Rapid Decompression Containment System

A Senior Project

presented to

the Faculty of the Mechanical Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science in Mechanical Engineering

by

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Abstract

Cal Poly students; Evan Domingue, Michelle Rudney and Daniel Trees; are working with General Atomics Aeronautical Systems, Inc. (GA, ASI) and engineer John Wilcox to complete a senior project. The senior project is focused on finding a solution to meet the requirement set forth in MIL-HDBK 1791 4.2.5.2 for rapid decompression which requires cargo items to be designed with pressure relief devices or to be configured for air shipment as to prevent any part from becoming a projectile in the event of catastrophic loss of aircraft cabin pressure.

The goal of this project is to design a safe, cost-effective, and reusable system to alleviate an 8.3 psi differential inside of a sealed UAV container in 0.5 seconds.

The solution that resulted from this Cal Poly design project is a disk panel design. The disk panel is held in place with magnets that disengage within the range of 1.0 psi to 1.5 psi differential across the container. Once the disk panel is disengaged, it can be reset for operation. The disk panel is held in place by four tethers as to not become a projectile during the event. For a container that is 5 feet X 7 feet X 35 feet in volume, two panels of 3.5 feet^2 will be implemented in order to reach the required exit area. Magnets were tested to optimize design and then one disk panel was tested under operating conditions.

Chapter 1: Introduction

General Atomics Aeronautical Systems, Inc. (GA, ASI) is an affiliate of privately held General Atomics and is a leading manufacturer of Unmanned Aircraft Systems, tactical reconnaissance radars, and surveillance systems. GA, ASI is sponsoring this Cal Poly senior project in order to find a solution to meet the requirement set forth in MIL-HDBK 1791 for rapid decompression. A team of three students; Evan Domingue, Michelle Rudney, and Daniel Trees; has been selected to find a solution for GA. Evan, Michelle and Daniel make up the team DME Systems and are advised by Cal Poly professor Patrick Lemieux. John Wilcox, lead engineer for Ground Support Equipment at GA, ASI will be the team's sponsor and main point of contact at GA, ASI throughout the course of this project.
Goals for this project are to find a cost-efficient solution that will allow GA, ASI containers to meet the requirement of a safe relief of an 8.3 psi pressure buildup within 0.5 seconds, ensuring that no part of the container will become a projectile in the event of a catastrophic loss of aircraft cabin pressure. This project will last 3 quarters, Fall 2012 to Spring 2013, and will allow students to become familiar with the design process while integrating knowledge and skills gained throughout their education.

Objectives

The main objective for this project is to design a safe and cost-effective system to alleviate an 8.3 psi differential inside of a sealed UAV container in 0.5 seconds. Ideally, this would be a "drop in" replacement that could be easily installed and work with existing containers; however, the sponsor is open to a new methodology.

According to our sponsor and Military Specifications the container must:

- Alleviate an 1.0-1.5 psi pressure differential in 0.5 seconds
- At no time can any part of the container become a projectile
- Hold to MIL-STD 648 structural testing and material requirements
- Be corrosion resistant and weatherproof
- Top of container has to be retained

A Quality Function Deployment (QFD) was used to identify our customer requirements and specifications (See Appendix A). This House of Quality is used to determine whom the product is being created for, what are the various requirements are, and how important each requirement is. Also, the House of Quality helps to determine how much time, effort, and money should be devoted to each customer requirement.
In our House of Quality we identified our customers as the manufacturers that will be fabricating the product, the Army/soldiers that will be using the container when deployed, and of course General Atomics, ASI Ground Support Equipment group supporting the project.

Customer requirements included in our House of Quality are as follows:

Drop-in replacement
Flush with container
MIL-Specs/Standards
Durable

Resettable/Reused
Retain top of container
Intuitive
Competitive Price
Delta 8.3 psi in 0.5 secs
Testable

Once we determined our customer requirements, we rated the importance of these requirements based on each customer's needs. We then rated the importance of these customer requirements versus current technology available including burst disks and one-time use latches.
We listed the engineering requirements included in our House of Quality as follows:

Dimensions (in)
Weight (lb)
Time to replace (min)
Steps to replace (#)
Number of parts (#)
Sales Prices ($)
Time to release pressure (secs)
Price to reuse ($)
Testing Pressure (psi)
Cases that interface (#)
Force on latch (lbf)

We then compared the engineering requirements against our customer requirements. Ratings are as follows:

Blank--no importance
1--minimal importance
3--moderate importance
9--high importance

The last step to our House of Quality was to quantify our engineering requirements for the existing technology and our target values for our solution.

We also developed a table of our Formal Engineering Requirements as shown in (See Appendix A). Our Formal Engineering Specification includes how each design requirement is to be met following a compliance method. The methods included are Analysis (A), Test (T), Similarity to Existing Design (S), and Inspection (I). We assigned high (H), medium (M) or low (L) risk of meeting each of the engineering targets and specification we have set.

Chapter 2: Background

Applicable Standards

The two military standards that are applicable to this project are MIL-HDBK 1791 and MIL-STD 648.

MIL-HDBK 1791 4.2.5.2 Rapid Decompression.
Cargo items shall be designed with pressure relief devices or shall be so configured for air shipment as to prevent any part from becoming a projectile in the event of catastrophic loss of aircraft cabin pressure.
Requirement Rationale
The shipment of cargo by air presents a special potential problem not encountered during surface transport. That is the problem of rapid or explosive decompression of the cargo compartment. The three USAF prime mission cargo systems which maintain compartment pressure at approximately 8.3 psi differential above outside air pressure when at flight altitude. If extremely rapid pressure loss should occur due to aircraft structural failure, it is possible that sealed items could explode under the influence of reduced external pressure. Parts of these items could become projectiles endangering crew members as well as the aircraft.
Requirement Guidance
This problem is associated principally with well sealed containers which enclose large volumes of air such as vans, ISO containers, and shelters configured as shops, repair, and test facilities, etc. the effects of rapid decompression on the item can be mitigated by providing for controlled breathing to accommodate air flow due to pressure changes or the use of devices to permit safe relief of an 8.3 psi pressure build-up within 0.5 sec. the intent of this requirement is to assure that this potential problem is considered in item design and provisions made to accommodate rapid decompression if the item will be adversely affected by it.
Requirement Lessons Learned
Most commercial vans, containers, and shelters are designed for surface movement where rapid decompression is not a factor. When such containers are used for military purposes where airlift is anticipated, provisions for attenuation of the potential damage due to decompression must be made.
Some commercial containers are designed to permit air to enter/exit the interior due to pressure changes. In general these passages are not designed to accommodate rapid decompression.

MIL-HDBK 5.2.5.2 Rapid Decompression Verification
Compliance with this requirement shall be verified by analysis or formal testing which confirms that the test item can withstand an internal pressure differential of 8.3 psi developed in 0.5 sec or less without any part of the item becoming a missile.
Verification rational (5.2.5.2)
The inherent design features and ruggedness of some items may be sufficient to withstand the effects of rapid decompression without modification. Where it can be shown by engineering analysis that this is the case, such analytical proof shall be adequate to verify compliance with this requirement. The alternative is dynamic testing of the item in its shipping configuration under the worst case conditions stated above and inspection of the item to determine no parts have become a missile.

Verification Guidance
where it can be shown analytically, using accepted engineering practices, that the subject item can withstand rapid decompression under the conditions of 5.2.5.2, this shall constitute compliance with the requirements of 4.2.5.2. in all other cases formal testing shall be accomplished to verify compliance.

MIL-STD 648 5.5.2.1 Test Pressures
The test for structural integrity will be accomplished after all other testing of the container (being qualified) is complete. The following are recommended test pressures for each style container. Based on known unique container lifetime logistics, the design agency may impose other pressure levels (higher or lower) to verify structural integrity.
b. Controlled-breathing containers. The test pressures will be set as follows: 1.50±0.25 psig above the required positive reseal pressure and 1.50±0.25 psig below the required vacuum reseal pressure. For containers issued to ground troops, the positive and vacuum cracking pressure will be 3.00±0.50/-0.00 psig and -3.00±0.00/-0.50 psig, respectively.

MIL-STD 648 4.6
4.5.11 Nonmetallic materials. Permanent deformation of nonmetallic materials shall not exceed 1 percent when loaded to 1.5 times the rated load, when measured 24 hours after removal of the load. To avoid creep, the design load should be selected in the range of 1/10 to 1/5 of the breaking strength; the former being preferred. In addition, the material will withstand a load not less than fie (5) times the rated load without any sign of failure.
4.6.12 Corrosion. All metal parts of the container, both internal and external, will be protected from corrosion. Parts will show no sign of corrosion, pitting, or scaling when exposed to 12 hours of salt spray per ASTM B 117. For containers meant for use aboard ships, or near marine environments, parts will show no sign of corrosion, pitting, or scaling when exposed to 96 hours of salt spray per ASTM B117. Additional corrosion testing information can be found in MIL-STD-810 method 509.

Existing Products

Current commercial products exist in the market that satisfies parts of the project's overall goal. These products consist of rupture disks, explosion-venting latches, and door release latches intended to be used in airliners. Each of these products has their strengths and weaknesses when looking at our requirements and will be discussed.

Rupture Disks are the current technology proposed for the containers and provide a solution to equalizing the pressure differential. These disks can be created to fit many different sizes and rupture at a wide range of pressures. These disks meet MIL-STD 648 section 4.6.12, where the material is made of an anti-corrosive material so the product can be exposed to most environmental conditions. It also meets MIL-HDBK 1791 section 4.2.5.2, since the rupture disks allow a 8.3 psi pressure differential to be equalized in 0.5 seconds rapid decompression. The container configuration has to be modified in order to install rupture disks and in the event that a disk blows out, they have to be sent back for rework and new disks have to be installed. For an ideal solution, the system would be reusable after an event without having to be sent back for rework.

Explosion Venting Latches closely meet the requirements set forth for this project. The latches will fail when a set amount of pressure in tension is applied to the latch. This process will immediately cause the latch to open and allow a pressure equalization to occur. The key features of this product are; its reusability, its fast reset, and that it can be tailored to any acceptable pressure the container might incur. The main problems with this latch are that it doesn't allow for venting and it does not stay attached to the top of the container upon rapid decompression. These latches are also vulnerable, as they would not be flush with the container once installed. These latches can be manufactured with non-corrosive materials to satisfy the military standard. Brixon is one company that we found that manufactures these types of latches; they have many different models, which can release and different pressure differentials and they cost around $200 per latch.

The final product researched is the "decompression release door latch and stop" system that Boeing used in the event of rapid compression or decompression. The system is designed for a door to allow normal operations of opening and closing, but the system will cause the door to open in the event that a rapid pressure differential occurs. The latch is an internal feature, which could lead to problems if the latch fails to unlock during regular operations. If this occurred on a container, the cost and time to fix the container would be higher than the cost of the burst disks. The military standard on corrosion will bring this system's viability into play, since the unspecified materials may cause an eventual failure. This product only functions as a latch and does not have the ability to equalize the pressure in case of rapid decompression, unless the pressure differential is enough to push the lid of the container up. The mechanisms involved in the latch's ability to detect a pressure differential should be analyzed and considered in the final design.

Chapter 3: Design Development

Once our requirements and objectives were set, we began the brainstorming process. We started with defining the basic function of our design as releasing a pressure differential of 8.3 psi in 0.5 seconds. After discussing with our sponsor, it was agreed that our system would react when there was a pressure differential between 1.0 psi to 1.5 psi. A 1.0 psi differential is not seen during normal operating conditions. Our secondary functions are to protect container contents, detect pressure differential, hold top shell of container, and withstand weather and use. Once these functions were defined, we made a morphological matrix in order to get as many ideas generated (See Appendix A).

Using our morphological matrix we sat down and started combining the different sections to come up with some viable solutions and concepts. We picked one characteristic from each category and came up with as many ideas as we could. From there, we narrowed our ideas down to five different concepts using three different approaches. Then, the five concepts were put through a prototype matrix to rate them against our specifications (See Appendix A). Overall, the lifting panel idea rated the highest and as a result is our top concept.

Our concepts had to satisfy multiple design specifications to be considered for a final design. The first specification was that this system needed to be reusable/resettable. Currently, GA, ASI has an option of using burst disks to alleviate the pressure, but they are one-time-use. The latch concepts are all resettable and reusable while, the vent and panel concepts are self-regulating and do not need to be reset. Another very important specification was that the top of the container needed to be retained in the event that separation of the top and bottom portions is needed to alleviate the pressure. Both the vent and panel concepts prevent the top from having to move, and the latch concepts each have some kind of mechanism to “catch” the top so it does not fly off and become a hazard. All concepts sit flush with the container, or as flush as the current setup, and can be installed into current or future containers, making them all “drop in replacements”. The final large specification was that the dangerous internal pressure inside of the container can be alleviated in 0.5 seconds as stated in the Military Specifications. The latch concepts work to separate the top and bottom half of the lid to allow enough air to escape in 0.5 seconds. Also, the vent concept and panel concept (whether implemented with a latch or magnet system) work to open up a surface area on the top or side of the container that will have sufficient area to alleviate the pressure differential on the 0.5 seconds required.

Below are sketches of our two top concepts: a panel that will be regulated with the use of latches or magnets and a latch and slide rail that control the separation of the lid from the bottom of the container. Both systems will react between the range of 1.0 psi to 1.5 psi differential.

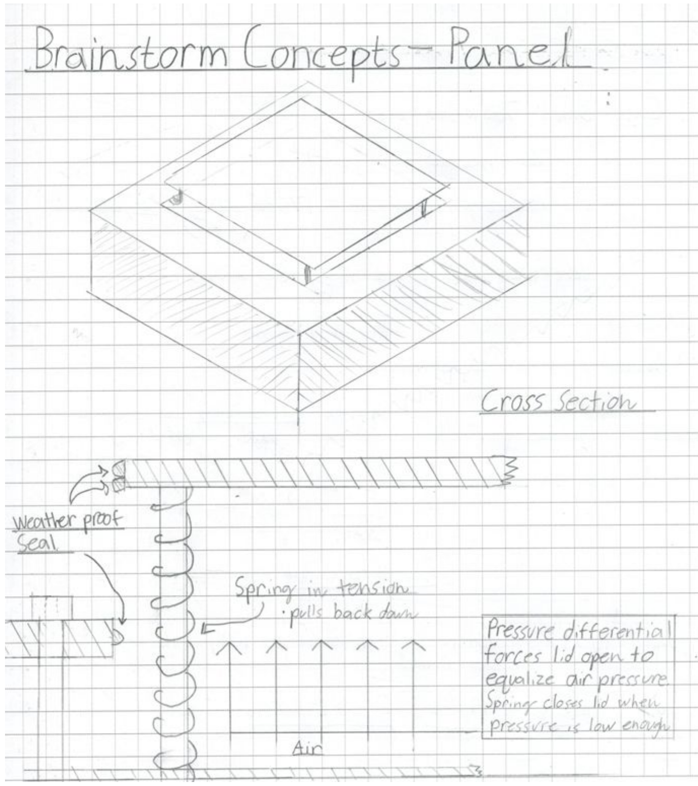


Figure 1. Brainstorm Concept Sketch for Panel Design

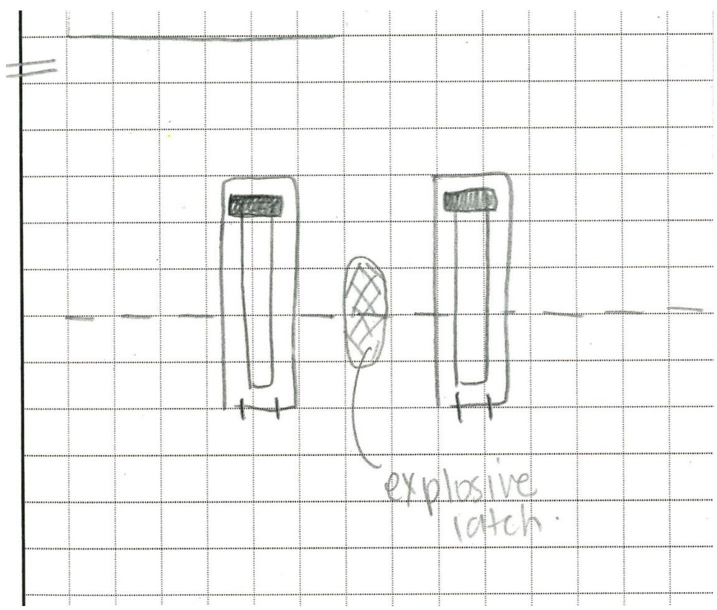


Figure 2. Brainstorm Concept Sketch for Latch Design

The Brixon latches meet our initial goal of releasing the panels if the minimum pressure differential of 1.0 psi is present. Features of this latch include the ability to fail under a set pressure, adjustable fail points, and the ability to reset without having to replace any components. The size of the latches needs to be considered since they will be protruding from the top of the container and may be damaged due to their increased height of 3.5 inches; this

makes the latches vulnerable to damage while the container is in use. With the base price of each latch being around $200 the total cost to implement four latches on each panel will become costly if they were damaged.

Neodymium magnets are a more cost effective solution when compared to the Brixon latches where a set only costs a third of the latches. The magnets are underneath the panel so they aren't exposed to the outside environment. Their position will be in the corners near the rods so the manufacturing cost will be decreased if the magnets are implemented. The rated pull force of the magnets can be changed according to the desired pressure to open the panels. A concern that needs to be addressed is the ability to perform routine maintenance on these panels. For example, if the magnets each have a pull force of 252 lbs then the operator must find a way to easily remove each magnet.

Preliminary fluid analysis was done using the equation provided by the Air Transportability Test Loading Agency (ATTLA) to come up with an estimated escape area of 6.6 ft2 is needed to evacuate the 8.3 psi in 0.5 seconds. Detailed analysis can be found to justify this area in Appendix E.

Preliminary force analysis was done for the separation of the panel. This concept would incorporate safety latches or magnets that release at a specified pressure differential. Detailed analysis to justify these calculations can also be found in Appendix E.

Preliminary magnet analysis was done to decide how many magnets to use on each panel and at what pull force the magnets should be set. This analysis can also by found in Appendix E.

Chapter 4: Description of the Final Design

Overall Description

The final design of our system has been designed and tailored to the client's request of a 1:1 scale implantation of the panel. This means that the team does not have to take any form of scaling into account and ignore specific conditions that cannot be scaled down. As shown in the figure below, the final design will be attached to a large plate that will simulate the top of a container, which will be affixed to our test rig. Not all of the components can be displaced in a single assembly view and must be pointed out as the sub components of the system have been discussed.

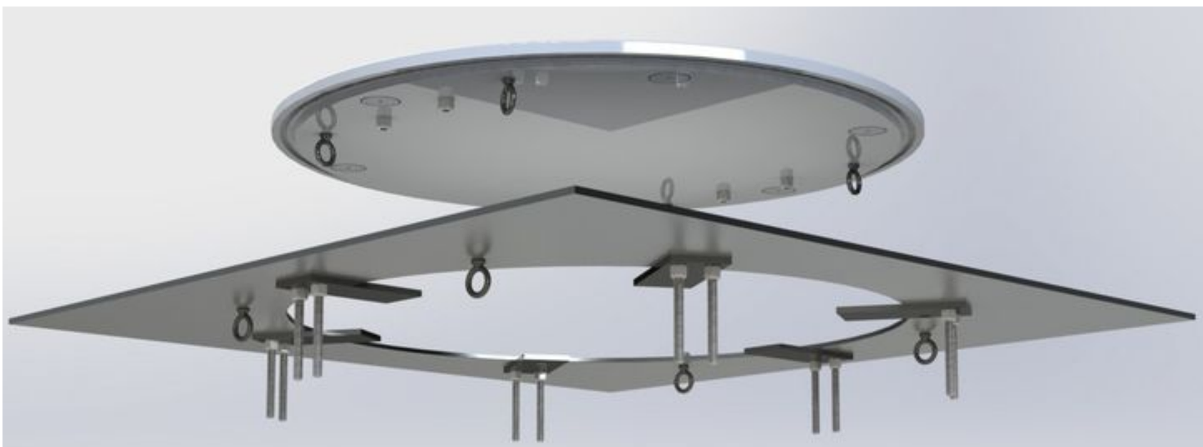


Figure 3. SolidWorks Render of Final Prototype Design

Detailed Design Description

Panel

The panel as seen below in Figure 4 is comprised of a solid aluminum plate that has been CNC milled down to the allow for a flush alignment with the top part of the container, while the upper portion of the panel is exposed to allow for mounting elements to put implemented on the upper and lower half of the panel. The underside has 6 counter sunk holes to allow the K&J Neodymium mounting magnets to be set flush with the lower half of the panel. These magnets act as a locking mechanism to the system until a 1 psi differential is met, where the magnetic attraction the steel plates cannot overcome the pressure separating it. Besides the magnets there are 4 eye-bolts which connect to the tethers on the container, preventing the panel from acting like a projectile. The other 4 nuts are the placements for the handle and the black ring is the compressive O-ring that has more detail in Figure 5.

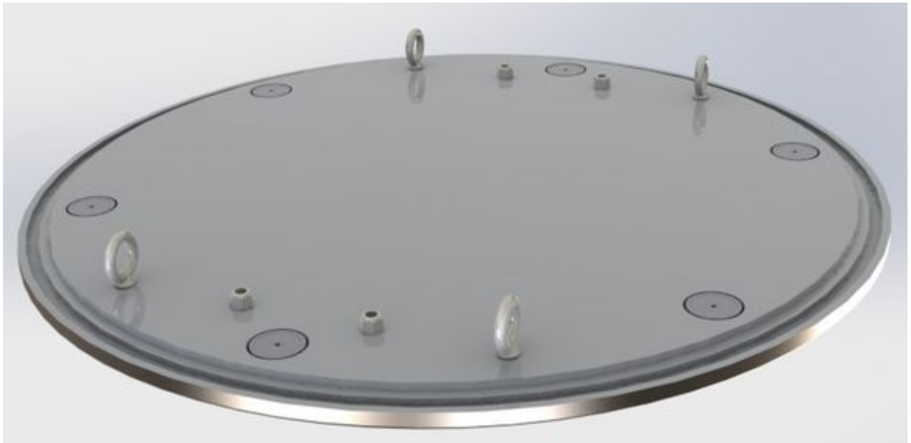


Figure 4. Panel Underside Assembly

Figure 5 is a upsidedown cross-sectional view of the panel. Going from right to left we have the o-ring resting in a grove, K&J mounting magnet with a bolt affixing it in place on the upper side, the handle with a hexnut securing it in place, and the eye-bolt for the thether system. The o-ring is used to keep any enviromental effects from entering the container when the panel is kept in place by the magnets.

Figure 5. Cross-Sectional View of Panel Underside

Figure 6. Top view of Disk Panel

Test Plate

In order for the magnets to stay secured, they must be attracted by some form of ferrous alloy, which is represented by the the 6 bolted steel plates as shown below in Figure 7. These 0.25in plates allow the magnets to suficcently attach without causing any significant deformation to the steel plates. The eye-bolts that are the ends to the tether system is also shown below.

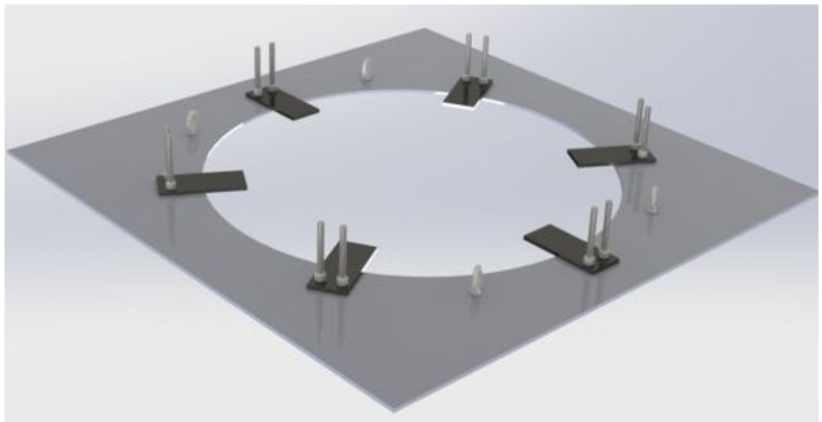


Figure 7. Underside of the test plate

Concept rendering of a duel panel system on a mockup container is shown in Figure 8, but location where the panels will be installed on the container is out of the scope for this project.

Figure 8. Conceptual Model Implementation

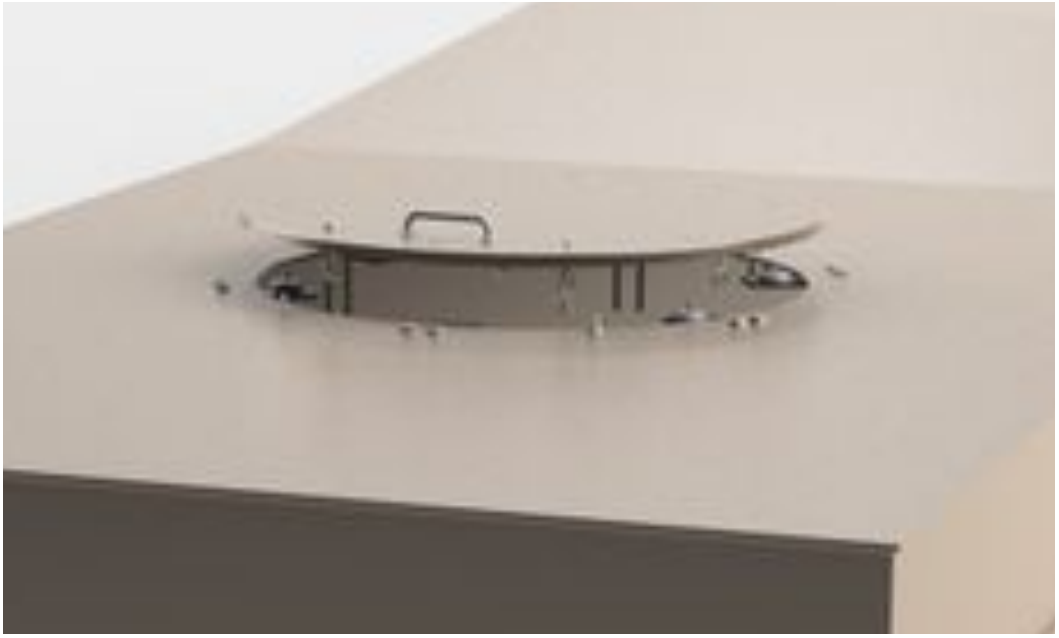


Figure 9. Conceptual Model of the panel

Analysis Results

Computational Finite Element Analysis (FEA) was done for multiple situations on the system. The first was confirming that the basic beam deflection calculation was true when for our case when the magnets are being pulled from the steel plates.

Cost Analysis

Included below in Table 1 is our Bill of Materials (BOM). This contains the items that we will need for our final design. Not included is the cost of machining for the aluminum plates or steel supports. We are still waiting on quotes and could not confidently estimate the cost of labor. Also, the costs of our testing materials are not included since that is not included in the estimated cost of implementation that our sponsor would use. Overall, even though our estimate of $742.73 is not completely accurate, it is still drastically lower that the $15,000 dollars needed to implement burst disks onto existing containers.

Table 1. Bill of Materials

Item	Quantity	Cost(ea)	Cost(total)
Aluminum Plate (3'x3'x.25")	1	118.29	118.29
Aluminum Plate (2.5'x2.5'x.75")	1	236.24	235.24
Magnets	6	9.60	57.60
Screws for Magnets	1 package of 50	10.25	10.25
Steel Supports	6 ft	36.31	36.31
Bolts for Steel Supports	12	3.17	38.04
Nuts for Steel Supports	1 package of 20	3.17	3.17
Steel Eyebolts for Tether	8	4.79	38.32
Nuts for Eyebolts	1 package of 20	2.91	2.91
Tether	25 ft	0.87	21.75
Wire Clips for Tether	8	2.52	20.16
Handles	2	16.34	32.68
Nuts for Handles	1 package of 20	3.17	3.17
Oring	20 ft	1.34	26.80
Epoxy and Supplies	3	3.99	11.97
Total Cost			656.66

Material and component selection

To accommodate to existing container specification, material was selected that currently exists on the container. In this case, we are designing to an aluminum container, so our final product will be made of the same material. Neodymium magnets have exceptional holding power for their size and were selected for use. They have multiple coatings to resist decay and can withstand high temperatures. The bolt, nuts, and handles selected are all rated to survive harsh conditions and are rated too much higher loads than our system will ever see for safety. The eyebolts are to go on the bottom of the panel and the inside bottom of the container. They are used, along with the wire rope clips, to attach the safety tether that will catch the panel as it is ejected during rapid decompression. Steel tethers were chosen because of their strength, corrosion resistance, and ease of accessibility. They are flexible, yet have the strength required to keep the panel from becoming a projectile. The silicon rubber tubing is used to seal the panel and keep moisture and other contaminants out of the container. This tubing is very strong as is rated too much higher temperatures than the system will be exposed to.

We decided to use a circular panel because any other shape would have stress concentrations too large and would most likely result in deformation during regular usage.

Manufacturing Drawings

Our manufacturing drawings are included in Appendix B, which is extensive and contains a variety of drawings and necessary information. Appendix A contains our initial brainstorming

documents including the QFD, Morphological Matrix, Decision Matrix, and the Formal Engineering Requirements. These documents helped us to narrow down our many ideas and decide on our final concept to move forward with. Appendix B contains our vast array of drawings and assemblies of our product. This includes the panel, test “container”, and steel supports. Appendix C outlines who we will be ordering parts from along with their contact information. Appendix D contains the spec sheets from the manufactures for the parts that we are ordering, not manufacturing. Appendix E contains calculations and supported analysis to verify our design and implementation.

Special Safety Considerations

During use of our Rapid Decompression Panel, there are a few safety conditions that need to be addressed. First, these Neodymium magnets are very strong and all appendages need to be kept clear of the panel when it is being placed on the steel supports. The magnets have a combined force potential of over 600 lbs so much care needs to be taken. Secondly, the panel will eject once the desired pressure differential is reached, thus nothing can be placed on the top of the container that could affect the force needed to eject the panel. Also, people need to stay away from the top of the container when the container is in transport and could possibly be exposed to rapid decompression.

In order to keep the panel from becoming a projectile, as stated in MIL-STD-1791, there are safety tethers that are attached to eye-bolts on the panel and container. It is essential that when the tether is attached, the wire rope clips are securely tied down so the tethers can act as intended.

Maintenance and Repair Considerations

The beauty of this design is that it requires no maintenance. Because these neodymium magnets hold their magnetic abilities permanently, the panel should stay intact and connected to the steel supports for as long as the container is in circulation. If the panel is damaged and is unable to be re-used for any reason, a new one will have to be manufactured. If the steel supports are bent or rendered to be unusable, they will also need to be manufactured. All bolts, nuts, and other hardware are standard and can easily be ordered if they become damaged.

Chapter 5: Product Realization

The main components of our design, the aluminum lid and square support piece, were manufactured using mills and the work had to be outsourced to Clint Precision Mfg due to the machines at Cal Poly not being large enough to accommodate the size of our design. The steel supports were cut from a single 6 foot piece of steel and the holes were machined using a mill. The housing for the load cell was created using a drill press to drill holes and a mill was used to smooth the surfaces. The frame that was used for testing was made from welded steel tubing.

Figure 10. Steel Supports being milled

Figure 11. Lid and Container delivered from Clint Precision Mfg.

If General Atomics decides to move forward with our design and implement it into product, there would have to be some changes from our original prototype. The bolts that we attached to the square part would need to be shortened in order to fit within the allowed space in the actual container. Also, a different technique to secure the magnets in would be used. Instead of using epoxy, a material that would not permanently place the magnets would be better. One example would be some sort of foam that would be injected in a similar way the epoxy was, however it would not “glue” the magnets to the inside of the panel. Also, the seal that was used during testing was a prototype seal made from a seal from McMaster Carr. A large seal could be custom ordered from a company such as Parker.

For manufacturing purposes, the steel supports should be manufactured with a more precise process to make sure that all the holes are properly located. Also, two or more people need to be involved during the installation of all the final components. All components will need to be powder coated to ensure that it is protected from rust and other weather conditions.

Chapter 6: Design Verification Plan (Testing)

Objectives

The main objective of this test is to focus on our design releasing the panel (Figure. 1) between 1 and 1.3 psi. The panel is held in place by 6 neodymium magnets that have a combined pull force of 630 lb. By using a 1000 lb load cell, the release force can be determined and checked to see if the design is acceptable. There have been notable problems from previous tests, where the team created a test rig to monitor the pull force using the tensile testing machines. This reviled that there was a 30% loss of pull force if the magnets were 0.1 inches away from a steel plate. The concern is that there might be a separation where the steel comes into contact with the magnet, which causes the panel to release at a much lower pressure. The plan is to simulate the pressure change using a direct force and measure it with a load cell, by using a linear actuator attached to an aluminum plate to distribute the load.

Design Specifics

Our test rig consists of two major components; .75 inch aluminum disk with a diameter of 26 inches with a larger lip as Appendix B and 36 x 36 x .25 inch aluminum plate with a 26 inch diameter hole in the middle for the panel. The final revision of the panel has 6 tapped holes where the magnets will be affixed by screws from the other side of the panel these magnets attach to the steel plates that are bolted to the aluminum plate.

Preliminary Analysis

In the previous quarter, finite element analysis using ABAQUS (Appendix ____) was performed on the main portions of the final design. The container, lid, and supports were analyzed by hand using Roark's formulas and compared to the FE models. The results as seen in Table 1 showed that the container had a deflection of 0.3 in and it was quite high for what should have been seen (Figure 2.). After discussing the issue with our project mentor John Wilcox and Dr. Schuster, it was determined that the analysis to predict the displacements did not exist in that book and could not be easily located elsewhere.

Table 2. Spring 2012 FEA project data

Parameter	FE Results (in)	Theoretical Calculation (in)
Steel Support	1.720E-03	3.521E-03
Aluminum Container Corner	0.311	0.355
Aluminum Container Frame	0.0174	-----
Aluminum Panel	3.658E-03	1.01E-03

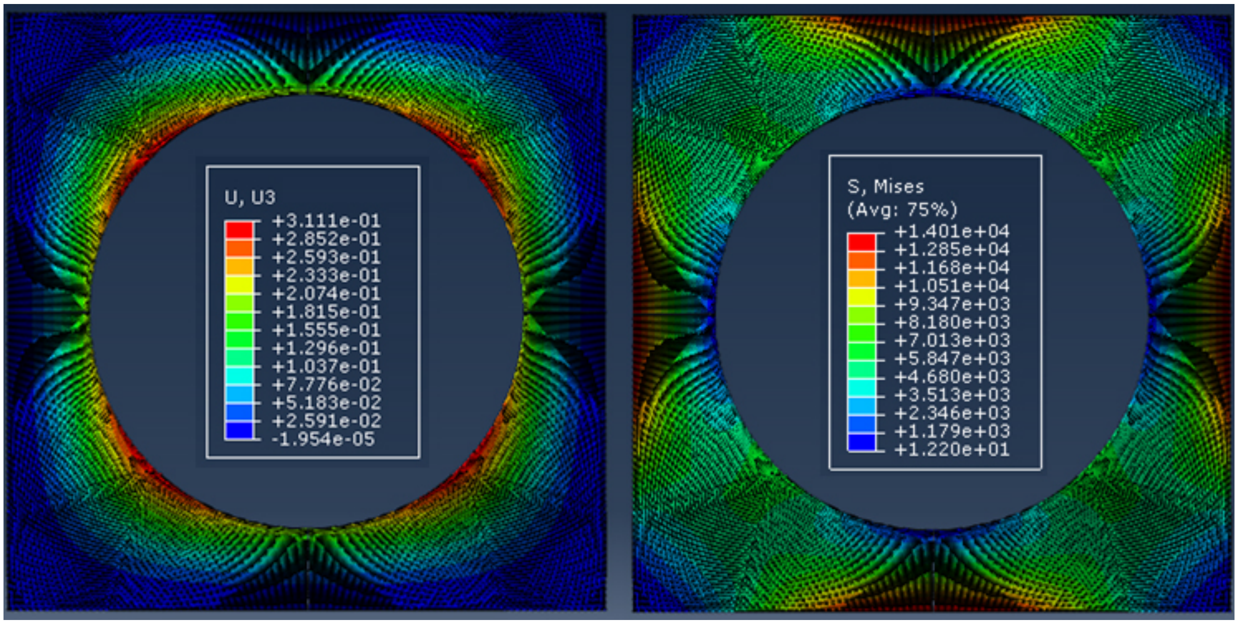


Figure 12. Fixed boundary conditions on edges

During the test design phase for our senior project, we decided upon using a picture frame like steel support structure, which clamped the container place by c-clamps and bolted to the strong floor. By remodeling the boundary conditions the resulting FE model had a reasonable result and reduced the displacement from 0.3 inches to 0.017 inches. In order to validate these results, stain gauges were used as an experimental method to compare the strains seen in the testing to that of the FE model

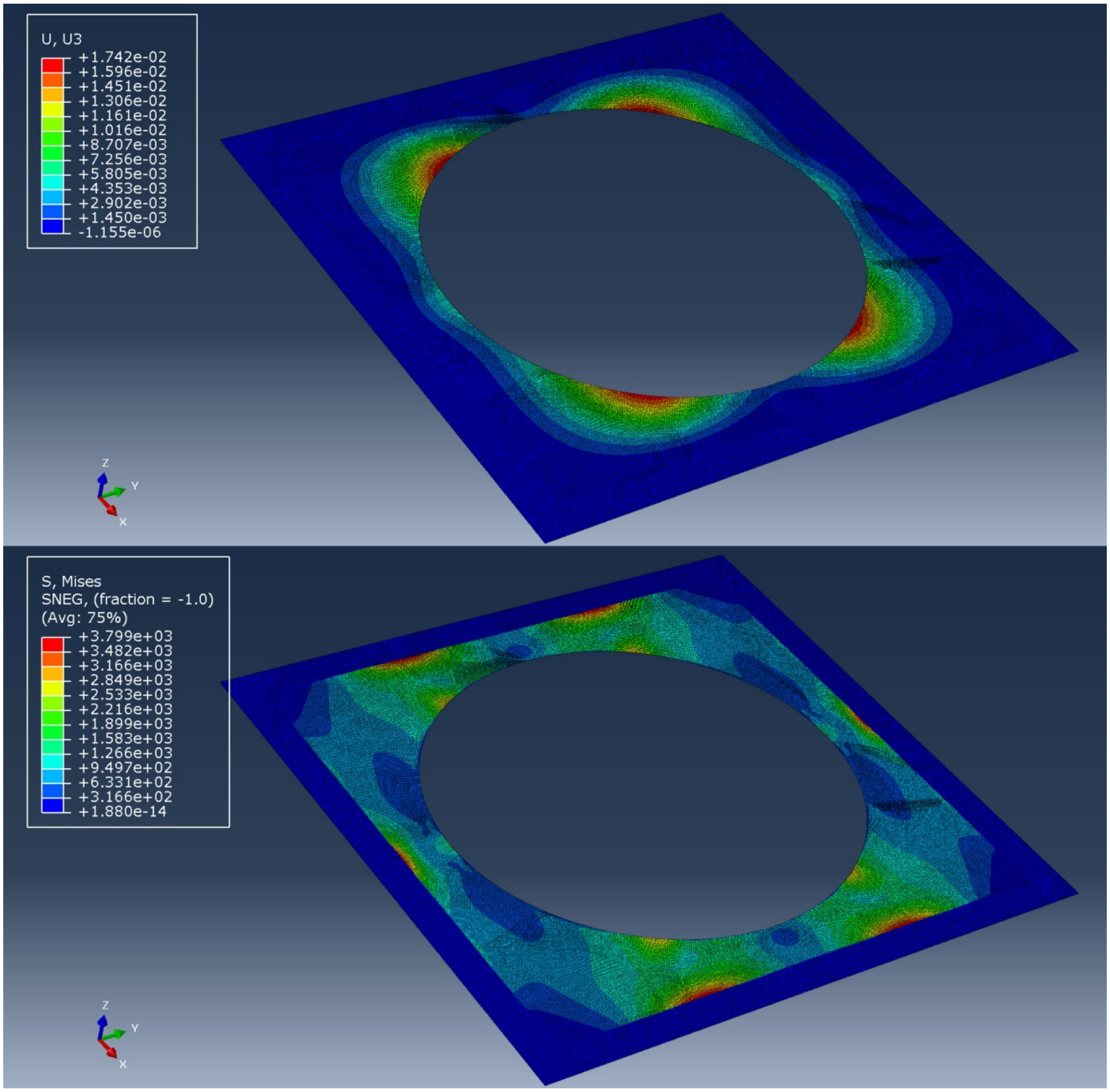


Figure 13. Picture framed boundary conditions

Test Plan

The prototype relief system will be affixed to the strong floor in the composites lab by a support structure. This structure insures the aluminum plate stays as ridged as possible to minimize the deformation and stress seen by the analysis. The design is affixed to the strong floor and c-clamps will be used to hold the plate down rather than bolts. A linear actuator attached to a aluminum plate will rise to force the panel open.

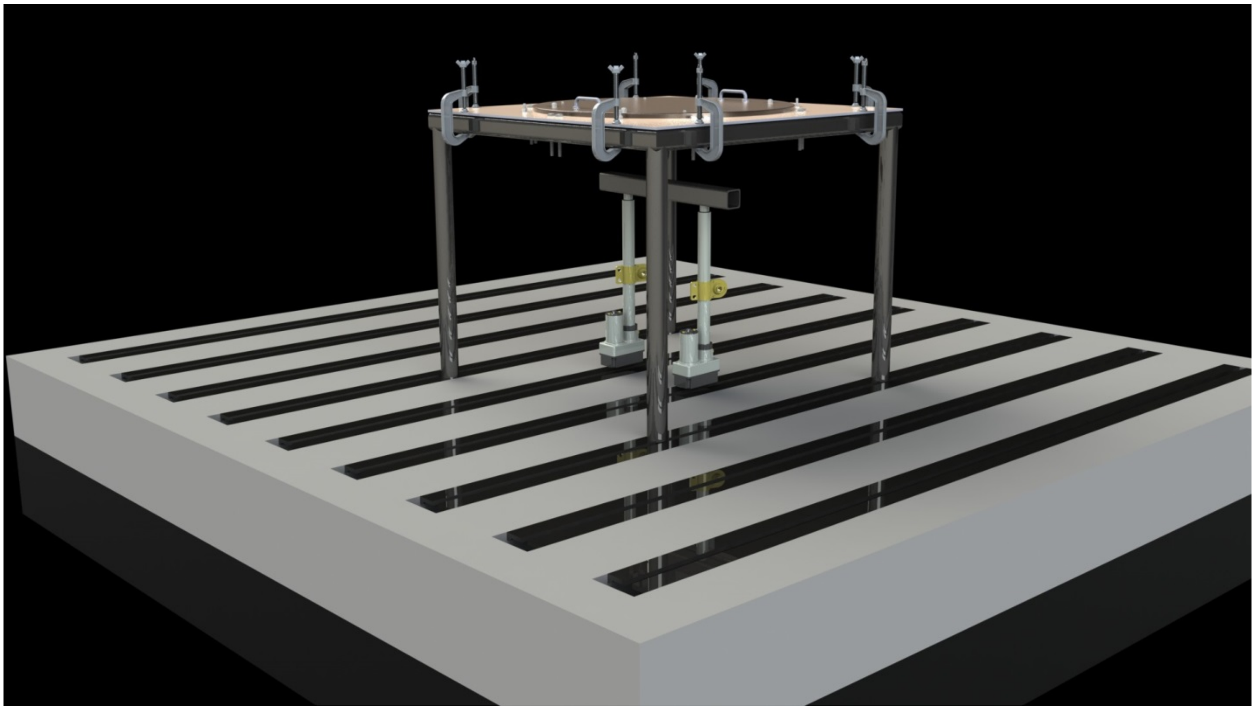


Figure 14. Current concept for testing

The test procedure was designed to be repeatable, and a total of 14 tests were performed on the prototype without any physical damage to the system. As per the request of our senior project advisor Dr. Lemieux, the room must be vacated during testing and only three magnets must be initially engaged. The first condition posed a problem, because the actuators available to the team were only usable at close range via a key pad. Thankfully a family friend working for Thompson Linear allowed the team to use a programmable Danaher Motion servo controller, where a delay can be introduced before proceeding.

Test Procedure:

- Three magnets
    - 4 times slow
    - 2 times fast
- Six magnets
    - 4 times slow
    - 4 times fast

Figure 15. Danaher Motion Industrial Devices

To mount the load cell to the actuator the team tapped holes in an aluminum plate that were the same placement as the load cell, so it could be bolted in place. The same plate was threaded so it would screw into the actuator.

The computer set up in the composites lab that already has areas for multiple strain gauges and load cell inputs to be connected. Lab view was used to simultaneously record all of data and monitor the current load on the system. Strain gauges will be placed on the underside near a steel support to validate the new FEA. The temperature won't affect the gauges in the current setup, so they can be wired as quarter bridges. Each strain gauge it set up perpendicular to each other in order measure strain in each axis relative to the center of the container.

Testing Materials:

- Micro-Measurements Strain Gauges: EA-06-240LZ-120/E (Appendix C)
- Load Cell: Omega LCH-1K (Appendix C)
- Load Cell DAQ: Omega DP87 (Appendix C)
- Main DAQ: National Instruments SC-2345 Signal Conditioning Connector Block
- C-Clamps (Mustang 60)
- Linear Actuator and Control System: Danaher Motion

Testing Setup

The Omega DP87 acquisition unit was subjected to the following calibration procedures; 3-point calibration, gain set, and output scale. 3-point calibration is done by taking three known weights and subjecting them to the load cell when instructed too. This was accomplished by using the Instron load cell calibration weights that consisted of 6 10 lb disks. Unfortunately, due to a flaw in our design the load cell will only accurately output data if a load is applied to it. Typically the load cell should be able to output data when no force is applied, but the screw that holds the plate and top of the load tell together causes tension in the system.

The gain set setting is what the manufacture set to output how many millivolts per volt the load cell outputs. This setting is embedded in the design of the load cell and cannot be changed, but the setting is to alter the range the DP87 should see. The LCH-1K load cell specifications indicate that the calibration factor is 3.0109 mV/V and a excitation voltage of 10.0 VDC. This would mean the range of the LCH-1K is 30.109mV and the range on the DAQ was set accordingly. (Appendix C)

The final calibration setting is the output scale the DP87 will send to the main DAQ. This is done by specifying the minimum and maximum load the cell shall feel, so the DAQ will output a portion of the voltage with respect to the load. The ranges for our tests were 0 to 900 lb, meaning that the DP87 would output 11.11 mV per pound seen by the load cell. A calibration curve can be seen in Figure 6 where the offset is only slight and only off by a few pounds.

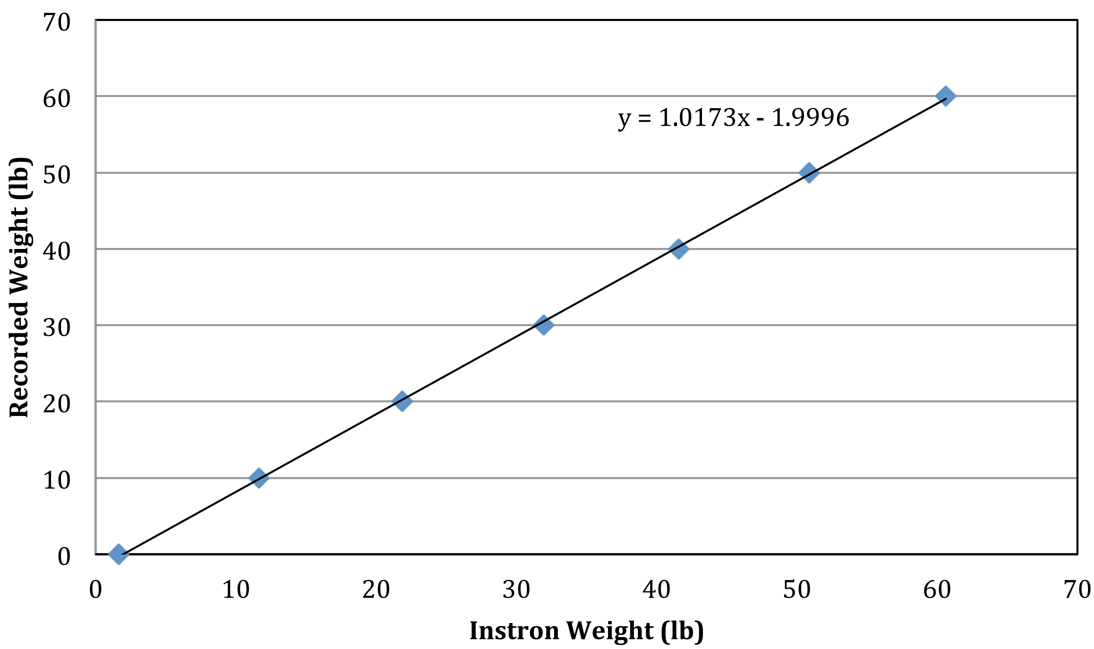


Figure 16. DP87 calibration

The servo control system has the unique ability be programed to allow for set commands such as distance, velocity, acceleration, waiting, and many others. For our test we wanted to have a 15 second delay, before triggering and the code looked like this: "WT15 VE10 AC1 DI4 GO DI-4 GO". What this code did was wait 15 seconds, set velocity to 10 in/s, set acceleration to 1 in/s^2, move 4 inches upward, and followed by the go command which makes it start the actuator. Since the velocity and acceleration are already set the only command needed is to go 4 inches down. This code was modified to a slower speed for the purposes of getting accurate data.

Results

In each of the 3 official and 2 practice runs, there was always one magnet that didn't fully disengage which caused a moment on the load cell and skewed the data to a specific point. The strain data was also skewed by the moment, resulting in data around 120 micro strains in each case in the shifted x and y axis relative to the center of the panel. Interestingly enough the magnets had a much smaller overall pull force seeing close to 50% of the overall force generated by the magnets.

Triggering the actuator to move at a faster velocity resulted in more promising data, but it also led to an unforeseen test setup flaw. While there wasn't a large moment generated by the same magnet in the slow testing, we notice that the load cell saw much larger forces than it should have. These ranged from 400 to 450 pounds and could be the result momentum from the actuator quickly forcing the load cell into the lid. The strain gauges typically saw around 10 micro strains each and some spikes of 80 micro strains when there was finally a moment on from the same magnet as the slow test.

The slower testing from the 6 Magnets did result in evener load distribution by the actuator, but again the same magnet in the two previous cases still was the last to release and resulted in smaller moments. With the 6 magnet tests the control system for the actuator was purposely set stop 1 inch before lower back into its resting position. This is due to the overall pull force required to remove the lid would have been too much and manually opening it with the actuator would have been a safety hazard. Once the lid was aligned the actuator was set to lower the lid back into its resting position. With the strain data, there was about 20 micro strains seen by each gauge, before a moment caused it to spike to about 108 micro strains.

The faster testing load cell data was the main purpose the team ran these tests, but we were caught by surprise to find that our load cell had hit its excitation voltage, meaning that it was seeing at least 900 lb for 0.4seconds before returning to load when the container was released. This meant that there was no useful load data, but the strain data was a good validation of the FE model.

Table 3. Maximum force seen by load cell

	Maximum Force (lb)				Max PSI
	3 Magnets		6 Magnets		
Test	Slow	Fast	Slow	Fast	Slow
1	167.26	215	547	N/A	1.032
2	164.71	205	522	N/A	0.985
3	133.03	254	553.09	N/A	1.044
4	-	-	548	N/A	1.034

Table 4. Maximum Strains read

	Stain (με)							
	3 Magnets				6 Magnets			
Test	Slow		Fast		Slow		Fast	
	X	Y	X	Y	X	Y	X	Y
1	25.82	24.6	9.86	9.59	52.21	25.35	70.12	57.94
2	26.56	21.76	10.148	8.29	64.56	35.00	48.01	35.00
3	23.59	20.40	7.14	6.36	108.30	53.66	35.07	32.57
4	-	-	-	-	56.08	31.35	29.79	22.93

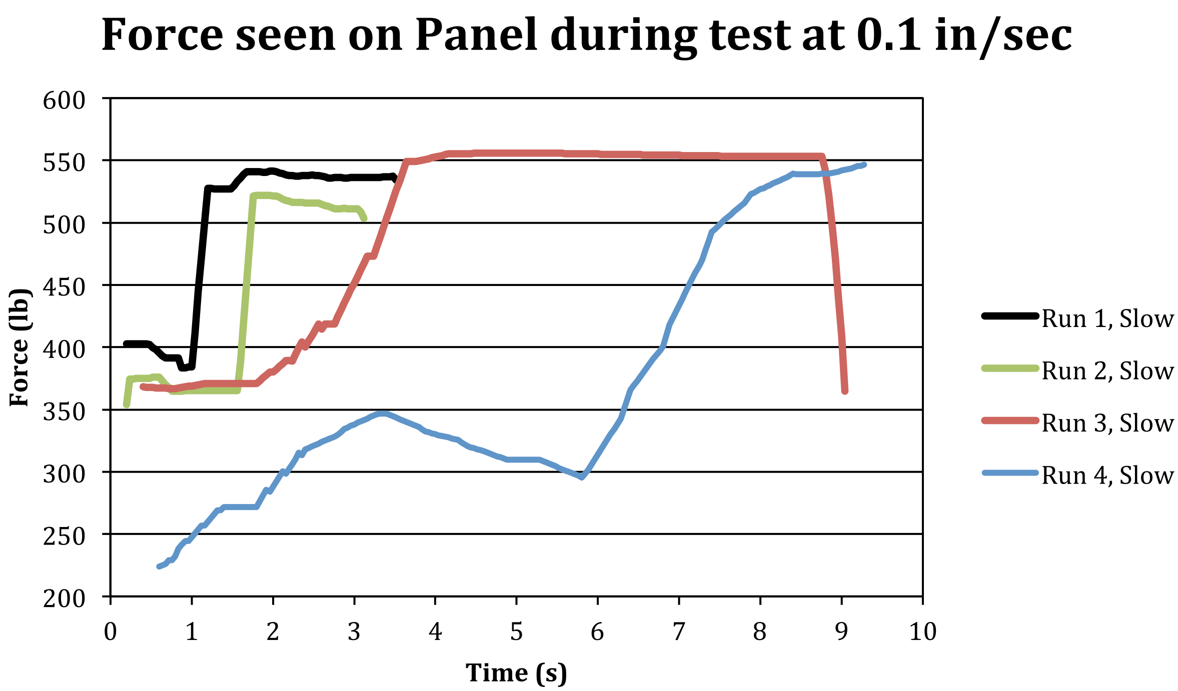


Figure 17. Six Magnets Slow Speed

Discussion

Comparing the FEA data to the actual data was somewhat close, but due to the magnet causing a moment on the load cell the strain data was larger than expected. Modifying the loads in ABAQUS to mimic what the team saw was very close to what the strain gauges recorded. Strain gauges should have been placed in multiple locations to account for the specific magnets having a better contact to the steel supports than others, so the data wouldn't be so obscure.

Throughout the testing the team ran into many issues with respect to the load cell and it is advised that future testing be done using a compression only load cell. This is mainly due to the current load cell, it can only measure strain through the screw holes on the top and bottom where it can be affixed for testing in tension. If we had more time the mounting plate for the load cell should be redone, so it wouldn't offset each run like we saw after each run. It could be corrected in excel, but the amount of time required to fix the data was unnecessary. Ideally the team wanted to test it the actuator as fast as possible, but the amount of force read by the load cells indicate that momentum is coming into play and the test concept with a point load is a bad idea. Overall see a pressure of 1.004 psi and it falls in range of our 1.0 to 1.3 psi goal. As a future design decision, a test method using airbags to allow for a distributed load will have a better chance of simulating the pressure differential in 0.5 seconds.

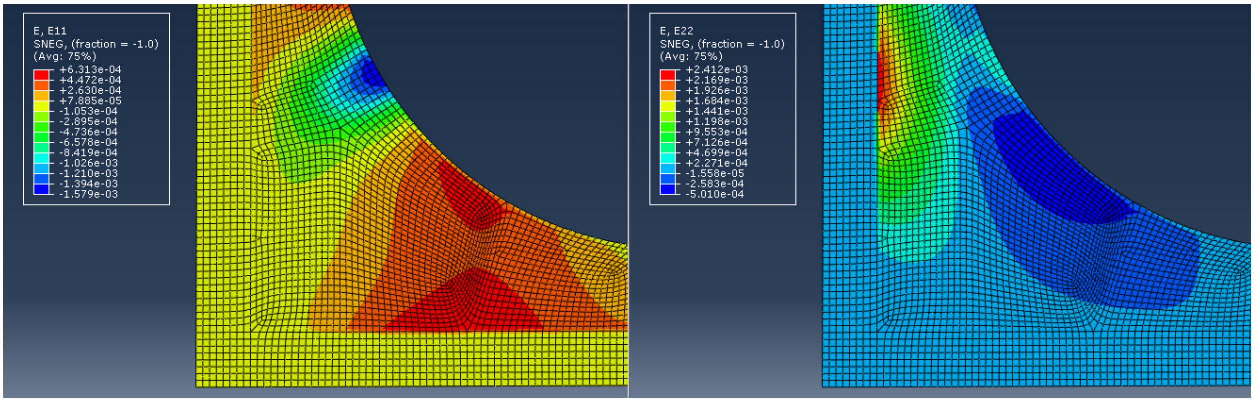


Figure 18. Corrected FEA Strains

Conclusion

The testing data does meet our expectations and confirms that our design is viable, but future testing may be necessary. Due to the unexpectedness of the neodymium magnets the FEA data was close in range of the recorded data, but it wasn't entirely clear how different it was due to the moment seen on that magnet.

The final test will involve the panel being able to withstand deflection when a load is applied. See Figure 12 for our Design Verification Plan.

Specification Verification Checklist (DVPR)

ME428/ME481 DVP&R Format

Report Date		DME Systems	General Atomics					
TEST PLAN								
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES Quantity	SAMPLES Type	TIM Start date
1	T	Add force to make panel come off at equivalent force seen at 1 PSI difference (504 lbs)	Pass- Comes off at desired force Fail- Stays on or comes off premature or not at all	DME	DV	1	B	
2	T	See if tether holds when panel is ejected	Pass- Holds Fail- Tether comes loose or breaks	DME	DV	1	B	
3	I	Seal needs to be undamaged and reusable after compressed under the magnet force	Pass- Undamamged Fail- Damaged	DME	PV	1	C	
4	T	See if panel can be removed by removing bolts from magnets	Pass- Opens w/o damage Fail- Does not open or breaks something	DME	DV	1	B	
5	I	Seal does not leak while under compression	Pass- Leak-free Fail- Leaks	DME	PV	1	C	
6	I	Make sure Disk Panel is reusable after pressure is applied, meets drawing requirements after test.	Pass- Panel is able to reseal and meets drawing requiremtents Fail- Panel deforms from pressure and is no longer reusable	DME	DV	1	C	

Figure 19. Design Verification Plan

Chapter 7: Conclusions and Recommendations

Overall, we believe that our concept is a cost-effective and viable solution to the rapid decompression problems that General Atomics faces. Once the design is completed and properly tested, we recommend that it be implemented in containers that do not meet the necessary rapid decompression requirements. While this design is made of aluminum and specifically designed for a single case, the technology can be applied to any material that GA uses for transporting the UAV's. In other words, our design is universal and can be retrofitted on any of GA's containers. While we decided to design to a range of 1.0 psi to 1.5 psi release pressure, the required surface are that will be exposed is enough to account for a 8.3 psi differential to be released in 0.5 seconds in case something goes wrong and our container sees a higher pressure difference. This added safety factor is essential in case of extreme rapid decompression cases. Our final product is much more innovative, reusable, cost-efficient than any other proposed solutions to General Atomics rapid decompression problem and we recommend implementation on all existing UAV containers.

Appendix A

Engineering Requirements (HOWS)

Rapid Decompression Containment System

Customer: General Atomics Requirements (Whats)

Customer Requirements (Step #2)	Weighting (Total 100)	Manufacturing	Army/Soldier	GA-GSE	Dimensions (in)	Weight (lb)	Time to replace (sec)	Steps to Replace (#)	Number of Parts (#)	Sales Price ($)	Time to release pressure (sec)	Price of Materials ($)	Testing Pressure (psi)	Cases that interface (#)	Force on Latch (lbf)	Burst Disks	One-Time Use Latch
Drop-in Replacement		1	10	3	9	3	9	9	9	3		9	9	9	9	5	3
Flush with Container		6	11	5	3									3		10	10
Corrosion Resistant		5	7	8								3				7	4
MIL-Specs/Standards		7	1	1	3	1					9		9		9	1	8
Durable		4	5	9		1			3	3		3	3	3	9	3	2
Resettable/Reused		2	4	6	9		9	9	3	1		9			9	4	9
Retain Top of Container		9	3	7			1	3			3		3		9	11	11
Intuitive		8	6	11			1	1						9		9	5
Competive Price		11	8	10						9						8	6
delta 8.3 psi in .5 sec		10	2	2							9		9			2	1
Testable		3	9	4			3	9			9		9		9	6	7
Units					in	lb	min	#	#	$	sec	$	psi	#	lbf		
Targets					3	2	10	1	6	200	0.5	0	variable	most	variable		
Burst Disks					1-5	.1	60	8	3	300	0.5	~1k	variable	all	variable		
One-time Latch					2-6	5	15	2-3	5	150	0.5	50	1.5	most	variable		

● = 9	Srong Correlation
○ = 3	Medium Correlation
Δ = 1	Small Correlation
Blank	No Correlation

Figure 20. QFD

Table 5. Morphological Matrix

WHAT	MATERIALS	METHODOLOGY (ACTION)		DETECTION
Latch	Magnets	Break	Lift	Electronics
Panel	Springs	Burst	Rotate	Force
Bubble	Ceramics	Open	Explode	Hydraulics
Door-Roll	Glass	Shatter	Push	Pressure differential
Vent	Plastic	Expand	Pull	Gauge/Valve
	Rubber	Eject	Melt	Lasers
	Metal	Roll	Yield	Spring
	Chemicals	Release	Deform	
	Polymers	Vent	Recede	
	Composites	Compress	Puncture	
		Extend		

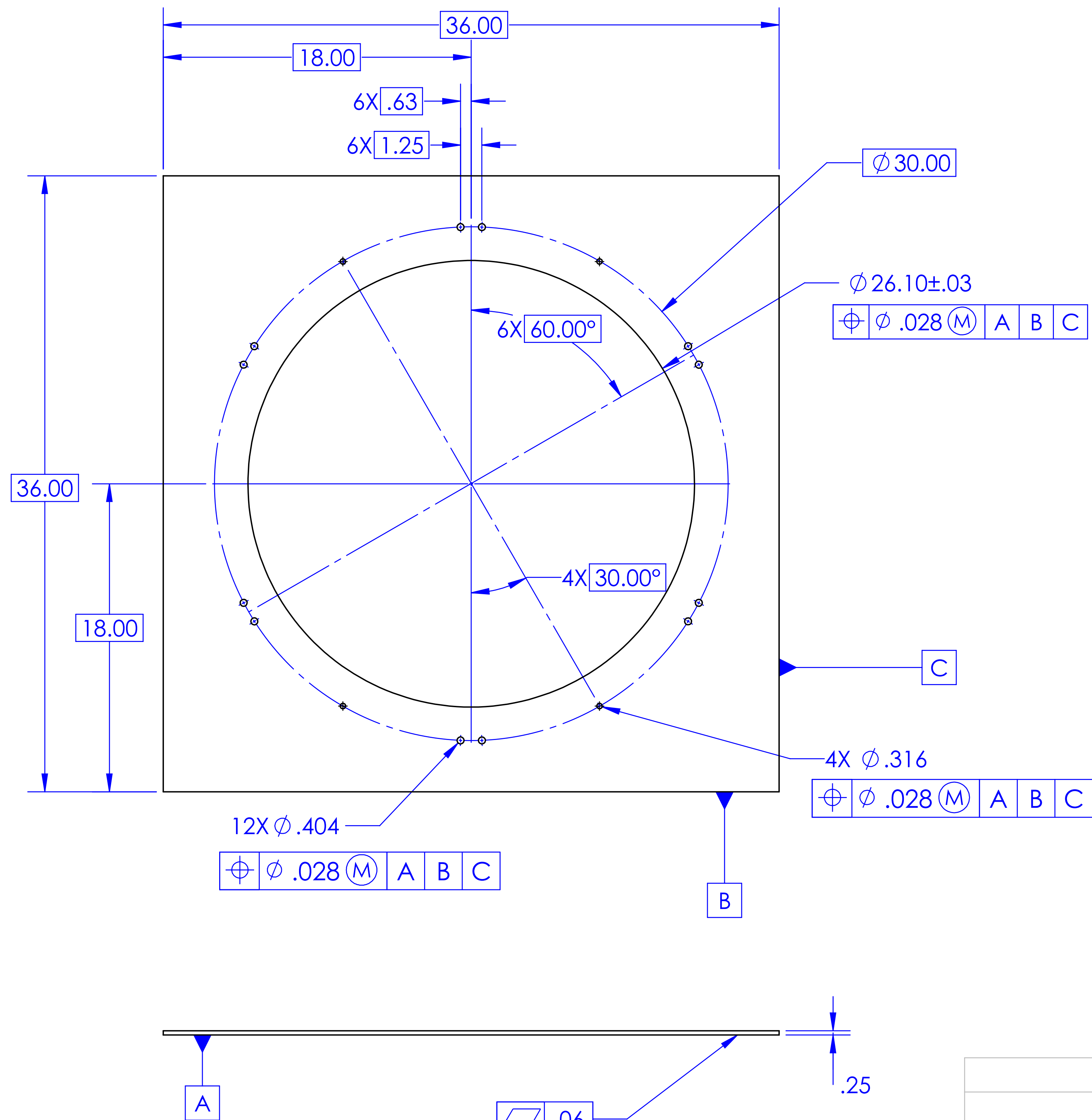
Table 6. Decision Matrix

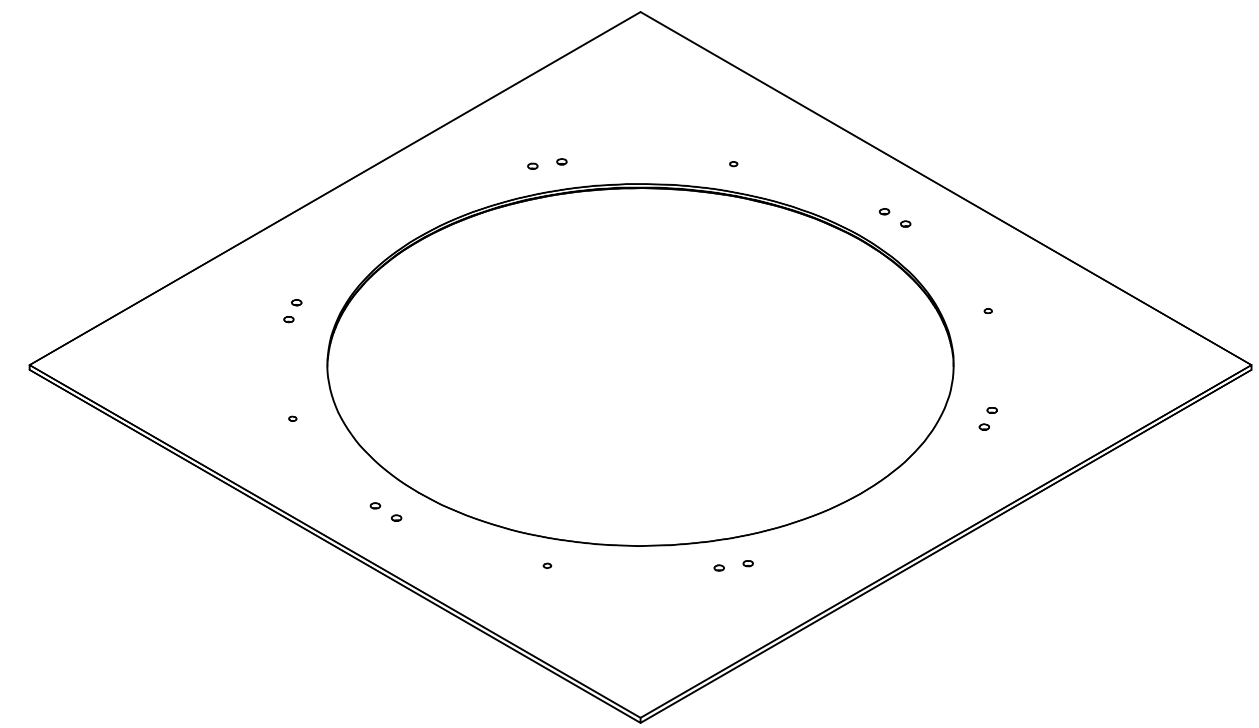
	Latch - Bolt	Latch - Rod Extend	Latch - Safety Catch	Vent - Rotating	Panel	Burst Disks
Initial Cost	+1	+1	+1	-1	0	0
Replacement Cost	+1	+1	+1	+1	+1	0
Drop in Replace	+1	+1	+1	0	0	0
Durability	-1	-1	-1	0	+1	0
Time to Replace	0	0	+1	+1	+1	0
Flush with Container	0	0	-1	0	0	0
MIL SPEC STD	0	0	0	0	0	0
Testable	+1	+1	+1	+1	+1	0
Re-usable	0	0	+1	+1	+1	0
Maintenance	-1	-1	-1	+1	+1	0
Sum of +1	4	4	6	5	6	0
Sum of -1	2	2	3	1	0	0
Total	2	2	3	4	6	0

Table 7. Formal Engineering Requirements

Spec #	Parameter Description	Requirement/Target	Tolerance	Risk	Compliance
1	Weight	5 lbs	Max	M	A,T,S,I
2	Size	4x8 in2	Max	M	A,T,S,I
3	Forces	~3000lb/30latches	Min	H	A,T
4	Energy	Δ8.3 psi	Min	H	A,T,S
5	Material	Corrosion Resistant	Min	L	A,T,S,I
6	Safety Factor	1.5	Min	M	A,T,I
7	Ergonomics	User-Friendly	Min	L	T,I,S
8	Quality Control	MIL-STD	Min	M	A,T,S,I
9	Assembly	Drop-In Replacement	Min	H	T,S,I
10	Operation	Weather-proof	Min	L	S,I
11	Costs	< $15,000 per container	Min	L	A
12	Conceptual Design Review	29-Nov-12	Min	M	A,I
13	Critical Design Review	5-Feb-13	Min	M	A,I
14	Manufacturing/Test Review	3-Mar-13	Min	M	A,T,I
15	Senior Design Expo	3-May-13	Min	M	I

Appendix B
Drawing Packet





NOTE: APPLY FLATNESS TO TOP AND BOTTOM

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL ALUMINUM 6061

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		4/11/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

TEST CONTAINER

SIZE	DWG. NO.	REV
B	CPSP-001	4

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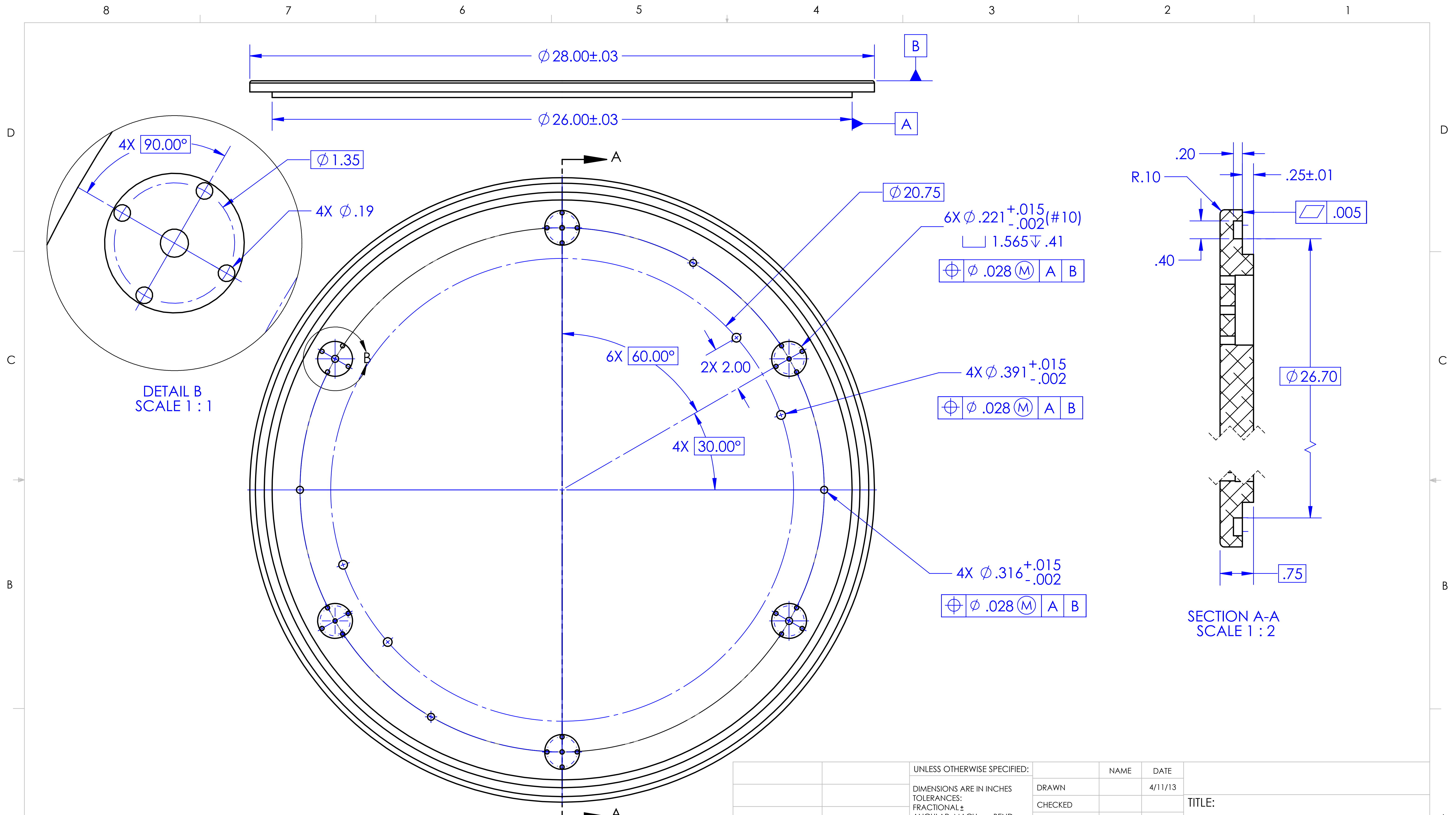

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
ALUMINUM 6061

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		4/11/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

PROTOTYPE LID

SIZE	DWG. NO.	REV
B	CPSP-002	6

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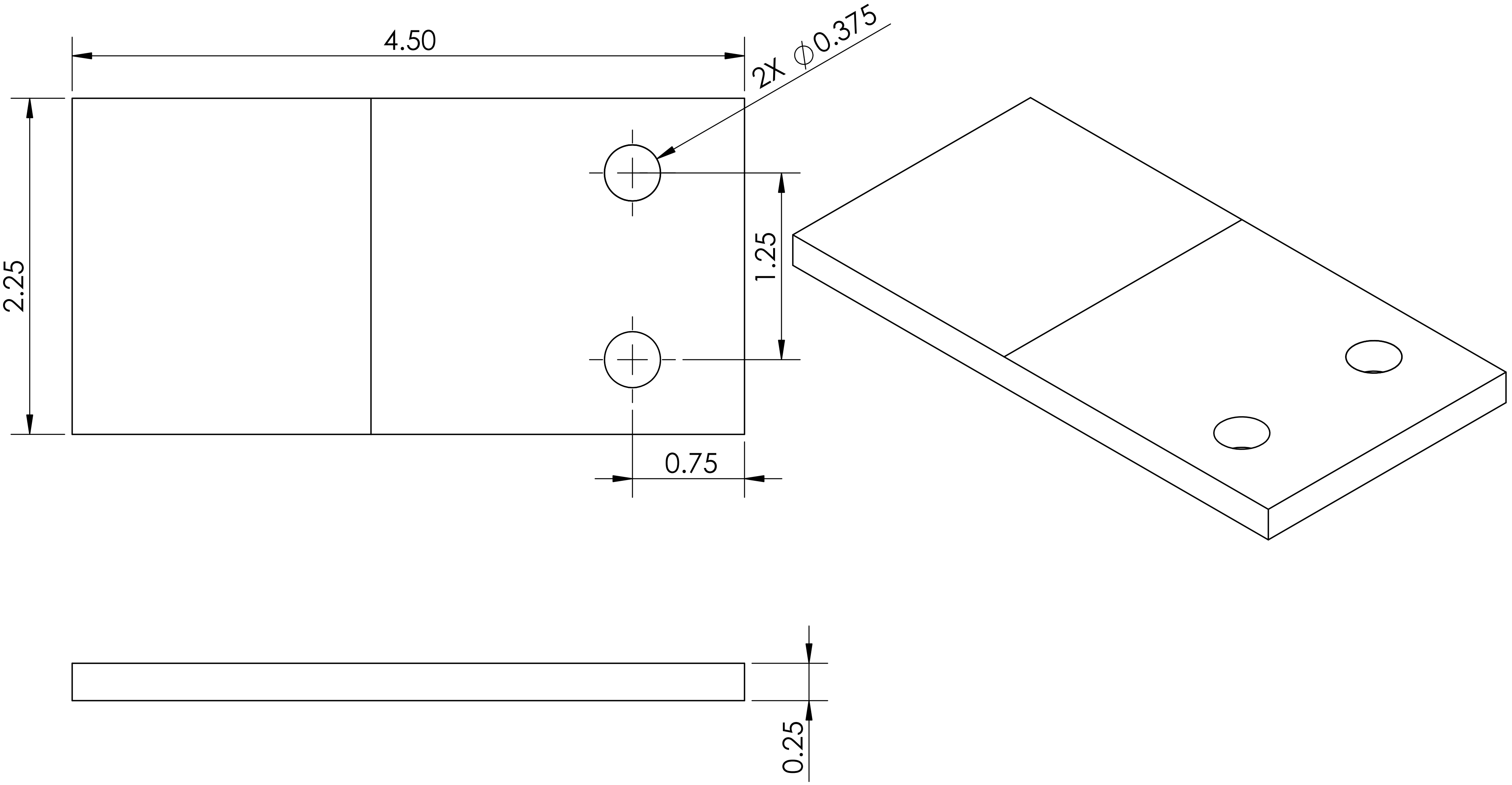

NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

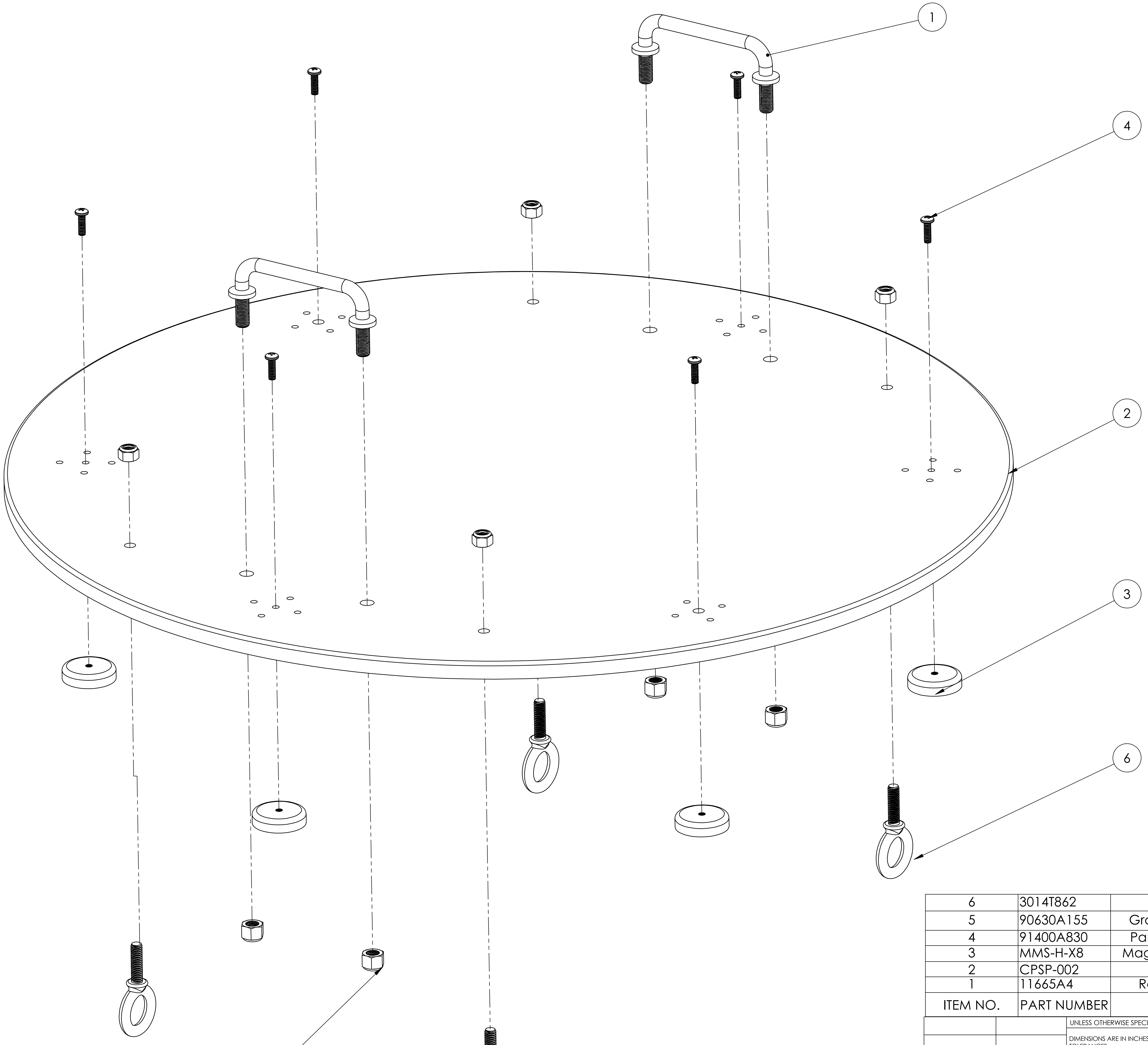
TITLE:

0.25in STEEL BAR

SIZE	DWG. NO.	REV
A	CPSP-003	A

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
6	3014T862	Steel Eyebolt, 5/16"-18 Thread	8
5	90630A155	Grade 8 Steel Nylon-Insert Hex Locknut 3/8"-24	4
4	91400A830	Pan Head Phillips Machine Screw, 10-32 , 5/8"	6
3	MMS-H-X8	Magnet - 1 1/2" Diameter #10-32 Internal Thread	6
2	CPSP-002	PANEL PROTOTYPE	1
1	11665A4	Round-Grip Pull Handle w/ Threaded Studs	2

CPSP-099
NEXT ASSY | USED ON
APPLICATION

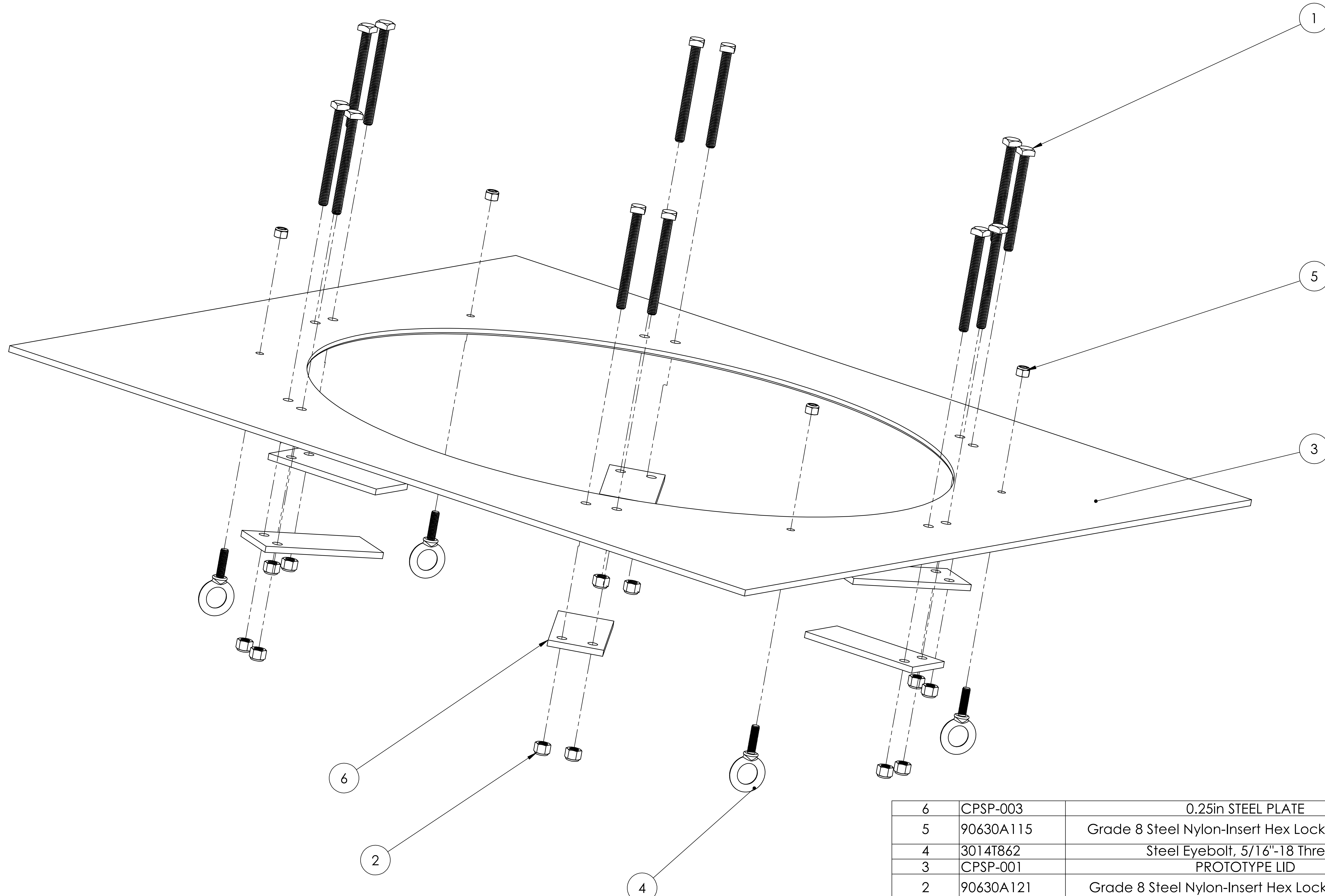
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
PANEL ASSEMBLY

SIZE C | DWG. NO. CPSP-098 | REV A
SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
6	CPSP-003	0.25in STEEL PLATE	6
5	90630A115	Grade 8 Steel Nylon-Insert Hex Locknut 5/16"-18	4
4	3014T862	Steel Eyebolt, 5/16"-18 Thread	4
3	CPSP-001	PROTOTYPE LID	1
2	90630A121	Grade 8 Steel Nylon-Insert Hex Locknut 3/8"-16	12
1	92327A294	Grade 5 Square Head Zinc-Plated Steel Bolt 3/8"-16 Thread, 4	12

NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
		FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

LID ASSEMBLY

SIZE	DWG. NO.	REV
C	CPSP-099	C
SCALE: 1:3	WEIGHT:	SHEET 1 OF 1

Appendix C

List of Vendors

Various hardware will be ordered from:
McMaster-Carr http://www.mcmaster.com (562) 692-5911

Magnets will be ordered from:
K&J Magnetics, Inc http://www.kjmagnetics.com (215) 766-8055

Appendix D

Vendor Supplied Component Specs and Data Sheets

National Instruments……………………………………………………………….NI-234 DAQ
Micro-Measurements…………………………………………EA-06-240LZ-120/E Stain Gauge
Omega……………………………………………………………………. …..DP87 Load Cell DAQ
Danaher Motion IDC……………………………………………………...B8961 Servo Controller
K&J Magnetics…………………………………………………………MMS-H-X8 Magnets
McMaster-Carr…………………………………………………………Screws 91400A830
McMaster-Carr…………………………………………………………Steel 8910K557
McMaster-Carr…………………………………………………………Bolts 92327A294
McMaster-Carr…………………………………………………………Nuts 90630A121
McMaster-Carr…………………………………………………………Steel Eyebolts 3014T86
McMaster-Carr…………………………………………………………Nuts 9063oA115
McMaster-Carr…………………………………………………………Tether 3461T37
McMaster-Carr………………………………………………………Wire Rope Clips 3465T11
McMaster-Carr…………………………………………………………Handles 11665A4
McMaster-Carr…………………………………………………………Seal 1142A84

OMEGA ENGINEERING, INC.
An OMEGA Technologies Company
One Omega Drive, Box 4047
Stamford, CT 06907-0047
Telex: 996404 Cable: OMEGA
FAX: (203) 359-7700

Model: LCH-1K

Range: 1000.000 LBS TENSION

Serial No.: 407565-

Input: 10.0 VDC

Calibration Factor: 3.0109 MV/V

Input Resistance: 467Ω

Output Resistance: 351Ω

Electrical Leakage to Case: ∞ MEGOHMS

Shunt Resistor of 59KΩ Across pins C and D = 1.4733 MV/V

CONNECTOR WIRING CODE

A & B	=	+ Input
C & D	=	- Input
E	=	- Output
F	=	+ Output

This calibration was performed using instruments and standards that are traceable to the United States National Institute of Standards Technology. This certificate has been prepared by an approved supplier/Lab of Omega Engineering, Inc.

Accepted and Ceritified: Douglas C. M[illegible]

Date: 06/08/94

Portable Modular DAQ Systems
SCC Signal Conditioning Overview

NI SCC

- Signal conditioning for DAQ systems
- Up to:
  - 16 analog inputs
  - 8 digital I/O lines
  - 2 unconditioned counter/timers
- Measurement type and connectivity selectable on a per-channel basis
- Low-profile carriers for portable, rack-mount, and desktop applications
- NI-DAQ driver software simplifies configuration, measurement, and scaling

Sensors/Signals

- Thermocouples
- RTDs
- Strain gauges
- Force/load/torque/pressure sensors
- IEPE accelerometers
- Isolated voltage/current input
- Frequency input
- Lowpass filtering
- Isolated voltage/current output
- Isolated digital I/O
- Relay switching

Connectivity Options

- BNC
- Minithermocouple
- Thermocouple
- LEMO (B-series)
- MIL-Spec
- 9-pin D-Sub
- Banana jack
- SMB
- Momentary pushbutton switch
- Toggle switch
- Rocker switch
- LED
- Potentiometer
- Strain relief

Overview

National Instruments SCC provides portable, modular signal conditioning to your DAQ system. SCC conditions a variety of analog I/O and digital I/O signals. With this modular design, you choose your conditioning on a per-channel basis. SCC systems offer custom options for various sensors or signal connection types. While the low-profile carrier is perfect for use with PCMCIA DAQCards and DAQPads for portable applications, you can also use the system for rack-mounted or desktop applications. SCC modules works with all E Series and Basic multifunction DAQ devices.

SCC DAQ Systems

SCC DAQ systems consist of an SC-2345 Series shielded carrier, SCC modules, a DAQ device, and a cable. Each carrier can hold up to 20 SCC modules. Conditioned analog signals are passed directly to the inputs of the DAQ device. SCC modules can also provide up to 300 V of working isolation to voltage and current input/output signals from the DAQ device. Optically isolated digital I/O modules can condition digital lines from the DAQ device or you can access them directly using the 42-pin screw terminal mounted inside the box. Relay modules add switching to your SCC DAQ system, and you can access Analog Input, Analog Output, Digital I/O, Counter/Timer signals as well as timing and triggering signals from the DAQ device using feedthrough modules.

Figure 1. SC-2345 with Configurable Connectors

SCC Features

SCC offers flexibility, customization, and ease of use in a single, low-profile package.

Flexible I/O Options

SCC signal conditioning modules are either single or dual-channel modules that condition analog or digital signals. SCC modules are available for thermocouples, RTDs, strain gauges, force/load/torque/pressure sensors, accelerometers, voltage and current input, isolated voltage and current output frequency-to-voltage conversion, lowpass filtering, isolated digital I/O, relay switching and breadboarding for your custom circuitry (see Table 1 on page 252).

Module Cascading

SCC includes provisions for cascading two SCC analog input modules on a single analog input channel. For example, you can pass an analog input signal through both an attenuator module and a filter module.

Portable Modular DAQ Systems
SCC Signal Conditioning Overview

Removable Connectors

All SCC modules except the SCC-TC01 have removable screw-terminal connectors. This simplifies signal connection and module swapping for quick reconfiguration. The SCC-TC01 has a minithermocouple connector for easy sensor connection and more accurate cold-junction sensing.

Connectivity Options

The SC-2345 with Configurable Connectors is a shielded carrier that offers custom I/O and interface panelettes to match your sensors. With interface panelettes, you can add hardware controls and displays to your system. Blank panelettes are also available to fill unused positions or for customization. See page 267 for complete panelette options.

SCC Module	Input Types	Number of Channels
SCC-AI Series	Isolated analog input	2
SCC-A10	±100 V (10:1 attenuator)	2
SCC-LP Series	Lowpass filters	2
SCC-TC Series	Thermocouples, ±100 mV	1
SCC-RTD01	RTD (2, 3, and 4-wire)	2
SCC-SG Series	Strain gauges and force/load/torque sensors	2
SCC-ACC01	Accelerometers	1
SCC-CI20	0 to 20 mA current input	2
SCC-AO10	Isolated voltage output, ±10 V	1
SCC-CO20	Isolated current output, 0 to 20 mA	1
SCC-FV01	Frequency-to-voltage	2
SCC-DI01	Isolated digital input	1
SCC-DO01	Isolated digital output	1
SCC-SG11	Shunt calibration	2
SCC-FT01	Unconditioned or custom	2
SCC-RLY01	Switch 5 A at 30 VDC or 250 VAC	1

Table 1. SCC Signal Conditioning Modules

Power Options

Each SCC system offers three different power options. Depending on the total power consumption of the SCC modules installed, you can power the SCC system from (1) the 5 VDC line of a DAQ device or an external 5 VDC source, (2) an AC power source, or (3) an external 7 to 42 VDC power supply. To determine which power option is best for your application, see the SC-2345 shielded carrier (page 254) or visit the online SCC Advisor at **ni.com/advisors**

Signal Routing

Many of the SCC analog input modules are dual-channel modules. When a dual-channel module is installed in the SC-2345, the two output voltages of the module are routed to two input channels of the DAQ device, channels X and X+8, where X is any integer 0 through 7. For example, if a dual-channel module is installed in the J1 socket of the SC-2345, the output voltages are routed to input channels 0 and 8 of the E Series DAQ device.

Digital modules connect directly to individual digital I/O lines of the DAQ device. For example, a digital output module installed in any of J16 slots J9 is controlled by a single DIO line of the DAQ device. The digital I/O lines of a DAQ device are line configurable, so you can choose any combination of eight digital I/O modules and relays.

Accessories

The SC-2345 with configurable connectors offers accessories such as a panel-mount kit, a rack-mount kit for 19 in. cabinets, a stacking kit, and a handle kit for use with multiple carriers and with DAQPad devices.

Software

You can develop your SCC DAQ System applications very quickly and easily with the NI-DAQ driver software or with LabVIEW. NI-DAQ is the robust driver software that makes it easy to access the functionality of your data acquisition and signal conditioning hardware, whether you are a beginner or an advanced user. Helpful features include:

Automatic Code Generation – DAQ Assistant is an interactive guide that steps you through configuring, testing, and programming measurement tasks and generates the necessary code automatically.

Cleaner Code Development – Basic and advanced software functions have been combined into one easy-to-use yet powerful set to help you build cleaner code and move from basic to advanced applications without replacing functions.

High-Performance Driver Engine – Software-timed single-point input (typically used in control loops) with NI-DAQ achieves rates of up to 50 kHz. NI-DAQ also delivers maximum I/O system throughput with a multithreaded driver.

Test Panels – NI-DAQ lets you test all four device functions before you begin development with test panels, accessible either from your development environment, such as LabVIEW, or the configuration utility.

Scaled Channels – Easily scale your voltage data into the proper engineering units using the NI-DAQ Channel Wizard. By choosing from a list of common sensors and signals or creating your own custom scale.

LabVIEW Integration – All NI-DAQ functions offer the waveform data type, which carries acquired data and timing information directly into more than 400 built-in analysis routines in LabVIEW, and displays the results in engineering units on a graph.

Operating System Compatibility

All modules work with Windows 2000/NT/XP

For information on other operating systems such as Linux and Mac OS X see page 187.

Portable, Shielded SCC Module Carriers

NI SC-2345 Series

- Shielded carriers for up to 20 SCC modules
- Portable, low-profile packaging
- Cables directly to an E Series or Basic multifunction DAQ device
- Powered by DAQ device (additional power options available)

SC-2345 Connector Block
- Strain relief for signal wiring
- Hinged lid for easy access

SC-2345 Carrier with Configurable Connectors
- Panelettes for sensor connectivity
- Panelettes for control and display
- Blank panelettes for filler

Operating Systems
- Windows 2000/NT/XP

Recommended Software
- LabVIEW
- LabWindows/CVI
- Measurement Studio
- Lookout
- VI Logger

Other Compatible Software
- Visual Basic
- C/C++, C#

Driver Software (included)
- NI-DAQ 7

Overview

The National Instruments SC-2345 Series consists of two types of carriers, the SC-2345 connector block and the SC-2345 with configurable connectors. These enclosures for SCC signal conditioning modules connect directly to 68-pin DAQ devices. They include sockets for SCC modules, along with screw terminals for convenient connection to digital I/O and counter/timer (GPCTR) signals from the DAQ device. These carriers offer three power options to increase the flexibility of deployment.

SC-2345 Connector Block

The SC-2345 includes 20 SCC sockets, labeled J1 through J20 (see Figure 1). Sockets J1 through J8 accommodate SCC modules for conditioning signals on the analog input channels of the DAQ device. For example, an SCC module plugged into socket J1 conditions signals for channels 0 and 8 of the device.

You can use sockets J9 through J16 for either digital I/O modules or dual-stage analog input conditioning. When using dual-stage conditioning of analog inputs (for applicable modules), wire your input signal to the first-stage module (in sockets J9 through J16). The SC-2345 routes the output signal of the first-stage SCC module to the input of the second stage SCC module internally (see Figure 2). When using sockets J9 through J16 for digital I/O, simply plug in a digital SCC module or the SCC-FT01 for custom digital applications. You can use any combination of SCC digital input or digital output modules. The digital I/O lines of E Series or Basic multifunction DAQ devices are configurable for input and output on a line-by-line basis. You can also access the DIO lines of the DAQ device using the screw terminal block.

Sockets J17 through J20 access the two analog output channels and the GPCTR channels 0 and 1.

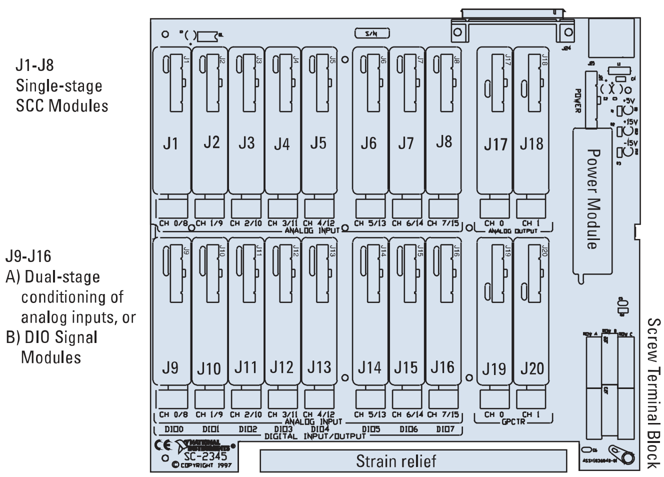


Figure 1. Diagram of Socket Layouts on SC-2345 Connector Block

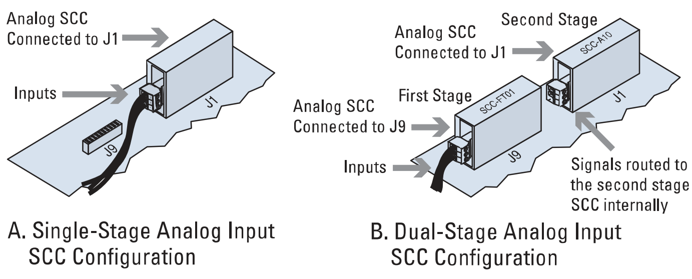


Figure 2. Single-Stage and Dual-Stage Analog Input SCC Configuration for the SC-2345 Connector Block

MICRO-MEASUREMENTS

General Purpose

STRAIN GAGES

FOR COMPLETE TECHNICAL DATA, VISIT WWW.VISHAYPG.COM

GRID RESISTANCE IN OHMS	TC OF GAGE FACTOR, %/100°C
120.0±0.3%	(+1.3±0.2)

GRID	GAGE FACTOR @ 24°C	TRANSVERSE SENSITIVITY
1	2.090±0.5%	(+0.7 ±0.2)%
2		
3		
NOM		

THERMAL OUTPUT COEFFICIENTS FOR 1018 Steel @ A G.F. OF 2.00

ORDER	FAHRENHEIT	CELSIUS
0	-2.13E+2	-8.27E+1
1	+5.15E+0	+5.49E+0
2	-3.66E-2	-9.41E-2
3	+8.20E-5	+4.41E-4
4	-5.05E-8	-5.30E-7

FOIL LOT NUMBER	BATCH NUMBER
A65AD877	VF526206

ITEM CODE	QUANTITY	CODE
6833	**10**	**222513**

Pb Pb-free RoHS COMPLIANT

MADE IN UNITED STATES

EA-06-240LZ-120/E

ACCURATELY MEASURE PRESSURE, STRAIN, FORCE, LOAD, THRUST, AND TORQUE

OMEGACARE℠ extended warranty program is available for models shown on this page. Ask your sales respresentative for full details when placing an order. OMEGACARE℠ covers parts, labor and equivalent loaners.

SPECIFICATIONS

Excitation Supplies:
DP87: 5, 10 and 15V; switch selectable, isolated; drives 2 parallel 350 Ω strain gages @ 15V (90 mA)
DP88: 5, 10, 15 and 20V; switch selectable, isolated; drives 8 parallel 350 Ω strain gages @ 15V (350 mA)
Accuracy: 0.01% FS, ±1 digit
Repeatability: ±1 digit
Zero Offset: Entire input range
Zero Stability: 0.5 µV/°C; no measurable drift with time
Span Stability: 0.005% of reading/°C; 0.1% of reading per year
Normal-Mode Noise Rejection: >60 dB @ 50/60 Hz
Common-Mode Noise Rejection: >120 dB @ 50/60 Hz input impedance; >10 MΩ to 500 MΩ depending on range
Display: 8-digit, 14-segment, alphanumeric LEDs; 14 mm (0.54") high; one negative (-) LED digit at left
Display Count Rate: ±100,000 active
Reading Rate: 2 readings per second
Overload Protection: 270 Vdc/Vac RMS across inputs and input to ground; power lead to ground 1500 Vdc/Vac RMS
Ambient Operating Conditions: 0 to 50°C (32 to 122°F); 0 to 90% RH, non-condensing
Storage Temperature: -40 to 65°C (-40 to 149°F)
Input Connections: AC power, quick-connect; DC power and sensors, screw terminals; RS232C, DB25 connector
Case Construction: Metal, black anodized, extruded aluminum
Power: 90 to 132 Vac; 48 to 400 Hz
Weight: DP87, 1.8 kg (4 lb); DP88/DP89, 2.7 kg (6 lb) without options
Dimensions:
DP87: 67 H x 136 W x 250 mm D (2.64 x 5.35 x 9.84"), cutout 68 H x 138 mm W (2.67 x 5.43"), bezel 72 x 142.5 mm (2.83 x 5.61")
DP88/DP89: 67 H x 272 W x 250 mm D (2.6 x 10.71 x 9.84"), cutout 68 H x 274 mm W (2.67 x 10.79"), bezel 72 x 284 mm (2.83 x 11.18")

AVAILABLE FOR FAST DELIVERY!

To Order *(Specify Model Number)*

MODEL NO.	DESCRIPTION	PRICE	SELECTABLE INPUT RANGE	FULL SCALE DISPLAY MIN GAIN	FULL SCALE DISPLAY MAX GAIN
DP87*	Single width	**$729**	-15 to 100 mV	0.01 cts/mV	1000 cts/mV
DP88*	Double width panel mount	**899**	-30 to 200 mV	0.05 cts/mV	500 cts/mV
			-75 to 500 mV	0.02 cts/mV	200 cts/mV
DP89*	Double width benchtop	**899**	-150 to 1000 mV	0.01 cts/mV	100 cts/mV

Comes complete with power cord and operator's manual.
*** *DP87 can accommodate 1 additional option. DP88 and DP89 can accommodate up to 4 additional options.*

OPTIONS

To Order *(Specify Model Number)*

MODEL NO.	PRICE	DESCRIPTION
DP80-ALM	**$169**	Alarms, dual limits (up to 2 per unit), selectable hysteresis and alarm delay
DP80-AOV	**189**	Analog output, 0 to 10 Vdc isolated, linearized and scalable (N/A DP80-AOC)
DP80-AOC	**189**	Analog output, 4 to 20 mA isolated, linearized and scalable (N/A DP80-AOV)
DP80-MTH	**99**	Math, min, max, average, rate of change
DP80-SER**	**189**	RS232C/20 mA serial output

**** *Selectable baud rate from 300 to 9600. Includes DB25 mating male connector.*

OMEGACARE℠ extended warranty program is available for models shown on this page. Ask your sales representative for full details when placing an order.

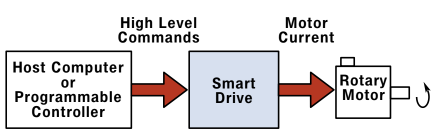
Ordering Example: DP89,** double-width benchtop strain gage indicator, **DP80-ALM,** alarm capability, **DP80-SER,** RS232C communications output, $899 + 169 + 189 = **$1257. OCW-1,** OMEGACARE℠ extends standard 1-year warranty to a total of 2 years **($125),** $1257 + 125 = **$1382.

Overview

IDC's B8961 (1–axis) and B8962 (2–axes) Brushless Servo Smart Drives are user friendly systems that offer you many compelling features and benefits. Consider these systems when your motion control application requires:

- A well integrated motion controller, digital servo drive, operator interface, power supply, 30 I/O, and built in Opto I/O rack
- CE cULus compliant
- A sophisticated servo controller capable of controlling position, velocity, and force/torque simultaneously. This capability makes the B8961/2 an ideal solution for clamping, pressing, drilling, and automated fastening applications
- A simple Machine Controller
- Interrupts
- Configurable I/O
- Linear Interpolation, and Registration
- Coordinated motion between two axis
- Go Immediate Mode. This mode of operation allows the controller to multitask between motion control and I/O operations. Immediate Mode also allows each axis to move completely independently of the other axis
- 1–99 axes of immediate control via host RS-232C communication
- Optional analog I/O for:
  – Reading an analog input proportional to temperature, distance, pressure, or force
  – Setting an analog output to control position of another axis of motion (for use with a D2500, H3501/4501, or B8501 analog position controls)

Compatible Actuators:
EC2-B, EC3-B, EC4-B, EC5-B, N2-B, NV-BN, R2A-BN, R3-B, R4-B, LM, LD Positioning Tables



Optional Keypad

- Both a programming and a operator interface
- Menu-driven setup, tuning, Help Function, Diagnostic Screens, Trace Mode-easy set up, troubleshooting and program debugging
- Easy to read 40 character display
- Keypad is protected to Nema 4 (IP65) when panel mounted

Drive Performance

- The B8961 and B8962 features the same outstanding dynamic performance and reliability as our DSP based B8001 digital brushless servo drive, described on page H-11

Motion Control

- 6K memory for up to 199 user programs (30K, 400 programs optional)
- User scaling of position, velocity, and acceleration
- Descriptive variables, math and conditional branching
- High Speed interrupt driven inputs–registration
- B8962–linear interpolated vector moves
- IDCMotion™ Windows Application Developer software included. See page H-26.

Opto Compatible I/O

- Accepts OPTO–22 (G4) digital modules and Grayhill (G5) analog and temperature modules
- 100% solid state, opto–isolation to 4000 volts
- 8 positions, all bidirectional
- Specify (intermix) Opto I/O modules: for AC, DC, analog, and temperature signals

Specifications

Common Specifications

Input Power — 90-240 VAC single phase, 50/60 Hz. 1150 VA Max @115 VAC, 2300 VA max @230 VAC. (B8962: X 2).

Motor Output

Current Capability	5A continuous, 10A peak
Protection	Protected against phase-to-phase shorts and shorts to ground. Fused.
Power Dump Capacity	See page H-40 for details.

Encoder Input

Type	Differential quadrature incremental encoder, with or without index
Maximum Rate	2MHz (post-quadratune)
Power	+5V @ 200 mA power encoder

Diagnostic Output

Format	0 to 5V analog signal (centered at 2.5V)
Variables	Configurable as actual, and commanded velocity; position error; velocity error; actual, and commanded torque—programmable scaling

Serial Interface

RS-232C, 3 wire implementation (Tx, Rx, & Com), 9600 Baud, 8 data bits, 1 stop bit, no parity.

Environmental

Operating Temperature	Shutdown occurs if heat-sink exceeds 55°C (131°). This temperature is a function of motor current, regen and ambient temperature. Some applications may require FK fan kit. See page H-39.
Humidity	0% to 90% non-condensing

Additional B8961 & B8962 Specifications

Motion

Position Range	±0-2,147,483,647 steps. Absolute and incremental.
Acceleration Range	0.01 to 999.99 rev/sec/sec
System Resolution	8,000 counts per revolution (IDC supplied motors)

OPTO-compatible I/O

8 Positions support OPTO-22 (G4) digital, Grayhill (G5) analog and temperature modules

Analog Opto Module	
Resolution	12 bits
Bandwidth	62.5 Hz

Inputs

8 programmable, Limits, Home	Optically isolated, 24 VDC compatible (via pull up terminal—disconnect jumper to 12 VDC), 12 mA sinking current required.
Incremental Encoder	Optically isolated, differential 5 VDC, 2 MHz max (post-quadrature). 5VDC, 200mA power available.

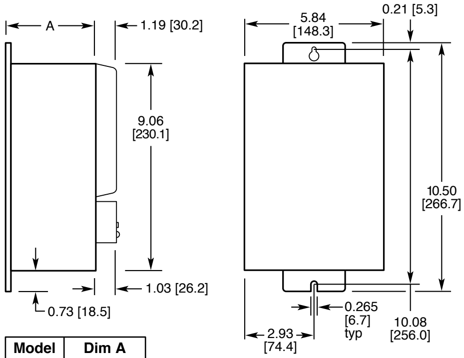
Outputs

8 Programmable	Open collector, sink current 100 mA max. Total of 350 mA for all I/O.

Mounting Dimensions

(B8961 and B8962)

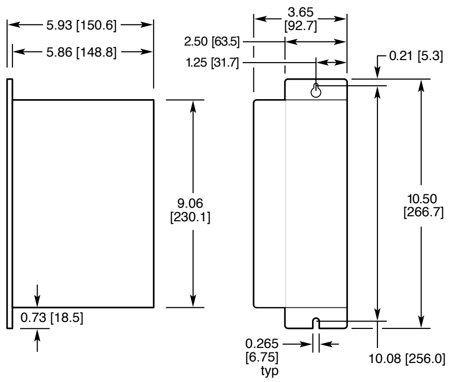
Minimum Depth Mounting in [mm]



Model	Dim A
B8961	3.73 [95.7]
B8962	6.79 [172.5]

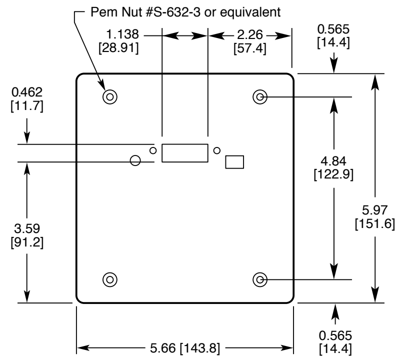
Minimum Width Mounting in [mm]

(B8961 only, front panel and opto modules removed)

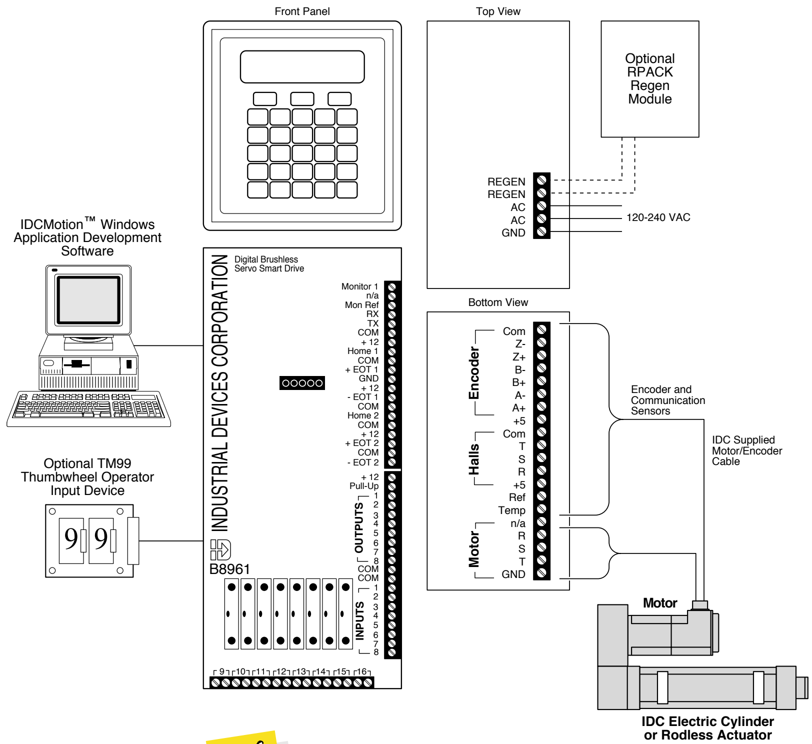


Remote Mounting

Front Panel (rear view) in [mm]



Operation



How To Order

Model	Description	Code I/O Module Description		Option	Description
		Position 1 2 3 4 5 6 7 8			
B8961	1-axis unit, with FP220 front panel	A	DC/AC In, 10-32 VDC, 12-32 VAC	-LMTR	For operation with an IDC Linear Motor
B8962	2-axis unit, with FP220 front panel	B	DC In, TTL	-FK1	Fan Kit, 115 VAC See page H-39.
B8961NP	1-axis unit, no front panel	C	DC In, 35-60 VDC	-FK2	Fan Kit, 230 VAC See page H-39.
B8962NP	2-axis unit, no front panel	D	AC In, 90-140 VAC	-30K	30K user program memory
		E	AC In, 180-240 VAC		
		F	DC Out, 5-60 VDC, 3 Amps		
		G	AC Out, 12-140 VAC, 3 Amps		
		H	AC Out, 24-280 VAC, 3 Amps		
		I	Input test switch		
		J	Analog In, 0-10 VDC		
		K	Analog In, 4-20 mA		
		L	Analog Out, 0-10 VDC		
		M	Analog Out, 4-20 mA		
		N	J Thermocouple In, 0-700°C		
		O	K Thermocouple In, -100-924°C		
		P	RTD In, 100 Ohm		
		X	Empty		

Accessories

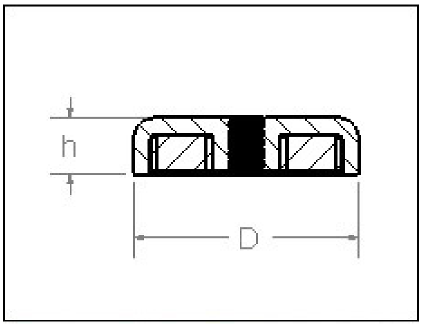
RPACK-1, 115 VAC Operation	External regenerative power dissipation module. See page H-40.
RPACK-2, 230 VAC Operation	External regenerative power dissipation module. See page H-40.
FP220	Operator interface, front panel. See page H-41.
TM99	Thumbwheel input module. See page H-42.

To confirm your selection, review the checklist on page H-6.

MMS-H-X8 Specification Sheet

Product Specifications

Type:	MOUNTING-MAGNET
Dimensions:	1.5 dia (in)
Tolerance:	All dimensions ± 0.004 in
Material:	NdFeB, Grade N42
Plating:	
Max Op Temp:	176ºF (80ºC)
Br max:	13,200 Gauss
BH max:	42 MGOe



Performance Specifications

Pull Force, Case 1,
Magnet to a Steel Plate: 103.6 lb

Surface Field values are derived from calculation and verification with experimental testing. These values are the field values at the surface of the magnet, centered on the axis of magnetization. Measurement of the B field with a magnetometer may yield varying results, depending on the geometry of your sensor. Pull Force values are based on extensive product testing in our laboratory. Different configurations of magnets and surrounding ferromagnetic materials may substantially alter your results.

K&J Magnetics, Inc.
www.kjmagnetics.com - Phone: 215.766.8055 - Fax: 215.766.8054
Printed: 06/07/2013

Pan Head Torx (Continued from previous page)

Lg.	Pkg. Qty.		Pkg.
18-8 Stainless Steel (Cont.)			
2-56 (Cont.)			
3/8"	25	96710A158	$7.26
4-40—T10 Torx Size			
3/16"	50	96710A213	10.00
1/4"	50	96710A215	5.85
5/16"	50	96710A216	10.25
3/8"	50	96710A218	5.79
1/2"	50	96710A221	6.14
6-32—T15 Torx Size			
1/4"	50	96710A255	7.26
5/16"	50	96710A257	10.26
3/8"	50	96710A258	7.75
1/2"	50	96710A261	8.17
5/8"	50	96710A264	8.59
3/4"	50	96710A267	9.01
1"	50	96710A270	9.42
8-32—T20 Torx Size			
1/4"	50	96710A312	8.46
3/8"	50	96710A315	9.12
1/2"	50	96710A318	9.77
5/8"	50	96710A321	10.43
8-32 (Cont.)			
3/4"	50	96710A324	$11.08
1"	50	96710A327	11.74
10-24—T25 Torx Size			
3/8"	50	96710A461	11.12
1/2"	50	96710A465	11.73
3/4"	25	96710A471	6.56
1"	25	96710A475	6.89
10-32—T25 Torx Size			
1/4"	50	96710A572	10.41
3/8"	50	96710A576	11.12
1/2"	25	96710A578	7.41
5/8"	25	96710A580	6.29
3/4"	25	96710A584	6.56
1"	25	96710A586	6.84
1/4"-20—T30 Torx Size			
1/2"	25	96710A733	6.80
3/4"	25	96710A737	7.07
1"	25	96710A742	7.35
1 1/2"	25	96710A745	7.89
2"	25	96710A748	8.43
Zinc-Plated Steel			
2-56—T8 Torx Size			
3/16"	100	90022A088	12.14
1/4"	100	90022A090	12.31
5/16"	100	90022A094	12.45
3/8"	100	90022A096	12.61
4-40—T10 Torx Size			
1/4"	100	90022A110	5.47
5/16"	100	90022A112	5.72
3/8"	100	90022A114	5.75
1/2"	100	90022A116	5.77
Zinc-Plated Steel (Cont.)			
6-32—T15 Torx Size			
1/4"	100	90022A142	$6.22
3/8"	100	90022A145	6.17
1/2"	100	90022A148	6.67
3/4"	100	90022A151	7.32
8-32—T20 Torx Size			
1/4"	100	90022A180	7.52
3/8"	100	90022A185	7.67
1/2"	100	90022A188	8.03
3/4"	100	90022A191	9.29
10-24—T25 Torx Size			
3/8"	100	90022A240	$9.49
1/2"	100	90022A242	10.18
3/4"	100	90022A245	11.54
1"	50	90022A247	7.07
10-32—T25 Torx Size			
3/8"	100	90022A264	9.49
1/2"	100	90022A267	10.18
3/4"	100	90022A269	11.54
1"	50	90022A271	7.07
Black-Coated Steel			
00-90—T2 Torx Size			
1/8"	50	93701A001	11.67
3/16"	50	93701A003	11.80
1/4"	50	93701A005	11.93
0-80—T5 Torx Size			
1/8"	50	93701A100	9.92
3/16"	50	93701A103	10.07
1/4"	50	93701A106	10.22
2-56—T7 Torx Size			
3/16"	50	93701A200	9.48
1/4"	50	93701A203	9.78
5/16"	50	93701A206	10.07
3/8"	50	93701A209	10.37
4-40—T10 Torx Size			
3/16"	50	93701A250	8.60
1/4"	50	93701A253	8.74
5/16"	50	93701A256	9.03
4-40 (Cont.)			
3/8"	50	93701A259	9.33
1/2"	50	93701A262	9.63
6-32—T15 Torx Size			
1/4"	50	93701A300	9.33
3/8"	50	93701A304	9.63
1/2"	50	93701A308	10.07
5/8"	50	93701A312	10.37
3/4"	50	93701A315	10.67
1"	50	93701A318	11.11
8-32—T20 Torx Size			
1/4"	50	93701A400	9.92
3/8"	50	93701A404	10.22
1/2"	50	93701A408	10.52
5/8"	50	93701A412	10.81
3/4"	50	93701A416	11.11
1"	50	93701A420	11.55

Mil. Spec. Pan Head Phillips

Strict military standards ensure performance and reliability. Materials and dimensions meet Fed. Spec. FF-S-92. Screws are fully threaded. Length is measured from under the head.

300 series stainless steel screws are passivated to meet QQ-P-35. **Cadmium-plated steel** screws meet QQ-P-416 and have a Class 3A thread fit.

Lg.	Dash No.	Pkg. Qty.		Pkg.
300 Series Stainless Steel				
0-80—#0 Drive; Meet MS-51958				
1/8"	120	100	91400A030	$12.50
3/16"	121	100	91400A035	14.25
1/4"	122	100	91400A041	10.78
5/16"	123	100	91400A043	14.29
3/8"	124	100	91400A046	14.77
7/16"	125	25	91400A047	10.00
1/2"	126	25	91400A049	10.00
2-56—#1 Drive; Meet MS-51957				
1/8"	1	100	91400A050	5.00
3/16"	2	100	91400A052	5.00
1/4"	3	100	91400A054	5.25
5/16"	4	100	91400A056	5.36
3/8"	5	100	91400A058	5.67
7/16"	6	100	91400A060	6.25
1/2"	7	100	91400A062	6.49
9/16"	141	100	91400A063	12.50
5/8"	8	100	91400A064	8.75
3/4"	9	100	91400A066	8.75
7/8"	10	25	91400A068	10.00
4-40—#1 Drive; Meet MS-51957				
1/8"	11	100	91400A101	8.75
3/16"	12	100	91400A104	5.88
1/4"	13	100	91400A106	5.89
5/16"	14	100	91400A107	6.04
3/8"	15	100	91400A108	6.13
7/16"	16	100	91400A112	6.92
1/2"	17	100	91400A110	7.92
9/16"	120	100	91400A111	9.59
5/8"	18	100	91400A114	6.75
3/4"	19	100	91400A116	11.75
7/8"	20	50	91400A118	4.38
1"	21	50	91400A119	8.75
1 1/8"	121	50	91400A121	11.25
1 1/4"	22	50	91400A124	10.63
1 3/8"	122	50	91400A127	14.63
1 1/2"	23	10	91400A130	6.00
6-32—#2 Drive; Meet MS-51957				
1/8"	24	50	91400A142	$9.00
3/16"	25	100	91400A143	10.50
1/4"	26	100	91400A144	7.00
5/16"	27	100	91400A145	7.75
3/8"	28	100	91400A146	7.75
7/16"	29	100	91400A149	8.82
1/2"	30	100	91400A148	9.00
9/16"	123	50	91400A147	10.00
5/8"	31	50	91400A150	5.65
3/4"	32	50	91400A151	7.00
7/8"	33	50	91400A152	7.30
1"	34	50	91400A154	7.39
1 1/8"	124	25	91400A155	7.50
1 1/4"	35	25	91400A156	6.56
1 3/8"	125	25	91400A157	11.25
1 1/2"	36	25	91400A158	6.88
1 3/4"	37	25	91400A160	10.00
2"	38	25	91400A162	12.50
6-40—#2 Drive; Meet MS-51958				
1/4"	26	25	91400A170	12.50
5/16"	27	25	91400A173	12.50
3/8"	28	25	91400A176	13.13
8-32—#2 Drive; Meet MS-51957				
3/16"	40	50	91400A189	8.75
1/4"	41	50	91400A190	7.63
5/16"	42	50	91400A191	4.75
3/8"	43	50	91400A192	5.25
7/16"	44	50	91400A193	6.38
1/2"	45	50	91400A194	5.50
9/16"	126	25	91400A195	11.25
5/8"	46	25	91400A196	3.29
3/4"	47	25	91400A197	4.21
7/8"	48	25	91400A198	5.69
1"	49	25	91400A199	6.88
1 1/4"	50	25	91400A201	10.38
1 1/2"	51	25	91400A203	11.25
2"	53	25	91400A206	14.38
10-24—#2 Drive; Meet MS-51957				
3/8"	61	50	91400A240	$8.63
1/2"	63	50	91400A242	13.13
5/8"	64	50	91400A244	10.25
3/4"	65	25	91400A245	9.19
1"	67	25	91400A247	10.00
1 1/4"	68	25	91400A251	13.75
1 1/2"	69	25	91400A255	10.62
2"	71	10	91400A257	8.00
10-32—#2 Drive; Meet MS-51958				
1/4"	59	50	91400A821	14.81
5/16"	60	50	91400A825	14.85
3/8"	61	50	91400A827	7.25
7/16"	62	50	91400A828	11.25
1/2"	63	50	91400A829	7.63
5/8"	64	50	91400A830	10.25
3/4"	65	25	91400A831	5.31
7/8"	66	25	91400A832	6.25
1"	67	25	91400A833	6.88
1 1/4"	68	25	91400A836	10.94
1 1/2"	69	25	91400A838	14.77
2"	71	10	91400A841	8.00
1/4"-20—#3 Drive; Meet MS-51957				
1/2"	79	25	91400A537	8.13
5/8"	80	25	91400A539	14.69
3/4"	81	25	91400A540	10.66
7/8"	82	10	91400A541	7.00
1"	83	10	91400A542	7.75
1 1/4"	84	10	91400A544	8.75
1 1/2"	85	10	91400A546	7.25
1/4"-28—#3 Drive; Meet MS-51958				
1/2"	79	25	91400A850	14.20
5/8"	80	25	91400A851	14.89
3/4"	81	10	91400A853	7.75
7/8"	82	10	91400A854	12.00
1"	83	10	91400A856	8.75
1 1/4"	84	10	91400A859	11.50
1 1/2"	85	10	91400A862	14.76
Cadmium-Plated Steel				
2-56—#1 Drive; Meet MS-35206				
1/8"	201	25	96880A108	6.12
3/16"	202	25	96880A112	6.20
1/4"	203	25	96880A115	6.33
2-56 (Cont.)				
5/16"	204	25	96880A119	6.42
3/8"	205	25	96880A123	6.51
1/2"	207	25	96880A127	6.65
4-40—#1 Drive; Meet MS-35206				
1/4"	213	25	96880A216	6.78
5/16"	214	25	96880A220	6.81
3/8"	215	25	96880A224	6.90

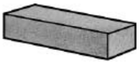
(Continued on following page)

For detailed performance properties and composition for steel, go to mcmaster.com and search for **88645KAC**.

General Purpose Low-Carbon Steel

One of the most widely used types of steel, low-carbon steel is weldable, machinable, and can be surface hardened by heat treating. It is suitable for a variety of applications, such as structural and power transmission components.

Rectangular Bars—Unpolished (Cold Drawn)



- Yield Strength: 54,000 psi
- Hardness: Medium (Rockwell B70)
- Can be surface hardened to Rockwell C60
- Meet ASTM A108

Material is 1018 carbon steel. Thickness and width tolerances are –0.006″ for 1⁄8″ to 4″ wide bars; they are –0.010″ for 4 1⁄2″ to 6″ wide bars; and they are –0.013″ for bars 7″ and wider.

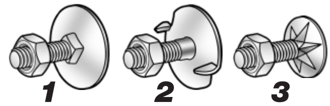
Wd.		½ ft.	1 ft.	2 ft.	3 ft.	6 ft.
1/8″ Thick						
1/8″	9143K261	—	—	$1.05	$1.35	$2.33
1/4″	8910K389	—	—	1.46	1.88	3.25
3/8″	8910K391	—	$1.20	2.15	2.77	4.78
1/2″	8910K392	—	1.47	2.65	3.42	5.89
5/8″	8910K393	$1.03	1.78	3.20	4.12	7.11
3/4″	8910K394	1.24	2.14	3.86	4.97	8.57
1″	8910K395	1.55	2.67	4.81	6.20	10.69
1 1/8″	8910K396	1.61	2.78	5.00	6.44	11.11
1 1/4″	8910K397	1.64	2.83	5.10	6.57	11.33
1 1/2″	8910K398	1.97	3.40	6.12	7.89	13.61
2″	8910K399	2.61	4.50	8.10	10.45	18.01
2 1/2″	8910K401	3.29	5.67	10.20	13.15	22.67
3/16″ Thick						
3/16″	9143K12	—	1.33	2.39	3.09	5.32
1/2″	8910K261	1.18	2.04	3.66	4.72	8.14
5/8″	8910K262	1.43	2.46	4.43	5.71	9.84
3/4″	8910K263	1.74	2.99	5.39	6.94	11.97
1″	8910K264	2.22	3.83	6.89	8.87	15.30
1 1/4″	8910K265	2.65	4.57	8.23	10.61	18.29
1 1/2″	8910K266	2.71	4.67	8.41	10.84	18.69
1 3/4″	8910K531	3.20	5.52	9.94	12.81	22.08
2″	8910K533	3.66	6.31	11.35	14.63	25.23
2 1/4″	8910K535	4.02	6.93	12.47	16.07	27.71
2 1/2″	8910K538	4.47	7.70	13.86	17.87	30.81
3″	8910K542	5.22	8.99	16.19	20.86	35.97
4″	8910K545	6.96	11.99	21.59	27.83	47.98
1/4″ Thick						
1/4″	9143K13	—	1.51	2.73	3.51	6.06
3/8″	8910K267	1.20	2.06	3.72	4.79	8.26
1/2″	8910K268	1.54	2.65	4.77	6.14	10.59
5/8″	8910K269	1.87	3.23	5.81	7.48	12.90
3/4″	8910K381	2.14	3.69	6.64	8.56	14.76
7/8″	8910K382	2.50	4.31	7.76	10.00	17.24
1″	8910K383	2.77	4.78	8.60	11.08	19.11
1 1/4″	8910K548	3.40	5.86	10.54	13.59	23.43
1 3/8″	8910K551	4.16	7.17	12.90	16.62	28.66
1 1/2″	8910K553	4.07	7.02	12.64	16.29	28.09
1 3/4″	8910K555	4.65	8.02	14.43	18.60	32.07
2″	8910K557	5.26	9.08	16.34	21.06	36.31
2 1/4″	8910K561	5.77	9.95	17.91	23.08	39.80
2 1/2″	8910K564	6.56	11.32	20.37	26.26	45.27
2 3/4″	8910K567	7.38	12.72	22.89	29.50	50.87
3″	8910K571	7.67	13.22	23.80	30.68	52.89
3 1/4″	8910K574	8.76	15.11	27.19	35.05	60.43
3 1/2″	8910K577	8.99	15.50	27.90	35.96	62.00
3 3/4″	8910K581	10.46	18.04	32.47	41.85	72.15
4″	8910K584	10.01	17.25	31.06	40.03	69.02
4 1/2″	8910K587	11.97	20.64	37.16	47.90	82.58
5″	8910K591	12.75	21.99	39.58	51.02	87.96
5 1/2″	8910K11	15.07	25.98	46.77	60.29	103.94
6″	8910K12	15.62	26.94	48.49	62.49	107.75
8″	9143K724	20.91	36.05	64.89	83.64	144.21
10″	9143K725	24.90	42.68	76.47	99.59	177.84
5/16″ Thick						
5/16″	9143K14	1.27	2.19	3.94	5.07	8.75
1/2″	8910K384	2.02	3.49	6.28	8.09	13.95
3/4″	8910K385	2.72	4.68	8.43	10.86	18.73
1″	8910K611	3.70	6.39	11.50	14.82	25.55
1 1/4″	8910K613	4.63	7.98	14.37	18.52	31.93
1 1/2″	8910K615	5.39	9.30	16.74	21.57	37.19
1 3/4″	8910K618	6.15	10.60	19.08	24.59	42.39
2″	8910K622	6.87	11.85	21.32	27.48	47.38
2 1/2″	8910K625	7.99	13.78	24.80	31.96	55.11
2 3/4″	8910K628	9.30	16.03	28.85	37.18	64.11
3″	8910K632	9.06	15.62	28.12	36.25	62.50
3 1/2″	8910K635	11.27	19.43	34.98	45.08	77.73
4″	8910K638	12.61	21.75	39.14	50.45	86.98
6″	8910K13	20.72	35.73	64.31	82.88	142.90

Wd.		½ ft.	1 ft.	2 ft.	3 ft.	6 ft.
3/8″ Thick						
3/8″	9143K15	$1.61	$2.78	$5.00	$6.45	$11.12
1/2″	8910K386	2.18	3.76	6.76	8.72	15.03
5/8″	8910K387	2.59	4.46	8.04	10.36	17.86
3/4″	8910K388	2.76	4.76	8.57	11.04	19.04
1″	8910K645	3.49	6.02	10.84	13.97	24.08
1 1/8″	9143K726	4.04	6.96	12.53	16.15	27.84
1 1/4″	8910K647	4.29	7.41	13.33	17.18	29.62
1 3/8″	8910K649	4.61	7.94	14.30	18.43	31.77
1 1/2″	8910K653	4.80	8.28	14.90	19.20	33.10
1 3/4″	8910K656	5.55	9.56	17.21	22.18	38.25
2″	8910K659	6.24	10.77	19.38	24.97	43.06
2 1/4″	8910K663	7.66	13.21	23.78	30.65	52.85
2 1/2″	8910K666	8.19	14.12	25.41	32.75	56.46
2 3/4″	8910K669	9.05	15.60	28.07	36.18	62.38
3″	8910K673	9.66	16.66	29.99	38.65	66.64
3 1/2″	8910K676	10.93	18.85	33.93	43.73	75.39
3 3/4″	8910K679	13.89	23.95	43.12	55.58	95.82
4″	8910K683	14.31	24.68	44.42	57.26	98.72
4 1/2″	8910K14	16.47	28.40	51.12	65.89	113.61
5″	8910K15	17.67	30.47	54.85	70.69	121.88
5 1/2″	8910K16	19.76	34.06	61.31	79.02	136.25
6″	8910K17	21.32	36.76	66.16	85.27	147.02
7/16″ Thick						
7/16″	9143K16	1.70	2.94	5.29	6.81	11.75
1/2″ Thick						
1/2″	9143K17	2.62	4.53	8.15	10.50	18.10
5/8″	8910K691	3.73	6.43	11.58	14.92	25.73
3/4″	8910K693	4.18	7.21	12.97	16.72	28.83
7/8″	8910K695	4.39	7.56	13.61	17.54	30.25
1″	8910K698	4.71	8.11	14.60	18.82	32.45
1 1/8″	9143K727	5.18	8.93	16.08	20.72	35.73
1 1/4″	8910K933	5.53	9.54	17.18	22.14	38.17
1 3/8″	8910K936	6.79	11.71	21.07	27.16	46.83
1 1/2″	8910K939	7.08	12.21	21.97	28.32	48.83
1 5/8″	8910K943	7.31	12.61	22.70	29.26	50.44
1 3/4″	8910K946	7.66	13.20	23.76	30.62	52.80
2″	8910K949	8.01	13.81	24.86	32.04	55.25
2 1/4″	8910K953	9.00	15.51	27.92	35.98	62.04
2 1/2″	8910K956	9.99	17.23	31.01	39.96	68.90
2 3/4″	8910K959	10.80	18.62	33.51	43.19	74.47
3″	8910K702	11.81	20.36	36.65	47.24	81.45
3 1/4″	8910K18	14.19	24.46	44.03	56.75	97.85
3 1/2″	8910K19	14.44	24.89	44.81	57.75	99.57
4″	8910K21	15.03	25.91	46.63	60.11	103.63
4 1/2″	8910K22	16.85	29.05	52.29	67.40	116.20
5″	8910K23	18.73	32.29	58.12	74.91	129.15
5 1/2″	8910K4	20.66	35.63	64.13	82.66	142.51
6″	8910K5	21.64	37.31	67.17	86.57	149.26
8″	9143K729	33.25	57.00	102.13	133.01	237.51
5/8″ Thick						
5/8″	9143K18	4.45	6.96	12.52	16.14	27.83
3/4″	8910K715	5.48	9.44	17.00	21.91	37.77
1″	8910K718	5.98	10.31	18.57	23.93	41.26
1 1/8″	8910K722	6.98	12.03	21.65	27.91	48.12
1 1/4″	8910K725	7.55	13.01	23.42	30.19	52.05
1 1/2″	8910K728	8.20	14.14	25.45	32.80	56.56
1 3/4″	8910K732	9.47	16.33	29.39	37.88	65.31
2″	8910K735	10.49	18.09	32.57	41.97	72.37
2 1/4″	8910K738	14.13	24.36	43.86	56.53	97.46
2 1/2″	8910K742	12.07	20.80	37.44	48.26	83.21
2 3/4″	8910K6	15.95	27.50	49.49	63.79	109.98
3″	8910K27	17.21	29.66	53.40	68.82	118.66
3 1/4″	8910K8	17.75	30.59	55.07	70.98	122.38
3 1/2″	8910K9	18.37	31.66	57.00	73.46	126.66
4″	8910K31	19.09	32.92	59.26	76.38	131.69
4 1/2″	8910K32	24.44	42.14	75.85	97.76	168.56
5″	8910K33	26.19	45.16	81.29	104.77	180.64
5 1/2″	8910K34	27.34	46.86	83.96	109.34	195.25
6″	8910K35	28.25	48.43	86.78	113.01	201.81

(Material continued on following page)

Warning! ***Hardness and yield strength are not guaranteed and are intended only as a basis for comparison.***

Large Diameter Flush-Head Low-Strength Bolts with Nut



Also known as elevator and step bolts, these low-profile bolts sit flush when installed. Frequently used in industrial belting systems, they have a Class 2A thread fit, min. Rockwell hardness of B88, and min. tensile strength of 74,000 psi. Bolts are fully threaded except fanged versions, which have an unthreaded shoulder. Bolt length is measured from the top of the head.

1 Square Neck—Bolts resist spinning when you tighten the nut.

2 Fanged—Sharp "teeth" hold tight so the bolts can't spin.

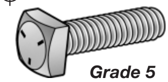
3 Ribbed with Slotted Drive—Also known as reliance bolts, these bolts provide a tight, vibration-free fit when used with a heavy washer. The head has a smaller diameter than the heads of square-neck and fanged styles.

18-8 stainless steel provides excellent corrosion resistance and may be slightly magnetic. For 18-8 stainless steel washers, see 93852A on pg. 3191. *Zinc-plated steel* is made from C1010-C1020 steel and offers good rust resistance. For steel washers, see 90108A on pg. 3191.

Also Available: Metric zinc-plated steel bolts with nut in square-neck and fanged styles. Minimum tensile strength is 74,000 psi. For square-neck style, ask for 93226A100; for fanged style, ask for 92963A200; then specify thread size and bolt length.

Lg.	Pkg. Qty.		Pkg.
(1) Square Neck—*18-8 Stainless Steel*			
1/4"-20—*Head: Ht. 3/32"; Dia. 31/32"*			
3/4"	5	92361A450	$12.32
1"	5	92361A452	12.43
1 1/4"	5	92361A454	12.80
1 1/2"	5	92361A455	13.60
5/16"-18—*Head: Ht. 7/64"; Dia. 1 3/16"*			
1"	1	92361A463	4.51
1 1/4"	1	92361A465	4.56
5/16"-18 (Cont.)			
1 1/2"	1	92361A467	$4.59
1 3/4"	1	92361A469	4.53
2"	1	92361A471	4.92
3/8"-16—*Head: Ht. 9/64"; Dia. 1 5/16"*			
1 1/4"	1	92361A426	6.91
1 1/2"	1	92361A428	7.38
2"	1	92361A435	8.40
(1) Square Neck—*Zinc-Plated Steel*			
1/4"-20—*Head: Ht. 3/32"; Dia. 31/32"*			
3/4"	25	92670A740	6.05
1"	25	92670A742	6.21
1 1/4"	25	92670A744	6.43
1 1/2"	25	92670A746	6.64
1 3/4"	25	92670A748	8.51
2"	25	92670A750	9.38
2 1/4"	25	92670A751	9.99
2 1/2"	25	92670A752	10.41
2 3/4"	10	92670A635	5.14
3"	10	92670A836	5.39
5/16"-18—*Head: Ht. 7/64"; Dia. 1 3/16"*			
3/4"	25	92670A781	6.92
1"	25	92670A783	7.28
1 1/4"	25	92670A785	7.63
5/16"-18 (Cont.)			
1 1/2"	25	92670A787	7.98
1 3/4"	25	92670A789	8.33
2"	25	92670A791	8.69
2 1/4"	25	92670A792	11.36
2 1/2"	25	92670A793	12.20
2 3/4"	10	92670A637	5.90
3"	10	92670A838	6.17
3/8"-16—*Head: Ht. 9/64"; Dia. 1 5/16"*			
1 1/4"	10	92670A826	6.89
1 1/2"	10	92670A828	7.40
1 3/4"	10	92670A630	7.77
2"	10	92670A632	8.27
2 1/2"	10	92670A834	9.33
3"	10	92670A840	10.77
(2) Fanged—*Zinc-Plated Steel*			
1/4"-20—*Head: Ht. 3/32"; Dia. 31/32"*			
3/4"	25	92221A240	11.21
1"	25	92221A242	12.20
1 1/4"	25	92221A244	12.55
1 1/2"	25	92221A246	12.95
5/16"-18—*Head: Ht. 7/64"; Dia. 1 3/16"*			
1"	10	92221A283	7.20
1 1/4"	10	92221A285	7.30
5/16"-18 (Cont.)			
1 1/2"	10	92221A287	6.72
2"	10	92221A291	8.82
3/8"-16—*Head: Ht. 9/64"; Dia. 1 5/16"*			
1 1/4"	10	92221A326	13.51
1 1/2"	10	92221A328	13.84
1 3/4"	10	92221A330	14.10
2"	10	92221A332	14.39
(3) Ribbed with Slotted Drive—*Zinc-Plated Steel*			
1/4"-20—*Head: Ht. 3/32"; Dia. 23/32"*			
3/4"	25	91488A240	8.35
1"	25	91488A242	8.57
1 1/4"	25	91488A244	8.90
1 1/2"	25	91488A246	9.20
5/16"-18—*Head: Ht. 7/64"; Dia. 7/8"*			
1"	25	91488A363	14.75
1 1/4"	10	91488A365	7.31
1 1/2"	10	91488A368	5.82

Square-Head Steel Bolts



Square heads offer plenty of surface for your wrench to grip—and that means less slippage. All have a Class 2A thread fit. Bolt length is measured from under the head. For square nuts, see page 3169.

Medium-Strength Steel—Grade 5 bolts have a zinc yellow-chromate plating and are marked on the head with three radial lines to indicate Grade 5. Each bolt has a min. Rockwell hardness of C25, min. tensile strength of 120,000 psi, and meets ASME B18.2.1 and SAE J429.

Low-Strength Steel—ASTM A307 Grade A bolts have a plain finish, min. Rockwell hardness of B69, and min. tensile strength of 60,000 psi.

Medium-Strength Steel—Grade 5

Lg.		Each
3/8"-16—*Head: Ht. 1/4"; Wd. 9/16"*		
1"	92327A279♣	$2.24
1 1/2"	92327A283♣	2.33
2"	92327A288♣	2.70
3"	92327A291♣	2.85
4"	92327A294♣	3.17
1/2"-13—*Head: Ht. 21/64"; Wd. 3/4"*		
2"	92327A304♣	3.03
2 1/2"	92327A308♣	4.11
3"	92327A311♣	4.72
4"	92327A314♣	6.00
5"	92327A317♣	6.90
5/8"-11—*Head: Ht. 27/64"; Wd. 15/16"*		
2"	92327A323♣	$4.52
2 1/2"	92327A327♣	4.86
3"	92327A332♣	5.08
4"	92327A338♣	6.15
5"	92327A341♣	7.82
3/4"-10—*Head: Ht. 1/2"; Wd. 1 1/8"*		
3"	92327A362♣	8.03
4"	92327A365♣	8.37
5"	92327A367♣	9.27
6"	92327A369♣	11.76

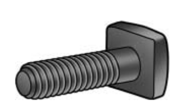
♣ Fully threaded.

Low-Strength Steel—ASTM A307 Grade A

Lg.	Pkg. Qty.		Pkg.
1/4"-20—*Head: Ht. 11/64"; Wd. 3/8" Minimum Thread Lg.: 3/4"*			
1"	25	91465A101	$5.11
1 1/4"	25	91465A104	5.22
1 1/2"	50	91465A107	9.56
2"	25	91465A110	6.48
5/16"-18—*Head: Ht. 13/64"; Wd. 1/2" Minimum Thread Lg.: 7/8"*			
3/4"	25	91465A113♣	5.48
1"	25	91465A116	5.59
1 1/4"	25	91465A119	7.63
1 1/2"	10	91465A122	4.26
2"	10	91465A125	4.74
3"	10	91465A128	6.07
4"	10	91465A131	6.95
3/8"-16—*Head: Ht. 1/4"; Wd. 9/16" Minimum Thread Lg.: 1"*			
1"	10	91465A134♣	4.31
1 1/4"	25	91465A137	9.83
1 1/2"	10	91465A140	4.83
1 3/4"	10	91465A143	4.31
2"	10	91465A146	5.28
2 1/2"	5	91465A149	4.14
3"	5	91465A152	4.48
3 1/2"	10	91465A155	8.14
1/2"-13—*Head: Ht. 21/64"; Wd. 3/4" Minimum Thread Lg.: 1 1/4"*			
1"	5	91465A158♣	4.31
1 1/2"	5	91465A161	5.61
1 3/4"	10	91465A164	8.03
2"	10	91465A167	9.29
2 1/4"	5	91465A170	5.79
2 1/2"	5	91465A173	6.03
3"	1	91465A176	1.34
3 1/2"	1	91465A179	1.62
4"	5	91465A182	7.81
5"	1	91465A185	1.98
1/2"-13 (Cont.)			
6"	1	91465A191	$2.11
8"	1	91465A194	2.69
5/8"-11—*Head: Ht. 27/64"; Wd. 15/16" Minimum Thread Lg.: 1 1/2"*			
2"	1	91465A209	1.72
2 1/2"	5	91465A212	10.40
3"	1	91465A215	2.03
3 1/2"	1	91465A218	2.38
4"	1	91465A221	2.52
4 1/2"	1	91465A224	2.72
5"	1	91465A227	2.99
6"	1	91465A230	3.27
7"	1	91465A233	4.03
11"	1	91465A236	10.31
3/4"-10—*Head: Ht. 1/2"; Wd. 1 1/8" Minimum Thread Lg.: 1 3/4"*			
2 1/2"	1	91465A242	2.36
3"	1	91465A245	2.97
3 3/4"	1	91465A248	3.33
4"	1	91465A251	3.39
4 1/2"	1	91465A254	4.03
5"	1	91465A257	4.33
5 1/2"	1	91465A260	4.53
6"	1	91465A263	4.44
7"	1	91465A266	4.66
8"	1	91465A269	5.03
9"	1	91465A272	6.70
10"	1	91465A275	6.91
12"	1	91465A278	8.06
1"-8—*Head: Ht. 21/32"; Wd. 1 1/2" Minimum Thread Lg.: 2 1/4"*			
6"	1	91465A287	11.05
7"	1	91465A290	11.14
9"	1	91465A293	11.20
10"	1	91465A296	13.40

♣ Fully threaded.

Square-Head Medium-Strength Steel T-Bolts



Also known as tugger bolts, these bolts clamp work securely without damaging your machine table. They're made from C1045 steel (which has strength comparable to Grade 5 steel) and have a black-oxide finish that offers lubricity and mild rust resistance. Each has a Class 2A thread fit, min. Rockwell hardness of C28, and min. tensile strength of 120,000 psi. Bolt length is measured from under the head. For nuts, see 91026A on page 3164.

Also Available: Heavy-duty black-oxide alloy-steel bolts in sizes marked with a ★. Forged from 4140 steel, they have a minimum tensile strength of 140,000 psi. Please ask for 91622A555 and specify thread size and bolt length.

Lg.	Thrd. Lg.		
3/8"-16—*Fits 3/8" Table Slot Head: Ht. 1/4"; Wd. 11/16"*			
1 1/2"	1"	90109A628★	$5.98
2"	1 1/2"	90109A632★	5.98
2 1/2"	2"	90109A634★	6.11
3"	2"	90109A636★	6.27
3 1/2"	2"	90109A638	6.44
4"	2"	90109A640	6.73
5"	2"	90109A644	6.94
6"	2"	90109A648	7.09
1/2"-13—*Fits 1/2" Table Slot Head: Ht. 5/16"; Wd. 7/8"*			
1 1/2"	1"	90109A716★	$6.11
2"	1 1/2"	90109A720★	6.11
2 1/2"	2"	90109A722★	6.60
3"	2"	90109A724★	6.73
3 1/2"	2"	90109A726★	6.73
4"	2"	90109A728★	7.29
4 1/2"	2"	90109A730	6.98
5"	2"	90109A732	7.75
6"	2"	90109A736★	7.94
5/8"-11—*Fits 5/8" Table Slot Head: Ht. 13/32"; Wd. 1 1/8"*			
2"	1 1/2"	90109A802★	$7.44
2 1/2"	2"	90109A804★	7.91
3"	2"	90109A806★	8.07
3 1/2"	2"	90109A808	8.60
4"	2"	90109A810	8.91
5"	2"	90109A814	9.33
6"	2"	90109A818★	10.00
8"	2"	90109A822★	11.94
10"	2"	90109A826	13.71
3/4"-10—*Fits 3/4" Table Slot Head: Ht. 17/32"; Wd. 15/16"*			
2 1/2"	2"	90109A845	$9.46
3"	2"	90109A847★	10.16
3 1/2"	2"	90109A849★	10.66
4"	2"	90109A851★	10.93
5"	2"	90109A855★	11.62
6"	2"	90109A859★	13.04
7"	2"	90109A861	14.56
8"	2"	90109A863★	14.84
10"	2"	90109A866	17.00

For information about nuts, materials, and finishes, see page 3158.

Nylon-Insert Hex Locknuts

The nylon insert provides vibration resistance and prevents loosening—without damaging mating threads. Nuts are reusable. Each has a Class 2B thread fit and is reliable at temperatures up to 250° F (unless noted).

Black-luster-coated Grade 2 steel nuts are resistant to 500 hours of salt spray per ASTM B117.

Thread Size	Wd.	Ht.	Thread Size	Wd.	Ht.	Thread Size	Wd.	Ht.	Thread Size	Wd.	Ht.	Thread Size	Wd.	Ht.
2-56	1/4"	9/64"	10-32	3/8"	15/64"	3/8"-24	9/16"	29/64"	5/8"-11	15/16"	3/4"	1"-14	1 7/16"	1 3/64"
3-48	1/4"	9/64"	12-24	7/16"	5/16"	7/16"-14	5/8"	29/64"	5/8"-18	15/16"	3/4"	1 1/8"-7	1 5/8"	1 3/16"
4-40	1/4"	9/64"	1/4"-20	7/16"	5/16"	7/16"-20	5/8"	29/64"	3/4"-10	1 1/16"	7/8"	1 1/4"-7	1 13/16"	1 13/32"
5-40	1/4"	9/64"	1/4"-28	7/16"	5/16"	1/2"-13	3/4"	19/32"	3/4"-16	1 1/16"	7/8"	1 1/2"-6	2 3/16"	1 5/8"
6-32	5/16"	11/64"	5/16"-18	1/2"	11/32"	1/2"-20	3/4"	19/32"	7/8"-9	1 1/4"	63/64"			
8-32	11/32"	15/64"	5/16"-24	1/2"	11/32"	9/16"-12	7/8"	41/64"	7/8"-14	1 1/4"	63/64"			
10-24	3/8"	15/64"	3/8"-16	9/16"	29/64"	9/16"-18	7/8"	41/64"	1"-8	1 7/16"	1 3/64"			

Thread Size	Pkg. Qty.		Per Pkg.
Zinc Yellow-Chromate Plated Grade 8 Steel			
1/4"-20	25	97135A210	$3.54
1/4"-28	25	97135A215	3.62
5/16"-18	20	97135A220	3.80
5/16"-24	20	97135A225	3.88
3/8"-16	20	97135A230	4.14
3/8"-24	20	97135A235	4.14
7/16"-14	10	97135A240	3.45
7/16"-20	10	97135A245	3.45
1/2"-13	10	97135A250	4.44
1/2"-20	10	97135A255	4.53
9/16"-12	5	97135A260	4.14
9/16"-18	5	97135A265	4.14
5/8"-11	5	97135A270	4.53
5/8"-18	5	97135A275	4.53
3/4"-10	5	97135A280	5.82
3/4"-16	5	97135A285	5.82
7/8"-9	1	97135A290	1.29
7/8"-14	1	97135A295	1.38
1"-8	1	97135A038	1.81
1"-14	1	97135A059	1.94
1 1/8"-7	1	97135A350	6.51
1 1/4"-7	1	97135A355	8.80
1 1/2"-6	1	97135A360	11.86
Plain Grade 8 Steel			
1/4"-20	25	90630A110	3.18
1/4"-28	25	90630A145	2.77
5/16"-18	20	90630A115	2.91
5/16"-24	20	90630A150	2.98
3/8"-16	20	90630A121	3.17
3/8"-24	20	90630A155	3.17
1/2"-13	10	90630A125	3.41
1/2"-20	10	90630A160	3.46
5/8"-11	5	90630A130	3.46
5/8"-18	5	90630A165	3.46
3/4"-10	5	90630A135	4.45
3/4"-16	5	90630A170	4.45
1"-8	1	90630A140	1.63
1"-14	1	90630A175	1.75
Zinc-Plated Grade 5 Steel			
1/4"-20	100	95615A120	4.35
1/4"-28	100	95615A130	4.35
5/16"-18	100	95615A160	6.33
5/16"-24	100	95615A170	5.75
3/8"-16	100	95615A140	8.83
3/8"-24	100	95615A150	9.31
7/16"-14	100	95615A180	11.95
7/16"-20	100	95615A190	11.23
1/2"-13	50	95615A210	9.96
1/2"-20	50	95615A220	9.96
9/16"-12	25	95615A230	8.22
9/16"-18	25	95615A240	8.28
Zinc-Plated Grade 5 Steel (Cont.)			
5/8"-11	25	95615A250	$9.63
5/8"-18	25	95615A260	10.66
3/4"-10	10	95615A270	7.14
3/4"-16	10	95615A280	7.14
7/8"-9	5	95615A290	8.62
7/8"-14	5	95615A310	6.15
1"-8	5	95615A320	9.06
1"-14	5	95615A330	9.71
1 1/8"-7	1	95615A340	5.56
1 1/4"-7	1	95615A350	7.48
1 1/2"-6	1	95615A360	9.96
Zinc-Plated Grade 2 Steel			
2-56	100	90631A003	3.45
3-48	100	90631A004	3.23
4-40	100	90631A005	2.55
5-40	100	90631A006	2.61
6-32	100	90631A007	2.67
8-32	100	90631A009	2.35
10-24	100	90631A011	2.79
10-32	100	90631A411	2.81
12-24	100	90631A120	4.77
1/4"-20	100	90640A129	4.27
1/4"-28	100	90640A140	5.42
5/16"-18	100	90640A130	5.16
5/16"-24	100	90640A145	5.67
3/8"-16	100	90640A131	7.21
3/8"-24	100	90640A150	7.97
7/16"-14	100	90640A132●	10.66
7/16"-20	100	90640A155●	9.83
1/2"-13	100	90640A133	17.92
1/2"-20	100	90640A160	20.63
9/16"-12	50	90640A134	18.94
9/16"-18	25	90640A165	7.25
5/8"-11	25	90640A135	9.85
5/8"-18	25	90640A170	10.49
3/4"-10	10	90640A320	6.18
3/4"-16	10	90640A330	6.26
7/8"-9	5	90640A340	7.98
7/8"-14	5	90640A350	4.70
1"-8	5	90640A360♦	6.75
1"-14	5	90640A370♦	7.23
1 1/8"-7	1	90640A400♠	4.14
1 1/4"-7	1	90640A410	5.57
1 1/2"-6	1	90640A420	6.44
Black Luster-Coated Grade 2 Steel ♥			
6-32	5	91333A110	7.01
8-32	5	91333A120	6.90
10-24	5	91333A130	7.24
10-32	5	91333A140	7.24
1/4"-20	5	91333A150	7.24
5/16"-18	5	91333A160	7.34
Black Luster-Coated Grade 2 Steel ♥ (Cont.)			
3/8"-16	5	91333A170	$7.67
1/2"-13	5	91333A180	8.55
Type 316 Stainless Steel			
4-40	100	90715A005♥	8.13
5-40	50	90715A006♥	6.13
6-32	100	90715A007	6.67
8-32	100	90715A009	9.04
10-24	100	90715A011	9.83
10-32	50	90715A115	5.43
1/4"-20	50	90715A125	9.26
1/4"-28	50	90715A130	10.69
5/16"-18	50	90715A135	10.30
5/16"-24	25	90715A140	6.45
3/8"-16	25	90715A145	8.54
3/8"-24	25	90715A148	10.68
7/16"-14	10	90715A032	6.17
7/16"-20	10	90715A034	7.71
1/2"-13	10	90715A165	8.37
1/2"-20	10	90715A170	9.17
9/16"-12	1	90715A173	2.07
5/8"-11	5	90715A185	9.02
5/8"-18	1	90715A187	2.17
3/4"-10	1	90715A036	2.89
3/4"-16	1	90715A038	3.22
7/8"-9	1	90715A045	12.67
1"-8	1	90715A055	18.49
1 1/8"-7	1	90715A210	20.69
1 1/4"-7	1	90715A215	30.32
1 1/2"-6	1	90715A220	59.48
18-8 Stainless Steel			
2-56	50	91831A002■	7.01
3-48	25	91831A004	1.95
4-40	100	91831A005	3.93
5-40	100	91831A006	4.52
6-32	100	91831A007	4.59
8-32	100	91831A009	5.92
10-24	100	91831A011	6.54
10-32	100	91831A411	6.54
12-24	50	91831A025	5.92
1/4"-20	50	91831A029	5.01
18-8 Stainless Steel (Cont.)			
1/4"-28	50	91831A120	$5.54
5/16"-18	50	91831A030	6.51
5/16"-24	50	91831A125	8.25
3/8"-16	25	91831A127	6.98
3/8"-24	25	91831A130	6.27
7/16"-14	25	91831A133	7.96
7/16"-20	25	91831A135	8.30
1/2"-13	10	91831A137	5.94
1/2"-20	10	91831A140	7.14
9/16"-12	1	91831A034	2.06
9/16"-18	1	91831A143	2.82
5/8"-11	5	91831A144	6.28
5/8"-18	5	91831A145	8.18
3/4"-10	5	91831A147	9.23
3/4"-16	1	91831A150	1.94
7/8"-9	1	91831A037	4.34
7/8"-14	1	91831A155	6.41
1"-8	1	91831A038	5.00
1"-14	1	91831A160	5.77
1 1/8"-7	1	91831A039	18.03
1 1/4"-7	1	91831A040	24.03
1 1/2"-6	1	91831A041	27.91
Brass			
6-32	25	92092A021	2.94
8-32	25	92092A023	4.66
10-24	25	92092A025♣	6.04
10-32	25	92092A027♣	5.91
1/4"-20	25	92092A029■	13.64
5/16"-18	10	92092A030■	11.91
3/8"-16	10	92092A031■	15.01
1/2"-13	5	92092A033■	16.41
5/8"-11	1	92092A035■	17.51
3/4"-10	1	92092A036■	15.92
Aluminum			
8-32	25	95856A215	3.67
10-24	25	95856A225	3.76
10-32	25	95856A235	3.76
1/4"-20	25	95856A245	4.32
5/16"-18	25	95856A255	7.27
3/8"-16	10	95856A265	4.06
1/2"-13	5	95856A275	3.99

550-Piece Assortments

Handy assortments come furnished in an 8 1/4" Lg. × 4 1/2" Wd. × 1 3/8" Dp. compartmented plastic case with lid chart.

Thread Size	No. of Pcs.	Thread Size	No. of Pcs.	Thread Size	No. of Pcs.
4-40	100	8-32	100	10-32	100
6-32	100	10-24	100	1/4"-20	50

Zinc-Plated Grade 2 Steel	93949A600	Each	$24.44
18-8 Stainless Steel	93949A300	Each	$44.44

● Height is 17/32". ♦ Height is 1 5/64". ♠ Height is 1 19/64". ♥ Maximum temperature is 194° F. ♣ Class 3B thread fit. ■ Not rated for hardness.

Mil. Spec. Nylon-Insert Hex Locknuts

Made to precise military specifications, these locknuts have a nylon insert that provides vibration resistance and prevents loosening—without damaging mating threads. ***Hex*** meet MS 21044; ***thin hex*** meet MS 21083. All have a Class 3B thread fit. They're reliable at temperatures up to 250° F but are not rated for hardness.

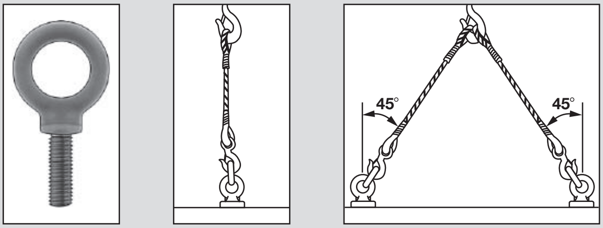
18-8 stainless steel locknuts are passivated (treated with nitric acid to protect against oxidation and corrosion) to meet QQ-P-35.

		CADMIUM-PLATED STEEL								18-8 STAINLESS STEEL							
				Hex			Thin Hex					Hex			Thin Hex		
Thread Size	Wd.	Dash No.	Pkg. Qty.	Ht.		Per Pkg.	Ht.		Per Pkg.	Dash No.	Pkg. Qty.	Ht.		Per Pkg.	Ht.		Per Pkg.
4-40	1/4"	N04	10	5/32"	95154A110	$7.78	1/8"	95496A310	$7.34	C04	10	5/32"	96345A210	$10.22	1/8"	97231A410	$10.00
6-32	5/16"	N06	10	3/16"	95154A120	6.22	9/64"	95496A320	7.77	C06	10	3/16"	96345A220	8.23	9/64"	97231A420	11.11
8-32	11/32"	N08	10	9/32"	95154A130	6.67	3/16"	95496A330	4.00	C08	10	9/32"	96345A230	7.78	3/16"	97231A430▲	7.46
10-32	3/8"	N3	10	9/32"	95154A140	4.00	3/16"	95496A340	4.44	C3	10	9/32"	96345A240	8.00	3/16"	97231A440▲	7.85
1/4"-28	7/16"	N4	10	23/64"	95154A150	8.89	7/32"	95496A350	7.11	C4	5	23/64"	96345A250	5.78	7/32"	97231A450	10.00

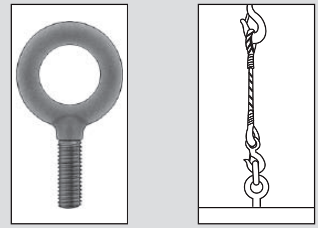
▲ Pkg. qty. is 5.

About Lifting with Eyebolts

Eyebolt with Shoulder



Eyebolt without Shoulder



Eyebolts with shoulder can be used for vertical lifts as well as angular lifts up to 45°. However, angular lifts significantly reduce the work load. For example, lifting at 45° reduces the work load limit by 75%. For angular lifts, we recommend using hoist rings, sold on pages 1483-1486.

Eyebolts without shoulder are for vertical lifts only.

The work load limit for all eyebolts is based on a straight vertical lift. *Note:* Any eyebolt that has been modified from its original design will have a reduced work load limit and should be discarded.

Steel Eyebolts—For Lifting CAD

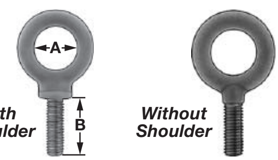
Also known as machinery eyebolts. All are made of forged carbon steel.

Steel eyebolts are good for general purpose applications where corrosion is not a factor. For hex nuts, see pages 3160-3166.

Zinc-plated steel eyebolts have good corrosion resistance in most environments. For hex nuts, see pages 3160-3166.

Galvanized steel eyebolts are hot dipped and offer better corrosion resistance than zinc-plated steel.

Also Available: Hex nuts for galvanized steel eyebolts. Please ask for 3013T777 and specify thread size.



Thread Size	Work Load Limit, lbs.	(A)	(B)	WITH SHOULDER Steel		WITH SHOULDER Zinc-Plated Steel		WITH SHOULDER Galvanized Steel		WITHOUT SHOULDER Steel		WITHOUT SHOULDER Zinc-Plated Steel		WITHOUT SHOULDER Galvanized Steel	
1/4″-20	500	3/4″	1″	3014T45	$2.89	3014T251	$4.16	3014T861	$4.54	3013T45	$2.89	3013T341	$4.16	3013T821	$4.54
1/4″-20	500	3/4″	2″	3014T901	10.22	3014T102	11.56	3014T201	12.46	3013T901	10.22	3013T128	11.56	3013T171	12.46
1/4″-20	500	3/4″	3″	3014T902	11.88	3014T103	13.43	3014T202	14.51	3013T902	11.88	3013T129	13.43	3013T172	14.51
1/4″-28	500	3/4″	1″	3014T256	4.86	3014T104	5.39	—	—	3013T111	4.86	3013T13	5.39	—	—
5/16″-18	900	7/8″	1 1/8″	3014T46	3.08	3014T252	4.49	3014T862	4.79	3013T46	3.08	3013T342	4.49	3013T822	4.79
5/16″-18	900	7/8″	2″	3014T903	10.73	3014T105	13.12	3014T203	14.24	3013T903	10.73	3013T131	13.12	3013T174	14.24
5/16″-18	900	7/8″	3″	3014T904	12.23	3014T106	14.22	3014T15	15.75	3013T904	12.23	3013T132	14.22	3013T175	15.75
5/16″-18	900	7/8″	4″	3014T905	13.94	3014T107	16.29	3014T151	17.61	3013T905	13.94	3013T133	16.29	3013T176	17.61
5/16″-24	900	7/8″	1 1/8″	3014T257	5.11	3014T108	5.71	—	—	3013T121	5.89	3013T134	5.71	—	—
3/8″-16	1,300	1″	1 1/4″	3014T471	3.67	3014T253	5.32	3014T863	5.82	3013T471	3.67	3013T343	5.32	3013T823	5.82
3/8″-16	1,300	1″	4 1/2″	3014T907	15.02	3014T11	18.52	3014T159	18.56	3013T907	15.02	3013T136	18.52	3013T179	18.56
3/8″-16	1,400	1″	2 1/2″	3014T62	12.21	3014T142	13.33	3014T162	14.39	3013T62	12.21	3013T101	13.33	3013T117	14.39
3/8″-16	1,400	1″	3″	3014T63	12.50	3014T143	13.76	3014T163	14.88	3013T63	12.50	3013T102	13.76	3013T118	14.88
3/8″-16	1,400	1″	4″	3014T906	13.88	3014T109	15.46	3014T157	16.57	3013T906	13.88	3013T135	15.46	3013T178	16.57
3/8″-24	1,400	1″	1 1/4″	3014T258	8.94	—	—	—	—	—	—	—	—	—	—
7/16″-14	1,800	1 1/16″	1 3/8″	3014T481	4.61	3014T144	5.68	3014T864	6.17	3013T481	4.61	3013T103	5.68	3013T824	6.17
7/16″-14	2,000	1 1/16″	2″	3014T908	11.84	3014T112	14.36	3014T16	15.53	3013T908	11.84	3013T137	14.36	3013T18	15.53
7/16″-14	2,000	1 1/16″	3″	3014T909	12.66	3014T113	14.86	3014T161	14.44	3013T909	12.66	3013T138	14.86	3013T181	14.44
7/16″-14	2,000	1 1/16″	4″	3014T911	14.23	3014T114	16.34	3014T17	17.54	3013T911	14.23	3013T139	16.34	3013T182	17.54
7/16″-14	2,000	1 1/16″	4 1/2″	3014T912	16.16	3014T115	18.21	3014T171	19.57	3013T912	16.16	3013T14	18.21	3013T183	19.57
1/2″-13	2,400	1 3/16″	1 1/2″	3014T491	4.94	3014T254	5.85	3014T865	6.43	3013T491	4.94	3013T104	5.85	3013T825	6.43
1/2″-13	2,600	1 3/16″	2 1/2″	3014T64	13.46	3014T145	14.73	3014T164	16.09	3013T64	13.46	3013T105	14.73	3013T119	16.09
1/2″-13	2,600	1 3/16″	3″	3014T65	14.10	3014T146	15.60	3014T165	16.83	3013T65	14.10	3013T106	15.60	3013T12	16.83
1/2″-13	2,600	1 3/16″	4″	3014T913	15.29	3014T116●	19.14	3014T172	18.56	3013T913	15.29	3013T141●	19.14	3013T184	18.56
1/2″-13	2,600	1 3/16″	4 1/2″	3014T914	17.11	3014T117●	21.00	3014T173	20.49	3013T914	17.11	3013T142●	21.00	3013T185	20.49
1/2″-20	2,600	1 3/16″	1 1/2″	3014T259	4.45	3014T118	7.44	—	—	3013T344	4.45	3013T143	7.44	—	—
1/2″-20	2,600	1 3/16″	2 1/2″	3014T263	11.09	3014T119	15.45	—	—	3013T126	17.92	3013T144	15.45	—	—
9/16″-12	3,000	1 1/4″	1 5/8″	3014T51	7.59	3014T147	7.82	3014T866	8.60	3013T51	7.59	3013T107	7.82	3013T826	8.60
9/16″-12	3,000	1 1/4″	2″	3014T915	14.75	3014T12	16.95	3014T174	18.22	3013T915	14.75	3013T145	16.95	3013T186	18.22
9/16″-12	3,000	1 1/4″	3″	3014T916	15.83	3014T121	17.86	3014T175	19.13	3013T916	15.83	3013T146	17.86	3013T187	19.13
9/16″-12	3,000	1 1/4″	4″	3014T917	17.68	3014T122	19.69	3014T176	20.60	3013T917	17.68	3013T147	19.69	3013T188	20.60
9/16″-12	3,000	1 1/4″	4 1/2″	3014T918	19.56	3014T123	21.56	3014T177	24.07	3013T918	19.56	3013T148	21.56	3013T189	24.07
5/8″-11	4,000	1 3/8″	1 3/4″	3014T52	7.81	3014T148	10.62	3014T867	11.61	3013T52	7.81	3013T108	10.62	3013T829	11.61
5/8″-11	4,000	1 3/8″	2 1/2″	3014T66	19.51	3014T149	21.14	3014T166	22.65	3013T66	19.51	3013T109	21.14	3013T125	22.65
5/8″-11	4,000	1 3/8″	3″	3014T67	20.40	3014T152	22.33	3014T167	24.01	3013T67	20.40	3013T11	22.33	3013T122	24.01
5/8″-11	4,000	1 3/8″	4″	3014T919	22.62	3014T124	26.94	3014T178	28.56	3013T919	22.62	3013T149	26.94	3013T19	28.56
5/8″-11	4,000	1 3/8″	4 1/2″	3014T921	24.94	3014T125	28.38	3014T179	29.93	3013T921	24.94	3013T15	28.38	3013T191	29.93
5/8″-18	4,000	1 3/8″	1 3/4″	3014T264	12.36	3014T126	12.46	—	—	3013T345	12.36	3013T151	12.46	—	—
3/4″-10	5,000	1 1/2″	2″	3014T531	8.07	3014T255	14.15	3014T868	15.11	3013T531	8.07	3013T112	14.15	3013T828	15.11
3/4″-10	6,000	1 1/2″	2 1/2″	3014T68	22.34	3014T153	24.70	3014T168	26.42	3013T68	22.34	3013T113	24.70	3013T123	26.42
3/4″-10	6,000	1 1/2″	3″	3014T69	23.34	3014T154	25.47	3014T169	27.96	3013T69	23.34	3013T114	25.47	3013T124	27.96
3/4″-10	6,000	1 1/2″	4″	3014T922	25.83	3014T127	28.92	3014T18	30.89	3013T922	25.83	3013T152	28.92	3013T192	30.89
3/4″-10	6,000	1 1/2″	4 1/2″	3014T923	27.24	3014T128	30.15	3014T181	32.21	3013T923	27.24	3013T153	30.15	3013T193	32.21
3/4″-10	6,000	1 1/2″	5″	3014T924	29.43	3014T129	32.21	3014T182	33.74	3013T924	29.43	3013T154	32.21	3013T194	33.74
3/4″-16	6,000	1 1/2″	2″	3014T261	11.94	3014T13	15.76	—	—	3013T346	11.94	3013T155	15.76	—	—
7/8″-9	7,000	1 11/16″	2 1/4″	3014T54	11.35	3014T155	18.88	3014T869	20.14	3013T54	11.35	3013T115	18.88	3013T827	20.14
7/8″-9	7,000	1 11/16″	3″	3014T925	26.02	3014T131	30.69	3014T183	33.36	3013T925	26.02	3013T156	30.69	3013T195	33.36
7/8″-9	7,000	1 11/16″	4″	3014T926	28.83	3014T132	32.65	3014T184	35.49	3013T926	28.83	3013T157	32.65	3013T196	35.49
7/8″-9	7,000	1 11/16″	4 1/2″	3014T927	31.03	3014T133	34.40	3014T185	37.40	3013T927	31.03	3013T158	34.40	3013T197	37.40
7/8″-9	7,000	1 11/16″	5″	3014T928	32.41	3014T134	35.84	3014T186	38.23	3013T928	32.41	3013T159	35.84	3013T198	38.23

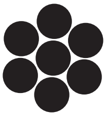
● Work load limit is 2,400 lbs.

Warning! Never exceed work load limits.

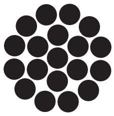
For information about wire rope, see page 1398.

ⓘ For additional information about selecting wire rope, go to mcmaster.com and search for **8912TAC**.

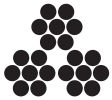
Type 302 and Type 304 Stainless Steel Wire Rope



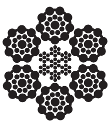
1×7 Strand



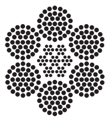
1×19 Strand



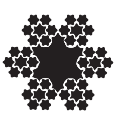
3×7 Hollow Core



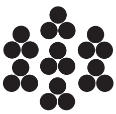
6×19 Class IWRC



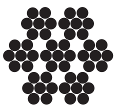
6×37 Class IWRC



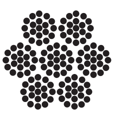
6×42 Fiber Core



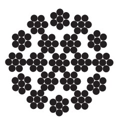
7×3 Strand Core



7×7 Strand Core



7×19 Strand Core



19×7 Strand Core

Key	Meets Specification
A	Fed. Spec. RR-W-410
C	MIL-DTL-83420
D	MIL-DTL-87161
E	MIL-DTL-83140

All are preformed and unlubricated (unless noted).

***1×7** and **1×19 Strand**—*Ideal for linear force applications, these single-strand constructions have good abrasion resistance, but low flexibility. The 1×19 strand is slightly more flexible, but less abrasion resistant than the 1×7 strand.

***3×7 Hollow Core**—*Perfect for light duty applications, this small diameter construction is extremely flexible.

***6×19** and **6×37 Class IWRC**—*IWRC rope is stronger and more crush resistant than fiber core rope. The 6×37 construction is more flexible, but less abrasion resistant than the 6×19.

***6×42 Fiber Core**—*This is the most flexible rope of all the six-strand constructions we offer. However, it is not as strong or abrasion resistant as the others.

***7×3 Strand Core**—*Offered in small diameters, this rope provides more flexibility and higher fatigue resistance than single-strand constructions, but has a lower breaking strength.

***7×7 Strand Core** and **7×19 Strand Core**—*These constructions are stronger, but less flexible than 6×19 and 6×37 class constructions. The 7×19 class construction is both more flexible and more fatigue resistant than the 7×7 construction.

***19×7 Strand Core**—*The most flexible of all our stainless steel constructions. The center strand of this rope lays in the opposite direction of its outer strands, resulting in a rotation-resistant rope.

To Order: Please specify length from those listed; continuous lengths greater than the longest length listed are also available.

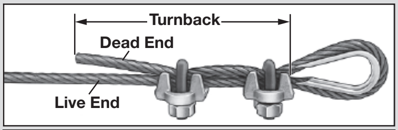
Dia.	Breaking Strength, lbs.	Available Lengths, ft.	Type 302 SS Meets Spec.	Type 302 SS	Type 302 SS Per Ft.	Type 304 SS Meets Spec.	Type 304 SS	Type 304 SS Per Ft.
1×7 Strand								
0.012"	25	50, 100, 200, 300, 500	—	3458T141	$0.08	—	3461T1	$0.07
1/64"	40	50, 100, 200, 300, 500	—	3458T11	.07	—	3461T2	.07
0.018"	55	50, 100, 200, 300, 500	—	3458T142	.07	—	3461T3	.07
0.021"	80	50, 100, 200, 300, 500	—	3458T115	.07	—	3461T4	.07
0.024"	100	50, 100, 200, 300, 500	—	3458T144	.07	—	3461T5	.07
0.027"	125	50, 100, 200, 300, 500	—	3458T145	.07	—	3461T6	.07
1/32"	150	50, 100, 200, 300, 500	D	3458T151 ♦	.10	—	3461T61	.07
0.038"	260	50, 100, 200, 300, 500	—	3458T1	.08	—	3461T8	.08
3/64"	375	50, 100, 200, 300, 500	D	3458T131 ♦	.16	—	3461T9	.12
1/16"	500	50, 100, 200, 300, 500	D	3458T14 ♦	.23	—	3461T11	.20
3/32"	1,200	25, 50, 100, 300, 500	—	3458T16	.42	—	3461T12	.47
1/8"	2,100	25, 50, 100, 300, 500	—	3458T17	.57	—	3461T13	.62
3/16"	4,700	10, 25, 50, 100, 300	—	3458T19	1.05	—	3461T131	1.21
1/4"	8,500	10, 25, 50, 100, 300	—	3458T195	1.32	—	3461T132	1.38
3/8"	18,000	5, 10, 25, 50, 100	—	3458T2	2.59	—	3461T133	2.68
1×19 Strand								
1/32"	150	50, 100, 200, 300, 500	—	3458T21	.15	—	3461T188	.14
3/64"	375	50, 100, 200, 300, 500	D	3458T22 ♦	.15	—	3461T175	.14
1/16"	500	50, 100, 200, 300, 500	D	3458T23 ♦	.26	—	3461T82	.24
5/64"	800	25, 50, 100, 300, 500	D	3458T24 ♦	.33	—	3461T829	.30
3/32"	1,200	25, 50, 100, 300, 500	D	3458T25 ♦	.40	—	3461T83	.36
1/8"	2,100	25, 50, 100, 300, 500	D	3458T26 ♦	.73	—	3461T84	.66
5/32"	3,300	10, 25, 50, 100, 300	D	3458T27 ♦	1.08	—	3461T85	.98
3/16"	4,700	10, 25, 50, 100, 300	D	3458T28 ♦	1.54	—	3461T18	1.40
1/4"	8,200	5, 10, 25, 50, 100	D	3458T91 ♦	2.10	—	3461T21	1.91
5/16"	12,500	2, 5, 10, 25, 50, 100	D	3458T93 ♦	3.04	—	3461T23	2.76
3/8"	17,500	2, 5, 10, 25, 50, 100	D	3458T94 ♦	4.19	—	3461T24	3.81
3×7 Hollow Core								
1/32"	110	50, 100, 200, 300, 500	A,C	3458T51 ♦	.18	—	3461T91	.17
6×19 Class IWRC								
7/16"	16,300	2, 5, 10, 25, 50, 100	A	3458T121	5.63	A	3461T76	5.63
1/2"	22,800	2, 5, 10, 25, 50, 100	A	3458T122	7.29	A	3461T75	7.29
6×37 Class IWRC								
3/16"	3,000	2, 5, 10, 25, 50, 100	A	3458T111	2.83	A	3461T26	2.98
1/4"	5,400	2, 5, 10, 25, 50, 100	A	3458T54	2.95	A	3461T22	3.10
5/16"	8,300	2, 5, 10, 25, 50, 100	A	3458T55	3.79	A	3461T25	3.98
3/8"	11,700	2, 5, 10, 25, 50, 100	A	3458T56	4.96	A	3461T27	5.22
6×42 Fiber Core								
1/8"	700	5, 10, 25, 50, 100, 200	A	3458T31 ♣	1.32	A	3461T53 ♣	1.37
3/16"	1,600	2, 5, 10, 25, 50, 100	A	3458T32 ♣	1.60	A	3461T54 ♣	1.67
1/4"	3,200	2, 5, 10, 25, 50, 100	A	3458T33 ♣	1.71	A	3461T55 ♣	1.79
5/16"	4,900	2, 5, 10, 25, 50, 100	A	3458T34 ♣	2.36	—	—	—
3/8"	6,900	2, 5, 10, 25, 50, 100	—	—	—	A	3461T56 ♣	2.41
7×3 Strand Core								
0.018"	40	25, 50, 100, 300, 500	—	3458T86	.29	—	—	—
0.024"	60	25, 50, 100, 300, 500	—	3458T87	.43	—	—	—
0.030"	110	25, 50, 100, 300, 500	—	3458T89	.52	—	—	—
7×7 Strand Core								
0.018"	40	10, 25, 50, 100, 300	—	—	—	—	3461T31 ♣	.44
0.027"	90	10, 25, 50, 100, 300	—	—	—	—	3461T32 ♣	.60
1/32"	140	25, 50, 100, 300, 500	—	3458T429	.35	—	3461T325	.36
0.036"	160	10, 25, 50, 100, 300	—	—	—	—	3461T33	.59
3/64"	270	25, 50, 100, 300, 500	A,C	3458T43 ♦	.33	A,C	3461T35 ♦	.34
1/16"	480	25, 50, 100, 300, 500	A,C	3458T44 ♦	.31	A,C	3461T44 ♦	.32
5/64"	650	25, 50, 100, 300, 500	—	3458T451	.36	—	3461T57	.37
3/32"	920	25, 50, 100, 300, 500	A,C	3458T46 ♦	.46	A,C	3461T45 ♦	.47
1/8"	1,700	10, 25, 50, 100, 300	—	3458T47	.61	—	3461T46	.63
5/32"	2,400	5, 10, 25, 50, 100	—	3458T48	.95	—	3461T47	.98
3/16"	3,700	5, 10, 25, 50, 100	—	3458T49	1.15	—	3461T48	1.17
1/4"	6,100	5, 10, 25, 50, 100	—	3458T118	2.21	—	3461T51	1.87
3/8"	12,000	2, 5, 10, 25, 50, 100	—	3458T53	3.54	—	3461T52	3.85
7×19 Strand Core								
0.024"	70	5, 10, 25, 50, 100	—	—	—	—	3461T62 ♣	1.32
0.038"	160	5, 10, 25, 50, 100	—	—	—	—	3461T63 ♣	1.15
3/64"	270	10, 25, 50, 100, 300	—	3458T74	1.20	—	3461T632	1.29
1/16"	480	10, 25, 50, 100, 300	A,C	3458T75 ♦	.66	A	3461T633	.73
3/32"	920	10, 25, 50, 100, 300	A,C	3458T76 ♦	.79	A,C	3461T64 ♦	.88
1/8"	1,760	5, 10, 25, 50, 100	A,C	3458T77 ♦	.94	A,C	3461T65 ♦	1.05
5/32"	2,400	5, 10, 25, 50, 100	A,C	3458T78 ♦	1.03	A,C	3461T66 ♦	1.15
3/16"	3,700	5, 10, 25, 50, 100	A,C	3458T79 ♦	1.29	A,C	3461T67 ♦	1.43
7/32"	5,000	5, 10, 25, 50, 100	A,C	3458T81 ♦	1.37	A	3461T78	1.52
1/4"	6,400	5, 10, 25, 50, 100	A,C	3458T82 ♦	2.07	A,C	3461T69 ♦	2.30
5/16"	9,000	2, 5, 10, 25, 50, 100	A,C	3458T84 ♦	3.39	A,C	3461T72 ♦	3.77
3/8"	12,000	2, 5, 10, 25, 50, 100	A,C	3458T85 ♦	4.17	A,C	3461T73 ♦	4.63
19×7 Strand Core								
1/8"	1,500	5, 10, 25, 50, 100	—	3458T61 ♦	.78	—	3461T37 ♦	.87
3/16"	3,330	2, 5, 10, 25, 50, 100	E	3458T63 ♦	1.36	E	3461T38 ♦	1.51
1/4"	5,760	2, 5, 10, 25, 50, 100	E	3458T65 ♦	2.39	E	3461T34 ♦	2.66
3/8"	10,800	2, 5, 10, 25, 50, 100	E	3458T67 ♦	4.46	E	3461T36 ♦	4.96

♦ Lubricated. ♣ Not preformed.

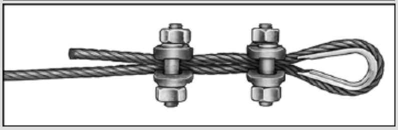
***Warning!** Breaking strength should never be considered the rope's working load.*

For wire rope, see pages 1398-1403.

About Wire Rope Clip Installation



Single-Saddle Clips



Double-Saddle Clips

Wire rope clips must match your wire rope diameter and be installed correctly to obtain maximum holding power. To get the clips you need, look at the tables below and find your wire rope diameter, the number of clips required, the amount of wire turnback on which to apply the clips, and the torque needed to properly tighten the nuts. Wire rope clips are not rated for work load; the work load limit is determined by the wire rope.

To install ***single-saddle clips,*** position the saddle on the "live" or long end of rope and the U-bolt on the "dead" or short end.

For ***double-saddle clips,*** orientation doesn't matter—just position a saddle on each end. There is no U-bolt; the saddles fasten together to apply equal pressure without crimping or crushing the wire.

Crosby Forged Wire Rope Clips—Not for Lifting

Single-Saddle Clip

Double-Saddle Clip

Forged construction makes these heavy duty clips ideal for use on support lines, tie downs, and other critical applications.

Single-Saddle Clips—*Zinc-plated steel* clips have a red-painted steel U-bolt.

Zinc-plated steel clips offer good corrosion resistance in most environments. All except 1/8" and 3/16" rope dia. sizes meet Fed. Spec. FF-C-450. ***Type 316 stainless steel*** clips provide maximum corrosion resistance.

	SINGLE-SADDLE CLIPS									DOUBLE-SADDLE CLIPS					
				Zinc-Plated Steel			Type 316 Stainless Steel						Zinc-Plated Steel		
For Rope Dia.	Min. Clips Req'd.	Rope Turn-back	Torque, ft.-lbs.		Each 1-9	Each 10-Up		Each 1-9	Each 10-Up	Min. Clips Req'd.	Rope Turn-back	Torque, ft.-lbs.		Each 1-9	Each 10-Up
1/8"	2	3 1/4"	4.5	3465T11	$2.52	$2.26	8913T12	$19.57	$16.61	—	—	—	—	—	—
3/16"	2	3 3/4"	7.5	3465T12	2.72	2.43	8913T13	22.14	18.79	2	4"	30	3466T12	$9.06	$8.21
1/4"	2	4 3/4"	15	3465T13	3.76	3.37	8913T14	25.89	21.97	2	4"	30	3466T12	9.06	8.21
5/16"	2	5 1/4"	30	3465T14	3.94	3.53	—	—	—	2	5"	30	3466T13	9.54	8.64
3/8"	2	6 1/2"	45	3465T15	4.21	3.77	8913T15	36.82	31.24	2	5 1/4"	45	3466T14	9.92	8.98
7/16"	2	7"	65	3465T16	6.67	5.98	—	—	—	2	6 1/2"	65	3466T16	11.96	10.87
1/2"	3	11 1/2"	65	3465T17	6.72	6.06	8913T16	49.81	43.08	2	11"	65	3466T16	11.96	10.87
9/16"	3	12"	95	3465T47	8.66	7.65	—	—	—	3	12 3/4"	130	3466T18	16.43	14.96
5/8"	3	12"	95	3465T38	8.65	7.65	8913T17	74.03	64.03	3	13 1/2"	130	3466T18	16.43	14.96
3/4"	4	18"	130	3465T19	11.06	9.92	—	—	—	3	16"	225	3466T19	24.12	22.00
7/8"	4	19"	225	3465T21	15.77	14.14	—	—	—	4	26"	225	3466T45	30.33	27.80
1"	5	26"	225	3465T22	18.30	16.41	—	—	—	5	37"	225	3466T37	38.94	35.64
1 1/8"	6	34"	225	3465T41	20.40	18.29	—	—	—	5	41"	360	3466T38	48.87	44.73
1 1/4"	7	44"	360	3465T42	29.93	26.82	—	—	—	6	55"	360	3466T39	51.89	47.49
1 3/8"	7	44"	360	3465T43	39.19	35.14	—	—	—	—	—	—	—	—	—
1 1/2"	8	54"	360	3465T44	40.36	36.19	—	—	—	—	—	—	—	—	—

Cast Wire Rope Clips—Not for Lifting

The choice when the extra strength of forged clips is not required. All are single saddle.

Malleable iron clips are good for applications where corrosion is not a factor. All except 1/16" and 3/32" rope dia. sizes meet Fed. Spec. FF-C-450. *Zinc-plated* clips provide good corrosion resistance. *Hot-dipped galvanized* clips offer better corrosion resistance than zinc-plated clips. ***Type 304*** and ***Type 316 stainless steel*** clips are mildly magnetic and provide better corrosion resistance than all of the malleable iron clips. *Type 316 stainless steel* clips provide maximum corrosion resistance.

				MALLEABLE IRON								
				Plain Finish			Zinc Plated			Hot-Dipped Galvanized		
For Rope Dia.	Min. Clips Req'd.	Rope Turn-back	Torque, ft.-lbs.		Each 1-9	Each 10-Up		Each 1-9	Each 10-Up		Each 1-9	Each 10-Up
1/16"	3	4 3/4"	2	—	—	—	30325T13	$0.34	$0.31	—	—	—
3/32"	3	4 3/4"	2	30325T14	$0.47	$0.44	30325T15	.55	.50	—	—	—
1/8"	3	4 3/4"	3	30325T61	.58	.51	30325T26	.58	.53	—	—	—
3/16"	3	5 1/2"	4.5	30325T62	.62	.56	30325T27	.64	.58	—	—	—
1/4"	3	7"	15	30325T63	.74	.67	30325T28	.79	.68	30325T83	$0.98	$0.88
5/16"	3	7 3/4"	15	30325T64	.84	.74	30325T29	.86	.77	30325T84	1.15	1.02
3/8"	3	9 1/2"	30	30325T65	1.14	1.04	30325T31	1.26	1.12	30325T85	1.57	1.39
7/16"	3	10 1/4"	40	30325T66	1.29	1.19	30325T32	1.46	1.34	30325T86	1.94	1.71
1/2"	4	15 1/4"	45	30325T67	1.44	1.33	30325T33	1.63	1.44	30325T87	2.25	1.99
9/16"	4	16"	50	30325T48	1.72	1.59	30325T49	1.97	1.84	30325T55	2.55	2.28
5/8"	4	16"	75	30325T39	1.80	1.67	30325T45	2.10	1.88	30325T46	2.75	2.56
3/4"	5	22 1/4"	75	30325T69	2.58	2.40	30325T35	2.89	2.58	30325T89	3.81	3.40
7/8"	5	23 1/2"	130	30325T71	3.95	3.66	30325T36	4.25	3.81	30325T9	5.48	4.91
1"	6	31"	130	30325T72	4.66	4.28	30325T37	5.31	4.73	30325T91	6.99	6.28

TYPE 304 STAINLESS STEEL

For Rope Dia.	Min. Clips Req'd.	Rope Turn-back	Torque, ft.-lbs.		Each 1-9	Each 10-Up
1/16"	2	—	—	31985T19	$1.08	$0.95
1/8"	2	3 1/4"	—	31985T71	1.50	1.32
5/32"	2	3 3/4"	—	31985T81	1.73	1.53
3/16"	2	3 3/4"	—	31985T72	1.81	1.59
1/4"	2	4 3/4"	8	31985T73	2.29	2.05
5/16"	2	5 1/4"	15	31985T83	3.54	3.12
3/8"	2	6 1/2"	30	31985T74	6.94	6.12
1/2"	3	11 1/2"	45	31985T75	11.30	9.95
5/8"	3	12"	95	31985T26	21.19	18.67
3/4"	4	18"	130	31985T27	33.72	29.16
7/8"	4	19"	225	31985T28	57.03	49.32
1"	5	26"	225	31985T29	68.75	59.46

TYPE 316 STAINLESS STEEL

For Rope Dia.	Min. Clips Req'd.	Rope Turn-back	Torque, ft.-lbs.		Each 1-9	Each 10-Up
5/64"	2	2 1/4"	3	3017T41	$5.40	$4.50
1/8"	2	3 1/4"	4.5	3017T54	5.84	4.86
5/32"	2	3 3/4"	7.5	3017T42	5.98	4.97
3/16"	2	3 3/4"	7.5	3017T43	6.83	5.71
1/4"	2	4 3/4"	15	3017T44	7.79	6.50
5/16"	3	5 1/4"	30	3017T45	12.64	10.53
3/8"	3	6 1/2"	45	3017T46	16.72	14.39
1/2"	3	11 1/2"	45	3017T47	26.09	21.73
5/8"	3	12"	95	3017T49	38.32	31.93
3/4"	4	18"	130	3017T51	44.74	37.30
7/8"	4	19"	225	3017T52	62.64	52.20
1"	5	26"	225	3017T53	91.70	78.60

Warning! ***Do not use with coated wire rope unless coating is removed.***

Pull Handles with Threaded Holes (Continued from previous page)

Round Grip (Cont.)—Style 2

	(A)	Proj.	Grip Size, Dia.	Thread Size	Thread Depth		
Extruded Type 304 Stainless Steel—Polished Finish							
2	3″	1 7/16″	1/2″	8-32	1/2″	1325A1	$5.82
2	3 1/2″	1 7/16″	1/2″	8-32	1/2″	1325A11	6.07
2	3 3/4″	1 7/16″	1/2″	8-32	1/2″	1325A12	6.07
Extruded Type 304 Stainless Steel—Polished Finish (Cont.)							
2	5 1/16″	1 7/16″	1/2″	8-32	1/2″	1325A13	$7.67
2	7 9/16″	1 7/16″	1/2″	8-32	1/2″	1325A14	8.69
2	10 1/16″	1 7/16″	1/2″	8-32	1/2″	1325A15	10.29

Oval Grip—Styles 3-8

	(A)	Proj.	Grip Size Ht.	Grip Size Wd.	Thread Size	Thread Depth		
Extruded Aluminum—Dull Finish								
3	2″	1 1/2″	7/16″	5/16″	10-32	5/16″	1897A92	$4.55
3	3″	1 5/16″	5/8″	5/16″	10-32	9/16″	1897A49	4.12
3	3 1/2″	1 1/2″	7/16″	5/16″	10-32	5/16″	1897A95	4.65
3	4″	1 5/16″	5/8″	5/16″	10-32	9/16″	1897A52	4.38
3	4″	1 1/2″	5/8″	5/16″	10-32	9/16″	1897A56	4.50
3	4 9/16″	1 1/2″	5/8″	5/16″	10-32	9/16″	1897A59	4.56
3	6″	1 1/2″	5/8″	5/16″	10-32	9/16″	1897A62	5.00
3	6″	1 3/4″	5/8″	5/16″	10-32	9/16″	1897A73	5.16
3	8″	1 3/4″	5/8″	5/16″	10-32	5/16″	1897A88	6.43
3	9″	1 3/4″	5/8″	5/16″	10-32	5/16″	1897A9	6.65
Extruded Aluminum—Black Anodized Finish								
3	2″	1 1/2″	7/16″	5/16″	10-32	5/16″	1897A91	8.11
3	3″	1 5/16″	5/8″	5/16″	10-24	9/16″	1897A21	6.00
3	3 1/2″	1 1/2″	7/16″	5/16″	10-32	5/16″	1897A94	8.25
3	4″	1 1/2″	5/8″	5/16″	10-32	9/16″	1897A24	7.08
3	4 9/16″	1 1/2″	5/8″	5/16″	10-24	9/16″	1897A35	7.15
3	6″	1 1/2″	5/8″	5/16″	10-32	9/16″	1897A36	8.55
3	6″	1 3/4″	5/8″	5/16″	10-24	9/16″	1897A37	8.63
3	8″	1 3/4″	5/8″	5/16″	10-32	5/16″	1897A89	10.86
3	9″	1 3/4″	5/8″	5/16″	10-24	9/16″	1897A41	11.04
Extruded Type 303 Stainless Steel—Dull Finish								
3	2″	1 1/2″	7/16″	5/16″	10-32	5/16″	11245A93	8.78
3	3″	1 5/16″	5/8″	5/16″	10-32	5/16″	11245A8	15.30
3	3″	1 5/16″	5/8″	5/16″	10-32	9/16″	11245A61	22.22
3	3 1/2″	1 1/2″	7/16″	5/16″	10-32	5/16″	11245A96	9.93
3	4″	1 5/16″	5/8″	5/16″	10-32	5/16″	11245A81	17.10
3	4″	1 1/2″	5/8″	5/16″	10-32	5/16″	11245A82	17.65
3	4 9/16″	1 1/2″	5/8″	5/16″	10-32	5/16″	11245A83	18.83
3	4 9/16″	1 1/2″	5/8″	5/16″	10-32	9/16″	11245A63	24.89
3	6″	1 1/2″	5/8″	5/16″	10-32	5/16″	11245A84	21.40
3	6″	1 3/4″	5/8″	5/16″	10-32	5/16″	11245A85	22.30
3	8″	1 3/4″	5/8″	5/16″	10-32	5/16″	11245A86	25.95
3	9″	1 3/4″	5/8″	5/16″	10-32	5/16″	11245A87	27.75
3	9″	1 3/4″	5/8″	5/16″	10-32	9/16″	11245A67	30.27
Extruded Type 303 Stainless Steel—Polished Finish								
3	3 15/16″	1 5/8″	9/16″	5/16″	M5	11 mm	11245A42	$28.11
3	4 15/16″	1 5/8″	9/16″	5/16″	M5	11 mm	11245A43	30.78
3	5 15/16″	2″	9/16″	5/16″	M5	11 mm	11245A44	37.89
NSF Certified Extruded Type 303 Stainless Steel—Dull Finish								
4	4 7/16″	1 7/16″	11/16″	7/16″	M5	15 mm	1855A1	35.56
4	5 5/8″	1 1/2″	11/16″	7/16″	M5	15 mm	1855A2	38.06
4	6 13/16″	1 5/8″	11/16″	7/16″	M5	15 mm	1855A3	42.67
4	8 3/8″	1 11/16″	11/16″	7/16″	M5	15 mm	1855A4	44.43
4	11 1/2″	1 3/4″	11/16″	7/16″	M5	15 mm	1855A5	57.78
Extruded Type 316 Stainless Steel—Dull Finish								
4	3 1/2″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A71	12.34
4	4″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A73	12.80
4	5″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A75	13.71
4	6″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A77	14.74
Extruded Type 316 Stainless Steel—Polished Finish								
4	3 1/2″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A7	12.34
4	4″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A72	12.80
4	5″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A74	13.71
4	6″	1 5/16″	9/16″	5/16″	8-32	3/8″	1855A76	14.74
Cast Zinc—Chrome Finish								
5	3″	3/4″	7/16″	1/8″	8-32	5/16″	1786A11	3.63
Cast Zinc—Bright Brass Finish								
5	3″	3/4″	7/16″	1/8″	8-32	5/16″	1786A1	3.52
Cast Type 304 Stainless Steel—Dull Finish								
5	2 3/4″	13/16″	11/16″	1/8″	8-32	1/2″	1786A15■	23.47
Cast Aluminum—Dull Anodized Finish								
6	5 1/2″	2 1/4″	3/4″	3/4″	1/4″-20	5/8″	1402A19	14.09
6	7 1/2″	2 3/8″	3/4″	3/4″	1/4″-20	5/8″	1402A24	20.42
Nylon—Black								
7	4″	15/16″	5/8″	3/16″	10-24	3/8″	1815A52■	2.82
8	3 7/16″	1 9/16″	1/2″	3/8″	M5	7.5 mm	1967A1■	6.32
8	3 15/16″	1 9/16″	1/2″	3/8″	M5	7.5 mm	1967A2■	5.94
8	4 3/4″	1 9/16″	1/2″	3/8″	M5	7.5 mm	1967A3■	6.46

■ Mounting screws not included.

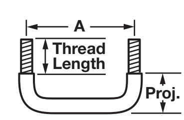
Rectangular Grip—Styles 9-11

	(A)	Proj.	Grip Size Ht.	Grip Size Wd.	Thread Size	Thread Depth		
Extruded Aluminum—Dull Finish								
9	2″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A31	$7.57
9	4″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A41	7.95
9	4 9/16″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A51	8.09
9	6″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A61	8.35
Extruded Aluminum—Black Anodized Finish								
9	2″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A33	7.97
9	4″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A43	8.38
9	4 9/16″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A53	8.55
9	6″	1 1/2″	1/2″	1/4″	8-32	7/16″	15145A63	8.80
NSF Certified Extruded Type 303 Stainless Steel—Polished Finish								
9	2 9/16″	7/8″	7/16″	1/4″	M3	10 mm	1855A61	10.13
9	3 3/8″	15/16″	7/16″	1/4″	M3	10 mm	1855A62	11.18
Extruded Type 304 Stainless Steel—Polished Finish								
9	4″	15/16″	7/16″	1/4″	6-32	5/16″	1855A64	$8.42
Extruded Aluminum—Dull Finish								
10	3″	1 1/16″	7/16″	3/16″	10-24	3/8″	1651A2	3.86
10	4″	1 1/16″	5/8″	3/16″	10-24	3/8″	1651A1	4.26
Extruded Aluminum—Black Anodized Finish								
10	4″	1 1/16″	5/8″	3/16″	10-24	3/8″	1651A4	4.26
Cast Zinc—Dull Chrome Finish								
11	4″	7/8″	3/8″	3/16″	10-24	1/2″	1678A56	2.07

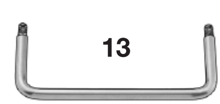
Pull Handles with Threaded Studs

Handles have a round grip.

	(A)	Proj.	Grip Size, Dia.	Thread Size	Thread Length		
Extruded Aluminum—Black Anodized Finish							
12	4 1/4″	1 3/16″	5/16″	5/16″-18	15/16″	11665A11	$11.97
12	6″	1 3/16″	5/16″	5/16″-18	15/16″	11665A12	13.25
13	4″	2 1/4″	5/16″	1/4″-20	1/2″	11665A6	12.60
Extruded Brass—Polished Nickel Finish							
12	4 1/4″	1 3/16″	5/16″	5/16″-18	15/16″	11665A21	12.03
12	6″	1 3/16″	5/16″	5/16″-18	15/16″	11665A22	13.27
Extruded Type 303 Stainless Steel—Dull Finish							
12	4 1/4″	1 3/16″	5/16″	5/16″-18	15/16″	11665A31	15.70
12	6″	1 3/16″	5/16″	5/16″-18	15/16″	11665A32	16.60
Extruded Type 303 Stainless Steel—Polished Finish							
12	4″	1 3/16″	3/8″	3/8″-24	15/16″	11665A4	16.34
12	5″	1 3/16″	5/16″	5/16″-18	15/16″	11665A3	17.04
13	5″	2 1/4″	5/16″	1/4″-20	1/2″	11665A7	17.50

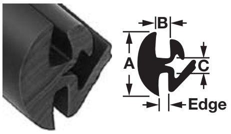


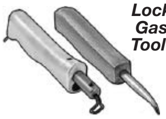

12


13

For information about rubber and durometer scales, see page 3514.

Glass-Locking Edge-Grip Seals





Locking Gasket Tool Set

By pushing the bottom end onto an edge and inserting glass into the top portion, this EPDM seal locks into place to secure gaps between glass and metal. Temperature range is –20° to +158° F. Durometer hardness is A70.

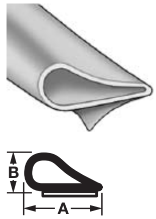
To install, lubricate with soap and water. Tape in place as glass is inserted. For easier installation, work into position with the set of locking gasket tools (sold separately).

To Order: Please specify 5-, 10-, 25-, 50-, or 100-ft. continuous length.

Fits Edge	O'all Ht. (A)	Fits Glass (B)	Clearance Between Glass and Edge (C)		Per Ft. 1-99	Per Ft. 100-Up
3/64"-1/16"	15/64"	3/16"-1/4"	5/16"	3275T15	$1.84	$1.36
3/32"-9/64"	57/64"	3/16"-1/4"	1/4"	3275T22	1.49	1.11
3/16"-1/4"	13/32"	3/16"-1/4"	13/32"	3275T16	1.96	1.46

Optional 2-Pc. Locking Gasket Tool Set .... 3275T44 Each $59.29

Fire-Rated Adhesive-Backed Rubber Bulb Seals



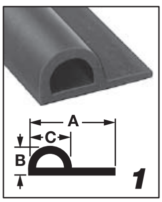
Tested in accordance with NFPA (National Fire Protection Association) standards 105 and 252, these silicone seals also meet ASTM E283, E90, and E413. UL classified for use on hollow metal and steel-covered composite-style fire doors rated up to and including three hours, as well as wood-covered composite and wood core-style fire doors rated up to and including 1 1/2 hours. Meet UL 10B, UL 10C, and UL 1784.

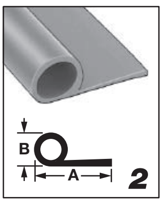
Cut to length with scissors or a knife. Temperature range of silicone is –100° to +550° F; acrylic adhesive has a temperature range of –40° to +250° F. For best adhesion results, install above 50° F. Durometer hardness is A70-A80.

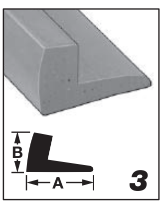
To Order: Please specify 10-, 25-, 100-, or 300-ft. continuous length and color: brown, charcoal, or white.

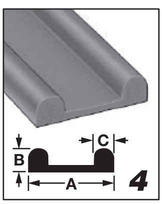
O'all Wd. (A)	O'all Ht. (B)		Per Ft. 1-299	Per Ft. 300-Up
1/2"	1/4"	1067A3	$1.28	$0.95

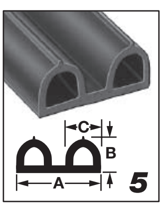
Rubber Bulb Seals

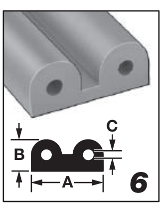


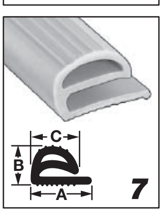


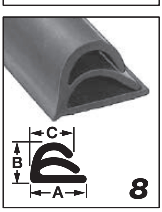


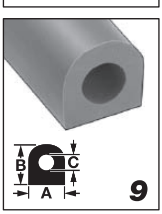


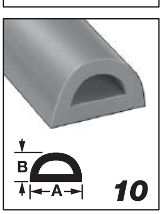


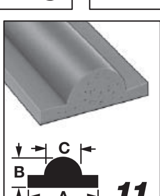












Use where a tight seal is needed. Cut to length with scissors or a knife. Install plain back with staples, tacks, or screws (not included); silicone-based adhesive can also be used for plain-back silicone.

EPDM Seals— Good resistance to weathering. Durometer hardness is A70, unless noted. Temperature range is –30° to +200° F. Color is black.

Silicone Seals— Good resistance to high temperatures. Color is orange/red. *Plain back* has a durometer hardness of A50 and a temperature range of –60° to +350° F. *Adhesive backed* has a durometer hardness of A60 and a temperature range of –100° to +500° F; acrylic adhesive has a max. temperature of 250° F.

Viton® Fluoroelastomer Seals— Resist acids. Durometer hardness is A75. Temperature range is –20° to +450° F. Color is black. Meets MIL-R-83248.

Vinyl Seals— Resist water. Durometer hardness is A73. Temperature range is –30° to +150° F. Color is gray. Meets UL 94HB for flammability.

To Order: Please specify length from those listed below. The last length listed is the maximum continuous length.

	O'all Wd. (A)	O'all Ht. (B)	(C)	Material	Available Lengths, ft.		Per Ft. 1-99	Per Ft. 100-Up
Plain Back								
1	3/4"	1/4"	1/4"	EPDM	6, 12	1142A11	$1.45	—
1	3/4"	1/4"	1/4"	Silicone	1, 5, 10, 20, 50, 100	1129A4	3.18	$2.55
1	3/4"	1/4"	1/4"	Viton®	1, 5, 10, 20, 50	2072T11	5.83	4.66
1	3/4"	11/32"	3/8"	EPDM	10, 20, 50	1142A81	.90	.67
1	7/8"	5/16"	1/2"	EPDM	6, 12	1142A14	1.83	.75
1	1 1/4"	5/8"	3/4"	EPDM	10, 20, 50	1142A82	1.46	1.09
1	1 3/8"	3/8"	9/16"	EPDM	6, 12	1142A15	2.15	—
1	1 3/8"	1/2"	5/8"	Vinyl	5, 10, 20, 50, 100	1142A63	2.29	1.71
2	1/2"	1/4"	—	EPDM	10, 20, 50	1142A75	.77	.58
2	3/4"	3/8"	—	EPDM	10, 20, 50	1142A77	1.03	.75
2	7/8"	3/8"	—	Silicone	5, 10, 20, 50, 100	1129A3	1.92	1.47
2	7/8"	3/8"	—	Viton®	1, 5, 10, 20, 50	2072T12	7.52	6.00
2	1"	1/4"	—	EPDM	10, 20, 50	1142A76	.90	.67
2	1"	1/4"	—	EPDM	10, 20, 50, 100	1142A83▲	1.10	.83
2	1 1/8"	3/8"	—	EPDM	10, 20, 50, 100	1142A84★	1.34	1.02
2	2"	1/2"	—	EPDM	10, 20, 50	1142A78	1.22	.91
2	2"	1"	—	EPDM	5, 10, 20, 25	1142A79	2.33	1.72
3	3/4"	0.40"	—	Silicone	5, 10, 20, 50, 100	1129A1	2.68	2.00
4	0.85"	0.23"	0.20"	Silicone	5, 10, 20, 50, 100	1129A2	2.37	1.77
5	3/4"	5/16"	5/16"	EPDM	6, 12	1142A48	1.90	—
6	1 1/4"	1/2"	5/32"	Silicone	1, 5, 10, 20, 50, 100	1129A9	5.05	3.77
7	9/16"	3/8"	3/8"	Silicone	1, 5, 10, 20, 50, 100	1129A5	4.93	3.68
7	9/16"	3/8"	9/16"	Vinyl	6, 12	1142A18	1.72	—
7	11/16"	1/2"	5/8"	Vinyl	10, 20, 50, 100	1142A39	.90	.67
7	13/16"	5/8"	3/4"	Vinyl	5, 10, 20, 50, 100	1142A61	1.61	1.21
7	7/8"	7/16"	11/16"	Vinyl	10, 20, 50, 100	1142A41	1.00	.74
7	15/16"	9/16"	13/16"	Vinyl	10, 20, 50, 100	1142A62	.86	.65
7	61/64"	1/2"	13/16"	Vinyl	10, 20, 50, 100	1142A42	.96	.72
8	13/16"	5/8"	3/4"	EPDM	1, 6, 12	1142A54	4.76	—
9	1/2"	1/2"	1/4"	Silicone	5, 10, 20, 50, 100	1129A6	2.23	1.66
9	1/2"	1/2"	1/4"	Viton®	1, 5, 10, 20, 50	2072T13	10.15	8.12
10	3/8"	3/8"	—	EPDM	10, 20, 50	1142A71	.90	.67
10	1/2"	1/2"	—	EPDM	10, 20, 50	1142A72	1.03	.77
10	5/8"	3/8"	—	Silicone	5, 10, 20, 50, 100	1129A7	2.44	1.82
10	5/8"	3/8"	—	Viton®	1, 5, 10, 20, 50	2072T14	11.74	10.41
10	3/4"	9/16"	—	Silicone	5, 10, 20, 50, 100	1129A8	2.37	1.77
10	1"	1/2"	—	EPDM	10, 20, 50	1142A73	1.28	.96
11	1"	3/8"	1/2"	Silicone	1, 5, 10, 20, 50, 100	1129A11	4.95	3.70
Adhesive Backed								
2	3/8"	1/8"	—	Silicone	10, 20, 50, 100	1129A962	1.58	1.18
2	3/8"	3/16"	—	Silicone	5, 10, 20, 50, 100	1129A963	1.75	1.31
2	1/2"	1/4"	—	Silicone	5, 10, 20, 50, 100	1129A964	1.86	1.38
10	7/64"	9/64"	—	Silicone	5, 10, 20, 50, 100	1129A93	1.71	1.27
10	11/64"	7/32"	—	Silicone	5, 10, 20, 50, 100	1129A94	1.88	1.40
10	3/8"	9/32"	—	Silicone	5, 10, 20, 50, 100	1129A95	2.07	1.54

▲ Durometer hardness is A65. ★ Durometer hardness is A60.

Appendix E

Fluid Analysis; Formula provided by ATTLA

$$t = \left(\frac{V}{A}\right)\frac{1}{\sqrt{\gamma R T_o}}\left[3.575\left(\sqrt{\frac{\gamma-1}{2}}\right)-\left(\sqrt{\left(\frac{2}{\gamma-1}\right)^{-\frac{\gamma+1}{\gamma-1}}}\right)ln\left(\frac{1.896P_f}{P_o}\right)\right]$$

t= 0.5 seconds
V= 1225 ft^3
ϒ=1.4 (for ideal gas)
R= 1717.61 ft^2/sec^2°R
P_f= 2.7 psi
P_o= 11 psi
T_o= 490.159 °R

Result: Escape Area required to release 8.3 psi in 0.5 seconds is 6.559 ft^2

Disk Panel Analysis

Required Escape Area of at least 6.6 ft^2

Two disks with area of 3.5 ft^2

$$2(3.5\ ft^2) = 7.0\ ft^2 Escape\ Area$$

Force on each disk panel from 1.0 psi

$$(1.0\ psi)\left(144\frac{in^2}{ft^2}\right)(3.5\ ft^2) = 504\ lbs\ force\ on\ each\ disk\ panel$$

Result: Each disk panel will experience a force of 504 lbs from 1.0 psi

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Magnet Analysis

Pull force 66.38 lbs
8 magnets= 531.04 lbs
531.04 lbs on a panel of area 3.5 ft^2=1.05 psi

Result: With 8 magnets that have a pull force of 66.38 lbs, the magnets will release at 531.04 lbs or 1.05 psi

Appendix F

Show Gantt for: Planned | Show Status? | What is current week? 18

#	List of Activties	Planned Start	Planned Dur	Actual Start	Actual Dur	% Done
1	Letter to Sponsor	1	1	1	1	100%
2	Team Logo	1	1	1	1	100%
3	Kick-off Teleconference	2	1	3	1	100%
4	Team Contract	3	1	3	1	100%
5	Background Research	1	5	2	5	90%
6	QFD-House of Quality	4	1	4	1	100%
7	Project Proposal	5	1	5	1	100%
8	Brainstorming	5	3	5	3	100%
9	Conceptual Modeling	7	2	7	4	100%
12	Continue Conceptual Design (analyses, drawing, etc)	9	4	8	6	80%
13	Conceptual Design Review	11	1	11	1	100%
14	Continue Design (analyses, drawing, etc)	13	3	13	0	70%
15	Test Plan Development	14	3	14	0	80%
16	Practice CDRs	16	1	16	1	100%
17	Work on Design Report	17	2	17	18	100%
18	Critical Design Review	17	1	17	17	100%
19	Ethics	17	2	17	18	100%
20	Manufacturing and Test	18	4	0	0	0%
21	End of Quarter Report	21	2	0	0	0%
22	Test Design (Test and Retest)	23	7	0	0	0%
24	Finalize Design	30	1	0	0	0%
25	Senior Expo	31	1	0	0	0%
26	Final Report Due	31	2	0	0	0%

Figure 21. Gannt Chart