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JME 4110: Door Cycling Station

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

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The objective of this project was to design and build a door cycling station to be used for fatigue testing commercial refrigerator doors, including the door gaskets, hinges, and handles. The system must be low maintenance and reliable for at least two million cycles, and it must fit within the provided budget. The design concept includes a rodless pneumatic cylinder and a system of wear-resistant ropes, eyebolts, and pulleys.

JME 4110
Mechanical Engineering
Design Project

Door Cycling Station

Alexander Clark
Seth Flamm
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1 INTRODUCTION

1.1 VALUE PROPOSITION / PROJECT SUGGESTION

The objective of this project was to design a door cycling station to be used for fatigue testing commercial refrigerator doors, including the door gaskets, hinges, and handles. The system must be low maintenance and reliable for at least two million cycles. The design concept includes a rodless pneumatic cylinder and a system of wear-resistant ropes and pulleys. Additional design specifications are included later in this report.

1.2 LIST OF TEAM MEMBERS

Alexander Clark, Mechanical Engineer
Seth Flamm, Project Manager
Briana Kagy, Quality Engineer
William Todd, Manufacturing Engineer

2 BACKGROUND INFORMATION STUDY

2.1 DESIGN BRIEF

Our aim is to design a fatigue testing system for doors on a refrigerated case. Tests will be performed under ambient conditions because the temperature, pressure, and humidity at the customer facility are uncontrolled and vary depending on the weather. This may affect the testing system performance or cabinet life. The test system must have a life of up to two million cycles. The current actuators used by the customer typically fail after about 2 million cycles. We need to design and develop a system which can quickly and precisely open doors. The doors will close on their own and the testing system shall not contribute to closing. The system must be able to cycle at least 2 doors at once. The system will focus on opening doors that swing left, but as a bonus requirement, it can work on French doors. It needs to work on all types of different styles of doors. Door dimensions can vary. Door weights range from 35-85 lbs. The approximate force needed to break the magnetic seals on the doors is 9 lbs. The system needs to be removable and transferable so it can be switched between cases. The most critical requirement of the system is to open doors with precision and speed for 2 million cycles with little maintenance.

2.2 BACKGROUND SUMMARY

The below patents were referenced as background information for the project.

Patent 1: Heat absorbing door for a refrigerated merchandiser

Patent number: 10888176

> We chose this patent to shed light on the product being tested. To be able to research patents on what we are trying to solve, we must first understand and know the patent of the door itself and how it operates. Even though our customer does not currently have a patent for the process of testing the doors, they do have one for the door itself [1].

Patent 2: Door closer assembly

Patent number: US9523230B2

This door closer assembly is a useful reference because it could be a potential idea of how we can open and close the doors safely and with a device known to work for a lot of cycles. Several ideas we have considered involve using a bar system that can connect the doors together so they can open and close together [2].

Patent 3: Door cycle tracker

Patent number: US20120014497A1

This door cycle tracker is a useful patent because we might need to incorporate a design that is able to count the number of cycles the door will go through when doing our own testing. This could help us with calculating the number of cycles the customer has requested. Primarily designed for garage doors but could easily be modified to work for refrigeration doors [3].

The below websites were referenced as background information for the project.

URL 1: https://www.assaabloyentrance.com/us/en/stories/blogs/the-life-cycle-of-a-door

This URL is helped because it provides a good list of items to be considered when developing a door and its life cycles. Some of the areas it discusses are our research, specifications, manufacturing, and installation. All are key areas to be considered [4].

URL 2: https://www.mcmaster.com

McMaster-Carr is a valuable resource for developing our prototype. We will use McMaster-Carr to order parts for the project. The website is also going to help with the 3D renderings and 2D drawings [5].

URL 3: https://www.xometry.com

Xometry was chosen because it is a powerful site for engineering and prototyping. This company may be useful for specific materials we might want printed. This site allows customers to request the following work to be performed: CNC, 3D printing, Laser cut, waterjet, injection molding, and to buy or source material/sheet metal [6].

URL 4: https://repair.geappliances.com/resources/faq/how-do-i-tell-if-a-refrigerator-door-seal-is-bad

This website describes how a uncontrolled test environment could be a risk to the success of the project. During our customer needs interview, the customer indicated that the first component to fail on the refrigerator doors is often the gasket, or seal. The attached source from GE Appliances indicates that the seal is more likely to fail if the fridge interior is too warm [9]. The testing floor at the customer is not temperature controlled, and ranges from approximately 65-98°F. The refrigerator/freezer cabinets are not plugged in when the doors are tested. This could compromise the results of the gasket testing.

The existing designs below were referenced as background information for the project.

1. Existing Design #1 closely fitting the project description:
   Refrigerator Door Endurance Testing System [7]

   https://neometrixgroup.com/products/refrigerator-door-endurance-testing-system#:~:text=Applications,be%20in%20side%20of%20gripper.

2. Existing Design #2 closely fitting the project description:
   Automatic Refrigerator Door Open and Close Testing Machine [8]
   https://www.sinuotek.com/sale-26565552-iec62552-automatic-refrigerator-door-open-and-close-testing-machine.html

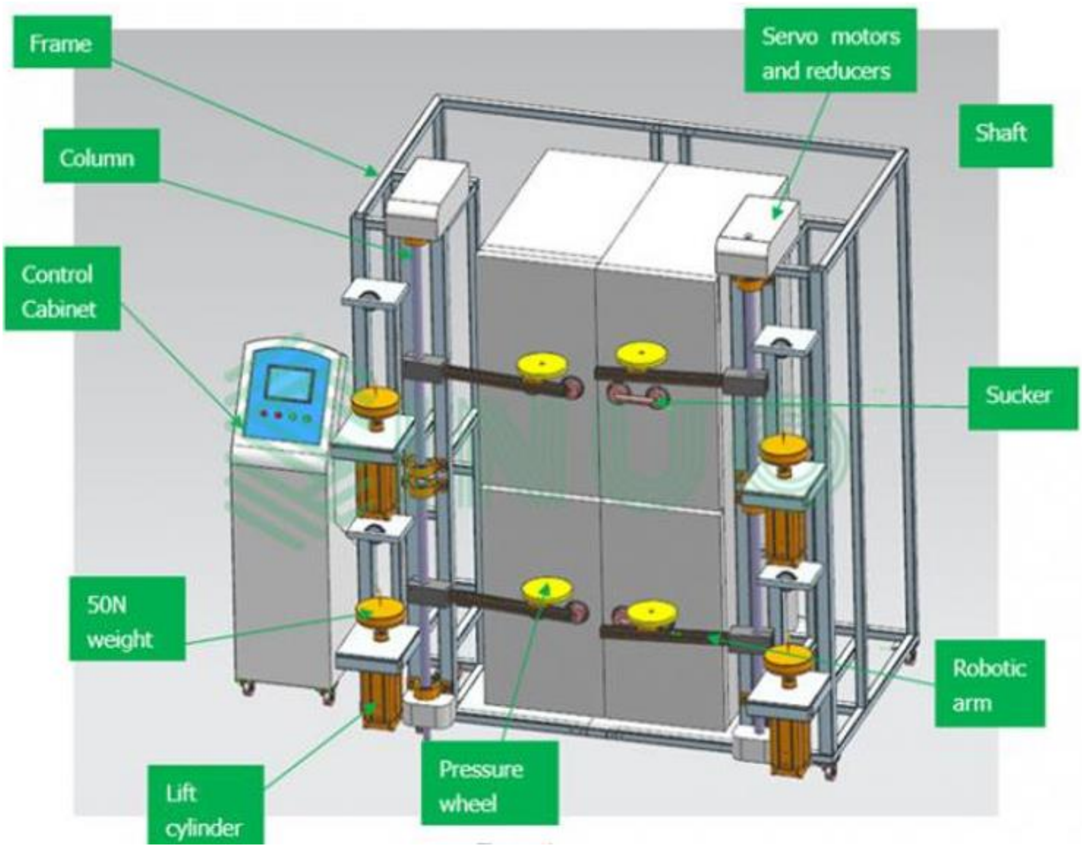


Figure 1: Sinuotek Door Open and Close Testing Machine

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS AND METRICS

3.1.1 Record of the user needs interview

Table 1: Customer Needs Interview

Project/Product Name: Door Cycling Station	
Customer Contact: Lead Design Engineer Customer Corporation Willing to do follow up? Yes Type of user: Lead Design Engineer	Interviewer(s): The Grand Slammers Date: 6/23/23 & 7/5/23 Currently uses: Compressed air cylinders, ropes, and pulleys to test refrigerated cabinet doors.

Question	Customer Statement	Interpreted Need	Importance 1-5 (lowest 1 to greatest 5)
What budget do we plan to have for this project?	$2,500 per 6-door testing station is the target. Customer will purchase materials directly.	Cost must not exceed $2,500 per 6-door unit.	4
Which parts of the cabinets fail first?	The rubber gasket along the perimeter of the door is the first to fail. Ropes, solenoid, and cylinders also have a low reliability rate. Cylinders are expensive to replace.	Design must last for at least the duration of the doors being tested.	5
How many cycles do the components last?	Cylinders are typically replaced after 2 million cycles (about 10 months of use). The gasket fails after about 180,000 cycles.	Design must last for at least 2 million cycles.	5
How many cycles does each door need to accomplish?	The goal is to reach 600,000 cycles to cover the 10-year customer warranty. Typically, 11,500 cycles occur each day.	Design must be reliable.	4
Do the doors in each case need to open consecutively or is there an order preferred?	This depends on the orientation of the doors. With French doors we might want to cycle between left and right when opening.	Design must function for left-opening doors. Wish list: Unit also works for French doors.	1
Are we limited to compressed air or is electrical means a possibility?	Not limited to compressed air, but that is what we have an abundance of and would significantly cut cost to continue using.	Wish list: Design is driven by compressed air to minimize cost.	3

Are there any environmental restrictions for testing?	The test conditions are ambient conditions. Temperatures in the shop range from about 65°F - 120°F.	Design must function within the shop temperature range at atmospheric pressure.	5
What is the weight of the doors?	There is a range of 35-85 lbs.	Design must function with doors weighing 35-85 lbs.	5
What are the cabinet dimensions?	Dimensions vary. The widest 6-door case is 12.5 feet wide.	Design must be usable for cabinets up to 12.5 feet wide.	1
How far do the doors need to open on each cycle?	Approximately 90°.	Doors must be pulled open to 70-90° during each cycle.	5
Should we try to close the doors too?	No, the doors have to be able to close on their own. Trying to force them to close could have a negative effect on the cabinets.	Unit must not contribute to doors closing.	5
What pull force is required to open the heaviest door?	The gasket magnet retention force is approximately 9 lbs (the force needed to open the door to break the magnetic seal).	Unit must exert pull force greater than 9 lbs.	3
What kind of handles are used?	There are a variety of handle types. The handles are also being tested during the cycles.	Unit must work with a variety of handle types.	4
How is the current system maintained?	There is one employee responsible for maintaining all the stations. If the system is improved, the customer would like to expand to more testing stations.	System must be low maintenance.	4
What footprint is required?	The design can take up slightly more space than the current design, if necessary, but it can't be huge.	Design fits within 2' x 15'.	3

3.1.2 List of identified metrics

Table 2: Metrics Table

Metric	Associated Needs	Metric	Units	Min Values	Max Values
1	1, 13, 14	Cost	Dollars	0	2500
2	3, 10, 12	Opening Angle	Degrees	0	90
3	7, 16	Contributes to door closing	Percentage	0	100
4	5, 8, 10	Pull Force	lbs.	0	20
5	3, 12, 16	Pull Direction (right=0, left=50, all=100)	Percentage	0	100
6	6, 15	Length	Feet	0	15
7	15	Width	Feet	0	2
8	9	Compatibility with Multiple Handle Types	Percentage	0	100
9	1, 14, 18	Utilizes Current System	Percentage	0	100
10	2, 11	Number of Cycles	# of Cycles	0	2,000,000
11	1, 18	Voltage Required	Volt	0	120
12	4, 14, 18	Compatibility with Environmental Conditions	Percentage	0	100
13	11,15,17,18	Maintenance	Minutes/day	0	6
14	16	Works with sliding glass doors	Binary	0	1
15	17	Simple to Operate	Percentage	0	100
16	18	Ease of manufacturing and installation	Hours	0	24

3.1.3 Tables of quantified needs equations and concept score results

Table 3: Quantified Needs Scores for Seth's Sliding Bar with Existing Actuator Concept

Grand Slammers Seth's Sliding Bar with Existing Actuator		Metric																		
		Cost	Opening Angle	Contributes to door closing	Pull Fource	Pull Direction (right=0, left=50, all=100)	Length	Width	Compatabily with Multiple Handle Types	Utilizes Current System	Number of Cycles	Voltage Required	Compatibility with Environmental Conditi	Maintenance	Works with Sliding Doors	Simple to Operate	Ease of Manufacturing and Installation	Need Happiness	Importance Weight	Total Happiness Value
Need	Need	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
1	Cost does not exceed $2,500 per 6-door unit.	0.85								0.1		0.05						0.475	0.06	0.0301587
2	Unit life lasts for at least 2 million cycles.										1							0.5	0.05	0.0238095
3	Unit functions for left-swinging doors.		0.6			0.4												0.8	0.08	0.0634921
4	Design functions within the shop temperature range at atmospheric pressure.												1					1	0.08	0.0793651
5	Unit functions with doors weighing 35-85 lbs.				1													0.75	0.08	0.0595238
6	Unit works with a variety of cabinet sizes, up to a total of 12.5' wide.						1											0	0.02	0
7	Unit does not contribute to doors closing. Doors close on their own.			1														1	0.08	0.0793651
8	Unit exerts pull force greater than 9 lbs. in order to break the magnetic seal.				1													0.75	0.05	0.0357143
9	Unit works with a variety of handle types.								1									1	0.06	0.0634921
10	Doors are pulled open to 70-90˚ during each cycle.		0.65		0.35													0.9125	0.08	0.0724206
11	Design is low maintenance.										0.4			0.6				0.5	0.06	0.031746
12	Design works with French Door style cabinets.		0.2			0.8												0.6	0.02	0.0095238
13	Design is driven by compressed air.	1																0.4	0.05	0.0190476
14	Design utilizes parts of the current test system structure.	0.15								0.8			0.05					0.79	0.02	0.0125397
15	Design fits within 2' x 15' footprint maximum.						0.45	0.45						0.1				0.05	0.05	0.002381
16	Design fits with sliding glass doors.			0.05		0.25									0.7			0.875	0.02	0.0138889
17	Design is simple to operate.													0.3		0.7		0.78	0.08	0.0619048
18	Design is easy to manufacture and install.									0.1		0.05	0.05	0.05			0.75	0.71	0.08	0.0563492
Units		Dollars	Degrees	Percentage	Pounds	Percentage	Feet	Feet	Percentage	Percentage	# of Cycles	Volts	Percentage	Minutes/Day	Binary	Percentage	Hours	Total Happiness		0.207381
Best Value		0	90	0	20	100	0	0	100	100	2000000	0	100	0	1	100	0			
Worst Value		2500	0	100	0	0	15	2	0	0	0	120	0	6	0	0	24			
Actual Value		1500	90	0	15	50	15	2	100	85	1000000	0	100	3	1	90	8			
Normalized Metric Happiness		0.40	1.00	1.00	0.75	0.50	0.00	0.00	1.00	0.85	0.50	1.00	1.00	0.50	1.00	0.90	0.67			

Table 4: Quantified Needs Scores for Will's Compressed Air Door Dampener Concept

Grand Slammers
Will's Compressed Air Door Dampener

		Metric																		
		Cost	Opening Angle	Contributes to door closing	Pull Fource	Pull Direction (right=0, left=50, all=100)	Length	Width	Compataibily with Multiple Handle Types	Utilizes Current System	Number of Cycles	Voltage Required	Compatibility with Environmental Condit	Maintenance	Works with Sliding Doors	Simple to Operate	Ease of Manufacturing and Installation	Need Happiness	Importance Weight	Total Happiness Value
Need	Need	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
1	Cost does not exceed $2,500 per 6-door unit.	0.85								0.1		0.05						0.48	0.06	0.0304762
2	Unit life lasts for at least 2 million cycles.										1							0.9	0.05	0.0428571
3	Unit functions for left-swinging doors.		0.6			0.4												0.9666667	0.08	0.0767196
4	Design functions within the shop temperature range at atmospheric pressure.												1					1	0.08	0.0793651
5	Unit functions with doors weighing 35-85 lbs.				1													0	0.08	0
6	Unit works with a variety of cabinet sizes, up to a total of 12.5' wide.						1											0.6666667	0.02	0.010582
7	Unit does not contribute to doors closing. Doors close on their own.			1														0.9	0.08	0.0714286
8	Unit exerts pull force greater than 9 lbs. in order to break the magnetic seal.				1													0	0.05	0
9	Unit works with a variety of handle types.								1									0.75	0.06	0.047619
10	Doors are pulled open to 70-90˚ during each cycle.		0.65		0.35													0.6138889	0.08	0.0487213
11	Design is low maintenance.										0.4			0.6				0.71	0.06	0.0450794
12	Design works with French Door style cabinets.		0.2			0.8												0.9888889	0.02	0.0156966
13	Design is driven by compressed air.	1																0.4	0.05	0.0190476
14	Design utilizes parts of the current test system structure.	0.15								0.8			0.05					0.87	0.02	0.0138095
15	Design fits within 2' x 15' footprint maximum.						0.45	0.45						0.1				0.3583333	0.05	0.0170635
16	Design fits with sliding glass doors.			0.05		0.25									0.7			0.995	0.02	0.0157937
17	Design is simple to operate.													0.3		0.7		0.77	0.08	0.0611111
18	Design is easy to manufacture and install.									0.1		0.05	0.05	0.05			0.75	0.6566667	0.08	0.0521164
	Units	Dollars	Degrees	Percentage	Pounds	Percentage	Feet	Feet	Percentage	Percentage	# of Cycles	Volts	Percentage	Minutes/Day	Binary	Percentage	Hours	Total Happiness		0.239718
	Best Value	0	90	0	20	100	0	0	100	100	2000000	0	100	0	1	100	0			
	Worst Value	2500	0	100	0	0	15	2	0	0	0	120	0	6	0	0	24			
	Actual Value	1500	85	10	0	100	5	2	75	95	1800000	12	100	2.5	1	85	10			
	Normalized Metric Happiness	0.40	0.94	0.90	0.00	1.00	0.67	0.00	0.75	0.95	0.90	0.90	1.00	0.58	1.00	0.85	0.58			

Table 5: Quantified Needs Scores for Alex's Motor Driven Door Dampener Concept

Grand Slammers Alex's Motor Driven Door Dampener		Metric																		
		Cost	Opening Angle	Contributes to door closing	Pull Fource	Pull Direction (right=0, left=50, all=100)	Length	Width	Compatabily with Multiple Handle Types	Utilizes Current System	Number of Cycles	Voltage Required	Compatibilty with Environmental Conditions	Maintenance	Works with Sliding Doors	Simple to Operate	Ease of Manufacturing and Installation	Need Happiness	Importance Weight	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
1	Cost does not exceed $2,500 per 6-door unit.	0.85								0.1		0.05						0.825	0.06	0.05238095
2	Unit life lasts for at least 2 million cycles.										1							1	0.05	0.04761905
3	Unit functions for left-swinging doors.		0.6			0.4												1	0.08	0.07936508
4	Design functions within the shop temperature range at atmospheric pressure.												1					1	0.08	0.07936508
5	Unit functions with doors weighing 35-85 lbs.				1													1	0.08	0.07936508
6	Unit works with a variety of cabinet sizes, up to a total of 12.5' wide.						1											0.2	0.02	0.0031746
7	Unit does not contribute to doors closing. Doors close on their own.			1														1	0.08	0.07936508
8	Unit exerts pull force greater than 9 lbs. in order to break the magnetic seal.				1													1	0.05	0.04761905
9	Unit works with a variety of handle types.								1									1	0.06	0.06349206
10	Doors are pulled open to 70-90° during each cycle.		0.65		0.35													1	0.08	0.07936508
11	Design is low maintenance.										0.4			0.6				0.7	0.06	0.04444444
12	Design works with French Door style cabinets.		0.2			0.8												1	0.02	0.01587302
13	Design is driven by compressed air.	1																0.8	0.05	0.03809524
14	Design utilizes parts of the current test system structure.	0.15								0.8			0.05					0.97	0.02	0.01539683
15	Design fits within 2' x 15' footprint maximum.						0.45	0.45						0.1				0.53375	0.05	0.02541667
16	Design fits with sliding glass doors.			0.05		0.25									0.7			1	0.02	0.01587302
17	Design is simple to operate.													0.3		0.7		0.5	0.08	0.03968254
18	Design is easy to manufacture and install.									0.1		0.05	0.05	0.05			0.75	0.72	0.08	0.05714286
	Units	Dollars	Degrees	Percentage	Pounds	Percentage	Feet	Feet	Percentage	Percentage	# of Cycles	Volts	Percentage	Minutes/Day	Binary	Percentage	Hours	Total Happiness		0.2519246
	Best Value	0	90	0	20	100	0	0	100	100	2000000	0	100	0	1	100	0		1.00	
	Worst Value	2500	0	100	0	0	15	2	0	0	0	120	0	6	0	0	24			
	Actual Value	500	90	0	20	100	12	.25	100	100	2000000	12	100	3	1	50	8			
	Normalized Metric Happiness	0.80	1.00	1.00	1.00	1.00	0.20	0.88	1.00	1.00	1.00	0.90	1.00	0.50	1.00	0.50	0.67			

Table 6: Quantified Needs Scores for Bri's Rodless Pneumatic Cylinder and Pulley System Concept

Grand Slammers Bri's Rodless Pneumatic Cylinder and Pulley System		Metric																		
		Cost	Opening Angle	Contributes to door closing	Pull Fource	Pull Direction (right=0, left=50, all=100)	Length	Width	Compatabily with Multiple Handle Types	Utilizes Current System	Number of Cycles	Voltage Required	Compatibility with Environmental Conditions	Maintenance	Works with Sliding Doors	Simple to Operate	Ease of Manufacturing and Installation	Need Happiness	Importance Weight	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
1	Cost does not exceed $2,500 per 6-door unit.	0.85								0.1		0.05						0.211	0.06	0.01339683
2	Unit life lasts for at least 2 million cycles.										1							0.5	0.05	0.02380952
3	Unit functions for left-swinging doors.		0.6			0.4												1	0.08	0.07936508
4	Design functions within the shop temperature range at atmospheric pressure.												1					1	0.08	0.07936508
5	Unit functions with doors weighing 35-85 lbs.				1													1	0.08	0.07936508
6	Unit works with a variety of cabinet sizes, up to a total of 12.5' wide.						1											0.8	0.02	0.01269841
7	Unit does not contribute to doors closing. Doors close on their own.			1														1	0.08	0.07936508
8	Unit exerts pull force greater than 9 lbs. in order to break the magnetic seal.				1													1	0.05	0.04761905
9	Unit works with a variety of handle types.								1									1	0.06	0.06349206
10	Doors are pulled open to 70-90° during each cycle.		0.65		0.35													1	0.08	0.07936508
11	Design is low maintenance.										0.4			0.6				0.75	0.06	0.04761905
12	Design works with French Door style cabinets.		0.2			0.8												1	0.02	0.01587302
13	Design is driven by compressed air.	1																0.16	0.05	0.00761905
14	Design utilizes parts of the current test system structure.	0.15								0.8			0.05					0.274	0.02	0.00434921
15	Design fits within 2' x 15' footprint maximum.						0.45	0.45						0.1				0.84541667	0.05	0.04025794
16	Design fits with sliding glass doors.			0.05		0.25									0.7			1	0.02	0.01587302
17	Design is simple to operate.													0.3		0.7		0.905	0.08	0.0718254
18	Design is easy to manufacture and install.									0.1		0.05	0.05	0.05			0.75	0.76458333	0.08	0.06068122
Units		Dollars	Degrees	Percentage	Pounds	Percentage	Feet	Feet	Percentage	Percentage	# of Cycles	Volts	Percentage	Minutes/Day	Binary	Percentage	Hours	Total Happiness		0.26409788
Best Value		0	90	0	20	100	0	0	100	100	2000000	0	100	0	1	100	0			
Worst Value		2500	0	100	0	0	15	2	0	0	0	120	0	6	0	0	24			
Actual Value		2100	90	0	20	100	3	0.25	100	25	1000000	0	100	0.5	1	90	5			
Normalized Metric Happiness		0.16	1.00	1.00	1.00	1.00	0.80	0.88	1.00	0.25	0.50	1.00	1.00	0.92	1.00	0.90	0.79			

3.2 CONCEPT DRAWINGS

Seth Flamm – Sliding Bar with Existing Actuator

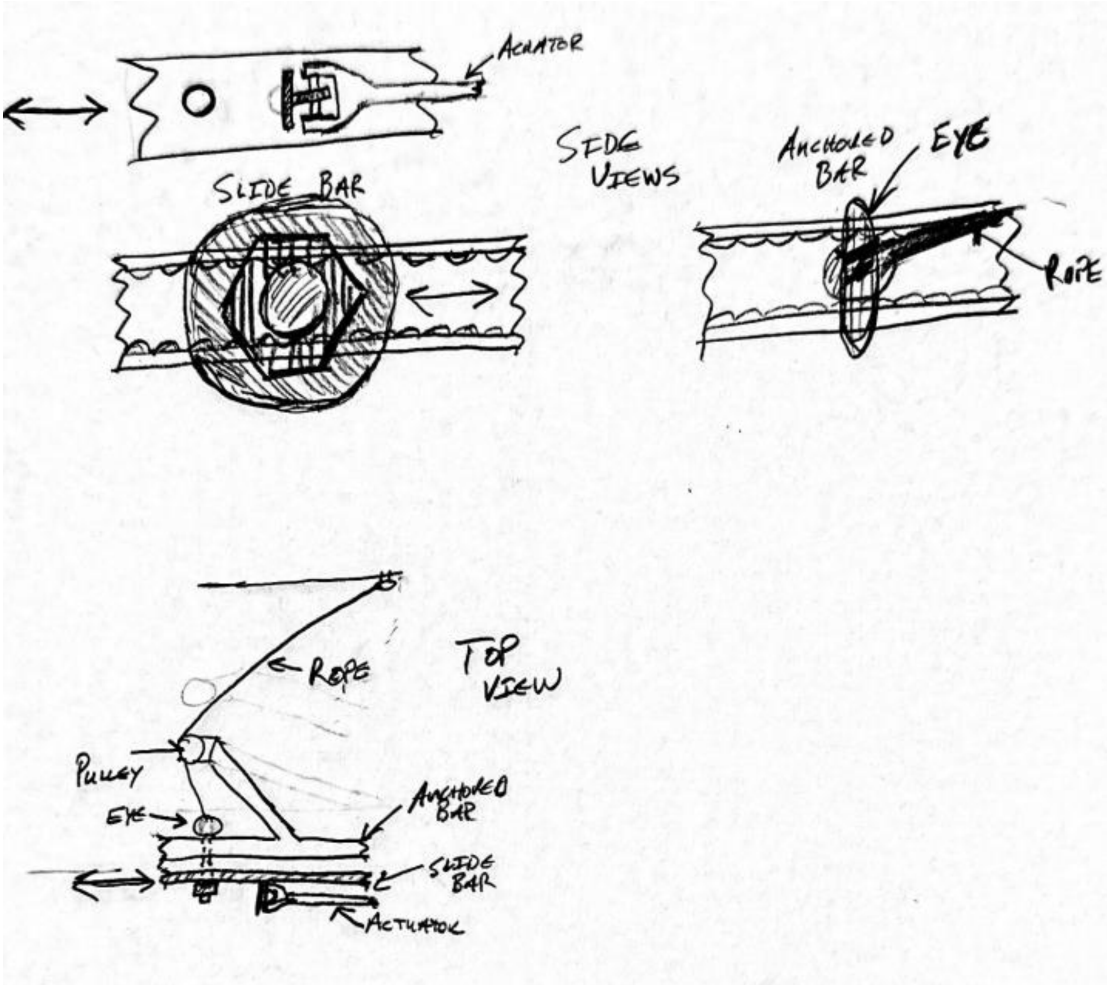


Figure 2: Sliding Bar with Existing Actuator Concept Drawing

My concept was to use an existing actuator but allowing it to freely rotate as it is designed to do. To achieve this, I would use a free rotating eye attached to the slide bar. This bar would attach up to (6) bolts. These bolts would go through the slide bar that has some type of roller balls or ball bearings to reduce friction and wear on the bolt as it is sliding. The bolt would have an eye on one end of it to allow the rope to be attached to it. The bolt would be pulled from left to right by the actuator and open the door using the pulley attached to the anchored bar. This will open the door and the angle of the pulley would allow the door to open to the 90 degrees we are trying to achieve.

Will Todd – Compressed Air Door Dampener

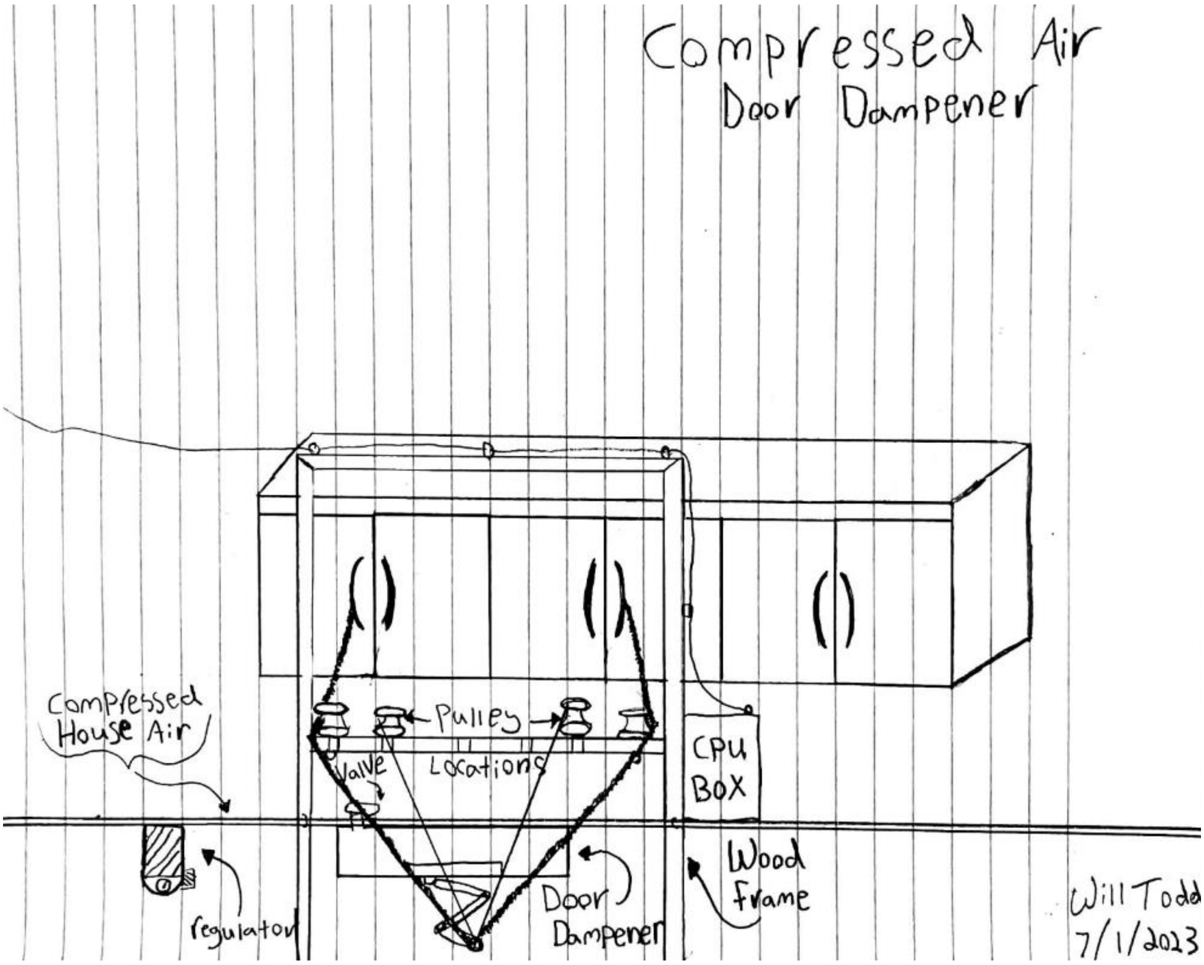


Figure 3: Compressed Air Door Dampener Concept Drawing

For this design I wanted to utilize the abundance of compressed house air we have at our disposal. This would significantly reduce costs and allow us to easily incorporate our design into the current setup. This involves a door dampener operating by compressed air in an open and closed position. The strategical placement of pulleys and length of cable allows us to accommodate several types of doors and orientations.

Alex Clark – Door Dampener pneumatic

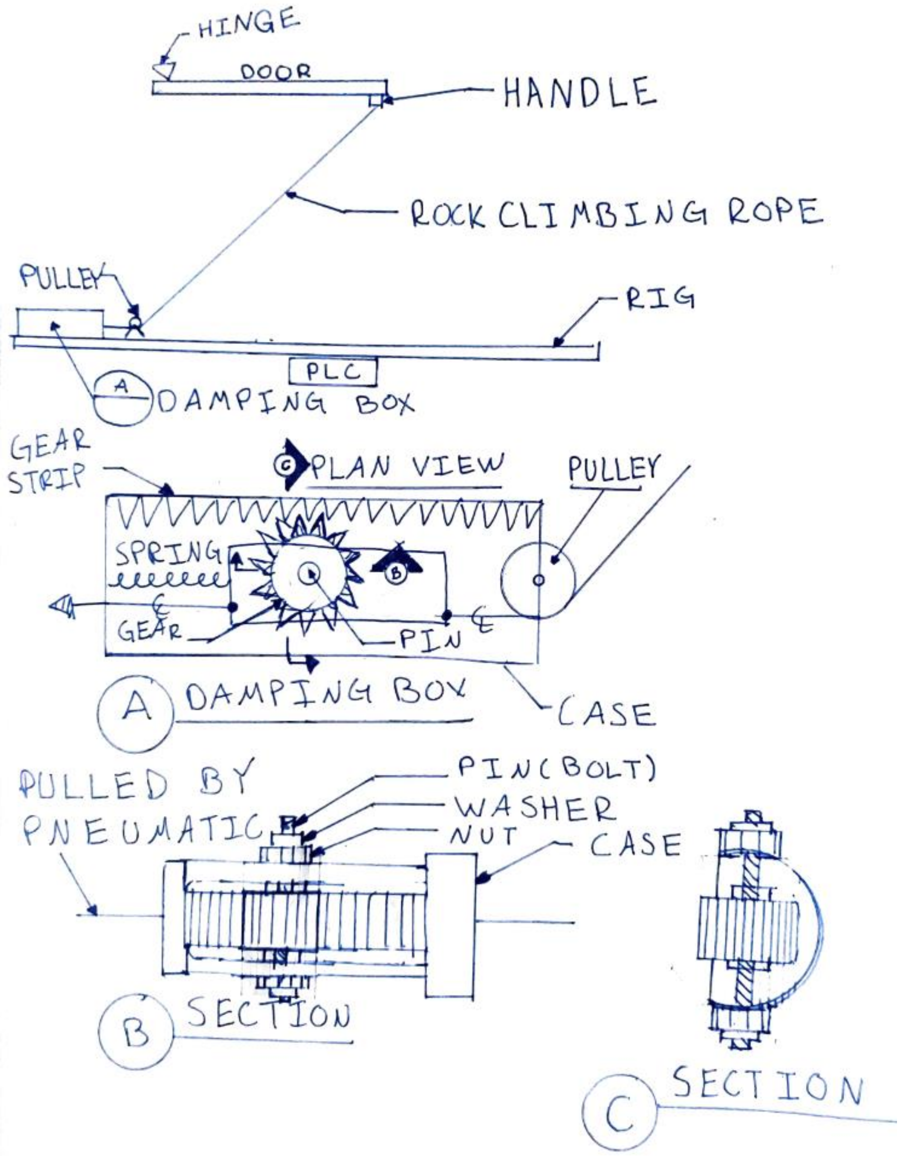


Figure 4: Motor Driven Door Dampener Concept Drawing

This design objective is to use the current layout that the customer uses already, with a pneumatic piston to pull open the door using the rope and pulley system. This system can be improved by upgrading the rope to rock climbing rope since it should be better suited from not fraying and rubbing against things, since that is what it is typically used for. The major improvement to the system would be the implementation of a dampener box, which will cause the force from the piston to be exerted to a spring, which will then absorb the energy from the door. When the kinetic energy has eventually fully transferred to potential energy, the spring will then force the cylinder inside the dampener box back quickly, creating slack in the rope, which will allow the door a free fall motion.

Briana Kagy – Rodless Pneumatic Cylinder and Pulley System

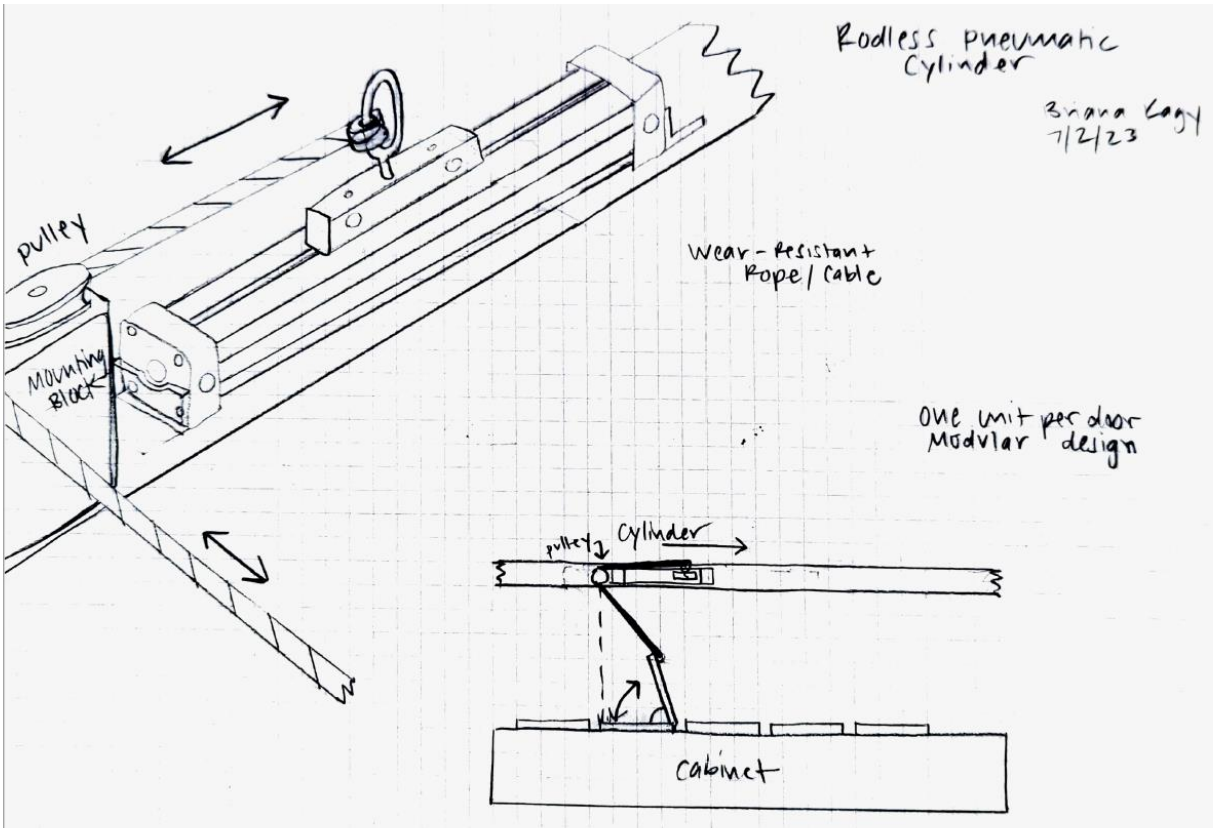


Figure 5: Rodless Pneumatic Cylinder and Pulley System Concept Drawing

The most expensive issue that the customer is facing with their current system is that their air cylinders fail after about 2 million cycles and need to be replaced. We identified that part of the issue is they are using a cylinder intended for vertical use in a horizontal orientation, which is causing unnecessary wear on the internals. The rod in their cylinders starts to sag and bend over time. The above design uses a rodless pneumatic cylinder. The cylinder would be used as intended, which would help extend its life. There is no moving rod to account for when installing these cylinders, so they can be installed closer together and prevent the ropes and pulleys from interacting and causing undue wear. Ideally, this system would be installed with one cylinder and pulley per door. The rope or cable we select will be wear-resistant. These two steps would prevent the fraying on the ropes and pulleys from crossing lines that the customer is currently experiencing. There is an option to size up the cylinder to work with multiple doors if the customer prefers to keep the cost lower per testing station.

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring (not screening)

The initial happiness scores for each design are:

1. Bri's Rodless Pneumatic Cylinder and Pulley System: 0.264
2. Will's Compressed Air Door Dampener: 0.240
3. Alex's Motor Driven Door Dampener: 0.252
4. Seth's Sliding Bar with Existing Actuator: 0.207

We found that the Happiness Equations are not a good indicator of the design happiness at this stage of the process. Many of the "Actual Value" scores are rough estimates because calculations have not been completed. The scores are quite subjective at this time. We expect that the final score for our completed and tested design will be much higher than what is shown here. We will not know the final score until the customer reports that our prototype has competed its full life cycle.

3.3.2 Preliminary analysis of each concept's physical feasibility

Alex's Door Dampener pneumatic

The motor driven door dampener was designed to attach to the existing test rig. It would benefit from the upgraded rope. It would be a creative solution to the problem. Automatic handicapped door openers and door closing dampeners were the motivation behind this design. The design was intended to slow down the doors to help prevent wear and, in turn, to have a longer life span. Some of the downfalls to this design involved the complexity of the design and the fact that we would have one dampener per door. This could get expensive fast. Some thought went into if we could get this to work for two doors at a time by strategic pully placement and rope length. The final design would not require a gear system.

Bri's Rodless Pneumatic Cylinder and Pulley System

The rodless pneumatic cylinder and pulley system was selected as our preferred concept for its many positive qualities. It was an easy and user-friendly set up. We could hook it up to the compressed shop air provided to us, using the existing rig. There was nothing to fabricate, as the catalog offered all the connections and parts we needed. This set up allowed us to have simple calculations by minimizing the rope contact points and aligning the forces along the line of action. The reliability seemed to be much greater than the customer's current solution. One negative point with this concept is the cost associated with the pneumatic, but it is still much lower cost than the customer's current station design. Another concern with the design was possible complications due to integrating our design with the available air pressure and control system.

Will's Compressed Air Door Dampener

The compressed air door dampener was designed to accommodate different types of opening doors. The multi-pulley system allows for various angles of opening and prevents the ropes from overlapping. This design involves having the forces acting perpendicular to the test rig and in line with the doors versus the opposing current solution. Some of the downfalls to this design include ambiguity of how the actuation works. We didn't know how this solution would allow the doors to close on their own. We would have to reverse engineer or modify an existing door dampener or casting to make it work. We expected that the design would be much more complicated to build than other concepts.

Seth's Sliding Bar with Existing Actuator

With this design, we wanted to leverage the use of existing components along with the ease of manufacturing in mind. There would be a minimal number of parts to fabricate. It would include an actuator rod support to improve reliability and life of the design. Some of the constraints working against this design include the tight tolerance of the actuator swivel connection and the restriction to building solely on site at the customer facility.

3.3.3 Concept Selection Summary Statement

We chose the rodless pneumatic cylinder approach because it was the simplest to construct with the time we had available. We felt confident that this would be a solution that would work for the customer and save them time, money, and frustration. It will also be the simplest option for the customer to replicate at additional stations if they decide to move forward with it. Our professors and the customer agreed with us that this would be the best option with which to move forward. We will modify the preliminary concept design by incorporating select ideas of the other team members and customer feedback.

Although we chose the rodless pneumatic cylinder option as the preferred driver for the testing station, we identified strong points about all four designs that we would like to incorporate. We plan to consider using climbing rope to prevent fraying. We will also move forward with a multi-pulley system that is adaptable depending on the configuration of the refrigerated cabinet. We will devote attention to ensuring that the ropes and pulleys will not cross each other and contribute to unnecessary wear. Rather than sticking with a one-to-one actuator-to-door assembly, we will work to use each actuator for 2-6 doors. This was encouraged by the customer, and it will help to keep total costs lower per station.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

The overall performance measure is reliability up to at least 2 million cycles. We identified this as the single user need based on our interviews with the customer. Our design must be able to accomplish this, ideally at a lower cost than the existing design.

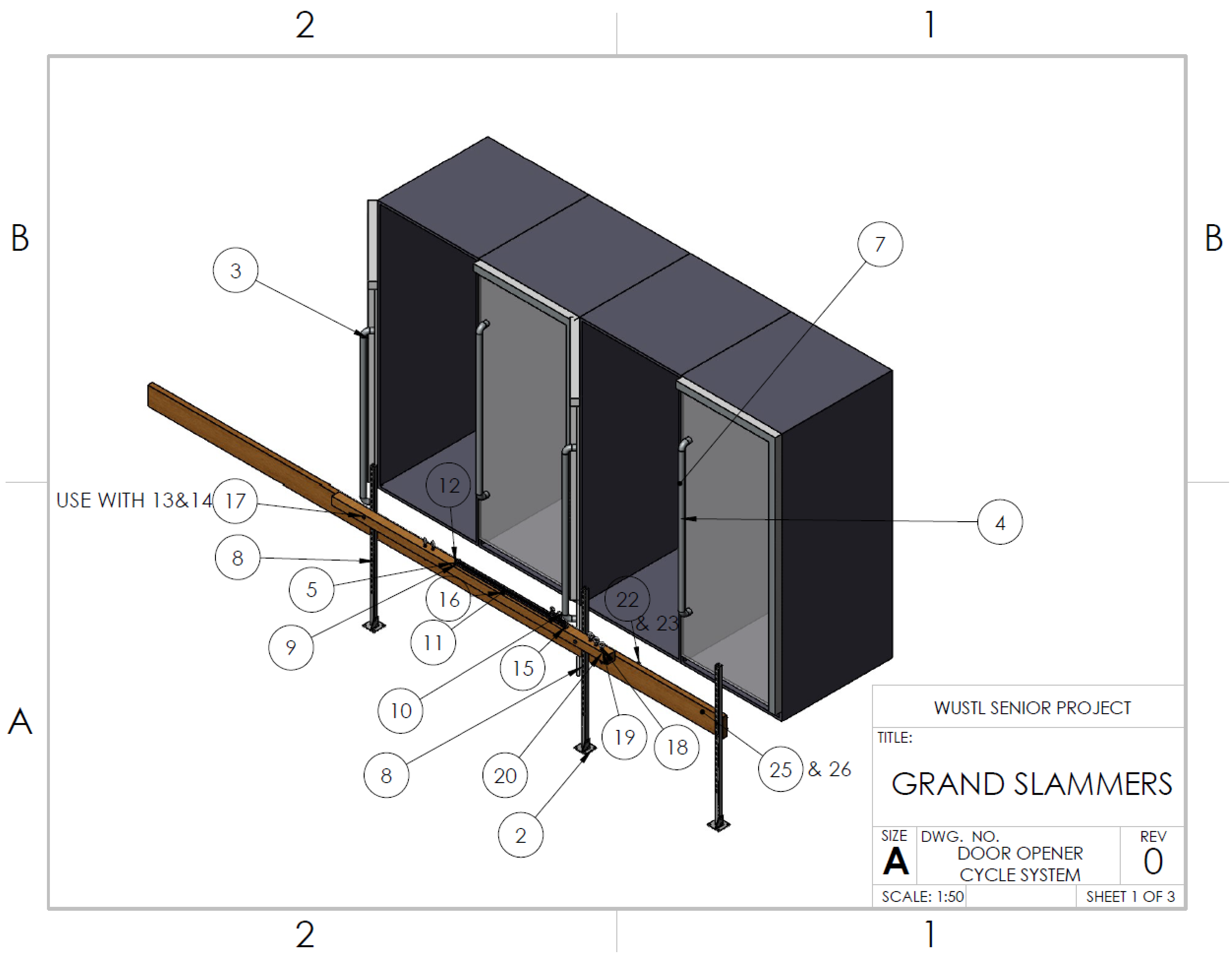
3.5 REVISION OF SPECIFICATIONS AFTER CONCEPT SELECTION

In the revised project brief, we clarified several parameters. The test will be performed under ambient conditions because the temperature, pressure, and humidity at the customer are uncontrolled and vary depending on the weather. This may affect the testing system performance or cabinet life. We want our system to last for up to 2 million cycles instead of 1 million as we wrote previously, because the current actuators tend to fail after about 2 million cycles. We added that the system is to open doors, not shut them; this was a requirement learned in our customer needs interview. The system must work for at least 2 doors at once, and the customer put multiple units at the same testing station as needed. We previously wrote that it needed to work on 6 doors. The customer informed us that they would like to have the assembly drawing shown with 5 left-swinging doors because that is the most common cabinet type. They can easily modify the testing assembly by adding one additional pulley for any door that is right swinging. We also added the range of door weights and approximate pull force needed, which we learned from the customer.

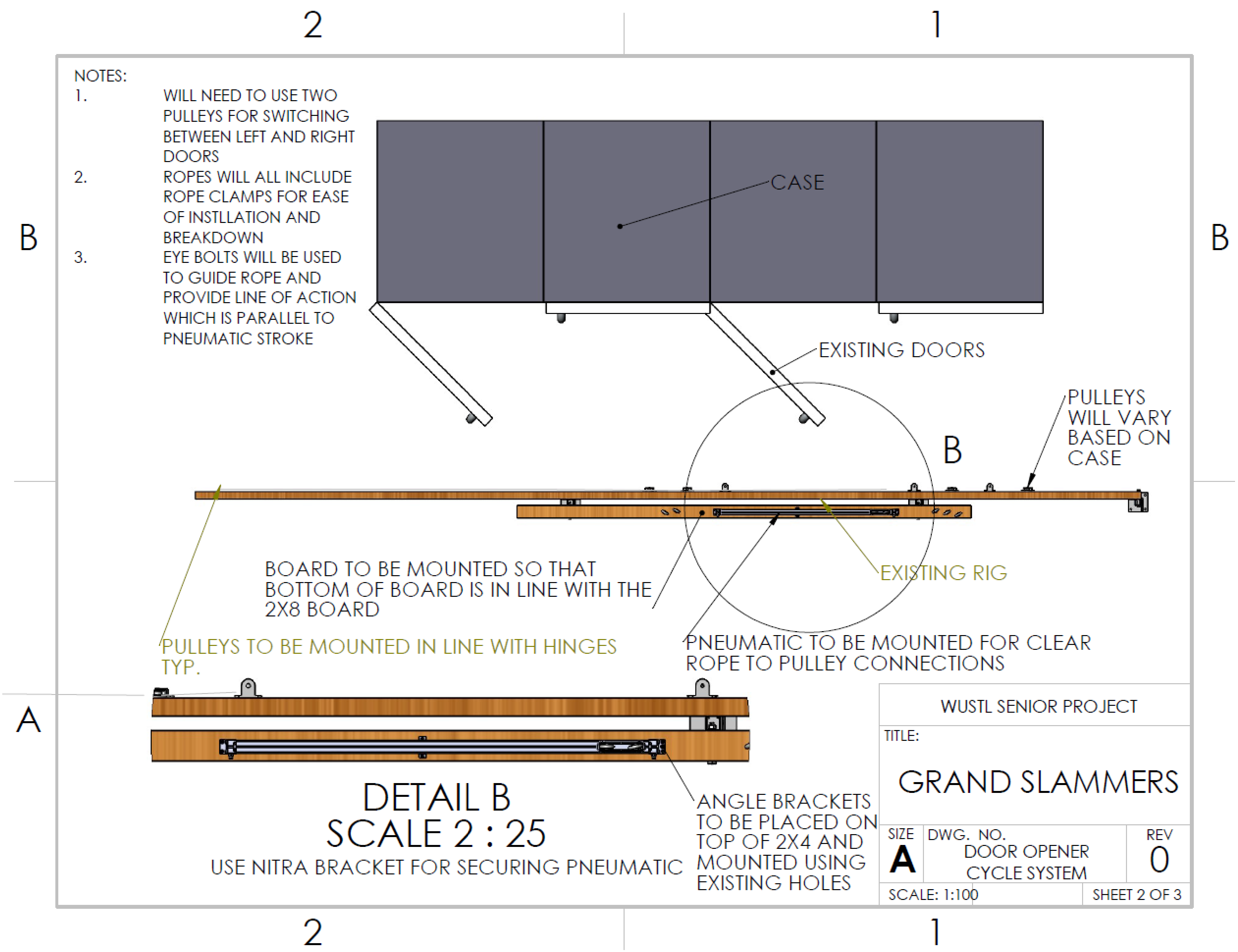
4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING

Please see the final assembly drawings on the following pages.



WUSTL SENIOR PROJECT		
TITLE: GRAND SLAMMERS		
SIZE A	DWG. NO. DOOR OPENER CYCLE SYSTEM	REV 0
SCALE: 1:50		SHEET 1 OF 3


2
1
B
A
NOTES:
1. WILL NEED TO USE TWO PULLEYS FOR SWITCHING BETWEEN LEFT AND RIGHT DOORS
2. ROPES WILL ALL INCLUDE ROPE CLAMPS FOR EASE OF INSTLLATION AND BREAKDOWN
3. EYE BOLTS WILL BE USED TO GUIDE ROPE AND PROVIDE LINE OF ACTION WHICH IS PARALLEL TO PNEUMATIC STROKE
CASE
EXISTING DOORS
PULLEYS WILL VARY BASED ON CASE
B
EXISTING RIG
BOARD TO BE MOUNTED SO THAT BOTTOM OF BOARD IS IN LINE WITH THE 2X8 BOARD
PULLEYS TO BE MOUNTED IN LINE WITH HINGES TYP.
PNEUMATIC TO BE MOUNTED FOR CLEAR ROPE TO PULLEY CONNECTIONS
DETAIL B
SCALE 2 : 25
USE NITRA BRACKET FOR SECURING PNEUMATIC
ANGLE BRACKETS TO BE PLACED ON TOP OF 2X4 AND MOUNTED USING EXISTING HOLES
WUSTL SENIOR PROJECT
TITLE:
GRAND SLAMMERS
SIZE
A
DWG. NO.
DOOR OPENER CYCLE SYSTEM
REV
0
SCALE: 1:100
SHEET 2 OF 3

4.2 PARTS LIST

2 1

B

ITEM NO.	PART NUMBER	DESCRIPTION	QTY
1	EXISTING	Strut Channel	3
2	EXISTING	Strut Channel Floor Mount	3
3	EXISTING	FRENCH DOORS	4
5	LEMB-25M	NITRA mounting bracket, end, stainless steel	2
6	36815T24	Easy-Install Rope Clamps - Not for Lifting Plastic Double Clamp, for 3/8"" Diameter Rope	6
7	91101A233	Steel Split Lock Washer for 1/2" Screw Size, 0.512" ID, 0.869" OD	5
8	EXISTING	EXISTING RIG	1
9	L25M1000MD-MC.STEP	NITRA pneumatic cylinder, rodless, 25mm bore, 1000mm stroke, double acting, magnetic piston, front and rear adjustable cushions, tapped end caps mount.	1
10	3019T32	Galvanized Steel Eye Nut - for Lifting	2
11	LCMB-25M.step	NITRA mounting bracket, center, aluminum. For use with L25M series rodless cylinders.	1
12	51235K107	Push-to-Connect Tube Fitting with Universal Thread	2
13	94645A102	High-Strength Steel Nylon-Insert Locknut	4
14	91166A240	Zinc-Plated Steel Washer	4
15	92095A486	Button Head Hex Drive Screw	4
16	90095A414	Screws for Softwood and Plastic-Wood Composites	18
17	91571A406	Heavy Hex Head Screw for Structural Application	4
18	90499A033	High-Strength Steel Hex Nut	14
19	95229A550	Cadmium-Plated Steel MIL. Spec. Washer	14
20	3013T967	Steel Eyebolt without Shoulder - for Lifting	5
21	3073T13	Mounted Pulley for Rope-for Horizontal Pulling	4
22	3071T2	Mounted Pulley for Rope-for Horizontal Pull	4
23	93048A115	Zinc-Plated Steel Male Hex Thread Adapter M5 x 0.8 mm to M8 x 1.25 mm Thread Size	2
24	3836T31	High-Strength Wear-Resistant Rope Not for Lifting Shock-Absorbing, 1/4"" Diameter	1
25	Item #77081 Model #2P020816S4	2-in x 8-in x 16-ft Southern Yellow Pine S4S Kiln-dried Lumber	1
26	Item #92331 Model #637630	4-in x 4-in x 8-ft Douglas Fir S4S Green Lumber	1

A

WUSTL SENIOR PROJECT

TITLE:

GRAND SLAMMERS

SIZE A | DWG. NO. DOOR OPENER CYCLE SYSTEM | REV 0

SCALE: 1:50 | SHEET 3 OF 3

2 1

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

The parts used in this project are all stock materials. No parts were specifically fabricated for the project. Please refer to Appendix C for a complete set of component drawings.

4.4 DESCRIPTION OF THE DESIGN RATIONALE

Below is the design rationale for each component, organized by item number, as shown on the above parts list.

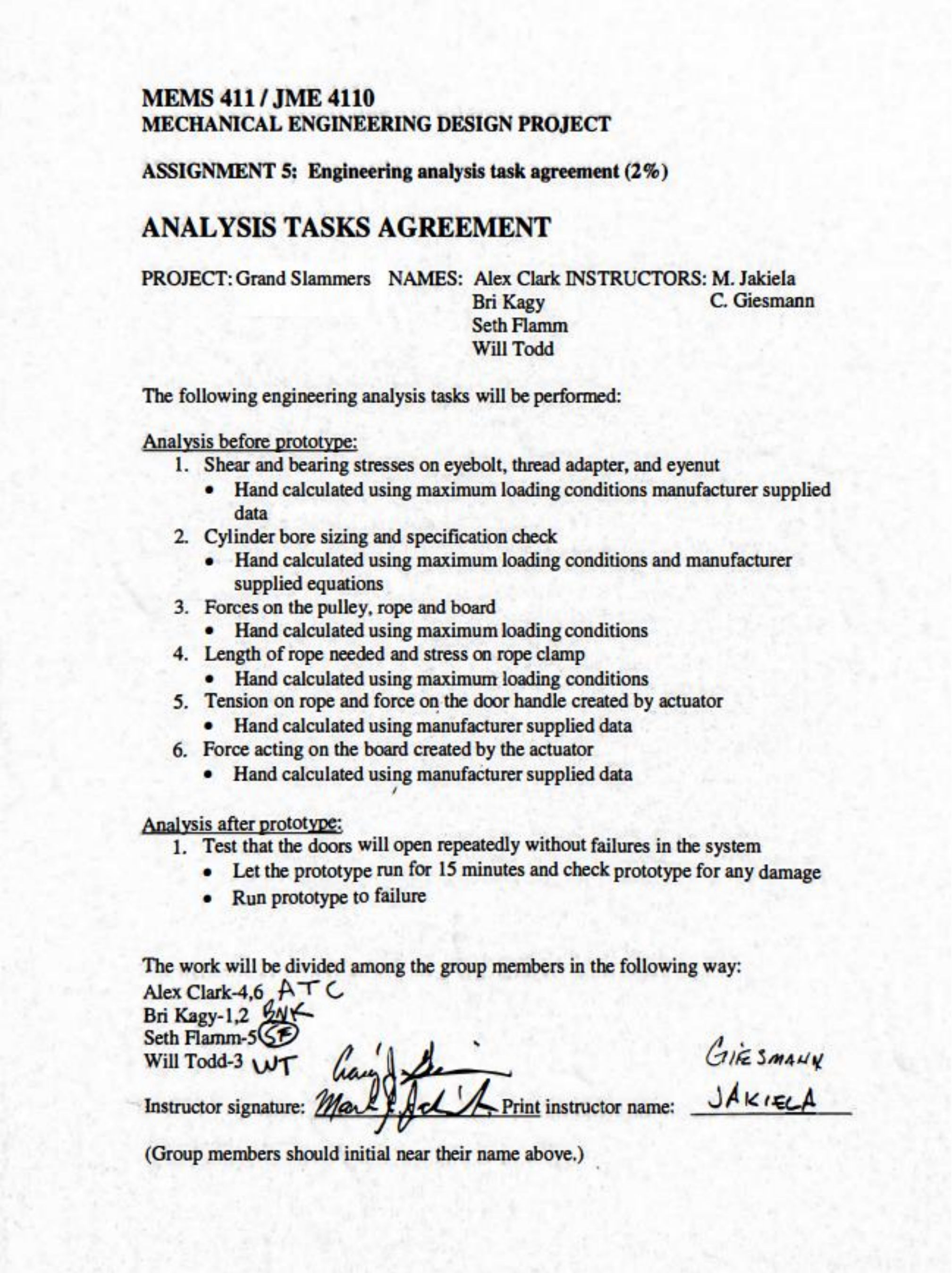
1. The strut channel was an existing part of the customer station structure. It was included at zero cost.
2. The strut channel floor mount was an existing part of the customer station structure. It was included at zero cost.
3. The French door cabinet was provided by the customer as the cabinet to use while building our prototype.
4. The door handle is part of the customer-provided cabinet.
5. The mounting brackets were chosen for the cylinder because they are the recommended attachments provided by the manufacturer of the cylinder.
6. The rope clamps were selected for ease of assembly and disassembly, because the cabinets are frequently moved and replaced at the facility. They prevent the need to knot and untie the ropes. This prevents unnecessary waste, because the rope no longer needs to be cut off the door handles at the completion of testing. It can now be reused.
7. The lock washers were chosen to add clamping strength to the connections for the eyebolts used to guide the ropes on either side of the cylinder.
8. This item denotes the existing rig.
9. The pneumatic cylinder was the key aspect of this design. It was chosen to prevent the issues with the single-rod cylinders the customer was experiencing. It was sized based on the forces and moments required to open the doors. The throw length was selected because it is nearly equal to the width of most cabinet doors.
10. The eye nuts were selected because we needed a secure connection for the ropes that could fit at least 3 ¼” ropes.
11. We wanted to reinforce the attachment of the cylinder to the 4x4. These brackets are sold by the manufacturer for this purpose. They come with screws to attach the brackets to the cylinder.
12. This tube fitting was selected to integrate our design with the shop air.
13. This nut is for mounting the cylinder to the 4x4, using the angle brackets.
14. This washer pairs with item 14.
15. The bolt pairs with items 13 and 14. We chose to bolt through the 4x4, knowing the station will be subjected to millions of cycles. We did not want to rely solely on screw friction as the attachment force. It is sized based on the 4x4 dimensions and the hole in the angle bracket. They have Phillips heads for easy installation.
16. These basic wood screws were chosen to attach the pulleys and center brackets on the cylinder. The pulleys will need to be moved in order to accommodate different cabinets, so they needed to be screwed, not bolted, to the 2x8. The mounting screws were determined by the diameter of the chamberer hole on the pulley. All screws are self-tapping to prevent the need for pilot holes. This will provide the customer with easier installation.
17. These bolts were sized to attach the 4x4 and 2x8 to the existing Unistrut structure. We chose the largest size that could fit the Unistrut.

18. The nut pairs with item 17.
19. The washer pairs with items 17 and 18.
20. These eyebolts were sized to accommodate the rope diameter. These could be sized down, but we had difficulty finding eyebolts that were long enough to go through the 4x4.
21. The pulleys must be able to mount perpendicular to the 2x8 board on the rig and need to accommodate a 1/4" rope.
22. We needed two orientations for the pulleys in order to be able to guide the ropes with minimal friction and avoid interference. The specification for item 21 also apply here.
23. The thread adapter was needed to adapt the M5 connection on the cylinder to an M8 in order to fit the eye nuts.
24. The rope needed to be between 1/4 - 1/2" diameter and have high wear resistance.
25. The 2x8 was chosen based on the necessary size, determined by the size of the average cabinet and the available Unistrut structure. The wood type does not have significant effect on the design. The low cost option was selected.
26. The 4x4 was chosen based on the necessary size, determined by the size of the average cabinet and the available Unistrut structure. The wood type does not have significant effect on the design. The low cost option was selected.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract



MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: Grand Slammers NAMES: Alex Clark INSTRUCTORS: M. Jakiela
Bri Kagy C. Giesmann
Seth Flamm
Will Todd

The following engineering analysis tasks will be performed:

Analysis before prototype:

1. Shear and bearing stresses on eyebolt, thread adapter, and eyenut
   - Hand calculated using maximum loading conditions manufacturer supplied data
2. Cylinder bore sizing and specification check
   - Hand calculated using maximum loading conditions and manufacturer supplied equations
3. Forces on the pulley, rope and board
   - Hand calculated using maximum loading conditions
4. Length of rope needed and stress on rope clamp
   - Hand calculated using maximum loading conditions
5. Tension on rope and force on the door handle created by actuator
   - Hand calculated using manufacturer supplied data
6. Force acting on the board created by the actuator
   - Hand calculated using manufacturer supplied data

Analysis after prototype:

1. Test that the doors will open repeatedly without failures in the system
   - Let the prototype run for 15 minutes and check prototype for any damage
   - Run prototype to failure

The work will be divided among the group members in the following way:
Alex Clark-4,6 ATC
Bri Kagy-1,2 BNK
Seth Flamm-5 SF
Will Todd-3 WT

Instructor signature: Print instructor name: GIESMANN
JAKIELA

(Group members should initial near their name above.)

Figure 6: Engineering Analysis Contract

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

Our group identified several calculations that we wanted to perform to make sure that our prototype would be capable of opening the case of doors without any issues. It was important to our group to make sure that the build would work on paper before we had our customer spend their funds on parts.

The majority of our calculations were sizing related, such as ensuring we had selected large enough fasteners, ropes, pulleys, and that the actuator was capable of pulling open all the doors at once. We also wanted to make sure the actuator was not going to pull too hard on the door handles and cause them to fail. We also calculated the length of rope we would need so we would make sure we ordered enough to set up our station.

5.2.2 Summary statement of analysis done

Shear and bearing stress were major calculations for our group so we used $\tau=P/A$ and $\sigma=P/tD$, where τ is the shear stress, P is the force, A is the area, σ is the bearing stress, t is the thickness, and D is the diameter. Finding the moment about a point was also important in our calculations, and we used M=Fh, where M is the moment, F is the force, and h is the distance.

5.2.3 Methodology

Please refer to Appendix D for a complete set of the design calculations performed. All members of our team contributed to doing the calculations by hand, as listed above. We wanted to make sure our prototype was going to work on paper before we ordered any parts.

5.2.4 Results

All our sizing was successful: all the pulleys, rope, fasteners, and the actuator can handle the work. The actuator does not pull with enough force to break the handles off the doors. Our group predicted that all of the materials selected would be more than enough to handle the smaller forces we were working with, and we were correct. The only real question we had was about the actuator being able to open the doors, but it too was able to work. After verifying the proper operation of our design, we began to record some metrics and make predictions on the output. We recorded that our design cycles doors every 7 seconds which results in 12,000 cycles a day. We predict that the design will be low maintenance and last for the targeted lifespan.

5.2.5 Significance

Our group ran into a snag in our design when doing the calculations. We found that the way we had originally wanted attach eyebolts to the shuttle was going to put the force on the shuttle in such a way to create a moment that it could not handle. This led to us updating the design to thread adapters and eye nuts, so we could transfer the force to be in line with the shuttle, where it was able to take a larger moment. We also added eyebolts on either side of the actuator to take any of the force that would not be acting on the shuttle in a linear fashion. We also updated some of the fasteners to bolts so we could minimize the chance they would work themselves out of the wood over time.

6 RISK ASSESSMENT

6.1 RISK IDENTIFICATION

To identify risks on this project, we considered the items that could go wrong throughout the project life. We found that the highest risk items were those that involve the customer.

1. **Schedule: Customer Approvals and Ordering of Materials**
We were concerned that the schedule could be impacted by the customer. We required customer approval of the Bill of Materials. Once approved, the customer ordered the material. We also needed to coordinate the fabrication at the facility with our customer contact's schedule.

2. **Environmental: Compressed Air**
Our design is powered by the customer's shop compressed air system. There was a small risk that the shop compressed air would be too dry to work with the pneumatic, causing the pneumatic to fail.

3. **Estimating: Pneumatic Cylinder**
We chose a pneumatic cylinder that we estimated would be sufficient for the design conditions. However, we could not be certain that the cylinder could handle the required force without performing the calculations. There was a risk that the cylinder would need to be scaled up and could exceed the budget given by the customer.

4. **Testing: Compressed Air System**
There was a risk that the shop compressed air required to power the design was not reliable enough to run the cycling station.

5. **Schedule: Engineering Phase Delay**
There was a risk that material ordering would be delayed due to the engineering phase, including concept design and calculations, would not be completed on schedule.

6.2 RISK ANALYSIS

1. **Schedule: Customer Approvals and Ordering of Materials**
The impact of this risk would be on the schedule. The customer's actions were outside of our control. If the customer was not responsive or quick to act, the tight schedule of the course could cause us to be unable to complete the project. In the worst case scenario, this would have had a devastating effect on the project because of the hard deadline. We estimated that the likely impact of this risk would be five days. We mitigated this risk by holding weekly customer meetings to stay in communication about each week's priorities.

2. **Environmental: Compressed Air**
If the pneumatic cylinder chosen for the project could not work with the shop air, we would have needed to completely redesign or find a new cylinder that could work with the shop air but was still an advancement over the customer's existing solution. This could have had a three day impact on schedule and major cost impact. New materials would have needed to be ordered after the initial order was placed. We researched the cylinder and learned that lubricant cannot be used with the chosen cylinder. The customer must be informed that they cannot use the lubricant they are currently using on the new cylinder.

3. **Estimating: Pneumatic Cylinder**
If the cylinder model required exceeded the budget provided by the customer, we would have needed to redesign to find a solution within budget. This would have had a five day schedule impact and some minor cost impact. The cost impact would be less than it is for

other risks because we could use calculations to determine the necessary cylinder prior to ordering parts. We mitigated this risk by performing calculations before ordering a cylinder.

4. **Testing: Compressed Air System**
If the shop air did not work with our cylinder type, it also would have required a redesign after purchasing the initial cylinder. The shop air pressure given to us was an approximate value. This causing the cylinder to fail would have had a severe schedule and cost impact. We mitigated this risk by using a customer-provided air regulator valve to lower the shop pressure to the optimal value.

5. **Schedule: Engineering Phase Delay**
There was a risk that material ordering would be delayed due to the engineering phase, including concept design and calculations, would not be completed on schedule. This risk would have a lower impact because it would occur earlier in the project and there would be more time available to make up for the delay. It also would not have a cost impact, unless it caused us to need expedited shipping. This risk actually occurred, and we absorbed a one week delay without significant project impact. The results of the calculations caused us to reconfigure our design, which required some alternate parts. It took about a week to redesign, update the Bill of Materials, get customer approval, and order the parts.

6.3 RISK PRIORITIZATION

We used a Risk Management Register to prioritize the risks and assess them for potential cost and schedule impact. Notably, the materials ordering delay due to engineering phase delays was the risk we identified as the highest ranking, and it was the only one that occurred on the project. The others were assessed as being low risk, and none of them occurred, in part due to our mitigation efforts.

Table 7: Risk Register

Risk Management Register

0	Open Red Risks
1	Open Yellow Risks
3	Open Green Risks
0	Risks w/ no Response Strategy
0	Closed risks

Project Name:	Door Cycling Station	Location:	Hussmann
Project Manager:	Seth Flamm	Add'l Info:	Grand Slammers (Hussmann #:
Start Date:	6/12/2023	Updated On:	7/17/2023
		Overall Project Risk Indicator:	14

Risk Level

Probability \ Impact	1	2	3	4
5	5	10	15	20
4	4	8	12	16
3	3	6	9	12
2	2	4	6	8
1	1	2	3	4

Impact: 1 2 3 4 5

Legend:

Impact
1 - Negligible
2 - Marginal
3 - Significant
4 - Critical
5 - Catastrophic

Probability
1 - Rare
2 - Unlikely
3 - Possible
4 - Likely
5 - Certain

Item	Project/ Phase	Risk Status	Risk	Potential Impact (Cause and Effect)	Risk Response Strategy	Triggers (Indicators that the risk will occur)	Estimated Schedule Impact (Days)	Maximum Exposure ($000)	Estimated Exposure (Contingency) ($000) $305	Risk Category	Risk Sub Category	Action Owner	Start Exposure	End Exposure	Baseline Risk Scoring: Impact: Tech Perf	Baseline: Impact: Schedule	Baseline: Impact: Cost	Baseline: Impact: Safety	Baseline: Probability	Baseline: Risk Ranking	Current Risk Score: Impact: Tech Perf	Current: Impact: Schedule	Current: Impact: Cost	Current: Impact: Safety	Current: Probability	Current: Risk Ranking
0			Short Term Holding						$0																1	0
1	Engineering	Open	Schedule: Customer Risks	Customer approvals delay production, e.g. design approval, build date(s) coordination.	Mitigate: Weekly customer meetings to maintain good communication.	Customer is not available for meetings.	5	$250	$26	Schedule	Permitting	Project Manager	06/19/23	08/14/23	0	2	2	0	2	4	0	2	2	0	2	4
2	Warranty	Open	Environmental: Compressed Air	The available compressed air is too dry to work with pneumatic, causing the pneumatic to fail.	Accept and mitigate: Lubricant cannot be used with the chosen cylinder. Hussmann must be informed that they cannot use the lubricant they are accustomed to using on the current single-rod cylinders.	Cylinder failure occurs before expected number of cycles completed.	3	$349	$9	Project Development	Performance Guarantees	Project Manager	08/04/23	08/04/25	5	1	3	0	1	5	5	1	3	0	1	5
3	Engineering	Open	Estimating: Pneumatic Cylinder	Pneumatic needed to work with 5 doors exceeds estimated budget.	Avoid: Perform calculations for required pneumatic before ordering.	Calulation for maximum force needed results in cylinder more expensive than their current solution.	5	$164	$4	Financial/Regulatory	Cost, Budget, Forecast in Alignment	Design Engineer	06/19/23	07/24/23	3	2	2	0	1	3	3	2	2	0	1	3
4	Testing	Open	Testing: Compressed Air System	Compressed air at door testing station is not reliable enough to work with cylinder. Low risk due to current, successful use of air cylinders.	Mitigate: Purchase regulator valve or air cylinder required lower shop air pressure (psi).	Testing fails.	15	$80	$2	Technology	Plant Modifications / Interfaces Required	Design Engineer	08/04/23	08/14/23	5	5	1	0	1	5	5	5	1	0	1	5
6	Engineering	Open	Schedule: Materials Risks	Material ordering is delayed due to engineering phase delays.	Mitigate: Set and keep hard deadlines for calculations to be completed and BOM finalized. Order materials with 7 days slack to ensure arrival in time.	Calculations not complete by hard deadline. Materials are not ordered by deadline.	3	$800	$264	Schedule	Material Constraints	Project Manager	07/17/23	08/04/23	0	1	5	0	3	15	0	1	5	0	3	15

7 CODES AND STANDARDS

7.1 IDENTIFICATION

[1] ANSI/ASHRAE Standard 72 – 2022: Method of Testing Open and Closed Commercial Refrigerators and Freezers

[2] ISO 23953-2 – 2021: Refrigerator Display Cabinets – Part 2: Classification, Requirements, and Test Conditions

[3] ASME B30.26 – 2015: Rigging Hardware: Safety Standard for Cableways, Cranes, Derricks, Hoists, Jacks, and Slings

[4] ASTM F3125/FD3125M – 2022: Standard Specification for High Strength Structural Bolts and Assemblies, Steel and Alloy Steel, Heat Treated, Inch Dimensions 120 ksi and 150 ksi Minimum Tensile Strength, and Metric Dimensions 830 MPa and 1040 MPa Minimum Tensile Strength

[5] AWC NDS – 2018: National Design Specification for Wood Construction

[6] ASTM D6815 – 2022: Standard Specification for Evaluation of Duration of Load and Creep Effects of Wood and Wood-Based Products

[7] ASTM F1470 – 2018: Standard Guide for Inspection of Nylon, Polyester, or Nylon/Polyester Blend, or Both Kernmantle Rope

[8] ANSI/CAGI B19.1 – 2011: Safety Standard for Compressor Systems

[9] OSHA 1910.212: General Requirements for All Machines: Machinery and Machine Guarding

[10] OSHA 1910 Subpart D: Walking-Working Surfaces

[11] OSHA 1910 Subpart G: Occupational Noise Exposure

[12] EU NO 1907 – 2006: Regulation of the European Parliament and of the Council Concerning the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH)

[13] VA Section 22 15 00 – 2020: General Service Compresses-Air Systems

7.2 JUSTIFICATION

[1] The purpose of this standard is to set a universal method of testing commercial refrigerators, in order to compare performance factors across products. It applies to vertical, closed refrigerators, such as the cases tested at the customer facility. The majority of the requirements therein apply to testing in while the unit is powered on, so the test conditions may or may not apply to testing in the customer's facility.

[2] The standard specifies requirements for construction and characteristics of refrigerated display cabinets used for the sale and display of foodstuffs. It provides test conditions and methods for testing that the requirements for the refrigerator cabinets have been satisfied.

[3] The scope of this standard applies to material-movement related equipment. The majority of the standard applies to lifting equipment, but some of the same engineering principles apply to this design project. The purpose of the standard is to prevent injury to workers, provide direction to

manufacturers and users, and provide guidance to regulatory bodies for the enforcement of safety directives.

[4] This standard provides the chemical, physical and mechanical requirements for the bolts used to attach the 4”x4”x8’ and the 2”x4”x16’ wood boards.

[5] The design specification defines the methods to be used in structural design with wood products, including the S4S lumber used for this project. It also provides guidelines for the application and selection of fasteners for use with wood products. It references specifications for appropriate fasteners, testing of the structural properties of lumber, and other applicable items.

[6] The specification provides a procedure for testing the duration of load and creep effects of wood materials, including the wood types used for this project. Creep occurs for materials that are under force for an extended period. The wood in this project must withstand millions of cycles. It would be beneficial to evaluate the creep strength of the wood to determine whether a different material may be more appropriate as the base structure of the door cycling station.

[7] The standard guide provides procedures for the management and care of nylon rope. It primarily is meant to be used by rescue personnel, but the inspection procedures may be used for the regular inspection of the nylon ropes used for this project.

[8] The standard provides practices, specific requirements, and recommendations for safe use of air compressors, drives, and auxiliaries. The requirements may apply to the shop air system used at the customer facility.

[9] The door cycling station has moving parts, which could be hazardous if used without appropriate care. The customer should consider implementing safe practices by adding guards around the cycling stations to comply with this specification.

[10] The standard includes requirements for keeping walkways clear and defining walking and working areas separately. The need to keep the cycling station footprint small enough to not encroach on the walking areas within the testing area was considered during the design and fabrication phases of the project.

[11] The combination of the pneumatic system, pulleys, and doors opening and closing creates a loud environment in the testing area. Multiple cabinets are tested at once, so the noise builds.

[12] The rope and pulleys purchased for use in the testing station comply with REACH requirements.

[13] The standard describes requirements for NFPA 99 Category 4 compressed air systems for non-medical air piping systems, including compressors, piping, fittings, valves, connections, and accessories. It applies to systems of 100 psig or less. The customer’s shop air supply is approximately 120 psig. At the testing station, a regulator is used to reduce the flow to the station to 50 psig. It is possible that the requirements in this standard or a similar standard are applicable to the shop air system. The group did not have access to this standard nor additional information about the shop air system.

7.3 DESIGN CONSTRAINTS

7.3.1 Functional

[2] 5.3.4.2 states that hinged lids and doors shall be opened to an angle greater than 60°. Sliding doors be opened greater than 80% of the maximum opening area. The focus for this project was on hinged doors, but the design may be adapted by the customer to also test sliding doors.

[6] The creep strength of the materials used to fabricate the door testing station will minimally impact its functionality and performance over time. The tolerances for the station are quite high, so creep of the wood over time is not expected to have negative impact.

[13] The shop air system constrains the selection and use of the pneumatic cylinder. The shop air is necessary to power the cycling station. The unit design must account for the properties of the available air system, which is subject to its own regulations and standards.

7.3.2 Safety

[3] This standard was not available for review in its entirety, but there may be important safety-related guidance that applies to this project. The key topics of interest to this project are eyebolts, rope clips, rigging-blocks, and load-indicating devices.

[8] The standard provides practices, specific requirements, and recommendations for safe use of air compressors, drives, and auxiliaries. The requirements may apply to the shop air system used at the customer facility.

[9] 1910.212: One or more methods of machine guarding should be added around the testing station to protect the operator and other employees in the area. The customer should consider adding barriers on the sides of the testing station to prevent entry between the cabinet and the cycling unit while the unit is running. They should also consider adding an additional guard behind the cycling unit to prevent access to the cylinder and ropes while the station is running.

[10] Working and walking areas shall be marked clearly and walking areas shall be kept clear. When assembling a new door testing station, these requirements shall be followed.

[11] The testing area shall comply with OSHA regulations for noise exposure. The noise level shall be evaluated so that appropriate safety measures can be employed to prevent hearing damage for employees and others in the testing area.

7.3.3 Quality

[7] The standard may be employed as the standard practice for the regular inspection of the nylon rope. The results of the inspection can help to determine whether the rope should remain in service or be retired.

7.3.4 Manufacturing

[2] 4.1.1.4 provides construction requirements for closed refrigerator cabinets such as those tested by the customer. Doors must be able to be opened by different angles of at least 60°. Door fasteners and hinges shall be smooth and positive in action and function without undue wear. The doors shall not

open without outside force. The gasket must be compatible with the operating conditions. This indicates that the door cycling system shall open the doors to at least 60° in each cycle.

[4] The requirements of the ASTM F3125 standard apply to the manufacturing of the bolts. Other ASTM specifications apply to the other fasteners used, but the ASTM material specification was not provided by the supplier for reference.

[5] This standard was not available for this project. It contains information that should be used to ensure the manufacturing of the testing station meets the recommendations for proper wood structures.

7.3.5 Timing

[2] 5.3.4.2 The tests for closed refrigerated cabinets must be carried out on the complete cabinet. Assembly of the cabinet must be complete prior to testing.

[7] After use over million of cycles, the ropes may become worn and need to be replaced. The specifications included in this standard can help to determine the average rope life. Eventually, the rope can be replaced at standardized intervals, determined by the inspection results over several trials.

7.3.6 Economic

[4] The standard provides recommendation for the nut and washer to be used with the bolts. McMaster-Carr does not provide information about material specifications for all their parts, so it was not possible to follow the recommendations. Alternate nuts and washers were chosen that exceed the strength necessary for secure fastening.

[6] Although there are materials with higher creep strength that could be used to ensure the longevity of the station through millions of cycles, the cost of the lumber is low enough to render the need for more durable material void.

7.3.7 Ecological

[12] The rope and pulleys used in the testing station comply with REACH requirements for the authorization and restriction of chemicals.

7.3.8 Aesthetic

[2] 4.1.2.2. Internal and external finishes of the refrigerator unit shall be resistant to wear under normal conditions of use. The door cycling station contributes to wear on the handles, hinges, and gaskets of the cabinet, so it contributes to the testing of the finishes.

[2] 4.1.2.3 Metal parts used to construct the refrigerator shall have appropriate corrosion resistance.

7.3.9 Life Cycle

[6] The creep strength of the wood will be a contributing factor in determining the life cycle of the lumber used in the door cycling station.

[7] The inspection procedures described in the standard will help to determine the life cycle of the ropes.

7.3.10 Legal

[9, 10, 11] OSHA regulations are a legal requirement for the customer's manufacturing and testing facility. The three standards cited here are part of a larger body of regulations that shall be followed to meet the legal requirements.

7.3.11 Test Conditions

[1] 5.1 sets requirements for preparation of the refrigerator being tested. The refrigerator must be installed on a level, nonperforated surface. It shall not be placed in an area adjacent to heating or cooling equipment unrelated to the test. It shall be tested in still air, away from air currents. These requirements are primarily related to testing for internal temperature of the refrigerator. These requirements most likely do not apply to the customer's testing procedure because the refrigerators are tested in the unpowered condition.

[1] Table A-1 states clearance from front of refrigerator to wall or partition facing the unit must be greater than or equal to 1500 mm, ±25 mm.

[2] 5.3.3.5 requires conditions to stabilize prior to testing. This includes temperature stability. Although this section indicates that the refrigerator should be powered on for testing, this is specific to performance testing. For the purposes od the door cycling station, the interpretation of this specification is that the temperature should not change drastically throughout the duration of the testing.

7.4 SIGNIFICANCE

[1] The standard should be used as a reference for recommendations, not requirements. It provides test conditions for refrigerators while powered on, so the majority of the specification does not apply, as the cabinets are tested disconnected from power at the customer facility. The applicable recommendations involve conditions for the testing room and placement of the cabinet in relation to other surfaces.

[2] The standard applies to timing of the testing, test conditions, and aesthetic concerns regarding the components of the refrigerator cabinet itself. It applies to the refrigerator unit more than the door cycling unit itself.

[3] The standard applies to safe assembly and use of the pulleys and ropes.

[4] The bolts used for the attachment of the lumber to the Unistrut frame were manufactured to this material specification. Properties of the bolts that apply to the design calculations may be found in this standard.

[5] The standard provides guidance for building wood structures. It was not available for review.

[6] The creep strength of the wood can be found following the procedures contained in this specification. The value will help to determine the life cycle of the testing unit.

[7] The life cycle of the rope can be determined after extensive testing of the door cycling station, using the inspection procedures included in this specification.

[8] This standard applies to the safety of the shop air system.

[9] It is a legal requirement to comply with OSHA standards. Safeguards shall be out in place to prevent injury from moving parts. This is within the customer's scope.

[10] It is a legal requirement to comply with OSHA standards. Walkways shall be clearly marked and kept clear. This is within the customer's scope.

[11] It is a legal requirement to comply with OSHA standards. Noise resulting from use of the door cycling stations shall be considered and address according to this standard. This is within the customer's scope.

[12] REACH is a common certification that relates to the safe regulation of chemicals. The pulleys and ropes used in this project are REACH compliant.

[13] The standard for service of compressed air systems may apply to the customer's shop air system. This is within the customer's scope.

8 WORKING PROTOTYPE

8.1 PROTOTYPE PHOTOS

Figure 7: Assembled prototype

This photograph shows the assembled prototype in action. This photograph includes the rodless pneumatic cylinder, PLC, air inlets, eyebolts, and rope attachments to the cabinet doors.

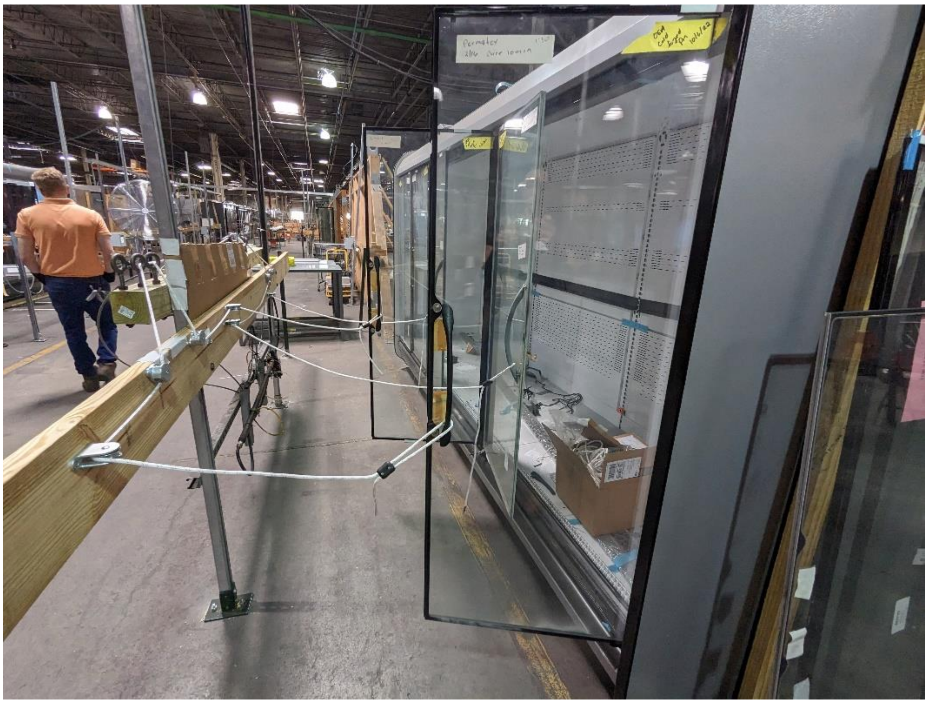
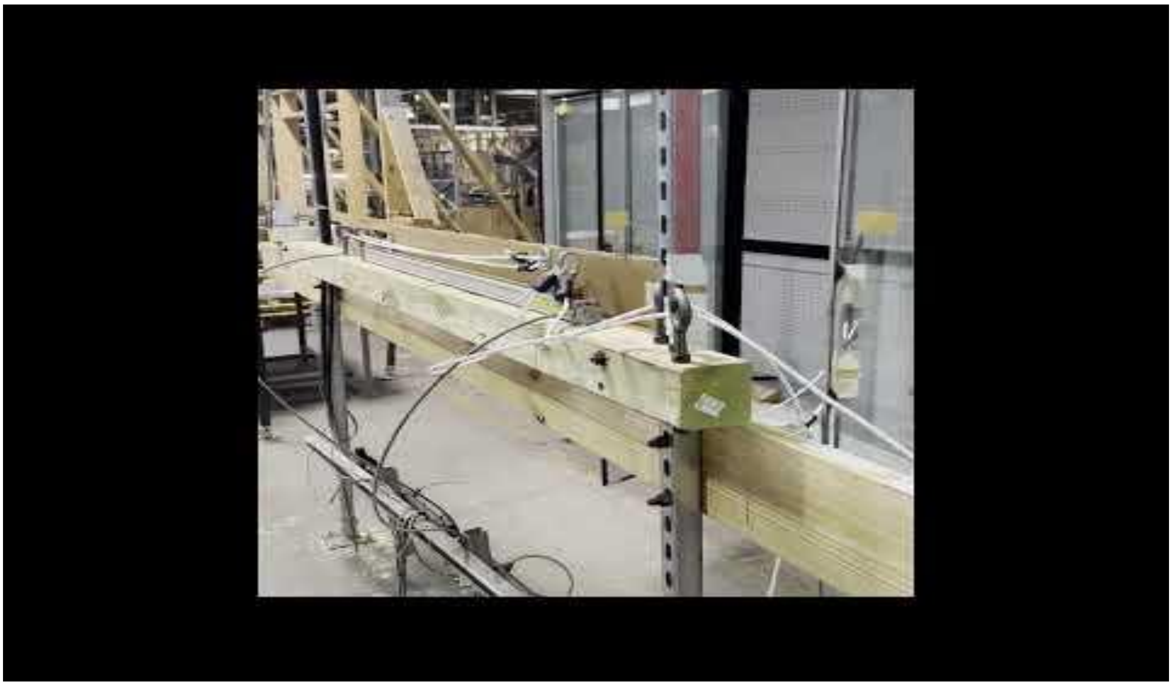


Figure 8: Pulley and rope configuration for cabinet with 4 French doors.

The French doors must be opened in alternating sequence, or the doors that open in opposite directions will crash into each other. The ropes are routed, using pulleys, to the correct orientation to pull the handles of the doors on the XY plane. This is an intentional orientation to simulate the pulling on the handle by the future users.

8.2 WORKING PROTOTYPE VIDEO

Grand Slammers Prototype Demo



8.3 PROTOTYPE COMPONENTS

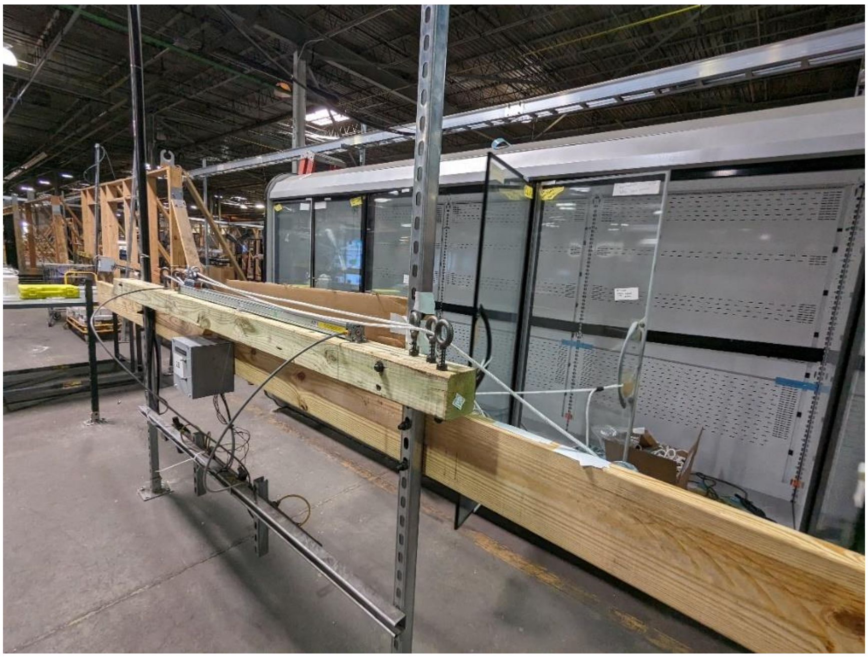


Figure 9: Rodless pneumatic cylinder with shown with two air inlet lines and PLC system.

Each inlet alternately feeds air into the cylinder to push the piston to the opposite side. The shuttle with eye nut attachments is magnetically attached to the piston.

Figure 10: Rope attachments to cabinet door handles using rope clamps.

We chose to use rope clamps so the ropes can be easily attached and removed. The cabinets are frequently swapped out for testing at the facility. Previously, the ropes were knotted onto the handles and then cut off after testing. The clamps prevent the need to waste rope.

Figure 11: The cardboard was added to prevent the rope slack from catching on the pulleys.

We found that a barrier was needed to prevent the rope slack from catching on the pulleys and stalling the system. This could be removed if the rope lengths and pulley installation locations were tuned further for optimal performance. The cardboard solution was effective for our purposes. The eyebolts help to route the ropes and keep them from sitting on the cylinder base.

Figure 12: The structural board orientation.

Here you can see the orientation of the boards in relation to the Unistrut, along with how we were able to bolt the boards to the Unistrut. The eye bolts needed to be high enough not to catch the board. We wanted to prevent rubbing as much as possible to keep the durability of the rope intact.

9 DESIGN DOCUMENTATION

9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings

See Appendix C for the individual CAD models.

9.1.2 Sourcing instructions

We used McMaster-Carr to source most of the components and hardware. The lumber was sourced from a local hardware store. We purchased the pneumatic from Automation Direct. Their website has many types of hydraulics and pneumatics with optional attachments for sale. Once we verified our calculations, we sized the appropriate pneumatic from the catalog.

9.2 FINAL PRESENTATION

Grand Slammers Prototype Discussion

10 TEARDOWN

The customer will keep the fabricated door testing station. They will perform further tests after this capstone course ends, in order to determine the life cycle of the cylinder in the field. They will start the official life cycle count after we present the functional prototype. The aim is for the cylinder to reach two million cycles.

11 APPENDIX A - PARTS LIST

Table 8: Initial list of parts for the cost of raw materials and components.

Cost Estimate									
The Grand Slammers									
Department: Project Management								**Updated: 7/20/23**	
Division: Estimates								**JME 4110**	
No.	**Item**	**Description**	**Sources**	**Unit**	**Unit Cost**	**Qty.**	**Lead Time**	**Material**	**Total**
1	3071T3	Mounted Pulley for Rope-for Horizontal Pull	https://www.mcmaster.com/3071T3/	Each	$20.56	9	1 Day	Steel	$185.04
2	L25M1000MD-MC	NITRA pneumatic cylinder, rodless, 25mm bore, 1000mm stroke, double acting, magnetic piston, front and rear adjustable cushions, tapped end caps mount.	Pneumatic Cylinder: rodless, 25mm bore, 1000mm stroke (PN# L25M1000MD-MC) | AutomationDirect	Each	$349	1	4 Days	Aluminum	$341
3	9494T31	Closed Eye Routing Eyebolt - Not for Lifting	https://www.mcmaster.com/9494T31/	Each	$11.40	7	1 Day	316 Stainless Steel	$79.80
4	3836T31	Comfort-Grip Wear-Resistant Rope - Not for Lifting Shock-Absorbing, 1/2" Diameter, 100 Feet Long	https://www.mcmaster.com/3848T48/	Per 100'	$96.41	1	1 Day	Nylon	$96.41
5	LEMB-25M	NITRA mounting bracket, end, stainless steel. For use with L25M series rodless cylinders. Mounting screws included	NITRA Mounting Bracket: for L25M series rodless cylinders (PN# LEMB-25M) | AutomationDirect	Each	$6.00	2	4 Days	Stainless Steel	$12.00
6	LCMB-25M	NITRA mounting bracket, center, aluminum. For use with L25M series rodless cylinders.	https://www.automationdirect.com/adc/shopping/catalog/pneumatic_components/rodless_air_cylinders/lcmb-25m	Each	$14.00	6	4 Days	Aluminum	$84.00
7	98273A310	Quick-Install Thread-Cutting Screw for Soft Metal 410 Stainless Steel, 10-32 Thread, 3/8" Long	https://www.mcmaster.com/98273A310/	Per 100 Pc	$15.05	1	1 Day	410 Stainless Steel	$15.05
8	96640a244	Black-Oxide 18-8 Stainless Steel Phillips Flat Head Screws 82 Degree Countersink Angle, 12-24 Thread, 1/2" Long	https://www.mcmaster.com/96640A244/	Per 25 Pc	$5.72	1	1 Day	Black-Oxide 18-8 Stainless Steel	$5.72
9	36815t25	Easy-Install Rope Clamps - Not for Lifting Plastic Double Clamp, for 1/2" Diameter Rope	https://www.mcmaster.com/36815T25/	Each	$8.33	6	1 Day	Plastic	$49.98
10	3577N134	Number 2 Premium SPF Softwood Board 2 x 4 Trade Size	https://www.mcmaster.com/3577N134/	Each	$5.77	2	1 Day	SPF Softwood	$11.54
11	50915k315	Brass Compression Tube Fitting for Air&Water Adapter, for 1/4" Tube OD x 1/4 NPTF Male	https://www.mcmaster.com/50915K315/	Each	$4.19	1	1 Day	Brass	$4.19
	Total Direct Cost	$884.73							
	Total before contingency	$884.73							
	Contingency (15%)	$133							
	Engineers estimate	$1,017							

12 APPENDIX B - BILL OF MATERIALS

Table 9: Final list of parts for the cost of raw materials and components.

Cost Estimate

The Grand Slammers

Department: Project Management — Updated: 8/9/23

Division: Estimates — JME 4110

No.	Item	Description	Installation Location	Sources	Unit	Unit Cost	Qty.	Lead Time	Material	Total
1	3071T2	Mounted Pulley for Rope-for Horizontal Pull Steel, for 3/8" Diameter, 7/8" Wide	Length of the 8x4, one at each hinge 4 per side	Mounted Pulley for Rope-for Horizontal Pull, Steel, for 3/8" Diameter, 7/8" Wide | McMaster-Carr	Each	$11.34	8	1 Day	Steel	$90.72
2	3019T32	Galvanized Steel Eye Nut - for Lifting M8x1.25 Thread Size	Eye bolt for the Shuttle	https://www.mcmaster.com/3019T32/	Each	$11.83	2	1 Day	Galvanized Steel	$23.66
3	93048A115	Zinc-Plated Steel Male Hex Thread Adapter M5 x 0.8 mm to M8 x 1.25 mm Thread Size	Shuttle adapter to eye bolt	Zinc-Plated Steel Male Hex Thread Adapter, M5 x 0.8 mm to M8 x 1.25 mm Thread Size | McMaster-Carr	Each	$10.14	2	1 Day	Zinc-Plated Steel	$20.28
4	3073T13	Mounted Pulley for Rope-for Horizontal Pulling Steel, for 3/8" Diameter, 1" Wide	Eyebolt rope to pulley	Mounted Pulley for Rope-for Horizontal Pulling, Steel, for 3/8" Diameter, 1" Wide | McMaster-Carr	Each	$16.93	6	1 Day	Steel	$101.58
5	L25M1000MD-MC	NITRA pneumatic cylinder, rodless, 25mm bore, 1000mm stroke, double acting, magnetic piston, front and rear adjustable cushions, tapped end caps mount.	N/A	Pneumatic Cylinder: rodless, 25mm bore, 1000mm stroke (PN# L25M1000MD-MC) | AutomationDirect	Each	$349	1	4 Days	Aluminum	$349.00
6	3013T967	Steel Eyebolt, 1/2"-13 Thread Size, 6" Thread Length	Pneumatic to eyebolt on 4x4	https://www.mcmaster.com/3013T967/	Each	$12.43	6	1 Day	Steel	$74.58
7	3836T31	High-Strength Wear-Resistant Rope Not for Lifting Shock-Absorbing, 1/4" Diameter	Rope for doors and pulleys	High-Strength Wear-Resistant Rope Not for Lifting, Shock-Absorbing, 1/4" Diameter | McMaster-Carr	Per 100'	$49.00	1	1 Day	Nylon	$49.00
8	LEMB-25M	NITRA mounting bracket, end, stainless steel. For use with L25M series rodless cylinders. Mounting screws included	Angle for the pneumatic ends	NITRA Mounting Bracket: for L25M series rodless cylinders (PN# LEMB-25M) | AutomationDirect	Each	$6.00	2	4 Days	Stainless Steel	$12.00
9	LCMB-25M	NITRA mounting bracket, center, aluminum. For use with L25M series rodless cylinders.	Support brackets for center of pneumatic	https://www.automationdirect.com/adc/shopping/catalog/pneumatic_components/rodless_air_cylinders/lcmb-25m	Each	$14.00	2	4 Days	Aluminum	$28.00
10	90095A414	Phillips Head, Corrosion-Resistant Steel, Number 6 Size, 1-1/4" Long	Screw for the pulleys and center brackets	Phillips Head, Corrosion-Resistant Steel, Number 6 Size, 1-1/4" Long	Per 245	$8.62	1	1 Day	Corrosion-Resistant-Coated Steel	$8.62
11	36815T24	Easy-Install Rope Clamps - Not for Lifting Plastic Double Clamp, for 3/8" Diameter Rope	Rope clamp one per door and at per rope at pneumatic	Easy-Install Rope Clamps - Not for Lifting, Plastic Double Clamp, for 3/8" Diameter Rope | McMaster-Carr	Each	$6.76	12	1 Day	Plastic	$81.12
12	Item #77081 Model #2P02081654	2-in x 8-in x 16-ft Southern Yellow Pine S4S Kiln-dried Lumber	Pulley mounting	2-in x 8-in x 16-ft Southern Yellow Pine S4S Kiln-dried Lumber in the Dimensional Lumber department at Lowes.com	Each	$13.74	1	1 Day	#2 Southern yellow pine	$13.74
13	Item #92331 Model #637630	4-in x 4-in x 8-ft Douglas Fir S4S Green Lumber	Pneumatic mounting	4-in x 4-in x 8-ft Douglas Fir S4S Green Lumber in the Dimensional Lumber department at Lowes.com	Each	$10.92	1	1 Day	#2 Southern yellow pine	$10.92
14	91571A406	Heavy Hex Head Screw for Structural Application, Grade A325 Steel, 1/2"-13 Thread Size, 4-1/4" Long	Board bolt mounting	https://www.mcmaster.com/91571A406/	per 5	$8.83	2	1 Day	Steel	$17.66
15	95229A550	Cadmium-Plated Steel MIL. Spec. Washer for 1/2" Screw Size, NAS 1149-F0863P	Board mounting hrdw	https://www.mcmaster.com/95229A550/	per 100	$17.42	1	1 Day	Steel	$17.42
16	33145T32	Strut Channel Floor Mount for Standard Channel, Straight Post, Zinc-Plated Steel, 6" Long	Floor Mounting hrdw	https://www.mcmaster.com/33145T32/	Each	$35.22	2	1 Day	Zinc-Plated Steel	$70.44
17	91578A116	Steel Stud Anchor for Concrete 1/2" Diameter, 3-3/4" Long	Concrete Anchor Bolts	https://www.mcmaster.com/91578A116/	Each	$2.08	4	1 Day	Steel	$8.32
18	B24SH-240GLV or equivalent	1-5/8" x 1-5/8" Slotted Hole Strut and Hardware for Strut Frame	Strut/Frame Fasteners	Various Distributors	Each	$2.00	2	3 Days	Steel	$2.00
19	92865A624	Medium-Strength Grade 5 Steel Hex Head Screw Zinc-Plated, 3/8"-16 Thread Size, 1" Long	Frame Fasteners	https://www.mcmaster.com/92865A624/	Per 50	$13.84	1	1 Day	Steel	$13.84
20	91247A591	Medium-Strength Grade 5 Steel Hex Head Screw Zinc-Plated, 5/16"-18 Thread Size, 2" Long, Partially Threaded	Frame Fasteners	https://www.mcmaster.com/91247A591/	Per 50	$15.65	1	1 Day	Steel	$15.65
21	91247A642	Medium-Strength Grade 5 Steel Hex Head Screw Zinc-Plated, 3/8"-16 Thread Size, 4-1/2" Long, Partially Threaded	Frame Fasteners	https://www.mcmaster.com/91247A642/	Per 10	$10.43	1	1 Day	Steel	$10.43
22	95462A031	Medium-Strength Steel Hex Nut Grade 5, Zinc-Plated, 3/8"-16 Thread Size	Frame Fasteners	https://www.mcmaster.com/95462A031/	per 100	$15.94	1	1 Day	Steel	$15.94
23	98026A031	Grade 8 Steel Washer Zinc Yellow-Chromate Plated, for 3/8" Screw Size, 1" OD	Frame Fasteners	https://www.mcmaster.com/98026A031/	Per 50	$14.26	1	1 Day	Steel	$14.26
24	5520K46	Solder-Connect Fitting for Copper Tubing Cap, Female Socket-Connect, 1 Copper Tube Size	Copper Fitting to Manifold	https://www.mcmaster.com/5520K46/	Each	$1.80	2	1 Day	Copper	$3.60
25	6124K512	Compressed Air Directional Control Valves	Fitting to Manifold	https://www.mcmaster.com/catalog/129/1233/6124K512	Each	$28.00	2	1 Day	Plastic/Aluminum	$56.00

Table 9, continued.

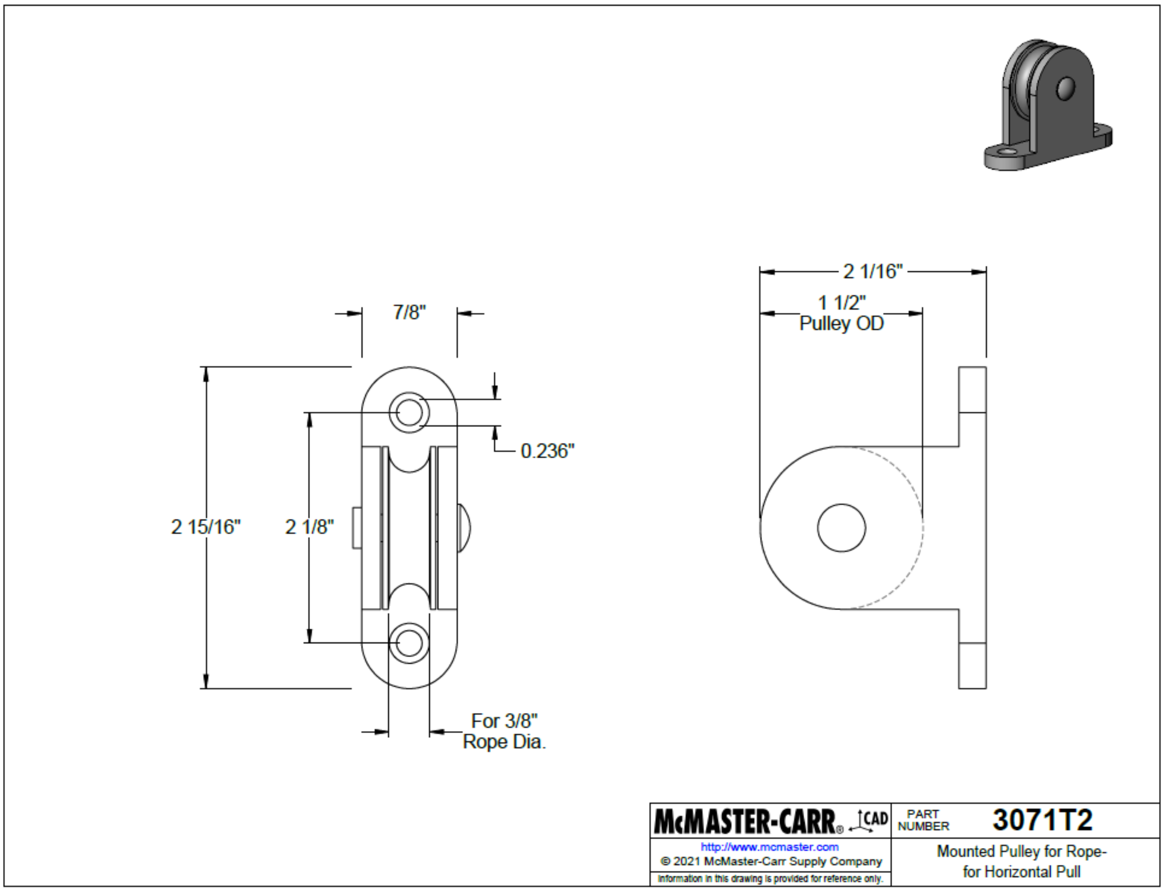
No.	Item	Description	Installation Location	Sources	Unit	Unit Cost	Qty.	Lead Time	Material	Total
26	1979T1	Crack-Resistant Hard Polypropylene Plastic Tubing for Air and Water, Semi-Clear, 11/64" ID, 1/4" OD	Wire Routing Tubing to Strut	https://www.mcmaster.com/1979T1/	Per 25'	$10.00	1	1 Day	Polypropylene Plastic	$10.00
27	75065K36	Indoor Enclosure with Lift-Off Cover and Knockouts, 8" x 8" x 6"	Control Box to Power connections	https://www.mcmaster.com/75065k36/	Each	$47.64	1	1 Day	Steel	$47.64
28	7343K711	Toggle Switch 2 Position, Round, Maintained, 2 Terminal, SPST-NO, 15A	Toggle Switch to Control Box	https://www.mcmaster.com/7343K711/	Each	$7.68	2	1 Day	Plastic/Aluminum	$15.36
29	8841T22	Quick and Secure Connect Terminal Block 3 Circuits, White	Electrical Wires to Quick Connect	https://www.mcmaster.com/8841T22/	Each	$2.60	2	1 Day	Plastic	$5.20
30	4910K82	Compressed Air Filter/Regulator Stacked Zinc Bowl with Sight Glass, 3/8 NPT Female	Regulator to Copper Manifold	https://www.mcmaster.com/4910K82/	Each	$133.55	1	1 Day	Plastic	$133.55
31	3303	Foster 3 Series Socket, 3/8 MPT Male Thread	Socket for Filter	John Henrey Foster	Each	$7.10	1	3 Days	Metal Fitting	$7.10
32	14-3	Foster 3 Series Plug, 3/8" MPT Male Thread	Plug for Filter	John Henrey Foster	Each	$2.10	1	3 Days	Metal Fitting	$2.10
33	5304K14	Air Hose EPDM Rubber, 1/4" ID, 1/2" OD, 200 PSI, Black	Pnuematic to Compressed Air Line	https://www.mcmaster.com/5304K14/	Per Foot	$1.17	15	1 Day	EPDM Rubber	$17.55
34	9936K21	Control Cable Seven 18-Gauge Wires, Flexible Multiconductor Cable Unshielded, 18/7 AWG, .34" OD, 600 VAC, Gray	Electrical Wires to Circuit Box	https://www.mcmaster.com/9936K21/	Per Foot	$4.40	30	1 Day	Copper Wire	$132.00
35	90499A033	High-Strength Steel Hex Nuts—Grade 8	Board mounting hrdw	https://www.mcmaster.com/90499A033/	per 50	$17.22	1	1 Day	Steel	$17.22
36	51235K107	Push-to-Connect Tube Fitting with Universal Thread for Air and Water, Adapter, 1/4" Tube OD x 1/8 Pipe	Fitting to pneumatic	Push-to-Connect Tube Fitting with Universal Thread, for Air and Water, Adapter, 1/4" Tube OD x 1/8 Pipe | McMaster-Carr	Each	$2.26	2	1 Day	304 Stainless Steel, Buna-N Rubber	$4.52
37	91166A240	Zinc-Plated Steel Washer for M5 Screw Size, 5.3 mm ID, 10 mm OD	Angle mounting hrdw	https://www.mcmaster.com/91166A240/	per 100	$3.48	1	1 Day	Zinc-Plated Steel	$3.48
38	94645A102	High-Strength Steel Nylon-Insert Locknut Class 10, Zinc Plated, M5 x 0.8 mm Thread, 5 mm High	Angle mounting hrdw	https://www.mcmaster.com/94645A102/	Per 100'	$16.62	1	1 Day	Steel Nylon	$16.62
39	92095A486	Passivated 18-8 Stainless Steel, M5 x 0.80 mm Thread, 100mm Long	Angle mounting hrdw	Passivated 18-8 Stainless Steel, M5 x 0.80 mm Thread, 100mm Long	per 10	$8.11	1	1 Day	Black-Oxide Alloy Steel	$8.11
40	91101A233	Steel Split Lock Washer for 1/2" Screw Size, 0.512" ID, 0.869" OD	For Eye bolt if bolting thru	https://www.mcmaster.com/91101A233/	Per 100'	$13.55	1	1 Day	Steel	$13.55
	Total Direct Cost	$1,542.78								
	Total before contingency	$1,542.78								
	Contingency (15%)	$231								
	Engineers estimate	$1,774								

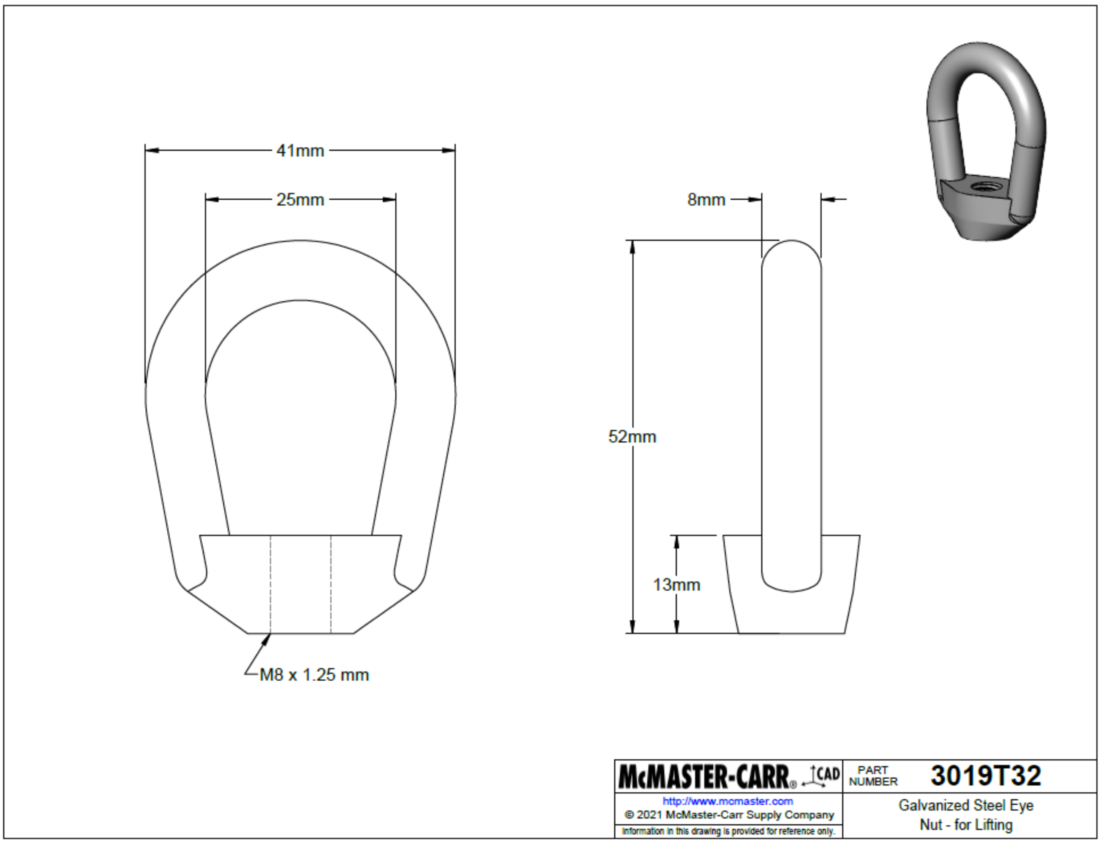
13 APPENDIX C – COMPLETE LIST OF ENGINEERING DRAWINGS

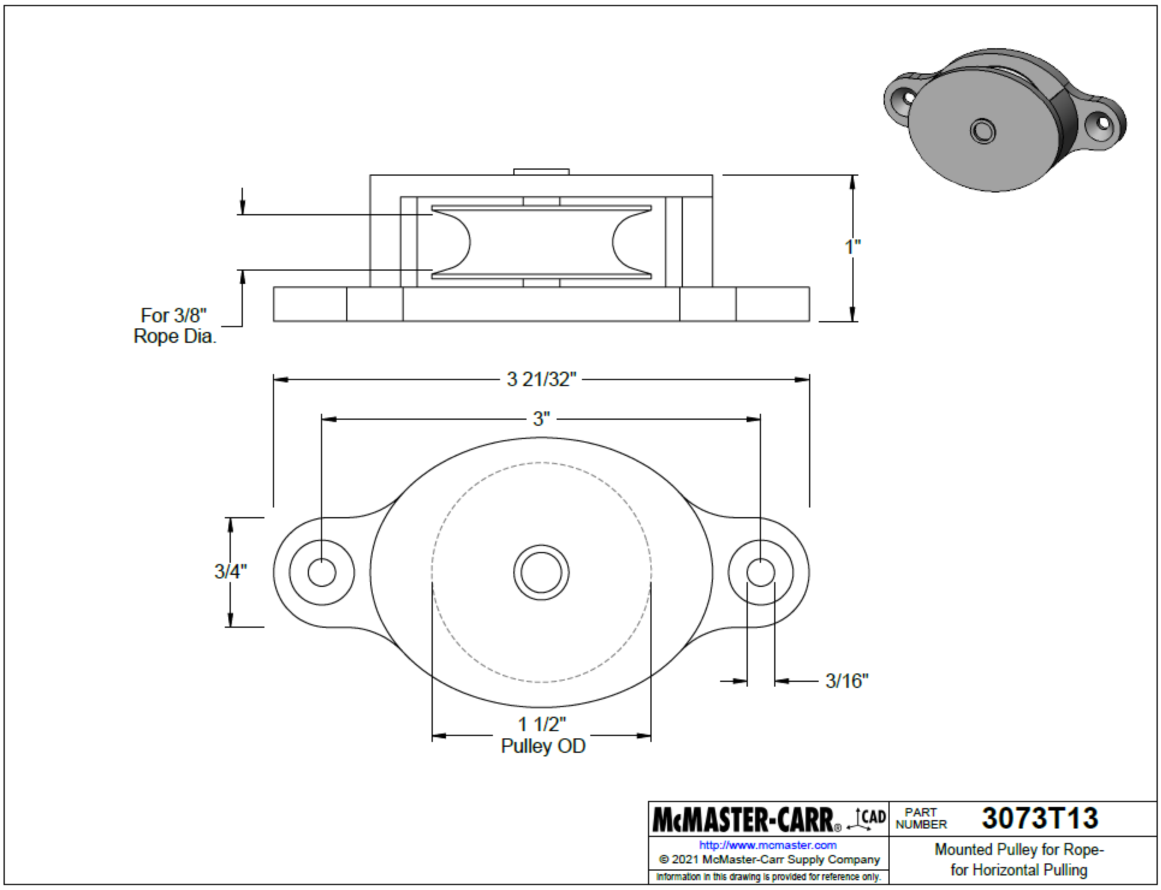
In the files below in the DWG file you can find the dwg drawing in that folder.

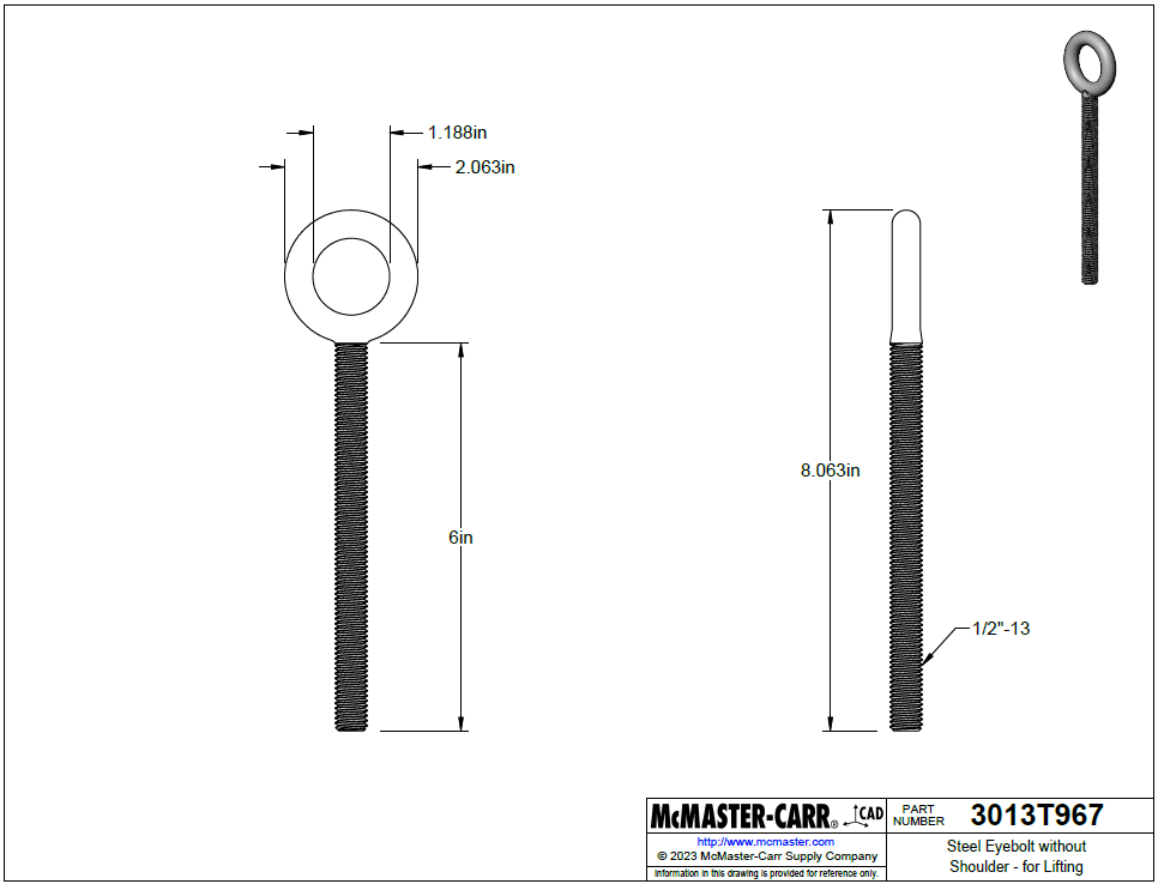
The final door cycle senior project has all the various models.

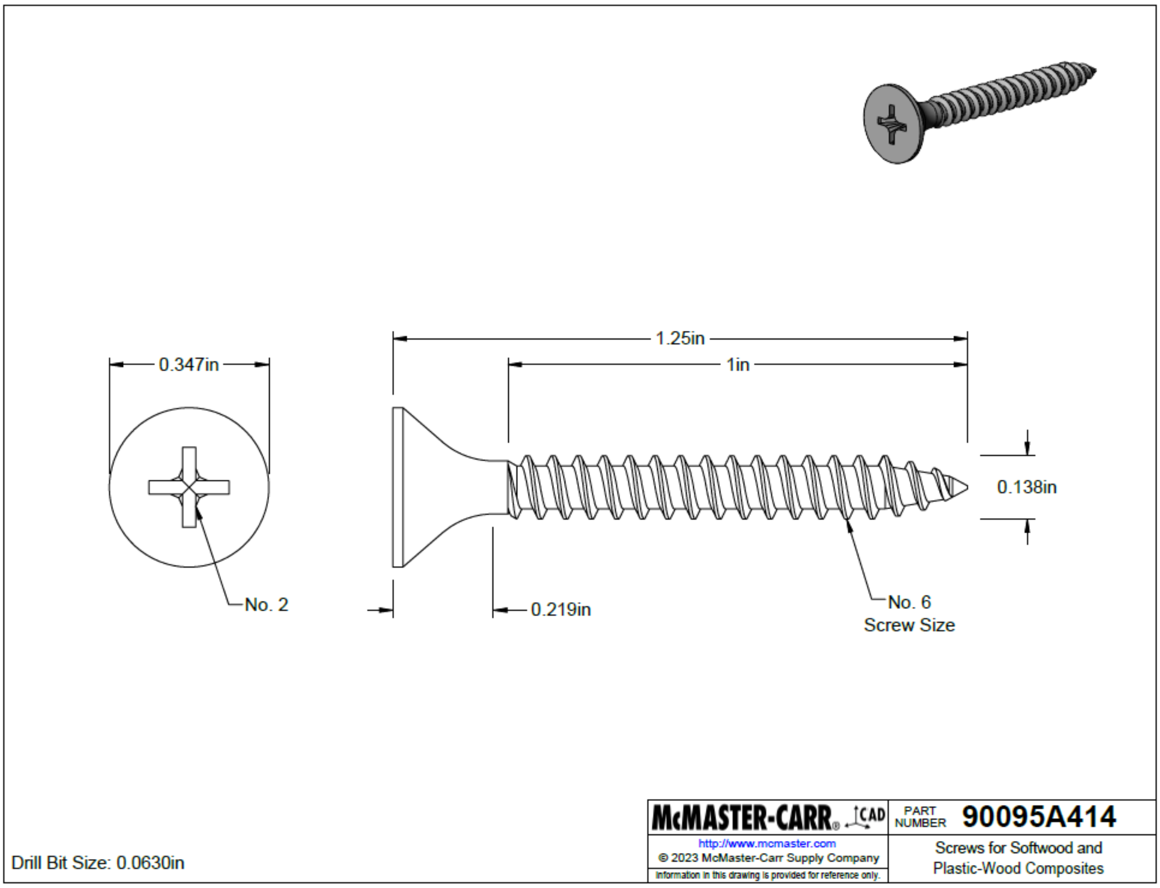
DWG file.zip   Final Door Cycle Senior Project.zip

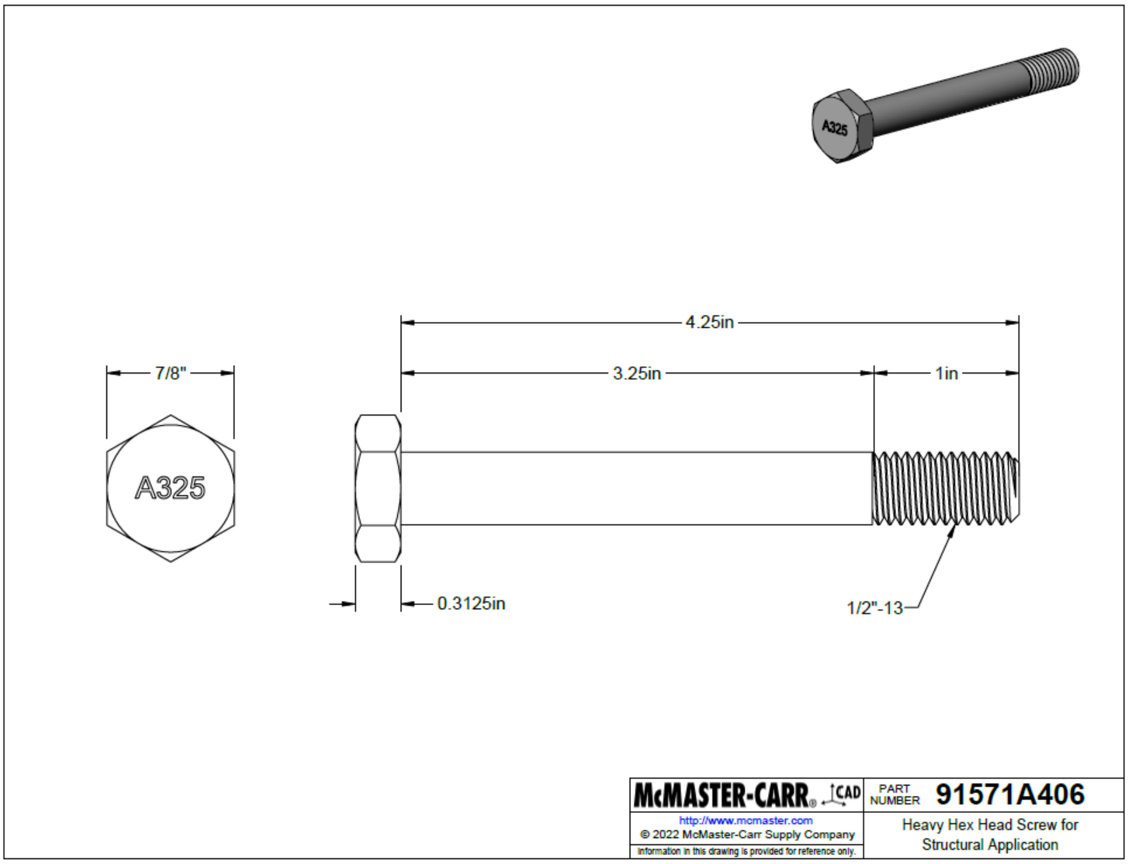


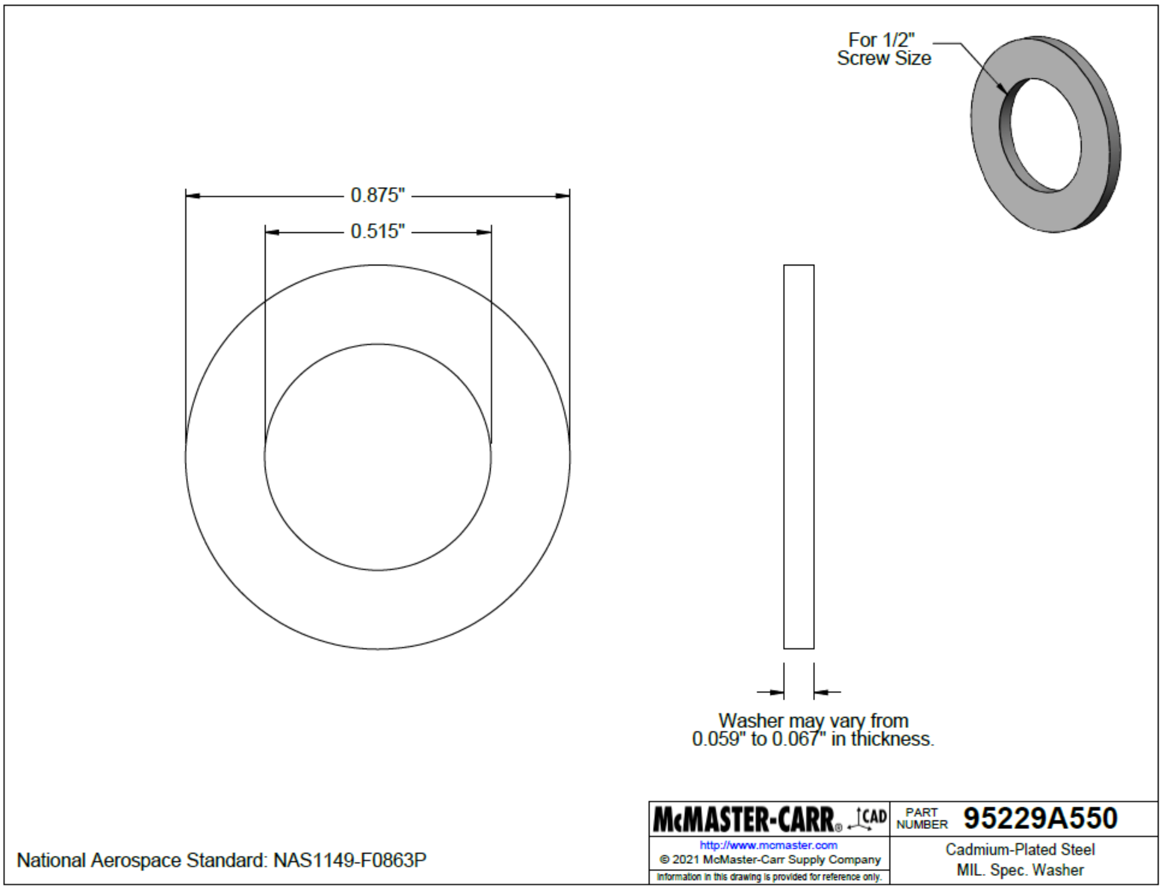

41mm
25mm
8mm
52mm
13mm
M8 x 1.25 mm
McMASTER-CARR
CAD
PART NUMBER
3019T32
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Galvanized Steel Eye Nut - for Lifting

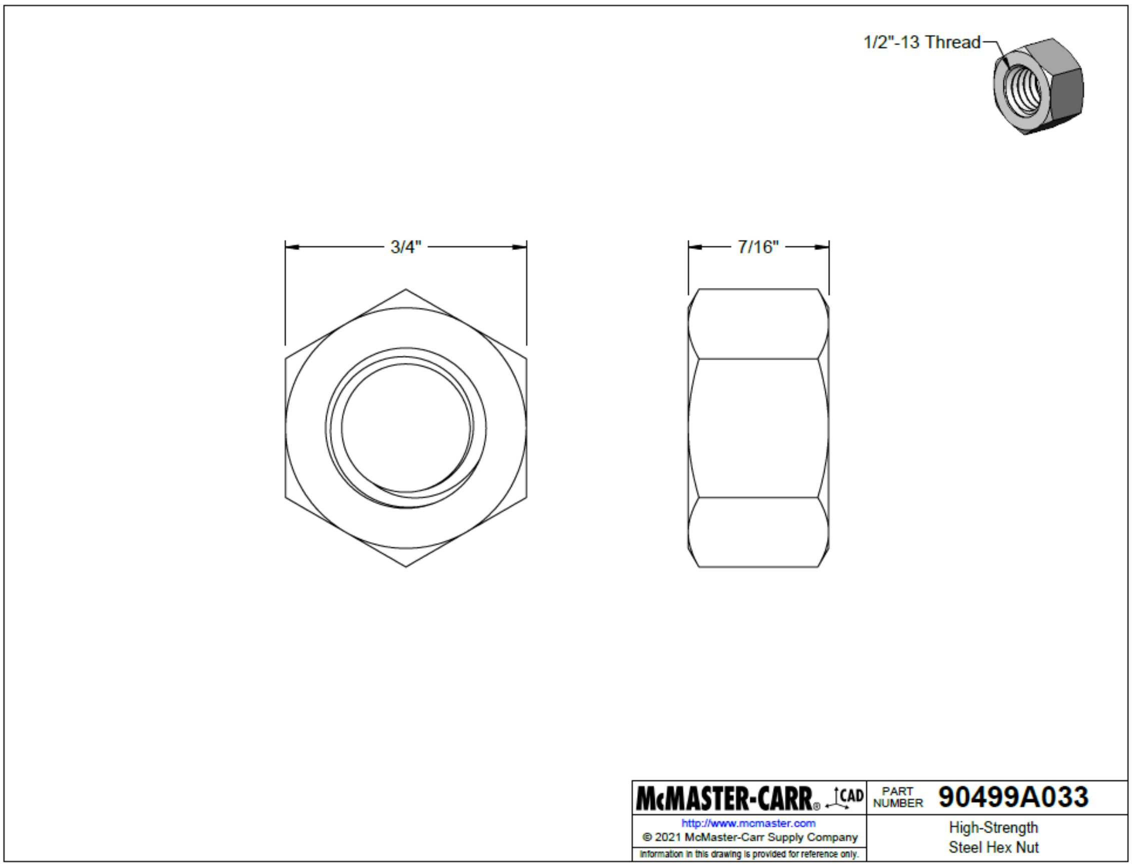

1"
For 3/8" Rope Dia.
3 21/32"
3"
3/4"
3/16"
1 1/2" Pulley OD
McMASTER-CARR
CAD
PART NUMBER
3073T13
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Mounted Pulley for Rope- for Horizontal Pulling

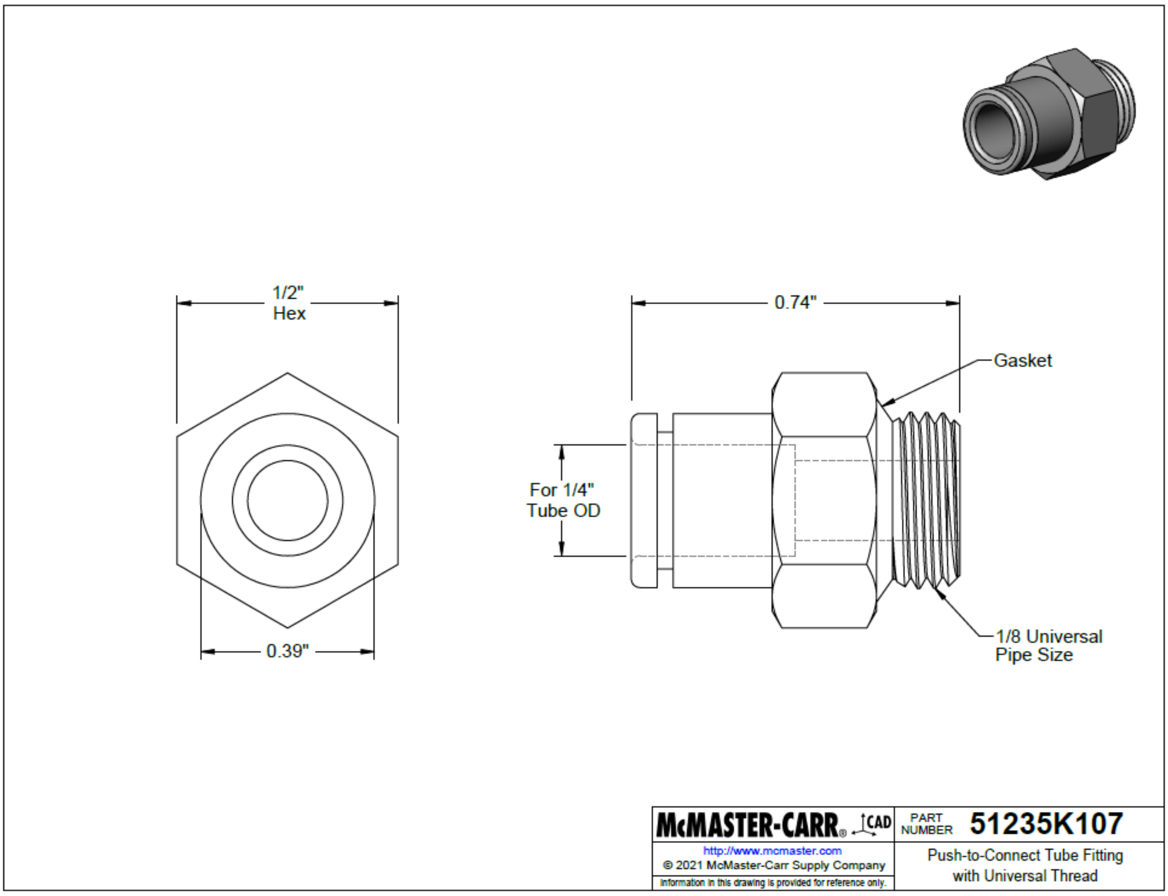

1.188in
2.063in
6in
8.063in
1/2"-13
McMASTER-CARR
CAD
PART NUMBER
3013T967
http://www.mcmaster.com
© 2023 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Steel Eyebolt without Shoulder - for Lifting

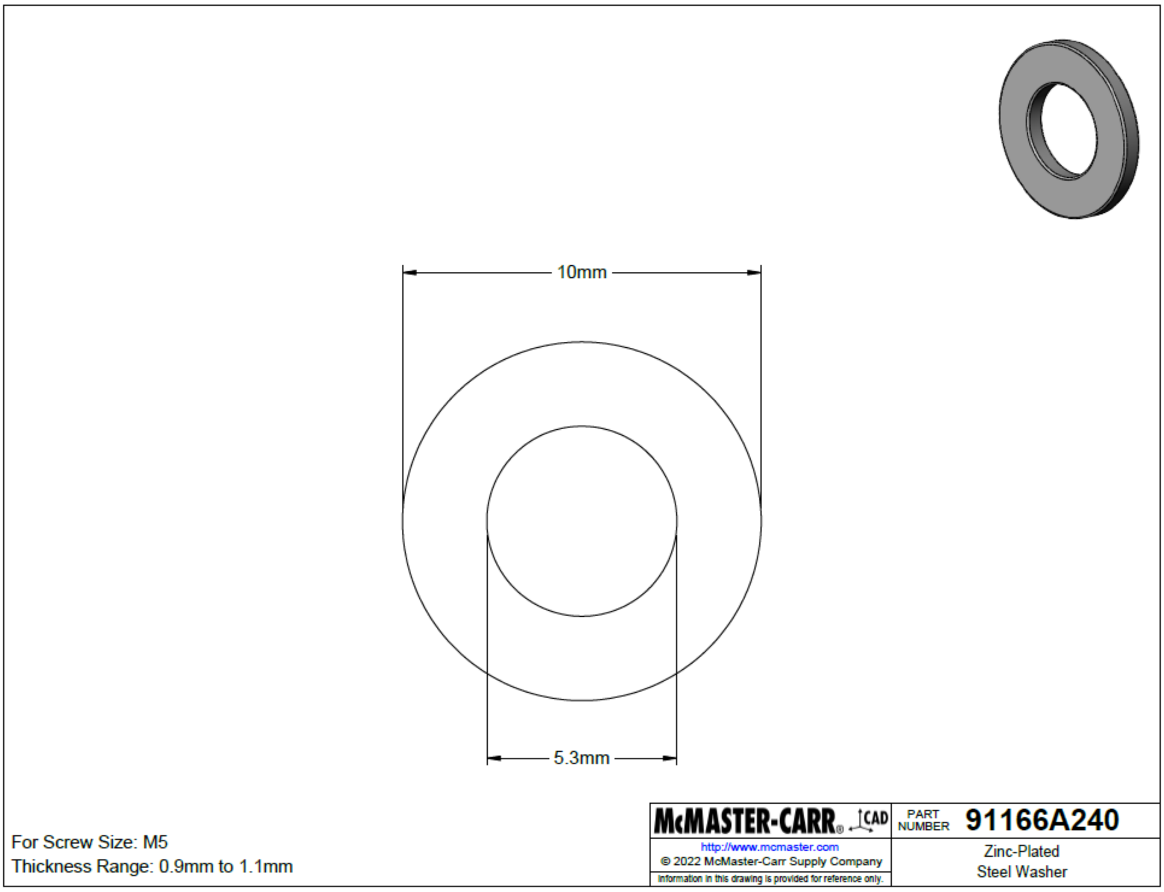

1.25in
1in
0.347in
0.138in
No. 2
0.219in
No. 6 Screw Size
Drill Bit Size: 0.0630in
McMASTER-CARR
CAD
PART NUMBER
90095A414
http://www.mcmaster.com
© 2023 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Screws for Softwood and Plastic-Wood Composites

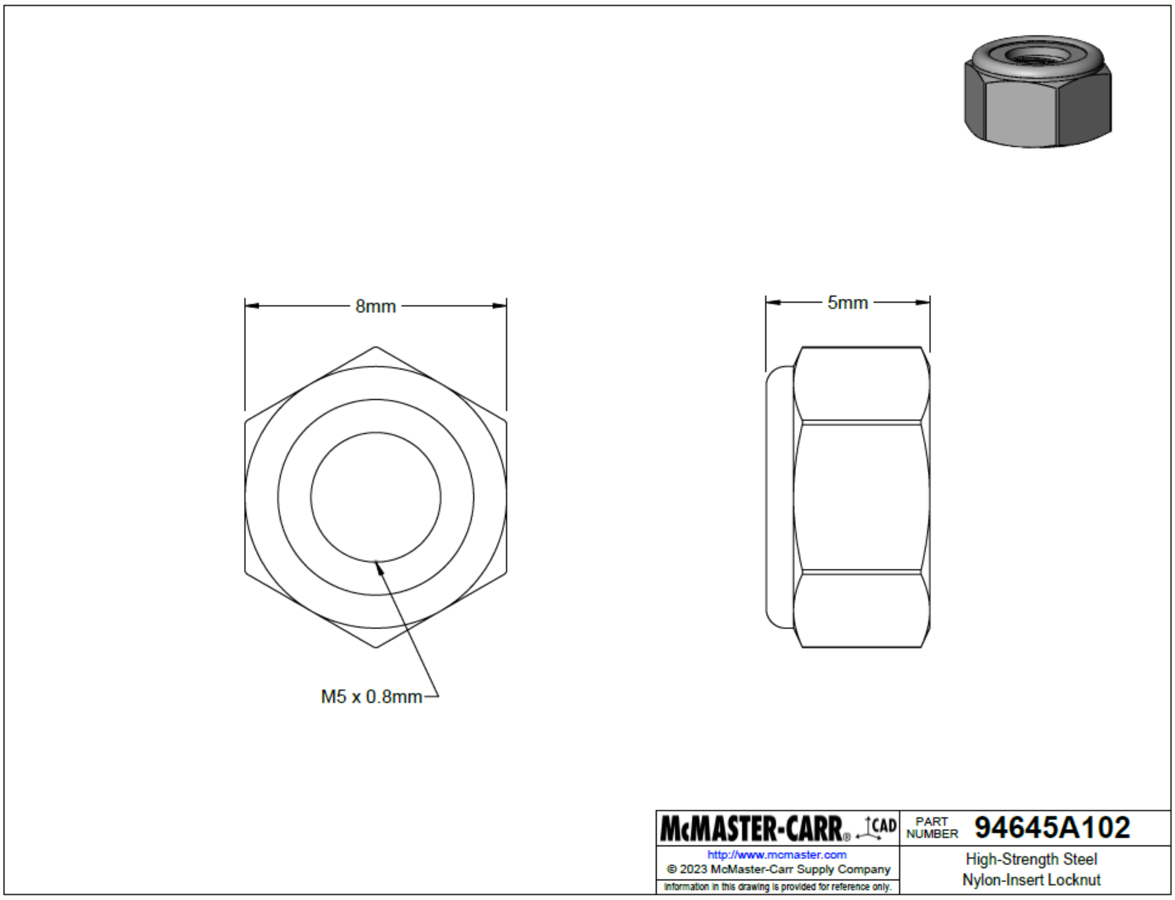

A325
4.25in
3.25in
1in
7/8"
A325
0.3125in
1/2"-13
McMASTER-CARR
CAD
PART NUMBER
91571A406
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Heavy Hex Head Screw for
Structural Application

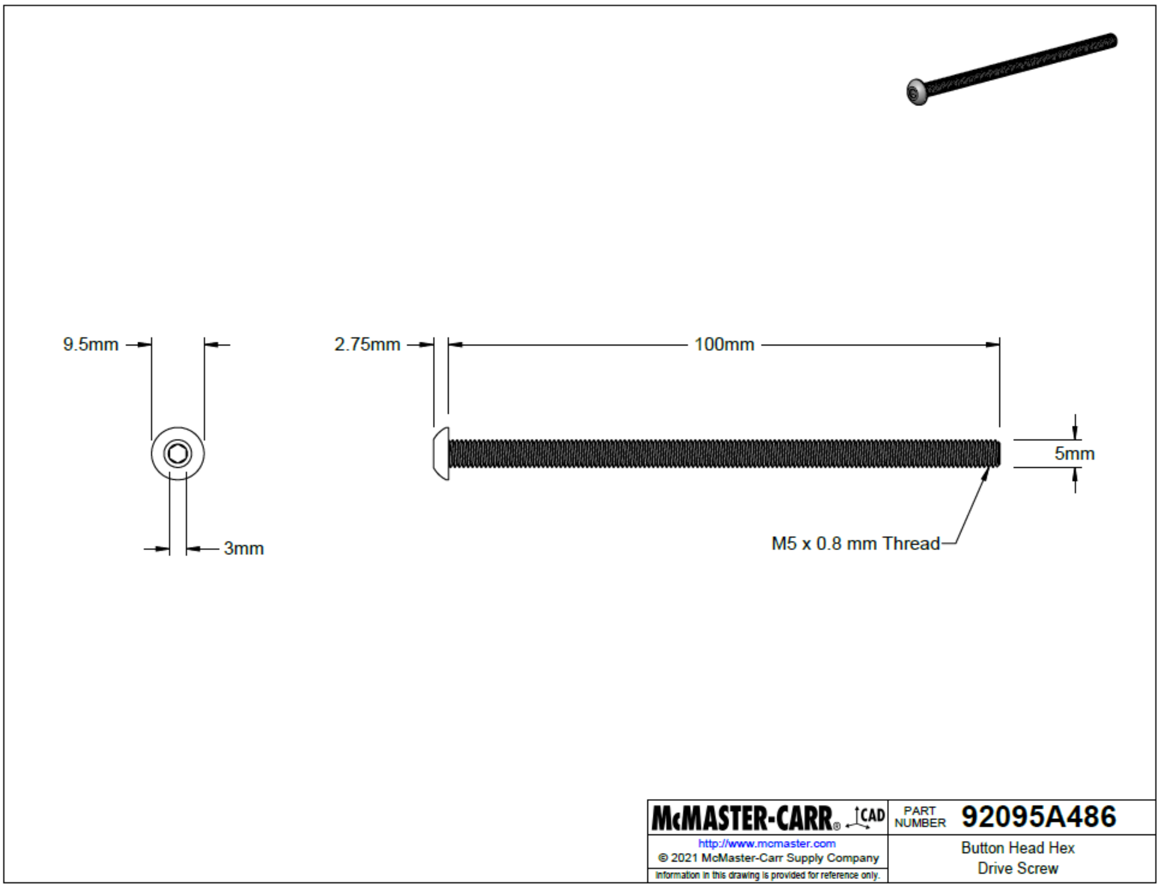

For 1/2"
Screw Size
0.875"
0.515"
Washer may vary from
0.059" to 0.067" in thickness.
National Aerospace Standard: NAS1149-F0863P
McMASTER-CARR
CAD
PART NUMBER
95229A550
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Cadmium-Plated Steel
MIL. Spec. Washer

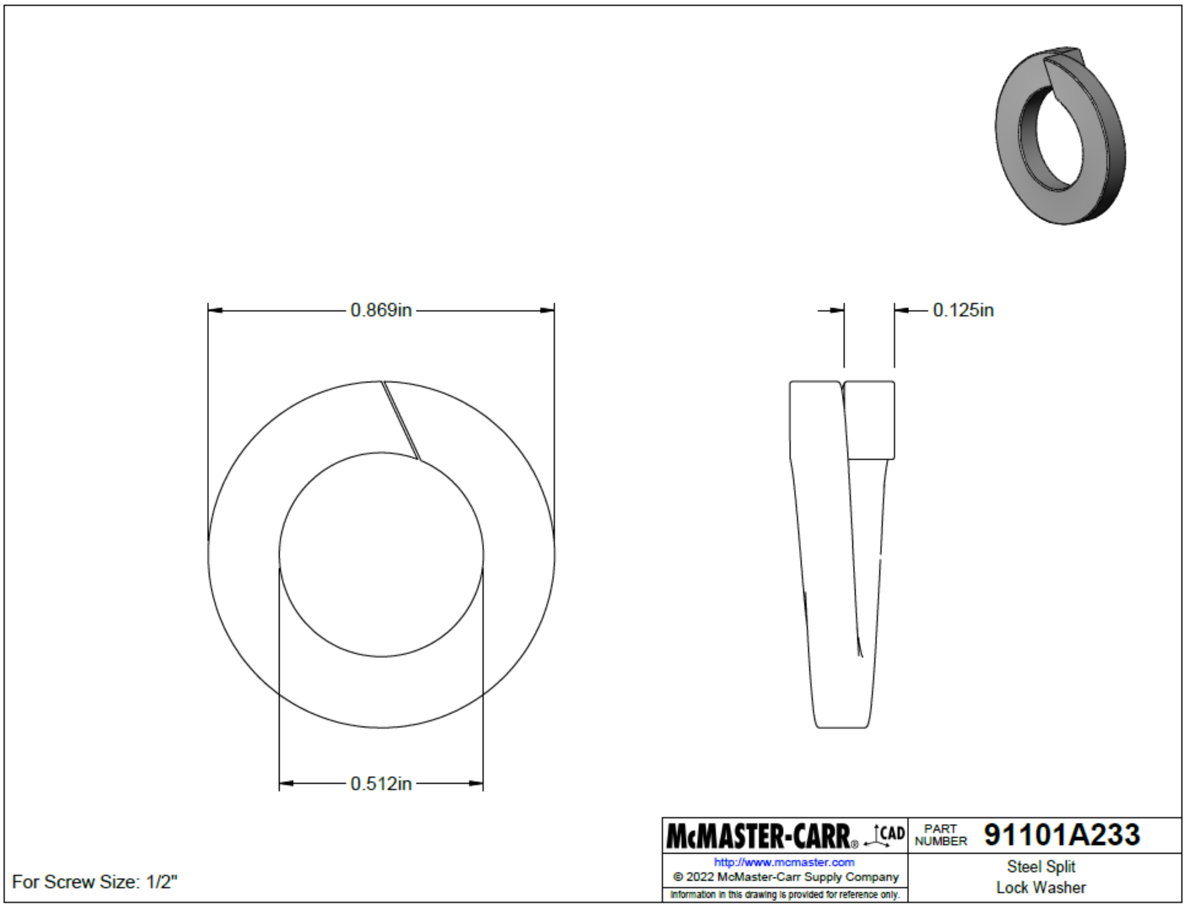

1/2"-13 Thread
3/4"
7/16"
McMASTER-CARR CAD
PART NUMBER 90499A033
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
High-Strength
Steel Hex Nut

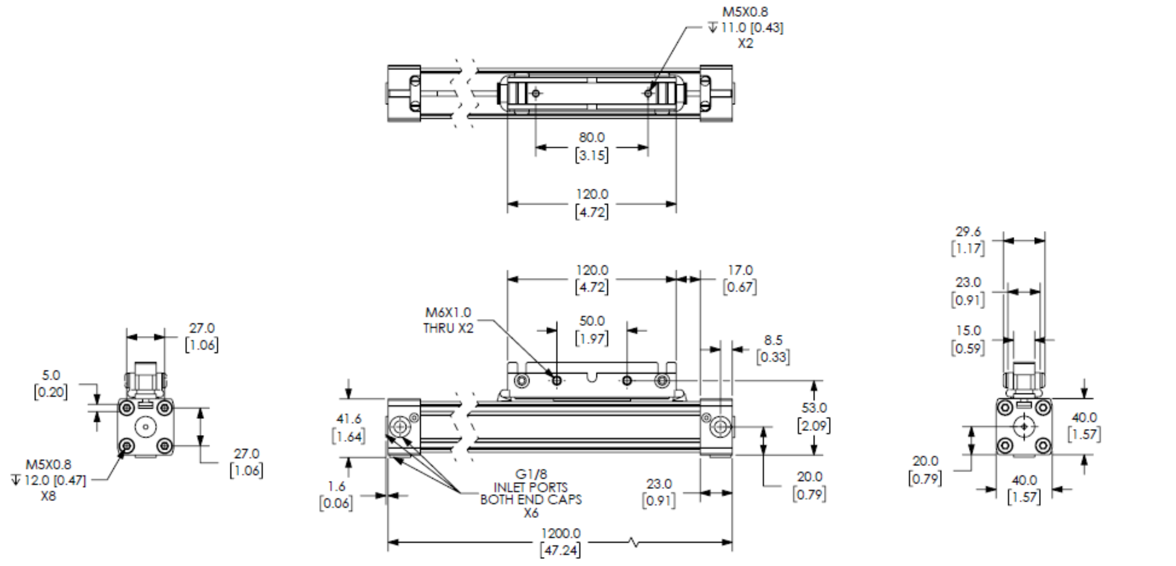

1/2"
Hex
0.39"
0.74"
Gasket
For 1/4"
Tube OD
1/8 Universal
Pipe Size
McMASTER-CARR CAD
PART NUMBER 51235K107
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Push-to-Connect Tube Fitting
with Universal Thread


10mm
5.3mm
For Screw Size: M5
Thickness Range: 0.9mm to 1.1mm
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
91166A240
Zinc-Plated
Steel Washer


8mm
5mm
M5 x 0.8mm
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2023 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
94645A102
High-Strength Steel
Nylon-Insert Locknut


9.5mm
3mm
2.75mm
100mm
5mm
M5 x 0.8 mm Thread
McMASTER-CARR CAD
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER 92095A486
Button Head Hex Drive Screw

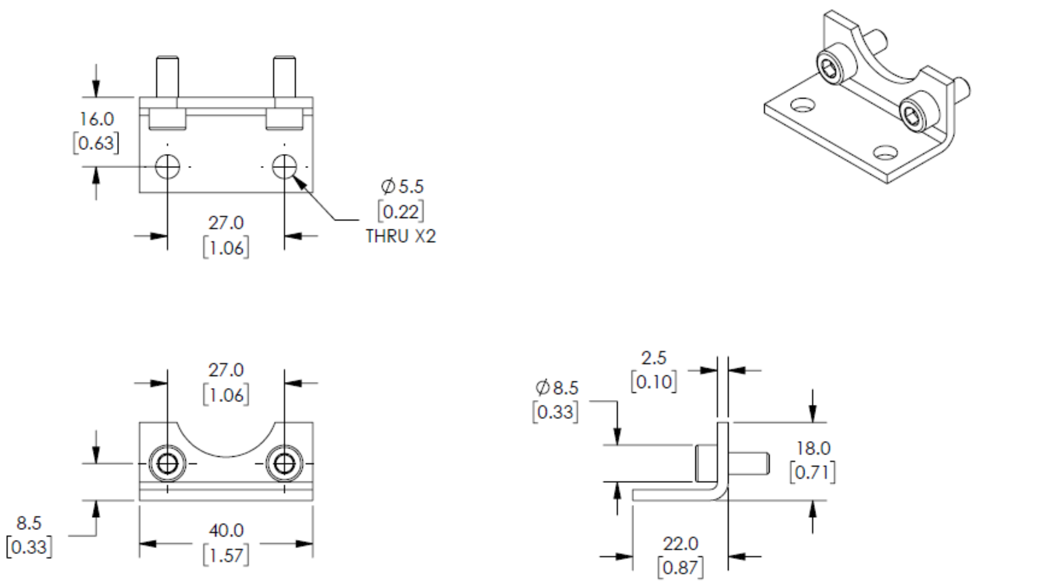

0.869in
0.512in
0.125in
For Screw Size: 1/2"
McMASTER-CARR CAD
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER 91101A233
Steel Split Lock Washer



L25M1000MD-MC
Units: mm [inches] Scale: Full
PNEUMATIC CYLINDER: RODLESS, 25MM BORE, 1000MM STROKE
AUTOMATIONDIRECT.com

NOTES:

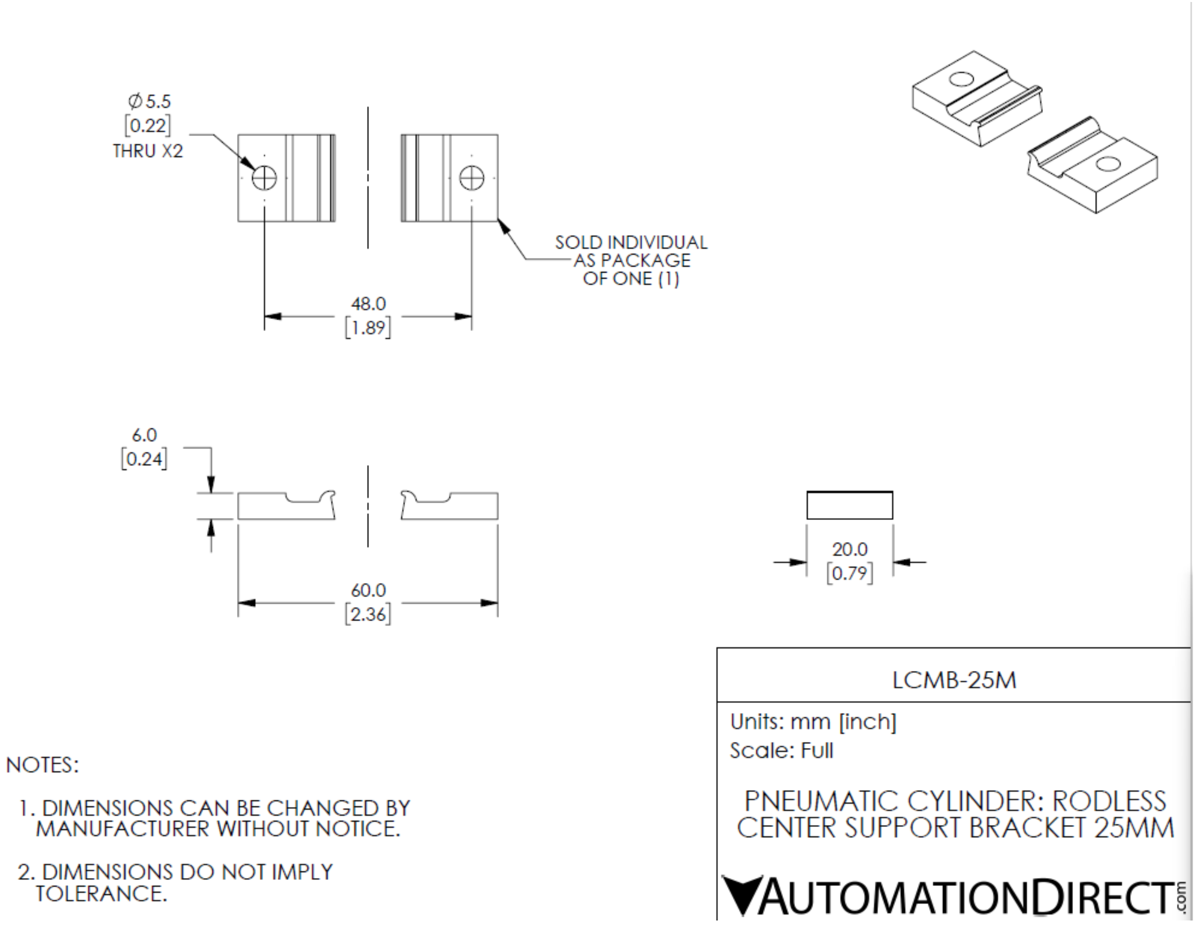
1. DIMENSIONS CAN BE CHANGED BY MANUFACTURER WITHOUT NOTICE.
2. DIMENSIONS DO NOT IMPLY TOLERANCE.

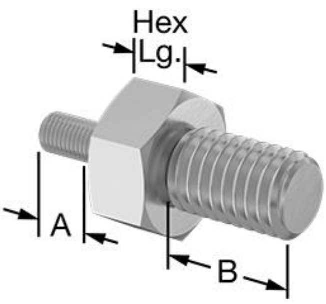


LEMB-25M
Units: mm [inch] Scale: Full
PNEUMATIC CYLINDER: RODLESS MOUNT BRACKET 25MM BORE
AUTOMATIONDIRECT.com

NOTES:

1. DIMENSIONS CAN BE CHANGED BY MANUFACTURER WITHOUT NOTICE.
2. DIMENSIONS DO NOT IMPLY TOLERANCE.



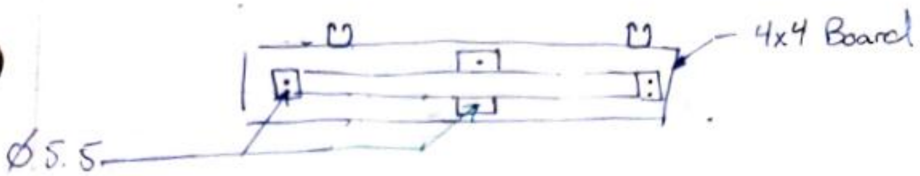


Hex Thread Adapter, size M5 to M8

Rope Clamp

14 APPENDIX D – DESIGN CALCULATIONS

Pneumatic to board Calc - Alex



410 Stainless steel 0.19"
#2 Southern yellow pine

$\tau = \frac{P}{A} \Rightarrow A = \frac{P}{\tau} = \frac{54\,lbs}{73\,GPa} = \frac{54\,lbs}{73{,}000\,lbs/in^2}$

$A = .00074\,in^2$

$.00074\,in^2$

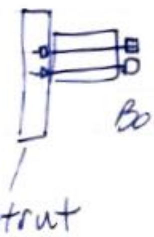
Bolt acceptable ✓

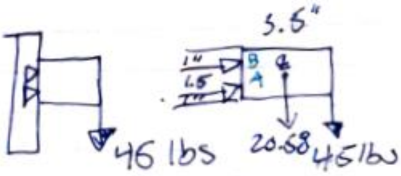
Bolt length

$3.5 + .25 + 1$

(.25 = 2 washers)

Bolt = 4.75"





Board wt. = 3.43 lb/ft

$3.43 \times 6 = 20.68$

$\curvearrowleft + \sum_A F_y = 0 \Rightarrow +45\,lbs\,(3.5) + F_{yB}(1.5") + 20.68(1.75")$

$F_{yB} = 129\,lbs \uparrow$ on Bolts

$A = \frac{129\,lbs}{79{,}300\,lbs/in^2}$

$A > .0016\,in^2$

$1/2\,in^2 > .0016\,in^2$ ✓

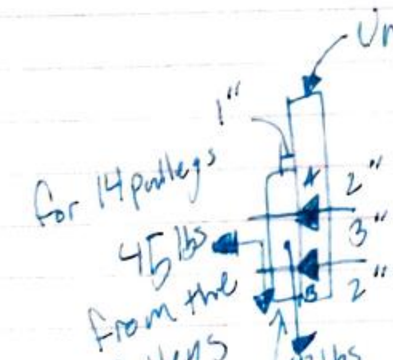
Rope to rope clamp Calc - Alex

Rope Clamp capacity 400lbs (given)
max is 45lbs, clamp acceptable ✓

Identical Circles = R_1
Out Side circle = R_2

R_2 given @ eye bolt = 1"

$R_1 = R_2 / \left(1 + \frac{2}{\sqrt{3}}\right) = .46 in^2$ max rope
3/8 acceptable



$(+\circlearrowleft)\ \sum_A F_y = 0 = -45\,lbs\,(1in) - 45lbs\,(2in)$

$F_{yB} = \frac{-135\,lb\,in}{2\,in}$

$F_{yB} = +67.5\ lbs$

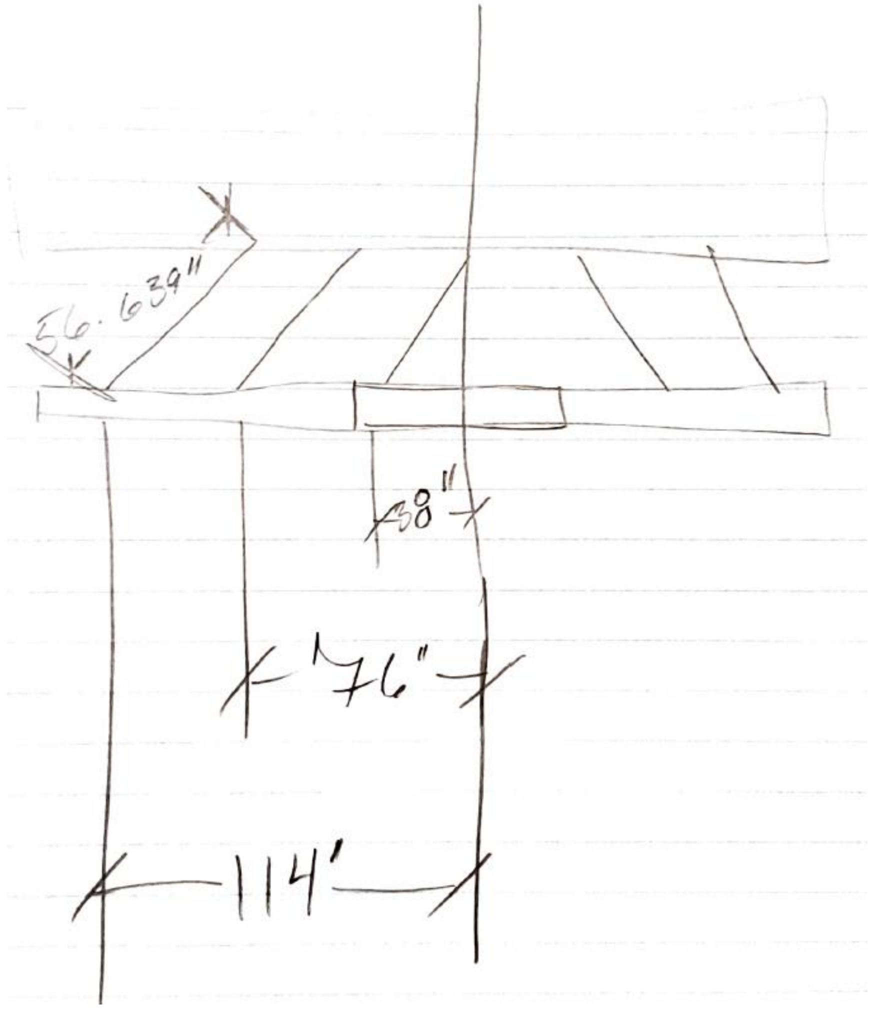
12 × 2x8 Board = 42 lbs

sear on bolt

A325 steal = 15 Kpsi $A = \frac{67.5\,lbs}{15{,}000\ lbs/in^2}$

Tensile = $\frac{45\,lbs}{1/2''^2} = 180psi$ $A = .0045in^2$

180psi < 120,000 rated ✓ 1/2 Ø acceptable


56.639"
38"
76"
114'

Will Todd

7/23/23

JME 4110

Screw Calc.

Screws for Softwood&Plastic-Wood Composites

Phillips Head, Corrosion-Resistant Steel, Number 6 Size, 1-1/4" Long

You can use the formula pitch diameter = major diameter - 0.6495 × thread pitch if you know the major diameter of the internal thread in question.

D_p = 0.138 - (0.6495 * 0.03) = **0.118515 in**.

Thread engagement = **1 in.**

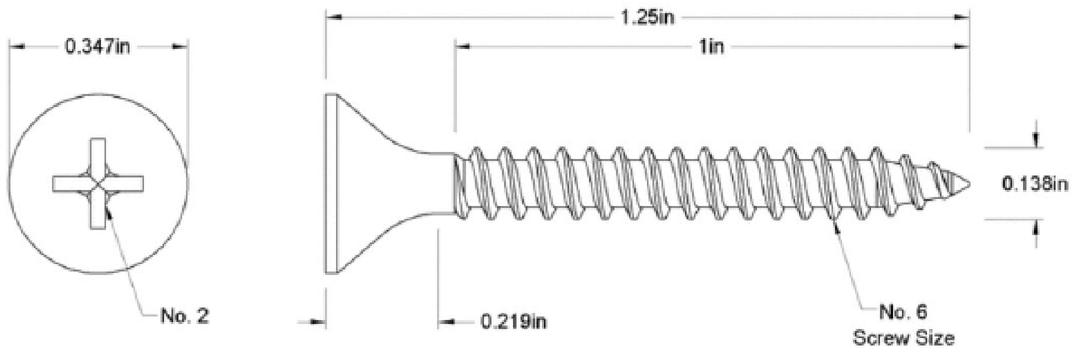
32 threads/in. with a friction coefficient for steel on wood between (0.25-0.35)

UNC - Unified Coarse Threads

UNC threads according ANSI B1.1:

Major Diameter *(in)*	Threads per inch *(tpi)*	Major Diameter		Tap Drill Size *(mm)*	Pitch *(mm)*
		(in)	*(mm)*		
#1 - 64	64	0.073	1.854	1.50	0.397
#2 - 56	56	0.086	2.184	1.80	0.453
#3 - 48	48	0.099	2.515	2.10	0.529
#4 - 40	40	0.112	2.845	2.35	0.635
#5 - 40	40	0.125	3.175	2.65	0.635
#6 - 32	32	0.138	3.505	2.85	0.794
#8 - 32	32	0.164	4.166	3.50	0.794
#10 - 24	24	0.190	4.826	4.00	1.058
#12 - 24	24	0.216	5.486	4.65	1.058

0.794 mm (about 0.03 in)



Design Variables	
Material Tensile Stress (S_t) [psi] =	60900.000
Pitch Diameter (D_p) [in] =	0.119
Pitch Radius (r) [inches] =	0.060
Thread engagement (L) [inches] =	1.000
Threads per [inch] =	32.000
Reciprocal of threads per inch (1/tpi = p) =	0.031
coefficient of friction (f) =	0.300
Results	
Thread Shear Area (A) [in^2] =	0.374
Shear Stress (S_s) [psi] =	35160.631
Pull-out Axial Force (f) [lbs] =	13144.691
Stripping Torque (T) [in-lbs] =	307.726
Pull-out Torque [ft-lbs] =	25.644

$F = S_S A = S_S \pi D_p L$

Where:

F = Pull out force

S_S = Shear stress = $S_t / 3^{1/3}$

S_t = Tensile yield stress

A = Shear area = $\pi D_p L$

D_p = Pitch diameter

L = Axial length of full thread engagement

Pull-out strength doe not generally decrease with time.

To calculate the stripping torque use:

$T = F r (p + 2 \pi fr) / (2 \pi r - fp)$

Where:

T = torque to develope pull-out force
r = Pitch radius of screw
p = Reciprocal of threads per unit length
f = Coefficient of friction

When designing for self-tapping screws, a number of factors are important:

Boss Hole Dimension: For the highest ratio of stripping to driving torque, use a hole diameter equal to the pitch diameter of the screw.**Boss Outside Dimension:** The most practical boss diameter is 2.5 times the screw diameter. If its wall is too thin, a boss may crack. Higher stripping torques are not achieved with thicker bosses.

Effect of Screw Length: Stripping torque increases rapidly with increasing length of engagement and levels off when the engaged length is about 2.5 times the pitch diameter of the screw.

Strip-To-Drive Ratio: The torque-turn curve in Figure 1 shows how a self-tapping screw responds to applied torque. Up to point "A", driving torque is applied to cut or form a thread and to overcome sliding friction on the threads. Successive turns require more torque as the area of thread engagement increases. At point "A", the head of the screw seats. Any further application of torque - now referred to as stripping torque - results in compressive loading of the threads. At point "B", stress in the threads reaches the yield point of the plastic, and the threads begin to shear off. Threads continue to strip off to point "C" when the fastening fails completely.

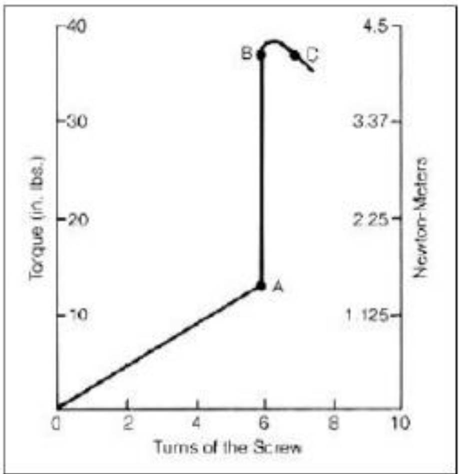


Figure 1
Torque Turn Plot

Strip-to-drive ratio (the ratio of stripping torque to driving torque) can be used to evaluate the performance of a fastened joint. For high volume production with power tools, this ratio should be about 4 to 1. With well trained operators working with consistent parts and hand tools, a 2 to 1 ratio may be acceptable. In any case, lubricants must be avoided because they drastically reduce this ratio.

Notes from:
https://www.mcmaster.com/90095A414/
https://www.engineeringtoolbox.com/unified-screw-threads-unc-unf-d_1809.html
https://www.engineersedge.com/hardware/self_tapping_screws_installation_design_9998.htm
https://engineeringlibrary.org/reference/fastener-torque-nasa-design-manual
https://www.schaefer-peters.com/uploads/tx_kkdownloader/Technical-Information_S_P_06.pdf

Will Todd

7/23/23

JME 4110

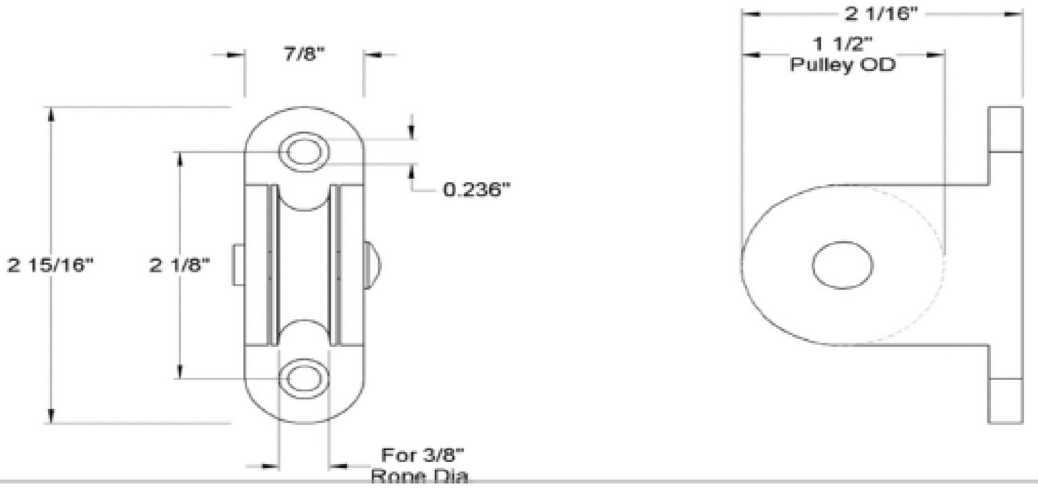
Pulley Calc.

Mounted Pulley for Rope-for Horizontal Pulling

Steel, for 3/8" Diameter, 1" Wide

Calculations performed at maximum worst case forces applied by pneumatic at 60 lbs. 45°

Acceleration = F/m where F = (100 psi) *(6894.76 N/m^2/1psi) and m = 0.11 kg



Speed difference	
Initial speed	0 m/s
Final speed	1,032.7 m/s
Time	2 sec
Acceleration	516.4 m/s²

Formula

$$\bar{a} = \frac{v - v_0}{t} = \frac{\Delta v}{\Delta t}$$

$\bar{a}$ = average acceleration

v = final velocity

v_0 = starting velocity

t = elapsed time

Tension in the pulley: T = T(Pneumatic) = m*a = [(60lbs.)/(9.81m/s^2)] * a-pneumatic (516.4 m/s^2) = 3,158 lbs.

Force Resultant: Fr = T * (Cos (45) + Sin (45)) = 1.41 * (3,158lbs.) = 4453lbs.

V=Sqrt[(2∗q/p)]

Where V is the velocity (m/s)

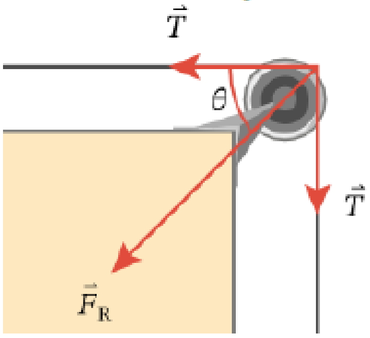
q is the dynamic pressure (pascals)

p is the fluid mass density (kg/m^3)

To calculate velocity from pressure, multiply the dynamic pressure by 2, divide by the fluid mass density, then take the square root of that result.

dv/dt = Acceleration

Mounted Pulley for Rope-for Horizontal Pulling



Formula

$$\bar{a} = \frac{v - v_0}{t} = \frac{\Delta v}{\Delta t}$$

$\bar{a}$ = average acceleration
v = final velocity
v_0 = starting velocity
t = elapsed time

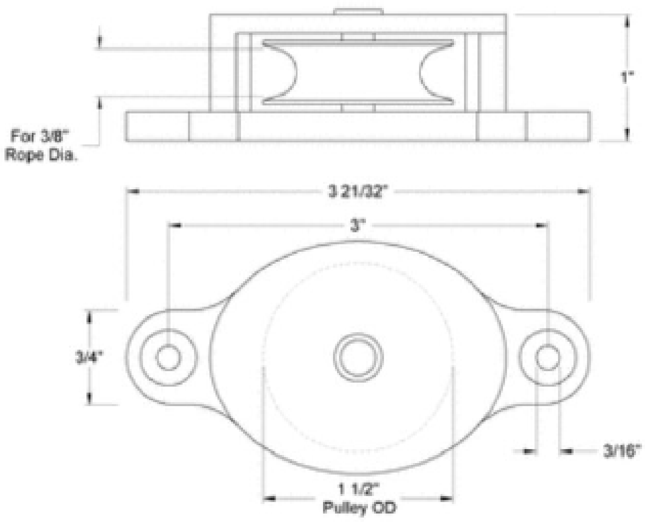
Steel, for 3/8" Diameter, 1" Wide

Calculations performed at maximum worst case forces applied by pneumatic at 60 lbs. 45°

Acceleration = F/m where F = (100 psi) *(6894.76 N/m^2/1psi) and m = 0.11 kg

Pulley Tension = T(Pneumatic) = m*a = [(60lbs.)/(9.81m/s^2)] * a-pneumatic (516.4 m/s^2) = 3158 lbs.

Force Resultant: Fr = T * (Cos (45) + Sin (45)) = 1.41* (3158) = 4453 lbs.

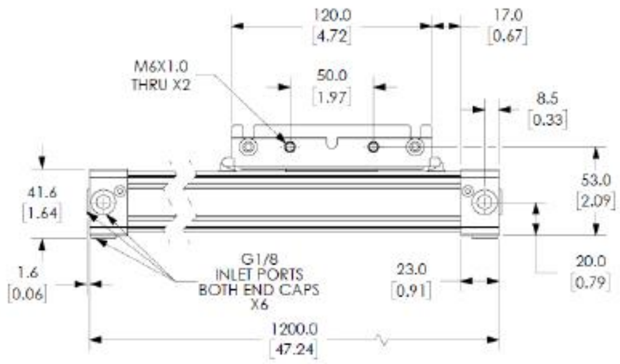


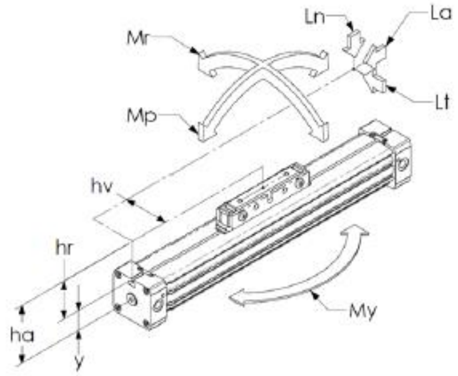
Dynamic Pressure (pascals) — Pascal (Pa)
689476

Fluid Density (kg/m^3) — Kg/m^3
1.293000000000

Velocity (m/s)
1032.702699064 — m/s

Maximum acuator force felt by door handle
Seth Flamm
7-29-23

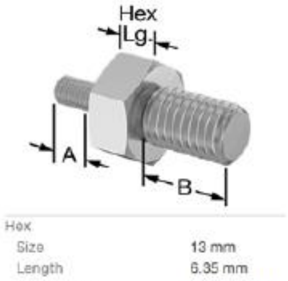




NITRA L-Series Rodless Pneumatic Cylinder Force and Torque Information							
Bore	Center Distance Y	Actual Force F at 6 bar [N]	Cushioning Stroke [mm]	Max. Load Ln [N]	Mp Max [Nm]	Mr Max [Nm]	My Max [Nm]
25	14	250	21	300	15	1	3

Note: When the cylinder is subjected simultaneously to torque and force, use the following equations, where the lengths have to be given in meters.

Mp = F x ha Mr = L x hv + Lt x hr My = F x hv



Mp = F x ha
F = Mp/ha

15 Nm	
0.05235 m	(53-20+6.35+13)mm
286.5329513 N	1N =0.2248090795lbs
64.41520903 lbs	Max Force and Tension in Rope

The moment Mp will have the maximum force that the actuator can enact on the system. Using the equation provided by the manufacturer (also basic physics) we can find the maximum force taking the maximum moment that the shuttle can withstand and dividing it by the distance from the middle of the actuator to where the load will be applied. The ropes will transfer the force from the actuator to the door handle and we will assume a minimal loss of force due to friction since we are using pulleys. The distance from the middle of the actuator to the load was found using the manufacturer's drawings of the actuator, the thread adapter, and the eyenut. One the force was found we then convert from Newtons to pounds. The door handle will be able to withstand the nearly 65lb maximum force that the actuator is capable of.

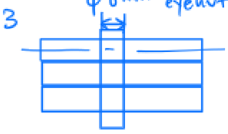
Sources:
https://www.mcmaster.com/3019T32/
https://www.mcmaster.com/93048A115/
https://www.automationdirect.com/adc/shopping/catalog/pneumatic_components/rodless_air_cylinders/l25m1000md

revised eye bolt calculations - BNK

Sunday, July 23, 2023 3:45 PM

Eyebolt to Rope

SHEAR STRESS



Rope $\phi = 3/8'' = 9.525\ mm$

Nylon Rope UTS = 11,800 psi = 81.36 MPa

$P = 27\ lbs = 120.10\ N$

$A_E = \frac{\pi D^2}{4} = \frac{\pi (0.008^2)}{4} = 50.26 \times 10^{-6}\ m^2$

$A_R = \frac{\pi D^2}{4} = \frac{\pi (0.009525)^2}{4} = 71.26 \times 10^{-6}\ m^2$

Eyebolt Shear Stress $= \tau_{ave_E} = \frac{P}{A_E} = \frac{120.10\ N}{50.26 \times 10^{-6}\ m^2} = 2.39\ MPa$

$2.39 \ll \tau_{ave_E} \ll UTS_E$

$2.39\ MPa \ll 400\ MPa$ ✓

Rope Shear Stress $= \tau_{ave_R} = \frac{P}{3 \cdot A_R} = \frac{120.10\ N}{3(71.26 \times 10^{-6})m^2} = 1.68\ MPa$

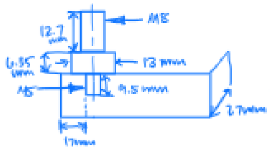
$1.68\ \tau_{ave_R} \ll UTS_R$

$MPa \ll 81.36\ MPa$ ✓

BEARING STRESS

$\sigma = \frac{P}{tD} = \frac{P}{D_R \cdot D_E} = \frac{120.10\ N}{3(.009525\ m)(.008\ m)} = 0.525\ MPa \ll UTS_R \ll UTS_E$ ✓

Hex Thread Adapter to Pneumatic Cylinder



$\phi M5 = 5\,mm$

$\text{Shear } A_{M5} = \frac{\pi D^2}{4} = \frac{\pi (0.005)^2}{4} = 19.63 \times 10^{-6}\ m^2$

$\text{Shear } A_{cyl.} = (0.005)(0.017) = 85 \times 10^{-6}\ m^2$

$\text{Bearing } A_{cyl.} = (0.0095)(0.005) = 47.5 \times 10^{-6}\ m^2$

$\text{Bearing } A_{cyl.} = \text{Bearing } A_{M5}$

Cylinder Material = Aluminum (3000 series)
- UTS = 90.0 MPa (conservative estimate)
- E = 68.0 GPa

Hex Thread Adapter (M5 to M8)
- Part No. 93048A115
- Zinc-Plated Steel
- UTS = 75000 psi = 517 MPa

$P = 27\ lbs = 120.1\ N$

SHEAR STRESS - CYLINDER

$\tau_{ave_{cyl.}} = \frac{P}{A} = \frac{120.1\ N}{85 \times 10^{-6}\ m^2} = 1.413\ MPa \ll UTS_{cyl.}\ (90\ MPa)$ ✓

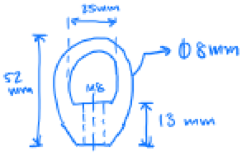
BEARING STRESS - CYLINDER & ADAPTER

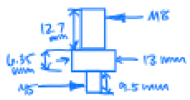
$\sigma_{cyl.} = \frac{P}{tD} = \frac{120.1\ N}{47.5 \times 10^{-6}\ m^2} = 2.53\ MPa \ll UTS_{cyl}\ (90\ MPa) \ll UTS_{M5}\ (517\ MPa)$ ✓

SHEAR STRESS - ADAPTER

$\tau_{ave_{M5}} = \frac{P}{A} = \frac{120.1\ N}{19.63 \times 10^{-6}\ m^2} = 6.12\ MPa \ll UTS\ (517\ MPa)$ ✓

Hex Thread Adapter to Eye Nut





Galvanized Steel Eye Nut - M8
- Part No. 3019T32
- Galvanized Steel
- Vertical Capacity = 800 lbs
- UTS ≈ 58 ksi = 400 MPa (low estimate)

Hex Thread Adapter (M5 to M8)
- Part No. 93048A115
- Zinc-Plated Steel
- UTS = 75000 psi = 517 MPa

SHEAR STRESS - Adapter

$\phi M8 > \phi M5 \therefore \tau_{M8} < \tau_{M5}$ ✓

BEARING STRESS - Adapter & Eyenut

$\text{Bearing } A_{M8} = (0.008)(0.0127) = 101.6 \times 10^{-6}\ m^2$

$\sigma_{M8} = \frac{P}{A_{M8}} = \frac{120.1\ N}{101.6 \times 10^{-6}\ m^2} = 1.18\ MPa \ll 400\ MPa\ (\text{UTS eyenut}) \ll 517\ MPa\ (\text{UTS adapter})$ ✓

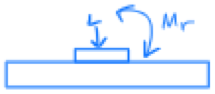
SHEAR STRESS — Eyenut

Shear $A_{eyenut} = \frac{\pi D^2}{4} = \frac{\pi (0.008)^2}{4} = 50.26 \times 10^{-6}\ m^2$

$\tau_{eyenut} = \frac{P}{A} = \frac{120.1\ N}{50.26 \times 10^{-6}\ m^2} = 2.39\ MPa << 400\ MPa$ (UTS eyenut) ✓

Cylinder Specifications

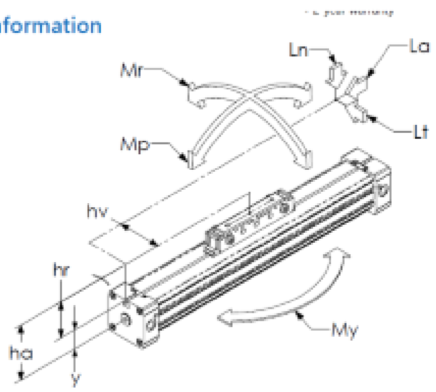
Max load = 300 N



Mr max = 1 Nm
Mp max = 15 Nm

L max = 120.01 N

hv ≈ 3.625 in
= 92.075 mm



$Mr = (L \times hv) + (Lt + \cancel{hr})^{\to 0}$

$= (120.10\ N \times 92.075 mm)$

$= 11.058\ NM$ ✗ $>> 1\ Nm$

Fails if pull direction is transverse to cylinder.
∴ Reconfigure design to pull in longitudinal direction.

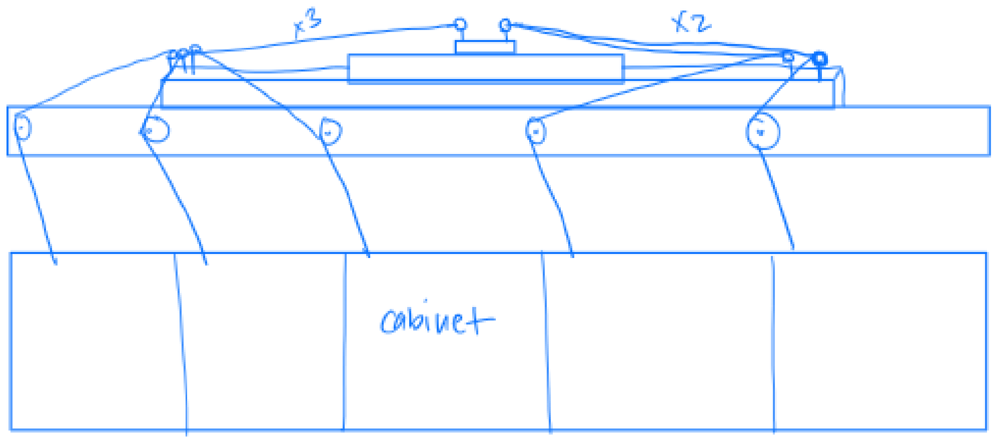
Pulling in longitudinal direction:

$Mp = F \times ha$

ha ≈ 1.805 in
= 0.045847 m

$= 250\ N \times .045847$
$= 11.46\ Nm < 15\ Nm$ ✓

Mr becomes negligible. ✓



15 ANNOTATED BIBLIOGRAPHY

[1] "US10888176B2 - Heat absorbing door for a refrigerated merchandiser - Google Patents." https://patents.google.com/patent/US10888176B2/en?oq=10888176, Accessed 10 Aug. 2023.

This was the first patent we referenced.

[2] "US9523230B2 - Door closer assembly - Google Patents." https://patents.google.com/patent/US9523230B2/en?q=(door+closer+assembly)&oq=door+closer+assembly, Accessed 10 Aug. 2023.

This was the second patent we referenced.

[3] "US20120014497A1 - Door cycle tracker - Google Patents." https://patents.google.com/patent/US20120014497A1/en?oq=US20120014497A1, Accessed 10 Aug. 2023.

This was the third patent we referenced.

[4] "The Life Cycle of a Door." https://www.assaabloyentrance.com/us/en/stories/blogs/the-life-cycle-of-a-door, Accessed 10 Aug. 2023.

This was the first background information website we referenced.

[5] "McMaster-Carr." https://www.mcmaster.com/, Accessed 10 Aug. 2023.

This was the second background information website we referenced.

[6] "Where Big Ideas Are Built | Production Parts and Prototypes | Xometry." https://www.xometry.com/, Accessed 10 Aug. 2023.

This was the third background information website we referenced.

[7] "Neometrix." https://neometrixgroup.com/products/refrigerator-door-endurance-testing-system#:~:text=Applications,be%20in%20side%20of%20gripper, Accessed 10 Aug. 2023.

This was a reference for an existing design for a door endurance test system.

[8] "IEC62552 Automatic Refrigerator Door Open And Close Testing Machine." https://www.sinuotek.com/sale-26565552-iec62552-automatic-refrigerator-door-open-and-close-testing-machine.html, Accessed 10 Aug. 2023.

This was a reference for an existing design for a door endurance test system.

[9] "How do I tell if a refrigerator door seal is bad? | FAQs | GE Appliances Factory Service." https://repair.geappliances.com/resources/faq/article/how-do-i-tell-if-a-refrigerator-door-seal-is-bad, Accessed 10 Aug. 2023.

This was an article describing how to test refrigerator cabinets and reporting the effects of an uncontrolled test environment.

[10] ANSI/ASHRAE Standard 72 – 2022: Method of Testing Open and Closed Commercial Refrigerators and Freezers

The standard should be used as a reference for recommendations, not requirements. It provides test conditions for refrigerators while powered on, so the majority of the specification does not apply, as the cabinets are tested disconnected from power at the customer facility. The applicable recommendations involve conditions for the testing room and placement of the cabinet in relation to other surfaces.

[11] ISO 23953-2 – 2021: Refrigerator Display Cabinets – Part 2: Classification, Requirements, and Test Conditions

The standard applies to timing of the testing, test conditions, and aesthetic concerns regarding the components of the refrigerator cabinet itself. It applies to the refrigerator unit more than the door cycling unit itself.

[12] ASME B30.26 – 2015: Rigging Hardware: Safety Standard for Cableways, Cranes, Derricks, Hoists, Jacks, and Slings

The standard applies to safe assembly and use of the pulleys and ropes.

[13] ASTM F3125/FD3125M – 2022: Standard Specification for High Strength Structural Bolts and Assemblies, Steel and Alloy Steel, Heat Treated, Inch Dimensions 120 ksi and 150 ksi Minimum Tensile Strength, and Metric Dimensions 830 MPa and 1040 MPa Minimum Tensile Strength

The bolts used for the attachment of the lumber to the Unistrut frame were manufactured to this material specification. Properties of the bolts that apply to the design calculations may be found in this standard.

[14] AWC NDS – 2018: National Design Specification for Wood Construction

The standard provides guidance for building wood structures. It was not available for review.

[15] ASTM D6815 – 2022: Standard Specification for Evaluation of Duration of Load and Creep Effects of Wood and Wood-Based Products

The creep strength of the wood can be found following the procedures contained in this specification. The value will help to determine the life cycle of the testing unit.

[16] ASTM F1470 – 2018: Standard Guide for Inspection of Nylon, Polyester, or Nylon/Polyester Blend, or Both Kernmantle Rope

The life cycle of the rope can be determined after extensive testing of the door cycling station, using the inspection procedures included in this specification.

[17] ANSI/CAGI B19.1 – 2011: Safety Standard for Compressor Systems

This standard applies to the safety of the shop air system.

[18] OSHA 1910.212: General Requirements for All Machines: Machinery and Machine Guarding

It is a legal requirement to comply with OSHA standards. Safeguards shall be out in place to prevent injury from moving parts. This is within the customer's scope.

[19] OSHA 1910 Subpart D: Walking-Working Surfaces

It is a legal requirement to comply with OSHA standards. Walkways shall be clearly marked and kept clear. This is within the customer's scope.

[20] OSHA 1910 Subpart G: Occupational Noise Exposure

It is a legal requirement to comply with OSHA standards. Noise resulting from use of the door cycling stations shall be considered and address according to this standard. This is within the customer's scope.

[21] EU NO 1907 – 2006: Regulation of the European Parliament and of the Council Concerning the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH)

REACH is a common certification that relates to the safe regulation of chemicals. The pulleys and ropes used in this project are REACH compliant.

[22] VA Section 22 15 00 – 2020: General Service Compresses-Air Systems

The standard for service of compressed air systems may apply to the customer's shop air system. This is within the customer's scope.