MECH 4860: Engineering Design
Final Design Report

Project: Wind Tunnel Interface System Design

Company: WestCaRD

Group Number: 23

Group Name: Tunnel Diggers

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Submitted to:

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MECH 4860 FINAL DESIGN REPORT SUBMISSION

Dear Dr. Labossiere,

The team *Tunnel Diggers* is pleased to present to you our final report entitled *MECH 4860-Final Design Report* on this Monday, the 7th of December 2015.

This report discusses three different design concepts for the wind tunnel interface design that manages the instrumentation cables and provides efficient, time saving feature to changeover between two different tests. The three design concepts were requested by the client, and these proposed designs include: the cable drag chain design, the sliding extension rail design, and the guide loops design.

A rough order of magnitude cost summary is included for each designs including the bill of materials. Various failure modes were identified for each designs using FMEA. This analysis helped us identify the most critical component of the designs. These analyses will aid the client in the design selection process.

If there are any inquiries regarding this report do not hesitate to contact any members of the team via their University of Manitoba email.

Sincerely,
Gethin James
Team Lead

Document Enclosed: *MECH 4860-Final Design Report-Wind Tunnel Interface System Design*

Executive Summary

The “Wind Tunnel Interface System Design” project was presented to Team 23 by the West Canitest R&D Inc. (WestCaRD). WestCaRD strives to aid in the development of technologies to advance the aerospace industry through the testing of jet engines and through the engineering analysis. The jet engine testing facility, operated by Standard Aero, is known as the General Electric Testing Research and Development Center (GE TRDC).

Currently the instrumentation cables at the testing site are routed to the wind tunnel through a fixed instrumentation rack. Disconnection and management of these cables is needed in order to change testing scenarios, but currently it takes 3 working days and 3 personnel to change between tests. Therefore, the objective of this project is to design three interface systems, as requested by the client, which are able to change over between tests within 1 to 2 days and reduces the labor employed to 2 personnel by managing the instrumentation cables. These designs should allow for small adjustments to the wind tunnel position up to 10 ft. without disconnection of the instrumentation cables. Moreover, the design should provide easy connection and disconnection of the instrumentation cables during the wind tunnel movement of up to 20 ft.

The three designs developed by the team includes the cable drag chain design, guide loops design, and the sliding extension rail design. The cable drag chain is capable of moving of up to 10 ft. in two directions of the wind tunnel movement. This design has a movable end that is connected to the instrumentation rack and the other end is fixed to the support rack which is mounted to the acoustic wall. The rough order of magnitude (ROM) cost of this design is $19,000. The second design consists of the guide loops to contain cables and pulleys to achieve the movement. This design is capable of moving of up to 20 ft. and has a ROM cost of $25,000. The third design consists of sliding rails which

are capable of bending to adjust to the movement of the wind tunnel. This design is capable of moving of up to 10.4 ft. and has a ROM cost of $ 16,800.

All of the three designs meet the client's need of 10 ft. movement adjustment. However, to provide an easy disconnection feature and to meet the 20 ft. movement requirement, the two lengths of cables at the instrumentation rack are connected by the bulk head connectors. This can be done by splicing the current cables and by fitting a male plug to one cut and the female plug to the other cut.

With these two features, the changeover time between two tests is reduced to a day as the instrumentation cables can be easily disconnected at the instrumentation rack. The small length of the cable connected to the wind tunnel can be easily managed in about an hour. This feature also reduces laborer required during the changeover process.

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1. Introduction

The “Wind Tunnel Interface” project was presented by West Canitest R&D Inc. (WestCaRD) to help the company solve problems faced in jet engine testing procedures. WestCaRD strives to develop technologies to advance the aerospace industry through the analysis and testing of jet engines. The testing facility, known as the General Electric Testing, Research, and Development Center (GE TRDC) is used to test General Electric (GE) gas turbine engines. The testing facility is operated by StandardAero and the testing is conducted in order to determine the operational abilities of gas turbine engines. Currently, the facility conducts icing tests, ingestion tests, and endurance tests [1]. Figures 1.1 and 1.2 show the wind tunnel site, and a gas turbine engine being tested in the wind tunnel for icing conditions, respectively.

Figure 1.1: The wind tunnel set up at the GE TRDC site on the grounds of the Winnipeg James Armstrong Richardson International Airport [1].

Figure 1.2: A GE gas turbine engine being tested in icing conditions at the GE TRDC [2].

In order to ensure proper operation of gas turbine engines, exhaustive testing must be performed under the situations that the engine undergoes while in operation. In order to be able to conduct tests on different models and sizes of the engines, it is necessary to move the inlet tunnel back and forth along its cylindrical axis to adjust for the varying engine length. Also, in order to accommodate for ingestion testing, the wind tunnel needs to be able to move in excess of 20 ft. along its central axis [1].

The movement of the setup is not an issue. The movement is possible through a set of installed rails that the wind tunnel is resting on. The GE and the StandardAero staff are concerned about the instrumentation and the power supply for the wind tunnel. The instrumentation and the power supply cables are connected from the wind tunnel to the control room and main power supply via electrical wiring. Currently, in order to change the wind tunnel configuration from one to another of the several possible configurations, all electrical connections (power and instrumentation) need to be disconnected, the wind tunnel needs to be moved, and then the instrumentation and power supply needs to be re-routed and reconnected.

Currently, the changeover process which is carried out by one external electrician and two technicians takes up to three days. The reduction of this changeover time is the primary concern for this project, as the time used in adjusting the testing rig is time that is not being used for the testing, and thus reduces the overall efficiency of the facility.

Figure 1.3 shows the runs of instrumentation cables required to measure parameters of the wind tunnel.

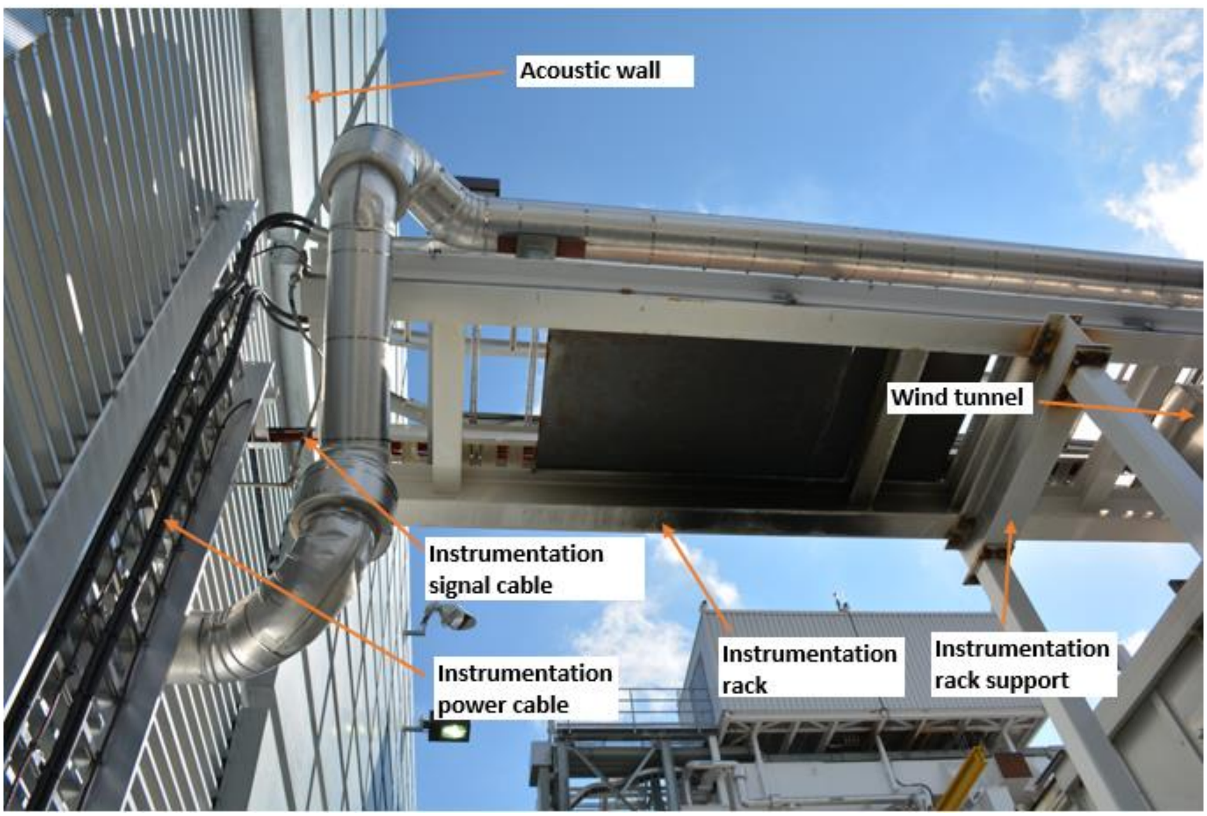


Figure 1.3: The current interface between the wind tunnel and the control room [1].

As illustrated in Figure 1.3, the instrumentation cables are currently routed to the wind tunnel through an instrumentation rack. The cabling for the instrumentation needs to be disconnected, pulled through the current support fixture, and then rerouted once the wind tunnel is in its new position. This process increases the time taken for changeover between the testing. This time taken, however, can be reduced by designing an interface system which will manage the cables. For this project, as power cables are not much of an issue, the team focused on designing an interface system that will manage the instrumentation cables. An interface system provides connections between the cables from the control room to the connection panels in the wind tunnel. This system allows for small movements of wind tunnel position of up to 10 ft. without disconnection, and provides easy connection and disconnection features for the wind tunnel movement of up to 20 ft.

To solve this changeover issue, the client requires multiple design concepts to select from. Therefore, three different systems are designed that focus on managing the instrumentation cables to provide easy and rapid changeover during testing. These systems reduce the time being consumed during the current changeover process. To aid in the client's design selection process, detailed cost analyses along with the design operation guidelines are also prepared in this project. The operation guidelines are included in Appendix D of this report.

1.1 Problem Statement

The wind tunnel position needs to be adjusted to accommodate for the different engine lengths and the need for different tests performed at the site. The types of testing performed at the wind tunnel site include the ingestion testing, the icing testing, and the endurance testing. Currently, the instrumentation cables are routed to the wind tunnel through an instrumentation rack. When the wind tunnel needs to be moved, the cabling for the instrumentation needs to disconnected, pulled through the current support fixture, and then rerouted once the wind tunnel is in its new position. This process is lengthy and to changeover between two tests, it takes 3 working days and 3 people which includes an electrician. The duration of the changeover and the number of people required for the changeover process can be reduced by designing an interface system that manages the instrumentation cables and connects the cables from the control room to the wind tunnel.

1.2 Objectives

The objectives of this report are broken down into three parts and are listed below.

- To design three interface systems that are able to change over between tests within 1 to 2 days by managing the instrumentation cables.
- To reduce the number of labourers employed for the changeover process from three to two.
- To ensure safety of the technicians and public during the operation and development of the interface system.

Moreover, the design of the interface system needs to meet the two operation scenarios:

i. The design must allow for small adjustments to the wind tunnel position of up to 10 ft. without disconnection of the instrumentation cables.
ii. The design must provide easy connection and disconnection of the instrumentation cables during the wind tunnel movement of up to 20 ft.

1.3 Deliverables

The key deliverables of this project are listed below.

- CAD models and the engineering drawings of the three working interface system with their bill of materials.
- Operator's manual that will explain various features of each designs and their installation procedures.

1.4 Customer Needs and Specification

After interviewing the contact persons, the team was able to summarize eleven needs and specifications for the design. These needs and specifications are listed below.

- Three design concepts of the interface system.
- The interface system operates year-round.
- The interface system design allows for small adjustments to the wind tunnel position of up to 10 ft. without disconnection of the instrumentation cables.
- The interface system provides easy connection and disconnection of the instrumentation cables during the wind tunnel movement of up to 20 ft.
- The interface system reduces working time during the wind tunnel setup from 3 days to 1 day (ideal), 2 days (marginal).
- The interface system reduces technicians required during the changeover period from 3 to 2.
- The interface system has a simplified structure for easy maintenance.
- The interface system adapts to weather conditions ranging from -40°C to 40°C.
- The interface system introduces desired error of 0 magnitude in the signal quality from instruments.
- The interface system remains electrically safe to operate under all conditions.
- The interface system avoids cutting out the acoustic wall if possible. The maximum cut out area is 0.25 m^2.

1.5 Constraints and Limitations

The design is largely limited by physical constraints, though some of these do not have a quantified limitation. These constraints and limitations were obtained by interviewing the client and are listed below:

- The system should operate normally year round under all weather conditions.
- The system should require low maintenance.
- The new design should not modify any part of the wind tunnel array.
- The system should require little to no modification of the current acoustic wall.
- The new system should not introduce more signal noise than that is present within the current system.
- The system's initial installation must fall within the April to October window that takes place between regular testing.

Based on the needs and the understanding of the problem, the team generated concepts for the design of the interface system using concept generation techniques. The concept generation techniques and the concepts are explained in Appendix A. Based on this concept selection process, three designs were selected and designed in detail as requested by the client.

2. Details of Design

The designs that are selected based on the concept selection process are cable the cable drag chain design, the guide loops design, and the sliding extension rail design. This section provides full features of these three designs, including the main components, and integrates CAD models of the major components and the assembly. Furthermore, this section provides overall cost for each of the designs, including the bill of materials. The engineering drawings are included in Appendix B.

2.1 Cable Drag Chain

The major components that make up the cable drag chain system are the pair of drag chains and the drag chain rack. Drag chains are designed to hold cabling or hoses in a desired orientation throughout the movement envelope, and to allow the cables to be placed in areas where large movements need to occur. Drag chains are made up of segmented links that can either be snapped or fastened together in order to create a chain of the desired length. Drag chains allow for the containment and the protection of sensitive cabling and therefore, using a cable drag chain alongside a supporting mechanism will allow for the secure retention of the instrumentation cabling.

The total length travelled by the drag chain is termed as the travel length. The nomenclatures for the cable drag chain are illustrated in Figure 2.1.

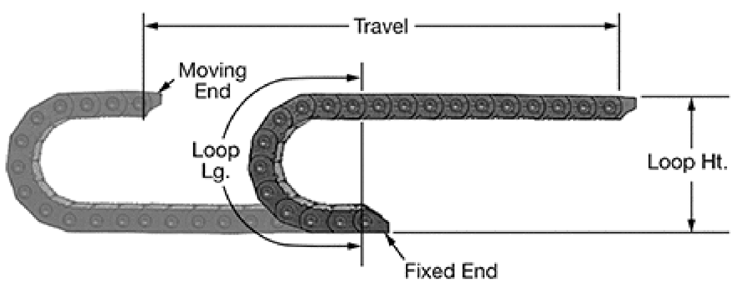


Figure 2.1: Cable drag chain nomenclature.

Figure 2.1 shows that the height between the two end links when the chain is at its minimum radius of curvature is called the loop height, and the loop length is the length of the curvature at the minimum radius position. The arrangement of the links that are connected to construct the entire length of the drag chain design is illustrated in Figure 2.2.

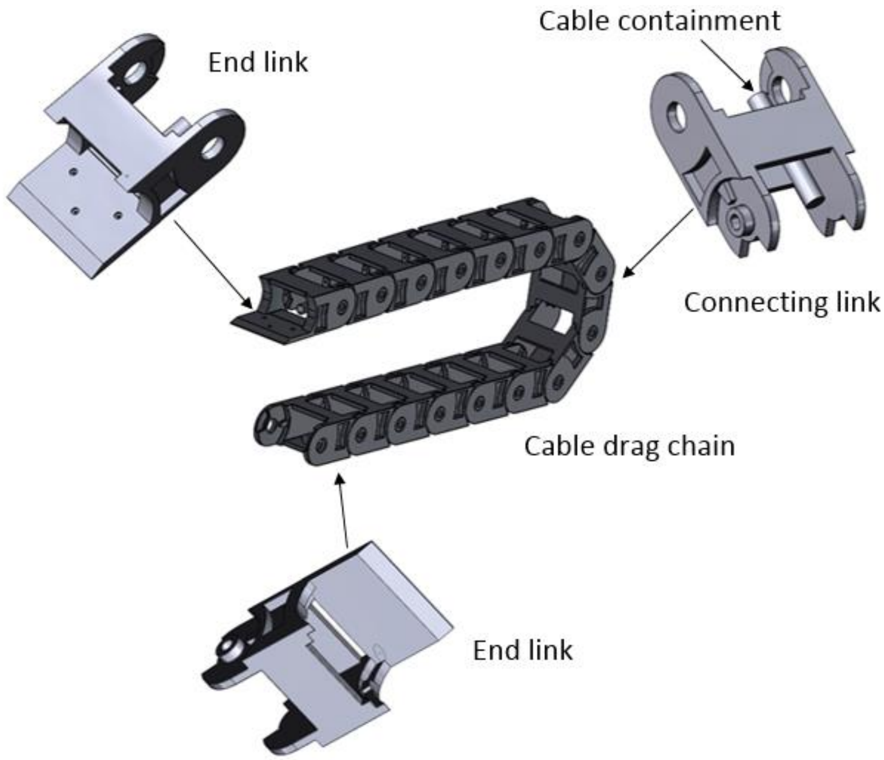


Figure 2.2: Cable drag chain.

Figure 2.2 illustrates the drag chain design with three different links which can be connected together to form the entire length.

Cable drag chains are advantageous because they allow for the complete support of the instrumentation cables while being moved. They can also be specified to have a minimum radius of curvature. This implies that the cable drag chains can only be mechanically bent up to a certain point before they cannot be bent further. This allows for the prevention of kinking or over-bending of the instrumentation cables, which could lead to potential problems in data acquisition.

2.1.1 Design Features

The client's needs are fulfilled by the two features of the design:

i. Drag chain containing instrumentation power cables and instrumentation signal cables capable of moving 5 ft. in either direction of the wind tunnel movement.

ii. Disconnecting feature of the instrumentation cables at the instrumentation rack.

The design feature used to achieve the adjustment to the wind tunnel position is the cable drag chain itself. The drag chain has been designed using three types of links: two end links and a link repeated fourteen times to join the end links which forms the drag chain with a total of sixteen links as seen in Figure 2.2. This results in the drag chain of total length of 18.6 ft.

In addition to the drag chain, the design incorporates the present instrumentation rack at the site. This rack is connected to the moving end of the drag chain as shown in Figure 2.3.

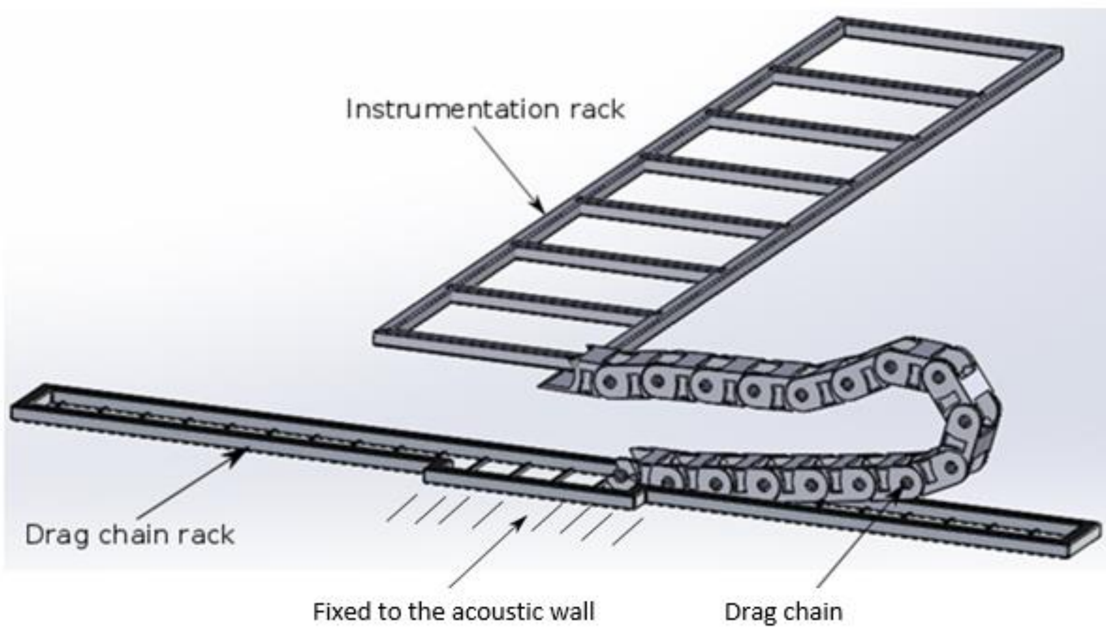


Figure 2.3: Drag chain design components.

As illustrated in Figure 2.3, the fixed end of the drag chain is bolted to the drag chain support rack with the help of mounting brackets. This rack supports the drag chain and connects to the acoustic wall. This rack is bolted to the acoustic wall from where the cables enter the drag chain. These cables pass through the instrumentation rack and connect to the wind tunnel. The movement of the wind tunnel moves the drag chain to a desired position during a small movement of up to 5 ft. on either direction of the wind tunnel movement. This design also incorporates a drag chain for the instrumentation power cables as an additional feature. An image of the assembly to the acoustic wall is illustrated in Figure 2.4.

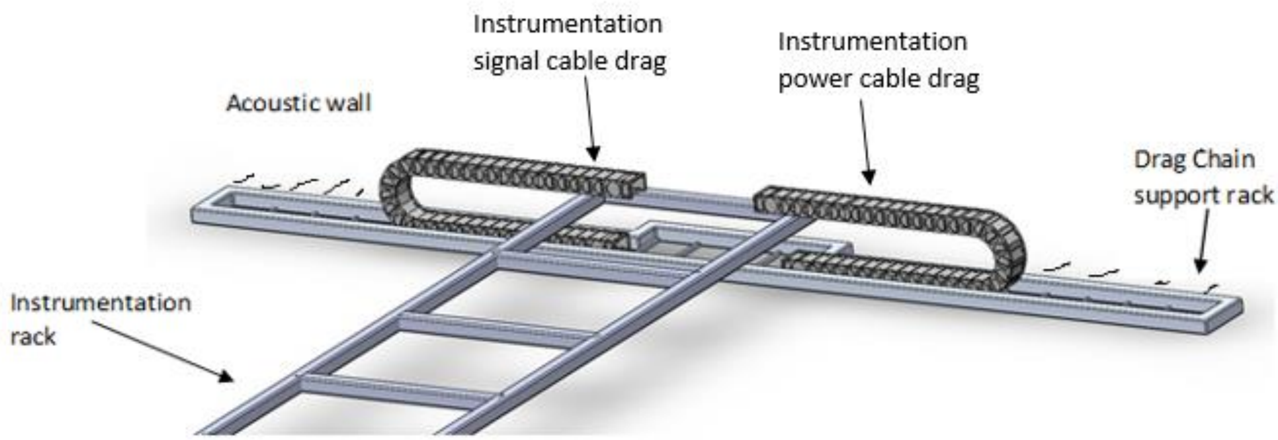


Figure 2.4: Drag chain assembly.

The drag chain was sourced from a manufacturer and is readily available through McMaster-Carr. The links can be snapped together to create the length that we need. The lengths can be easily joined with screws. This drag chain has the capacity to accommodate large volume of cables as required for this problem and can operate at a temperature of -40℃ . The design consists of enclosed lay-in carriers that protect the cable from damage caused by dirt, chips, and debris. They have snap-on cross bars that allow access at any point along the length, which makes it easy to install cables without threading it through [3]. The drag chain rack is a fixture which supports the drag chains. This is needed in order to maintain the drag chain orientation without stressing the cables within drag chain.

Figure 2.5 gives an underside view of the drag chain assembly that shows the support brackets for the drag chain rack. The supporting brackets are made from an l-channel steel, which allows for easy and inexpensive manufacturing.

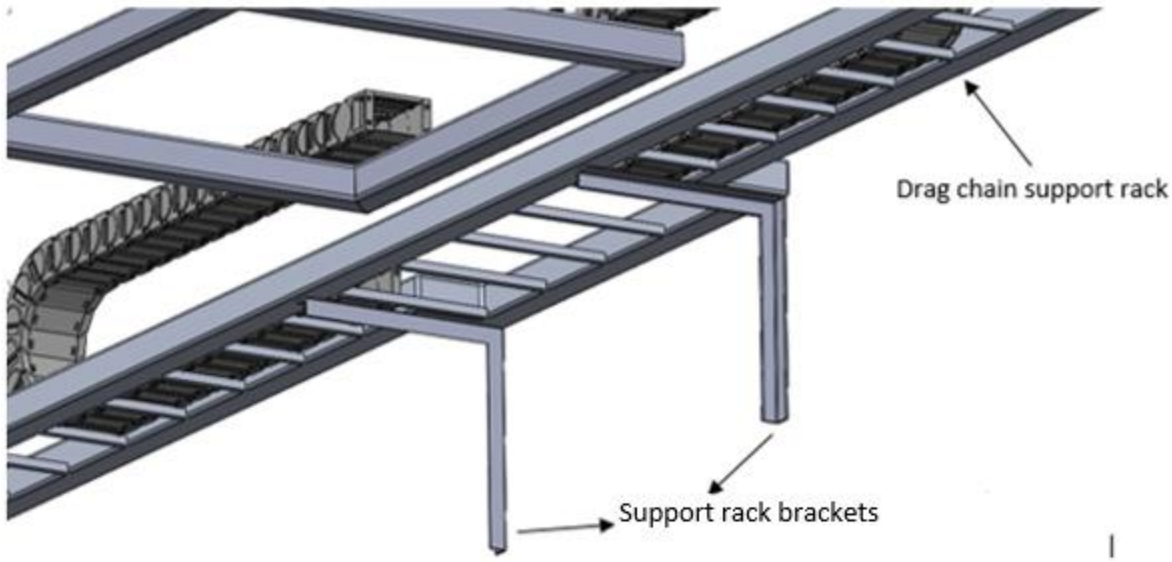


Figure 2.5: Support rack brackets.

As shown in Figure 2.5, two brackets are used to attach the rack to the acoustic wall. These brackets are fitted at a distance of 9.8 ft. from the ends of the rack and have the ability to support the load of the rack as well as the drag chains.

The key design components, their specifications, and their functions in the design are listed in Table I.

TABLE I: CABLE DRAG CHAIN DESIGN COMPONENTS, SPECIFICATIONS, AND FUNCTIONS

Component	Width	Length	Function
Instrumentation signal cable drag chain	7.9" width, 7.9" bend radius, 20" loop height	3.4 ft. loop length	Contain instrumentation signal cable, adjust to the wind tunnel position of 5 ft. in each direction of the wind tunnel movement, and protect cables.
Instrumentation power cable drag chain	7.9" width, 7.9" bend radius, 20" loop height	3.4 ft. loop length	Contain instrumentation power cable, adjust to the wind tunnel position of 5 ft. in each direction of wind tunnel movement, and protect cables.
Drag chain mounting bracket	7.9" carrier width	4.3" carrier height	Connect drag chain with the instrumentation rack and the support rack.
Drag chain support rack	22.83" width, 3.5" thickness	24.54 ft.	Support the drag chains and connect the chains to the acoustic wall
Instrumentation rack	5.17 ft. width, 3" thickness	28.14 ft.	Connect the cables the wind tunnel, moves along with the free end of the drag chain.
Support rack brackets	24" width, 0.25" thickness	24"	Connect the support rack to the acoustic wall.

This design uses a disconnection feature of the cables at the instrumentation rack using bulk head connectors as shown in Figure 2.6.

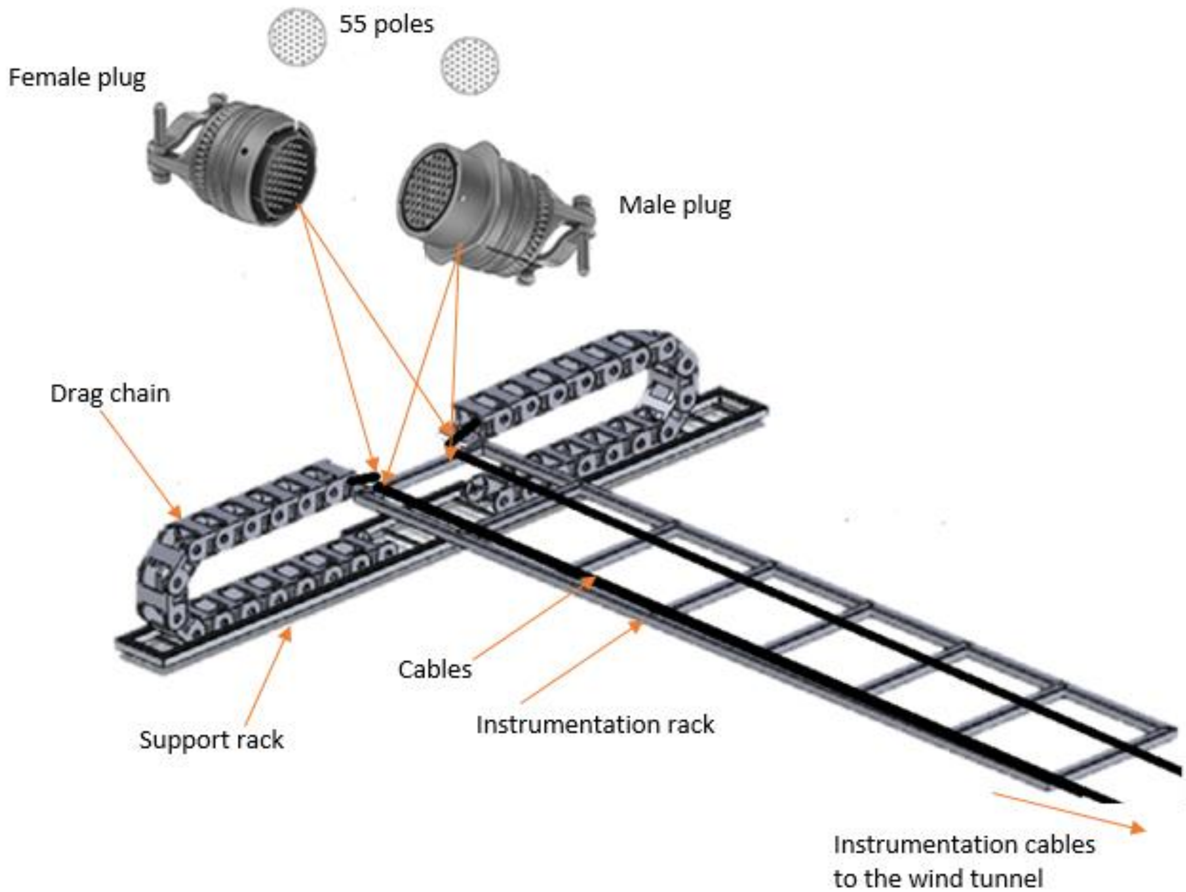


Figure 2.6: Bulk-head connectors to connect cables.

Figure 2.6 illustrates the use of the bulk-head connectors in the cables at the instrumentation rack. The bulk-head connectors can be fitted in the current cables by splicing these cables. This fitting process requires an electrician. The electrician's labor cost is estimated in Table II. A male plug is connected to the length of the cable connected to the wind tunnel while the female plug is connected to the length of the cable coming from the drag chains. With this connection, the current process of disconnecting the cables becomes easier as the small length of the cables at the instrumentation rack can be easily managed reducing the time to disconnect the cables to about an hour. Due to this feature, the changeover time is reduced to a day.

2.1.2 Design Operation

The movement of the drag chain design is possible due to the movement of the wind tunnel. The cables that come from the control room are routed through the drag chains from where they are routed to the instrumentation rack and then is connected to the wind tunnel.

As the wind tunnel moves, the cables connected to the wind tunnel force the instrumentation rack, the movement of which enables the moving end of the drag chain mounted to the instrumentation rack to change the travel length and an illustration is shown in Figure 2.7.

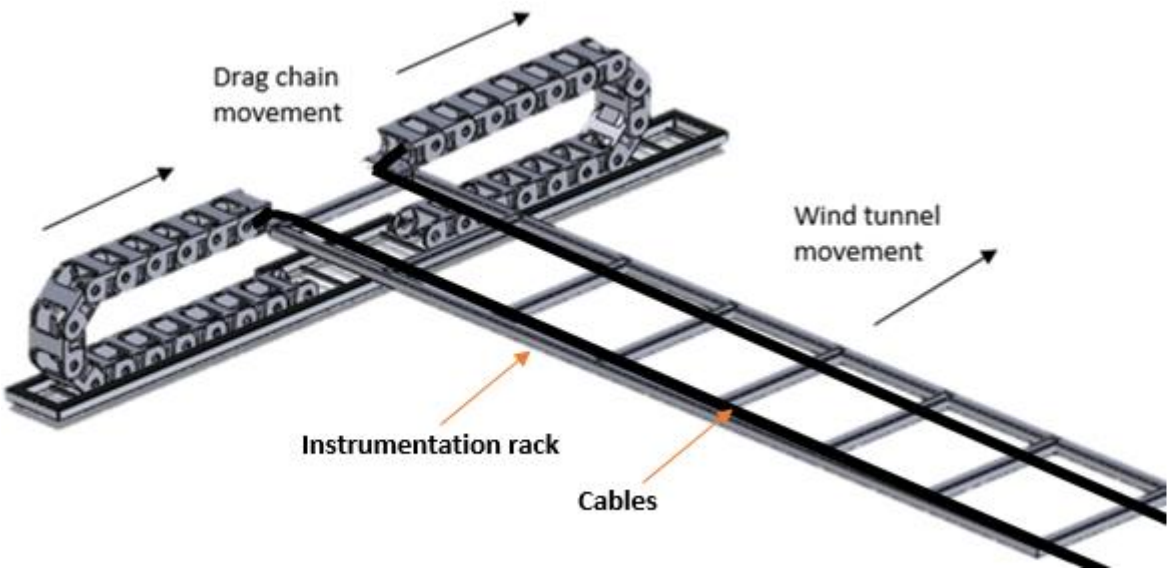


Figure 2.7: Drag chain movement illustration.

As illustrated in Figure 2.7, the length the drag chain can move in one direction is 5 ft. Similarly, the design is able to move 5 ft. in the reverse direction. Therefore, the total length of movement possible with this design is 10 ft. For the eventual need to disconnect the system, the bulk head connectors shown in Figure 2.6 are used at the connection point between the chain and the instrumentation rack. In this way, the small length of the instrumentation cables to the wind tunnel side can be folded and positioned on the wind tunnel platform when the wind tunnel needs to be moved to the 20 ft. position. This setup reduces the changeover time to a day due to the less effort required to disconnect and manage the instrumentation cables.

2.1.3 CAD Model of the Major Components

The major component of the drag chain design is the cable drag chain itself. The CAD model of the cable drag chain is illustrated in Figure 2.8.

Figure 2.8: Drag chain.

Figure 2.8 illustrates that the drag chain consists of 16 links. Two of the links are the outer links, one that is fixed and the other end link is free to move. The CAD model of the connecting links is shown in Figure 2.9.

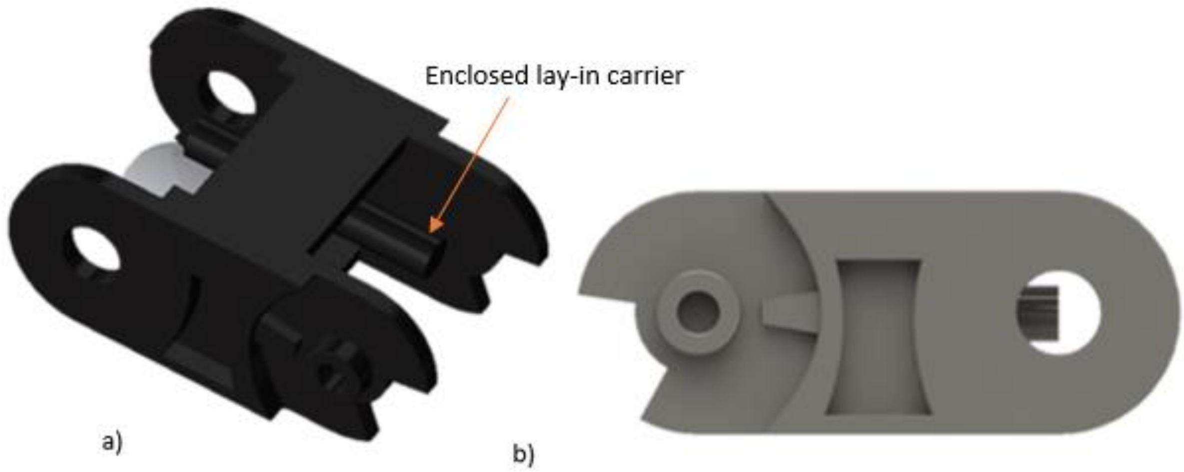


Figure 2.9: Links a) general view, b) side profile with the material changed for the better view.

Figure 2.9 shows a general view of the link with an enclosed lay-in carrier that protects the cables. A front view of the link is also shown to illustrate the shape of the link.

The cable drag chains are mounted to the instrumentation rack and the drag chain rack with the help of mounting brackets. These brackets are connected using mounting fasteners. The CAD model of the mounting bracket is shown in Figure 2.10.

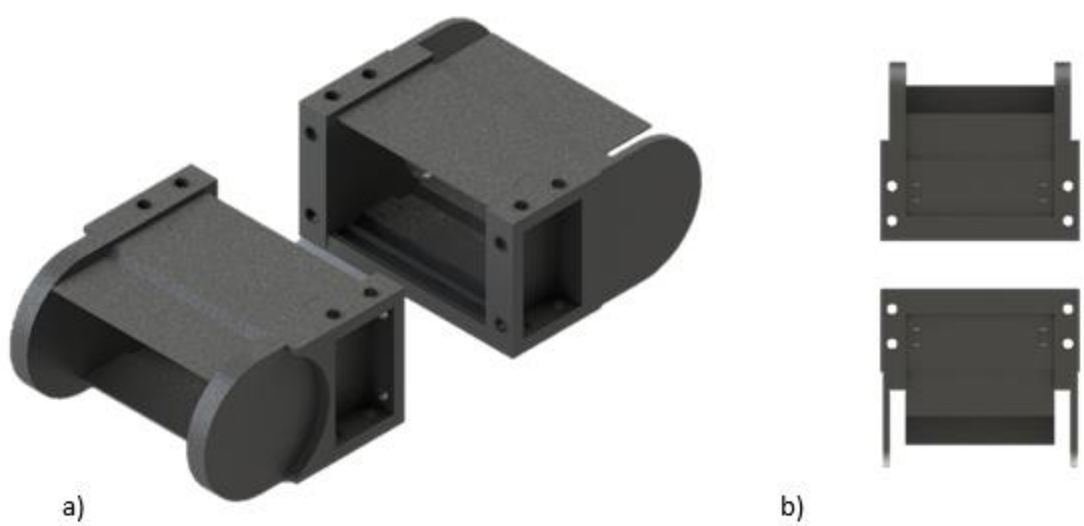


Figure 2.10: Drag chains mount to the racks: a) isometric view, b) bottom view.

Figure 2.10 illustrates the isometric view and the bottom plane view of the mounts. These mounts connect the one end of the drag chain to the instrumentation rack and the other end to the support rack. The support rack carries the load of the drag chains and is fixed to the acoustic wall. The CAD model of the drag chain rack is shown in Figure 2.11.

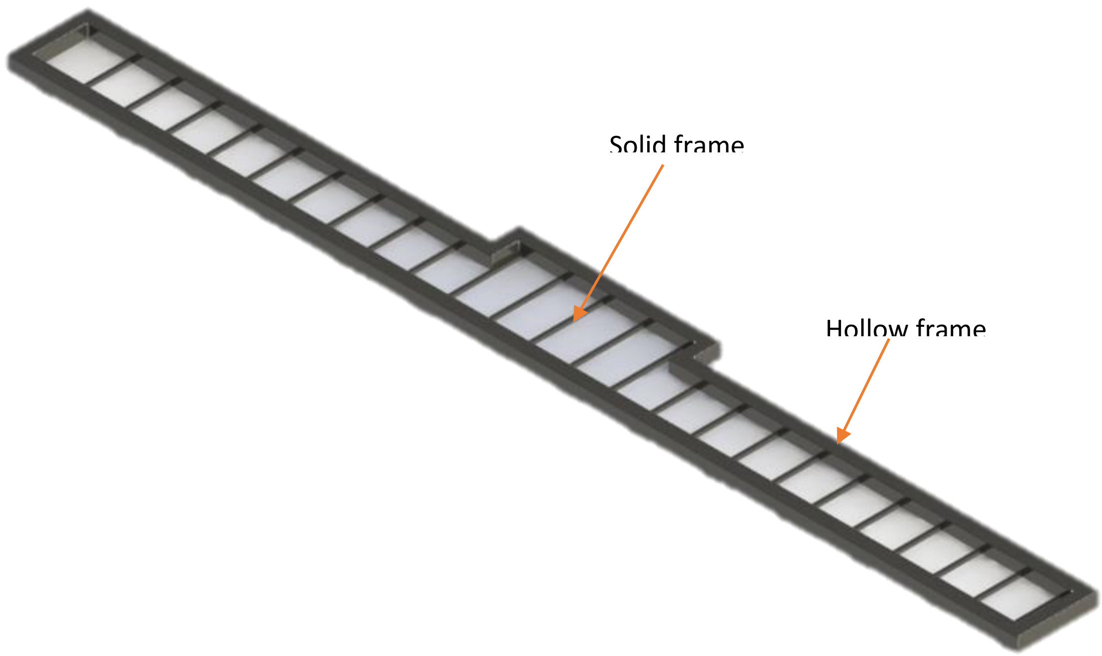


Figure 2.11: Isometric view of the drag chains support rack.

Figure 2.11 illustrates the isometric view of the drag chains support rack. The central rails are made up of solid frame while the side rails are made from hollow frame. These hollow frames form a total length of 24.54 ft. while the solid frame provides the width of 16.54” (24.01” at the center). The details for these frames can be found in section 2.1.5. This rack is connected in parallel with the acoustic wall at a distance of 9.8 ft. from each ends. The drag chains are positioned on the two sides of the rack.

The drag chains, the drag chain support rack, and the instrumentation rack form the assembly of the cable drag chain design. The assembly of the design is shown in Figure 2.12 in section 2.1.4. This assembly model illustrates the different components and their position within the assembly.

2.1.4 CAD Model of the Assembly

An assembly of the cable drag chain design is illustrated in Figure 2.12.

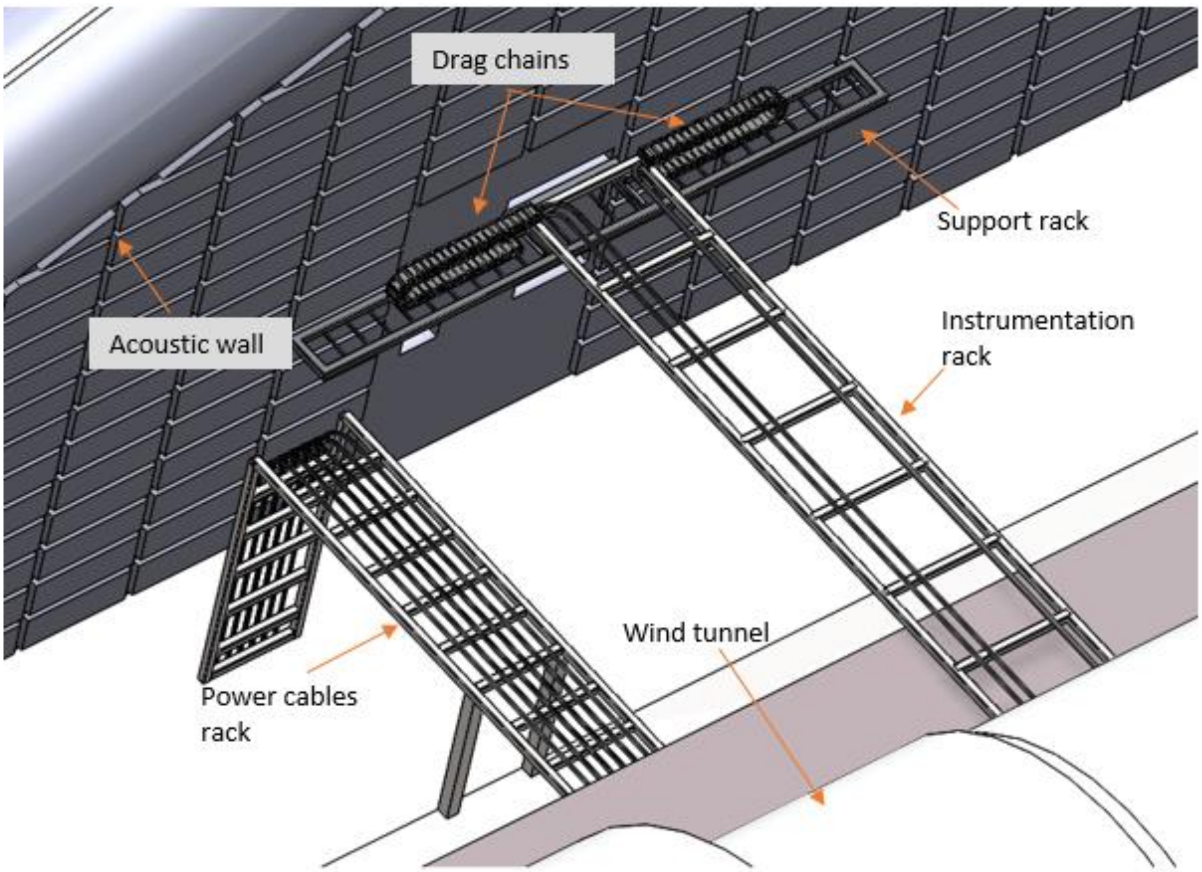


Figure 2.12: Cable drag chain assembly.

Figure 2.12 shows the guide loop interface system design mounted to the acoustic wall with the help of two support brackets. The cables are routed through the enclosed lay-in carriers present in the chains. These cables are then routed to the instrumentation rack from where it connects to the acoustic wall as seen in the figure, the drag chains are supported by the support rack which is mounted to the wall. With all these components, the drag chain design is able to operate.

2.1.5 Overall Cost and Bill of Materials

The cable drag chain design components are sourced from McMaster-Carr adjusting the size of the components as available. The costs of the components are shown in Table II along with the quantity required. Moreover, the table also lists the part number for easy reference while purchasing the components.

TABLE II: CABLE DRAG CHAIN BOM

Item	Description	Raw Mat'l	Source/ Part No.	Qty	Unit of Meas	Unit Price (USD)	Total Price (USD)
Cable Drag Chain	Snap-together cable and hose carrier	Black nylon	McMaster-Carr/4617T65	4	5 ft. length, bend radius 7.9"	$427.35	$1,709.4
	Mounting bracket for 7.9" wide enclosed style snap-together cable and hose carrier	Black nylon	McMaster-Carr/4617T87	8	7.9" carrier width	$28.50	$228.00
						Subtotals:	$1,937.4
Racks	Drag chain support rack hollow frame	Carbon steel alloy	Discountsteel.com	3	3"x3"x0.375", 20 ft. length	$197.12	$591.36
	Drag chain support rack solid frame	304 stainless steel	McMaster-Carr/1471T18	5	1"x1", 0.08" thickness,8 ft. length	$47.38	$236.90
	Bulk head Connector	Aluminum housing	McMaster-Carr/6134T48 male, 6134T78 female	4	55 number of poles	$189.36	$757.44
	Galvanized low-carbon steel 90 degree angle-mount to acoustic wall	Zinc-Galvanized	McMaster-Carr/8968K63	4	1/4" wall thickness, 3 ft. length	$39.90	$159.60
						Subtotals:	$1,745.30
	Laborer Type	Number	Hourly Rate (USD)	Days			Total Rate (USD)
Labor Cost	Electrician	1	90	3			$2,160
	Construction	3	90	6			$12,960
						Subtotals:	$15,120.00
						Totals:	$18,802.70

For this design, the current instrumentation rack at the site needs to be raised by 11.81” (30 cm) in order for the rack to be mounted at the free end of the drag chain. This can be done either by adding a height which can done by welding a solid frame of height 11.81” to the base of the current instrumentation rack. However, the desired height of the instrumentation rack can be achieved by making a new rack. A cost estimate for raising the current rack to the desired height is included in the labor cost estimation.

Moreover, the drag chain rack is built by welding small pieces together. The 20 ft. long hollow frame needs to be welded to a 4.54” frame. These two pieces are welded to create a length of 24.54 ft. on each side. These two frames are connected by 1”X1” pieces. Considering the modification requirement and the need for an electrician to route the cable, a cost estimation is made assuming the labor rate of $90 per hour and a working day of right hours. Overall, the rough order of magnitude (ROM) cost of the guide loops design is $19,000.

2.2 Guide Loops

The guide loops design consists of wire ropes with several pulleys and supporting loops. These guide loops allow for movement of the wind tunnel, as extra cable length would be contained in the guide loops and can extend to the required position. Once the cables are coiled through the supporting loops, the cables do not need to be adjusted for the regular operation. The guide loops design for this project is illustrated in Figure 2.13.

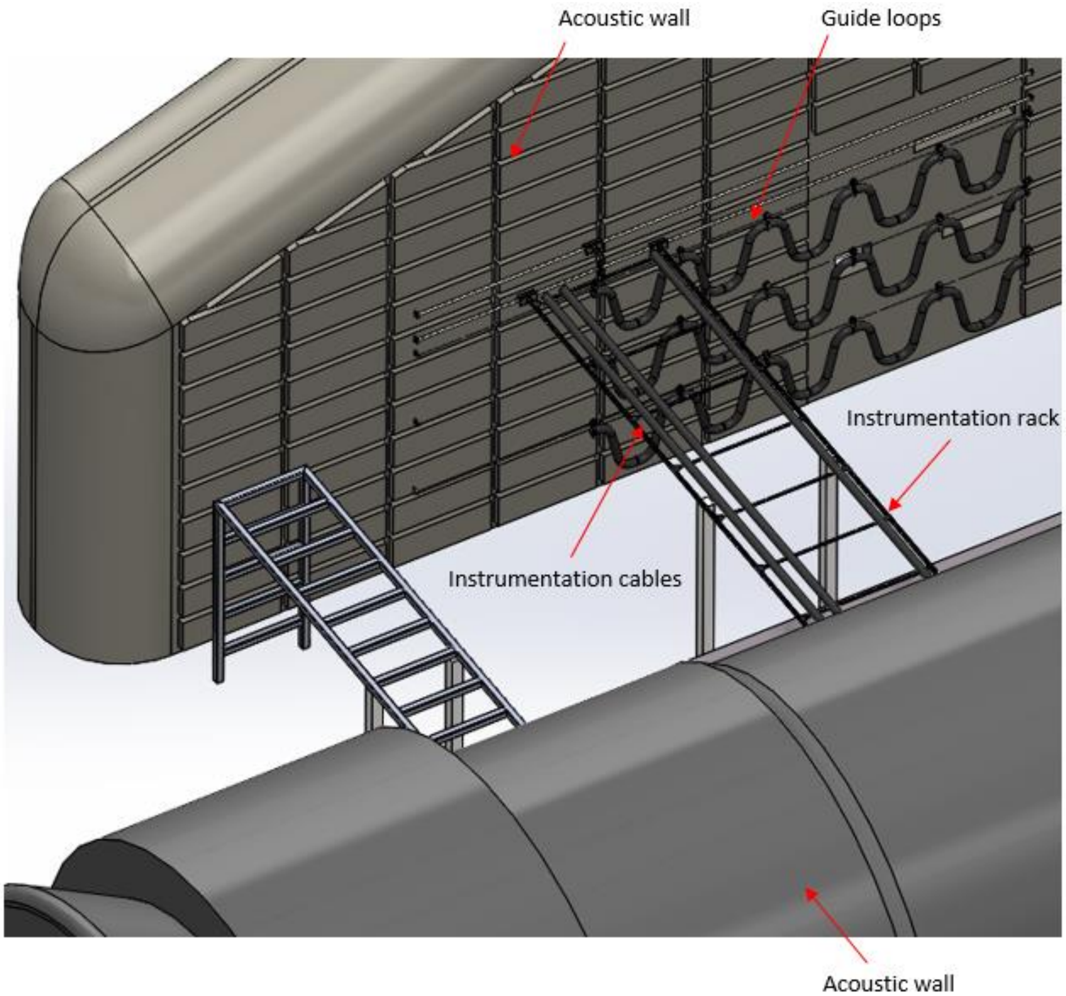


Figure 2.13: Guide loops arrangement.

Figure 2.13 shows that the design consists of three wire ropes to support the guide loops and to provide a path for the loops to move to a position of up to 20 ft.

The guide loops are constructed with pulleys and hangers bolted together. The cables pass through these loops and to the instrumentation rack from where the cables connect to the wind tunnel. The instrumentation cable slides linearly with the movement of the wind tunnel due to the instrumentation cables that are in the rack. The movement is possible as the instrumentation rack is bolted with two linear bearings, one at each end of the instrumentation rack, that are capable of movement along a hardened precision shaft. To prevent the rotation of the rack, the centre of the rack is connected to a second precision shaft that is parallel to the first precision shaft with the help of bolt-together framing. The separation between the two shafts is 1.35 ft. The frame is bolted to a linear bearing and hence, moves along with the instrumentation rack.

The design features of the guide loops design are illustrated in this section along with the CAD model. This section also includes the bill of materials of the design and the approximate overall cost.

2.2.1 Design Features

The client's needs are fulfilled by the three features of the design:

i. Guide loops that consists of the cable carrying hangers bolted with pulleys.

ii. Instrumentation rack capable of moving linearly due to linear bearings and a shaft.

iii. Disconnecting feature of the instrumentation cables at the instrumentation rack.

The design features used to achieve the adjustment to the wind tunnel position is illustrated in Figure 2.14 and Figure 2.15.

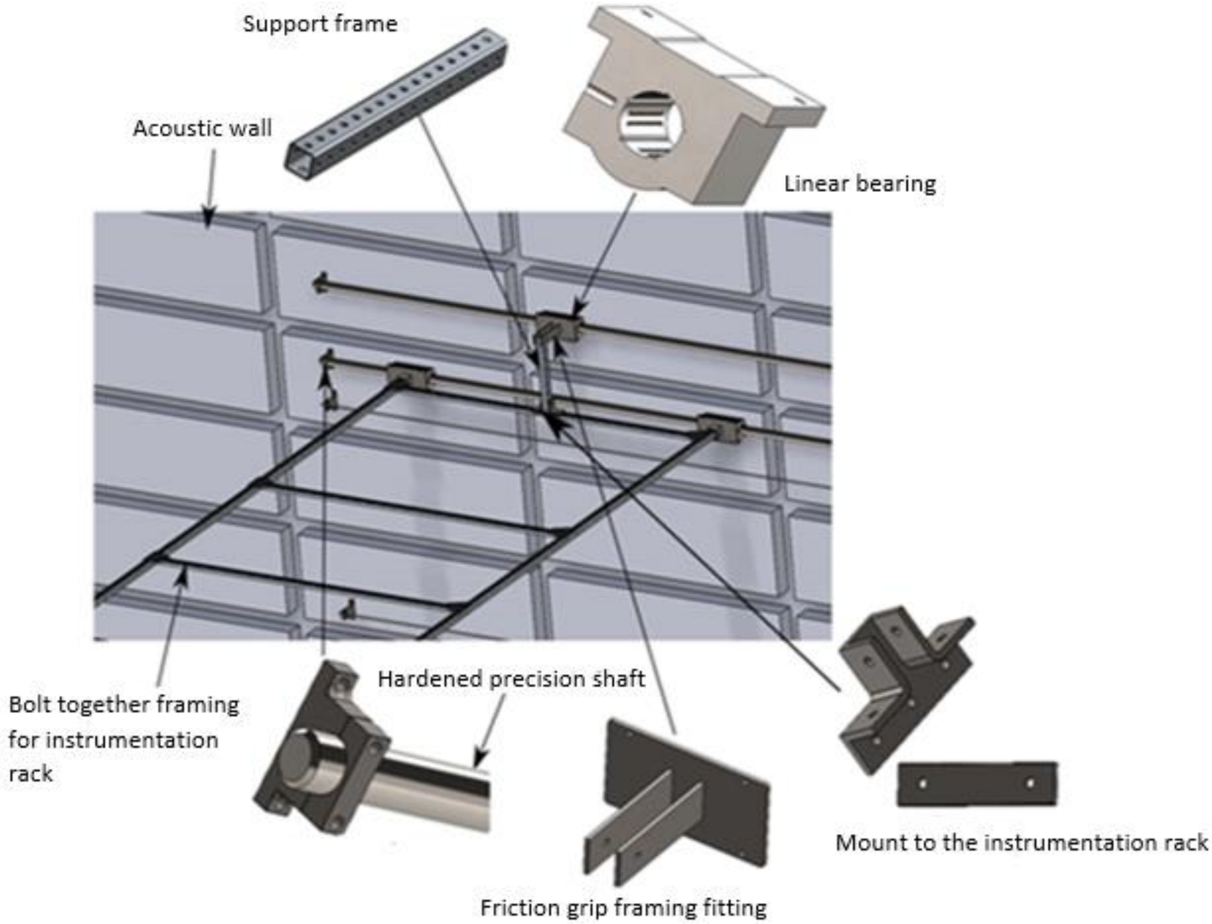


Figure 2.14: Instrumentation rack and shaft fitting for the guide loops design.

Figure 2.14 illustrates design components for the instrumentation rack and shaft assembly. The shafts are bolted at their ends to the acoustic wall using a mount. As illustrated in the figure, one of the design features that makes this design easy to build is the use of heavy duty steel bolt-together frame. The use of this frame makes it easy to bolt the other parts together.

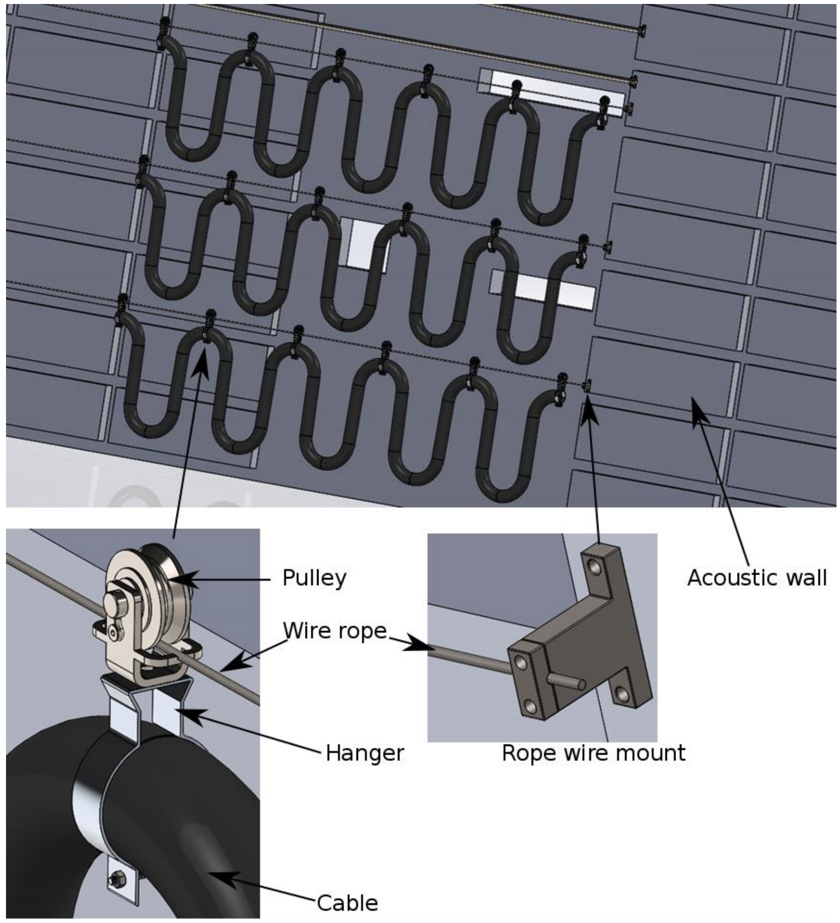


Figure 2.15: Instrumentation rack and shaft fitting for the guide loops design.

Figure 2.15 illustrates the assembly of the guide loops in the acoustic wall. The high strength wire ropes bear the loads of the cables and the pulleys. Three wire ropes are used in parallel separated equally by a distance of 45”. These wire ropes are bolted to the acoustic wall using the rope wire mounts. The key design components, their specifications, and their functions in the design are listed in Table III.

TABLE III: GUIDE LOOPS KEY DESIGN COMPONENTS AND SPECIFICATIONS

Component	Diameter	Height	Length	Function
Bolt-together framing for instrumentation rack (thickness 0.074”)	-	$1\frac{1}{2}$”	Width $1\frac{1}{2}$”	Provide easy bolt-together function to construct rack and connect bearings.
Linear bearing	$1\frac{1}{2}$”	$3\frac{1}{4}$”	9” length, $4\frac{3}{4}$” width	Provide easy sliding of the instrumentation rack
Hardened precision shaft	$1\frac{1}{2}$”	--	28.3”	Provide a path to connect cables to the wind tunnel
Pulley	O.D – 3” Groove Diameter – 2.406”	--	--	Attach hanger to the rope, slide along the wire rope
Wire rope	0.25”	-	28.3”	Support cables, pulley and hangers, provide a path for the loop
Hanger	I.D – 4”	5 3/4"	1 1/4"	Clamp the cables
Friction grip frame fitting	--	4”	Length= width =3”	Connect support shaft and bearing.

Moreover, this design uses the similar disconnection approach as used by the drag chain design. The two pieces of cables can easily be disconnected at the instrumentation rack due to the bulk head connectors shown in Figure 2.19, and the small length of the cables at the instrumentation rack can easily be managed. Therefore, the changeover time is reduced to a day. Moreover, these bulk head connectors can be fitted to the cables by cutting the cables at the rack. This fitting process requires an electrician. The electrician’s labor cost is estimated in Table IV.

2.2.2 Design Operation

The movement of the guide loops is possible due to the movement of the wind tunnel. The cables that come from the control room are routed through the hangers and up to the instrumentation rack. At this position with the use of the bulk head connectors, two pieces of cables can be easily connected and disconnected. The position of the rack and the loop when the wind tunnel is at its reference position is shown in Figure 2.16.

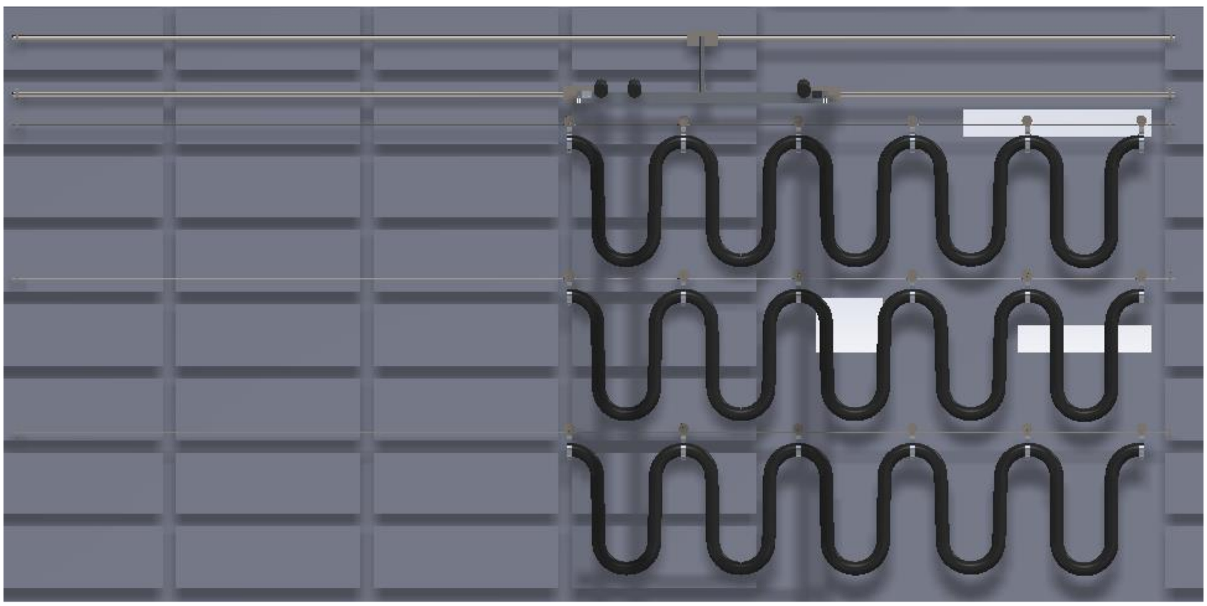


Figure 2.16: Guide loops position 1.

The position of the rack and the loop at the reference position of the wind tunnel is termed as position 1. If the wind tunnel moves, the instrumentation cables attached to the wind tunnel changes the position of the instrumentation rack and the guide loops with the speed of the wind tunnel movement. A position is shown in Figure 2.17 to illustrate the position of the interface system during the wind tunnel movement.

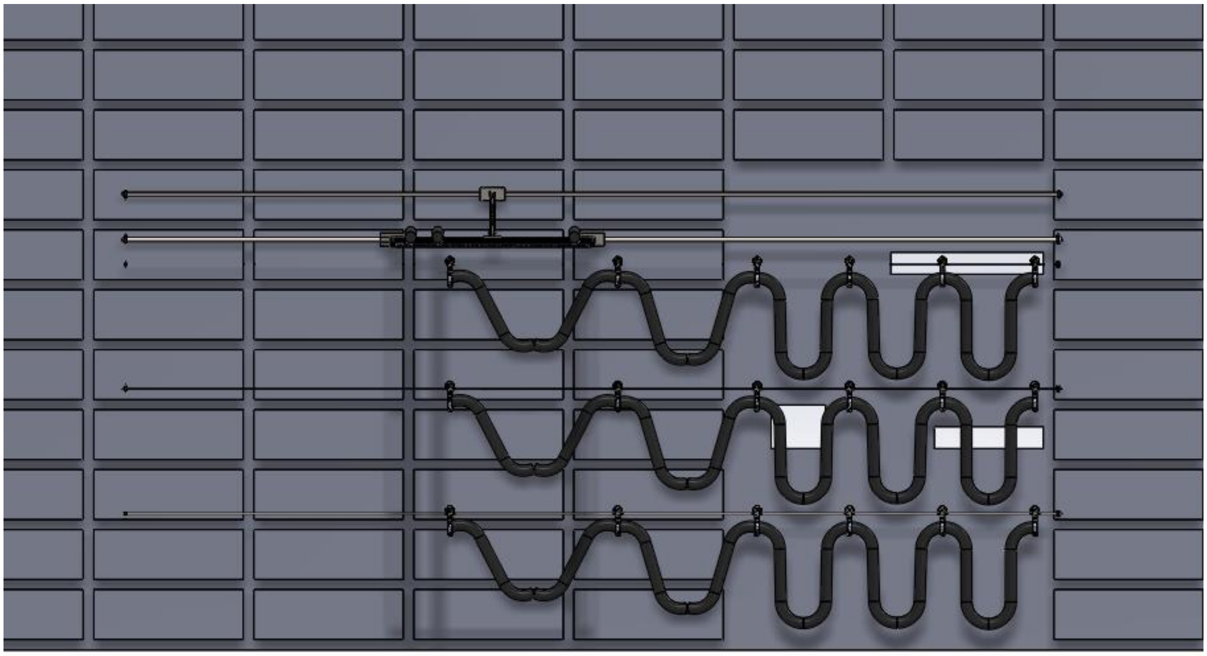


Figure 2.17: Guide loops position 2.

As illustrated in Figure 2.17, the instrumentation rack and the sixth pulley is always at the same position as the cables from the sixth pulley are routed up to the instrumentation rack. As the wind tunnel moves, the cables enable the instrumentation rack which in turn moves the pulley. Moreover, Figure 2.18 shows the total distance the wind tunnel can move without disconnecting the instrumentation cables. It must be noted that the vertical support between the two shaft move along with the instrumentation rack. This support prevents the rack from rotating and also provides support to the rack.

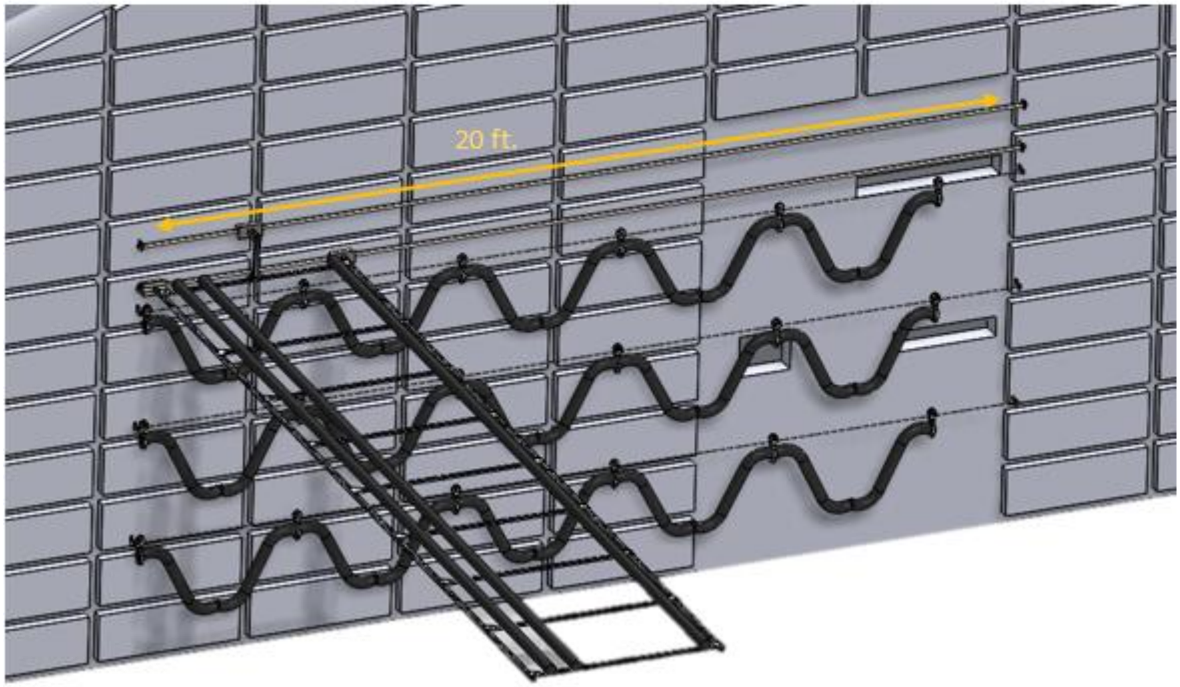


Figure 2.18: Guide loops position 3.

Figure 2.18 shows the total distance the instrumentation rack is capable of moving. This distance is 20 ft. The extra length of the shaft and the wire is to accommodate this length of the movement. Therefore, this design meets the client's need that the wind tunnel allows for small movement of wind tunnel position of up to 10 ft. This design is also capable to move up to 20ft without the full disconnection of the cables. However, to provide easy disconnection feature for the eventual need of disconnection of the instrumentation cables, the cables at the instrumentation rack are connected by bulk head connectors as shown in Figure 2.19.

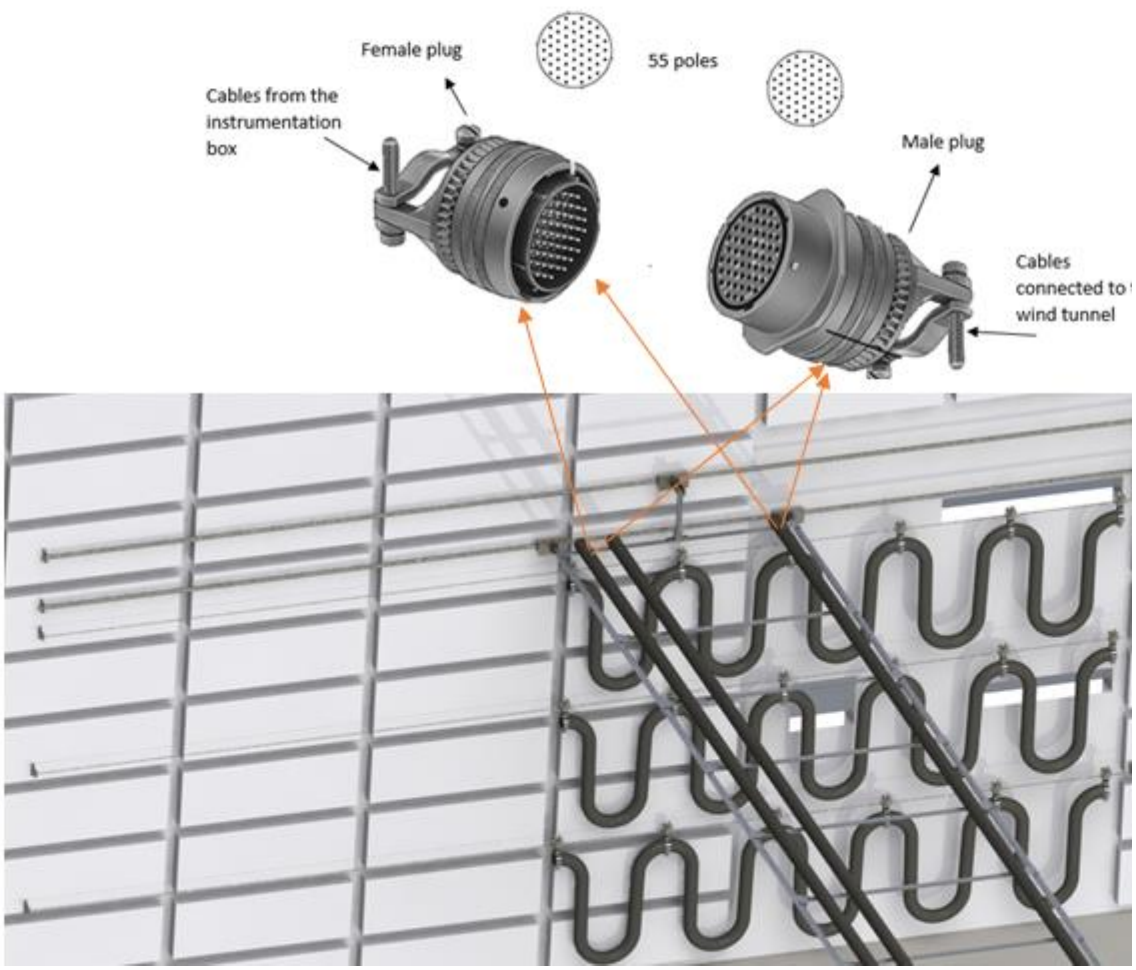


Figure 2.19: Bulk head connection, guide loops design.

Figure 2.19 shows the use of bulk head connectors at the instrumentation rack. The female plug with the cables from the acoustic wall side is connected to the male plug with the cables to the wind tunnel. With these two features, the changeover time between two tests is reduced to a day as the instrumentation cables can be easily disconnected at the instrumentation rack and the small length of the cable connected to the wind tunnel can be folded and managed in about an hour.

2.2.3 CAD Model of the Major Components

There are different interacting components that makes this guide loops design functional. However, CAD models of the important components that ensure the design's operation are illustrated in this section. The engineering drawings of the components can be found in Appendix B.

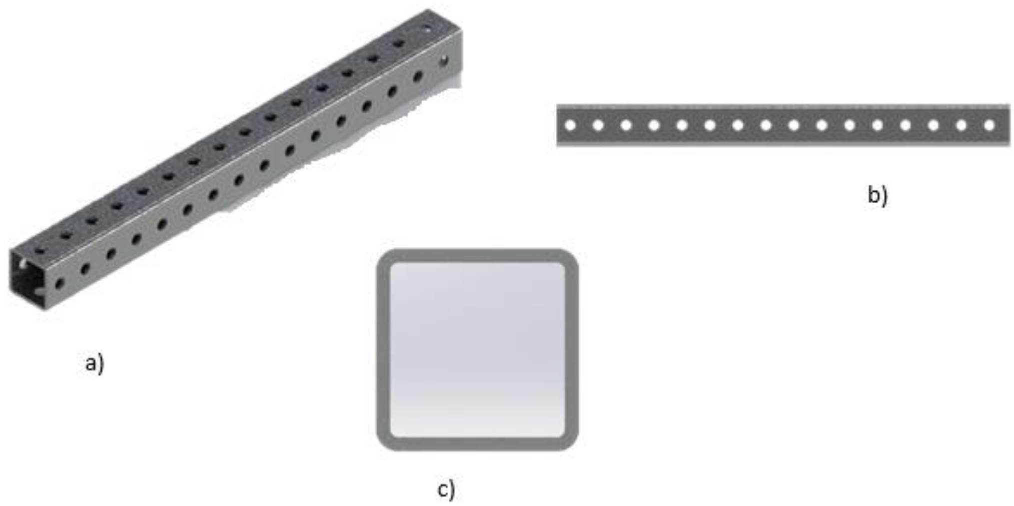


Figure 2.20: Heavy duty steel bolt-together framing for the vertical support: a) isometric view, b) right plane view, c) front view.

Figure 2.20 illustrates the three different views: isometric view, right plane view, and the front view, of the steel bolt-together framing that is used to prevent the instrumentation rack from rotating and also to provide support to the rack. This bolt-together framing has a cross-section of 1.5" length, 1.5" width, and 0.11" thickness. Moreover, the framing support is 16.25" long which is also the vertical separation between the two horizontal shafts. The same framing is used for the instrumentation rack and is of length 28.33 ft. However, the instrumentation rack horizontal framing is made up of a standard L shaped frame. The dimensions for the horizontal support of the instrumentation rack is shown in Figure 2.21.

Figure 2.21: Bolt-together framing for the instrumentation rack horizontal framing: a) zoomed in isometric view, b) front view.

Figure 2.21 illustrates the L-shaped framing for the instrumentation rack. The first view illustrated in the figure is zoomed as the frame is long. The total length of this horizontal instrumentation rack frame is 5.9 ft. and the height is 1.50". This length implies that the width of the instrumentation rack is 5.9 ft. This instrumentation rack is connected to the precision shaft by the means of linear bearings. The specifications of the linear bearing is illustrated in Figure 2.22.

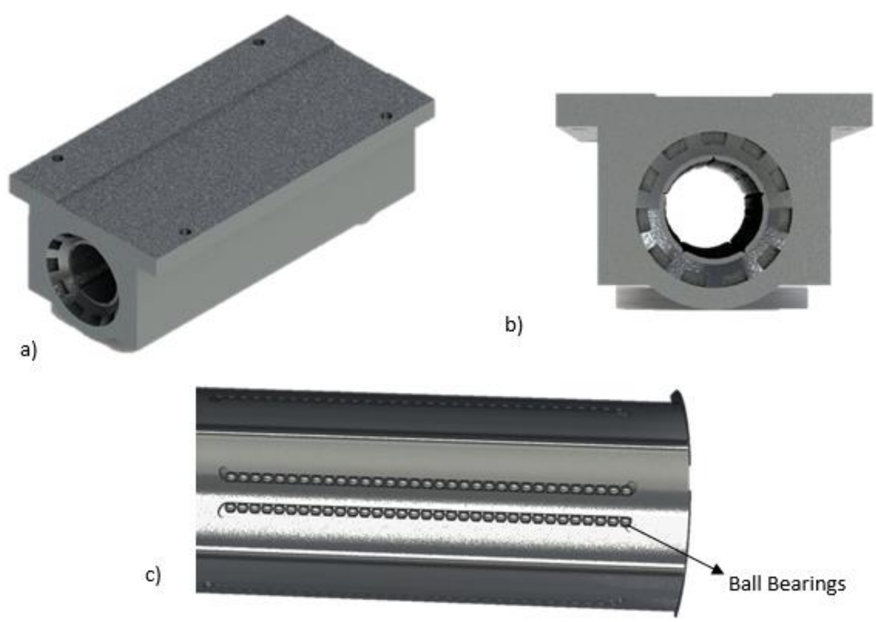


Figure 2.22: High capacity pillow-block linear bearing: a) isometric view, b) front view, c) zoomed in section view.

Figure 2.22 illustrates the linear bearing with three different profile views. The section view shown is zoomed in to show the ball bearings present in the design. The outer diameter of the linear bearing is 3” and the inner diameter is 1.5”. This implies that the shaft of diameter 1.5” can fit through this linear bearing.

In the guide loops arrangement, a hanger is attached to a pulley which can move along the wire rope. The total length of the wire rope is 28.3 ft. and the diameter is 0.25”. The pulley can slide along the length of the wire rope the groove diameter equal to the diameter of the wire rope. The CAD model of the pulley is illustrated in Figure 2.23.

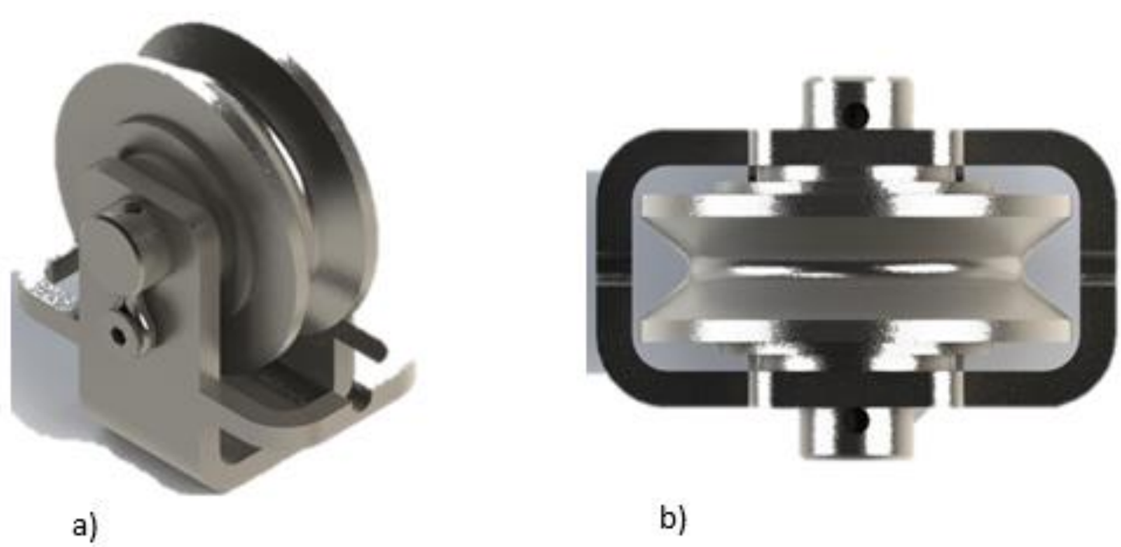


Figure 2.23: Heavy duty steel pulley with the pulley mount: a) isometric view, b) left view.

Figure 2.23 shows that the pulley system consists of two parts. These parts are the pulley and a mount to connect pulley to the hanger. The pulley has a groove diameter of 0.26” which is an inch greater than the ropes diameter. This difference in the diameter is to ensure that the pulley can slide smoothly along the length of the wire. The pulley connects the hanger at a height of 1” with the help of the mount. A CAD model of the hanger is shown in Figure 2.24.

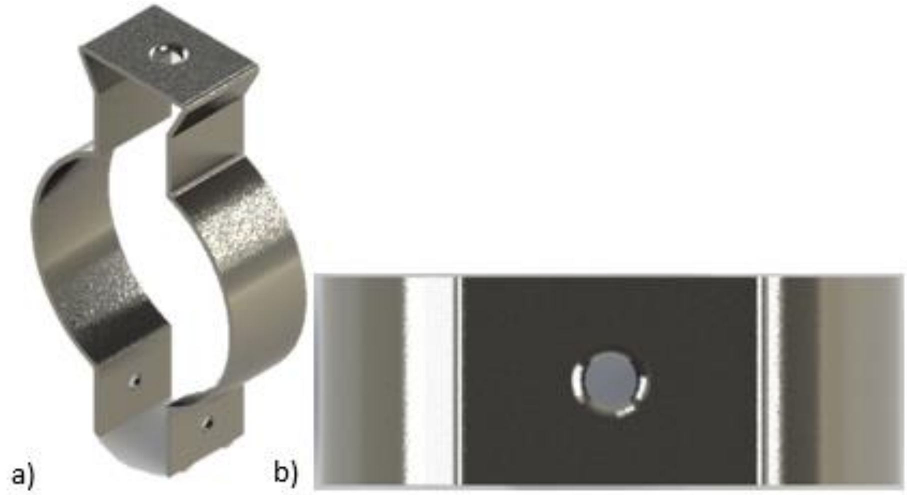


Figure 2.24: Hanger: a) isometric view, b) top view.

Figure 2.24 illustrates the CAD model of the hanger. This design carries the cable and connects it to the pulleys so that the pulleys can move along with the movement of the wind tunnel. The total diameter of the hanger is 4" and this diameter can be adjusted to the size of the cable using a zinc yellow-chromate plated steel hex nut.

The engineering drawings of these components are shown in Appendix B. A CAD model of the assembly is shown in section 2.2.4. This assembly figure illustrates the different components and the position within the assembly.

2.2.4 CAD Model of the Assembly

An assembly of the guide loop design with the components is illustrated in Figure 2.25.

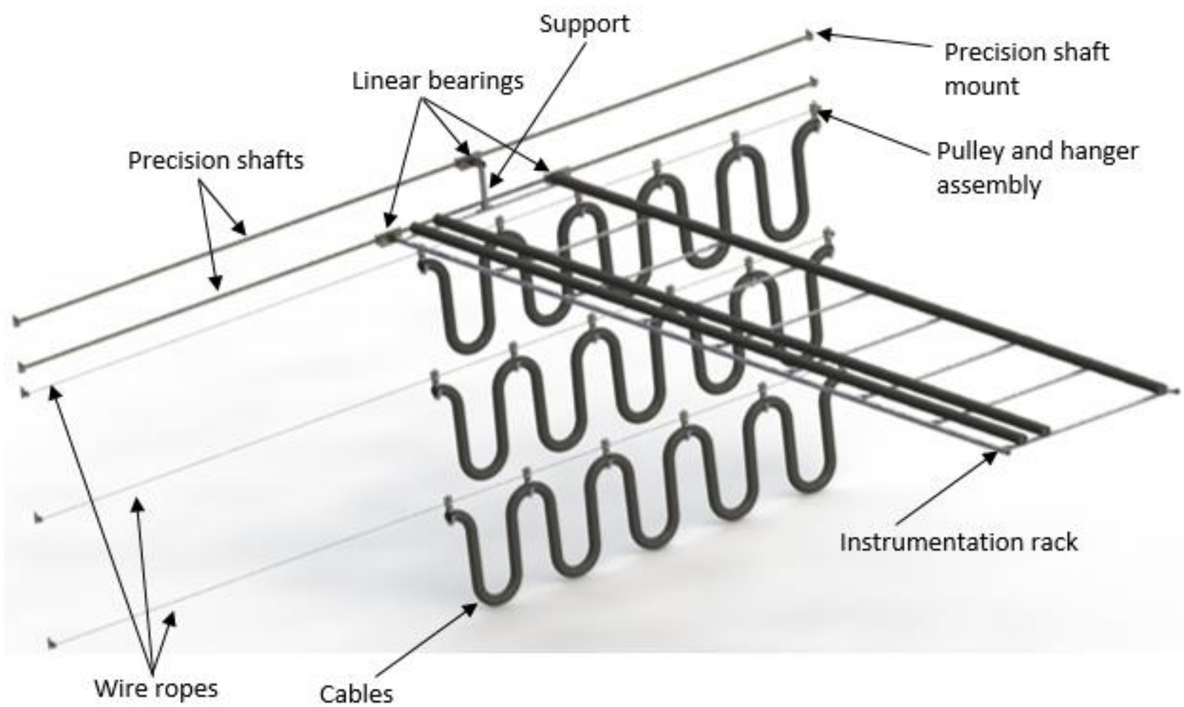


Figure 2.25: Guide loops assembly.

Figure 2.25 shows the use of three wire ropes to account for the number of instrumentation cables. These wire ropes are placed in parallel, vertically, with equal separation of 45". Instrumentation cables are routed to the instrumentation rack through six set of hangers in one wire rope which are fixed to the pulleys. These pulleys slide along the wire rope as the instrumentation rack slides. Moreover, two precision shafts are used in this design as seen in the figure. Linear bearings fitted to these shafts enable the movement of the instrumentation rack. A vertical support that connects the instrumentation rack to the upper shaft prevents the rack from rotation. With all these interacting components, the guide loops design is able to operate.

2.2.5 Overall Cost and Bill of Materials

The guide loops design components are sourced from McMaster-Carr except for the mount for the pulleys. This mount needs to be custom made and can be manufactured in-house. A cost approximation of the custom manufacturing of the mount and the costs of the components are shown in Table IV along with the quantity required. Moreover, the table also lists the part number for easy reference while purchasing the components.

TABLE IV: GUIDE LOOPS BOM

Item	Description	Raw Mat'l	Source/Part no.	Qty	Unit of Meas	Unit Price (USD)	Total Price (USD)
Instrumentation Rack Assembly	Hardened Precision Shafts with Machinable Ends	1566 steel	McMaster-Carr/1144K63	6	1-1/2" Diameter, 36" Length	$126.28	$757.68
	Quick-Access Base Mount Shaft Support	Aluminum	McMaster-Carr/1865K8	4	Length 4", Height 2 11/16", thickness 1 3/4"	$35.84	$143.36
	High-Capacity Pillow-Block Linear Bearing	Bearing Acetal, Housing 6061 Aluminum, Ball - Steel	McMaster-Carr9338T13	3	1-1/2" Shaft Diameter	$444.75	$1,334.25
	Friction-Grip Framing Fitting	Steel	McMaster-Carr/47045T66	4	3" length, 3" width, 4" height	$10.91	$43.64
	Heavy Duty Steel Bolt-Together Framing	Steel	McMaster-Carr/4931T13	5	1-1/2" Square Tube, 12 ft. length	$50.87	$254.35
	Bolt-Together Framing	Zinc-Plated Steel	McMaster-Carr/4664T18	7	8 ft. length, 1 1/2" × 1 1/2"	$16.32	$114.24
	Bulk head Connector	Aluminum housing	McMaster-Carr/6134T48 male, 6134T78 female	4	55 number of poles	$189.36	$757.44
	Aluminum Tee	Anodized Aluminum	McMaster-Carr/8809T63	18	4 1/2" length	$12.94	$232.92
						Subtotals:	$3,637.88

Item	Description	Raw Mat'l	Source/ Part no.	Qty	Unit of Meas	Unit Price ($) (USD)	Total Price (USD)
Loop Assembly	Heavy Duty Steel Pulley	Steel	McMaster-Carr/3434T119	18	For Rope Diameter 1/4"	$10.15	$182.70
	Clamping Hanger	304 stainless steel	McMaster-Carr/3006T7	18	4" I.D.	$8.35	$150.30
	Wire rope	ASTM A1023 Steel	McMaster-Carr/3440T56	1	100 ft. length	$133.00	$133.00
	Quick-Access Base Mount Shaft Support	Aluminum	McMaster-Carr/1865K1	6	Length 1-5/8", Height 7/8", Thickness 3/8"	$11.81	$70.86
						Subtotals:	$536.86
Bolts	High-Strength Grade 8 Steel Cap Screw	Steel	McMaster-Carr/92620A564	3	Thread size 1/4"-28, Head width 7/16"	$8.52	$25.56
	Zinc Yellow-Chromate Plated Steel Hex Nut	Steel	McMaster-Carr/94895A029	2	Grade 8, 1/4"-20 Thread Size, 7/16" Wide, 7/32" High	$3.31	$6.62
						Subtotals:	$32.18
	Laborer Type	**Number**	**Hourly Rate (USD)**	Days			**Total Rate (USD)**
Labor Cost	Electrician	1	90	3			$2,160
	Construction	3	90	6			$10,800
						Subtotals:	$12,960.00
	Type	**Number**	**Hourly Rate (USD)**	Days			**Total Rate (USD**
Manufacturing Cost of Pulley Mount	Machinist	1	90	5			$3,6000
	Material (Heavy duty steel alloy, Grade A514) from McMaster-Carr (3845T211)	6x18 (6" length, 8" width, 0,25" thickness, 0.8" shaft diameter)	35.68 each	--			$3,853.44
						Subtotals:	$7,453.44
						Totals:	**$24,620.36**

For this design, the current instrumentation rack at the site needs to be replaced by the new rack.

The racks can easily be bolted together which is achieved by the use of the bolt-together framing.

Considering the modification requirement and the need for an electrician to route the cable, a cost estimation is made assuming the labor rate is USD 90 per hour and the working day is eight hours long.

Furthermore, to manufacture the pulley mount, a machinist is employed. The labor rate of the machinist is assumed to be USD 90 per hour and it is estimated that it will take five days of eight working hours to manufacture the component. The design specifications for the pulley mount can be found in the engineering drawings of the guide loops design in Appendix B.

Also, the need to adjust the current cables to fit the bulk head connectors and route the cables through the design, an electrician is employed. The labor rate of an electrician is shown in Table IV and the rate also includes the required cable adjustment need. Overall, the rough order of magnitude (ROM) cost of the guide loops design is USD 25,000.

2.3 Sliding Extension Rail

The sliding extension rail concept consists of a track with sliding rails and pivot points along these sliding rails. The concept of this design is adapted from an existing server cable management system by Seagate [4]. In this design, the instrumentation cables moves along with the sliding rails when the wind tunnel moves to its required position. The arrangement of the extension rail is shown in Figure 2.26.

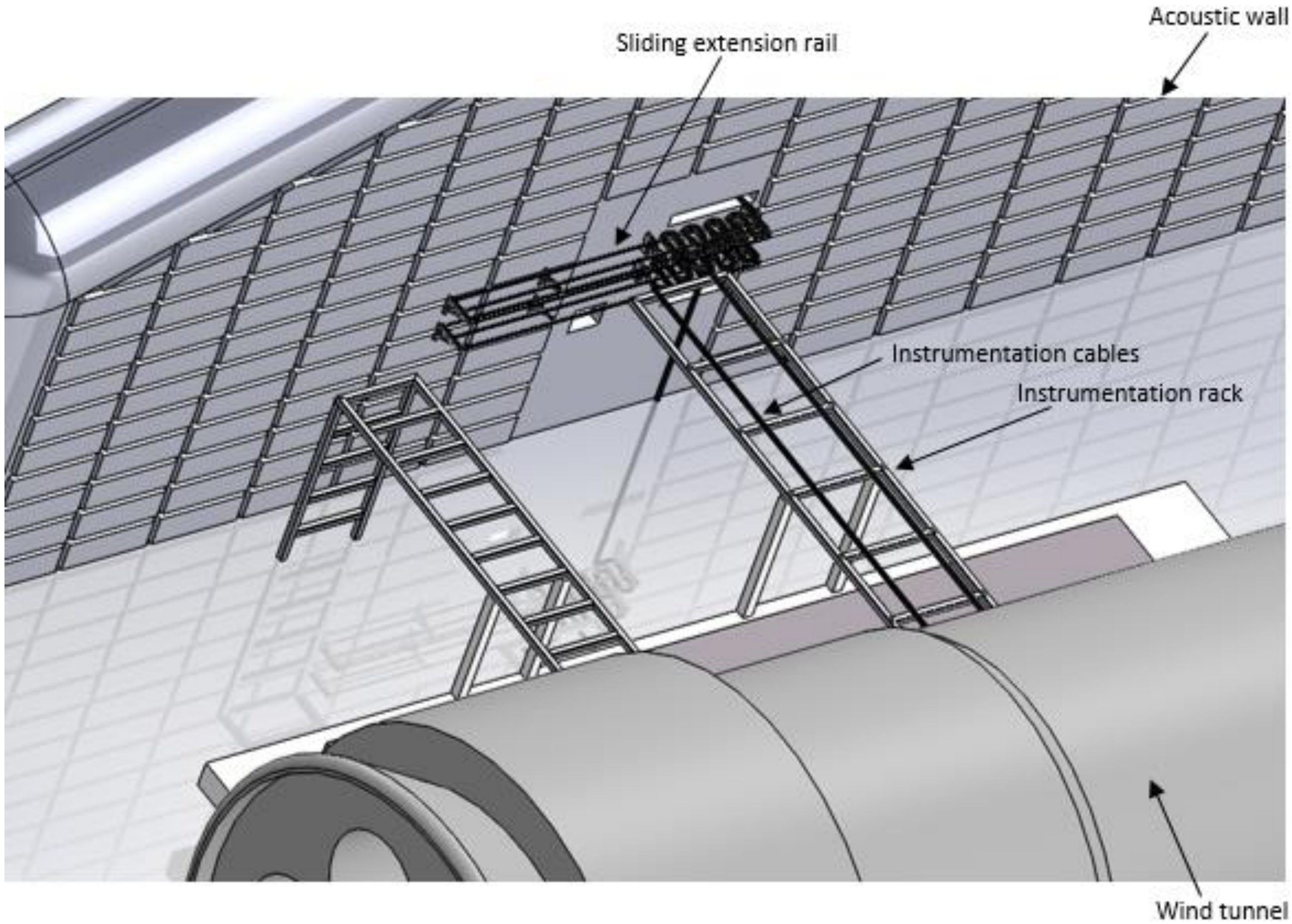


Figure 2.26: Sliding extension rail arrangement.

The design illustrated in Figure 2.26 allows for rapid changes in position of the wind tunnel of up to 13 ft. without the instrumentation cables being disconnected. This is achieved by the extension of the sliding rails along with the instrumentation cables to adjust to the change in the wind tunnel position. Therefore, this design meets the client's need of adjustment of up to 10 ft. without full disconnection. For the wind tunnel movement of more than 10 ft. and up to 20 ft., the instrumentation cables are disconnected at the instrumentation rack which allows for wind tunnel movement, reducing the time it takes to change over to a day. To contain multiple cables, two track assemblies are installed in parallel with a vertical separation height of 18" between the two track assemblies.

2.3.1 Design Features

The client's needs are fulfilled by the two features of the design:

i. Extension rail with sliding guide.

ii. Disconnecting feature of the instrumentation cables at the instrumentation rack.

The design features used to achieve the adjustment to the wind tunnel position is illustrated in Figure 2.27.

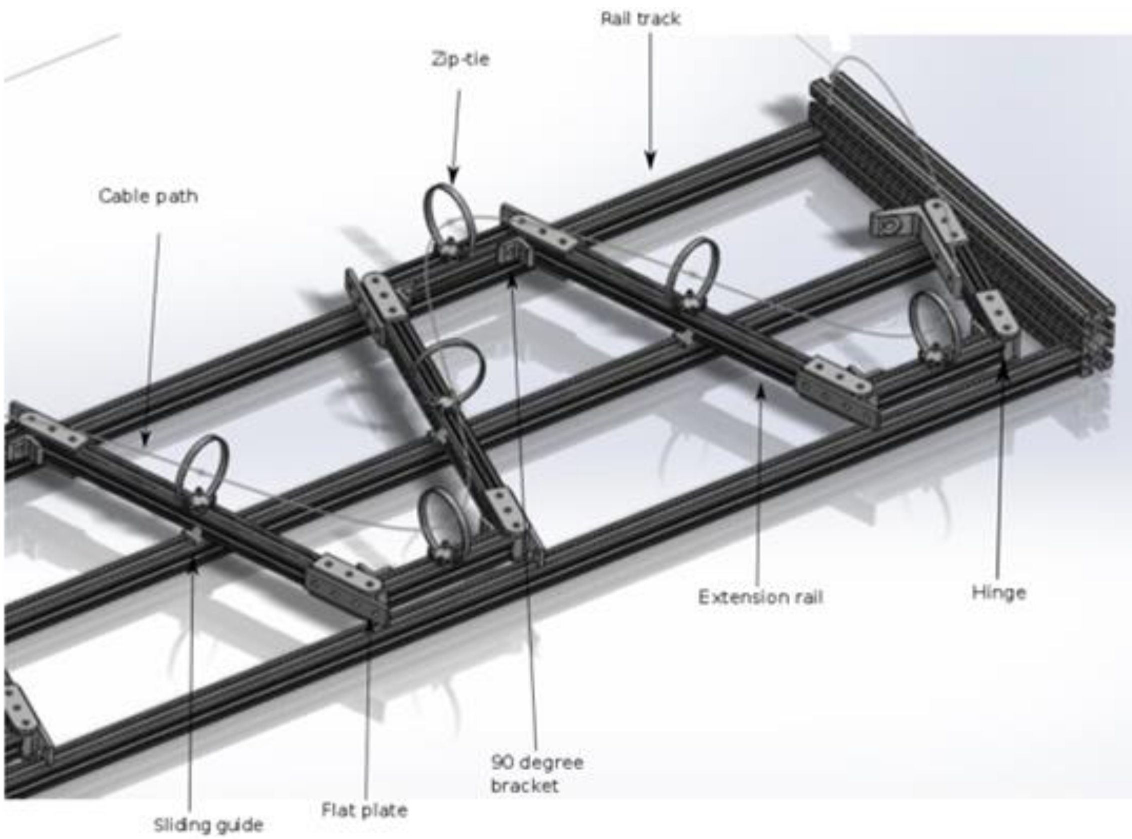


Figure 2.27: Design features of sliding extension rail.

As illustrated in Figure 2.27, the instrumentation cables are fitted through the zip-tie along the extension rail. The rail structures are connected to each other by hinges which allows the rail to extend by providing easy point of rotation in its horizontal plane. To prevent excessive rotation, a 90° bracket is bolted to the 9.25" rail and the flat plate is connected to the hinge. The zip-tie is fixed to the rails with the help of a clip. Moreover, three 15.75 ft. long rails provide tracks for the extension rail to slide. These three rail tracks are bolted to the two 18” long double rails. The close up of the 90° bracket, flat plate, and zip-tie position is illustrated in Figure 2.28.

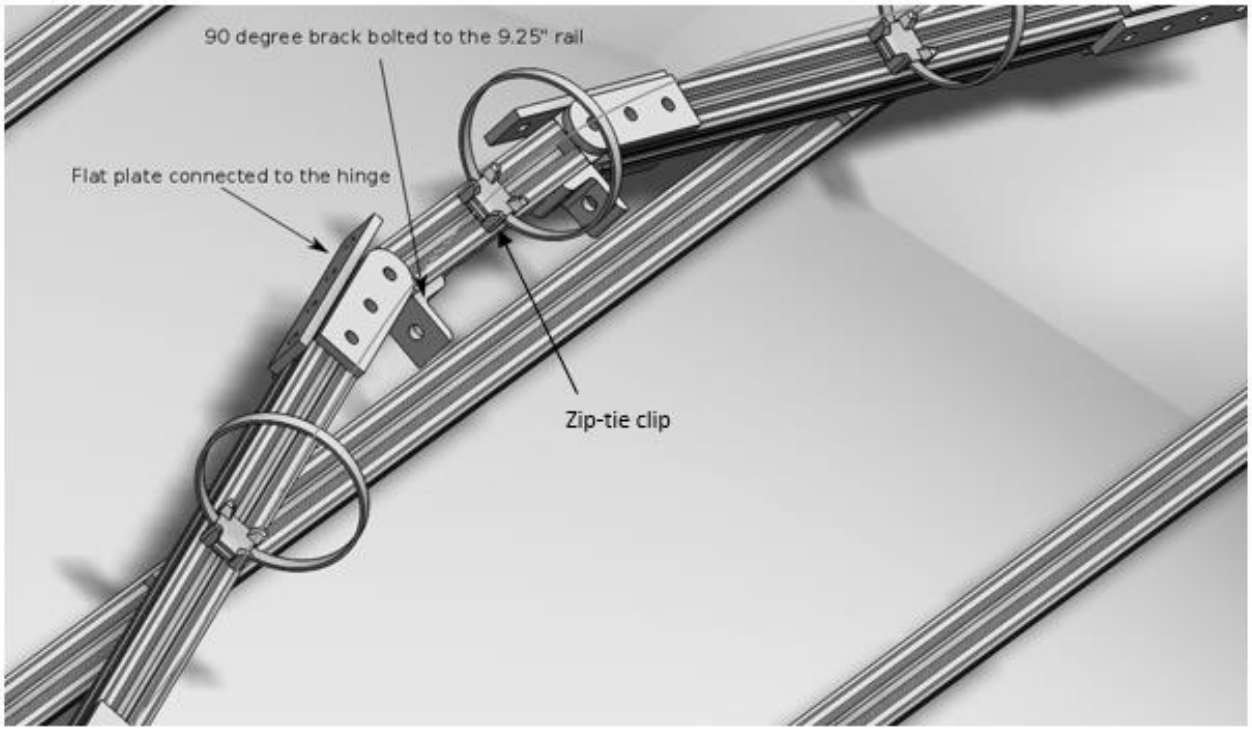


Figure 2.28: Flat plate, 90 degree bracket, and zip-tie position.

The key design components, their specifications, and their functions in the design are listed in Table V.

TABLE V: SLIDING EXTENSION RAIL KEY DESIGN COMPONENTS AND SPECIFICATIONS

Component	Extrusion Height	Extrusion Length	Function
Hinge	1"	3"	Provide connection between two rails, allow easy rotation of the rails
Flat Plate	1”	4”	Restrict the rotation of the joints to $180°$
90 Degree Bracket	1"	1”	Ensure the joints do not bend to less than$90°$
Zip-tie clip	1"	7/8”	Connect extension rail and the cable
Sliding Glide	1"	--	Provide smooth sliding of the rails through the tracks.
Extension Rail (T-slot Frame Single Profile Extrusions)	1”	9.25”	Extend to move along the wind tunnel
Extension Rail (T-slot Frame Single Profile Extrusions)	1”	15.25”	Extend to move along the wind tunnel
Rail Track (T-slot Frame Single Profile Extrusions)	1”	15.75 ft.	Provide a track for the extension rails, support the rail
Extension Rail (T-slot Frame Double Profile Extrusions) for rail and track connection)	$1\frac{1}{2}$”	18”	Connect vertical rails at the two ends

These components were used to build a model of the track and rail system as illustrated in Figure 2.29.

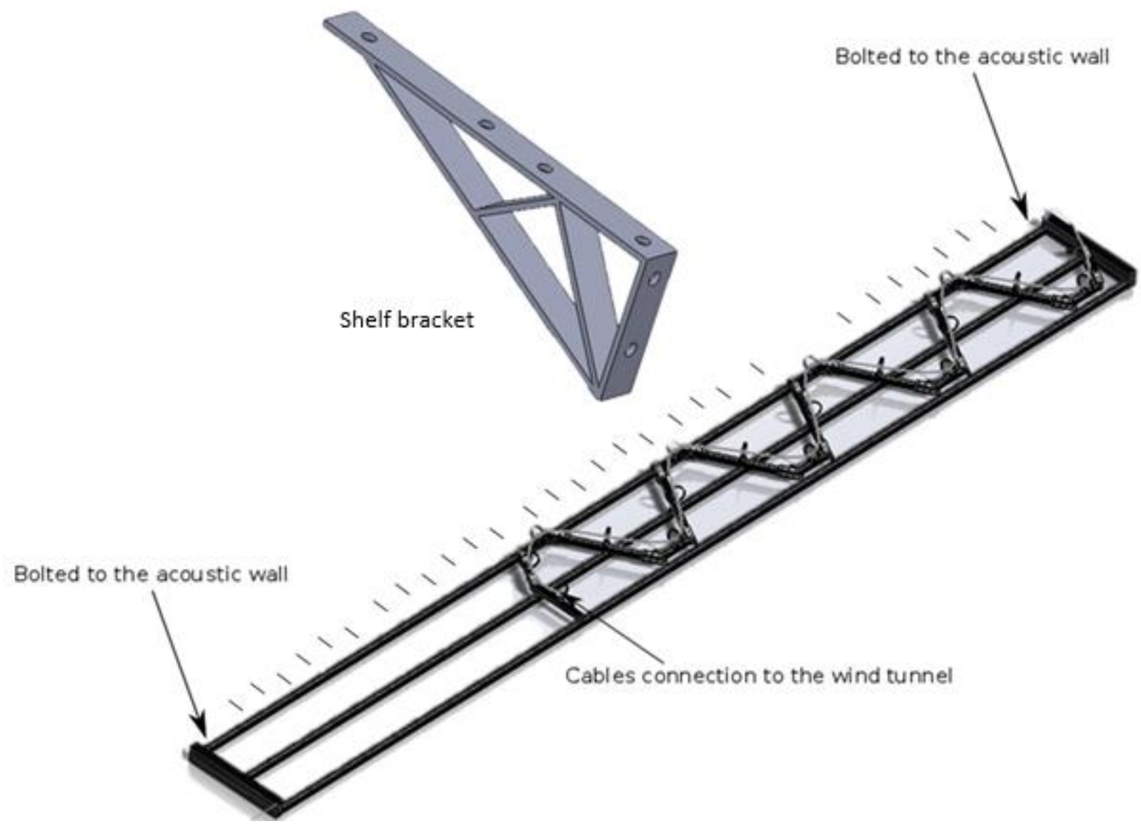


Figure 2.29: Full view of the key design feature.

The instrumentation cables connect to the instrumentation rack from the end of the last rail, and then to the wind tunnel as shown in Figure 2.29. This track and rail system is fixed to the acoustic wall in parallel. The instrumentation rack slides in the track along with the movement of the extension rail due to the movement of the wind tunnel.

2.3.2 Design Operation

The movement of the sliding extension rail design is possible due to the movement of the wind tunnel. The cables that come from the control room are routed through the zip-ties in the extension rail and up to the instrumentation rack from where the cables connect to the wind tunnel. At the instrumentation rack, the two pieces of cable can be easily connected and disconnected with the use of the bulk head connectors. The setup of the design with the wind tunnel is shown in Figure 2.26.

The position of the sliding extension rail during its compressed state is shown in Figure 2.30. This position is termed as position 1 for the reference.

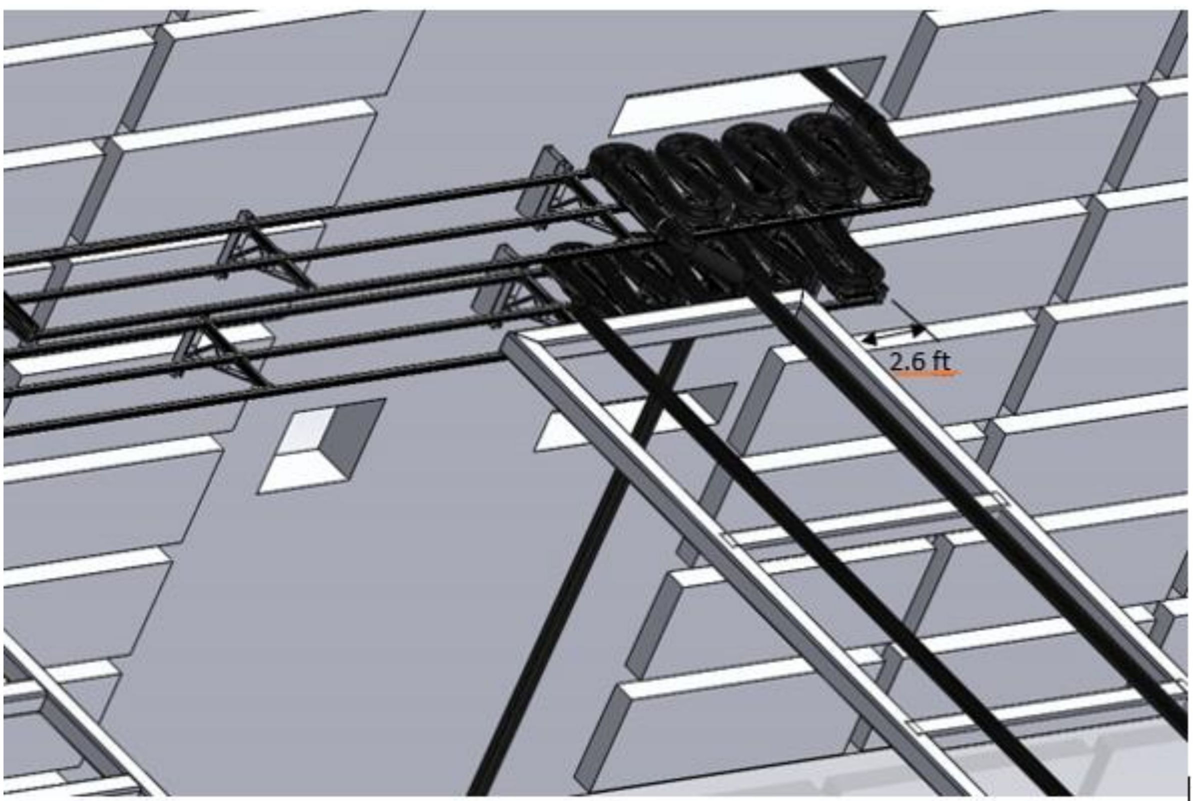


Figure 2.30: Sliding extension rail position 1.

Figure 2.30 shows that the instrumentation rack is 2.6 ft. from the end of the sliding extension rack. At this position, the wind tunnel is at its stationary reference position. As the wind tunnel moves, the cables routed through the zip-tie enables the extension rails to expand and moves the instrumentation rack. To show the movement of the extension rail, a reference position 2 is illustrated in Figure 2.31.

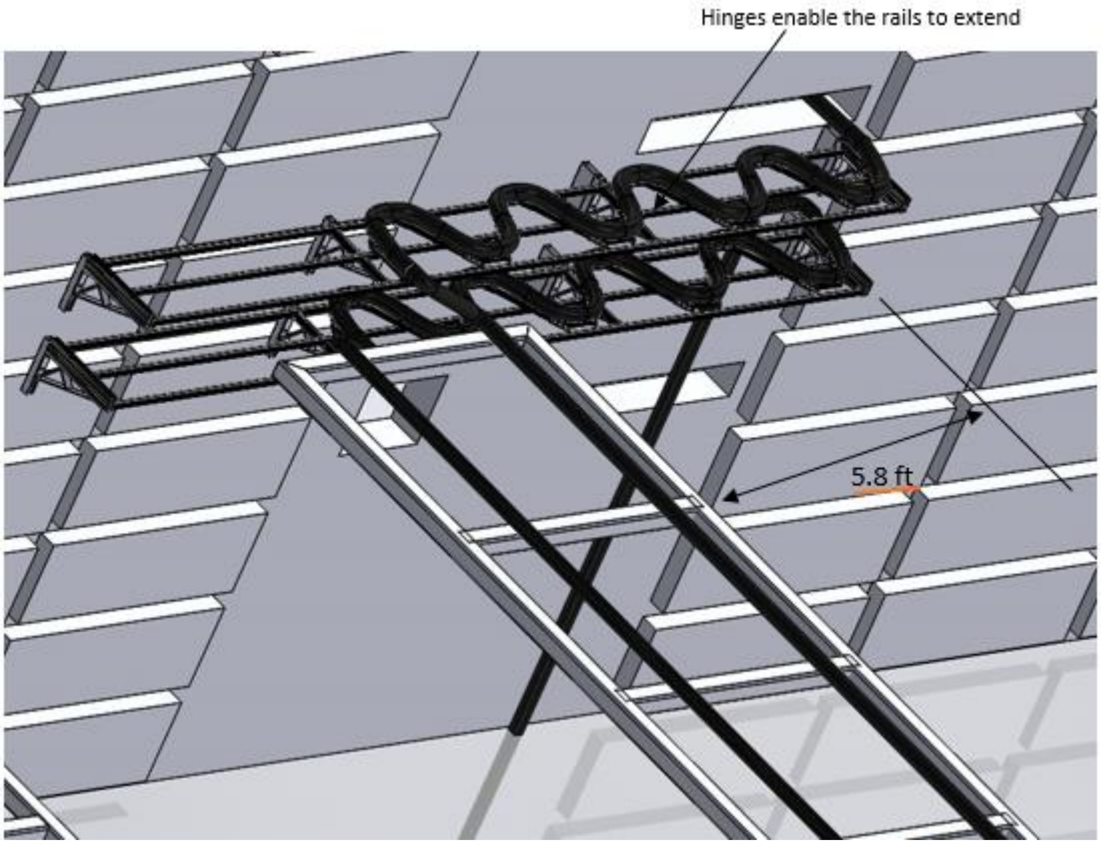


Figure 2.31: Sliding extension rail position 2.

At this position 2, the instrumentation rack moved 3.2 ft. from its initial position. At this position, the hinges are extended allowing for the extension of the rail. The 90 degree bracket present in the rail prevents the rail from bending to less than 90 degrees while the flat plate prevents the rail from bending to more than 180 degrees. The sliding glide enables the smooth movement of the rail. Moreover, to analyze the total length of movement a reference position 3 is shown in Figure 2.32.

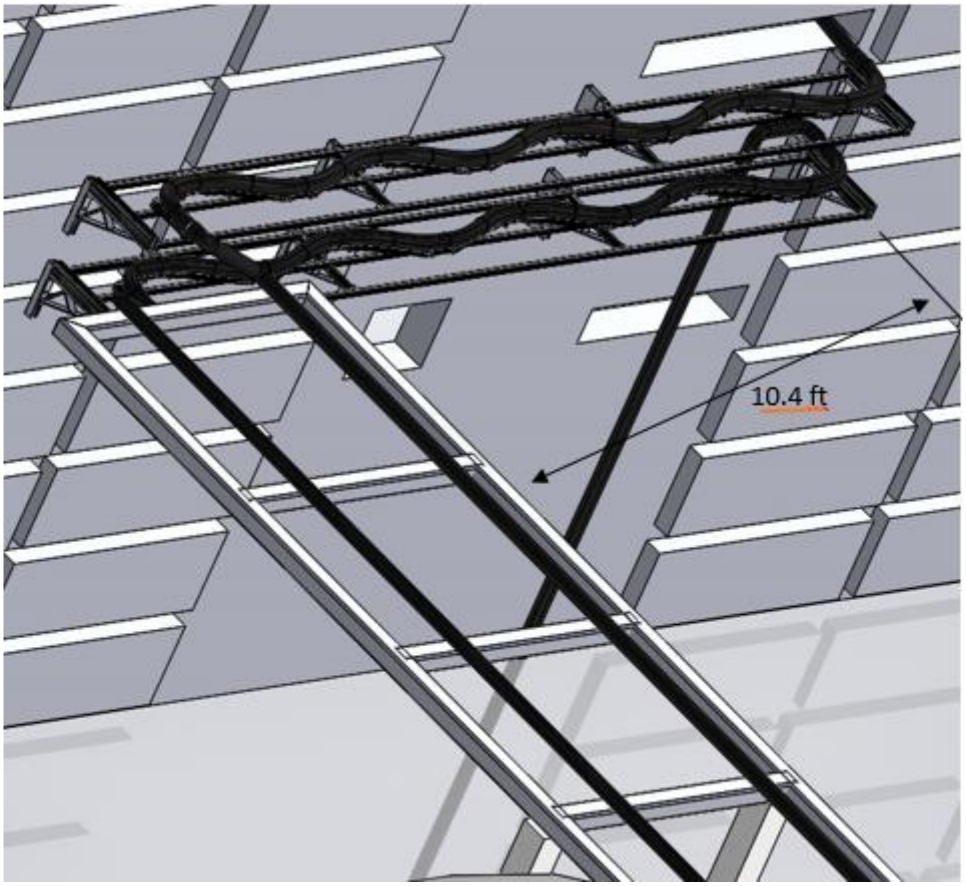


Figure 2.32: Sliding extension rail position 3.

The position 3 illustrates the maximum distance the rails can move, which is 10.4 ft. Therefore, this design meets the client's need that the wind tunnel allows for small movement of wind tunnel position of up to 10 ft. To provide easy disconnection feature for the eventual need of disconnection of the instrumentation cables for the movement of up to 20 ft., the cables at the instrumentation rack are connected by bulk head connectors as seen in Figure 2.33 .

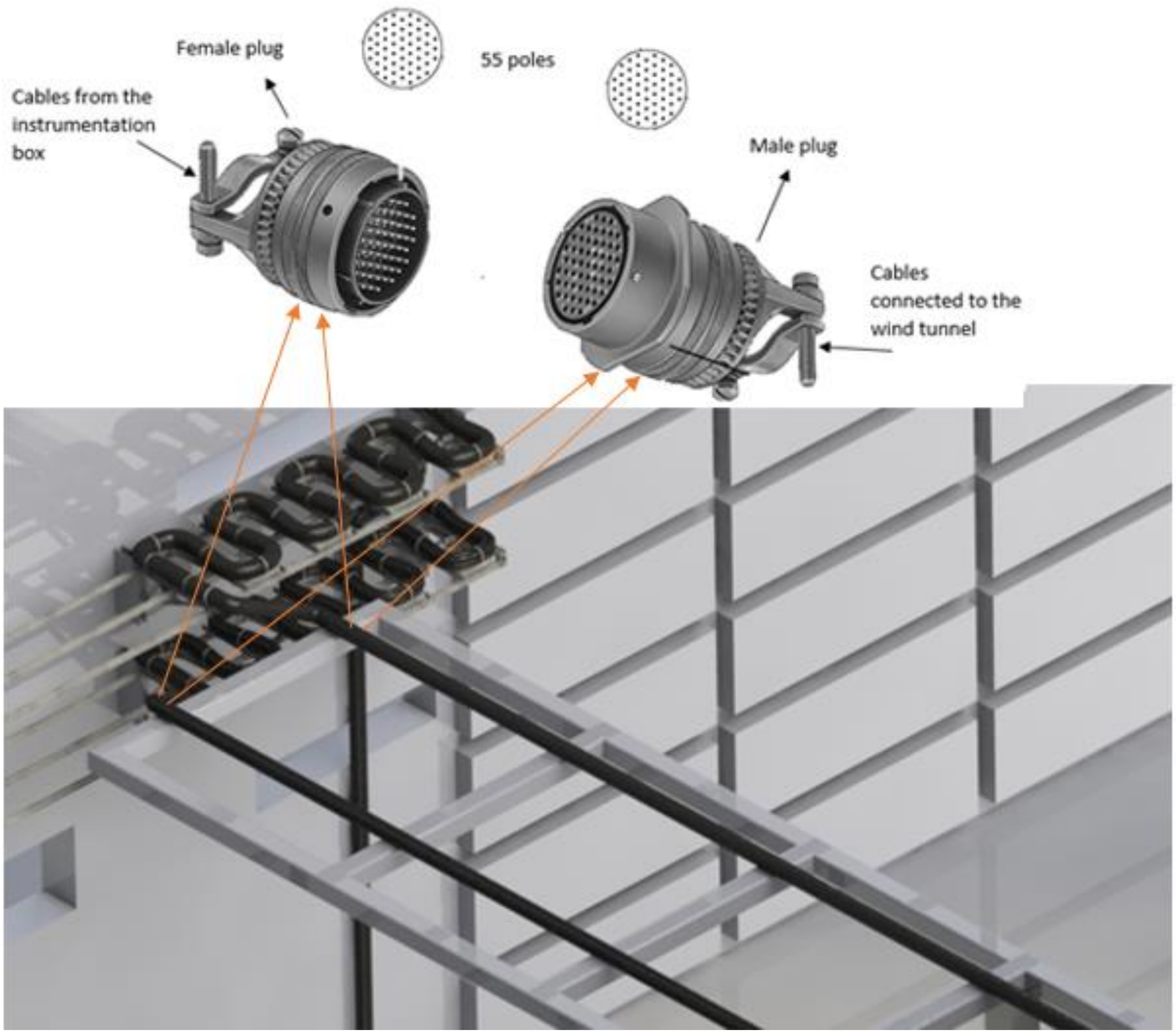


Figure 2.33: Bulk head connection at the instrumentation rack.

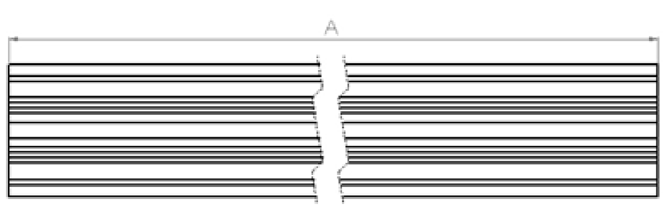
Figure 2.33 shows the use of bulk head connectors at the instrumentation rack. The female plug with the cables from the acoustic wall side is connected to the male plug with the cables to the wind tunnel. With these two features, the changeover time between two testing is reduced to a day as the instrumentation cables can be easily disconnected at the instrumentation rack and the small length of the cable connected to the wind tunnel can be easily managed in about an hour. Moreover, these bulk head connectors can be fitted to the cables by cutting the cables at the rack. This fitting process requires an electrician. The electrician's labor cost is estimated in Table VI.

2.3.3 CAD Model of the Major Components

There are different interacting components that make the sliding rail extension design functional. However, CAD model of the important components that ensure the design's operation are illustrated in this section.

Figure 2.34: 1" T-slotted framing, single extrusion.

One of the key components of the design is the sliding rails that enable the design to adjust to the wind tunnel position. The 1" T-slotted framing, as illustrated in Figure 2.34, is used to create the rails and the rail track for this design. The framing has the extrusion height and the extrusion width of 1". Moreover, this framing profile is used in different lengths which is shown in the table in Figure 2.35



ITEM NO.	A
Longitudinal Rail	189.00
Cross-Brace Rail	7.50
Starter Member	7.00
Short Member	6.00
Long Member	15.25
End Member	9.25

Figure 2.35: Usage of 1" single extrusion T-slotted framing in inches.

Figure 2.35 illustrates different lengths of the t-slotted framing used. From the figure we can see that the total length of the rail formed by the longitudinal rail is 15.75 ft. The illustration of how these lengths make the rail is shown in Figure 2.36.

Figure 2.36: Different members of the track and rail system.

Figure 2.36 shows the different lengths used in the track and rail system. The pieces of rails are connected to each other with a hinge which provides easy bending of the rail components. The CAD model of the hinge is shown in Figure 2.37.

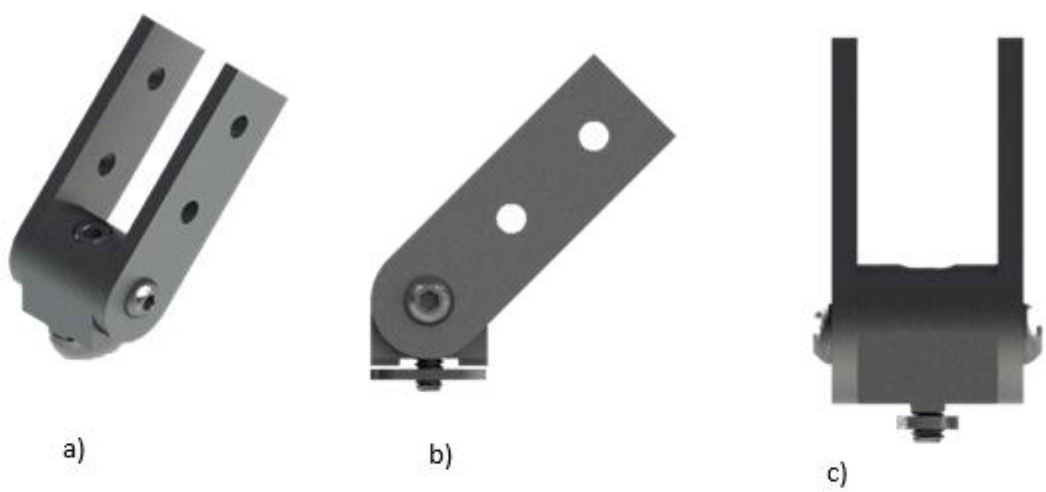


Figure 2.37: Pivot joint: a) isometric view, b) right plane view, c) front view.

Figure 2.37 shows three different views of the hinge. These views are isometric view, right plane view, and the front view. The hinge model shown in Figure 2.37 has a thickness of the hinge is 0.19” and the length of the hinge is 3”. The radius profile of 0.26” represents the hole for the bolts to connect the hinge to the t-slotted framing. The width of the hinge is matched to the extrusion profile of the t-slotted framing so that the frames can fit in the hinge. However, these hinges do not restrict the bending of the rails. The rail can bend more than 90 degrees or more than 180 degrees which is not a desired bending as it creates tension in the cable. Therefore, to prevent the rail from bending to less than 90 degrees a 90 degree bracket is used. This bracket is shown in Figure 2.38.

a) b)

Figure 2.38: 90 degree bracket: a) Isometric view, b) front view.

Figure 2.38 shows two different views of the 90 degree bracket which are the isometric view and the front view. This bracket has an extrusion height and width of 1” and is connected to only one member of the rail. This bracket ensures that the rail do not bend to less than 90 degrees during the extension of the rail. Moreover, to ensure that the rail do not bend to more than 180 degrees, a flat bracket is used. The CAD model of this bracket is shown in Figure 2.39.

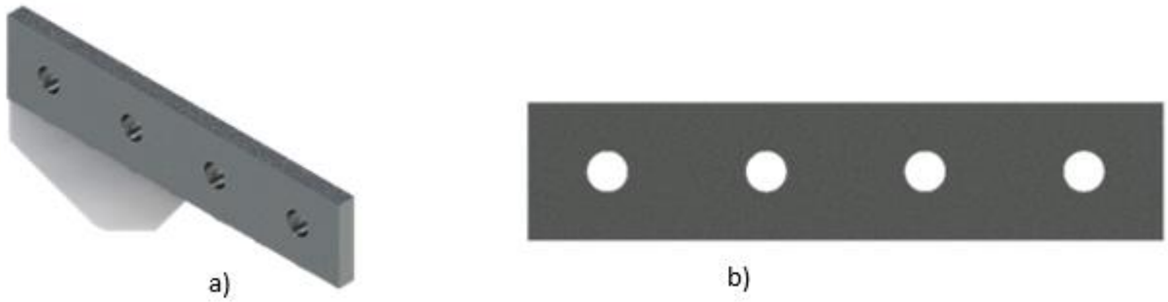


Figure 2.39: Flat bracket: a) isometric view, b) front view.

Figure 2.39 shows two view: isometric view and the front plane view of the flat bracket. This flat bracket has a total length of 4” and a thickness of 0.19”. After the rail is setup, a plastic sliding guide is used to enable the rail to slide smoothly. This sliding guide is fixed to the rail but it slides along the longitudinal rail track. The CAD model of the sliding guide is shown in Figure 2.40.

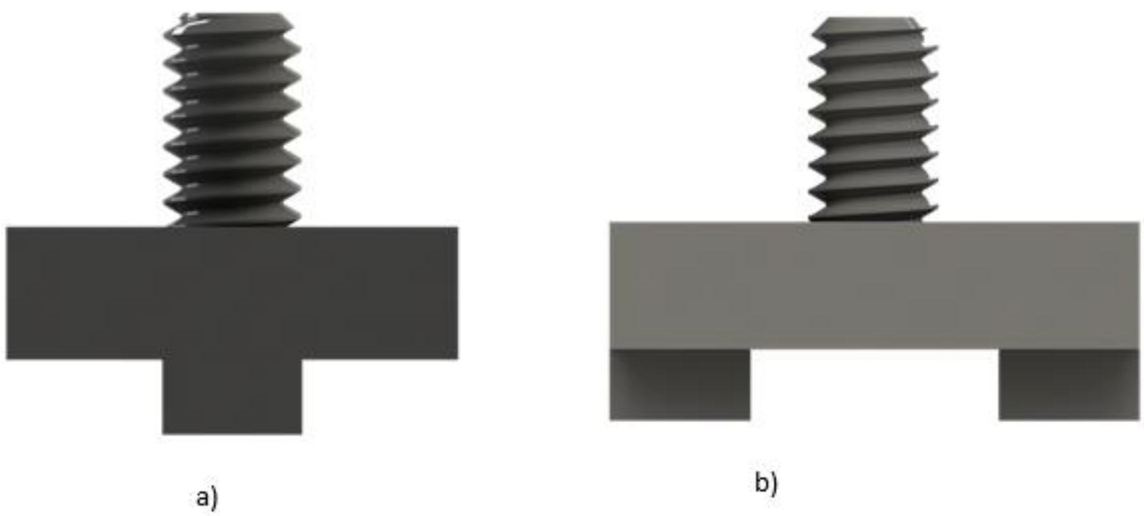


Figure 2.40: Plastic sliding guide: a) front plane view, b) right plane view.

Figure 2.40 illustrates two different views: the front plane view and the right plane view, of the sliding glide design. The sliding glide shown in the figure has a ¼”-20 thread profile. This profile connects the guide with the rail. All these components connect together with bolts to form an assembly. A CAD model of the assembly is shown in section 2.3.4.

2.3.4 CAD Model of the Assembly

An assembly of the sliding extension rail design is illustrated in Figure 2.41. This assembly consists of the rail and the track with their interacting components.

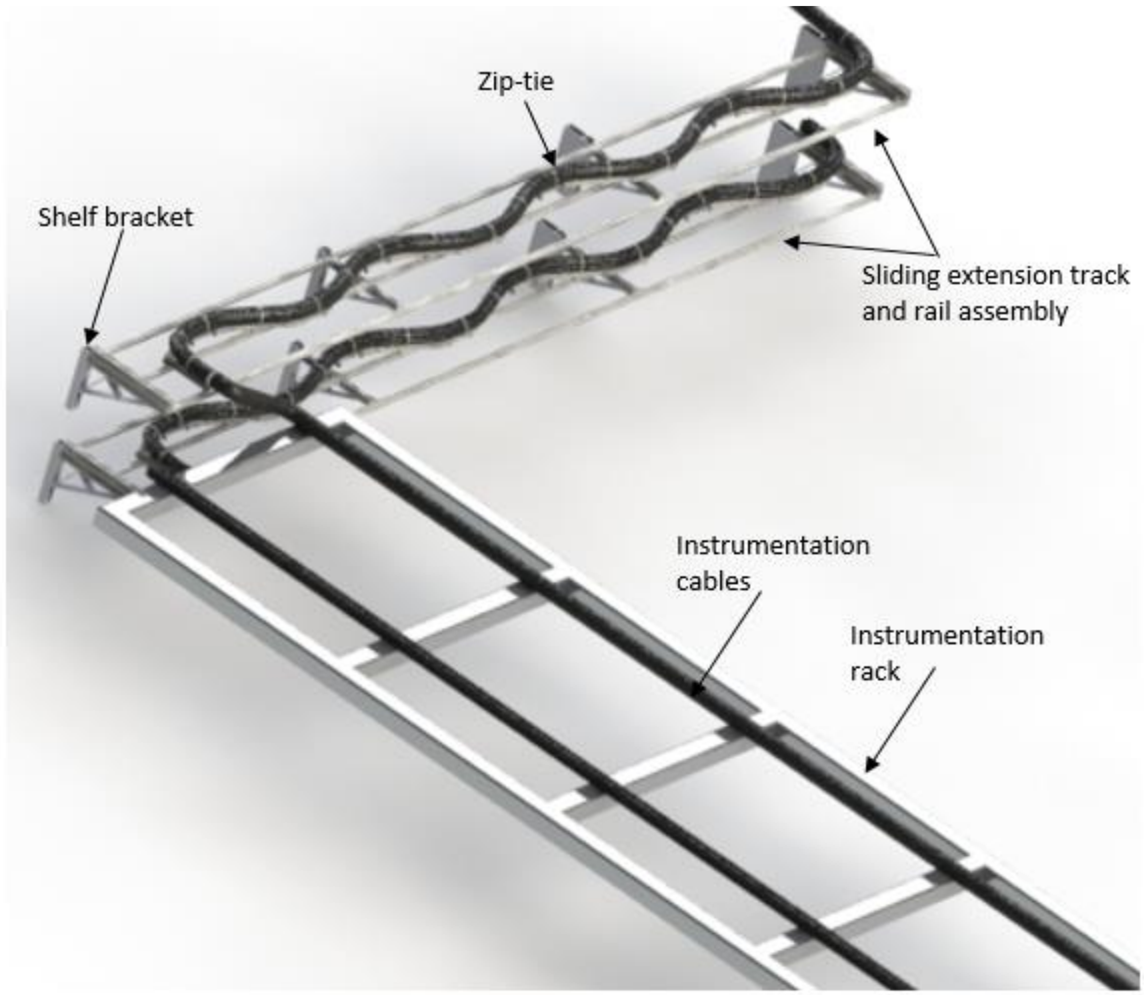


Figure 2.41: Sliding extension rail design rail and track assembly.

Figure 2.41 shows a general assembly of the design. The rail and track system as seen in the figure consists of the components such as different lengths of the T-slotted framing, zip-ties for the cables, the zip-tie holders, sliding guides, hinges and mounts that connect the rail-track system to the acoustic wall and the instrumentation rack. The engineering drawings of the design components can be found in Appendix B.

2.3.5 Overall Cost and Bill of Materials

The sliding extension rail design components are sourced from McMaster-Carr online. The costs of the components are shown in Table VI along with the quantity required. Moreover, the table also lists the part number for easy reference while purchasing the components.

TABLE VI: SLIDING EXTENSION RAIL BOM

Item	Description	Raw Mat'l	Source/ Part No.	Qty	Unit of Meas	Unit Price (USD)	Total Price (USD)
Sliding Rail	Hinge	Aluminum	McMaster-Carr/47065T191	17	1" height, 3" length	$16.33	$277.61
	Flat Plate	Aluminum	McMaster-Carr/47065T259	17	1" height, 4" length, 0.257" diameter, 1" holes separation	$6.74	$114.58
	Zip-tie	Nylon	McMaster-Carr/7177K44	4	0.50" width, 0.0" thickness, 15" length	$4.22	$16.88
	Zip-tie clip	Nylon	McMaster-Carr/47065T268	16	1" height	$0.72	$11.52
	90 Degree Bracket	Aluminum	McMaster-Carr	16	1" height, 1" length, 0.281" diameter	$5.79	$92.64
	Plastic Sliding Glide	UHMW	McMaster-Carr/47065T3	18	1" length, 1/4"-20 thread	$2.89	$52.02
	Floor-Mounting Bracket	Aluminum	McMaster-Carr/47065T841	1	1" height, 3/8" mounting hole diameter, 5" length	$12.00	$12.00
	T-slot Frame (Single Profile Extrusions)	Aluminum	McMaster-Carr/47065T101	2	Extrusion Size 1" sq., T-Slot Width 0.255", length 10 ft.	$31.59	$63.18
						Subtotals:	$640.43
Track	T-slot Frame (Single Profile Extrusions)	Aluminum	McMaster-Carr/47065T101	5	Extrusion Size 1" sq., T-Slot Width 0.255", length 10 ft.	$31.59	$157.95
	T-slot Frame (Double Profile Extrusions)	Aluminum	McMaster-Carr	1	Extrusion Size: width 1.5", height 3", T-Slot Width 0.32", length 4 ft.	$50.25	$50.25
	Shelf Bracket	Zinc-plated steel	McMaster-Carr/3200T91	4	16.5" length, 6" height 0.25" thickness	$15.90	$63.60
	Bulk head Connector	Aluminum housing	McMaster-Carr/6134T48 male, 6134T78 female	4	55 number of poles	$189.36	$757.44
						Subtotals:	$1,029.24

	Type	Number	Hourly Rate (USD)	Days			Total Rate (USD)
Labor Type	Electrician	1	90	3			$2,160.00
	Construction	3	90	6			$12,960.00
						Subtotals:	$15,120.00
						Totals:	$16,789.67

These components have the ability to withstand the -40℃ climate condition and can withstand the high load. Moreover, this design requires a modification to the current instrumentation rack height at the site. The rack height must be lowered by 1 ft. in order to connect to the cables from the extension rail. Considering the modification requirement and the need for an electrician to route the cable, a cost estimation is made assuming the labor rate is USD 90 per hour. Overall, the rough order of magnitude (ROM) cost of the sliding extension rail design is USD 16,800.

2.4 Cost Summary

From the cost analysis of the three designs, we can conclude that the sliding extension rail design is the most cost effective design with ROM cost of USD 16,800 and the guide loops is the most expensive design with the ROM cost of USD 25,000 due to the requirement to custom build the mount for the pulley. The overall cost approximation for the cable drag chain design is USD 19,000. As the cost is not a constraint, the ultimate decision is to be made by the client considering their selection criteria. In order to assist in this selection, a risk assessment is performed on the three designs and a summary is described in Section 3 of this report.

3. Risk Assessment Summary

To identify potential hazards and to analyze its effect, the team conducted FMEA for the three designs. A detailed analysis can be found in Appendix C of this report.

From the FMEA analysis, we can conclude that since the sliding extension rail design has many components interacting together, this design has higher chances of failure than the other two designs. Moreover, the connecting points between two interacting components have higher modes of failure. As the components interact together to create the entire system, it is crucial to ensure that these connections are securely held.

All of these three designs use bolts to connect the interacting components. Therefore, before using a design these connections must be inspected and ensured that they are tightly fit. Although the method can be costly, other option for connecting the components is to weld the two components together. An example is that the parts of the instrumentation rack for the guide loops design can be bolted together rather than fitting the parts together with bolts.

4. Conclusion

In this project, three different designs were developed to solve the client's problem of managing the instrumentation cables during the wind tunnel movement. Two operation scenarios were presented to the team which are: a) the designs must adjust to the small movement of the wind tunnel of up to 10 ft. without full disconnection of the instrumentation cables and b) the designs should provide easy connection and disconnection of the instrumentation cables during the wind tunnel movement of up to 20 ft. Based on these requirements, the three designs developed are the cable drag chain design, the guide loops design, and the sliding extension rail design.

The cable drag chain design uses cable drag chain supported by a supporting rack as the key design feature. This design utilizes two drag chains: one for the instrumentation signal cables and the other for the instrumentation power cables. This design meets the client's need of small movement with a total chain range of motion of 10 ft. with 5 ft. of motion in each direction of the wind tunnel movement.

The guide loops design uses pulleys and hangers supported by a wire rope as the key design features. The design consists of three wire ropes, with six pulleys in each of the ropes. Moreover, this design consists of linear bearings to provide movement of the instrumentation rack. This design has the total range of motion of 20 ft. and therefore, meets the client's requirement of 10 ft. movement.

The sliding extension rail uses extension rails and a track as the key design feature. Two track and rail assemblies are used in this design, where the rails can slide with the help of the sliding guides. This design meets the client's need of small movement of up to 10 ft. by extending and compressing the cables as the wind tunnel moves, with a total range of motion of 10.4 ft.

The three designs also meet 20 ft. movement requirement. The cables from the instrumentation box can be connected with the cables connected to the wind tunnel at the instrumentation rack by fitting electrical bulkhead connectors to the cables at the instrumentation rack. This operation requires an electrician. These connectors enable the cables going through the acoustic wall to remain in place; there is no need for pulling them through to the other side. In doing this, the amount of time it takes to move the wind tunnel for large moves of up to 20 ft. is reduced from three working days to one working day.

According to the cost analysis, the sliding cable drag chain design is the cheapest design with ROM cost of USD 16,800 and the guide loop is the most expensive design with the ROM cost of USD 25,000. The overall cost approximation for the cable drag chain design is USD 19,000. As the cost is not a constraint, the ultimate decision is to be made by the client considering their selection criteria.

A risk assessment, in the form of an FMEA was conducted to assist in the final selection between the three designs. From this analysis, we conclude that since the sliding extension rail design has many components interacting together, this design has higher chances of failure than the other designs. Moreover, the connecting points between two interacting components have higher modes of failure. As the components interact together to create the entire system, it is crucial to ensure that these connections are securely held.

Overall, among the three designs the cable drag chain design is the most suitable design based on the client's needs. This is due to the fact that the drag chains are durable, expandable, and can operate well in the -40°C to 40°C weather conditions. Moreover, only the drag chain design had a positive scoring during concept screening process and was ranked the highest during the concept scoring process.

5. References

[1] R. Baillie and K. P. Owusu, Interviewees, *GE RDTC Site Tour.* (Interview), September 25, 2015.

[2] WestCaRD. *WestCaRD (West Canitest R&D Inc.)* [Online]. Available: http://www.westcard.ca/. [September 30, 2015].

[3] McMaster-Carr. *Snap-Together Cable and Hose Carrier* [Online]. Available: http://www.mcmaster.com/#4617t65/=zzv9om. [November 27, 2015].

[4] Seagate. (2015). *Seagate 8-Bay Rackmount NAS User Manual* [Online]. Available: http://www.seagate.com/ca/en/manuals/network-storage/8-bay-rackmount/setting-up/. [October 28, 2015].

Appendix A Concept Generation and Selection

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A. Concept Generation

For the project, concepts were generated based on the customer needs and the target specifications. In order to generate the concepts, the team went through a concept generation procedure which is described in this section along with the concepts that were generated.

A.1. Concept Generation Method

The team used the brainstorming method as the concept generation technique. During the concept generation process, **Error! Reference source not found.** was referenced, which essentially describes that the concepts are based on the customer needs and the target specifications.

Figure 1: Concept generation process [1].

The initial step of the concept generation was understanding the problem of the project which was completed in the project definition phase of the project. After the problem decomposition, the team searched externally for design concepts that allows for easy movement of instruments. This was achieved individually by searching through the internet and was aimed at finding any existing solutions to the problem.

The external search, mostly through online searches for ideas, led to internal searches which was accomplished through brainstorming. An individual brainstorming session was done preliminarily where each team members thought of any concepts they could generate, and sketched those concepts. Sketches of the concepts were useful in clarifying the ideas for other team members. The concepts generated through brainstorming were screened as a team, using go/no-go screening method. During this method, evaluation was made by comparing each alternative concept with the customer requirements. Concepts with more no-go responses were eliminated, while the concepts with few no-go responses were not eliminated.

The concept generation approach followed by the team is summarized in Figure 2.

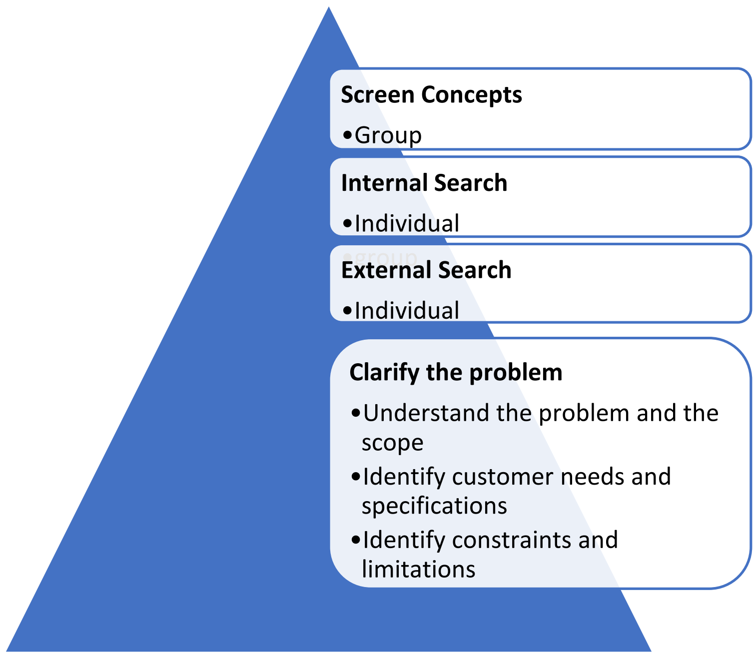

Figure 2: Concept Generation Pyramid.

Seven concepts were selected at the end of this process and the concept screening method was then used to screen these concepts.

A.2. Concepts

The concepts that were selected during the brainstorming phase are illustrated in this section. There are a total of 7 concepts and each concept is described in this section, under its own sub-section. The description of the concepts includes how the concepts were generated, how they can be used as an interface system, and their advantages and disadvantages.

A.2.1. Cable Drag Chain Design Concept

A cable drag chain is a set of large linkages connected in a chain that allows for the containment and protection of sensitive cabling. An example of which is shown in Figure 3.

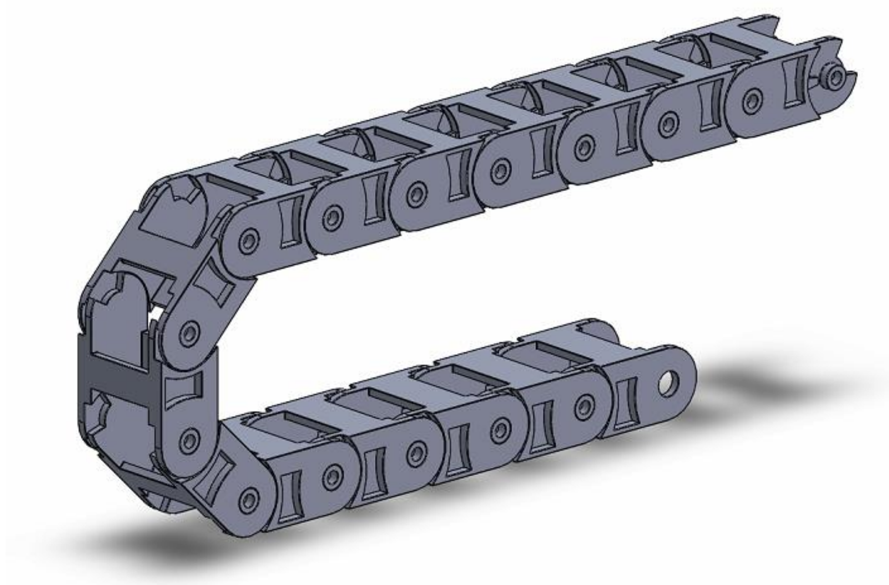

Figure 3: Cable drag chain example, CFD model.

Using a cable drag chain alongside a supporting mechanism will allow for the secure retention of the instrumentation cabling.

A.2.2. Scissor Arm

For this conceptual design, the inspiration of the interface system is from the scissor arm awnings. The scissor arm awnings is shown in Figure 4.

Figure 4: The scissor arm awning [2].

The figure illustrates the two main functions of the scissor arm. At first, this structure has a certain load capacity. As shown in Figure 4, the scissor arm structure is able to support the weight of the entire light and the weight of the wires running through the scissor arm structure. Therefore, this scissor arm structure when used in the interface system, can support the weight of any cables and connectors at the end without failing.

A.2.3. Telescoping Rack System

Telescoping is described as the movement of one part sliding out from another, lengthening the object from its rest state. Telescoping concept for the cable rack, for this project, arose from the same concept as a telescope, which was further expanded to a telescoping ladder as shown in Figure 5.

Figure 5: Telescoping ladder [3]

Figure 6 illustrates the telescoping rack concept for this project as a result of the concept generation phase.

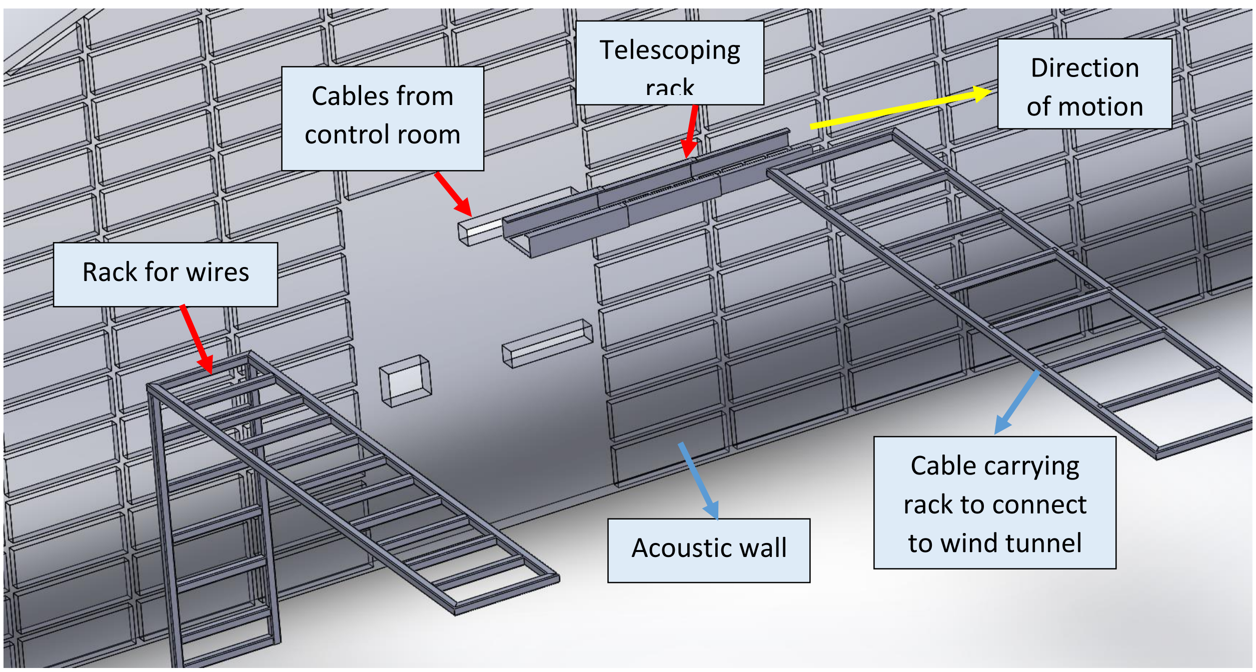

Figure 6: Telescoping rack system, CAD model.

As seen in Figure 6, a rack carrying cables is attached to the telescoping rack. The rack carrying cables has linear bearings to slide throughout the length of the telescoping rack. As in a telescope, this rack has parts with offset dimensions so that one part can slide into the other part. The telescoping rack parts are also fitted with linear springs to facilitate sliding of one part out form another. The cables run through the acoustic wall to the telescoping rack, and then to the cable carrying rack from which the cables are connected to the wind tunnel.

A.2.4. Guide Loops

The concept of guide loops is one of the simplest methods that the team came up with, to take up the slack in the wires and cables for this project. It consists of either a structural cable or a rail with several pulleys and supporting loops as seen in Figure 7 and Figure 8. These guide loops would allow for movement of the wind tunnel, as extra cable length would be contained in the guide loops and could extend to the required position.

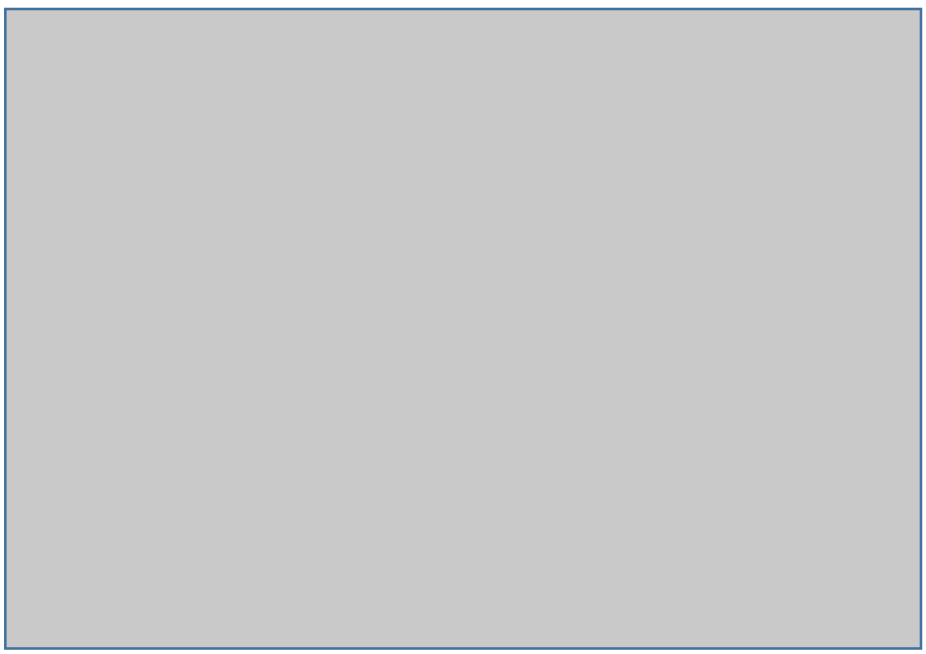

Figure 7: An example of how the loops would contain and support long lengths of cables [4].

As seen in Figure 7, the cables pass through these guided loops. A rough CAD model illustrating how these loops would be used as an interface system is shown in Figure 8.

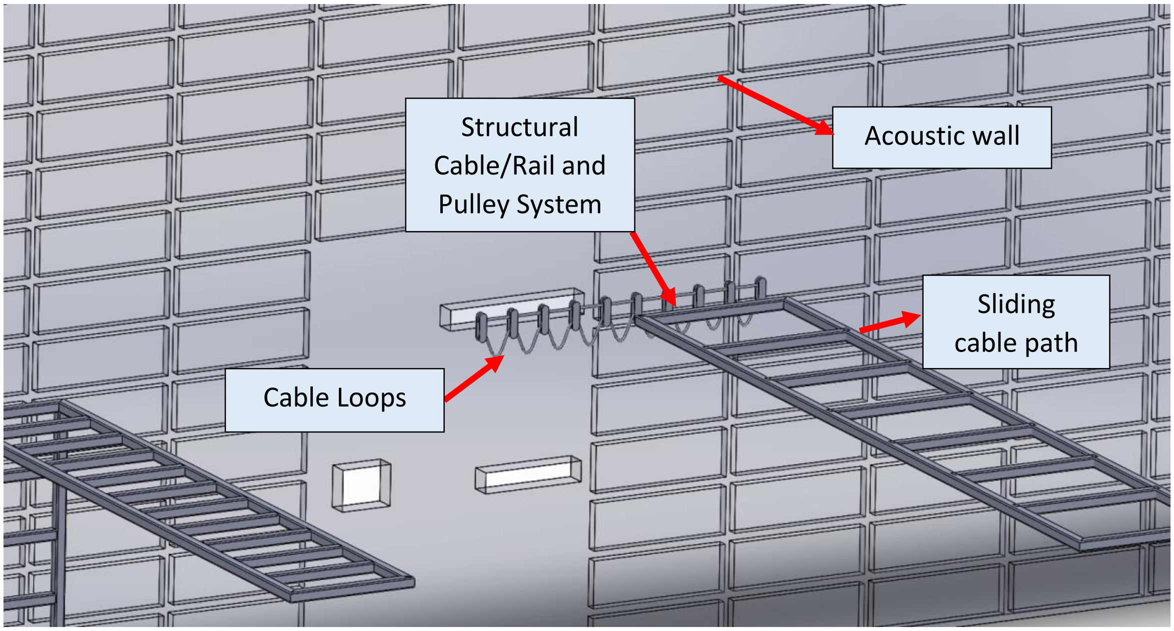

Figure 8: An example of how the guide loop would be implemented for the wind tunnel interface.

A.2.5. Retractable Reels

The retractable reels concept was derived from looking at commercially available retractable reels, which are common to find in industrial workplaces and home workshops. An example of the retractable reels is shown in Figure 9.

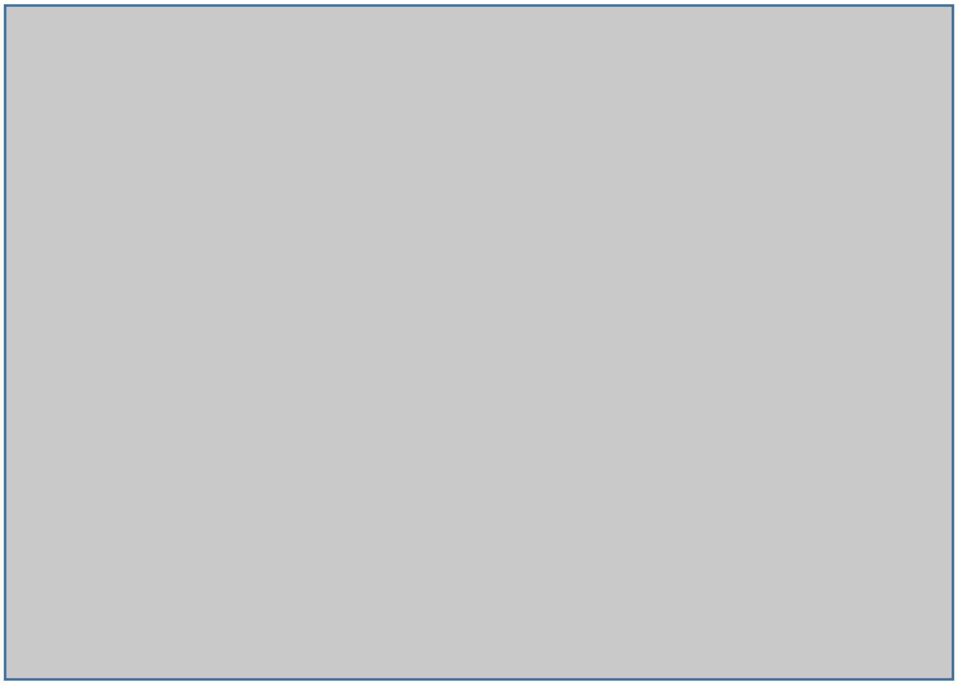

Figure 9: Commercially available retractable reels [5].

To implement this concept to the wind tunnel interface, several large reals would be required. All of the instrumentation cabling could be contained on one reel, but each power cable would require its own separate reel. These reels could be sourced, or designed and built if necessary.

A.2.6. Sliding Extension Rail

The sliding extension rail concept consists of a track with sliding rails and pivot points along these sliding rails. The concept of this design is adapted from an existing server cable management system by Seagate [6]. The cables moves along with the sliding rails as the wind tunnel moved to its required position. This concept is shown in Figure 10.

Figure 10: The sliding extension rail concept [6].

This design would enable the cables to adjust to the required length, similarly to the other concepts. Multiple cables would be able to be contained within a single track and rail assembly, but likely not all of them. In this case, several track assemblies could be installed in parallel.

A.2.7. Coil Retention Assembly

Coil retention concept, for this project, was initiated from the concept of the telephone cables in the landlines as shown in Figure 11.

Figure 11: Sample coil retention for the concept generation [7]

These cables have the ability to stretch and retain back to their original position based on the working principle of a coil spring. This concept can be used in designing a similar retention assembly for the interface system.

In this concept, a corrugated pipe contains the instrumentation cables. These cables are contained inside, along the corrugated wall, such that the cables are not jammed while stacking inside. Below the corrugated wall is a retractable cord reel, through which the cables from the control room pass to the tube and then to the wind tunnel.

The retractable cable reel has a spring motor therein. It also has a latching and unlatching mechanism for controlling the length and retraction of the cord. A CAD model of the concept is shown in Figure 12.

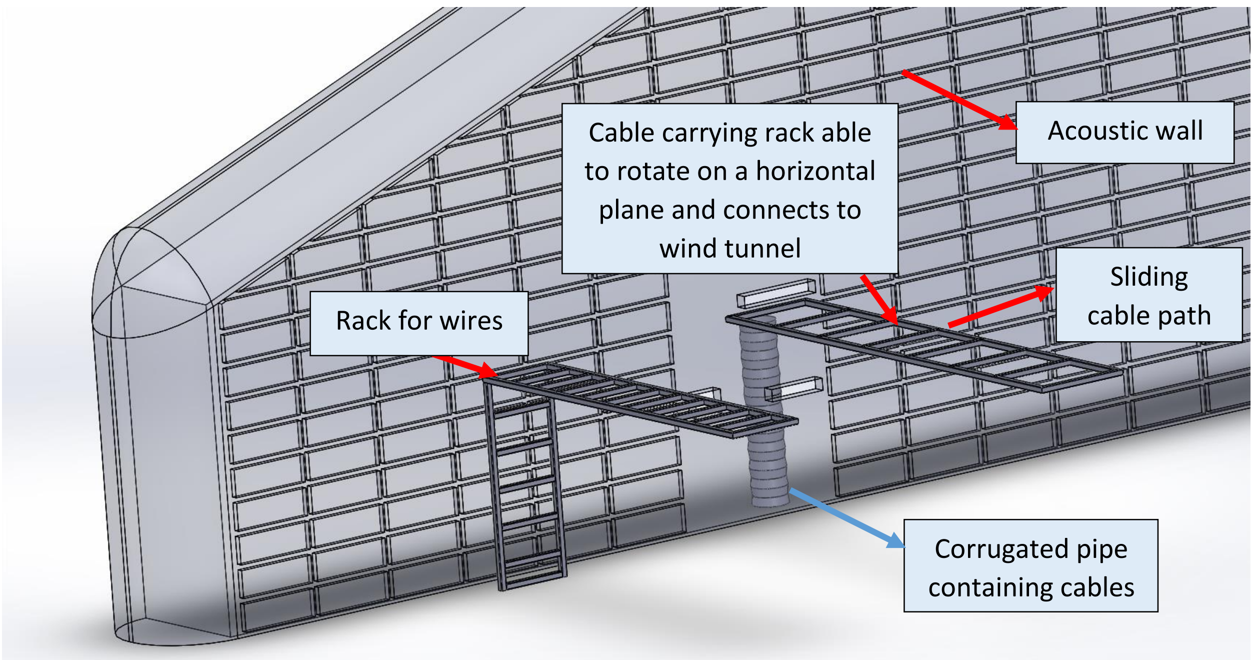

Figure 12: Coil retention assembly, CAD model.

The reel is placed on the other side of the wall, through which the cables are wound and go through the corrugated tube, and to the rack. This rack is able to rotate horizontally to adjust to the wind tunnel position.

A.3. Concepts Summary

At the end of the brainstorming stages, the team had come up with 7 concepts in total. These concepts all had their unique advantages and disadvantages, which were further analyzed in Section A.4, to determine which concepts were viable to move forward with.

A.4. Concept Analysis and Selection

In this section, as our customer specifically requested multiple final designs, the team selected three conceptual designs to develop for the next stage. The concept selection was performed through concept screening, criteria weighting, and concept scoring of the seven basic concept ideas.

A.4.1. Selection Criteria

In order to properly evaluate the generated concepts, the design criteria had to be established. Based on customer needs and specifications, the team came up with nine selection criteria shown below.

- Easy to use – The interface system should be simple to operate with fewer technicians during the change-over process.
- Durability – The interface system has to last a long time and withstand all weather conditions.
- Safety – The interface system must operate without compromising personal safety (risk of equipment falling, and electric shock).
- Easy to install – The installation process should be simple, and not require major changes to the wind tunnel and acoustic wall.
- Aesthetics – The idea and appearance of the interface system is more distinctive.

- Expandability – The interface system should allow for increased test capabilities in the future by being expandable and scalable.
- Cost – The cost should be reasonable, even though there is not a strict budget. Less expensive options are better than more expensive options if they both have the same features and capabilities.
- Low-maintenance – The interface system should not require long or frequent periods of maintenance.
- Load capacity – The interface system should be capable of supporting the weight of the power and instrumentation cables.

The nine criteria identified were ranked and weighted. The specific importance of each of these criteria is explained further in Section A.4.3.

A.4.2. Concept Screening Matrix

To determine the concepts to move forward to the scoring stage, a concept screening matrix was developed. The team developed the matrix shown in Table I by comparing each concept to the current interface system with a positive (+), negative (-), or zero (0) to indicate whether the concept was better, worse, or the same as the current system.

TABLE I: CONCEPT SCREENING MATRIX

Selection Criteria	Cable Drag Chain	Scissor Arm	Telescoping Support System	Guide Loops	Retraction Reels	Sliding Extension Rail	Coil Retention	Current System
Easy To Use	+	+	0	+	+	0	-	0
Durability	0	-	-	0	-	-	+	0
Safety	+	+	+	0	-	+	+	0
Easy to Install	-	-	-	0	-	0	0	0
Aesthetics	+	+	+	-	+	0	-	0
Expandable	+	0	0	+	0	+	-	0
Cost	-	-	-	+	-	-	+	0
Low Maintenance	-	-	-	-	-	-	-	0
Load Capacity	+	0	0	-	0	+	+	0
Negatives	**3**	**4**	**4**	**3**	**5**	**3**	**4**	**0**
Positives	**5**	**3**	**2**	**3**	**2**	**3**	**4**	**0**
Score	**2**	**-1**	**-2**	**0**	**-3**	**0**	**0**	**0**
Continue?	**Yes**	**No**	**No**	**Yes**	**No**	**Yes**	**Yes**	

Concept Selection Legend	
Better	+
Same	0
Worse	-

After conducting the preliminary screening of the concepts, four concepts were selected to move forward to the concept scoring stage. Concepts with negative scores were eliminated, and the concepts with positive score and zeros were selected on which further concept selection analysis was performed. The concepts selected for further analysis are Cable Drag Chain, Guide Loops, Sliding Extension Rail, and Coil Retention.

A.4.3. Selection Criteria Weighting

Before scoring the selected concepts, the selection criteria were ranked and weighted. In order to determine the correct weight for each of the criteria, they were compared to each other. The criterion which the team felt are important (based on client needs), were listed in the matrix, and then summed and proportioned. This process is shown in Table II.

TABLE II: SELECTION CRITERIA WEIGHTING

		A	B	C	D	E	F	G	H	I
		Easy To Use	Durability	Safety	Easy to Install	Coolness	Expandable	Cost	Low Maintenance	Load Capacity
A	Easy To Use		B	C	A	A	A	A	H	I
B	Durability			C	B	B	B	B	B	B
C	Safety				C	C	C	C	C	C
D	Easy to Install					D	F	D	H	I
E	Aesthetics						F	G	H	I
F	Expandable							F	F	F
G	Cost								G	G
H	Low Maintenance									I
I	Load Capacity									
	Total	**4**	**7**	**8**	**2**	**0**	**5**	**3**	**3**	**4**
	Weight	**11%**	**19%**	**22%**	**6%**	**0%**	**14%**	**8%**	**8%**	**11%**

The results give the weighting that will be assigned to the scores created in the proceeding section. The most important criterion was determined to be safety (22% weighting), and the least important was coolness (0% weighting).

A.4.4. Concept Scoring

The next step of the concept selection was to score the four concepts that were selected in the concept screening stage. These concepts are scored based on the established weighting. Each criterion was assigned a value ranging from 1 to 5 for each concept, 1 being the lowest and 5 being the highest rating. The scores were multiplied by their weights and were summed. The four team members rated the concepts individually, and then the ratings were averaged. Table III shows the averaged scoring for the top four concepts from the screening stage.

TABLE III: CONCEPT SCORING MATRIX

		Concepts							
		Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Easy to Use	11%	4	0.44	3	0.33	3	0.33	3	0.33
Durability	19%	3	0.58	3	0.58	3	0.58	2	0.39
Safety	22%	4	0.89	4	0.89	4	0.89	4	0.89
Easy to Install	6%	3	0.17	3	0.17	3	0.17	3	0.17
Aesthetics	0%	2	0.00	1	0.00	2	0.00	1	0.00
Expandable	14%	3	0.42	3	0.42	3	0.42	2	0.28
Cost	8%	3	0.25	3	0.25	3	0.25	3	0.25
Low Maintenance	8%	3	0.25	2	0.17	2	0.17	2	0.17
Load Capacity	11%	3	0.33	2	0.22	3	0.33	3	0.33
	Total Score	**3.33**		**3.03**		**3.14**		**2.81**	
	Rank	**1**		**3**		**2**		**4**	
	Continue?	Develop		Develop		Develop		No	

Through the scoring process, the concepts were ranked in order of best to worst. According to the client's request, the team has chosen to move forward with three concepts to move forward to the final design phase. From the scoring results, the three concepts that will be carried forward are Cable Drag Chain, Guide Loops, and Sliding Extension Rail.

A.4.5. Sensitivity Analysis

Sensitivity analysis is a method to determine how resistant the concept rankings are to any deviations in the scoring process. Sensitivity analysis is carried out by changing the score of a concept's particular attribute by +1 or -1, and then analyze any deviations in the concept's ranking. For example, suppose the safety score of the Guide Loops is changed by +1 and -1. The adjusted scores can be seen in Table IV.

TABLE IV: ADJUSTED SCORES FOR SENSITIVITY ANALYSIS EXAMPLES

		Guide Loops					
		Original Scoring		Safety +1		Safety -1	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Easy to Use	11%	3	0.33	3	0.33	3	0.33
Durability	19%	3	0.58	3	0.58	3	0.58
Safety	22%	4	0.89	5	1.11	3	0.67
Easy to install	6%	3	0.17	3	0.17	3	0.17
Aesthetics	0%	1	0.00	1	0.00	1	0.00
Expandable	14%	3	0.42	3	0.42	3	0.42
Cost	8%	3	0.25	3	0.25	3	0.25
Low Maintenance	8%	2	0.17	2	0.17	2	0.17
Load Capacity	11%	2	0.22	2	0.22	2	0.22
	Total Score	**3.03**		**3.25**		**2.81**	

The overall score for the Guide Loops increases if its safety rating increases, and decreases if its safety rating decreases. The next step in a sensitivity analysis is to see how the ranking would be affected by these deviated scores. This is shown in Table V.

TABLE V: ADJUSTED RANKINGS FOR SENSITIVITY ANALYSIS EXAMPLES

Original Scoring		
Ranking	**Concept**	**Score**
1	Cable Drag Chain	3.33
2	Sliding Extension Rail	3.14
3	Guide Loops	3.03
4	Coil Retention	2.81
Guide Loops Safety +1		
Ranking	**Concept**	**Score**
1	Cable Drag Chain	3.33
2	Guide Loops	3.25
3	Sliding Extension Rail	3.14
4	Coil Retention	2.81
Guide Loops Safety -1		
Ranking	**Concept**	**Score**
1	Cable Drag Chain	3.33
2	Sliding Extension Rail	3.14
3	Guide Loops	2.81
3	Coil Retention	2.81

Table V shows that when the safety score of the Guide Loops concept is increased by 1, it alters the overall ranking. The Guide Loops moves to the second rank. And, when the safety score for Guide Loops is decreased, it remains in the third ranking. The overall sensitivity analysis is done in this manner for every attribute and for all the concepts. The overall sensitivity analysis is shown in Table VI.

Table VI: SENSITIVITY ANALYSIS RESULTS

	Adjusted Safety Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.56	3.11	3.25	2.81	3.36	2.92	3.03	2.58
Adjusted Rank	1	2	2	3	1	3	3	4

	Adjusted Durability Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.53	3.14	3.22	2.83	3.33	2.94	3.00	2.61
Adjusted Rank	1	1	2	3	1	3	4	4

	Adjusted Expandability Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.47	3.19	3.17	2.89	3.28	3.00	2.94	2.67
Adjusted Rank	1	1	2	3	2	3	4	4

	Adjusted Ease of Use Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.44	3.22	3.14	2.92	3.25	3.03	2.92	2.69
Adjusted Rank	1	1	2	3	2	2	4	4

	Adjusted Load Capacity Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.44	3.22	3.14	2.92	3.25	3.03	2.92	2.69
Adjusted Rank	1	1	3	3	2	2	4	4

	Adjusted Cost Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.42	3.25	3.11	2.94	3.22	3.06	2.89	2.72
Adjusted Rank	1	1	3	3	2	2	4	4

	Adjusted Low-Maintenance Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.42	3.25	3.11	2.94	3.22	3.06	2.89	2.72
Adjusted Rank	1	1	3	3	2	2	4	4

	Adjusted Ease of Installation Scores							
	Cable Drag Chain		Guide Loops		Sliding Extension Rail		Coil Retention	
Score Adjustment	+1	-1	+1	-1	+1	-1	+1	-1
Adjusted Score	3.39	3.28	3.08	2.97	3.19	3.08	2.86	2.75
Adjusted Rank	1	1	3	3	2	2	4	4

From the analysis, it was found that the top three concepts only changed in 1 out of the 64 possible scenarios. Therefore, the team concluded that the ranking is an accurate reflection of the scoring process.

A.4.6. House of Quality

The house of quality shows whether the performance of a design matches the customers' needs and specifications by comparing it to the other competitive products. Moreover, the house of quality helps engineers to identify the point of concern for meeting different customers' requirements. Identification of the point of concern is achieved by illustrating the relationship between customers' needs and specifications.

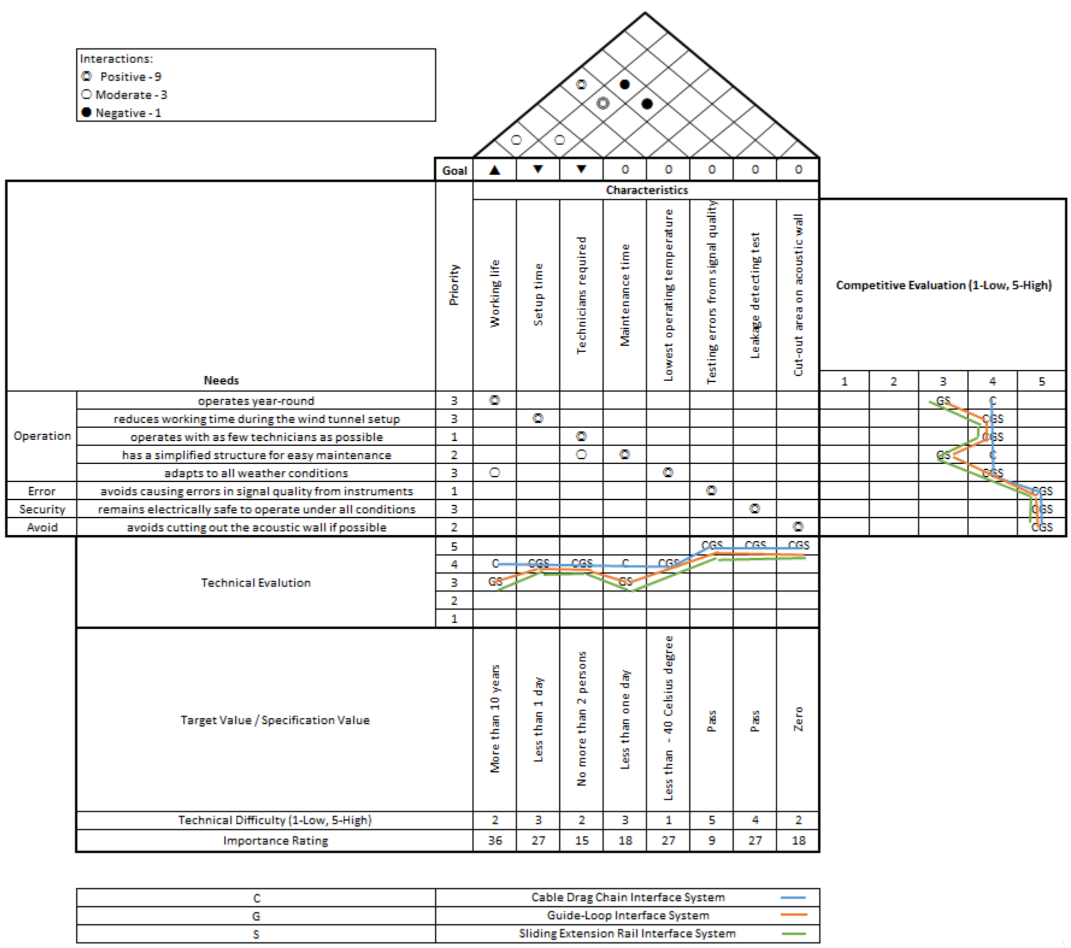

Figure 13: House of quality

The goal of our design project is to reduce the set up time during the changeover process, while also reducing the technicians required during the change-over process. As part of the competitive evaluation, due to the lack of other interface system designs, we only compared the three final concept designs that we selected from the concept scoring process.

Figure 14 illustrates the house of quality for our interface system design. As shown in the figure, the evaluation for each design was based on the concept selection matrix and concept scoring. The cable drag chain interface with the highest ranking gets a better performance than the guide-loop interface system and the sliding extension rail interface system. The latter two interface systems have the same performance.

A.5. Concept Selection Summary

Three concepts were ruled out using the concept screening matrix. The remaining four concepts were scored to identify the concepts that will be developed moving forward. Even though the drag chain scored the highest, three concepts were chosen during this scoring process based on the client's requirement of multiple design concepts. These three concepts developed are cable drag chain, cable loops, and sliding extension rail which are explained in detail in section 3 of the report.

A.6. References

[1] K. T. Ulrich and S. D. Eppinger, Product Design and Development, New York: McGraw Hill, 2008.

[2] SOONS ZONWERING & ROLLUIKEN. *Private sector - Scissor-arm Awnings* SOONS [Online]. Available: http://www.terrace-roofs.com/product_en.php?id=106. [November 3, 2015].

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[7] Alibaba. *GE 15' Phone Coil Cord Black* [Online]. Available: http://guide.alibaba.com/shop/ge-15-phone-coil-cord-black_35017117.html. [October 26, 2015].

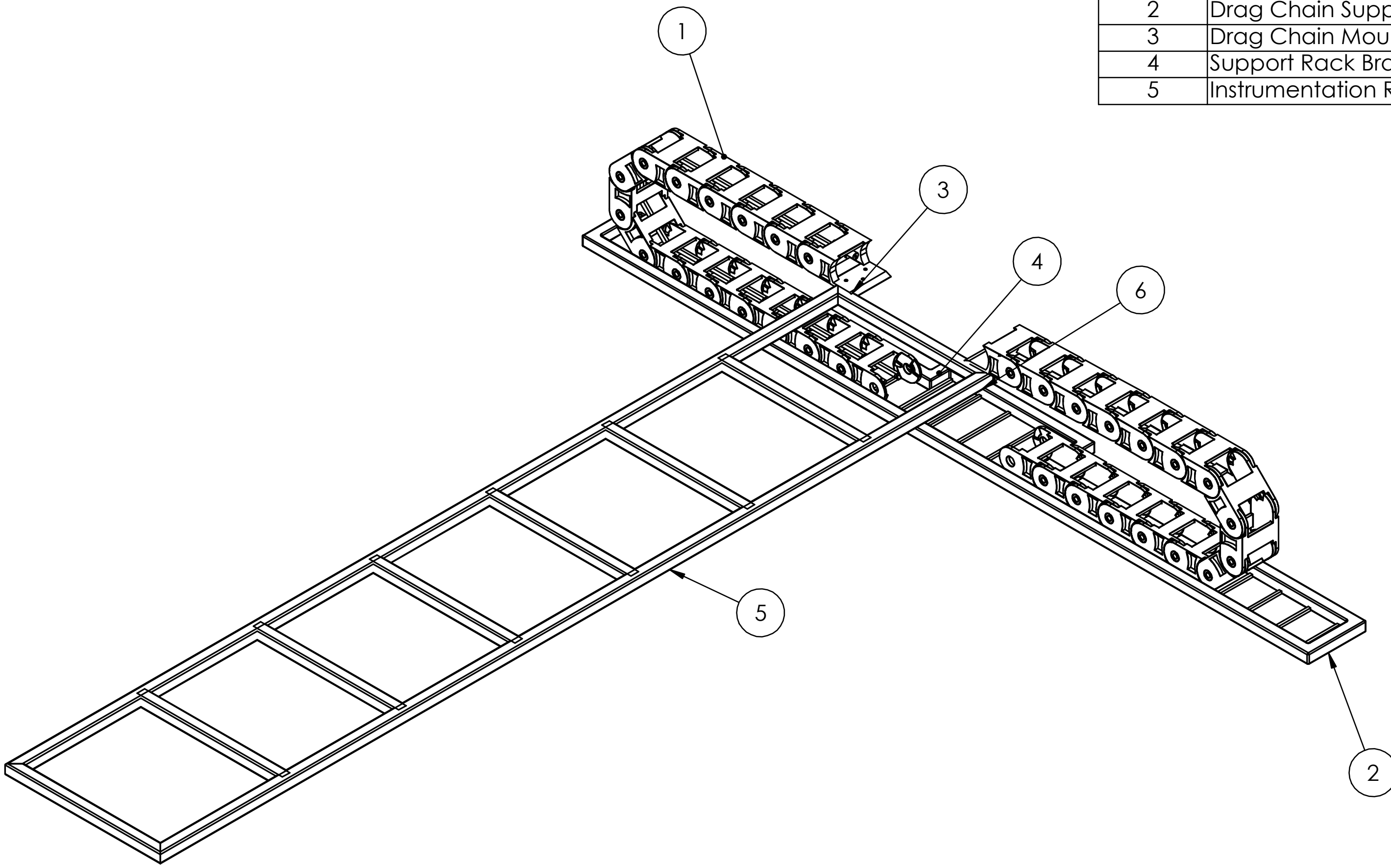
Appendix B Engineering Drawings

Table of Contents

In order to facilitate the design specifications review by the client, the team put together engineering drawings of the components of the cable drag chain design. The engineering drawings of the drag chain, the support rack, drag chain mount, and the mounting bracket are shown below.

B.1. Engineering Drawings of Cable Drag Chain

ITEM NO.	PART NO.	QTY.
1	Cable Drag Chain	2
2	Drag Chain Support Rack	1
3	Drag Chain Mount	8
4	Support Rack Bracket	2
5	Instrumentation Rack (Existing)	1



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

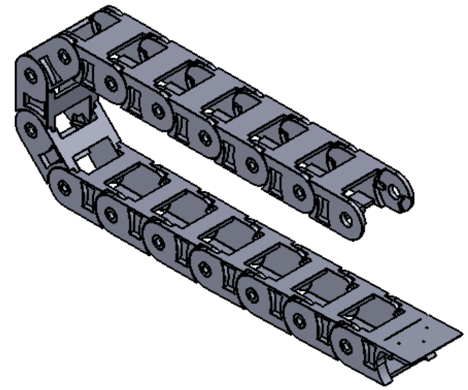
UofM MECHANICAL ENGINEERING

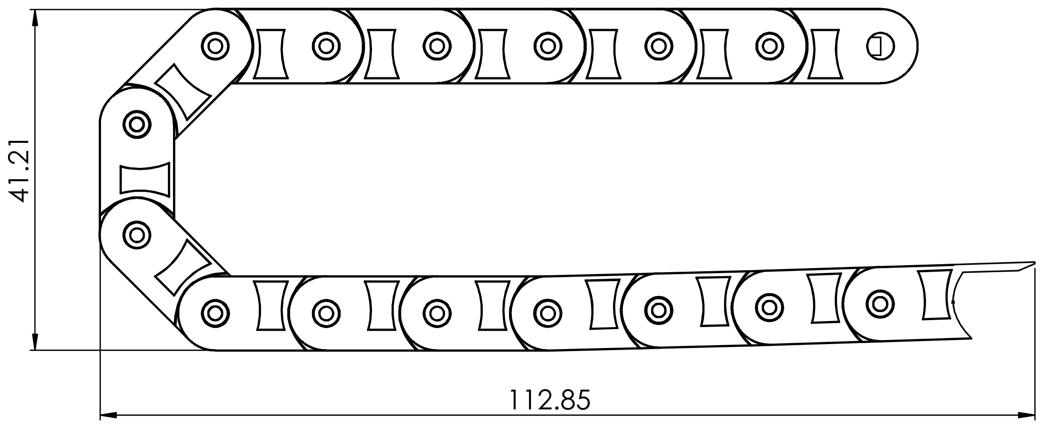
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	07/12/2015
FINISH J.W.	TEAM	23	

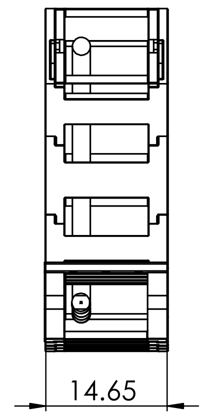
PROJECT: **Cable Drag Chain**

SIZE	TITLE:	REV
B	Cable Drag Chain	0

SCALE: 1:35 | WEIGHT: | SHEET 1 OF 5







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MECH 4860 ENGINEERING DESIGN

PROJECTION

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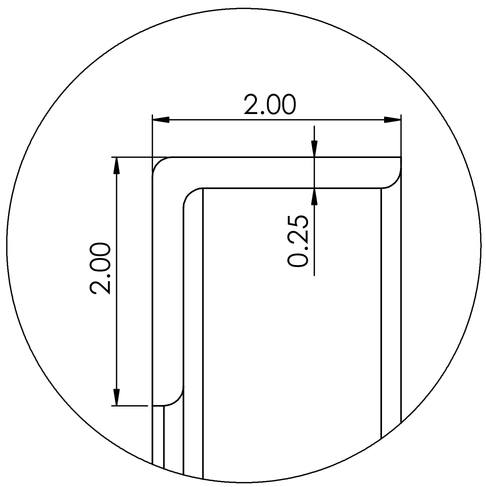
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

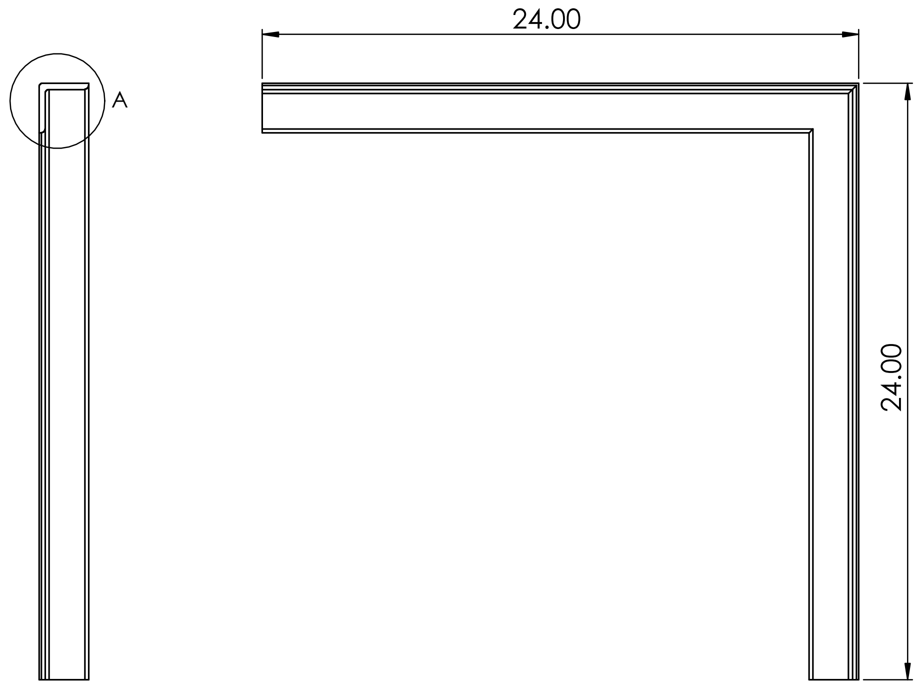
		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	07/12/2015
FINISH J.W.	TEAM	23	

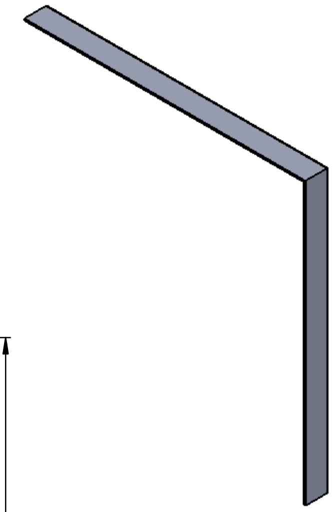
PROJECT: **Cable Drag Chain**

SIZE	TITLE:	REV
B	Cable Drag Chain	0
SCALE: 1:15	WEIGHT:	SHEET 2 OF 5



DETAIL A
SCALE 1 : 1





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PROJECTION

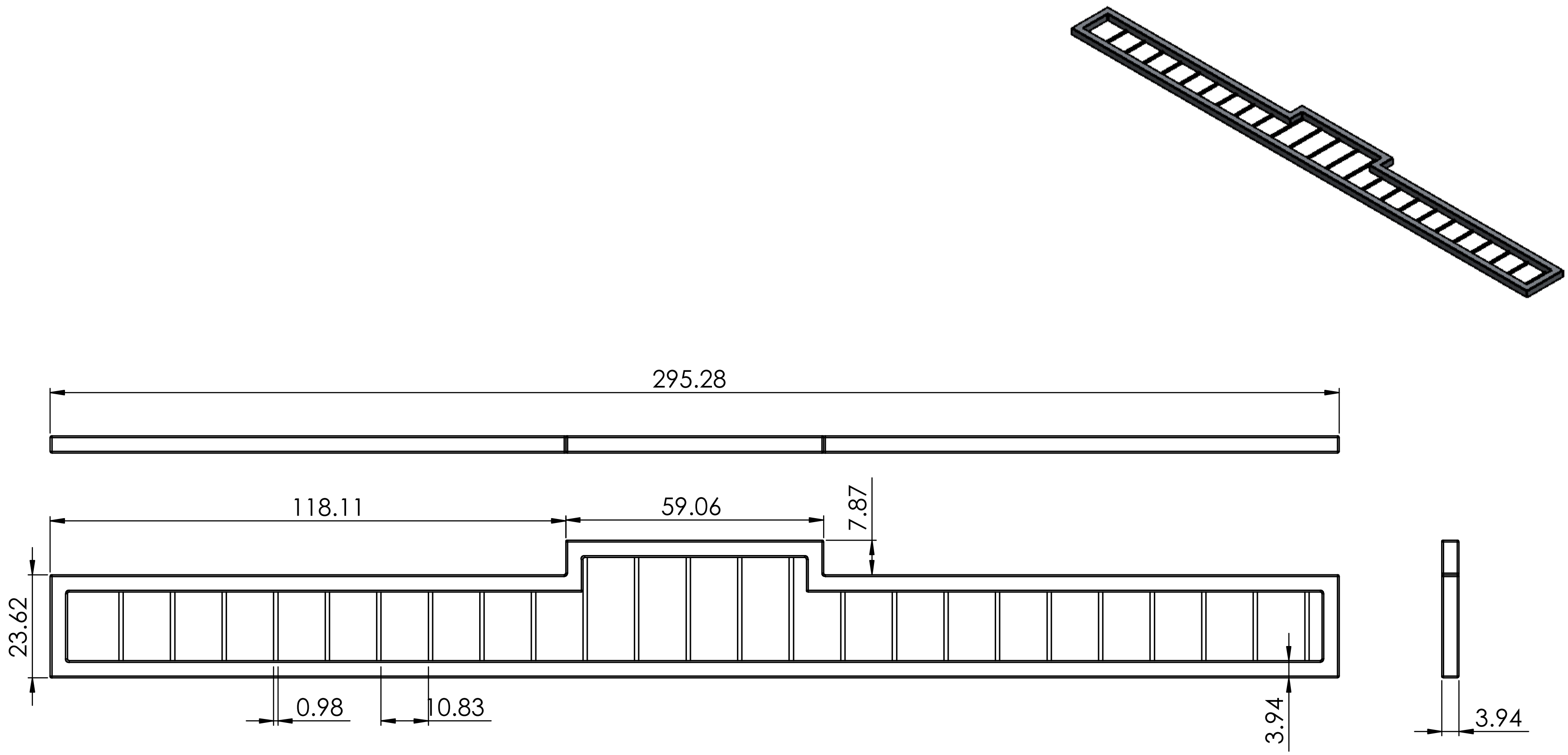
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	07/12/2015
FINISH J.W.	TEAM	23	

PROJECT:
Cable Drag Chain

SIZE	TITLE:	REV
B	Support Bracket	0
SCALE: 1:5	WEIGHT:	SHEET 3 OF 5



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PROJECTION

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TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

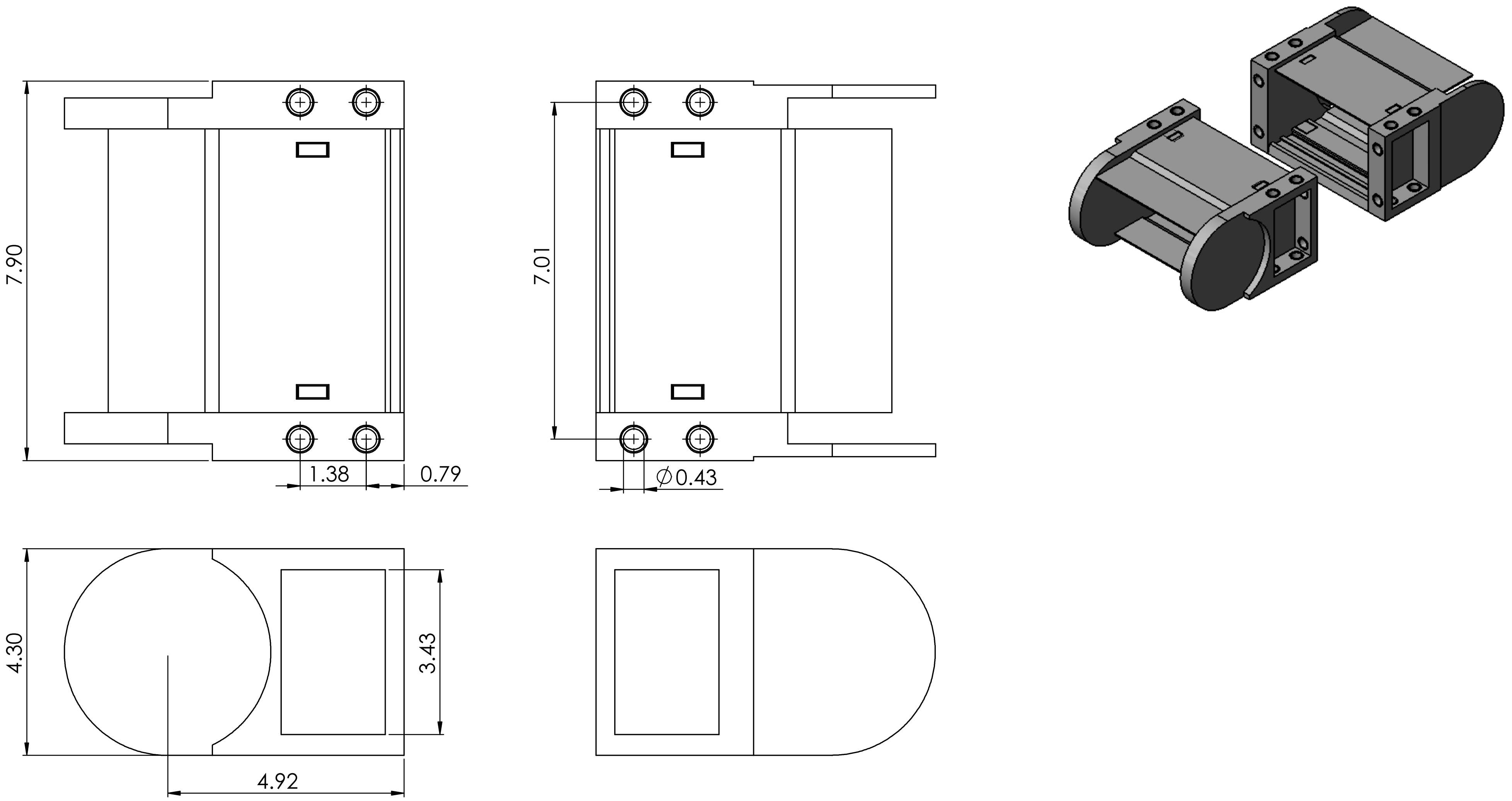
UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	07/12/2015
FINISH J.W.	TEAM	23	

PROJECT: **Cable Drag Chain**

SIZE **B** TITLE: Support Rack REV 0

SCALE: 1:25 WEIGHT: SHEET 4 OF 5



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TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL:

FINISH J.W.

	NAME	DATE
DRAWN	J.W.	26/11/2015
CHECKED	J.W.	07/12/2015
TEAM	23	

PROJECT:

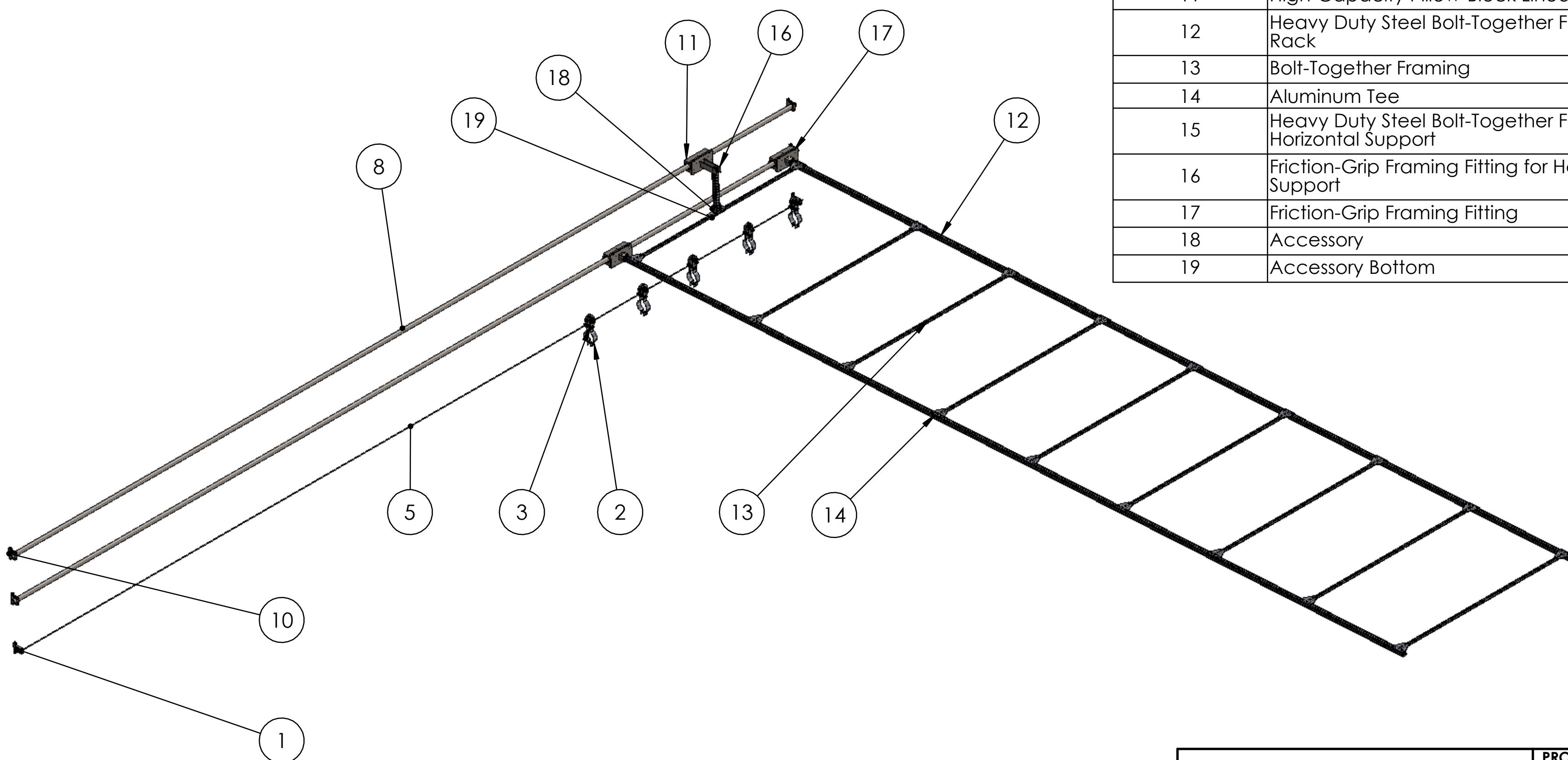
Cable Drag Chain

SIZE	TITLE:	REV
B	Drag Chain Mounts	0

SCALE: 1:2 | WEIGHT: | SHEET 5 OF 5

B.2. Engineering Drawings of Guide Loops

ITEM NO.	PART NUMBER	QTY.
1	Bottom Base Mount Rope Support	2
2	Hanger	5
3	Heavy Duty Steel Pulley	5
4	Top Base Mount Rope Support	2
5	Wire Rope	1
6	Bolt Nut	5
7	Hanger Bolt	5
8	Hardened Precision Shafts	2
9	Top Base Mount Shaft Support	4
10	Bottom Base Mount Shaft Support	4
11	High-Capacity Pillow-Block Linear Bearing	3
12	Heavy Duty Steel Bolt-Together Framing for Rack	2
13	Bolt-Together Framing	9
14	Aluminum Tee	18
15	Heavy Duty Steel Bolt-Together Framing for Horizontal Support	1
16	Friction-Grip Framing Fitting for Horizontal Support	1
17	Friction-Grip Framing Fitting	2
18	Accessory	1
19	Accessory Bottom	1



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MECH 4860 ENGINEERING DESIGN

PROJECTION

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TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

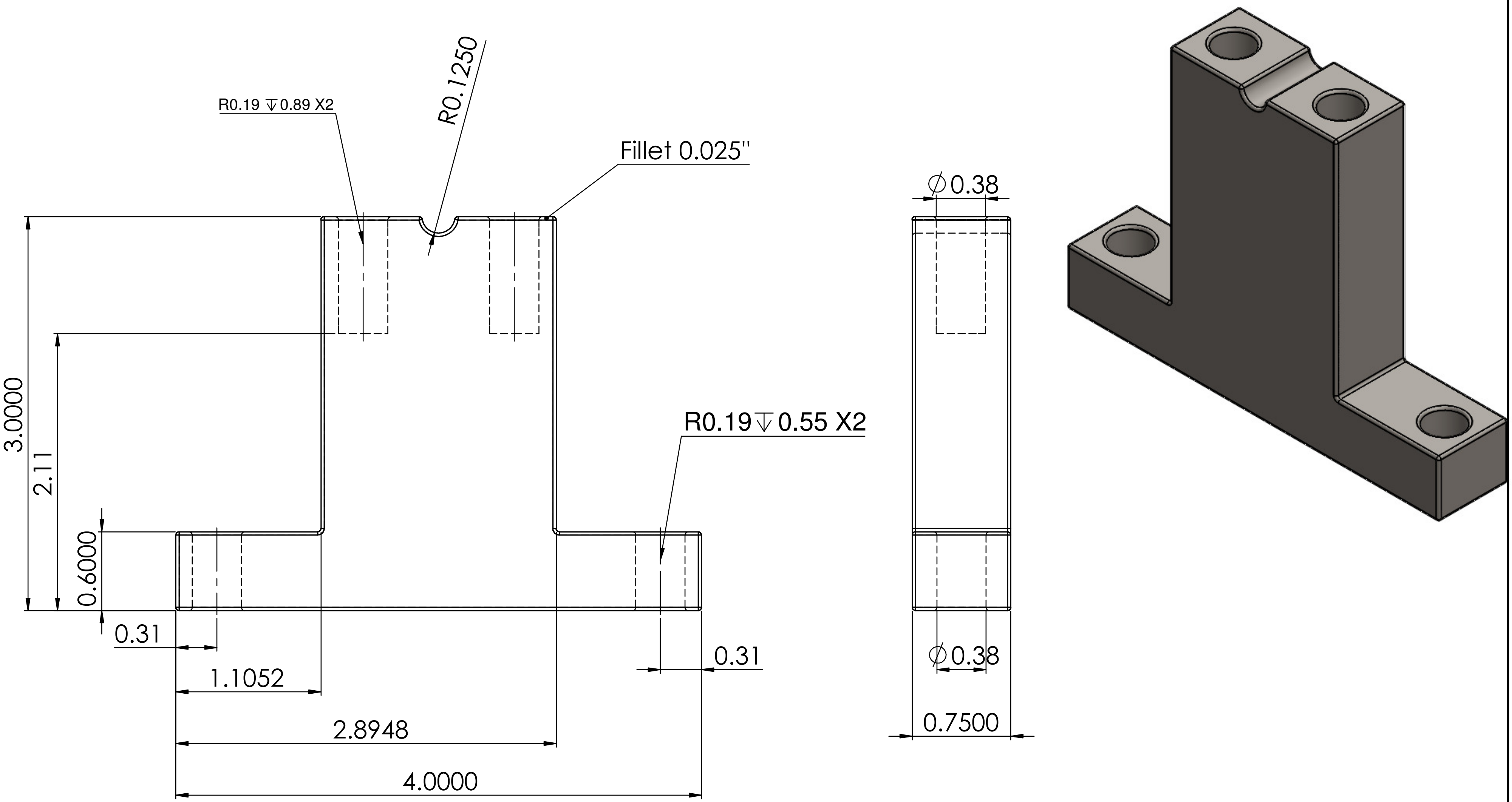
UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL:	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Guide Loop	0

SCALE: 1:50 | WEIGHT: 509.32 | SHEET 1 OF 16



University of Manitoba

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
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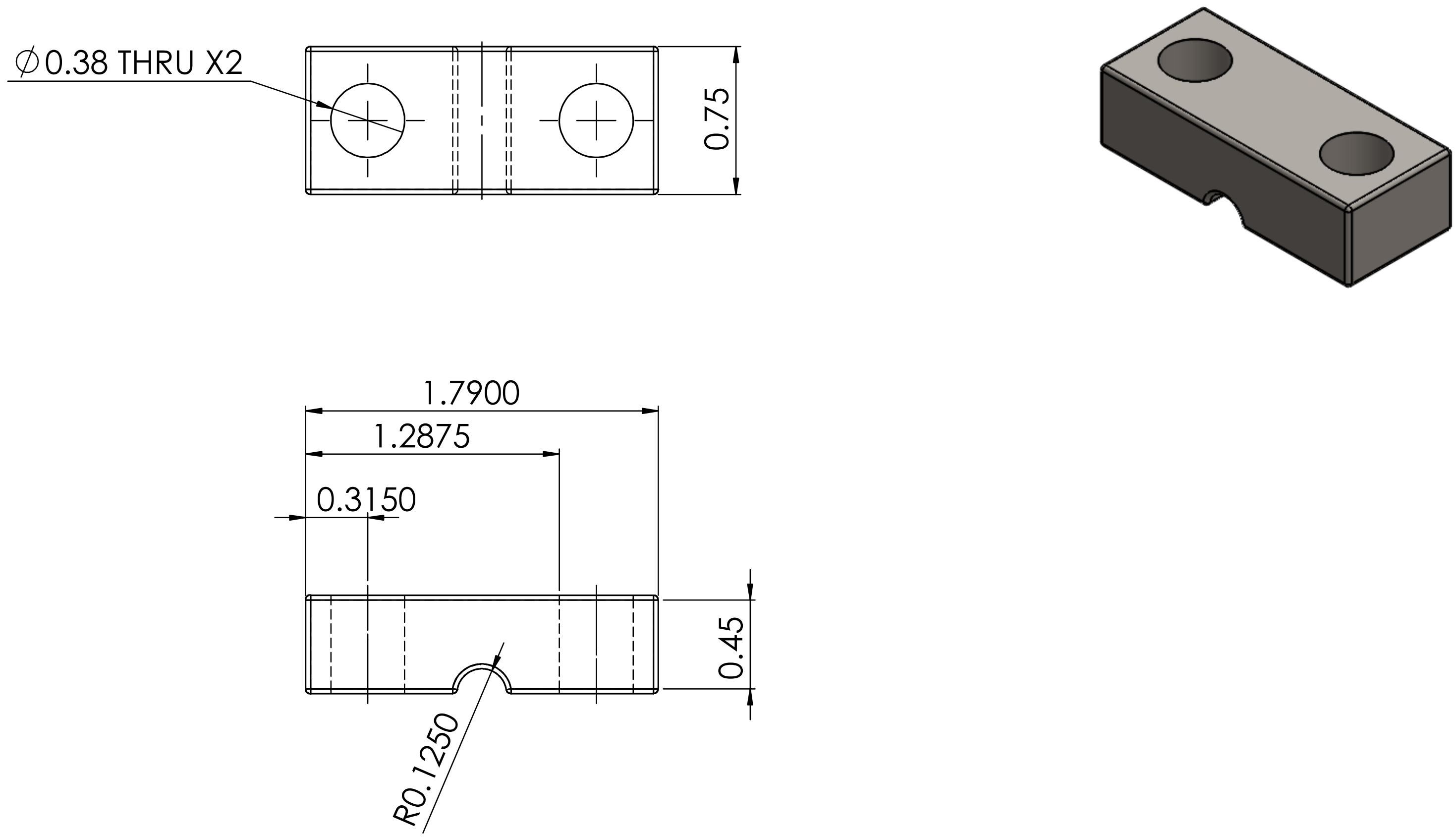
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Bottom Base Mount Rope Support	0
SCALE: 1:1	WEIGHT: 1.32	SHEET 2 OF 16



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MECH 4860 ENGINEERING DESIGN

PROJECTION

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DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

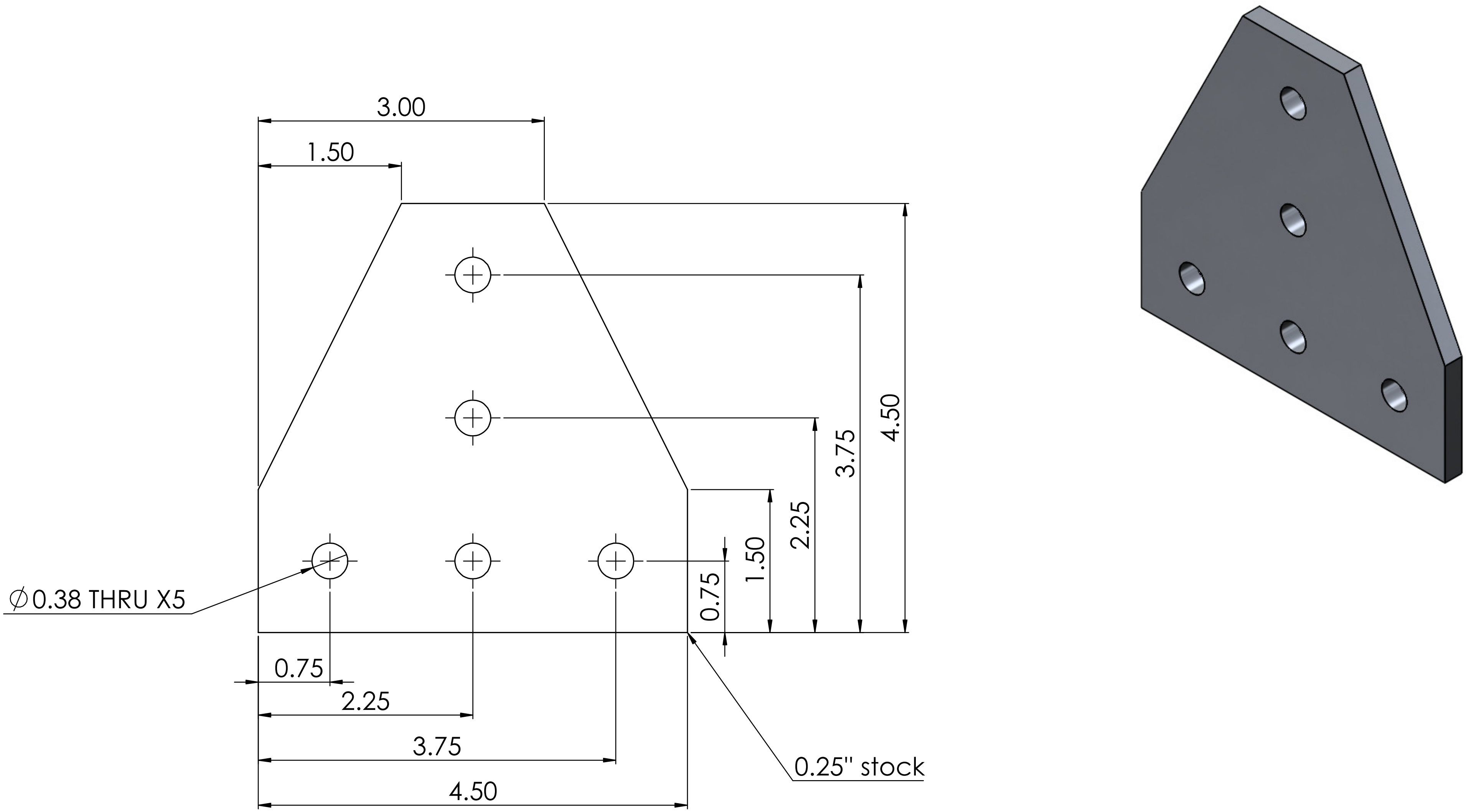
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Top Base Mount Rope Support	0

SCALE: 1.6:1 | WEIGHT: 0.15 | SHEET 3 OF 16



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MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

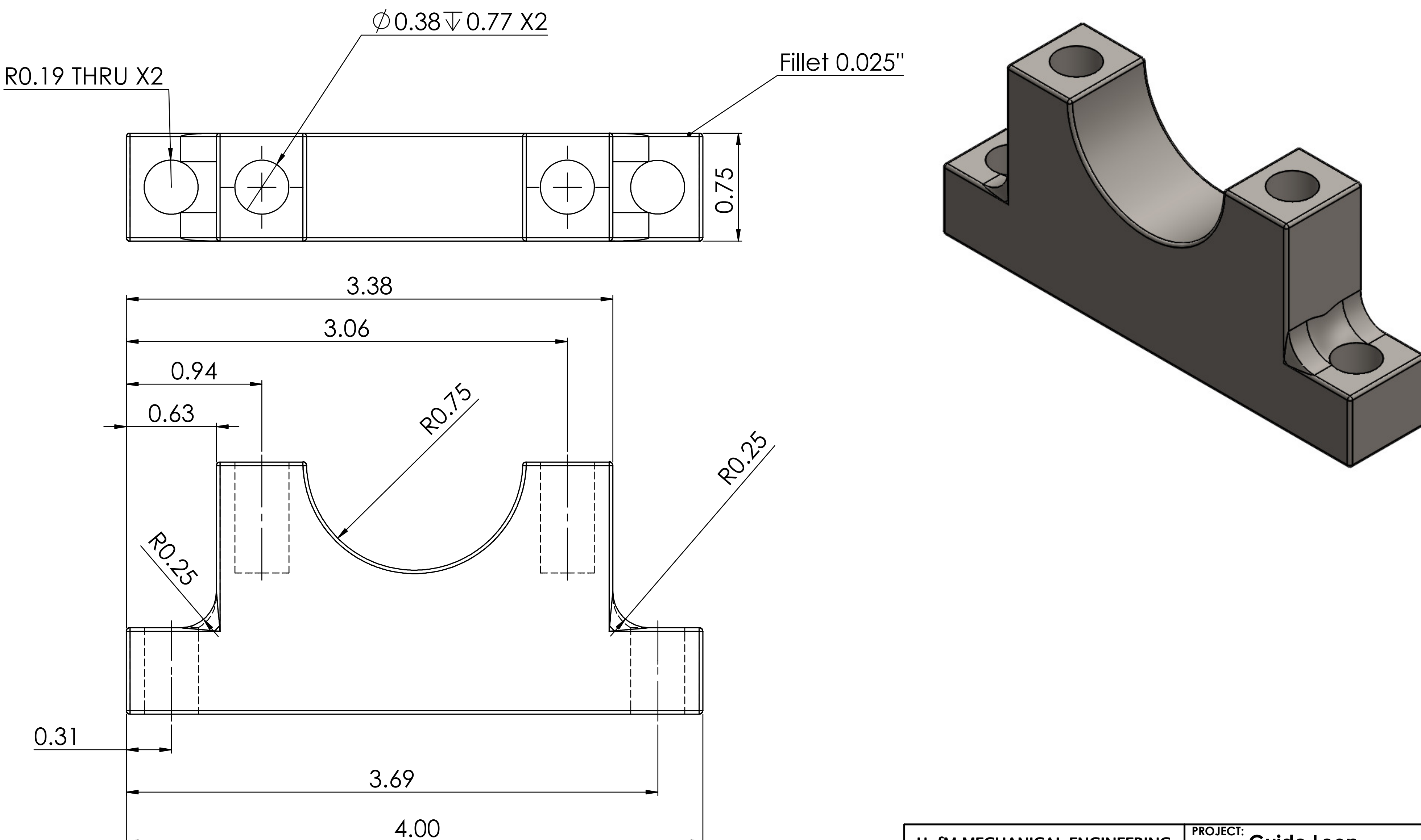
UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: 6061 Alloy	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Aluminum Tee	0

SCALE: 1:1 | WEIGHT: 0.37 | SHEET 4 OF 16



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MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

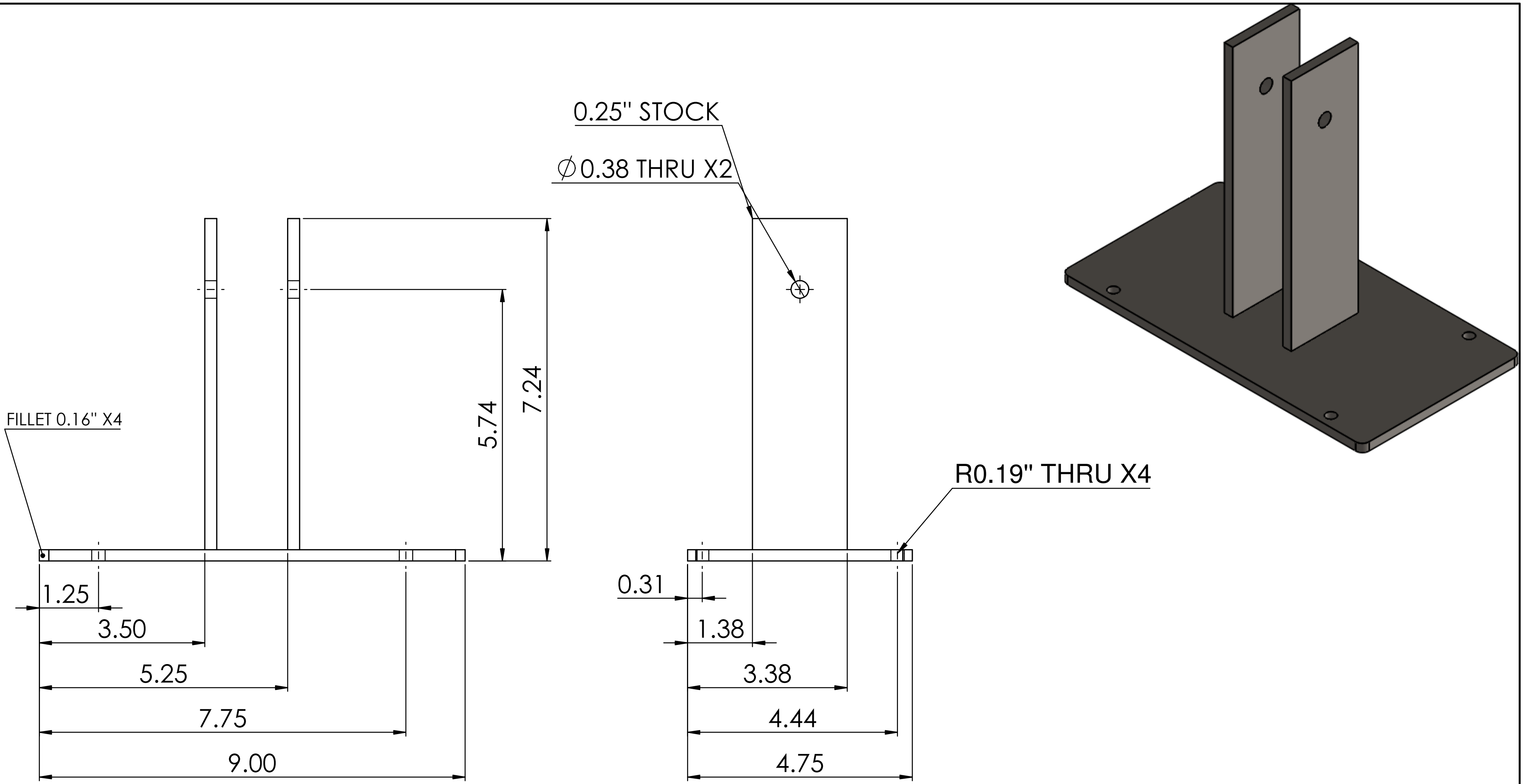
UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Bottom Base Mount Shaft Support	0

SCALE: 1:1 | WEIGHT: 0.91 | SHEET 5 OF 16



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

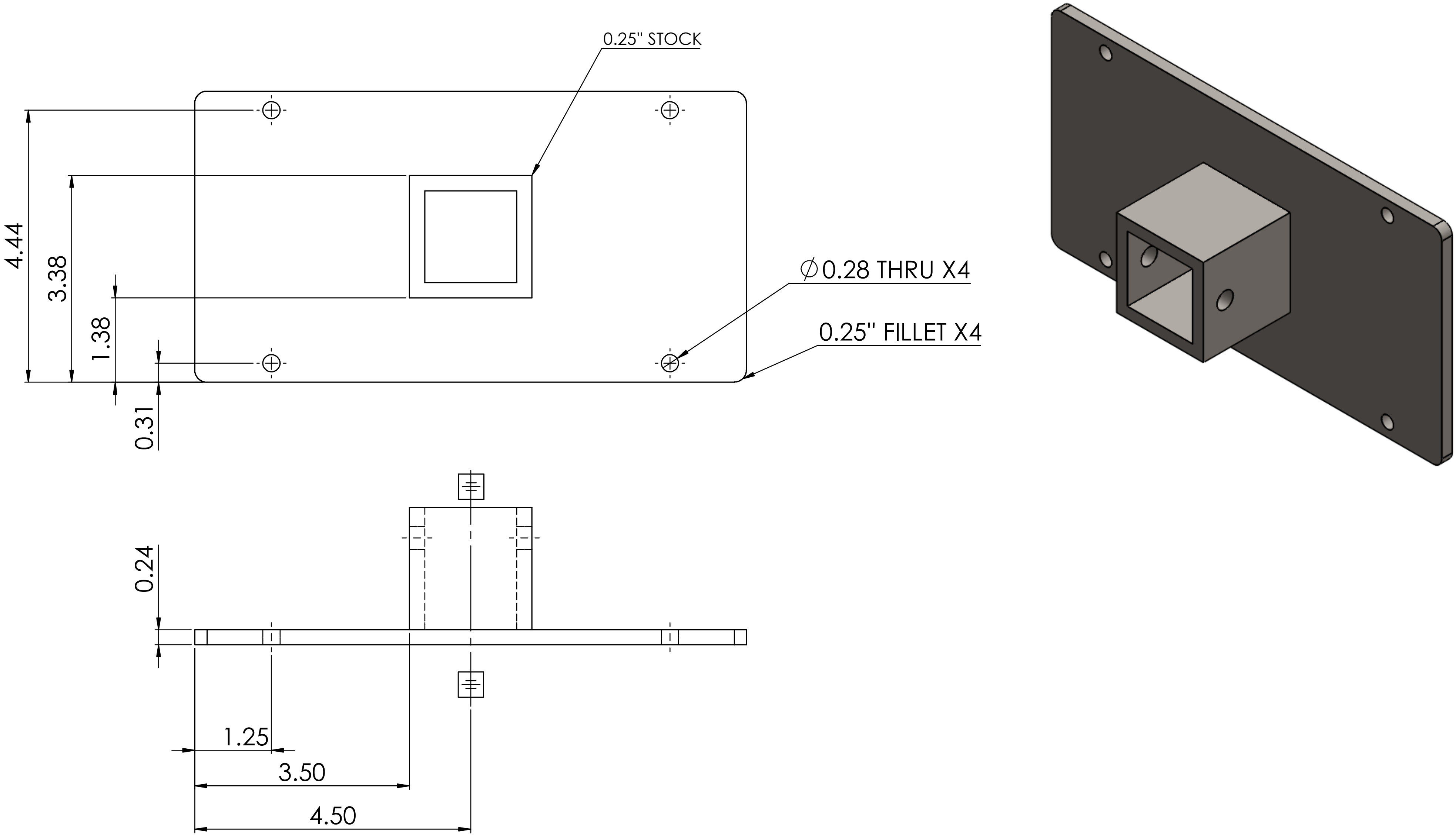
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
DO NOT SCALE DRAWING — DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS) — CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP — TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Friction-Grip Framing Fitting for Horizontal Support	0
SCALE: 1:1	WEIGHT: 4.86	SHEET 6 OF 16



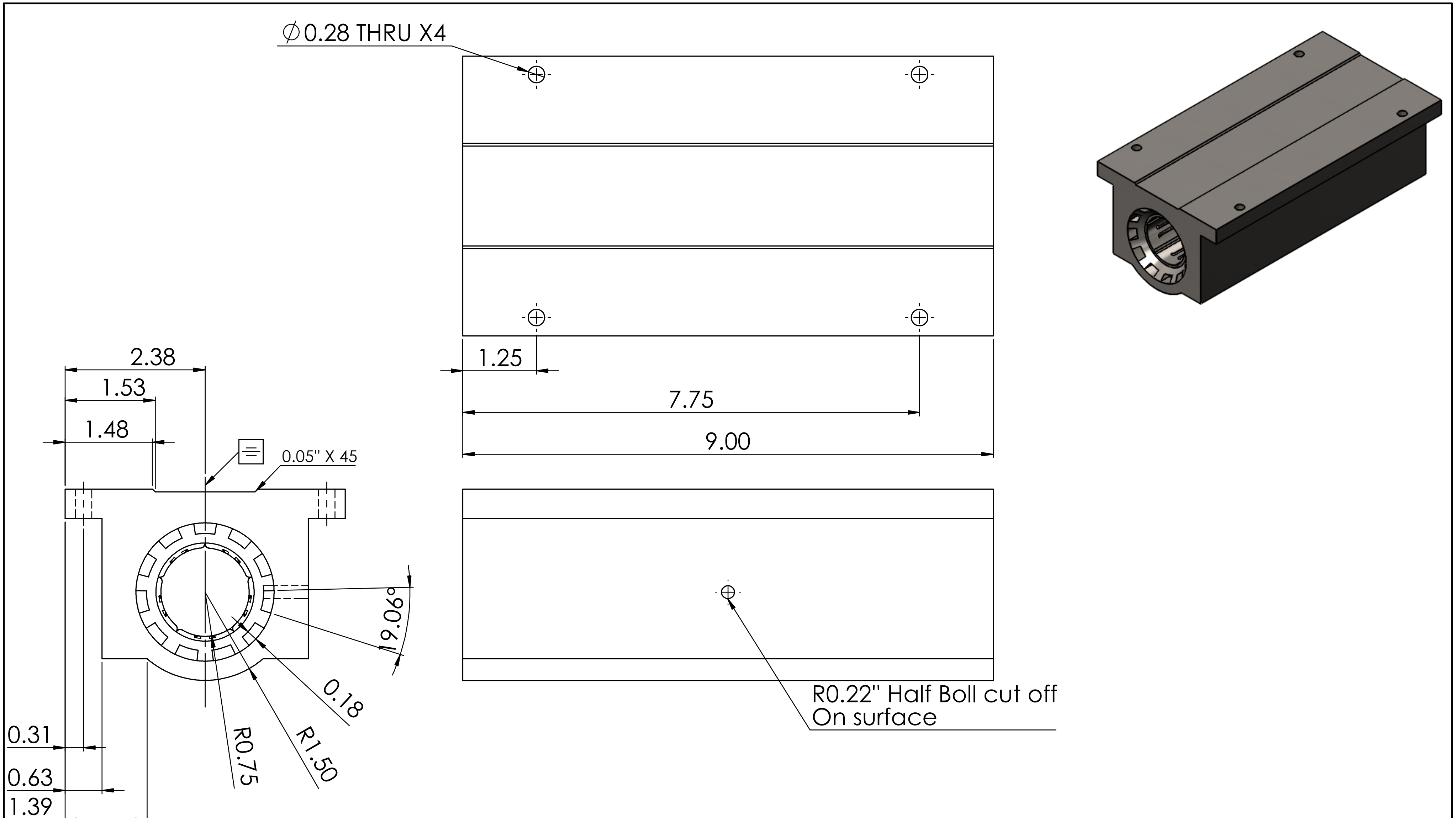
UNIVERSITY OF MANITOBA	MECH 4860 ENGINEERING DESIGN	PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Friction-Grip Framing Fitting	0
SCALE: 1:1.5	WEIGHT: 3.87	SHEET 7 OF 16



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

	NAME	DATE
DO NOT SCALE DRAWING / DRAWN	Z. ZP	26/11/2015
MATERIAL: 201 Annealed Stainless Steel (SS) / CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP / TEAM	23	

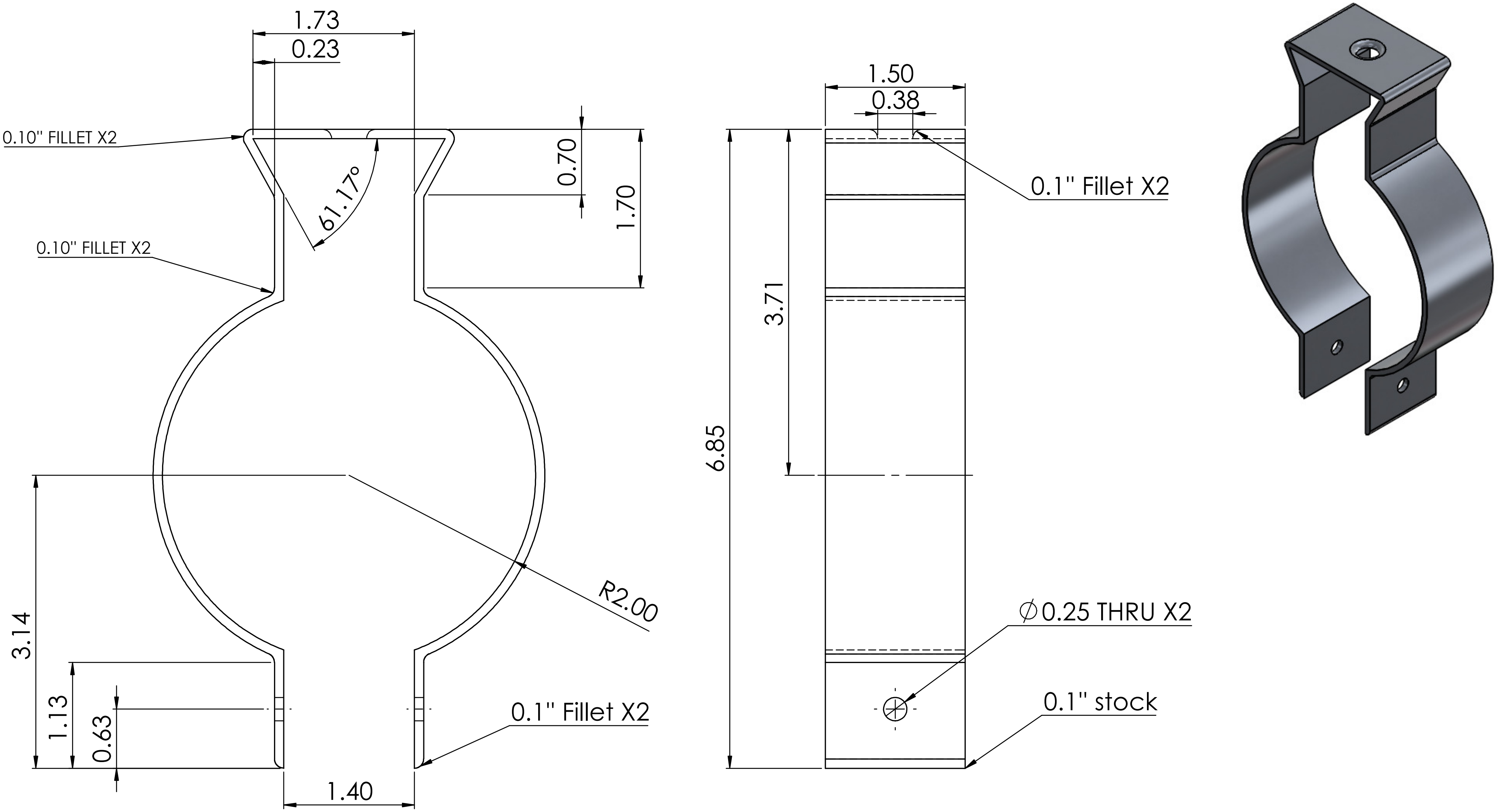
PROJECT: **Guide Loop**

SIZE **B**

TITLE: High-Capacity Pillow-Block Linear Bearing

REV 0

SCALE: 1:1.5 | WEIGHT: 23.42 | SHEET 8 OF 16



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

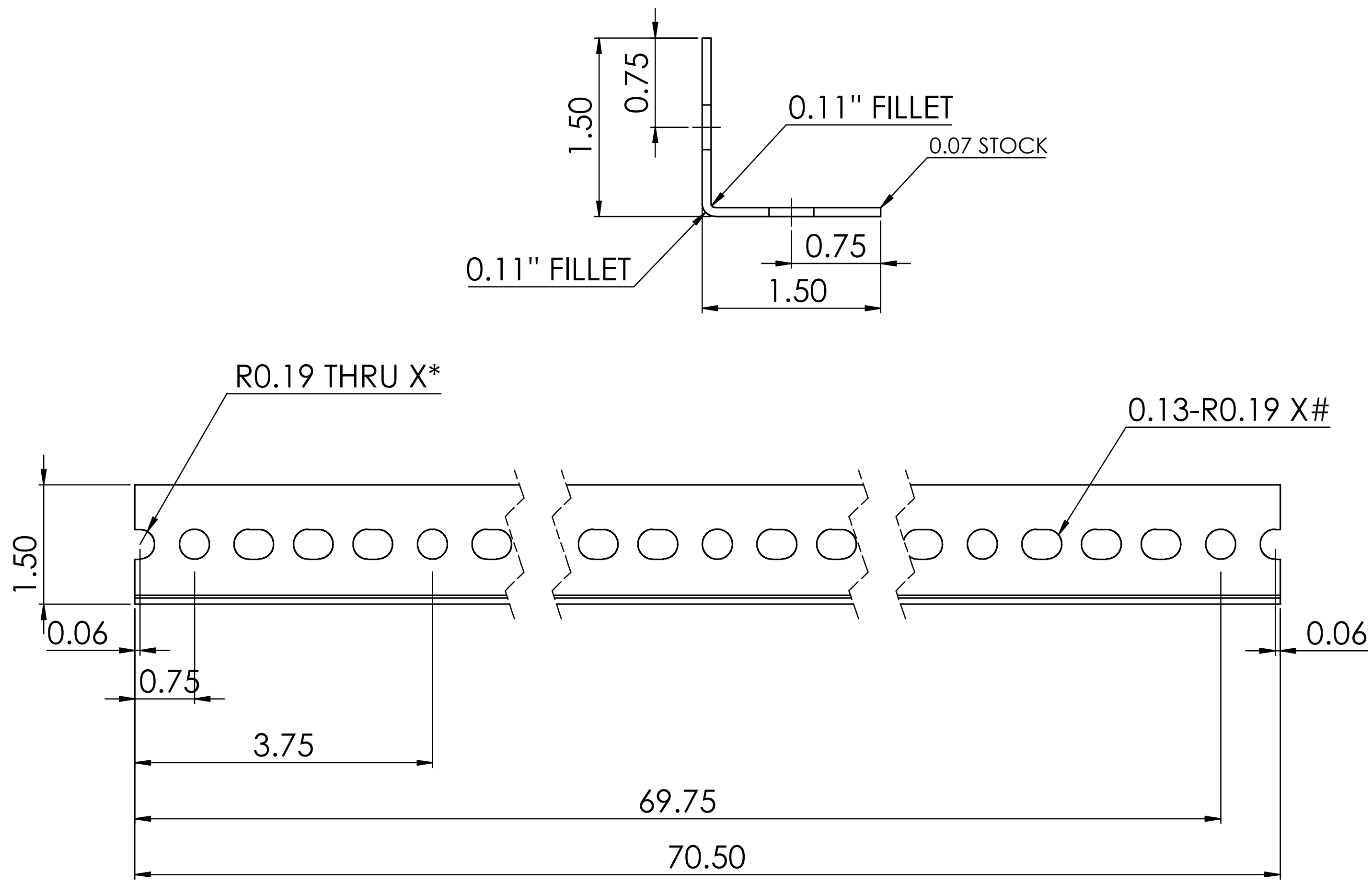
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

	NAME	DATE
DO NOT SCALE DRAWING — DRAWN	Z. ZP	26/11/2015
MATERIAL: 6061 Alloy — CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP — TEAM	23	

PROJECT: **Guide Loop**

SIZE B | TITLE: Hanger | REV 0

SCALE: 1:1.5 | WEIGHT: 0.26 | SHEET 9 OF 16



University of Manitoba

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

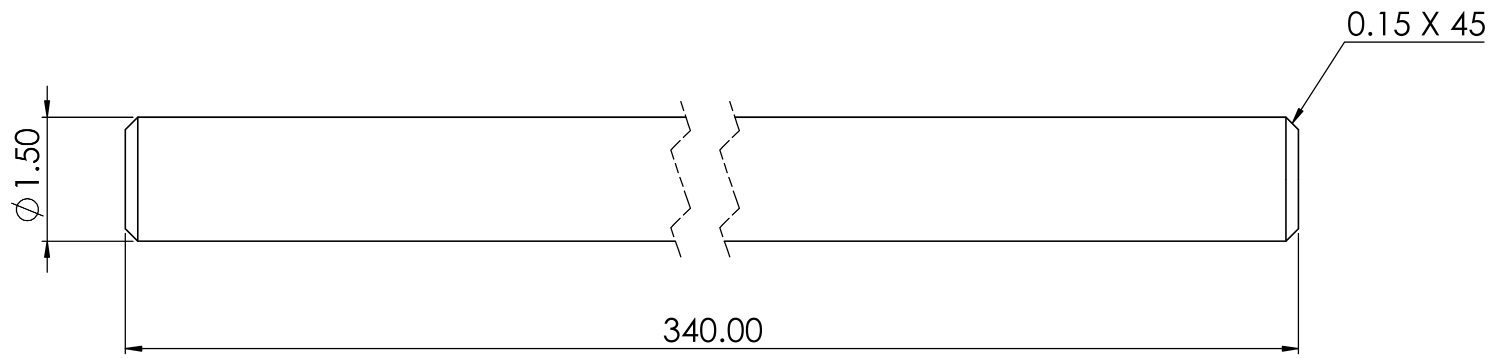
UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: 6061 Alloy	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Bolt-Together Framing	0

SCALE: 1:1.5 | WEIGHT: 1.28 | SHEET 10 OF 16



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

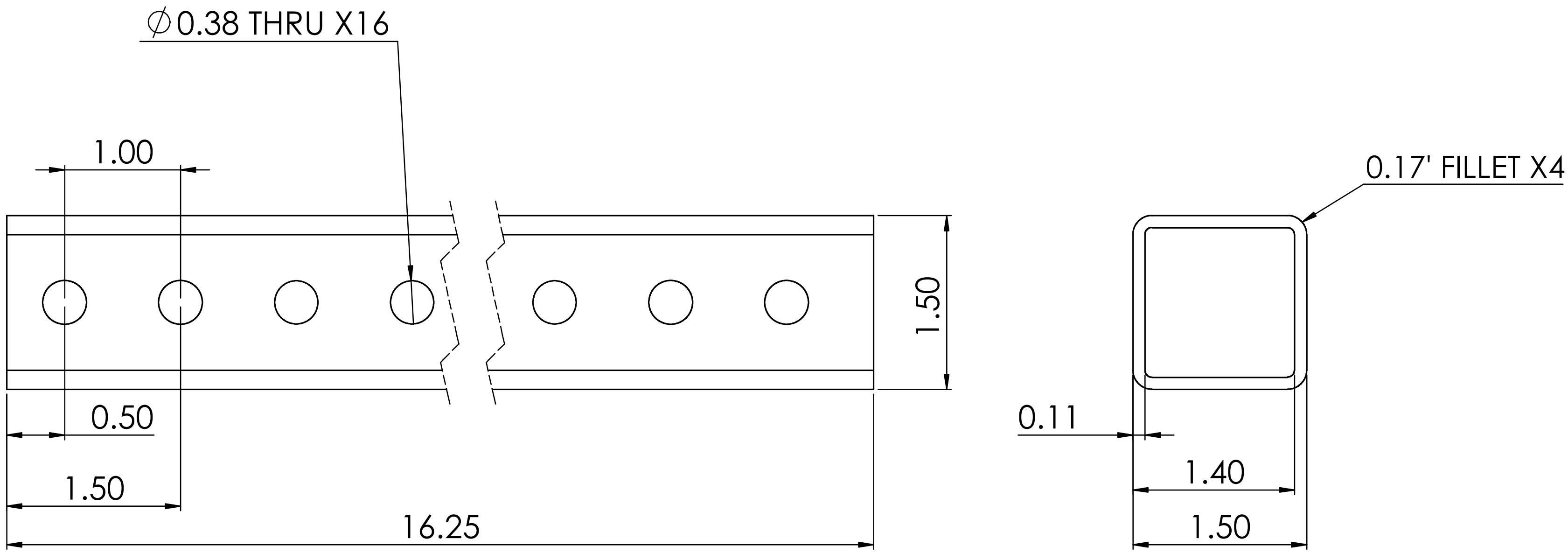
UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: 201 Annealed Stainless Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Hardened Precision Shafts	0

SCALE: 1:1.5 | WEIGHT: 170.584 | SHEET 11 OF 16



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

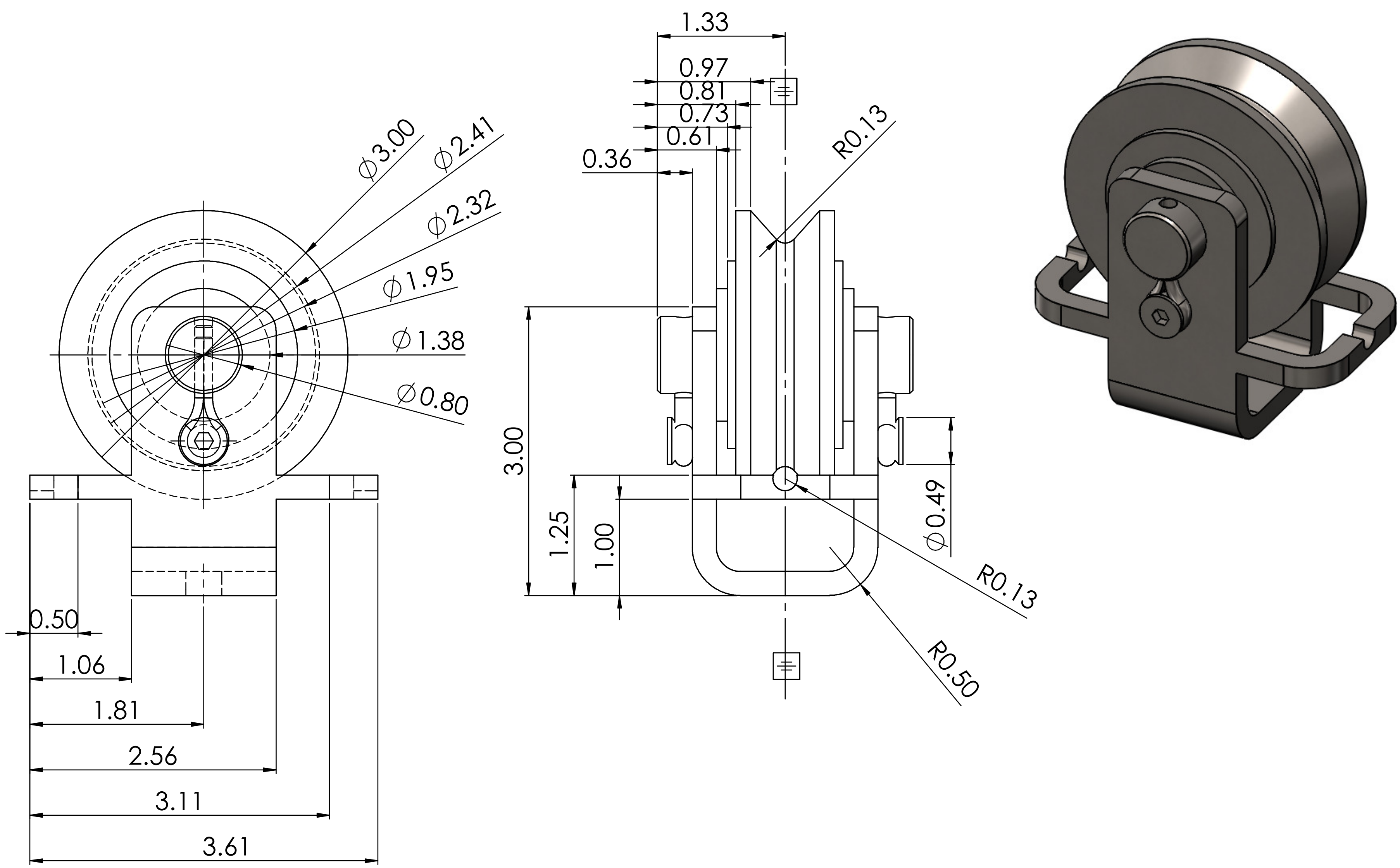
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: 6061 Alloy	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Heavy Duty Steel Bolt-Together Framing for Horizontal Support	0
SCALE: 1:1.5	WEIGHT: 0.82	SHEET 12 OF 16



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

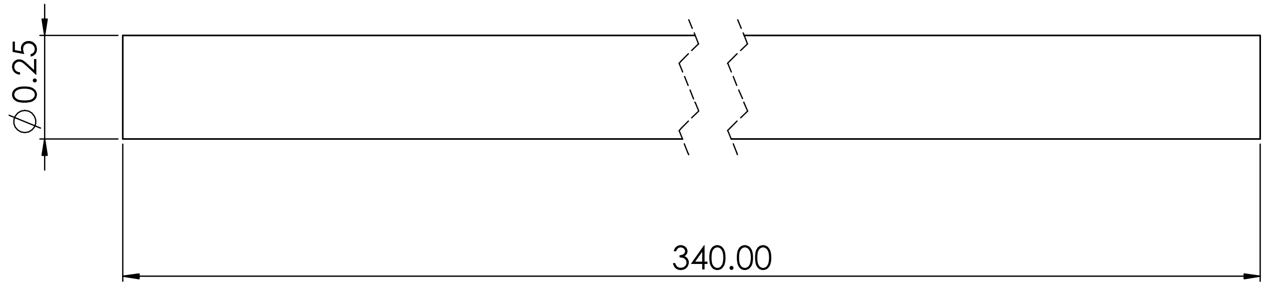
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: 201 Annealed Stainless Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Heavy Duty Steel Pulley	0
SCALE: 1:1	WEIGHT: 2.94	SHEET 13 OF 16

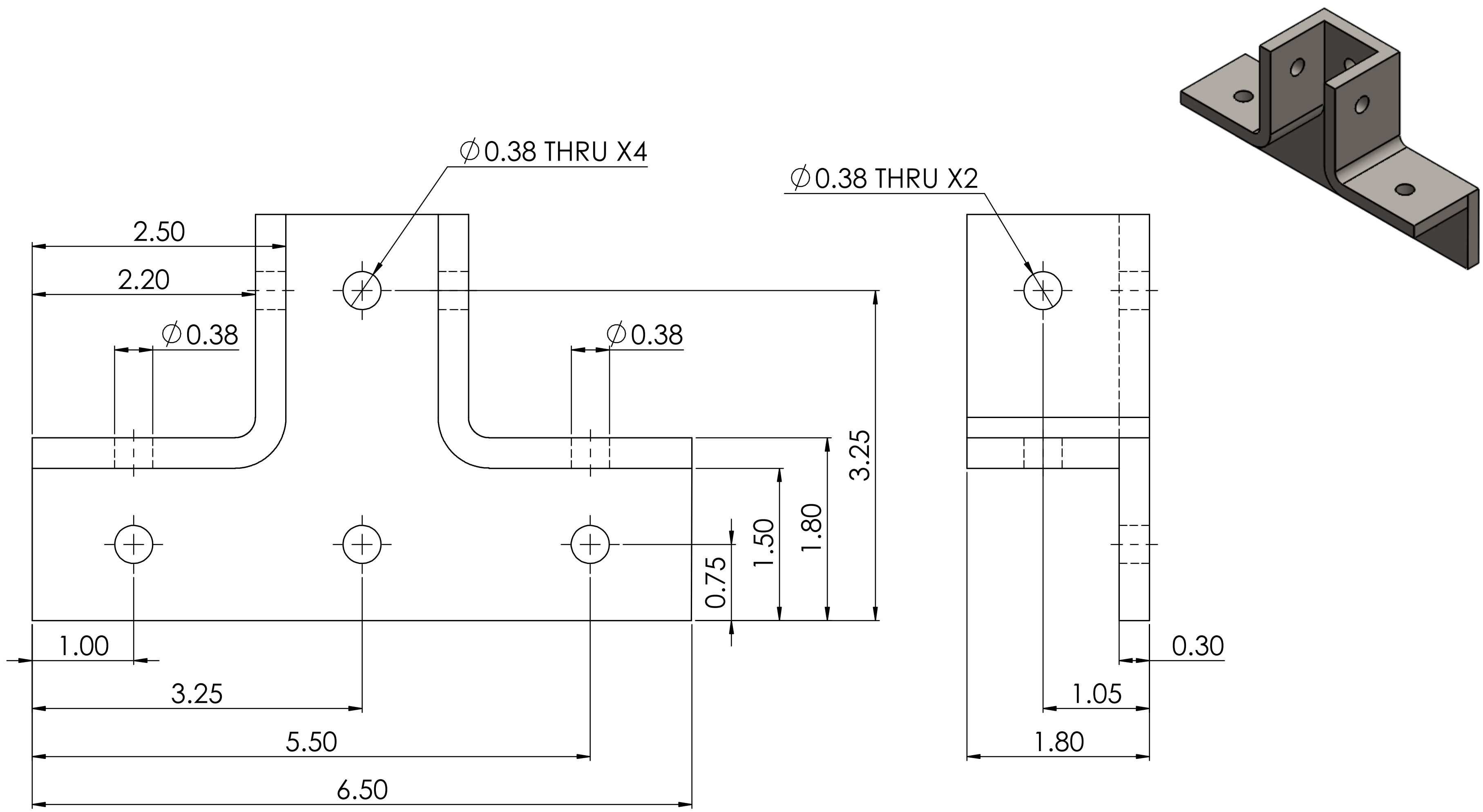


UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING		
		INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
		DO NOT SCALE DRAWING / DRAWN	Z. ZP	26/11/2015
		MATERIAL: AISI 1035 Steel (SS) / CHECKED	Z. ZP	07/12/2015
		FINISH Z. ZP / TEAM	23	

PROJECT: Guide Loop		
SIZE B	TITLE: Wire Rope	REV 0
SCALE: 1:1	WEIGHT: 4.73	SHEET 14 OF 16



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MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

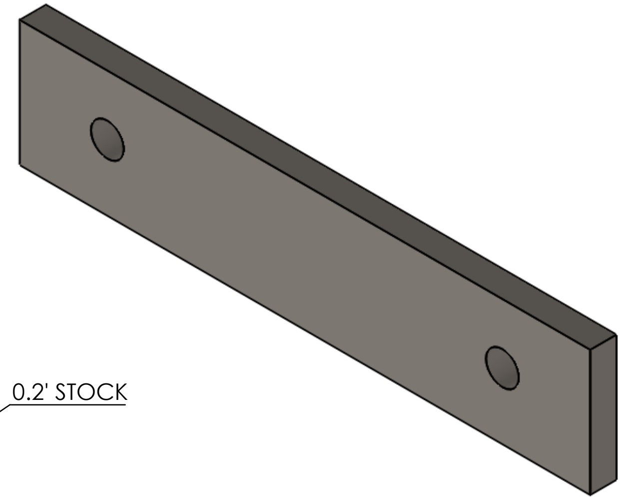
UofM MECHANICAL ENGINEERING

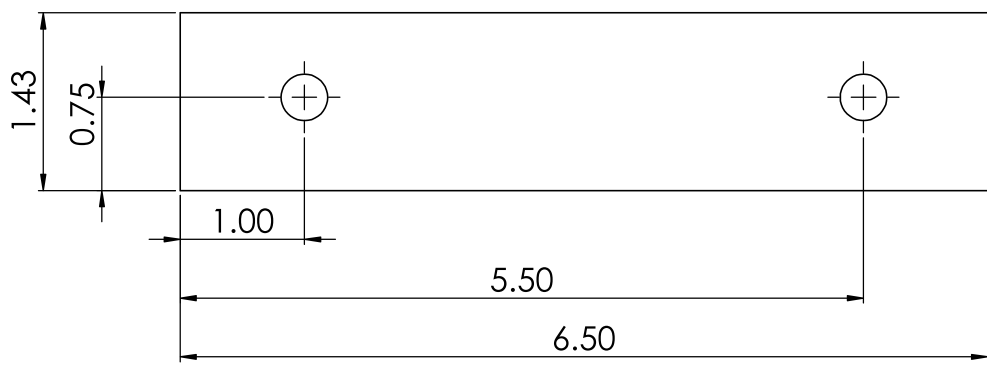
		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE **B** | TITLE: Accessory | REV 0

SCALE: 1:1 | WEIGHT: 2.48 | SHEET 15 OF 16





UNIVERSITY OF MANITOBA	MECH 4860 ENGINEERING DESIGN	PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	07/12/2015
FINISH Z. ZP	TEAM	23	

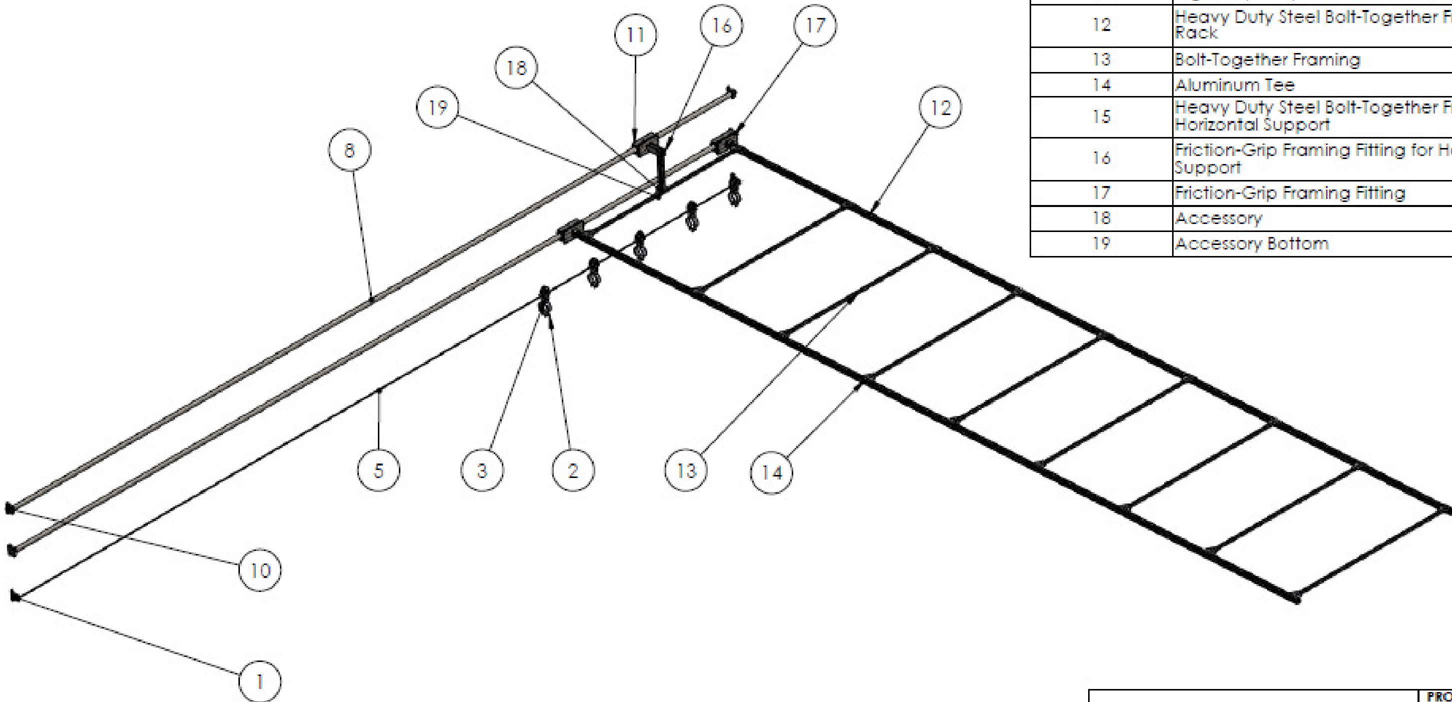
PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Accessory Bottom	0
SCALE: 1:1	WEIGHT: 0.77	SHEET 16 OF 16

B.3. Engineering Drawings of Sliding Extension Rail

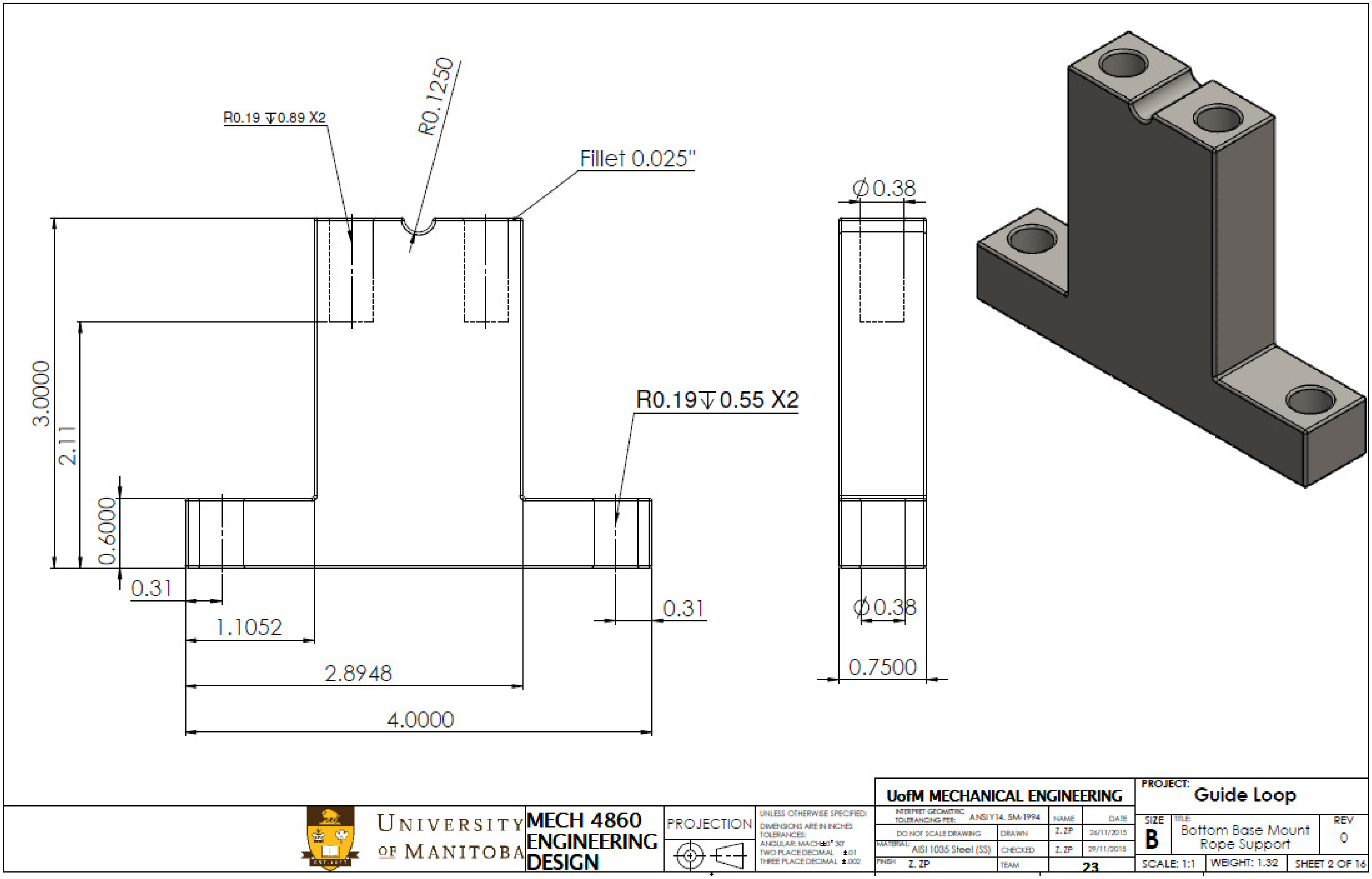
B.4. Engineering Drawings for the Guide Loops Design

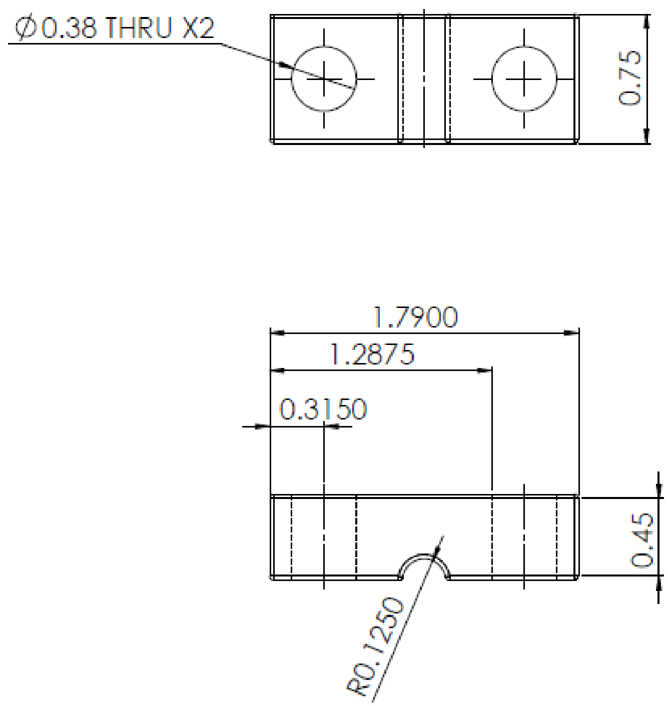
ITEM NO.	PART NUMBER	QTY.
1	Bottom Base Mount Rope Support	2
2	Hanger	5
3	Heavy Duty Steel Pulley	5
4	Top Base Mount Rope Support	2
5	Wire Rope	1
6	Bolt Nut	5
7	Hanger Bolt	5
8	Hardened Precision Shafts	2
9	Top Base Mount Shaft Support	4
10	Bottom Base Mount Shaft Support	4
11	High-Capacity Pillow-Block Linear Bearing	3
12	Heavy Duty Steel Bolt-Together Framing for Rack	2
13	Bolt-Together Framing	9
14	Aluminum Tee	18
15	Heavy Duty Steel Bolt-Together Framing for Horizontal Support	1
16	Friction-Grip Framing Fitting for Horizontal Support	1
17	Friction-Grip Framing Fitting	2
18	Accessory	1
19	Accessory Bottom	1

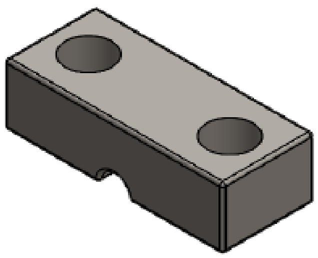


UNIVERSITY OF MANITOBA
MECH 4860 ENGINEERING DESIGN
PROJECTION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002
UofM MECHANICAL ENGINEERING
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
DO NOT SCALE DRAWING
MATERIAL:
FINISH Z. ZP
NAME DATE
DRAWN Z. ZP 26/11/2015
CHECKED Z. ZP 29/11/2015
TEAM 23
PROJECT: Guide Loop
SIZE B
TITLE: Guide Loop
REV 0
SCALE: 1:50
WEIGHT: 509.32
SHEET 1 OF 16

B.5.


R0.19 ↧0.89 X2
R0.1250
Fillet 0.025"
R0.19↧0.55 X2
3.0000
2.11
0.6000
0.31
1.1052
2.8948
4.0000
0.31
∅0.38
∅0.38
0.7500
UNIVERSITY OF MANITOBA
MECH 4860 ENGINEERING DESIGN
PROJECTION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002
UofM MECHANICAL ENGINEERING
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
NAME
DATE
DO NOT SCALE DRAWING
DRAWN
Z. ZP
26/11/2015
MATERIAL: AISI 1035 Steel (SS)
CHECKED
Z. ZP
29/11/2015
FINISH Z. ZP
TEAM
23
PROJECT: Guide Loop
SIZE
B
TITLE: Bottom Base Mount Rope Support
REV
0
SCALE: 1:1
WEIGHT: 1.32
SHEET 2 OF 16





UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

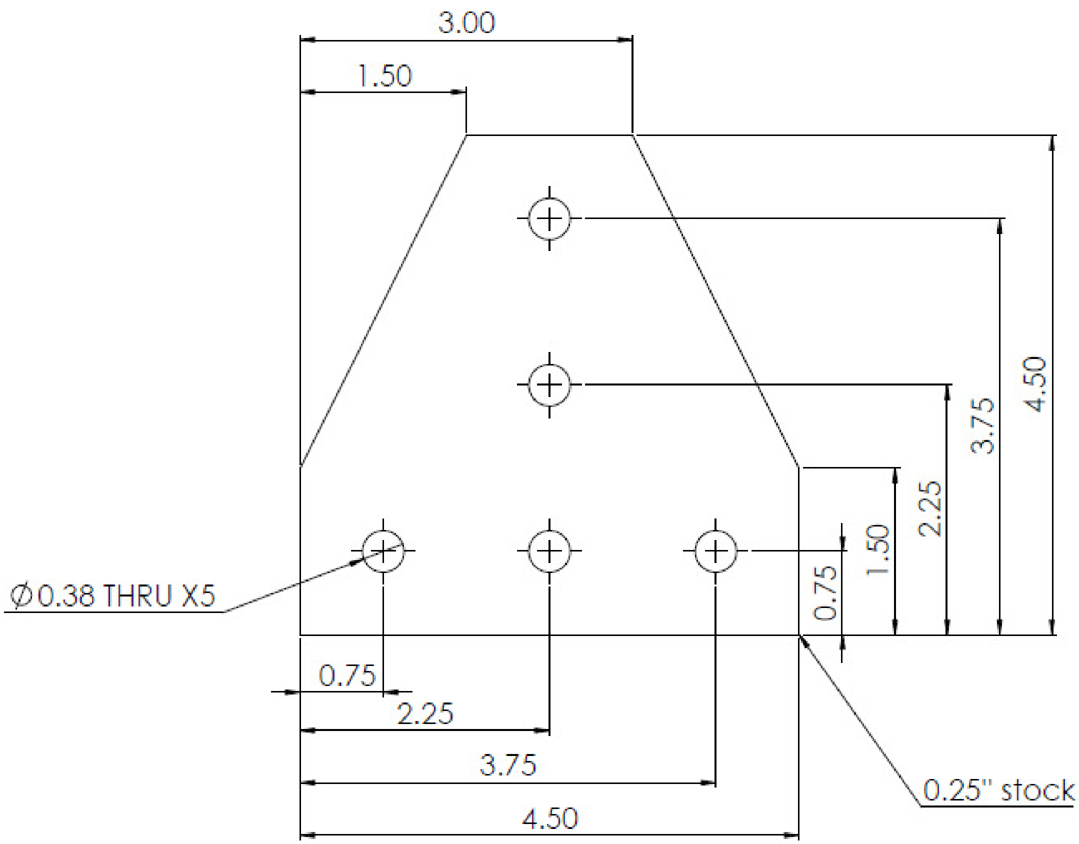
UofM MECHANICAL ENGINEERING

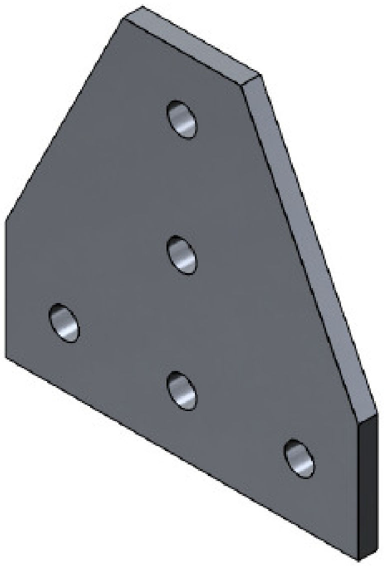
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: AISI 1035 Steel (SS)	CHECKED	Z. ZP	29/11/2015
FINISH Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE:	REV
B	Top Base Mount Rope Support	0

SCALE: 1.6:1 | WEIGHT: 0.15 | SHEET 3 OF 16





UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

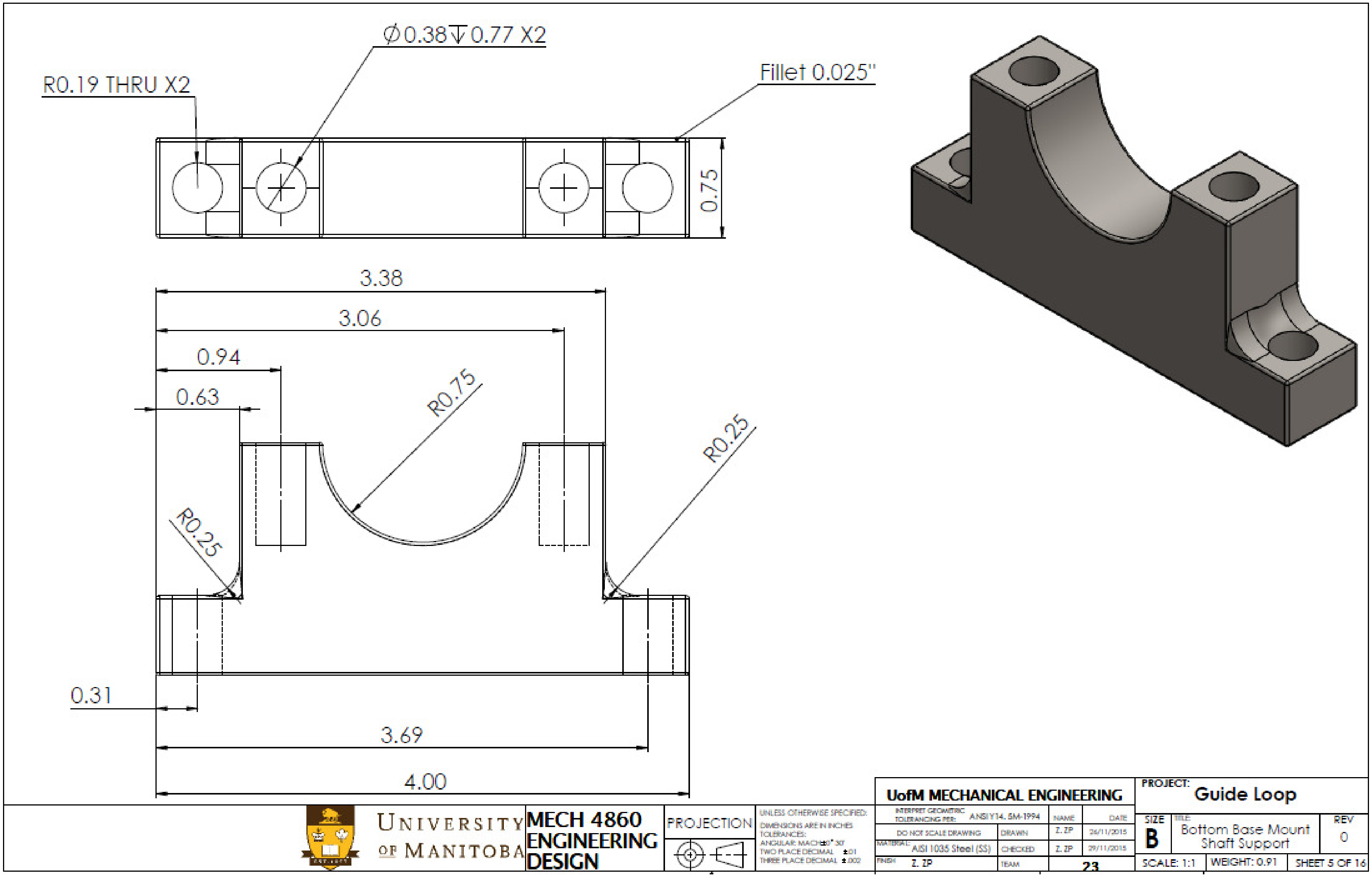
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

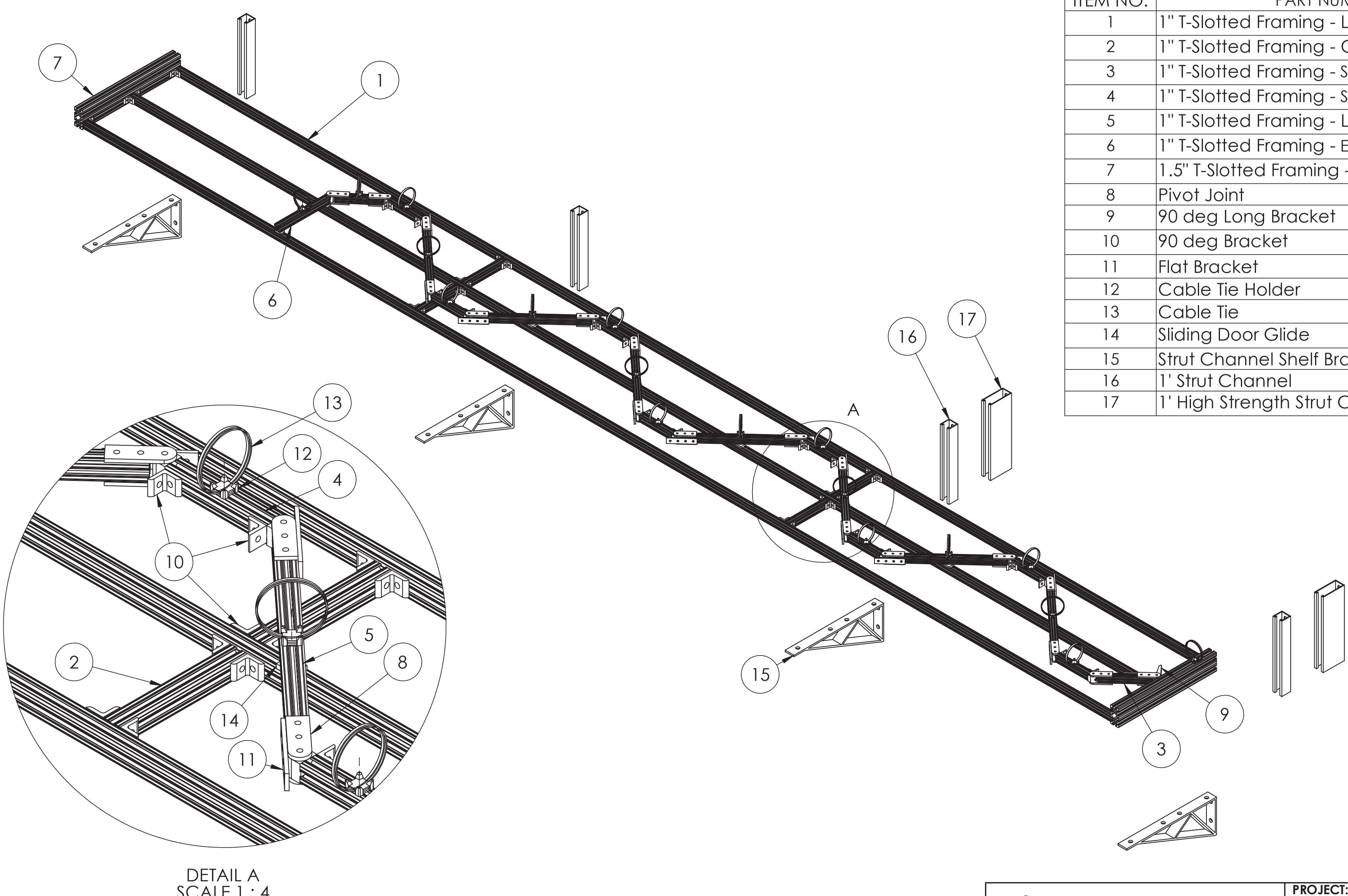
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Z. ZP	26/11/2015
MATERIAL: 6061 Alloy	CHECKED	Z. ZP	29/11/2015
FINISH: Z. ZP	TEAM	23	

PROJECT: **Guide Loop**

SIZE	TITLE	REV
B	Aluminum Tee	0
SCALE: 1:1	WEIGHT: 0.37	SHEET 4 OF 16



R0.19 THRU X2
∅0.38 ↧0.77 X2
Fillet 0.025"
0.75
3.38
3.06
0.94
0.63
R0.75
R0.25
R0.25
0.31
3.69
4.00
UNIVERSITY OF MANITOBA
MECH 4860 ENGINEERING DESIGN
PROJECTION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002
UofM MECHANICAL ENGINEERING
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
NAME
DATE
DO NOT SCALE DRAWING
DRAWN
Z. ZP
26/11/2015
MATERIAL: AISI 1035 Steel (SS)
CHECKED
Z. ZP
29/11/2015
FINISH Z. ZP
TEAM
23
PROJECT: Guide Loop
SIZE B
TITLE: Bottom Base Mount Shaft Support
REV 0
SCALE: 1:1
WEIGHT: 0.91
SHEET 5 OF 16



ITEM NO.	PART NUMBER	QTY.
1	1" T-Slotted Framing - Longitudinal Rails	3
2	1" T-Slotted Framing - Cross-Brace Rails	4
3	1" T-Slotted Framing - Starter Member	1
4	1" T-Slotted Framing - Short Member	8
5	1" T-Slotted Framing - Long Member	7
6	1" T-Slotted Framing - End Member	1
7	1.5" T-Slotted Framing - End Rails	2
8	Pivot Joint	18
9	90 deg Long Bracket	1
10	90 deg Bracket	40
11	Flat Bracket	15
12	Cable Tie Holder	18
13	Cable Tie	18
14	Sliding Door Glide	9
15	Strut Channel Shelf Bracket	4
16	1' Strut Channel	4
17	1' High Strength Strut Channel	2

UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

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TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL:

FINISH J.W.

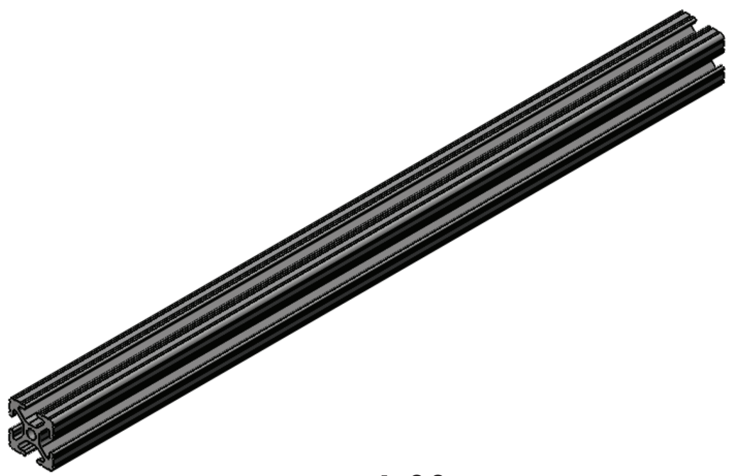
	NAME	DATE
DRAWN	J.W.	26/11/2015
CHECKED	J.W.	29/11/2015
TEAM	23	

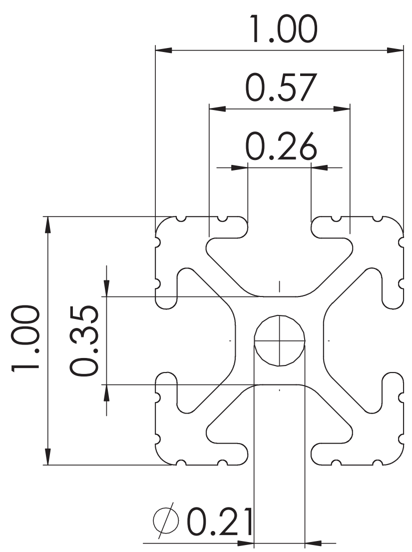
PROJECT: **Sliding Extension Rail**

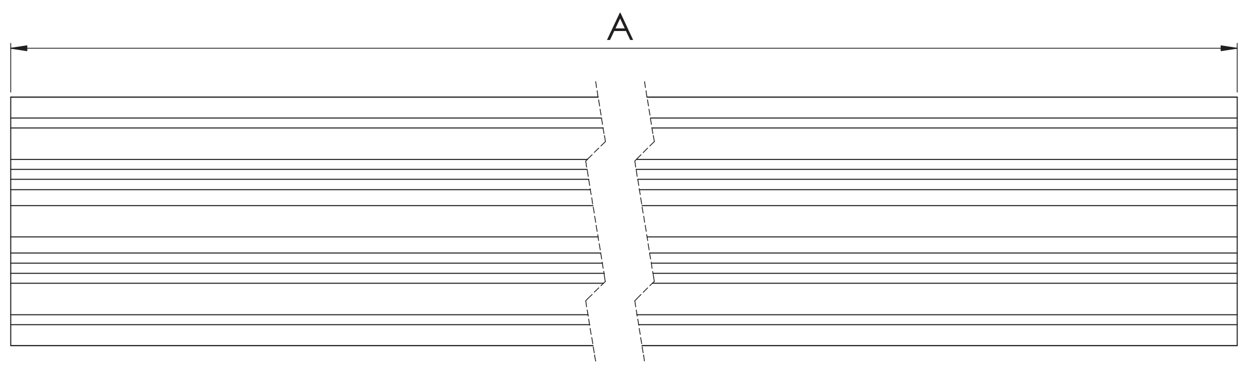
SIZE B | TITLE: Sliding Extension Rail | REV 0

SCALE: 1:50 | WEIGHT: | SHEET 1 OF 12

ITEM NO.	A
Longitudinal Rail	189.00
Cross-Brace Rail	7.50
Starter Member	7.00
Short Member	6.00
Long Member	15.25
End Member	9.25







UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

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TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL:

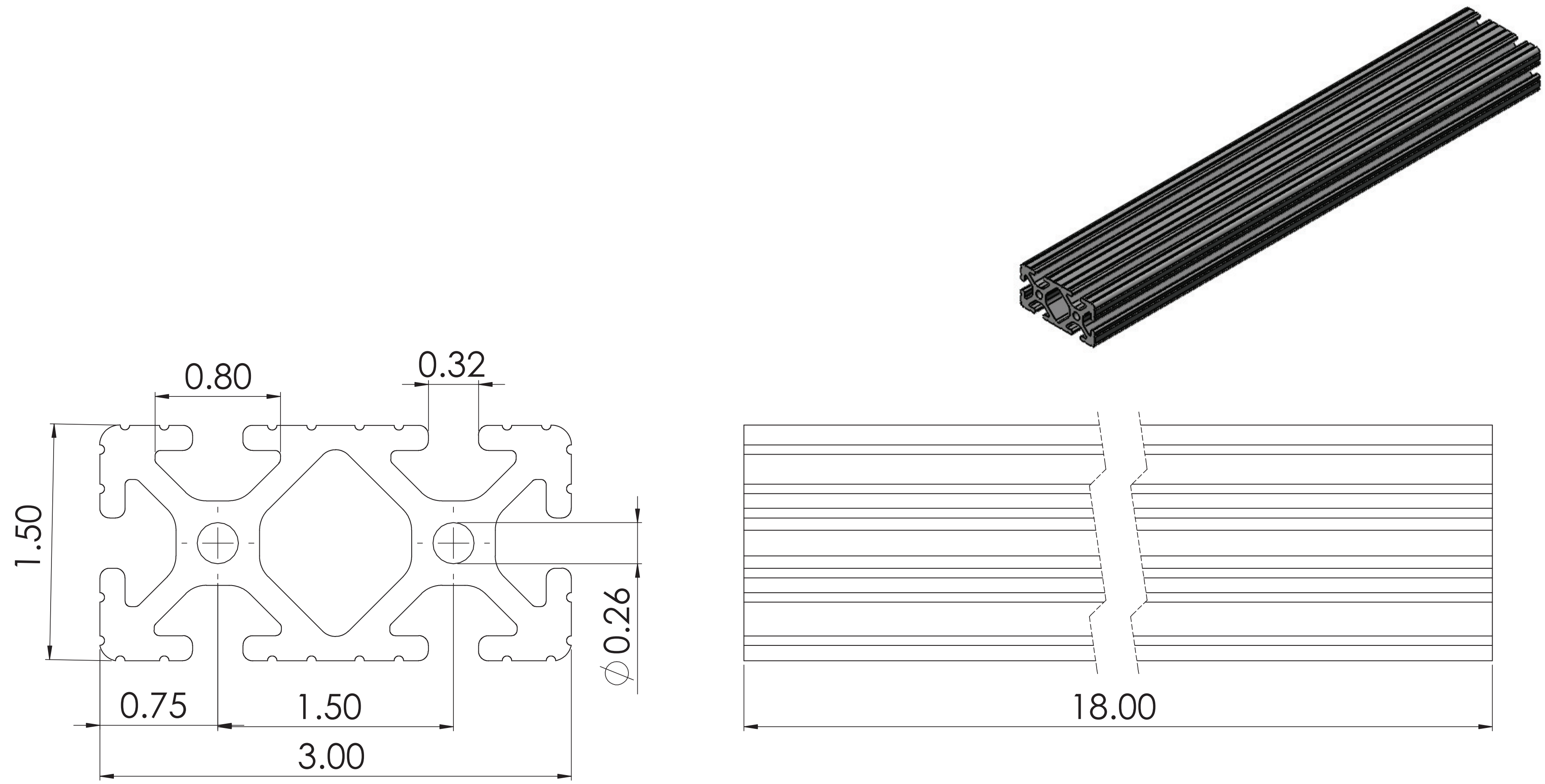
FINISH J.W.

	NAME	DATE
DRAWN	J.W.	26/11/2015
CHECKED	J.W.	29/11/2015
TEAM	23	

PROJECT: **Sliding Extension Rail**

SIZE B | TITLE: 1" T-Slotted Framing | REV 0

SCALE: 1:1 | WEIGHT: | SHEET 2 OF 12



UofM MECHANICAL ENGINEERING				PROJECT: Sliding Extension Rail
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE B	TITLE: 1.5" T-Slotted Framing
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015	REV 0
MATERIAL:	CHECKED	J.W.	29/11/2015	
FINISH J.W.	TEAM	23	SCALE: 1.6:1 WEIGHT:	SHEET 3 OF 12

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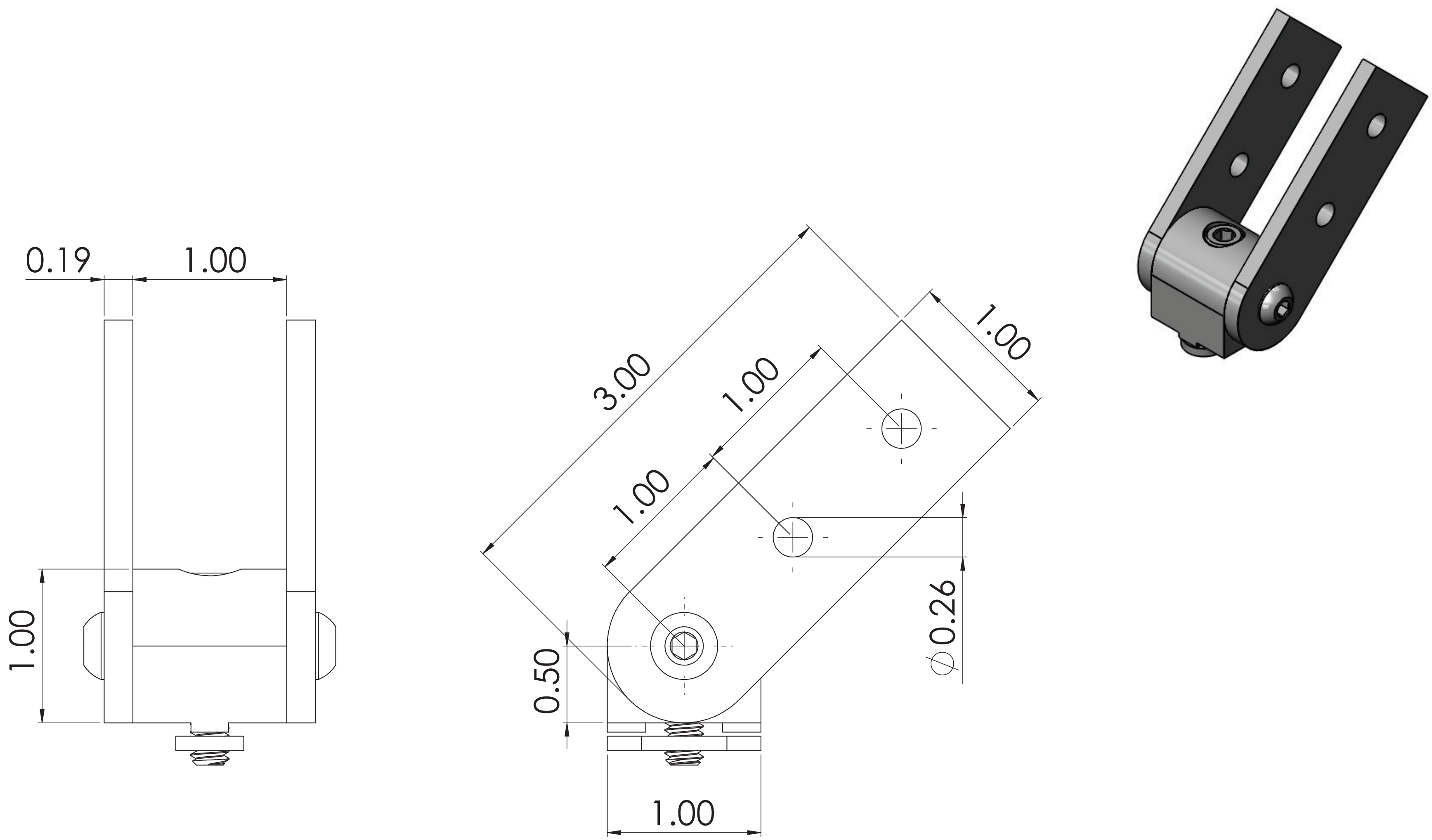
MECH 4860 ENGINEERING DESIGN

PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002



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MECH 4860 ENGINEERING DESIGN

PROJECTION

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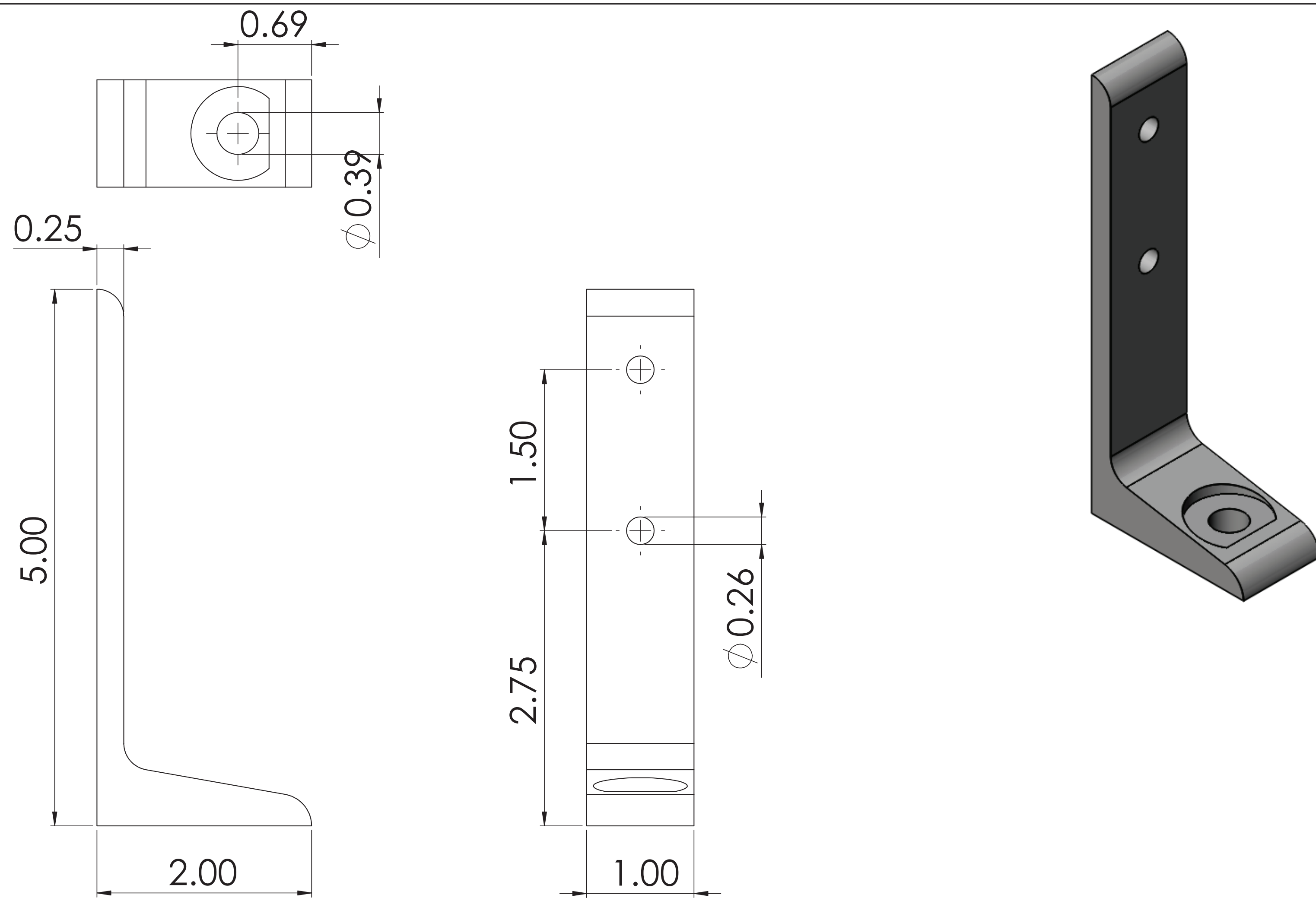
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING			
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT: Sliding Extension Rail		
SIZE B	TITLE: Pivot Joint	REV 0
SCALE: 1:1	WEIGHT:	SHEET 4 OF 12



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

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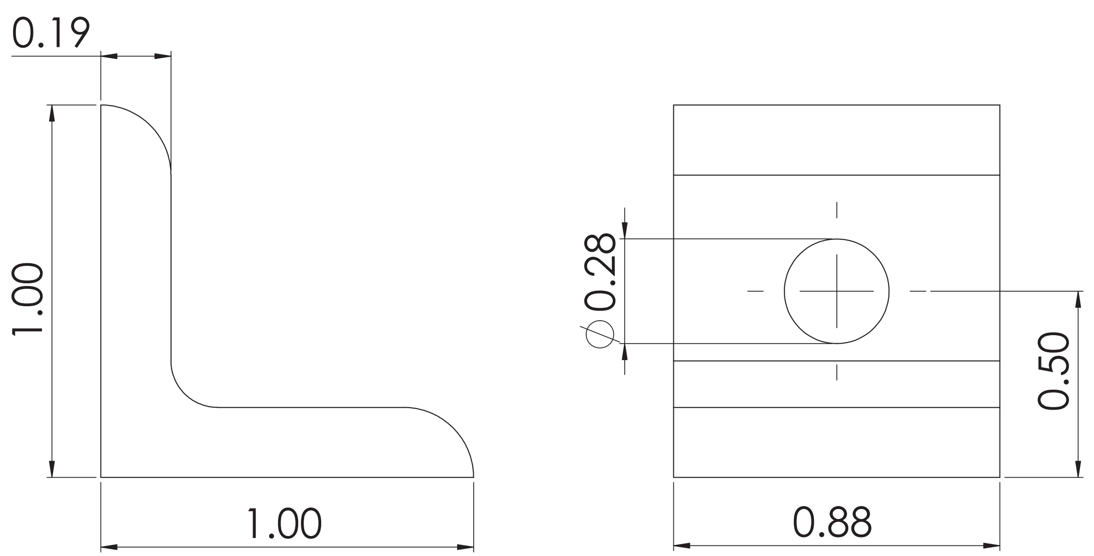
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

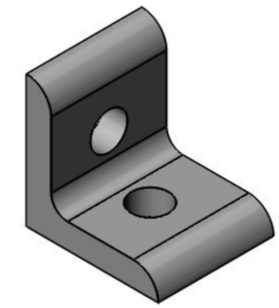
UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT: **Sliding Extension Rail**

SIZE	TITLE:	REV
B	90 deg Long Bracket	0
SCALE: 1:1	WEIGHT:	SHEET 5 OF 12





UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

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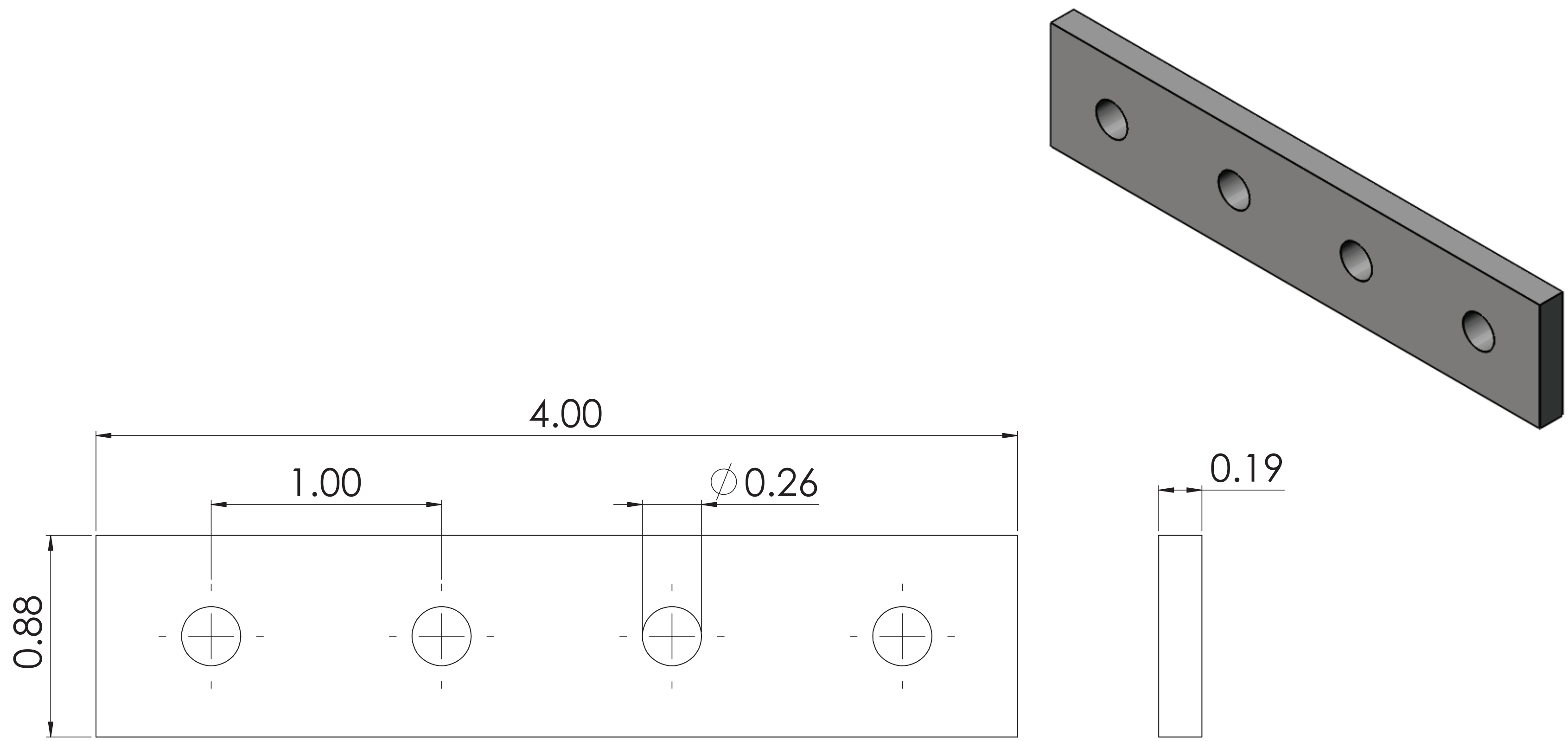
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT: **Sliding Extension Rail**

SIZE	TITLE:	REV
B	90 deg Bracket	0
SCALE: 1:1	WEIGHT:	SHEET 6 OF 12



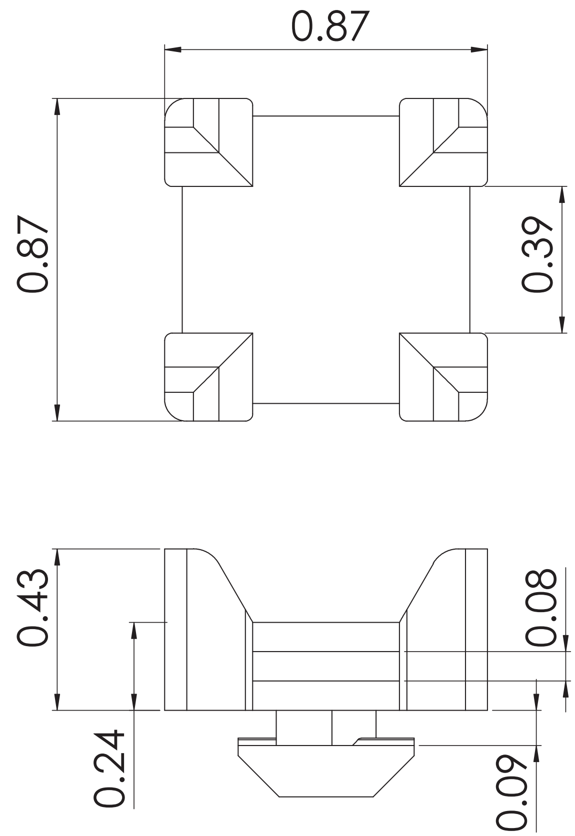
UNIVERSITY OF MANITOBA	MECH 4860 ENGINEERING DESIGN	PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002

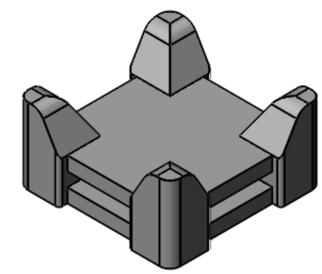
UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT: **Sliding Extension Rail**

SIZE	TITLE:	REV
B	Flat Bracket	0
SCALE: 1:1.5	WEIGHT:	SHEET 7 OF 12





UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

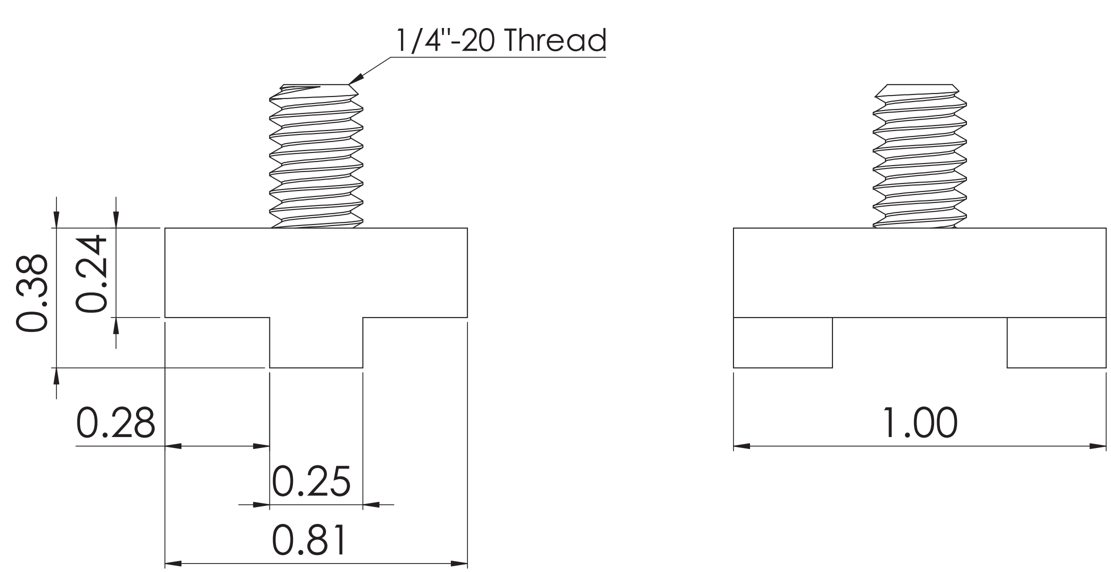
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

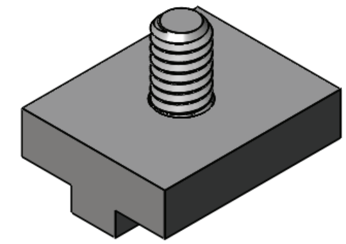
UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT: **Sliding Extension Rail**

SIZE B	TITLE: Cable Tie Holder	REV 0
SCALE: 1:1.5	WEIGHT:	SHEET 8 OF 12





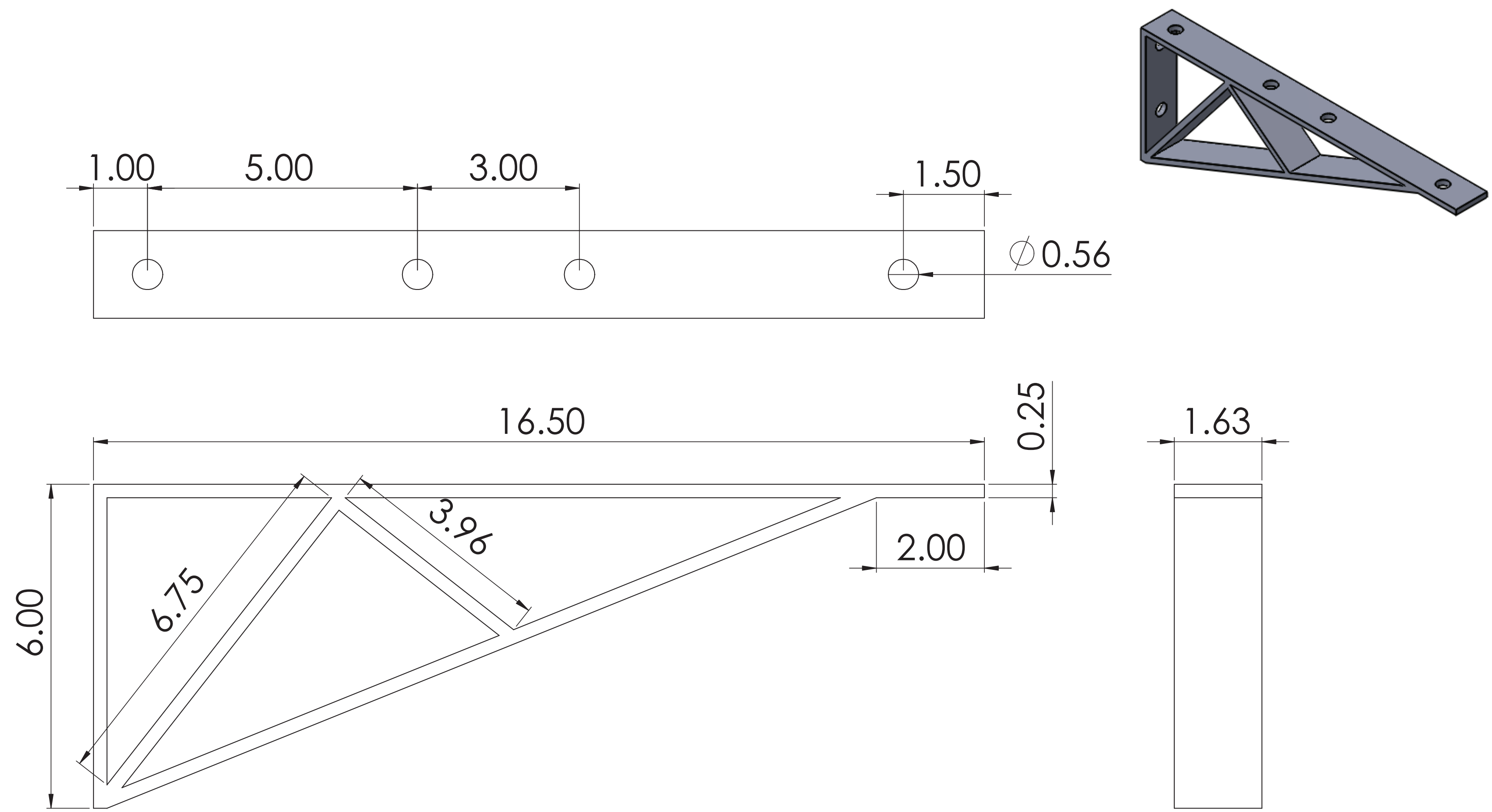
UNIVERSITY OF MANITOBA	MECH 4860 ENGINEERING DESIGN	PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

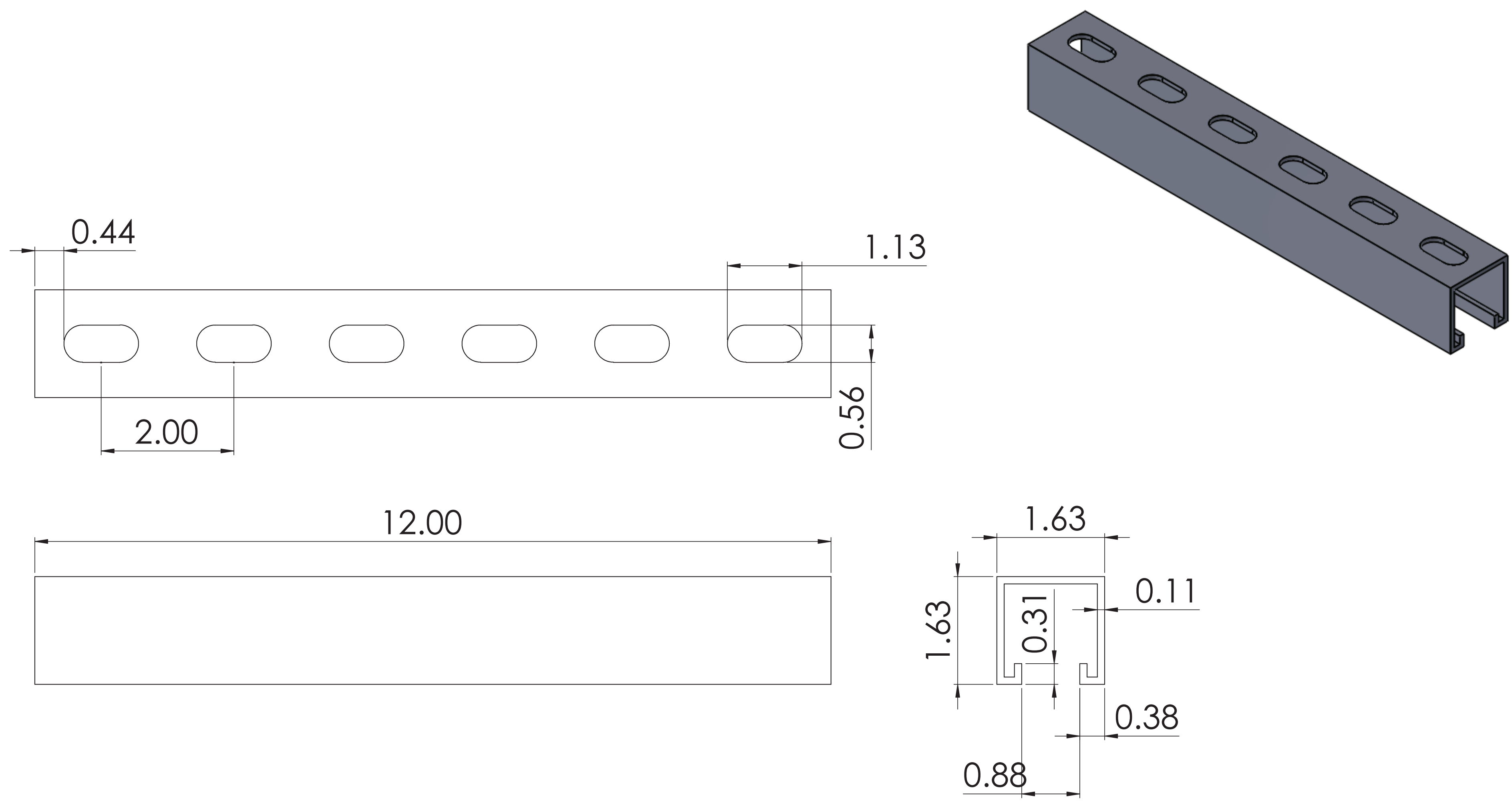
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT:
Sliding Extension Rail

SIZE	TITLE:	REV
B	Sliding Door Glide	0
SCALE: 1:1.5	WEIGHT:	SHEET 9 OF 12



UNIVERSITY OF MANITOBA	MECH 4860 ENGINEERING DESIGN	PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING		PROJECT: **Sliding Extension Rail**
				INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME / DATE	SIZE: B
				DO NOT SCALE DRAWING / DRAWN	J.W. 26/11/2015	TITLE: Strut Channel Bracket
				MATERIAL: / CHECKED	J.W. 29/11/2015	REV 0
				FINISH J.W. / TEAM	23	SCALE: 1:1.5 WEIGHT: SHEET 10 OF 12



UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

PROJECTION

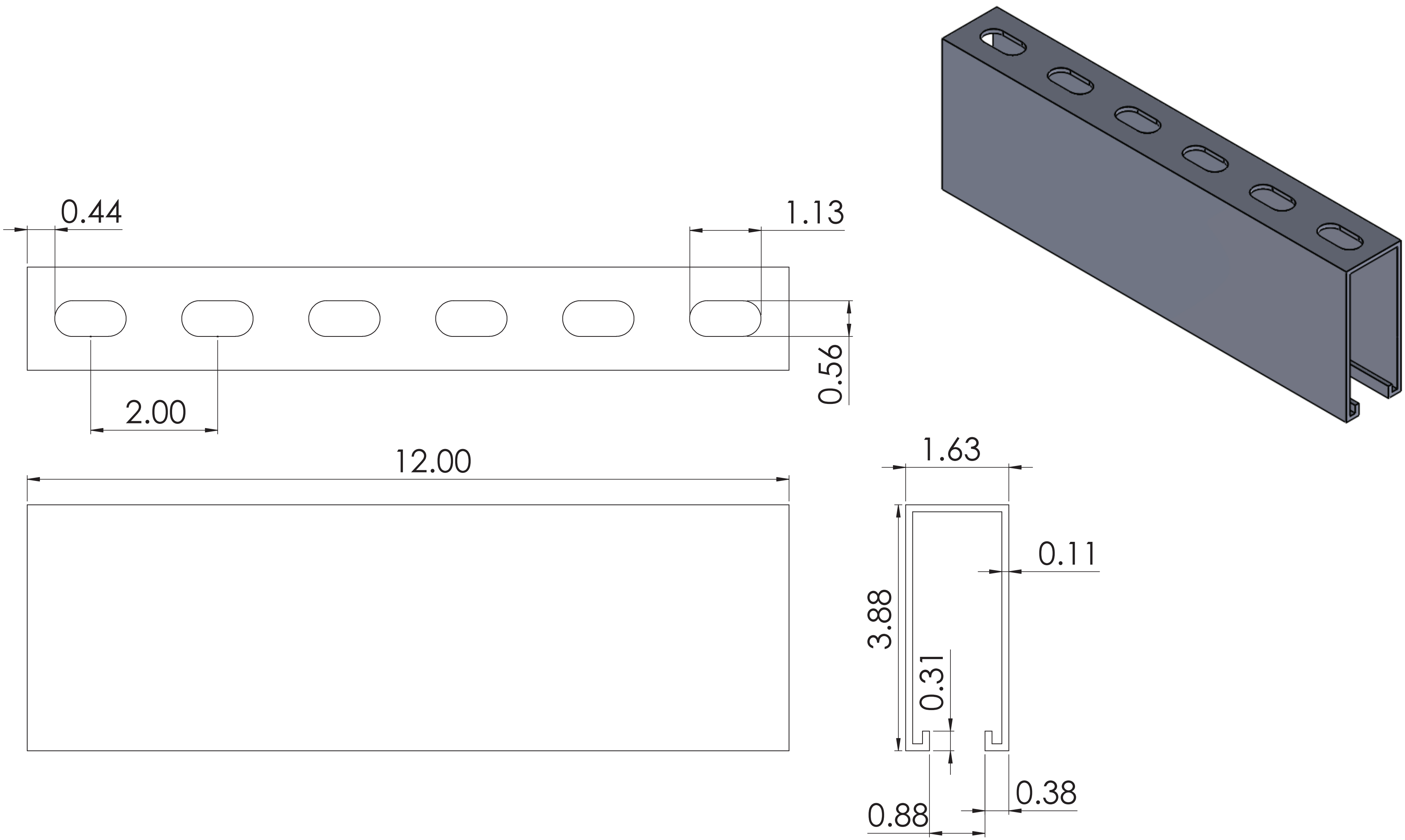
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT:
Sliding Extension Rail

SIZE	TITLE:	REV
B	1' Strut Channel	0
SCALE: 1:1.5	WEIGHT:	SHEET 11 OF 12



UNIVERSITY OF MANITOBA	MECH 4860 ENGINEERING DESIGN	PROJECTION	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	J.W.	26/11/2015
MATERIAL:	CHECKED	J.W.	29/11/2015
FINISH J.W.	TEAM	23	

PROJECT: **Sliding Extension Rail**

SIZE	TITLE:	REV
B	1' High Strength Strut Channel	0
SCALE: 1:1	WEIGHT:	SHEET 12 OF 12

Appendix C Risk Assessment

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List of Tables

C. FMEA Introduction

To identify potential hazards and to analyze its effect, the team conducted FMEA for the three designs. The failure modes were ranked based on the severity of failure, probability of occurrence, and detectability of the failure by the current design control. Risk priority number (RPN) was calculated by multiplying the three rankings. A function with a risk priority number greater than fifty was assumed to be critical and an action was recommended for that failure mode.

Each failure modes were ranked from 1 to 10 based on the severity of the failure. Safety was considered to be the most critical factor. Three scenarios were considered for the safety: failure mode gives warning, failure mode does not give warning, and the failure mode does not compromise safety. The failure mode that affects the safe system operation without warning was given the highest ranking of 10 while if there is no effect of the failure, a ranking of 1 is given to the failure mode. Table I provides the ranking matrix for the severity of the failure mode.

TABLE I: SEVERITY RANKING [1]

Effect	SEVERITY of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning	**10**
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe system operation with warning	**9**
Very High	System inoperable with destructive failure without compromising safety	**8**
High	System inoperable with equipment damage	**7**
Moderate	System inoperable with minor damage	**6**
Low	System inoperable without damage	**5**
Very Low	System operable with significant degradation of performance	**4**
Minor	System operable with some degradation of performance	**3**
Very Minor	System operable with minimal interference	**2**
None	No effect	**1**

After identifying the failure effects, potential causes of the failure were identified and were ranked based on the probability of failure. 10 scenarios of occurrence were identified and hence, the probability was ranked from 1 to 10. If the probability of failure is greater than 1 in 2 cases, a ranking of 10 was given to this failure while if the probability of failure is less than 1 in 1,500,000 cases, a ranking of 1 was assigned to the failure. Table II provides the ranking matrix for the probability of the failure mode.

TABLE II: PROBABILITY OF OCCURRENCE RANKING [1]

PROBABILITY of Failure	Failure Probability	Ranking
Very High: Failure is almost inevitable	>1 in 2	**10**
	1 in 3	**9**
High: Repeated failures	1 in 8	**8**
	1 in 20	**7**
Moderate: Occasional failures	1 in 80	**6**
	1 in 400	**5**
	1 in 2,000	**4**
Low: Relatively few failures	1 in 15,000	**3**
	1 in 150,000	**2**
Remote: Failure is unlikely	<1 in 1,500,000	**1**

Moreover, any design controls in the current design were identified and were ranked based on their detectability of the failure mode. If the current design control can certainly detect the failure, lowest ranking of 1 was assigned while if the control absolutely cannot detect the failure, highest ranking of 10 was given. Table III provides the ranking matrix for the detectability of the failure mode.

TABLE III: DETECTABILITY RANKING [1]

Detection	Likelihood of DETECTION by Design Control	Ranking
Absolute Uncertainty	Design control **cannot** detect potential cause/mechanism and subsequent failure mode	**10**
Very Remote	**Very remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	**9**
Remote	**Remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	**8**
Very Low	**Very low** chance the design control will detect potential cause/mechanism and subsequent failure mode	**7**
Low	**Low** chance the design control will detect potential cause/mechanism and subsequent failure mode	**6**
Moderate	**Moderate** chance the design control will detect potential cause/mechanism and subsequent failure mode	**5**
Moderately High	**Moderately High** chance the design control will detect potential cause/mechanism and subsequent failure mode	**4**
High	**High** chance the design control will detect potential cause/mechanism and subsequent failure mode	**3**
Very High	**Very high** chance the design control will detect potential cause/mechanism and subsequent failure mode	**2**
Almost Certain	Design control **will** detect potential cause/mechanism and subsequent failure mode	**1**

Using these matrices, FMEA for the three designs were created. The FMEA for the cable drag chain is discussed in section C.1, the FMEA for the guide loops is discussed in C.2, and the FMEA for the sliding extension rail is discussed in section C.3.

C.1. Cable Drag Chain FMEA

A failure mode analysis was performed for the components of the cable drag chain design by considering the various ways the design might fail. An RPN value of greater than fifty was considered to be critical and an immediate action to the failure mode must be taken before constructing the model. Table IV shows all the possible failure modes considered for the drag chain design.

TABLE IV: CABLE DRAG CHAIN FMEA

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
1	Acoustic wall	Wall unable to handle the weight	Hole in the wall	9	Heavy drag chain	3	Drag chain rack	3	**81**	Install support structure
2	Cable drag chain mount to drag chain rack	Connection will not sustain/ drag chain might fall	Failure of the interface system, safety issues, unmanaged wires	9	Fitting not held in place/loose bolts	4	Support rack	1	**36**	
3	Cable drag chain mount to instrumentation rack	Instrumentation rack will fall	Failure of the interface system, safety issues, unmanaged wires	9	Fitting not held in place/loose bolts	4	Mounting bracket	5	**180**	Install support structure
4	Cable chains	Damaged internal links	System fall apart, unable to hold cables	6	Components not inspected	1	Inspection of the order	2	**12**	
5	Cable drag chain	Breaking	Unmanaged cables	8	Material requirement overlooked	3		2	**48**	
6	Cable drag chain	Cables entangled	Increased time for testing, system failure	7	Improper fixing of cable	3	Path through instrumentation rack	2	**42**	
7	Cable drag chain	Cannot contain large number of cables	Customer requirements not met	4	Requirement overlooked	7	Determination of number of cables to be contained	4	**112**	Obtain size requirements
8	Cable drag chain	Bends more than allowable limit	Kinks, twists in cable	7	Overpressure	6	Specified minimum radius of curvature	1	**42**	
9	Cable drag chain	Corrosion	Cannot sustain, wires jam	7	Material, requirements overlooked	3	Weather resistant cable chains	2	**42**	
10	Drag chain rack	Breaking	Cable drag chain not supported	8	Material, requirements overlooked	3	Rectangular rack, supporting leg, metal	1	**24**	

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
11	Drag chain rack	Cables get entangled in the rack	Increased time for testing	7	Improper fixing of cables in the drag chain	4	Cables contained within drag chain	1	**28**	
12	Cable drag chain	Two drag chains collide	Breaking of the chains	7	Spacing between the chains	4	Minimum distance between power cables and instrumentation cables are met	3	**84**	Spacing between drag chains is half of the length of the chains
13	90 degrees bend of cables to the wind tunnel through drag chains	Sharp bending of cables	Cables break	4	Overpressure	3	Support at the bend	5	**60**	Increase angle at the bend
14	Mounting plate	Bends	Bolts loosens	8	Overpressure	3	Aluminum plate	2	**48**	

As shown in Table IV, the team identified a total of 14 failure modes for the drag chain design. The critical failure modes with RPN greater than fifty are highlighted with the orange color. The cable drag chain mount to the instrumentation rack scored a RPN value of 180. This scoring is based on the fact that this connection is the most important connection in the design, the result of which the drag chain is able to adjust to the change in the wind tunnel position. Therefore, in order to maintain the functionality of the design, the mount must be securely fixed and the bolts should be tight.

C.2. Guide Loops Rail FMEA

A failure mode analysis was performed for the components of the guide loops design considering the various ways the design might fail. An RPN value of greater than fifty was considered to be critical and an immediate action to the failure mode must be taken before constructing the model. Table V shows all the possible failure modes considered for the guide loops design.

TABLE V: GUIDE LOOPS FMEA

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
1	Hardened Precision Shaft mount	Connection will not sustain, shaft might fall	Failure of the interface system	6	Fitting not held in place	3	Shaft support	4	**72**	Secure connecting locks
2	Hardened Precision Shaft mount to the acoustic wall	Connection will not sustain, shaft might fall	Failure of the interface system	6	Heavy shaft	2	Stainless steel material fixed at both ends	2	**24**	
3	Hardened Precision Shaft	Corrosion	Framing support unable to slide smoothly	3	Material requirement overlooked	3	Stainless steel material fixed at both ends	1	**9**	
4	Hardened Precision Shaft	Bending	Framing support unable to slide smoothly	6	Material requirement overlooked	3	Hollow shafts	2	**36**	
5	Wire Rope	Corrosion	Cables jammed	7	Material requirement overlooked	3	ASTM A1023 Steel	2	**42**	
6	Wire Rope	Rotation of the wire rope	Cables get entangled	4	Material requirement overlooked	3	ASTM A1023 Steel	5	**60**	Use 19X7 rotation resistant - wire stand core
7	Wire Rope	Ropes break	Guide loops fall, cables unmanaged	7	Material requirement overlooked	3	ASTM A1023 Steel	2	**42**	
8	Wire Rope	Abrasion	Guide loops unable to slide	6	Material requirement overlooked	3	ASTM A1023 Steel	2	**36**	
9	Wire Rope	Cannot sustain load of cables, pulley and hangers	Wire rope mount falls off	7	Material requirement overlooked	3	ASTM A1023 Steel	2	**42**	
10	Wire Rope	Unable to hold pulley and hangers	Pulleys and hangers fall, cables unmanaged	7	Material requirement overlooked	3	ASTM A1023 Steel	2	**42**	
11	Pulley	Corrosion	Loop cannot slide	6	Material requirement overlooked	3	Aluminum	2	**36**	
12	Pulley	Rotates	Cables entangle	4	Wire rope smaller than the pulley	2	Flat plate pulley balancer	2	**16**	

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
13	Pulley	Pulley's attachment to hanger loosens	Hangers fall	5	Loose fitting	3	Bolts	3	**45**	
14	Hanger	Cables are crammed	Cables cannot slide	6	Small loop diameter	2	Diameter of loop slightly greater than cable diameter, 4"	2	**24**	
15	Hanger	Corrosion	Cables cannot slide smoothly	3	Material requirement overlooked	3	Aluminum	2	**18**	
16	Hanger	Cables get entangled	Increased time for testing, system failure	7	Distance between two loops overlooked	2	Connected pulleys	2	**28**	
17	Horizontal Framing Support	Rack rotates	Unnecessary lengthening of cables, connection to the wind tunnel degrades, cables might break	9	Framing support is not accurately positioned	3	Framing support connected perpendicular to the rack, the rack is supported by shafts	2	**54**	Additional support structure for the rack
18	Horizontal Framing Support	Breaks	Rack rotates	9	Material requirement overlooked	3	Hollow aluminum frame	1	**27**	
19	Rack	Bends	Degraded performance of the system	4	Material requirement overlooked	3	Hollow aluminum frame	1	**12**	
20	Rack	Rotates	Unnecessary lengthening of cables, connection to the wind tunnel degrades, cables might break	9	No support structure	2	Horizontal framing support	1	**18**	
21	Rack	Corrosion	Cables cannot slide smoothly	3	Material requirement overlooked	3	Hollow aluminum frame	3	**27**	
22	Block Linear Bearing	Corrosion	Rack cannot slide smoothly	4	Material requirement overlooked	3	Aluminum	2	**24**	
23	Wire Rope Support	Connection will not sustain	Wire rope falls	8	Fitting not held in place	3	Bolt and screw	3	**72**	Ensure connections are tight

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
24	Frame Fitting	Fitting loosens	Rack disassembles	8	Fittings not secured	3	Bolt and screw	3	**72**	Ensure connections are tight

As shown in Table V, the team identified a total of 24 failure modes for the guide loops design. The critical failure modes with the RPN value of greater than fifty are highlighted with the orange color. Three failure modes score an RPN value of 72. This implies that the three modes are equally critical. The failure modes correspond to the connection of the hardened shaft to the acoustic wall, connection of the wire rope, and fittings of the frame. These connections ensure that the design is intact and that the operation of the interface system is safe. Therefore, these connections must be secured and must be inspected before operating the system. Moreover, corrosion of the hardened precision shaft has the lowest RPN value of 9. This RPN value is based on the fact that the system can operate even if there is corrosion. However, the extent of the corrosion must be determined and action must be taken accordingly. This action might include replacing the shaft with a new shaft.

C.3. Sliding Extension Rail FMEA

A failure mode analysis was performed for the components of the sliding extension rail design by considering the various ways the design might fail. An RPN value of greater than 50 was considered to be critical and therefore, an immediate action to the failure mode must be taken before constructing the model. Table VI shows all the possible failure modes considered for the guide loops design.

TABLE VI: SLIDING EXTENSION RAIL FMEA

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
1	Acoustic wall	Unable to handle the racks	Hole in the wall	9	Heavy rail racks, materials overlooked	3	light weight rack materials	2	**54**	Follow standards
2	Length of rail rack	Not able to fit in the acoustic wall	Extra support needs to be designed to accommodate the extra length	2	Requirement overlooked	2	Length smaller than the wall length from the wind tunnel.	1	**4**	
3	Rail racks in parallel	Wall unable to handle the total weight	Hole in the wall	9	Heavy total weight, materials overlooked	3	Additional support	2	**54**	Follow standards
4	Rail racks in parallel	Unable to connect all the cables to the instrumentation rack	Design not functional	5	Design overlooked	2	Two rail racks	4	**40**	
5	Material of rail rack	Unable to withstand extreme weather range	Material become brittle, Crack in the rails	9	Material requirement overlooked	2	Use of aluminum alloy	2	**36**	
6	Material of rail rack	Unable to withstand extreme weather range	Corrosion of material, Rails unable to slide	6	Material requirement overlooked	2	Use of aluminum alloy	2	**24**	
7	Zip-tie	Cables not held in place	Cable won't slide smooth, might get caught in the rail	4	Large cable to zip-tie diameter ratio	3	Diameter of zip-tie is equal to the diameter of the cable	3	**36**	
8	Zip-tie	Wearing of cables	Losses from the cable	4	Diameter of zip-tie is equal to the diameter of the cable	3	Use of nylon	4	**48**	
9	Zip-tie clip	clip comes off	Cables are not secured to the path	7	Clips not secured	3	Screw zip-tie to the rail	3	**63**	Quality check
10	Hinge	Unable to connect rails	System disassembles	8	Hinge is not securely connected	4	Use of available manufacturer's hinge	5	**160**	Insure hinge is secured

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
11	Hinge	Unable to move	Rails will not slide and extend	6	Corrosion of the material, material overlooked	4	Use of aluminum alloy	2	**48**	
12	Hinge	Bends less than 90 degrees	Two rails collide, cables get caught in the rails	4	No control system in place	5	Use of 90 degree bracket	1	**20**	
13	Hinge	Bends more than 180 degrees	Cables go off track, cables gets stretched	4	No control system in place	5	Use of flat plate	1	**20**	
14	Hinge	Breaks	Two rails collide, cables get caught in the rails	6	Material becomes brittle, material overlooked	4	Use of aluminum alloy	2	**48**	
15	90 degree bracket mount	Mount comes off	Hinges bends less than 90 degrees	4	Mount not secured	3	Bolt the bracket to the rail	3	**36**	
16	90 degree bracket	Bending of the bracket	Hinges bends less than 90 degrees	4	Stress	4	Use of aluminum alloy	2	**32**	
17	90 degree bracket	Wearing of the bracket	Hinges bends less than 90 degrees	4	Corrosion of the material, material overlooked	4	Use of aluminum alloy	2	**32**	
18	90 degree bracket	Breaks	Hinges bends less than 90 degrees	4	Material becomes brittle, material overlooked	4	Use of aluminum alloy	2	**32**	
19	Flat plate	Connection loosens	Hinges bend more than 180 degrees	4	Connection not secured	3	Screw the bracket to the rail	3	**36**	
20	Flat plate	Bending	Hinges bend more than 180 degrees	4	Stress	2	Use of aluminum alloy, connection to hinge	3	**24**	
21	Flat plate	Breaks	Hinges bend more than 180 degrees	4	Becomes brittle, material overlooked	4	Use of aluminum alloy	2	**32**	

#	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
22	Flat plate	Wears off	Hinges bend more than 180 degrees	4	Corrosion of the material, material overlooked	4	Use of aluminum alloy	2	**32**	
23	Plastic sliding guide	Connection to rail track loosens	Rail will not move in its path	3	Connection not secured	4	Screw the guide to the rail	3	**36**	
24	Plastic sliding guide	Unable to withstand extreme weather range, it cracks	Rail will not move in its path	3	Material requirement overlooked	4	Use of Ultra High Molecular Weight Polyethylen e	2	**24**	
25	Rail track	Sliding guide falls	Rail will not move in its path	3	Size smaller than the sliding guide	2	Width of track is greater than the width of sliding guide	1	**6**	
26	Rail track	Sliding guide cannot slide	Rail will not move in its path	4	Corrosion of the material, material overlooked	4	Use of aluminum alloy	2	**32**	
27	Rail track	Cracks	Rail will not move in its path	4	Material becomes brittle, material overlooked	4	Use of aluminum alloy	2	**32**	
28	Rail track	Bends	Obstruction in sliding of rails	4	Heavy weight of cables, material overlooked	4	Use of aluminum T-slotted frame	2	**32**	
29	Shelf bracket	Corrodes	Bracket unable to hold the rack	6	Material requirement overlooked	4	Zinc-plated steel	2	**48**	
30	Shelf bracket	Bends	Position of the rack changes, cables might not connect properly	4	Material requirement overlooked	4	Zinc-plated steel	2	**32**	
31	Shelf bracket	Connections loosens	Extension rail rack falls	9	Connections not held tight	3	Use of blts	4	**108**	Tighten the bolts, welding if possible

As shown in Table VI, the team identified a total of 31 failure modes for the sliding extension rail design. The critical failure modes with the RPN value of greater than fifty are highlighted with the orange color. A failure mode corresponding to the hinge scored an RPN value of 160. If these hinges are not secured, they fail to assemble the rail. Since the key feature of the design is the sliding rail, disconnection of these connections causes system to fail. Moreover, failure mode corresponding to the shelf bracket scored 108. Shelf brackets support the rack and connect the rack to the acoustic wall. If the brackets fail, the system will also fail.

C.4. FMEA Summary

From the FMEA analysis of the three designs, we can conclude that since the sliding extension rail design has many components interacting together, this design has higher chances of failure than the other designs. Moreover, the connecting points between two interacting components have higher modes of failure. As the components interact together to create the entire system, it is crucial to ensure that these connections are securely held. All of these three designs use bolts to connect the interacting components. Therefore, these connections must be inspected prior to the use of the designs and must ensure that they are tightly fit.

C.5. References

[1] A. Dembski. (July 31, 1998). *FMEA* [Online]. Available: http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&ved=0ahUKEwjGpJSIkMPJAhVTpoMKHT8mARkQFggtMAU&url=http%3A%2F%2Fwww.lehigh.edu%2F~intribos%2FResources%2FFMEA-template.xls&usg=AFQjCNELyhPgcP0qqfRUilLlO5adye1pBA. [November 16, 2015].

Appendix D Installation Guidelines

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D.1. Cable Drag Chain

D.1.1. Support Rack Brackets

- Mount I-channel steel brackets to acoustic wall as shown.

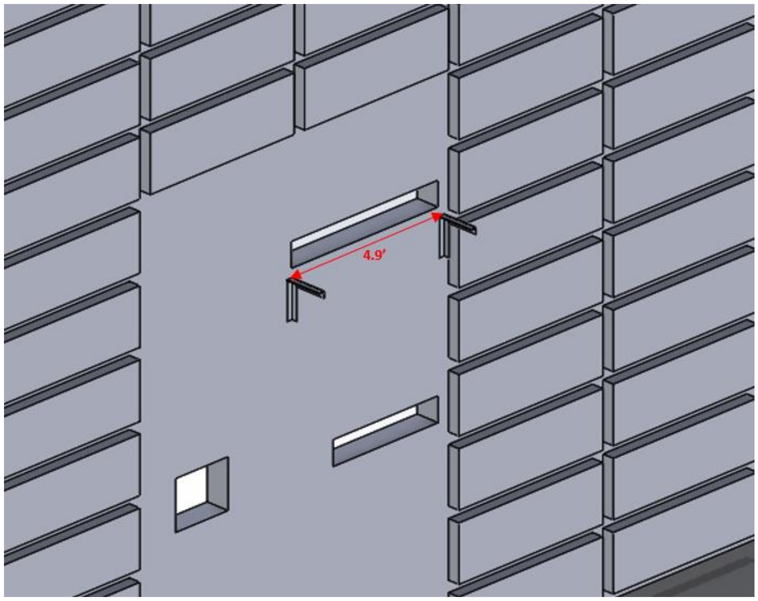

Figure 1: I-channel steel bracket locations.

D.1.2. Drag Chain Support Rack

- Mount drag chain support rack to the tops of support brackets as shown.

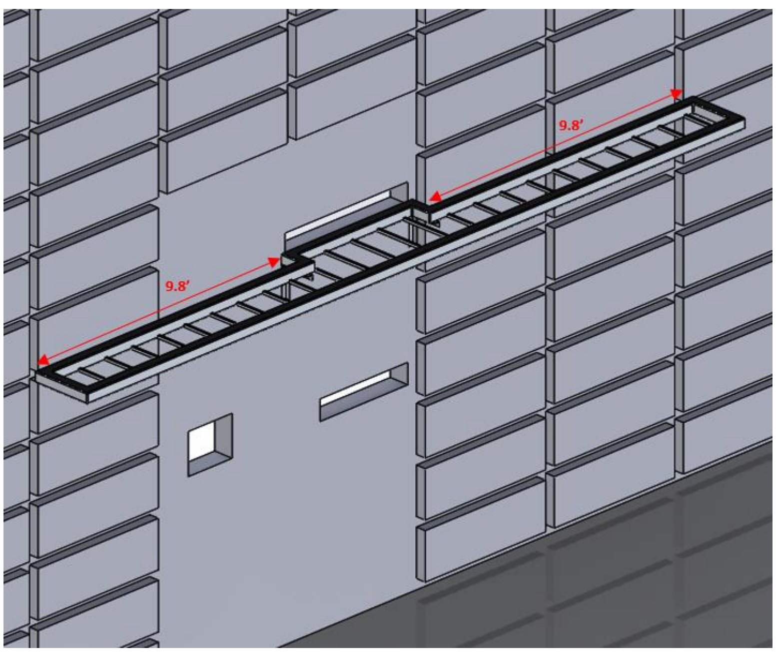

Figure 2: Drag chain support rack location.

D.1.3. Drag Chains

- Mount drag chains to drag chain support rack as shown.

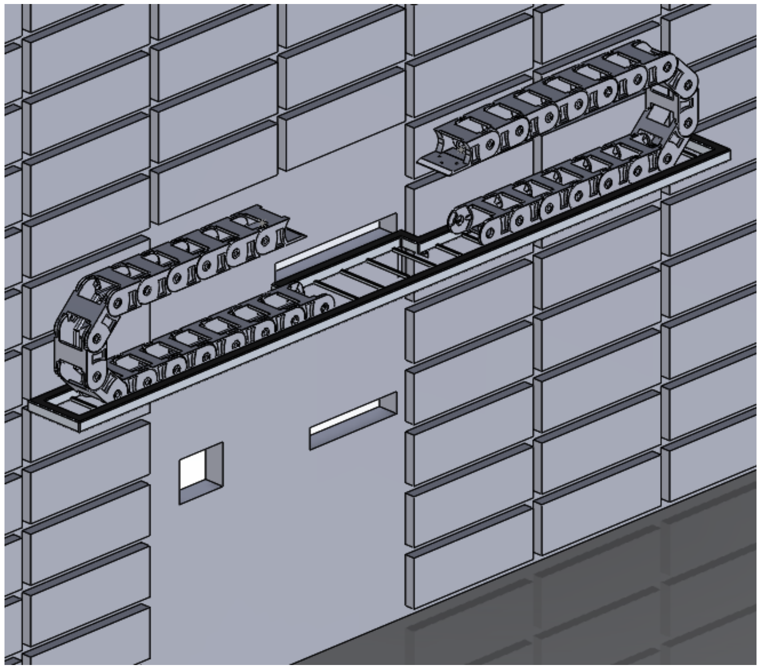

Figure 3: Drag chain mounting locations.

D.1.4. Instrumentation Rack

- Raise existing instrumentation support rack by 11.81” to line up with drag chains.

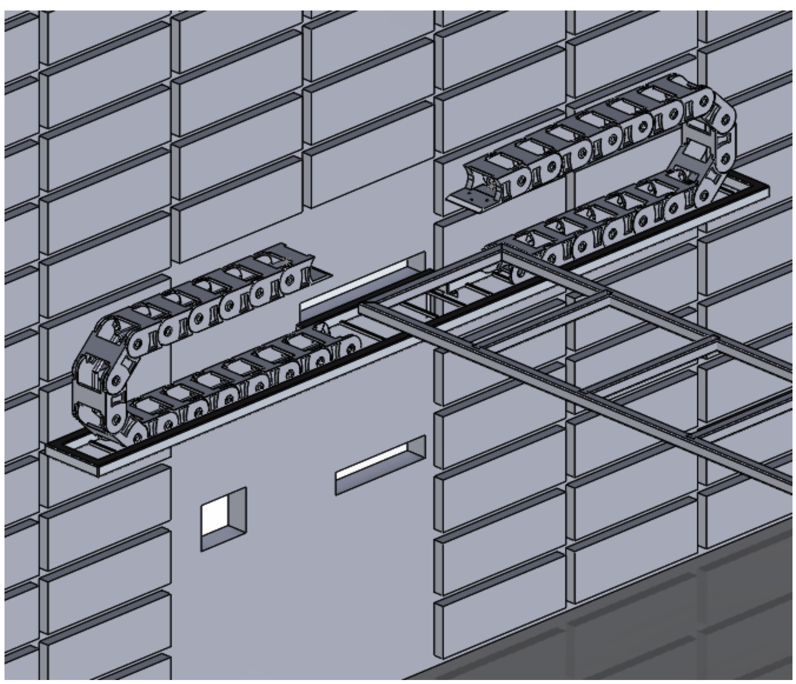

Figure 4: Instrumentation rack location.

D.1.5. Cable Routing & Mounting

- Open drag chain sections to lay in instrumentation signal and instrumentation power cables.
- Feed all cables through acoustic wall opening above drag chain support rack.
- Secure all cables to instrumentation support rack with zip-ties.

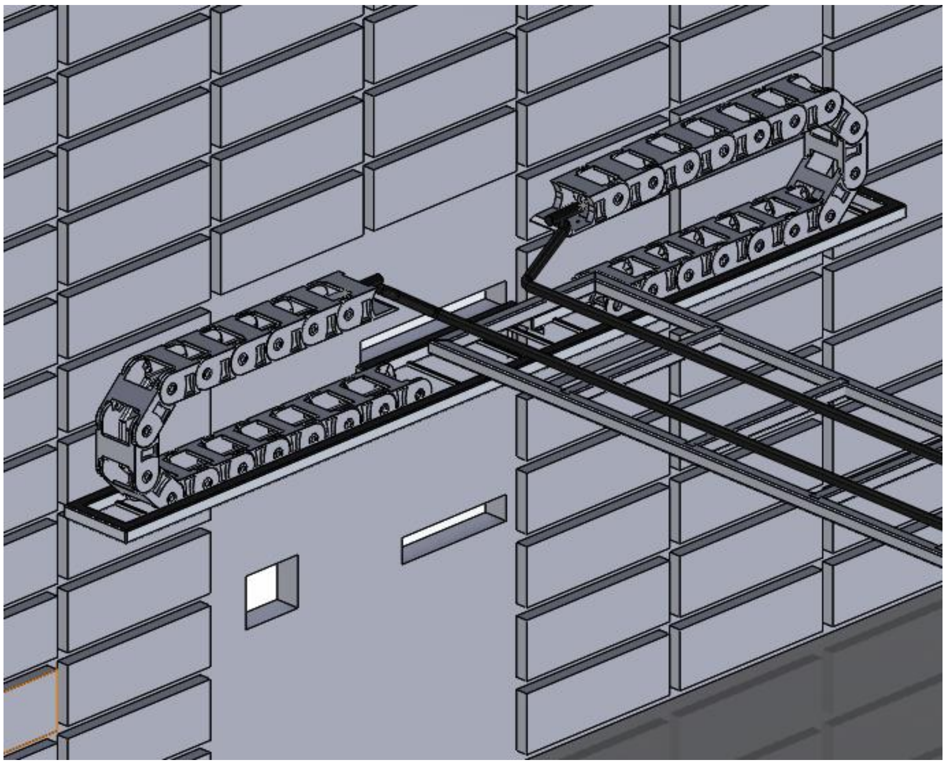

Figure 5: Cable routing and mounting locations.

D.2. Guide Loops

D.2.1. Quick-Access Base Mount Shaft Support

- The mount shaft support consists of two pieces, the base one will fix on the acoustic wall at a 12 feet height and top one will cover and hold the shaft. The distance between two mounts on one shaft is 28 ft. The right mounts is right beside the instrumentation cable holes.

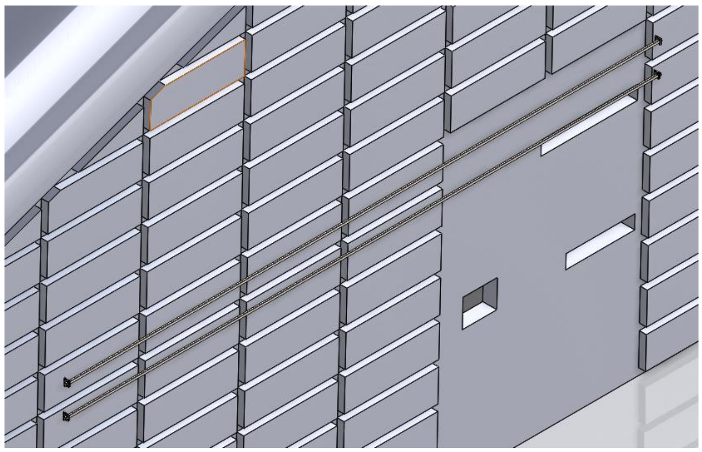

Figure 6: Mounts and Shafts

D.2.2. High-Capacity pillow-Block Linear Bearing

- The linear bearings will put on and go through the shaft. Two bearings are for fixing the instrumentation rack. One bearing is to go to the top shaft and to prevent the rotation of the rack.

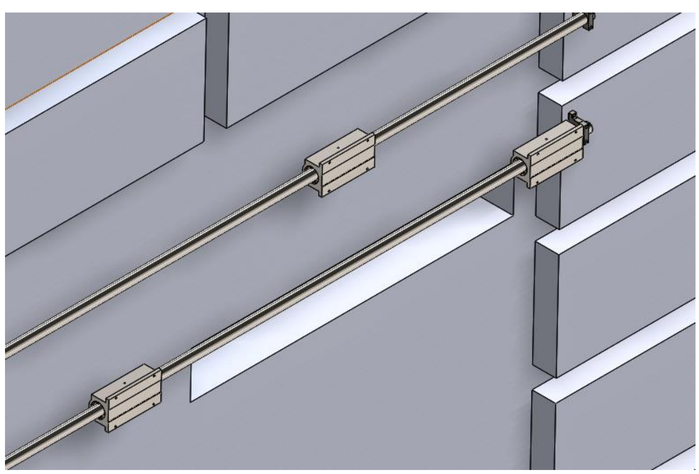

Figure 7: Linear Bearings

D.2.3. Hardened Precision Shafts

- The total length of hardened precision shafts is 28 ft.

D.2.4. Instrumentation Rack

- The instrumentation rack is remade by heavy duty aluminum bolt-together framing. The dimension of new rack is as same as the current one.

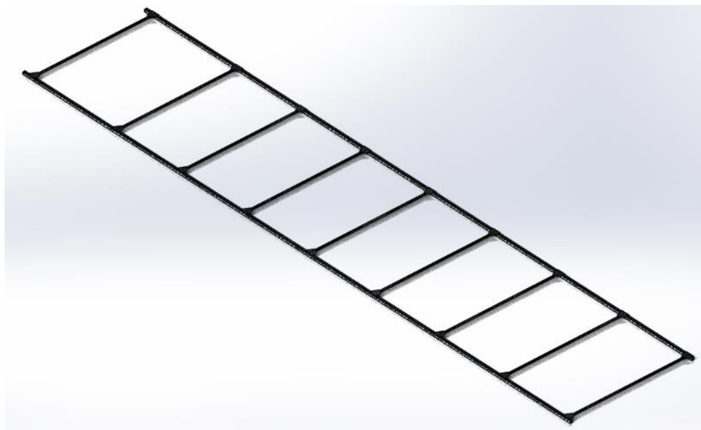

Figure 8: Instrumentation Rack

D.2.5. Mount to the Instrumentation Rack

- This mount will used to assemble the instrumentation rack and vertical support.

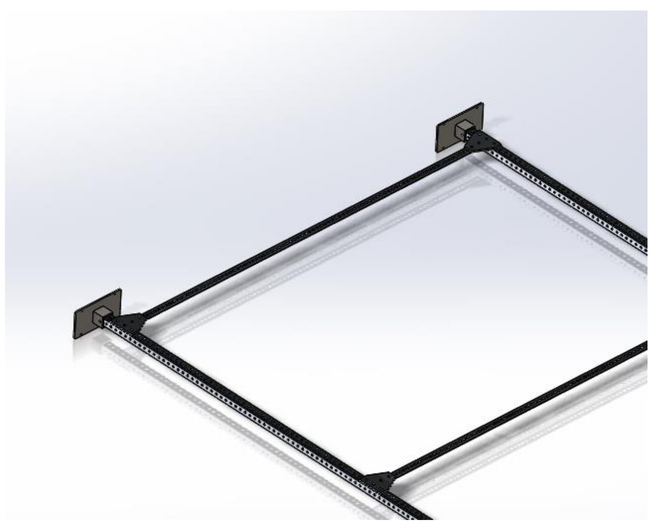

Figure 9: Mounts for the instrumentation rack

D.2.6. Friction Grip Framing Fitting

- The rear side of this fitting is connected to the linear bearing. The front side is bolted with mount of the instrumentation rack to prevent the rotation of the rack.

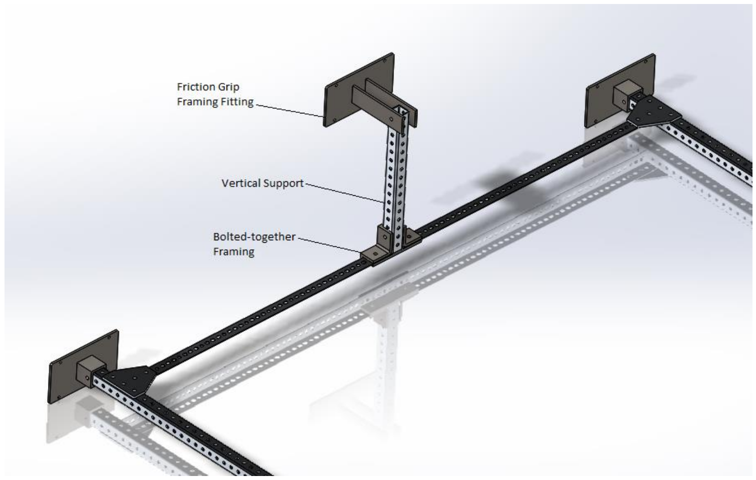

Figure 10: Detail on the Instrumentation Rack

D.2.7. Vertical Support

- It is also made by heavy duty aluminum bolt-together framing for easy set up.

D.2.8. Bolted-Together Framing

- The bolted-together framing is on the middle of the first beam on the instrumentation rack to connect with vertical support.

D.2.9. Heavy Duty Steel Pulley and Hanger position on Wire Rope

- Each pulley bolts with a hanger. The cable goes through the inside circle of the hanger and fixes with bolt. There are six pulley assembles on each wire rope.

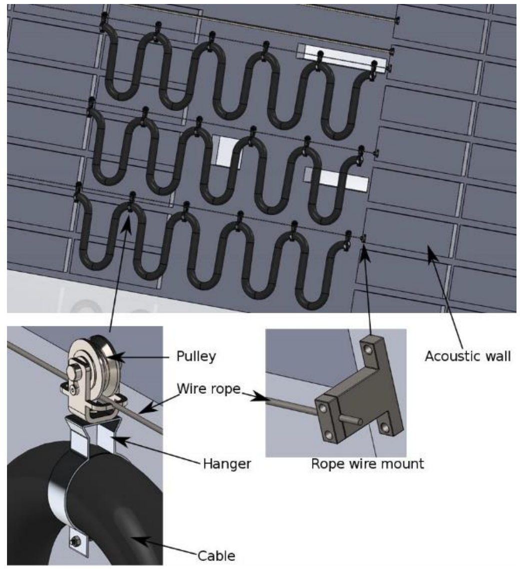

Figure 11: Pulley and Hanger

D.2.10. Wire Rope

- The length of each wire rope is also 28 feet. Each wire rope is held by two wire rope mounts. The separation between two wire rope is 3.75 feet.

D.2.11. Cable Routing and Mounting

- All the cables come from the holes that have already been on the acoustic wall. Each cable will go through the hangers on the same wire rope from right one to the left. And then, cables will go up and put on the instrumentation rack. Finally, they will connect to the wind tunnel.

D.3. Sliding Extension Rail

D.3.1. Strut Mounts

- Mount 1 ft. sections of channel strut to the acoustic wall as shown.

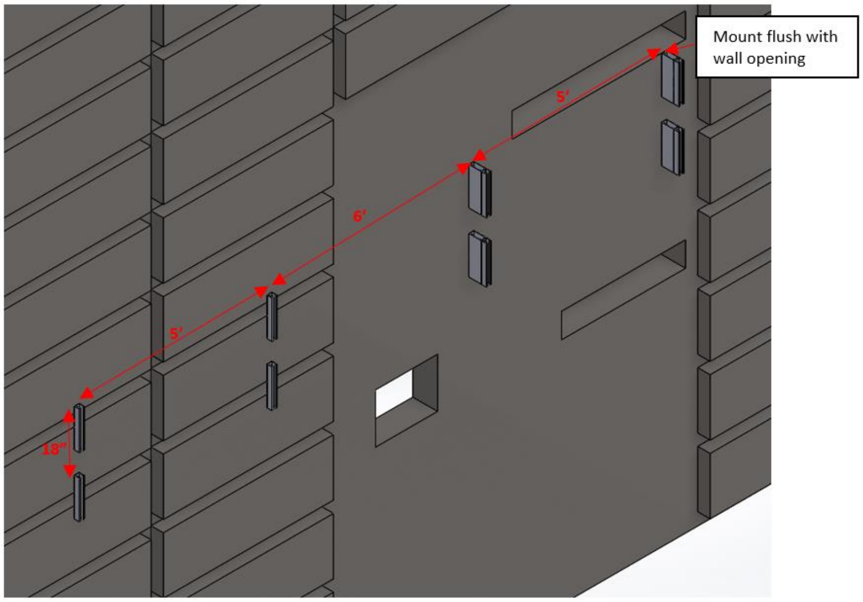

Figure 12: Channel strut mount locations.

D.3.2. Strut Brackets

- Mount support brackets to channel sections as shown.

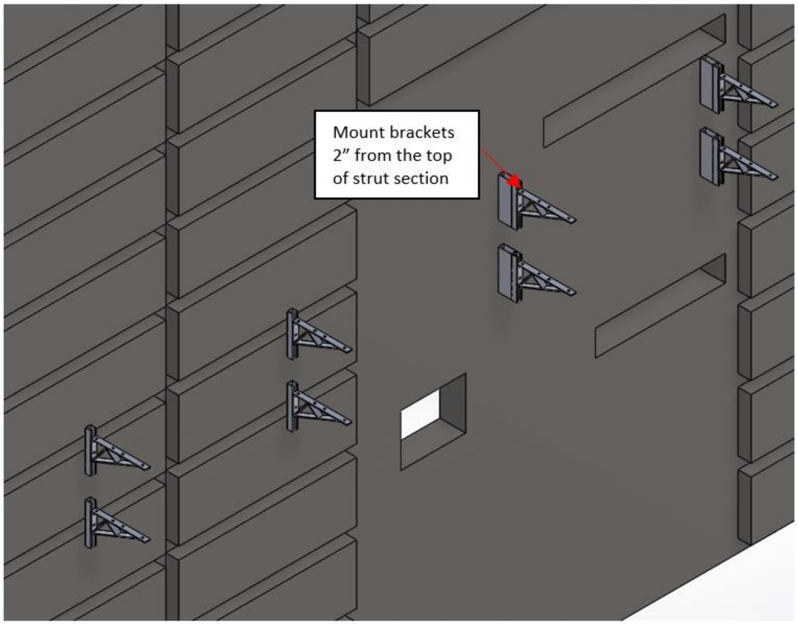

Figure 13: Strut bracket mounting locations.

D.3.3. Rail Structure

- Construct rail structure with T-slotted framing as shown. Refer to engineering drawings for cut lengths and further details.

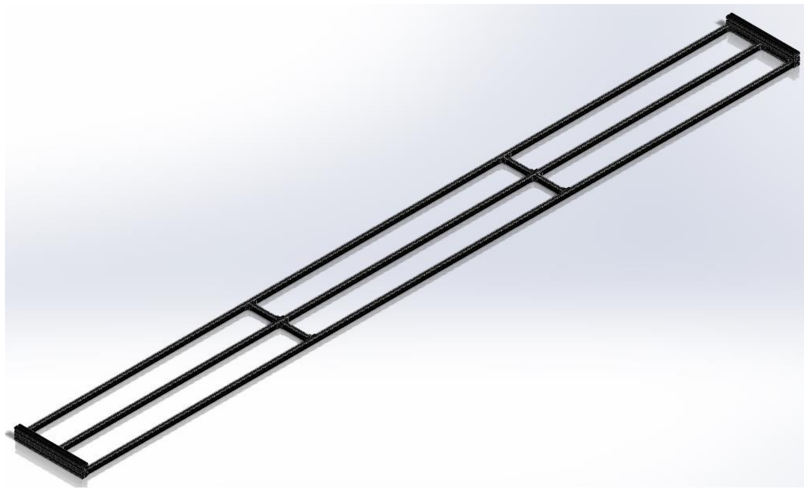

Figure 14: Rail structure assembly.

- Mount rail structures on top of strut brackets as shown.

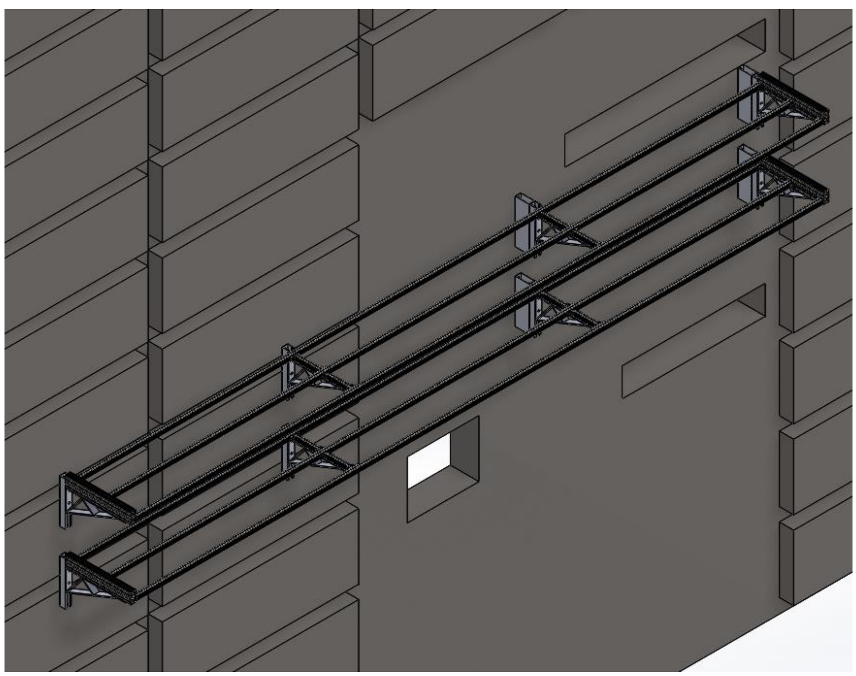

Figure 15: Rail structures mounted to strut brackets.

D.3.4. Sliding Rails

- Construct sliding rails as shown. Refer to engineering drawings for cut lengths.

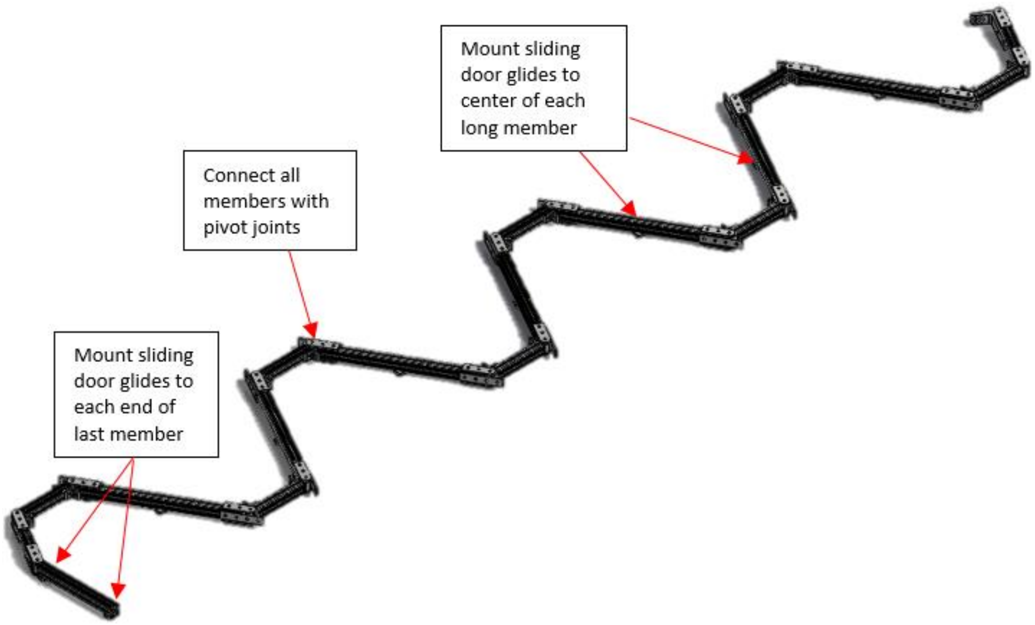

Figure 16: Sliding rails assembly.

- Mount sliding rails to rail structure assembly.

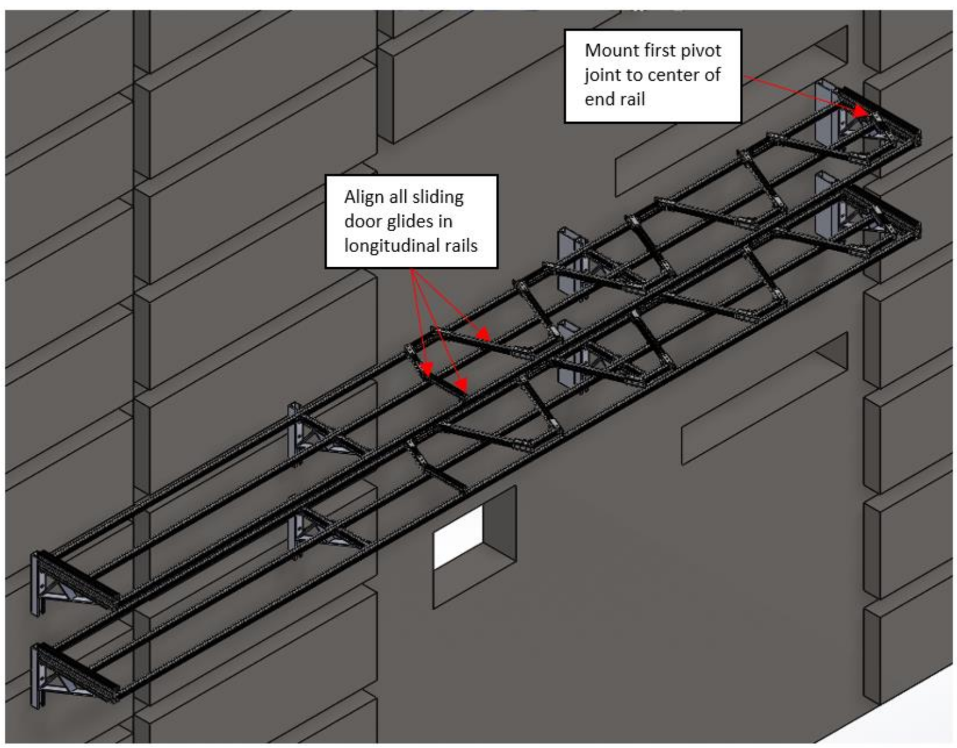

Figure 17: Sliding rails mounting location.

D.3.5. Cable Routing and Mounting

- Route and connect instrumentation signal cables and instrumentation power cables as shown.

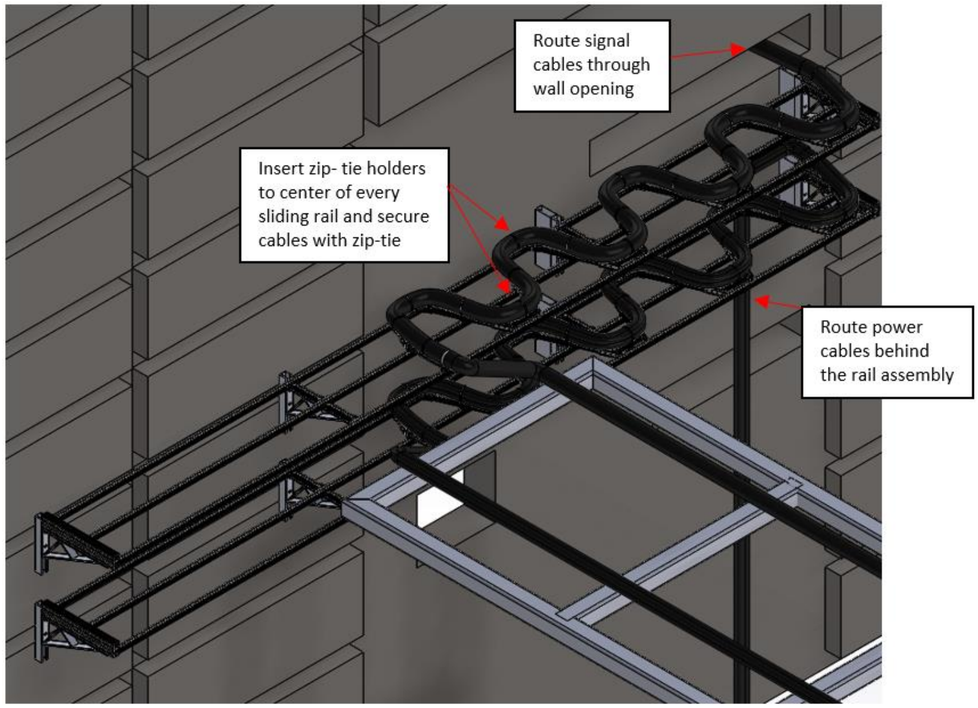

Figure 18: Instrumentation cable routing and mounting locations.