Design of a Device to Cyclically Stretch Isolated Cells

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Abstract

Cells in the musculoskeletal system are constantly subjected to numerous mechanical forces *in vivo*. Years of research in the field of mechanobiology has shown mechanical forces, including tension and compression, significantly impact various cellular functions such as gene expression, cell proliferation and differentiation, and secretion of matrix proteins. Mechanical signals are also converted into a cascade of cellular and molecular events, initialized by mechanotransduction mechanisms. Multiple commercially produced and custom-built devices are available to study cellular responses to substrate strain. However, real-time data analysis of dynamic cellular responses is not available or easily feasible. WPI has both commercially manufactured and custom built stretch devices available and these devices are currently being used by Professor Billiar. However, they unfortunately do not allow for real-time analysis of cellular response to mechanical stimuli. We have developed a novel stretch device optimized for live-cell imaging. The device assembles on a standard inverted Zeiss microscope and can apply constant cyclic stretch for extended periods of time on the silicone STREX 4cm^2 X-Y culture wells (B-Bridge International). The magnitude and rate of stretch are variable, with maximum stretch of 20%, and a stretch frequency of 1.9 Hz (114 rpm). Interchangeable arms, and a movable linear guide allow for equibiaxial and strip biaxial (pure uniaxial) stretch profiles. Strain analysis achieved by HDM validates and shows reproducible applications of stretch. This device will be used in the future to study molecular dynamics, and cell response to mechanotransduction. Post interpretations verify the stretch device is a novel tool and is compatible with live-cell microscopy for studying dynamic structural remodeling and cellular responses under mechanical strain.

Authorship Page

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1 – Introduction

The human body is a dynamic example of constant changes. On a macroscopic level, people grow, age, and mature. On a microscopic level, cells are growing, dying, proliferating, and constantly changing. These cells are responding to various mechanical forces, and the study of mechanobiology suggests that these forces are crucial to the creation of specific tissue types in the body.

Bone cells for instance need to undergo a compressive force in order to create cortical bone that can withstand the normal forces bones are exposed to on a regular basis. Muscle cells also need an external force constantly acting upon them in order to maintain mechanical strength. In order to ensure these tissues are able to function under the same conditions present in the body, the mechanical properties need to be tested. It is important to see how the individual cells respond to this external force because tissues are not isotropic so the force will not be distributed evenly amongst the tissue (Mizutani et. al, 2006).

Ideally, these different mechanical forces created in the body could be replicated in a laboratory setting; however, no machine can function exactly like the body. For quite some time, devices to stretch cells have been created that attempt to mimic the in vivo conditions that would be present in the body. Stresses can be applied to test the mechanical properties in tension, compression, and shear situations. Cells can be stretched in many different directions so that they can experience similar stresses and forces that would be present in the body. The device allows those properties to be tested, and see how much stress or strain in any loading situation the cells can handle. Most devices focus on one specific type of stretch such as uniaxial, equibiaxial or strip biaxial, and some contain viewing platforms to see the individual cell responses to this stretch while others do not. By stretching the cells various ways, we will be able to view how the cells respond to that stretch and how they change in orientation and other pathways because of that stretch.

In order to keep cells alive during testing, tissue stretching devices have been equipped with various mechanisms to maintain cell homeostasis so a realistic cell response can be seen from the different stretches the cells are subject to. Each individual cell responds to the forces acted on it during a stretch, so it is important to see not only the collective movements of a tissue membrane, but also the movements of each individual cell. This method will help to see if there are any trends in the movement of cells or if some cells experience more stress or strain than others and causes them to respond to stimuli in a different manner than the collective tissue. In order to see these cell responses, the cells need to be examined on the microscopic level while it is experiencing the stretch.

The goal of this project is to design, build, and test a cell stretching device that can stretch cells biaxially from equibiaxial to strip biaxial strain. The device must allow observation of individual cell responses to the stretch applied to the membrane before, during (through the use of cameras), and after the stretch to see how they reorient over that period of time. The machine should stretch along two axes in order to assure an area with uniform strain to see the true movement of the cells to the stretch. This project will be accomplished this with our budget of $1000 and our time constraint of completion of the project of April 2011.

2- Background

2.1- Mechanobiology

Mechanical stimuli have been found to play a crucial role in the development of many tissues, and these mechanical stimuli effect tissues at the cellular level (Wang D. et. al, 2010). The interactions at the cellular level can cause tissues to develop differently if they were somehow changed. Different microenvironments have the potential to initiate different signal pathways in cells, which can effect gene expression.

In vitro model systems are commonly used to explore the effects of mechanical stimulus on cells. Generally, deformable materials with smooth culture surfaces are used to apply cyclic mechanical stretching to cells (Wang, J. et. al, 2005). Cyclic stretching model systems have shown mechanical stimulus induces various responses, including cell reorientation, actin cytoskeletal remodeling, and altered cell proliferation, gene expression, and protein synthesis (Wang D. et. al, 2010).

These model systems have some limitations, the most significant limitation regarding the smooth deformable material. Previous cell stretch studies on smooth substrates have shown cells randomly orient initially, and then reorient in a direction with minimal deformation after stretching (Wang, H. et. al, 1995). This induces potential for heterogeneous strain on the cells, which changes depending on their orientation to the stretching direction. To avoid heterogeneous strain on the cells equibiaxial stretch systems have been developed. These systems offer isotropic strain gradients on smooth culture substrates, allowing the cells to experience the same strain despite their orientation (Wang, J. et. al, 2005). However, equibiaxial stretching does not physiologically mimic what many cells experience. For example, tendon and ligament fibroblasts are subjected to uniaxial stretching in vivo (Wang, J. et. al, 2005). Another limitation of these systems is the variation in organization and shape. Cells in vivo are well organized and have defined shapes, whereas cells in vitro follow a random trend. Considering cell organization and cell shape influence cell function and phenotype, it is quite possible to recognize variation in data (Chen et. al, 1997). Currently to avoid these issues culture systems are being developed which promote/control cell organization, shape and mechanical conditions more precisely.

Cells in the musculoskeletal system are subjected to various mechanical forces in vivo. Years of research have shown that these mechanical forces, including tension and compression, greatly influence various cellular functions such as gene expression, cell proliferation and differentiation, and secretion of matrix proteins. Cells also use mechanotransduction mechanisms to convert mechanical signals into a cascade of cellular and molecular events (Wang, J. et. al, 2010).

Mechanical forces act on humans at different levels, from the body as a whole to individual organs, tissues, and cells. It is well known that appropriate mechanical loads are beneficial to bone and muscle by enhancing their mass and strength. On the other hand, excessive mechanical forces can also be detrimental; for example, excessive mechanical loading of tendons plays a major role in the development of tendinopathy (Fredberg et. al, 2008)(Wang, JH. et. al, 2006). Thus, mechanical forces have a profound effect on tissue homeostasis and pathophysiology. The central players in the human body's response to mechanical forces are various types of mechano-sensitive cells. Examples of such cells include tenocytes in tendons, fibroblasts in ligaments and skin, osteocytes in bone, chondrocytes in articular cartilage, and endothelial cells in blood vessels. Mechanical forces induce a wide range of cellular events, including proliferation, differentiation, and gene and protein expression by both adult differentiated and stem cells (Wang, JH et. al, 2008).

2.1.1 External Mechanical Forces

Two basic ways to apply tensile mechanical forces to cells a substrate such as silicon include uniaxial or biaxial. Uniaxial stretching is appropriate for application of mechanical forces to cells originating from tendons and ligaments; these cells are aligned with the long axis of the tissue and are primarily subjected to uniaxial stretching *in vivo* (Chen et. al, 1997). On the other hand, biaxial stretching is applied to cells that are subjected to tensile forces in all directions *in vivo*, such as dermal fibroblasts. Several biaxial stretching systems have been devised, which typically use circular elastic membranes to produce isotropic strains independent of stretching direction (Wang, J. et. al, 2010). In addition to tensile forces, compressive forces can also be applied to cells that are subjected to compression *in vivo*. A common means of applying compressive forces is through applications of hydrostatic pressure (Wang, J. et. al, 2010). Other techniques use direct platen abutment to apply compressive forces to cells. These types of loading systems include unconfined compression, in which constant or low-cycle intermittent loads are delivered by manually applying weights (Wang, J. et. al, 2010). These compressive loading systems can be used to investigate mechanobiological responses of cells in tissues primarily subjected to compression *in vivo*, such as articular cartilage.

2.1.2 Internal Mechanical Forces

In the body, cells generate mechanical forces themselves; these forces are commonly referred to as intracellular tension. However, in non-muscle cells, intracellular tension is produced by the cross-bridging of actomyosin. This process is caused by ATP hydrolysis (Wang, J. et. al, 2010). These tensile forces are then transmitted to the ECM via focal adhesions, and the forces acting on ECM are called cell traction forces (CTFs). CTFs play a critical function in cell mechanobiology, as they direct ECM assembly, control cell shape, permit cell movement, and uphold cellular tensional homeostasis (Balaban et. al, 2001). CTFs also deform the ECM network and cause stress and strain in the network, which in turn modulate cellular functions such as gene expression and protein secretion. Hence, CTFs are critical in many fundamental biological processes such as embryogenesis, angiogenesis, and wound healing (Wang, J. et. al, 2010).

However, mechanobiology studies rely on cell-substrate adhesions which transmit external mechanical forces to cells. This is because external forces acting on cells can alter their internal forces, thus affecting cellular mechanobiological responses. Interestingly, factors such as substrate stiffness also have a significant influence on cell behavior. For example substrate stiffness only can direct specific differentiation of human mesenchymal stem cells (hMSCs); soft substrates (0.1-1 kPa) mimicking brain tissues are neurogenic, whereas stiffer substrates (8-17 kPa) mimicking muscle are myogenic. Finally, even stiffer substrates (25- 40 kPa) resembling osteoid matrix can induce hMSCs to undergo osteogenic differentiation" (Wang, J. et. al, 2010).

2.1.3 Mechanobiological Responses

Depending cell type and loading conditions, various mechanical forces on cells promotes a variety of cellular responses/functions, including cell proliferation, differentiation, gene expression and synthesis of ECM proteins, production of cytokines and growth factors (Wang, J. et. al, 2010). In a study conducted by Rehfeldt et al, human tendon fibroblasts were stretched at different magnitudes and showed increase in proliferation as well as gene expression and protein production of type I collagen (Rehfeldt et. al, 2007). Another study, conducted by Yang et al, cyclically stretched human tendon fibroblasts at a magnitude of 5% and a frequency of 1 Hz for

24 hours, resulted showed significant increases in cell proliferation. However, when the cells were stretched for 48 hours cell proliferations was inhibited, this of course indicating stretching-induced proliferation of tendon fibroblasts depends on stretching duration (Yang, G. et. al, 2004). Another test in human periodontal ligament fibroblasts, conducted at 10% cyclic equibiaxial compression test which decreased type I collagen mRNA expression and reduced synthesis of fibronectin as well as the amount of total protein; however, the same level of cyclic stretching increased type I collagen mRNA levels and total protein levels (He et. al, 2004).

These studies illustrate how tensile and compressive forces with the same magnitude induce differential cellular mechanobiological responses. Other than affecting cell proliferation and protein expression, mechanical forces also promote the expression and production of inflammatory mediators, including COX-2, PGE2, and LTB4, in a stretching magnitude-dependent fashion (Wang, J. et. al, 2010). These results suggest that when tissues such as tendons are injured, appropriate levels of exercise could be beneficial as it may reduce the inflammatory response. On the other hand, excessive loading of injured tendons, which may worsen tissue inflammation, could be detrimental. These various mechanical forces have noteworthy effects on cells, understanding these forces and their affects can eventually lead to a better understanding of cell function, homeostasis and equilibrium. Understanding these can lead to future success in various biomedical applications such as: tissue-engineering, wound healing, cancer treatment, gene therapy and tissue remodeling.

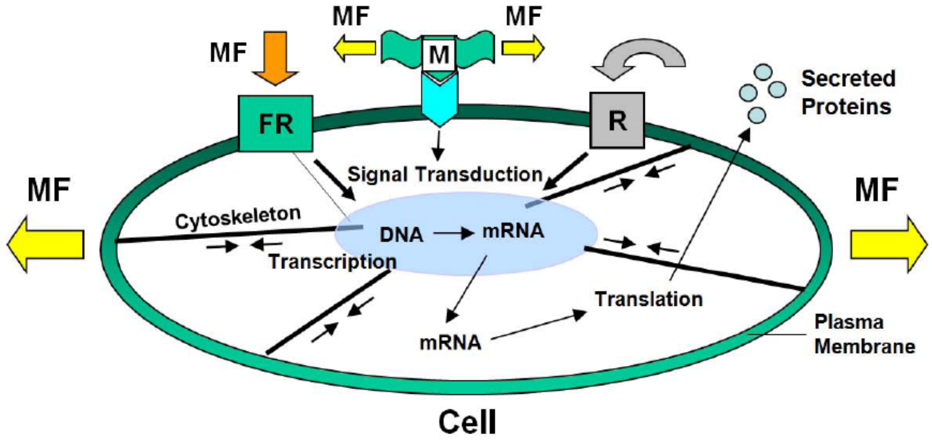


Figure 2.1: Schematic illustration of the "mechanical nature" of cellular mechanotransduction mechanisms (Taylor and Francis, 2008).

Mechanical forces (**MF**) can induce mechanotransduction by directly altering conformation of an extracellular matrix (**ECM**) protein and integrin configuration and transmitting forces to the cytoskeleton and nucleus, thus eventually affecting transcription and translation. Also, mechanical forces can unfold a domain of the extracellular protein (**M**) and expose a cryptic site that may serve as an activating ligand for a cell surface receptor, resulting in a series of signaling events. Also, when mechanical forces are applied to "force receptors" (**FR**), such as integrins and G proteins, they initiate signal transduction, resulting in transcription followed by translation. As a result, soluble factors are secreted into the ECM, which act on the receptor (**R**) and then initiate a cascade of signaling events. Note that double arrows indicate intracellular tensions in the actin filaments (Modified with permission from Wang and Thampatty, Taylor & Francis. 2008).

2.1.4 Cellular Chemical Signaling (Mechanotransduction)

For cells to respond to mechanical forces, these forces must be transformed into chemical signals inside the cell to induce a cascade of cellular and molecular responses. The cellular process of converting mechanical stimulus into chemical signals is called cellular mechanotransduction. Figure 2.1 illustrates and describes this process above. The mechanism of cellular mechanotransduction is still not entirely clear, however, it is generally established that external mechanical forces are transferred to a cell through integrin-mediated adhesions in the ECM (Juliano et. al, 1993). Integrins hold large ECM domains responsible for binding substrates to cytoplasmic domains, and are the primary adhesive receptors and mechanotransducers which link the cytoskeleton to the ECM. Consequently this ECM-integrin-cytoskeleton network plays a key role in mechano-signaling processes. Presence of mechanical stress to integrins is capable of altering the cytoskeleton and activated gene expression in a stress-dependent manner.

2.2 Cell Stretch Devices

In order to determine the various means to stretch cells, an extensive literature review of devices currently in existence was conducted. Each device has its own specific function to obtain specific stretching of cells, and its own specific way to obtain those desired results. The main methods of stretching cells can be broken down into systems using motors, vacuums, and a pressure force.

2.2.1 Pressure to Achieve Stretch

The direct platen abutment approach of compressing the cells uses a manual application of a force directly downward on the membrane to stretch (Brown, 2000). It has been used widely in collagen applications because it mimics in vivo conditions closely. A device that uses this method has been developed by Tanaka to target specifically the low strain regime in bone. This device uses an actuator to drive the force of the platen to compress the membrane, which in this case is a 3-D bone matrix (Tanaka, 1999). This device runs at a frequency of 100Hz and can produce cyclic loading and normal sinusoidal wave loading, but also non-typical loading (Tanaka, 1999).

Another device design uses pneumatics to compress the cells (Torzilli et al, 1997). Advantages of these devices are the ability to have cyclic loading which produces sinusoidal compression of the membrane or non-sinusoidal loading of the membrane. The forms of stretch it can attain include unconfined compression with no support of the materials from the sides as well as confined compression with support on the sides. This has been shown to be an effective form of stretching cartilage cells to determine metabolic responses (Torzilli et. al, 1996). This study involved stretching of cartilage cells with stresses ranging from 0.5-24MPa were loaded at 1Hz sinusoidal for a 2-24 hour period of time. It is also able to obtain homogeneous compression as in the hydrostatic pressurization mechanism. Disadvantages would be its ability to attain strip biaxial strain, as well as keep the cells alive during the stretch (Brown, 2000).

2.2.2 Vacuum to Achieve Stretch

A widely used means of placing cells under compression is through the use of hydrostatic pressure (Brown, 2000). The pressure can use vacuum pressure which is negative or positive pressure to compress cells, and thus stretch them. There are several devices which have been designed using this basic method, and are useful for their given applications. Some specific advantages of this device are the ability to obtain homogeneous compression, which allows for equibiaxial strain to be easily attainable. Also, the pressure does not prevent the cells from obtaining any nutrients from the cell media which allows them to remain alive during the stretch (Brown, 2000).

Some disadvantages of this device also come with the homogeneous compression in that it becomes that much more difficult for the cells to attain strip biaxial strain. Modifications to the compression chamber would have to be made for the stretch device to be able to attain strip and equibiaxial strain. Other disadvantages are the use of either pressurized O_2 or CO_2 can prove to be harmful to the cells under strain. In order to keep the cells alive, modifications need to be made to the cell media to compensate for that pressurized environment. Another disadvantage of hydrostatic pressurization as a cell compression method is that cells experience forces regularly that are different than just hydrostatic in nature, which therefore does not serve as a totally useful in vitro model (Brown, 2000).

This form of applying a mechanical load to cells includes circular substrates that have loads applied to them, and subsequently produce the strain on cells. There are four main ways to attain this strain on the cells. A curved platen may be used to provide the uniform strain on the cells (Williams et al, 1992). This study did show that surface strains due to bending, however, are not negligible and result in large strains near the clamped regions of the membrane (Williams et al, 1992). Another way to apply this load is through prong displacement, in which a collagen substrate is loaded and unloaded with a prong being moved by a stepper motor control (Vandenburgh, 1988). The third means of displacing the membrane would be though a fluid movement. The final option for movement of the membrane would be through vacuum displacement, in which the pressure is applied to the underside of the well and the substrate is then stretched from the pressure (Brown, 2000). These four methods can be seen below in Figure 2.2.

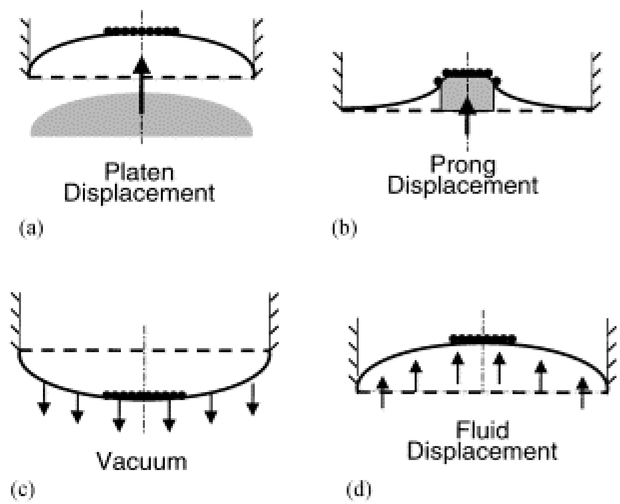


Figure 2.2: Methods of out-of-plane circular substrate distention (Brown, 2000).

There is one commercially available device that actually takes that concept of vacuum circular substrate distention, and that device is called the Flexcell® System. This system attempts to account for the various stresses experienced in the body, and mimic them as close to in vivo conditions as possible using a vacuum pump to push down on the substrate and apply strain (Flexcell International Corporation, 2004).

This device has been used extensively used in literature for various applications. In one application, it was used to test the development of tissue engineered tendons for anterior cruciate ligament replacement (Garvin et al, 2003). This used the Flexcell device to apply strain to the tendon to test the mechanical properties. With this device, the cells were alive with 5% CO_2 and 37˚C by placing the base plate in an incubator while still applying the vacuum pressure for a period of 1.5 hours (Garvin et al, 2003). The cells are loaded in a circular six plate well with anchors on both sides of nonwoven mesh, holes to accommodate the vacuum flow, and the rubber membrane from one side to the other. This can be seen below in Figure 2.3.

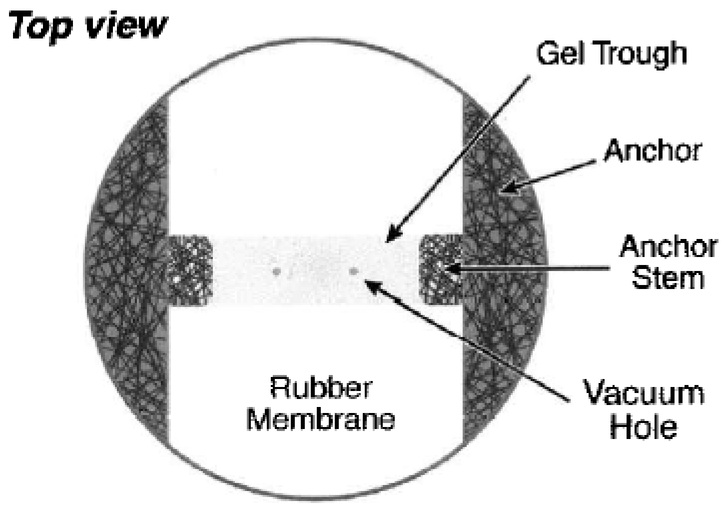


Figure 2.3: Top view of Flexcell well with substrate (Garvin et al, 2003).

The cells were placed in a six well dish with a Delrin Trough Loader insert that allows for the space beneath the culture to be entirely filled. The insert has holes that allow for air to escape from the top of the rubber membrane and push down on the loader (Garvin et al, 2003). Once the cells have been seeded properly on the gel, the trough loader is removed, leaving a space for the deformation of the substrate, which can be seen in Figure 2.3, which shows the side view of the substrate loading process.

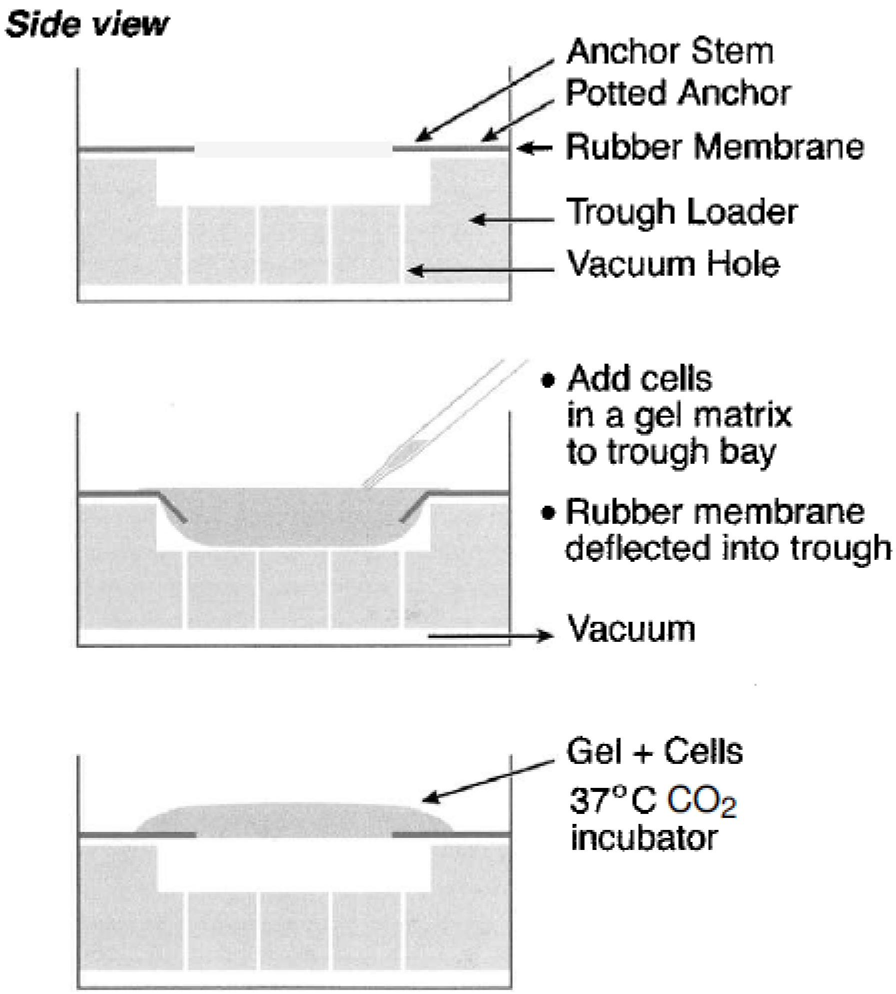


Figure 2.4: Flexcell side view of well with substrate (Garvin et al. 2003).

This design allows for uniaxial movement of the substrate, as well as equibiaxial strain applied to the substrate (Garvin et al, 2003). The archtangle shape of the rubber (rectangle with circular ends) allows for a nice long axis of a fixed substrate, and then provides the sides that are not fixed to move downward when the vacuum force is applied (Triantafillopoulos et al, 2004). Some limitations of this device are the overall uniform strain and the anisotropy of the strain profiles because cells and tissues do not always experience uniform strain (Brown, 2000).

The Flexcell device is in Professor Billiar's lab currently, and does a very good job of obtaining strip and equibiaxial stretch on a soft substrate. The main issue with this device is the inability to see the real time realignment of the cells in reaction to the stretch.

2.2.3 Motor Driven Stretch Devices

Finally, this stretch can be achieved through biaxial strain which physically pulls the substrate outward in two directions perpendicular of one another (Brown, 2000). This can be seen in multiple devices. In a device that was used by Norton et al, a cross-shaped PTFE membrane was clamped to a two micrometer-driven mechanism with an accuracy of 5µm, to move the arms of the cross substrate and stretch the membrane (Norton et al, 1995). The top-view of the device can be seen below in Figure 2.5.

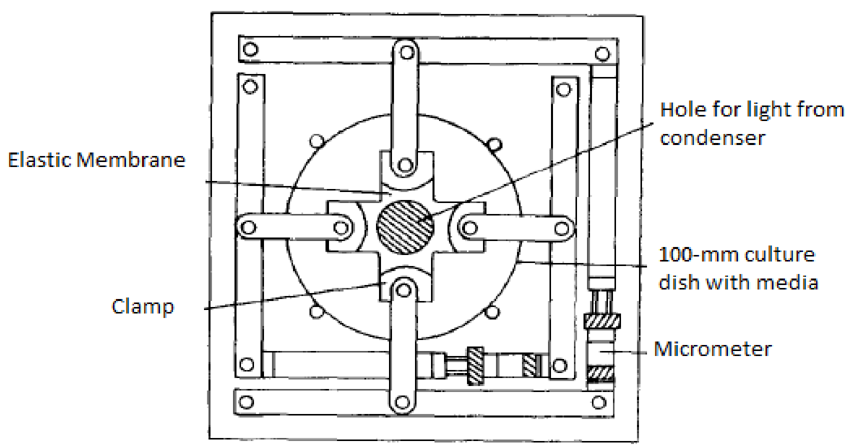


Figure 2.5: Micrometer-driven biaxial device (Adapted from Norton et al, 1995).

Other devices driven by motors include the Strex Cell Stretching System, which is made by B-Bridge International, Inc. The system can be seen below in Figure 2.6. It seeds cells on a soft-substrate silicon membrane that is shaped with a cross structure to reduce the Poisson effect created in biaxial stretch. The device allows for the biaxial stretch with a two motor system that drive threaded rods to move the corners of the silicon well to stretch it, and the cells seeded on top of the well (B-Bridge International, Inc., 2009).

Figure 2.6: Strex Cell Stretch Device (B-Bridge International, Inc. 2009).

The motors are controlled by a computer driven program that will dictate the desired amount to stretch the membrane. To overcome the moment created by pull on any one axis, the arms are also attached to bearing slides that will keep the membrane in perpendicular alignment with the device and keep the stretch either strip biaxial if only one motor is running or equibiaxial if the two motors are running (B-Bridge International, Inc., 2009).

Various other devices currently used in labs are driven by four motors to obtain equibiaxial and strip biaxial strain. With each motor controlling one of the four axes of the membrane being stretched, it allows for more precise control to ensure the desired percentage of stretch is obtained at any given point in time due to the Poisson effect created. Currently in Professor Billiar's lab is a four motor driven device.

3 – Design Approach

Our goal is to design, build, and test a cell stretching device. The main objective was for the device to be able to stretch the cells biaxially, meaning both strip and equibiaxial stretching. The client expressed desire for the device to stretch the tissue for a minimum of six hours, but with the hopes of obtaining a stretching period closer to that of ten to twelve hours. Also, the device should be able to strain the tissue sample at a uniform rate between 2-20% at 1 Hz. The cells also need to be kept alive and at homeostatic conditions during testing.

After these objectives, other less critical, yet still important features were for the device to have a suitable cell viewing area of 1 square cm, have a stationary viewing area during the stretching process, and to have the device itself be inexpensive.

3.1 – Design Alternatives

In order to determine the client's priorities in the design, a pairwise comparison chart was constructed so that objectives could be ranked in importance. Once a final design was determined, this was a useful chart in the event that some aspects of the machine cannot be completed because the cost or time constraints cannot be met. From here, we were able to determine the top priorities of this machine should be stretching with strip and equibiaxial strain, keeping the cells alive during the stretch through the use of incubation, fitting the device under a microscope stage for real-time viewing of the cells during stretch, outfitting the device to stretch the pre-manufactured Strex well, and to keep the cost under $1000. Secondary objectives include being able to adjust the strain rates and strain percentages of the motor and to minimize the cost. The smaller objectives are keeping the device inexpensive and maximizing the viewing area to see the cellular response of the stretch. The filled our Pairwise Comparison Chart from our advisor can be seen in Appendix A.

From the objectives, we were able to determine a list of functions the machine needed to perform in order to successfully meet the constraints and objectives of the project. From those functions, we were able to determine means to achieve them, which led into preliminary design options for our machine. In the functions means tree in Appendix B, we started with basic functions and brainstormed possible ways to make this happen based on previously reviewed stretching machines or other methods of stretching membranes that may not necessarily be associated with cells.

3.1.1 – Four Motors System

A stretch system based off a clamped four motor platform has several advantages. This system can certainly achieve strip biaxial and equibiaxial strain and can do so without moving the center of the tissue sample in order to view its response to the stretch under the microscope. Each motor is responsible for moving one axis of the square well, and would be able to be controlled independently of each other. This allows for easy controlling for strip and equibiaxial strain. This type of system can also perform various strain percentages, strain rates, and duty cycles, though this is all based off the power, accuracy, and capabilities of the motor.

Another design option is a four motor system with linkages. This system is useful to create a stationary viewing area to see the cellular response to the stretch of the cells. Each motor is able to control the linkage movements and ensure strip and equibiaxial strain on the tissue. This will be easy to add or remove strain on the cells and have a quick response to create variable duty cycles in the movement of the motors with proper programming.

A concern with a four motor system is the design space that is reduced in order to have enough room for all four motors to move and be properly vented to prevent overheating and keep within the size constraint of the microscope viewing area. This could be overcome by moving the motors to a plane different from the membrane being stretched, however, this would involve more design of parts that would allow for the motors to be on a different plane that that of the stretched membrane. Each motor will also have to be equipped with a motor controller board to run it, which is expensive and could increase the cost of the device.

3.1.2 – Two Motors Systems

The two motor threaded rod system is yet another design option. The two motors have an advantage over the four motor systems because they take up less room around the microscope stage; require less power than four motors do, and cost less money. Threaded rods are also an advantageous stretching mechanism because they are an easily obtainable system used in many applications. This aspect makes them easy to understand and work with because they are so commonly used. Using this method allows for both strip and equibiaxial stretching.

A commercially available version of this design is known as the Strex®. It involves two motors with threaded rods attached to guide rods that are connected to each corner of a square soft membrane. The bottom left corner remains stationary, but the other three corners move, stretching the plate in either one or two directions simultaneously. Reverse-engineering this is a design option, and a 3-D image model of it made in SolidWorks can be seen below.

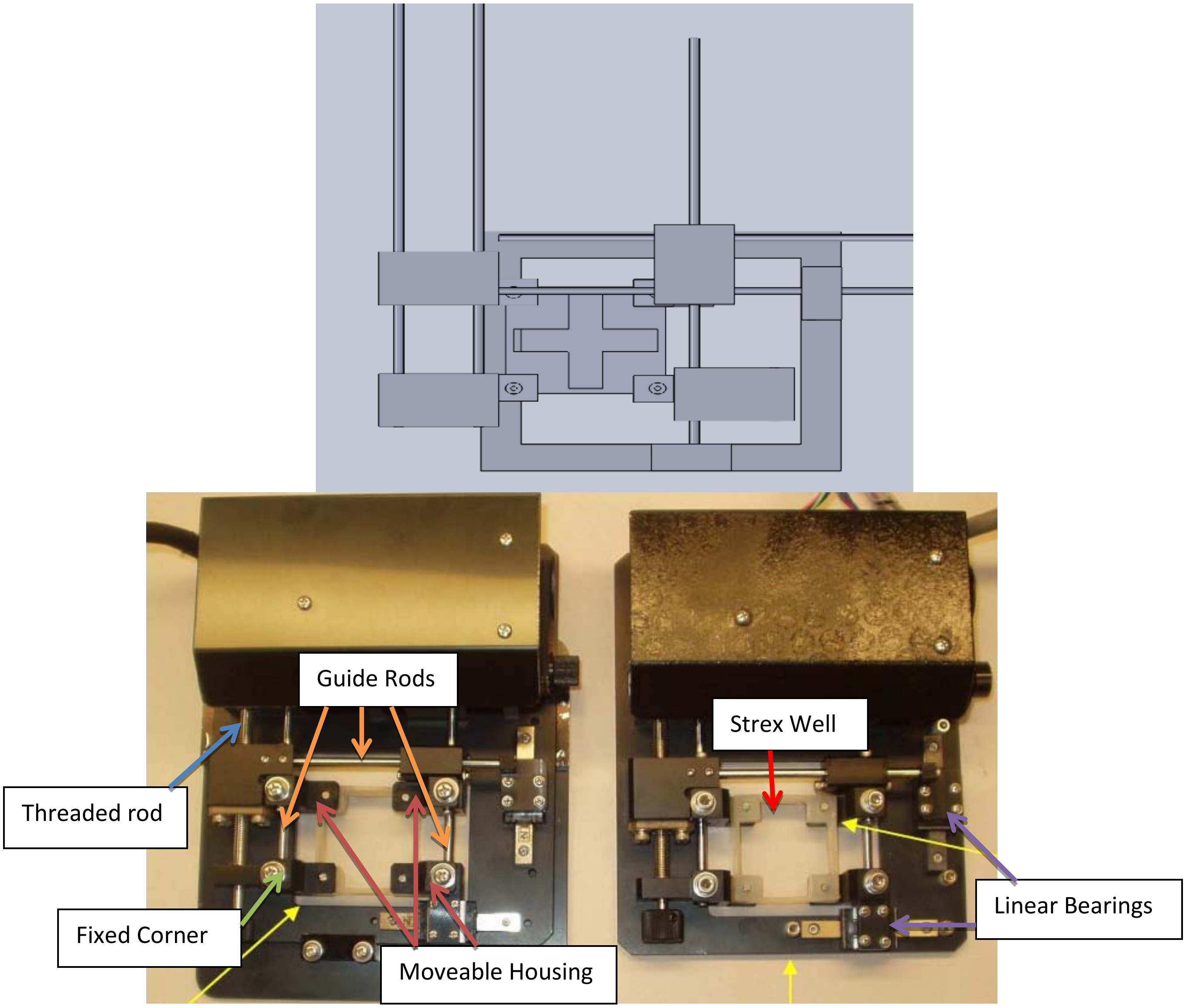


Figure 3.1 3-D Model Drawing of Strex design (top) and view of Strex device (bottom)

Each corner is attached to a moving carriage that is attached to a threaded rod driven by motor control and a guide rod that keeps the movement perfectly perpendicular to the threaded rod. To overcome the moment force created there are linear bearings attached to the rails which will allow for the motion to remain in the correct direction. The motor drives threaded rods to move the housings attached to each arm away from the original location of the Strex well it is attached to, and allows for the aligned movement of the well (B-Bridge International, 2010).

There are some disadvantages to this design, though. For example, the main concern with using the threaded rods to stretch the tissue sample is that the rods may not be able to move fast enough to strain at the desired varying duty cycles because of the threaded design. Another major concern is that when the tissue it being stretched, it does not stay centered over the viewing area, making it difficult to monitor cell response throughout the entire stretching process. One last issue is that two motors may not be able to generate enough power to move the machine at the desired rate.

Adding linkages is another variation to the two motor design. Two motors being the benefits of having a larger viewing area, a cheaper cost, and do not need as much power as four motors do to run the device. Linkages are also a useful tool for tissue stretching, being able to both biaxially stretch and provide means for varying duty cycles.

A major disadvantage of the linkage system, as touched upon before, is the possibility of unwanted stresses occurring on the edges where the linkages are attached to the tissue sample, which could potentially alter the collected data. Disadvantages of the two motor system include not having enough power to move the machine itself and not keeping the tissue in a centered position.

Another potential stretching design will resemble the four motor design however; the motors will be replaced by pistons driven by compressed air. A piston driven stretching device, much like the four motor design, will be able to achieve both strip biaxial and equibiaxial strain. An advantage to pistons is that there will be no need to learn how to then write complicated programs to run them, although the air pressure would still need to be controlled. There can be multiple compressors giving out different levels of compressed air in order to achieve both types of strain. Compressed air can be easily dispersed at different rates to perform variable duty cycles, strain rates and strain levels.

Although there are many benefits to using pneumatic driven pistons, there are some drawbacks. Compressors can be big and bulky and can take up valuable space. There is limited space to deal with around a microscope and compressors could impede. Also, though the pistons would be faster than motors, in order to power the pistons air hoses need to be run to them which could become cumbersome when attempting to run experiments. The intended design of this stretch device with two sets of opposing motors may be large and may prove difficult to fit within the given space under the scope. An exterior structure may have to be built in order to support the system instead of mounting it directly to the microscope.

Using hydraulic motors to stretch the tissues is another design option. Hydraulics are useful because there is direct control of the motor via control valves, which can be useful to ensure pure strip biaxial and equibiaxial strain on the membrane. A noteworthy advantage of this option is the ability of hydraulic motors to apply significant power with very small tubes and hoses. This reduces the amount of parts around the microscope stage which can aid in the visibility of the tissue with the microscope.

This option, however, could prove difficult in programming the motors to work in synchronization, especially if four different hydraulic pumps are used. Another drawback could be in the variable duty cycles, because the pumps can quickly add or remove fluid to add or remove the force, but the acceleration of the piston at that speed may not be quick enough or slow enough for the needs of a fast or slow recovery in the stretch mechanisms.

3.1.3 – Vacuum (Flexcell)

A vacuum based system works especially well for stretching cells equibiaxially. These systems are consistent, and exhibit good homogeneous stress on the cell samples. A system like the Flexcell would work very well, provide consistent data during testing, and culture plates would be easily available. The Flexcell device is existent in the lab at WPI, but its main issue is the inability to view the real time reaction to the cell stretch because of the closed top design of the vacuum chamber. Attempts have been made to modify the device however the results have not been able to view the results in real time. However, this device would not need any building or programming which can save large amounts of time in the design process. Ultimately this system would allow for more time testing samples and obtaining data.

3.1.4 – One motor system

This design consists of one motor which applies downward pressure to the tissue sample to stretch it over stationary posts. Stretching the tissue over stationary posts will achieve strain over the tissue. One of the advantages of this design is first and foremost its simplicity. There is only one motor which moves upwards and downwards and can be programmed to achieve variable duty cycles and strain rates. The motor pushing the tissue is the only moving part of this design which also contributes to its simplicity. This design will be a relatively small structure so it will not be difficult to fit under the microscope stage, but will be difficult to find a way to view the cells during the stretch. Also due to the one motor, both strip biaxial and equibiaxial strain is more difficult to achieve, and would most likely require some movement of parts to make sure. Like with all motors, a drawback is that programs must be written in order for them to function correctly; these complicated programs will have to be learned and executed.

Another one motor design angles the motor at 45° in the upper right corner of the Strex well to obtain equibiaxial strain. Linear bearings are attached to guide rods which are then attached to the four corners of the Strex plate. The motor attaches to an arm and flywheel and motor which then causes the movement of the upper right corner linear bearings which translate the motion to the other two corners of the membrane. Strip biaxial strain is attained by adjusting the angle at which the motor pulls to as close to zero as possible, and then accounting for some error in the Poisson effect which will be seen. This can be seen below in Figure 3.2.

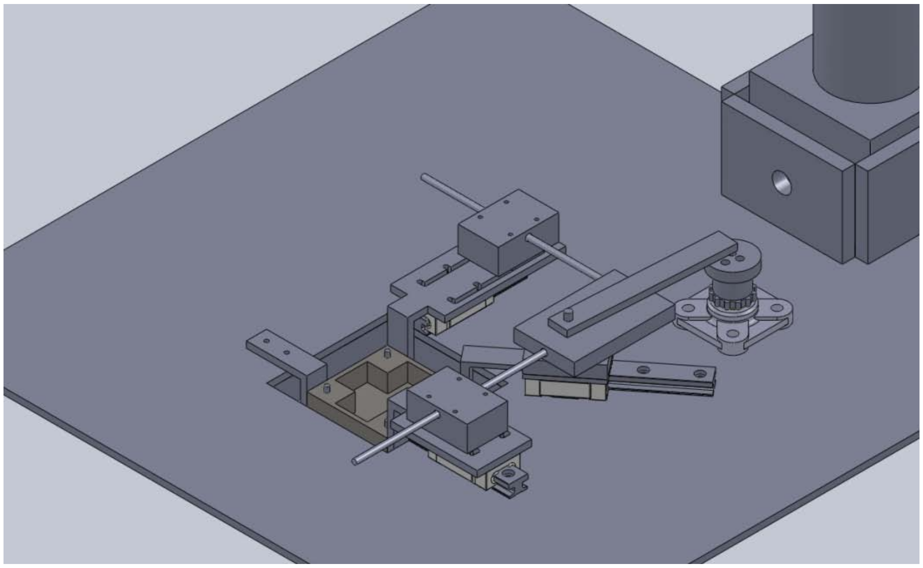


Figure 3.2: Linear Bearings One Motor design (equibiaxial set up)

This device allows for no programming, and the parts are easily available off the shelf. However, the adjustment of the motor and linear bearing system will leave room for error, so the precise angles at which the device needs to be to obtain specific strains will need to be very accurate.

3.2 – Design Process

In order to determine what design would meet the most objectives desired by the client and fulfill all the constraints, we developed a function and means chart to determine what ways these various objectives could be obtained in our designs.

We developed this chart, shown in Appendix B, in order to help give us a better visual idea of which design would be the most efficient at completing our intended tasks. On the Y-axis, we had both our constraints and objectives listed. On the X-axis, we listed our potential design ideas. Where the design ideas meet with the individual constraints is where we assigned values. These assigned values are on a scale of 0-100 with 0 meaning the design will not be able to perform the constraint/objective and 100 meaning the design will definitely be able to complete the constraint/objective. We assigned these values based upon our personal opinions gained through research on whether or not the constraints and objectives could be achieved. After assigning values, we tallied the total points up per design and ranked them accordingly.

The two main designs that are being considered are reverse engineering the Strex design, and the one motor linear bearing design. A comparison of the two designs can be seen below in Table 3.1.

Table 3.1 Comparison of Strex and One motor design

Strex Design Reverse Engineer	**Functions**	**One motor design**
Capable of uniaxial stretch	**-Uniaxial stretch**	Capable of uniaxial stretch
Capable of equibiaxial stretch	**-Equibiaxial stretch**	Capable of equibiaxial stretch
The Strex based design would be capable of achieving 2-20% strain with any strain % in-between.	**-Strain rates**	This design would allow for variable strain %, however it would most likely be capable of a particular set of strain percentages: 2,5,10,15,20% strain
Adjusting frequency will not be an	**-Frequency**	Adjusting frequency and varying

issue with this device, frequencies of (.5, 1, 1.5, and 2) Hz can easily be achieved. Also the frequency is not limited to these numbers it can go anywhere between and above.		frequency is possible, however the device will most likely be limited to several predetermined frequency setting that would be dependent of power source/ current.
This device will be capable of varying duty cycles.	**-Duty cycles**	Varying duty cycles with this device will require modifications; the user would have to change an electrical component (diode).
These devices will both fit on the Zeiss stage this design will be slightly larger.	**Size**	Slightly smaller/lighter than Strex design.
Compatible with Strex silicon well.	**Well type**	Compatible with Strex silicon well.
Will require time consuming programming. Motor control boards or stepper motor drivers. Programming is difficult to learn and small mistakes in program can cause un-noticed/unwanted results.	**Programming**	None is required. This system relies completely on mechanics and current for motion.
Will use stepper motors, however, the other components would most likely be custom made with some being premade. The fabrication will be more difficult in comparison to a model with mostly premade parts. Also the device will require a computer with expensive motor control boards to run the device. Also the motors will have to change direction often which results in greater power consumption which may cause overheating. (High stress on motors)	**Parts**	Most parts will be premade from a distributor such as PIC -Design or small parts. These components are reliable, available in various sizes and finishes. Some components may be customized, however these components will include mostly simple parts which are cheaper to make from free scraps or cheap aluminum. The motor in this system will turn in one direction, allowing for a smooth stretch and minimal power consumption. (Should be minimal stress on motor)
More intricate design, with more components. Both systems require near perfect assembly, however, with more components it increases difficulty of having whole system in sync. Though, if the device is made properly is should allow for smooth stretch with minimal friction.	**Mechanics/Dynamics**	With fewer components this device is dynamically and mechanically simpler. However, like the Strex design to prevent friction/jamming, the components need to be assembled with no error. Also with the motor never having to change direction it may provide a smoother more homogeneous stretch.
Greater cost due to the second motor, more components and more intricate mechanics. Also the motor control boards can become quite expensive if not available. Stepper motor drivers are much cheaper however adds cost as well.	**Cost**	Lower cost due to minimal components and no motor controlling hardware.
This system will allow for simple use once ready. The user can simply	**User Friendliness**	This device requires the user to manually adjust the device to change

command the device to perform whichever stretch it wants and can run it.		strain type, strain %, and duty cycles. The user would carefully have to read the manual to ensure the device was appropriately adjusted. (If user does not pay attention to detail it is possible for miss-setup)

3.3- Final Design

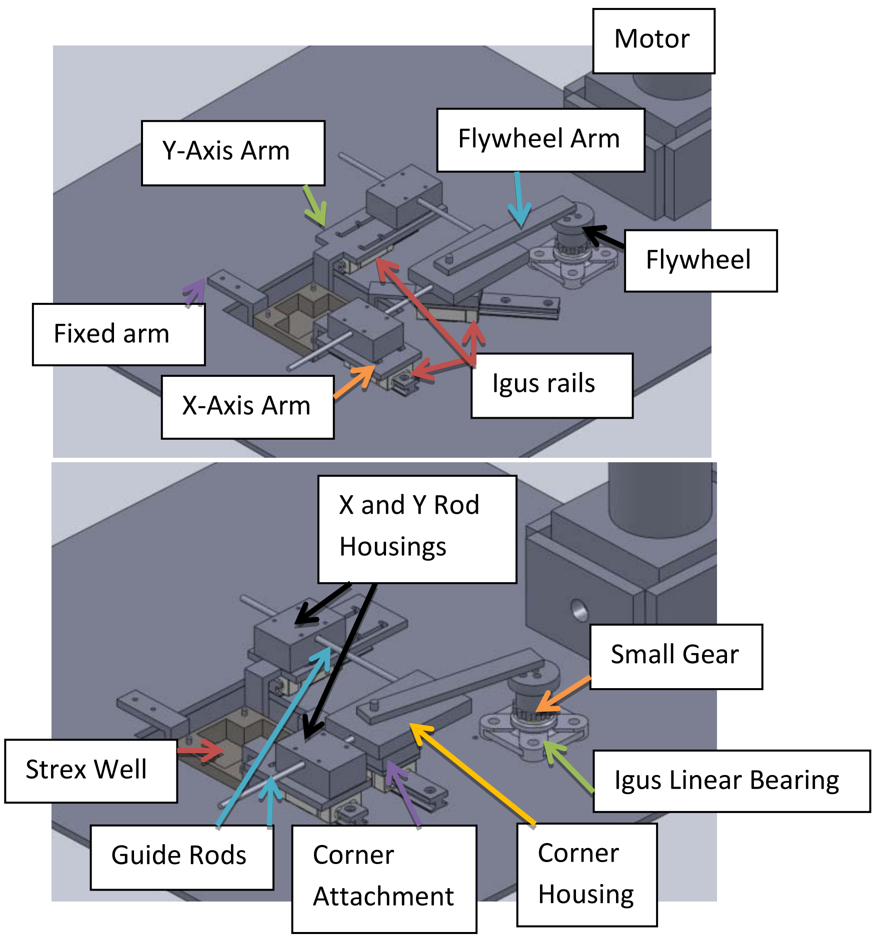


Figure 3.2: Design in equibiaxial (top) and uniaxial (bottom)CAD

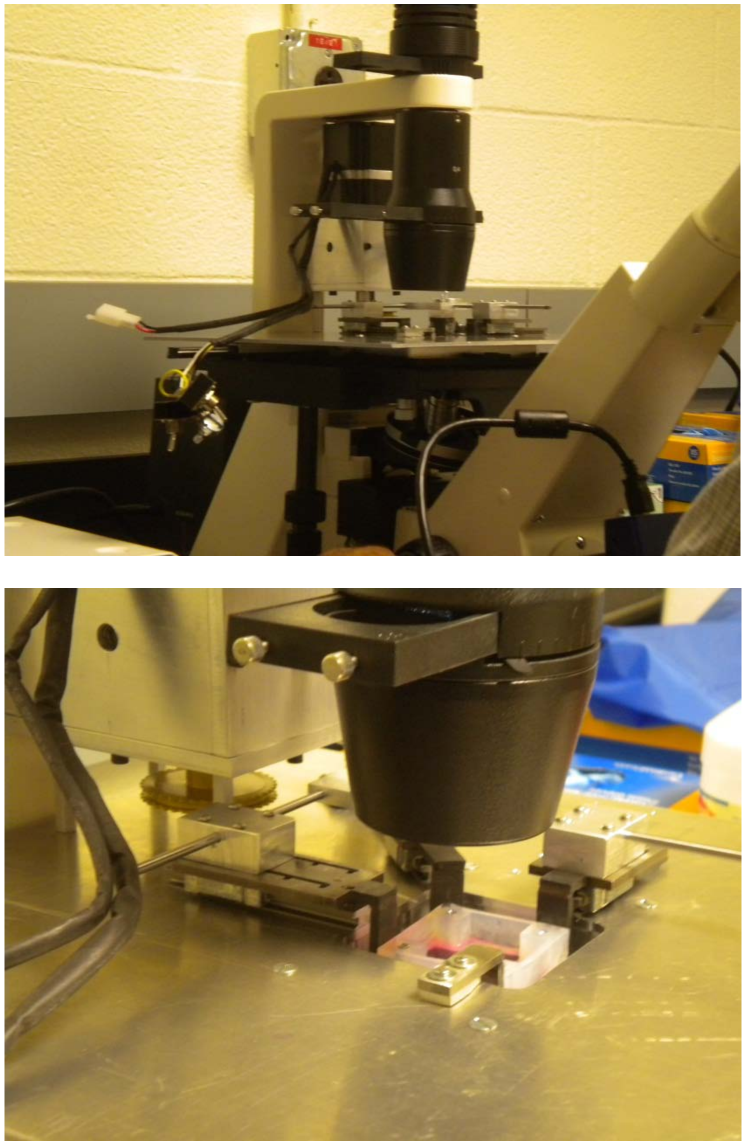


Figure 3.3: Our device on the Zeiss microscope (top) and close up with cells seeded on the well

3.4 - Device Description

Through careful deliberation, our team decided that a one-motor concept for a stretch device would give us the best opportunity to meet all objectives taken from our client statement. Having chosen the general design, we began to search for materials and parts that could be used to achieve major aspects of the device: the device must be powered by a single motor and must stretch a Strex silicone well both uniaxially and equibiaxially.

3.4.1 – Motor Selection

Calculations for determining the force, torque and power needed to stretch the wells were accomplished for initial considerations regarding choices of motors. For this design a synchronous motor suits the device best, having a system that limits the stretch to its pre-configured state the motor simply has to turn at the specified frequency in a single direction. This is why stepper motors were not considered; they do offer precise motion due to the fact that as the drivetrain turns it does so in steps not in a smooth/fluid motion. The material properties of the ST-190-XY well from B-Bridge were not available in the specifications, however, the well itself is made from silicone elastomer comprised mainly of polydiethylsiloxane (B-Bridge International). In order to determine certain specifications needed for our motor, we set up an experiment on an Instron machine to stretch the Strex well and find its material properties. We know from calculations prior to the test that the max distance needed in travel at maximum strain (20%) for the well would be 6 mm or 0.006m. We programmed the Instron machine to stretch to this distance and record all exerted forces. At the completion of the test we found that the maximum force produced was approximately 19 Newtons. Using this number, along with the maximum distance needed in stretch for at maximum strain, we calculated that needed torque would equal 0.114 Nm. However, this calculation is solely for uniaxial stretch as the Instron machine could only pull in one axis. Therefore, we multiplied our initial uniaxial torque value by two in order to account for the two axes of stretching. This new value of 0.228 Nm would be used as the value or torque necessary to achieve stretch in the equibiaxial position. These two values depict bare minimum values of torque needed to successfully complete uniaxial and equibiaxial stretching of the Strex well. We decided to increase they torque due to certain aspects of our device's potential usage. Our device may potentially undergo experiments where it is continuously running for long periods of time which would place a large strain on the motor.

Extra torque would be beneficial in ensuring the motor is pulling at a steady pace for the extended period of the test. Also concerning to our group was the fact that we are utilizing a 1:3 gear ratio in order to increase speed to meet one of our objectives. However, using a 1:3 gear ratio exhibits its 1/3 fractional percentage on the motor's torque as well. To conclude the original torque of our chosen motor, when divided by 3, must be well over the 0.228 Nm torque needed for equibiaxial stretch to achieve this goal, as well as, to provide a factor of safety for the overall effect of friction throughout the device.

Taking all of these factors into consideration, our team was able to decide upon a motor that would be efficient for achieving all specifications necessary for our device as described above. The motor chosen is a brushless 12V DC Synchronous Gear Motor manufactured by Wonder Motor. Unlike stepper motors which provide movement in choppy steps, synchronous motors provide smooth operation. This will reduce vibrations which could disturb the seeded cells on the Strex well. This particular motor has a maximum output of 38 RPM while providing 8.4 Nm of torque. As stated above, the chosen motor's torque, when divided by 3, must well exceed the 0.228 Nm needed for equibiaxial stretch. If you take 8.4 Nm and divide by 3, you are still left with 2.8 Nm of torque. This value well exceeds 0.228 Nm which is excellent seeing as though we also need to account for all friction experienced throughout the device. Overall, the chosen motor will effectively stretch the well to our certain specifications and provide this stretch for extended periods of time without over exerting itself and failing.

To place this motor in the appropriate position on the device, it was necessary to devise a bracket system to contain the motor. The mounting bracket was designed in order to utilize the motor in an inverted position. This inversion allows us to have a direct belt drive design rather than run the belt off of numerous gears which would increase the net friction in the system.

3.4.2 – Gear and Pulley System

We are utilizing a 2:1 gear and pulley system to achieve desired rates of stretch as described in our project's objectives. Gears are necessary because we chose our motor based upon specifications needed for torque; rate of stretch was a secondary concern for us. The motor has a maximum speed of 38 RPM's; this equates to approximately 0.633 Hz. Referencing our objectives it is clear that we are aiming for a rate of stretch which can vary from anywhere between 1-2 Hz. In order to achieve the maximum rate of 2 Hz, we must utilize a 1:3 gear ratio. This 1:3 ratio essentially means that the gear coming off of the motor shaft will be three times the diameter and have three times as many gear teeth than the gear which will help directly stretch the well. So, by the time the gear on the motor completes one revolution, the gear directing stretch will have completed three revolutions which is where the increase of speed originates. The gears we are using are manufactured by W.M. Berg. Respectively on the motor and directing the stretch the diameters measure 47.24 mm with 36 gear teeth and 16.8 mm with 12 gar teeth. These are 3-d pulleys which entail they are turned by a belt with teeth that interlock with the teeth coming off of the gears. The belt being used to conjoin these two gears is a 3-d pulley also from W.M. Berg.

The gear directly causing stretch will do so by turning a crankshaft which will be placed within the inner bore of the gear. This assembly of gear and crankshaft will sit within a custom made bearing with the gear sitting above the top of the bearing to ensure it will spin freely and not be impeded. The crankshaft has a one inch diameter flat top surface with three pre-drilled holes. These holes are off center by 3mm, 4.5 mm, and 6 mm representing varying strain percents of 10, 15, and 20 percent. Depending on the type of stretch being tested, the location of the crankshaft will change. To achieve stretch, an arm will be positioned over one of these holes and secured; the other end of the arm will be anchored to a housing which will be explained in the following section.

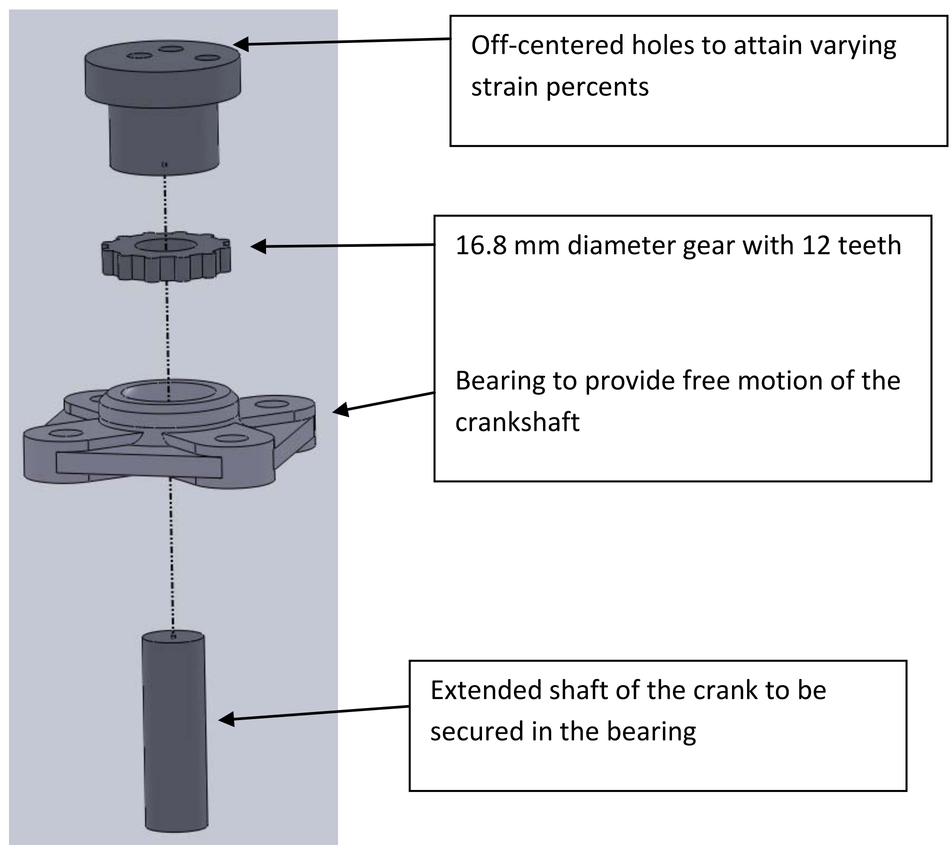


Figure 3.4 –Exploded View of Crank Shaft

3.4.3 – Linear Guide System to Directly Stretch Strex Well

This stretch device must achieve both uniaxial, as well as, equibiaxial stretch on a silicone Strex well. To ensure this stretch occurs as smoothly and linearly as physically possible, a rail system had to be installed to counter the Poisson Effect from the silicone material.

The platform which our entire device will sit upon is a 12”x12” piece of aluminum with a 6mmx6mm square milled out in the center for viewing of cells. Because our chosen microscope came equipped with a movable X-Y stage which added height, we also needed to install an adapter to clear this distance. The adapter plate was designed with two functional aspects in mind, one was to allow the device to be compatible to the microscope stage and second to allow the plate to clear the vertical distance between the of the movable X-Y stage equipped to the microscope platform. The adapter plate was designed to fit snugly in the X-Y stage, which is why no fasteners are necessary to secure the device in place. One can simply insert and remove the device with little trouble. To provide for smoother travel and to counter the moment the motor causes in the rear of the device, acrylic spacers were made. The acrylic spacers have a height of 9/16” this is because the adapter itself is 1/2” in height, though it is sitting on a 1/16” lip. The combination of both the adapter and spacers provide a level foundation for the device and allow smooth motion due to positive weight distribution. Also the acrylic can slide on the stage without scratching the coated surface of the microscope platform. Dimensions of both the adapter and the spacers can be viewed in Appendix H.

For stretch in both the X and Y axis linear rails were implemented to keep forces exerted in one direction with only negligible tolerance in the axis of stretch. A corner rail is used to apply direct strain to the upper right corner of the Strex well; stretch will be initiated from that corner. However, the type of stretch will depend on the angle of the rail. For uniaxial stretch, the rail acting upon the top right corner of the well will be parallel to the X-axis rail and be aligned so that the back edges of both the rail and Strex well line up. As the motor applies a force through the crankshaft, the Strex well will only deform in the X-axis through movement along only two rails. Conversely, if equibiaxial stretch is being tested, the rail will shift up 45 degrees towards the Y-axis. The end of the rail will line up so it is centered with the top right corner of the Strex well. In this stretch set-up, when the motor applies force through the crankshaft, that force is applied at a 45 degree angle through the top right corner of the well. Exerting force at a 45 degree angle will evenly distribute along both the X and Y axis and be kept linear by the rigid rails. The rails used in our device are manufactured by the company Igus. They are composed of 6063-T6 Aluminum. The main reason for choosing these particular rails had to do with their extremely low profile in comparison to other similar products. They stand a mere centimeter tall which helped our team to decreases overall height of the device to fit well underneath our microscope.

Sitting directly atop the rails are cast zinc chromated carriages which will slide along the rail to provide a smooth means of stretch. Unlike most bearings, these carriages do not glide using a ball bearing system. Instead, the inner surface which interacts with the aluminum rail is coated with a wear-resistant iglide® J plastic sliding pad. This custom plastic created by Igus is self lubricating which does away with the need for ball bearings or constant application of lubrication to avoid binding. Each carriage has four screw holes for attachment to other pieces.

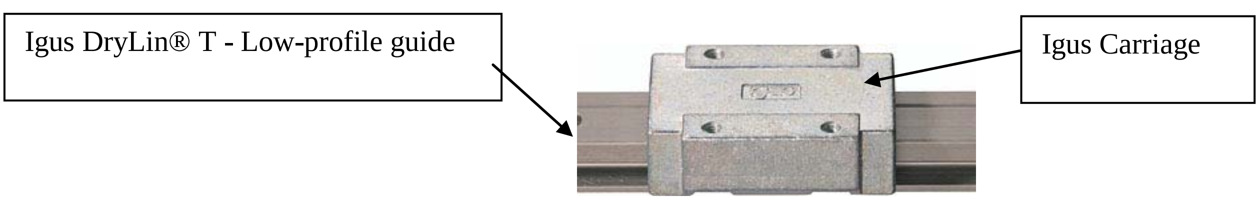
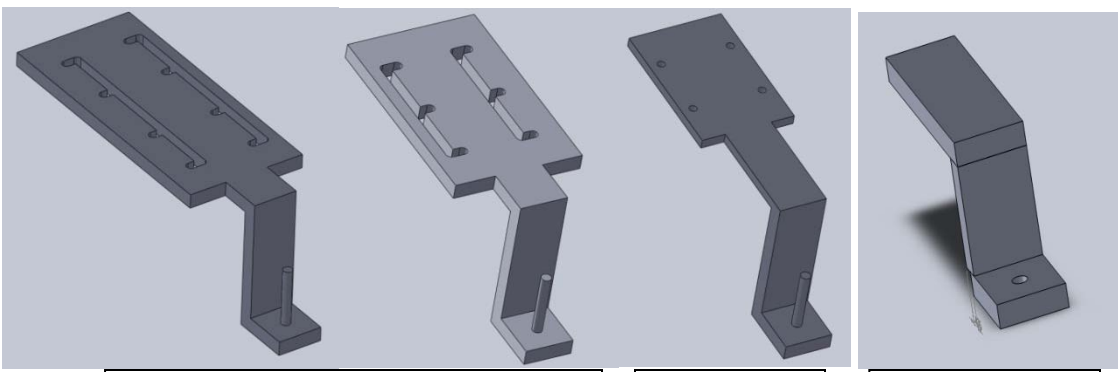


Figure 3.5 –Igus Linear Rail and Carriage System

The next component of the linear guide system which is being placed upon each carriage is an arm that will create a bracket to hold the Strex well in place close to the objective lens. Each arm is made out of 1/8” oil hardened steel and has been cut and welded into a precise position to hold the well perfectly. What is particularly innovative about both the X and Y axis arms is their multi-positional design. Each arm has channels and locking slots enabling the user a more simplistic means to change the stretch position between uniaxial and equibiaxial stretch. Finally, there is a stationary arm anchored to the device platform which will remain rigid to secure the bottom left corner of the Strex well.



X and Y Axis Custom Slotted Arms

Arm for Top Corner

Stationary Arm to secure Strex

Figure 3.6 – Four Stretch Arms

The final component of the linear guide system consists of pieces which are the same for the X and Y axis rails, but slightly modified for the rail acting upon the top right corner of the well. For the X and Y axis the last component is simply a 3mmx2mm piece of ½” aluminum. The piece has four threaded holes which line up directly with the four holes on the carriage. The threads from this housing in combination with the carriage holes will create a very tight connection to reduce vibrations during operation. In addition to these four holes, there is also a clear hole through the 3mm long face of the housing. The clear hole will be 1/8” in diameter and sit in the center of that face; the center of the hole be 1/8” from the top edge. However, the housing sitting atop the arm on the rail applying force to the top corner of the well is a bit different and consists of a two part system. The first part will consist of a 2.5cmx2cm piece of aluminum and have four screw holes that match up with those in the carriage, however, this piece will be only ¼” thick and have one additional hole. The additional hole will be centered 7.5 mm in from the 2cm side and 1 cm in from the 2.5 cm side. A screw will protrude through this hole from the bottom and be countersunk to maintain a level surface. The protruding screw is where the second part of this housing will be attached. The second part of the housing is a 3cmx5cm piece of ¼” aluminum. There will be a threaded hole 15mm in from both the 3cm side and 5cm side that will attach both pieces.

In order to further increase the linearity of the forces being distributed in each axis, stainless steel rod will be inserted into the 1/8” clear holes in the sides of each of the three housings.

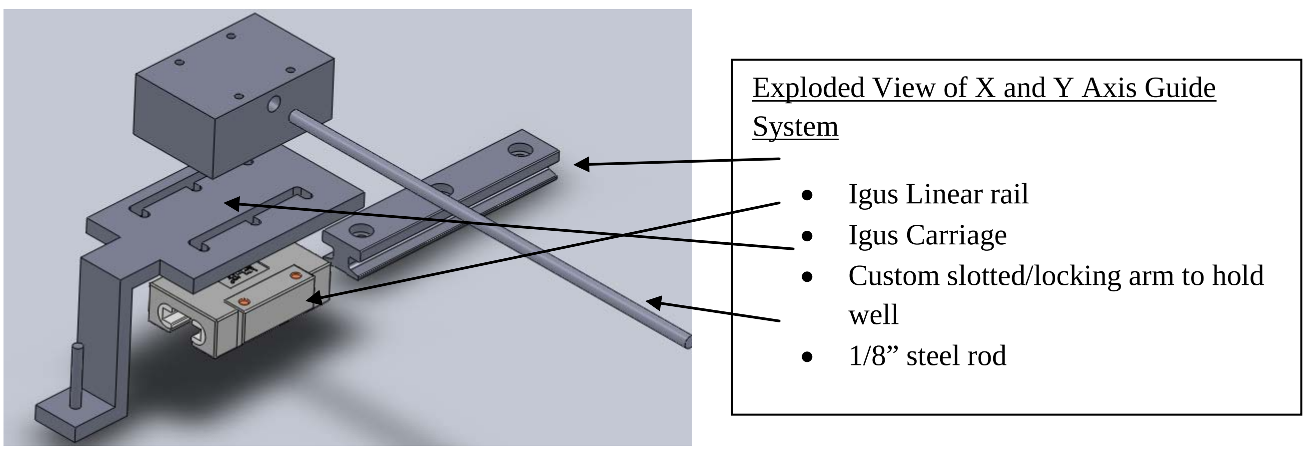


Figure 3.7 – Exploded View of X and Y Guided System

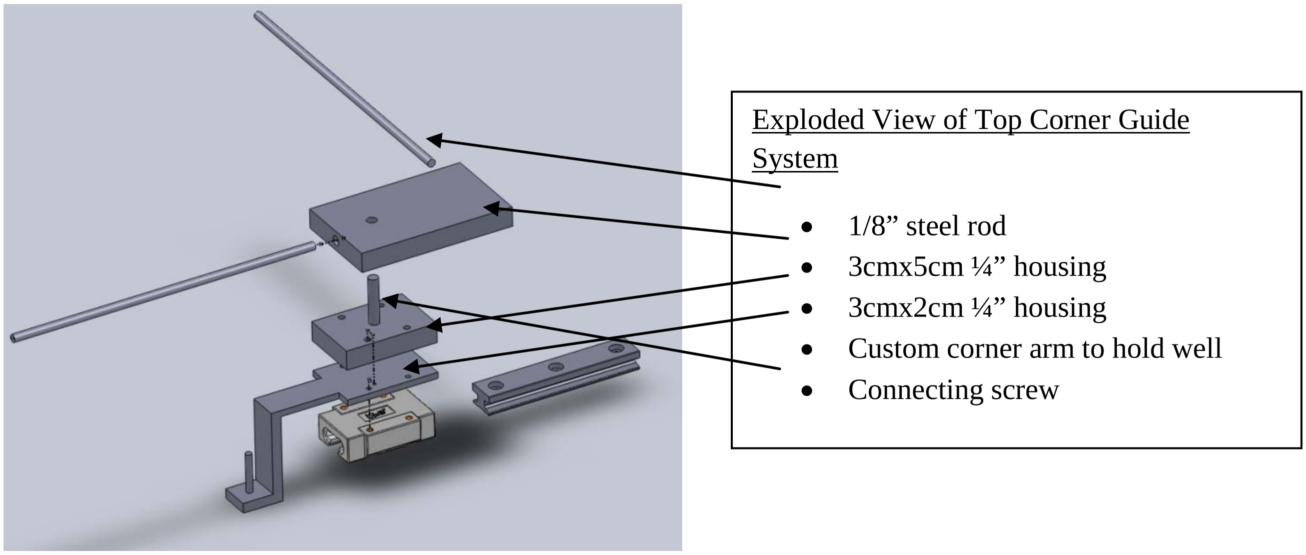


Figure 3.8 – Exploded View of Corner Assembly

3.4 – Microscopy Methods Currently Used

In order to choose a suitable microscope to use in combination with our device, our group first decided on objectives and constraints needed in a microscope for it to be considered sufficient. There are many microscopes at our team’s disposal, however we needed to carefully research each one in order to find the best fit.

Objectives

Although not quite as important to achieve as constraints, objectives (if met) will make our device much more professional and successful. The device should move fluidly around the platform of our chosen microscope to provide a smooth transition between viewing cells. To achieve that our group wants to keep the device as light as possible to keep torque down which would increase friction with the surface. Also the device was designed with protecting the microscope in mind, considerations are included in the Device Description.

Constraints

One of our main concerns was the ability to view cells through the Strex well. We could not successfully complete our project if the cells that we are stretching could not be viewed. Due to its importance, the ability to view cells through the Strex well fell under constraints. Another concern of the group was the dimensions of available microscopes. We want to view the cells being stretched in real time; therefore our device has to fit within the dimensions of a microscope's platform. The most important dimension needed in a proper microscope is the distance been the objective and the seeded cells on the Strex device. Through trial and error, we found that a 60X objective lens would be necessary to view cell movements such as cytoskeleton realignment. With that in mind, it is key to know that as the magnification strength increases in an objective lens the closer it needs to be to what it is viewing in order to be effective.

In order to precisely move the stretched Strex well around to view individual cells, a microscope with this ability was necessary. Given our constrained supplies, the group decided a movable X-Y platform would suffice for Strex well movement. However, movable X-Y plates take away from the overall height that our device could be so the group had to take that into consideration upon designing our project.

Best-Fit Microscope

Through careful examination of available microscopes and much deliberation, the group was able to decide upon one microscope which would be utilized for our project. That microscope is the Axiovert CFL40. This is an inverted microscope which allows us more height to design our device with. Also, because it is inverted the light source comes from above while the objective lens comes from below. This allows sufficient light for viewing and the objective lens is able to move quite close to the Strex well to compensate for the increased magnification of the 60X lens. The dimensions of the microscope platform allow ample space for our device to be anchored upon. A movable X-Y plate is already installed on this microscope which is beneficial, however, our group will need to design around the fact that it decreases the available height between the top of our device and the light source.

3.5 – Incubation Methods Currently Used

Systems are needed to control isolated environments to maintain specific conditions for cells. Generally speaking these conditions are the same; maintaining appropriate temperature, CO_2 & O_2 levels, humidity and pH. These systems can be applied to microscopy by using microscope cage incubators, which have been shown to work as well as regular bench-top incubators. Most of these cage incubators use gentle streams of warm air to control the temperature. To monitor the temperature most systems use a thermocouple is inserted into a reference well to control the temperature as close as possible to the sample. Most systems aim to ensure a specimen temperature stability of ±0.1°C.

These cage incubators can be designed for virtually any inverted or upright microscope that is available. These models are generally customizable for specific needs and include various chambers and interchangeable plate adapters which allow for the use of any cell culture support (petri, glass slides, multiwell plates, and others). These cages also are compatible with manual and digital CO_2 / O_2 gas controllers. pH is generally controlled with buffers however, humidity is important to ensure water from the cell bath does not evaporate out of solution increasing the concentrations of potentially harmful chemicals. All these systems generally function at similar accuracies and specifications.

The amount of time the cells need to survive is related to the type of accuracy in a system one would look for. The longer a test needs to be run, the higher accuracy one needs to maintain appropriate temperatures for their samples.

4 – Device Validation

In order to ensure the device could work properly, validation had to be conducted on mechanical components as well as the ability of the device to view cells under the microscope during stretch. High density mapping was used to map strain fields in the well, and other tests were performed to validate the mechanical function of the device.

4.1 Test Trials – High Density Mapping

Precision and validation are key components to a successful project. Although the Strex manual states that the seeded cells are subject to the same strain as the well is being pulled to (B-Bridge International, 2009), we wanted to personally validate this fact on our own to confirm uniform strain across the well. To give our device supporting evidence, our group decided to use high density mapping, or HDM, as a validation tool. HDM is a technique that uses pixel displacement after a sample it stretched to map its strain (Kelly D et al., 2007). Kelly, along with other researchers, developed this technique to observe a heart over the course of a heartbeat. A camera capturing the sample's movement is connected to a computer, where the data is processed. Once the test is complete, the user can review the pictures side by side to see how far each area moved between frames. This information is exported to an excel spreadsheet to calculate the exact values (Kelly D et al, 2007). This tool is very useful for mapping strain at various points on the sample, to ensure the correct strain value is being used. This is exactly what we used the program for.

To validate the strain field, the Strex well was stretched to 20% strain. This value was chosen because it is the highest strain our device will stretch the well to. The area that was focused on was a 20 mm^2 region, because this is where the cells will lie during stretching. This region is shown in the figure below.

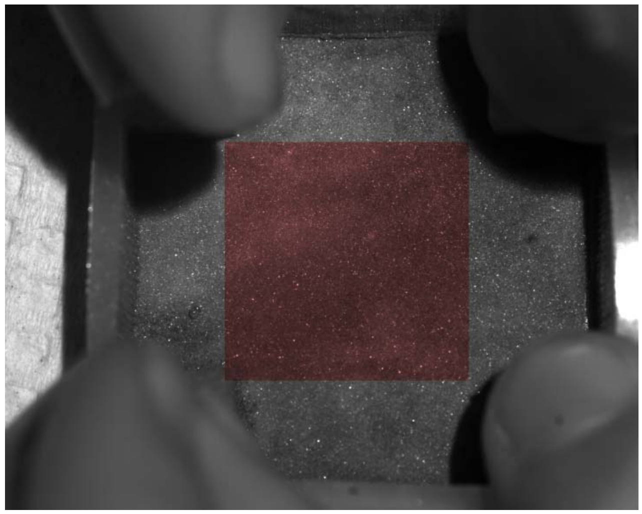


Figure 4.1: Hand stretched Strex well to 20%

As a reference, there are 31 pixels per mm. The HDM program was set to record 16 pixel shifts for 32 x 32 pixel boxes. After the high speed camera, a Photron Fastcam 1280 PCI , captured the well being pulled to this strain, the images were compiled using MATLAB. The data was also filtered using a Gaussian filter by inputting the function *fspecial('gaussian', hsize, sigma)*. The code for the compiling function is included in Appendix I. From there, the matrices for both the u and v displacement were totaled using the function *utotal=sum(udata_s, 3)*. The s signifies that the data has been smoothed. Once the matrices were condensed, the strain was able to be calculated using the displacement of each point.

To calculate the strain, the displacement of one point was subtracted from the following point, and the total was divided by the pixel shift used. For example, $(X_{1,2}-X_{1,1})/16$ would be the formula for the first strain point in the X direction. $(Y_{2,1}-Y_{1,1})/16$ would be the formula for the first strain point in the Y direction. $\{[(X_{2,1}-X_{1,1})/16]+[(Y_{1,2}-Y_{1,1})/16]\}/2$ would be the formula for the first shear strain point. These calculations produced another set of matrices. MATLAB was then used to create a contour plot. The figures below show the X axis strain, the Y axis strain, and the shear strain respectively.

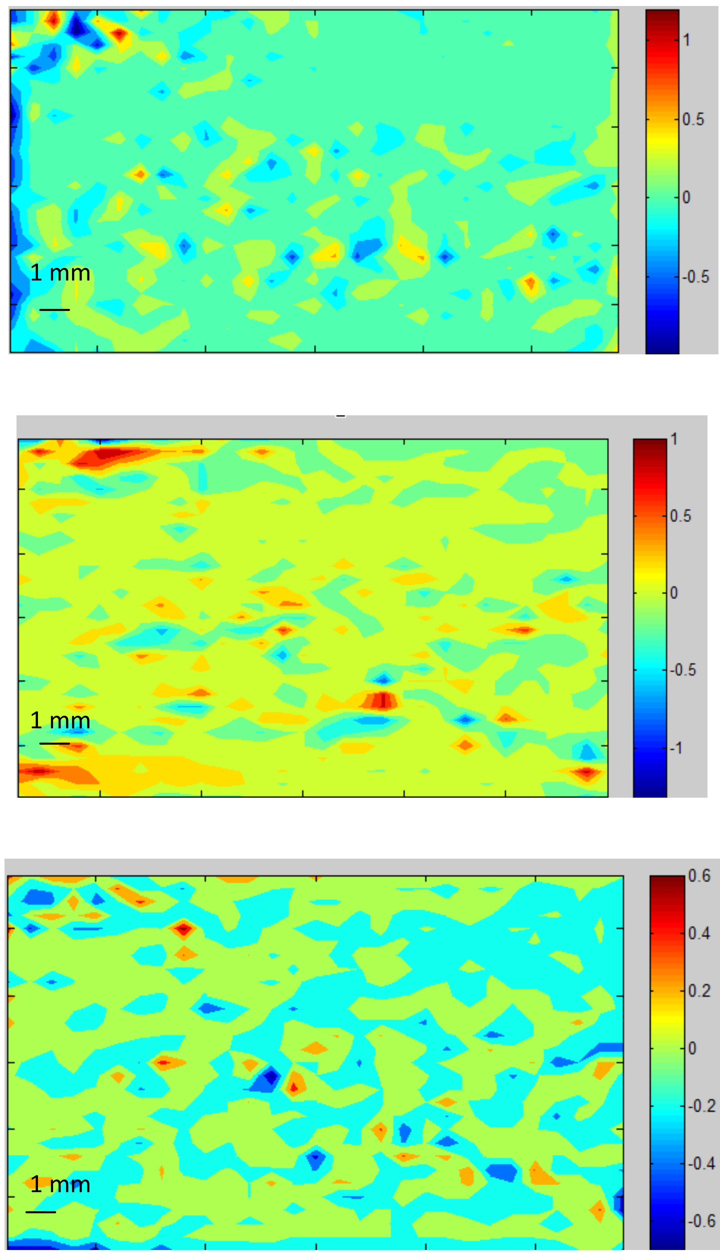


Figure 4.2: HDM results in x axis (top), y axis (middle) and shear strain (bottom)

The green color represents 20% strain, the warmer colors represent a higher strain, and the cooler colors represent a lower strain. As depicted in the pictures, the strain is fairly uniform across the selected section of the well. The abnormal pockets are most likely due to the method used to stretch the well. In the future, these strain fields can be used as a template to compare our device's strain percentages. This will ensure the wells are being homogeneously stretched to the correct strain.

4.2 Device Validation

- Arms reached well (well fit on device)

  As seen earlier, the Strex well has holes 30mm apart that allow the device to mount to a stretch device. The arms of our device were obviously designed to work within this constraint. In both Equibiaxial and Uniaxial positions the arms reached the appropriate distance to allow the standoffs to slide into place.

- Speed Change

  Using a stop watch and counting rotations change in rpms were validated. The device can accurately stretch between 0 and 1.9 Hz with increments of 0.5 Hz or 30 rpm.

- Both strain types work

  The device was simply tested in both equibiaxial and uniaxial setting, and in both cases the device functioned as designed. The

- Can change % strain

  By utilizing the three off-centered holes on the top face of the crankshaft, strain percentages exhibited on the well can vary between 10, 15, and 20 percent.

- Stretched well
  - The device was capable of stretching the well in both settings and the steel rods or linear bearings did not bind during the stretch.

- Device compatibility with Zeiss Microscope:

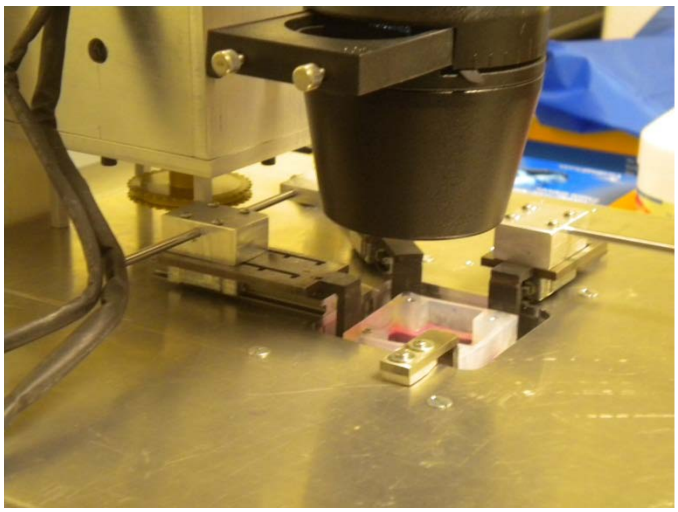


Figure 4.3: Stretch Device on Zeiss Microscope

The device was outfitted with an adapter below the 1/8” plate, the adapter had dimensions based of the X-Y stage of 5.25” x 3.5”. The adapter was checked to ensure it would mount securely in place, then clearance was checked to ensure it cleared the back of the moving piece. After 6 cm^2 viewing area was milled in the center to allow the light to come down through the well. The hole also allows the arms to come down and allows enough space for them to move.

- Motion on scope:

  Motion of the device and X-Y stage was simply validated by placing the entire device on the stage and checking the weight would not exceed the X-Y stages weight limit. Also in the rear of the device acrylic spacers were used to support the weight of the motor and avoid scratching the stage.

- Viewing cells:

  The arms on the linear guides drop to ensure the cells are close enough to the objective. The device was placed on the scope and the distance to the objective was checked. The objective could come up all the way to the bottom of the well using the coarse adjustment, using the fine adjustment the cells can be viewed in focus. A picture of the seeded cells was taken below on the Zeiss microscope to validate they in fact can be seen.

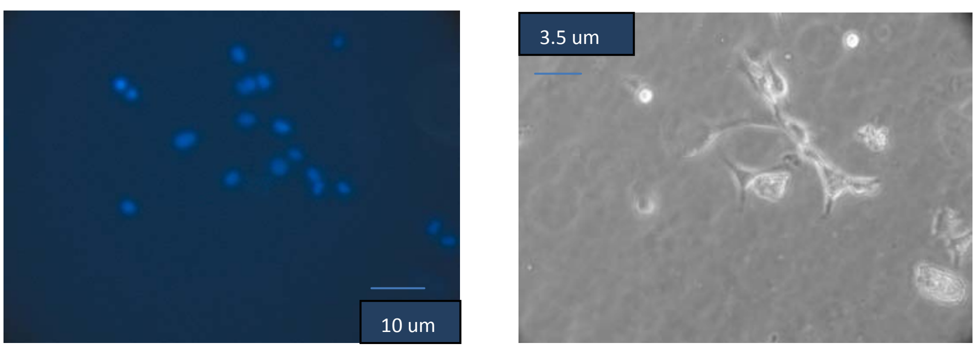


Figure 4.4: Rat Aorta Cells at 40X magnification with Hoescht and Phase Views

Additional Photos can be found in Appendix P.

- Heat Test:

- The motor was ran for an extended period of time (4 hrs) at room temperature and the temperature was taken every half hour. The results of the test show the temperature never reached a level that can damage the motor or ruin any data.

Table 4.1: Heat Test Results

Heat Test Results	
Time (hrs)	Temperature (Celcius)
0	25
.5	26
1	25
1.5	27
2	31
2.5	32
3	33
3.5	33
4	34

Graphical analysis of the heat test shows a steady but slow increase in temperature. From (Figure x) using a best fit line the change in temperature attained was 2.5 degrees/hour, therefore for every hour the temperature increased only 2.5 degrees. If the test would have ran for another 4 hours the expected temperature would have been 45 degrees. This temperature is not very high nor is it anywhere near a temperature that could damage the motor or cause complications.

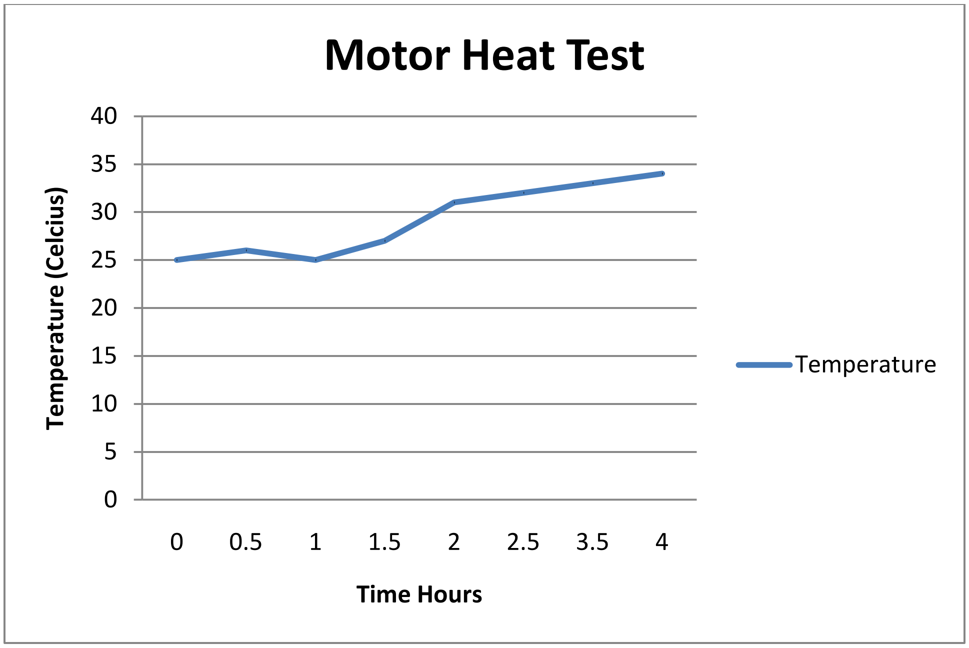


Figure 4.4: Graphical Results of Heat Test Over Time

5 – Conclusions and Recommendations

5.1 Conclusions

Our completed device was able to meet our constraints of achieving strip and equibiaxial stretch, however, the corner linear bearing needs to be moved to achieve this. The device can stretch at different rates by adjusting which hole on the flywheel the arm is attached to by simply changing the distance from the corner housing screw to the crank shaft hole or changing the hole distances on the arm. This change is described in Appendix E (Device General Use).

The device can be equipped to the Zeiss Axiovert CFL40 microscope and is capable of viewing cells during stretch, while placed on the microscope stage. The device fits in an incubator that fits around the Zeiss microscope to keep the cells alive during stretch. It can run for extended periods of time and the motor does not cause a change in temperature that will compromise the cells. The device is able to stretch cells at 1.9Hz at percent strains of ten, fifteen, and twenty percent strain.

The overall cost of the device was around $880, including the cost of shipping of various parts. This came in well under the $1000 budget. A large component of this cost was the $250 spent to purchase Strex wells. The wells had to be purchased in bulk from B-Bridge, but this will be useful for many future tests. If the initial cost of the Strex wells were removed, the cost of the device would be $630, which is significantly less than the $1000 budget. A complete budget breakdown can be seen in Appendix C.

5.2 Recommendations

First, we would suggest allowing the device to include variable duty cycles. This aspect would allow the user to study how cells react to variable loading and unloading rates. A resistor can be used to change the speed of the motor to attain these variable duty cycles. Because the body is subject to many non-uniform stretching rates, observing cell reaction during these variable cycles can be extremely useful.

We also recommend making the device more compact. Currently, our device fits well on the microscope stage and allows for motion on the X-Y stage. However, a smaller and lighter device would allow for a much more marketable device. The majority of the device's bulk is derived from the motor. Using a smaller/lighter motor would decrease the device's weight significantly. Also using different materials could significantly lower the device's mass, many strong but light plastics are available for these types of applications.

As discussed before, our device can be modified to stretch cells either uniaxially or equibiaxially. This transition between strain types requires the user to follow several steps to before successfully changing the device setting (full directions can be found in Appendix E). In the future, we suggest creating an easier and more user friendly transition. For example, creating a sliding arm mechanism with a locking pin could accomplish this. This would allow for a shorter setup time for experiments and a reduction in the chance for error in the process.

Creating an easier transition between strain percentages would also be a useful aspect. Currently, there are multiple arms used for this transition (full directions can be found in the User Manual in Appendix E). Creating one arm that can transition between strain percentages would be much simpler. This can be accomplished by using Heim joints and a turnbuckle. This mechanism is shown in the figure below. Also by being able to lengthen the arm, the device could potentially be used to compress the wells.

Figure 5.1: Heim Joints (Lunsford, 2010).

Heim joints allow for smoother stretch, because they are designed for dynamic applications. The turnbuckle has opposing threads, so it can either bring rods closer together or farther apart. These threaded rods can be marked to indicate where the correct distance for each strain percentage is located. This design would allow for a much more user friendly transition.

Linear bearings on the inside of the housing on the X and Y linear guides would be a smart design alteration. They allow for more fluid motion and reduce the amount of friction in the system. Over time, this will be a better design because friction may cause the rods to bend, bind and possibly lead to other mechanical problems. Some linear bearings available through Igus can be seen below in Figure 5.2. The linear bearings come with plastic inserts to allow them to be run without lubrication, and will remove the metal on metal contact in the design. Another potential modification to minimize friction and increase fluidity of stretch would be to ball bearings at the point of contact between the arm and the crankshaft, as well as the arm and the corner housing.

Figure 5.2: Igus plain linear bearing (left) and Igus enclosed linear bearing (right) (Igus, 2010).

Another recommendation would be to find an easier method of determining what speed the motor is running at. Currently, the only way to determine this is through counting the number of rotations experienced over the course of a period of time. The best way to improve this issue would be through a tachometer, which can measure the revolutions per minute of the crank shaft. This would be an inexpensive purchase, but would just have to fit in the design space currently available.

One final recommendation is to use stainless steel arms instead of oil hardened arms. Stainless steel rods have a higher wear resistance and are already heat treated, the oil hardened arms are much more brittle and often difficult to work with. They are also become very brittle when welded, unless allowed to anneal properly. Some of our steel arms broke due to cooling to quickly when being TIG welded.

Overall these improvements would increase the user-friendliness of our device and would reduce the time to change between strip and equibiaxial strain. This device is an innovative approach to stretching cells and with these improvements can reduce time spent in the lab setting up experiments.

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6.1 – Appendix A – Pairwise Comparison Chart

This was filled out by Professor Billiar (the client) in order to determine the necessities of tasks to be completed for this design.

	Homeostatic Conditions	Biaxial Stretch	Inexpensive	Culture Viewing Area	Duration of Stretch	Variable Duty Cycles	Total	Importance
Homeostatic Conditions		0	1	1	0.5	0	2.5	2
Biaxial Stretch	1		1	1	1	1	4	1
Inexpensive	0	0		0.5	0	0	0.5	3
Culture Viewing Area	0	0	0.5		0	0	0.5	3
Duration of Stretch	0.5	0	1	1		0	2.5	2
Variable Duty Cycles	1	0	1	1	0		4	1

6.2 – Appendix B – Functions Means Tree

1. Strip Biaxial stretch 2-20% at different rates of loading/unloading
    a. One motor with other side anchored (spreading anchor)
    b. Pull at uniform strain rate
2. Equal Biaxial stretch To perform biaxial stretch
    a. Two motors pulling at equal rates
    b. One motor with linkage mechanism
    c. One motor modified to pull in two opposing directions
3. Homogeneous strain area
    a. Pull membrane in two directions
        i. 4 motor system, all moving at the same rates
        ii. 2 motor system in circuits
        iii. 4 motor system with linkages
    b. Possibly achievable with strip biaxial stretch
4. Control temperature and pH of the media to maintain homeostasis
    a. Incubator
    b. Cell humidifier
    c. Hot air heater
    d. Acrylic polymer cage
5. See visual cell response to stimuli
    a. Microscope (inverted)
    b. Photography
6. Variable Duty cycles
    a. Stepper motor
    b. Pneumatics
    c. Hydraulics
7. Usability
    a. Computer program to integrate all functions to perform when needed
    b. Compatible with computer system

6.3 – Appendix C- Budget Breakdown

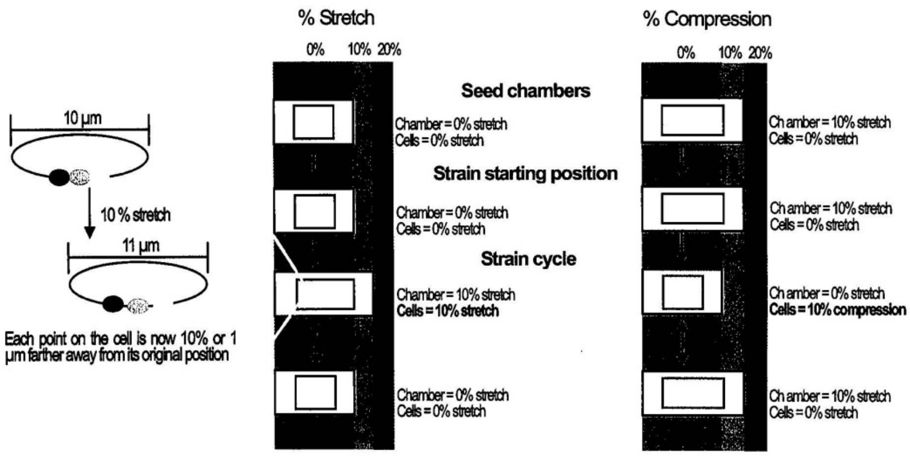
Date	Vendor	Desc.	Cost	Shipping	Total
1/19/2011	BBridge	Stretch Chamber	$250.00	$31.00	$281.00
2/18/2011	McMaster-Carr	Steel Rods & Sheets	$64.21	$9.75	$73.96
2/18/2011	IGUS	IGUBAL Rod end	$20.40	$5.49	$25.89
2/23/2011	IGUS	Rail & Float	$57.71	$5.49	$63.20
3/21/2011	S&S Tech	Electric motor	$129.99	$10.95	$140.94
4/11/2011	WM Berg	Pulleys & chains	$65.76	$50.00	$115.76
4/11/2011	IGUS	IGUBAL flange bearing	$7.99	$5.49	$13.48
4/11/2011	Lyn-Tron	Standoffs (samples)	$0.00	$0.00	$0.00
4/15/2011	Vangy Tool	Axis Arm	$155.00	$0.00	$155.00
4/15/2011	Brierly Lombard	M2 tap	$14.00	$0.00	$14.00
Total					$883.23
Budget					($624.00)

6.4 – Appendix D- Strain Parameter Examples

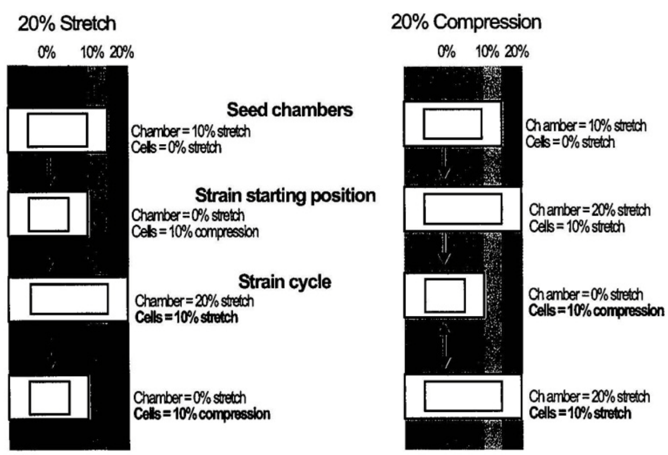
Examples of strain parameters

► **Stretching Cells**
Strain Program: 10% stretch

► **Compressing Cells**
Strain Program: 10% compression



► **10% Stretch & 10% Compression of Cells**
Strain Program: 20% stretch or compression



Use the Chamber Length Adjustment Knob to manually stretch the chamber. Use the knob to adjust for the seeding and start positions. Each 360°turn of the knob changes the total chamber length by 5%. or 1mm. ST-CH-04-XY chamber length is 20 mm.

12

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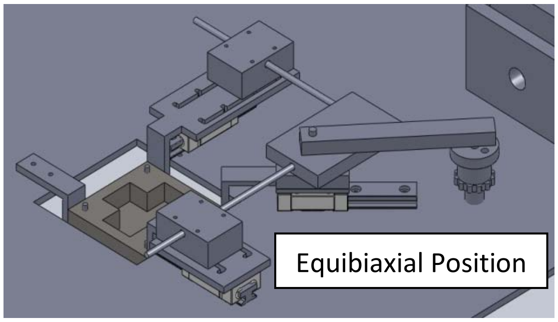
Rev103007

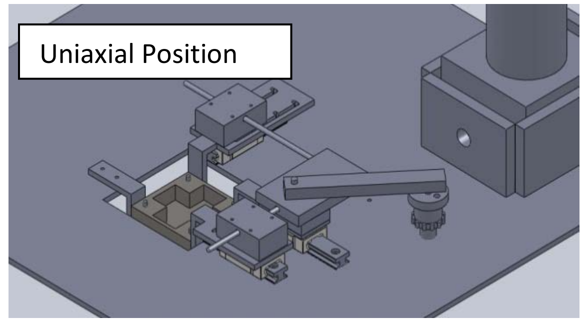
6.5 - Appendix E- General Use Manual

1. Strain Type Control

The arms in the X-axis & Y-axis have slots to control the type of strain, as the corner linear guide/crank shaft move from one angle to another the arm lengths should change as well. To move from equibiaxial strain to uniaxial strain as seen below four steps need to be taken:

1. Loosening of the motor placement screw and switching from the shorter biaxial belt to the longer uniaxial belt.
    - The motor should be loosened and the belt should be removed first, however, the belt being put on should be placed and secured last.
2. Removal of crank shaft screw (4)
    - The crank shaft is also secured by four 4-40 screws, this must be done before the third step.
3. Loosening of X/Y-axis screws (8)
    - After **loosening** not removing the screws securing the x & y arms, slide and lock arms to desired position. These are M2x.4 screws and require a small flat screw driver.
4. Removal of linear guide screws (4)
    - Four M2x.4 screws secure the Igus linear guide in the top right corner of the device need to be removed to slide the guide to and from strain types.

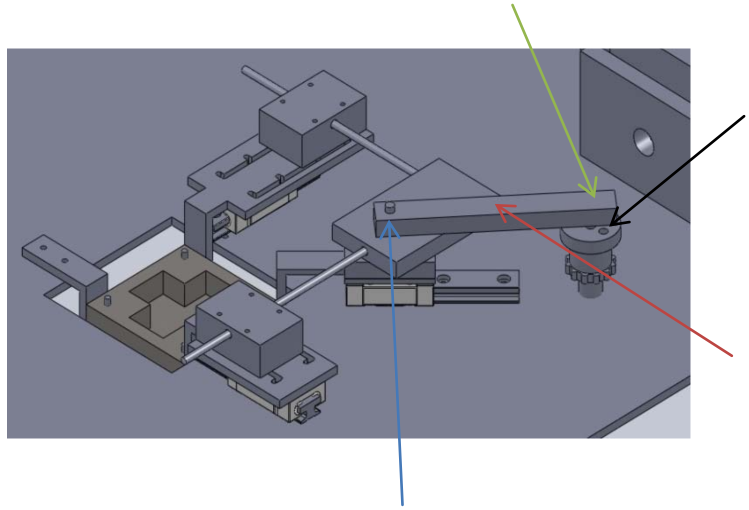




2. Strain Percent Control

Available strain percentages include 5, 10 and 15 percent strain. In the diagram below the arm is tagged by the red arrow, the housing connecting screw is indicated by the blue arrow and the strain percent positions are indicated by the black arrow (three 2-56 threaded holes), and the arm/crank shaft connecting point is indicated by the green arrow. Due to the closeness of the crank shaft holes the device will require separate arms for each strain percent. Changing strain percent is simple it requires two steps:

1. Removal of arm
   - Two nuts and washers (green & blue positions) hold the arm down, they simply need to be removed to remove the arm.
2. Addition of new arm
   - After removing the unwanted arm the new arm can be put in place (does not matter which way) then the washers and nuts should be securely re-tightened. Each arm should be labeled which strain percent it is for (5%,10%,and 15%).



3. Motor Control

The motor being used puts out 8.4 Nm at 35rpm for torque which is more than enough to stretch the silicone wells. However, a 1:3 gear ratio is also being used, (this reduces the torque to 2.6Nm) which brings the top speed from 35 rpm to 114 rpm or 1.9 Hz. The motor is capable of turning clockwise or counterclockwise, and is also capable of variable speeds.

4. Running Device

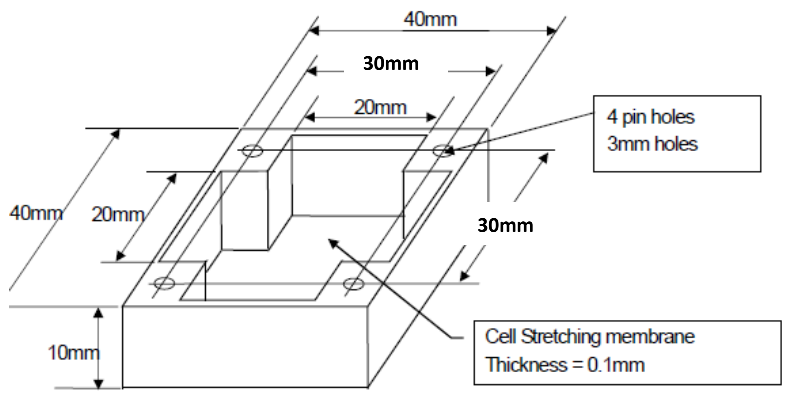
When running the device to ensure wanted results the crank shaft must start at the zero strain point, this is to ensure the well is stretched and not compressed. Therefore before securing the belt in place the crank shaft should be already adjusted for whichever strain percentage is desired.

5. Strex Well Use

Adhesiveness and strength of chamber is not guaranteed for more than 3 uses. The chambers are durable enough to withstand approximately 900,000 stretches of 20%. Also the wells should not ever be stretched past 20%, because strain past 20% will significantly decrease the integrity of the silicone (B-Bridge International, Inc. 2009).

6. Mounting Strex Well

The Strex well has 4 pin holes that are 3mm in diameter, and these holes are used to mount the well to the stretch device. The holes are 30mm apart from their center, and 1/8" outer diameter standoffs will be used to secure the well. The 1/8" is slightly larger than 3mm, allowing the standoffs to provide a snug fit limiting vibration and motion in the Z-axis.



(B-Bridge International, Inc. 2009)

7. Autoclaving Strex Well

Sterilize chambers in an autoclave for 20 minutes at 121°C. The silicone chambers can withstand temperatures up to 180°C. Use of an autoclave is preferable. However, if an autoclave is not available, the chambers may be sterilized by submerging them in 70% ethanol, rinsing with water, then drying in a sterile environment. Place the sterile silicone chambers in a Petri dish in preparation for coating (B-Bridge International, Inc. 2009).

8. Preparing Strex Well

- **Protein Coatings (Strex)** (B-Bridge International, Inc. 2009)

►**Fibronectin Coating**
Preparation of fibronectin solution:
1. Dilute human or bovine fibronectin to a final concentration of 50 to 100 µg/ml in Phosphate Buffered Saline (PBS)
Coating with fibronectin solution:
2. Pour 3-6 ml of the fibronectin solution into each strain chamber
3. Incubate at 37oC for more than 30 minutes.
4. Aspirate the fibronectin solution. If coating is successful, water will not be repelled after removing the fibronectin solution.
5. The liquid solution can be used to coat 3 or 4 chambers before discarding.

PBS (per liter):	
NaCl	8.00 g
KCl	0.20 g
Na_2HP_4 (anhyd.)	1.15 g
KH_2PO_4 (anhyd.)	0.20 g

Note: Dulbecco's PBS in powder form for tissue culture applications is commercially available.

(B-Bridge International, Inc. 2009)

►**Gelatin Coating**
Preparation of gelatin solution:
1. Add gelatin powder to PBS at a concentration of 2%
2. Autoclave the mixture to dissolve and sterilize
Coating with gelatin solution:
3. Pour 3-6 ml of the gelatin solution into each strain chamber
4. Incubate at 37°C for more than 30 minutes.
5. Aspirate the gelatin solution. If coating is successful, water will not be repelled after removing the gelatin solution.
6. The liquid solution can be used to coat 3 or 4 chambers before discarding.

►**Collagen Coating (Cellmatrix 1-C, P, Type 3 or 4)**
Preparation of collagen solution:
1. Combine 1 part collagen to 10 parts HCl, pH 3, in a sterile tube
Coating with collagen solution:
2. Coat chamber with a thin layer
3. Aspirate excess
4. Dry in biological safety cabinet at 25°C or below. The chamber can be stored at the same temperature.
5. Wash the chamber twice with culture medium. If coating is successful, water will not be repelled.

- **Cell Culture** (B-Bridge International, Inc. 2009)

Seed cells at the appropriate concentration in the freshly coated chamber. Do not over expose the cells to dissociation enzymes. Cells should be treated in the same manner (type and concentration of enzyme, temperature, and time for digestion) for all experiments.

Cells should not be cultured at a high cell density in the chambers. For example, epithelial cells often form a cell-sheet and the cell-cell adhesion seems to be stronger than a cell-surface adhesion. When this happens cells may detach from the chamber. Additionally, cultures that are grown over a week in the chambers may detach.

After overnight incubation, inspect cells with the microscope to ensure that they have adhered to the chamber.

9. Strex Well Issues

The PDMS (silicone) chambers are unfortunately very hydrophobic with two methyl-base on the surface. Cells adhere to surfaces coated with fibronectin or collagen through integrins. Compared to adhesion on plastic or glass wells Strex wells are slightly different because they are not charged. If the cells on the Strex well are not attaching or are detaching during stretch, a higher concentration of either fibronectin or silicone may be necessary. These coatings of course must be applied before culturing the cells. (B-Bridge International, Inc. 2009)

10. Additional Information

- If there are wrinkles or bubbles on the bottom surface of the strain chamber when seeding cells this is because of the wells thin structure. The well is designed not to have any heterogeneous regions, though it is difficult to achieve. B-Bridge recommends using a small volume of ethanol in a Petri dish and lightly placing the chamber in the culture dish starting at one edge and moving toward the opposite edge of the chamber to remove air bubbles between the dish and chamber. The ethanol obviously must be evaporated before spreading a cell suspension on the chamber. (B-Bridge International, Inc. 2009)

- Obtaining protein or mRNA samples from the cells:

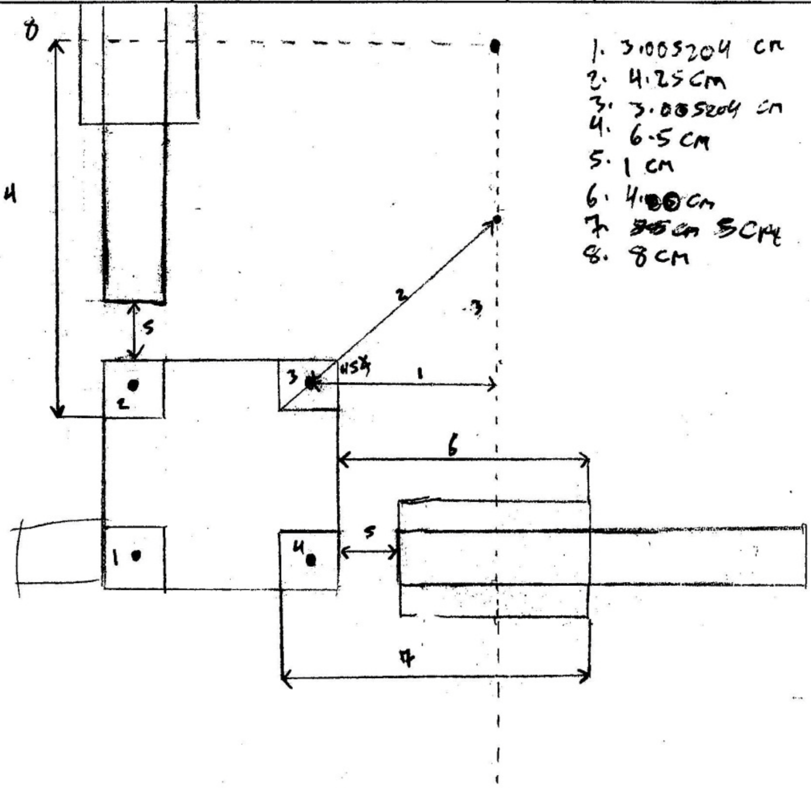
1. Proteins for Western blotting: Wash the cells once with PBS. Add SDS-PAGE sample loading dye directly into the chamber, and collect the cell extract by using a cell scraper (B-Bridge International, Inc. 2009).

2. Proteins for Immunoprecipitation: Wash the cells once with PBS. Add cell extract buffer directly into the chamber, and collect the cell extract by using a cell scraper (B-Bridge International, Inc. 2009).

3. RNA: Wash the cells once with PBS (for RNA preparation). Add RNA extraction buffer directly into the chamber, and collect the cell extract by using a cell scraper (B-Bridge International, Inc. 2009).

6.6 – Appendix F- Design Drawings

spec sheet to determine binx arm length	custom alluminum	2/8/2011

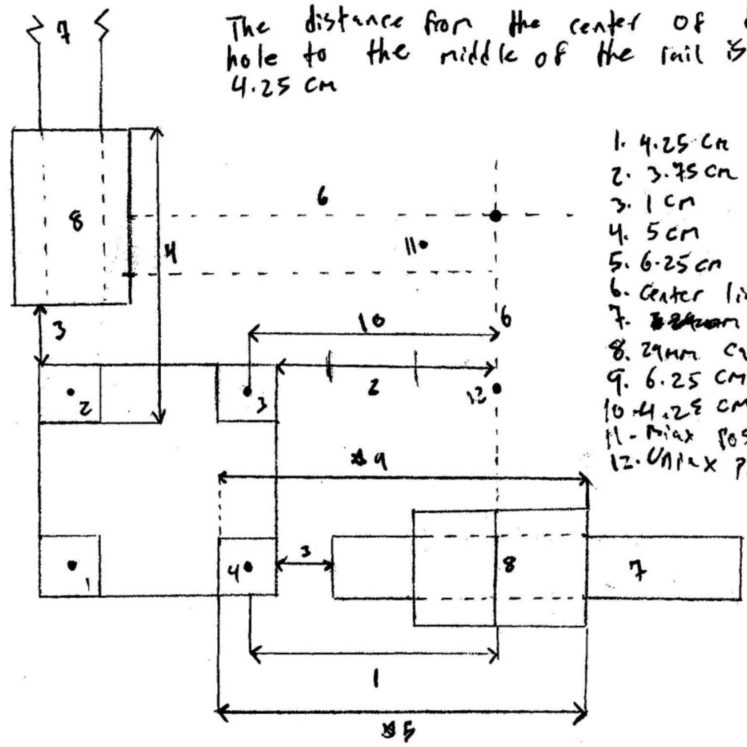


C2 Notes: The minimum length for this corner should be 8 cm.

C4 Notes: The minimum length for this arm should be 5 cm.

Spec Sheet to determine Uniax ~~Rail~~ arm length	Custom (alluminum)	2/17/2011

The distance from the center of the hole to the middle of the rail is 4.25 cm



1. 4.25 cm
2. 3.75 cm
3. 1 cm
4. 5 cm
5. 6.25 cm
6. Center line rails
7. ~~[illegible]~~ 7cm
8. 29mm Carriage
9. 6.25 cm
10. 4.25 cm
11. Max position
12. Uniax position

C4

Notes: the total arm length should be 6.25 cm (min) a longer arm will work, though the arm can not be any shorter than 6.25cm.

C2

Notes: The total arm length must be 5cm (min) like C4 a longer arm could work, though the arm can not be any shorter.

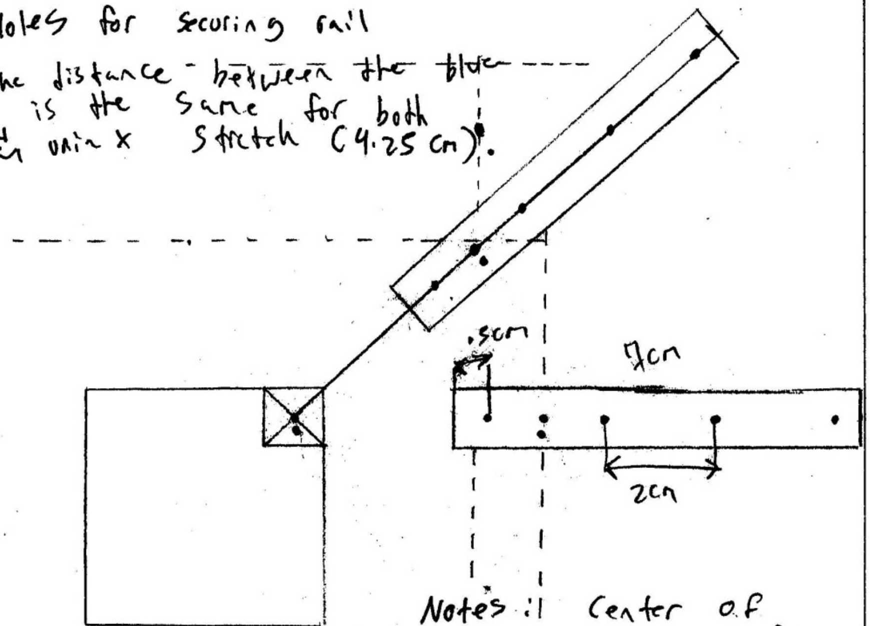
Spec Sheet showing where to place holes for rails	1:1 Scale	8 holes / biax (4) uniax (4)

3/21

• = 4.25 cm from top right corner well

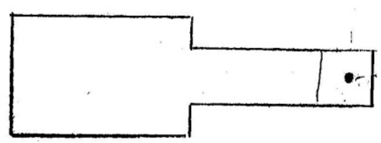
• = Holes for securing rail

• = The distance between the blue dots is the same for both Biax & uniax stretch (4.25 cm).

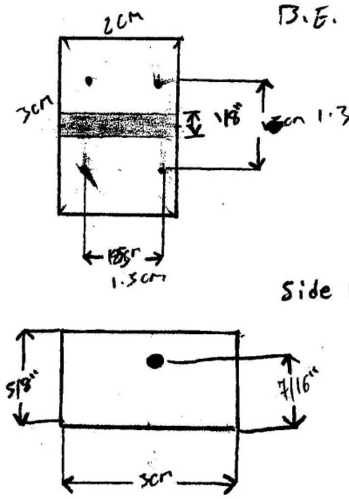


Notes: Center of carriage is 1.5 cm from edge of rail. To have center of drain at 4.25 cm or slightly over, rail must be (4.25 cm - 1.5 cm) or 2.75 cm from center of the right corner of the well.

Arm for top corner rail (1:1)

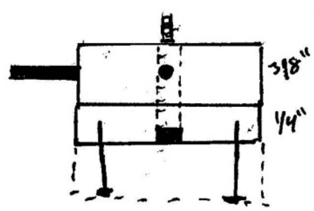


1:1 Scale | Housing design rails | 3/20



3/16 + 4/16
7/16

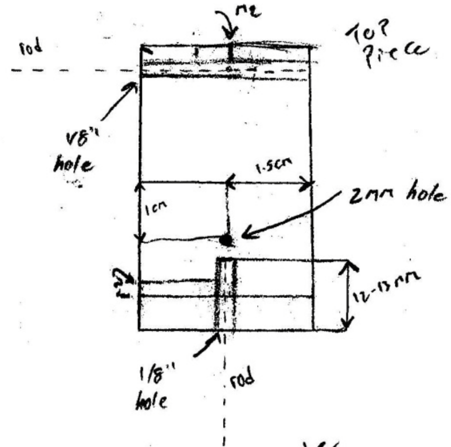
1:1 Scale Top right corner design



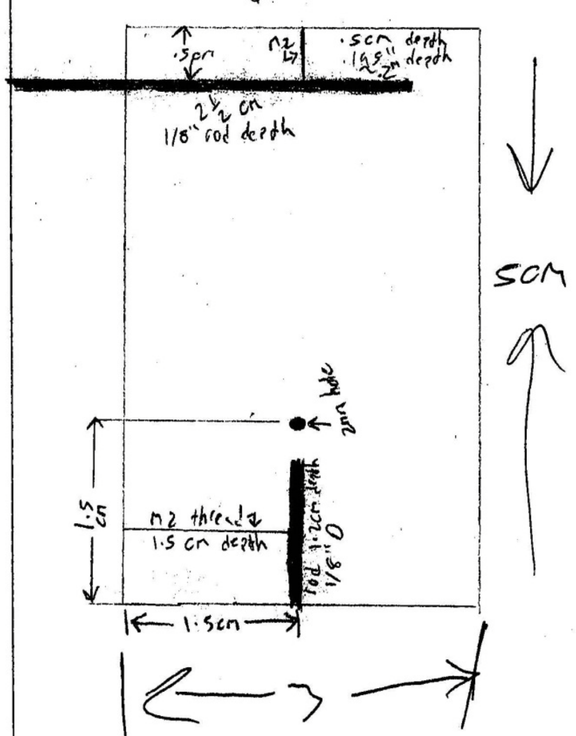
To make design. Speaker top piece, will be switched to 1/4" or 2/8" piece. also this will allow to use a ~~set~~ less longer screw & will not bring rail as high up.

Also to ensure rails remain at propper height plates will have to sit under the tracks on the X & Y carriages. ~~Also~~ unless the height / thickness of ~~the~~ the arms sitting on the carriage is the same height as the sliding bridge for the moving rails/carriage.

1:1 revised corner housing

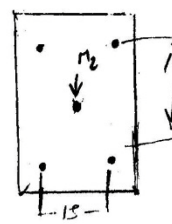


2:1 scale



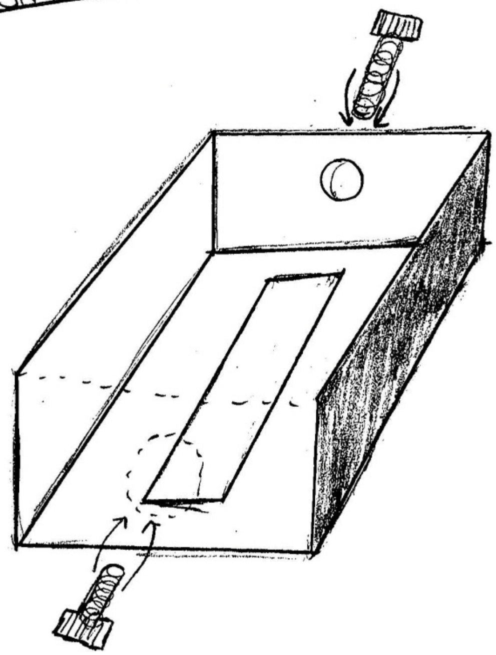
Bottom piece:

This piece have the same birds eye as the other housings except it need a m2 tap in middle.

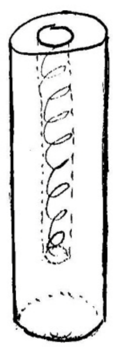


3-D Rendering of Motor Bracket with
Drawing of Motor Leg Supports

CONSTRUCTED BRACKET



LEG SUPPORTS



- 1cm Diam
- 30mm height
  - height restraints
  - should leave ample room for belt
- 6/32 screw
- Not located in each corner
  - leave space for belt position in equi/uni stretch

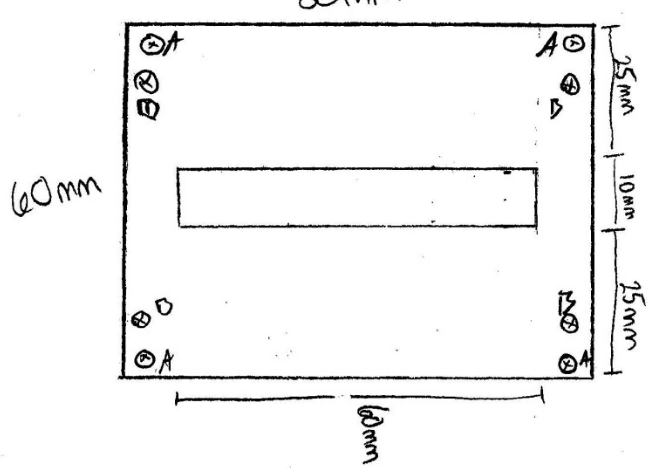
Motor Bracket Base and Sides

- Will use 6/32 screws to attach entire bracket

1/8" A1

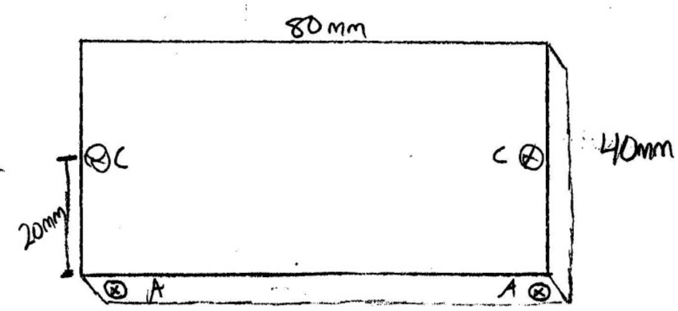
BASE

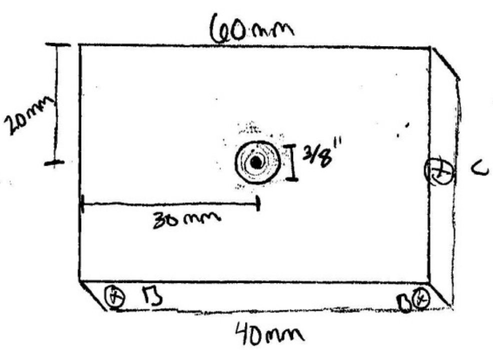
1X



TWO LONG SIDES (80mm) => 1/4" A1

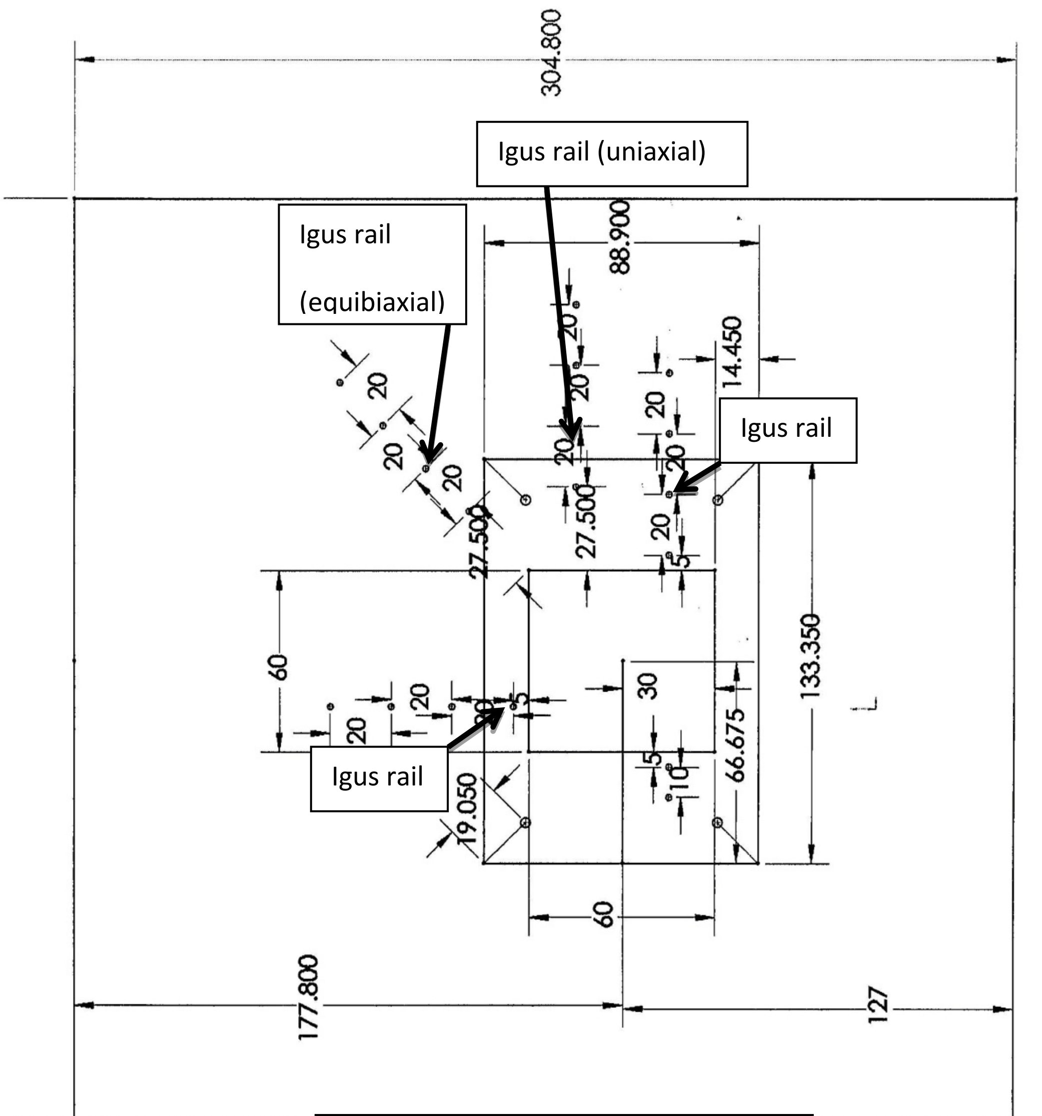
2X



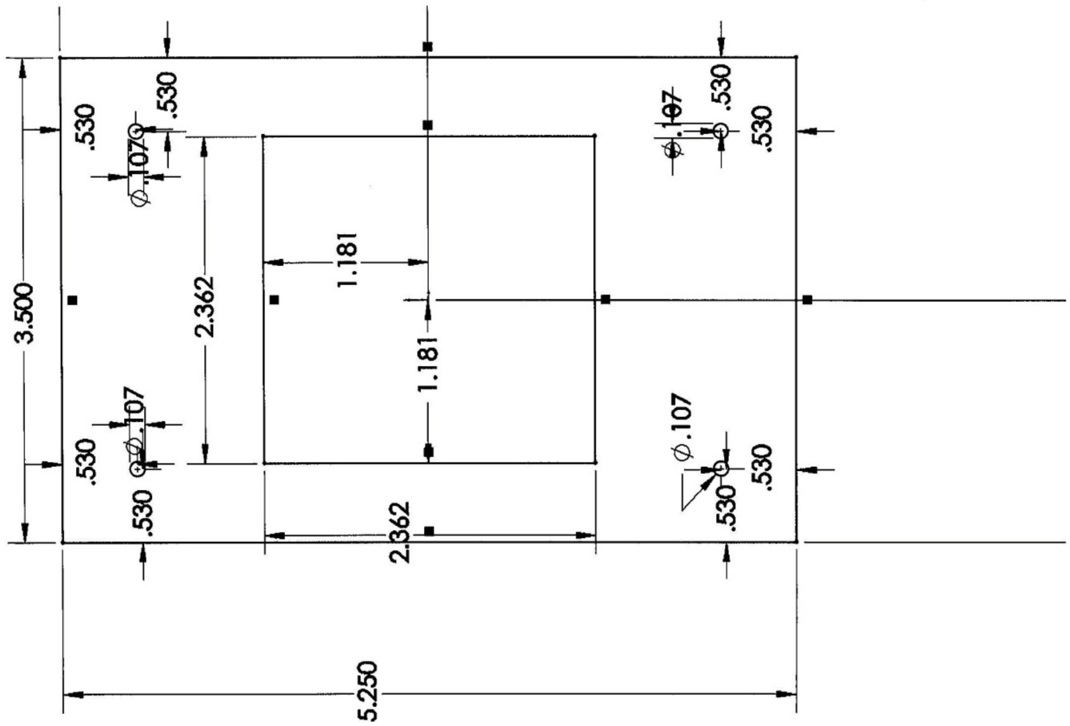


TWO SHORT ENDS

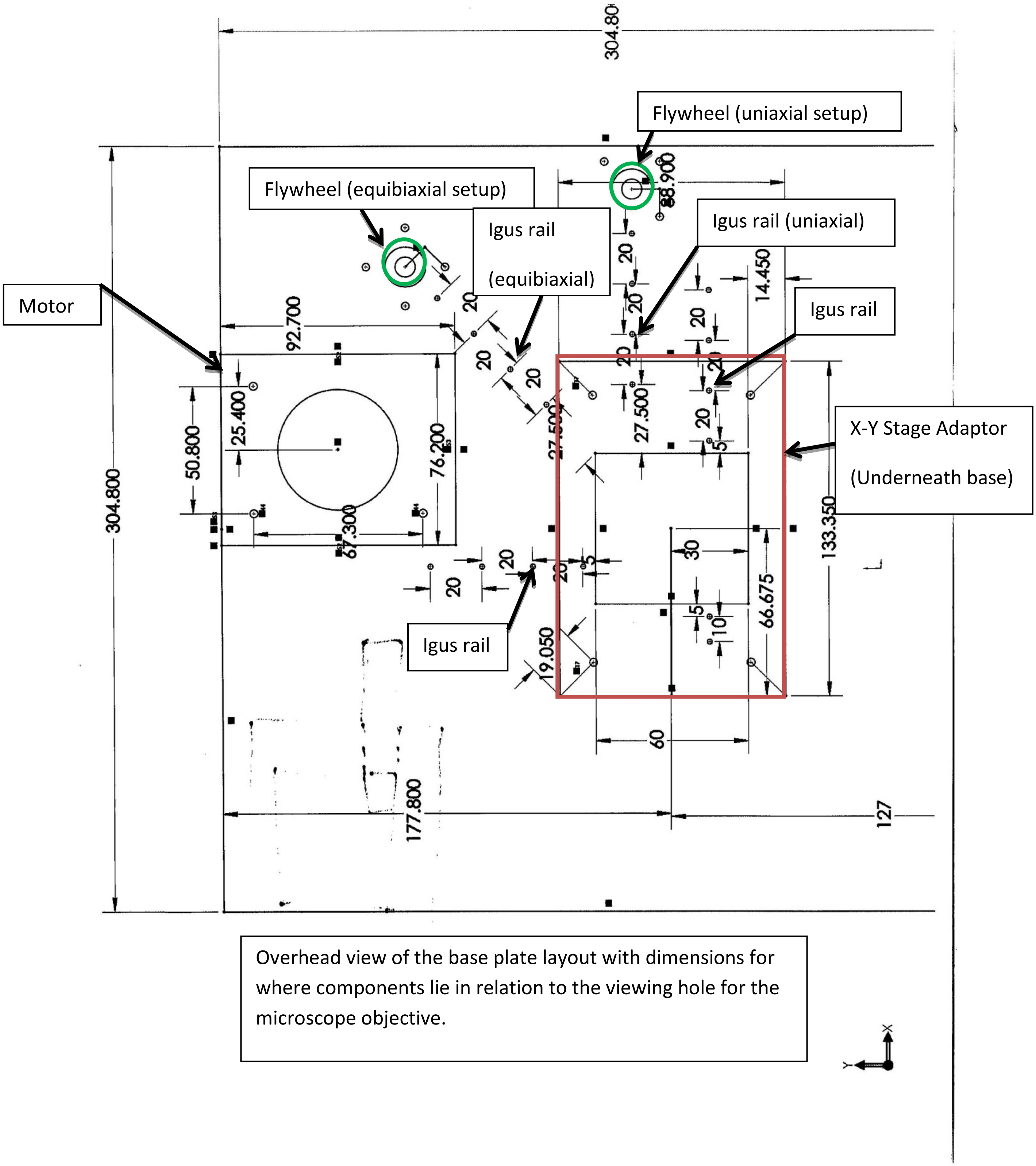
- 1/4" A1
- 3/8" screw



This is an overhead view of the device's layout on the base plate.



This is the X-Y stage adaptor that attaches below the base in order to maintain a level device while on the microscope stage.

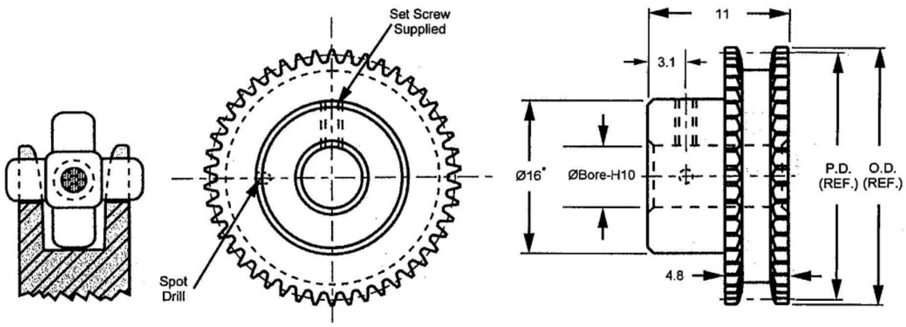


Overhead view of the base plate layout with dimensions for where components lie in relation to the viewing hole for the microscope objective.

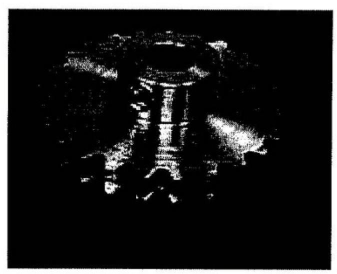
6.7 – Appendix G- Ordered Parts

3-D PULLEYS => 3 day lead time

CIR. PITCH	BORE	STYLE	MATERIALS	BERG'S ® NAME	BELT
4mm	Ø8	PIN HUB	Aluminum per DIN 3.1355 Anodized	Min-E-Pitch® Three D Drive	Operates with 3TDF Series



STOCK NO.	NO. OF TEETH	PITCH DIA.	OUTSIDE DIA.
3TDP263A-12	12•*	15.22	16.80
3TDP263A-13	13•*	16.49	18.07
3TDP263A-14	14•*	17.76	19.34
3TDP263A-15	15•*	19.03	20.61
3TDP263A-16	16•	20.29	21.87
3TDP263A-17	17	21.56	23.14
3TDP263A-18	18	22.83	24.41
3TDP263A-19	19	24.10	25.68
3TDP263A-20	20	25.37	26.95
3TDP263A-22	22	27.90	29.48
3TDP263A-24	24	30.44	32.02
3TDP263A-25	25	31.71	33.26
3TDP263A-26	26	32.98	34.56
3TDP263A-28	28	35.51	37.09
3TDP263A-30	30	38.05	39.63
3TDP263A-32	32	40.59	42.17
3TDP263A-35	35	44.39	45.97
3TDP263A-36	36	45.66	47.24
3TDP263A-40	40	50.47	52.32
3TDP263A-45	45	57.10	58.66
3TDP263A-50	50	63.42	65.00
3TDP263A-55	55	69.76	71.34
3TDP263A-60	60	76.10	77.68
3TDP263A-65	65	82.45	84.02
3TDP263A-70	70	88.79	90.37
3TDP263A-75	75	95.13	96.71
3TDP263A-80	80	101.47	103.05

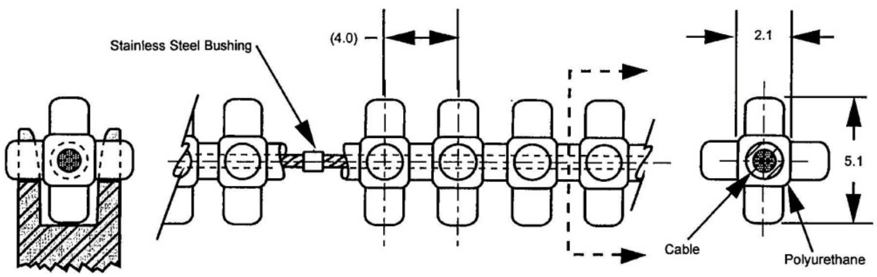


* Sprockets with Ø19.0mm P.D. and smaller are recommended for idler use only.
• For 12-16 teeth, hub diameter equals 10.0.
Other numbers of teeth are available on request.
Stainless Steel equivalent available.
Teeth could be anodized.

1-800-232-BERG (U.S.A ONLY) MA 38 WWW.WMBERG.COM

3-D BELT =) 1 day lead time

CIRCULAR PITCH	MATERIALS	BERG'S ® NAME	PULLEY
4mm	Polyurethane (Green) 8mm Dia. Stainless Steel Cable*	**Min-E-Pitch®**	Operates with 3TDP, 3TF, and 3MTB series.



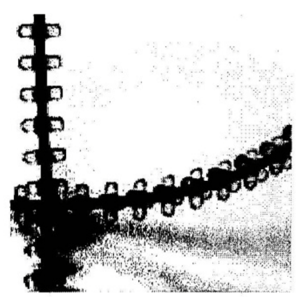
STOCK NO.	NO. OF PITCHES	LENGTH (Ref.)
3TDF-30-E	30	120.0
3TDF-35-E	36	144.0
3TDF-40-E	40	160.0
3TDF-45-E	46	184.0
3TDF-50-E	50	200.0
3TDF-55-E	56	224.0
3TDF-60-E	60	240.0
3TDF-70-E	70	280.0
3TDF-80-E	80	320.0
3TDF-90-E	90	360.0
3TDF-100-E	100	400.0
3TDF-110-E	110	440.0
3TDF-120-E	120	480.0
3TDF-130-E	130	520.0
3TDF-140-E	140	560.0
3TDF-150-E	150	600.0
3TDF-160-E	160	640.0
3TDF-170-E	170	680.0
3TDF-180-E	180	720.0
3TDF-190-E	190	760.0
3TDF-200-E	200	800.0
3TDF-210-E	210	840.0
3TDF-220-E	220	880.0
3TDF-230-E	230	920.0
3TDF-240-E	240	960.0
3TDF-250-E	250	1000.0
3TDF-260-E	260	1040.0
3TDF-270-E	270	1080.0
3TDF-280-E	280	1120.0
3TDF-290-E	290	1160.0
3TDF-300-E	300	1200.0
3TDF-310-E	310	1240.0
3TDF-320-E	320	1280.0
3TDF-330-E	330	1320.0
3TDF-340-E	340	1360.0
3TDF-350-E	350	1400.0
3TDF-370-E	360	1440.0
3TDF-400-E	400	1600.0
3TDF-440-E	440	1760.0

- For Field Splice Kit order 3CCR-7.

* Available with Aramid Core. See page A-2 for alternate belt construction and reverse bending applications.
** Reduce Operating Load Rating by 50% for field splices.

- Three Dimensional Drive
- Zero Backlash
- Silent Drive
- Infinite Lengths
- 90A Durometer
- No Lubrication
- Mass11 Grams/Meter
- Positive Drive
- Ultimate Tensile Strength 222N - 40N/PIN When belt is used in open loop configuration (without splice, no crimp bushing).
- Temperature Range +82°C to -26°C
- Recommended Operating Load 53N
- Recommended Max. Operating Speed 1.91 M/S

BULK FOOTAGE - NOT SPLICED	
STOCK NO.	LENGTH
3TDF-1.5M	1.5M
3TDF-3.0M	3.0M
3TDF-7.5M	7.5M
3TDF-15.0M	15.0M
3TDF-30.0M	30.0M



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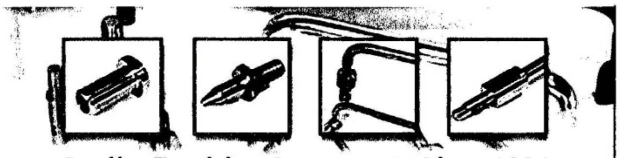

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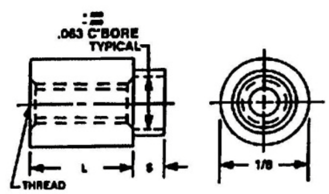

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Results 1 - 25 of 30 | 1 2

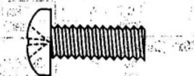
Item #	Item Name	Length (in.)	Thread/Thread Code	Type
6700	1/8 Swage Standoff	1/8	0-80 / 080	1/8 Round Swage Standoffs
6701	1/8 Swage Standoff	3/16	0-80 / 080	1/8 Round Swage Standoffs
6702	1/8 Swage Standoff	1/4	0-80 / 080	1/8 Round Swage Standoffs
6703	1/8 Swage Standoff	5/16	0-80 / 080	1/8 Round Swage Standoffs
6704	1/8 Swage Standoff	3/8	0-80 / 080	1/8 Round Swage Standoffs
6705	1/8 Swage Standoff	7/16	0-80 / 080	1/8 Round Swage Standoffs
6706	1/8 Swage Standoff	1/2	0-80 / 080	1/8 Round Swage Standoffs

Screws - Alloy Steel

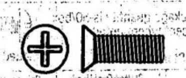
100/Box Except Where Noted

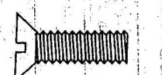
Zinc Plated Steel									
Pan Head Phillips		Pan Head Slotted		Flat Head Phillips		Flat Head Slotted		Cheese Head Slotted	
Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100
09169244	$3.51			65165912	$5.57	09169863	$3.51	09170119	$3.51
09169251	3.51	09169624	$3.51	65165920	5.10	40042319	3.51	09170127	3.51
09169269	3.10			65165938	3.66	09169871	3.10	09170135	3.10
09169277	3.31			65165946	3.67	09169889	3.42	09170143	3.28
09169202	3.07			65165870	3.47	09169855	3.17	09170077	3.14
09169210	3.28			65165888	3.70			09170085	3.17
09169228	3.28	09169616	3.31	65165896	4.13			09170093	3.28
09169236	3.39			65165904	5.53			09170101	3.48
09169178	3.24			48500219	3.24	09169822	3.69	09170036	3.63
7829915	3.28			65165847	3.24	66002098	3.69	09170044	3.66
09169186	3.31	09169590	3.10	65165854	3.24	09169830	3.31	09170051	3.24
09169194	3.34	09169608	3.14	65165862	3.01	09169848	3.34	09170069	3.31
09169137	3.34	09169566	3.39	65165805	3.70	09169780	3.42	09170002	3.34
09169152	3.45	09169574	3.45	65165813	3.70	09169798	3.48	09170010	3.45
09169160	4.39	09169582	3.63	65165821	3.70	09169806	9.72	09170028	3.69
				65165839	3.70	09169814	11.22		
		67408005	5.38						
		67408047	5.38						
414904	3.04	67408088	3.39	65166027	4.16	09169897	3.80	09170168	3.80
414920	3.04	67408120	3.39	65166050	3.38	67397281	3.30	09170176	3.84
414961	3.07	67408161	3.39	65166076	2.79	67397323	3.30	68087121	4.28
415000	3.05	67408203	3.39	65166084	2.79	67397364	3.30	68087162	4.28
415042	3.19	67408245	3.50	65165953	2.80	67397406	3.30	68087204	4.28
415083	3.33	67408286	4.14	65165961	3.24	67397448	3.99	68087246	5.01
359829	3.84	67408328	7.48	65165979	3.70	67397489	8.58		
415125	3.55	67408369	4.05	65165987	3.24	67397521	3.99	68087287	5.01
15166	3.88	67408401	4.13	65165995	3.24	67397562	4.20	09234956	4.05
169285	4.28	67408443	4.78	65166001	3.94	67397604	6.05	09234204	4.25
169293	4.67	67977736	4.70	65166019	4.63	67397646	5.80	09170150	4.59
169301	5.76	67408484	5.43	65166035	10.19	09169905	5.76	78357381	5.72
				[2]65166043	19.45				
		09169632	6.83	[2]65166068	20.84			09170184	6.79
415182	3.04	09169657	4.36			67397687	5.14	09170192	6.11
415190	3.77	67408526	4.36	65166183	3.47	67397729	3.68	09234220	4.67
415208	3.93	67408567	4.36	65166209	3.99	67397760	3.88	68087329	4.80
088004	4.39	67408609	4.36	65166092	3.24	67397802	3.88	68087360	5.38
68088046	4.57	67408641	4.36	04079604	3.47	67397844	3.88	68087402	5.45
09169319	5.06	67408682	5.43	65166100	4.63				
68088087	5.80	67408724	5.43	65166118	3.47	67397927	4.13	68087444	6.31
						67397968	11.24		
68088129	6.39	67408807	6.09	65166126	4.16	67398008	4.55	68087485	6.33
68088160	7.13	67408849	6.09	65166134	5.10	67398040	7.39	68087527	7.64
60844339	5.96	67408880	7.66	65166142	5.57	67398081	6.97	09234238	5.92
09169327	6.18	67408922	7.66	65166159	6.02	67398123	8.91	09234287	6.11
09169335	6.76	67408963	8.33	[2]65166167	14.38	09169913	6.76	09234311	6.66
09169343	7.42	09169640	7.03	65166175	11.58	09169921	7.12	09234329	5.92
09169350	18.93			[2]65166191	8.33			09170200	10.84
09169368	21.68			[2]65166217	32.42				
09169418	5.99	67409003	7.03	09169772	5.96	09169954	5.96	09170234	5.96
68088202	5.71	67409045	7.03	07112071	4.65	67398164	5.58	09234378	6.07
68088244	6.32	67409086	6.97	65166225	4.69	67398206	5.58	68087568	8.48
68088285	6.71	67409128	6.97	65166233	4.72	67398248	5.70	68087600	8.25
				65166241	5.57				
68088327	6.74	67409169	8.09	65166258	6.31	67398289	7.35	68087642	9.35
68088368	8.10	67409201	8.25	65166266	6.68	67398321	7.74	68087683	11.05
68088400	9.29	67409243	9.95	65166274	8.33	67398362	10.91	68087725	11.98
09169376	8.74	67409284	10.86	65166282	9.26	67898404	9.43	09234543	8.65
09169384	10.10	09169665	9.24	65166290	8.30	09169939	9.17	09234568	9.17
09169392	10.35	67409326	12.09	65166308	10.10	09169947	10.15	09170218	10.15
09169400	12.55	09169673	11.51	65166316	10.82	67898446	15.60	09170226	11.45
09169426	13.07			[3]07112063	27.80	09169962	17.09	09170242	15.41
09169483	6.70	09169715	7.12	[3]07112204	20.97	67398487	9.50	09170259	7.12
68088442	8.91	67409367	8.74	07112089	7.41	67398529	9.27	68087766	11.07
68088483	9.39	67409409	9.24	07112097	7.88	67398560	9.63	68087808	12.59
		67409441	10.23	[3]07112105	25.99				
68088525	10.14	67409458	10.23	07112113	8.33	67398602	12.98	68087840	12.59
68088566	12.61	09169681	9.80	07112121	9.26	67398644	13.16	68087881	12.59
68088608	13.97	67409482	13.75	07112139	10.65	67398685	15.95	68087923	15.80
68088640	15.18	67409524	15.18	07112147	10.19	67398727	14.05	09234576	11.61
09169434	11.54	67409565	18.76	07112154	11.58	67398768	24.16	09234600	12.76
09169442	12.37	67409607	18.84	07112162	12.97	67398800	19.28	09234626	13.25
09169459	12.37	09169699	13.14	07112170	8.80	09169970	14.46	09234642	14.08

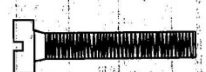
head, under head for all other types [2] 50/box [3] 25/box


Pan Head Phillips


Pan Head Slotted


Flat Head Phillips


Flat Head Slotted


Cheese Head Slotted

11a

HAND TOOLS

MACHINE SCREWS

Continued from previous page

Metric Machine Screws - Alloy Steel

[1]Length (mm)	Pan Head Phillips Order #	Price/100	Pan Head Slotted Order #	Price/100	Zinc Plated Steel Flat Head Phillips Order #	Price/100	Flat Head Slotted Order #	Price/100	Cheese Head Slotted Order #	Price/100
M6x1 (Cont'd)										
50	09169467	$13.94	67409649	$23.75	07112188	$16.21	67398842	$21.61	09234659	$14.97
60	09169475	17.63	09169707	19.97	[3]07112196	23.16	09169988	25.01	09234758	19.63
80					[3]07112212	14.51	09169996	33.18		
M8x1.25										
16	09169491	21.19	09169723	22.06	[2]07112220	17.18	67398883	19.53	09170267	22.24
20	09169509	23.00	67409656	25.10	[2]07112238	19.45	67398925	19.28	09170275	24.74
25	09169517	24.74	09169731	26.14	[2]07112246	23.16	67398966	24.83		
30	09169525	26.21	09169749	27.71	[3]07112253	38.72	67399006	23.69	09170283	27.71
35	09169533	26.56	09169756	29.73	[2]07112261	28.59	67399048	32.31	09170291	29.93
40	09169541	29.28	67409672	31.27	[2]07112279	30.10	67399089	25.75	09170309	31.59
50	09169558	31.72	09169764	34.81	[2]07112287	27.96	[2]67399121	31.39	09170317	33.01

[1]Length overall for flat head, under head for all other types [2]50/box [3]25/box

Metric Machine Screws - 18-8 & 316 Stainless Steel

- Package quantity is 50/box except where noted

Slotted Oval Head | Phillips Oval Head | Slotted Pan Head | Phillips Pan Head | Slotted Flat Head | Phillips Flat Head | Slotted Fil

18-8 Stainless Steel

L (mm)	Slotted Oval Head Order #	Price/100	Phillips Oval Head Order #	Price/100	Slotted Pan Head Order #	Price/100	Phillips Pan Head Order #	Price/100	Pozi Pan Head Order #	Price/100	Slotted Flat Head Order #	Price/100	Phillips Flat Head Order #	Price/100	Pozi Flat Head Order #	Price/100
M1.6x0.35																
3											[1]86725058	$40.69				
4					81997611	$25.92					[1]86725066	38.93				
5					81997629	48.20					[1]86725074	38.93				
6											[1]86725082	38.93				
8											[1]86725090	38.93				
10											[1]86725108	42.69				
12											[1]86725116	42.69				
14																
16																
M2x0.4																
3					81997637	5.85										
4					81997645	5.51	[1]85601102	$2.76	02633691	$4.87	[1]86725124	10.94	85310753	$3.08	02627016	$4.74
5					81997652	5.15	[1]85601110	2.81	02633709	7.28	[1]86725132	4.30	85310761	2.63	02627024	3.86
6					81997660	6.85	[1]85601128	2.86	02633717	4.51	[1]86725140	6.15	85310779	2.42	02627032	5.07
8					81997678	6.89	[1]85601136	2.95	02633725	6.85	[1]86725157	6.86	85310787	3.20	02627040	7.19
10					81997686	9.48	[1]85601144	3.34	02633733	5.51	[1]86725165	7.06	85310795	9.37	02627057	5.85
12					81997694	9.48	[1]85601151	3.67	02633741	4.30	[1]86725173	7.06	85310803	9.80	02627065	6.29
16					81997702	10.90					[1]86725181	7.85				
20					81997710	10.49					[1]86725199	9.72				
25											[1]86725207	10.45				
M2.5x0.45																
3																
4					81997728	7.49	[1]85601169	4.30	02633758	8.96	[1]86725215	9.50			02627073	5.51
5					68012368	8.21	[1]85601177	3.63	02633766	4.09	[1]86725223	7.39	85310811	3.63	02627081	6.08
6					06316657	3.52	[1]85601185	3.82	02633774	5.29	[1]86725231	7.39	85310829	4.87	02627099	6.71
8					04995221	3.84	[1]85601193	4.46	02633782	7.94	[1]86725249	7.85	85310837	3.34	02627107	6.71
10					05026687	5.10	[1]85601201	5.01	02633790	4.63	[1]86725256	7.85	85310845	3.86	02627115	9.04
12					81997736	8.70	[1]85601219	5.47	02633808	5.04	[1]86725264	8.95	85310852	8.25	[illegible]	9.84
14							[1]85601227	5.42								
16					81997744	9.86	[1]85601235	5.91	02633816	7.88	[1]86725272	10.20	85310860	11.30	02627131	9.64
20					81997751	9.74	[1]85601243	7.27	02633824	8.95	[1]86725280	10.20	85310878	7.16	02627149	9.54
25					81997769	12.72			02633832	17.08	[1]86725298	12.50			02627156	9.74
30																
M3x0.5																
4					81997777	13.94							85310886	4.01		
5					81997785	5.63	[1]68019165	9.12	02633840	4.22	86725306	9.23	68018001	10.01		
6	93334423	$8.25	02632792	$5.73	68012608	9.74	[1]68019207	9.65	02633857	5.04	86725314	7.27	68018043	8.83	02631661	5.73
7					81997793	6.53										
8	93334431	8.13	02632800	5.73	81997801	11.98	[1]68019249	5.50	02633865	10.44	86725322	4.93	[1]68018084	9.44	02631679	4.35
10	93334449	9.39	02632818	8.77	81997819	9.48	[1]68019280	5.95	02633873	6.53	86725330	6.93	[1]68018126	11.29	02631687	4.35
12	93334456	8.83	02632826	11.00	81997827	11.19	[1]68019322	6.44	02633881	8.48	86725348	7.53	[1]68018167	11.27	02631695	9.74
14					81997835	11.30			02633899	11.48	86725355	8.13	85310894	6.23	02631703	7.67
16	93334464	10.67	02632834	12.29	81997843	11.58	[1]68019363	7.26	02633907	7.55	86725363	7.82	[1]68018241	12.99	02631711	9.74
20	93334472	11.00	02632842	19.00	81997850	12.22	[1]68019405	8.09	02633915	4.69	86725371	11.98	[1]68018282	13.91	02631729	9.96
25	93334480	11.58	02632859	9.39	81997868	15.14	[1]68019421	9.92	02633923	5.39	86725389	11.83	85310902	12.68	02631737	10.44
30	93334498	22.60	02632867	11.22	81997876	16.35	85601250	11.30	02633931	11.58	86725397	20.91	85310910	15.01	02631745	15.49
35			02632875	11.12	81997884	21.82	85601268	7.07			86725405	20.91	85310928	18.24		
40	[2]93334506	55.79	02632883	11.48	81997892	25.24	85601276	8.10			86725413	16.06	85310936	18.59		
45											86725421	35.09				
50																
M3.5x0.6																
5					81997900	19.04			02633949	10.32	86725439	8.13			02631752	35.48
6					81997918	18.01			02633956	50.86	86725447	27.99			02631760	4.58
8					81997926	38.21			02633964	49.82	86725454	27.99	85310944	6.44	02631778	8.38
10					81997934	40.28	85601284	6.64	02633972	9.39	86725462	29.14			02631786	11.48
12					81997942	35.48	85601292	6.79	02633980	40.28	86725470	29.50	85310951	50.97	02631794	9.52

…rews - 18-8 & 316 Stainless Steel

IMPORT

Phillips Oval Head Order #	Phillips Oval Head Price/100	Slotted Pan Head Order #	Slotted Pan Head Price/100	Phillips Pan Head Order #	Phillips Pan Head Price/100	Pozi Pan Head Order #	Pozi Pan Head Price/100	Slotted Flat Head Order #	Slotted Flat Head Price/100	Phillips Flat Head Order #	Phillips Flat Head Price/100	Pozi Flat Head Order #	Pozi Flat Head Price/100	Slotted Fillister Head Order #	Slotted Fillister Head Price/100	Slotted Truss Head Order #	Slotted Truss Head Price/100
		81997967	$18.47					86725496	$33.75			02631810	$12.84	02623775	$16.64		
		81997975	13.87			02634012	$39.46	86725504	33.75			02631828	12.16				
								86725512	13.87			02631836	17.79				
		81997983	42.45					86725520	15.83								
		81997991	19.84														
		82432519	22.24					86806049	19.84								
		82432527	26.26														
		82432535	12.62	[1]68019447	$13.56	02634038	14.22			85310969	$11.22	02631851	8.25	02623783	11.83		
[illegible]	$14.77	82432543	10.75			02634046	8.02	86806056	12.53	[1]68018324	13.22	02631869	5.84	02623791	10.35		
[illegible]	5.58	82432550	11.65	[1]68019488	14.09	02634053	8.70	86806064	12.53	[1]68018365	10.56	02631877	9.52	02623809	11.07	02626083	$16.72
[illegible]	5.33	[1]68013002	13.18	[1]68019520	10.46	02634061	8.13	86806072	11.28	[1]68018407	11.03	02631885	7.07	02623817	11.19	02626091	19.72
[illegible]	15.43	[1]68013044	18.96	[1]68019561	12.36	02634079	9.96	86806080	11.85	[1]68018449	10.60	02631893	13.33	02623825	12.29	02626109	19.72
		82432568	19.95			02634087	5.84	86806098	14.22			02631901	10.32	02623833	16.72		
[illegible]	13.09	[1]68013085	18.67	[1]68019603	14.54	02634095	11.12	86806106	13.89	[1]68018480	14.38	02631919	13.64	02623841	14.77	02626117	20.74
								86806114	13.94					02623858	19.72		
[illegible]	20.89	[1]68013127	20.06	[1]68019645	20.63	02634103	22.48	86806122	15.87	[1]68018522	13.01	02631927	8.83	02623866	15.75	02626125	22.48
[illegible]	25.56	[1]68013168	20.63	[1]68019660	18.19	02634111	22.48	86806130	15.58	[1]68018563	18.80	02631935	17.79	02623874	22.08	02626133	24.77
[illegible]	14.13	82432576	30.64	[1]68019686	26.36	02634129	26.16	86806148	15.58	[1]68018605	19.77	02631943	22.72	02623882	23.31	02626141	31.10
[illegible]	18.36	82432584	23.28	85601326	21.11			86806155	26.88	85310977	22.08	02631950	27.32	02623890	23.89	02626158	30.74
[illegible]	25.36	82432592	35.09	[1]68019702	28.88	02634145	31.34	86806163	26.88	85310985	23.89	02631968	30.88	02623908	24.61	02626653	29.94
		82432600	32.93	85601334	20.31			86806171	29.59			02631976	33.26	02623916	27.45		
[illegible]	17.73	82432618	38.33	[1]68019728	41.46			86806189	34.18	85310993	42.22	02631984	40.97	02623924	34.66	02626661	70.46
		82432626	65.53					86806197	56.93					02623932	43.72		
		82432634	29.14	[1]68019744	24.66	02634152	29.03	86806205	23.51	85311009	26.16			02623940	16.60		
[illegible]	21.46	[1]68013366	17.35	[1]68019769	21.45	02634657	22.60	86806213	17.38	[1]68018647	14.27	02631992	13.64	02623957	18.59	02626679	25.13
[illegible]	11.61	82432642	25.04	[1]68019785	21.06	02634665	17.64	86806221	15.20	[1]68018688	14.27	02632008	17.79	02623965	17.02	02626687	24.77
[illegible]	21.16	[1]68013440	22.75	[1]68019801	27.93	02634673	15.95	86806239	18.89	[1]68018720	13.78	02632016	9.39	02623973	17.38	02626695	26.26
		82432659	28.68			02634681	29.94	86806247	26.36			02632024	25.92	02623981	27.06		
[illegible]	22.92	82432667	32.89	[1]68019827	21.53	02634699	24.91	86806254	16.06	[1]68018761	15.74	02632032	13.33	02623999	23.89	02626703	32.48
				85601342	22.33			86806262	23.05								
[illegible]	21.53	82432675	20.16	[1]68019843	31.35	02634707	22.37	86806270	16.27	[1]68018803	15.98	02632040	10.20	02624005	23.89	02626711	38.68
[illegible]	40.42	82432683	45.65	[1]68019884	32.74			86806288	28.56	[1]68018845	26.67	02632057	23.97	02624013	31.05	02626729	41.65
[illegible]	22.72	82432691	35.91	[1]68019926	39.64	02634723	39.46	86806296	35.91	[1]68018886	33.16	02632065	31.10	02624021	32.11	02626737	42.67
[illegible]	33.41	82432709	36.49	85601359	29.88	02634731	41.20	86806304	45.00	85311017	23.89	02632073	45.20	02624039	36.23	02626745	31.19
[illegible]	38.44	82432717	62.33	85601367	38.21	02634749	38.91	86806312	45.00	85311025	31.82	02632081	43.27	02624047	43.72	02626752	37.64
		82432725	63.36	85601375	51.92	02634756	49.56	86806320	45.00					02624054	52.44	02626760	42.67
02633097	38.56	82432733	56.83	85601383	55.64	02634764	52.08	86806338	45.00	85311033	58.21	02632099	57.61	02624062	70.11	02626778	79.09
		82432741	123.51											02624070	70.11		
02633105	39.72	82432758	69.20	85601391	72.20	02634772	92.16	86806346	47.62	85311041	51.88	02632107	45.91	02624088	70.11	02626786	74.70
		[2]82432766	78.74														
		[2]82432774	81.14					86806353	69.47					02624096	146.94		
		[2]82432782	108.47														
		[2]82432790	120.30					86806361	78.74					02624104	107.21		
		[2]82432808	136.32											02624112	107.21		
		[2]82432816	146.60					86806379	99.76								
		82432824	25.01	85601409	24.32	02634780	35.78	86806387	29.59					02624120	24.86	02626794	41.65
02633113	21.26	82432832	24.20	[1]68019967	38.06	02634798	32.48	86806395	20.89	68018928	23.76	02632115	22.60	02624138	24.86	02626802	40.45
02633121	22.76	68013846	23.61	[1]68020007	29.93	02634806	18.36	86806403	25.45	68018969	20.71	02632123	19.84	02624146	24.86	02626810	40.04
		82432840	33.49	85601417	31.66	02634814	43.37	86806411	30.53			02632131	26.07	02624153	33.04		
02633139	19.88	82432857	27.45	[1]68020049	29.84	02634822	26.07	86806429	23.31	68019009	21.76	02632149	20.09	02624658	30.64	02626828	43.61
														02624666	23.86		
02633147	47.51	82432865	33.04	[1]68020080	42.58	02634830	43.04	86806437	23.73	[1]68019041	24.70	02632156	16.64	02624674	31.43	02626836	52.79
02633164	21.82	82432873	36.28	[1]68020122	40.70	02634848	43.37	86806445	25.36	[1]68019082	32.17	02632651	25.72	02624682	35.24	02626844	55.43
02633659	37.52	82432881	26.26	[1]68020163	42.76	02634855	51.54	86806452	37.32	[1]68019124	41.03	02632669	41.20	02624690	36.23	02626851	52.34
		[2]82432899	60.14	[2]85601425	48.70	02634863	70.11	[2]86806460	53.49	85311058	33.62	02632677	50.27	02624708	42.39	02626869	53.70
02633667	38.56	[2]82432907	53.24	[2]85601433	53.32	02634871	66.90	[2]86806478	53.49	85311066	39.19	02632685	50.97	02624716	72.32	02626877	48.20
		[2]82432915	62.33			02634889	91.35	[2]86806486	53.49	85311074	51.56			02624724	72.45		
02633675	49.46	[2]82432923	63.22	[2]85601441	54.73	02634897	71.16	[2]86806494	53.49	85311082	61.79	02632693	61.28	02624732	75.57	02626885	53.24
		[2]82432931	90.90														
02633683	54.62	[2]82432949	102.16	[2]85601458	64.29	02634905	90.69	[2]86806502	78.18	85601086	65.81	02632701	72.42	[2]02624740	84.01	02626898	57.16
		[2]82432956	97.55					[2]86806510	110.19								
		[2]82432964	146.14					[2]86806528	84.92					[2]02624757	84.01		
		[2]82432972	147.82					[2]87828612	97.06								
		[2]82432980	153.01					[2]87828620	118.91					[3]02624765	84.01		
		[2]82432998	161.54					[2]87828638	134.88					[2]02624773	84.01		
		[2]82433004	174.25					[2]87828646	145.43					[2]02624781	106.84		
		[2]85130003	76.68					87828653	98.83					02624799	54.06		
		[2]85130011	72.65			02634913	87.47	87828661	70.27			02632719	59.20	02624807	50.93		
		[2]85130029	74.26					87828679	41.43			02632727	59.33	02624815	66.57	02626901	92.96
		[2]85130037	131.30			02634939	154.85	87828687	43.61			02632735	89.63	02624823	65.81	02626919	112.84
		[2]85130045	80.58	85601466	113.66	02634947	157.93	87828695	62.00			02632743	111.24	02624831	68.70	02626927	122.36
		[2]85130052	119.52	85601474	99.48	02634954	162.99	87828703	80.80			02632750	92.86	02624849	94.56	02626935	126.26
		[2]85130060	116.52			[2]02634962	169.20	[2]87828711	123.39			[2]02632768	146.48	02624856	87.68	02626943	115.14
		[2]85130078	149.36	[2]85601482	214.42	[2]02634970	221.21	[2]87828729	106.16			[2]02632776	102.97	[2]02624864	118.22	[2]02626950	151.29
		[2]85130086	190.10			[2]02634988	114.91	[2]87828737	106.16					[2]02624872	132.91		
		[2]85130094	143.72			[2]02634996	284.00	[2]87828745	106.40			[2]02632784	150.61	[2]02624880	146.36	[2]02626968	164.72
		[2]85130102	148.77														
		[2]85130110	144.64					[2]87828752	129.45					[2]02624898	133.40	[2]02626976	133.40

Qty.: 25 [3]Pkg. Qty.: 10 [4]Pkg. Qty.: 5 *Limited Supply

Continued on next page

Continued from previous page

Metric Machine Screws - 18-8 & 316 Stainless Steel

L (mm)	Slotted Oval Head Order #	Slotted Oval Head Price/100	Phillips Oval Head Order #	Phillips Oval Head Price/100	Slotted Pan Head Order #	Slotted Pan Head Price/100	Phillips Pan Head Order #	Phillips Pan Head Price/100	Pozi Pan Head Order #	Pozi Pan Head Price/100	Slotted Flat Head Order #	Slotted Flat Head Price/100	Phillips Flat Head Order #	Phillips Flat Head Price/100	Pozi Flat Head Order #	Pozi Flat Head Price/100
M8x1.25 (Cont'd)																
65					[2]85130128	$150.27					[2]87828760	$201.48				
70	[2]02122745	$124.53			[2]85130136	189.08					[2]87828778	279.31				
75					[2]85130144	192.38					[2]87828786	179.08				
80	[2]02122752	232.79			[2]85130151	191.24					[2]87828794	148.28				
90	[2]02122760	232.79			[2]85130169	255.43					[2]87828802	179.08				
100					[2]85130177	258.47					[2]87828810	191.84				
M10x1.5																
16	02122778	119.84			85130185	239.12					87828828	131.88				
20	02122786	193.52			85130193	322.47					87828836	147.84				
25	02122794	211.90			85130201	344.52					87828844	147.84				
30	02122802	224.65			85130219	262.17					87828851	167.37				
35					[2]85130227	392.36					[2]87828869	196.07				
40	[2]02122810	200.41			[2]85130235	378.60					[2]87828877	196.07				
45					[2]85130243	436.23					[2]87828885	196.07				
50	[2]02122828	382.29			[2]85130250	656.63					[2]87828893	248.07				
55					[2]85130268	535.08										
60	[2]02122886	382.29			[2]85130276	255.17					[2]87828901	248.07				
65					[2]85130284	437.06					[2]87828919	271.99				
70	[2]02122844	539.08			[2]85130292	372.75					[2]87828927	271.99				
75					[2]85130300	379.33					[2]87828935	500.84				
80	[2]02122851	603.84			[2]85130318	482.37					[2]87828943	279.41				
90					[2]85130326	495.00										
100					[2]85130334	501.29					[2]87828950	396.02				
M12x1.75																
20											87828968	244.96				
25											87828976	316.13				
30											87828984	291.47				
35											[2]87828992	659.99				
40											[2]87829008	494.89				
45											[2]87829016	605.45				
50											[2]87829024	665.80				
55											[2]87829032	343.71				
60											[3]87829040	400.30				
65											[3]87829057	400.30				
70											[3]87829065	400.30				
75											[3]87829073	522.33				
80											[3]87829081	1338.12				
90											[3]87829099	604.05				
100											[3]87829107	604.05				

[1]Pkg. Qty.: 100 [2]Pkg. Qty.: 25 [3]Pkg. Qty.: 10 [4]Pkg. Qty.: 5 *Limited Supply

316 Stainless Steel

L (mm)	Slotted Oval Head Order #	Slotted Oval Head Price/100	Slotted Pan Head Order #	Slotted Pan Head Price/100	Slotted Flat Head Order #	Slotted Flat Head Price/100	Slotted Fillister Head Order #	Slotted Fillister Head Price/100
M1.6x0.35								
3							[1]02834059	$24.18
4					02635019	$41.91	[1]02834067	24.18
5					02635027	33.70	[1]02834075	31.61
6					02635035	51.79	[1]02834083	19.96
8					02635043	34.28	[1]02834091	20.55
10			03016144	$25.36	02635050	36.39	[1]02834109	32.76
12					02635068	81.48	[1]02834117	29.56
16					02635076	51.21	[1]02834125	32.76
M2x0.4								
3							[1]02834133	31.92
4			03016151	14.44	02635084	10.55	[1]02834141	7.64
5			03016656	11.02	02635092	17.37	[1]02834158	10.26
6			03016664	9.86	02635100	11.61	[1]02947653	10.26
8			03016672	10.18	02635118	6.69	[1]02947661	11.44
10			03016680	18.66	02635126	9.97	[1]02947679	19.58
12			03016698	14.77	02635134	10.32	[1]02947687	8.90
14							[1]02947695	7.84
16			03016706	16.20	02635142	8.57	[1]02947703	9.97
20			03016714	16.20	02635159	15.94	[1]02947711	12.32
M2.5x0.45								
3							[1]02947729	25.26
4			03016722	10.32	02635654	9.51	[1]02947737	12.90
5			03016730	10.32	02635662	7.72	[1]02947745	11.93
6			03016748	7.25	02635670	6.80	[1]02947752	8.90
8			03016755	12.20	02635688	10.44	[1]02947760	11.24
10			03016763	14.57	02635696	11.75	[1]02947778	10.91
12			03016771	11.86	02635704	7.96	[1]02947786	15.61
14			03016789	9.15				
16			03016797	14.19	02635712	12.79	[1]02947794	9.03
20			03016805	13.14	02635720	13.03	[1]02947802	21.01
M3x0.5								
5			03016813	10.08	02635738	12.42	[1]02947810	12.28
6	02821841	$15.71	03016821	8.79	02635746	13.24	02947828	20.74

L (mm)	Slotted Oval Head Order #	Slotted Oval Head Price/100	Slotted Pan Head Order #	Slotted Pan Head Price/100	Slotted Flat Head Order #
8	02821858	$7.03	03016839	$15.61	0263576[illegible]
10	02821866	7.96	03016847	10.91	02635761
12	02821874	8.90	03016854	11.50	02635779
14					02635787
16	02821882	11.40	03016862	10.32	0263579[illegible]
20	02821890	10.18	03016870	18.07	0263580[illegible]
25	02821908	19.02	03016888	16.55	0263581[illegible]
30	02821916	22.20	03016896	31.46	0263582[illegible]
35	02821924	17.58			02635837
40	02821932	56.83			02635846
50					02635862
M4x0.7					
5			03016904	20.17	
6	02821940	14.28	03016912	16.08	02635860
8	02821957	17.73	03016920	18.78	02635878
10	02821965	19.43	03016938	16.08	02635886
12	02821973	20.65	03016946	21.50	02635894
16	02821981	19.04	03016953	20.65	02635902
20	02821999	17.58	03016961	25.57	02635910
25	02822005	38.18	03016979	33.00	02635928
30	02822013	20.78	03016987	39.80	02635936
35	02822021	17.26	03016995	29.36	02635944
40	02822039	41.45	03017001	42.85	02635951
45					02635969
50	02822047	29.58	03017019	58.14	02635977
60	02822054	63.88			
M5x0.8					
6			03017027	34.28	
8	02822062	33.57	03017035	39.22	02635985
10	02822070	36.52	03017043	32.29	02635993
12	02822088	29.94	03017050	38.40	02636009
16	02822096	31.36	03017068	39.32	02636017
18					02636025
20	02822104	44.74	03017076	57.31	02636033
25	02822112	35.56	03017084	41.45	02636041

[1]Pkg. Qty.: 100 [2]Pkg. Qty.: 25 [3]Pkg. Qty.: 10 *Limited Supply

Screw Nuts - Military Specification 35649 / 35650

made in USA

Pkg. Qty.	Military Equivalent	Order #	Price/100
100	MS35649-222	72056625	$34.15
100	MS35649-242	72056666	47.41
100	MS35649-262	72056674	34.26
100	MS35649-282	72056682	41.58
100	MS35649-202	72056617	39.70

Thread Size	Hex Size (In.)	Hex Ht. (In.)	Pkg. Qty.	Military Equivalent	Order #	Price/100
10-32	11/32	0.130	100	MS35650-302	72056690	$39.70
1/4-20	7/16	0.193	100	MS35649-2252	72056633	56.22
5/16-18	9/16	0.225	100	MS35649-2312	72056641	61.87
3/8-16	5/8	0.257	100	MS35649-2382	72056658	122.96

- Material: steel
- Grade: 60M
- Finish: cadmium yellow plated

…ts

IMPORT

…s 8 Zinc Plated Order #	Price/100	Class 8 Plain Steel Order #	Price/100	[1]Class 10 Plain Steel Order #	Price/100	18-8 Stainless Steel Order #	Price/100	316 Stainless Steel Order #	Price/100
…45	$2.72	09170424	$2.62			68024009	$6.12	[2]62323555	$11.07
…55	2.97	09170432	2.83			68024041	7.30	[2]62323563	11.12
…40	1.85	67476960	1.21			68024082	4.93	[2]65093940	7.60
…99	3.07	09170457	2.89					[2]65093957	14.56
…81	1.86	67477000	1.39			68024124	6.68	65093965	8.87
…23	1.85	67477042	1.63	01010339	$4.59	68024165	6.91	65093973	9.31
…64	2.11	67477083	1.86	67477406	5.38	68024207	8.87	65093981	10.27
…06	4.39	01010693	4.25			[3]81707804	30.67		
…48	4.74	67477125	3.72	67477448	9.42	68024249	23.85	65093999	28.83
…89	8.17	67477166	6.84	67477489	18.83	68024280	43.10	65094005	55.19
…21	12.90	67477208	9.59	67477521	26.89	68024322	60.77	65094013	80.19
	Price Ea.		Price Ea.		Price Ea.		Price Ea.		Price Ea.
…62	0.25			67477562	0.39	68024363	1.03	65094021	2.07
…04	0.22	67477240	0.15	67477604	0.52	68024405	1.28	65094039	2.12
…46	0.49	67477281	0.39	67477646	1.25	68024447	2.90	65094047	3.12
…87	0.58	67477323	0.58	67477687	0.96	68024488	2.93	65094054	3.32
…73	0.92	09170440	0.65	09170515	0.85	81707887	3.73	65094062	3.68
…29	1.21	67477364	1.17	67477729	1.95	68024520	4.77	65094070	7.21
…81	1.99	81195430	1.87	09170523	2.34	81707903	15.69	65094088	13.61
…07	2.31	08018848	2.18	07366826	2.85	81707911	13.34	65094096	22.09
		09170465	2.49	09170531	3.16	81707929	34.25	65094104	25.96
		05736798	2.86	09170556	3.42	81707937	23.11	65094112	36.69
								65094120	43.11
								65094138	44.44
								65094146	45.09
								65094153	96.02
								65094161	117.17

…de 8 in inch sizes [2]Pkg. Qty.: 200 [3]Pkg. Qty.: 50

Metric Fine Pitch Hex Nuts

Screw Size	W. Across Flats (mm)	Ht. (mm)
M2	4.0	1.6
M2.5	5.0	2.0
M3	5.5	2.4
M4	7.0	3.2
M5	8.0	4.0
M6	10.0	5.0
M7	11.0	5.5
M8	13.0	6.5
M10	17.0	8.0

Screw Size	W. Across Flats (mm)	Ht. (mm)
M12	19.0	10.0
M14	22.0	11.0
M16	24.0	13.0
M18	27.0	15.0
M20	30.0	16.0
M24	36.0	19.0
M30	45.0	25.0
M36	54.0	30.0

Class 8 Zinc Plated - Fine Threaded

Thread Size	Pkg. Qty.	Order #	Price/100
M8x1	100	67488643	$15.57
M10x1.25	100	67488684	29.45
M12x1.25	100	67488726	41.44
			Price Ea.
M14x1.5	1	67488767	0.67
M16x1.5	1	67488809	0.77
M18x1.5	1	67488841	0.85
M20x1.5	1	67488882	1.07

…Nuts

IMPORT

…on

…teel with a bright finish of zinc plating for rust and corrosion resistance.
…gth, for use with Grade 2 fasteners.
…pose grade of low carbon steel with no finish unless a grade of nuts is …2, 5 & 8.
…rength, for use with Grade 5 fasteners.

Grade 8 Yellow Zinc Dichromate - For use with Grade 8 screws and washers for the highest available strength and resistance to cracking and metal fatigue. Corrosion-resistant gold-colored coating.
Grade 8 Steel - High strength, for use with Grade 8 fasteners.
L9 Yellow Zinc Dichromate - For use with Grade L9 screws and washers for the highest available strength and resistance to cracking and metal fatigue. Corrosion-resistant gold-colored coating.

… nuts with screws or bolts of similar material to prevent galvanic corrosion, especially in moist or wet environments.

…Sold in Pkg. Qty. Only

…nc Plated Price/100	Grade 2 Plain Steel Order #	Price/100	Left Hand Plain Steel Order #	Price/100	Grade 5 Zinc Plated Order #	Price/100	Grade 5 Plain Steel Order #	Price/100	Grade 8 Yellow Zinc Dichromate Order #	Price/100	Grade 8 Plain Steel Order #	Price/100	L9 Yellow Zinc Dichromate Order #	Price/100
$1.70	67473728	$1.61	67475442	$7.67	67471045	$2.51	52593324	$1.56	05724406	$3.04	67470245	$4.51	67512905	$23.33
1.91	67474601	1.77	67475962	9.23	67472928	2.84	52593332	2.45	85724409	4.01	67472126	4.08	03835923	15.86
2.60	67473769	2.60	67475483	9.46	67471086	3.82	52593340	2.97	05724414	4.13	67470286	5.07	67512913	38.75
2.67	67474643	2.75	67476002	10.56	67472969	3.87	52593357	3.74	85724417	4.50	67472167	5.71	03835931	38.31
3.59	67473801	3.58	67475525	14.30	67471128	5.06	52593365	3.05	05724422	6.09	67470328	9.37	[1]67512921	36.36
3.93	67474684	3.79	67476044	15.85	67473009	5.57	52593373	4.90	85724425	6.80	67472209	7.69	[1]03835949	37.18
7.19	67473843	6.07	67475566	30.11	67471169	8.43	52593381	5.37	05724430	11.69	67470369	12.59	[2]67512962	53.91
7.47	67474726	6.88	[3]67476085	30.12	67473041	9.71	[3]52593399	9.43	85724433	14.02	[3]67472241	17.98	[3]03835956	54.46
9.03	[3]67473884	6.41	[3]67475608	32.03	[3]67471201	12.43	[3]52593407	7.27	[3]05724448	14.04	[3]67470401	20.84	[2]67513002	61.17
10.36	[3]67474767	7.97	[3]67476127	35.65	67473082	12.82	[3]52593415	5.80	[3]85724441	15.13	[3]67472282	21.11	[2]67513366	62.11
17.12	67473926	11.66	67475640	75.13	67471248	20.20	52593423	12.41	05724455	30.91	67470443	30.86	67513044	73.72
17.36	67474809	13.61	[1]67476168	144.27	67473124	22.79	52593431	28.26	85724458	32.58	[1]67472324	33.78	[3]67513408	74.01
Price Ea.		Price Ea.		Price Ea.		Price Ea.		Price Ea.		Price Ea.		Price Ea.		Price Ea.
0.19	67473967	0.12	[1]67475681	0.65	67471284	0.21	52593449	0.13	05724463	0.26	[3]67470484	0.32	67513085	1.24
0.20	67474841	0.18	[1]67476200	0.67	67473165	0.24	52593456	0.20	85724466	0.36	[1]67472365	0.39	67513440	1.28
0.28	67474007	0.21	[2]67475723	0.80	67471326	0.34	52593464	0.38	05724471	0.43	[1]67470526	0.53	67513127	2.13
0.30	67474882	0.30	[2]67476242	1.15	67473207	0.36	52593472	0.40	85724474	0.56	[1]67472407	0.62	67513481	2.26
0.47	[4]67474049	0.34	67475764	1.24	[4]67471367	0.55	[4]52593480	0.91	[4]67470807	0.78	67470567	0.80	67513168	4.32
0.57	67474924	0.38	[2]67476283	1.99	67473249	0.63	52593498	0.94	67472688	0.81	[2]67472449	0.88	67513523	4.40
0.78	67474080	0.68	[2]67475806	2.63	[2]67471409	0.97	[2]52593225	0.42	67470849	1.14	[2]67470609	1.47	[2]67513200	6.71
0.84	67474965	0.75	[2]67476325	2.96	67473280	0.97	52593233	0.82	67472720	1.16	[2]67472480	1.30	67513564	6.82
1.13	67474122	1.04	67475848	9.80	[4]67471441	3.51	[4]52593241	0.98	67470880	2.26	[2]67470641	2.12	67513242	20.09
1.39	67475004	1.11	[5]67476366	7.12	52592276	1.40	52593258	1.79	[5]67472761	2.44	[5]67472522	2.56	[5]67513606	20.09

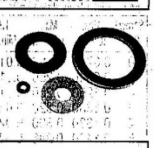
[3]Pkg. Qty. 100 [4]Pkg. Qty. 15 [5]Pkg. Qty. 1 [6]Pkg. Qty. 10

Continued on next page

Flat Washers - Military Specification Stainless Steel

made in USA

- Manufactured from 18-8 stainless steel, these washers are burr-free and passivated to meet stringent military specifications
- Conform to MS, AN or NAS chemical and physical specifications
- MS washers have larger ID and OD's and are thicker than AN and NAS washers
- The "L" in the Dash Number column refers to the light (thinner) series of washers
- Tolerance: +.0081/-.005"



Screw Size	Dash Number	ID (In.)	OD (In.)	Thick. (In.) Min.	Thick. (In.) Max.	Pkg. Qty.	Order #	Price/Pkg.
MS15795 Military Specification								
0	801	0.078	0.188	0.016	0.025	500	82294620	$12.84
2	802	0.094	0.250	0.016	0.025	500	07322779	12.37
4	803	0.125	0.250	0.017	0.028	500	07322787	13.58
4	804	0.125	0.312	0.025	0.040	500	07322795	17.02
6	805	0.156	0.312	0.027	0.048	500	07322803	19.73
6	806	0.156	0.375	0.036	0.065	250	07322811	13.83
8	807	0.188	0.382	0.036	0.065	250	07322829	14.14
8	841	0.188	0.445	0.036	0.065	250	07322837	16.08
10	808	0.219	0.445	0.036	0.065	250	07322845	15.30
10	842	0.219	0.507	0.036	0.065	250	07322852	19.61
12	809	0.257	0.579	0.051	0.080	100	07322878	19.61
¼	810	0.296	0.632	0.051	0.080	100	07322886	14.98
¼	811	0.327	0.739	0.051	0.080	100	07322894	20.91
5/16	812	0.351	0.693	0.051	0.080	100	07322902	21.24
5/16	813	0.382	0.897	0.064	0.104	50	07322910	20.57
⅜	814	0.413	0.817	0.051	0.080	50	82294638	14.99
⅜	815	0.445	1.022	0.064	0.104	50	82294646	24.86
7/16	816	0.476	0.927	0.051	0.080	50	82294653	19.86
7/16	817	0.507	1.272	0.064	0.104	25	82294661	22.52
½	818	0.538	1.084	0.074	0.121	25	82294679	20.27
½	819	0.569	1.397	0.086	0.132	20	82294687	24.86
⅝	820	0.678	1.334	0.074	0.121	20	82294695	20.57
⅝	821	0.710	1.772	0.108	0.160	10	82294703	24.94
¾	822	0.834	1.491	0.108	0.160	10	82294711	19.39
¾	823	0.834	2.022	0.122	0.177	5	82294729	16.74
⅞	824	0.960	1.772	0.108	0.160	5	82294737	16.08
⅞	825	0.960	2.272	0.136	0.192	1	82294745	5.70
1	826	1.084	2.022	0.108	0.160	1	82294752	4.15
1	827	1.084	2.522	0.136	0.192	1	82294760	5.36
AN960 Aeronautics Specifications								
2L	C2L	0.101	0.262	0.014	0.018	500	05401427	14.72
2	C2	0.101	0.262	0.028	0.036	500	05401435	15.89
3L	C3L	0.107	0.262	0.014	0.018	500	05388970	18.03
3	C3	0.107	0.262	0.028	0.036	500	05401443	16.86
4L	C4L	0.127	0.330	0.014	0.018	500	05401450	17.53
4	C4	0.127	0.330	0.028	0.036	500	05401468	21.69
6L	C6L	0.151	0.387	0.014	0.018	500	05401476	20.40
6	C6	0.151	0.387	0.028	0.036	500	05401484	22.50
8L	C8L	0.176	0.387	0.014	0.018	500	05401492	20.41
8	C8	0.176	0.387	0.028	0.036	500	05401500	22.33
10L	C10L	0.205	0.450	0.028	0.036	500	05401518	29.69
10	C10	0.205	0.450	0.057	0.069	250	05401526	26.28
¼L	C416L	0.267	0.512	0.028	0.036	250	05401534	18.11
¼	C416	0.267	0.512	0.057	0.069	100	05401542	12.70
5/16L	C516L	0.330	0.574	0.028	0.036	100	05401559	9.43
5/16	C516	0.330	0.574	0.057	0.069	100	05401567	16.53
⅜L	C616L	0.392	0.637	0.028	0.036	100	05388988	11.52
⅜	C616	0.402	0.637	0.057	0.069	100	05388996	18.43
7/16L	C716L	0.455	0.762	0.028	0.036	100	05389002	14.35
7/16	C716	0.455	0.762	0.057	0.069	100	05389010	28.38
½L	C816L	0.525	0.895	0.028	0.036	100	05389028	15.94
½	C816	0.525	0.895	0.057	0.069	100	05401369	30.99
9/16	C916	0.580	1.074	0.028	0.036	50	05401377	23.00
⅝	C1016	0.642	1.200	0.057	0.069	50	05401385	26.94
¾	C1216	0.767	1.324	0.082	0.098	25	05401393	24.83
⅞	C1416	0.892	1.512	0.082	0.098	10	05401401	18.72
1	C1616	1.017	1.762	0.082	0.098	10	05401419	22.82
NAS620 National Aeronautics Standards								
0	C0	0.065	0.106	0.014	0.018	250	05388814	16.49
2	C2	0.091	0.156	0.014	0.018	500	05388822	16.12
3L	C3L	0.104	0.187	0.014	0.018	500	05388830	18.07
3	C3	0.104	0.187	0.029	0.035	500	05388848	19.33
4L	C4L	0.117	0.216	0.014	0.018	500	05388855	19.33
4	C4	0.117	0.216	0.029	0.035	500	05388863	20.03
5L	C5L	0.130	0.245	0.014	0.018	500	05388871	20.70
5	C5	0.130	0.245	0.029	0.035	500	05388889	20.70
6L	C6L	0.145	0.282	0.014	0.018	500	05388897	21.79
6	C6	0.145	0.282	0.029	0.035	500	05388905	23.34
8L	C8L	0.171	0.311	0.014	0.018	500	05388913	23.00
8	C8	0.171	0.311	0.029	0.035	250	05388921	13.21
10L	C10L	0.197	0.361	0.029	0.035	250	05388939	14.36
10	C10	0.197	0.361	0.0585	0.0655	100	05388947	12.12
¼L	C416L	0.257	0.475	0.029	0.035	100	05388954	9.53
¼	C416	0.257	0.475	0.0585	0.0655	100	05388962	12.17

F436 Structural Washers

- Made to ASTM F436 specifications • For structural applications
- Designed for use with A325 and A490 high strength structural bolt

Screw Size	OD (In.)	ID (In.)	Thick. (In.) Min.	Thick. (In.) Max.	Pkg. Qty.	Plain Steel Order #	Plain Steel Price/100	Galvaniz… Order #
¼	⅝	9/32	.051	.080	100	07812142	$5.15	√7028415
5/16	11/16	11/32	.051	.080	100	07812217	5.87	√7028416
⅜	13/16	13/32	.051	.080	100	07812183	7.38	√7028417
½	1 1/16	17/32	.097	.177	50	07812134	14.29	√7028418
⅝	1 5/16	11/16	.122	.177	25	07812209	22.28	√7028419
¾	1 15/32	13/16	.122	.177	20	07812191	29.10	√7028420
⅞	1¾	15/16	.136	.177	15	07812225	48.26	√7028421
1	2	1⅛	.136	.177	10	07812126	53.09	√7028422
1⅛	2¼	1¼	.136	.177	10	07812159	91.45	√7028423
1¼	2½	1⅜	.136	.177	5	07812175	94.19	√7028424
1½	3	1⅝	.136	.177	5	07812167	182.04	√7028425

Flat Washers - Extra Thick

Bolt Size (In.)	Pkg. Qty.	Order #	Price/100
¼	100	67492447	$19.25
5/16	100	67492488	25.45
⅜	100	67492520	33.29
7/16	100	67492561	35.12
½	100	67492603	61.36

Bolt Size (In.)	Pkg. Qty.	Order #	Price/…
9/16	50	67492645	$98…
⅝	50	67492686	111…
¾	50	67492728	239…
⅞	25	67492769	408…
1	25	67492801	582…

Metric Flat Washers - Corrosion Resistant

- High visibility blue color allows the user to easily distinguish the…
- Metric Blue coating is 40x more corrosion resistant than standa…

Bolt Size	ID (mm)	OD (mm)	Thick. (mm)	Pkg. Qty.	Order #	Price/100
M6	7.4	12.0	3.00	100	79207718	$28.7…
M8	9.6	17.0	3.50	100	79207726	29.6…
M10	12.0	21.5	4.50	100	79207734	36.8…
M12	15.0	27.0	4.60	100	79808028	53.7…
M16	18.4	34.0	4.60	50	79808036	99.2…
M20	22.5	42.5	4.60	50	79808044	103.…
M24	26.5	50.0	4.60	25	79808051	129.…
M30	33.6	60.0	4.60	20	79808069	196.…

Metric Flat Washers

Bolt Size	ID (mm)	OD (mm)	Nom. Thick. (mm)	Pkg. Qty.	Zinc Plated Steel Order #	Zinc Plated Steel Price/100	18-8 Stainless Order #
M2	2.2	5.0	0.3	100	09063496	$1.52	68024926
M2.5	2.7	6.0	0.5	100	09170358	1.56	68024967
M3	3.2	7.0	0.5	100	67492843	0.91	68025006
M3.5	3.7	8.0	0.5	100	09170882	1.63	0355081…
M4	4.3	9.0	0.8	100	67492884	1.16	68025048
M5	5.3	10.0	1.0	100	67492926	1.35	68025089
M6	6.4	12.5	1.6	100	67492967	1.58	6802512…
M7	7.4	14.0	1.6	100	67493007	2.58	0917034…
M8	8.4	16.0	1.6	100			
M8	8.4	17.0	1.6	100	67493049	2.74	6802516…
M10	10.5	20.0	2.0	100			
M10	10.5	21.0	2.0	100	67493080	4.36	6802520…
M12	13.0	24.0	2.5	100	67493122	8.22	6802524…
M14	15.0	28.0	2.5	100	67493163	10.45	6802528…
M16	17.0	30.0	3.0	100	67493205	12.78	6802532…
M18	19.0	34.0	3.0	100	67493247	20.91	6802536…
M20	21.0	37.0	3.0	50	67493288	20.91	6802540…
M22	23.0	39.00	3.0	50	09170366	23.23	0355092…
M24	25.0	44.0	4.0	25	67493320	25.55	68025444
M27	28.0	50.00	4.0	25	09170374	59.26	03550944
M30	31.0	56.0	4.0	25	67493361	72.04	[5]03550951
M33	34.0	60.00	5.0	10	—		03550969
M36	37.0	66.00	5.0	5	09170390	117.35	[5]03550977
M39	40.0	72.00	6.0	10			03550985
M45	46.0	85.0	7.0	5			
M48	50.0	92.0	8.0	5			

[1]Pkg. Qty.: 200 [2]Pkg. Qty.: 50 [3]OD: 12.00mm [4]Pkg. Qty.: 100 [5]Pkg…

Machine Screws - Zinc Plated Steel

100/Pkg. Except where noted ALL FASTENERS OFFERED IN FULL BOX QUANTITIES ONLY - NOT SOLD IN BROKEN PACKAGES

L Under Head (In.)	¹Flat Head Slotted		¹Flat Head Phillips		Round Head Slotted		Round Head Phillips		Pan Head Slotted		Pan Head Phillips		Fillister Head Slotted		Truss Head Slotted	
	Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100	Order #	Price/100
#2-56 UNC																
1/8	40915423	$19.05	40914632	$8.90	40918443	$4.80			40920043	$4.73	40920811	$4.24	67419200	$18.13		
3/16	09173220	5.00	40914640	12.63	40918450	4.18	40918542	$6.89			67413286	6.21	67419242	10.11		
1/4	09173238	6.25	40914657	6.20	87909503	3.69	07112980	8.83	67409680	5.09	67413328	3.60	67419283	10.01		
5/16	40915431	5.52	40914665	5.35	40918468	4.26	07112998	8.87	67409722	5.91	67413369	5.91	67419325	10.01		
3/8	40915449	5.68	40914673	5.35	87909529	3.51	07113004	5.74	67409763	4.70	67413401	3.81	67419366	10.01		
7/16			40914681	5.44	40918476	4.69			67409805	7.04	67413443	15.17	67419408	10.11		
1/2	40915456	6.02	40914699	5.52	87909545	3.89	07113012	6.23	67409847	3.71	67413484	5.97	67419440	10.01		
5/8	40915464	7.48	40914707	5.82	40918484	5.20	40918559	7.74	67409888	3.98	67413526	4.59	67419481	9.55		
3/4	40915472	8.24	40914715	5.96	87909560	3.81	07113020	6.29	67409920	4.49	67413567	8.49	67419523	10.11		
3-48 UNC																
3/16	67391961	3.88	40914723	8.05	40918492	5.11			40920050	4.65	40920829	5.96	40923625	6.10		
1/4	67392001	7.81	40914731	7.53	87909586	5.99	07113038	8.88	40920068	4.83	40920837	6.10	40923633	6.26		
5/16	67392043	5.99	40914749	7.75	87909594	5.28	40918567	8.98	40920076	5.01	40920845	6.32	40923641	6.43		
3/8	67392084	4.67	40914756	7.86	87909602	5.44			67409961	8.44	40920852	7.46	40923658	6.00		
7/16	67392126	4.66	40914764	8.09	87909610	6.13			40920084	5.75	40920860	5.49				
1/2	67392167	4.05	40914772	8.22	87909628	4.68	07113046	4.49	67410001	5.63	40920878	8.05	40923666	6.26		
5/8	67392209	6.01			87909636	5.14	07113053	11.62			40920886	8.26				
3/4	67392241	6.17	40914780	7.98	87909644	6.22	07113061	7.93			40920894	9.69				
7/8	67392282	8.19			87909651	9.25					40920902	6.68				
1	67392324	6.23			87909669	6.37			40920092	6.50	40920910	7.10				
40 UNC																
	67392365	9.60			87909677	3.91	40918575	6.66	67410043	2.41	40920928	9.22	41188020	6.99		
	67392407	6.31	²65165607	6.85	87909685	3.46	07113079	9.48	67410084	2.39	67413609	2.32	67419564	7.95		
	67392449	2.78	67399162	3.35	87909701	1.29	40918583	3.40	67410126	1.55	67413641	1.59	67419606	5.54	08704702	$6.07
	67392480	4.67	67399204	3.21	87909693	2.90	87913919	4.20	67410167	1.82	87913307	1.65	09173188	6.99		
	87911707	2.52	67399246	3.14	87909727	1.69	87913927	3.75	67410209	1.55	87913315	1.68	67419689	5.69	40923369	6.34
	67392522	8.16	40914798	6.37	87909719	3.66	87913935	6.52	40920100	4.48	09173865	5.70	40923674	9.99		
	87911715	2.90	67399287	3.35	87909743	1.89	87913943	3.90	67410241	1.55	87913331	1.87	67419721	3.80	40923377	6.96
	87911723	3.74	67399329	7.50	87909750	1.82	07113087	4.35	67410282	1.72	87913349	1.98	67419762	5.54		
	87911731	4.21	67399360	3.57	87909768	2.17	87913968	4.80	67410324	1.82	87913356	2.27	67419804	7.34		
	67392563	8.53	67399402	8.23	87909735	2.93	07113095	5.68	67410365	2.16	87913364	3.34	67419846	12.34		
	87911749	5.67	67399444	10.01	87909784	2.34	07113103	6.06	67410407	2.16	87913372	2.64	67419887	4.33		
	67392605	7.00	40914806	7.89	87909792	5.22	07113111	13.71	67410449	5.10	09173873	7.62	40923682	14.22		
	67392647	6.17	07112451	8.71	87909800	4.24	40918591	12.01	40920118	15.38	09173881	11.49	32852287	18.16		
UNC																
	67392688	28.97									60359783	5.91	40923690	9.23		
	67392720	11.92			87909776	4.27	03958535	5.21	40920126	5.25	40920936	5.64	40923708	9.03		
	67392761	5.25	40914814	7.15	67401927	4.17	40918617	6.49	67410480	2.43	40920944	7.71	67419929	20.05		
	67392803	5.14	40914822	7.23	67401968	7.38	04412466	7.19	67410522	6.80	40920951	6.94	67419960	11.81		
	67392845	4.46	09173329	6.12	67402008	5.84			67410563	7.09	40920969	7.44	67420000	12.52		
					67402040	9.08					40920977	5.73	67420042	11.07		
	67392928	6.41			67402081	4.56	03958584	5.58	67410605	6.80	40920985	10.95	67420083	16.67		
	67392969	4.75			67402123	5.03	03958642	4.63	40920134	6.12	40920993	8.10	67420125	12.48		
	67393009	6.22			67402164	5.03	07113129	4.63	40920159	6.60	40921009	9.49	67420166	12.48		
	67393041	6.54			67402206	14.44					40921017	6.37				
	67393082	7.96	40914830	9.41	67402248	4.39	07113137	10.20	40920167	8.35	40921025	7.38	40923716	14.49		
	67393124	8.23			67402289	6.13			40920175	11.58	40921033	10.25				
	67393165	10.29			67402321	7.99	40918625	12.06	40920183	12.06	40921041	10.85				
	09178246	12.49			67402362	7.95					40921058	14.21				
NC																
					87909925	4.66			40920191	9.66	40921066	5.84	40923724	14.45		
	67393207	2.80	²65165615	9.82	87909933	1.75	40918633	6.40	67410647	2.16	09173899	1.88	67420208	34.49		
	67393249	2.22	67399485	3.46	87909941	1.77	87913984	2.60	67410688	1.55	87913398	2.12	67420240	5.16	67416602	2.35
	67393280	2.22	67399527	3.21	87909958	1.77	87913992	3.06	67410720	2.13	87913406	2.27	67420281	3.56	67416644	2.77
	67393322	1.94	67399568	3.14	87909966	1.70	87914008	2.07	67410761	1.87	87913414	2.65	67420323	2.68	67416685	1.48
	67393363	3.70	67399600	7.22	87909974	1.82	87914016	7.96	67410803	2.64	87913422	2.83	67420364	7.19	67416727	5.22
	7911806	2.03	67399642	3.21	87909982	1.89	87914024	2.41	67410845	2.28	87913430	2.46	67420406	4.78	67416768	2.78
	7911814	2.54	67399683	3.43	87909990	2.00	87914032	2.76	67410886	2.09	87913448	2.60	67420448	5.78	67416800	6.16
	7911822	2.15	67399725	3.46	87910006	1.99	87914040	3.19	67410928	2.16	87913455	2.63	67420489	5.63	67416842	3.93
	7911830	3.94	67399766	10.11	87910014	2.67	87914057	5.08	67410969	3.40	67413682	3.74	67420521	12.48	67416883	10.48
	7911848	2.56	67399808	4.35	87910022	2.34	87914065	3.90	67411009	2.50	87913463	3.34	67420562	6.06	67416925	3.70
	7911855	3.10	67399840	4.86	87910030	2.82	87914073	5.49	67411041	2.63	67413724	4.65	67420604	11.86	40923385	9.89
	7911863	3.21	67399881	5.94	87910048	3.35	87914081	6.52	67411082	3.23	67413765	4.76	67420646	10.17	09173444	8.75
	911871	6.55	40914848	13.71	87910055	3.53	87914099	14.24	67411124	6.19	40921074	10.36	09173196	24.48		
	911889	3.86	84809078	4.24	87910063	4.75	40918641	13.53	67411165	4.99	08047862	6.25	67420687	16.39	09173451	9.74
	393405	5.99	40914855	18.12	67402404	5.10			40920209	18.29	40921082	30.02				
	393447	6.31	78624434	10.11	67402446	5.61	40918658	27.96	40920217	19.29	08047904	24.24				
	393488	6.43			67402487	5.22					40921090	31.75				
	393520	8.98	78624616	19.98	67402529	6.94	40918666	30.22	40920225	30.22	09173907	27.47			40923393	9.44
					67402560	11.52			40920233	42.17	40921108	51.32				
	173253	14.99	40914863	61.86	67402602	12.80	40918674	52.08	40920241	43.99	40921116	61.86				
					67402644	12.08										
	93561	17.63	40914871	63.93	67402685	10.79	40918682	54.40	40920258	45.14	40921124	63.93			09173477	12.24
	93603	7.65			67402727	2.44	40918690	6.40	67411207	3.11	40921140	4.42	40923732	13.98	09173485	4.24
	93645	2.40	67399923	3.67	67402768	2.00	87914107	2.80	67411249	2.09	67413807	2.94	67420729	6.42	67416966	2.77

¹Overall length ²Head is undercut ³50/Box ⁴10/Box ⁵25/Box

CALL MSC TODAY 800-645-7270 FOR ALL YOUR INDUSTRIAL NEEDS

- Zinc Plated Steel

IMPORT

Flat Head Phillips Order #	Price/100	Round Head Slotted Order #	Price/100	Round Head Phillips Order #	Price/100	Pan Head Slotted Order #	Price/100	Pan Head Phillips Order #	Price/100	Fillister Head Slotted Order #	Price/100	Truss Head Slotted Order #	Price/100	Binding Head Slotted Order #	Price/100
0914889	$4.36	67402800	$2.56	87914115	$7.69	67411280	$3.71	67413849	$3.08	67420760	$5.05	67417006	$4.74	67415968	$3.62
7399964	3.45	67402842	2.11	87914123	2.96	67411322	2.28	67413880	2.75	67420802	4.76	67417048	2.79	67416008	3.81
7400002	5.88	67402883	2.87	40918708	4.03	67411363	3.40	67413922	4.25	67420844	8.99	67417089	4.16	40923294	6.24
00044	3.52	87910188	2.15	87914149	3.02	67411405	2.46	87913505	2.82	67420885	4.08	67417121	3.19	67416040	3.81
00085	3.80	87910196	2.84	87914156	3.29	67411447	3.08	87913547	3.62	67420927	6.28	67417162	4.33	67416081	4.59
00127	3.93	87910204	2.56	87914164	3.65	67411488	3.31	87913554	3.32	67420968	4.32	67417204	4.19	67416123	4.64
00168	4.30	87910212	3.42	87914172	5.23	67411520	3.95	67413963	4.26	67421008	25.35	67417246	8.34	67416164	13.07
00200	4.34	87910220	2.84	87914180	3.86	67411561	3.70	87913562	3.94	67421040	6.83	67417287	4.42	67416206	5.38
00242	4.98	87910238	3.05	87914198	5.06	67411603	4.74	67414003	6.02	67421081	8.27	67417329	7.15	40923302	13.38
7400283	6.26	87910246	3.18	87914206	6.04	67411645	4.84	87913570	6.22	67421123	8.99	67417360	6.20	40923310	16.55
78337	15.24	87910253	5.67	67407569	8.62	67411686	6.86	74084740	4.49	67421164	23.78	09173493	5.25		
24798	6.37	87910261	3.73	87914214	9.63	67411728	7.47	08991101	6.99	67421206	19.10	53464327	5.87	40923328	19.59
14897	21.39	87910279	7.90	40918716	24.56	40920266	23.02	40921165	32.34						
781	9.49	87910287	8.17	40918724	27.79	09173725	7.49	09173915	9.49	40923740	33.94	09173501	7.99		
14905	26.84	87910295	9.43	40918732	30.74	40920274	31.65	40921173	37.48						
24756	10.48	87910303	8.78	40918740	34.16	40920282	26.85	40921181	18.03	40923757	20.25				
14913	45.25	67402925	12.42	40918757	61.00	40920290	53.94	40921199	66.96	40923765	59.02				
14921	69.13	67402966	14.20	40918765	63.48	40920308	85.75	40921207	69.13						
		67403006	87.74					40921215	85.75						
		67403048	82.84					40921223	86.81						
		09173584	5.00			09173733	7.49	40921281	7.63						
		67403089	2.84	07113145	4.07	67411769	3.38	67414045	4.05	09173204	8.75	40923401	8.18	40923336	4.60
		67403124	2.54	04312401	5.58	67411801	3.56			40923773	10.35				
7400325	4.35	40918500	2.54	87914255	4.16	67411843	3.08	67414086	4.08	67421248	5.62	67417402	3.70	40923344	5.00
7400366	10.27	67403162	2.77	87914263	12.99	67411884	7.17	67414128	4.62	40923781	9.14	67417444	12.76		
7400408	4.37	87910386	2.50	87914271	3.82	67411926	3.07	87913604	3.86	67421289	5.01	67417485	3.95	67416248	4.89
7400440	3.94	87910394	2.84	87914289	4.23	67411967	3.70	87913646	4.09	67421321	5.00	67417527	4.42		
7400481	4.56	87910402	2.80	87914305	4.31	67412007	4.09	87913653	4.47	67421362	7.09	67417568	4.96	67416289	6.04
173352	10.24	87910410	4.57	87914313	12.36	67412049	5.30	67414169	7.54	67421404	23.94	67417600	8.49		
7400523	5.28	87910428	3.15	87914321	5.06	67412080	4.59	87913661	5.82	67421446	8.16	67417642	6.37		
7400564	5.91	87910436	3.79	87914339	6.92	67412122	5.00	08047953	4.61	67421487	8.22	67417683	7.40		
7400606	6.93	87910444	4.10	87914347	7.02	67412163	6.19	87913679	7.60	67421529	12.52	67417725	8.71		
09173360	10.24	87910451	6.30	07113152	9.71	67412205	15.18	87913687	9.68	67421560	20.76	67417766	16.91		
0588876	10.24	87910469	6.64	87914362	10.47	67412247	9.15	87913695	9.20	67421602	16.44	67417808	15.74		
40914939	32.52	87910477	7.94	40918773	24.71	40920316	27.90	40921249	30.63	67421644	26.84	09173519	11.11		
5298438	10.48	87910485	8.55	40918781	26.67	40920324	26.90	08047987	7.24	67421685	37.89	09173527	11.24		
40914947	31.27	40918518	7.06	40918799	41.92	40920332	39.90	40921256	41.92						
024830	10.99	87910493	9.85	40918807	43.97	40920340	13.30	08047995	8.75	67421768	67.96	09173535	11.49		
		67403246	18.42					40921264	57.63						
09173378	42.58	87910501	13.71	40918815	38.12	40920357	57.87	40921272	66.40			82066531	18.74		
40914954	16.28	87910519	13.43	40918823	44.29	40920365	75.73								
40914962	70.44	87910527	17.94	40918831	49.94	40920373	75.23	40921280	70.44						
40914970	76.17	87910535	20.83	40918849	50.60			40921298	76.17						
40914988	69.45	87910543	40.07												
40914996	77.24	87910550	22.52	40918856	76.85	40920381	95.49	40921306	77.48						
09173345	8.50	87910568	3.10	07113160	5.13	67412288	3.36	67414243	4.00	67421800	7.17	40923419	10.55	67416321	5.39
67400648	9.55	87910576	3.35	07113178	9.21	67412320	4.42	67414284	4.26	67421842	23.40	40928427	9.04		
67400689	4.77	87910584	2.37	87914396	3.56	67412361	3.23	67414326	3.79	67421883	6.04	67417840	3.04	67416362	4.59
67400721	8.84	87910592	3.28	87914404	12.99	67412403	6.23			67421925	19.49			67416404	6.13
67400762	4.20	87910618	2.56	87914412	3.75	67412445	3.38	87913737	4.23	67421966	7.04	67417881	3.72	67416446	4.89
67400804	4.31	87910626	2.84	87914420	3.99	67412486	3.98	87913745	4.96	67422006	6.52	67417923	5.50	67416487	5.52
67400846	4.36	87910634	2.90	87914438	4.37	67412528	3.70	87913752	5.66	67422048	7.71	67417964	4.84	67416529	5.93
67400887	8.51	87910642	4.45	87914446	8.21	67412569	5.03	67414409	6.98	67422089	8.70	40923435	13.02		
67400929	5.38	87910659	3.39	87914453	4.59	67412601	4.51	87913760	5.78	67422121	9.00	67418004	6.94	67416560	6.59
67400960	5.48	87910667	4.08	87914461	6.90	67412643	6.23	67414441	7.69	67422162	11.41	67418046	7.38		
67401000	7.24	87910675	4.53	87914479	7.75	67412684	7.33	87913778	8.59	67422204	13.69	67418087	9.32		
67401042	14.34	87910683	6.30	67407601	11.12	67412726	21.95	87913786	11.38	67422246	13.62				
67401083	10.71	87910691	5.45	87914487	11.48	67412767	8.67	87913794	11.14	67422287	15.75	67418129	11.19		
40915001	33.07	87910709	8.53	40918864	30.70	40920399	31.40	40921314	33.22	40923799	36.63				
40915019	15.53	87910717	8.90	40918872	33.93	40920407	73.11	40921322	13.07	40923807	38.47	40923443	16.51		
40915027	44.52	40918584	10.99			40920415	44.90	40921330	45.00	40923815	27.47				
40915035	16.96	87910725	9.83	40918880	35.15	40920423	10.24	08048068	8.99	40923823	37.63	40923450	31.19		
40915043	72.40	87910733	14.29	40918898	62.53	40920431	72.40	40921348	62.53						
40915050	78.75	87910741	20.00	40918906	69.56	40920449	78.75	40921355	69.70						
		67403287	20.74	40918914	77.85			40921363	66.56						
		67403329	23.41					40921371	81.41						
		67403360	32.05												
		67403402	5.25	40918922	11.39	40920456	11.39	40921389	11.39	40923883	21.29				
		67403444	5.76												
67401125	10.85	67403485	4.83	67407643	7.52	40920464	12.34	40921397	16.52	40923849	11.30				
		67403527	16.55												
67401166	9.67	87910774	4.86	67407684	15.76	09173741	14.36	74084708	9.12	67422329	10.58	40923468	13.85		
67401208	16.86	87910782	6.98	67407726	10.87	09173758	14.74	09173981	11.74	67422360	16.86				
67401240	17.68	87910790	5.75	67407767	7.91	40920472	14.53	88131388	10.61	67422402	12.50	40923476	16.03		

Head is undercut [3] 50/Box [4] 10/Box [5] 25/Box

Continued on next page

Machine Screws - Zinc Plated Steel

L Under Head (In.)	[1]Flat Head Slotted Order #	Price/ 100	[1]Flat Head Phillips Order #	Price/ 100	Round Head Slotted Order #	Price/ 100	Round Head Phillips Order #	Price/ 100	Pan Head Slotted Order #	Price/ 100	Pan Head Phillips Order #	Price/ 100	Fillister Head Slotted Order #	Price/ 100	Truss Head Slotted Order #	Price/ 100	Binding Head Order #
#12-24 UNC (Cont'd)																	
⅞	87912556	$15.48	67401281	$16.79	87910808	$14.58					09173956	$12.99	67422444	$42.99			
1	87912564	8.24	67401323	16.02	87910816	6.53	67407809	$21.21	40920480	$16.04	74084732	11.37	67422485	16.53			
1¼	87912572	10.70	67401364	12.91	87910824	8.74	67407841	8.79	40920498	22.65	09173964	15.86	67422527	19.05			
1½	87912580	11.54	67401406	22.43	87910832	8.01	67407882	21.95	40920506	24.68	01837103	16.36	67422568	34.38			
1¾			40915068	27.69	67403568	18.55	40918930	31.49			40921405	25.92	67422600	24.43			
2	87912606	12.52	40915076	33.35	87910840	9.52	40918948	33.35	40920514	30.74	40921413	35.73	67422642	44.34			
2¼			40915084	38.18	87910857	33.39											
2½	87912622	14.43	40915092	40.65	87910865	14.99	40918955	40.08			40921421	41.23					
3	87912648	26.46	40915100	51.03	87910873	16.34	40918963	51.03			40921439	51.03					
¼-20 UNC																	
¼					87910907	6.52	07113186	14.71	40920522	18.19	40921447	20.17			40923484	$23.60	
5/16	87912655	22.11			87910915	8.56	40918971	21.04	40920530	15.39	40921454	11.47	40923856	17.01	40923492	24.95	
⅜	87912663	5.44	67401448	5.75	87910923	3.64	87914503	5.03	67412809	5.50	09173980	4.61	40923872	20.24	67418160	6.90	
7/16	87912671	18.39			87910931	9.20					40921462	16.12	40923880	23.60			
½	87912689	5.30	67401489	6.35	87910956	3.68	87914511	5.01	67412841	5.87	87913836	6.73	67422683	9.49	67418202	6.01	
⅝	87912697	5.97	67401521	7.45	87910964	5.57	87914529	5.14	67412882	6.58	87913844	8.28	67422725	8.61	67418244	8.51	
¾	87912705	5.12	67401562	7.85	87910972	4.22	87914537	7.59	67412924	6.65	87913851	7.45	67422766	8.57	67418285	8.23	
⅞	87912713	7.41	67401604	11.07	87910980	7.86	67407924	9.93	67412965	12.88	67414482	9.80	67422808	28.34	67418327	16.25	
1	87912721	5.80	67401646	8.49	87910998	4.75	87914545	8.16	67413005	7.79	87913869	10.27	67422840	9.13	67418368	9.41	
1¼	87912739	5.80	67401687	8.99	87911004	4.74	87914552	9.84	67413047	8.95	67414524	12.47	67422881	11.92	67418400	12.02	
1½	87912747	7.20	67401729	10.46	87911012	5.80	87914560	10.48	67413088	10.26	87913877	12.85	67422923	16.21	67418442	14.46	
1¾	87912754	10.52	67401760	13.07	87911020	7.11	67407965	11.49	67413120	14.85	87913885	16.12	67422964	50.95	67418483	12.13	
2	87912762	9.68	67401802	12.30	87911038	7.46	87914578	12.21	67413161	13.37	67414565	16.90	67423004	27.71	67418525	16.67	
2¼	87912770	13.13	67401844	19.98	87911046	8.33	07113194	12.66	40920548	45.52	09173998	10.48	[3]67423046	55.69	09173550	8.50	
2½	87912788	8.87	[3]07112469	17.18	87911053	8.91	87914586	15.46	40920555	20.75	67414607	22.90	[3]67423087	33.21	67418566	23.82	
2¾	87912804	17.33	40915118	48.73	87911061	12.18	40918989	30.47	40920563	50.49	40921470	50.50	[3]67428129	65.52			
3	87912812	14.31	67401885	19.24	87911079	10.49	88324223	15.43	40920571	25.70	08991135	12.73	[3]67423160	59.73	67418608	22.60	
3½	40915506	18.62	[3]07112477	26.00	87911087	17.71	40918997	49.41	40920589	60.21	40921488	69.47	40923898	63.66	09173568	13.98	
4	87912853	22.90	[3]07112485	27.14	87911095	18.92	09173428	16.73	40920597	69.61	09174004	14.24	40923906	96.23	09173576	14.24	
4½	87912861	31.39			[3]87911103	22.97	40919003	65.24			40921496	77.60					
5	87912879	34.69	40915126	71.36	[3]87911111	23.54	40919011	60.03			40921504	77.85	40923864	20.62	40928500	48.56	
5½	67394361	37.12			[3]67403600	34.28	40919029	62.85									
6	87912887	36.53	40915134	74.87	67403642	32.99	09173436	64.06			40921512	85.75			40923518	85.75	
¼-28 UNF																	
½	67394445	36.07	[3]07112493	10.05	67403683	8.09	40919037	22.81	40920605	15.53							
⅝	67394486	31.51	40915142	27.69	67403725	19.17	40919045	26.85	40920613	18.50	40921520	25.10	40923914	26.65			
¾	67394528	39.69	[3]07112501	12.34	67403766	8.26			40920621	17.29	40921538	26.86	40923922	27.69			
1	67394569	54.54	40915159	36.44	67403808	10.15			40920639	36.42	40921546	28.59	40923930	28.59			
1¼	67394601	86.82	40915167	38.45	67403840	33.67					40921553	36.44	40923948	32.80			
1½	67394643	78.47	40915175	41.68	67403881	14.49					40921561	38.52					
1¾	67394684	92.19									40921579	35.31					
2					[3]67403923	39.70					40921587	41.76					
5/16-18 UNC																	
⅜																	
7/16	67394726	20.89			67403964	15.95			40920647	29.15	40921595	27.73					
½	87912903	11.26	[2]65165623	14.79	67404046	10.76					40921603	23.60	40923955	42.62	67418640	14.32	
⅝	87912911	15.80	09173386	33.47	67404087	11.25	40919052	26.62	40920654	15.88	67414649	21.85	40923963	48.14	67418681	13.91	
¾	87912929	13.93	[3]07112519	9.69	08807331	9.24	40919060	28.43	40920662	43.65	67414680	16.81	67423202	31.76	67418723	16.84	
⅞	67394767	17.97	40915183	27.45	87911178	10.62	[3]07113202	19.04	67413203	7.83	09174012	9.74	40923971	53.23	40923526	38.87	
1	87912937	15.37	[3]07112527	8.54	87911186	12.23	87914594	20.72	67413245	15.63	67414722	24.38	67423244	40.45	67418764	18.54	
1¼	87912952	17.86	[3]07112535	8.66	87911194	14.29	40919078	35.82	40920670	24.58	40921611	31.74	09173212	16.98	67418806	18.86	
1½	87912960	21.14	[3]07112543	14.38	87911202	15.87	[3]87914602	30.39	40920688	40.35	05245360	12.99	40923989	75.80	67418848	22.62	
1¾	67394809	22.51	40915191	49.65	87911210	18.15	40919086	46.48	40920696	45.14	40921629	40.59	40923997	50.64	[3]67418889	43.72	
2	87912978	24.09	[4]07112550	46.77	87911228	18.94	[3]87914610	55.71	40920704	55.82	67414763	47.73	40924003	94.35	[3]67418921	27.76	
2¼	87912986	25.39	40915209	56.86	87911236	20.00			40920712	58.83	40921637	44.34					
2½	87912994	27.02	[4]07112568	50.83	87911244	23.11	40919094	59.18	40920720	61.25							
2¾	87913000	26.41			67404129	28.83											
3	87913018	32.41			87911251	27.13	40919102	64.52	40920738	64.52	40921645	56.19					
3½	87913026	35.90	[4]07112576	55.80	[3]87911269	30.46					40921652	46.87			[3]67418962	37.14	
3¾					[3]67404160	36.27					[3]67414805	86.15	[3]40924011	111.95	[3]67419002	43.72	
4	[3]87913034	43.83	40915217	72.89	[3]87911277	31.48	40919110	69.36			40921660	66.54			40923534	63.71	
4½	[3]87913042	46.41			[3]87911285	45.11					40921678	85.31					
5	[3]87913059	50.42															
5½	67394882	70.05			[3]67404202	84.08											
6	[3]87913067	69.32	40915225	133.83	[3]67404244	51.01	40919128	113.43									
⅜-16 UNC																	
½	[3]87913083	18.10			67404285	15.44											
⅝	40915514	37.80	40915233	58.32	67404327	18.67			40920746	50.34	40921686	51.03					
¾	[3]87913109	18.44	40915241	68.28	67404368	20.19					40921694	58.32			[3]40928542	36.44	
⅞	[3]87913117	28.92	40915258	75.21	67404400	25.44	40919136	63.84	40920753	59.77	40921702	63.85	40924029	86.82	[3]67419044	24.70	
1	[3]87913125	19.17	[5]07112584	34.60	87911350	18.95	40919144	60.02	40920761	60.01	09174020	51.21	40924087	94.15	[3]67419085	38.90	
1¼	[3]87913133	23.14	09173394	14.24	87911368	19.33	40919151	70.21	40920779	77.69	82914912	81.41	40924045	103.30	40923559	39.83	
1½	[3]87913141	28.03	[4]07112592	41.68	87911376	21.64	40919169	70.60			09174038	82.42			40923567	43.57	
1¾	[3]87913158	26.45	40915266	101.82	87911384	25.88			40920787	85.66	40921710	67.60			40923575	78.97	
2	[3]87913166	32.96	40915274	101.91	87911392	28.48	40919177	88.27	40920795	88.27	67414847	111.31	40924052	144.34	[3]67419127	62.37	
2¼	[3]87913174	38.74	40915282	130.64	[3]87911400	25.65	40919185	113.57			40921728	113.38			40923583	113.56	

[1]Length is overall length [2]Head is undercut [3]50/Box [4]10/Box [5]25/Box

[redacted] page

[redacted]ws - Zinc Plated Steel

IMPORT

[redacted]	Flat Head Phillips Order #	Flat Head Phillips Price/100	Round Head Slotted Order #	Round Head Slotted Price/100	Round Head Phillips Order #	Round Head Phillips Price/100	Pan Head Slotted Order #	Pan Head Slotted Price/100	Pan Head Phillips Order #	Pan Head Phillips Price/100	Fillister Head Slotted Order #	Fillister Head Slotted Price/100	Truss Head Slotted Order #	Truss Head Slotted Price/100	Binding Head Slotted Order #	Binding Head Slotted Price/100
[redacted]	40915290	$120.57	[3]87911418	$28.68	40919193	$136.37			40921736	$120.57			40923591	$136.37		
			[3]87911426	59.37												
	[4]07112600	61.94	[3]87911434	38.56	40919201	135.38	40920803	$131.42	67414888	137.31			40923609	94.78		
	40915308	141.87	[3]87911442	41.09					40921744	118.65						
	40915316	148.96	[3]87911459	43.14					40921751	148.96						
			[3]87911467	52.38												
	40915324	162.80	[3]87911475	53.17												
			[3]87911483	58.39												
	40915332	166.35	[3]87911491	53.73												
			[3]09173592	88.16												
	40915340	109.40	[3]87911509	65.99									40923617	118.25		
	40915357	146.70	[3]87911517	72.51												
	40915365	180.84	[3]87911525	63.97												
			[3]87911533	86.95												
	40915373	192.76	[3]87911541	69.55												
			[3]67404483	138.93												
	40915381	218.08	[3]87911558	100.24												
	40915399	182.05	[3]87911574	114.67												
			[5]87911582	147.95												
	[2]40915407	252.85	[5]87911590	145.18												
			[5]87911616	218.24												
	40915415	331.53	[5]87911632	166.17												

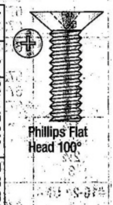
[redacted]th [2]Head is undercut [3] 50/Box [4] 10/Box [5] 25/Box

[redacted]rews - Military Specification 24693/35206

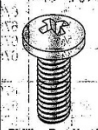
made in USA

[redacted]	Phillips Flat Head 100° Military Equiv.	Phillips Flat Head 100° Order #	Phillips Flat Head 100° Price/100	Phillips Pan Head Military Equiv.	Phillips Pan Head Order #	Phillips Pan Head Price/100
[redacted]	[redacted]24693-S218	72057078	$4.92			
	[redacted]24693-S16	72057037	5.37	MS35206-201	72057516	$5.37
	[redacted]24693-S17	72057045	5.45			
				MS35206-202	72057524	5.54
				MS35206-203	72057532	5.64
				MS35206-204	72057540	5.64
				MS35206-205	72057557	5.79
				MS35206-206	72057565	5.95
				MS35206-207	72057573	5.95
				MS35206-208	72057581	6.23
				MS35206-209	72057599	6.37
				MS35206-210	72057607	6.67
				MS35206-211	72057615	5.95
	MS24693-S1	72057003	6.04	MS35206-212	72057623	6.09
	MS24693-S2	72057052	6.31	MS35206-213	72057631	6.17
	MS24693-S3	72057250	6.45	MS35206-214	72057649	6.45
	MS24693-S4	72057318	6.59	MS35206-215	72057656	6.45
	MS24693-S5	72057359	6.87	MS35206-216	72057664	6.98
	MS24693-S6	72057441	7.00	MS35206-217	72057672	7.10
				MS35206-218	72057680	7.28
				MS35206-219	72057698	7.74
	MS24693-S9	72057474	7.98	MS35206-220	72057706	8.01
				MS35206-221	72057714	8.29
				MS35206-222	72057722	8.98
	MS24693-S14	72057029	9.68	MS35206-223	72057730	9.68
	MS24693-S213	72057060	9.26			
	MS24693-S24	72057086	7.12	MS35206-226	72057748	7.12
	MS24693-S25	72057094	7.40	MS35206-227	72057755	7.40
	MS24693-S26	72057102	7.67	MS35206-228	72057763	6.48
	MS24693-S27	72057110	7.82	MS35206-229	72057771	6.59
	MS24693-S28	72057227	8.10	MS35206-230	72057789	6.79
	MS24693-S29	72057243	8.65	MS35206-231	72057797	7.20
				MS35206-232	72057805	7.62
	MS24693-S31	72057268	9.60	MS35206-233	72057813	7.95
	MS24693-S32	72057276	10.16	MS35206-234	72057821	8.37
				MS35206-235	72057839	9.09
	MS24693-S35	72057284	11.79			
	MS24693-S36	72057292	12.07	MS35206-236	72057847	9.85
	MS24693-S38	72057300	13.18	MS35206-237	72057854	10.68

L (In.)	Pkg. Qty.	Phillips Flat Head 100° Military Equiv.	Phillips Flat Head 100° Order #	Phillips Flat Head 100° Price/100	Phillips Pan Head Military Equiv.	Phillips Pan Head Order #	Phillips Pan Head Price/100
#8-32 UNC							
¼	100				MS35206-241	72057862	$8.37
5/16	100	MS24693-S47	72057326	$8.65	MS35206-242	72057870	8.62
⅜	100	MS24693-S48	72057334	9.01	MS35206-243	72057888	9.01
7/16	100	MS24693-S49	72057342	9.26	MS35206-244	72057896	9.26
½	100	MS24693-S50	72057367	9.62	MS35206-245	72057904	9.62
⅝	100	MS24693-S51	72057375	10.37	MS35206-246	72057912	10.37
¾	100	MS24693-S52	72057383	11.09	MS35206-247	72057920	10.99
⅞	100	MS24693-S53	72057391	11.73	MS35206-248	72057938	11.73
1	100	MS24693-S54	72057409	12.48	MS35206-249	72057946	12.48
1 3/16	100	MS24693-S55	72057417	13.10			
1¼	100	MS24693-S56	72057425	13.85	MS35206-250	72057953	13.85
1½	100	MS24693-S58	72057433	15.10	MS35206-251	72057961	15.10
1¾	100				MS35206-252	72057979	16.44
#10-24 UNC							
5/16	100				MS35206-260	72057987	10.49
⅜	100				MS35206-261	72057995	10.99
7/16	100				MS35206-262	72058001	11.48
½	100				MS35206-263	72058019	11.99
⅝	100				MS35206-264	72058027	12.99
¾	100	MS24693-S74	72057458	13.85	MS35206-265	72058035	13.85
⅞	100				MS35206-266	72058043	14.85
1	100				MS35206-267	72058050	15.82
1⅛	100	MS24693-S77	72057466	16.72			
1¼	100				MS35206-268	72058068	17.69
1½	100				MS35206-269	72058076	21.69
1¾	100				MS35206-270	72058084	21.53
#10-32 UNF							
⅜	100	MS24693-S270	72057128	11.09			
7/16	100	MS24693-S271	72057136	11.48			
½	100	MS24693-S272	72057144	11.52			
⅝	100	MS24693-S273	72057151	11.21			
¾	100	MS24693-S274	72057169	13.85			
⅞	100	MS24693-S275	72057177	14.85			
1	100	MS24693-S276	72057185	15.82			
1⅛	100	MS24693-S277	72057193	16.72			
1¼	100	MS24693-S278	72057201	17.69			
1⅜	100	MS24693-S279	72057219	18.68			
1½	100	MS24693-S280	72057235	20.55			
¼-20 UNC							
7/16	100				MS35206-278	72058092	17.69
½	100				MS35206-279	72058100	18.55
⅝	100	MS24693-S95	72057482	20.17	MS35206-280	72058118	20.17
¾	100				MS35206-281	72058126	32.09
⅞	100				MS35206-282	72058134	23.28
1	100				MS35206-283	72058142	24.78
1¼	100				MS35206-284	72058159	27.97
1½	100				MS35206-285	72058167	31.10
1¾	100				MS35206-286	72058175	34.21



Phillips Flat Head 100°



Phillips Pan Head

- Material: cadmium yellow plated steel

READY TO ORDER? - mscdirect.com

MACHINE SCREWS

Machine Screws - 18-8 Stainless Steel

Length (In.)[1]	Flat Head Slotted Order #	Flat Head Slotted Price/100	Flat Head Phillips Order #	Flat Head Phillips Price/100	Round Head Slotted Order #	Round Head Slotted Price/100	Pan Head Slotted Order #	Pan Head Slotted Price/100	Pan Head Phillips Order #	Pan Head Phillips Price/100	Oval Head Slotted Order #	Oval Head Slotted Price/100
#2-56 UNC												
1/8							67568642	$6.24	67570564	$5.00		
3/16							67568683	5.04	67570606	4.57		
1/4	67563809	$4.76	67566364	$3.49	67568287	$5.09	67568725	5.54	67570648	4.17		
5/16									67570689	4.69		
3/8	67568841	5.70	67566406	3.65	67568329	6.13			67570721	5.15		
1/2			67566448	5.70	67568360	7.16			67570762	5.70		
#4-40 UNC												
1/8							67568766	12.81	67570804	6.75		
3/16							67568808	6.22	67570846	4.82		
1/4	67563882	4.96	67566489	4.47	87924007	4.96	67568840	5.30	67570887	3.64		
5/16									67570929	4.03		
3/8	67563924	6.22	67566521	4.63	87924023	6.22	67568881	5.79	67570960	4.13	67574681	$5.80
1/2	67563965	6.41	67566562	5.23	87924049	6.87	67568923	6.41	67571000	5.19	67574723	6.39
5/8			67566604	6.12	87924056	7.25			67571042	5.15		
3/4			67566646	5.70	87924064	7.85			67571083	5.30		
1					87924080	8.84						
1 1/4					87924106	11.86						
1 1/2					87924114	16.05						
#6-32 UNC												
1/4	67564005	6.52	67566687	5.04	87924155	7.01	67568964	5.93	67571125	5.20		
5/16									67571166	5.54		
3/8	67564047	6.73	67566729	5.33	87924163	6.73	67569004	6.39	67571208	5.68		
1/2	67564088	7.56	67566760	5.99	87924171	7.56	67569046	7.65	67571240	6.46	67574764	7.32
5/8	67564120	9.03	67566802	6.69	87924189	8.80	67569087	8.32	67571281	8.29		
3/4	67564161	9.68	67566844	7.56	87924197	9.68	67569129	8.84	67571323	7.60	67574806	9.87
1	67564203	11.39	67566885	8.32	87924213	10.64	67569160	10.40	67571364	9.15	67574848	10.30
1 1/4					87924221	14.72						
1 1/2					87924239	15.25						
2					87924254	22.10						
#8-32 UNC												
1/4			67566927	6.74	87924288	8.06	67569202	8.06	67571406	9.09		
5/16									67571448	8.59		
3/8	67564245	9.65	67566968	6.52	87924296	9.65	67569244	8.98	67571489	8.29		
1/2	67564286	9.87	67567008	7.32	87924304	9.87	67569285	9.88	67571521	8.89		
5/8	67564328	11.04	67567040	8.05	87924312	11.04	67569327	11.04	67571562	9.71		
3/4	67564369	10.95	67567081	10.23	87924320	12.31	67569368	11.50	67571604	10.76	67574889	12.47
7/8					87924338	14.06						
1	67564401	15.13	67567123	11.86	87924346	14.13	67569400	14.31	67571646	13.65	67574921	15.54
1 1/4	67564443	17.49	67567164	16.36	87924353	17.49	67569442	17.43	67571687	14.03	67574962	17.94
1 1/2	67564484	18.93	67567206	18.16	87924361	18.93	67569483	18.80	67571729	17.31	67575001	19.39
1 3/4					87924379	24.48						
2					87924387	26.90						
2 1/2					87924395	33.63	40626699	45.27				
3					87924403	41.67						
#10-24 UNC												
3/8	67564526	12.40	67567248	11.00	87924437	12.13	67569525	12.85	67571760	10.35	67575043	12.97
1/2	67564567	12.00	67567289	13.13	87924445	12.85	67569566	14.01	67571802	11.11	67575084	15.71
5/8	67564609	14.31	67567321	11.43	87924452	13.94	67569608	16.26	67571844	15.36	67575126	17.31
3/4	67564641	15.54	67567362	11.43	87924460	15.54	67569640	16.78	67571885	15.83	67575167	17.60
7/8					87924478	19.59						
1	67564682	20.99	67567404	17.20	87924486	20.51	67569681	19.68	67571927	18.02	67575209	21.03
1 1/4	67564724	23.83	67567446	20.57	87924494	23.28	67569723	23.10	67571968	27.40	67575241	25.12
1 1/2	67564765	27.33	67567487	23.28	87924502	27.33	67569764	22.03	67572008	26.54	67575282	27.72
1 3/4					87924510	29.04						
2	67564807	33.10	67567529	33.16	87924528	33.10	67569806	30.76	67572040	32.52	67575324	36.93
2 1/2					87924536	45.75						
3					87924544	61.50						
#10-32 UNF												
3/8	67564849	12.29	67567560	11.27	87924569	12.29	67569848	12.00	67572081	10.71	67575365	12.95
1/2	67564880	13.59	67567602	13.13	87924577	13.02	67569889	13.13	67572123	11.86	67575407	15.71
5/8	67564922	15.82	67567644	10.75	87924585	15.82	67569921	15.88	67572164	14.62	67575449	17.31
3/4	67564963	16.08	67567685	13.68	87924593	16.08	67569962	16.85	67572206	15.42	67575480	17.60
7/8					87924601	19.59						
1	67565002	20.51	67567727	14.80	87924619	19.14	67570002	19.59	67572248	17.61	67575522	20.52
1 1/4	67565044	24.17	67567768	19.15	87924627	24.17	67570044	23.10	67572289	19.97	67575563	26.08
1 1/2	67565085	27.05	67567800	22.29	87924635	27.05	67570085	26.74	67572321	22.81	67575605	28.16
1 3/4					87924643	30.20						
2	67565127	32.34	67567842	28.30	87924650	32.34	67570127	30.84	67572362	32.52	67575647	35.12
2 1/2			40626715	31.62	87924668	45.75	40626707	41.55				
3					87924676	61.50						
#12-24 UNC												
1/2					67568402	23.89						
3/4					67568444	28.63						
1					67568485	33.85						
1 1/4					67568527	39.67						
1 1/2					67568568	56.32						
1/4-20 UNC												
3/8	67565168	26.14	67567883	21.80	67568600	26.14	67570168	23.01	67572404	20.11		
1/2	67565200	26.02	67567925	23.86	87924700	26.02	67570200	23.67	67572446	28.43	67575688	26.74
5/8	67565242	29.37	67567966	23.12	87924718	29.37	67570242	26.41	67572487	20.13	67575720	30.50
3/4	67565283	30.96	67568006	30.81	87924726	18.32	67570283	25.28	67572529	29.96	67575761	33.78
1	67565325	32.20	67568048	35.62	87924742	32.20	67570325	31.86	67572560	35.62	67575803	39.86
1 1/4	67565366	39.93	67568089	40.25	87924759	39.93	67570366	37.46	67572602	43.11	67575845	44.95

[1] Length is measured overall for flat head screws, under head for round head screws. [2] 50/Pkg.

10 FASTENERS & HARDWARE

...is page

...ws - 18-8 Stainless Steel

IMPORT

...ad Slotted Price/100	Flat Head Phillips Order #	Flat Head Phillips Price/100	Round Head Slotted Order #	Round Head Slotted Price/100	Pan Head Slotted Order #	Pan Head Slotted Price/100	Pan Head Phillips Order #	Pan Head Phillips Price/100	Oval Head Slotted Order #	Oval Head Slotted Price/100	Oval Head Phillips Order #	Oval Head Phillips Price/100
$38.58	67568121	$45.02	87924767	$41.32	67570408	$39.18	67572644	$45.02	67575886	$50.33	67574525	$46.14
			87924775	53.00								
56.85	67568162	57.53	87924783	56.85	67570440	56.85	67572685	52.05	67575928	57.68	67574566	57.27
69.57	67568204	70.79	87924791	69.57	67570481	69.42	67572727	66.49	67575969	69.42	67574608	68.04
90.02	67568246	84.71	87924809	90.02	67570523	86.00	67572768	82.76	67576009	90.02	67574640	82.18
75.15			87924866	72.23								
78.78			87924882	84.37								
94.76			87924890	97.04								
104.45			87924908	107.00								
			87924916	118.82								
130.76			87924924	130.76								
167.83			87924932	163.95								
176.11			87924940	176.11								
107.16												
107.40			87925012	109.97								
120.20			87925020	122.99								
136.60			87925038	139.85								
			87925046	166.00								
181.74			87925053	181.74								
210.46			87925061	215.41								
255.94			87925079	255.94								
278.97												
299.39												
314.28												
329.44												
388.14												
465.12												

...overall for flat head screws, under head for round head screws. [2] 50/Pkg.

...rews - Military Specification 24693/51957/51958 - 18-8 Stainless Steel

made in USA

...nt specifications than commercial grades • Chemical and physical paperwork available upon request
...Finish: black oxide MIL-C-13924 • Procurement specification: FF-S-92

Phillips Flat Head

Phillips Pan Head

...ecification

Military Spec. Number	Phillips® Flat Head 100° Order #	Phillips® Flat Head 100° Price/100
MS24693-2B	93036507	$19.57
MS24693-3B	93036515	21.63
MS24693-4B	93036523	22.66

Thread Size	OAL (In.)	Pkg. Qty.	Military Spec. Number	Phillips® Flat Head 100° Order #	Phillips® Flat Head 100° Price/100
4-40	½	100	MS24693-6B	93036531	$24.72
4-40	⅝	100	MS24693-7B	93036549	25.75
4-40	¾	100	MS24693-8B	93036556	27.81

Thread Size	OAL (In.)	Pkg. Qty.	Military Spec. Number	Phillips® Flat Head 100° Order #	Phillips® Flat Head 100° Price/100
4-40	1	100	MS24693-10B	93036499	$27.81

...ecification

Pkg. Qty.	Military Spec. Number	Phillips® Pan Head Order #	Phillips® Pan Head Price/100
100	MS51957-2B	93036648	$16.48
100	MS51957-3B	93036705	22.66
100	MS51957-4B	93036762	16.48
100	MS51957-5B	93036853	18.54
100	MS51957-7B	93036861	19.57
100	MS51957-8B	93036879	19.57
100	MS51957-9B	93036887	21.63
100	MS51957-11B	93036564	19.57
100	MS51957-12B	93036572	19.57
100	MS51957-13B	93036580	21.63
100	MS51957-14B	93036598	22.66

Thread Size	L Under Head (In.)	Pkg. Qty.	Military Spec. Number	Phillips® Pan Head Order #	Phillips® Pan Head Price/100
4-40	⅜	100	MS51957-15B	93036606	$24.72
4-40	½	100	MS51957-17B	93036614	25.75
4-40	⅝	100	MS51957-18B	93036622	28.84
4-40	¾	100	MS51957-19B	93036630	31.93
4-40	1	100	MS51957-21B	93036655	33.99
6-32	3/16	100	MS51957-25B	93036663	55.62
6-32	¼	100	MS51957-26B	93036671	27.81
6-32	5/16	100	MS51957-27B	93036689	28.84
6-32	⅜	100	MS51957-28B	93036697	30.90
6-32	½	100	MS51957-30B	93036713	33.99
6-32	⅝	100	MS51957-31B	93036721	37.08

Thread Size	L Under Head (In.)	Pkg. Qty.	Military Spec. Number	Phillips® Pan Head Order #	Phillips® Pan Head Price/100
6-32	¾	100	MS51957-32B	93036739	$40.17
6-32	⅞	100	MS51957-33B	93036747	43.26
6-32	1	100	MS51957-34B	93036754	46.35
8-32	¼	100	MS51957-41B	93036770	61.80
8-32	5/16	100	MS51957-42B	93036788	40.17
8-32	⅜	100	MS51957-43B	93036796	43.26
8-32	½	100	MS51957-45B	93036804	46.35
8-32	⅝	100	MS51957-46B	93036812	52.53
8-32	¾	100	MS51957-47B	93036820	55.62
8-32	⅞	100	MS51957-48B	93036838	61.80
8-32	1	100	MS51957-49B	93036846	67.98

...y Specification

Pkg. Qty.	Military Spec. Number	Phillips® Pan Head Order #	Phillips® Pan Head Price/100
50	MS51958-61B	93036895	$61.80
50	MS51958-62B	93036903	33.99
50	MS51958-63B	93036911	69.01

Thread Size	L Under Head (In.)	Pkg. Qty.	Military Spec. Number	Phillips® Pan Head Order #	Phillips® Pan Head Price/100
10-32	⅝	50	MS51958-64B	93036929	$75.19
10-32	¾	50	MS51958-65B	93036937	84.46
10-32	⅞	50	MS51958-66B	93036945	91.67

Thread Size	L Under Head (In.)	Pkg. Qty.	Military Spec. Number	Phillips® Pan Head Order #	Phillips® Pan Head Price/100
10-32	1	50	MS51958-67B	93036952	$98.88

...d Machine Screws - Zinc Plated Steel

IMPORT

...r #	Price/100
848	$6.61
889	6.34
921	12.52
962	6.64
4002	12.22
4044	8.50

L Under Head (In.)	Order #	Price/100
#8-32 UNC		
⅜	67424085	$6.87
½	67424127	7.32
⅝	67424168	12.08
¾	67424200	8.22
⅞	67424242	17.96
1	67424283	8.04

L Under Head (In.)	Order #	Price/100
#10-24 UNC		
⅜	67424325	$11.33
½	67424366	7.71
⅝	67424408	6.35
¾	67424440	6.86
⅞	67424481	21.52
1	67424523	7.11

L Under Head (In.)	Order #	Price/100
#10-32 UNF		
⅜	67424564	$9.41
7/16	67424606	16.84
½	67424648	8.50
⅝	67424689	12.45
¾	67424721	9.80
⅞	67424762	20.34
1	67424804	10.42

L Under Head (In.)	Order #	Price/100
#12-24 UNC		
⅜	67424846	$17.24
½	67424887	16.39
⅝	67424929	18.12
¾	67424960	19.99
1	67425009	24.20

100/Pkg.

Zinc-plated steel screws have an indented head.

Self-Sealing Machine Screws - Pan Head & Flat Head - 18-8 Stainless Steel

18-8 S.S. with Silicone O-Ring

- Seal out air, water, lubricants and other liquid or gaseous contaminants
- Temperature range: -160°F to +600°F • Pressure range: Up to 6000 psi, internal and external
- Resistant to: salt water, weather, dirt, dust, sunlight, ozone, and most acids

RoHS compliant

LENGTH · "O" RING · THREAD SIZE

Pan Head

L Under Head (In.)	Pkg. Qty.	Mfr's #	Order #	Price/Pkg.
4-40				
¼	10	R4-40X¼	06766265	$15.53
5⁄16	10	R4-40X5⁄16	06766299	7.29
⅜	10	R4-40X⅜	06766281	6.20
½	10	R4-40X½	06766257	6.20
¾	10	R4-40X¾	06766273	7.29
6-32				
¼	10	R6-32X¼	06766323	16.43
5⁄16	10	R6-32X5⁄16	06766356	7.29
⅜	10	R6-32X⅜	06766349	6.58
½	10	R6-32X½	06766315	$6.58
⅝	10	R6-32X⅝	06766364	7.67
¾	10	R6-32X¾	06766331	6.58
1	10	R6-32X1	06766307	7.67
8-32				
¼	10	R8-32X¼	06766398	8.39
⅜	10	R8-32X⅜	06766414	7.29
½	10	R8-32X½	06766380	7.29
¾	10	R8-32X¾	06766406	7.29
1	10	R8-32X1	06766372	9.13
10-32				
⅜	10	R10-32X⅜	06766232	$9.50
½	10	R10-32X½	06766216	8.77
⅝	10	R10-32X⅝	06766240	9.35
¾	10	R10-32X¾	06766224	9.35
1	10	R10-32X1	06766208	9.50
¼-20				
½	5	R¼-20X½	06766182	7.49
¾	5	R¼-20X¾	06766190	7.49
1	5	R¼-20X1	06766174	7.49

Flat Head

L Under Head (In.)	Pkg. Qty.	Mfr's #
4-40		
¼	10	SFR4-40X
⅜	10	SFR4-40X
½	10	SFR4-40X
6-32		
¼	10	SFR6-32X
⅜	10	SFR6-32X
½	10	SFR6-32X
¾	10	SFR6-32X
8-32		
½	10	SFR8-32X
¾	10	SFR8-32X
10-32		
½	10	SFR10-32X

Machine Screws - Sems® Pan Head

Pre-Assembled Screws and Washers
100/Package

Length (In.)	Pan Head Phillips External Tooth Lock Washer Order #	Price/100	Pan Head Phillips Internal Tooth Lock Washer Order #	Price/100	Pan Head Slotted External Tooth Lock Washer Order #	Price/100	Pan Head Slotted Internal Tooth Lock Washer Order #	Price/100
#2-56 UNC								
3⁄16			67200980	$30.75				
¼			67201004	26.21				
⅜			67201020	25.13				
#4-40 UNC								
3⁄16	67200006	$13.61	67201046	13.42	67201822	$14.42	67202408	$13.86
¼	67200022	8.66	67201061	9.07	67201848	9.49	67202424	9.49
5⁄16	67200048	9.49	67201087	20.42	67201863	10.54	67202440	10.81
⅜	67200063	9.17	67201103	9.17	67201889	10.35	67202465	10.35
7⁄16	67200089	11.66						
½	67200105	9.90	67201129	9.92	67201905	10.49	67202481	10.52
¾	67200121	14.22	67201145	14.97				
#6-32 UNC								
3⁄16	67200162	12.16	67201160	11.84	67201921	12.73	67202507	13.32
¼	67200188	7.44	67201186	7.42	67201947	6.87	67202523	7.42
5⁄16	67200204	8.07	67201202	8.65			67202549	7.42
⅜	67200220	7.54	67201228	7.55	67201962	7.85	67202564	7.86
7⁄16	67200246	12.66						
½	67200261	7.70	67201269	8.33	67201988	7.91	67202580	7.91
9⁄16			67201285	12.42				
⅝	67200287	10.10	67201301	9.92	67202002	13.29	67202606	13.29
¾	67200303	10.17	67201327	9.89	67202028	13.22		
⅞	67200329	13.66	67201343	14.33				
1	67200345	23.47	67201368	13.32				
1¼			67201384	16.18				
#8-32 UNC								
3⁄16	67200360	14.61						
¼	67200386	9.07	67201400	9.80	67202044	10.16	67202622	10.16
5⁄16	67200402	12.09	67201426	8.38				
⅜	67200428	8.14	67201442	8.14	67202085	8.64	67202648	8.64

Length (In.)	Pan Head Phillips External Tooth Lock Washer Order #	Price/100	Pan Head Phillips Internal Tooth Lock Washer Order #	Price/100	External Tooth Lock Washer Order #	Price/100
7⁄16	67200444	$11.01	67201467	$11.41	67202101	[illegible]
½	67200469	8.38	67201483	9.01	67202127	[illegible]
⅝	67200485	12.84	67201509	13.50		
¾	67200501	11.49	67201525	13.75	67202143	[illegible]
⅞	67200527	18.14	67201541	18.38		
1	67200543	19.26				
1¼	67200568	17.59				
#10-24 UNC						
⅜	67200584	11.84	67201566	9.03	67202168	[illegible]
½	67200600	9.34	67201582	9.94	67202184	[illegible]
⅝	67200626	19.51				
¾	67200642	18.55				
1	67200667	19.81				
#10-32 UNF						
¼	67200683	17.38	67201608	17.04	67202200	15.91
5⁄16	67200709	15.10	67201624	16.18	67202226	[illegible]
⅜	67200725	9.03	67201640	9.03	67202242	[illegible]
½	67200766	9.34	67201665	9.34	67202267	[illegible]
⅝	67200782	11.56	67201681	10.96	67202283	[illegible]
¾	67200808	16.68	67201707	16.70	67202309	[illegible]
⅞	67200824	24.98				
1	67200840	18.47				
¼-20 UNC						
⅜	67200865	25.89	67201749	14.73	67202325	[illegible]
½	67200881	20.78	67201764	17.90	67202341	[illegible]
⅝	67200907	28.50	67201780	19.54	67202366	27.78
¾	67200923	24.01	67201806	21.62	67202382	32.87
1	67200949	35.07				
1¼	67200964	39.81				

Machine Screws - Sems®

Size (In.)	Unslotted Hex Head w/External Lock Washer Order #	Price/100	Pan Head Stainless Steel w/Internal Lock Washer Order #	Price/100	Pan Head Stainless Steel w/External Lock Washer Order #	Price/100
#4-40						
3⁄16			67205765	$27.82		
5⁄16			67205849	23.48	67206326	$23.48
½			67205922	24.03		
⅝			67205963	27.99	67206367	27.99
#6-32						
¼	67202945	$11.15				
5⁄16					67206441	24.93
⅜	67202960	11.43				
½			67206086	25.74	67206524	25.74
#8-32						
¼	67202986	12.55	67206128	28.37	67206565	28.40
⅜	67203000	10.54	67206169	31.10	67206607	31.08
⅜L	67203026	10.92				
½			67206201	32.91	67206649	32.91
½L	67203042	10.92				

Size (In.)	Unslotted Hex Head w/External Lock Washer Order #	Price/100	Pan Head Stainless Steel w/Internal Lock Washer Order #	Price/100	Pan Head Stainless Steel w/External Lock Washer Order #	Price/100
#10-24						
⅜	67203067	$15.99				
½	67203083	16.81				
⅝	67203109	16.84				
#10-32						
⅜	67203125	13.90				
½			67206243	$39.10	67206680	$39.18
¼-20						
⅜L	67203166	19.77				
7⁄16L	67203182	19.54				
½L	67203190	20.78				
¾L	67203216	23.98				
⅞L	67203224	24.72				
1½L	67203257	34.20				
1¾L	67203265	38.75				
⅜-16						
¾	67203349	55.87				

Unslotted Head

Size	#8 (In.)
Standard	¼
Large	5⁄16

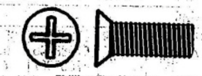
L Denotes Large Head

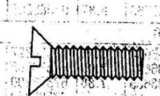
10 FASTENERS

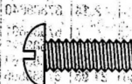
ews - 316 Stainless Steel

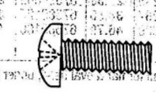
IMPORT

Phillips Flat Head Order #	Price/100	Slotted Flat Head Pkg. Qty.	Order #	Price/100	Slotted Round Head Pkg. Qty.	Order #	Price/100	Phillips Pan Head Pkg. Qty.	Order #	Price Qty.
								50	37007283	$12.92
								50	37007291	14.13
								50	37007309	14.71
09629544	$12.51	100	09340738	$10.29	100	09904251	$11.20	100	37007317	11.51
09629569	12.73	100	09340753	12.64	100	09904269	13.54	100	37007325	12.78
09629577	14.62	100	09340761	13.68	100	09904277	14.91	100	37007333	12.90
09629585	17.60	100	09340779	15.81	50	09904285	17.21	50	37007341	16.11
09629593	20.57	50	09340787	17.38	50	09904293	18.93	50	37007358	20.04
09720657	36.29	50	09340795	31.39	50	09904301	25.51			
09720665	45.01	25	09340803	29.23						
					100	09904319	14.62	50	37007366	13.41
09720673	16.00	100	09340811	13.19	50	09904327	15.14	50	37007374	14.28
09720681	19.77	100	09340829	15.18	50	09904335	19.65	50	37007382	17.43
								50	37007390	19.59
09720699	24.73	50	09340837	16.95	50	09904343	21.19	50	48442420	21.53
09720707	29.91	50	09340845	20.32	50	09904350	23.31	25	48442438	27.73
09720715	46.55	25	09340852	27.49						
09720723	49.99	25	09340860	32.11	25	09904368	38.89			
09720731	25.57	50	09340878	16.02	50	09904376	17.99	50	48442446	22.64
09720749	29.86	50	09340886	18.33	50	09904384	20.22	25	48442453	25.93
09720756	34.12	50	09340894	21.93	25	09904392	27.41	25	48442461	29.27
09720764	38.80	25	09340902	25.17	25	09904400	30.27	25	48442479	32.94
09720772	45.73	25	09340910	29.27	25	37007135	36.35			
09720780	53.87	25	09340928	36.44	25	37007143	40.91			
09720798	25.55				50	37007150	17.99	50	48442487	21.24
09720806	29.86	50	09340936	17.76	50	37007168	20.22	25	48442495	23.75
09720814	34.12	50	09340944	22.18	50	37007176	25.84	25	48442503	26.82
09720822	43.05	50	09340951	27.32	50	37007184	27.59	25	48442511	32.94
09720830	45.73				25	37007192	35.13			
09720848	53.87	25	09340969	36.44	25	37007200	40.91			
					50	37007218	26.63			
09720855	39.43	25	09340977	31.47	50	37007226	28.27	25	48442529	33.98
09720863	38.22	25	09340985	38.48	25	37007234	36.53	25	48442537	34.65
09720871	43.49	25	09340993	39.92	25	37007242	37.90	25	48442545	41.04
09720889	51.52	25	09629338	43.98	25	37007259	47.58	25	48442552	47.16
09720897	65.39	25	09629346	48.73	25	37007267	51.41	10	48442560	59.24
09720905	76.57	25	09629353	57.86	25	37007275	62.24	10	48442578	77.44
09720913	81.81	10	09629361	75.11						
09904145	93.77	10	09629379	85.95						
09904152	79.02	10	09629387	67.50						
09904160	90.21	10	09629395	77.91						
09904178	101.82	10	09629403	88.19						
09904186	113.44	10	09629411	104.73						
09904194	125.07	10	09629429	124.50						
		10	09629437	136.78						
09904202	117.57	10	09629445	94.78						
09904210	131.09	10	09629452	98.91						
09904228	140.27	10	09629460	119.26						
09904236	153.33	10	09629478	145.86						
09904244	156.92	5	09629486	167.10						
		5	09629494	195.15						
		5	09629502	211.68						
		5	09629510	205.65						
		5	09629528	255.94						
		5	09629536	297.30						


Phillips Flat Head


Slotted Flat Head


Slotted Round Head


Phillips Pan Head

d overall for flat head screws

crews - Hex Washer Head

IMPORT

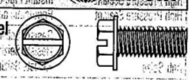
Order #	Price/100
3285	$14.83
3327	14.83
3368	19.90
3400	27.02

L Under-Hd. (In.)	Order #	Price/100
#8-32 UNC		
1/4	67423442	$15.33
5/16	67423483	18.13
3/8	67423525	12.90
1/2	67423566	13.67

L Under-Hd. (In.)	Order #	Price/100
#10-24 UNC		
3/8	67423608	$20.37
1/2	67423640	19.92
#10-32 UNF		
3/8	67423681	16.76

L Under-Hd. (In.)	Order #	Price/100
1/2	67423723	$17.22
1/4-20 UNC		
1/2	67423764	24.26
3/4	67423806	27.72

Zinc Plated Steel
100/Pkg.



Low profile, slotted hex head with washer is ideal for use in enlarged holes. Screws have an indented head.

Machine Screws - Slotted Brass

[1]OAL (In.)	Flat Head Order #	Flat Head Price/100	Round Head Order #	Round Head Price/100	Binding Head Order #	Binding Head Price/100	Oval Head Order #	Oval Head Price/100
#2-56 UNC								
¼	67586362	$6.09	67588004	$5.95	67590489	$5.82		
⅜	67586404	6.82	67588046	6.68	67590521	6.46		
½			67588087	7.10				
#4-40 UNC								
¼	67586446	5.17	67588129	5.17	67590562	5.67		
⅜	67586487	5.91	67588160	5.91	67590604	6.62		
½	67586529	6.74	67588202	6.74	67590646	7.68		
⅝			67588244	8.32				
¾	67586560	8.87	67588285	8.87	67590687	9.96		
#6-32 UNC								
¼	67586602	6.05	67588327	6.05	67590729	6.62	67598649	$7.48
⅜	67586644	7.00	67588368	7.00	67590760	7.51	67598680	9.52
½	67586685	7.80	67588400	7.80	67590802	8.52	67598722	10.45
⅝			67588442	9.29				
¾	67586727	9.47	67588483	9.47	67590844	10.69	67598763	12.82
1	67586768	12.61	67588525	12.61	67590885	13.55	67598805	17.33
#8-32 UNC								
¼	67586800	9.12	67588566	8.58	67590927	9.82		
⅜	67586842	10.68	67588608	10.04	67590968	11.43	67598847	11.36
½	67586883	12.14	67588640	12.14	67591008	13.55	67598888	16.94
⅝			67588681	13.78				
¾	67586925	14.61	67588723	14.61	67591040	16.69	67598920	20.69
1	67586966	21.13	67588764	18.14	67591081	21.05	67598961	25.72
1¼	67587006	21.05	67588806	21.05				
1½	67587048	23.81	67588848	23.81				
#10-24 UNC								
⅜	67587089	14.60	67588889	14.60	67591123	16.63		
½	67587121	16.53	67588921	16.53	67591164	18.52	67599001	22.98
⅝			67588962	19.60				
¾	67587162	20.51	67589002	20.51	67591206	22.95	67599043	29.37
1	67587204	23.85	67589044	23.85	67591248	27.92	67599084	35.97
1¼	67587246	27.38	67589085	27.38				
1½	67587287	33.85	67589127	33.85				
2	67587329	46.79	67589168	44.72				

[1]OAL (In.)	Flat Head Order #	Flat Head Price/100	Round Head Order #	Round Head Price/100	Binding Head Order #	Binding Head Price/100
#10-32 UNF						
⅜	67587360	$14.60	67589200	$14.60	67591289	$16.22
½	67587402	16.53	67589242	16.53	67591321	16.88
⅝			67589283	19.60		
¾	67587444	20.51	67589325	20.51	67591362	22.48
1	67587485	25.42	67589366	23.85	67591404	27.29
1¼	67587527	31.31	67589408	27.38		
1½	67587568	33.85	67589440	33.85		
2	67587600	50.53	67589481	41.85		
¼-20 UNC						
⅜	67587642	36.83	67589523	36.83		
½	67587683	33.32	67589564	33.32		
⅝			67589606	36.94		
¾	67587725	38.16	67589648	37.88		
1	67587766	45.32	67589689	45.32		
1¼	67587808	56.26	67589721	56.26		
1½	67587840	61.53	67589762	59.26		
2	67587881	83.10	67589804	80.57		
2½	67587923	97.62	67589846	94.50		
3	67587964	106.18	67589887	108.35		
5/16-18 UNC						
¾			67589929	80.52		
1			67589960	98.60		
1¼			67590000	115.05		
1½			67590042	119.11		
2			67590083	160.34		
2½			67590125	175.69		
3			67590166	233.90		
⅜-16 UNC						
¾			67590208	136.90		
1			67590240	159.43		
1¼			67590281	181.67		
1½			67590323	213.91		
2			67590364	267.40		
2½			[2]67590406	299.84		
3			[2]67590448	329.62		

[1]Length overall for flat & oval head, under head for all other types. [2]50/Pkg.

Thread Locking Compounds, Sealants & Anti-Seize

Threadlocker VC3 | Threadlocker Gel | Threadlocker | Retaining Compound | High Pressure Sealant | Anti-Seize | Anti-Cam Out Fluid (DriveGrip)

Type	Application	Working Time	Strength	Container Size	Container Type	
Threadlocker VC3	Makes Any Fastener Self-Locking & Self-Sealing	—	—	1 oz.	Bottle	
Threadlocker VC3	Makes Any Fastener Self-Locking & Self-Sealing	—	—	8 oz.	Can	
Threadlocker VC3	Makes Any Fastener Self-Locking & Self-Sealing	—	—	1 Gal.	Can	
Threadlocker Gel	Medium Strength Threadlocker Locks Nuts & Bolts Larger than ¼" in Diameter	10 - 30 Mins.	Medium	35 ml	Pump Dispenser	[illegible]
Threadlocker Gel	Permanently Locks Nuts & Bolts Larger than ¼" Diameter	5 - 20 Mins.	High	35 ml	Pump Dispenser	[illegible]
Threadlocker	Fasteners Under ¼"	Set up: 30 Mins., Full Strength: 24 Hrs.	Low	10 ml	Bottle	Purple
Threadlocker	Fasteners Under ¼"	Set up: 30 Mins., Full Strength: 24 Hrs.	Low	50 ml	Bottle	Purple
Threadlocker	Medium Strength - Nuts and Bolts ¼" Diameter or Larger	Set up: 30 Mins., Full Strength: 24 Hrs.	Medium	10 ml	Bottle	Blue
Threadlocker	Medium Strength - Nuts or Bolts ¼" Diameter or Larger	Set up: 30 Mins., Full Strength: 24 Hrs.	Medium	50 ml	Bottle	Blue
Threadlocker	Medium Strength - Oil Tolerant for Nuts or Bolts ¼" Diameter or Larger	10 Mins. - 24 Hrs.	Medium	10 ml	Bottle	Blue
Threadlocker	Medium Strength - Oil Tolerant Nuts and Bolts ¼" Diameter or Larger	10 Mins. - 24 Hrs.	Medium	50 ml	Bottle	Blue
Threadlocker	Medium to High Strength - Capillary Action Locks Pre-Assembled Fasteners	10 Mins. - 24 Hrs.	Medium to High	10 ml	Bottle	Green
Threadlocker	Medium to High Strength - Capillary Action Locks Pre-Assembled Fasteners	10 Mins. - 24 Hrs.	Medium to High	50 ml	Bottle	Green
Threadlocker	Very High Strength - Fasteners up to 1" Diameter	20 Mins. - 24 Hrs.	Very High	10 ml	Bottle	Red
Threadlocker	Very High Strength - Fasteners up to 1" Diameter	20 Mins. - 24 Hrs.	Very High	50 ml	Bottle	Red
Retaining Compound	High Strength: Retains Spindle Bearings, Lip Seals, Bearing Races	10 Mins. - 24 Hrs.	High	10 ml	Bottle	Green
Retaining Compound	High Strength: Retains Spindle Bearings, Lip Seals, Bearing Races	10 Mins. - 24 Hrs.	High	50 ml	Bottle	Green
Retaining Compound	Very High Strength: Retains Gears, Wheels, Pulleys, Cams, Collars, Flywheels, Rotors to Shaft	20 Mins. - 24 Hrs.	Very High	10 ml	Bottle	Green
Retaining Compound	Very High Strength: Retains Gears, Wheels, Pulleys, Cams, Collars, Flywheels, Rotors to Shaft	10 Mins. - 24 Hrs.	Very High	50 ml	Bottle	Green
High Pressure Sealant	Instant Pipe Sealant for High Temp., High Strength - General Purpose Stainless Steel and Other Inert Materials	4 Hrs. - 24 Hrs.	10,000 psi	50 ml	Tube	White
High Pressure Sealant	Instant Pipe Sealant - Industrial Grade, Controlled Locking Strength, Metal Fittings	4 Hrs. - 24 Hrs.	10,000 psi	50 ml	Tube	White
High Pressure Sealant	Pneumatic and Hydraulic High Pressure Sealing Fluid, Power and Gas Systems Connections	4 Hrs. - 24 Hrs.	10,000 psi	50 ml	Bottle	Purple
Anti-Seize	Resists Seizing, Galling, Galvanic Attack and Excessive Wear	—	—	4 oz.	Brush-Top	Silver
Anti-Seize	Resists Seizing, Galling, Galvanic Attack and Excessive Wear	—	—	8 oz.	Brush-Top	Silver
Anti-Seize	Resists Seizing, Galling, Galvanic Attack and Excessive Wear	—	—	16 oz.	Brush-Top	Silver
Anti-cam Out Fluid (DriveGrip)	Increases the Grip-Strength Between the Fastener Head and Tool as Much as 700%	—	—	5 oz.	Tube	Gray
Instant Super Glue	Non-Running Gel for Porous Surfaces - General Purpose	Fixture: 30 Secs., Full Strength: 24 Hrs.	High	3 g	Tube	Clear
Instant Super Glue	Non-Running Gel for Porous Surfaces - General Purpose	Fixture: 30 Secs., Full Strength: 24 Hrs.	High	20 g	Tube	Clear
Instant Super Glue	Low-Medium Viscosity for Plastic and Vinyl Surfaces	Fixture: 30 Secs., Full Strength: 24 Hrs.	High	1 oz.	Bottle	Clear

...ue page

...ket Set Screws - Alloy Steel

Import Order #	Import Price Ea.	Holo-Krome Order #	Holo-Krome Price Ea.	Unbrako Order #	Unbrako Price Ea.
...nt'd)					
...7161	$1.48	75567156	$1.60		
...1177	1.92	75567172	1.90		
...7801	2.07	75567206	2.08		
...1055	3.23				
...7250	2.35	75567255	2.55		
...7300	2.31	75567305	2.90		
...1063	3.55				
...5552	5.58				
...5560	7.62				
...3580	2.56				
...1071	1.46				
...7089	2.14				
...1097	2.37				
...1105	2.74				
...7081	5.70				
...1113	3.98				
...7121	2.30	75568089	2.33		
...1139	2.49	75568105	2.49		
...5594	2.90				
...1147	3.10				
...5602	4.40				
...1154	4.23				
...5610	4.84				
...1162	5.23	75568154	4.77		

OAL (In.)	Order #	Price Ea.	Order #	Price Ea.
3	04321170			
3½	07073935			
4	04495628			
⅞-14 UNC ½″ Key				
1	0449563...			
1¼	0449564...			
1½	0449565...			
2	0449566...			
2½	0449567...			
3	0449568...			
1-8 UNC 9/16″ Key				
1	055691...			
1¼	044956...			
1½	05569157	3.77		
1¾	04495701	3.97		
2	05569207	4.11	75569202	4.99
2¼	04495719	4.44		
2½	05569256	4.78		
2¾	04495727	5.94		
3	05569306	6.18	75569301	6.61
3½	04495735	10.72		
4	04495743	11.94		
4½	04495750	23.11		
5	04495768	25.36		
6	04495776	32.42		

BOLTS

BOLTS

Carriage Bolts

These self-anchoring sc...
applications. Length...
Grade 2 Zinc-Plated...
resistance in mos...
Grade 5 Zinc-P...
18-8 Stainle...
Can be m...

Price/100

$124.08

Import Order #	Import Price Ea.
97247860	$6.71
04495784	6.22
04495792	8.11
04495800	8.65
04495818	13.59
04495826	15.49

OAL (In.)	Import Order #	Import Price Ea.
1⅛-7 UNC 9/16″ Key		
1	04495941	$15.68
1¼	04495958	16.75
1½	04495966	17.77
1¾	04495974	20.65
2	04495982	21.44
2½	04495990	23.53
3	04496006	28.74

OAL (In.)	Import Order #	Import Price Ea.
1¼-7 UNC ⅝″ Key		
1	32146227	$17.52
1¼	04495834	14.04
1½	67859397	19.08
2	04495842	18.38
2½	04495859	19.62
3	04495867	23.53
3½	04495875	28.06
4	04495883	30.53

OAL (In.)	Import Order #	Import Price Ea.
1½-6 UNC ¾″ Key		
1½	86407632	$30.86
2	04495891	27.65
2½	04495909	31.57
3	04495917	36.29
3½	04495925	38.77
4	04495933	43.54

...cket Set Screws - Alloy Steel - Convenience Packs

made in USA

...he finest steels available and critically inspected at every production step, each lot of high strength precision socket screws is ...
... back-to-the-source accountability
...M specifications • All fasteners offered in full package quantities only - not sold in broken packages

Price/Pkg.
$8.66
9.86
8.36
9.83
9.86
12.84
15.84
3.37
3.37
3.53
3.64
3.73
4.42
4.38
4.38
4.48
4.48
4.87
5.29
6.92
7.49

OAL (In.)	Pkg. Qty.	Order #	Price/Pkg.
1	50	09698432	$14.82
8-32 UNC 5/64″ Key			
⅛	25	67657189	4.38
3/16	25	67657205	4.41
¼	25	67657221	4.48
5/16	25	67657247	4.56
⅜	25	67657262	4.55
½	25	67657288	5.29
⅝	25	67657304	6.92
¾	25	67657320	7.44
⅞	50	09698440	11.07
1	50	09698457	11.61
10-24 UNC 3/32″ Key			
3/16	25	67657387	4.48
¼	25	67657408	4.48
5/16	25	67657429	4.58
⅜	25	67657445	5.07
½	25	67657460	5.37
⅝	25	67657486	6.92
¾	25	67657502	7.44
1	50	75913434	11.65
1¼	25	09698465	10.12
10-32 UNF 3/32″ Key			
3/16	25	67658609	4.48
¼	25	67658625	4.48

OAL (In.)	Pkg. Qty.	Order #	Price/Pkg.
5/16	25	67658641	$4.58
⅜	25	67658666	5.07
½	25	67658682	5.37
⅝	25	67658708	6.92
¾	25	67658724	7.44
1	50	09698903	16.12
1¼	25	09698911	8.99
¼-20 UNC ⅛″ Key			
3/16	25	67657544	3.34
¼	25	67657569	3.38
5/16	25	67657585	3.40
⅜	25	67657601	3.43
½	25	67657627	3.74
⅝	25	67657643	4.97
¾	25	67657668	5.13
⅞	50	09698473	9.38
1	50	75913442	8.86
1¼	25	75913459	5.94
1½	25	09698481	9.90
1¾	25	09698499	11.10
2	25	09698507	12.41
¼-28 UNF ⅛″ Key			
3/16	25	67658765	4.55
¼	25	67658781	4.58
5/16	25	67667360	4.56

OAL (In.)	Pkg. Qty.	Order #	Price/Pkg.
⅜	25	67658807	$4.86
½	25	67658823	5.29
⅝	25	67658849	6.70
¾	25	67658864	7.28
1	50	09698929	11.51
1¼	25	09698937	7.77
5/16-18 UNC 5/32″ Key			
¼	25	67657783	5.69
5/16	25	67657809	4.86
⅜	25	67657825	4.86
½	25	67657841	5.53
⅝	25	67657866	7.20
¾	25	67657882	7.99
1	50	09698515	12.22
1¼	25	09698523	7.90
1½	25	09698531	10.79
1¾	25	75913467	9.20
2	25	75913475	10.43
5/16-24 UNC 5/32″ Key			
¼	25	67658922	5.69
5/16	25	67658948	4.86
⅜	25	67658963	4.86
½	25	67658989	5.53
⅝	25	67659003	7.20
¾	25	67659029	7.99

OAL (In.)	Pkg. Qty.	Order #	Price/Pkg.
1	50	09698945	$15.20
⅜-16 UNC 3/16″ Key			
¼	25	67658021	6.86
⅜	25	67658062	5.87
½	25	67658088	6.24
⅝	25	67658104	7.17
¾	25	67658120	7.82
⅞	50	09698549	10.16
1	25	09698556	7.94
1¼	25	09698564	8.46
1½	25	09698572	11.17
1¾	10	09698580	6.49
2	10	09698598	6.20
2½	10	09698606	7.80
⅜-24 UNC 3/16″ Key			
⅜	25	67659060	5.87
½	25	67659086	6.24
¾	25	67659102	7.82
1	25	09698952	11.17
1¼	25	09698960	8.53
1½	25	09698978	10.83
7/16-14 UNC 7/32″ Key			
⅜	25	09698614	8.65
7/16	25	09698622	8.99
½	25	09698630	9.29

OAL (In.)	Pkg. Qty.	Order #	Price/Pkg.
⅝	25	09698648	$10.26
¾	25	09698655	12.36
⅞	25	09698663	13.20
1	10	09698671	6.84
1¼	10	09698689	7.88
1½	10	09698697	7.63
2	10	09698705	10.08
7/16-20 UNC 7/32″ Key			
⅜	25	09698986	8.65
½	25	09698994	9.24
½-13 UNC ¼″ Key			
⅜	25	75913483	7.61
½	25	09698713	9.61
⅝	25	09698721	10.43
¾	25	09698739	11.22
1	10	09698747	5.74
1¼	10	09698754	7.00
1½	10	09698762	8.05
1¾	10	09698770	9.17
2	10	09698788	10.16
½-20 UNF ¼″ Key			
¾	25	75913632	8.96
1	10	75913640	4.48

Continu...

Socket Head Cap Screws - Alloy Steel

IMPORT · made in USA · HOLO-KROME · Unbrako

Price/100	Made in USA Order #	Price/100	Holo-Krome Order #	Price/100	Unbrako Order #	Price/100
(Cont'd)						
$126.75	85326981	$151.34			**67804344**	$382.53
121.46					**67804351**	652.07
314.80					**67804385**	704.52
526.23						
539.19						
665.08						
603.88						
672.91						
54.06						
8.84	60673068	12.00	75511055	$16.05		
9.36	60673076	12.24	75511063	16.37	[4]67804401	26.88
10.25	60673084	13.87	75511071	18.58	67804443	29.51
10.71	60673092	14.50	75511089	19.35	67804484	32.64
11.56	60673100	15.68	75511105	20.98	67804526	33.23
12.15	60673134	16.43	75511121	21.98	67804567	34.80
13.51	60673167	18.26	75511154	24.43	67804609	38.99
14.92	60673183	20.27	75511170	27.10	67804641	42.58
16.18	60673209	22.38	75511204	29.92	67804682	47.51
18.98	60673233	25.69	75511220	34.36	67804724	57.46
21.35	60673266	28.90	75511253	38.66	67804765	64.90
	00841247	52.72			**67804773**	297.32
61.93	00841254	71.62	74633017	83.78	**67804781**	240.89
121.44						
74.89	[2]00841262	93.81	74633025	233.80	**[2]67804799**	468.61
177.96			74633033	289.97	**[2]67804823**	581.03
179.49						
201.40						
258.33						
513.30						
50.25						
14.52			75522052	17.16	67804807	29.88
13.30	60668076	14.20	75522060	18.28	67804849	31.32
10.37	60668084	14.54	75522078	19.45	67804880	32.03
11.70	60668092	15.85	75522086	21.24	67804922	35.14
12.65	60668100	19.10	75522102	25.53	67804963	35.99
32.84	00841270	36.89			**67804989**	385.59
15.41	60668134	18.51	75522128	24.74	67805002	39.24
38.64	00841288	47.44			**67805028**	166.64
15.19	60668167	20.58	75522151	27.53	67805044	42.83
68.02						
16.39	60668183	22.16	75522177	29.63	[2]67805085	49.56
21.27	[2]60668209	24.36	75522201	32.58	[2]67805127	53.62
21.53	60668233	29.12	75522227	38.93	[2]67805168	66.94
24.86	60668266	33.65	75522250	44.99	67805200	73.67
44.57	60668282	44.89	75522276	60.05	67805242	98.86
48.89	60668308	54.82	75522300	65.31	67805283	107.74
64.75	60668332	65.63	75522326	87.78	67805325	130.28
74.28	60668365	79.98	75522359	89.59	67805366	148.05
79.99					**67805382**	288.67
83.12	60668407	87.37	75522409	104.73	67805408	173.47
134.41						
101.70			75522458	121.57	67805440	207.67
151.49						
121.86			75522508	156.23	67805481	250.02
136.15			75522532	164.25		
					67805507	1345.12
157.72	[1]85326999	166.83	[2]75522540	214.73	[2]67805523	353.20
300.18					**[2]67805531**	729.91
370.72						
450.37					**67805549**	743.69
935.62						
y.						
93.83						
14.18	60674066	19.10	75512053	24.59	67805564	44.51
15.18	60674074	19.42	75512061	24.96	67805606	51.59
15.69	60674082	19.84	75512079	26.50		
17.74	60674090	21.39	75512087	27.52	67805689	41.27
19.20	60674108	21.82	75512103	29.16	67805721	42.00
85.47						
19.38	60674132	23.67	75512129	31.65	67805762	45.23
98.94						

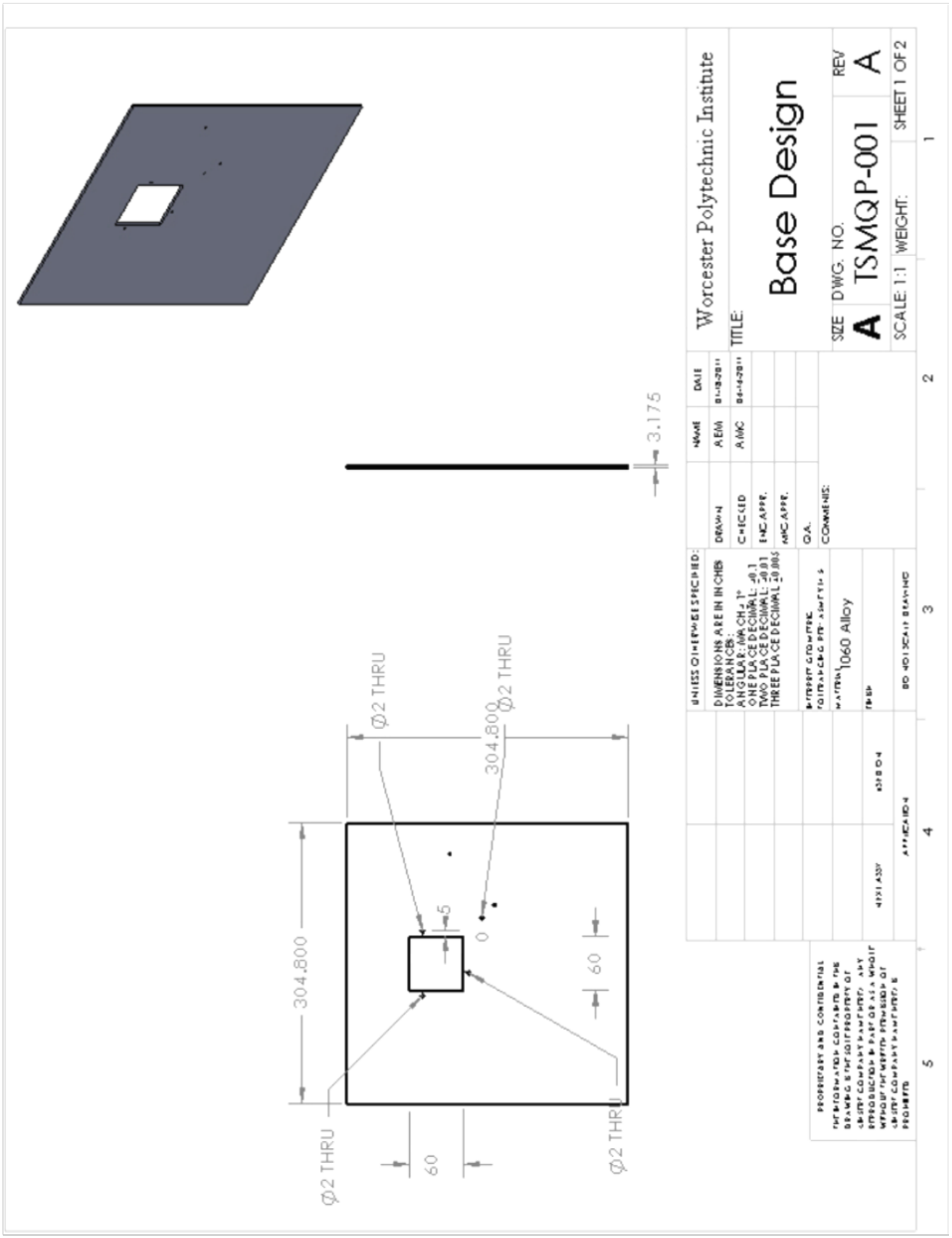
L Under Head (In.)	Pkg. Qty.	Import Order #	Price/100	Made in USA Order #	Price/100	Holo-Krome Order #	Price/100	Unbrako Order #	Price/100
1½	100	05512157	$20.20	60674165	$26.06	75512152	$34.83	6780580	
1⅝	100	76588540	107.96						
1¾	100	05512173	21.91	[2]60674181	28.66	[2]75512178	38.34	[2]67805846	
2	100	05512207	23.51	[2]60674207	29.57	[2]75512202	39.56	[2]67805887	
2¼	100	05512223	24.00	[2]60674231	40.39	75512228	54.01	[2]67805929	
2½	50	05512256	24.97	[2]60674264	43.20	[2]75512251	57.78	[2]67805960	8
2¾	50	00103291	42.21	00841296	65.89	[2]75512277	70.78		
3	50	[4]05512306	42.21	[2]60674306	55.43	[2]75512301	74.14	[2]67806000	118.7
3½	50	00103309	75.18	00841304	79.07	[2]75512350	117.10		
3¾	50	00103317	79.99						
4	50	00103325	84.09			[2]75512400	131.43		
4½	50	76588557	131.11			74633041	153.43		
5	50	00103333	112.98			75512509	189.18		
5½	25	04162335	153.01			74633058	190.83		
6	25	76588565	203.98			74633066	250.66		
7/16-14 UNC ⅜" Key									
½	100	98678139	26.35	85327005	28.63				
⅝	100	03773629	35.73						
¾	100	05523071	32.37	00841411	34.10	[2]75523076	40.61	67806042	68.27
⅞	100	05523089	33.56	00841429	35.18	75523084	47.42	67806083	73.67
1	100	05523105	35.08	00841312	37.05	75523100	48.53	67806125	74.99
1¼	100	05523121	39.40	[2]00841320	39.71	[2]75523126	51.40	[2]67806166	81.82
1½	100	05523154	42.77	[2]00841338	43.23	[2]75523159	59.32	[2]67806208	89.15
1¾	100	05523170	45.60	[2]00841346	47.47	[2]75523175	65.69	[2]67806240	101.57
2	50	05523204	47.53	00841353	52.05	75523209	67.26	67806281	107.49
2¼	50	03773637	53.48	00841361	60.29	75523217	71.78	67806323	117.94
2½	50	05523253	59.66	00841379	65.27	75523258	83.19	67806364	125.72
2¾	50	05523279	68.67	[4]00841387	75.26	[4]75523274	92.65	[4]67806406	147.21
3	50	05523303	71.90	[4]00841395	79.38	[4]75523308	103.56	[4]67806448	156.80
3¼	50	03773645	86.60						
3½	50	05523352	88.36	[4]00841403	91.73	[4]75523357	122.45	[4]67806521	180.33
4	50	05523402	108.43			[4]75523456	136.50	[4]67806562	201.08
4½	50	00103341	138.08						
5	25	00103358	157.35			75523506	214.00		
5½	25	04162376	307.70						
6	25	76588573	461.55						
7/16-20 UNF ⅜" Key									
⅝	100	55327886	77.20						
¾	100	04162392	77.31						
⅞	100	40084097	84.15						
1	100	05513106	39.46	00841437	40.74	75513101	51.76	67806604	83.26
1¼	100	05513122	41.60	[2]00841445	43.66	[2]75513127	59.05	[2]67806646	89.87
1½	100	05513155	44.99	[2]00841452	47.50	75513150	66.25	[2]67806687	99.93
1¾	100	04162400	65.85	[2]00841460	76.44				
2	50	05513205	52.82	00841478	57.04	75513200	76.94	67806729	118.65
2¼	50	76588581	83.93	00841486	96.92				
2½	50	00103366	91.91	00841494	110.65	74633074	238.32	**67806737**	1256.25
3	50	00103374	97.09	[4]00841510	120.89	74633082	264.77	**[4]67806745**	1129.66
3½	50	00103382	103.19	[4]00841528	125.72	74633090	294.21	**[4]67806752**	589.55
4	50	76588599	245.18						
5	25	76588607	401.15						
6	25	76588615	508.94						
½-13 UNC ⅜" Key									
⅜	100	76588623	86.57						
½	50	03575842	33.27	60669066	37.99	75524058	48.90	67806760	154.29
⅝	50	03575859	35.34	60669074	38.71	75524066	49.83	67806802	157.28
¾	50	05524079	36.99	60669082	39.45	75524074	50.12	67806844	75.83
⅞	50	05524087	37.89	60669090	40.42	75524082	51.40	67806885	84.11
1	50	05524103	38.52	60669108	43.20	75524108	57.78	67806927	83.63
1⅛	100	76588631	48.10	[2]00841536	57.72				
1¼	50	05524129	38.83	60669132	42.93	75524124	57.43	67806968	88.66
1⅜	50	00103390	45.36	00841544	57.98				
1½	50	05524152	42.81	60669165	45.14	75524157	60.41	67807008	99.33
1⅝	50	76588649	112.44						
1¾	50	05524178	45.64	60669181	49.13	75524173	65.72	67807040	110.25
2	50	05524202	58.45	60669207	65.05	75524207	80.31	67807081	118.65
2¼	50	05524228	67.70	[4]60669231	74.17	[4]75524223	89.87	[4]67807123	133.53
2⅜	50	76588656	79.05						
2½	50	05524251	75.01	[4]60669264	82.61	[4]75524256	95.76	[4]67807164	142.16
2¾	50	05524277	79.96	[4]60669280	86.71	[4]75524272	109.30	[4]67807206	164.00
3	50	05524301	83.73	[4]60669306	93.89	[4]75524306	116.25	[4]67807248	175.16
3¼	25	[4]05524327	89.85	60669330	94.75	75524322	113.37	67807289	189.31
3½	25	05524350	93.84	60669363	101.95	75524355	118.32	67807321	201.31

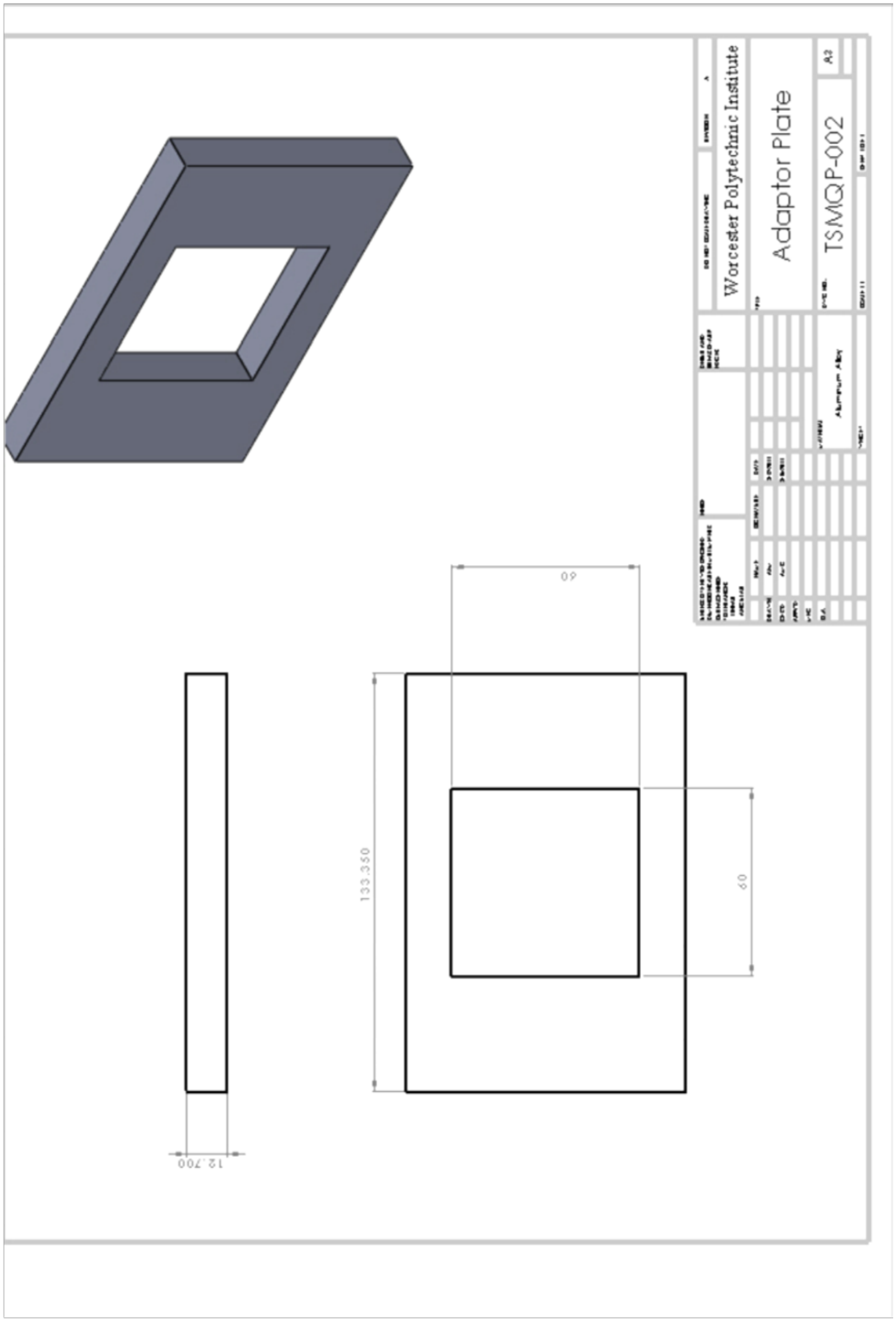
ox [3] ⅜" Key [4] 25/Box *Limited Supply Unbrako order numbers in bold are hard to find semi-standard sizes.

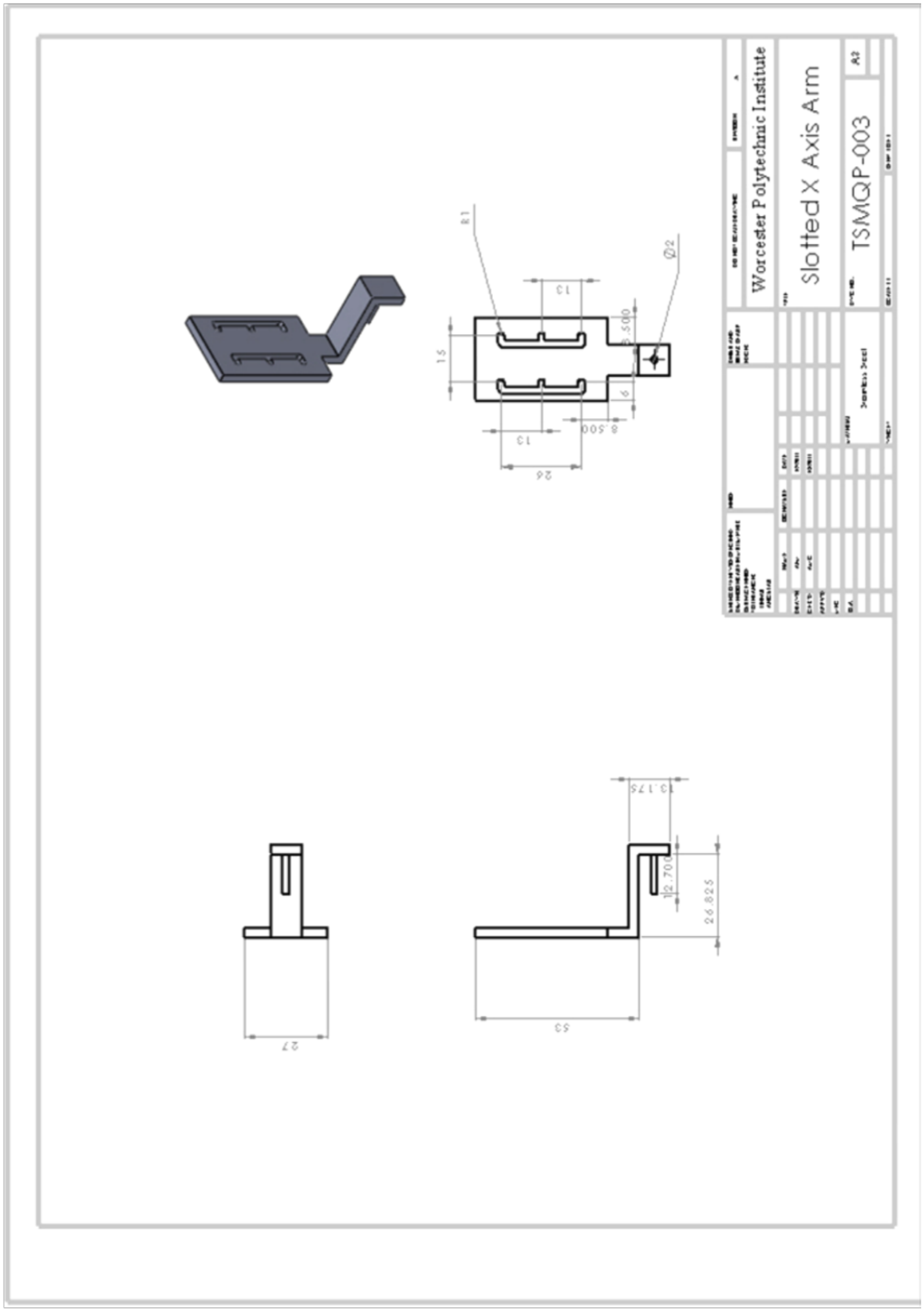
Continued on next page

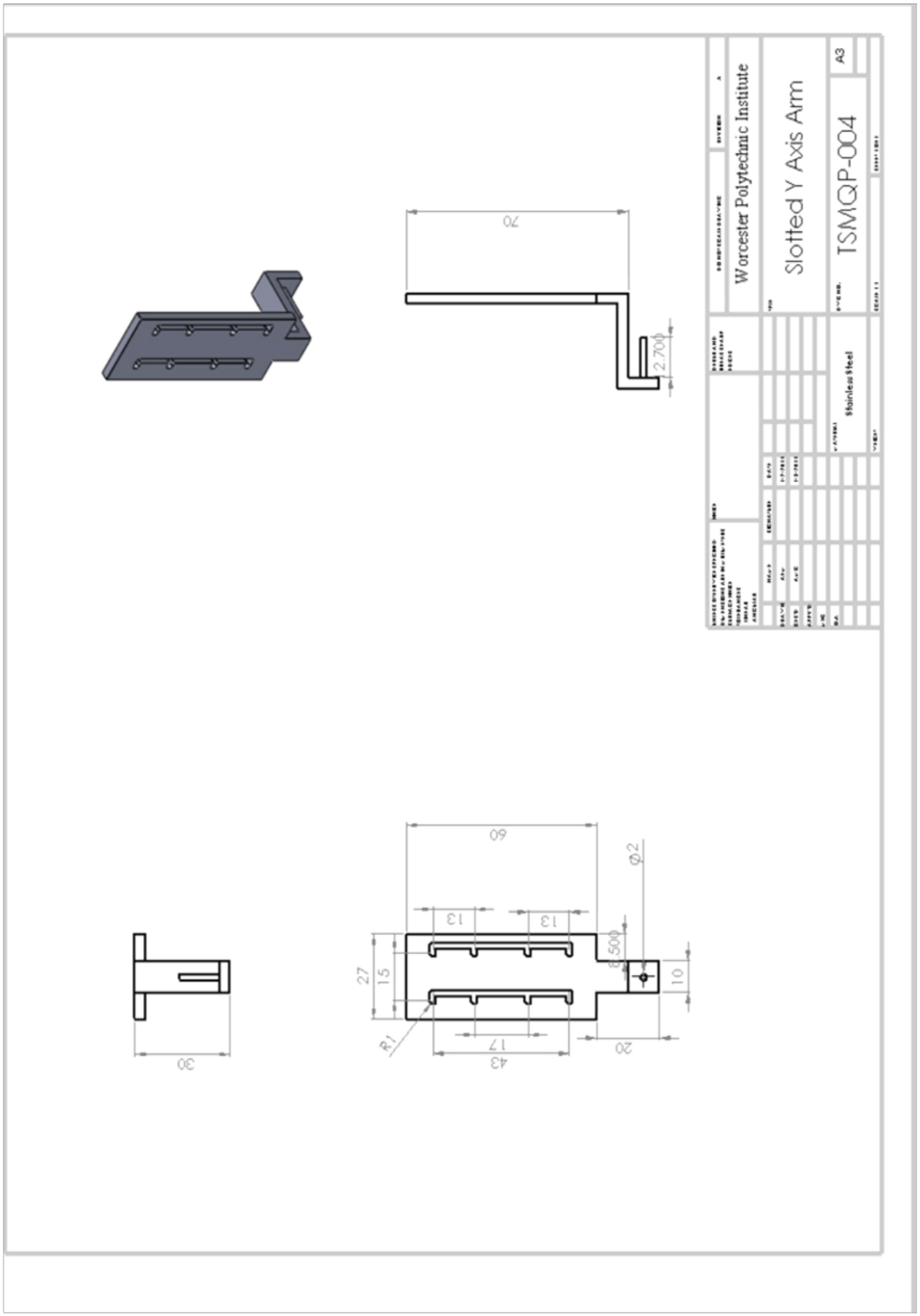
...duct Categories Printed in Bold — *Can't Find It?...See Our More Extensive Main Index.*

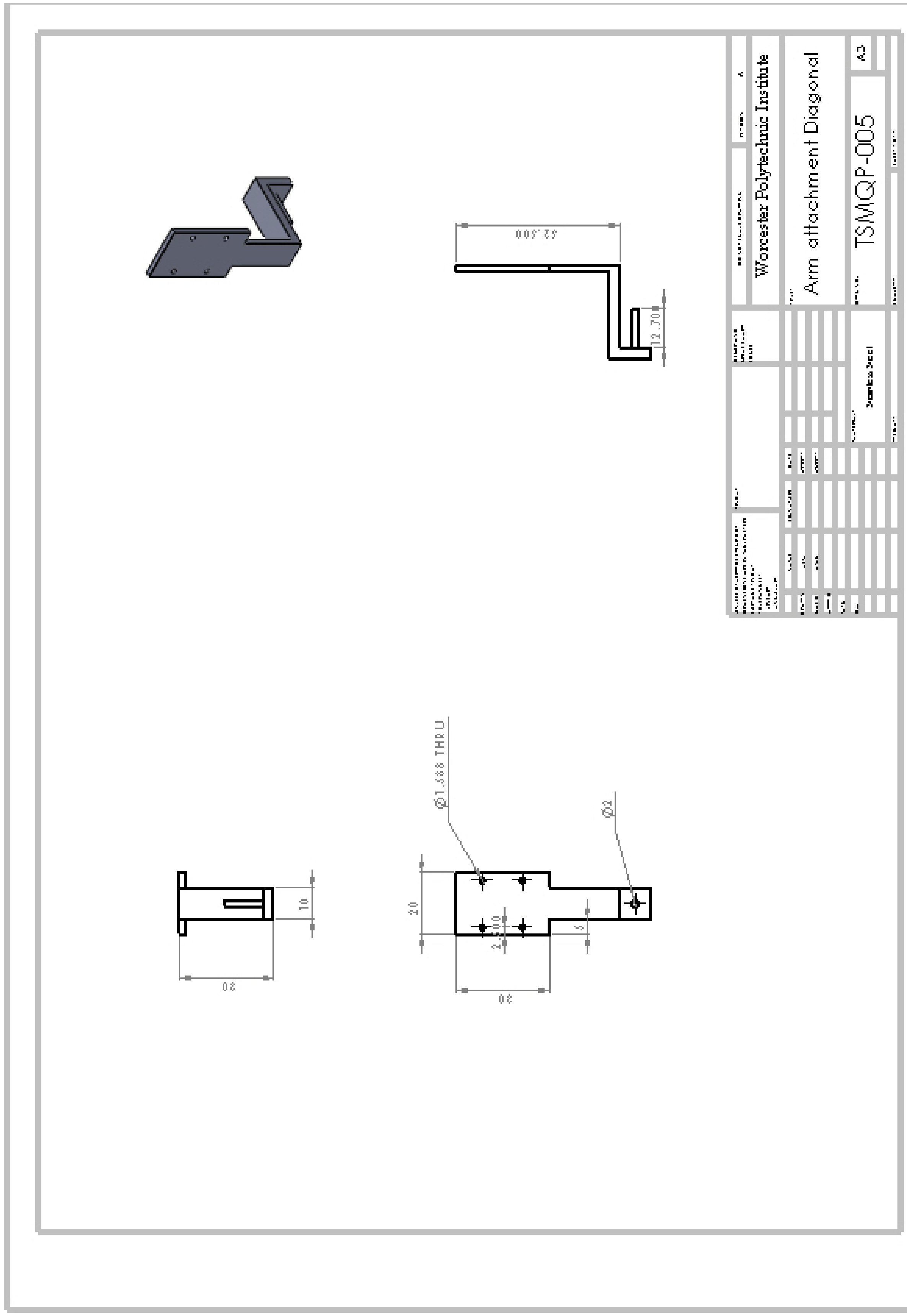
6.8 - Appendix H- Custom Parts

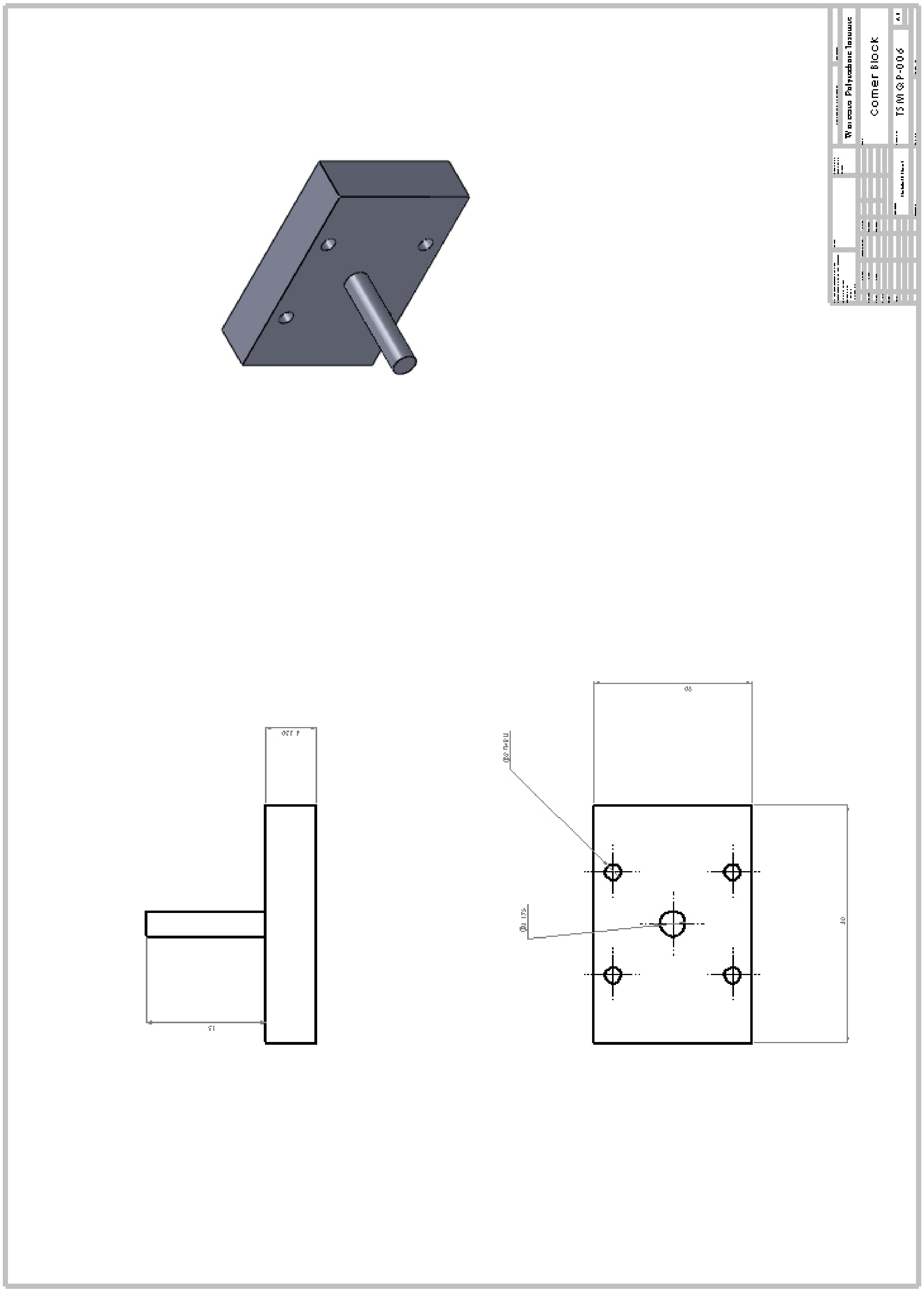



Worcester Polytechnic Institute
Adaptor Plate
TSMQP-002
A2
60
60
133.350
12.700

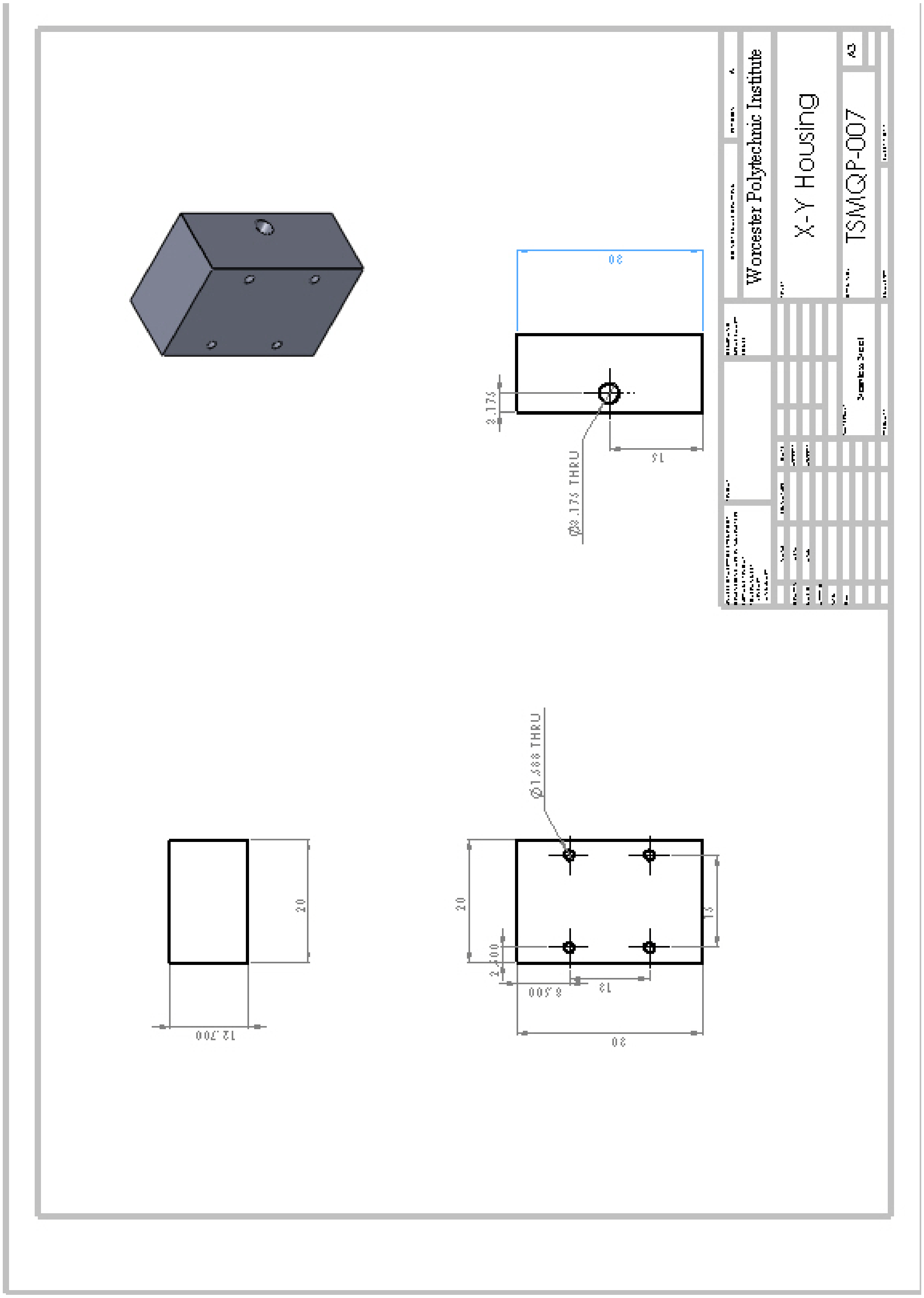

Worcester Polytechnic Institute
Slotted X Axis Arm
TSMQP-003
A2
R1
Ø2
13
15
3.500
6
8.500
13
26
13.175
12.700
26.825
53
27

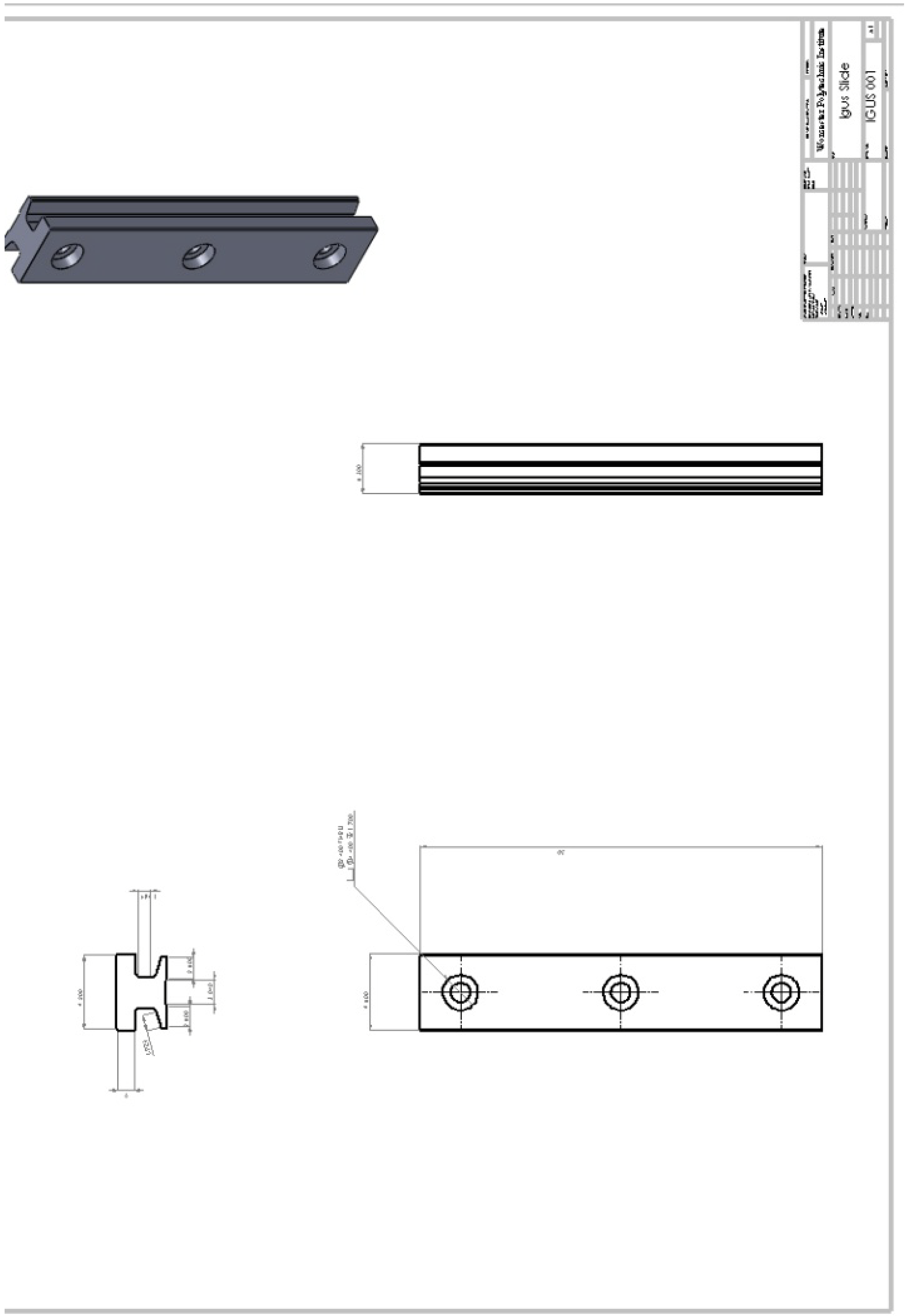

Worcester Polytechnic Institute
Slotted Y Axis Arm
TSMQP-004
Stainless Steel
A3

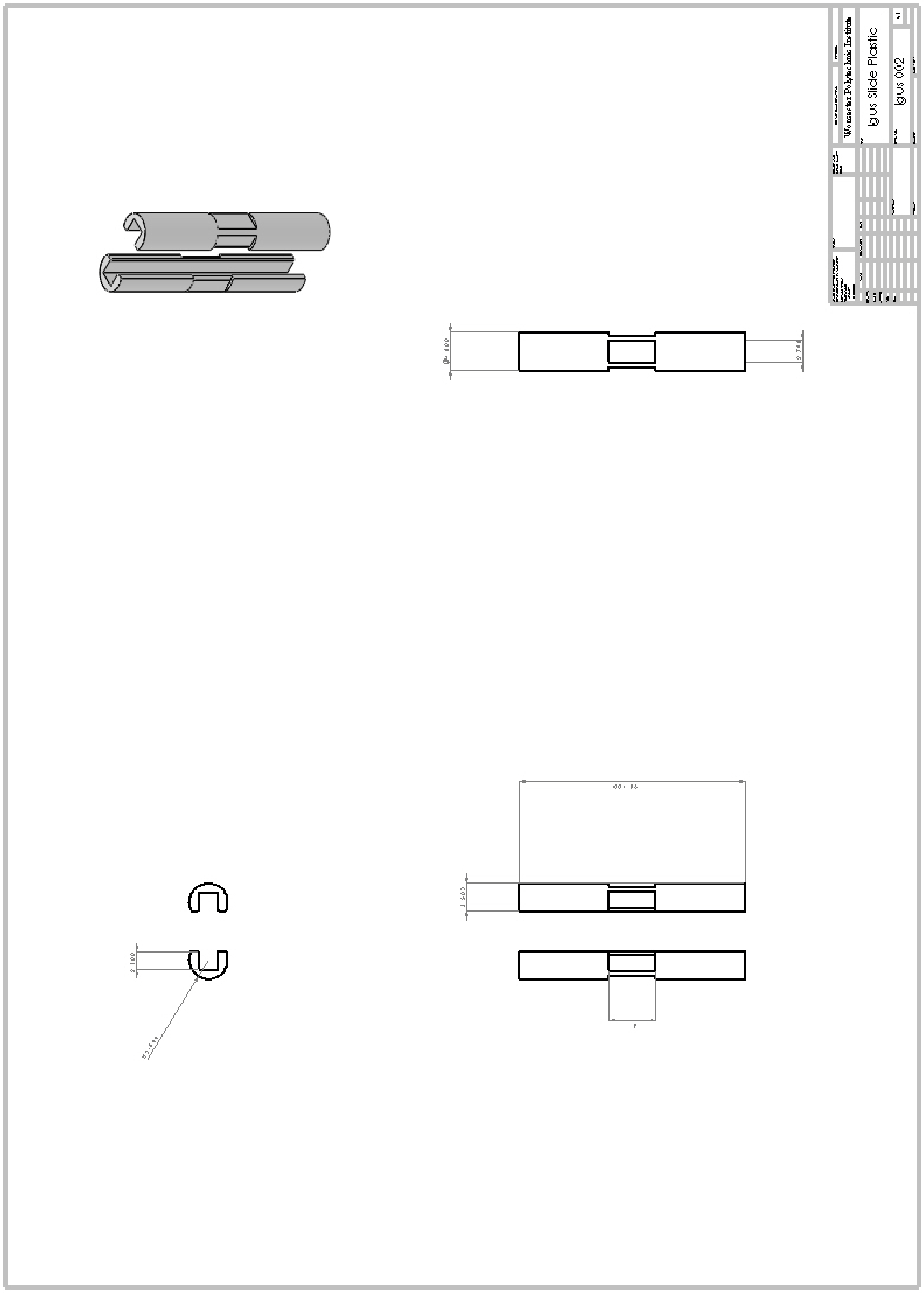

Worcester Polytechnic Institute
Arm attachment Diagonal
TSMQP-005
A3
Stainless Steel
52.500
12.70
Ø1.588 THRU
Ø2
20
10
30
5
2.500

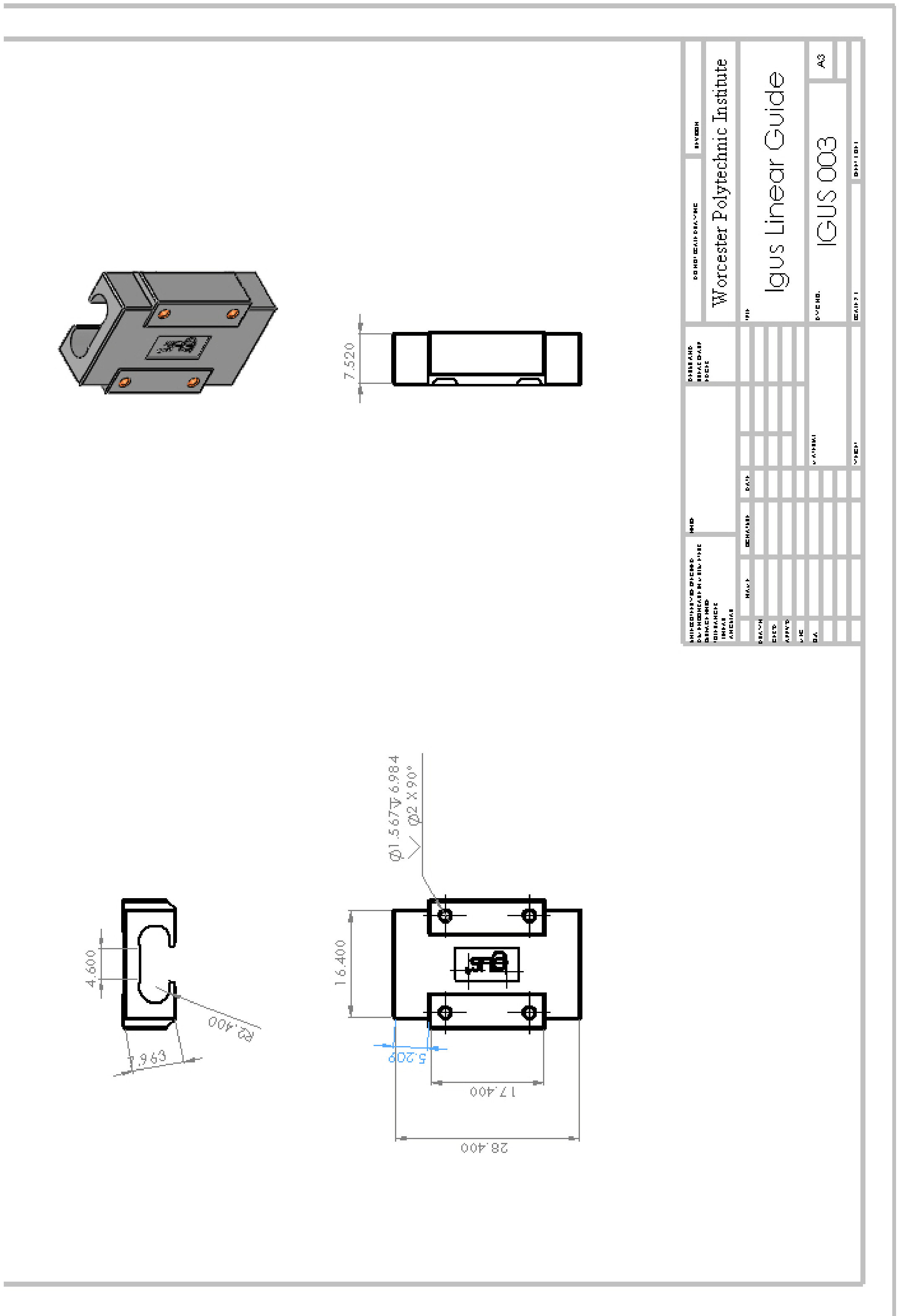


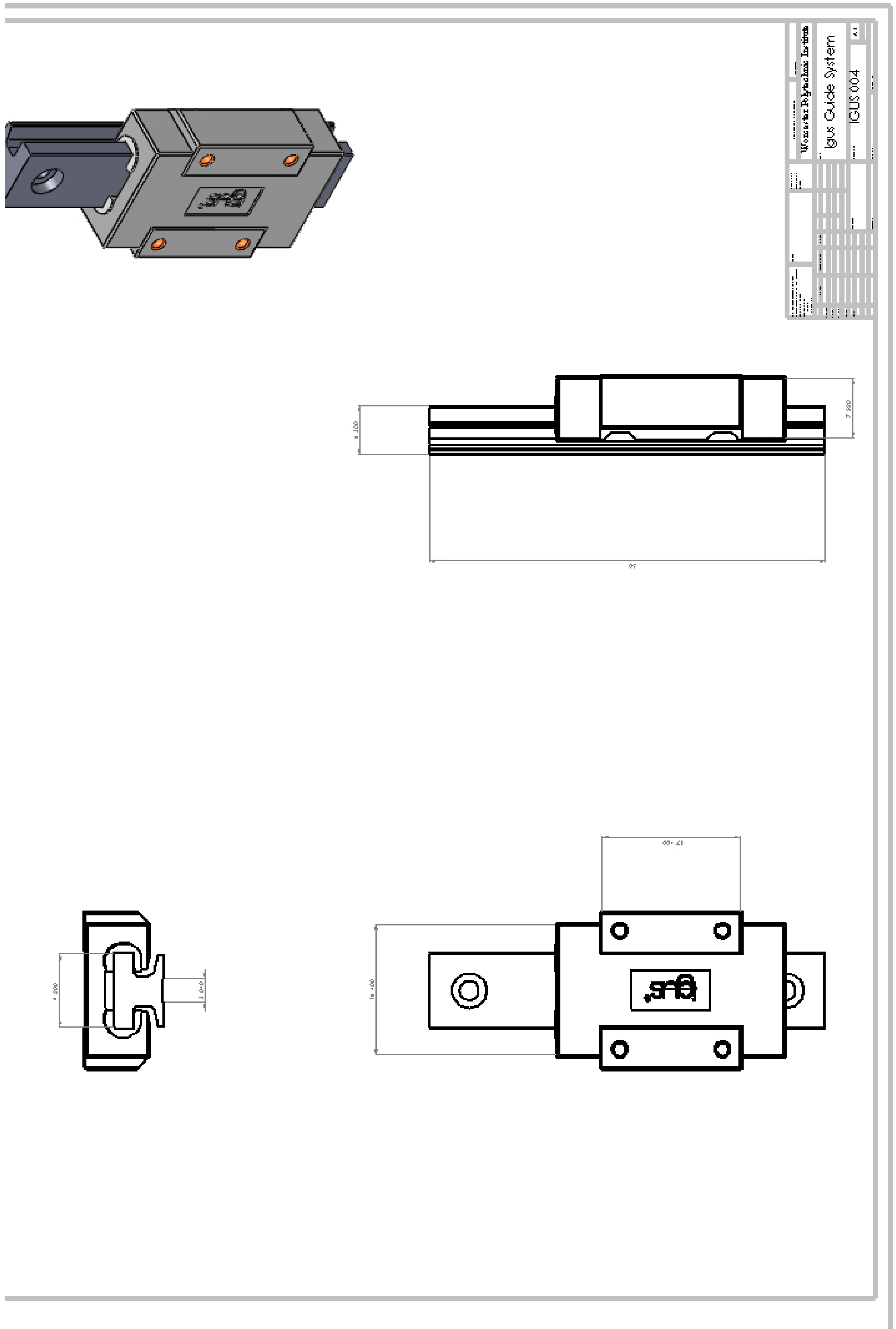
Comer Block
TSM QP-006

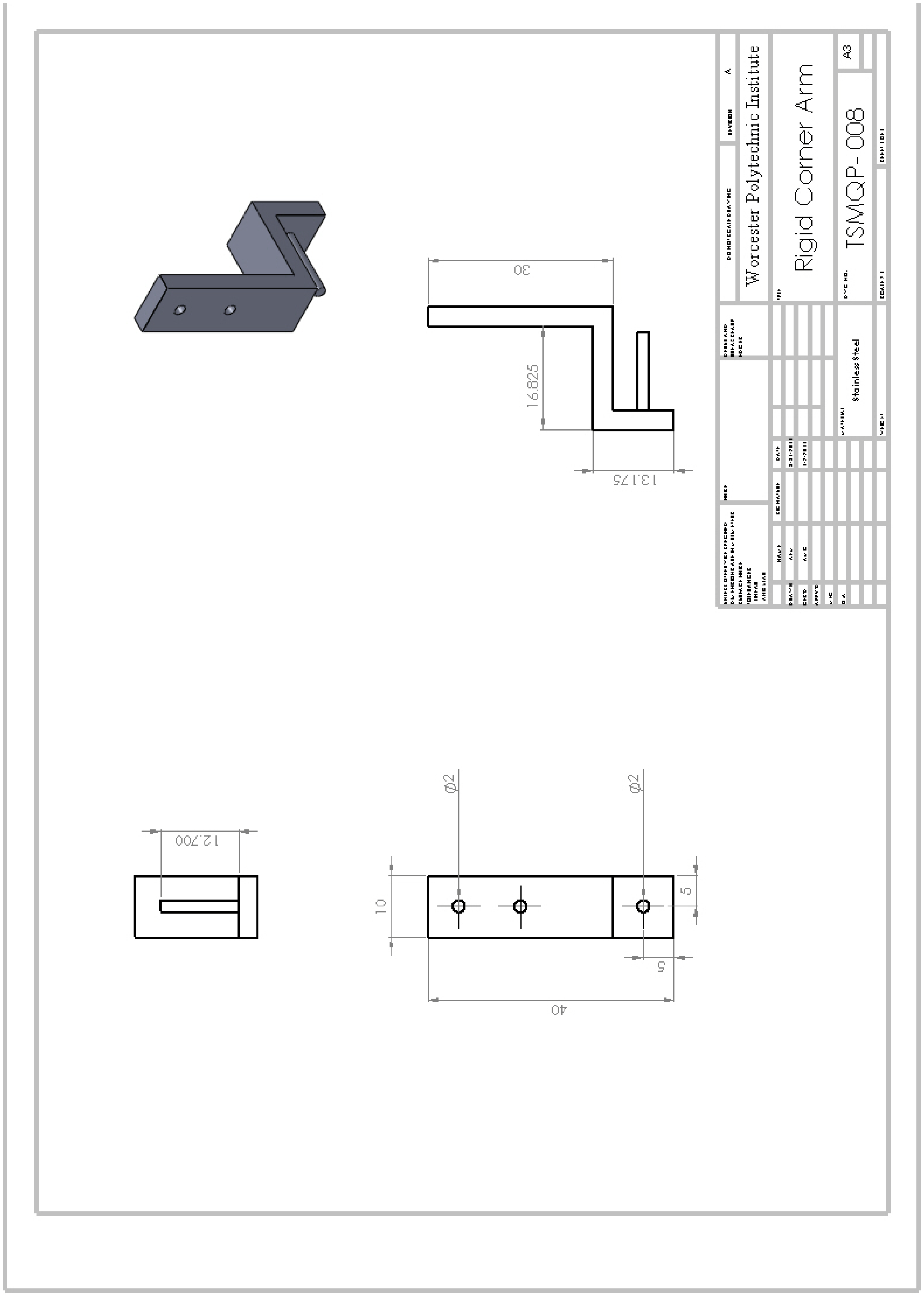

Worcester Polytechnic Institute
X-Y Housing
TSMQP-007
A3
Ø3.175 THRU
3.175
15
80
Ø1.588 THRU
20
13
18
2.500
6.500
80
20
12.700

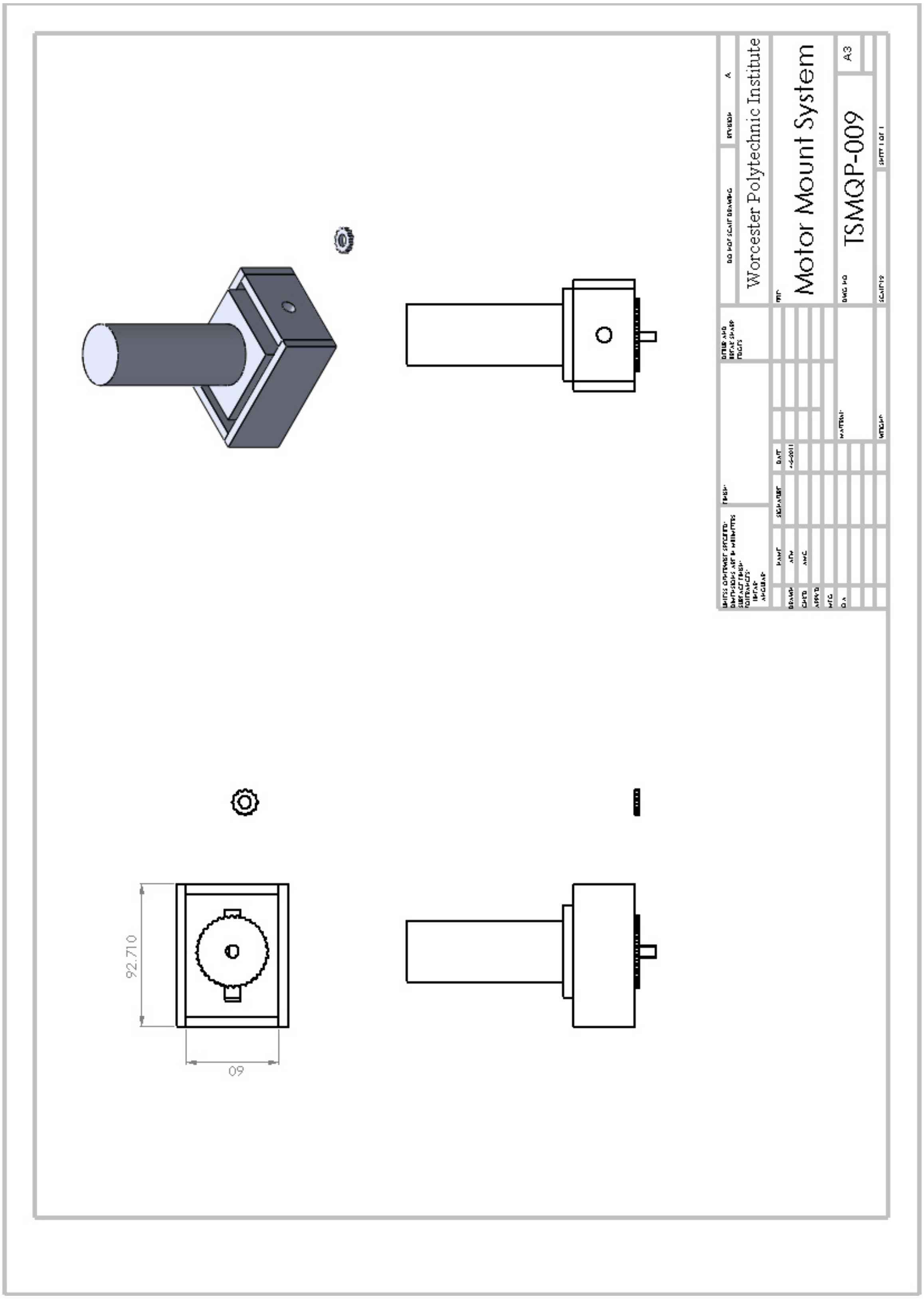

Igus Slide
IGUS 001

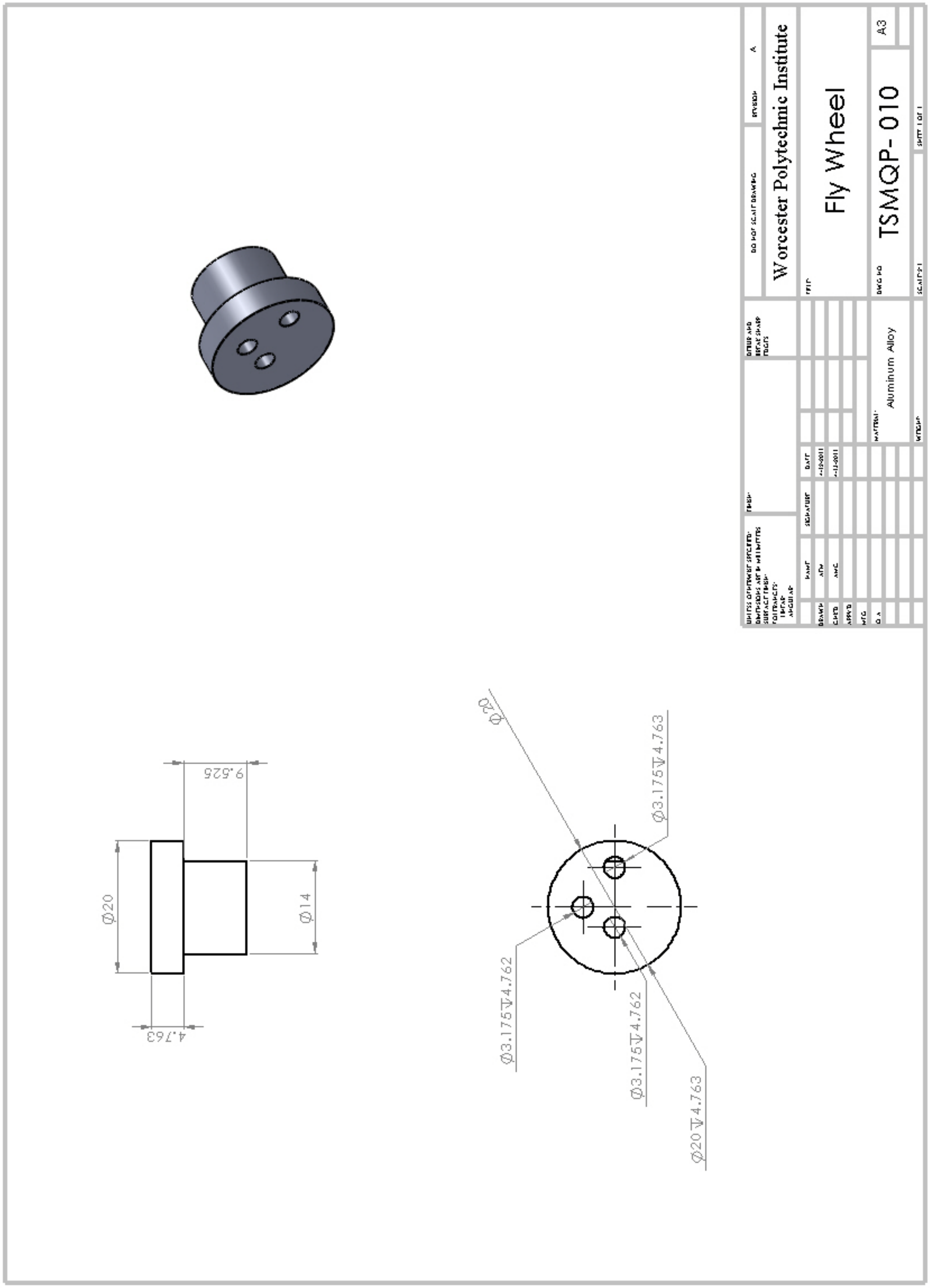

Worcester Polytechnic Institute
Igus Slide Plastic
Igus 002

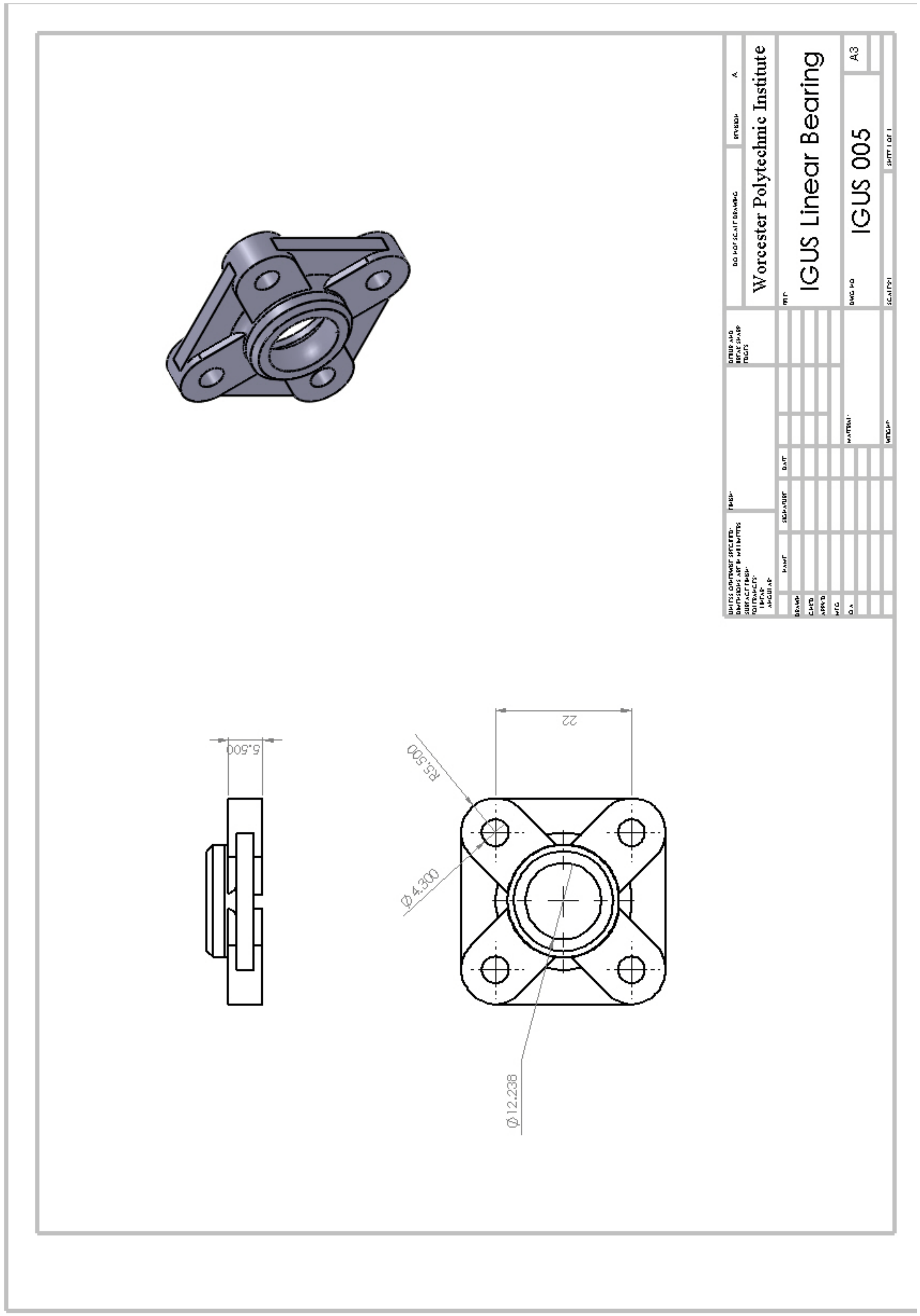

Worcester Polytechnic Institute
Igus Linear Guide
IGUS 003
A3
7.520
16.400
4.600
R2.400
1.963
5.209
17.400
28.400
Ø1.567 ↧ 6.984
Ø2 X 90°

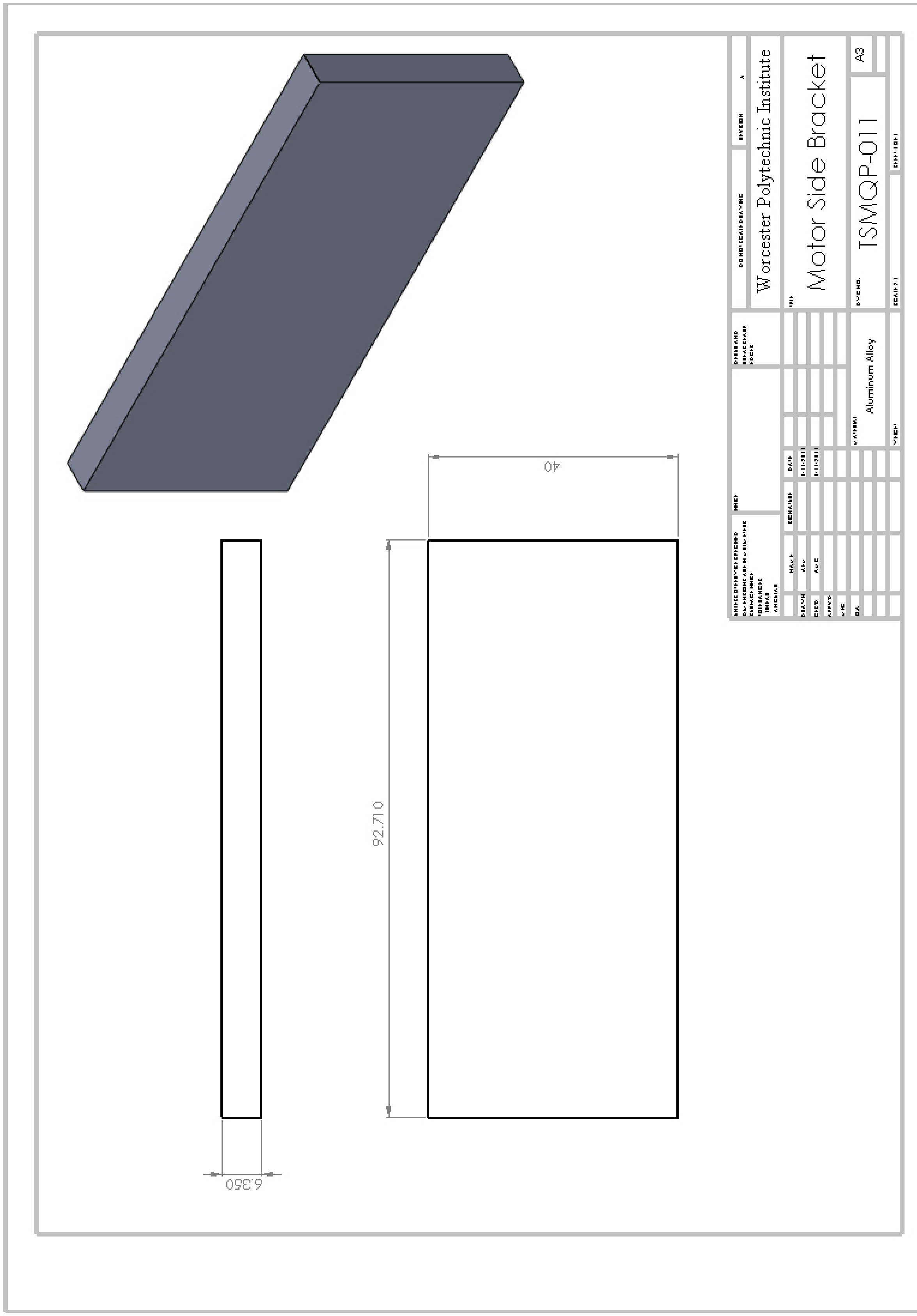

Worcester Polytechnic Institute
Igus Guide System
IGUS 004

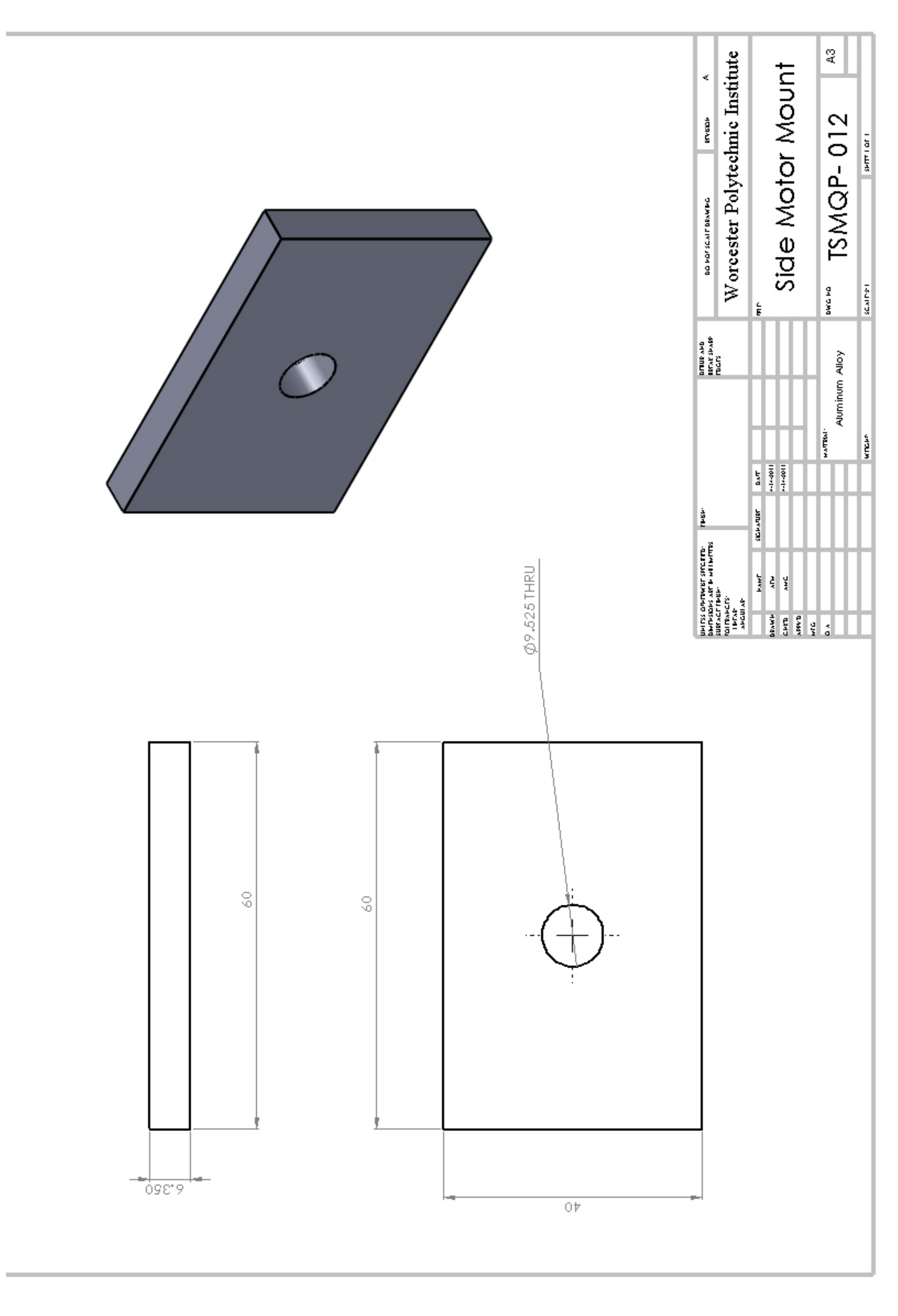

Worcester Polytechnic Institute
Rigid Corner Arm
TSMQP- 008
A3
Stainless Steel
30
16.825
13.175
12.700
Ø2
Ø2
10
5
5
40

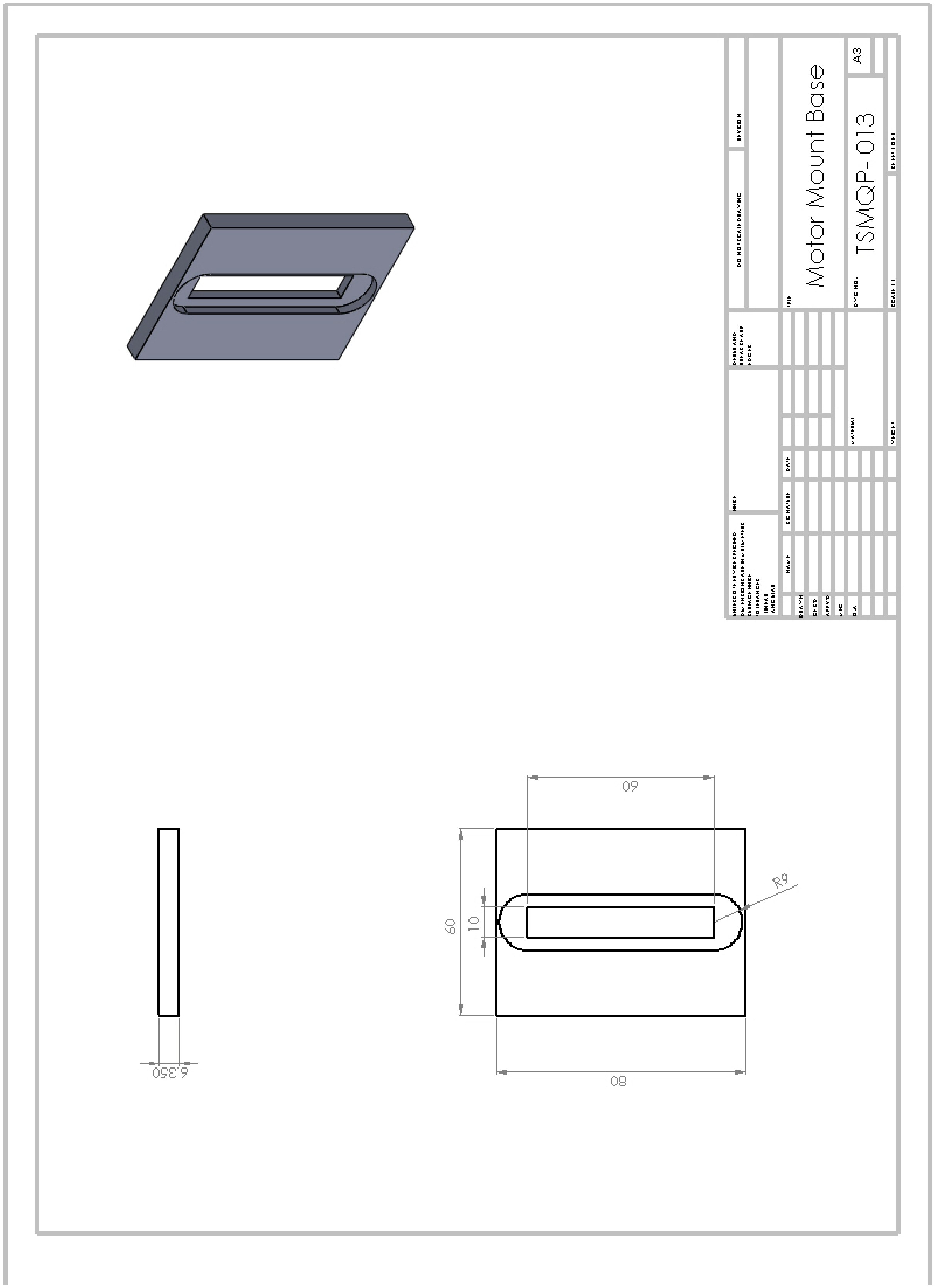

Worcester Polytechnic Institute
Motor Mount System
TSMQP-009
A3
92.710
60

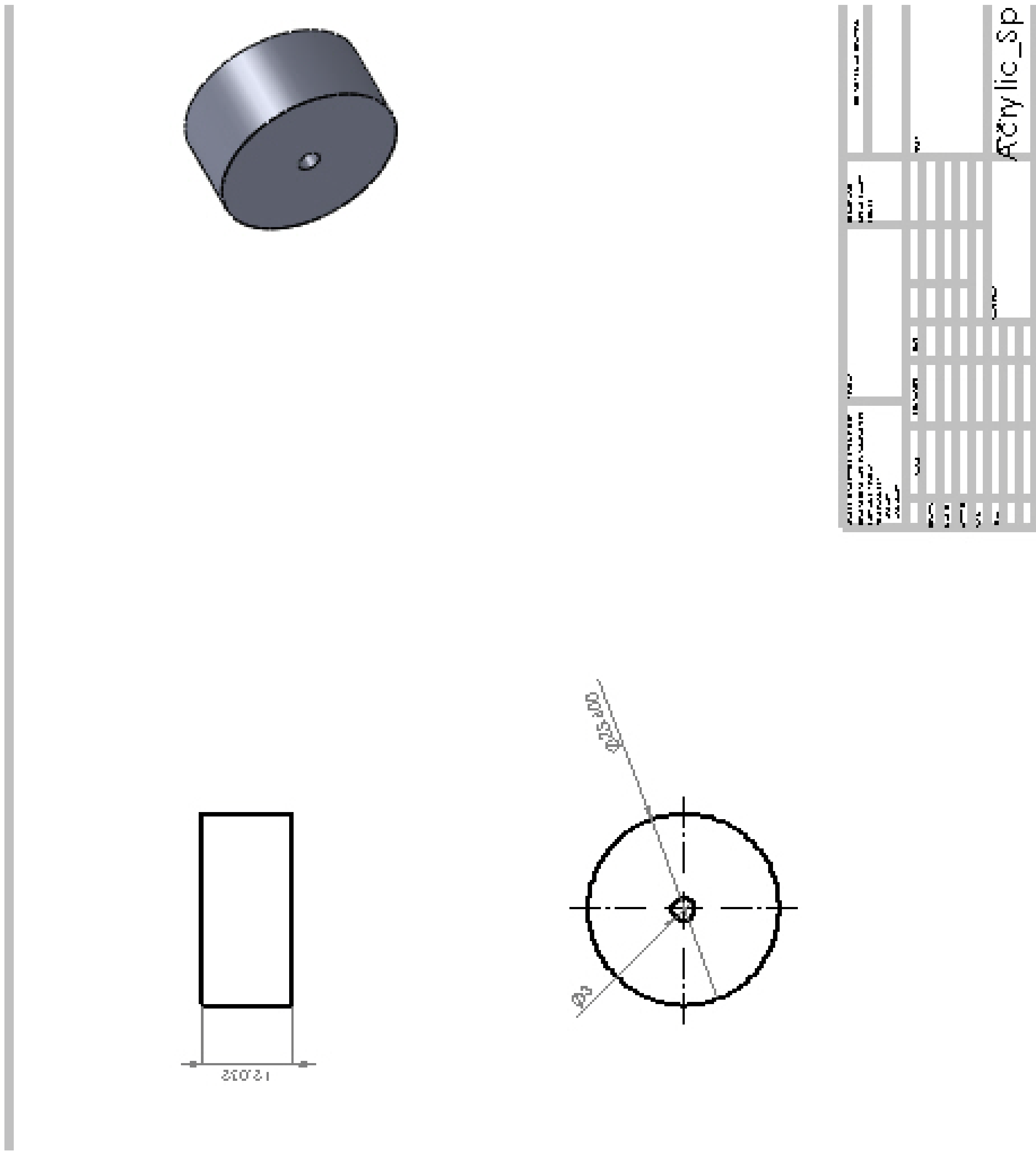

Worcester Polytechnic Institute
Fly Wheel
TSMQP- 010
A3
Aluminum Alloy
Ø20
Ø14
9.525
4.763
Ø20
Ø3.175↧4.763
Ø3.175↧4.762
Ø3.175↧4.762
Ø20↧4.763


Worcester Polytechnic Institute
IGUS Linear Bearing
IGUS 005
A3
22
R5.500
Ø 4.300
Ø 12.238
5.500


Worcester Polytechnic Institute
Motor Side Bracket
TSMQP-011
A3
Aluminum Alloy
40
92.710
6.350


Worcester Polytechnic Institute
Side Motor Mount
TSMQP- 012
A3
Aluminum Alloy
Ø9.525 THRU
60
60
40
6.350


Motor Mount Base
TSMQP-013
A3
60
10
60
80
R9
6.350



6.9 - Appendix I- HDM Matlab Compile Function

This Matlab code was used to compile the over 100 images taken by the camera and put them into matrices.

```
function compile_data(dataset,framerate,res,loadext)
%COMPILE_DATA Compiles and stores data from the HDM Program
%   Imports and reads the HDM data from the input video folder.  This data
%   is then stored in a .mat file as a large multidim matrix along with
```

```
%   several descriptive variables to identify the data.
%   Also, saves data in both a smoothed (using datasmooth.m) and a raw form
%


%% Prepare global variables
    disp('***************************************************************');
    disp(['Compiling data for: ',dataset])
    tic;
    top_dir=['data_store\',dataset,'\'];

%% Verify input
    if framerate < 1
        error('framerate must be a real positive number')
    end
    if ~exist('loadext','var')
        error('loadext input must be specified')
    end

%% Create the output directories
    disp('>>Creating output directories');
    if ~exist([top_dir,'HDM_Data\'],'dir')
        mkdir([top_dir,'HDM_Data\'])
    end
    if ~exist([top_dir,'matlab_data\'],'dir')
        mkdir([top_dir,'matlab_data\'])
    end

%% Check for the existence of HDM data and move it to the correct folder
    disp('>>Checking HDM input');
    % Check for the data files in the correct location
    if ~exist([top_dir,'HDM_Data\start00+im-0001_U.dat'],'file')
        % Check for files in the images folder
        if ~exist([top_dir,'images\start00+im-0001_U.dat'],'file')
            % Return an error
            error('The HDM Data does not exist for this dataset');
        else
            % Move the files to the correct location
            movefile([top_dir,'images\*.dat'],[top_dir,'HDM_Data\']);
            movefile([top_dir,'images\*.txt'],[top_dir,'HDM_Data\']);
        end
    end

%% Load the correlation report file into variables
    disp('>>Loading correlation report')
    %Open summary file and extract xy corner data throughout the data
    %collection process
        file=fopen(strcat(top_dir,'HDM_Data\CorrelationReport.txt'));
        textscan(file,'%s%s',1);
        str='%*s %*s %u %*s %u %d %d %d %d %*s %d %*s %d';
        rawdata=textscan(file,str);
        xxyy=double([rawdata{3} rawdata{5} rawdata{4} rawdata{6}]);
        subsize=double(rawdata{1}(1,1));%#ok<NASGU>
        shift=double(rawdata{2}(1,1));
        pixelshift=double([rawdata{7} rawdata{8}]);%#ok<NASGU>
        fclose(file);
```

```
    clearvars file str rawdata

%% Prepare to loop through the dataset
    disp('>>Preparing to loop through dataset')
    % Overapproximate the width of the data matrix
        cols = round(1.1*(xxyy(1,2)-xxyy(1,1))*shift);
    % Create a format string for data processing
        format='%9f';
        for i = 2:cols
            format = [format,' %9f']; %#ok<AGROW>
        end
    % Load the first data file and determine the exact # of columns
        filename = [top_dir,'HDM_Data\start00+im-0001_U.dat'];
        file = fopen(filename);
        testdata=textscan(file,format,'multipledelimsasone',...
            1,'collectoutput',1,'emptyvalue',0);
        testdata=testdata{1};
        for i = 1:cols
            if testdata(1,i)==0
                break;
            end
        end
        cols = i-1;
        fclose(file);
    % Create the final format string for data processing
        format='%9f';
        for i = 2:cols
            format = [format,' %9f']; %#ok<AGROW>
        end
    % Determine the number of rows and columns in the data file
        file = fopen(filename);
        testdata=textscan(file,format,'multipledelimsasone',...
            1,'collectoutput',1,'emptyvalue',0);
        testdata=testdata{1};
        [rows,cols]=size(testdata);
    % Determine the number of data files to be processed
        filelist = dir([top_dir,'HDM_Data\*.dat']);
        filecount = numel(filelist)/2;
        fclose(file);
    clearvars filename file testdata filelist

%% Prepare data filter
    hsize=[res,res];
    sigma = 0.5;
    filt = fspecial('gaussian', hsize, sigma);

%% Loop through each data file
    disp('>>Beginning loop');
    % Preallocate memory to output variables
        udata_r = zeros(rows,cols,filecount);
        udata_s = zeros(rows,cols,filecount);
        vdata_r = zeros(rows,cols,filecount);
        vdata_s = zeros(rows,cols,filecount);
        errorcount = 0;
        bar= waitbar(0,'Compiling...');
    % Begin time loop
```

```
        tstart=now();
    for t = 0:filecount-1
        waitbar((t+1)/filecount,bar);
        %disp(['>>>>Compiling data at time ',num2str(t+1),' of
',num2str(filecount)]);

    %% Determine file names
        if t==0
            uf='start00+im-0001_U.dat';
            vf='start00+im-0001_V.dat';
        elseif t==(filecount-1)
            uf=['im-',numpad(t,4),'+end0000_U.dat'];
            vf=['im-',numpad(t,4),'+end0000_V.dat'];
        else
            uf=['im-',numpad(t,4),'+im-',numpad(t+1,4),'_U.dat'];
            vf=['im-',numpad(t,4),'+im-',numpad(t+1,4),'_V.dat'];
        end
        uf = [top_dir,'HDM_data\',uf]; %#ok<AGROW>
        vf = [top_dir,'HDM_data\',vf]; %#ok<AGROW>

    %% Process X-Direction data
        curfile = fopen(uf);
        try
            rawdata = textscan(curfile,format,'multipledelimsasone',...
                1,'collectoutput',1,'emptyvalue',0);
        catch err
            err,
        end
        rawdata = rawdata{1};
        smoothdata = filter2(filt,rawdata);
        %errorcount = errorcount + error1;
        udata_r(:,:,t+1)=rawdata;
        udata_s(:,:,t+1)=smoothdata;
        fclose(curfile);

    %% Process Y-Direction data
        curfile = fopen(vf);
        rawdata = textscan(curfile,format,'multipledelimsasone',...
            1,'collectoutput',1,'emptyvalue',0);
        rawdata = rawdata{1};
        smoothdata = filter2(filt,rawdata);
        vdata_r(:,:,t+1)=rawdata;
        vdata_s(:,:,t+1)=smoothdata;
        fclose(curfile);
    %% Calculate remaining time and update waitbar
            tleft = ((1-((t+1)/filecount))/...
            ((t+1)/filecount))*(now()-tstart);
        waitbar((t+1)/filecount,bar,...
            ['Estimated time remaining:',datestr(tleft,'HH:MM:SS')]);
    end
    delete(bar);
    %errpercent = errorcount/(rows*cols*filecount); %#ok<NASGU>
    % Clear extra variables
        clearvars uf vf curfile rawdata smoothdata error1 errorcount t

%% Mark the area of interest in the first image and save it
```

```
    disp('>> Creating overlay image');
    % Load image
        srcimg = imread([top_dir,'images\start00.tif']);
    % Create RGB image container
        outimg(:,:,1) = double(srcimg);
        outimg(:,:,2) = double(srcimg);
        outimg(:,:,3) = double(srcimg);
    % Create a polygon over the region of interest
        x = [xxyy(1,1),xxyy(1,2),xxyy(1,2),xxyy(1,1)];
        y = [xxyy(1,3),xxyy(1,3),xxyy(1,4),xxyy(1,4)];
        [h,w]=size(srcimg);
        poly = poly2mask(x,y,h,w);
    % Reduce the blue and green channels in the ROI
        poly=double(poly);
        poly(poly == 1) = 0.6;
        poly(poly == 0) = 1;
        outimg(:,:,2) = round(outimg(:,:,2).*poly);
        outimg(:,:,3) = round(outimg(:,:,3).*poly);
        outimg=uint8(outimg);imshow(outimg);
    % Save the image to the matlab data directory
        imwrite(outimg,[top_dir,'matlab_data\overlay2.tif'],'tiff');
%% Check for external data and process
     if loadext > 0
         disp('Getting external data files');
     % Check if the external data mat file exists, if not run the helper
        if ~exist([top_dir,'matlab_data\ext_data.mat'],'file')
            comp_ext_helper(dataset);
        end
        load([top_dir,'matlab_data\ext_data.mat']);
     end

%% Export data variables to compiledhdm.mat
    disp('>>Saving data file')
    clearvars bar cols filecount format h i loadext outimg poly rows...
        srcimg w x y;
    engine='HDM1'; %#ok<NASGU>
    save(strcat(top_dir,'matlab_data\compiledhdm.mat'));
    tfinal = toc;
    disp(['Compile data complete in: ',...
        datestr(datenum(0,0,0,0,0,tfinal),'HH:MM:SS')])
    clearvars
end

function num = numpad(num,len)
    if isnumeric(num)
        num = num2str(num);
    end

    if length(num) < len
        num = numpad(['0',num],len);
    end
end
```

6.9 – Appendix J – HDM Displacement in the X Direction Raw Data

-73.78508022	-73.71655226	-79.60941818	-83.87772739	-80.22951883	-81.47400462	-77.29646976	-72.94405112	-70.77668425	-68.62770013	-65.56736077	-63.14018719	-61.28233962	-59.23774052	-56.0877774	-53.29333479	-50.53239329	-48.91594648	-46.91839768	-44.62256384	-42.51373076	-40.39801457	-38.18905777	-35.34893004	-34.09684921	-32.27860939	-30.88581851	-32.60776103	-31.43319817	-22.97956776

-82.17724779	-82.22123719	-80.3652447	-85.63889416	-90.08098457	-93.369115	-92.1982484
-88.81157095	-88.62061156	-91.39818425	-94.75976318	-98.43451148	-97.36129978	-92.96267975
-87.71959477	-91.42168378	-93.8656273	-92.27668136	-92.78360105	-96.43758753	-96.44625323
-89.31652009	-91.92339704	-92.59659147	-90.31967256	-94.22626862	-93.74303669	-94.313364
-83.74240006	-85.30926914	-85.71791167	-84.03563259	-88.09009927	-91.62606406	-91.16331727
-81.33184147	-82.74908484	-83.45654255	-84.48432805	-82.74449713	-87.56414012	-88.62337021
-79.88400966	-81.2443718	-81.89661604	-86.62240251	-82.95951799	-82.71300817	-84.99202304
-74.02867805	-74.22834748	-78.7272802	-80.31395278	-79.85331368	-80.59690028	-80.97284454
-72.67840114	-72.3334041	-75.79480397	-77.00680931	-77.35965602	-76.58552079	-74.82980804
-71.11325202	-72.52858594	-73.09256614	-73.88804831	-73.89948762	-72.52282432	-75.24959294
-68.54392838	-68.16623884	-70.53393689	-71.23414386	-71.83166936	-71.73829751	-73.10867459
-66.6847268	-66.80315196	-67.64958785	-68.14477328	-69.70118966	-68.45624167	-70.32376114
-62.72187583	-57.10637479	-63.74009081	-65.18942301	-66.28937571	-66.40464052	-68.75642405
-61.05394922	-61.18806797	-62.13506801	-62.99941936	-61.50464371	-63.83583997	-65.32904956
-61.32188283	-59.47855361	-59.80407435	-59.99190703	-59.96319703	-60.92500121	-61.08213652
-58.16443664	-55.24656239	-58.07699814	-54.04523766	-57.3133421	-58.82735603	-59.09908877
-56.75615891	-56.51487462	-62.31146432	-55.68738048	-56.03706081	-55.86464981	-56.14373967
-53.77848042	-55.61543221	-55.75698674	-53.99954076	-53.59490901	-53.84599031	-53.79270828
-55.53293586	-51.26584481	-51.29850828	-52.28600798	-51.37358884	-51.5139752	-51.38793544
-50.21837824	-48.12019551	-49.79926575	-48.92821039	-48.7471195	-49.75498827	-48.54934614
-45.35513797	-45.60975204	-46.72116423	-46.4366046	-43.54528598	-47.06341718	-47.30137482
-44.99813563	-45.58643279	-45.94834625	-45.33723247	-44.56110726	-44.2226626	-45.45259699
-43.32699429	-42.45725848	-48.24416669	-44.25547916	-43.13982047	-43.03867596	-42.76841466
-41.84771832	-41.63946569	-42.38645543	-40.37638752	-38.9885705	-40.87314075	-40.97064589
-38.40044486	-42.62001631	-45.30009613	-39.532965	-38.587952	-38.32918085	-38.40398924
-36.0012261	-29.17935281	-36.65125224	-36.69500909	-36.39073822	-35.08057831	-36.76690844
-35.3905884	-34.58906455	-35.51722845	-34.20516363	-31.84456068	-31.43979949	-34.2124325
-35.2081248	-34.24569054	-32.77682314	-30.69073947	-28.36930028	-29.55200392	-31.26279251
-40.8786813	-34.71636141	-31.72974163	-26.12673289	-25.33421844	-31.18890509	-33.93726891
-32.01451542	-28.20476352	-25.73050701	-26.02377508	-25.51602535	-27.36470247	-28.05968708

-75.04461904	-75.1468258	-76.52466806	-76.63285608	-76.47694965	-78.5838413	-82.72362928
-81.67107689	-77.72193717	-83.35510625	-84.7346017	-85.54500519	-86.16725094	-88.34514364
-80.61016457	-79.47063521	-80.94534176	-82.23925973	-83.92454828	-90.27588994	-81.55610197
-79.6338258	-78.74507363	-74.20506181	-76.32023148	-77.6178813	-83.08155306	-81.19137741
-74.99736151	-78.54960986	-77.99193681	-80.07770032	-78.85337915	-80.51923052	-81.81317494
-76.02866838	-81.13814121	-77.02773388	-76.72086173	-78.443404	-79.21451373	-80.25659777
-74.66385553	-73.44988022	-70.03522819	-73.99013833	-75.29149906	-81.67773401	-78.51251478
-72.64109982	-72.81946306	-71.42193013	-72.95863499	-70.19218131	-74.51426758	-76.91146863
-68.9625169	-69.26703708	-70.33283129	-71.21676881	-68.84893003	-66.77041751	-68.60373337
-69.64833108	-66.20137798	-70.16309883	-68.4263159	-69.31518694	-74.07032644	-71.24443301
-65.89129871	-67.82840005	-66.22651519	-66.3704488	-66.99911365	-68.62689015	-68.99018493
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-61.06079763	-58.88072135	-60.64708267	-61.59170202	-61.92251969	-61.86392255	-62.49575155
-59.23590014	-56.63067651	-60.45980695	-60.27401632	-60.58950752	-57.31160049	-56.76334354
-58.714123	-57.34020279	-59.76678295	-58.52795707	-58.4282286	-58.58826991	-65.32044278
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-55.28323086	-50.49444637	-53.35490546	-54.22993943	-52.86202051	-48.4717116	-47.51826418
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-49.35547082	-50.82709626	-50.90870167	-55.81860073	-54.95411087	-59.21301725	-52.51698673
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-42.78884257	-43.05126228	-42.99822287	-43.08237923	-41.24554552	-42.70550025	-42.98718745
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-29.39608525	-34.89202351	-37.13819662	-36.41599079	-38.89019979	-34.92571801	-33.3745182
-31.21356866	-35.33720953	-34.44131758	-35.60471891	-34.54181219	-33.81608826	-33.63929098
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-76.95642254	-71.36028887	-77.37487852	-78.84298168	-79.2827836	-80.68286926	-81.85314124
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-56.50871934	-57.1215617	-57.46083986	-51.53136963	-56.45242499	-58.93641041	-61.17207507
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-49.33446022	-49.22583844	-46.30375768	-49.6340268	-48.11889239	-51.7419003	-48.38031523
-47.34905439	-47.51831459	-47.52997499	-49.81094712	-49.60003453	-49.42098601	-48.90156794
-45.20427452	-44.96658211	-46.97231229	-51.43864101	-48.31433293	-46.84176112	-46.24565333
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-57.69575721	-57.12632097	-54.19685887	-53.04641249	-54.04776521	-57.20264405	-57.03659061
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-44.51751753	-48.19185816	-49.89388142	-49.80386	-49.69603789	-49.97646869	-50.75091269
-44.35126677	-45.2337149	-47.03326451	-47.84451166	-48.38344284	-48.70017318	-49.16779383
-43.50874179	-43.62413261	-46.08506097	-46.02838849	-46.01496708	-46.28549739	-46.35786167
-41.65899508	-41.56229715	-44.11544932	-44.01964081	-44.43166177	-44.96643982	-45.70295833
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-37.17432964	-38.62902161	-39.34564495	-37.58025147	-38.87803789	-38.61077356	-38.01532488
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-26.16684024	-26.20709125	-25.48127104	-26.91583832	-28.0297205	-27.33146518	-26.91460166

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6.11 – Appendix K- HDM Displacement in the Y Direction Raw Data

5.578534	10.11806	7.38725	5.951777	4.486088	2.203809	7.520539	3.974051	-6.10189	-12.8247	-13.8686
6.263864	7.702092	7.255365	6.101267	3.207882	5.140925	5.512594	7.802004	-8.36874	-9.15932	-14.7797
9.111347	8.225746	7.583588	5.653534	5.678908	11.51807	4.814772	4.371748	-5.23469	-9.94431	-10.3125
9.310844	8.676324	11.92402	4.019557	6.042693	16.9828	5.620788	2.857015	-5.14548	-11.9733	-10.5381
9.032394	7.979337	7.744074	5.521701	5.061678	6.302239	6.269172	2.352209	-1.99062	-8.63036	-9.20717
8.596685	5.881861	5.849196	5.229022	3.828929	3.714629	2.818338	-1.51838	-5.90798	-9.8227	-13.9682
8.813399	6.24731	5.88053	2.325402	0.863219	2.847127	2.53394	-0.96048	-3.41991	-9.35375	-10.2656
9.788691	6.758629	1.279457	3.168402	-2.06315	2.179552	2.445272	-0.97858	-5.24291	-8.08807	-6.84603
8.259836	7.1185	2.741031	9.877633	5.474016	3.656819	2.458011	-1.17464	-5.22365	-9.85813	-8.48142
8.835851	7.898377	-2.61614	4.368208	3.884687	3.561404	1.47035	-0.73353	-5.20993	-8.10843	-7.84918
8.222374	7.594442	5.787688	3.162151	0.377872	3.566579	1.423761	-0.54583	-4.19196	-8.78618	-7.85879
7.710182	7.589897	5.19915	-0.52325	1.683839	3.922229	2.387628	-0.32436	-3.49292	-6.88046	-6.69556
8.844604	8.078447	5.806366	4.154233	-0.66754	2.927582	1.763717	-1.11533	-2.97455	-5.34663	-5.79695
8.574807	8.387685	10.44246	9.053573	3.687271	4.427657	2.145418	0.96524	-2.6525	-2.09776	-5.26274
9.36437	7.098137	8.173553	8.623567	3.447759	3.164831	2.906505	0.362011	-1.78926	-3.49556	-4.97002
8.825836	6.718791	3.33328	-2.52796	-2.12708	2.7716	5.352436	1.930578	-0.72026	-3.04951	-3.95822
8.110475	5.165087	3.25976	-0.42701	3.351539	8.069499	3.416503	1.142554	-0.39142	-2.95339	-4.1379
7.66968	7.560472	3.108751	-4.18516	4.717553	7.703695	2.348376	0.00044	-0.06052	-2.40721	-3.96013
8.548996	21.56106	7.52517	-6.42966	2.808106	3.697319	2.035794	0.773207	1.06709	-1.8183	-3.38226
8.830602	5.711545	7.029084	4.221363	5.175182	4.270134	2.978009	1.205572	-1.39435	-2.31853	-3.18521
9.866064	6.384914	9.345816	5.997669	4.344862	4.25649	2.996636	0.657907	1.37382	-0.77197	-2.41216
8.23705	5.062438	4.290196	6.247692	6.346174	5.192456	3.503599	2.635939	1.20003	-0.64695	-0.73103
12.08987	7.451439	4.156875	2.895267	15.93729	13.61509	4.308516	2.677962	1.925389	1.120303	-0.25312
8.495399	6.944301	6.464459	4.880663	5.791145	6.283296	4.364761	3.522363	1.853144	2.126958	0.560649
5.875299	7.448509	8.036433	4.448981	-6.02642	-0.58377	3.496906	3.28618	2.57713	2.258103	1.240737
10.91719	10.69385	7.725077	7.093413	3.376241	5.024533	4.447996	3.762169	3.761717	2.532634	1.175112
8.718493	8.92892	8.996005	7.693639	5.343352	5.295314	5.328058	4.186679	1.48041	2.023144	2.035925
9.106809	7.617126	7.287658	7.042612	5.623661	5.479816	6.774781	7.3852	3.072742	3.341913	5.04946
7.866667	6.048922	7.135771	7.569729	6.130933	5.936012	13.63366	23.38794	8.316503	3.40453	9.141245
5.969036	8.017322	7.943734	6.521759	4.937178	5.413241	4.170099	6.795436	4.098881	3.227135	3.64635

14.96673	15.95152	14.07651	13.4069	7.964413	6.79789	10.69978	11.33787	10.97236	10.10549	8.739087
15.74525	16.54615	16.86628	15.59899	13.36172	12.90302	13.29767	12.88423	12.76003	11.70269	9.128915
17.61362	20.29025	17.27907	15.3589	14.36814	13.73843	14.95553	13.11769	12.54043	11.24542	10.40626
18.13952	17.53072	16.38277	16.48631	16.5479	14.49423	13.94163	12.79406	11.40851	5.836011	10.63593
18.3158	17.19092	16.3796	16.41909	15.21547	13.71186	13.78731	15.93496	11.53291	9.934063	9.01236
18.45005	18.29306	17.41491	15.85737	13.14264	14.08347	13.22787	11.18441	5.79216	10.88456	9.900376
18.70634	18.10383	17.23569	18.18809	15.18951	13.936	10.97272	9.611108	11.37344	18.38571	10.52134
18.09425	17.28772	17.02185	17.55638	15.00123	13.06685	5.691188	2.460381	10.47237	14.70519	10.41992
17.77284	18.10741	16.70995	17.61221	16.24579	14.44662	12.18533	7.353419	10.64053	11.90527	10.79479
19.00631	17.45921	17.7572	23.69872	16.90367	14.07483	13.47522	14.34036	10.53277	16.30462	12.88716
18.88362	17.98158	17.56865	17.49467	16.02988	14.5382	13.70318	12.8484	15.50536	11.75053	10.37933
19.5389	18.2587	17.3085	16.5151	15.33354	14.3027	14.37018	6.701585	12.49418	11.29407	9.998334
18.36973	18.70398	17.58327	16.26739	19.85693	12.39218	12.68457	12.51539	16.97423	9.988273	10.1043
19.3995	18.47928	18.05433	19.0952	17.16986	12.56165	5.123141	8.742422	-3.33939	-0.72928	8.409382
18.51793	18.7634	17.70689	17.18838	14.64068	12.81356	6.395582	10.72321	9.767163	11.06257	7.242405
19.38428	18.47415	16.98999	15.68469	11.34313	14.14717	14.295	12.69117	11.21626	9.332639	8.225859
19.02918	17.93044	16.13905	10.40148	14.3927	13.66226	15.55956	15.12101	9.938681	9.7728	9.22237
18.81421	17.04213	16.08448	14.76285	14.45899	9.978376	7.993024	9.414287	10.84062	10.00667	8.148393
18.98626	18.33139	16.9719	16.92805	14.98172	13.12641	11.96941	10.90572	10.90071	8.722466	7.163153
18.94763	17.54145	16.62061	20.4415	13.96444	13.59492	13.52543	12.42263	11.18026	10.50673	8.268692
18.34216	16.96687	16.05856	15.82421	9.050978	13.54545	15.07443	11.00036	10.52692	10.24652	4.5181
17.26533	17.63617	17.57107	15.2044	13.34541	13.41695	12.0259	9.948907	4.588039	9.550061	12.34754
17.34867	16.0646	14.55438	14.05485	14.70485	16.06165	12.13375	10.93602	8.740915	8.771812	10.04198
16.74735	15.80409	15.03405	14.61349	13.94156	11.12403	15.02483	12.54713	9.729794	9.158105	9.792505
15.78708	16.23583	14.60837	13.42169	12.12629	11.03364	11.60751	11.0593	4.904247	8.553829	6.508197
15.70192	16.72368	14.24006	13.82317	13.01866	11.64888	11.46835	16.6998	5.259608	8.565219	9.556765
14.83898	14.58431	13.40871	12.65673	14.32185	16.74336	10.49611	7.987068	7.709056	8.607778	9.901737
15.47732	13.27356	12.12899	9.736348	18.48409	15.11092	11.2751	5.834519	4.859317	7.071555	9.351534
12.73884	12.36539	11.93936	10.89416	12.1026	10.15321	14.41306	10.74482	9.451813	9.196481	9.39791
9.941836	9.650677	9.161062	9.677025	10.38238	8.549698	8.601415	8.579167	9.605906	7.562437	2.664813

20.18337	30.1964	30.026	25.56962	20.88594	17.18351	16.18361	15.3137
26.16414	37.9555	24.01172	25.3793	23.52698	27.13143	21.77604	18.72819
39.03829	29.28541	24.11309	21.72837	20.73539	21.53715	16.9967	18.56234
32.2487	34.2428	29.39697	15.65143	22.05154	23.48114	18.83664	18.46935
23.98531	45.15818	28.96579	17.6142	15.45846	22.77178	20.57837	19.67672
25.05095	37.10433	21.50564	15.61843	19.11754	21.69138	20.36992	19.05587
26.48727	30.44066	19.36048	15.72682	21.39755	21.83017	20.06689	19.70967
21.50392	28.45147	21.34474	20.98997	20.29209	19.65946	18.20554	18.06862
25.27871	27.06885	20.84194	21.60309	19.78075	16.42486	19.26816	12.68475
24.39493	24.48839	16.36532	19.88606	23.76523	28.29958	22.63069	19.58691
23.26909	17.92034	20.57471	21.43951	22.96803	23.25658	22.51254	20.62002
18.49334	23.1017	21.84649	22.78982	23.41327	23.50916	20.71767	20.54063
25.09584	31.96971	22.55582	22.80326	23.46693	21.82269	21.51797	21.35453
22.45407	24.3462	23.37788	21.31689	22.2943	21.58397	22.04908	20.47421
19.03598	20.622	21.43338	22.46559	22.20412	22.44789	21.93323	20.67213
23.096	22.26983	22.03812	22.59165	21.94695	21.05286	21.31887	21.31363
20.14205	21.9247	21.23977	20.82641	21.50866	20.89551	21.4975	19.59295
20.40959	20.59006	21.00316	20.79017	20.40716	20.69101	20.78094	19.6027
17.28652	18.84781	21.32736	20.41403	20.66515	20.42205	20.18548	19.77941
17.29673	18.98485	20.61573	19.98268	19.70125	19.7112	20.3513	19.39728
17.63051	20.35542	20.67251	19.03392	18.87612	19.59455	18.93278	18.47953
16.89547	19.10732	18.98508	19.11654	18.14253	18.90343	18.52353	17.90474
15.16398	18.35021	18.18092	19.10727	18.21503	18.77337	18.38461	17.74325
14.37823	17.77122	18.38124	18.78659	18.58542	18.37929	17.71849	15.53271
15.01206	17.8158	17.91277	17.45905	17.34003	17.45961	16.97782	14.91944
13.49685	15.62763	15.25792	15.1612	15.92001	16.78139	16.97369	13.80916
12.36746	15.08628	13.40964	14.23103	15.18396	14.88674	14.99643	14.59213
11.36446	13.67686	13.94206	13.85086	12.91579	13.29031	13.7754	14.41434
10.66007	12.76862	13.34058	13.4576	13.44472	13.43155	13.36086	13.55883
7.999584	10.11644	10.17968	10.83321	10.56566	10.59339	11.30213	11.17875

6.12 – Appendix L- HDM Strain in the X Direction Raw Data

-0.56675	-0.47396	-0.35134	-0.41465	-0.39996	-0.68956	-0.57005	-0.5221	-0.24951	-0.04778	0.004283
0.101279	-0.25679	0.424315	0.068249	-0.17507	-0.15422	0.155193	0.353182	0.057732	-0.21772	-0.3683
0.394167	0.449646	0.022795	-0.09981	-0.03136	0.079315	0.122313	-0.09017	0.168409	0.133306	-0.26677
-0.07722	0.160145	-0.03886	0.348383	0.413383	0.429917	0.392752	0.383511	0.132311	0.196878	0.228013
0.025623	0.081545	0.097286	0.15066	0.160012	0.141336	-0.02804	0.3341	0.25387	0.158747	-0.07778
0.196994	-0.15395	0.109005	0.090489	0.094045	0.097495	-0.13363	-0.01344	0.303196	0.226959	0.261096
0.318707	0.447717	0.100065	0.365958	0.438502	0.198083	0.394278	0.194138	0.132257	0.251199	0.272026
0.083953	0.483991	0.519233	0.084392	0.118434	0.18328	0.206696	0.155854	0.250711	0.38394	0.13546
-0.02914	-0.45624	-0.16504	0.097822	-0.0122	0.16889	0.194923	0.216261	0.253919	-0.02624	0.134312
0.144755	0.340215	0.140891	0.160583	0.272647	0.159914	0.165869	0.129239	0.049033	0.133807	0.191271
0.142596	0.185476	0.187368	0.1162	0.085193	0.180272	0.193086	0.133155	0.205128	0.174057	0.151698
0.174691	0.237209	0.218534	0.247678	0.606049	0.244344	0.184709	0.213238	0.128225	0.097959	0.116115
0.083313	0.28452	0.358276	0.104245	-0.25511	0.100314	0.136875	0.299046	0.16055	0.214211	0.127787
0.13508	-0.07979	-0.53482	-0.01675	0.106845	0.145687	0.18797	0.09634	0.181927	0.265432	0.196873
0.313388	0.089792	0.484412	0.19734	0.264499	0.107942	0.371667	0.165616	0.131103	0.12394	0.174653
0.0345	0.542493	0.628224	0.088017	-0.07927	-0.26465	-0.10263	0.079768	0.185169	0.184709	0.172559
-0.01763	-0.30744	-0.49327	0.186105	0.056215	0.409655	0.10549	0.152634	0.126166	0.146939	0.101028
-0.11313	-0.3639	0.180846	-0.10965	0.271849	0.278655	0.107096	0.138833	0.145751	0.150298	0.124847
0.399391	0.619489	0.292338	0.33216	0.196603	0.093703	0.209862	0.164154	0.109937	0.177412	0.14349
0.265668	0.252814	0.685983	0.303953	0.156903	0.192381	0.155725	0.325115	0.168223	0.077998	0.131802
-0.01969	-0.05627	-0.53886	0.022313	0.001457	0.048301	0.068711	-0.06349	0.177547	0.115549	0.132232
0.211419	0.21569	0.156151	0.104446	0.195573	-0.14349	0.06761	0.08883	0.073999	0.167761	0.13806
0.054101	0.148243	0.226952	0.092455	0.051112	0.366107	0.242443	0.259453	0.135346	0.112361	0.177508
0.090853	0.282744	0.157753	0.215455	-0.06128	-0.1821	0.052714	0.025039	0.158997	0.160416	0.078255
0.476184	0.225087	-0.03217	0.149951	0.840041	0.540553	0.177372	0.137326	0.203038	0.102318	0.11364
-0.47393	-0.16984	0.248252	0.038165	-0.33811	0.070876	0.155615	0.284136	0.227549	0.159655	0.087049
0.271774	0.069352	-0.01655	0.011404	0.021461	0.171275	0.219652	0.217204	0.117987	0.184352	-0.10762
0.111349	-0.0445	0.029088	-0.35441	-0.02942	0.065443	0.28525	0.189693	-0.10231	-0.16715	0.07341
0.160484	0.134991	0.245403	0.55401	0.406975	0.374952	0.006435	-0.01136	0.239013	0.367349	0.528352

-0.67714	-0.98576	-0.58301	-0.47037	-0.39359	-0.53066	-0.50669	-0.41415	-0.16094	-0.4269	-0.50636
0.238909	0.4157	0.07746	0.047518	0.11664	0.099691	0.068506	0.066307	-0.10929	0.15061	0.155959
0.137123	-0.22494	0.059881	0.119545	0.18552	0.174313	0.196688	0.061021	0.045348	0.421267	0.369939
0.086495	0.015283	0.107342	0.160961	0.072306	0.123879	0.124457	0.289779	0.012216	-0.23668	-0.23484
0.125426	0.178232	0.091085	0.162505	0.160033	0.088314	0.070758	-0.06446	-0.16178	0.060263	0.209802
0.091766	0.06184	0.130501	0.35552	0.049164	0.068933	0.08958	0.085301	0.480516	0.437032	0.17067
0.136981	0.103901	0.142603	-0.11868	0.016163	0.203141	0.825745	0.126422	0.039401	-0.08667	0.064469
0.070937	0.145186	0.098322	0.093354	0.179352	0.084827	-0.46235	0.229911	0.222027	0.068069	0.108867
0.102795	0.084945	0.117764	0.423562	0.205421	0.122044	0.060307	-0.04286	0.191604	0.010608	0.174403
0.112377	0.096981	-0.18675	-0.24559	0.07653	0.099213	0.144432	0.234815	-0.10169	0.246036	0.128492
0.158025	0.199996	0.381099	0.065547	0.117583	0.247087	0.5504	0.209898	0.328216	0.646645	0.245472
0.133146	0.170598	0.182599	0.34965	0.350842	0.481097	-0.1769	0.092009	0.231014	-0.29793	0.0532
0.12291	0.057899	0.120182	0.340602	0.013984	-0.33369	-0.13056	0.114056	0.140628	0.011705	0.082355
0.036233	0.155343	0.176783	-0.16731	0.075542	0.094683	0.002305	0.032611	-0.04435	0.043314	0.109129
0.193681	0.133257	0.128748	0.119291	0.578937	0.249348	0.357067	0.172201	0.138511	0.32723	0.159005
0.118825	0.080997	0.087683	-0.00796	-0.26634	0.09327	-0.12682	0.04223	0.289349	0.073512	0.109621
0.099652	0.123885	0.304103	0.174562	0.132704	0.012356	0.566936	0.238851	-0.08248	0.028308	0.059007
0.124088	0.10672	-0.07664	-0.01106	-0.09257	0.145057	-0.03258	0.131634	0.06169	0.12458	-0.1583
0.134049	0.159483	0.034854	-0.10173	0.080356	0.161202	0.165995	0.279702	0.262318	0.307059	0.380645
0.118663	0.143171	0.227301	0.409561	0.059164	0.065332	0.328363	0.035904	0.051746	0.085562	0.015359
0.032646	0.003888	0.222907	0.186216	0.234376	0.144565	-0.15756	0.00038	0.194467	0.023562	0.189343
0.173208	0.121773	-0.09971	0.018334	0.074723	0.400011	0.131951	0.094428	-0.02254	0.078222	0.210668
0.066515	0.157329	0.153704	0.114852	0.242823	0.14946	0.139329	-0.10474	0.107695	0.127405	0.122213
0.087711	0.095167	0.09183	0.095432	0.049433	-0.16782	0.040321	0.276259	0.116128	0.084076	0.024425
0.134388	0.126745	0.138073	0.12972	0.039968	0.009566	0.104923	0.367176	0.416481	0.093518	0.192591
0.080897	0.019573	-0.0058	0.052325	-0.18117	-0.06391	0.19414	0.298356	-0.13035	0.061252	0.077421
0.114164	0.088362	0.006508	-0.01564	0.059194	-0.05683	0.37337	-0.11359	-0.02782	0.168555	0.050704
0.055041	0.097301	0.199335	0.193291	0.385583	0.361496	-0.05195	-0.30914	0.09847	0.074394	0.124146
0.262692	0.259658	0.264274	0.280507	0.346369	0.254969	0.067149	0.422298	0.201615	0.285615	0.199246

-0.47558	-0.56836	0.41983	0.740719	-0.56124	0.444908	-0.19631	-0.39977
-0.06537	-0.0682	0.204194	-0.02329	-0.02981	-0.56761	0.042259	0.027022
0.743414	1.14442	0.428979	-0.37667	-0.53709	-0.173	-0.08492	0.13715
-0.29736	-0.83262	-0.95853	0.261868	0.418156	0.52159	0.180928	0.13524
-0.16772	0.670625	-0.17811	-0.69906	0.274193	-0.06833	0.059506	0.078177
-0.15811	-0.08756	1.231549	0.525631	0.370217	0.087651	0.095286	0.144315
0.76464	0.112951	-0.15604	0.31221	0.0488	-0.00057	0.202882	0.113497
-0.13131	-0.02573	0.108579	0.230263	0.598445	0.108826	0.004512	-0.27129
0.202451	0.18942	-0.04599	-0.04379	-0.37291	0.211457	0.14385	0.394504
0.051388	-0.05692	-0.02444	0.095835	-0.02638	0.058485	0.208105	0.201318
-0.30963	0.139145	0.100355	0.107715	0.227494	0.206519	0.364826	0.14782
0.29195	-0.10177	0.014076	0.127145	0.14182	0.120594	-0.24306	0.133622
0.255608	0.375503	0.240869	0.058331	-0.04846	0.066815	0.144163	0.040146
0.191204	0.17076	0.048761	0.084418	0.025894	0.062724	0.132148	0.100906
0.030909	0.223797	0.255967	0.132739	0.069827	-0.01493	0.042747	0.166125
0.115626	0.05358	0.012808	-0.00655	0.155395	0.157377	0.132578	0.085679
0.044964	0.010391	0.184884	0.178789	0.122459	0.082037	0.079768	0.098945
0.145255	0.052658	0.100599	0.059263	0.113508	0.14803	0.150917	0.175621
-0.04451	0.115609	0.128865	0.123101	0.125547	0.098957	0.082441	0.040931
-0.00886	-0.00801	-0.0247	0.106449	0.052618	0.052659	0.065504	0.158906
0.10017	0.180468	0.082411	0.040963	-0.0069	0.047832	0.103458	0.067144
0.184214	-0.02511	0.170971	0.041098	0.163705	0.191458	0.109233	0.151984
0.076552	0.132941	-0.04536	0.109603	0.193044	0.055153	0.119035	0.102443
0.031342	0.116411	0.164219	0.236569	0.04511	0.091235	0.043136	0.031742
0.105019	0.051316	0.083121	0.067817	0.065463	0.122202	0.13106	0.094727
0.038814	0.067289	0.081068	0.046952	0.106027	0.064356	0.12246	0.125692
0.137701	0.10455	0.082006	0.093482	0.154356	0.151933	0.083163	0.103833
-0.0382	0.052912	0.138922	0.136881	0.041382	0.027253	0.040988	0.07218
0.295863	0.295489	0.227035	0.284822	0.254189	0.221041	0.28415	0.265621

6.13 – Appendix M- HDM Strain in the Y Direction Raw Data

0.197535	-0.28372	0.170675	0.089717	0.091606	0.142642	-0.3323	0.221656	0.629747	0.420176	0.065241
0.179066	-0.08989	0.02792	0.072131	0.180837	-0.12082	-0.02323	-0.14309	1.010672	0.049411	0.351271
0.080932	0.05535	0.040135	0.120628	-0.00159	-0.36495	0.418956	0.027689	0.600402	0.294351	0.023013
0.082818	0.039657	-0.20298	0.494029	-0.12645	-0.68376	0.710126	0.172736	0.500156	0.426739	-0.0897
-0.00125	0.065816	0.014704	0.138898	0.028751	-0.07754	0.002067	0.24481	0.271427	0.414983	0.036051
0.081481	0.169676	0.002042	0.038761	0.087506	0.007144	0.056018	0.271045	0.27435	0.24467	0.259095
0.106746	0.160381	0.022924	0.222195	0.091386	-0.12399	0.019574	0.218401	0.153714	0.370865	0.056991
0.039452	0.189379	0.342448	-0.11806	0.326972	-0.26517	-0.01661	0.213991	0.266521	0.177822	-0.07763
0.158435	0.071333	0.273592	-0.44604	0.275226	0.113575	0.074925	0.227041	0.253063	0.289655	-0.08604
0.253207	0.058592	0.657158	-0.43652	0.03022	0.020205	0.130691	0.137743	0.279775	0.181156	-0.0162
0.13481	0.039246	0.112922	0.164096	0.174017	-0.19929	0.133926	0.123099	0.227883	0.287139	-0.05796
0.14301	0.007518	0.149422	0.35765	-0.13794	-0.1399	0.095913	0.169499	0.198035	0.211722	-0.01156
0.078731	0.047885	0.142005	0.103258	0.301361	-0.2247	0.072742	0.179941	0.116201	0.148255	0.028145
-0.01034	0.011695	-0.12842	0.086805	0.335394	-0.04627	0.14264	0.073761	0.226109	-0.03467	0.197811
-0.13262	0.14164	-0.06721	-0.02813	0.323488	0.017683	0.016145	0.159031	0.134454	0.106644	0.092154
-0.0375	0.13169	0.211594	0.366328	-0.02505	-0.30617	-0.1613	0.213866	0.165677	0.145578	0.056795
0.069493	0.184087	0.119083	0.230423	-0.23616	-0.29487	0.290812	0.142122	0.095873	0.160123	0.074032
0.02992	0.006825	0.278233	0.455869	-0.55642	-0.18663	0.334707	0.146746	0.00381	0.146668	0.097057
-0.08662	-0.81325	0.877243	0.872177	-0.57736	-0.05558	0.103845	0.078912	-0.01837	0.180337	0.097747
-0.03512	0.194941	-0.08235	0.175483	-0.05961	0.056565	0.080758	0.110777	0.162495	0.057762	0.054167
-0.33425	0.217572	-0.18506	0.209259	0.1033	0.005523	0.078741	0.146171	-0.04474	0.134112	0.102512
0.256906	0.198413	0.048265	-0.12234	-0.00616	0.072107	0.105554	0.054229	0.089744	0.115436	0.005255
-0.12799	0.289902	0.20591	0.078851	-0.81513	0.145137	0.581661	0.10191	0.047036	0.050318	0.085839
0.081069	0.096944	0.02999	0.098987	-0.05691	-0.03076	0.119908	0.05265	0.104326	-0.01711	0.097894
0.039556	-0.09833	-0.03675	0.224216	0.654712	-0.34017	-0.25504	0.01317	0.044316	0.019939	0.063585
-0.08503	0.013959	0.185548	0.039479	0.232323	-0.10302	0.036034	0.042864	2.82E-05	0.076818	0.084845
0.073953	-0.01315	-0.00419	0.081398	0.146893	0.003002	-0.00205	0.071336	0.169142	-0.03392	-0.0008
0.015295	0.093105	0.020592	0.015315	0.088684	0.00899	-0.08094	-0.03815	0.269529	-0.01682	-0.10672
0.095703	0.113609	-0.06793	-0.02712	0.089925	0.012183	-0.4811	-0.60964	0.941965	0.306998	-0.35854
-0.20651	-0.12802	0.004599	0.088873	0.099036	-0.02975	0.077696	-0.16408	0.168535	0.054484	-0.0262

0.021685	-0.06155	0.117188	0.041851	0.340155	0.072908	-0.24387	-0.03988	0.022844	0.054179	0.0854
0.186434	-0.05006	-0.02001	0.079206	0.139829	0.028669	-0.02467	0.02584	0.007762	0.066084	0.160861
0.059295	-0.16729	0.188199	0.12001	0.061922	0.039357	-0.07607	0.114865	0.036079	0.080938	0.052448
0.020614	0.03805	0.071747	-0.00647	-0.00385	0.128354	0.034537	0.071723	0.086597	0.348281	-0.29999
0.085058	0.070305	0.050708	-0.00247	0.075226	0.093976	-0.00472	-0.13423	0.275128	0.099928	0.057606
0.037863	0.009812	0.054884	0.097346	0.169671	-0.0588	0.053475	0.127716	0.337016	-0.31827	0.061511
0.062708	0.037657	0.054258	-0.05952	0.187411	0.078344	0.185205	0.085101	-0.11015	-0.43827	0.491523
-0.0016	0.050408	0.016616	-0.03341	0.159697	0.120899	0.460979	0.201925	-0.50075	-0.26455	0.267829
-0.31801	-0.02091	0.087341	-0.05639	0.085401	0.112448	0.141331	0.301994	-0.20544	-0.07905	0.069405
0.036287	0.096694	-0.01862	-0.37135	0.424691	0.176802	0.037476	-0.05407	0.237974	-0.36074	0.213591
0.108525	0.056377	0.025808	0.004623	0.09155	0.09323	0.052189	0.053424	-0.16606	0.234676	0.0857
0.062608	0.080013	0.059388	0.049587	0.073848	0.064427	-0.00422	0.479287	-0.36204	0.075007	0.080983
0.18655	-0.02089	0.070045	0.082242	-0.22435	0.466547	-0.01827	0.010574	-0.27868	0.436623	-0.00725
0.067169	0.057514	0.026559	-0.06505	0.120333	0.288013	0.464907	-0.22621	0.755113	-0.16313	-0.57117
0.134638	-0.01534	0.066032	0.032407	0.159232	0.114195	0.401123	-0.27048	0.059753	-0.08096	0.23876
0.120585	0.056883	0.09276	0.081581	0.271347	-0.17525	-0.00924	0.100239	0.092182	0.117726	0.069174
0.035236	0.068671	0.111962	0.358599	-0.24945	0.045652	-0.11858	0.02741	0.323895	0.010368	0.034402
0.049281	0.110755	0.059854	0.082602	0.018991	0.280038	0.124085	-0.08883	-0.08915	0.052122	0.116142
0.049571	0.04093	0.084968	0.002741	0.121646	0.115957	0.072313	0.06648	0.000313	0.13614	0.097457
0.028103	0.087886	0.057552	-0.23881	0.404816	0.023095	0.004343	0.068925	0.077649	0.042096	0.139877
0.008585	0.085956	0.056769	0.014647	0.423327	-0.2809	-0.09556	0.254629	0.02959	0.017525	0.358026
0.039963	-0.02318	0.004068	0.147917	0.116187	-0.00447	0.086941	0.129812	0.335054	-0.31013	-0.17484
0.024662	0.080254	0.094389	0.031221	-0.04063	-0.0848	0.245494	0.074859	0.137194	-0.00193	-0.07939
-0.07591	0.058953	0.048128	0.026285	0.041996	0.176095	-0.2438	0.154857	0.176083	0.035731	-0.03965
-0.05423	-0.02805	0.101716	0.074168	0.080962	0.068291	-0.03587	0.034263	0.384691	-0.2281	0.127852
-0.1183	-0.06386	0.155226	0.026056	0.050282	0.085611	0.011283	-0.32697	0.715012	-0.2066	-0.06197
-0.01543	0.015917	0.073475	0.046999	-0.10407	-0.15134	0.390453	0.156815	0.017376	-0.05617	-0.08087
-0.06644	0.137735	0.071536	0.14954	-0.54673	0.210823	0.239739	0.340036	0.06095	-0.13826	-0.1425
0.05125	0.02334	0.026627	0.065325	-0.07553	0.121837	-0.26624	0.229265	0.080813	0.015958	-0.01259
0.077307	0.018197	0.030601	-0.03225	-0.04408	0.114543	-0.00323	0.00139	-0.06417	0.127717	0.306102

-0.62581	0.01065	0.278524	0.29273	0.231401	0.062494	0.05437
-0.73696	0.871486	-0.08547	0.11577	-0.22528	0.334712	0.190491
0.609555	0.323271	0.149044	0.062061	-0.05011	0.283778	-0.09785
-0.12463	0.302865	0.859096	-0.40001	-0.08935	0.290282	0.022955
-1.3233	1.012025	0.709474	0.134734	-0.45708	0.137088	0.056353
-0.75334	0.974918	0.367951	-0.21869	-0.16086	0.082591	0.082128
-0.24709	0.692511	0.227104	-0.35442	-0.02704	0.110205	0.022326
-0.43422	0.444171	0.022173	0.043617	0.039539	0.09087	0.008557
-0.11188	0.389182	-0.04757	0.113896	0.209743	-0.17771	0.411463
-0.00584	0.507692	-0.22005	-0.24245	-0.2834	0.354306	0.190237
0.334297	-0.1659	-0.05405	-0.09553	-0.01803	0.046503	0.118282
-0.28802	0.078451	-0.05896	-0.03897	-0.00599	0.174468	0.011065
-0.42962	0.588368	-0.01547	-0.04148	0.102765	0.019045	0.010215
-0.11826	0.06052	0.128812	-0.06109	0.044396	-0.02907	0.098429
-0.09913	-0.05071	-0.06451	0.016342	-0.01524	0.032167	0.078818
0.051635	0.014482	-0.0346	0.040294	0.05588	-0.01663	0.000328
-0.11142	0.042808	0.025835	-0.04264	0.038322	-0.03762	0.119034
-0.01128	-0.02582	0.013312	0.023938	-0.01774	-0.00562	0.07364
-0.09758	-0.15497	0.057083	-0.0157	0.015194	0.014786	0.02538
-0.10551	-0.10193	0.039566	0.017589	-0.00062	-0.04001	0.059626
-0.17031	-0.01982	0.102412	0.009863	-0.0449	0.041361	0.028328
-0.13824	0.00764	-0.00822	0.060876	-0.04756	0.023744	0.038674
-0.19914	0.010581	-0.0579	0.055765	-0.0349	0.024297	0.040085
-0.21206	-0.03813	-0.02533	0.012573	0.012883	0.0413	0.136611
-0.17523	-0.00606	0.028357	0.007439	-0.00747	0.030112	0.128649
-0.13317	0.023107	0.006045	-0.04743	-0.05384	-0.01202	0.197783
-0.16993	0.10479	-0.05134	-0.05956	0.018576	-0.00686	0.025269
-0.14453	-0.01657	0.0057	0.058441	-0.02341	-0.03032	-0.03993
-0.13178	-0.03575	-0.00731	0.000805	0.000823	0.004418	-0.01237
-0.1323	-0.00395	-0.04085	0.016722	-0.00173	-0.0443	0.007711

6.14 – Appendix N- HDM Shear Strain Raw Data

0.016545	-0.00966	0.125247	-0.0124	-0.03857	0.033785	0.102053	0.258439	0.031915	0.077954	-0.60388
0.114309	0.035809	0.078316	0.000584	0.071252	0.286085	0.083242	0.00764	0.064401	-0.16199	-0.46184
0.0589	0.21256	-0.13685	0.141547	0.127059	0.247146	-0.02447	-0.03149	0.116975	-0.06314	-0.5332
0.03185	0.148959	-0.18969	0.300853	0.050808	-0.31273	-0.05089	0.106306	0.083488	0.12229	-0.28452
-0.05188	-0.01349	-0.01878	0.051142	0.010441	-0.06809	-0.16041	0.005746	-0.01192	-0.05172	-0.49046
0.060602	0.035517	0.033544	-0.05714	-0.04839	-0.005	0.023231	-0.03694	0.228366	0.047756	-0.10771
0.071145	0.215549	-0.2427	0.069203	-0.04894	-0.00048	0.14491	-0.11503	-0.06467	0.110772	-0.13362
-0.13423	0.146311	0.120587	0.119576	0.241776	0.186756	0.049982	-0.02052	0.023839	-0.04357	-0.30201
-0.05599	-0.04058	-0.11012	-0.04484	-0.06045	0.105187	0.007011	0.024811	-0.02376	-0.00019	-0.1069
0.008606	0.1391	0.174311	-0.04179	-0.06536	0.017786	0.023403	0.006223	-0.01121	0.064032	-0.20723
0.00364	0.050726	-0.00704	-0.12911	0.029009	0.085105	0.052002	0.025594	0.018927	0.102378	-0.19932
0.106534	0.044695	0.029383	0.16781	-0.06978	-0.00463	-0.00402	0.02392	-0.02271	0.106292	-0.19641
0.001907	0.007833	0.164623	0.160171	-0.0394	0.254181	0.05722	0.099391	0.013666	0.17502	-0.21687
0.034533	-0.14273	-0.08804	0.120644	-0.00329	-0.00987	0.050795	-0.06556	0.099826	0.002982	-0.18121
-0.01995	-0.00685	0.059122	-0.47344	-0.23182	-0.00212	0.082305	0.048121	0.063463	0.01885	-0.12445
-0.10266	0.068246	0.010773	0.084235	0.080023	0.25401	-0.18649	0.077503	0.057589	0.011495	-0.18704
-0.05652	-0.06234	-0.03451	0.171242	0.035148	0.169712	-0.24038	-0.02476	0.004953	0.02579	-0.1698
0.023049	0.445224	0.201133	-0.12114	-0.00227	-0.12078	-0.06469	0.011504	0.043084	0.016738	-0.13434
-0.01822	-0.36221	-0.22475	0.427093	-0.05938	0.018921	0.060304	-0.015	-0.07253	-0.01957	-0.13352
-0.00403	0.044085	0.026722	0.129847	-0.09152	0.052045	-0.02664	-0.02277	0.118001	0.010654	-0.09855
-0.21245	-0.01186	-0.42025	0.273166	0.070498	0.063981	0.00695	-0.02854	0.104511	0.011343	-0.09708
0.063375	0.122415	-0.02513	-0.12	0.318107	0.274517	0.006056	-0.02294	0.012091	0.093662	-0.14302
-0.16973	0.029776	0.080915	0.072663	-0.34425	-0.04828	-0.12289	-0.00848	-0.00542	0.023012	-0.11767
-0.10522	0.014309	0.018572	0.064378	-0.37581	-0.19125	-0.08994	-0.05075	0.081517	0.007145	-0.15443
0.101	0.004024	0.022213	0.131656	0.425695	0.259012	-0.1505	-0.01466	0.028932	0.010917	-0.13665
-0.26707	-0.027	0.200286	-0.02328	-0.15171	0.241959	0.028869	0.003757	-0.11223	0.036776	-0.11336
0.089454	-0.16488	-0.10186	0.042658	-0.01629	0.034771	0.004208	0.026185	0.037112	0.127856	-0.00978
-0.07197	-0.07169	-0.01027	0.065498	-0.01422	-0.03165	0.14915	0.427541	0.200827	0.055419	0.169899
-0.08612	0.116759	-0.01707	0.208026	-0.22988	-0.10967	-0.47083	-0.54328	0.051158	0.080343	-0.24997

0.006904	-0.22221	0.307394	0.155732	0.255359	0.157527	0.114151	0.054647	0.059059	0.09297	0.015563
0.179646	0.030519	0.031736	0.023404	0.079755	0.061385	0.072786	-0.03265	-0.13027	0.161747	0.083026
0.031751	-0.26111	0.159947	0.08111	0.081861	0.067371	0.004887	-0.04896	-0.07098	-0.12296	0.047612
0.020839	-0.00447	0.045447	0.013946	-0.06088	0.024907	0.020561	0.127143	-0.02389	-0.01381	0.015363
0.043898	0.0762	0.031869	-0.02832	-0.03969	0.035182	0.007612	-0.20213	-0.06839	0.012276	0.092931
0.024087	0.009442	0.037488	0.026362	0.090284	0.054821	-0.0366	-0.03523	0.334086	0.105961	0.009815
0.023225	0.004815	0.002076	-0.17872	0.173614	0.022384	-0.1415	-0.20738	-0.06609	-0.22172	0.120421
0.020567	0.072473	-0.02034	-0.02659	0.150968	-0.00083	-0.08481	0.518645	0.010829	-0.13117	0.059737
-0.10196	-0.01052	0.045566	0.164348	0.089634	-0.0083	0.026144	0.237949	0.006149	0.170786	0.09301
0.001519	0.034983	-0.00946	-0.37263	0.15084	0.059488	0.023827	0.024569	0.047676	-0.01851	-0.13264
0.070301	0.035017	0.130167	-0.17995	-0.00467	0.026306	0.014937	-0.16609	-0.03356	-0.06432	-0.00741
0.008184	0.019287	0.056331	0.000699	0.132425	-0.09079	-0.21024	0.377934	0.141377	-0.25008	0.208396
0.077139	-0.02038	0.056465	0.013283	-0.0935	-0.09092	-0.06486	-0.05611	-0.70293	-0.27972	-0.02345
-0.02397	0.02803	-0.00026	-0.24488	0.074746	0.085497	0.109628	0.001394	0.328167	0.488156	-0.04227
0.062986	-0.04944	-0.02252	-0.06024	-0.07069	0.109729	0.36291	-0.01416	0.002349	0.02177	-0.00798
0.011038	-0.02718	-0.02445	-0.17362	-0.10217	0.217695	0.101712	0.092707	-0.06601	-0.00477	0.07654
-0.00116	-0.01904	-0.00291	0.175593	-0.06621	-0.06208	-0.06421	-0.24609	-0.12146	0.096698	-0.00622
0.010585	0.036895	-0.06358	0.171733	-0.03101	0.211595	0.019212	0.142898	0.012894	-0.00614	-0.01879
0.029767	-0.0194	-0.01061	0.181076	-0.03838	0.009046	0.032394	0.061588	0.054724	0.058308	0.187982
-0.0345	-0.02538	0.045115	-0.00472	-0.25118	-0.04756	0.029778	-0.08712	0.034264	-0.02795	-0.00056
-0.02911	0.001234	0.06788	0.029074	0.211765	-0.05312	-0.24541	0.070702	-0.13883	-0.05849	0.396413
0.024391	-0.05441	-0.18317	0.030865	0.095967	0.078451	0.004287	0.055439	0.079493	0.024404	-0.0032
-0.00762	0.012274	0.036838	0.025222	0.001436	-0.32114	0.225292	0.093701	0.039103	0.010414	-0.00517
-0.00087	-0.0115	0.010358	-0.01005	-0.09542	-0.12298	0.033221	0.118895	-0.24882	-0.0304	-0.09741
-0.00151	-0.01347	0.013819	0.037936	0.012189	0.007695	0.031592	0.223686	-0.00685	0.004869	0.13032
-0.04564	-0.09175	-0.00631	-0.00689	0.069903	0.162872	-0.04212	-0.35598	0.03394	0.167325	-0.0037
0.02367	-0.0352	-0.00764	-0.09076	0.275996	-0.10597	-0.11642	-0.20308	0.082694	0.022186	-0.03976
-0.08702	-0.00972	0.067353	0.047759	-0.09091	-0.15188	-0.2578	0.261115	0.272379	0.038407	0.037806
-0.08028	-0.0873	-0.06456	-0.02344	-0.04139	-0.03501	-0.33075	0.168588	-0.07013	-0.06702	-0.19893

0.538465	0.108781	-0.04043	-0.30687	0.541583	0.187026	0.133384
0.07144	-0.1942	-0.30902	0.174346	-0.44719	0.183519	0.123228
0.498712	-0.16844	-0.27109	0.305975	0.057283	0.085438	0.133123
0.484396	0.010685	0.382976	0.139021	-0.20768	0.038325	0.062727
0.159241	-0.14602	-0.35093	0.381257	-0.27099	0.147713	0.028438
-0.21649	0.444441	-0.0247	-0.14847	-0.06163	0.080839	0.058936
-0.10569	-0.08607	0.489349	-0.17655	0.007482	0.028325	-0.03729
0.239109	-0.02929	0.10991	-0.02628	-0.00108	0.017973	-0.10956
0.148889	-0.22063	-0.02375	-0.06988	0.715896	0.142003	0.412274
0.030793	0.168514	0.077353	-0.05475	-0.10497	0.067035	0.103539
0.452113	0.060477	0.010867	0.045189	0.018085	-0.06017	0.072167
0.342932	0.062295	-0.03459	-0.02694	-0.03202	-0.05823	0.208586
0.024433	0.007894	-0.13799	-0.0726	0.023832	0.115187	-0.0327
0.086339	-0.01124	0.03562	0.014624	0.000654	0.056296	0.053005
0.264437	0.12942	-0.01417	0.038668	-0.08835	0.006006	0.082487
0.105713	0.069488	-0.01166	0.064464	-0.0073	0.001946	-0.05302
0.105814	0.107429	0.052056	-0.03724	-0.00976	-0.01363	0.024506
0.110362	0.037708	0.044482	0.033414	0.008437	-0.00871	0.020135
0.215388	-0.01863	0.063424	-0.03189	-0.02263	0.013636	-0.00968
0.173875	-0.00125	0.050137	-0.02878	0.00923	-0.02762	-0.00566
0.091615	-0.04741	0.016795	0.000997	-0.00874	-0.0025	-0.04165
0.06681	0.029221	0.034648	0.050121	-0.01858	-0.02186	-0.01057
0.177038	-0.03743	0.089853	-0.00187	-0.0407	0.002773	-0.09598
0.16833	0.03082	-0.01909	-0.09409	0.011816	-0.0315	-0.03777
0.056022	-0.06141	-0.08559	-0.00381	-0.0037	0.015568	-0.04761
0.134337	-0.05211	-0.0352	0.018737	-0.07008	-0.05052	0.029724
0.092972	0.015401	-0.00095	-0.05868	-0.03993	-0.05594	-0.00192
0.125208	-0.00876	-0.0071	-0.00171	0.015584	0.003647	-0.03343
0.025156	-0.13175	-0.0758	-0.06046	-0.07046	-0.0546	-0.09667

6.15 – Appendix O- Instron Data of Strex Well Stretch

The mechanical properties of the Strex well were not available, and the manufacturing methods were not either. Knowing the mechanical properties of the well was necessary for determining motor specifications. This is why it was necessary to perform tensile testing on a well to determine the maximum load necessary to achieve a strain of 20%. Of three separate tests the maximum force ever needed to obtain 20% stretch was 18.72N. This value was used to determine the motor specifications.

Instron Uniaxial Test 1

Dimension : Length	30	mm
Dimension : Thickness	1	mm
Dimension : Width	30	mm
Maximum Load : Maximum Load	16.408	N
Maximum Load : Tensile extension at Maximum Load	6.07	mm
Maximum Slope (Automatic Young's) : Maximum Slope (Automatic Young's)	3.303	N/mm

Instron Uniaxial Test 2

Dimension : Length	30	mm
Dimension : Thickness	1	mm
Dimension : Width	30	mm
Maximum Load : Maximum Load	17.474	N
Maximum Load : Tensile extension at Maximum Load	6.08	mm
Maximum Slope (Automatic Young's) : Maximum Slope (Automatic Young's)	3.112	N/mm

Instron Uniaxial Test 3

Dimension : Length	30	mm
Dimension : Thickness	1	mm
Dimension : Width	30	mm
Maximum Load : Maximum Load	18.72	N
Maximum Load : Tensile extension at Maximum Load	6.32	mm
Maximum Slope (Automatic Young's) : Maximum Slope (Automatic Young's)	3.21	N/mm

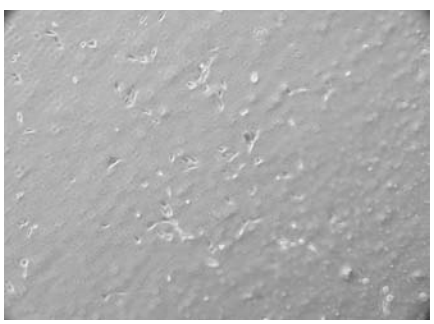
6.16 – Appendix P- Cells imaged on the stretch device

10X Hoescht

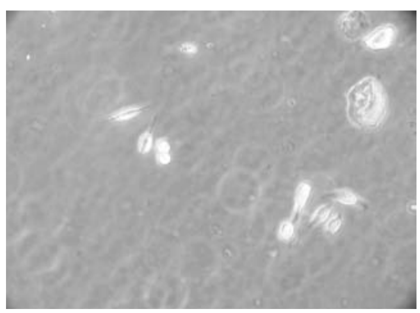
20X Hoescht

30X Hoescht

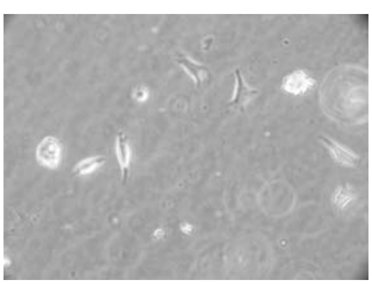
40X Hoescht



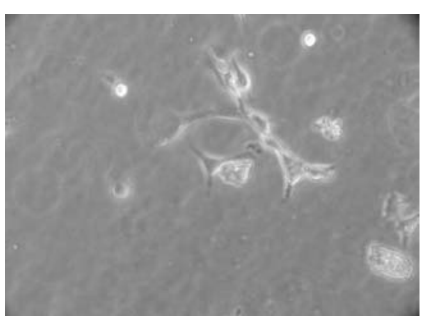
10X Phase



20X Phase



30X Phase



40X Phase