SINGLE DOOR THRUST
RECOVERY VALVE

By

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In Partial Fulfillment of the Bachelors Degree
With Honors in

Mechanical Engineering

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STATEMENT BY AUTHOR

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ABSTRACT

Honeywell Aerospace, a division of Honeywell International, is a major provider in aerospace technology. The campus in north Tucson has a division dedicated to aircraft cabin pressure control. Within the realm of cabin pressure control, there exists pressure relief valves specially designed to improve the specific fuel consumption of an aircraft. They do this by directing airflow towards the rear of the aircraft, contributing a small thrust vector. These are known as Thrust Recovery Outflow Valves (TROV).

Currently, the most widely used Honeywell TROV product consists of two doors linked together and connected to an actuator. This design has performed very well, but the complexity and number of moving components raises the manufacturing cost. The team's mission was to design, manufacture, and test a prototype TROV with equal performance to the current design, but with only a single door. The purpose of utilizing a single door is to decrease the number of components and in turn the cost of the valve. There were several performance requirements in the project scope. Upon the completion and testing of the team's prototype, all requirements were met, and most of all the innovative design proved to operate as intended during flight simulation. As a result, the design is patent pending.

STATEMENT OF ROLES AND RESPONSIBILITIES OF GROUP MEMBERS

Joseph Daniel Rainey, Mechanical Engineering

Mechanical Design Lead. Prototyping Lead. Deliverables Specialist. Report Editor. Set milestones for team to keep design progress in timely manner. Design Day Presenter.

Michael T. Dzurak, Engineering Management

Management Lead. Presentation Editor. Man contact with sponsor Darrell Horner. Kept team on track with organization of weekly meetings. Gantt Chart.

Andrew T. Brown, Mechanical Engineering

Mechanical Design Specialist. Drafting Lead. Video Lead. Lead Poster Designer. Primary Outsourced Machining Contact. Report Editor. Design Day Presenter.

Ondrej Dvorak, Mechanical Engineering

Mechanical Design Specialist. ANSYS Analysis Lead. In-house Machining Lead. Outsourced Machining Contact.

Francisco Olea, Engineering Management

Budget Lead. Parts ordering lead. Francisco was in charge of ordering all parts and presentation supplies.

Timur Suleymanov, Engineering Management

Book Keeping. Presentation Editor. Timur was mainly responsible for organizing the team and keeping track of deliverable deadlines.

Final Report
Single Door Thrust Recovery Valve
Honeywell Aerospace, Tucson, AZ

4 May 2011

Senior Design Team 4571:

Andrew Brown

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1. Introduction

Team 4571 worked with Honeywell Aerospace, represented by Darrell Horner, in order to design a Thrust Recovery Valve (TRV) for executive sized aircraft. At the time of the Critical Design Review (CDR), Team 4571 had selected and optimized a design shown in Figure 1.

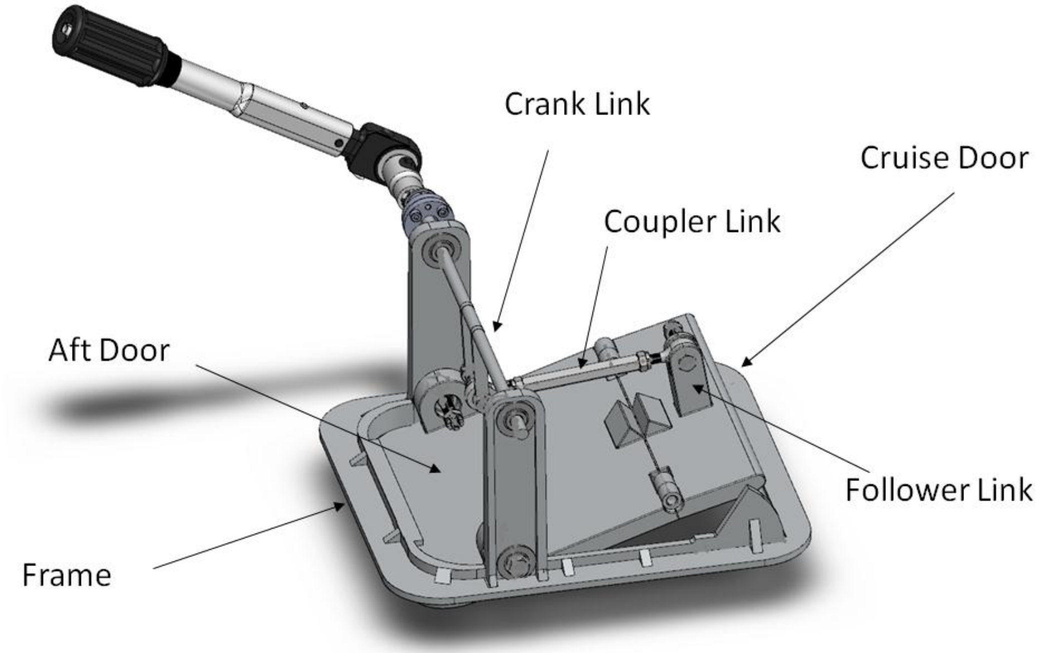


Figure 1: Proposed TRV

In order to accommodate financial restrictions and manufacturing equipment available to the team, the design in Figure 1 was redesigned and shown in Figure 2.

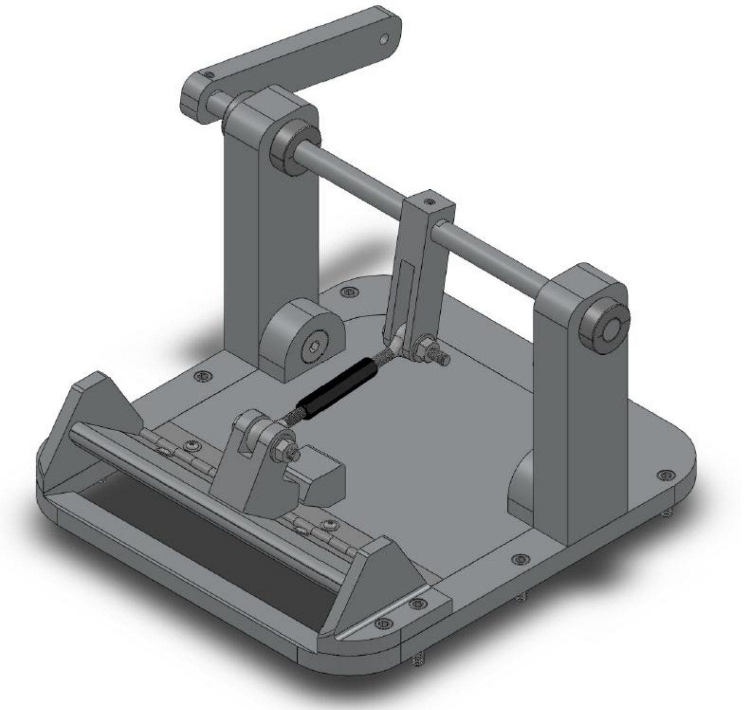


Figure 2: Redesigned TRV for machining purposes

The design is referred to as the cruise door design. It combines the idea of using a small door during cruise altitudes when the differential pressure is high causing a large closing torque and a large door to allow maximal airflow when necessary. The assembly requires only one linkage which is less than the current industry standard two door design shown in Figure 3.

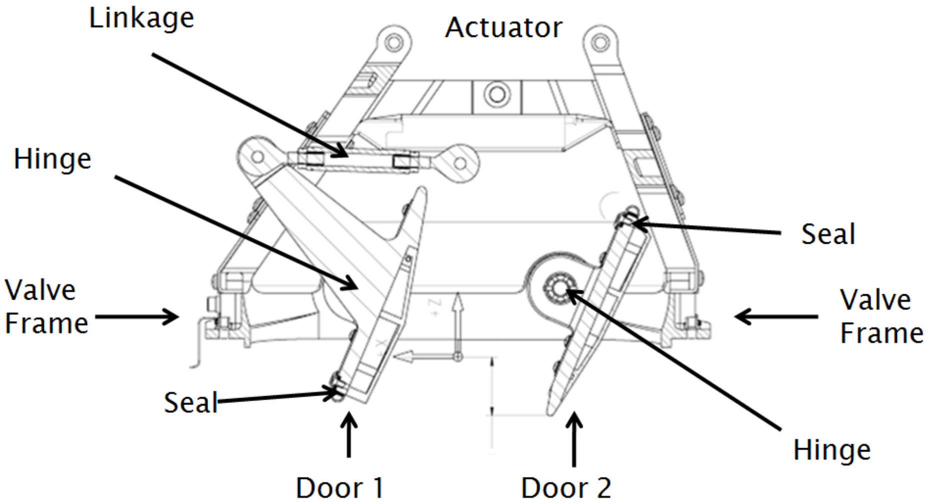


Figure 3: Standard Two Door TRV

The cruise door design also eliminates the need to perform computational fluid dynamics upon the aerodynamic flap on the design suggested by Honeywell Aerospace shown in the Figure 4.

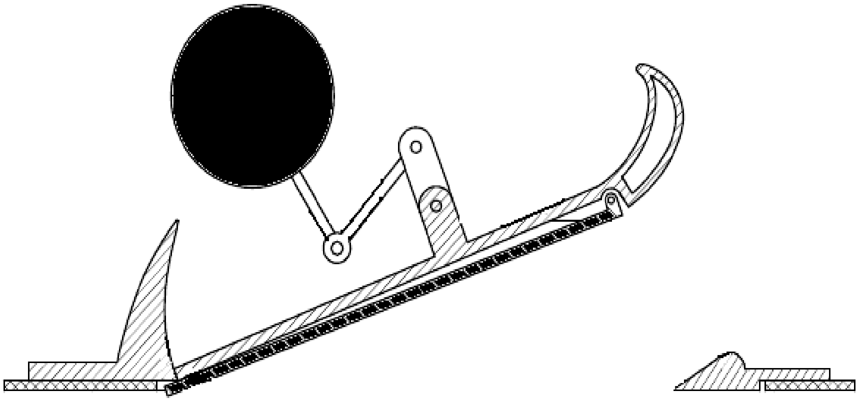


Figure 4: Aerodynamic Flap Door TRV

1.1 Scope of the Document

This document begins by covering the theoretical basis for the design including the system requirements, summary of the preliminary design review, top-level design of the final design concept, subsystems/sub-assembly, interface of the hardware design, and analysis used for support of the subsystem-level decisions. The later parts of the document cover the development plan, the budget, supplies necessary, vendors, the acceptance test plan and the planned testing methods. The final portion of the document summarizes the risks involved with the chosen design and the projected schedule for prototyping.

1.2 Changes Made Since Preliminary Design Review

By the time of the preliminary design review (PDR), Team 4571 had decided on the general characteristics of three different concepts, and finalized the choice of the design to be the cruise door design. Once the decision was made at PDR, the time between PDR and CDR was spent establishing the exact parameters of the design.

Since the PDR, the team quantified the exact dimensions, torque, parts, and budget impacts of the design. Numerous risks associated with the design were mitigated by refining the methods of optimization and eliminating all hand calculations. Also, a professional machining vendor was contracted to machine the components associated with the prototype.

1.3 Problem Statement

Since the start of the project, the problem statement had been modified because the cruise door design eliminated some of the expected problems and added complexities which were not present at first. The modified problem statement was to design, analyze, and test a single door thrust recovery valve based on a concept created during the course of the project.

A TRV is mounted on the bottom of the aircraft and is controlled by a cabin pressure controller (controls not in scope of project). The TRV is designed to regulate the cabin pressure and is oriented in such a way that the exit airflow is in the aft direction to create a small thrust component to increase the specific fuel consumption of the aircraft.

Included in the project scope was to design and prototype the valve frame, doors, hinges, linkage, hinge seals, and testing apparatus. Also, the aft and cruise doors must be loaded closed under all conditions and be optimized to operate with an actuator which is limited to 200 in-lbs of torque. The valve door must be able to withstand a maximum pressure differential of 10 psi and present little to no drag when compared to the previous design during cruise altitudes.

1.3.1 Design Aspects

- Mechanical design - valve design
- Aerodynamic design/analysis - drag reduction
- Mechanical structural/stress analysis – loading
- Prototyping, machining and assembly
- Effective area requirements
- Project management

1.3.2 Design Constraints

- Fit to existing aircraft rib footprint
- Actuator torque
- Ease of assembly
- Feasibility of machining

1.3.3 High Flow Testing

- Determine if doors were be loaded closed under pressure differential
- Aft door remains closed during cruise door operation
- Adequate effective area during entire flight

1.4 Scope of the Project

Team 4571 was to design, manufacture, and test a single door thrust recovery valve for an executive sized aircraft. The project involves analyzing available designs and creating iterations or new designs. Based on the analysis conducted up to the CDR, Team 4571 elected to create a new design that combines the benefits of previous designs and optimizes multiple features. The design has been evaluated using a mechanical study of the torque on the doors, drag reduction, structural and stress analysis, and loaded closed design.

Constant communication with the sponsor is also a part of the project. While the design process continues through the two semesters, the team maintains contact with the project sponsor Darrell Horner of Honeywell Aerospace via weekly teleconferences. The sponsor has approved the concept proposed by Team 4571.

The second semester is comprised of building and testing of the approved model. The team was to obtain a preliminary prototype of the model using inexpensive materials for preliminary calibration. Producing inexpensive scale models is intended to minimize complications associated with the final model. The final model was to be manufactured out of aluminum either at the University of Arizona machine shop or outsourced to a professional third party vendor. The final design will be presented during the senior design competition on May 3, 2011.

1.5 Expectations of the Project

Team 4571 and the sponsor of the project expect to create a proof of concept model that will perform the functions of the existing thrust recovery valve, and improve on the key characteristics presented in the problem statement. The final product shall be a functioning TRV which can be attached to a test bench and adjusted for various angles of operation.

1.6 Description of Customer

Honeywell is an international corporation which has aerospace, automotive, engineered materials, and automated control systems segments. The company has a cabin pressure control system sector based in Tucson, Arizona. Honeywell is sponsoring a University of Arizona senior design project and the sponsor for the project is Darrell Horner.

Darrell Horner is a University of Arizona alumnus and has worked at Honeywell for 23 years. At the moment, he is a Chief Engineer focused primarily on the cabin pressure controls product line. Most of his time spent at the company has been as a cabin pressure control systems engineer working with TRV systems, valves, electronics, and software for commercial and civil aircraft.

He is also a holder of 14 U.S. Patents and an additional 8 U.S. Published Patent Applications with subjects including: all-electric turbine engine guide vane actuation method, composite fail-safe outflow valves, independent and redundant high cabin altitude warning system, control and monitor architecture CPCS, and brushed DC motor CPCS. Needless to say, the company and the contact are well versed in the subject of TRVs.

2. System Requirements

There are two separate requirement standards presented. One set of requirements is directly tied to sponsor's initial problem statement and the resulting specifications; the list is displayed under section 2.1 - Testing Requirements. The other is designed for the inspection of machined components from Industrial Tool, Die and Engineering (ITDE), displayed under section 2.2 - Assembly Requirements.

2.1 Testing Requirements

- Functional – Defines a function of the system or a component in the system.
- Technology – Defines what technology is needed to fulfill the requirement.
- Performance – Defines the system's or a component's capabilities.

TYPE	**DESCRIPTION**	**PRIORITY**	**SUBSYSTEM**	**PASS/FAIL**
Functional	The valve shall provide a higher velocity outflow than the baseline.	Desired	Cruise Door	PASS
Functional	The system shall release cabin pressure at variable altitudes.	Must	Both Doors	PASS
Functional	The system shall be loaded closed in case of failure.	Must	Hinges	PASS
Functional	The system shall reduce the number of moving parts to increase reliability.	Desired	All Subsystems	PASS
Technology	The system shall adjust to changing pressures via actuation.	Desired	All Subsystems	PASS
Technology	The system shall be manufactured out of aluminum or composite material.	Desired	Doors/Linkage	PASS
Performance	The device shall optimize the amount of thrust provided to plane.	Must	Cruise Door	PASS
Performance	The system shall be lighter than the current design.	Desired	All Subsystems	PASS
Performance	The system shall have fewer mechanical components.	Desired	All Subsystems	PASS
Performance	The system shall require less torque input than the baseline amount.	Desired	All Subsystems	OBTAINED

Table 1a: System Requirements – Functional, Technology, and Performance

2.2 Assembly Requirements

- Assembly – Defines the machined components retrieved from ITDE.
- Attachment – Defines the characteristics of the test bench attachment

TYPE	DESCRIPTION	PRIORITY	PASS/FAIL
Assembly	Are all components of the prototype present?	Must	PASS
Assembly	Are the set screws and bolts been tightly fastened?	Desired	PASS
Assembly	Is the surface finish between essential components at least 125 RMS?	Must	PASS
Assembly	Have the dynamic bolts and hinges been lubricated?	Desired	FAIL
Assembly	Do any components of the assembly require rework?	Must	PASS
Assembly	Are components assembled correctly?	Must	PASS
Attachment	Does the assembly fit the test bench attachment?	Desired	PASS

Table 1b: System Requirements – Assembly

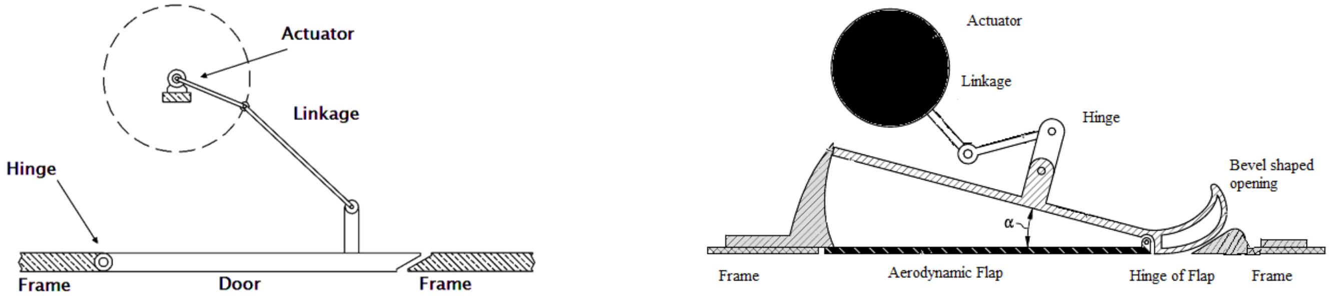
3. Summary of PDR Results

3.1 Concepts Considered

The design phase of the project consisted of analyzing three possible concepts. The first concept involved the idea of having a single door mounted to the valve frame with an end hinge. This concept would allow for near complete elimination of drag forces during operation, and an excellent thrust component vector, but would require a very large amount of torque to operate due to the large lever arm. This end hinge concept is illustrated below in Figure 4.

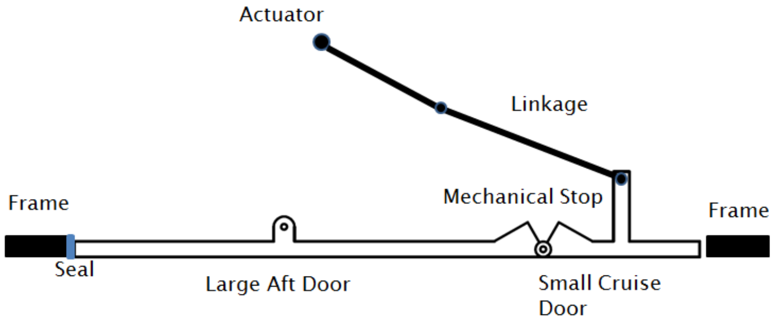
The second design concept consisted of having a single door mounted to the valve frame on a centered hinge. An aerodynamic flap would be hinged to the door with the purpose of remaining flush with the aircraft body to reduce drag during cruise operating conditions. During ascent and descent, where a greater effective area is required, the door would open to nearly 90 degrees. The aerodynamic flap would become flush with the door via a tension spring connected between the door and the flap. This arrangement would decrease the amount of torque to operate the valve due to the center-mounted hinge. The major drawback of this concept was the complexity of design, and possibly introduction of fluttering effects from the aerodynamic flap. A depiction of this concept is shown below in Figure 4.

The third and final concept considered was the idea of using a smaller, end-mounted door attached to a larger, center-mounted door. The logic behind the final concept was to allow for a decrease in actuation torque required at the maximum pressure differential experienced during cruise altitudes. A sketch of this concept is included below in Figure 4, and the rest of this document will expand upon this concept.



Concept 1

Concept 2



Concept 3

Figure 5: Valve Concepts (1, 2, 3)

3.2 Preferred Concept

TRV with Cruise Door (Concept 3)

The cruise door design outweighed the other two designs because it minimized drag forces and the optimized the required torque for operating the valve during flight. The cruise door TRV is configured to minimize drag by keeping the aft door flush with the aircraft body during cruise altitudes and releases pressure when the small cruise door is engaged.

At low altitudes, during takeoff and decent, the required effective area for the valve is much larger, and therefore the cruise and aft doors will be actuated. At cruise altitudes, the required effective area is much smaller, therefore only the cruise door will be actuated. The greatest vector of thrust component is also obtained when only the cruise door is actuated. The idea behind this design is to satisfy the effective area requirements while also satisfying the maximum actuator torque requirement.

At high altitudes, the static pressure differential may reach up to 10 psi from aircraft to ambient. The smaller nature of the cruise door will allow it to be actuated with a modest torque input. At lower altitudes, where the pressure differential is significantly smaller, the larger aft door may then be actuated with similar torque input.

This concept was designed so that the aft door would remain shut during cruise door operation, and the mechanical stops will be fully engaged during aft door operation. This idea was put to the test in our testing analysis described later in the document. In theory, this design will minimize the drag component introduced at cruise altitudes, optimize the thrust component during cruise altitudes, satisfy requirements for maximum actuation torque and required effective area, and most of all, require fewer components than the previous design and have an overall simplified scheme.

Analysis on risk, cost, and practicality versus the current two-door valve design were contributing factors in determining the preferred concept. In general, the preferred concept will reduce the amount of mechanical components required to operate the valve. As a result, this will make it more reliable and lighter. Fewer components will lead to a reduction in materials which yields a reduction in manufacturing costs.

4. Top-Level Design of Final Design Concept

4.1 Terminology

- Cruise Door – Small, front door hinged to the aft door and actuated during flight with a mechanical stop at the rear edge
- Aft Door – Large, back door hinged to the frame used only during ascent and descent with a mirroring mechanical stop on the front edge to match with the cruise door
- Crank Link – Link controlled by actuator
- Follower Link – Link fastened to the interior of the cruise door
- Coupler Link – Link connecting the crank link to the follower link
- Closing Torque – Torque caused by pressure differential forcing doors closed
- Actuator Torque – Torque required by actuator to open or close the valve
- Effective Area – Area needed for required mass flow rate through valve

4.2 Design Overview

The design consists of a 2” x 8” cruise door, 7” x 8” aft door hinged to the frame, 2.75” crank link, 2” follower link, and a 4.25” coupler link. The cruise door and aft door are hinged together using a piano hinge, but the cruise door will open independently from the aft door from 0° to 57°. At 57°, the mechanical stops on each door will engage to activate the motion of the aft door. The closing torque for the duration of the flight is greater on the aft door than on the cruise door which ensures the aft door will remain closed during cruise door operation. The crank link will rotate from 41° to 148° without causing buckling between the coupler link and the follower link. In order to prevent leakage, the doors will be sealed on top of the piano hinge and held in tight tolerance between the edges of the doors and the frame.

4.3 Analysis

4.3.1 Torque

- The lengths of the doors were chosen based on the closing torques.
- The total actuator torque cannot exceed 200 in-lbs.
- Hinge location on aft door must be chosen so that the closing torque on the aft door is larger than the cruise door at all possible positions.
- Figure 1 was plotted using values obtained from the Excel files provided by Honeywell.
- Figures 2, 3, and 4 are excerpts from the Excel files from Honeywell.

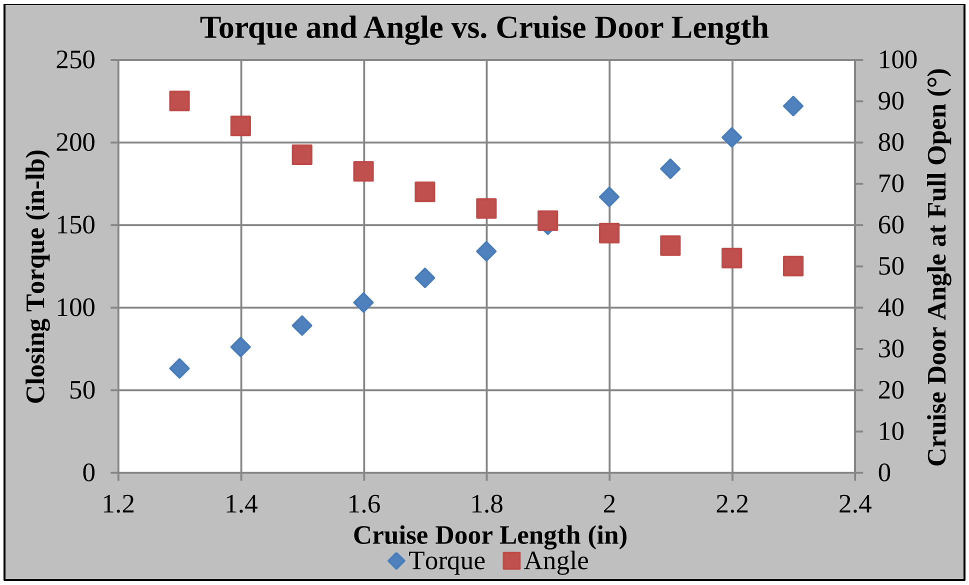


Figure 6: Closing Torque on Cruise Door
(Honeywell: single_door_torque_calculations_1.xls)

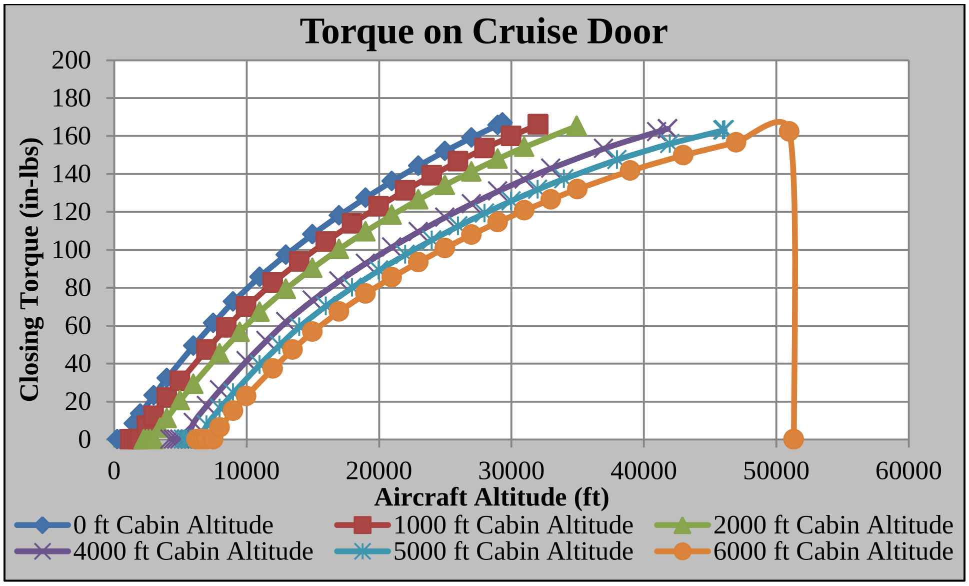


Figure 7: Closing Torque on Cruise Door
(Honeywell: single_door_torque_calculations_1.xls)

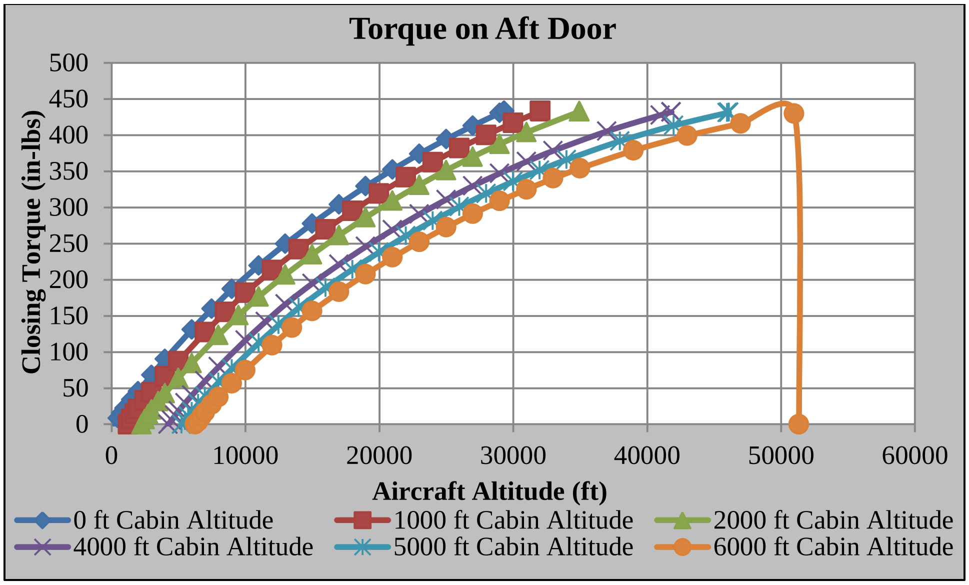


Figure 8: Closing Torque on Aft Door
(Honeywell: single_door_torque_calculations_1.xls)

4.3.2 Operating Conditions

- The lengths of the doors were also designed to achieve the required effective area during flight.
- The maximum opening angle of the cruise door before it engages the aft door with the mechanical stops was designed in accordance with the necessary effective area.

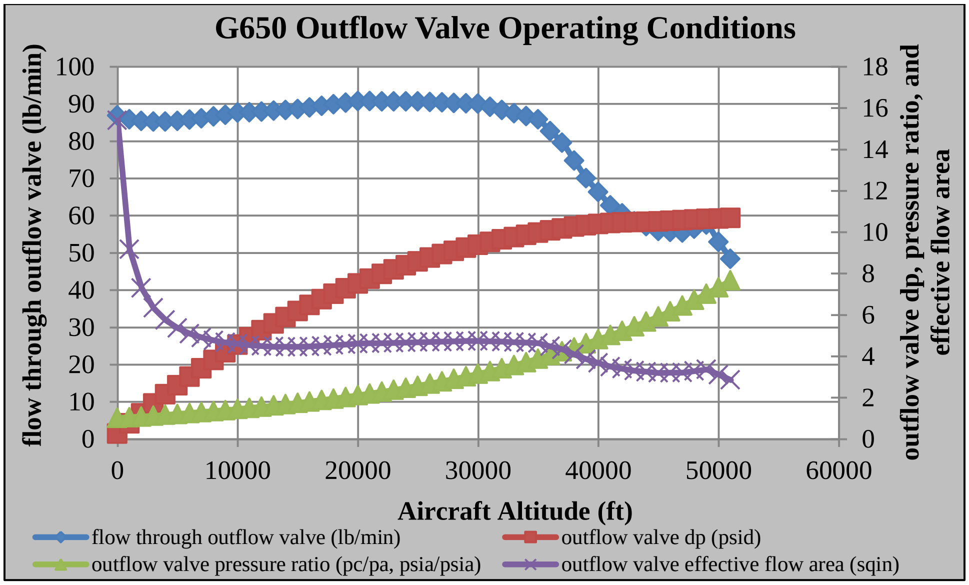


Figure 9: TRV Operating Conditions
(Honeywell: outflow_valve_operating_conditions.xls)

4.3.3 Buckling

- The lengths of the links are designed to give the doors a full range of motion to satisfy the effective area requirement.
- The coupler link and follower link do not buckle during actuation meaning the angle θ between the two links is never greater than 180°.
- SolidWorks was used to simulate these situations.

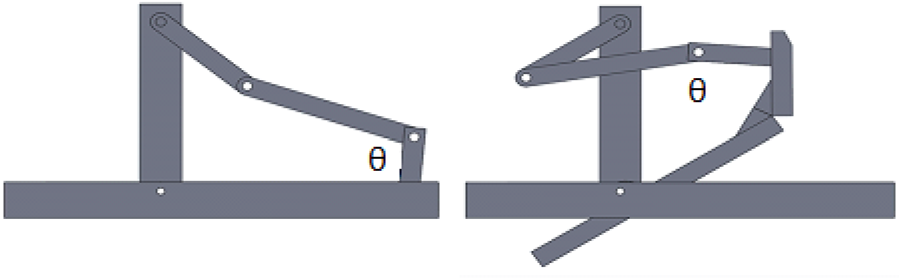


Figure 10: Link Position at Fully Closed Position (Left) and Fully Opened Position (Right)

4.3.4 Actuator Torque

- The actuator torque cannot exceed 200 in-lbs.
- The maximum actuator torque was determined using the closing torque on the cruise door at the fully closed position.
- Using the free-body diagrams in Figure 6, the mechanical advantage is determined and the actuator torque is calculated using MATLAB (See Appendix C.

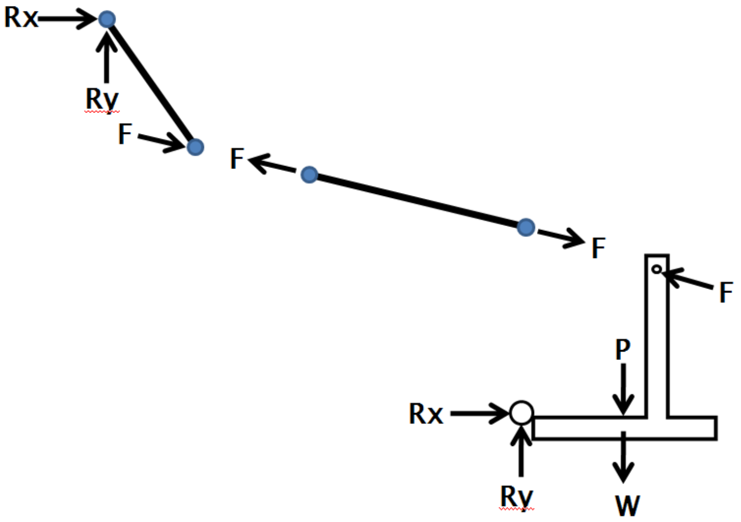


Figure 11: Free-Body Diagrams of Crank Link, Coupler Link, and Cruise Door with Follower Link

4.3.5 – Stress Analysis

- Maximum stress concentration is located at hinge that connects valve to frame.
    - Maximum stress is when the valve is fully closed and the pressure differential is the greatest.
    - Maximum stress is approximately 451 psi, located 2.75” from the end of the aft door.
    - Maximum deflection is 0.000353”, which is easily considered negligible.
    - Analysis was conducted using ANSYS.

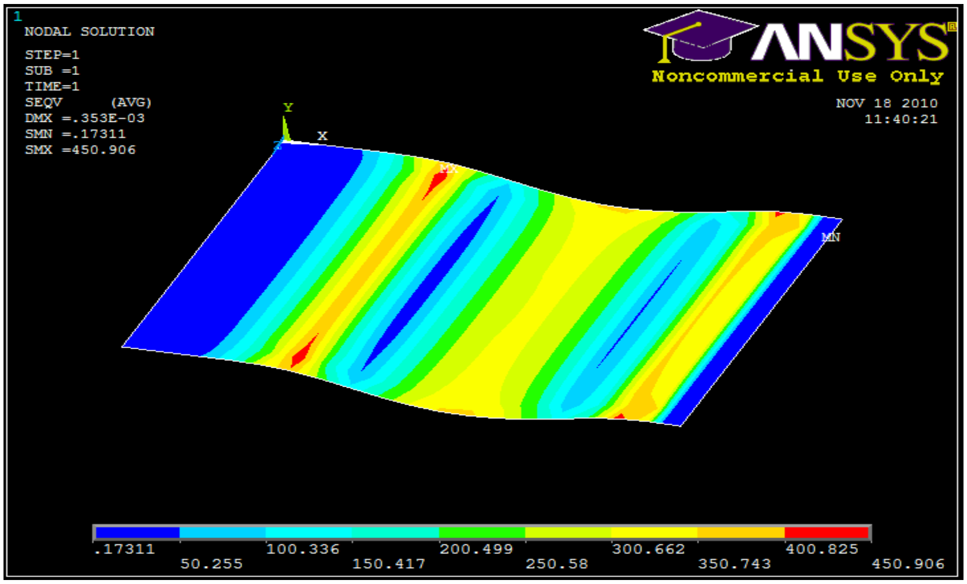


Figure 12: ANSYS Model of TRV Doors

4.3.6 Material Selection

- Material selected based on stress analysis was 6061-O Aluminum.
- Cheap and easy to machine material.
- Yield stress for 6061-O is 8000 psi.
- Factor of safety is about 17.

4.3.7 Sealing

- Flow must only be regulated through the front of cruise door.
- Tight tolerances between the edges of the doors and the frame will minimize leakage around the doors.
- A 1” x 8” piece of rubber will be fixed to the top of the piano hinge. As the cruise door is engaged the rubber will stretch with the door.

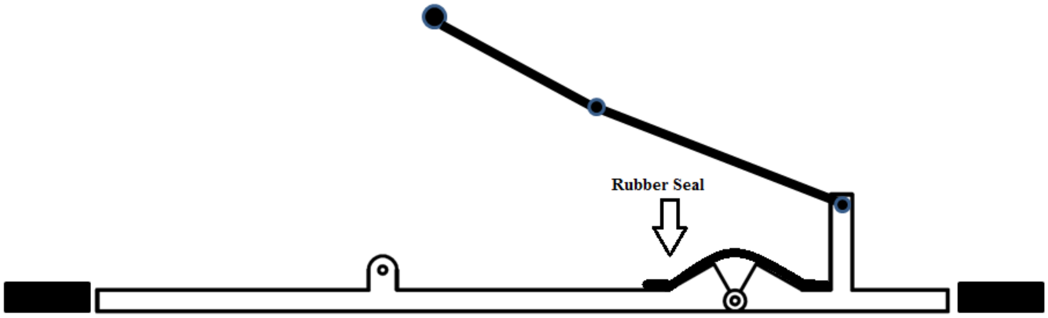


Figure 13: Depiction of Rubber Seal at Fully Closed State

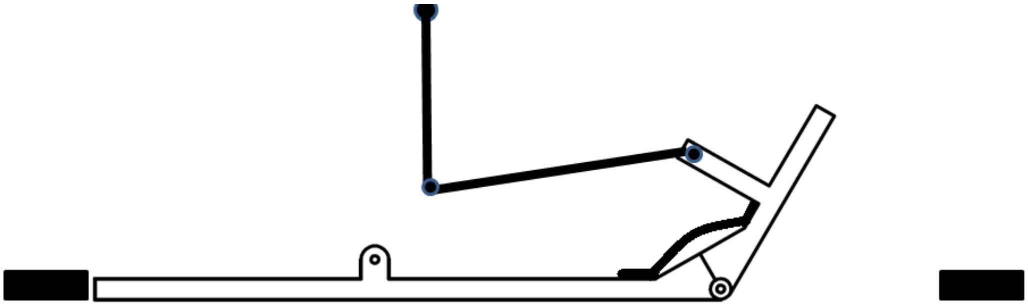


Figure 14: Rubber Seal at Fully Engaged

5. Subsystem/Sub-assembly

The whole TRV system comprised of four subsystems:

- Frame Subsystem
- Cruise Door Subsystem
- Aft Door Subsystem
- Linkage Subsystem

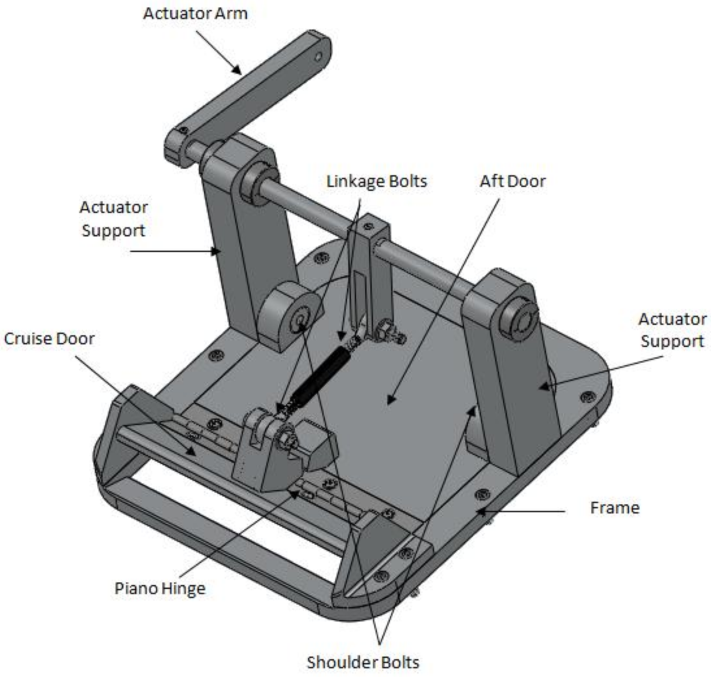


Figure 15: TRV Assembly Diagram

5.1 Frame Subsystem

The frame is the foundation of TRV assembly and was professionally milled from a solid 2” x 12” x 12” block 6061-O1 aluminum. The base is a flat, 0.5” thick piece of aluminum. The auxiliary actuator supports were fixated from the bottom using a 0.75” tap screw. Bearings were excluded due to small number of opening and closing cycles experienced by the TRV prototype. The bearings were replaced with shoulder bolts; therefore, the frame subsystem has milled holes that are coincident with the surface of the shoulder on the shoulder bolts. The frame has five 0.75” tap screws that fixate the frame to the test bench attachment, which is necessary for analysis. The frame is designed to minimize weight and cost while maximizing structural strength. Figure 15 displays the schematic of the frame subsystem. The following components make up the frame subsystem:

- Frame Base
- Frame Mount (2)

- Shaft Collar (3)
- Actuator Shaft
- Actuator Arm
- Tap Screw 1.25” (4)
- Tap Screw 0.75” (5)
- Set Screw 0.25”

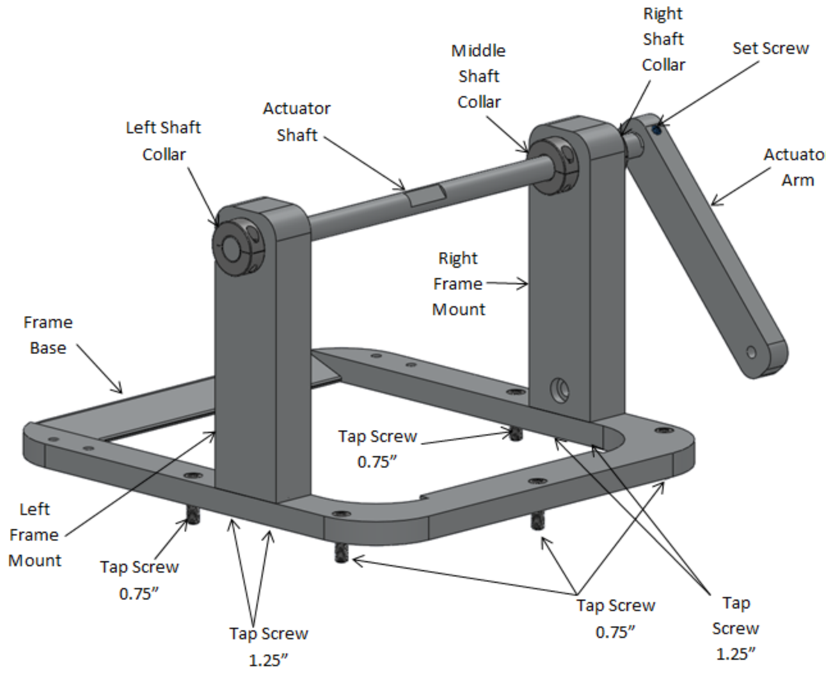


Figure 16: Frame Subsystem.

5.2 Cruise Door Subsystems

The cruise door subsystem is the main assembly that moves when the plane has reached cruising altitude. Slight changes in position due to the actuator cause the small cruise door to release the desired air flow in conjunction with readings from pressure sensors. A piano hinge, which spans across the whole width of the cruise door, connects the aft door to the cruise door. A rubber sealant was placed on the top of the piano hinge to reduce unwanted leakage. The follower link acts as a mechanical stop, and is engaged when the cruise door has reached a 58^o angle with the frame. At this angle, the cross sectional area of the cruise door is not sufficient to provide the necessary mass flow; therefore, the aft door needs to open. The cruise door subsystem is comprised of the following elements and is depicted in figure 16.

- Cruise Door
- Piano Hinge
- Follower Link
- Cruise Door Guard (2)
- 0.75” Tap Screw (6)

- 1.25” Tap Screw (2)
- 0.375” Cap Screw (8)
- 0.375” Washer

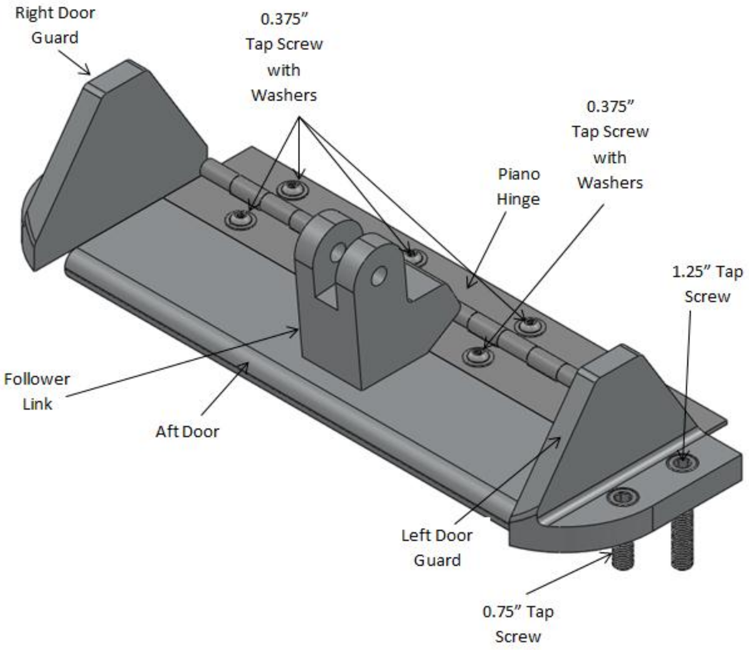


Figure 17: Cruise Door Subsystem

5.2 Aft Door Subsystems

The primary purpose of the aft door subsystem is to increase available cross sectional area to allow desired air flow, which is necessary when the airplane is in ascent or decent. The aft door is joined to the frame with two shoulder bolts. The shoulder bolts allow the aft door to rotate, while remaining attached to the frame. The aft and cruise doors are united with a piano hinge that spans across the whole width of the doors. The dynamic system and the components of the linkage system are depicted in greater detail below. The aft door subsystem is comprised of the following elements and is illustrated in figure 17.

- Aft Door
- Aft Door Hinge (2)
- Shoulder Bolt (2)
- Aft Door Stop
- 0.75” Tap Screw (6)

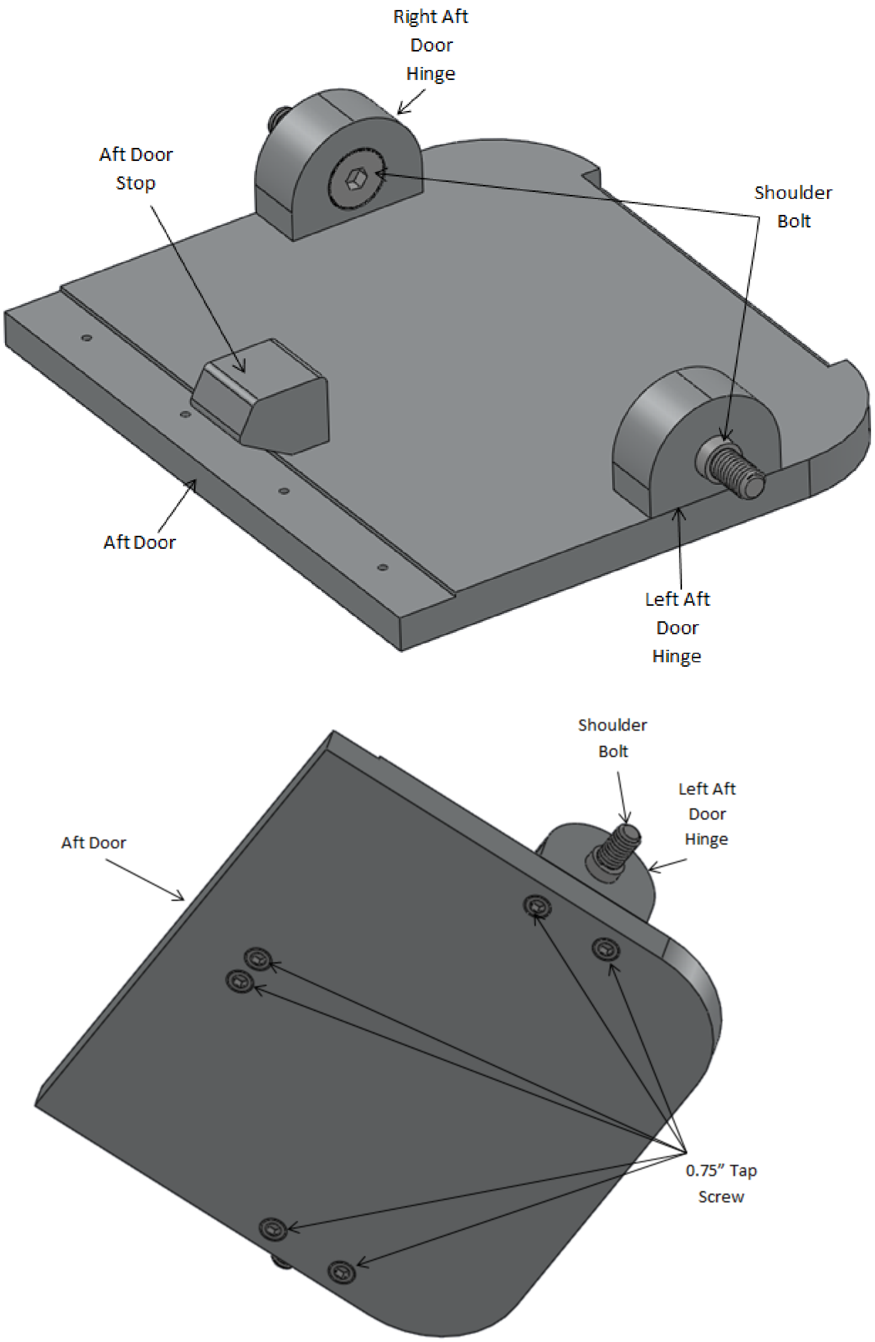


Figure 18: Aft Door Subsystem

5.3 Linkage Subsystem

The linkage subsystem is responsible for connecting the actuator to the valve doors and opening and closing the doors during flight. This is system is fairly simply, and consists of two links. The hex rod link is adjustable; therefore, different lengths can be achieved until an optimal length is found. The linkage subsystem consists of the following parts:

- Crank Link
- Rod End (2)
- Hex Rod
- Linkage Bolt (2)
- Linkage Nut (2)
- Linkage Washer (4)
- Set Screw

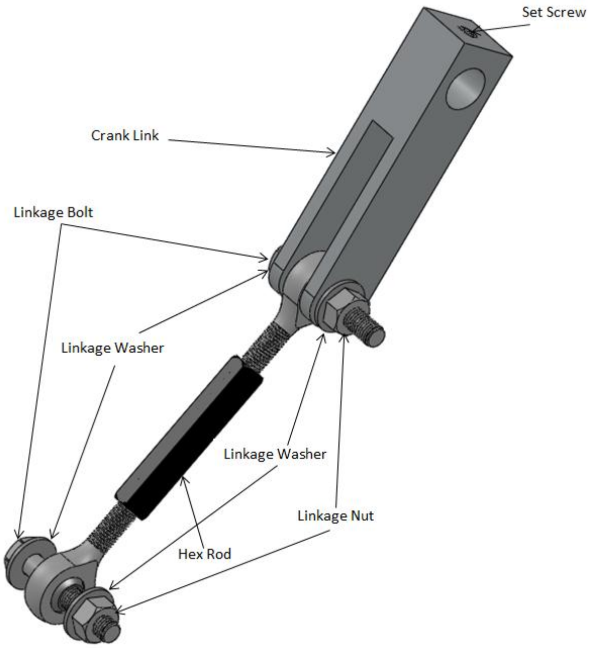


Figure 19: Linkage Subsystem

5.4 Rod End

Part Number: 8405K111 is the thrust-rated ball joint rod ends made of hardened steel with zinc plating. The polyurethane injection molded race material provides a maximum ball swivel of 36° at a thrust load capacity of 662 lbs. Rod end$_1$ will house linkage bolt$_1$ to the actuator shaft mount and locked by linkage nut$_1$. Threaded hex rod$_1$ will unite rod end$_{1\rightarrow 2}$. Safety lock wire will be utilized to bind linkage locking nuts$_{2,\ 3}$ to the threaded hex rod$_1$ to prevent loosening and failure during test simulations. Rod end$_2$ will house linkage bolt$_2$ between the mount on the cruise door and will be locked using linkage nut$_4$.

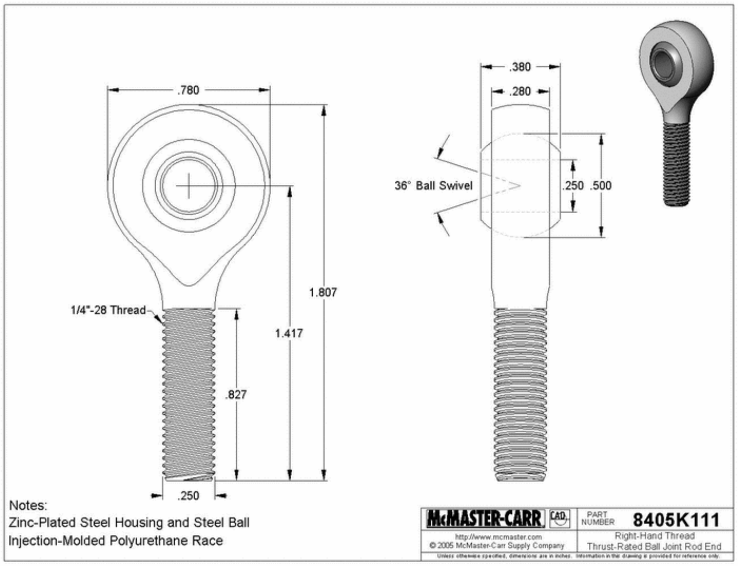


Figure 20: Rod End

5.5 Threaded Hex Rod

Part Number: 8419K25 is a female-threaded hex rod constructed of 6061-T6 high-strength aluminum. Threaded hex rod$_1$ will unite rod end$_{1\rightarrow 2}$. Safety lock wire will be strung through drill holes in threaded hex rod$_1$ and attached with a cap to linkage locking nuts$_{2, 3}$. The safety wire aims to prevent rotation due to axial torque, which may lead to failure during test simulations.

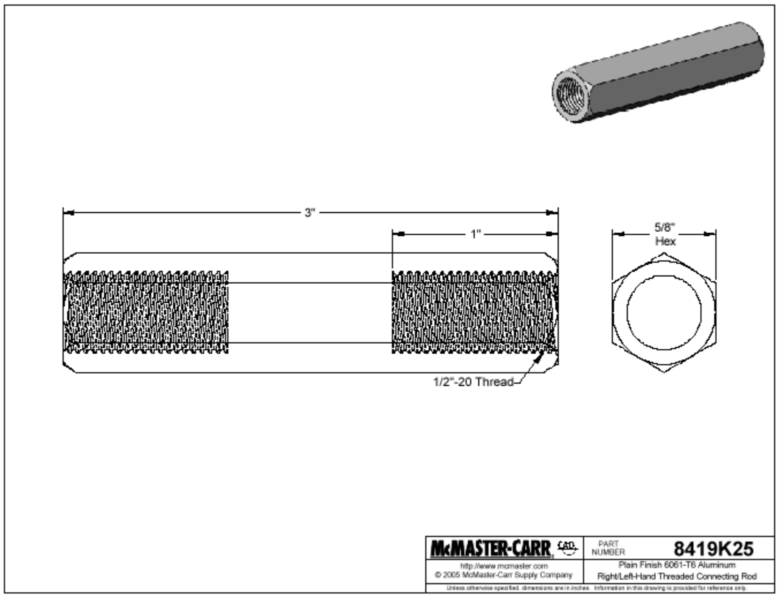


Figure 21: Threaded Hex Rod

5.6 Shoulder Bolts

Part Number: 91259A709 is a plain steel, shoulder screw. The portion of the screw that does not contain threads is called the shoulder. The shoulder length is 0.625” The cap of the screw is 0.3125” inches, and has a 0.25” hex head. The shear strength of the screw is rated at 84,000 psi, and the minimum tensile strength of the screw is 140,000 psi. Due to these relative high strengths, this particular shoulder screw was chosen in the design. As aforementioned, this screw fixates the large aft door to the frame. The shoulder screw threads into the aft door, while the frame stays in contact with the smooth, shoulder portion of the screw.

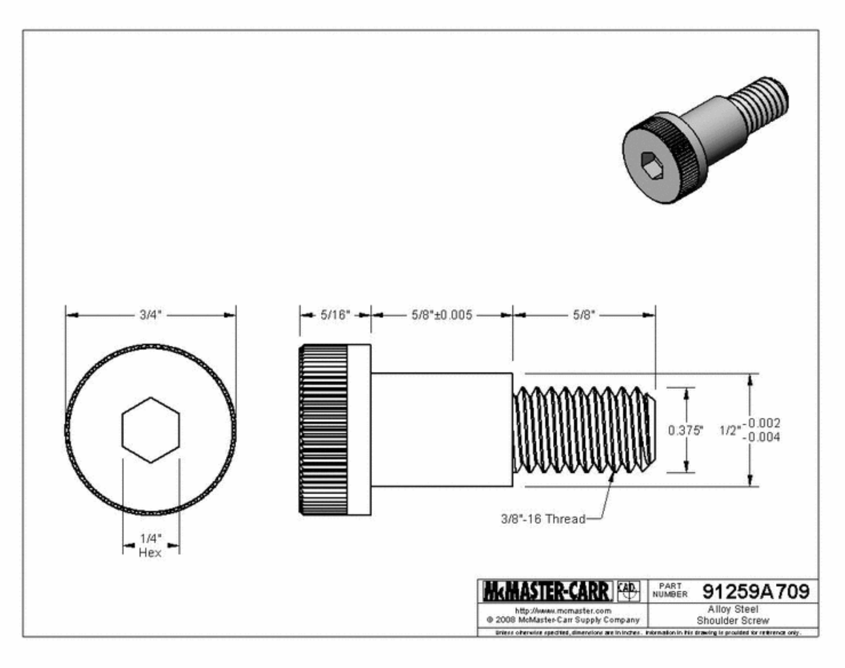


Figure 22: Frame Shoulder Bolts

5.7 Linkage Bolts

Part Number: 92186A321 is a standard hex bolt made of 316 Stainless Steel. Two 316 stainless steel, linkage bolts$_{1, 2}$ will be used to attach the actuator shaft to rod end$_{1}$ and rod end$_{2}$ to a mount on the cruise door. The frame bolt is larger in diameter that is designed to handle the greater lateral forces applied to the aft door during testing.

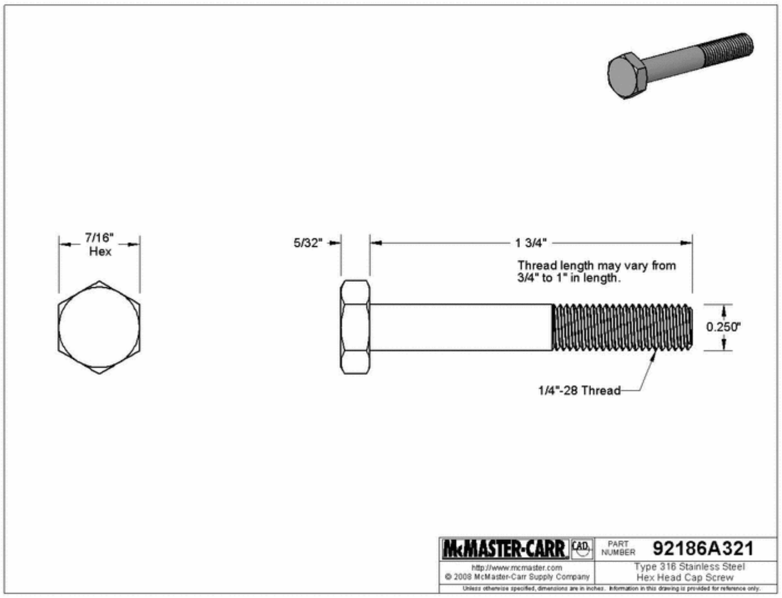


Figure 23: Linkage Bolt

5.8 Linkage Washers

Part Number: 98019A390 is a round hole washer made of 300 stainless steel. Four linkage washers will be used to distribute the force applied from the linkage bolt to the actuator shaft mount and rod end$_1$ from linkage nut$_1$. Similarly, washers will be placed between linkage nut$_1$ to rod end$_2$ and between the mount on the cruise door and linkage bolt$_2$. The frame washer correspond with the frame bolts and have a larger diameter to better distribute the greater forces applied to the aft door during testing.

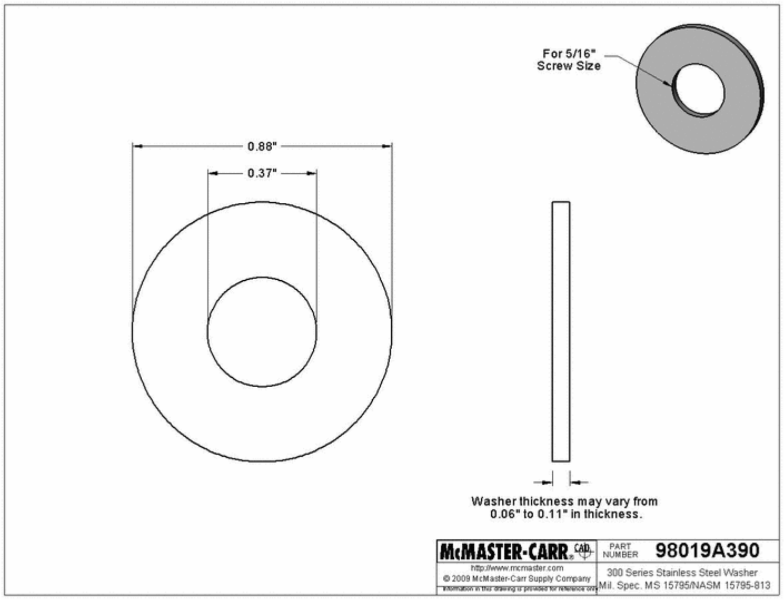


Figure 24: Linkage Washer

5.9 Linkage Nuts

Part Number: 91853A515 is a18-8 stainless steel slotted hex nut style B, 1/4"-28 thread size, 7/16" width, 9/32" overall height. The linkage nuts will be threaded with nylon tape or non-solidifying Loctite to ensure a tight, non-permanent fit.

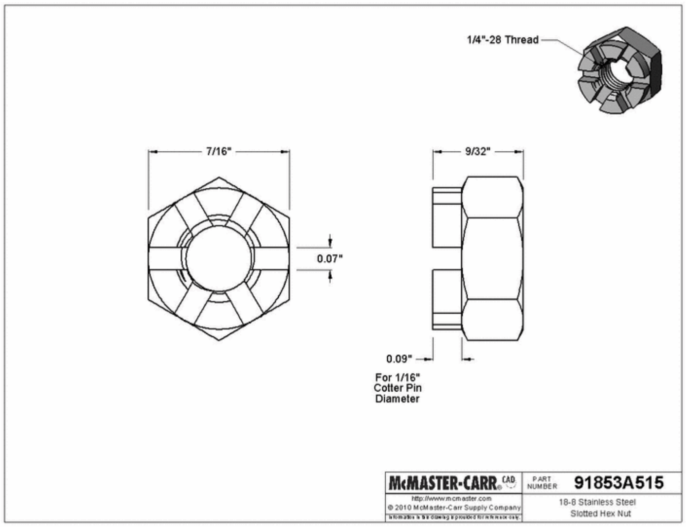


Figure 25: Linkage Nuts

5.10 Piano Hinge

Part Number: 1569A235 is a piano hinge, which was implemented in the design to connect the aft and the cruise doors. The plain steel hinge was carefully chosen to allow smooth operation, without the need of a constant lubricant. This hinge mechanism was chosen because it prevented buckling of the doors outwards away from the cabin of the airplane.

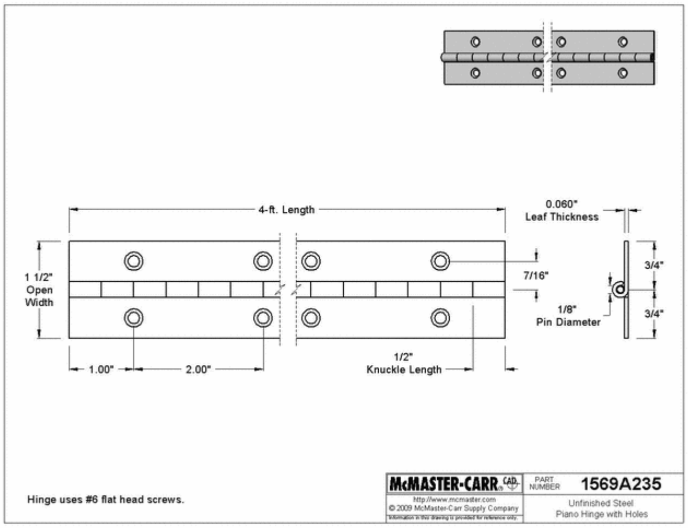


Figure 26: Piano Hinge

5.11 Tap Screw (0.75”)

Part Number: 90128A365 was a 0.75” tap screw that was used to fasten the aft door to the aft door hinges, the aft door to the aft door stop, the cruise door to the follower link, the cruise door guards to the frame, and the frame to the test bench assembly. This screw was employed due to its high tensile strength of 180,000 psi. It is a 0.1875” hex head screw of 0.75” length, which is fabricated from steel, and is zinc plated for increased strength. The total quantity used in the TRV was 17 due to its versatility between strength and size.

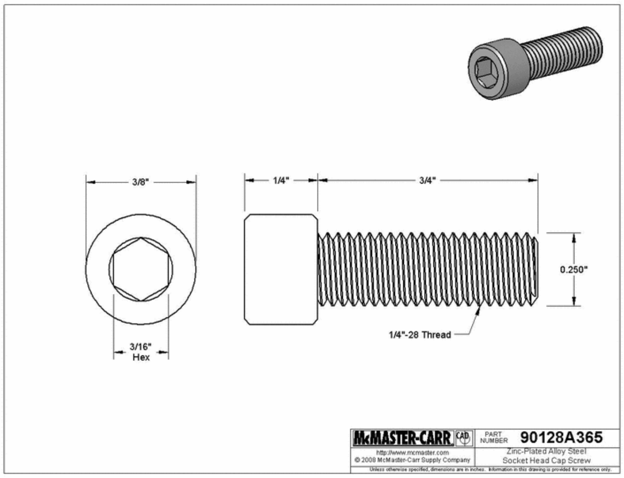


Figure 27: Tap Screw (0.75”)

5.12 Tap Screw (1.25”)

Part Number: 90128A376 was a 1.25” tap screw that was used to fixate the cruise door guards to the frame and the frame mounts to the frame. The material properties are identical to the 0.75” tap screw. The only difference is the length of the screw. A total of six 1.25” tap screws were used.

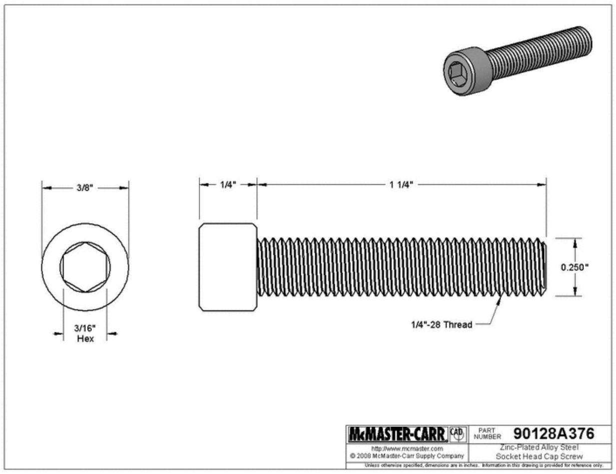


Figure 28: Tap Screw (1.25”)

5.13 Cap Screw (0.375”)

Part Number: 91306A322 was a zinc platted, hex head screw. This screw was used to attach the piano hinge to the aft and cruise doors. Due to the relative shortness (0.375”) and high tensile strength of 144,000 psi, this screw was an ideal candidate for fastening the piano hinge to the valve doors. It did not penetrating too deep into the valve doors; therefore, material strength was not sacrificed. A total of eight cap screws were used; four screwed into the aft door and four screwed into the cruise door.

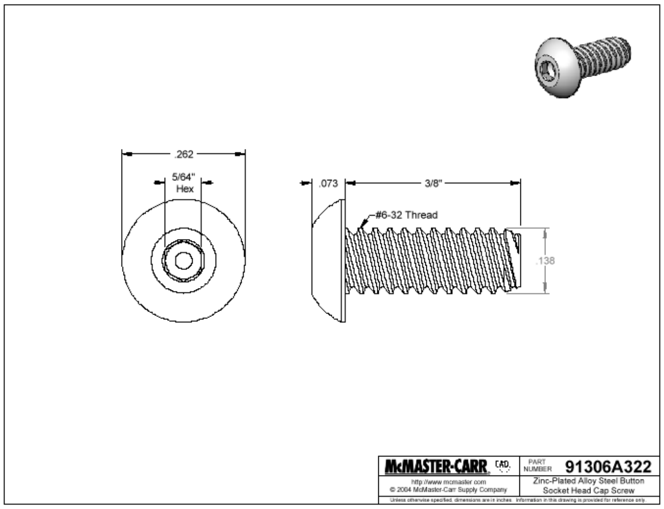


Figure 29: Cap Screw 0.375”

5.14 Set Screw (0.3125”)

Part Number: 91375A557 was asset screw used to fixate the actuator arm to the actuator shaft and also used to fasten the crank link to the actuator arm. A total of two screws were implemented in the prototype.

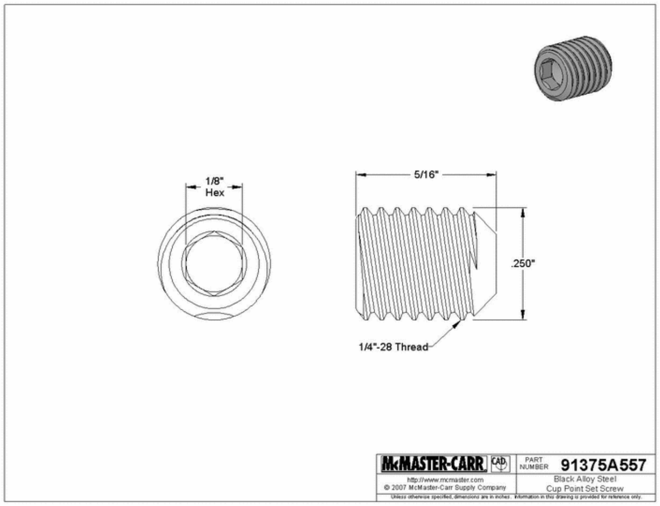


Figure 30: Set Screw (0.3125”)

5.14 Additional Parts

The drawings and descriptions of the parts not available at McMaster Carr are included in the appendix.

6. Design Analysis of Model

The overall system performance was analyzed using the Excel files provided by Honeywell to evaluate the outflow valve operating conditions. The numerical analysis consisted of finding closing torques and effective areas based on lengths of doors. These were then matched to the requirements. Once these values were found to be satisfactory, the parts were designed and put together using SolidWorks. The assembly was then tested using the physical dynamics feature of SolidWorks which detects collisions to animate the range of motion of the doors. This ensured that the linkage and mechanical stops operated correctly. All analysis was done to ensure all requirements were meant and the design would function as desired.

7. Development Plan

The new design for the TRV progressed through distinct steps. The build timeline, introduced in the CDR report, is outlined below with details in each section pertaining to the completion of each milestone.

7.1 Honeywell's Current TRV

The currently implemented two-door design TRV was provided for us at the first meeting with our sponsor. This was used to introduce the team to the valve concept, as well as serve as a reference for our own designs. The actuator was also included with the valve so we could gain a spatial understanding of the final product, since including an actuator mechanism was not in the scope of our project.

7.2 Three Different TRV Designs

At PDR, the team had designed three different concepts for the new TRV. These were mostly detailed by hand, and roughly sketched in AutoCAD. The concepts included the *end hinge* design, *aerodynamic flap* design, and *cruise door* design.

7.3 Detailed Sketch for Chosen Design

The cruise door design was chosen at PDR. The overall function was decided, but exact dimensions were not fully calculated. The cruise door design was to be optimized according to each of the requirement categories. As mentioned, an Excel spreadsheet was used to determine proper cruise door/aft door dimensions. MATLAB in combination with a rough SolidWorks model was used to design the linkage and pseudo-actuator mechanism.

7.4 SolidWorks Assembly

Once final dimensions of the design were decided, a detailed SolidWorks model was created as the final stepping stone for the CDR. Each subsystem was created as an individual part, including all fasteners and shoulder bolts. These parts were compiled in a SolidWorks assembly, and a fully functional physical environment was implemented using the Physical Dynamics and mating functions of the SolidWorks utility. An supplementary animation showing the action of this SolidWorks model is included with this report.

7.5 Preliminary Prototype

A preliminary prototype made using wood was outlined in the CDR report. The team chose not to follow through with this wood prototype. Instead, professional modeling board was donated to all of the Senior Capstone Design teams by Raytheon. The team used the modeling board to practice with the CNC machines in the AME machine shop. The doors and test bench attachment were cut out using the CNC machines. However, a fully functional model of the prototype would not be feasible using this modeling board. It did not have the structural integrity to machine the meticulous details associated with our design.

Final Prototype

The final prototype is the finished product of the design team. It is comprised of CNC machined aluminum for each subsystem, with exception of one of the linkage parts and all of the fasteners. A piano hinge was implemented in place of the previously designed hinge system that deemed the design impossible to accurately CNC. Many of the parts with close tolerance were professionally machined by Industrial Tool, Die, and Engineering. The final prototype was fully operational upon completion. The functionality of each of the subsystems worked together within the tolerances specified. Details for each subsystem, including photographs of the final prototype are included in Appendix A.

8. Budgets and Suppliers

8.1 Budget

A budget of $3,000 was assigned to this project. Costs were minimized in attempt to fall under budget but did not exceed the $3,000 limit.

8.2 Outsource Contracting

Our budget allowed for the outsourcing of labor for machining our system components. The group consulted with a professional engineering firm in Tucson, AZ that delivered a full assembly of our prototype valve. The company provided all the materials required for producing each subsystem.

Contractor	Contact Information	Lead times (Weeks)	Price
Industrial Tool Die & Engineering	(520)745-8771 4765 S Overland Drive Tucson, AZ	4-5	$1,900

Table 2: ITD&E Contractor Information

8.3 Bill of Materials

Table 3 is an outline of the materials that were purchased to test the prototype valve. An aluminum block was purchased for machining the test bench attachment mount that was bolted onto the valve. Miscellaneous supplies were purchased at Ace Hardware. The piano hinge was used to link the two doors together and an inclinometer was purchased to allow the team to determine the flow of air at different angles during testing.

Part	Part Number	Quantity	Vendor	Price/Unit	Total
Aluminum Block (12” x 12” x 2.5”)	9246K24	1	McMaster-Carr	$197.76	$197.76
Steel Piano Hinge	1569A235	1	McMaster-Carr	$5.88	$5.88
Inclinometer	3353A77	1	McMaster-Carr	$45.76	$45.76
Miscellaneous Supplies	-	-	Ace Hardware	$16.00	$16.00
Shipping					$30.00
				TOTAL	**$295.40**

Table 3: Bill of Materials

8.4 Suppliers

Supplier	Contact Information	Lead times
McMaster-Carr	(562)692-5911 9630 Norwalk Blvd Santa Fe Springs, CA 90670	1 DAY
Ace Hardware	(520) 882-5700 745 E. 9th St Tucson, AZ 85719	----

Table 4: Suppliers

9. Requirements Review/Acceptance Test Plan

The purpose of the acceptance test plan is to define the testing strategies that were implemented to determine if the prototype met the project requirements. For the scope of this project, comparison testing was conducted to compare baseline figures from the current two-door valve versus the data derived from the new design. This allowed for the quantification of the critical requirements for this project. Our testing strategies consisted of four cases: Manual analysis, Computer analysis, Test Bench analysis and Visual analysis. These four cases are detailed in the following section of this report along with tables demonstrating the specific testing strategy performed per individual requirement.

Detail for Acceptance Test Plan cases:

9.1 Manual Analysis

Manual analysis consisted of traditional hand-written mathematical calculations. These calculations were used to determine the feasibility of the design and to quantify values for the system requirements.

9.1.1 Force Analysis

Force and Stress Calculations

- To determine appropriate material selection
- To determine the required physical dimensions of components
- Will provide a measure of reliability
- Will allow for the measurement of thrust

9.1.2 Dynamic Analysis

Actuation Calculations

- To determine the appropriate linkage configuration
- To determine the required torque input for operation of the valve

9.2 Computer Analysis

Computer analysis was used for the iterative implementation of the manual calculations. Excel spreadsheets were provided by Honeywell as a resource to estimate torque requirements and outflow effective areas for valves under specific pressure differentials. Other programs were used with the assistance of professors from the Department of Aerospace and Mechanical Engineering at the University of Arizona.

9.2.1 MATLAB

- Program for analyzing linkage configurations
- Derivation of actuation torque

9.2.2 Excel

- Verification of torque input for operation of the valve
- Verification of effective area required to release pressure from plane.

9.2.3 ANSYS

- Program to determine stresses, and deflections

9.3 Test Bench Analysis

Test bench analysis was used to determine how the prototype responded during physical simulation. The test bench generated airflow through the valve allowing the valve to be tested in real flight conditions. During testing, a 4000 lb·F car jack was used to engage the linkage for operation of the valve, a force gage was attached to the lever arm that simulated the actuator, and two inclinometers were used to measure the angle of the cruise and aft doors as they opened. These tools allowed us to accurately measure the pressure differentials that were being generated at the effective area of flow. The force gage allowed us to measure the torque that was required to engage the linkage for opening the cruise and aft doors. Measurements of force, air flow, and pressure differential were taken for every two degrees that the cruise and aft doors opened. This allowed us to generate data plots to analyze our test results.

9.3.1 Physical Simulation

- Vacuum testing at Honeywell facility

9.4 Visual Testing

Visual testing was used to validate requirements that did not require modeling. These included minor requirements that were critical for reliability and performance.

9.4.1 Observation

- Checking for fluttering of valve doors during simulation
- Verifying that aft door remained closed until mechanical stop engaged
- Verifying smooth linkage engagement during simulation

9.5 Requirements Review

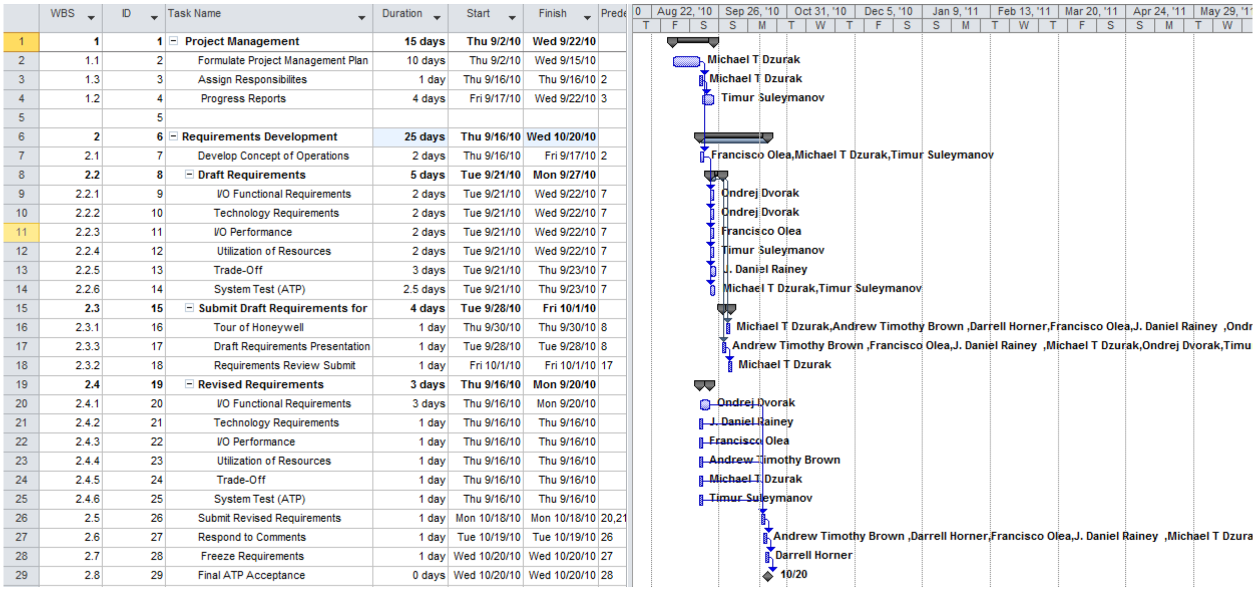
Type	Description	Priority	Tests Performed	Pass?
Functional	The system shall release cabin pressure at variable altitudes	Must	Force analysis, Dynamic analysis, Test bench analysis	**Yes**
Functional	The system shall be loaded closed in case of failure	Must	Force analysis	**Yes**
Functional	The system shall reduce the number of moving parts to increase reliability	Desired	Visual analysis	**Yes**
Functional	The system shall adjust to changing pressures	Desired	Force analysis, Test Bench analysis	**Yes**
Technology	The system shall be manufactured out of aluminum or composite material	Desired	Force analysis	**Yes**
Performance	The device shall optimize the amount of thrust provided to plane	Must	Force analysis, Test Bench analysis	**Yes**
Performance	The system shall have fewer mechanical componenets	Desired	Visual analysis	**Yes**

Table 5: System Requirements Review

10. Project Management Update (Gantt Charts)

The Gantt charts listed below gives a detailed description of the various phases involved in the planning and time dependent execution of the project. The charts are divided into four phases. Phases one and two, which span over the months of August thru December 2010, dealt with project management, design, simulation, and preparation for prototyping. After the submission and approval of the CDR report on 8 December 2010, phases 1 and 2 will be completed. A large portion of phase 3, which occurred from 17 January through 16 March 2011, consisted of consulting with ITDE and waiting from ITDE to machine and assembled the prototype. Pretest diagnosis and Acceptance Test Plans were completed in the time of 16 March to 8 April. 8 April consisted on physical testing and verification of design onsite at Honeywell. The final stages consisted of design compilation, sponsor approval, presentation material construction, design day competition, and finalized project report occurred from 11 April to 4 May 2011. All major time dependent operations had pre-programmed lead times to account for shipping delays, conflict resolutions, and resolving unforeseen issues.

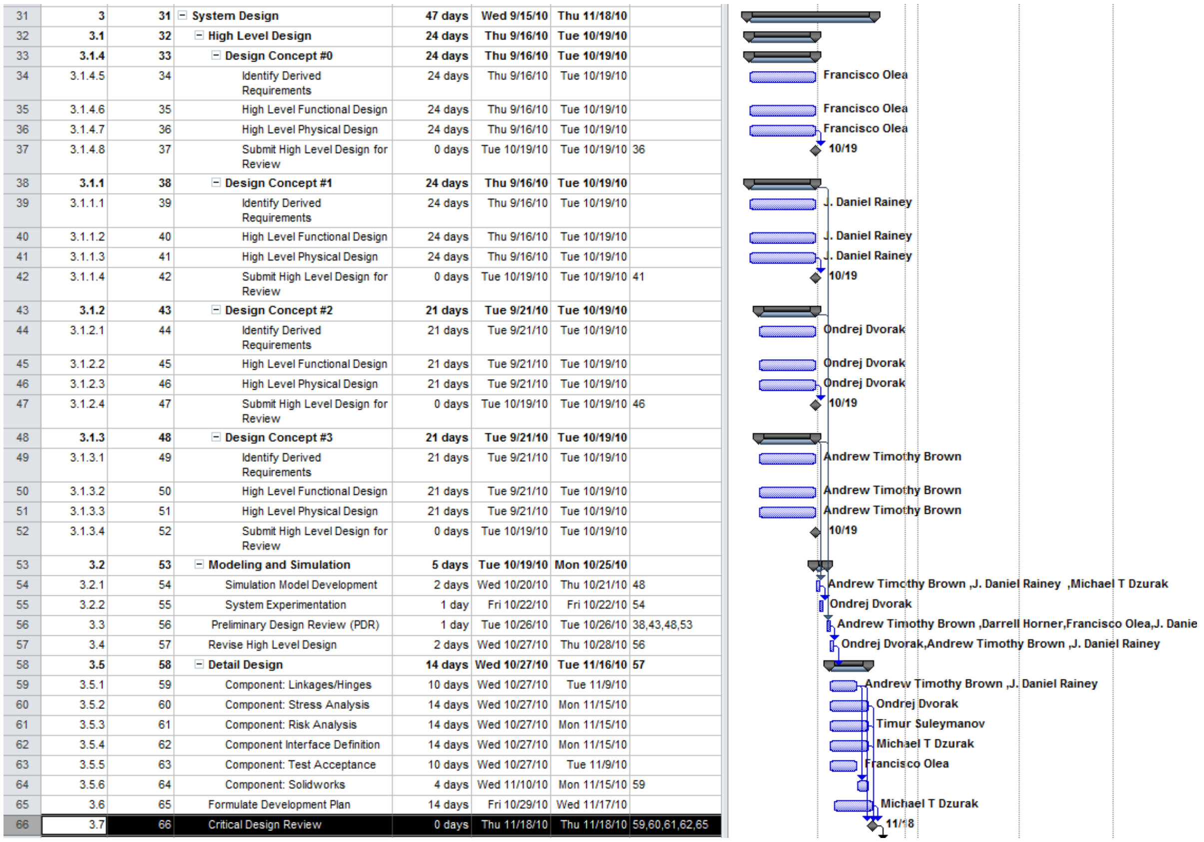
Phase 1 involved project management and requirements development through review, Concept of Operations, and the System Requirements Review presentation. In addition, a tour of Honeywell's facilities, the formulation and drafting of the cruise door concept, and the final acceptance test plan guidelines were proposed to the sponsor, Darrell Horner. Phase 1 was completed on Wednesday 20th November.



	WBS	ID	Task Name	Duration	Start	Finish	Prede
1	**1**	**1**	⊟ **Project Management**	**15 days**	**Thu 9/2/10**	**Wed 9/22/10**	
2	1.1	2	Formulate Project Management Plan	10 days	Thu 9/2/10	Wed 9/15/10	
3	1.3	3	Assign Responsibilites	1 day	Thu 9/16/10	Thu 9/16/10	2
4	1.2	4	Progress Reports	4 days	Fri 9/17/10	Wed 9/22/10	3
5		5					
6	**2**	**6**	⊟ **Requirements Development**	**25 days**	**Thu 9/16/10**	**Wed 10/20/10**	
7	2.1	7	Develop Concept of Operations	2 days	Thu 9/16/10	Fri 9/17/10	2
8	**2.2**	**8**	⊟ **Draft Requirements**	**5 days**	**Tue 9/21/10**	**Mon 9/27/10**	
9	2.2.1	9	I/O Functional Requirements	2 days	Tue 9/21/10	Wed 9/22/10	7
10	2.2.2	10	Technology Requirements	2 days	Tue 9/21/10	Wed 9/22/10	7
11	2.2.3	11	I/O Performance	2 days	Tue 9/21/10	Wed 9/22/10	7
12	2.2.4	12	Utilization of Resources	2 days	Tue 9/21/10	Wed 9/22/10	7
13	2.2.5	13	Trade-Off	3 days	Tue 9/21/10	Thu 9/23/10	7
14	2.2.6	14	System Test (ATP)	2.5 days	Tue 9/21/10	Thu 9/23/10	7
15	**2.3**	**15**	⊟ **Submit Draft Requirements for**	**4 days**	**Tue 9/28/10**	**Fri 10/1/10**	
16	2.3.1	16	Tour of Honeywell	1 day	Thu 9/30/10	Thu 9/30/10	8
17	2.3.3	17	Draft Requirements Presentation	1 day	Tue 9/28/10	Tue 9/28/10	8
18	2.3.2	18	Requirements Review Submit	1 day	Fri 10/1/10	Fri 10/1/10	17
19	**2.4**	**19**	⊟ **Revised Requirements**	**3 days**	**Thu 9/16/10**	**Mon 9/20/10**	
20	2.4.1	20	I/O Functional Requirements	3 days	Thu 9/16/10	Mon 9/20/10	
21	2.4.2	21	Technology Requirements	1 day	Thu 9/16/10	Thu 9/16/10	
22	2.4.3	22	I/O Performance	1 day	Thu 9/16/10	Thu 9/16/10	
23	2.4.4	23	Utilization of Resources	1 day	Thu 9/16/10	Thu 9/16/10	
24	2.4.5	24	Trade-Off	1 day	Thu 9/16/10	Thu 9/16/10	
25	2.4.6	25	System Test (ATP)	1 day	Thu 9/16/10	Thu 9/16/10	
26	2.5	26	Submit Revised Requirements	1 day	Mon 10/18/10	Mon 10/18/10	20,21
27	2.6	27	Respond to Comments	1 day	Tue 10/19/10	Tue 10/19/10	26
28	2.7	28	Freeze Requirements	1 day	Wed 10/20/10	Wed 10/20/10	27
29	2.8	29	Final ATP Acceptance	0 days	Wed 10/20/10	Wed 10/20/10	28

Figure 31: Gantt Chart Phase 1

Phase 2 comprised of system design, design concept$_{0, 1, 2, 3}$, modeling, simulation in SolidWorks and ANSYS, the Critical Design Review (CDR) presentation, and the CDR formal report. The design modeling utilized trade studies to identify useful design features to incorporate into the finalized design. Detailed design consisted of the following components: linkages, hinges, stress analysis, risk analysis, interface definition, acceptance test planning and computer aided drafting. MATLAB calculations, Solidworks drafting, and ANSYS analysis was used to validate the proposed model within the prescribed time limits. Phase 2.3.8 of the CDR presentation was finished on Thursday 18th of November and Phase 2.3.9 was finished on Wednesday 8th December with the submission of the CDR report. The calculated $576.21 dollars of raw materials will be purchased before the end of the semester to ensure timely arrival.



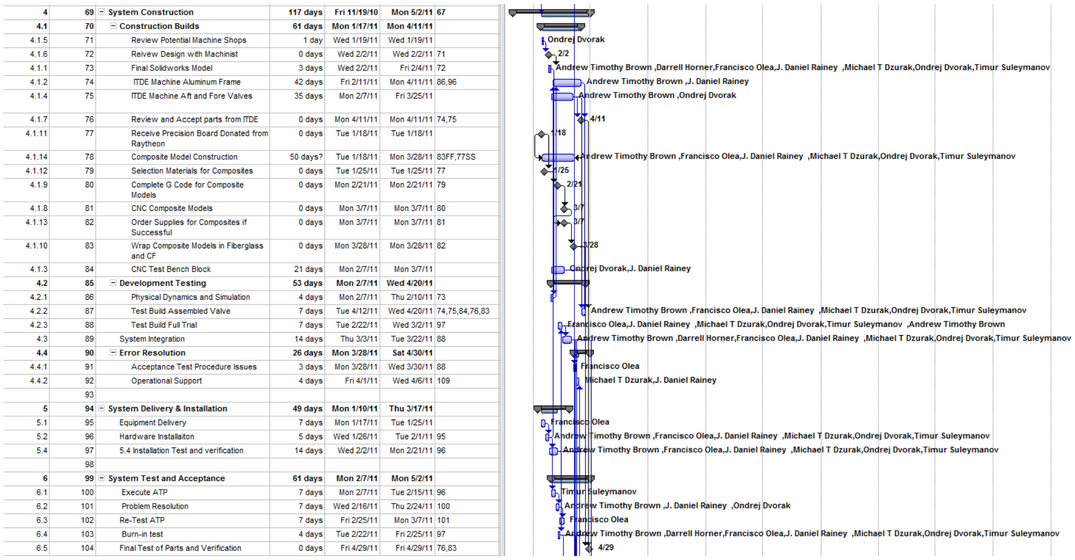
31	**3**	**31**	**System Design**	**47 days**	**Wed 9/15/10**	**Thu 11/18/10**	
32	**3.1**	**32**	**High Level Design**	**24 days**	**Thu 9/16/10**	**Tue 10/19/10**	
33	**3.1.4**	**33**	**Design Concept #0**	**24 days**	**Thu 9/16/10**	**Tue 10/19/10**	
34	3.1.4.5	34	Identify Derived Requirements	24 days	Thu 9/16/10	Tue 10/19/10	
35	3.1.4.6	35	High Level Functional Design	24 days	Thu 9/16/10	Tue 10/19/10	
36	3.1.4.7	36	High Level Physical Design	24 days	Thu 9/16/10	Tue 10/19/10	
37	3.1.4.8	37	Submit High Level Design for Review	0 days	Tue 10/19/10	Tue 10/19/10	36
38	**3.1.1**	**38**	**Design Concept #1**	**24 days**	**Thu 9/16/10**	**Tue 10/19/10**	
39	3.1.1.1	39	Identify Derived Requirements	24 days	Thu 9/16/10	Tue 10/19/10	
40	3.1.1.2	40	High Level Functional Design	24 days	Thu 9/16/10	Tue 10/19/10	
41	3.1.1.3	41	High Level Physical Design	24 days	Thu 9/16/10	Tue 10/19/10	
42	3.1.1.4	42	Submit High Level Design for Review	0 days	Tue 10/19/10	Tue 10/19/10	41
43	**3.1.2**	**43**	**Design Concept #2**	**21 days**	**Tue 9/21/10**	**Tue 10/19/10**	
44	3.1.2.1	44	Identify Derived Requirements	21 days	Tue 9/21/10	Tue 10/19/10	
45	3.1.2.2	45	High Level Functional Design	21 days	Tue 9/21/10	Tue 10/19/10	
46	3.1.2.3	46	High Level Physical Design	21 days	Tue 9/21/10	Tue 10/19/10	
47	3.1.2.4	47	Submit High Level Design for Review	0 days	Tue 10/19/10	Tue 10/19/10	46
48	**3.1.3**	**48**	**Design Concept #3**	**21 days**	**Tue 9/21/10**	**Tue 10/19/10**	
49	3.1.3.1	49	Identify Derived Requirements	21 days	Tue 9/21/10	Tue 10/19/10	
50	3.1.3.2	50	High Level Functional Design	21 days	Tue 9/21/10	Tue 10/19/10	
51	3.1.3.3	51	High Level Physical Design	21 days	Tue 9/21/10	Tue 10/19/10	
52	3.1.3.4	52	Submit High Level Design for Review	0 days	Tue 10/19/10	Tue 10/19/10	
53	**3.2**	**53**	**Modeling and Simulation**	**5 days**	**Tue 10/19/10**	**Mon 10/25/10**	
54	3.2.1	54	Simulation Model Development	2 days	Wed 10/20/10	Thu 10/21/10	48
55	3.2.2	55	System Experimentation	1 day	Fri 10/22/10	Fri 10/22/10	54
56	3.3	56	Preliminary Design Review (PDR)	1 day	Tue 10/26/10	Tue 10/26/10	38,43,48,53
57	3.4	57	Revise High Level Design	2 days	Wed 10/27/10	Thu 10/28/10	56
58	**3.5**	**58**	**Detail Design**	**14 days**	**Wed 10/27/10**	**Tue 11/16/10**	**57**
59	3.5.1	59	Component: Linkages/Hinges	10 days	Wed 10/27/10	Tue 11/9/10	
60	3.5.2	60	Component: Stress Analysis	14 days	Wed 10/27/10	Mon 11/15/10	
61	3.5.3	61	Component: Risk Analysis	14 days	Wed 10/27/10	Mon 11/15/10	
62	3.5.4	62	Component Interface Definition	14 days	Wed 10/27/10	Mon 11/15/10	
63	3.5.5	63	Component: Test Acceptance	10 days	Wed 10/27/10	Tue 11/9/10	
64	3.5.6	64	Component: Solidworks	4 days	Wed 11/10/10	Mon 11/15/10	59
65	3.6	65	Formulate Development Plan	14 days	Fri 10/29/10	Wed 11/17/10	
66	3.7	66	Critical Design Review	0 days	Thu 11/18/10	Thu 11/18/10	59,60,61,62,65

Figure 32: Gantt Chart Phase 2

Phase 3 entailed the prototyping, assembly, test bench trials, and data analysis in preparation for the final senior design competition and report. Post CDR report submission, the team revised detailed design elements suggested by the team sponsor. Prototyping commenced with system construction, which included several design revisions after consulting with ITDE before the construction of components began. The lead times of professional machining took approximately 3-5 weeks and delivery of prefabricated parts from McMaster-Carr took less than one week post payment. The system delivery and installation will begin on Monday 28th February and lasted until the 16th March. Estimates of professional machining were to be paid in full upon delivery of approved parts. The current estimates ranged from approximately $1000-$4000 dollars depending upon location. ITDE provided a discount rate for the machining and assembly of all components, which resulted in a total cost approximately $2000.

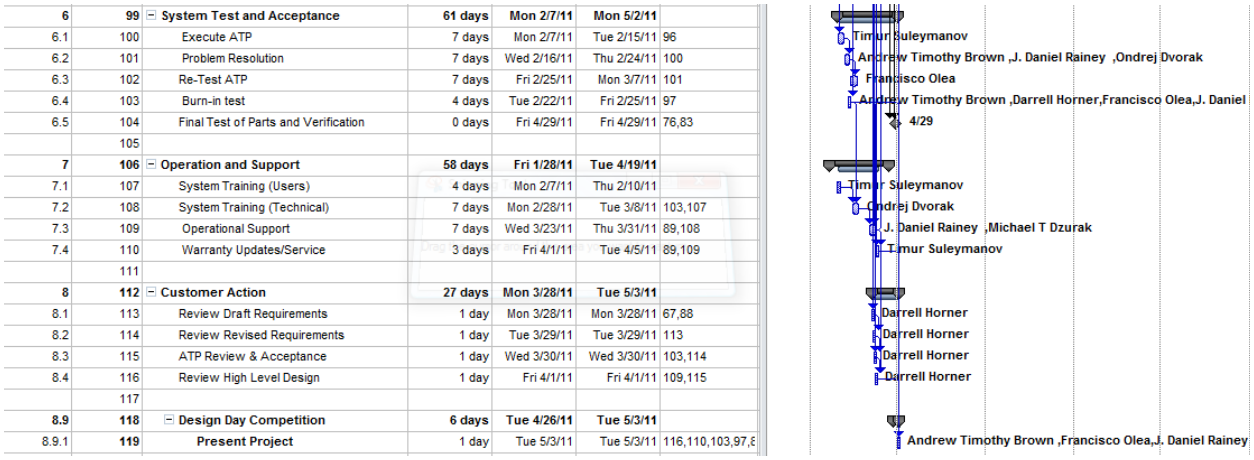
System Testing and Acceptance (STA) and Operation and Support (OS) begin simultaneously after the completion of system installation. The four days of slack time were utilized to incorporate system integration and installation period. It was essential for the project to be executed in no greater than 3 weeks in delays to not catastrophically affect the critical path. Furthermore, the STA and OS are scheduled to include three independent test trials for quality assurance. STA is scheduled to begin on the 28th February with the initial execution of the Acceptance Test Plan (ATP). Problem resolution, re-test ATP, and burn-in tests are estimated to last until the 8th April. OS aided in rapidly resolving issues that may emerge during STA, and will extend until phase 4 to mitigate potential complications until the 20th of April.

To conclude phase 3, the team complied findings collected from the test at Honeywell on 8th April. The test bench trials to the Honeywell were deemed a complete success from our sponsor and completed prior to the design competition. All success, unexpected outcomes, and failures were reported in a timely manner to be processed by the sponsor. After receiving input from the sponsor, the team has formulated recommendations for future projects. The customer actions regarding recommendation will be completed by 26th April and amended in this report submitted on 4th May.



4	**69**	**⊟ System Construction**	**117 days**	**Fri 11/19/10**	**Mon 5/2/11**	**67**
4.1	**70**	**⊟ Construction Builds**	**61 days**	**Mon 1/17/11**	**Mon 4/11/11**	
4.1.5	71	Review Potential Machine Shops	1 day	Wed 1/19/11	Wed 1/19/11	
4.1.6	72	Reivew Design with Machinist	0 days	Wed 2/2/11	Wed 2/2/11	71
4.1.1	73	Final Solidworks Model	3 days	Wed 2/2/11	Fri 2/4/11	72
4.1.2	74	ITDE Machine Aluminum Frame	42 days	Fri 2/11/11	Mon 4/11/11	86,96
4.1.4	75	ITDE Machine Aft and Fore Valves	35 days	Mon 2/7/11	Fri 3/25/11	
4.1.7	76	Review and Accept parts from ITDE	0 days	Mon 4/11/11	Mon 4/11/11	74,75
4.1.11	77	Receive Precision Board Donated from Raytheon	0 days	Tue 1/18/11	Tue 1/18/11	
4.1.14	78	Composite Model Construction	50 days?	Tue 1/18/11	Mon 3/28/11	83FF,77SS
4.1.12	79	Selection Materials for Composites	0 days	Tue 1/25/11	Tue 1/25/11	77
4.1.9	80	Complete G Code for Composite Models	0 days	Mon 2/21/11	Mon 2/21/11	79
4.1.8	81	CNC Composite Models	0 days	Mon 3/7/11	Mon 3/7/11	80
4.1.13	82	Order Supplies for Composites if Successful	0 days	Mon 3/7/11	Mon 3/7/11	81
4.1.10	83	Wrap Composite Models in Fiberglass and CF	0 days	Mon 3/28/11	Mon 3/28/11	82
4.1.3	84	CNC Test Bench Block	21 days	Mon 2/7/11	Mon 3/7/11	
4.2	**85**	**⊟ Development Testing**	**53 days**	**Mon 2/7/11**	**Wed 4/20/11**	
4.2.1	86	Physical Dynamics and Simulation	4 days	Mon 2/7/11	Thu 2/10/11	73
4.2.2	87	Test Build Assembled Valve	7 days	Tue 4/12/11	Wed 4/20/11	74,75,84,76,83
4.2.3	88	Test Build Full Trial	7 days	Tue 2/22/11	Wed 3/2/11	97
4.3	89	System Integration	14 days	Thu 3/3/11	Tue 3/22/11	88
4.4	**90**	**⊟ Error Resolution**	**26 days**	**Mon 3/28/11**	**Sat 4/30/11**	
4.4.1	91	Acceptance Test Procedure Issues	3 days	Mon 3/28/11	Wed 3/30/11	88
4.4.2	92	Operational Support	4 days	Fri 4/1/11	Wed 4/6/11	109
	93					
5	**94**	**⊟ System Delivery & Installation**	**49 days**	**Mon 1/10/11**	**Thu 3/17/11**	
5.1	95	Equipment Delivery	7 days	Mon 1/17/11	Tue 1/25/11	
5.2	96	Hardware Installaiton	5 days	Wed 1/26/11	Tue 2/1/11	95
5.4	97	5.4 Installation Test and verification	14 days	Wed 2/2/11	Mon 2/21/11	96
	98					
6	**99**	**⊟ System Test and Acceptance**	**61 days**	**Mon 2/7/11**	**Mon 5/2/11**	
6.1	100	Execute ATP	7 days	Mon 2/7/11	Tue 2/15/11	96
6.2	101	Problem Resolution	7 days	Wed 2/16/11	Thu 2/24/11	100
6.3	102	Re-Test ATP	7 days	Fri 2/25/11	Mon 3/7/11	101
6.4	103	Burn-in test	4 days	Tue 2/22/11	Fri 2/25/11	97
6.5	104	Final Test of Parts and Verification	0 days	Fri 4/29/11	Fri 4/29/11	76,83

Figure 33: Gantt Chart Phase 3



6	**99**	⊟ **System Test and Acceptance**	**61 days**	**Mon 2/7/11**	**Mon 5/2/11**	
6.1	100	Execute ATP	7 days	Mon 2/7/11	Tue 2/15/11	96
6.2	101	Problem Resolution	7 days	Wed 2/16/11	Thu 2/24/11	100
6.3	102	Re-Test ATP	7 days	Fri 2/25/11	Mon 3/7/11	101
6.4	103	Burn-in test	4 days	Tue 2/22/11	Fri 2/25/11	97
6.5	104	Final Test of Parts and Verification	0 days	Fri 4/29/11	Fri 4/29/11	76,83
	105					
7	**106**	⊟ **Operation and Support**	**58 days**	**Fri 1/28/11**	**Tue 4/19/11**	
7.1	107	System Training (Users)	4 days	Mon 2/7/11	Thu 2/10/11	
7.2	108	System Training (Technical)	7 days	Mon 2/28/11	Tue 3/8/11	103,107
7.3	109	Operational Support	7 days	Wed 3/23/11	Thu 3/31/11	89,108
7.4	110	Warranty Updates/Service	3 days	Fri 4/1/11	Tue 4/5/11	89,109
	111					
8	**112**	⊟ **Customer Action**	**27 days**	**Mon 3/28/11**	**Tue 5/3/11**	
8.1	113	Review Draft Requirements	1 day	Mon 3/28/11	Mon 3/28/11	67,88
8.2	114	Review Revised Requirements	1 day	Tue 3/29/11	Tue 3/29/11	113
8.3	115	ATP Review & Acceptance	1 day	Wed 3/30/11	Wed 3/30/11	103,114
8.4	116	Review High Level Design	1 day	Fri 4/1/11	Fri 4/1/11	109,115
	117					
8.9	**118**	⊟ **Design Day Competition**	**6 days**	**Tue 4/26/11**	**Tue 5/3/11**	
8.9.1	**119**	**Present Project**	1 day	Tue 5/3/11	Tue 5/3/11	116,110,103,97,8

Figure 34: Gantt Chart Phase 4

Phase 4 brings the senior design project to a close. The preparation for the design day competition is expected to last approximately one week and ended on May 3rd. The remainder of the allocated budget was spent on presentation materials that will augment the attributes associated with the project. During that time, the team amassed all necessary visual aids, exhibition models and additional materials. The group presentation was rehearsed in preparation to impressed the judges and strive for top awards. Two semesters of diligent team work has resulted in acclaim from our mentor and team sponsor. We await word about the proceedings of our patent pending project.

11. Closure

As specified in the project management update section, the submission of this report on 4th May 2011 marks the end of the design phase of senior capstone. Safety protocols, weekly meetings with the team's sponsor, and periodic status checks will ensure that the project remains on time and under budget. The system requirements have mapped out the functional, technology, and performance requirements specified by Honeywell along with additional desired constraints. This report acknowledges the changes proposed at the preliminary design review, explains in detail the various concepts considered, and justifies the selection of the preferred concept.

The top-level design of the final concept and sub-assembly/interface design provide an in-depth analysis of the mechanical component calculation and drafting details incorporated into the proposed model. The analysis section explains the torques, operating conditions, buckling characteristics, and actuator torque accounted for in the valve model. The calculations and the description of MATLAB code acts as justification for the dimensions selected in the sub-assembly section. The subsystem/assembly section offers detailed descriptions of each individual component of the model and the human interfaces to be used during simulation. Analysis also validates the logic imposed in both of these sections.

The development plan guides the reader through the various stages of the project to date. It structured the technology foundation of the current TRV from Honeywell all the way to the methods used for the final prototype. The prototyping options were numerous; however one of the largest limiting factors for the senior design team was cost. The proposed budget, bill of materials, suppliers, and professional contractors were listed as variable means of obtaining similar results. The primary attribute to consider was the budget. The acquisition of materials began shortly after the submission of the CDR written report on 8th December 2010, which was contingent upon approval from our sponsor. Prototyping, system assembly, and testing occurred in a time and cost effective manner.

The acceptance test plan structures how the test bench analysis will be performed post prototyping. Visual and physical testing substantiated the research and computational analysis done in this report. As arranged within the Gantt charts, the physical testing trials will begin at latest by February 18th until April 20th. That enabled the team to modify any faulty components of the design and collect enough data to make an accurate conclusion of the project design. Trials, modifications, and verification were scheduled until the final customer approval scheduled for April 26th. However, the initial test at Honeywell proved successful and we received the approval from our sponsor. No further sessions were necessary to verify our calculations. The residual time until the design competition on the 3rd May was spent perfecting the presentable materials and compiling the considerable data accrued over the term of the spring semester. This report is to be submitted before 4th May 2011 for evaluation from our sponsor and group mentor.

Appendix

APPENDIX A: REFERENCES A-1

APPENDIX B: HARDWARE A-2

CONTAINS THE DIMENSIONED SOLIDWORKS MODELS AND OUTSOURCED PARTS

APPENDIX C: SOFTWARE A-3

CONTAINS THE MATLAB CODE USED TO DETERMINE THE MAXIMUM ACTUATOR TORQUE

APPENDIX C: BUDGET A-4

COSTS OF MATERIALS, MANUFACTURING EXPENSES, AND SUPPLIER INFORMATION

Appendix A: *References*

1. Honeywell Aerospace, Tucson, Arizona. Darrell Horner. 14 Sept. 2010.
   File name: single_door_torque_calculations_1.xls.
2. Honeywell Aerospace, Tucson, Arizona. Darrell Horner. 19 Oct. 2010.
   File name: outflow_valve_operating_conditions.xls.
3. *McMaster-Carr*. Web. 25 Oct. 2010. <http://www.mcmaster.com/>.
4. "Bevel Protractor BPRO Series - Moore and Wright." *Moore & Wright - Moore and Wright*. Web. 26 Nov. 2010. <http://www.moore-and-wright.com/products/show/9666>.
5. "CDI Micro Adjustable Torque Wrench Comfort Grip -Dual Scale: Pro Torque." *ProTorqueTools: CDI Torque Products | Wrenches | Screwdrivers*. Web. 15 Nov. 2010. <http://www.protorquetools.com/Cat-36-1-111/Newton_Meter_Torque_Wrenches_Single_Scale.htm>.

Appendix B: Hardware

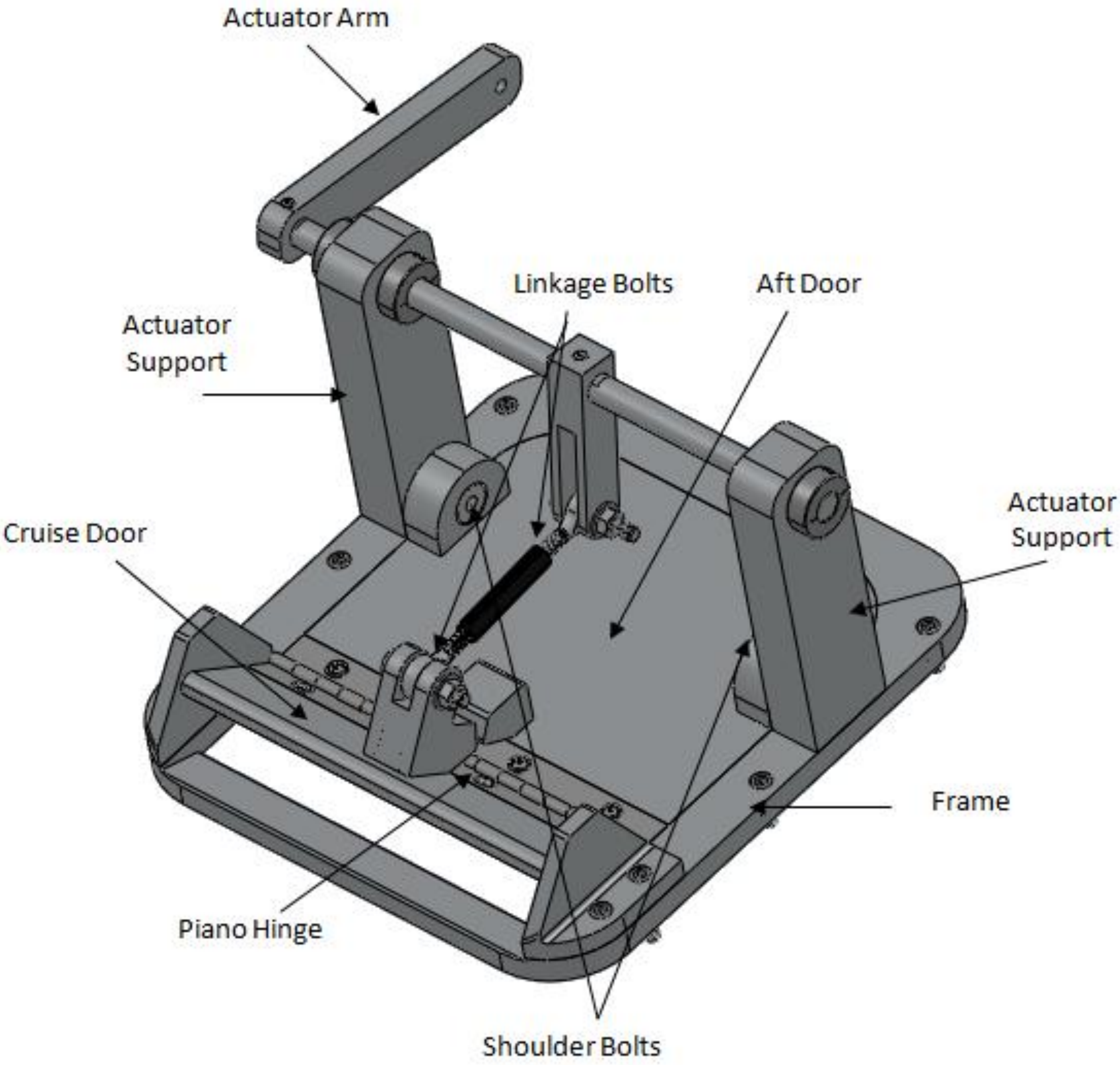


Figure A1: Assembly Overview

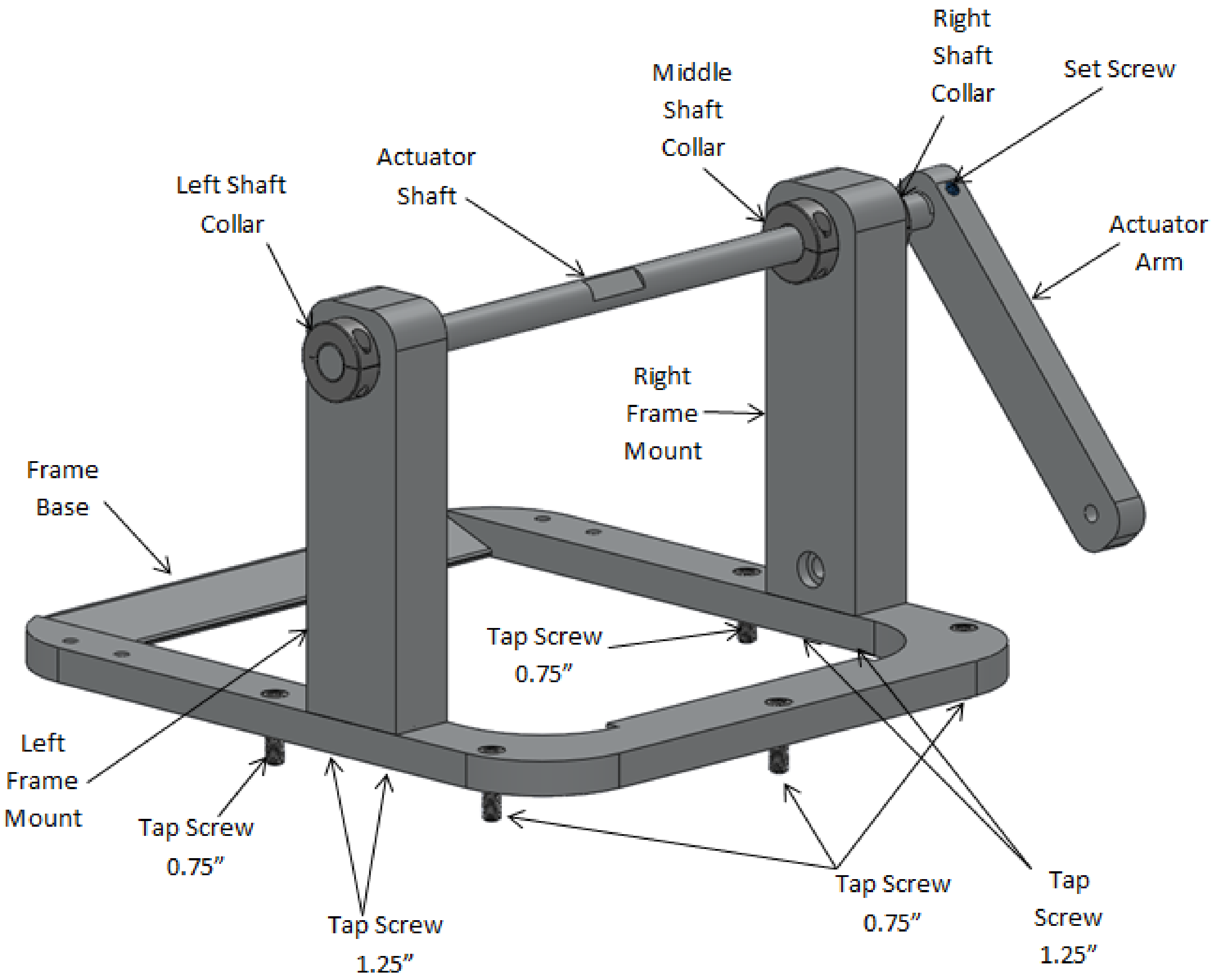


Figure A2: Valve Frame

Figure A3: Cruise Door

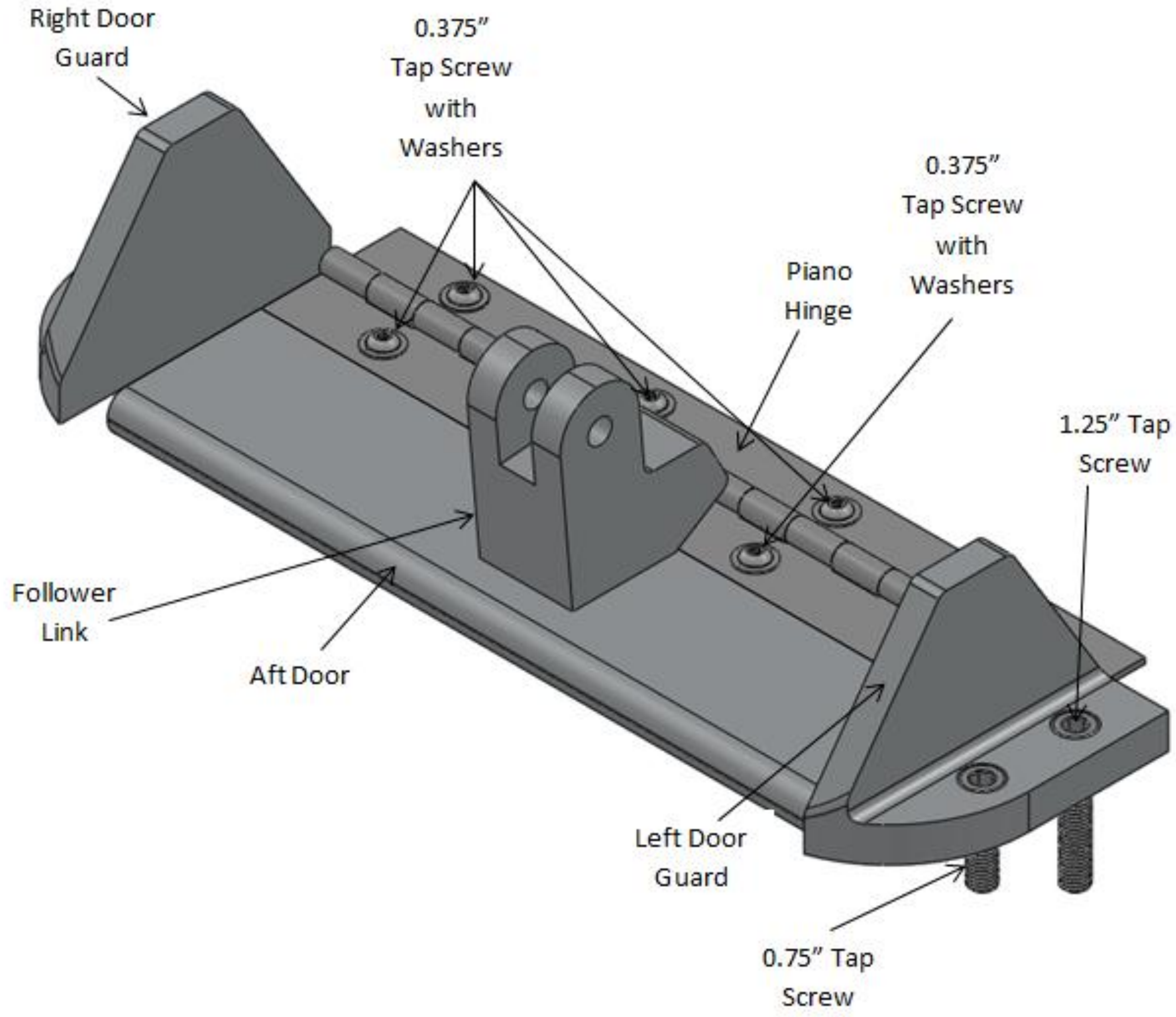
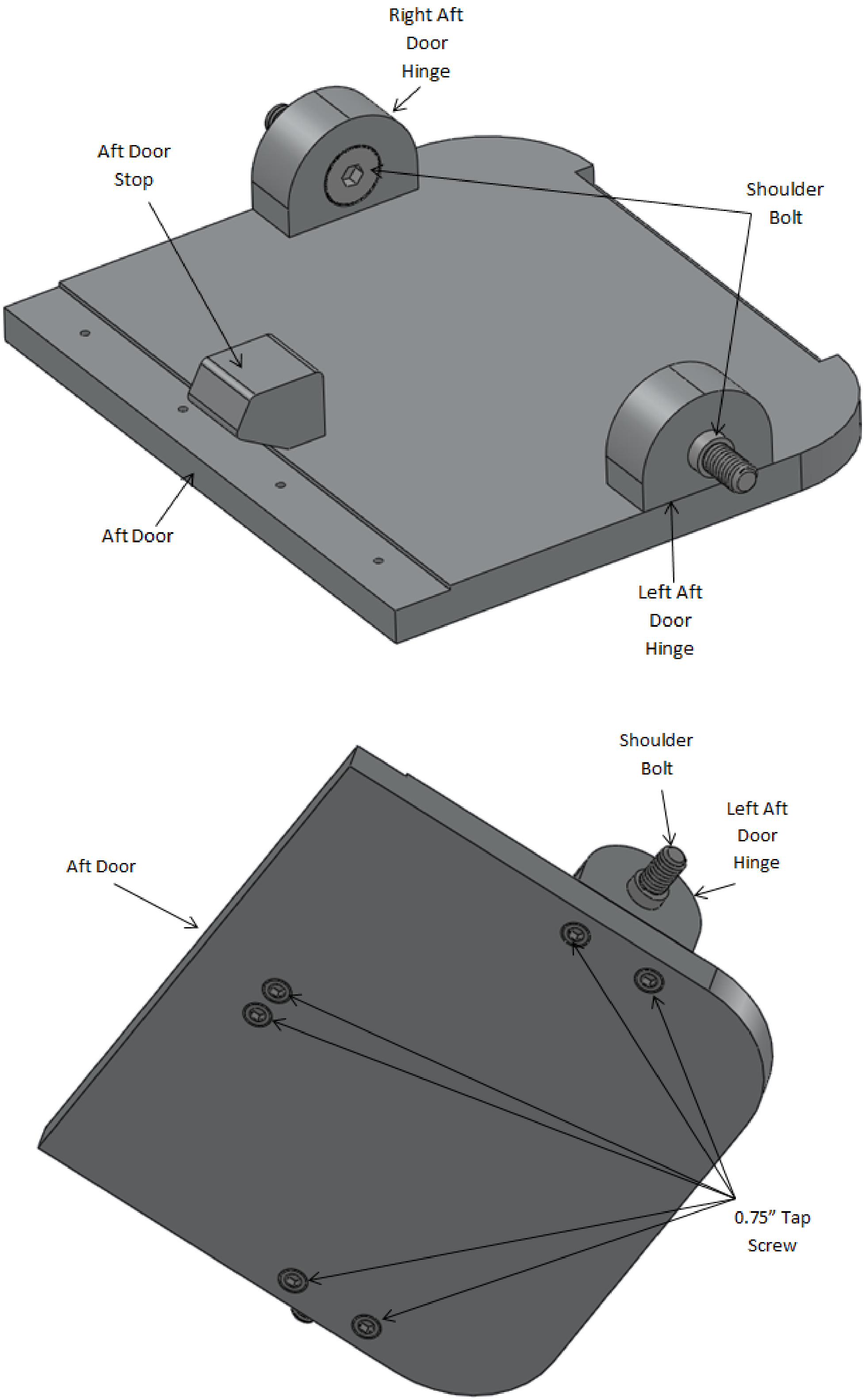
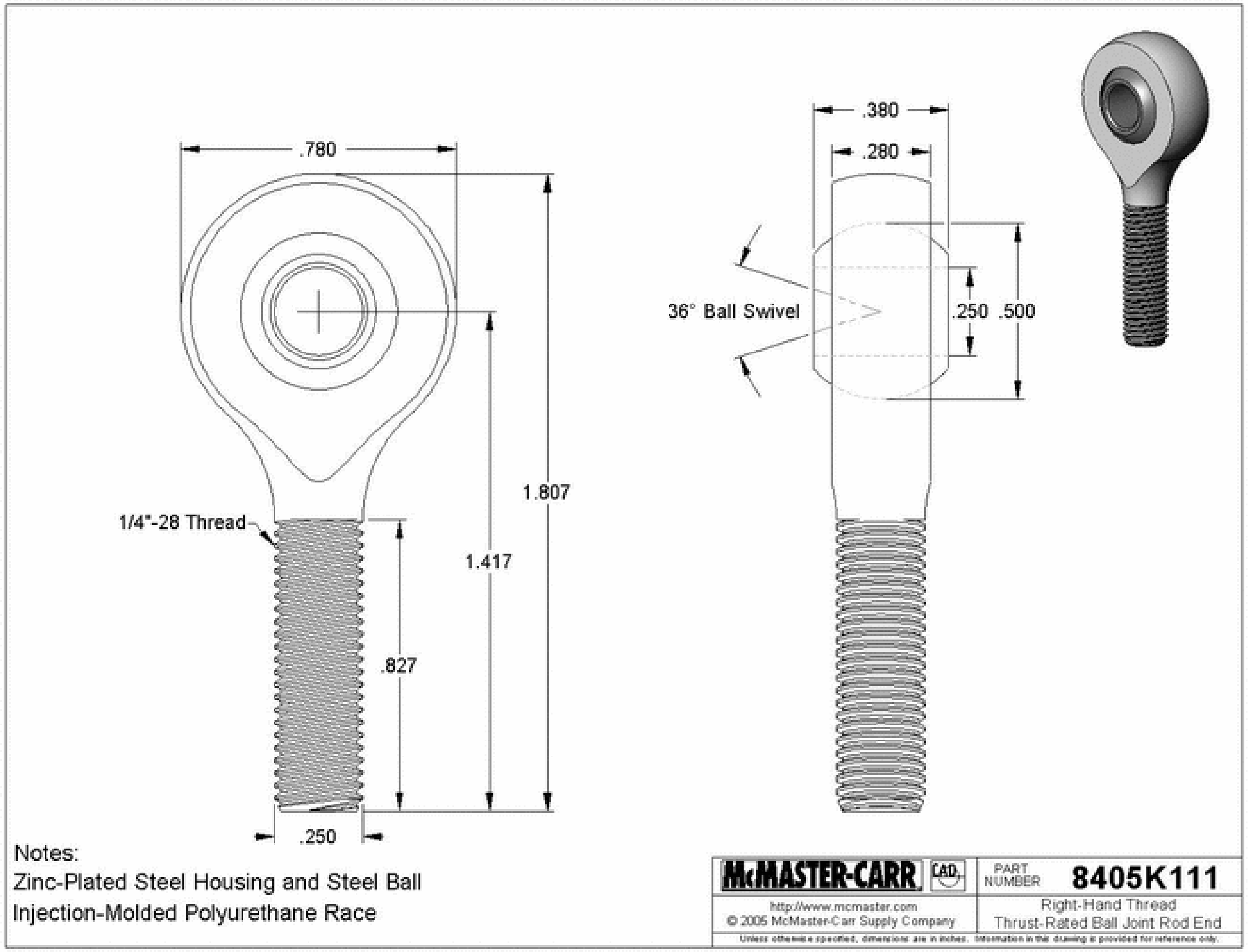


Figure A4: Aft Door



Figures A5: Rod End Detail (Part of Coupler Link)



Notes:
Zinc-Plated Steel Housing and Steel Ball
Injection-Molded Polyurethane Race

PART NUMBER 8405K111

http://www.mcmaster.com
© 2005 McMaster-Carr Supply Company

Right-Hand Thread
Thrust-Rated Ball Joint Rod End

Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.

Figure A6: Threaded Hex Rod Detail (Part of coupler link)

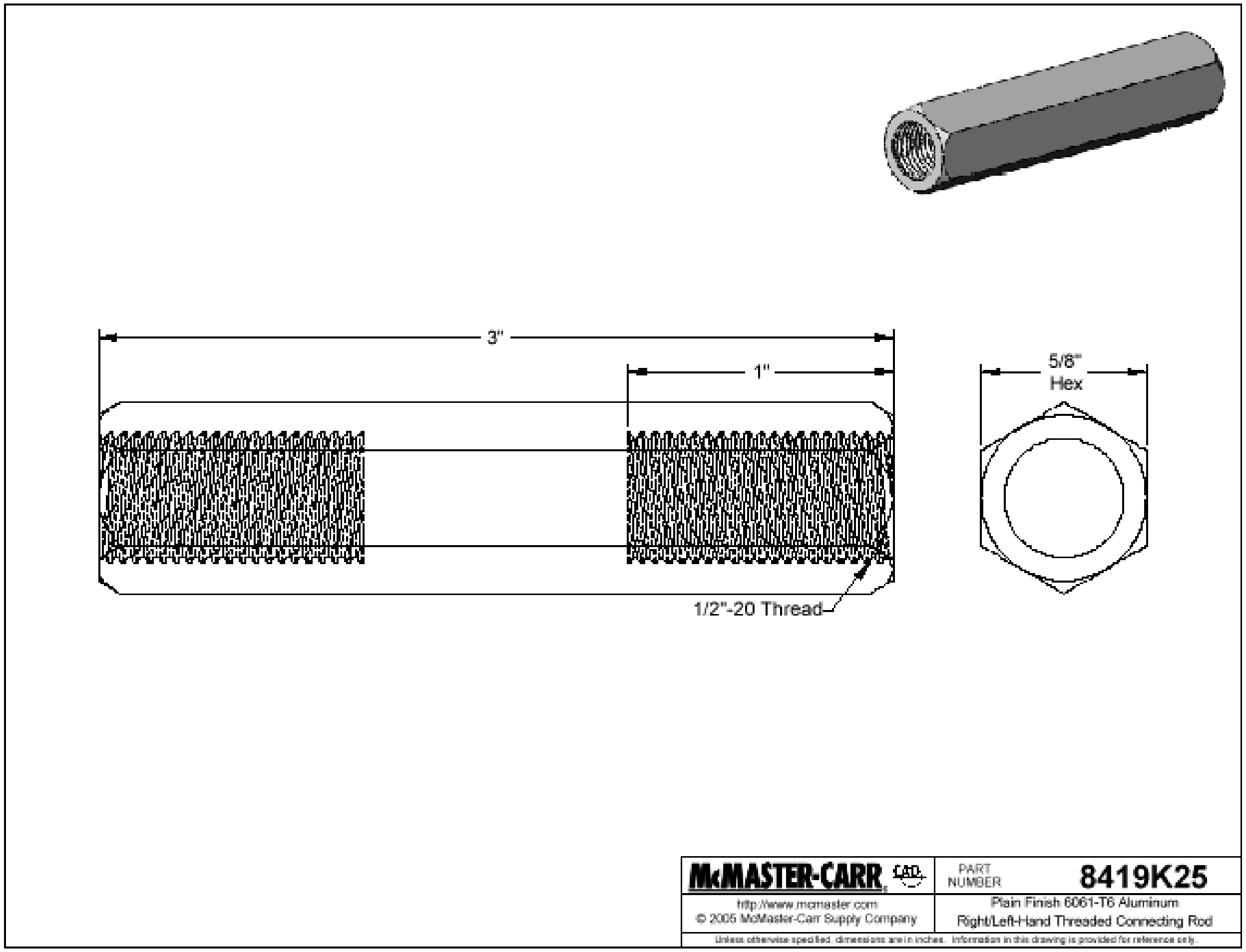


Figure A7: Frame / Linkage Bolts

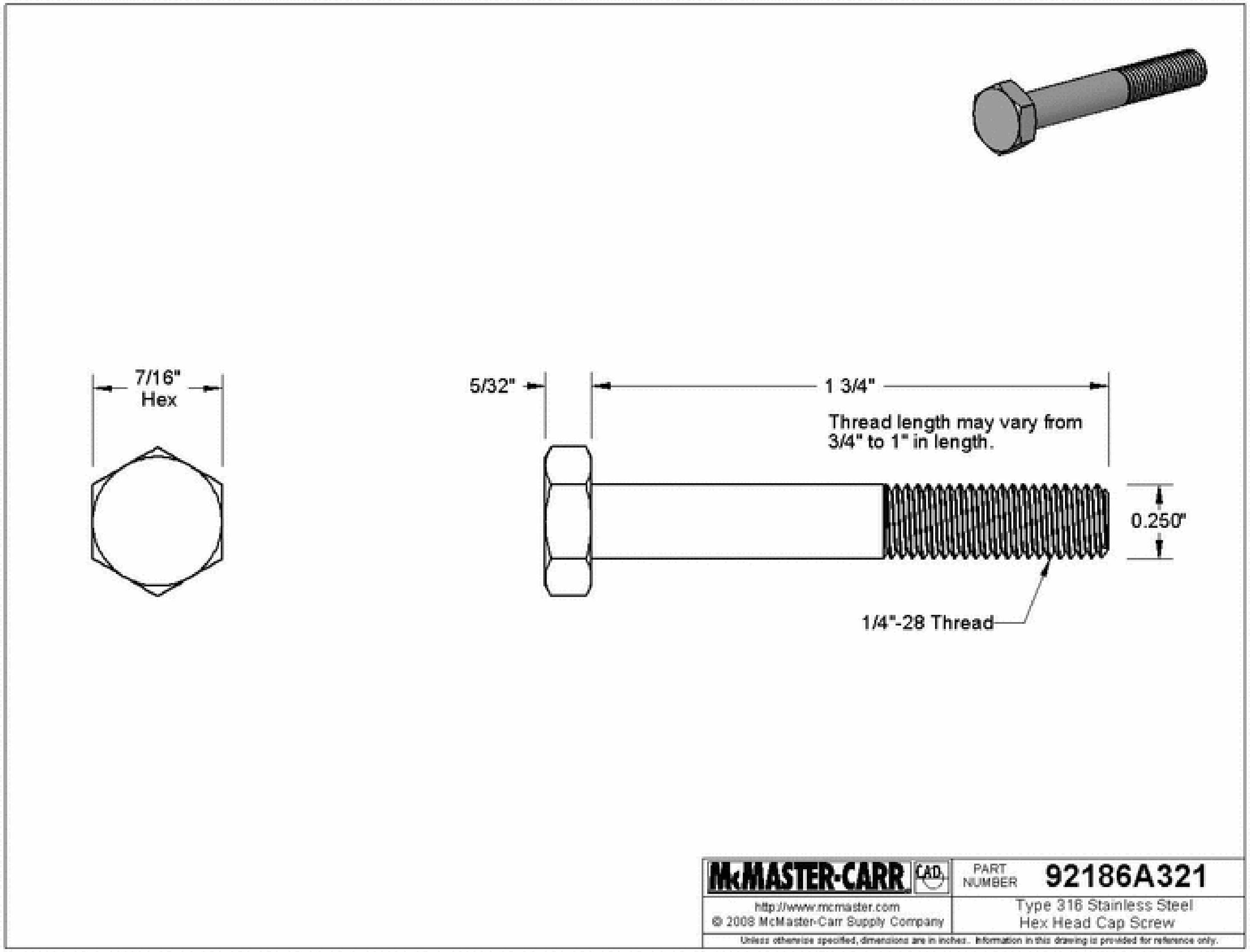


Figure A8: Frame / Linkage Washers

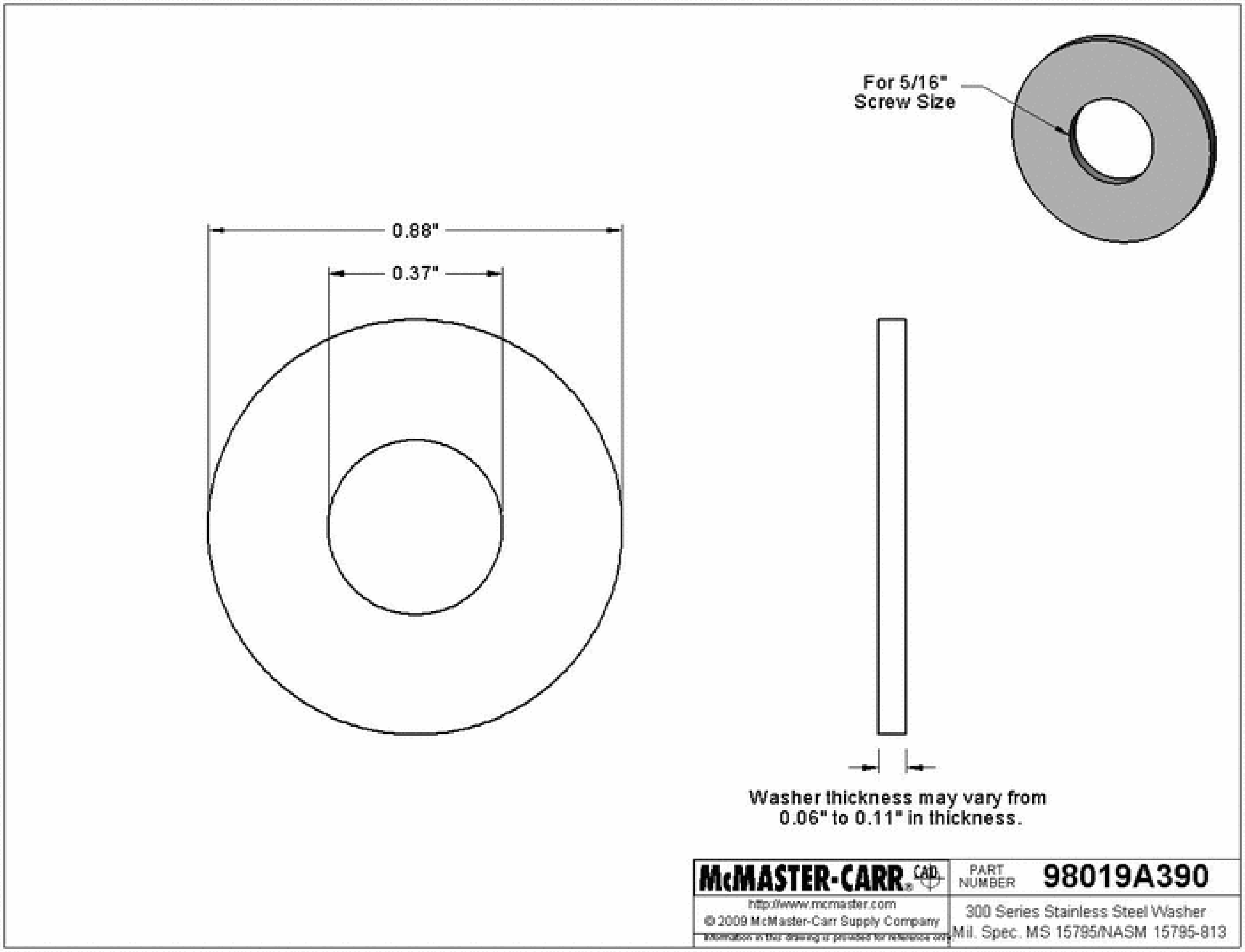


Figure A9: Frame / Linkage Nuts

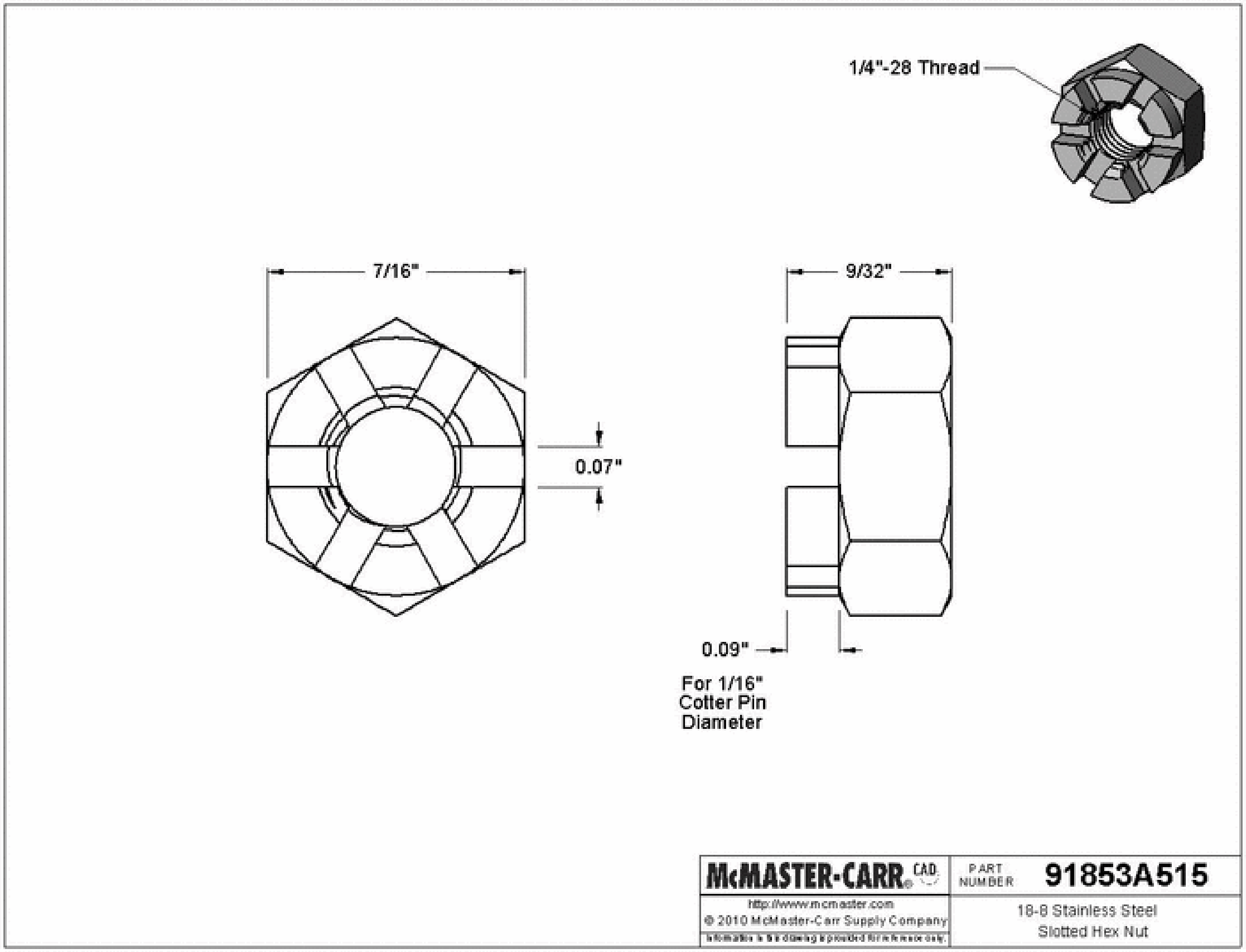


Figure A10: Frame Shoulder Bolts

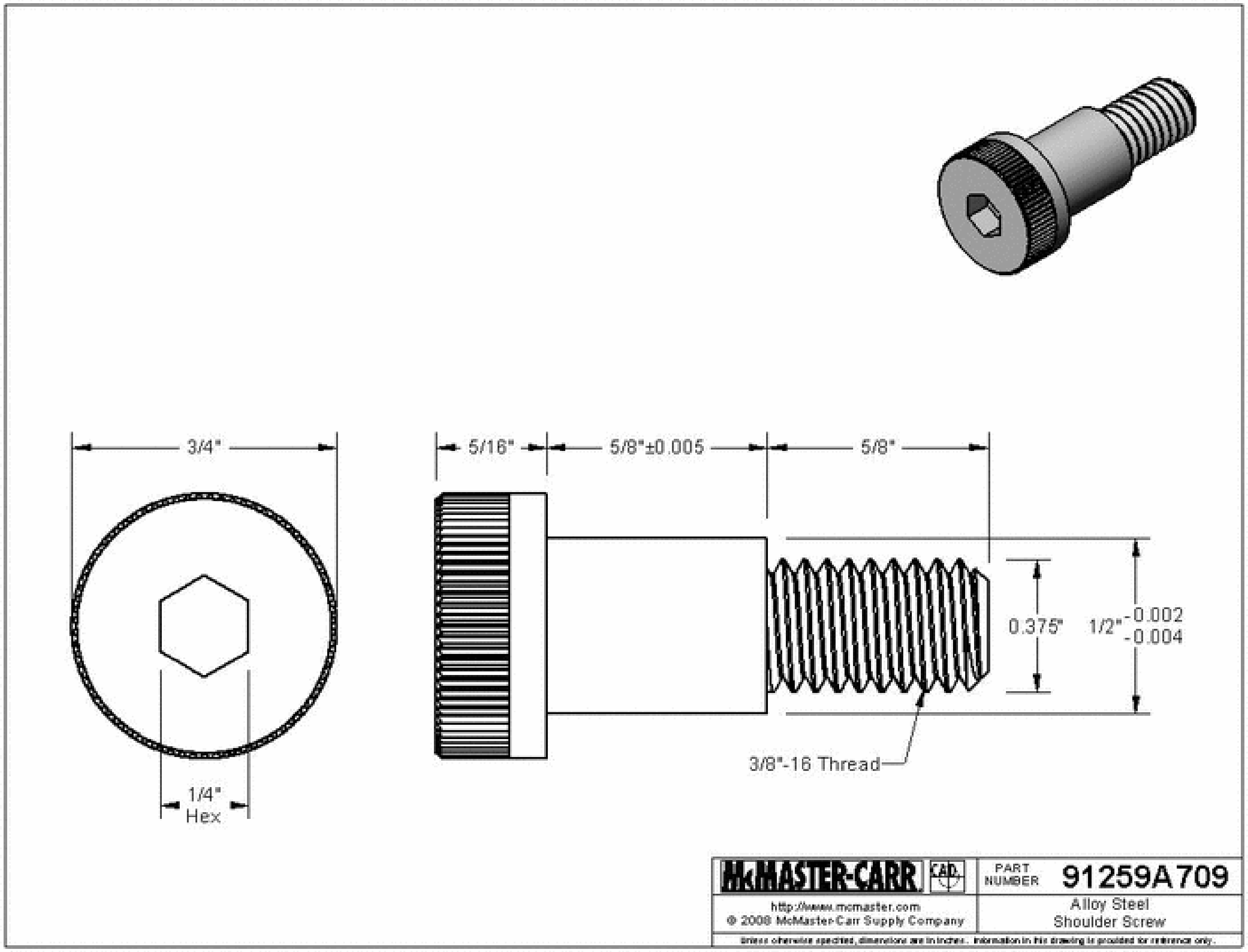


Figure A11: 1.25” Piano Hinge

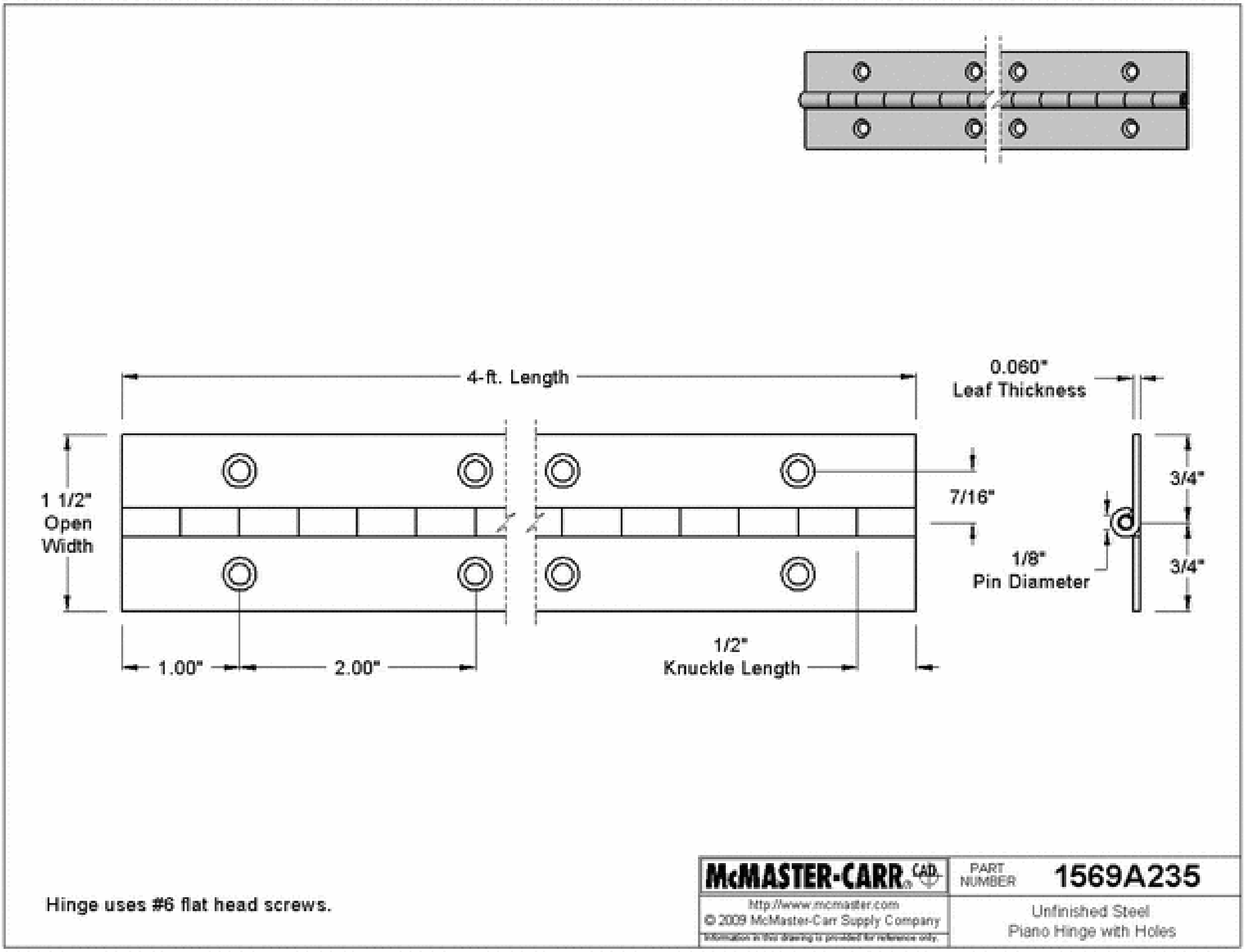


Figure A12a: Tap Screw (0.75”)

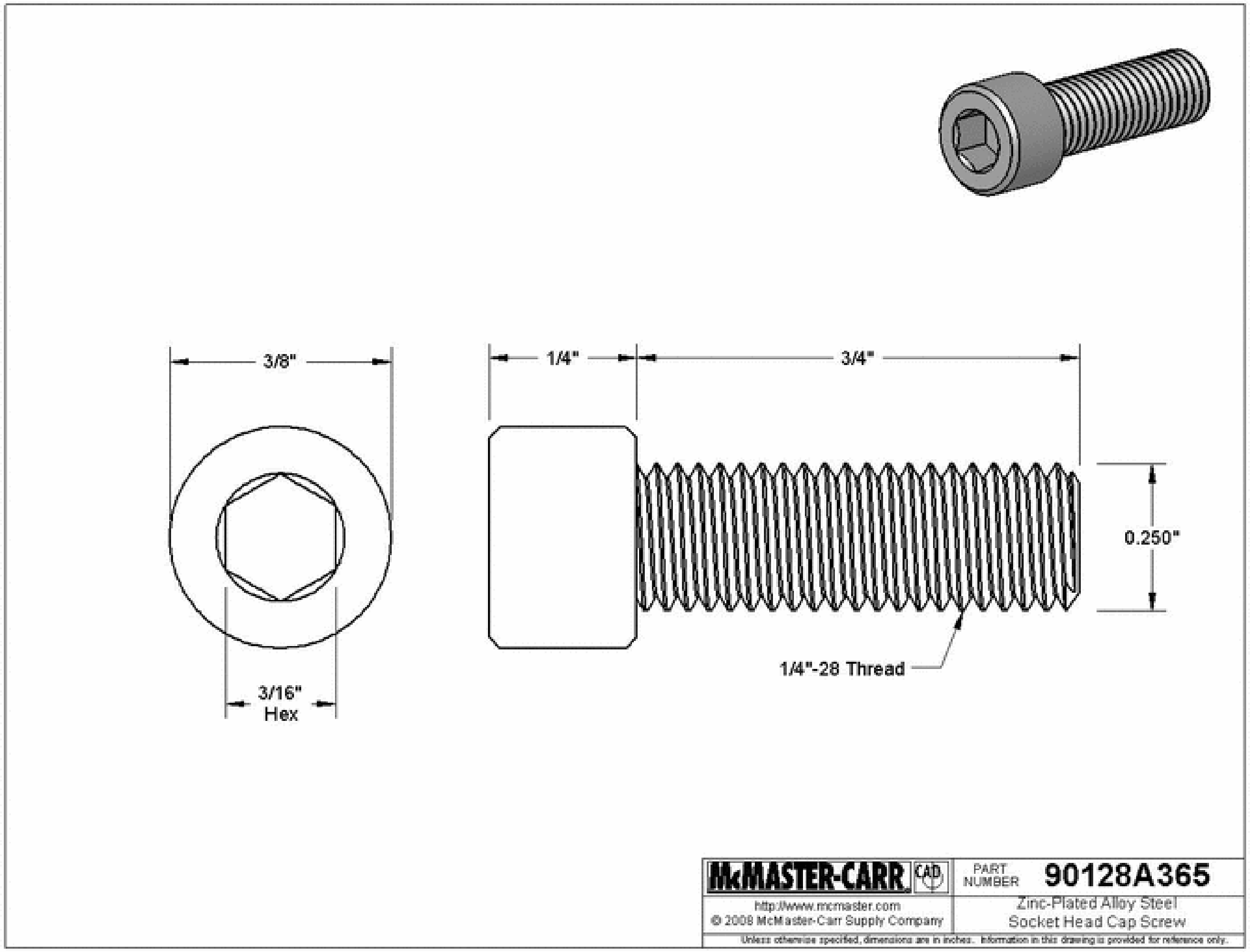


Figure A12b: Tap Screw (1.25”)

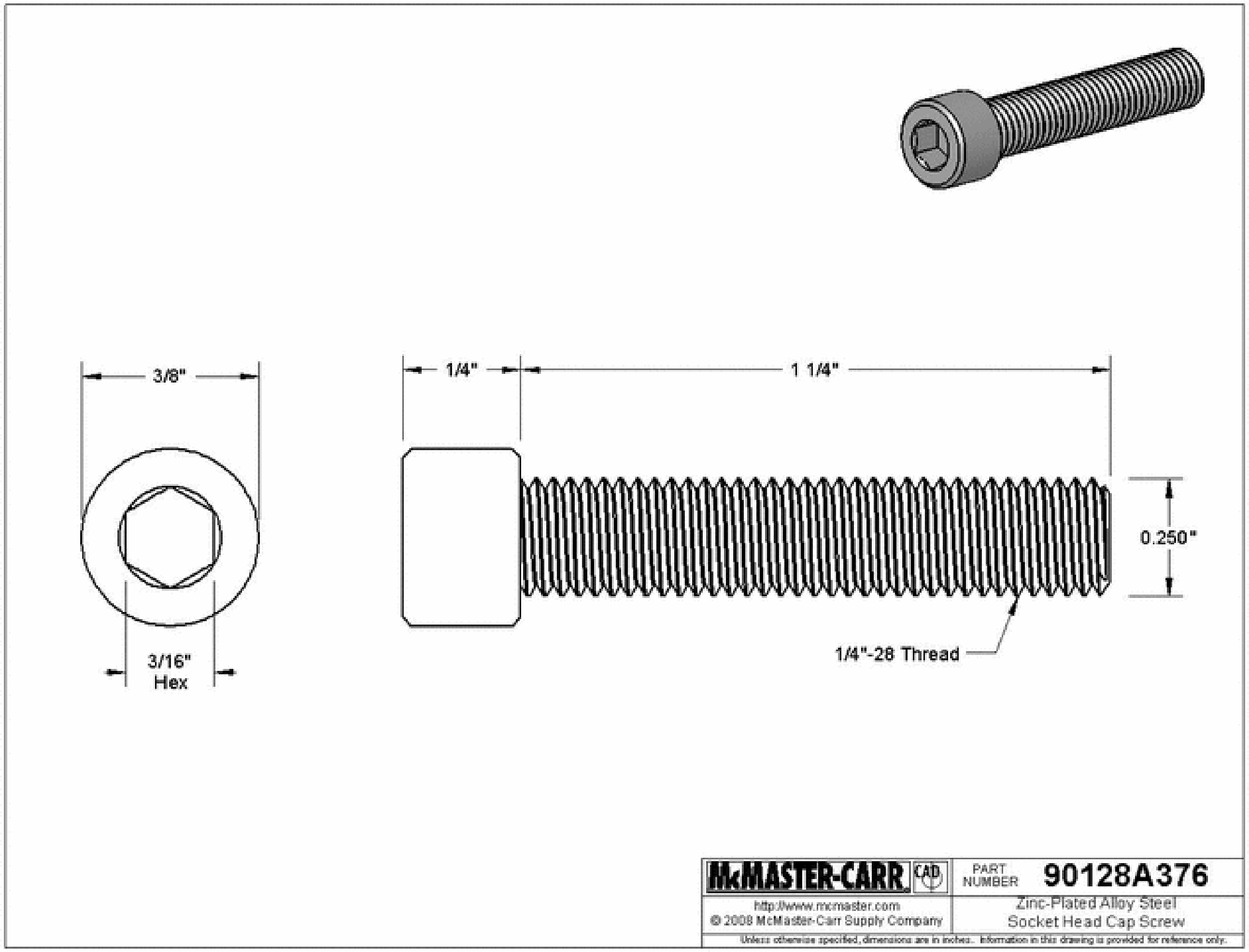


Figure A13: Cap Screw (0.375”)

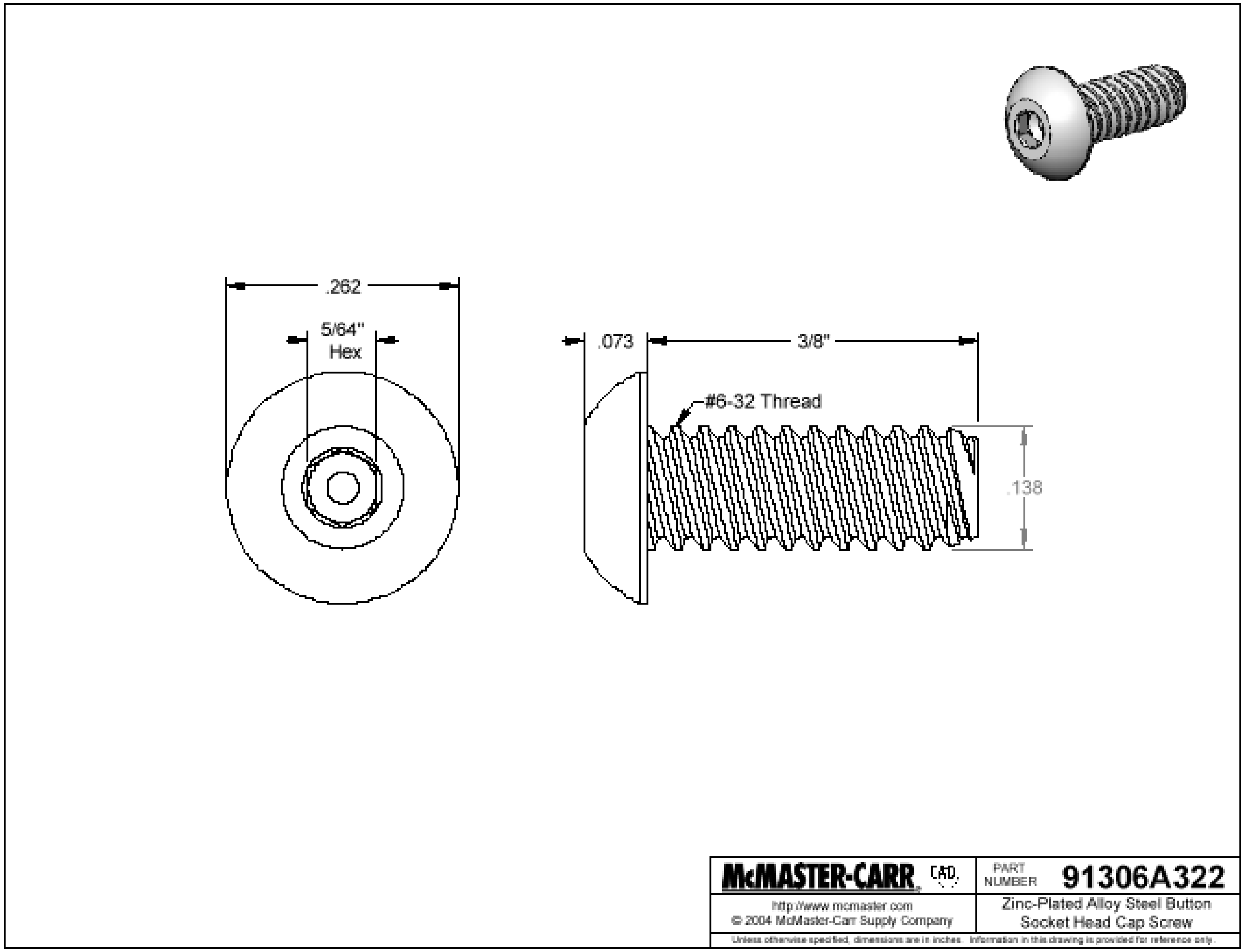


Figure A14: Set Screw (0.3125”)

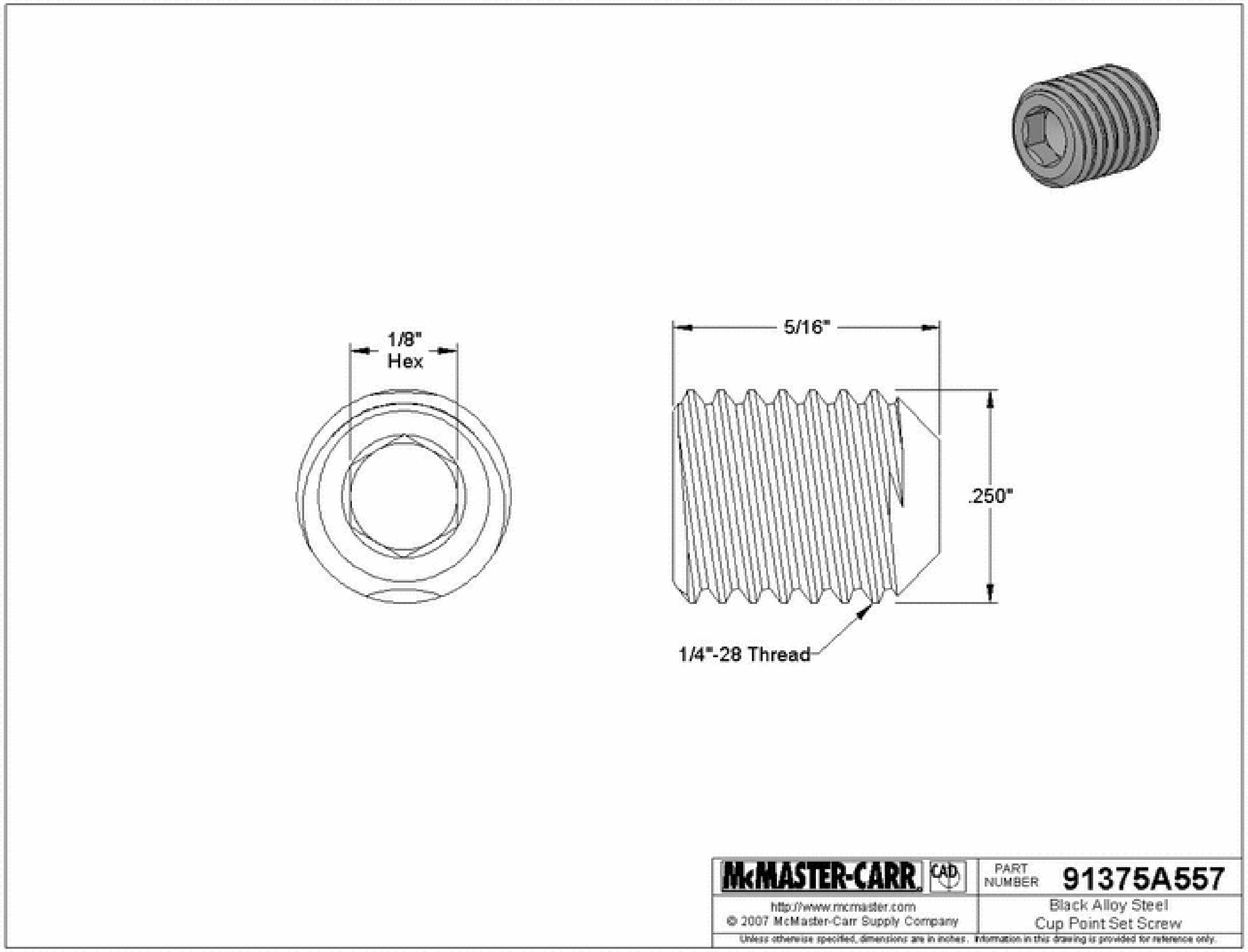


Figure A15: Frame Mount

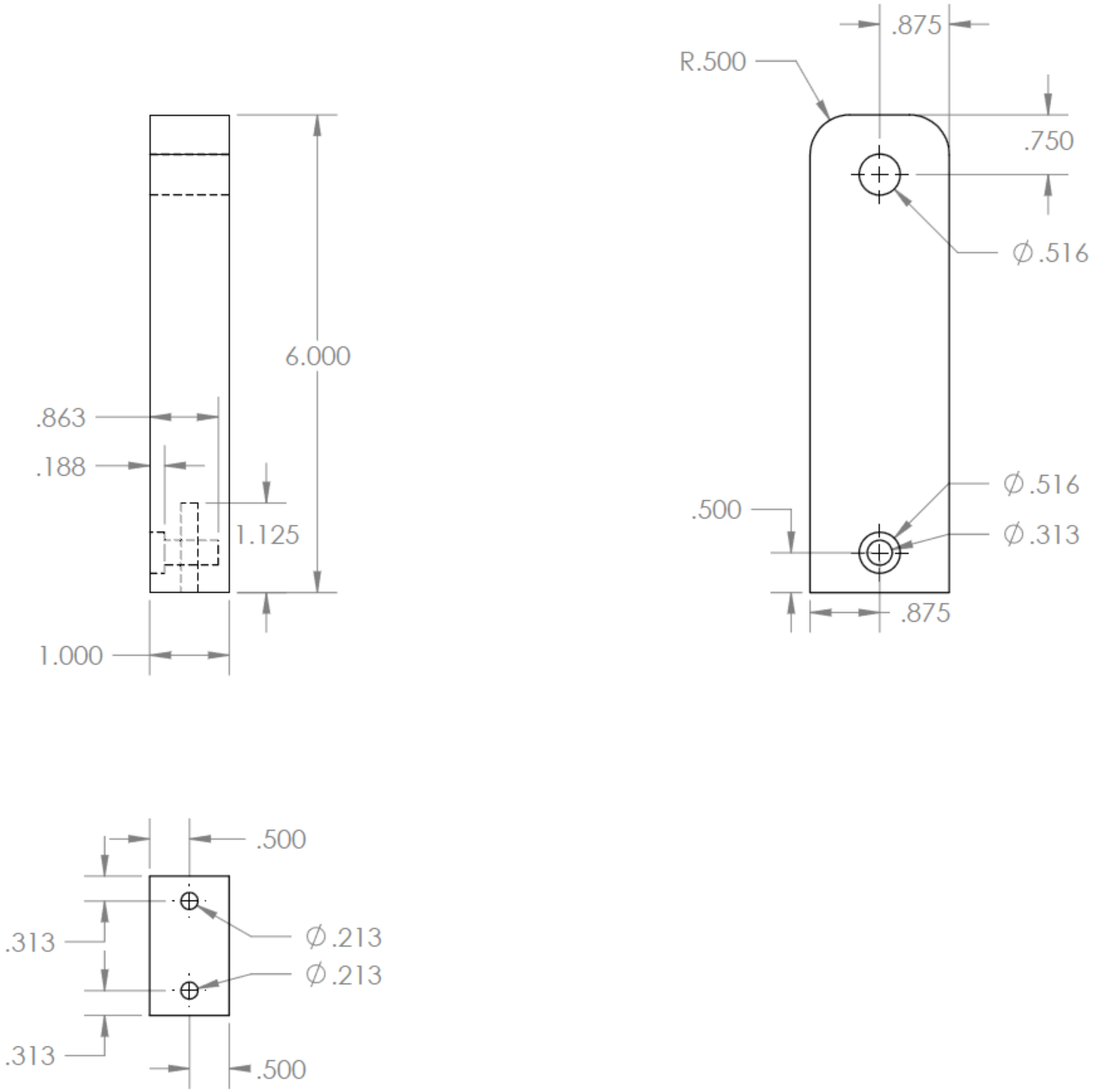


Figure A16: Actuator Shaft

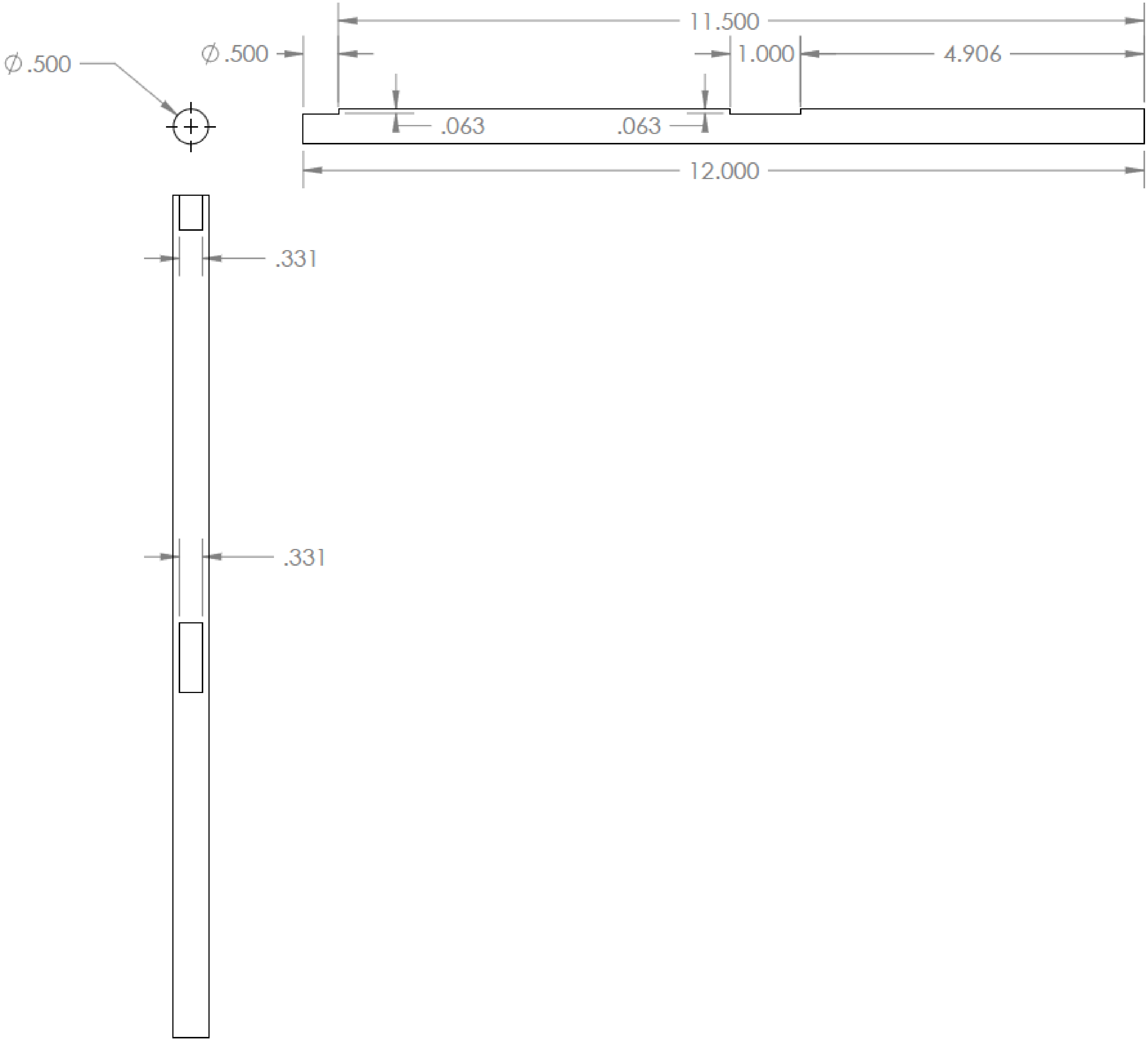


Figure A17: Actuator Arm

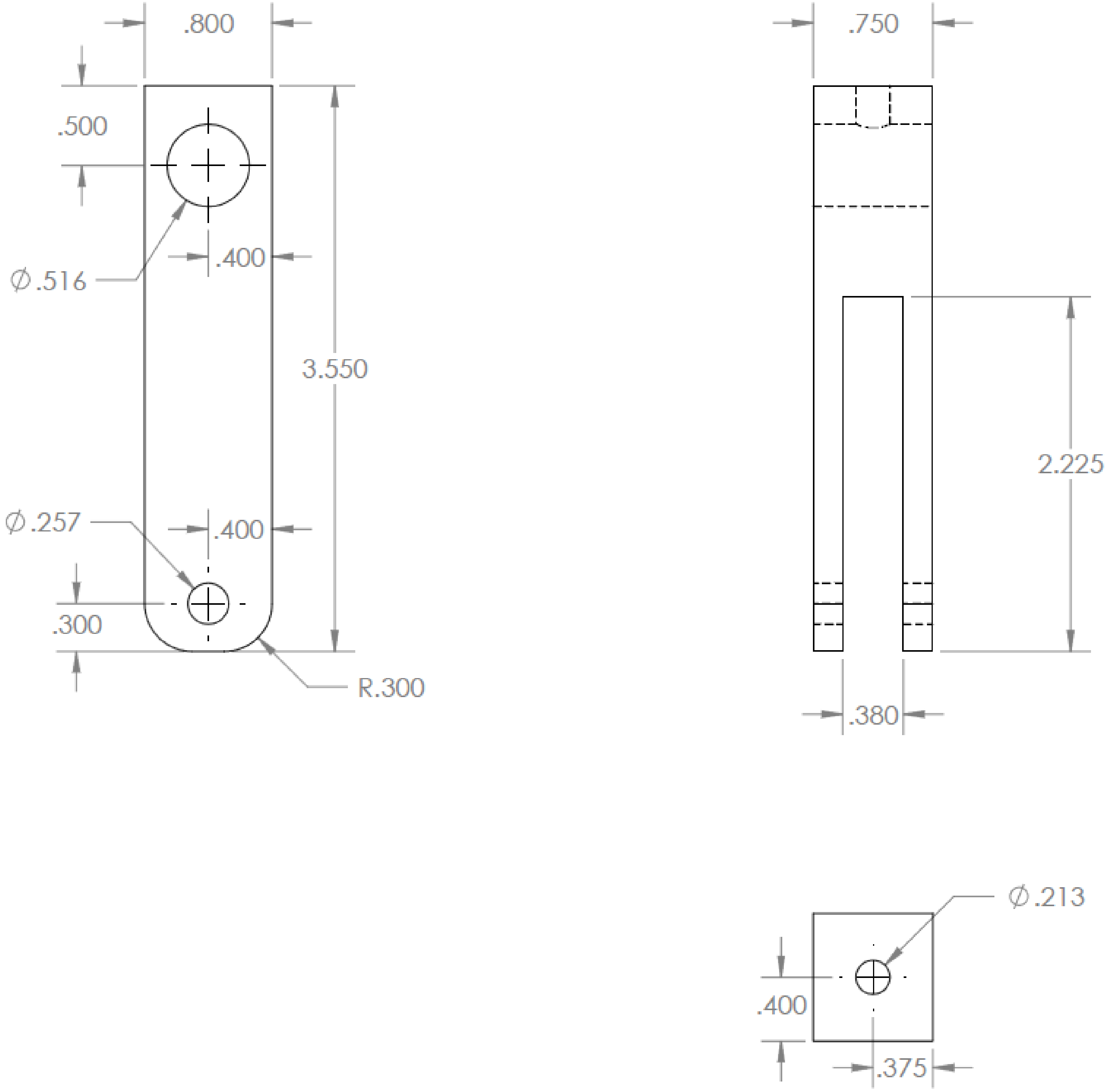


Figure A18: Cruise Door

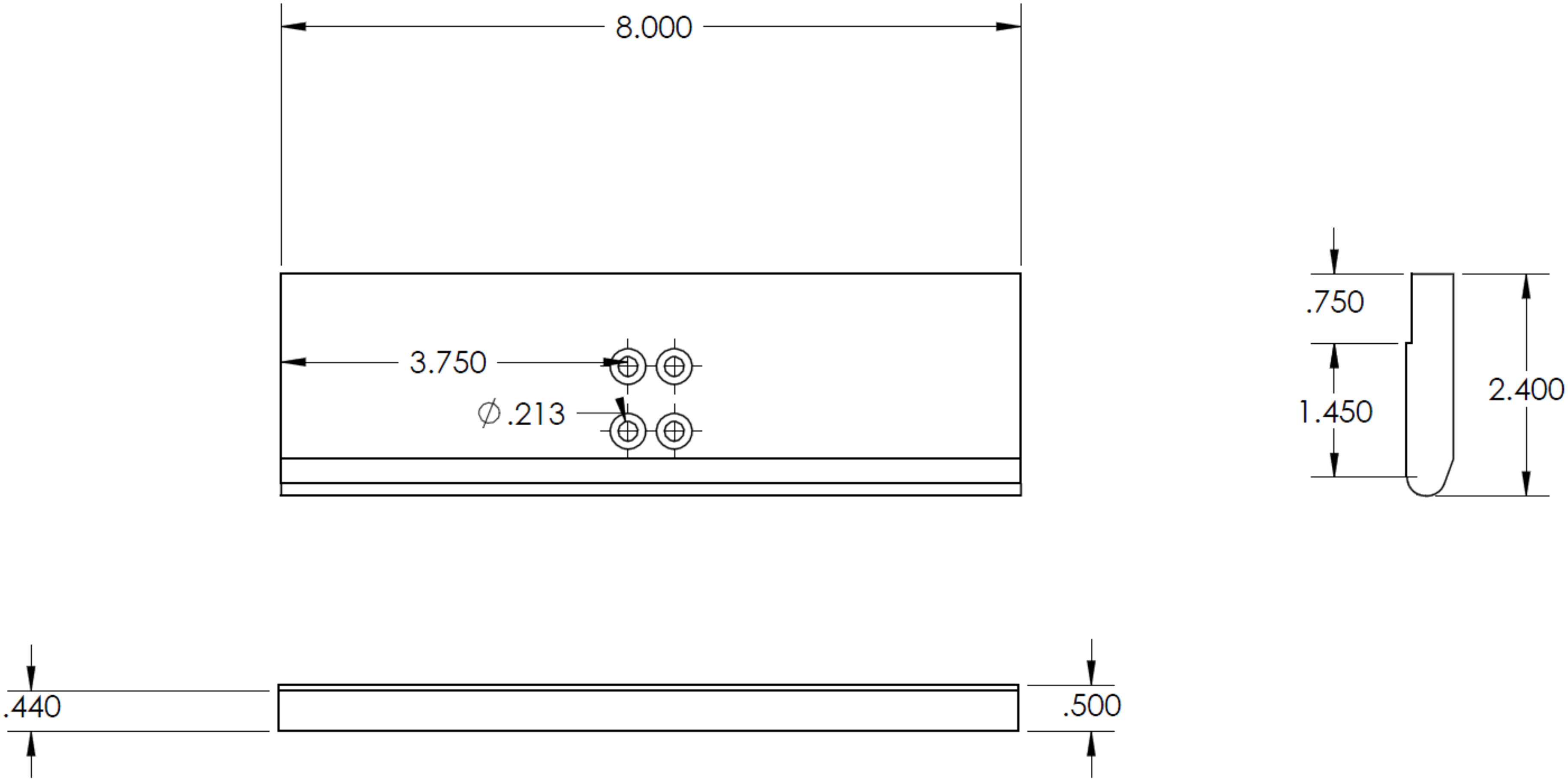


Figure A19: Follower Link

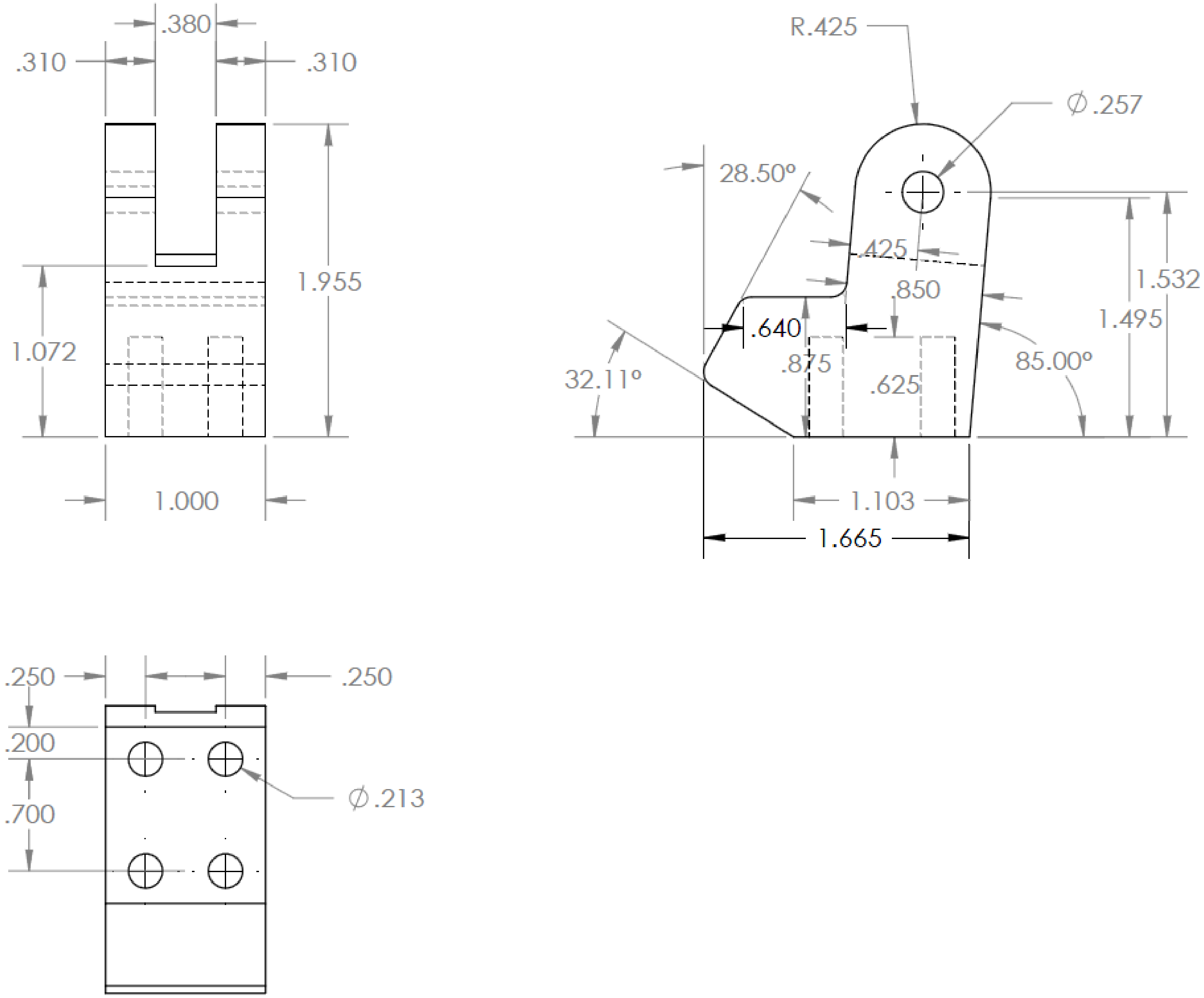


Figure A20: Cruise Door Guards

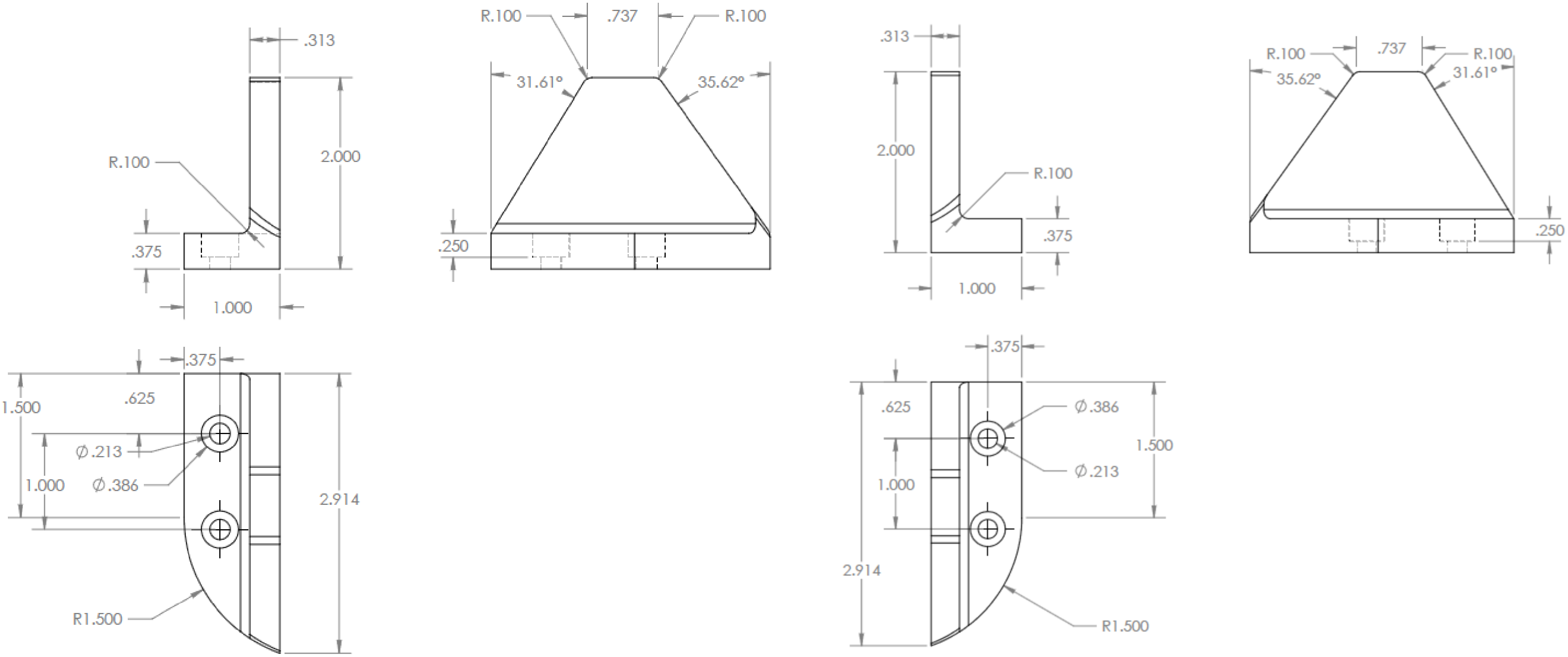


Figure A21: Aft Door

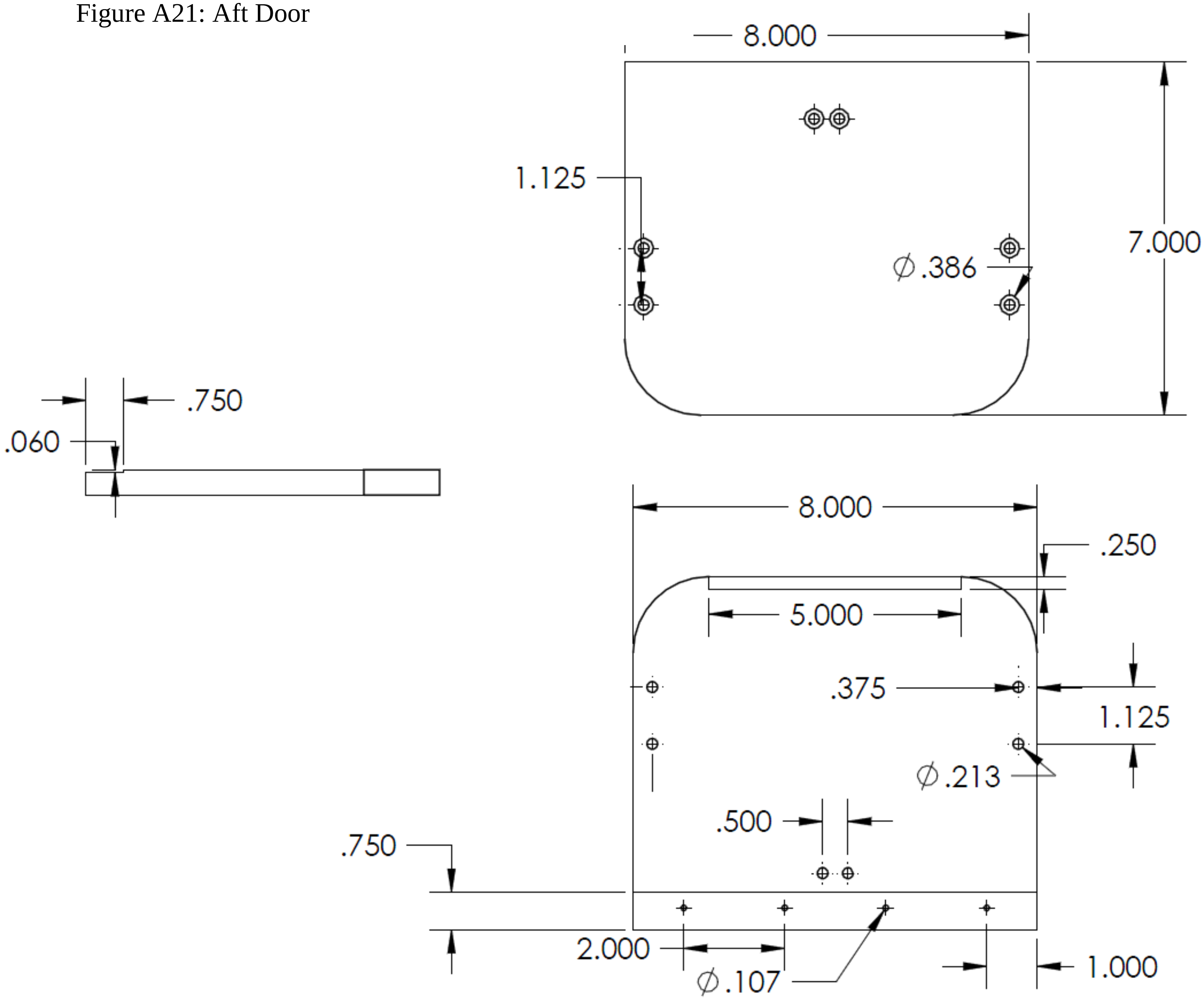


Figure A22: Aft Door Hinges

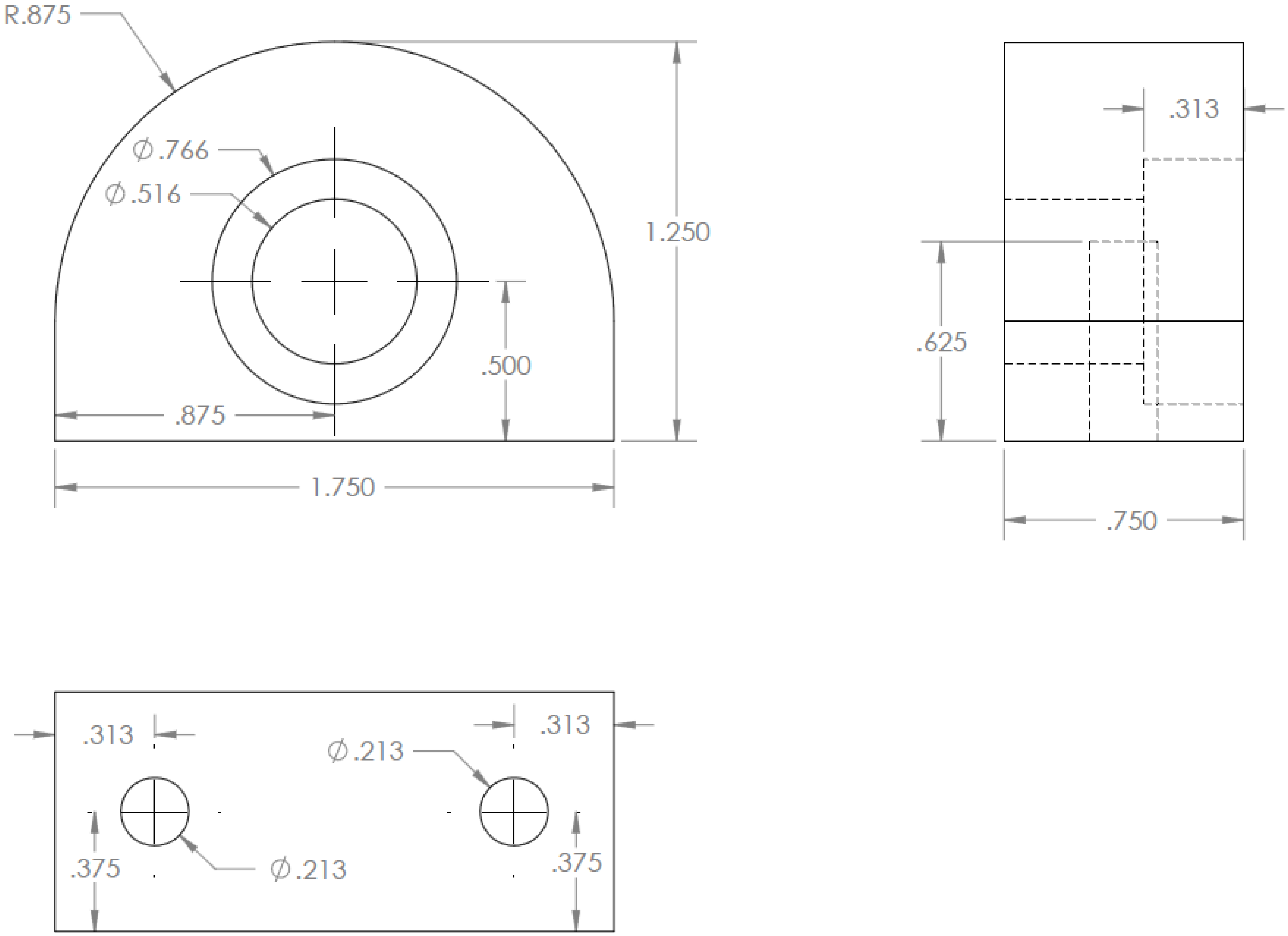


Figure A23: Aft Door Stop

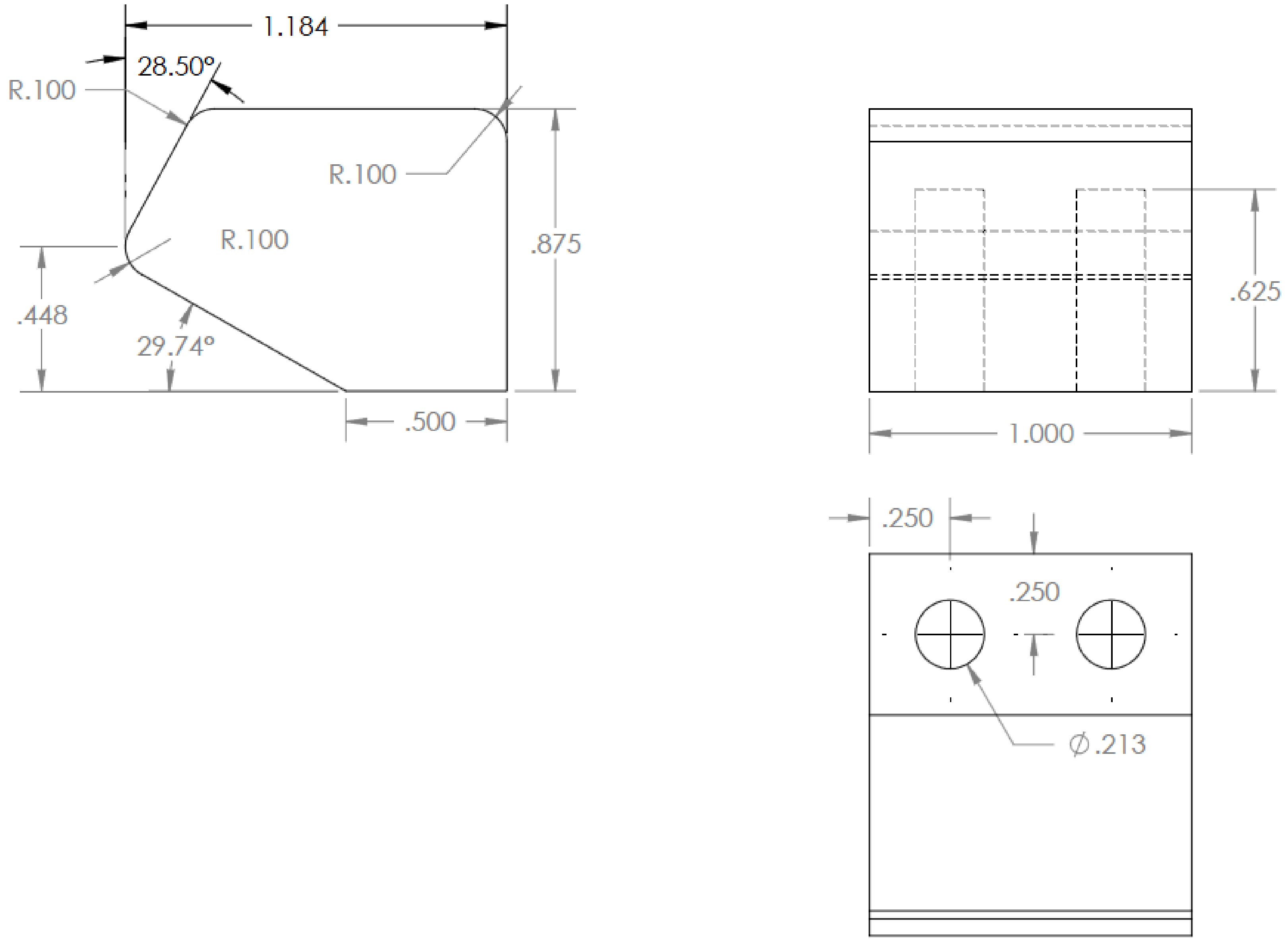


Figure A24: Test Bench Attachment

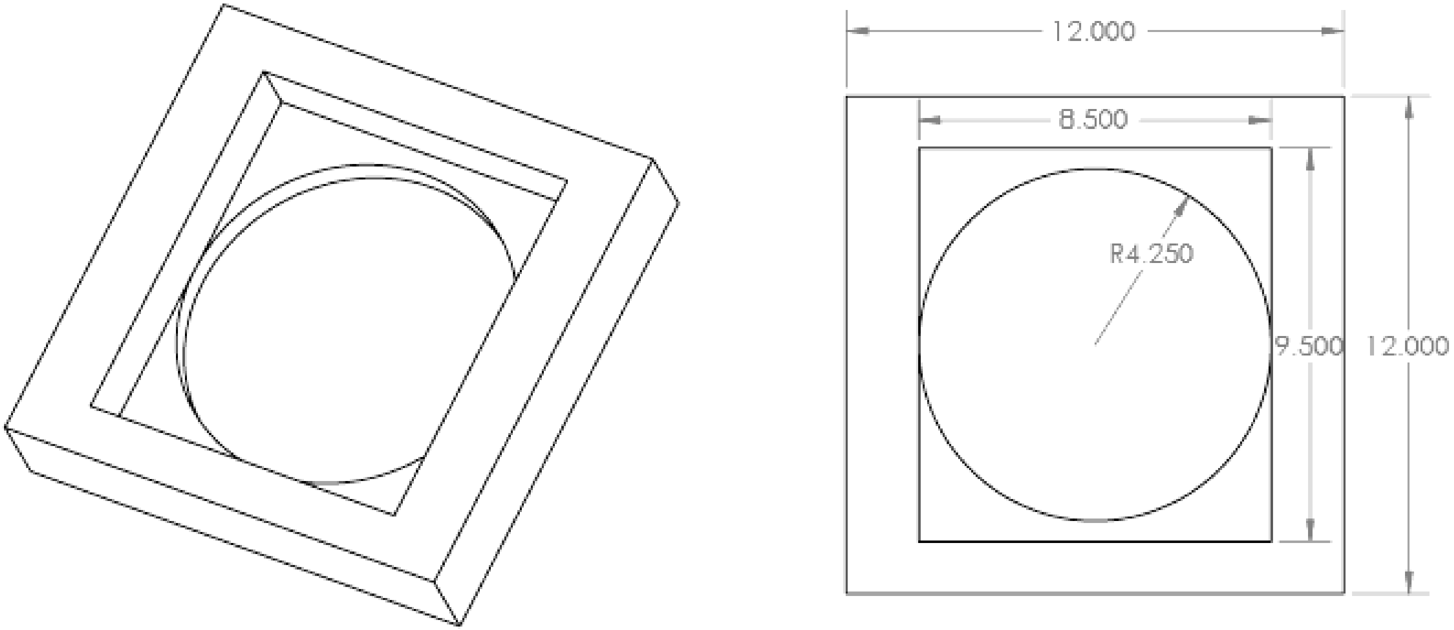
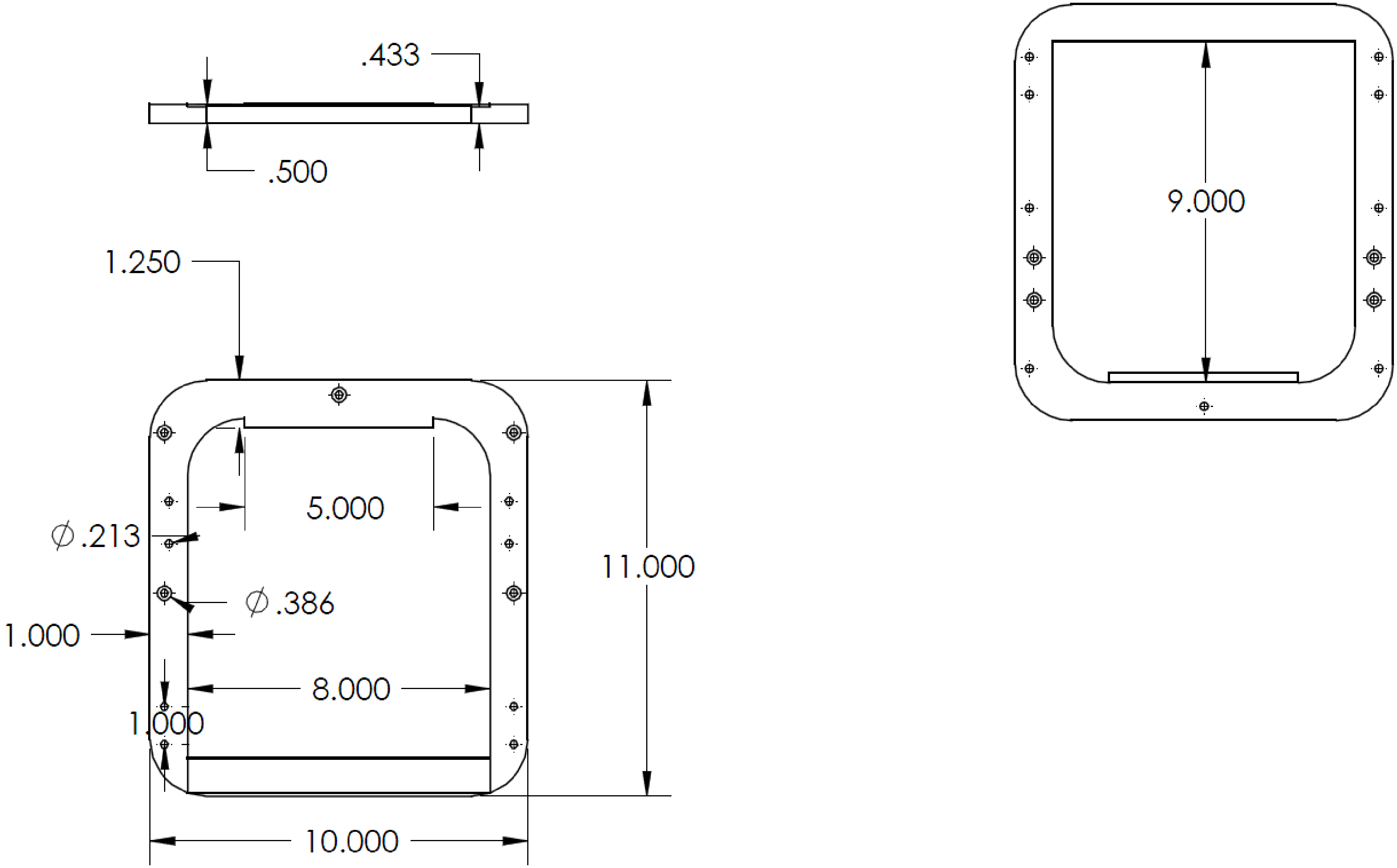


Figure A25: Frame Base



Appendix C: *Software*

The following is the MATLAB code used for determining the actuator torque:

```
% Cruise Door Torque Calculation

   clear all; clc

% Input Dimensions
   fprintf('\n All lengths in inches and angles in degrees.\n\n')
   L_CD = input(' Length of the Cruise Door: ');
   l_3y = input(' Length of the Follower Link: ');
   delta_l = input(' Distance from Center of Cruise Door to Follower Link:
                                        ');
   theta_1 = input(' Angle of the Crank Link: ');
   theta_2 = input(' Angle of the Coupler Link: ');
   theta_3 = input(' Angle of the Follower Link: ');
   l_1 = input(' Length of Crank Link: ');

% Constant Data
   w = 8;
   l_3x = L_CD/2;
   P = 10;
   A = L_CD*w;
   F = P*A;
   dl = delta_l-(l_3y*cosd(theta_3));
   h = l_3y*sind(theta_3);

% Calculate Actuator Torque
   F2 = (F*l_3x)/((sind(theta_2)*(l_3x+dl))+(cosd(theta_2)*h));
   T = (F2*cosd(theta_2)*(l_1*sind(theta_1)))-
            (F2*sind(theta_2)*(l_1*cosd(theta_1)));

% Display Actuator Torque
   fprintf('\n The required actuator torque to open the cruise door is %3.2f
                        in-lbs.\n\n',T)
```

Appendix D: *Budget*

Contractor	Contact Information	Lead times (Weeks)	Price
Industrial Tool Die & Engineering	(520)745-8771 4765 S Overland Drive Tucson, AZ	4-5	$1,900

Part	Part Number	Quantity	Vendor	Price/Unit	Total
Aluminum Block (12” x 12” x 2.5”)	9246K24	1	McMaster-Carr	$197.76	$197.76
Steel Piano Hinge	1569A235	1	McMaster-Carr	$5.88	$5.88
Inclinometer	3353A77	1	McMaster-Carr	$45.76	$45.76
Miscellaneous Supplies	-	-	Ace Hardware	$16.00	$16.00
Shipping					$30.00
				TOTAL	**$295.40**

Supplier	Contact Information	Lead times
McMaster-Carr	(562)692-5911 9630 Norwalk Blvd Santa Fe Springs, CA 90670	1 DAY
Ace Hardware	(520) 882-5700 745 E. 9th St Tucson, AZ 85719	----