Kitchen Cabinet Design

VM350 Design and Manufacturing II

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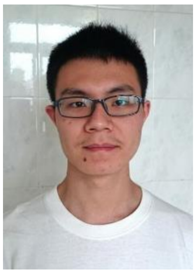

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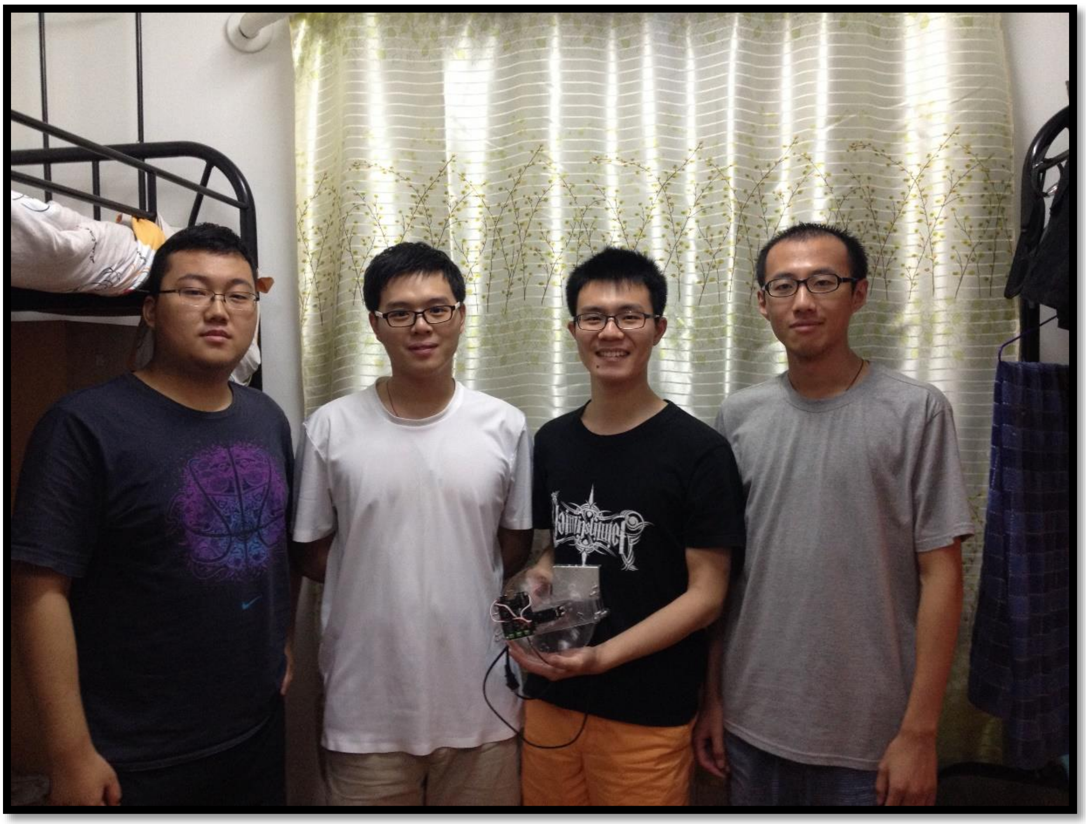
Abstract

We need to design a cabinet with software *SolidWorks* which can conveniently use the space around the corners. Although Professor Xu provided us with two possible solutions, our team thought that both of the solutions had obvious disadvantages and we wanted to find the balance between the space utilization percentage and the access to the space. We finally decided to use the design which could be pulled out fully with only one step. The space utilization percentage is about 74%. The total cost of the material of our final design is about $1264.



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1. INTRODUCTION

Kitchen cabinets are the built-in furniture installed in many kitchens for storage of food, cooking equipment, and often silverware and dishes for table service.[1] In the design of a modern kitchen, the design of kitchen is a principal part because the volume of the cabinets will determine the spare space for other electric appliances like refrigerators and the capacitance of the cabinets will determine the storage location of cooking equipment such as bowls, sterilized cupboard and so on. Besides, the design of the functionality of the kitchen cabinets is very important because the utilization percentage of the cabinets and the access for the user to the storage space should be balanced, which is the combination of science and art. However, there is also a conspicuous problem that how we can conveniently use the space around the corners of kitchen cabinets in a design which is also the main purpose of this project.

There are two solutions provided by Professor Xu for us to do some further detailed design (shown in Figure 1.1).[2]

(A) (B)

Figure 1.1: Two possible solutions.

In solution A, 4-bar linkage is used to transfer a shelf partially out of the cabinet. It is relatively easy for the user to access the space after the cabinet is pulled out but the space utilization percentage of this solution is relatively low. Besides, the irregular shape of this kind of cabinet will affect the capacitance of the cabinet badly. In solution B, sliders and 4-bar linkage are used. When the right part of the cabinet is pulled out and turned to the right, the left part of the cabinet will be pulled to the right by the 4-bar linkage with translation on the sliders. The space utilization percentage is relatively high in this solution but the user may not be able to access the space conveniently because the left part of the cabinet cannot be fully pulled out.

Hence, our team decided to design a cabinet which had a relatively high space utilization percentage and could be pulled out fully with only one pull with sliders, spindles and bearings which overcame the disadvantages of solution A and B. This report shows all the processes of design, calculation and material selection of our team in this project.

2. PRODUCT DESIGN

2.1 Problem Statement

In Project 3, we are required to design a kitchen cabinet in detail. Two extant solutions are provided, as mentioned previously. Apparently, there are many disadvantages. For example, the space utilization of solution A is relatively low while its accessibility is relatively high. The space utilization of solution B is relatively high but it may not be convenient to use.

To avoid these advantages, we decided to figure out a new solution. We started with the design specification. First, the kitchen cabinet should be convenient to use and it will be most convenient if the entire shelf can be completely taken out of the cabinet. Second, the area of the shelf should be as large as possible. Since we are designing a kitchen cabinet with mobility, it will be great challenge to make use of the entire area.

To sum up, we decided to design a cabinet with both the convenience of solution A and the high space utilization of solution B.

2.2 Concept Generation

2.2.1 Semi-Circular Shelf with Sub-Shelf

Figure 2.1 shows our first concept design—semi-circular shelf with a sub-shelf. It contains a semi-circular shelf, a sub-shelf, a shaft, a mounted bearing, and a slide.

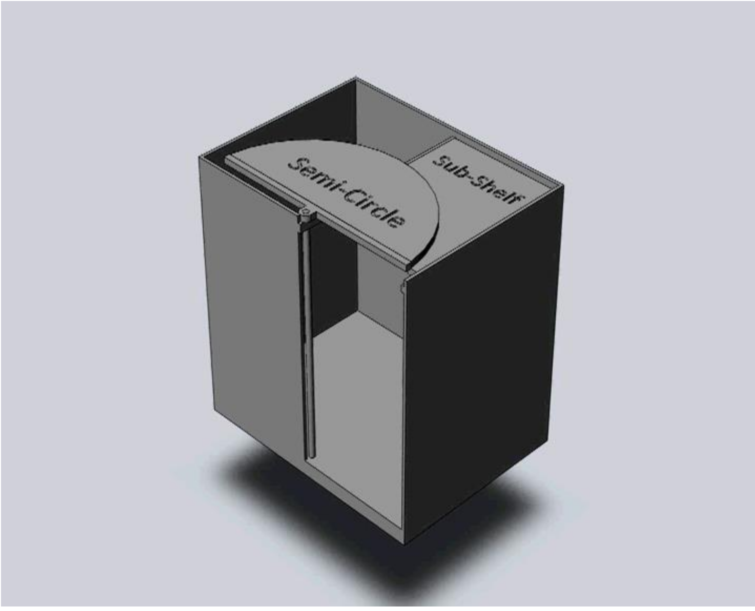
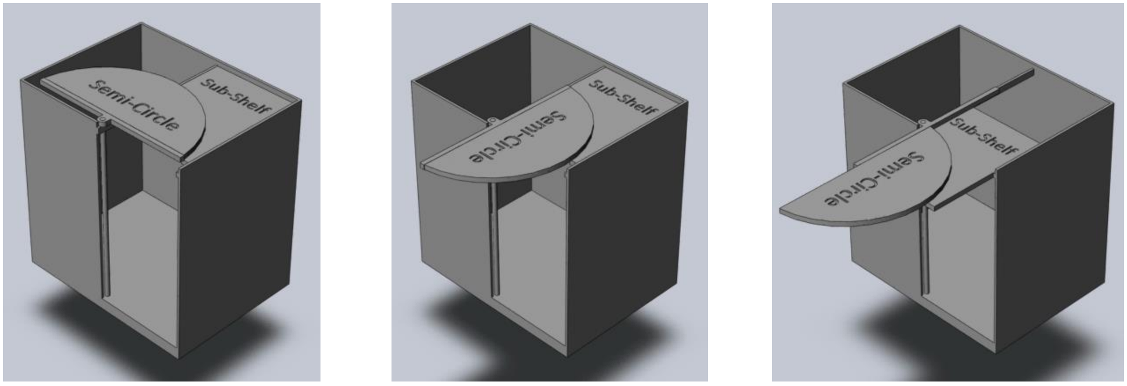


Figure 2.1: Semi-circular shelf with sub-shelf.

As we can see, the semi-circular shelf is attached to a slide, which can rotate about the shaft through a bearing. To optimize the space utilization, a sub-shelf is added. It can follow the semi-circular shelf when taken out of the cabinet. Figure 2.2 shows the mechanism.



(a) (b) (c)

Figure 2.2: Mechanism of semi-circular shelf with sub-shelf.

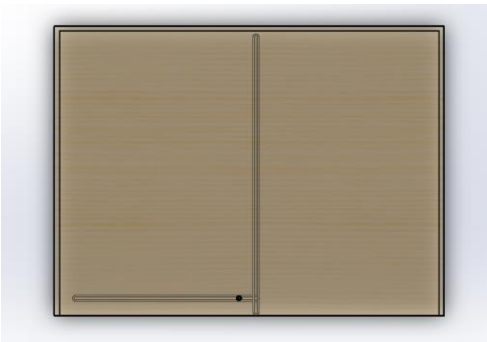
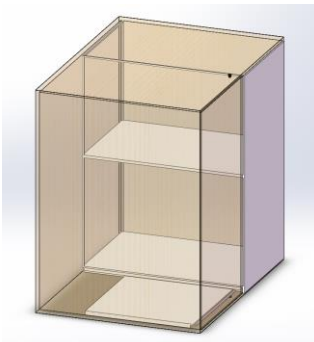
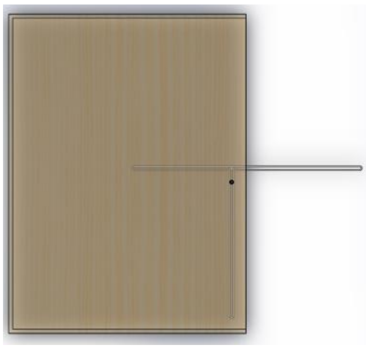
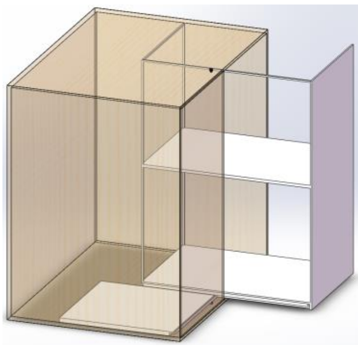
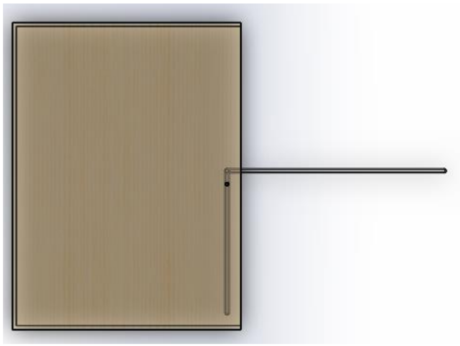
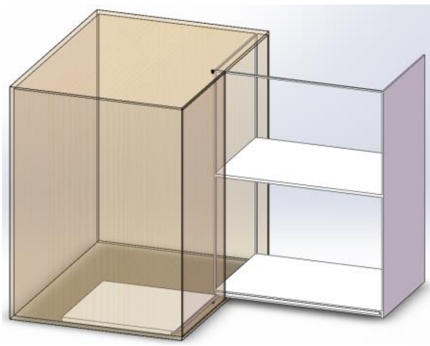
After optimization, the space utilization percentage is determined to be

$$\frac{\frac{\pi}{4}\times 360^2+580\times 360}{800\times 600}\times 100\% = 65\%. \tag{2.1}$$

Although the design seems convenient to use, there exists many disadvantages. First, only 65% of the entire area is used, which is barely satisfactory. Second, the slide may fail when the whole shelf is completely taken out of the cabinet. The large bending moment may exceed the capacity of single-sided slide. Third, both of the semi-circular shelf and the sub-shelf have irregular shapes, which is impractical to store kitchen stuff. Therefore, we have a further design.

2.2.2 Final Design Concept Generation

Our final design is quite different from the solution A and the solution B, or in other words, the combination of these two solutions. We want both the convenience of the solution A and the high space utilization of the solution B. To achieve this goal, first, the shape of the shelves should be rectangle. In order to move the inner shelves out, we need a structure to pull them out after the outer shelves are out. The user should be able to pull out and push in both shelves within one motion or the design is not good enough.

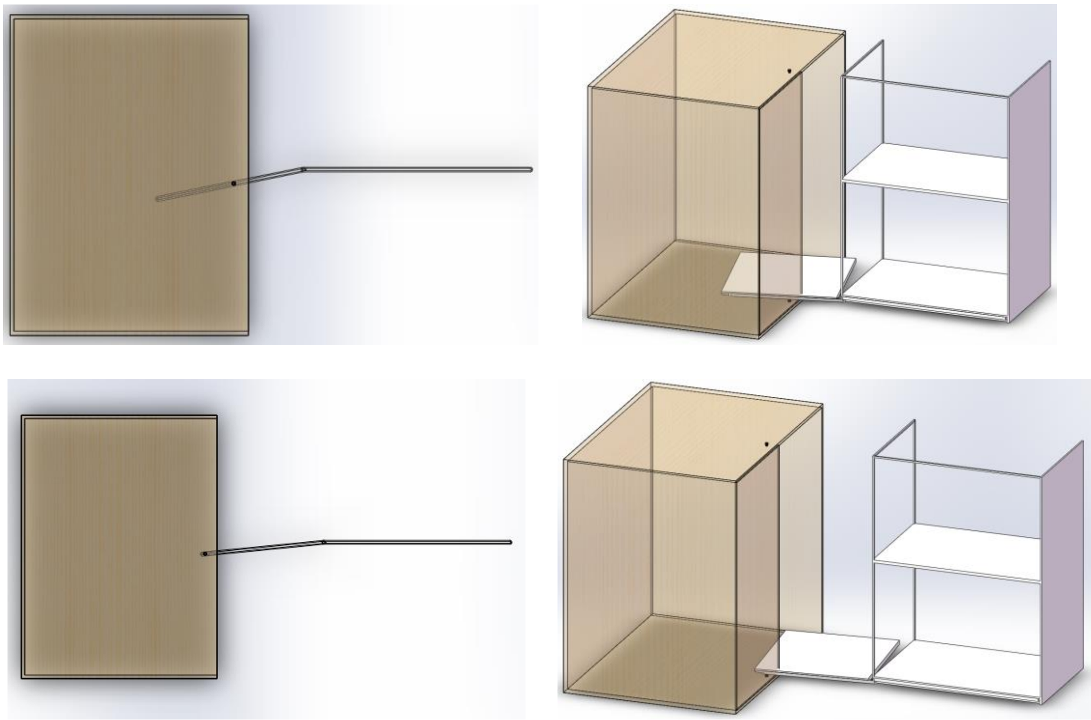


Figure 2.3: Moving path of the shelves.

After the brainstorming, we got our initial design. We use slides and shafts to satisfy the requirement of motion we discussed previously. There are slides installed on the left bottom of the outer shelves and the front bottom of the inner ones. A shaft is installed on the right end of the inner slide to hook it to the outer slide. Another shaft is installed on middle front of the cabinet. It makes the inner slide rotate and slide. First we pull out the outer shelves. With the help of the slide installed on the left bottom of the outer shelves, the inner shelves will keep static. After the outer shelves are totally pulled out, the shaft on the slide of the inner shelves reaches the end of the slide of the outer shelves. Keep pulling the outer ones, the inner ones will rotate about 90 degrees and move out since the inner slide is pulled by the outer one. Keep pulling until the shaft installed on the cabinet reach the end of the inner slide. To push the shelves in, just push the outer ones. The outer shelves will push the inner ones into the cabinet and then move into the cabinet. It is just the reversion of the pulling out motion.

Since this design meets our requirement of convenience and high space utilization, we decided to improve this one and get the final design.

3. FINAL DESIGN

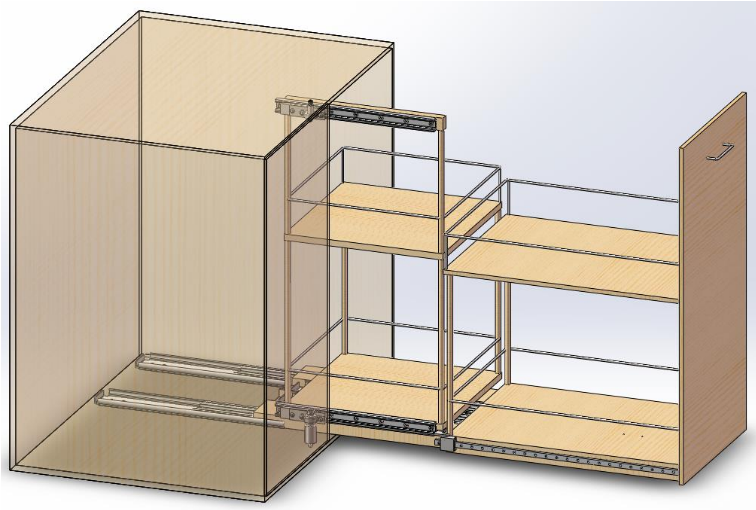


Figure 3.1: The final design.

The appearance of the final design is shown in Figure 3.1. It took us a lot of time to adjust the dimension of the shelves since the motion of the inner shelves is the combination of linear motion and angular motion. We mostly meet the requirement we discussed in the concept design part. The space utilization is 74.4%. From the top view of the cabinet, about 87.7% of the shelves space is out of the cabinet. With only one motion, all shelves can easily move in and out of the cabinet.

The design of the outer shelves is easier than the inner ones since there is only linear motion. We used slides to move the shelves linearly. Since one pair of slide is not long enough, we use two pairs here. The placement of the slides is shown in Figure 3.2. We first considered installing the slides on the right side of the cabinet. It caused a huge waste of the space. Another severe problem is that it is a single shear structure. The strength of single shear structure is very low. Hence we finally put the slides on the bottom.

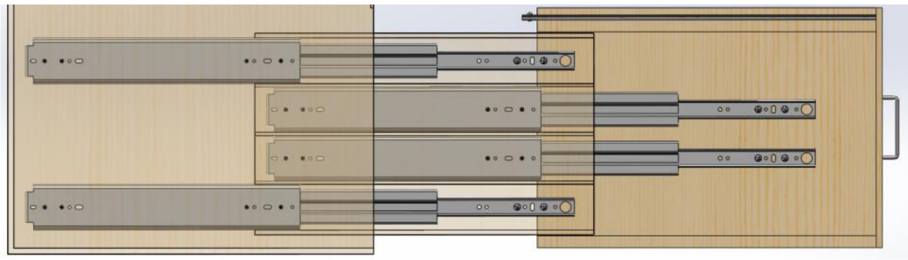


Figure 3.2: The bottom view of the outer shelves.

To maximize the space utilization, we designed the bottom of the shelves like a sandwich. The inner pair of the slides is connected to the bottom of the cabinet and the middle board. The outer pair is connected to the middle board and the bottom of the outer shelves. There is a trough on the bottom board of the outer shelves. When the shelves are pushed in, all the structures can be held in it.

Figure 3.3: The right view of the outer shelves.

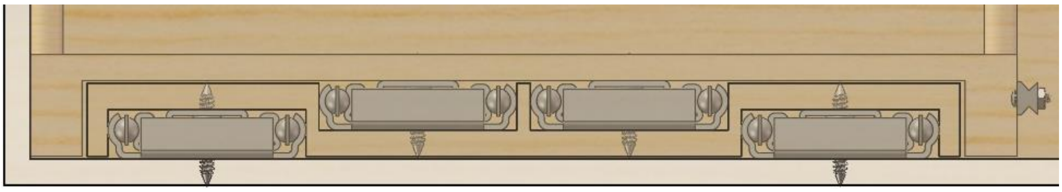


Figure 3.4: The back view of the outer shelves.

The connection between the inner shelves and the outer shelves is one of the key points of out design. It consists of a slide, a carriage, a self-made connector. With its help we can pull out all the shelves by pulling the outer ones.

The inner shelves cannot move until the outer ones move out. Hence we installed a slide on the side of the outer ones. At first the carriage moves freely on the slide and the inner shelves keep static. Then the carriage moves to the end of the slide and the bolt stops it.

Figure 3.5: The left slide of the outer shelves.

Since the carriage cannot move anymore, it will move as the outer shelves. The self-made connector will then turn the inner shelves and pull it out.

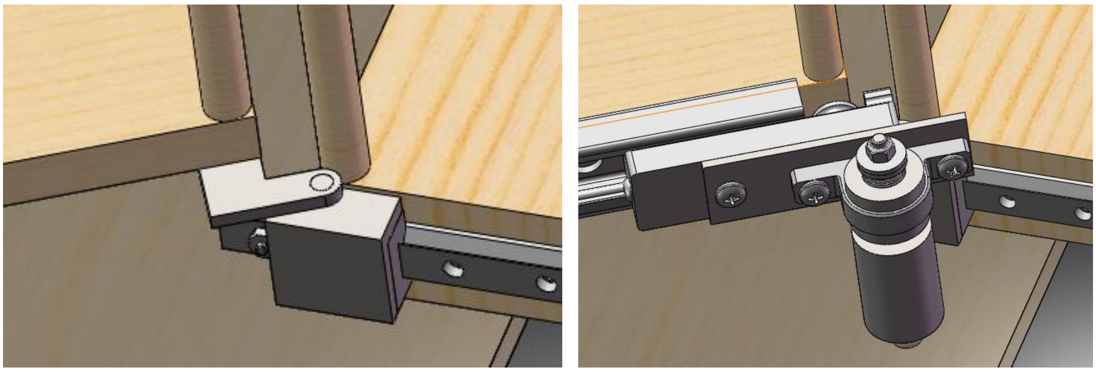


Figure 3.6: The connector and the shaft.

The motion of the inner shelves is the combination of linear motion and angular motion. Hence we used slide and shaft there to meet the requirement. The only problem of the structure is that it is a single shear structure. Since the motion of the inner shelves is quite complex, this is the only structure we can use. We have to decrease the load capacity of the inner shelves.

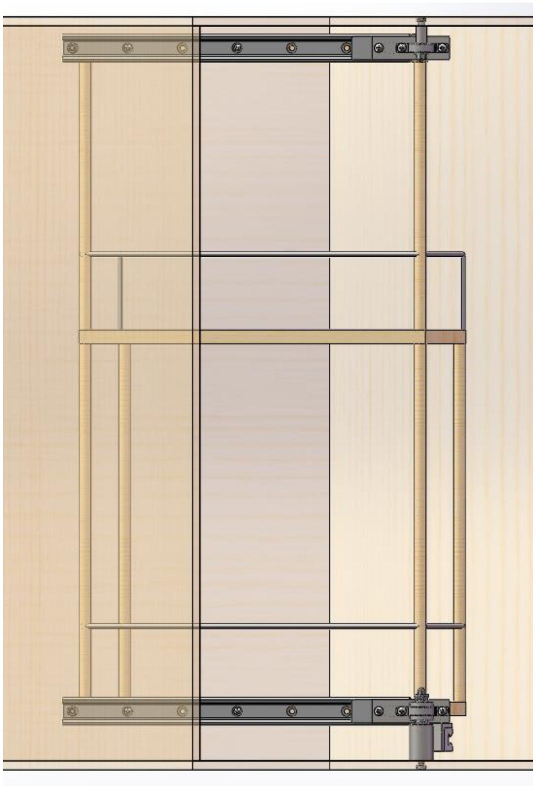


Figure 3.7: The structure holding the inner shelves.

There are two shafts in the cabinet. Both shafts work as the rotating axis but only the bottom one hold the axial load. This can simplify the design of the top shaft.

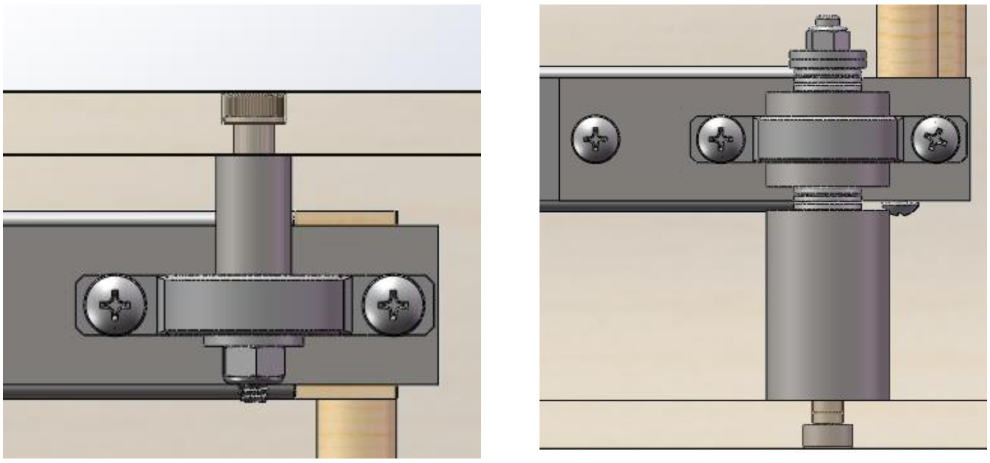


Figure 3.8: The shaft of the inner shelves.

We still choose slides to meet the requirement of linear motion. The mounted bearings are directly connected with the carriage to increase the strength. Since the position of the holes does not fit, we use a piece of spacer to transfer. The whole motion ends when the carriage moves to the end of the rail.

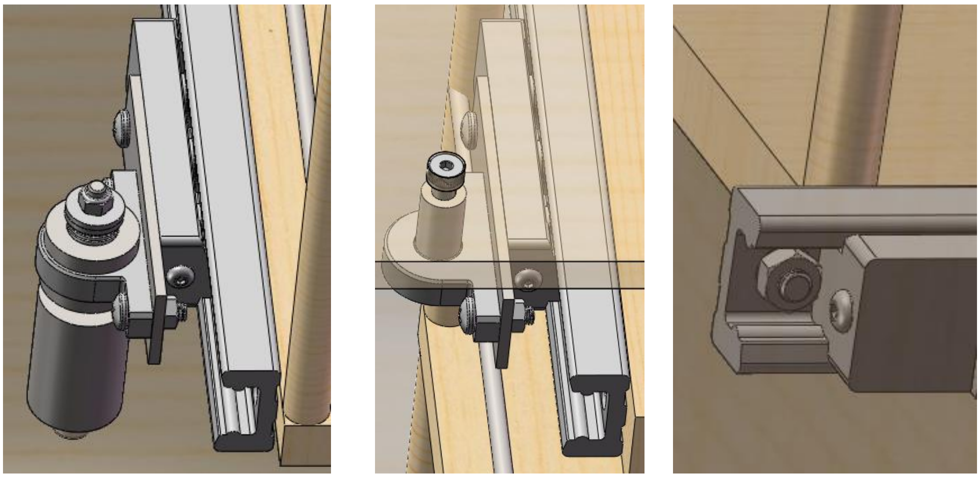


Figure 3.9: The carriage and guide rail of the inner shelves.

Although the design works quite well, there are a lot to be further improved. The utilization is affected by the dimensions of the shelves. Since the motion of the whole system is quite complex, the dimensions especially of the inner ones should be carefully calculated to avoid interference. The minimum distance between the inner shelves and any other part is about 5mm through the motion process. It can decrease to about 1mm. We decrease the length of the outer shelves since there is not enough room for the inner ones when they are taken out. Another way to solve this problem is decrease the width of the inner shelves. This needs further calculation. Also the position of the shaft will affect the dimensions since it will change the rotating axis. Hence it is better to use computer to optimize the length and the width of the shelves, the position of the shafts and the dimensions of the connector.

4. CALCULATION AND SELECTION

4.1 Outer Shelves

4.1.1 Base-Mount Drawer Slide

Since our design was to stand 15 kg of loads for each layer, we had two layers to sand load and we wanted the safety factor to be $X_1 = 2$. Hence, the maximum load of the slide could stand should be:

$$\text{Max Load} = 2\times 2\times 15[\text{kg}] = 60[\text{kg}] = 133.33[\text{lbs}]. \quad (4.1)$$

According to our design, we needed to find two pairs of slides that could stand more than 133.33lbs of loads and the slide should have a base to be fixed on the wood boards, so we searched on the McMaster. Then we choose the following **base-mounted drawer slide**[1] with closed length 18", 18" of extension and max load 150lbs/pair (shown in Figure 4.1). A more detailed figure containing the information of the slid can be shown in the Appendix B.

Figure 4.1: Base-mount drawer slide.

[1] Professor Xu asked about whether the slides we chose can be used in a horizontal way. According to the information on the McMaster, this kind of slide could be used as we designed because it is base-mounted.

4.1.2 Screws

Before selecting the screws we used, we need to analysis the forces and moments act on the screws.

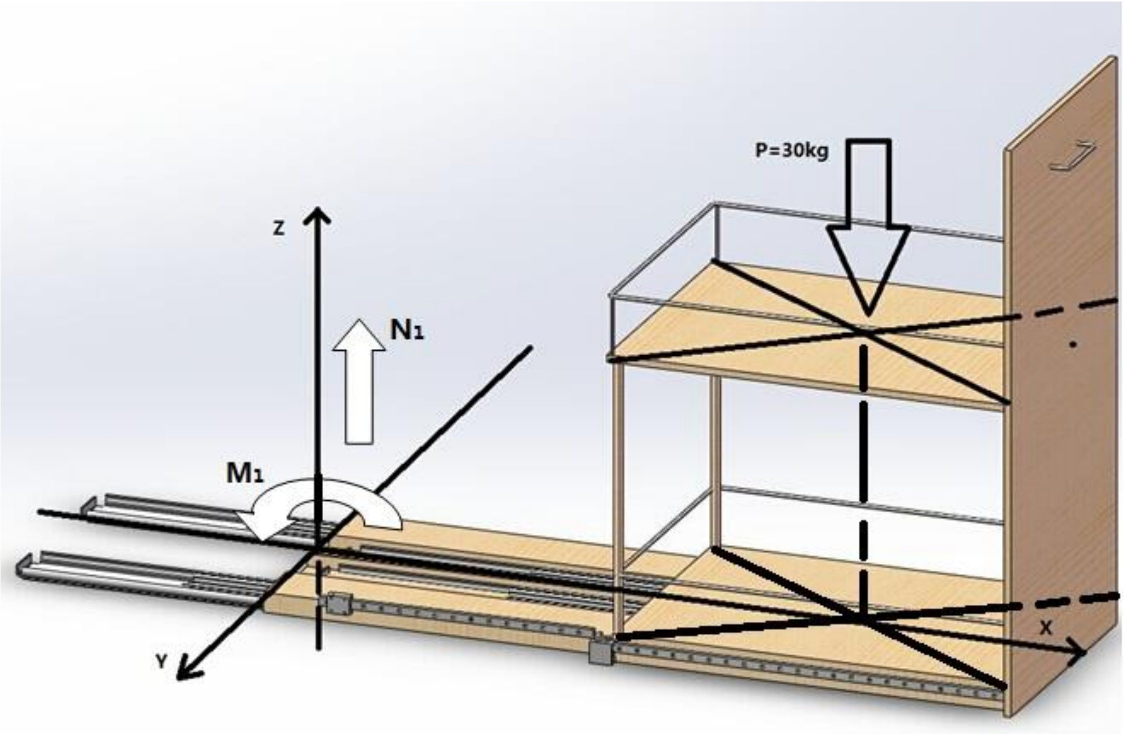


Figure 4.2: Free body diagram of the right part.

In Figure 4.2, we supposed that the load acted at the center of the wood boards and center lay on the X axis. Y axis lay on the edge of the slide base which could take the largest moment due to the largest distance. Hence, we just needed to consider the two slide bases which had the largest distance which was 597.5mm with respect to the center of the wood board because they could take the largest bending moment. Apply force equilibrium and moment equilibrium and we can get:

$$\begin{aligned} N_1 &= 300\,[\mathrm{N}] \\ M_1 &= 179.25\,[\mathrm{N} \bullet \mathrm{m}] \end{aligned} \tag{4.2}$$

Hence, we could let each of the slide base to stand half of the loads because they are symmetric about the X axis in the X-Y plane. Then, we considered a single slide base and the free body diagram is show in Figure 4.3.

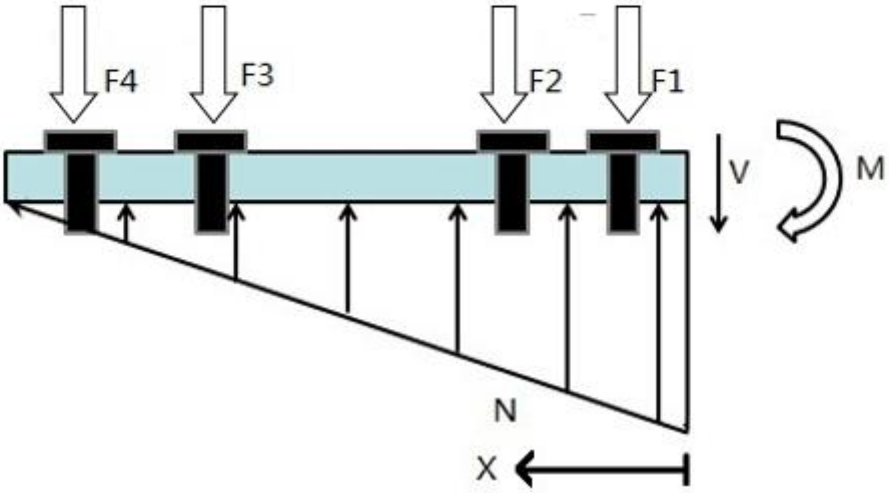


Figure 4.3: Free body diagram for a single slide base.

When dealing with the simplified mode of the slide base, we made the following summations:

1. The normal force exerted on the slide base was linearly distributed.

2. The forces provided by the screws F_n was proportional to the position X, $F_n = F \ \ x_n$.

3. We used 4 screws to fix each slide base.

4. The Safety factor was $SF = 5$.

5. The length of the slide base is $L = 457.2\,\text{mm}$.

Apply forces equilibrium and moment equilibrium about the right edge of the slide base:

$$\begin{aligned} \Sigma F_y &= N - V - F_1 - F_2 - F_3 - F_4 = 0 \\ \Sigma M_z &= F_1x_1 + F_2x_2 + F_3x_3 + F_4x_4 - N\frac{L}{3} - M = 0 \end{aligned} \tag{4.3}$$

where

$x_1 = 31.75\,\text{mm}, x_2 = 88.90\,\text{mm}, x_3 = 368.30\,\text{mm}, x_4 = 425.45\,\text{mm}，V = 150\,\text{N}, M = 89.625\,\text{N} \bullet \text{m}.$

Plugging the numerical values in the equation, we could get:

$$F_{\max} = Fx_4 = 602.813 \times 0.42545 = 256.47\,[\text{N}]. \tag{4.4}$$

Since, we needed to fix the slide base on the plywood board, we decided to use tapping screws which were stable and easy to assembly. Considering about that and the dimension of the slide screws as well as the thickness of the plywood board 10mm, we chose to use the screws show in Figure 4.4. A more detailed figure containing the information of the screws can be shown in the Appendix B.

Figure 4.4: Flat head Phillips screw.

Then we needed to verify the choice of the screws. According to the table provided in Lecture 7[3],

		Coarse Series—UNC			Fine Series—UNF		
Size Designation	Nominal Major Diameter in	Threads per Inch N	Tensile-Stress Area A_t in²	Minor-Diameter Area A_r in²	Threads per Inch N	Tensile-Stress Area A_t in²	Minor-Diameter Area A_r in²
0	0.0600				80	0.001 80	0.001 51
1	0.0730	64	0.002 63	0.002 18	72	0.002 78	0.002 37
2	0.0860	56	0.003 70	0.003 10	64	0.003 94	0.003 39
3	0.0990	48	0.004 87	0.004 06	56	0.005 23	0.004 51
4	0.1120	40	0.006 04	0.004 96	48	0.006 61	0.005 66
5	0.1250	40	0.007 96	0.006 72	44	0.008 80	0.007 16
6	0.1380	32	0.009 09	0.007 45	40	0.010 15	0.008 74
8	0.1640	32	0.014 0	0.011 96	36	0.014 74	0.012 85

from which we could find out the tensile stress area $A_t = 0.014in^2 = 9.03\cdot 10^{-6}m^2$.

Hence, we could calculate the maximum tensile stress in screws:

$$\sigma_{\max} = SF\frac{F_{\max}}{A_t} = 5\times\frac{256.74}{9.03\ 10^{\ 6}} = 142.17\,[\mathrm{MPa}]. \qquad (4.5)$$

According to the table in Lecture 7[3],

SAE Grade No.	Size Range Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
1	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$–$\frac{3}{4}$ $\frac{7}{8}$–$1\frac{1}{2}$	55 33	74 60	57 36	Low or medium carbon	
4	$\frac{1}{4}$–$1\frac{1}{2}$	65	115	100	Medium carbon, cold-drawn	
5	$\frac{1}{4}$–1 $1\frac{1}{8}$–$1\frac{1}{2}$	85 74	120 105	92 81	Medium carbon, Q&T	
5.2	$\frac{1}{4}$–1	85	120	92	Low-carbon martensite, Q&T	
7	$\frac{1}{4}$–$1\frac{1}{2}$	105	133	115	Medium-carbon alloy, Q&T	
8	$\frac{1}{4}$–$1\frac{1}{2}$	120	150	130	Medium-carbon alloy, Q&T	

we could read that the minimum tensile strength of this kind of screws is about:

$$\sigma_Y = 150[\text{kpsi}] = 1034.21[\text{MPa}], \tag{4.6}$$

which was much more larger than the maximum tensile stress we got.

Hence, our choices of this kind of screws was reasonable.

4.2 Inner Shelves

4.2.1 Load Estimation

The dimensions of the base of the inner shelves is designed to be 37.5cm x 38cm, which has an area slightly larger than a 15” laptop. For one layer of the shelf with this size, we estimate the maximum load it can stand to be 10 kilograms. When we pull out the entire shelves, the inner shelves firstly rotate through one axis then slide out. In order to achieve these two motions successively, we use bearings attached on the roller carriage to support the shelves. **First, we should apply force analysis using the**

estimated load to evaluate the structure of the inner shelves.[2] Since the working condition of the inner shelves is the worst case when it is in fully extension state, we generate the front view of it at the fully extension state. Use it as the free body diagram to analyze the force and it is shown in Figure 4.5.

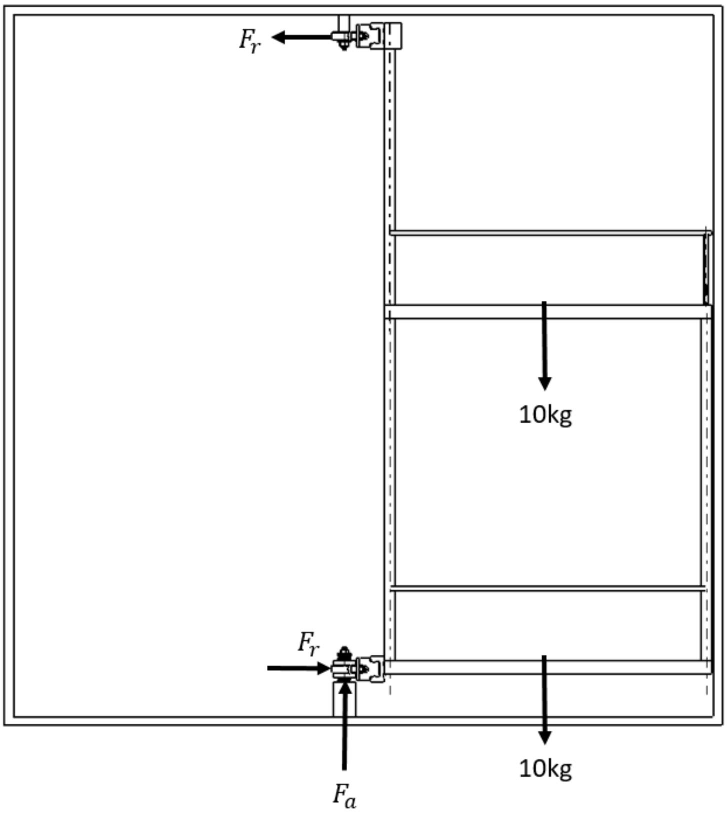


Figure 4.5: Front view free body diagram.

Here, we use the thrust bearing at the bottom of the shelves to take the axial load. On the top and the bottom of the shelves, a couple of radial loads act on the shafts. We need to use the sliding bearings at these two places to take the radial loads as well as make the rotation of the shaft more fluently. Hence, the upper node of the shelves can only take the radial load, while the lower node need to take both axial load and radial load to support the inner shelves. Then according to the dimensions, F_r and F_a can be evaluated as

$$F_r = 2 \times 10 \text{ kg} \times \frac{232.5 \text{ mm}}{722 \text{ mm}} = 6.44 \text{ [kg]} = 14.20 \text{ [lbs]}, \tag{4.7}$$

$$F_a = 2 \times 10 \text{ kg} = 20 \text{ [kg]} = 44.09 \text{ [lbs]}. \tag{4.8}$$

[2] According to Professor Xu's comment, we should apply force analysis before component selection.

For safety consideration, we take the safety factor of 2.0 for both loads. Hence the designed values of F_r and F_d are 28.20 lbs and 88.18 lbs, respectively. Bearings need to have capacities larger than the designed values to be applied on those positions.

4.2.2 Design and Selection at the Upper Shaft

Design of the upper shaft assembly includes selection of bearing, selection of roller carriage and guide rail, and correct mounting of all the components here. In the presentation, we did not consider the mounting well so make the design here unreasonable. **Then we redesign this part and reselect the correct component to make the assembly with no interference and make it mount reasonably.**[3] Figure 4.6 and Figure 4.7 show the overall layout of the upper shaft from two different views respectively.

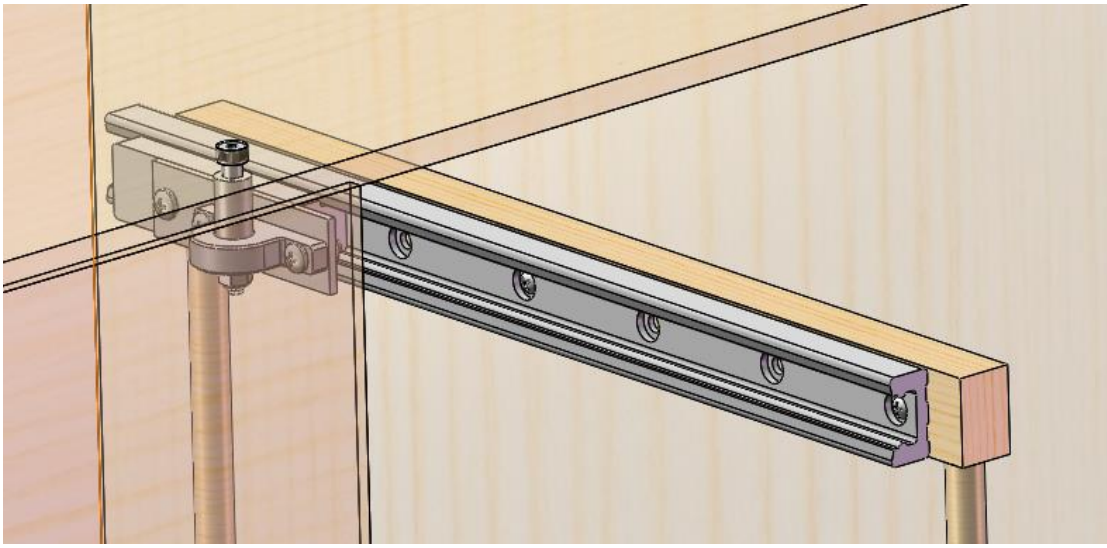


Figure 4.6: Overall layout of the upper shaft (front).

[3] Professor Xu's comment: I don't see the design here works. It makes no sense.

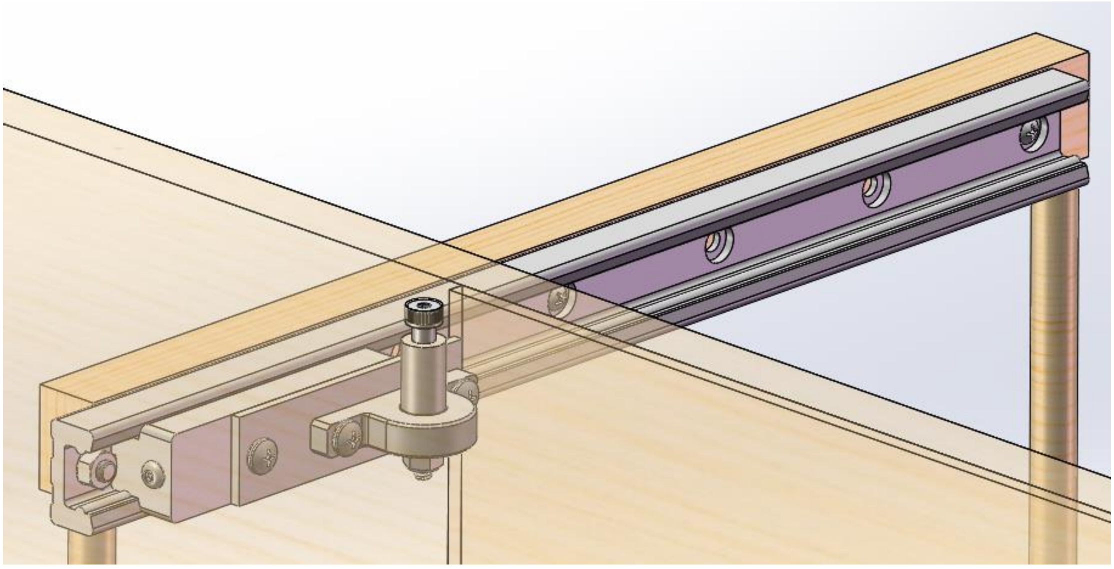


Figure 4.7: Overall layout of the upper shaft (back).

From the overall layout, we fix a guide rail on the upper frame of the shelf, and a roller carriage is sliding on the guide rail. By this structure, the inner shelves can be pulled out and the linear motion relies on this linear bearing. Moreover, a sliding bearing housing is attached to the roller carriage by three M5 Pan Head Machine Screws to reach the rotational motion of the inner shelves. A Stainless Steel Shoulder Screw with 1/4" Diameter is used as the upper shaft. The bushing and the Steel Nylon-Insert Locknut are used to hold the vertical position of the sliding bearing. A cross-section view of the upper shaft is shown in Figure 4.8.8.

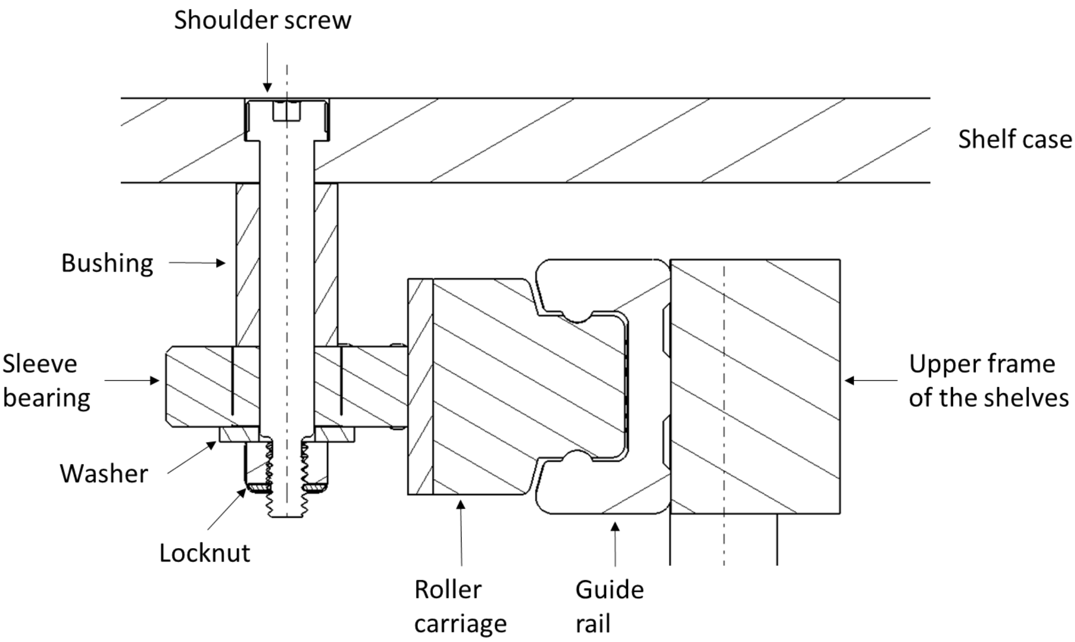


Figure 4.8: Cross-section view of the upper shaft.

The sliding bearings used here is the Self-Lubricating Aluminum-Mounted Bronze Bearing of the base mounted, with 1/4” shaft diameter and 2-1/4” long. It is the sleeve bearing which is used to undertake radial load, which accords with our design requirement. The detailed specifications of this sleeve bearing are shown in 4.9.

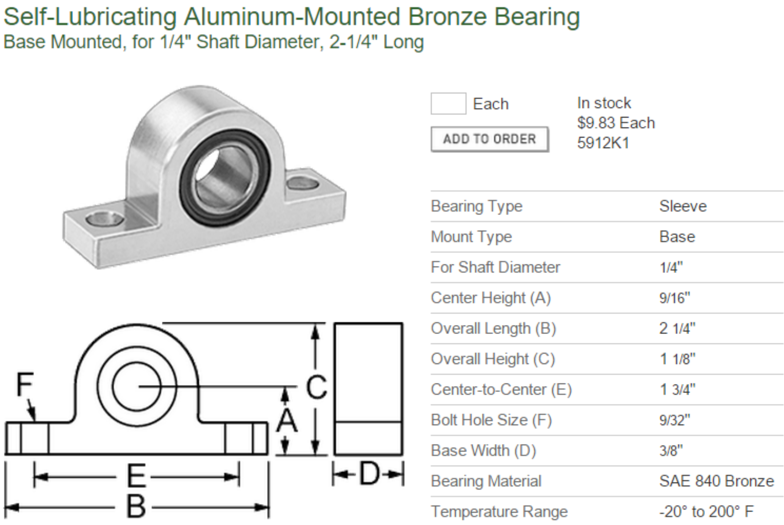


Figure 4.9: Specifications of the sleeve bearing.

For the linear bearing, it consists of a Side-Mount Track Roller Carriage with 87 mm length and a corresponding guide rail. This type of roller carriage is intended to mount vertically and take vertical load. We chose this roller carriage primarily to apply it on the lower corner of the inner shelves to use it undertake the vertical load of the shelves. To make the shelves balanced, it is also mounted at the upper corner of the shelves. 4.10 shows the specifications of this roller carriage and the related guide rail.

Figure 4.10: Specifications of the roller carriage and the guide rail.

To fix the guide rail to the upper frame of the shelf, three self-tapping screws for sheet metal are inserted through the holes of the guide rail into the frame. In addition, a pair of machine screw and hex nut is set at the end of the guide rail to provide the limit of the roller carriage movement in case the inner shelves are pulled out too away and cause the shelves loose support. This linear limit is illustrated at the left bottom corner of Figure 4.7.

4.2.3 Design and Selection at the Lower Shaft

Design of the lower shaft assembly is similar to the design of the upper shaft assembly. The sleeve bearing housing, the roller carriage and the guide rail at the bottom are the same as those at the top. Moreover, the mounting of these parts are also in the same way as at the upper shaft, except for the guide rail at the lower shaft is directly fixed to the lower layer shelf instead of the upper frame. The only difference part at the lower shaft is the application of thrust bearing to take the axial load we evaluated in force analysis section. It is also the critical part in this inner shelves design because all the loads on the inner shelves are supported by the thrust bearing at this position. Figure 4.11 and Figure 4.12 show the overall layout of the lower shaft from two different views respectively.

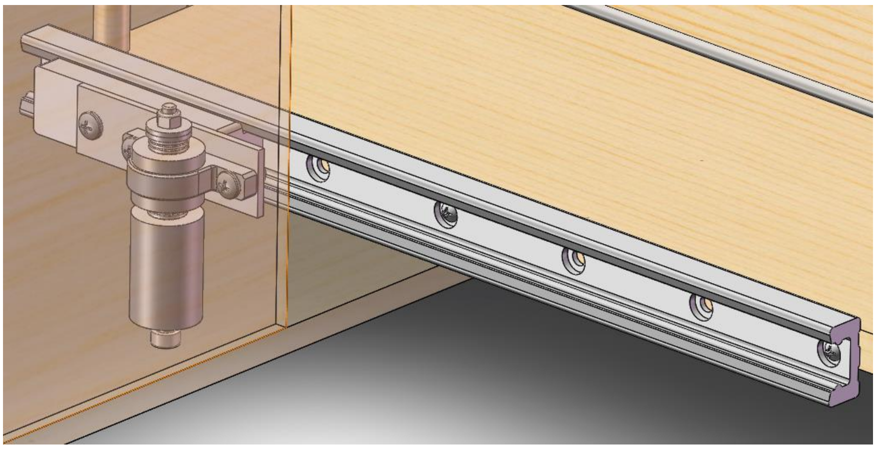


Figure 4.11: Overall layout of the lower shaft (front).

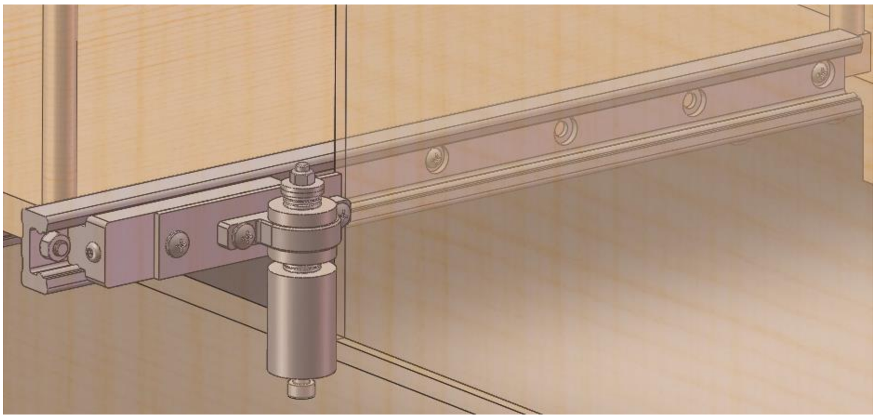


Figure 4.12: Overall layout of the lower shaft (back).

In order to apply the thrust bearing here, we redesign the distribution of components among the lower shaft. Basically we put two thrust bearings on the top and on the bottom of the sleeve bearing. Then the sleeve bearing undertakes the radial load, and the thrust bearing beneath the sleeve bearing is used to support the axial load. The thrust bearing above the sleeve bearing is used to allow the locknut tighten the whole shaft structure and to hold the vertical position of the entire inner shelves. Two spacers are put between the thrust bearings and the sleeve bearing to provide the contact surfaces. Then the sandwich structure of thrust bearing-sleeve bearing- thrust bearing allows simultaneous rotation of the sleeve bearing with the entire inner shelves and the thrust bearings as well as lets the thrust bearing to undertake the axial load. A cross-section view of the lower shaft is shown in Figure 4.13.

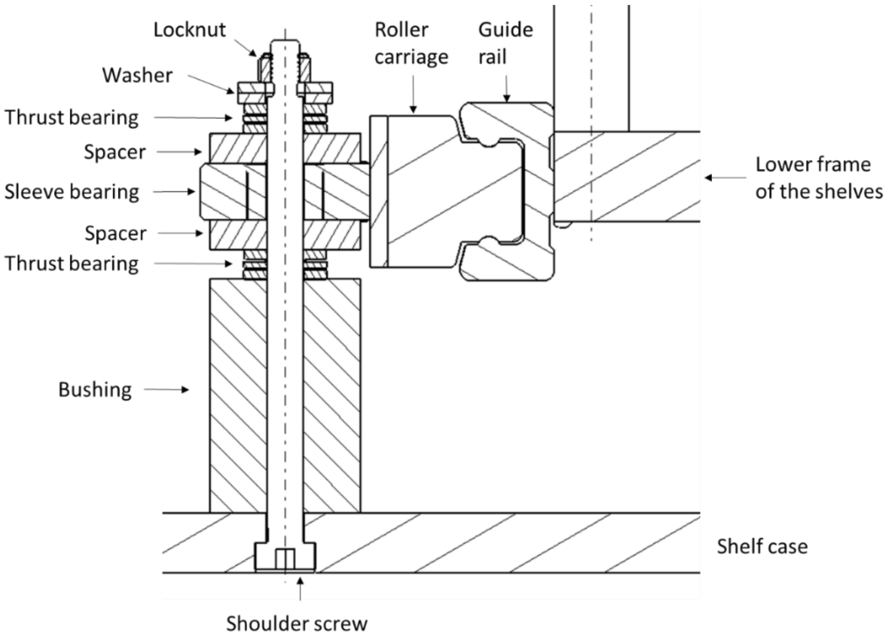


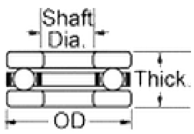
Figure 4.13: Cross-section view of the lower shaft.

Recall the designed axial load value the thrust bearing has to take is 88.18 lbs that we evaluate in the force analysis section, we need to find a proper thrust bearing which not only has the load capacity larger than that designed load value but also has the proper inner diameter dimension that can meet with the sleeve bearing. **The result we choose is the High-Performance Steel Thrust Ball Bearing[4], with 6mm Shaft Diameter.** The dynamic load capacity of this thrust bearing is 280 lbs, which is greater than our designed value so it is capable of being applied at the lower shaft. The detailed specifications of this thrust bearing are shown in Figure 4.14.

High-Performance Steel Thrust Ball Bearing
for 6 mm Shaft Diameter, 14 mm Outside Diameter

Each
ADD TO ORDER

In stock
$8.66 Each
7806K59



Bearing Type	Ball
Bearing Material	Steel
Ball Cage Material	Bronze
Temperature Range	-65° to 250° F
For Shaft Diameter	6 mm
For Shaft Diameter Tolerance	-0.008 mm to +0 mm
OD	14 mm
OD Tolerance	-0.008 mm to +0 mm
Thickness	5 mm
Thickness Tolerance	-0.12 mm to +0 mm
Dynamic Load Capacity	280 lbs.
Maximum rpm	11,500
RoHS	Compliant

Figure 4.14: Specifications of the thrust bearing.

To meet with the inner diameter of the thrust bearing, an ISO7379 Shoulder Bolt of M6 is used as the shaft with a M5 Steel Nylon-Insert Locknut. In addition, the washer in the layout is used to cover the shoulder of the shoulder screw so that the lock nut could tighten the whole shaft structure. Otherwise the locknut can only reach the shoulder of the screw so the vertical position of the shelves cannot be ensured on the certain height.

[4] The thrust bearing selection is under Professor Xu's comment, since we did not choose a proper thrust bearing to take axial load in presentation.

5. ASSEMBLY

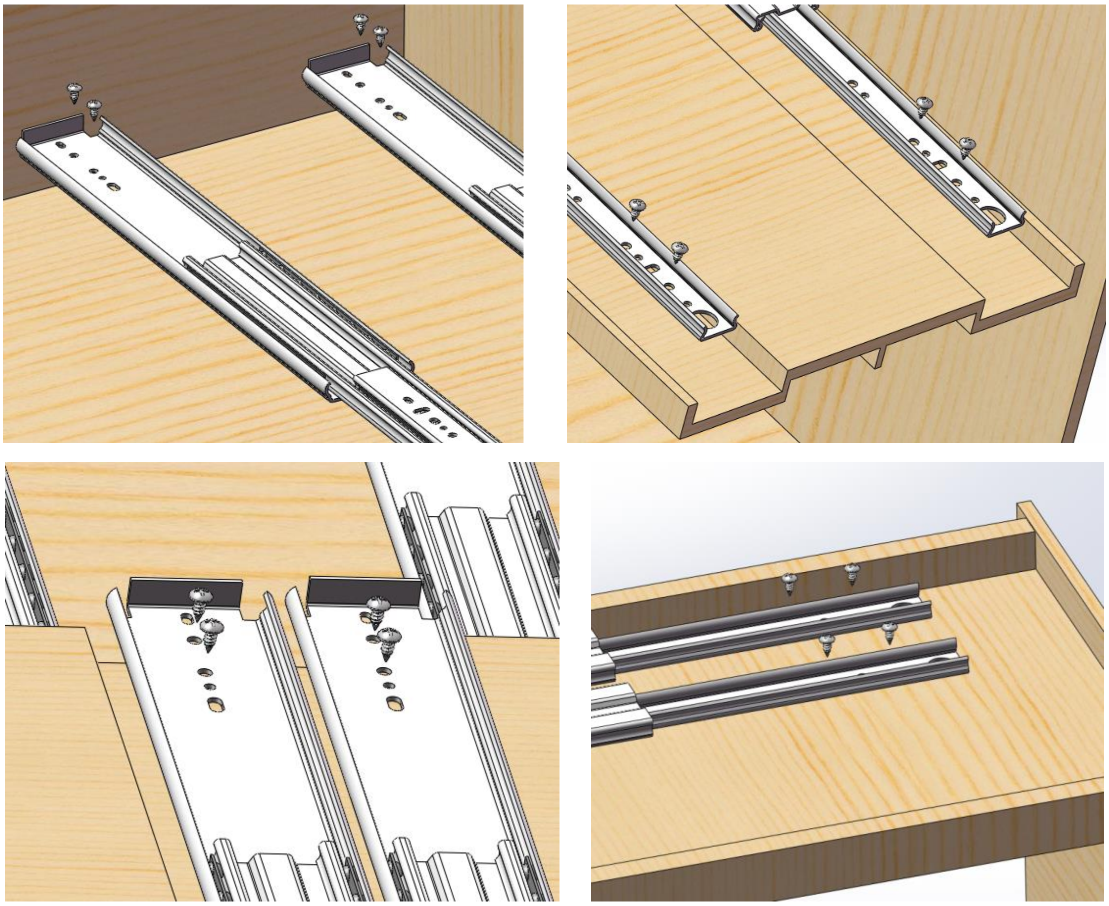


Figure 5.1: Base-mount drawer slide assembly.

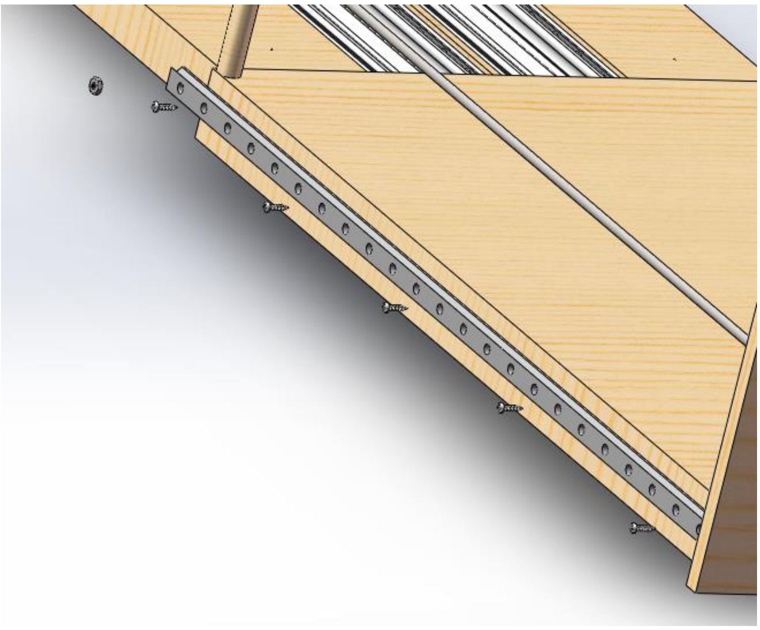


Figure 5.2: Guide rail assembly.

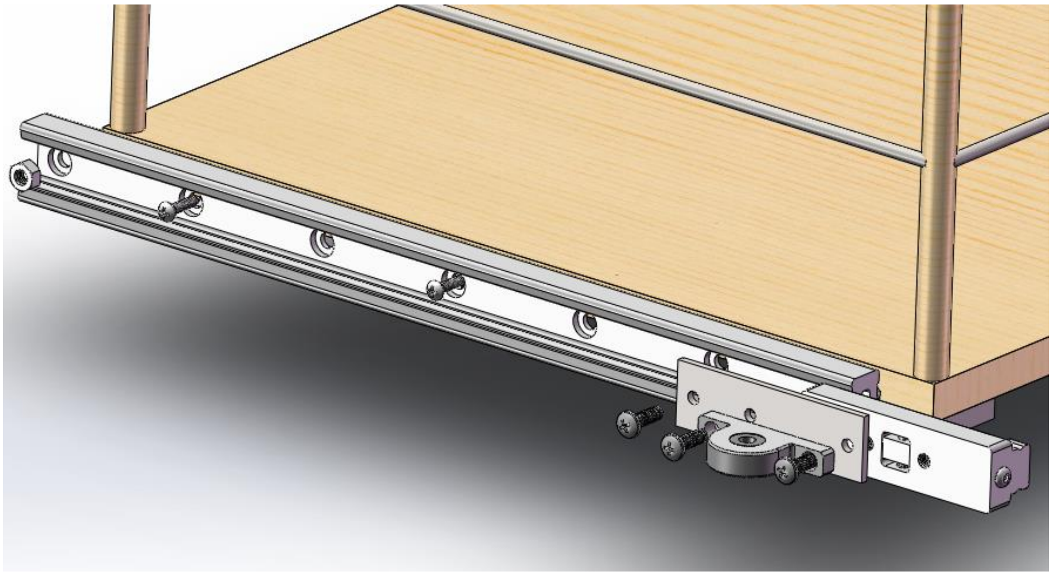
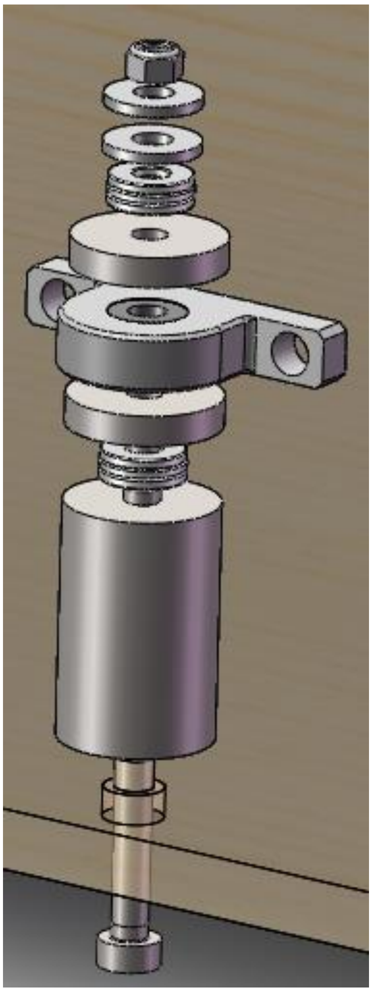
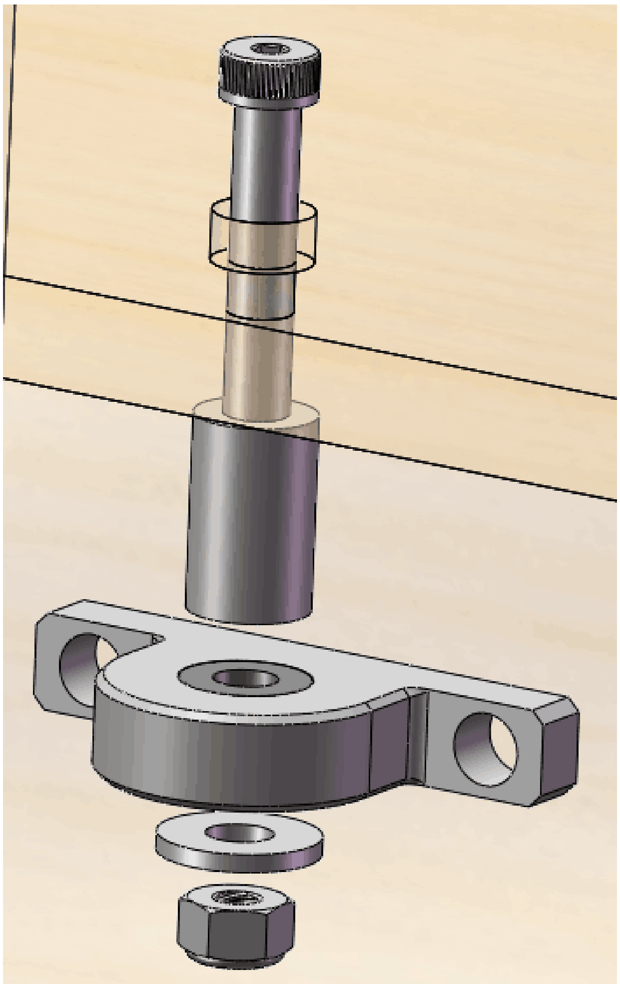


Figure 5.3: Roller carriage assembly.



(a) Lower.



(b) Upper.

Figure 5.4: Sleeve bearing assembly.

6. CONCLUSION

In Project 3, we are required to design a kitchen cabinet in detail. Two extant solutions are provided, as mentioned in INTRODUCTION section. Apparently, there are many disadvantages. For example, the space utilization of solution A is relatively low while its accessibility is relatively high. The space utilization of solution B is relatively high but it may not be convenient to use.

To avoid these advantages, we decided to figure out a new solution. We started with the design specification. First, the kitchen cabinet should be convenient to use and it will be most convenient if the entire shelf can be completely taken out of the cabinet. Second, the area of the shelf should be as large as possible. Since we are designing a kitchen cabinet with mobility, it will be great challenge to make use of the entire area.

Based on the design specification, we came up with our first concept design. It consists of a semi-circular shelf and a sub-shelf. Although the design seems convenient to use, there exists many potential problems. Therefore, we had a further design. The final design consists of two rectangular shelves with different sizes. We actually made a compromise that convenience is relatively more important than space utilization. As a result, for our final design, almost the entire shelf can be taken out of the cabinet while the space utilization only increase by 10%, which is good enough from our perspectives. Then we conducted a detailed force analysis before material selection to make sure the design will not fail. The total material cost of our final design is about $1264, which will decrease dramatically if put into mass production.

7. REFERENCES

[1] https://en.wikipedia.org/wiki/Kitchen_cabinet

[2] K. Xu, *00 – Overview_2015* [online], URL: http://sakai.umji.sjtu.edu.cn/access/content/group/5ccfc4aa-226e-4343-a52f-4de309d25b16/Lecture%20Notes/00%20-%20Overview_2015.pdf

[3] K. Xu, *07 – Helical Kinematic Pairs* [online], URL: http://sakai.umji.sjtu.edu.cn/access/content/group/5ccfc4aa-226e-4343-a52f-4de309d25b16/Lecture%20Notes/07%20-%20Helical%20Kinematic%20Pairs.pdf

APPENDIX A: BOM OF STANDARD COMPONENTS

Component	Serial Number	Unit Price	Num.	Total Price
Self-Lubricating Aluminum-Mounted Bronze Bearing, Base Mounted, for 1/4" Shaft Diameter, 2-1/4” Long	5912K1	9.83	2	19.66
Side-Mount Track Roller Carriage, 87mm Length	6738K221	111.78	2	223.56
Guide Rail for 87mm Long Side-Mount Track Roller Carriage	6738K74	57.60	2	115.20
High-Performance Steel Thrust Ball Bearing, for 6 mm Shaft Diameter, 14 mm Outside Diameter	7806K59	8.66	2	17.32
Type 316 Stainless Steel Shoulder Screw, 1/4" Diameter x 1-3/8" Long Shoulder, 10-24 Thread	97345A168	7.62	1	7.62
ISO7379 Shoulder Bolt M6X75	ISO7379	No reference	1	No reference
Alloy 20 Stainless Steel Flat Washer, 1/4" Screw Size, 0.260" ID, 0.625" OD	90770A029	1.17	3	3.52
Low-Strength Steel Nylon-Insert Locknut, Zinc-Plated, 10-24 Thread Size, 3/8" Wide, 15/64" High	90631A011	0.03	1	0.03
Zinc-Plated Class 8 Steel Nylon-Insert Locknut M5, M5x0.8 Thread Size, 8mm Wide, 5mm High	90576A104	0.04	1	0.04
18-8 Stainless Steel Metric Pan Head Phillips Machin Screw, M5 Size, 16mm Length, .8mm Pitch	92000A326	0.15	6	0.87
Zinc Plated Steel Hex Nut, Class 8, M5x0.8 Thread Size, 8mm Wide, 4mm High	90591A260	0.03	2	0.05
18-8 Stainless Steel Metric Pan Head Phillips Machin Screw, M6 Size, 12mm Length, 1mm Pitch	92000A424	0.21	1	0.21
Zinc Plated Steel Hex Nut, Class 8, M6x1 Thread Size, 10mm Wide, 5mm High	90591A151	0.02	1	0.02
18-8 Stainless Steel Pan Head Phillips Machin Screw, 5-40 Thread, 1/2" Length	91772A128	0.07	1	0.07
Low-Strength Steel Hex Nut, Zinc Plated, 5-40 Thread Size, 5/16" Wide, 7/64" High	90480A006	0.02	1	0.02

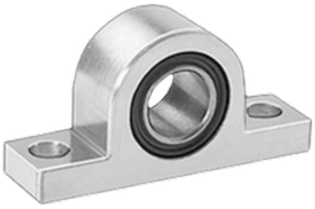
Pan Head Phillips Screw for Sheet Metal, 18-8 Stainless Steel, Number 12 Size, 1/2" Length	92470A291	0.10	24	2.45
Pan Head Phillips Screw for Sheet Metal, 18-8 Stainless Steel, Number 4 Size, 1/2" Length	92410A110	0.05	5	0.27
Pan Head Phillips Screw for Sheet Metal, 18-8 Stainless Steel, M3.9 Size, 19 mm Length	94997A425	0.33	6	1.97
Base-Mount Drawer Slide, Full Extension, 18" Closed Length	1102A65	48.29	4	193.14
Polyethylene Sleeve-Bearing Carriage, Threaded Through-Hole, for 1/2" Rail Width	9728K31	29.94	1	29.94
Guide Rail, 1/2" Wide, for Polyethlene Sleeve Bearing Carriage	9728K6	65.25	1	65.25
Marine-Grade Plywood, 1/2"thick, 24"x24"	125T33	35.36	7	247.52
Oak Dowel Rod, 1/2" Diameter, 36" Length	96825K77	1.78	5	8.90
Marine-Grade Plywood, 1/2"thick, 24"x36"	125T34	48.89	2	97.78
Marine-Grade Plywood, 1/2"thick, 36"x48"	125T35	88.89	2	177.78
Multipurpose 304 Stainless Steel Rod, 5mm Diameter	1272T35	7.20	7	50.40
			Total Price	**1263.60**

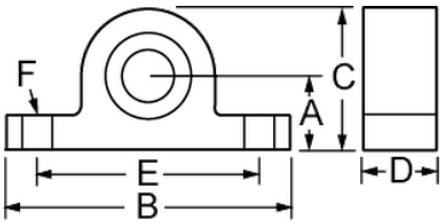
Table A-1: List of standard components.

APPENDIX B: MAJOR SPECIFICATION

Self-Lubricating Aluminum-Mounted Bronze Bearing

Base Mounted, for 1/4" Shaft Diameter, 2-1/4" Long



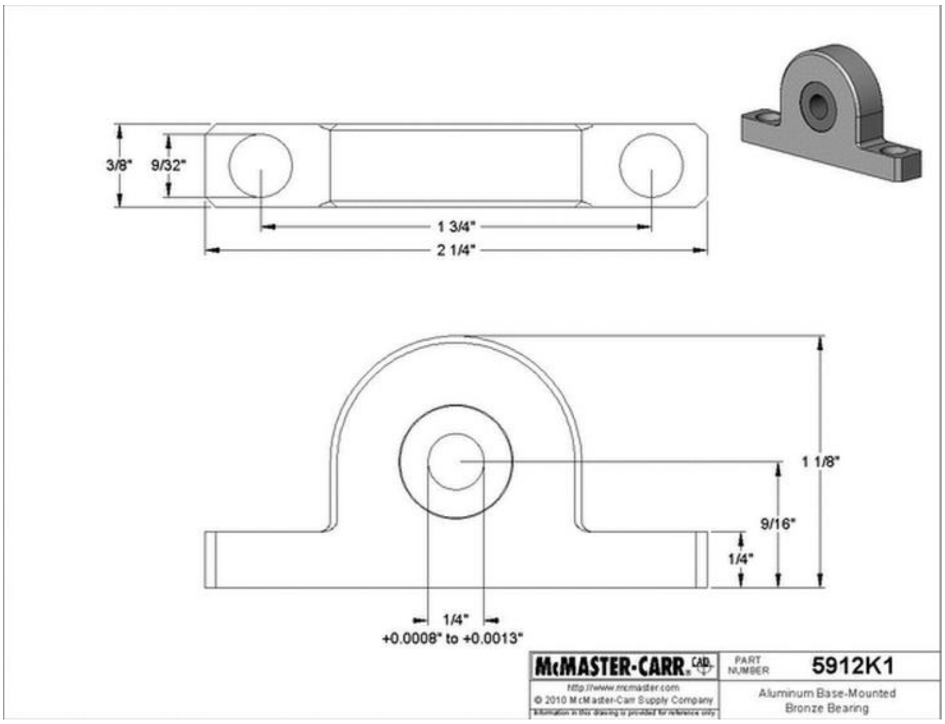


Each

ADD TO ORDER

In stock
$9.83 Each
5912K1

Bearing Type	Sleeve
Mount Type	Base
For Shaft Diameter	1/4"
Center Height (A)	9/16"
Overall Length (B)	2 1/4"
Overall Height (C)	1 1/8"
Center-to-Center (E)	1 3/4"
Bolt Hole Size (F)	9/32"
Base Width (D)	3/8"
Bearing Material	SAE 840 Bronze
Temperature Range	-20° to 200° F
P Maximum	2,000
V Maximum	1,200
PV Maximum	25,000
For Shaft Diameter Tolerance	0.0008" to 0.0013"
RoHS	Compliant



http://www.mcmaster.com/#5912k1/=ybelfr

Side-Mount Track Roller Carriage

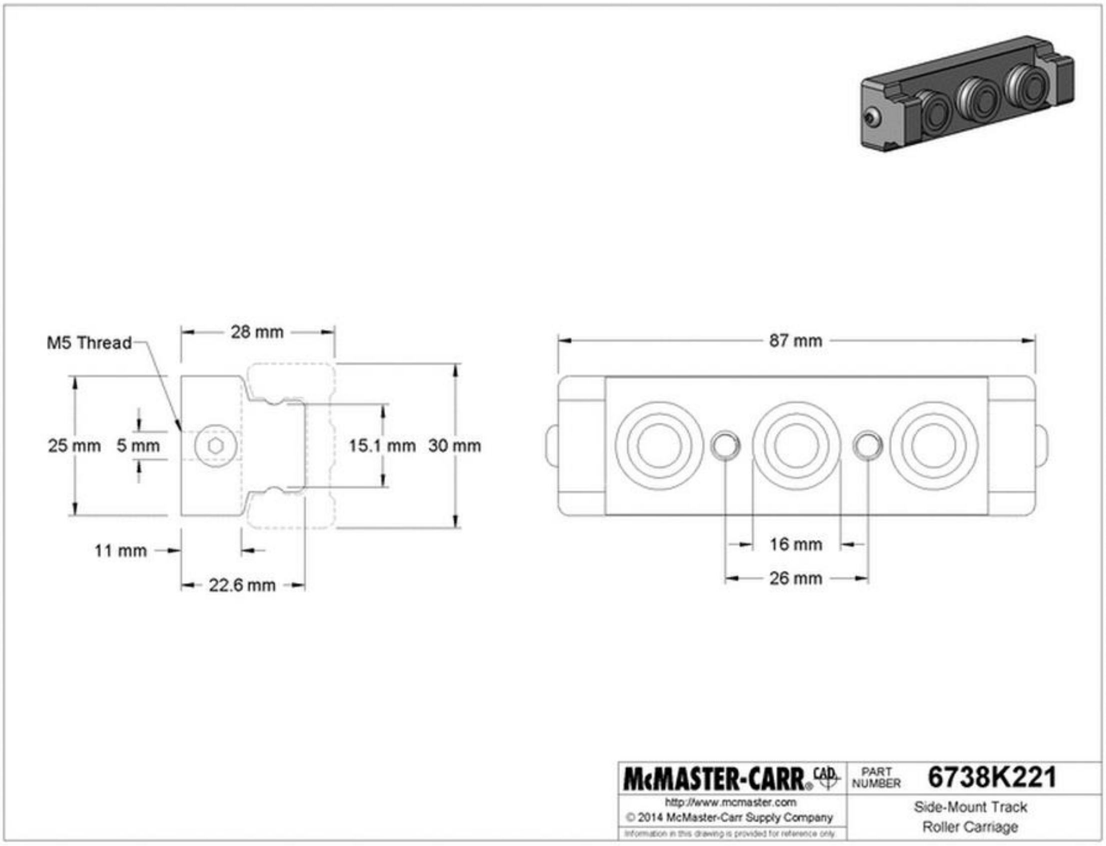
87 mm Length

Each

ADD TO ORDER

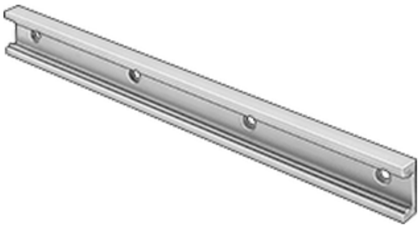
In stock
$111.78 Each
6738K221

Rail Height	30 mm
Dynamic Load Capacity	225 lbs.
Overall Width	28 mm
Length	87 mm
Height	25 mm
Mounting Holes	
Screw Size	M5
Depth	11 mm
Additional Specifications	Metric Carriages with Steel Track Rollers
RoHS	Compliant
Related Product	Guide Rails



http://www.mcmaster.com/#6738k221/=yay5up

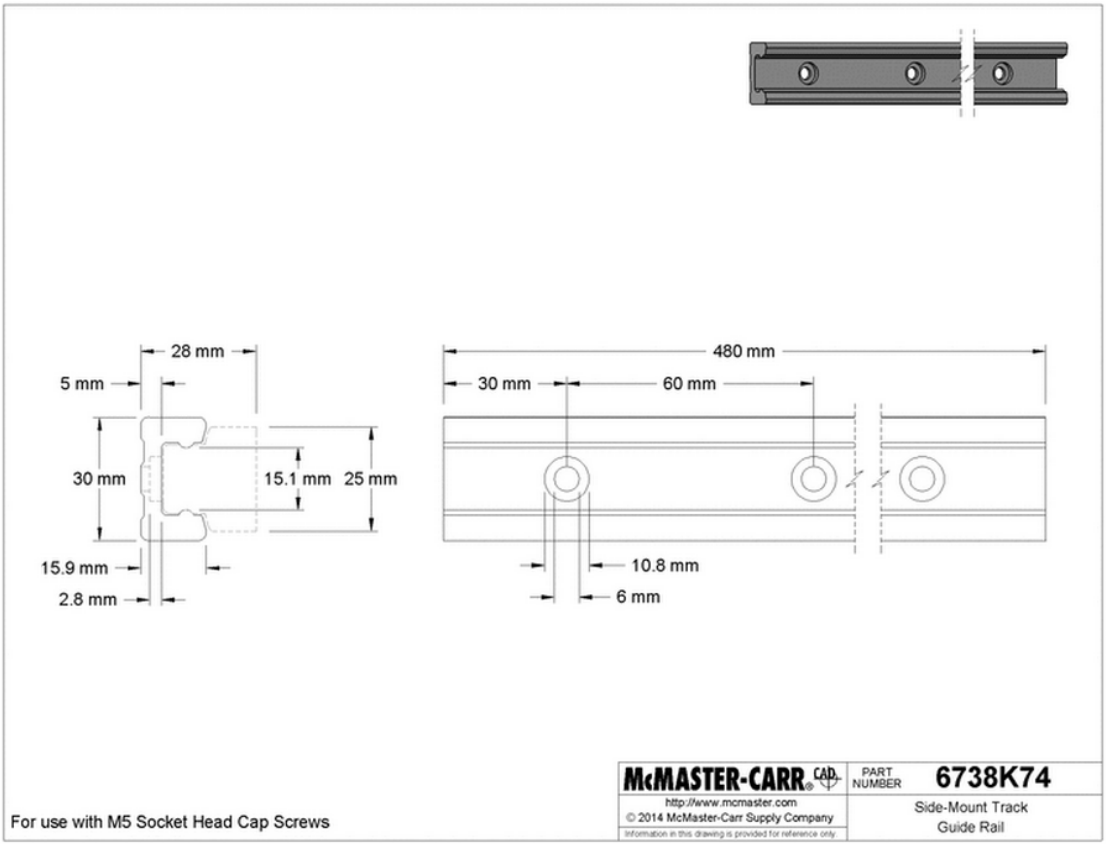
Guide Rail for 87mm Long Side-Mount Track Roller Carriage



Length, mm	Each
480	6738K74
720	
960	
1,440	

ADD TO ORDER

Socket Head Cap Screw Size	M5
Additional Specifications	Metric Carriages with Steel Track Rollers
RoHS	Compliant

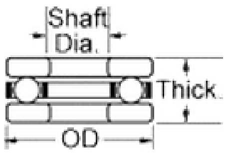


http://www.mcmaster.com/#6738k74/=ybpkpt

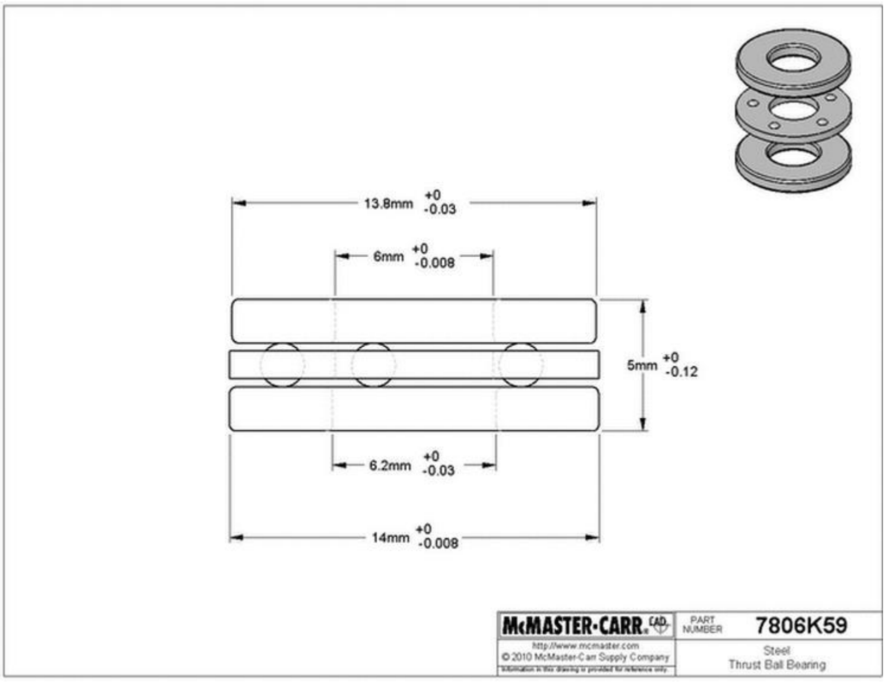
High-Performance Steel Thrust Ball Bearing
for 6 mm Shaft Diameter, 14 mm Outside Diameter

Each — ADD TO ORDER

In stock
$8.66 Each
7806K59



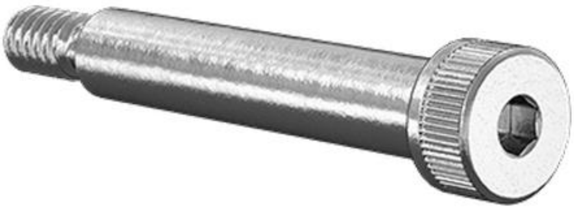
Bearing Type	Ball
Bearing Material	Steel
Ball Cage Material	Bronze
Temperature Range	-65° to 250° F
For Shaft Diameter	6 mm
For Shaft Diameter Tolerance	-0.008 mm to +0 mm
OD	14 mm
OD Tolerance	-0.008 mm to +0 mm
Thickness	5 mm
Thickness Tolerance	-0.12 mm to +0 mm
Dynamic Load Capacity	280 lbs.
Maximum rpm	11,500
RoHS	Compliant



http://www.mcmaster.com/#7806k59/=ybplbt

Type 316 Stainless Steel Shoulder Screw

1/4" Diameter x 1-3/8" Long Shoulder, 10-24 Thread

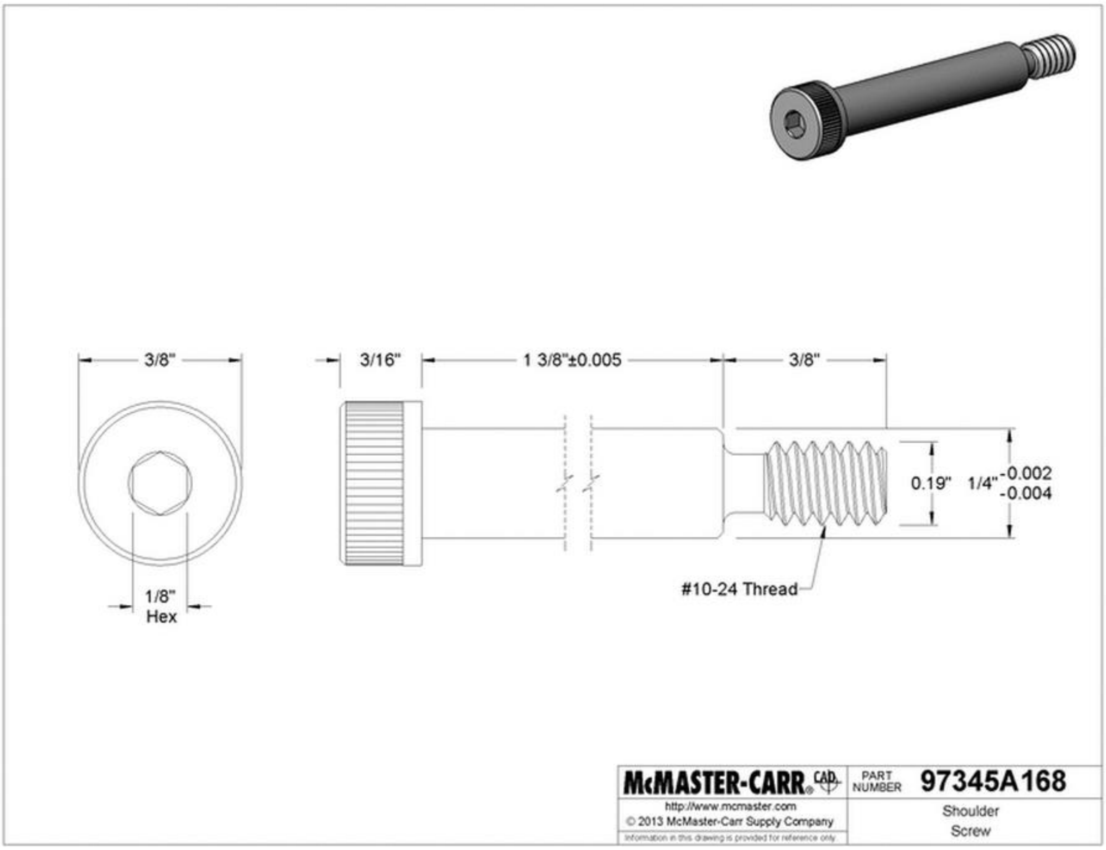


Each

ADD TO ORDER

In stock
1-4 Each $7.62
5 or more $6.48
97345A168

Shoulder Diameter	1/4"
Shoulder Diameter Tolerance	-0.002" to -0.004"
Shoulder Length	1 3/8"
Shoulder Length Tolerance	-0.005" to +0.005"
Drive Style	Socket
Head Diameter	3/8"
Head Height	3/16"
Thread Size	10-24
Thread Length	3/8"
Material	Type 316 Stainless Steel



http://www.mcmaster.com/#97345a168/=ybpmny

Alloy 20 Stainless Steel Flat Washer

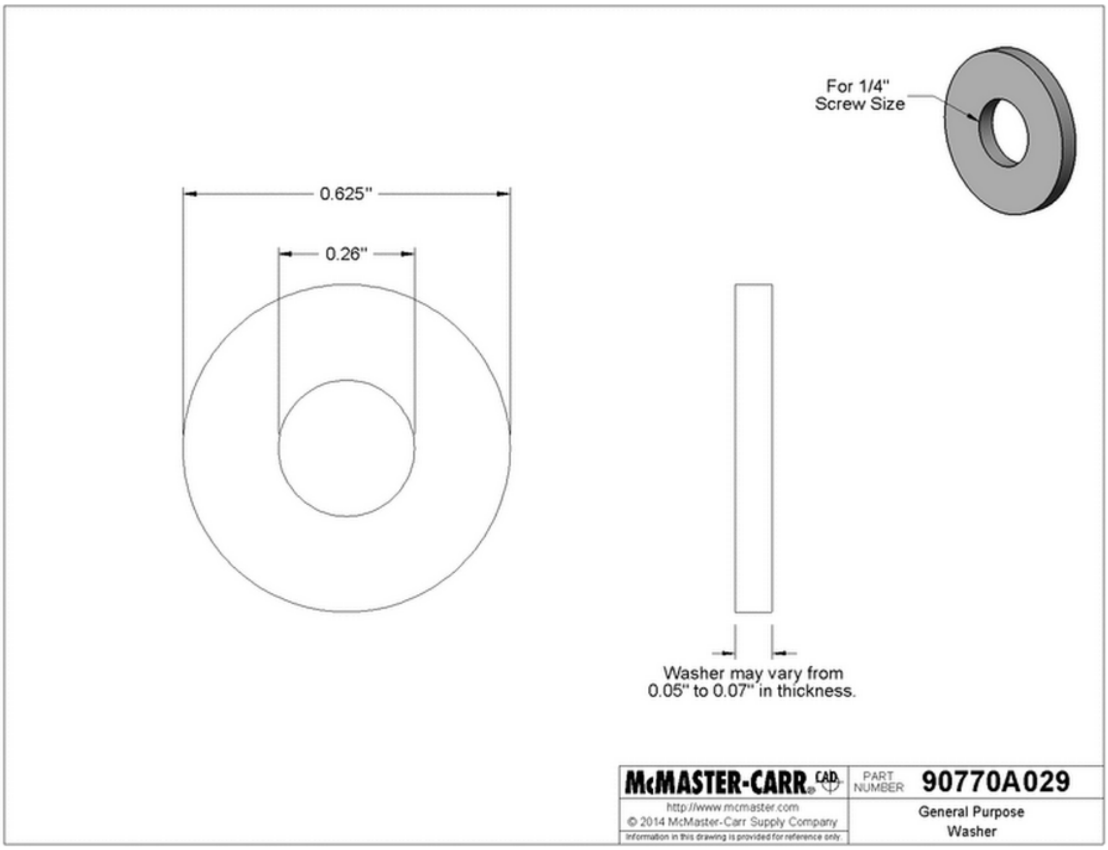
1/4" Screw Size, 0.260" ID, 0.625" OD

Packs of 5

ADD TO ORDER

In stock
$5.86 per pack of 5
90770A029

Material	Alloy 20 Stainless Steel
Screw Size	1/4"
ID	0.260"
OD	0.625"
Thickness	
Minimum	0.050"
Maximum	0.070"



http://www.mcmaster.com/#90770a029/=ybpnvr

Low-Strength Steel Nylon-Insert Locknut

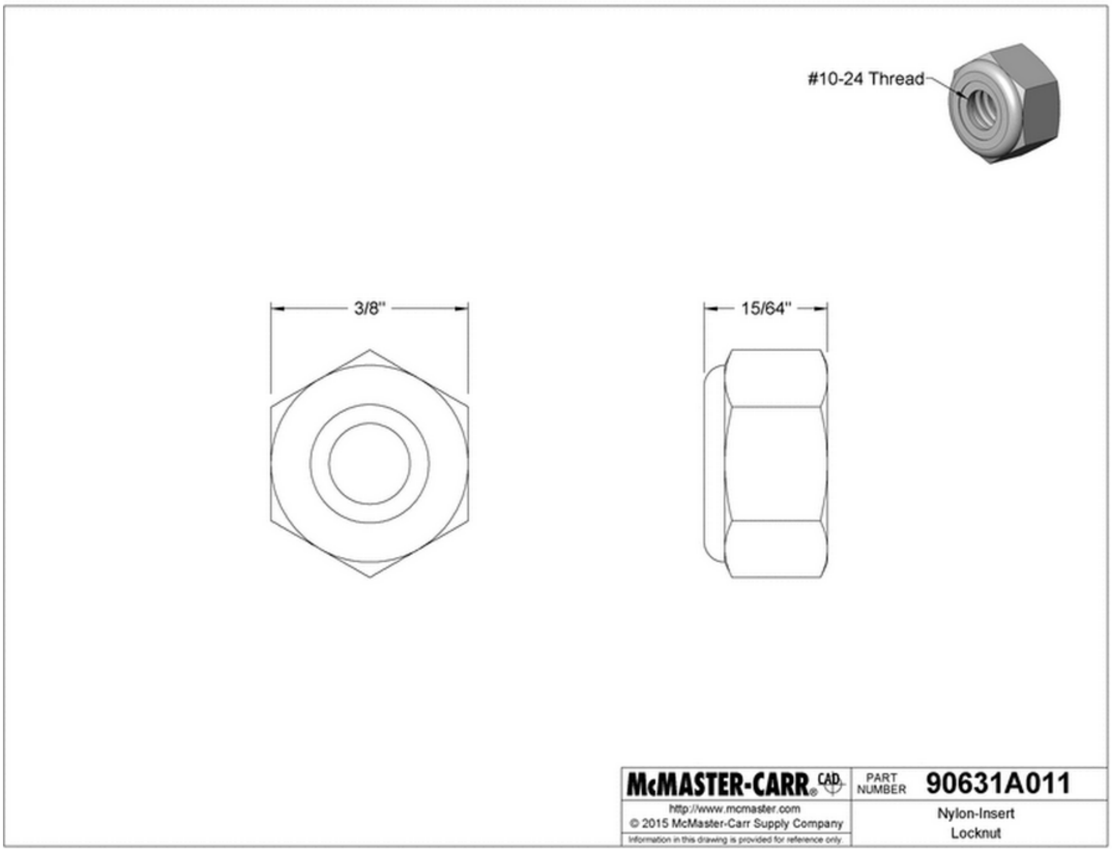
Zinc-Plated, 10-24 Thread Size, 3/8" Wide, 15/64" High

Packs of 100

ADD TO ORDER

In stock
$3.27 per pack of 100
90631A011

Material	Steel
Finish	Zinc Plated
Thread Direction	Right Hand
Reusability	Up to 15 times
Thread Size	10-24
Width	3/8"
Height	15/64"



http://www.mcmaster.com/#90631a011/=yb5kta

Zinc-Plated Class 8 Steel Nylon-Insert Locknut

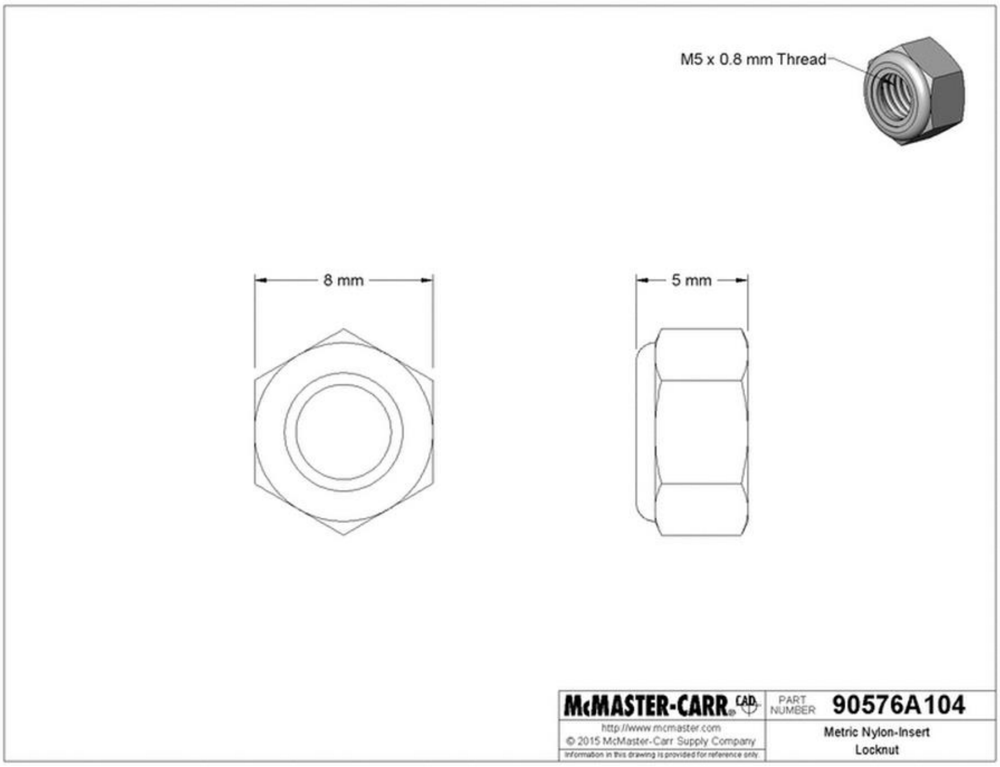
M5x0.8 Thread Size, 8mm Wide, 5mm High

Packs of 100

ADD TO ORDER

In stock
$4.27 per pack of 100
90576A104

Material	Steel
Class	8
Finish	Zinc Plated
Thread Direction	Right Hand
Specifications Met	DIN 985
Reusability	Up to 15 times
Thread Size	M5 × 0.8
Width	8 mm
Height	5 mm
RoHS	Not Compliant



http://www.mcmaster.com/#90576a104/=ybie1v

18-8 Stainless Steel Metric Pan Head Phillips Machine Screw

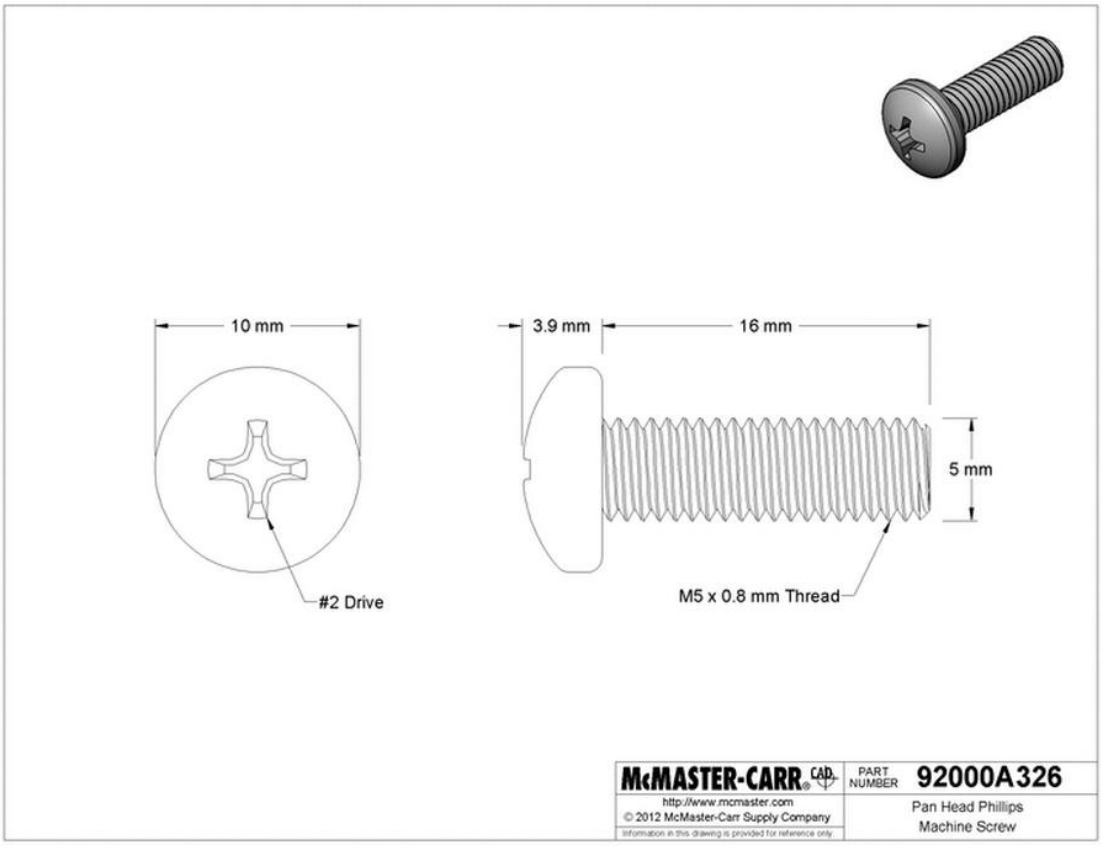
M5 Size, 16mm Length, .8mm Pitch

Packs of 50

ADD TO ORDER

In stock
$7.27 per pack of 50
92000A326

Length	16 mm
Additional Specifications	18-8 Stainless Steel—DIN 7985 M5—#2 Drive; Pitch: 0.8 mm
RoHS	Compliant



http://www.mcmaster.com/#92000a326/=yb5wv1

Zinc Plated Steel Hex Nut

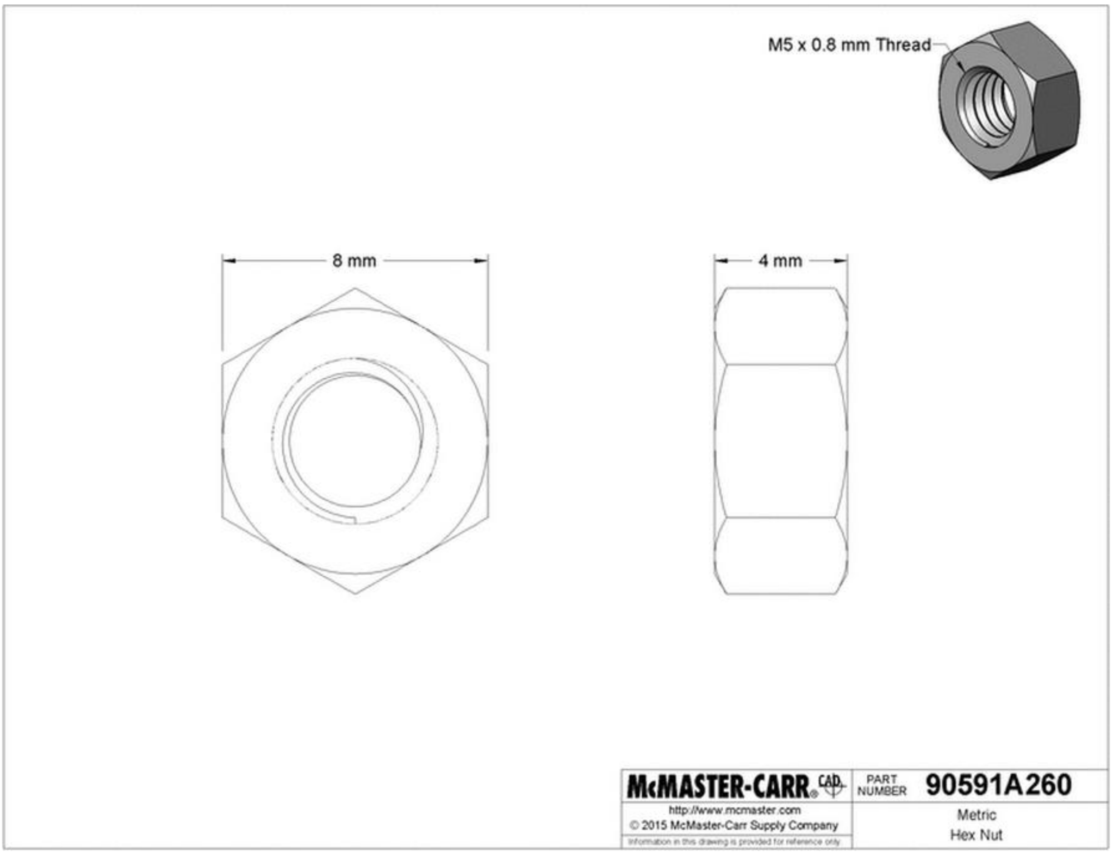
Class 8, M5x0.8 Thread Size, 8mm Wide, 4mm High

Packs of 100

ADD TO ORDER

In stock
$2.61 per pack of 100
90591A260

Material	Steel
Class	8
Finish	Zinc Plated
Thread Direction	Right Hand
Specifications Met	DIN 934
Thread Size	M5 × 0.8
Width	8 mm
Height	4 mm



http://www.mcmaster.com/#90591a260/=yb5w36

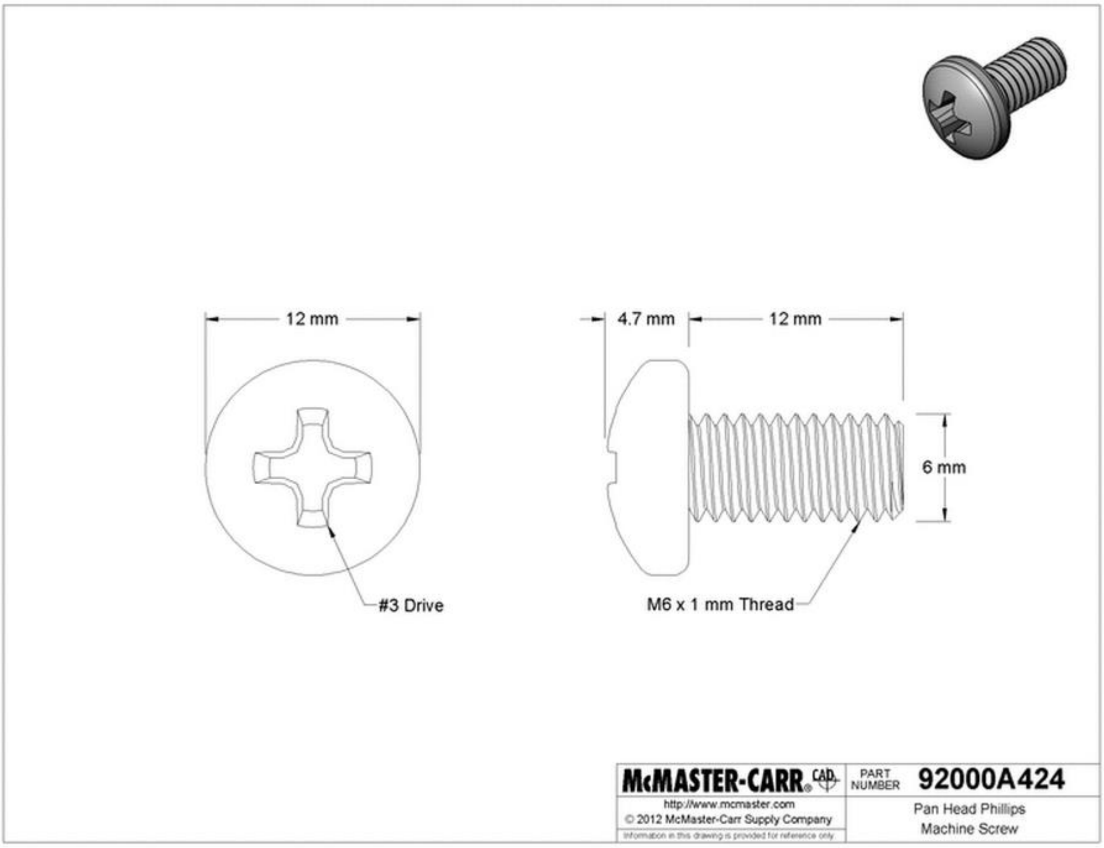
18-8 Stainless Steel Metric Pan Head Phillips Machine Screw
M6 Size, 12mm Length, 1mm Pitch

Packs of 25

ADD TO ORDER

In stock
$5.34 per pack of 25
92000A424

Length	12 mm
Additional Specifications	18-8 Stainless Steel—DIN 7985 M6—#3 Drive; Pitch: 1 mm
RoHS	Compliant



http://www.mcmaster.com/#92000a424/=yb648b

Zinc Plated Steel Hex Nut

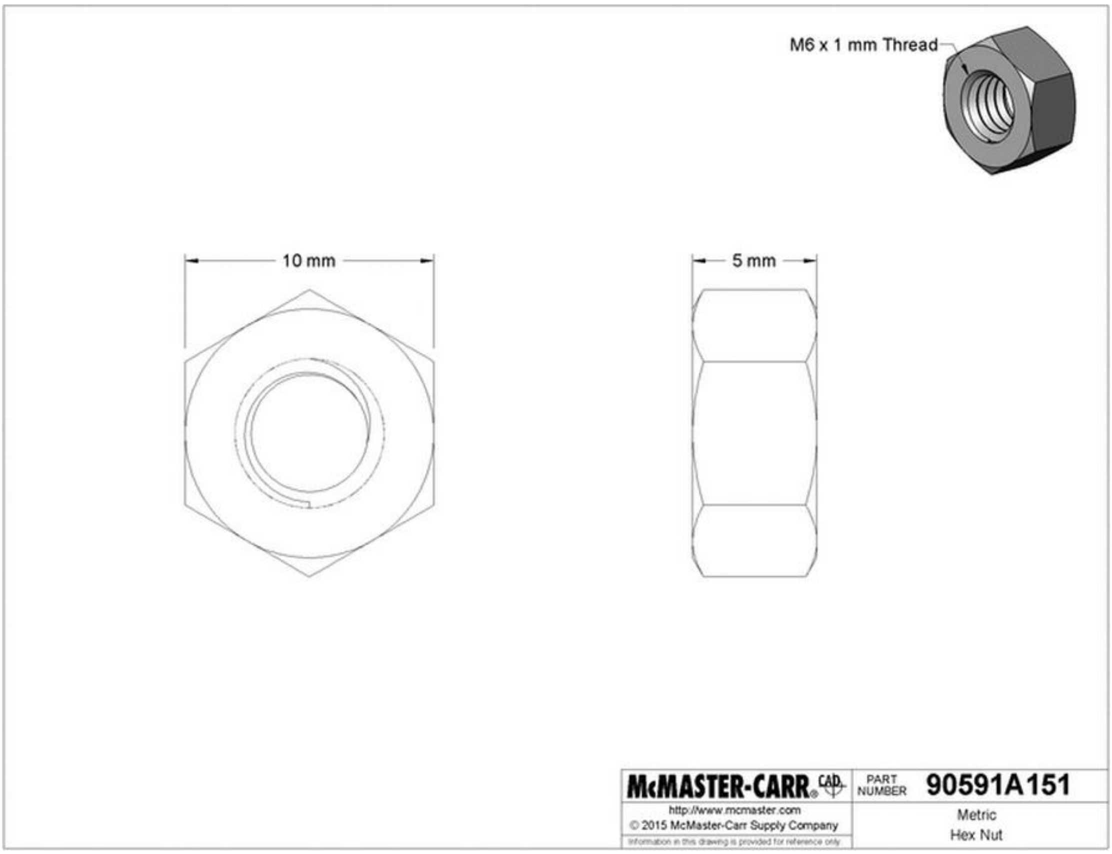
Class 8, M6x1 Thread Size, 10mm Wide, 5mm High

Packs of 100

ADD TO ORDER

In stock
$2.30 per pack of 100
90591A151

Material	Steel
Class	8
Finish	Zinc Plated
Thread Direction	Right Hand
Specifications Met	DIN 934
Thread Size	M6 × 1
Width	10 mm
Height	5 mm
RoHS	Compliant



http://www.mcmaster.com/#90591a151/=yb63p2

18-8 Stainless Steel Pan Head Phillips Machine Screw

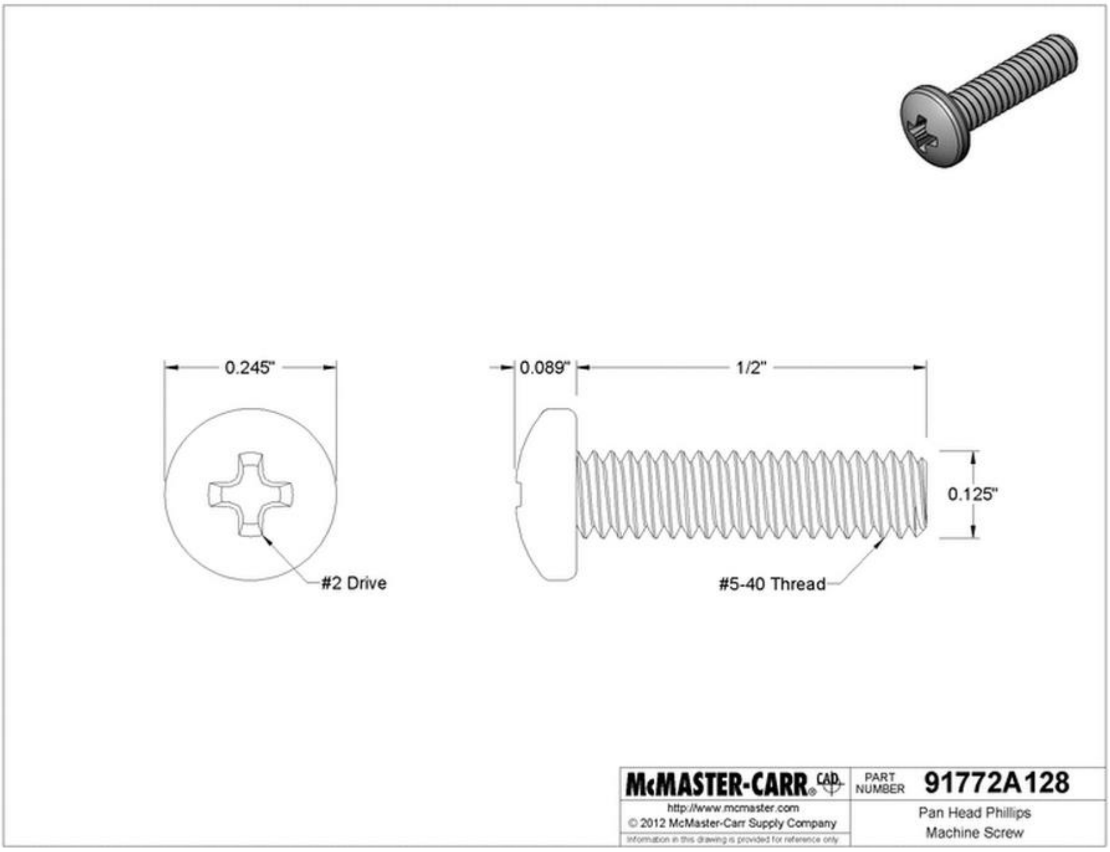
5-40 Thread, 1/2" Length

Packs of 100

ADD TO ORDER

In stock
$7.01 per pack of 100
91772A128

Length	1/2"
Additional Specifications	18-8 Stainless Steel 5-40—#2 Drive
RoHS	Compliant



http://www.mcmaster.com/#91772a128/=ybd1yi

Low-Strength Steel Hex Nut

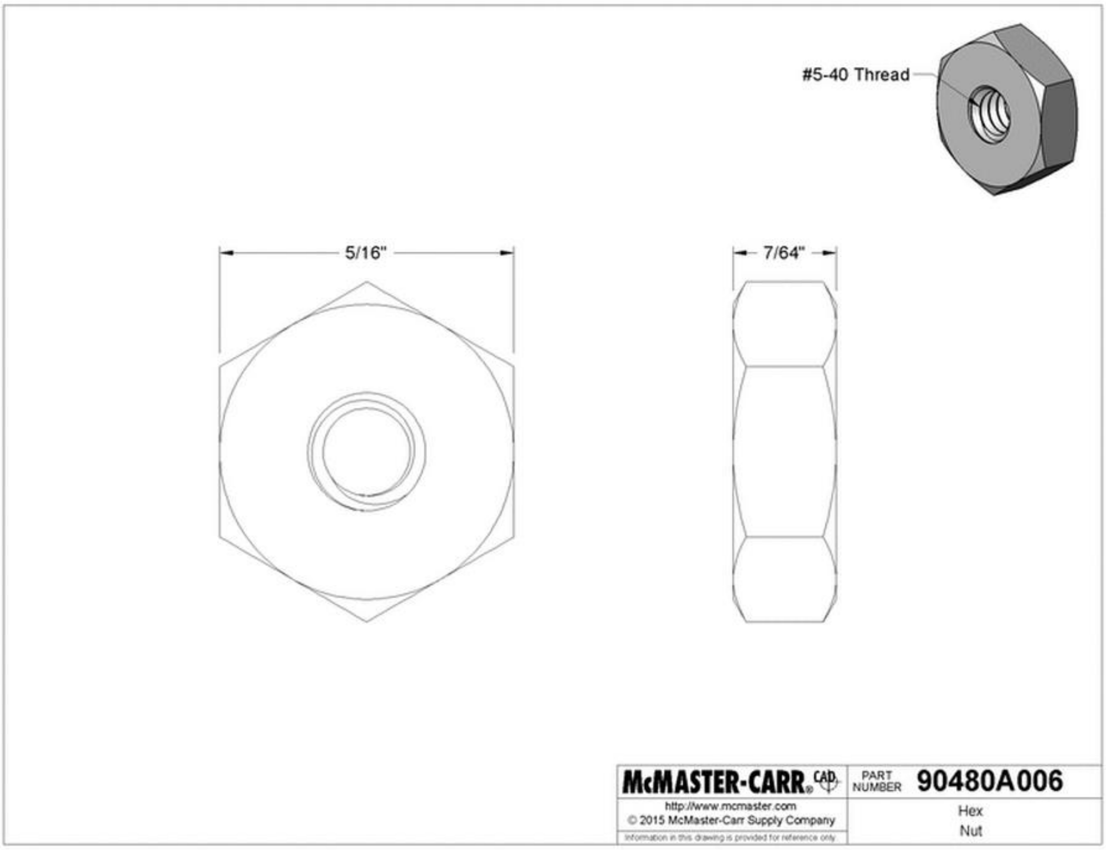
Zinc Plated, 5-40 Thread Size, 5/16" Wide, 7/64" High

Packs of 100

ADD TO ORDER

In stock
$1.71 per pack of 100
90480A006

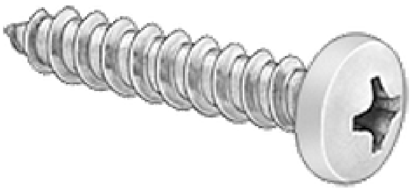
Material	Steel
Finish	Zinc Plated
Thread Direction	Right Hand
Thread Size	5-40
Width	5/16"
Height	7/64"
RoHS	Not Compliant



http://www.mcmaster.com/#90480a006/=yb69hq

Pan Head Phillips Screw for Sheet Metal

18-8 Stainless Steel, Number 12 Size, 1/2" Length

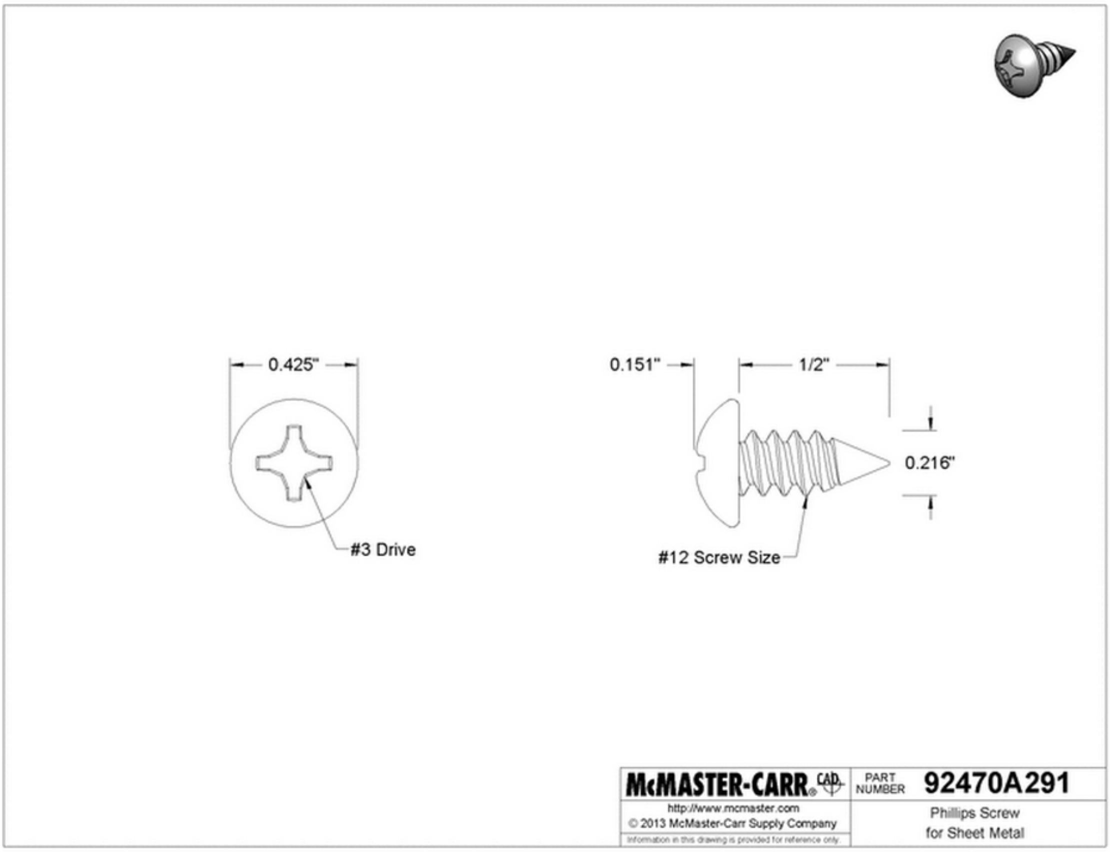


Packs of 100

ADD TO ORDER

In stock
$10.22 per pack of 100
92470A291

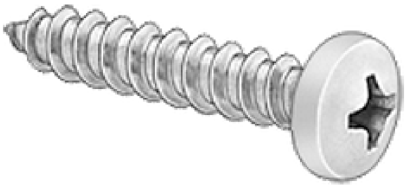
Length	1/2"
Additional Specifications	18-8 Stainless Steel No. 12—#3 Drive
RoHS	Compliant



http://www.mcmaster.com/#92470a291/=yb6lqg

Pan Head Phillips Screw for Sheet Metal

18-8 Stainless Steel, Number 4 Size, 1/2" Length

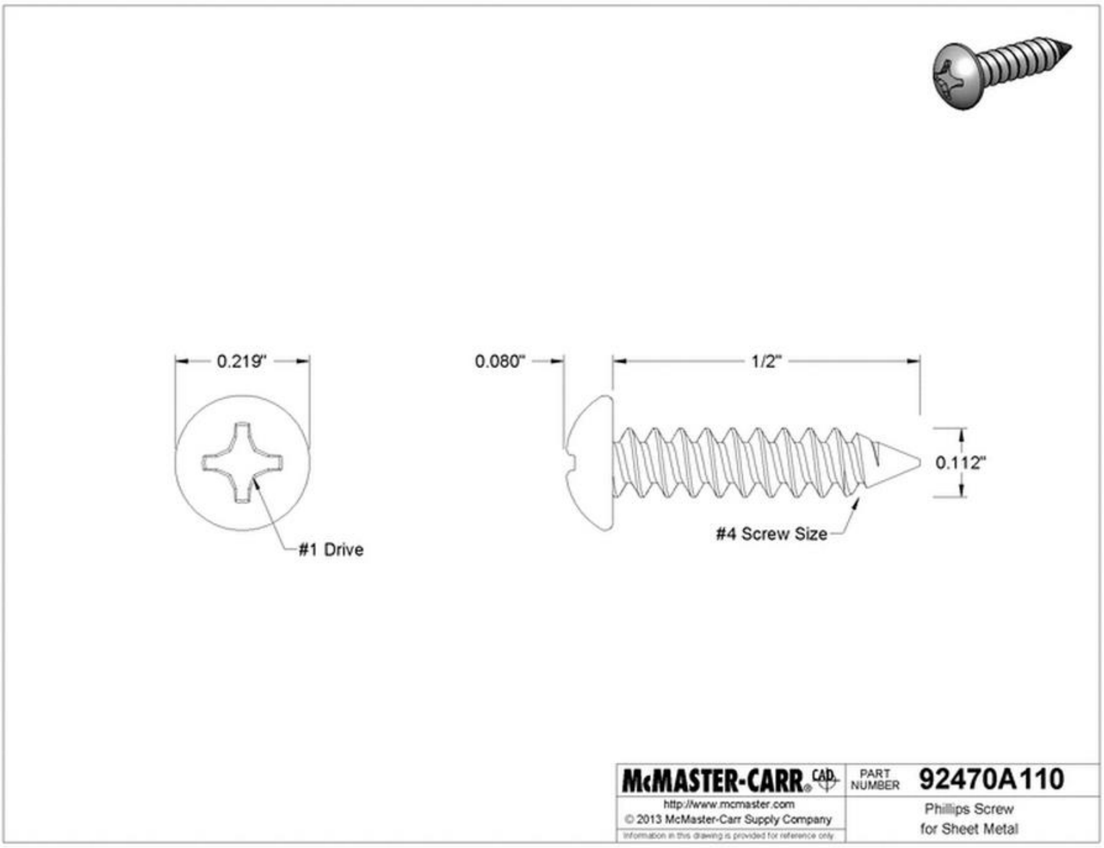


Packs of 100

ADD TO ORDER

In stock
$5.35 per pack of 100
92470A110

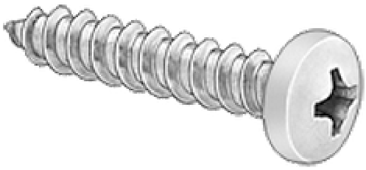
Length	1/2"
Additional Specifications	18-8 Stainless Steel No. 4—#1 Drive
RoHS	Compliant



http://www.mcmaster.com/#92470a110/=yb6dfq

Pan Head Phillips Screw for Sheet Metal

18-8 Stainless Steel, M3.9 Size, 19 mm Length

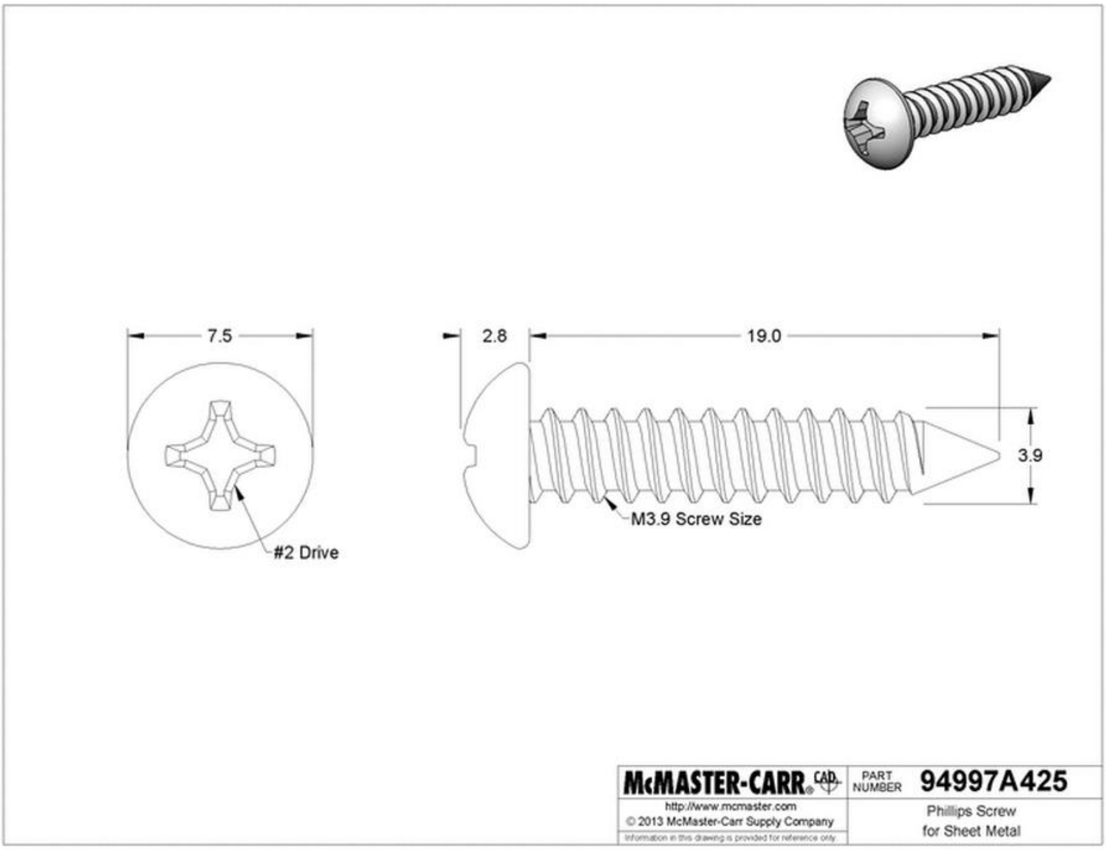


Packs of 25

ADD TO ORDER

In stock
$8.21 per pack of 25
94997A425

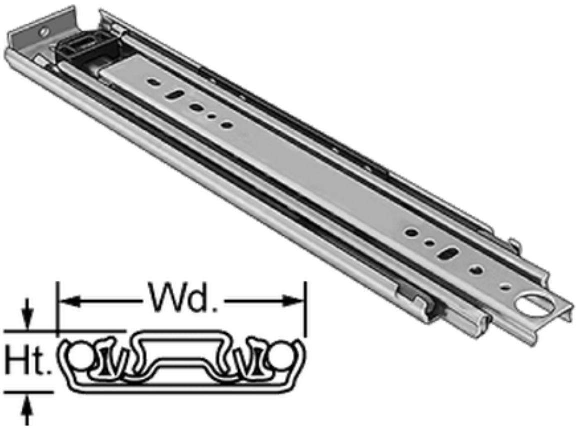
Length	19 mm
Additional Specifications	Metric 18-8 Stainless Steel—DIN 7981 M3.9—#2 Drive



http://www.mcmaster.com/#94997a425/=yb5s7r

Base-Mount Drawer Slide

Full Extension, 18" Closed Length

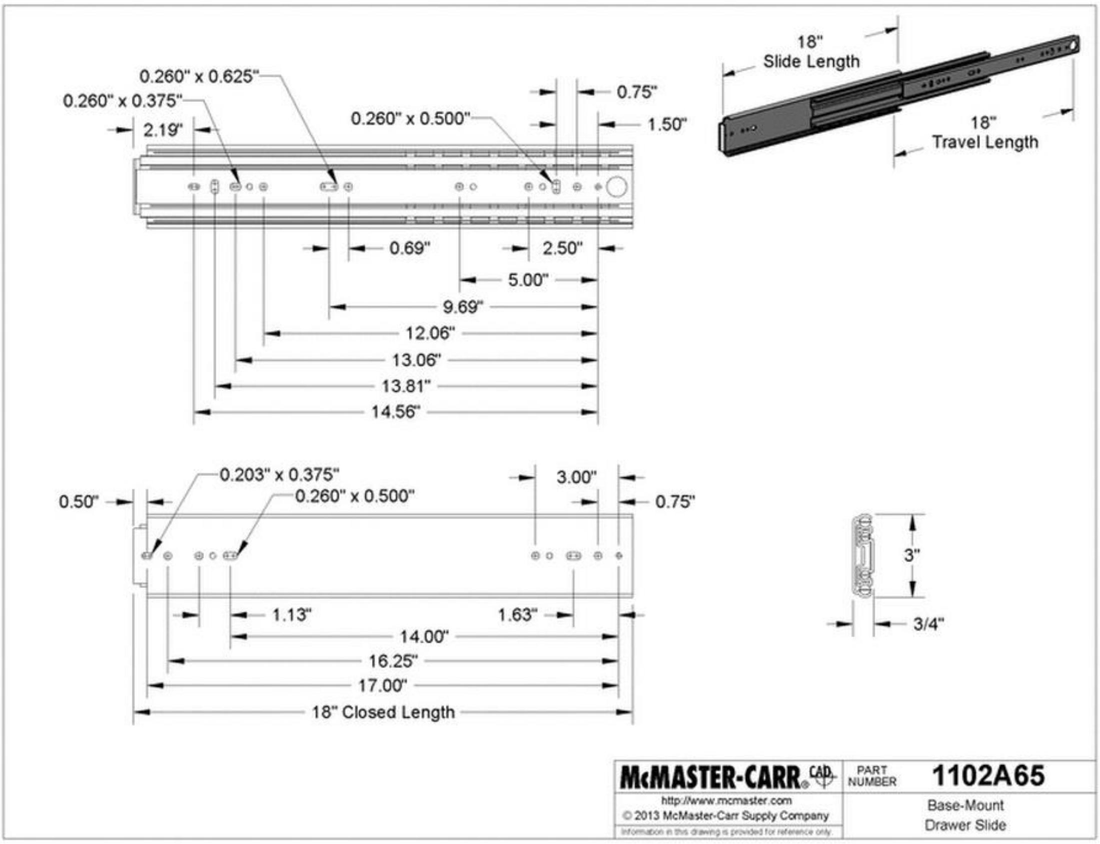


Pairs

ADD TO ORDER

In stock
$96.57 per pair
1102A65

Extension	Full
Closed Length	18"
Extension	18"
Width	3"
Height	3/4"
Feature	None
Load Rating	150 lbs./pair
Drawer Release	None
Additional Specifications	Style A—Steel
RoHS	Compliant



http://www.mcmaster.com/#1102a65/=ybd60d

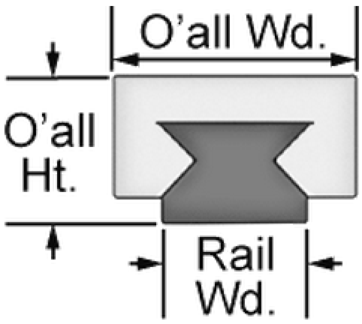
Polyethylene Sleeve-Bearing Carriage

Threaded Through-Hole, for 1/2" Rail Width

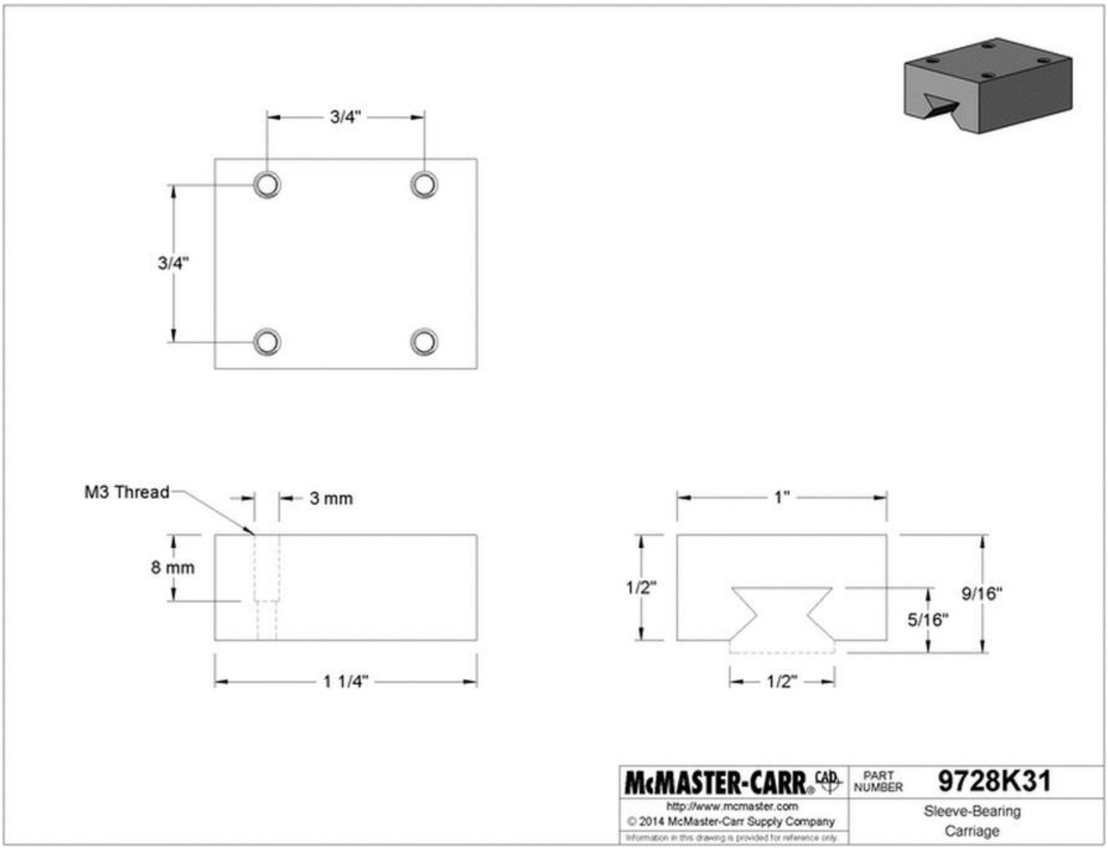
Each

ADD TO ORDER

In stock
$29.94 Each
9728K31



Rail Width	1/2"
Static Load Capacity	100 lbs.
Overall Height	9/16"
Overall Size	
Width	1"
Length	1 1/4"
Mounting Holes	
Screw Size	M3
Depth	8 mm
Additional Specifications	Polyethylene Carriages and Guide Rails
RoHS	Compliant
Related Product	Guide Rails



http://www.mcmaster.com/#9728k31/=ybd6rd

Guide Rail, 1/2" Wide, for Polyethylene Sleeve-Bearing Carriage

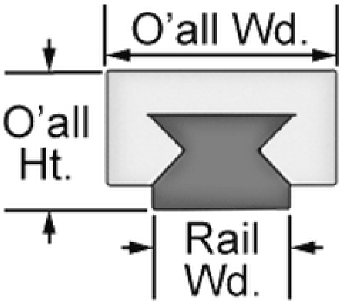
Inches: Select from list...

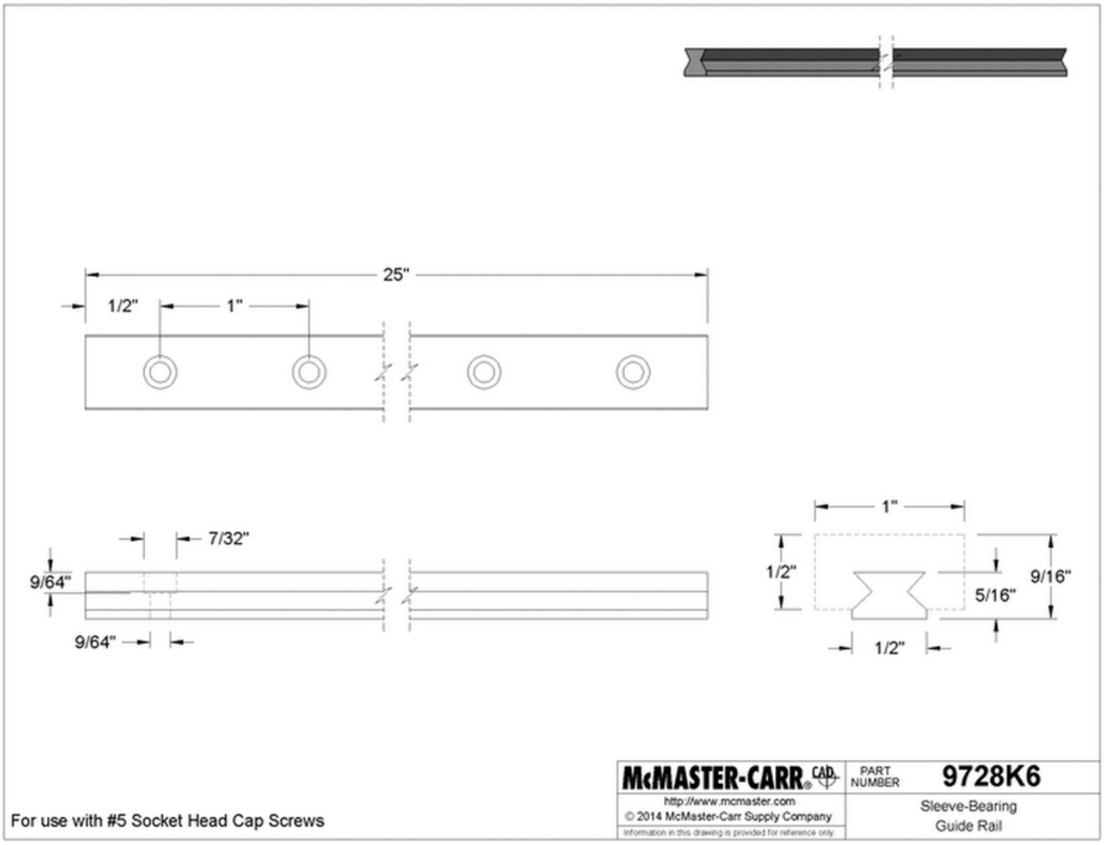
Each

ADD TO ORDER

9728K6

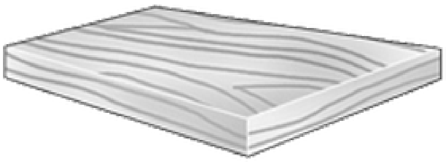
Available Lengths	7"; 13"; 19"; 25"; 31"
Socket Head Cap Screw Size	#5
Additional Specifications	Polyethylene Carriages and Guide Rails
RoHS	Compliant





http://www.mcmaster.com/#9728k6/=ybd773

Marine-Grade Plywood
1/2" Thick, 24" x 24"



Each

ADD TO ORDER

In stock
$35.56 Each
1125T33

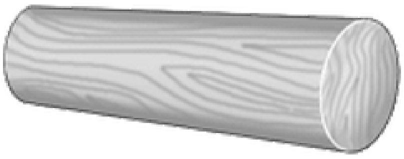
Thickness	1/2"
Thickness Tolerance	-0.048"
Additional Specifications	24" × 24"

When exposed to weather, water, steam, or dry heat, this premium plywood won't bubble, buckle, or delaminate. It is sanded equally on both sides and is free of surface and core defects. Width and length tolerances are ±3/8". Meets BS1088 marine standards.

http://www.mcmaster.com/#1125t33/=ybir33

Wood

Oak Dowel Rod, 1/2" Diameter, 36" Length



Each

ADD TO ORDER

In stock
$1.78 Each
96825K77

Shape	Dowel Rods
Material	Oak
Color	White to Red
Surface Finish	Smooth
Grain	Straight
Diameter	1/2"
Diameter Tolerance	±0.015"
Length Tolerance	±1/16"
Length	36"

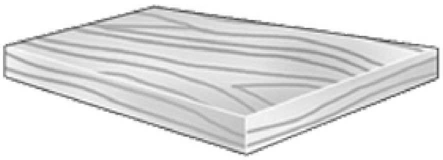
Oak is a heavy wood with high wear resistance and is much harder than birch. The surface is less smooth than birch and typically has a straight grain.

Diameter tolerance is ±0.015" and length tolerance is ±1/16".

http://www.mcmaster.com/#96825k77/=ybf0ae

Marine-Grade Plywood

1/2" Thick, 24" x 36"



Each

ADD TO ORDER

In stock
$48.89 Each
1125T34

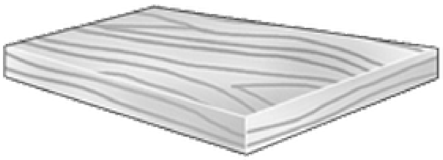
Thickness	1/2"
Thickness Tolerance	-0.048"
Additional Specifications	24" × 36"

When exposed to weather, water, steam, or dry heat, this premium plywood won't bubble, buckle, or delaminate. It is sanded equally on both sides and is free of surface and core defects. Width and length tolerances are ±3/8". Meets BS1088 marine standards.

http://www.mcmaster.com/#1125t34/=ybis12

Marine-Grade Plywood

1/2" Thick, 36" x 48"



Each

ADD TO ORDER

In stock
$88.89 Each
1125T35

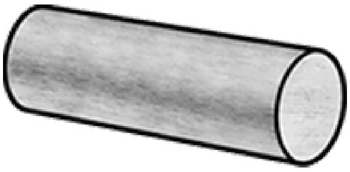
Thickness	1/2"
Thickness Tolerance	-0.048"
Additional Specifications	36" × 48"

When exposed to weather, water, steam, or dry heat, this premium plywood won't bubble, buckle, or delaminate. It is sanded equally on both sides and is free of surface and core defects. Width and length tolerances are ±3/8". Meets BS1088 marine standards.

http://www.mcmaster.com/#1125t35/=ybis21

Multipurpose 304 Stainless Steel Rod

5 mm Diameter



Length, ft.	Each
1	
1 1/2	ADD TO ORDER
3	1272T35

Alloy	304
Shape	Rod
Finish	Unpolished
Diameter	5 mm
Diameter Tolerance	-0.043 mm
Straightness Tolerance	1 mm
Yield Strength	30,000 psi
Hardness	Medium (Rockwell B80)
Construction	Cold Drawn
Material Condition	Annealed
Material Composition	
Chromium	17.5-24%
Nickel	8-15%
Carbon	0-0.08%
Manganese	0-2%
Copper	0-1%
Molybdenum	0-2.5%
Silicon	0-1%
Sulfur	0-0.35%
Phosphorus	0-0.2%
Cobalt	0-0.29%
Nitrogen	0-0.1%
Iron	53.48-74.5%
Nominal Density	0.29 lbs./cu. in.
Modulus of Elasticity	28-29 ksi × 10^3
Elongation	30-70%
Melting Range	2400°-2750° F
Thermal Conductivity	89-113 Btu/hr. × in./sq. ft. @ 212° F
Electrical Resistivity	421-469 Ohm-Cir. Mil/ft. @ 68° F
RoHS	Compliant

http://www.mcmaster.com/#1272t35/=ybj1i1