 20 Gauge Galvenized Steel	COMMENTS: DFX'S Attached		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE B | DWG. NAME: Outlet Stiffener Detail
SCALE: 1:2 | DWG 1 OF 1

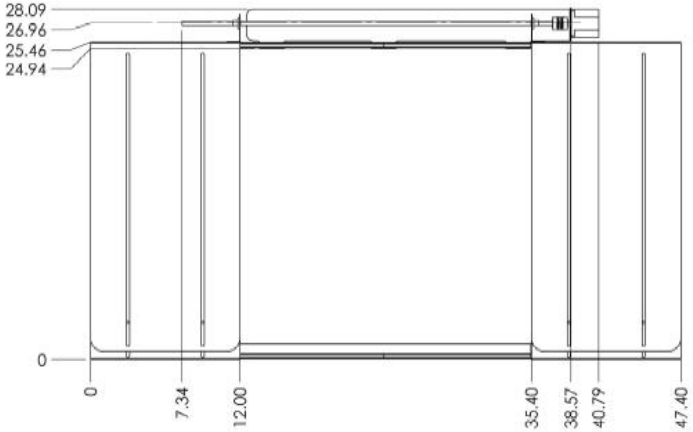
SOLIDWORKS Educational Product. For Instructional Use Only.

Outlet Shutter

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	OUTLET SHUTTER DOOR	DETAIL DRAWING 3	2
2	RAIL BRACKET	12 TO 24 IN DRAWER SLIDES	4
3	BALL SCREW	.25 - 20 TPI LH AND RH THREADED ROD	1
4	BALL SCREW COUPLING MOUNT	DETAIL DRAWING 6	2
5	OUTLET SHUTTER DOOR SMALL	DETAIL DRAWING 4	2
6	NEMA 23 STEPPER MOTOR		1
7	MOTOR MOUNT	DETAIL DRAWING 5	1
8	T8 THREADED ROD LEAD SCREW NUT	.25 - 20 TPI LH AND RH NUTS	2
9	BASE BOARD	1.5 X 0.75 X 23.625 IN PINE BOARD	1



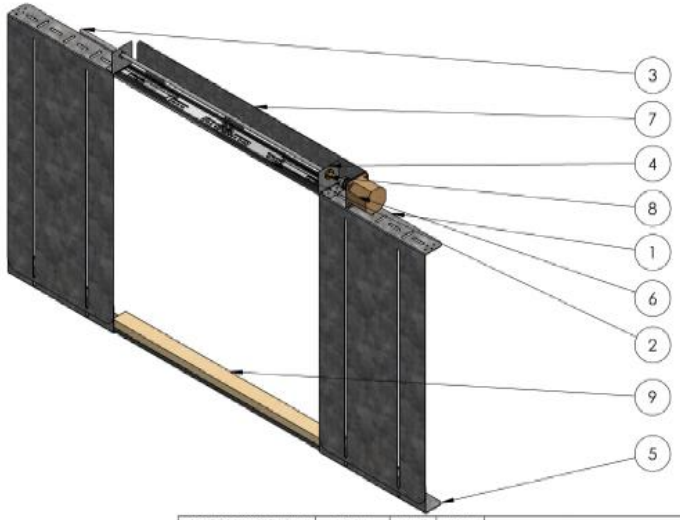
Top View



Front View



Side View



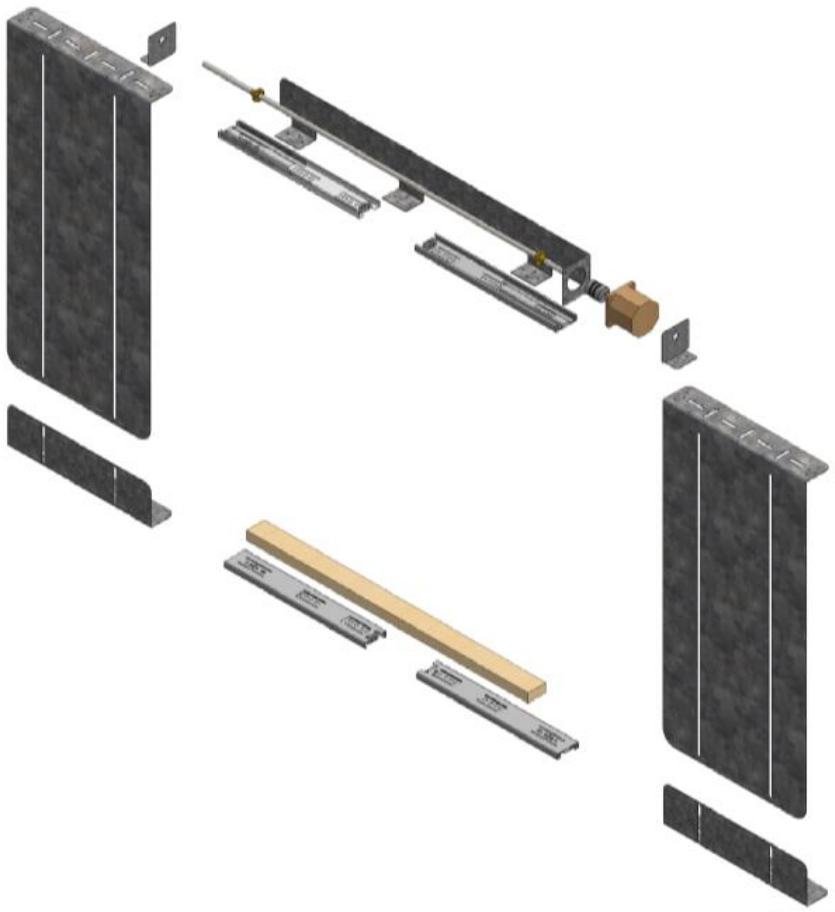
UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL	COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Outlet Shutter
SCALE: 1:8	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	OUTLET SHUTTER DOOR	DETAIL DRAWING 3	2
2	RAIL BRACKET	12 TO 24 IN DRAWER SLIDES	4
3	BALL SCREW	.25 - 20 TPI LH AND RH THREADED ROD	1
4	BALL SCREW COUPLING MOUNT	DETAIL DRAWING 6	2
5	OUTLET SHUTTER DOOR SMALL	DETAIL DRAWING 4	2
6	NEMA 23 STEPPER MOTOR		1
7	MOTOR MOUNT	DETAIL DRAWING 5	1
8	T8 THREADED ROD LEAD SCREW NUT	.25 - 20 TPI LH AND RH NUTS	2
9	BASE BOARD	1.5 X 0.75 X 23.625 IN PINE BOARD	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/32
ANGULAR: ±1 DEG
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005
MATERIAL

	NAME	DATE
CAD BY:		
CHECKED BY:	Justin D.	4/18/2020
ENG APPR.	James D.	4/18/2020
MFG APPR.	James D.	4/18/2020
Q.A.		
COMMENTS:		

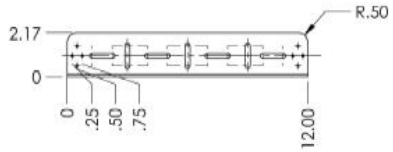
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

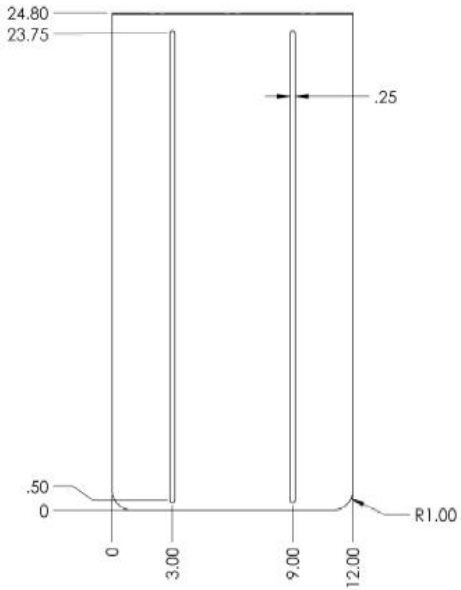
SIZE B | DWG. NAME: Exploded View
SCALE: 1:6 | DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	OUTLET SHUTTER DOOR	DETAIL DRAWING 3	2

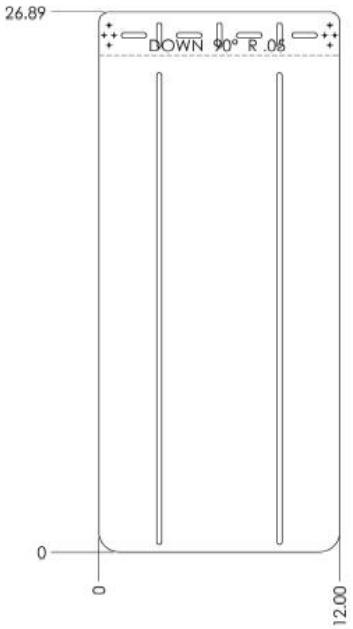


Top View



Front View





Flat Pattern

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL: 20 Gauge Galvenized Steel	COMMENTS: DXF's Attached		

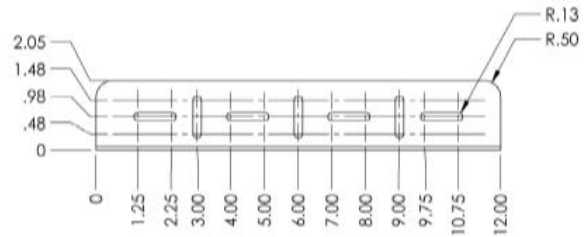
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Outlet Shutter Door
SCALE: 1:5	DWG 1 OF 1

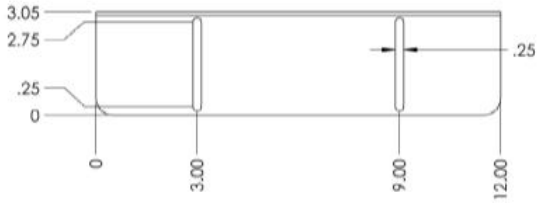
SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	OUTLET SHUTTER DOOR SMALL	DETAIL DRAWING 4	2

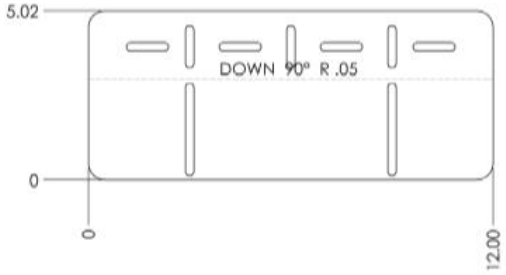


Top View





Front View



Flat Pattern

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL: 20 Gauge Galvenized Steel	COMMENTS: DXF's Attached		

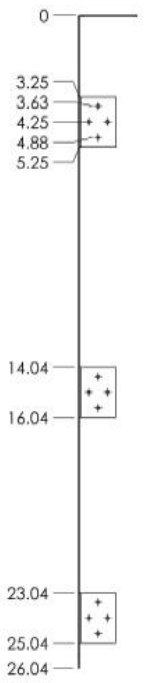
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

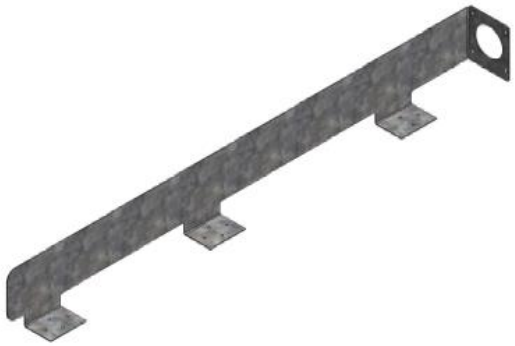
SIZE	DWG. NAME
B	Outlet Door Small
SCALE: 1:3	DWG 1 OF 1

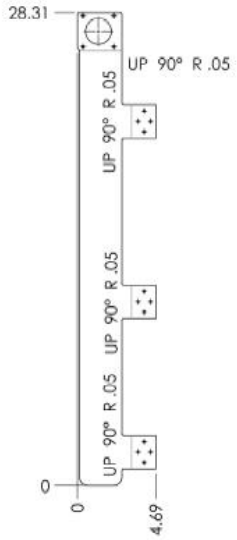
SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MOTOR MOUNT	DETAIL DRAWING 5	1

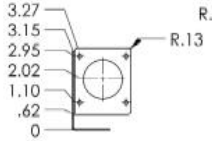


Top View

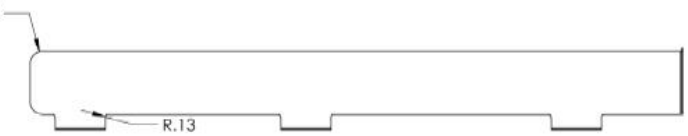




Flat Pattern



Side View



Front View

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL: 20 Gauge Galvenized Steel	COMMENTS: DXF's Attached		

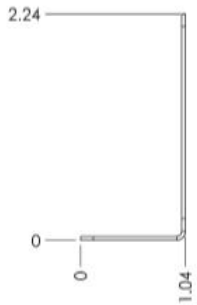
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

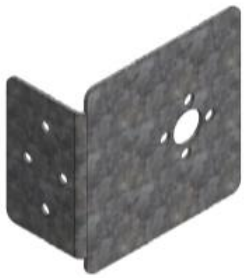
SIZE	DWG. NAME
B	Motor Mount
SCALE: 1:4	DWG 1 OF 1

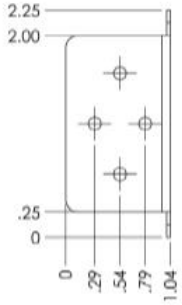
SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BALL SCREW COUPLING MOUNT	DETAIL DRAWING 6	1

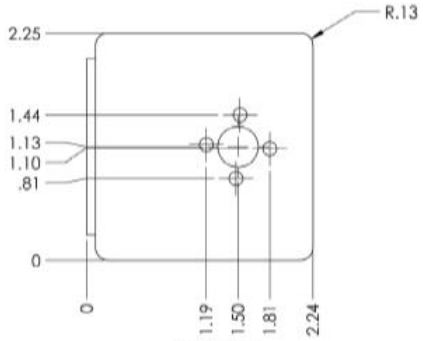


Side View

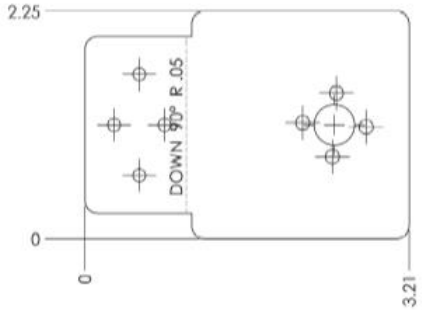




Top View



Front View



Flat Pattern

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL 20 Gauge Galvenized Steel	COMMENTS: DXF's Attached		

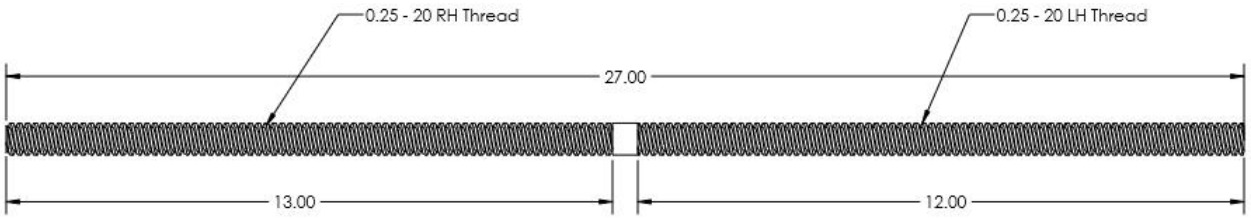
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Coupling Mount
SCALE: 1:1	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Dual Threaded Rod		2



Not to Scale

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL			
	COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

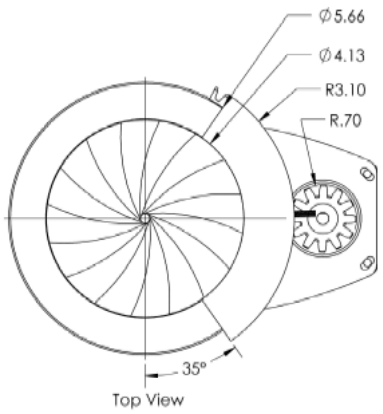
VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME	
B	Dual Threaded Rod	
SCALE: 1:2		DWG 1 OF 1

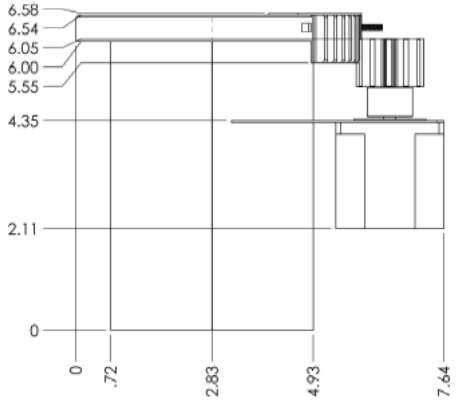
SOLIDWORKS Educational Product. For Instructional Use Only.

Iris Shutter

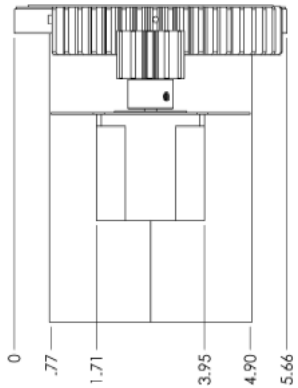
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PIPE MOUNT	DETAIL DRAWING 3	1
2	IRIS DIAPHAGM	EDMUND OPTICS	1
3	BOTTOM IRIS MOUNT	DETAIL DRAWING 4	1
4	NEMA 23 STEPPER MOTOR	STEPPER MOTOR	1
5	IDLER GEAR 6 IN	MCMASTER 6867K840	1
6	PINION GEAR 1.2 IN	MCMASTER 6325K133	1
7	GEAR STABLIZER	DETAIL DRAWING 4	1
8	MOTOR MOUNT	DETAIL DRAWING 7	1
9	IRIS MOUNT BOTTOM		1



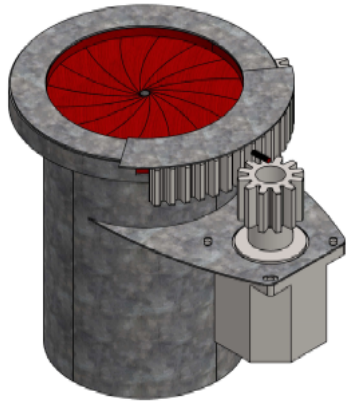
Top View



Front View



Side View



UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL	COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

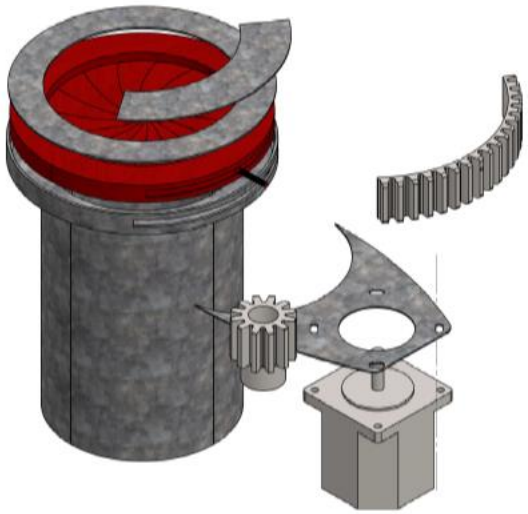
VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	4 in Iris Shutter
SCALE: 1:2	DWG 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

A36

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Pipe Mount	dETAIL DRAWING 2	1
2	Iris Diaphagm	eDMUND oPTICS	1
3	Top Iris Mount	DETAIL DRAWING 3	1
4	Nema 23 Stepper Motor	Stepper Motor	1
5	Idler Gear 6 in	MCMASTER 6867K840	1
6	Pinion Gear 1.2 in	MCMASTER 6325K133	1
7	Gear Stablizer	detail Drawing 3	1
8	Motor Mount	Detail drawing 6	1
9	Iris Mount Bottom		1



SOLIDWORKS Educational Product. For Instructional Use Only.

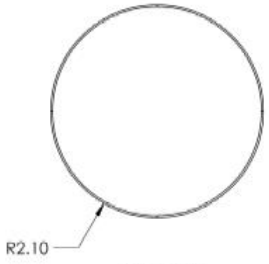
UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG. APPR.	James D.	4/18/2020
	MFG. APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL			
	COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

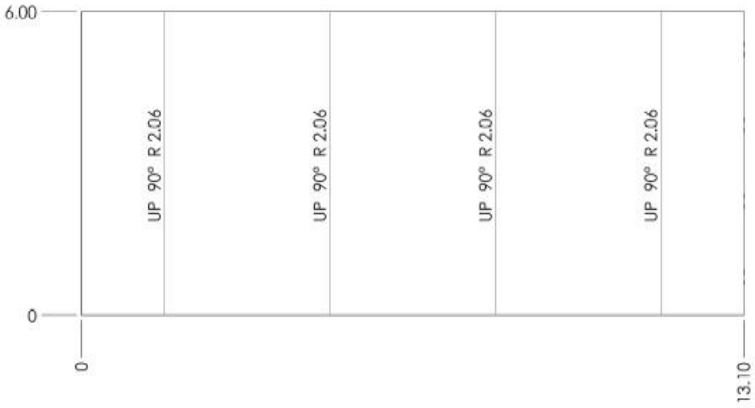
SIZE	DWG. NAME	
B	Exploded View	
SCALE: 1:2		DWG 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PIPE MOUNT	dETAIL DRAWING 2	1

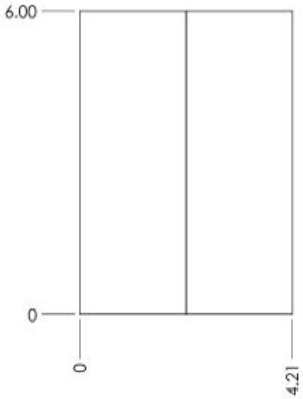


Top View





Flat Pattern



Side View

SOLIDWORKS Educational Product. For Instructional Use Only.

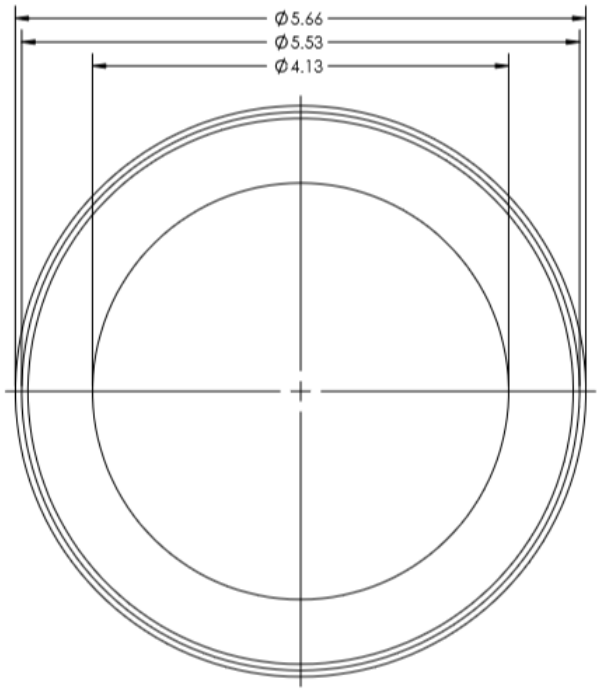
UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL: 20 Gauge Galvenized Steel	COMMENTS: DXF's Attached		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

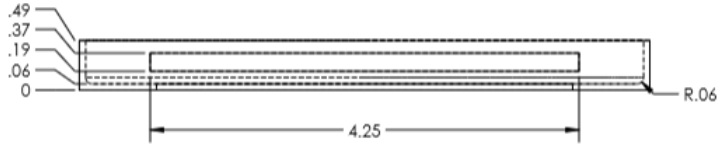
VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Pipe Mount Detail
SCALE: 1:2	DWG 1 OF 1

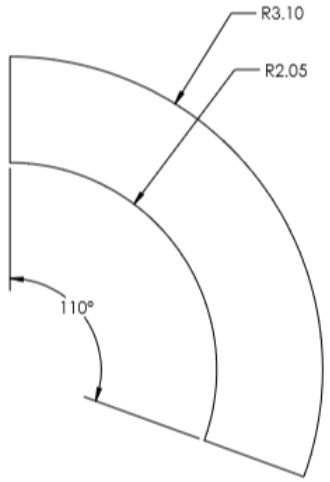
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BOTTOM IRIS MOUNT	DETAIL DRAWING 4	1
2	GEAR STABLIZER	20 GAUGE GALVENIZED STEEL	1



Top View
Bottom Iris Mount



Front View
Bottom Iris Mount



Top View
Gear Stablizer

SOLIDWORKS Educational Product. For Instructional Use Only.

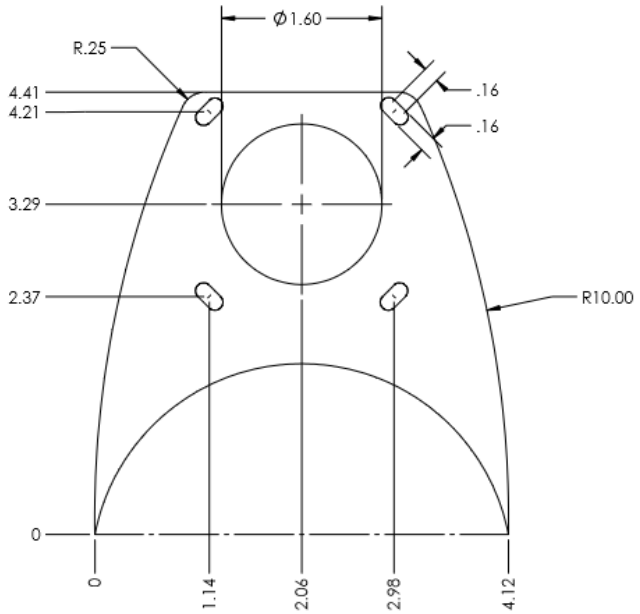
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CAD BY:		
	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.	James D.	4/18/2020
	MFG APPR.	James D.	4/18/2020
	Q.A.		
MATERIAL 20 GAUGE GALVENIZED STEEL	COMMENTS: DXF's Attached		

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

VISIONARY ENGINEERING
OUR FUTURE IS 2020

SIZE	DWG. NAME
B	Mount & Stablizer Details
SCALE: 1:1	DWG 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MOTOR MOUNT	Detail drawing 6	1



Top View

UNLESS OTHERWISE SPECIFIED:		CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES		CHECKED BY:	Justin D.	4/18/2020
TOLERANCES:		ENG APPR.	James D.	4/18/2020
FRACTIONAL ±1/32		MFG APPR.	James D.	4/18/2020
ANGULAR: ±1 DEG		Q.A.		
TWO PLACE DECIMAL	±0.010			
THREE PLACE DECIMAL	±0.005			

MATERIAL: 20 Gauge Galvenized Steel

COMMENTS: DXF's Attached

VISIONARY ENGINEERING
OUR FUTURE IS 2020

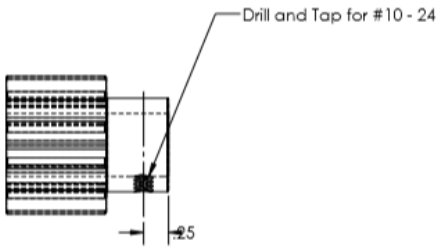
SIZE: B | DWG. NAME: Motor Mount Detail

SCALE: 1:1 | DWG 1 OF 1

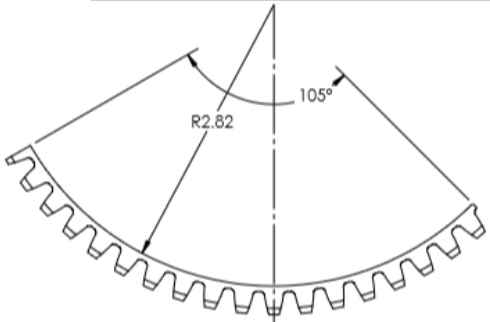
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

SOLIDWORKS Educational Product. For Instructional Use Only.

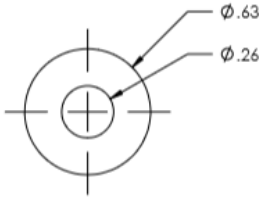
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PINION GEAR 1.2 IN	MCMASTER 6325K133	1
2	DRIVEN GEAR 6.2 IN OD	PROVIDED GEAR	1
3	SHAFT SPACER	CR STEEL	1



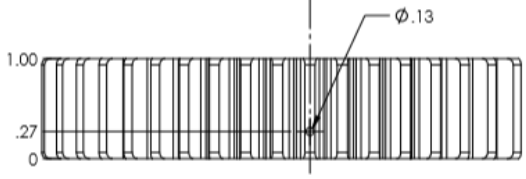
Pinion Gear



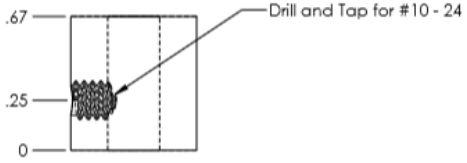
Top View Driven Gear



Top View Shaft Spacer



Front View Driven Gear



Side View Shaft Spacer

UNLESS OTHERWISE SPECIFIED:	CAD BY:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 ANGULAR: ±1 DEG TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	CHECKED BY:	Justin D.	4/18/2020
	ENG APPR.		4/18/2020
	MFG APPR.		4/18/2020
	Q.A.		
MATERIAL Material is specified in the description	COMMENTS:		

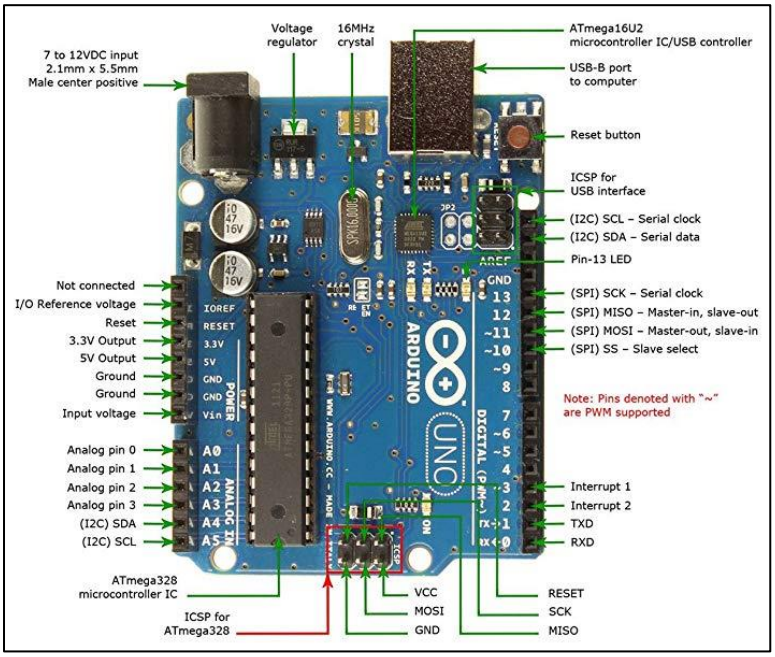
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE UNIVERSITY OF TEXAS AT TYLER. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT PERMISSION OF THE UNIVERSITY OF TEXAS AT TYLER IS PROHIBITED.

SIZE B | DWG. NAME: Gears and Spacer Details | DWG 1 OF 1

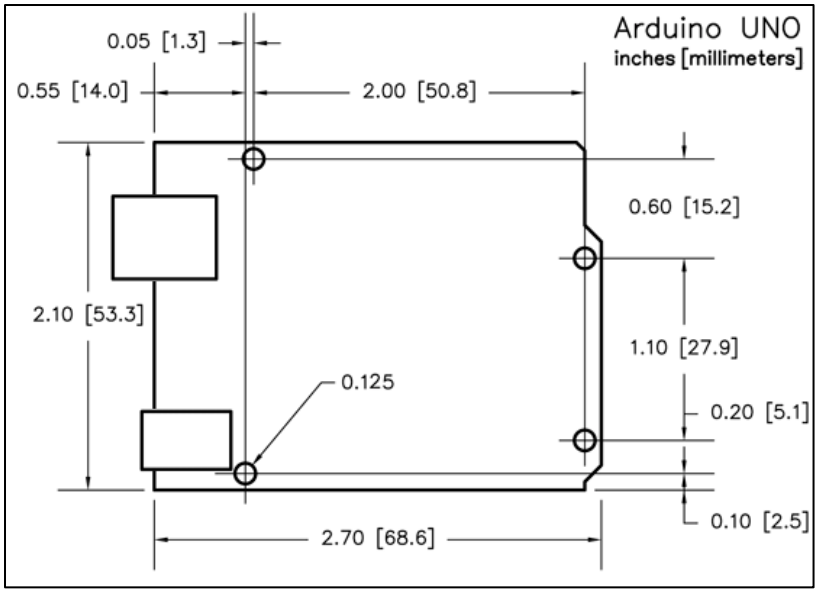
SOLIDWORKS Educational Product. For Instructional Use Only.

Appendix G

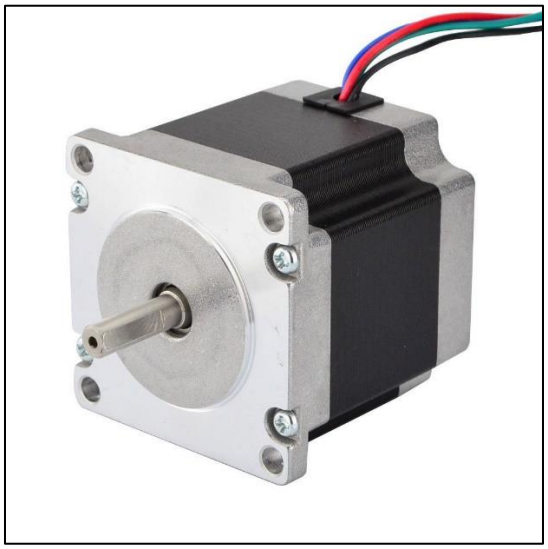
Electronic Components and Circuit Diagrams



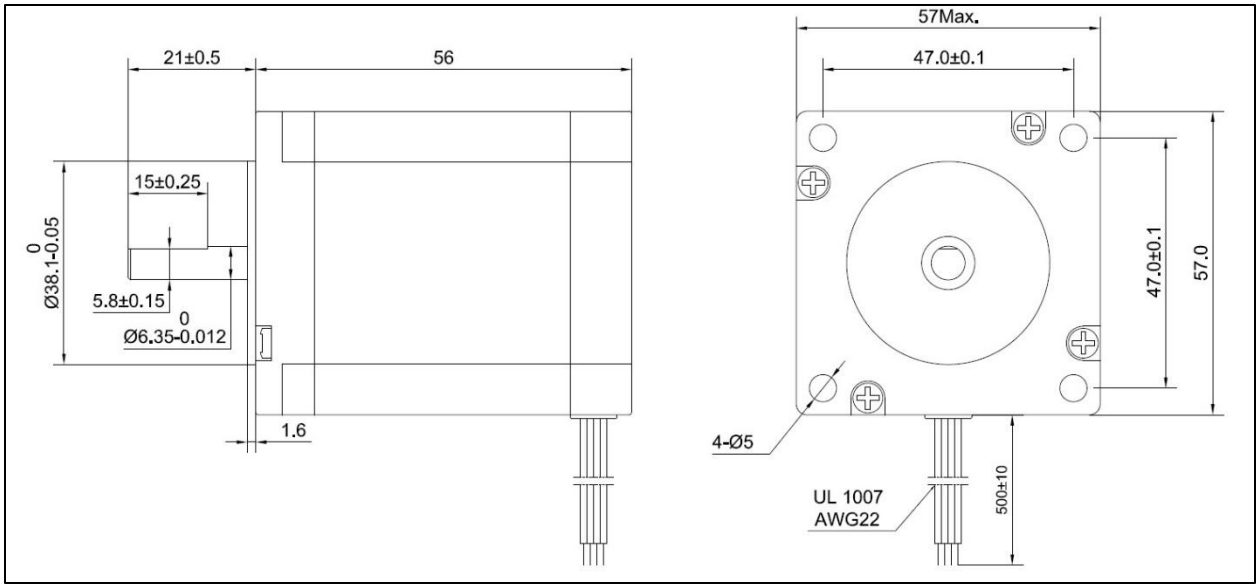
Arduino Uno 3 General Layout



Arduino Dimensions.



NEMA 23 Bipolar Stepper Motor



NEMA 23 Dimensions

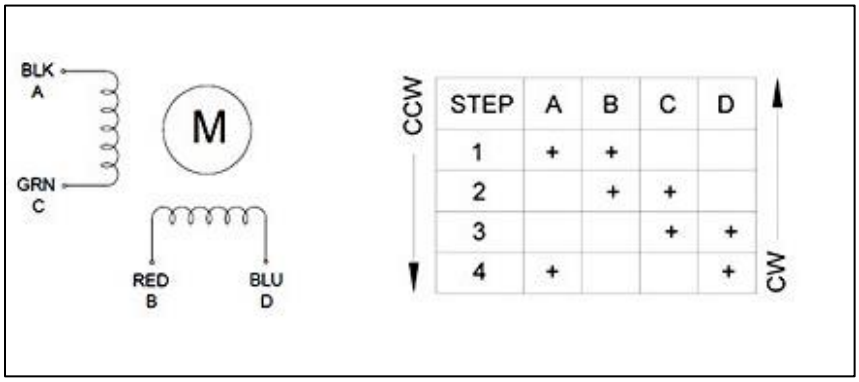
NEMA 23 General Specifications

Step Angle	1.8º
Positional Accuracy	±5%
Number of Phase	2
Temperature Rise	80º C Maximum
Rotor Inertia	300 gcm^2
Dielectric Strength	500 V AC
Insulation Resistance	100 MΩ (500V DC)
Ambient Temperature	-10º C to 50º C
Insulation Class	B

Weight	0.7 kg

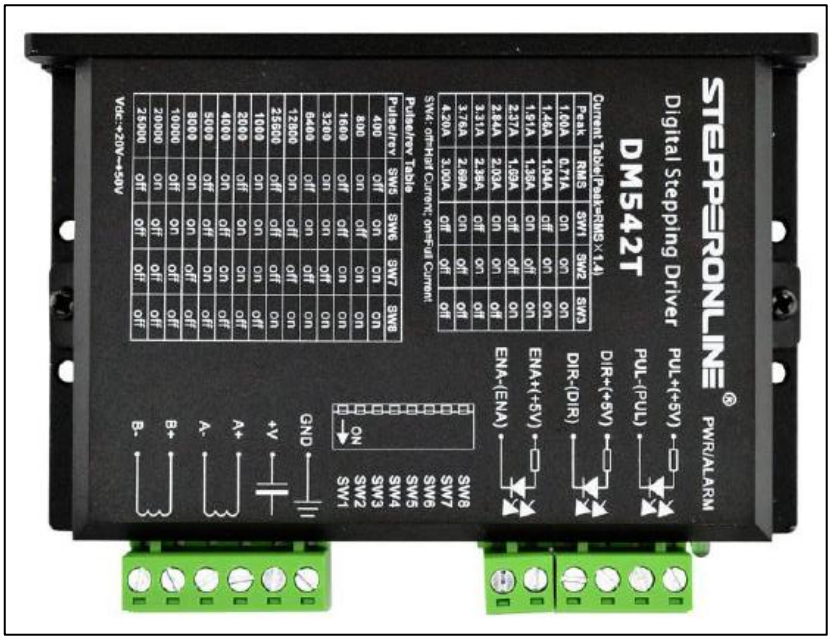
NEMA 23 Electrical Specifications

Voltage Per Phase	2.5 V DC
Rated Current Per Phase	2.8 A DC
Resistance Per Phase (±10%)	0.9 Ω
Induction Per Phase (±20% 1 kHz)	2.5 mH
Holding Torque	1.26 Nm (178.5 oz.in)

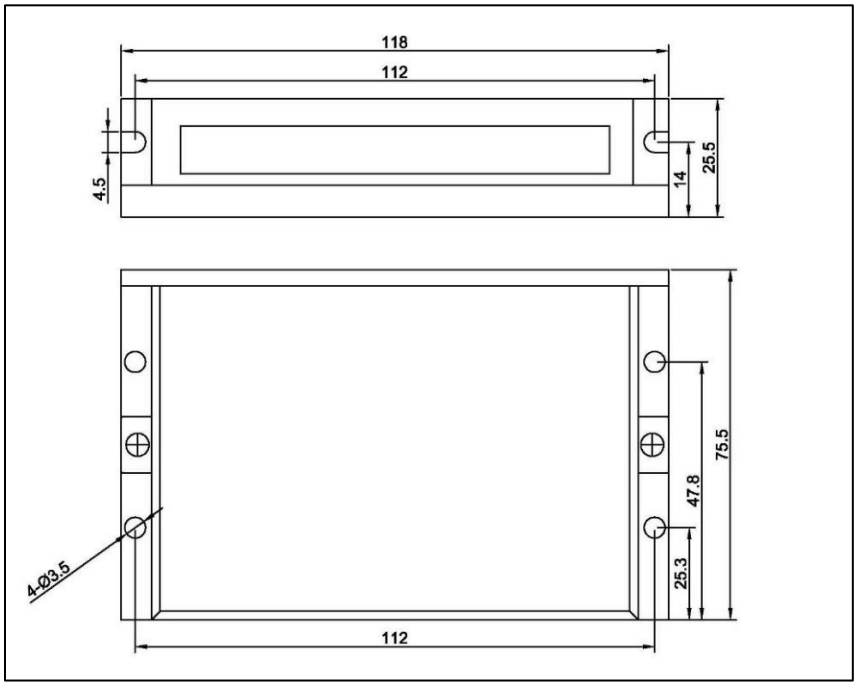


A+	A-	B+	B-
Black	Green	Red	Blue

Connections



DM542T Stepper Motor Driver.



DM542T Dimensions.*DM542T Electrical Specifications.*

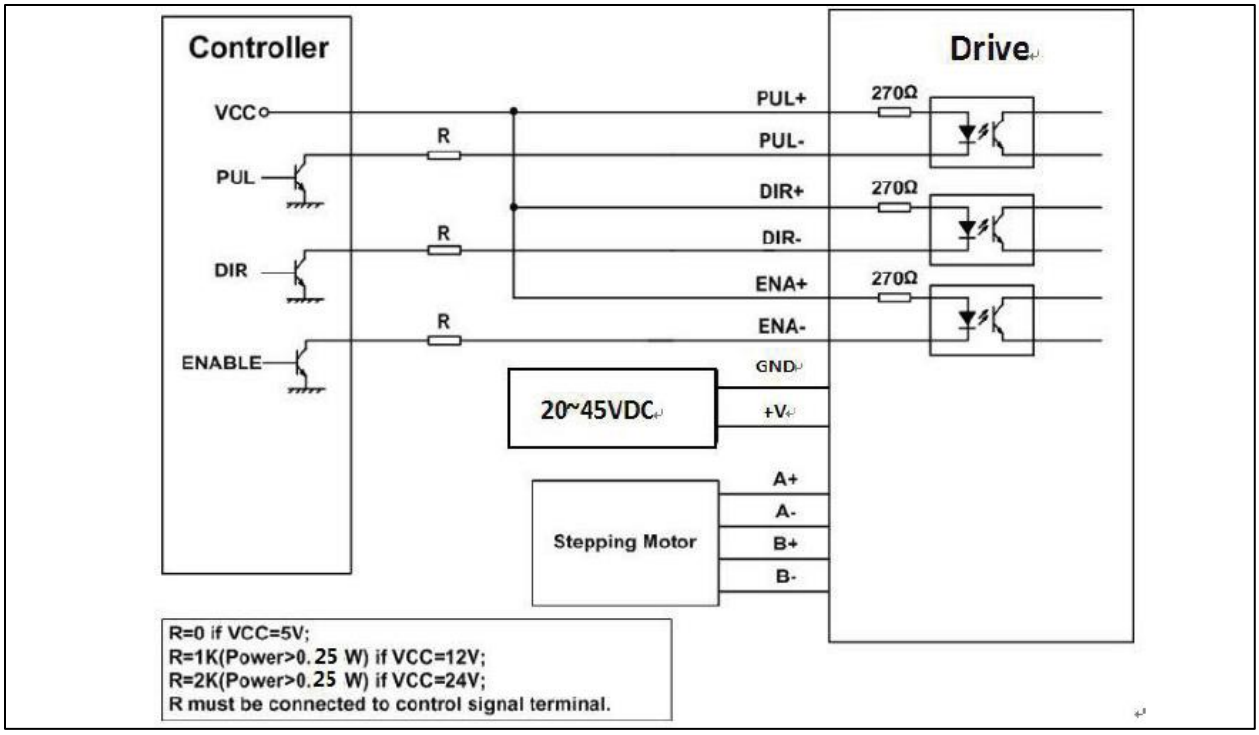
Ambient Temperature	0º C to 65º C
Operating Temperature	-10º C to 45º C
Humidity	40%RH to 90%RH
Vibration	10 Hz to 55Hz (0.15mm)
Storage Temperature	-20º C to 65º C
Weight	0.21kg

DM542T Electrical Specifications.

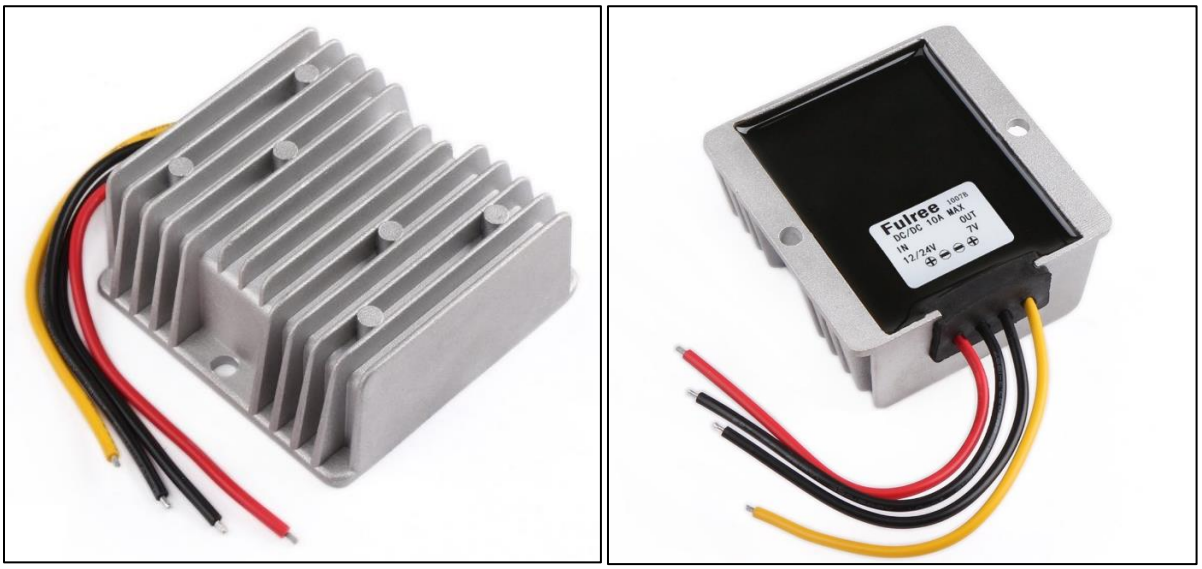
Input Voltage	20 V DC to 50 V DC (Typical 36 V DC)
Output Current	1 A DC to 4.2 A DC
Micro step	400 to 25600 (steps/rev)
Pulse Input Frequency	0 kHz to 200 kHz
Logic Signal Current	7 mA to 16 mA (Typical 10 mA)
Pulse Width	2.5 µs
Isolation Resistance	500 MΩ

Connector Configurations.

Pin Function	Details
PUL+/ PUL-	Pulse signal: In single pulse (pulse/direction) mode, this input represents pulse signal, each rising edge active; 4-5V when PUL-HIGH, 0-0.5V when PUL-LOW. The DM542T drive has no double pulse mode (pulse/pulse). For reliable response, pulse width should be longer than 2.5μs
DIR+/DIR-	DIR signal: In single-pulse mode, this signal has low/ voltage levels, representing two directions of motor rotation; The DM542T drive has no double pulse mode (pulse/pulse). 4-5V when DIR-HIGH, 0-0.5V when DIR-LOW. Please note that rotation direction is also related to motor-drive wiring match. Exchanging the connection of two wires for a coil to the drive will reverse motor direction.
ENA+/ENA-	Enable signal: This signal is used for enabling/disabling the drive. High level for enabling the drive and low level for disabling the drive. Usually left unconnected i.e. enabled.
GND	Power Ground
+V	Power supply. 20~50 VDC including voltage fluctuation and EMF voltage.
A+/A-	Motor Phase A
B+/B-	Motor Phase B



Typical Connection Example (A resistor will not be needed because VCC will be 5V).



Step down DC to DC Transformer/Converter.

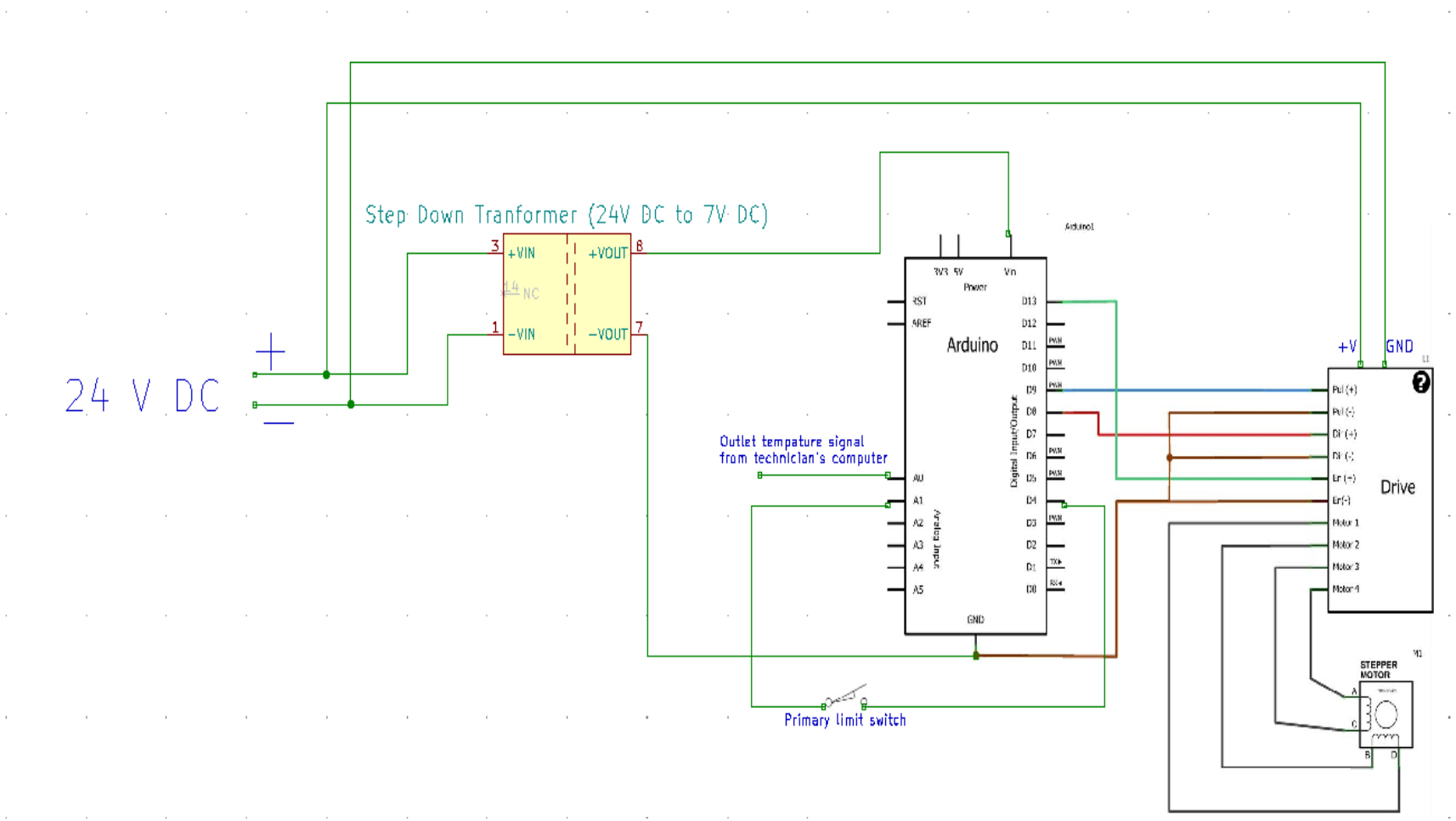
Transformer Specifications.

Input Voltage	10 V DC to 35 V DC
Output Voltage	7 V DC
Output Current	10 A DC
Working Temperature	-25º C 50º C
Dimensions (l x w x h)	74mm x 74mm x 32mm
Weight	0.25 kg

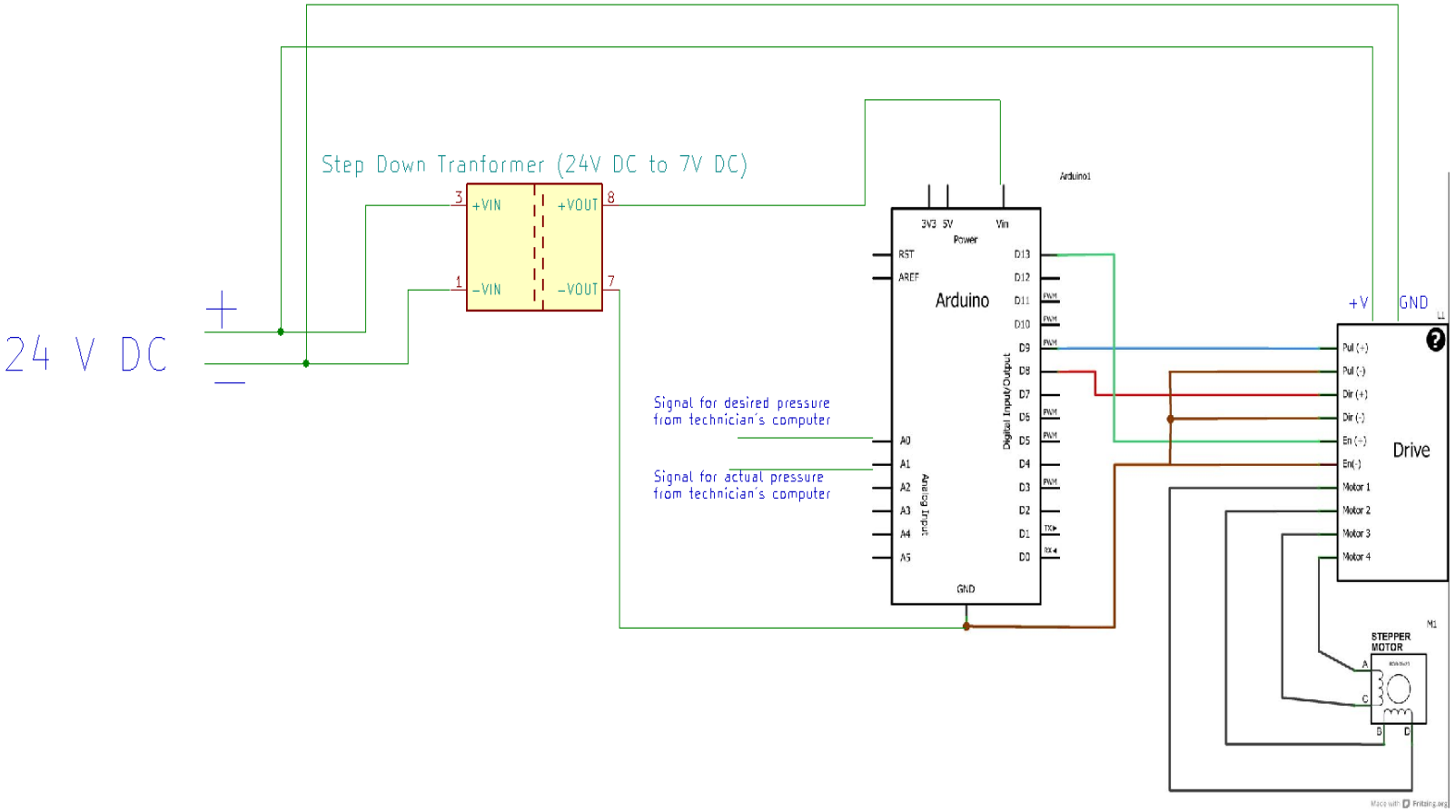
Transformer Configuration.

Red	Black (1)	Black (2)	Yellow
Input +	Input -	Output -	Output +

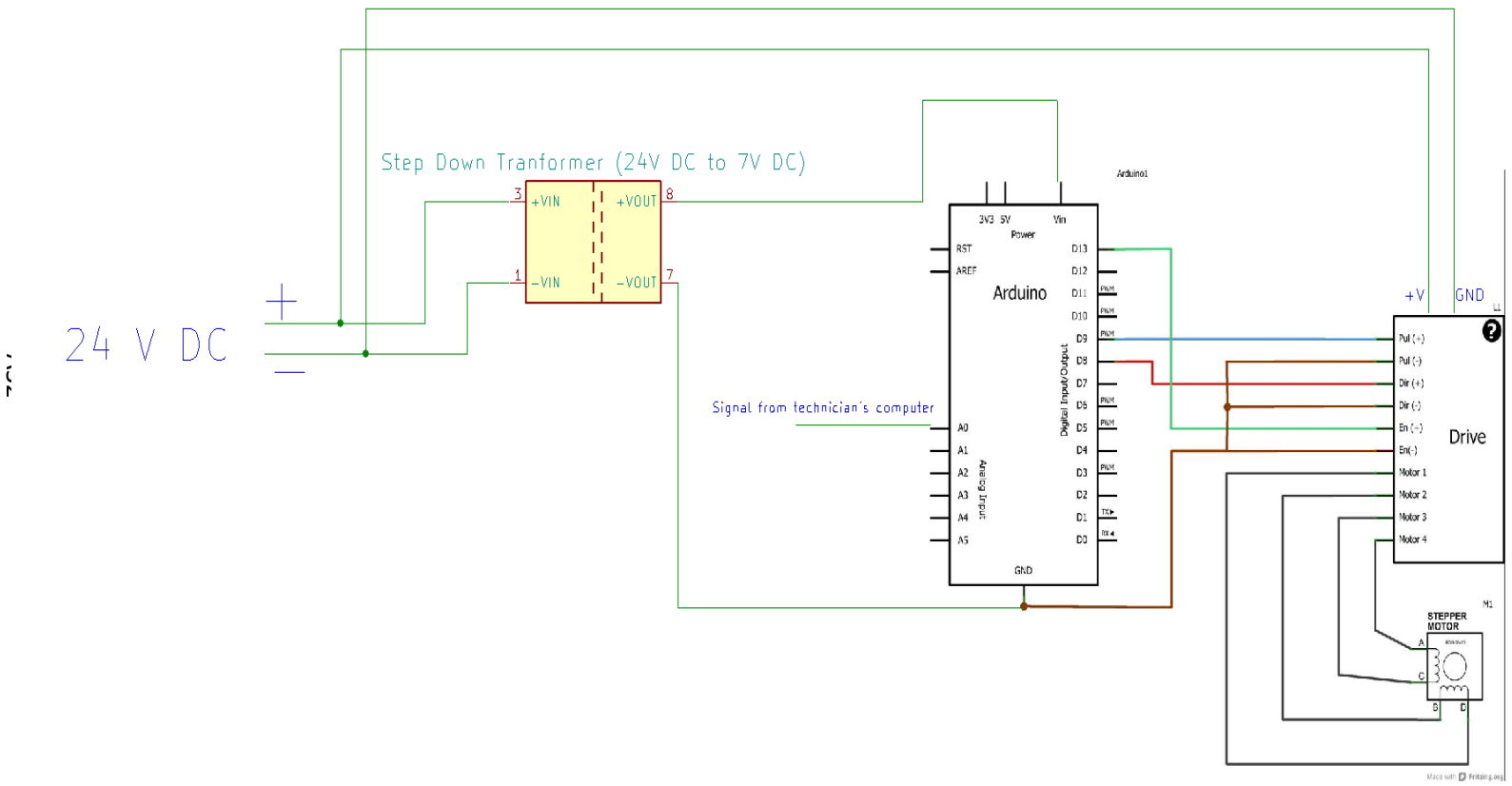
Inlet Shutter Wiring Diagram



Outlet Shutter Wiring Diagram



Iris Shutter Wiring Diagram

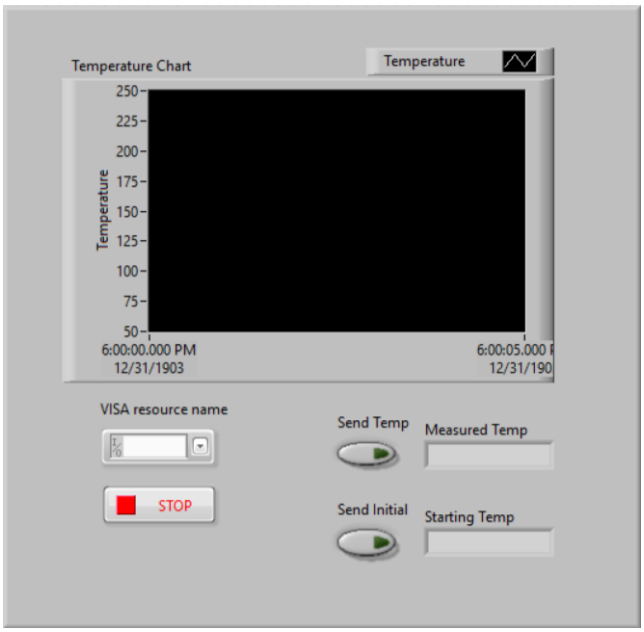


Appendix H

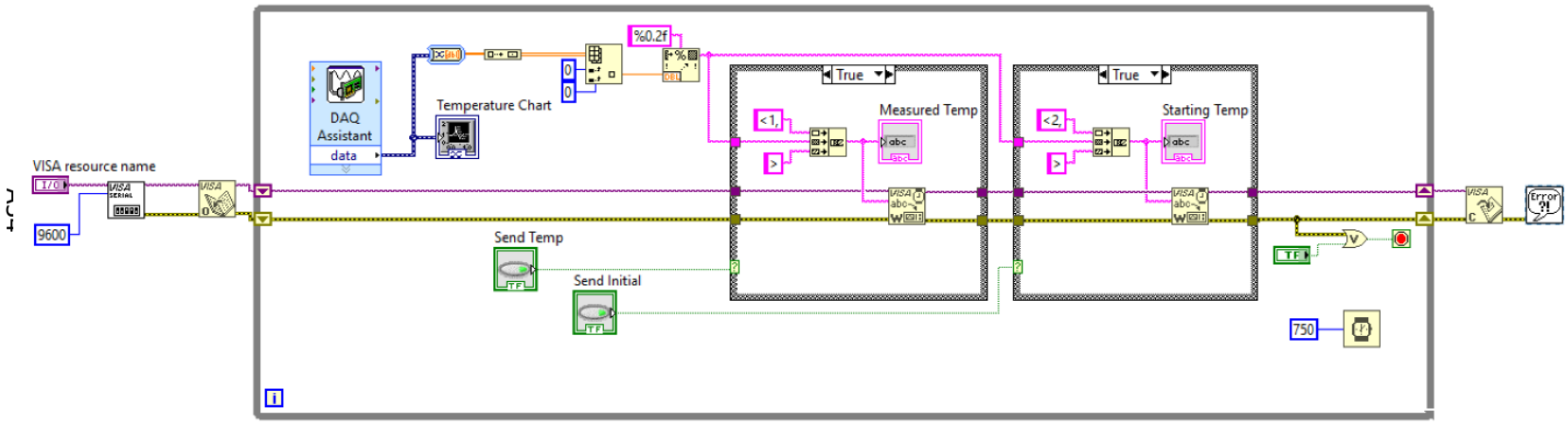
Programming Code

Inlet Shutter

This section contains documentation of the inlet shutter's programming. Shown below is the LabVIEW programming for the inlet shutter. Following the LabVIEW figures is the Arduino code for the shutter.



LabVIEW Interface for Inlet Shutter Control



LabView Program Layout for Inlet Shutter

Inlet Arduino Code

```
#include <LiquidCrystal.h>
const byte numChars = 32;
char receivedChars[numChars];
char tempChars[numChars];        // temporary array for use when parsing
// variables to hold the parsed data
char messageFromPC[numChars] = {0};
int integerFromPC = 0;
float startTemp = 0.0;
float floatFromPC = 0.0;
int DC = 0;
int OVar = 0;
boolean newData = false;
//               BS E  D4 D5  D6  D7
LiquidCrystal lcd(7, 8, 9, 10, 11, 12);
#include <PID_v1.h>
double Setpoint ; // will be the desired value
double Input; //PID input
double Output ; //PID output - max output is 255.00
double Kp=1, Ki=1, Kd=5; ////////////////////////////////////////PID Parameters
PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd, DIRECT);
#include <AccelStepper.h>
int StepSpeed = 0;
//AccelStepper stepper; // Defaults to AccelStepper::FULL4WIRE (4 pins) on 2, 3, 4, 5
//AccelStepper stepper(1,PULSpin, DIRpin);
AccelStepper stepper(1,6,5);
```

```
//================================================================
=====

void setup() {
   Serial.begin(9600);
   lcd.begin(16, 2);
   myPID.SetMode(AUTOMATIC);  //Turn the PID on
   myPID.SetTunings(Kp, Ki, Kd);  //Adjust PID values
   stepper.setMaxSpeed(9000);
}

//================================================================
=====

void loop() {
   recvWithStartEndMarkers();
   stepperMotor();
   if (newData == true) {
      strcpy(tempChars, receivedChars);
         // this temporary copy is necessary to protect the original data
         //   because strtok() used in parseData() replaces the commas with \0
      parseData();
      showParsedData();
      counter();
      pid();
     // stepperMotor();
```

```
        newData = false;


    }
}

//=================================================================
====

void recvWithStartEndMarkers() {
    static boolean recvInProgress = false;
    static byte ndx = 0;
    char startMarker = '<';
    char endMarker = '>';
    char rc;

    while (Serial.available() > 0 && newData == false) {
        rc = Serial.read();

        if (recvInProgress == true) {
            if (rc != endMarker) {
                receivedChars[ndx] = rc;
                ndx++;
                if (ndx >= numChars) {
                    ndx = numChars - 1;
                }
            }
```

```
            else {
                receivedChars[ndx] = '\0'; // terminate the string
                recvInProgress = false;
                ndx = 0;
                newData = true;
            }
        }

        else if (rc == startMarker) {
            recvInProgress = true;
        }
    }
}

//============================================================================

void parseData() {      // split the data into its parts

    char * strtokIndx; // this is used by strtok() as an index

    strtokIndx = strtok(tempChars, ","); // get the first part - the string
    integerFromPC = atoi(strtokIndx);     // convert this part to an integer

    strtokIndx = strtok(NULL, ",");
    floatFromPC = atof(strtokIndx);     // convert this part to a float
```

```
    if (integerFromPC == 2) {
      startTemp = floatFromPC;
    }

}

//=====================================================================
====

void showParsedData() {

    lcd.setCursor(0, 0);
    lcd.print("Temp            ");
    lcd.setCursor(0, 1);
    lcd.print("SetT          F  ");
    lcd.setCursor(5, 0);
    lcd.print(floatFromPC);
    lcd.setCursor(5, 1);
    lcd.print(startTemp);
    //lcd.setCursor(11,0);
    //lcd.print(Output);

}

//=====================================================================
====
```

```
void counter() {
  if (startTemp > 0){startTemp = startTemp + 0.010;}
}

//================================================================
====

void pid() {
  if(startTemp > floatFromPC){myPID.SetControllerDirection(DIRECT);DC = 1;}
  if(startTemp < floatFromPC){myPID.SetControllerDirection(REVERSE);DC = -1;}
    Input = floatFromPC;
    Setpoint = startTemp;
    myPID.Compute();
}

//================================================================
====

void stepperMotor() {
   OVar = DC*Output;
   StepSpeed = map(OVar,0,255,0,25);
   stepper.setSpeed(StepSpeed);
   stepper.runSpeed();
}
```

Outlet Shutter

Outlet Arduino Code

/*Description:

* This project is about an air duct will have two doors at the end with a pressure transducer in the duct. As doors close or open, pressure changes.

* The doors are opened and closed by a threaded rod turned by a stepper motor. I will need a code (with a home sensor) to move the doors to desired pressure and stop.

* Logic Sequence:

* Prog. Start – homes to switch (motor turns threaded rod to bring together the two doors)

* Inputs desired pressure in WC

* Stepper motor moves via PID until pressure is achieved

* Program end

*

* Components:

* - STEPPERONLINE Nema 23.

* - Stepper Motor Driver DM542T

* - Pressure transducer: Linear relationship between 0-5v and 0-1 in water column

* - home switch

*

* This offer is for the code of arduino and wiring diagram

Linear relationship between 0-5v and 0-1 in water column

* Circuit:

* Arduino Component

* 6 -------> step pin driver DM542T

* 7 -------> dir pin driver DM542T

* 8 -------> en pin driver DM542T

* 5 -------> home switch

```
 *      A0 -------->  pressure sensor

 */

//Libraries
#include <PID_v1.h>

#define PIN_INPUT 0

 //Define Variables we'll be connecting to
double Setpoint, Input, Output , OutputLast;

//Specify the links and initial tuning parameters
double Kp=2, Ki=5, Kd=1;
PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd, DIRECT);

//Pins definitions
#define stepPin 6         // STEP- pin
#define dirPin 7         // DIR- pin
#define enPin 8          // ENABLE- pin
#define homeSwitch 5    //home Switch
#define pressurePin A0

//Declare variables
float voltage;
float pressure;
//float setPoint=0.5;
```

```
void setup() {
Serial.begin(9600);// initialize serial monitor


 //initialize the variables we're linked to
  Input = analogRead(PIN_INPUT);
  Setpoint = 512;  // Pressure transducer: Linear relationship between 0-5v and 0-1 in water column
                //Ex: pressure desired: 0.5 ---> 2.5V ----> 1023/2=512


  //turn the PID on
  myPID.SetMode(AUTOMATIC);


pinMode(homeSwitch,INPUT_PULLUP);
pinMode(stepPin, OUTPUT);
pinMode(dirPin, OUTPUT);
pinMode(enPin, OUTPUT);
digitalWrite(enPin, LOW);
//Prog. Start – homes to switch (motor turns threaded rod to bring together the two doors)
homePosition();
}


void loop() {
  pressureSensing();


  controlPID();


}
```

```
void homePosition(){
  while(digitalRead(homeSwitch)==HIGH){
    digitalWrite(dirPin, LOW); // Moves the motor counterclockwise until botton (0-feet)

    digitalWrite(stepPin, HIGH);
    delayMicroseconds(75);
    digitalWrite(stepPin, LOW);
    delayMicroseconds(75);
  }
}

void pressureSensing(){
  voltage=analogRead(pressurePin);
  voltage=voltage*5/1023.0;
  pressure=voltage/5.0;
  Serial.print("Pressure=");
  Serial.println(pressure);
}

void controlPID(){
  Input = analogRead(PIN_INPUT);
  myPID.Compute();
  Serial.println(Output);
  delay(200);

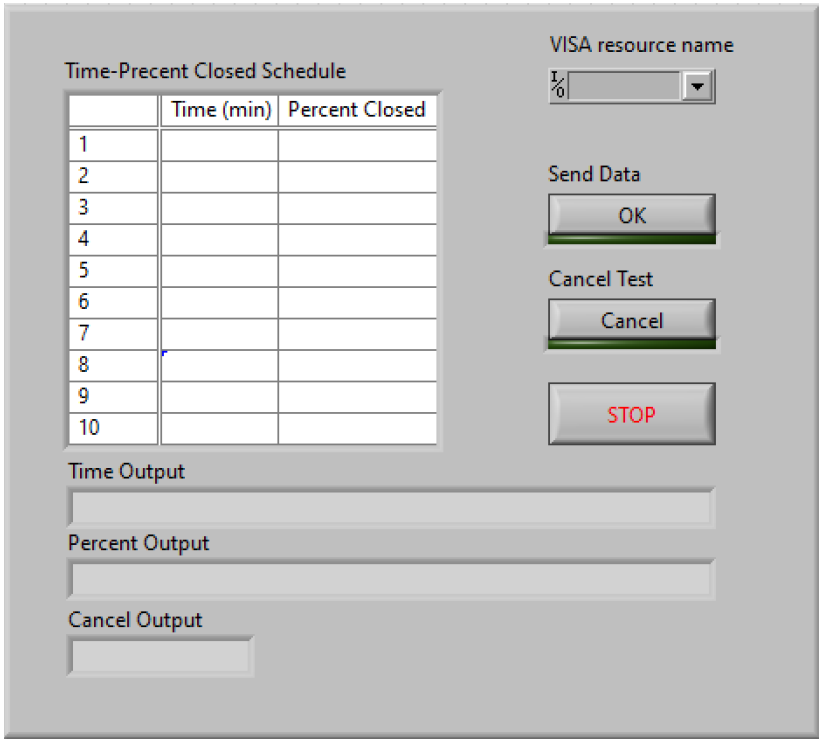
if(Output!=OutputLast){
  if(OutputLast>Output) digitalWrite(dirPin, LOW);
  else digitalWrite(dirPin, HIGH);
```

```
  OutputLast=Output;

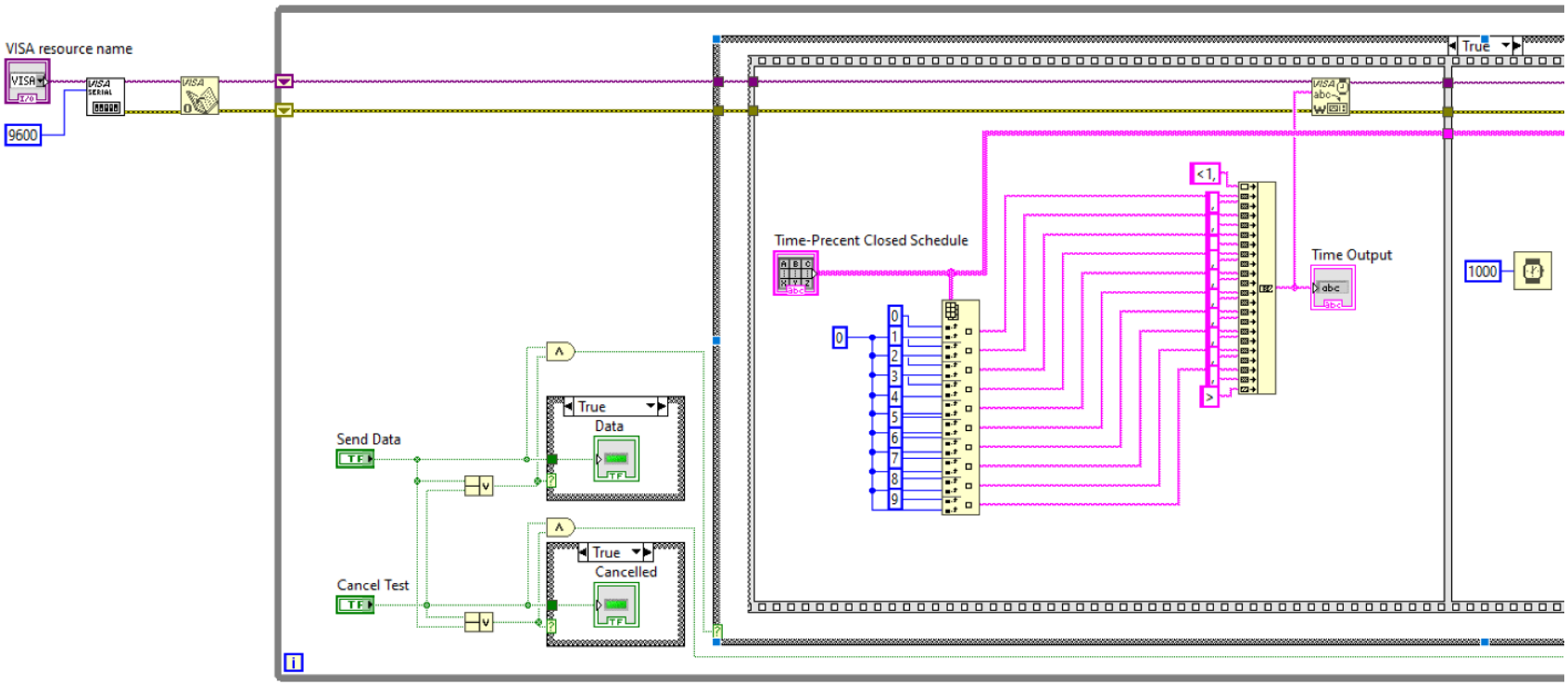
  for(int i=0;i<=Output;i++){
    digitalWrite(stepPin, HIGH);
    delayMicroseconds(75);
    digitalWrite(stepPin, LOW);
    delayMicroseconds(75);
  }
}
}
```

Iris Shutter

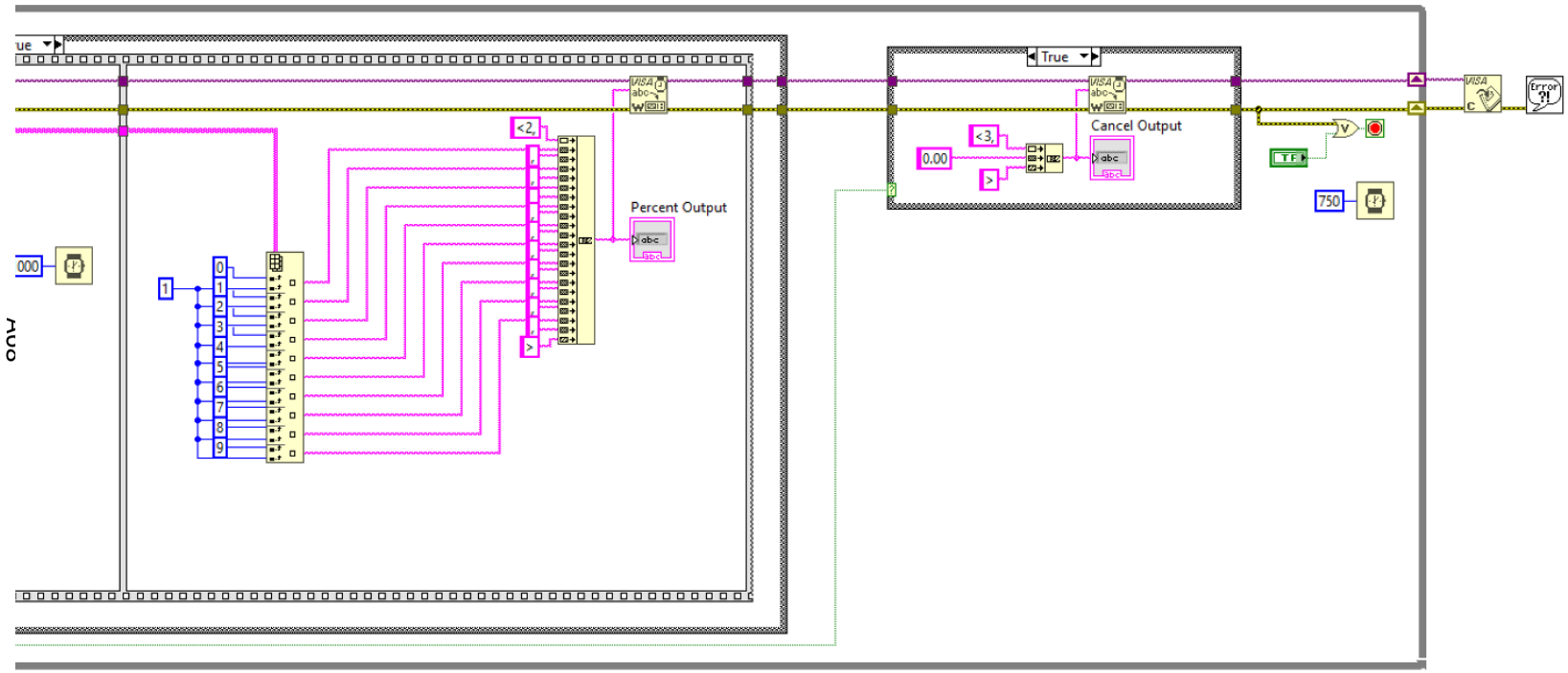
This section contains documentation of the iris shutter's programming. Shown below is the LabVIEW programming for the iris shutter. Following the LabVIEW figures is the Arduino code for the shutter.



LabVIEW Interface for Iris Shutter Control



LabView Program Layout for Iris Shutter



LabView Program Layout for Iris Shutter Continued

Iris Arduino Code (Note: This code is in an unfinished state)

```
//For testing Iris LabVIEW program

#include <LiquidCrystal.h>

const byte numChars = 32;
char receivedChars[numChars];
char tempChars[numChars];        // temporary array for use when parsing

// variables to hold the parsed data
char messageFromPC[numChars] = {0};
int integerFromPC = 0;
float cancelValue = 0.0;

//Arrays for time and position
float T[10];
float P[10];

//Variables for holding data points
float a1 = 0.0;
float a2 = 0.0;
float a3 = 0.0;
float a4 = 0.0;
float a5 = 0.0;
float a6 = 0.0;
float a7 = 0.0;
float a8 = 0.0;
```

```
float a9 = 0.0;
float a10 = 0.0;

boolean newData = false;

//              BS E  D4 D5  D6  D7
LiquidCrystal lcd(7, 8, 9, 10, 11, 12);

//============================================================================

void setup() {
   Serial.begin(9600);
   lcd.begin(16, 2);
}

//============================================================================

void loop() {
   recvWithStartEndMarkers();
   if (newData == true) {
      strcpy(tempChars, receivedChars);
         // this temporary copy is necessary to protect the original data
         //   because strtok() used in parseData() replaces the commas with \0
      parseData();
      showParsedData();
      newData = false;
   }
```

```
}

//================================================================
====

void recvWithStartEndMarkers() {
    static boolean recvInProgress = false;
    static byte ndx = 0;
    char startMarker = '<';
    char endMarker = '>';
    char rc;

    while (Serial.available() > 0 && newData == false) {
        rc = Serial.read();

        if (recvInProgress == true) {
            if (rc != endMarker) {
                receivedChars[ndx] = rc;
                ndx++;
                if (ndx >= numChars) {
                    ndx = numChars - 1;
                }
            }
            else {
                receivedChars[ndx] = '\0'; // terminate the string
                recvInProgress = false;
                ndx = 0;
                newData = true;
```

```
        }
      }

      else if (rc == startMarker) {
        recvInProgress = true;
      }
    }
}

//============================================================================

void parseData() {      // split the data into its parts

  char * strtokIndx; // this is used by strtok() as an index

  strtokIndx = strtok(tempChars, ","); // get the first part
  integerFromPC = atoi(strtokIndx);     // convert this part to an integer

  strtokIndx = strtok(NULL, ",");
  a1 = atof(strtokIndx);     // convert this part to a float

  strtokIndx = strtok(NULL, ",");
  a2 = atof(strtokIndx);

  strtokIndx = strtok(NULL, ",");
  a3 = atof(strtokIndx);
```

```
    strtokIndx = strtok(NULL, ",");
    a4 = atof(strtokIndx);

    strtokIndx = strtok(NULL, ",");
    a5 = atof(strtokIndx);

    strtokIndx = strtok(NULL, ",");
    a6 = atof(strtokIndx);

    strtokIndx = strtok(NULL, ",");
    a7 = atof(strtokIndx);

    strtokIndx = strtok(NULL, ",");
    a8 = atof(strtokIndx);

    strtokIndx = strtok(NULL, ",");
    a9 = atof(strtokIndx);

    strtokIndx = strtok(NULL, ",");
    a10 = atof(strtokIndx);

//====_____====_____====_____====_____====_____====_____====_____====
====

    if (integerFromPC == 1) {
      T[0] = a1;
      T[1] = a2;
      T[2] = a3;
```

```
    T[3] = a4;
    T[4] = a5;
    T[5] = a6;
    T[6] = a7;
    T[7] = a8;
    T[8] = a9;
    T[9] = a10;
  }

  if (integerFromPC == 2) {
    P[0] = a1;
    P[1] = a2;
    P[2] = a3;
    P[3] = a4;
    P[4] = a5;
    P[5] = a6;
    P[6] = a7;
    P[7] = a8;
    P[8] = a9;
    P[9] = a10;
  }

  if (integerFromPC == 3) {
    cancelValue = a1;
  }

}
```

```
//=================================================================
====

void showParsedData() {

   lcd.setCursor(0, 0);
   lcd.print(integerFromPC);
   lcd.setCursor(4, 0);
   lcd.print(T[0]);
   lcd.setCursor(10, 0);
   lcd.print(T[1]);
   lcd.setCursor(4, 1);
   lcd.print(P[0]);
   lcd.setCursor(10, 1);
   lcd.print(P[1]);

   delay(500);

}
```

Appendix I

Test Results and Parameters

Test Results – Round 1 and 2 of Inlet Shutter Testing

Location: Trane Gas Lab

Purpose: To evaluate inlet shutter performance and adjust control parameters (Table 1) to produce ideal shutter operation. This ideal shutter operation (per Trane Engineers) would consist of a relatively smooth line of outlet temperature increase (within test specs.) up to the point of furnace shutdown.

Table 1. Control Parameters Studied During Testing.

Parameter	Effect
PID Constants	Reactive sensitivity of the system.
Stepper Motor Speed	The speed at which the shutter closes.
Delay Constant	The duration between data sampling intervals.
Ramp Time Constant	The speed at which the desired temperature increases.

Results: Results are presented as screen shots taken from Trane software, "WonderWare," which is used to observe test variables which in this case are furnace outlet temperature (shown by a blue line) and ambient room temperature (shown by a black/red line). Figures 1 and 2 show a 4-hour time window which is a sufficient amount of time to display all test runs during both rounds of testing.

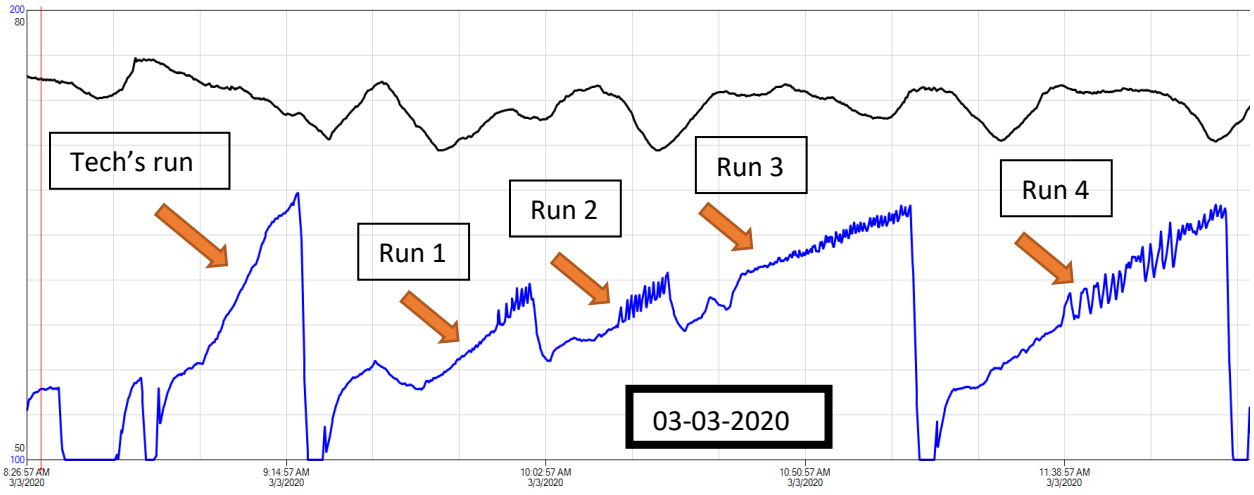


Figure 1. 1st Round of Testing on 03-03-20.

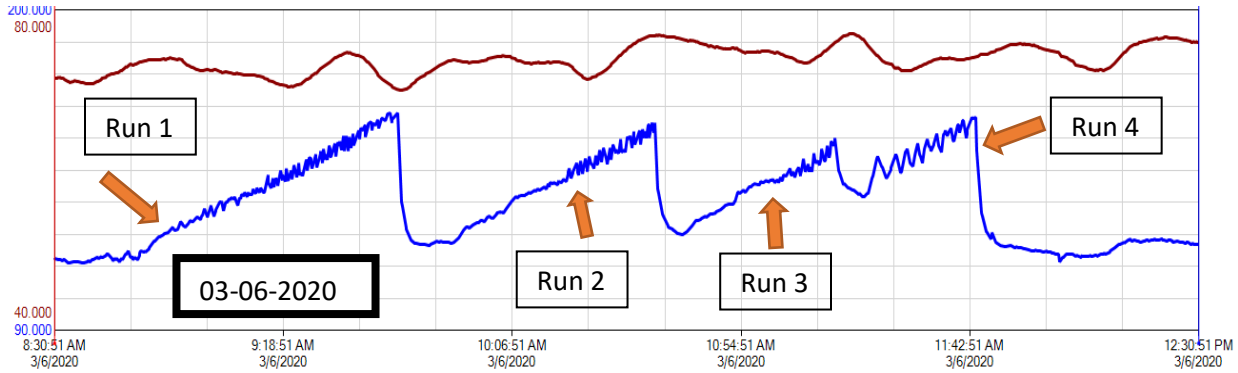


Figure 2. 2nd Round of Testing on 03-06-20.

Discussion: The idea behind testing was not to track individual physical parameters such as temperature or pressure, but instead was to isolate and refine apparatus control parameters. Based on conversations with Trane Engineers the results of testing yielded a good upward trend (ramp rate) but contained too much noise (up and down variation) to be useful at this time. From the testing results it is clear to see that some test runs faired better than others. Such as Run 3 on round 1 and Run 1 on round 2. It is also worth noting that in most cases the variation becomes more pronounced as the testing continues. This is due to the exponential increase in sensitive of the operation as the test continues which results in smaller shutter movements for a larger increase in outlet temperature.

Conclusion: Further testing will be required. The team has several ideas to combat the increasing sensitivity such as an exponential decaying stepper speed and fine tuning PID constants.

Appendix J

User Manual

VISIONARY
ENGINEERING

Trane Gas Lab Automated Apparatuses:

User Manual

TRANE TECHNOLOGIES

The University of Texas at TYLER

Senior Design Project 2019 - 2020

Table of Contents

Introduction
- Manufacturing

Software
- Arduino Software
- LabVIEW

Hardware
- Arduino UNO
- DM542T Stepper Motor Driver
- NEMA 23 Stepper Motor

Setup
- Electrical Connections

1. Inlet Shutter
- 1.1 LabVIEW Programming Specifics
- 1.2 Arduino Code
- 1.3 Technical Drawings

2. Outlet Shutter
- 2.1 LabVIEW Programming Specifics
- 2.2 Arduino Code
- 2.3 Technical Drawings

3. Iris Shutter
- 3.1 LabVIEW Programming Specifics
- 3.2 Arduino Code
- 3.3 Technical Drawings

Acknowledgement

Introduction:

This user manual accompanies the three apparatuses (Inlet, Outlet, and Iris shutters) built by University of Texas at Tyler senior design team, Visionary Engineering. This document provides details for the operation, maintenance, refinement, and methods of reproduction for the three apparatuses.

Manufacturing:

The steps for reproducing any of the following apparatuses are as follows:

1. Select parts to be reproduced refer to technical drawings within user manual for the specific apparatus.
    i. Note: Each part of each apparatus should have its own drawing as well as it should be depicted in the assembly drawing.
2. Print of the specific part drawing and if necessary the assembly drawing.
3. Turn the print into the model shop and tool room for fabrication.
    i. Note: The procedure may change over time.
        A. Find the DLP and ask for the method of submitting print for construction.
        B. It may be necessary to provide material needed to construct.
4. For any uncertainties in the prints refer to the assembly drawings and discuss with the worker assigned to the job.
5. The DLP will establish a completion timeline.
6. Once the part is complete the DLP should notify the tech the location in which the part or assembly will be.

Software:

Arduino Software (IDE):

The software for all three apparatuses are Arduino-based. Therefore, to edit or refine their programming it is essential to have the Arduino USB connection cable (Figure 1) and the Arduino IDE software downloaded to a USB capable computer from www.arduino.cc.

7.



8.

Figure 1. Arduino USB Connection Cord.

Arduino is used as the platform for each shutter's motor control software. As such, it breaks apart the string sent to it by LabVIEW as that it may then interpret the data gathered. Like the LabVIEW VIs, the Arduino communication programming for all three shutters follow a similar structure. In general, once a string is received its float values are assigned to their proper Arduino variables based on the string's integer identifier.

First, serial communication is initiated within the Arduino program. Then, once it receives a string from LabVIEW it recognizes its start character and begins to break it into its different components. The first value after the start character would be assigned to the variable titled "integerFromPC." Then, reading the comma following the first value, the program would move to the second value and assign it to the variable entitled "floatFromPC." Finally, upon reading the termination character the program would cease parsing and wait for the next string.

Using the previous string example of "<1,122.56>", the variables would be as is listed below:

integerFromPC = 1 floatFromPC = 122.56

These variables are then used in if statements to store them for use by the program logic. For example, "if integerFromPC == 1, measuredTemp = floatFromPC" would be used to store the current temperature of the furnace while "if integerFromPC == 2, startTemp = floatFromPC" would be used to store the temperature of the furnace at the start of the test. Specific details for each shutter are also outlined in their respective sections below.

LabVIEW:

The LabVIEW control software interfaces with the Arduino control board using serial communication through USB. The standard operation of this communication is the same for each shutter with only minor alterations depending on the design variant. In general, a string of data values separated by commas is first compiled in LabVIEW. This string is then sent to the Arduino board where the program parses the string, saving the data points to their appropriate variables for use in the program. The method used for reading this string format was modified from code examples given in an Arduino forum post while the LabVIEW compilation methods and code alterations were developed solely by the design team [1].

As mentioned earlier, the software platform used for gathering and sorting data and controlling each shutter is LabVIEW. Once the command is made within the Virtual Instrument (VI), LabVIEW must compile the information it has gathered and transmit it to Arduino in a format that the control board can decipher to appropriately adjust the motor. The VIs for all three types of shutter utilize the same basic string format, which is as follows:

<INTEGER,FLOAT(1),FLOAT(2), … ,FLOAT(N-1),FLOAT(N)>

The first character in the string is always a less-than symbol (<) which is used to signal the start of the string. Similarly, the greater-than symbol (>) serves as the termination character, signaling the string's conclusion. The string then contains an integer value followed by a varying number of float values (numbers with decimals), each separated by commas. The integer serves an identifier for the float's data type. For example, a string sent to Arduino from the inlet shutter VI could be "<1,122.56>." In this case, the integer value 1 indicates that following float value of 122.56 is the measured temperature at the furnace's outlet.

To create the string that is read by Arduino, several different string elements are combined with the measured data into one string using the Concatenate Strings Function, circled in red in Figure 2 below. The Concatenate Strings function allows for as many elements as required to be parsed together into one string, reading from top to bottom.

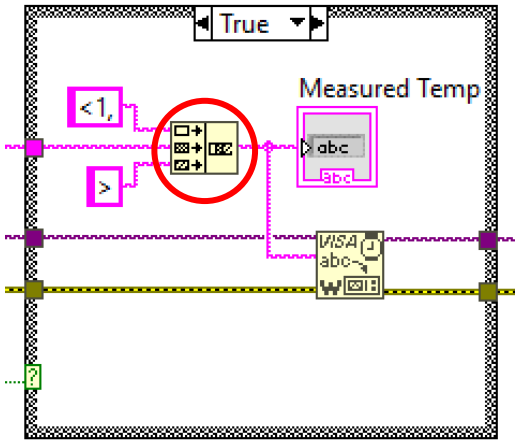


Figure 2. String assembly with the Concatenate Strings Function circled.

In the example shown in Figure 1, the constant “<1,” forms the beginning of the string. The second segment of data input in this case is the float value being measured or assigned. As in the previous example, this would be “122.56”. Finally, the constant “>” forms the end of the string. When the Boolean operator controlling this event (such as a button within the VI) signals true, the string “<1,122.56>” will be transmitted to Arduino via serial communication.

Hardware:

The hardware section consists of the same schematics and diagrams found in Appendix G.

Setup:

The electrical connections (Figure 6 and Table 1) are the same for each apparatus.

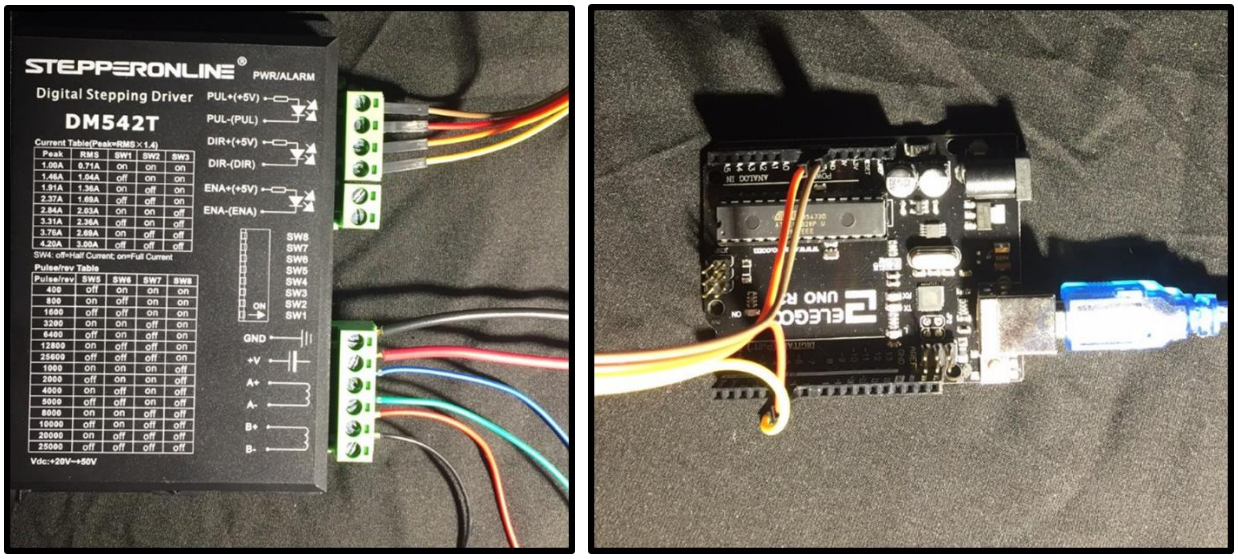


Figure 6. Close up of electrical connections.

Table 1. Table showing connections to and from components.

To	From
DM542T Stepper Driver	**Arduino UNO**
PUL (+5)	*GND*
PUL (PUL)	*PIN 6*
DIR (+5)	*GND*
DIR (DIR)	*PIN 5*
DM542T Stepper Driver	**24V DC Power Supply**
V+	*V+*
GND	*GND*
DM542T Stepper Driver	**NEMA 23 Stepper Motor**
A+	*Blue*
A-	*Green*
B+	*Red*
B-	*Black*
Arduino UNO	**Computer**
Arduino Connection Port	*USB Port (via Arduino Connection Cord)*

Inlet Shutter

1.1 LabVIEW Programming Specifics:

There are three different integer identifiers, 1, 2, and 3, that are used in the LabVIEW VI for the inlet shutter. These integers correspond to the measured temperature, the starting temperature, and the cancel command, respectively. The measured temperature is the exiting air temperature of the furnace measured by the Data Acquisition (DAQ) system and the starting temperature is the initial temperature used for Blocked Vent testing. The Arduino will use the starting temperature as the baseline for increasing the target temperature over time, as dictated by the test. The cancel command is an integer identifier used to signal the Arduino to halt testing. Each command is tied to its own respective button within the VI. A figure for the LabVIEW VI code controlling the inlet shutter are shown below.

The images for this section are found in Appendix H.

1.2 Arduino Code:

Within the Arduino code there are a few variables that can be manipulated to increase or decrease the inlet shutters reactivity to outlet temperature. These variables are the PID constants and the maximum stepper motor speed shown below with arrows. The PID operates by taking the difference between the set point and the actual point and creates an output from

this difference based on the Kp, Ki and Kd values. Another variable is the rate adjustment which increases the set point temperature a certain amount every time the programming loops. This can be adjusted to achieve a rate greater than or less than 1F per 1 minute.

The images for this section are found in Appendix H.

1.3 Technical Drawings:

The images for this section are found in Appendix F.

Outlet Shutter

2.1 LabVIEW Programming Specifics:

There are three different integer identifiers, 1, 2, and 3, that are used in the LabVIEW VI for the outlet shutter. Like the inlet shutter, these integers correspond to the measured static pressure, the desired static pressure, and the cancel command, respectively. Each command is tied to its own respective button within the VI.

2.2 Arduino Code:

Within the Arduino code there are a few variables that can be manipulated to increase or decrease the outlet shutters reactivity to outlet static pressure. These variables are the PID constants shown below with arrows. The PID operates by taking the difference between the set point and the actual point and creates an output from this difference based on the Kp, Ki and Kd values.

The images for this section are found in Appendix H.

2.3 Technical Drawings:

The images for this section are found in Appendix F.

Iris Shutter

3.1 LabVIEW Programming Specifics:

The iris shutter has two different commands: a start command, which sends the time and percent closure schedule to Arduino, and the cancel command. The start command uses two integer identifiers to send the testing schedule from the table in LabVIEW to Arduino. These consist of a string containing all of the time data points labeled “1” and, after a one second delay, a string containing all of the percent closure values, designated “2.” Using the integer identifiers, Arduino stores these points in their respective variables and proceeds to run the timed sequence that was ordered. Like the inlet and outlet shutters, integer identifier “3” is used to signal the Arduino to immediately halt the test sequence and return to the home position. These two commands are controlled by their respective buttons within the VI. A figure for the iris shutter’s LabVIEW VI code is shown below.

The images for this section are found in Appendix H.

3.2 Iris Arduino Code:

The images for this section are found in Appendix H.

3.3 Technical Drawings:

The images for this section are found in Appendix F.

Acknowledgements

The University of Texas at Tyler 2020 Senior Design Team, Vision Engineering, would like to thank those responsible for facilitating the creation of this project:

Trane Technologies:

Mr. John Bailey

Mr. Trent Clark

Mr. Jeffery O'Daniel

The Technicians of Trane's Gas Lab

University of Texas at Tyler:

Dr. Nael Barakat

Dr. Alwathiqbellah Ibrahim

Dr. Nelson Fumo

Gas Lab Testing Equipment

VISIONARY ENGINEERING
OUR FUTURE IS 2020

Project Start: Mon, 1/13/2020
Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Inlet Shutter				
Tasks				
Establish Arduino/Labview data communication	Blake Merritt	25%	1/13/20	1/31/20
Build Inlet shutter control system small scale setup	Blake Merritt	10%	1/24/20	1/31/20
Test small scale set up with information from Labview connection	Blake Merritt	0%	1/31/20	2/14/20
Complete Control Box for inlet shutter	Justin Davenport	0%	1/31/20	2/21/20
Complete motor-to-frame assembly	Justin Davenport	10%	1/24/20	2/21/20
Device testing and refinement	Blake Merritt	0%	2/21/20	3/6/20
Outlet Shutter				
Tasks				
Redesign motor mount	James Davis	100%	1/13/20	1/24/20
Finalize fastener choice and verification	James Davis	50%	1/13/20	1/31/20
Assembly of outlet shutter metal components	James Davis	0%	1/24/20	2/7/20
Finalize electrical connections	James Davis	0%	1/24/20	2/7/20
Develop logic	James Davis	0%	1/24/20	2/7/20
Test logic with outlet shutter automation	James Davis	0%	2/7/20	2/21/20
Completed device testing and refinement	James Davis	0%	2/21/20	3/6/20
Iris Shutter				
Tasks				
LabVIEW and Arduino research	William Urwiller	50%	1/13/20	1/31/20
LabVIEW and Arduino programming	William Urwiller	50%	1/13/20	2/7/20
Hardware assembly	William Urwiller	25%	1/31/20	2/7/20
Hardware testing	William Urwiller	0%	2/7/20	2/21/20
Program testing	William Urwiller	0%	1/31/20	2/21/20
Device testing	William Urwiller	0%	2/7/20	2/21/20
Completed device testing and refinement	William Urwiller	0%	2/14/20	3/6/20
Programming				
Tasks				
PID controller concept research	Zaeem Siddiqui	50%	1/13/20	1/31/20
PID controller implementation in Arduino research	Zaeem Siddiqui	50%	1/13/20	1/31/20
LabVIEW and Arduino interfacing research	Zaeem Siddiqui	50%	1/13/20	1/31/20
Collaborate with Liam for implementation using LabVIEW	Zaeem Siddiqui	25%	1/24/20	2/7/20
Finalize equations for shutter movement for each test	Zaeem Siddiqui	0%	2/7/20	2/14/20
Implementation of equations in the code	Zaeem Siddiqui	0%	1/31/20	2/7/20
Translate into steps for the stepper motor	Zaeem Siddiqui	0%	1/31/20	2/14/20
Finalize on whether to use micro stepping	Zaeem Siddiqui	0%	2/7/20	2/21/20
Testing	Zaeem Siddiqui	0%	2/21/20	3/6/20

Insert new rows ABOVE this one

