Testing apparatus for comparing the performance of inertial measurements units

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TITLE

TESTING APPARATUS FOR COMPARING THE PERFORMANCE OF INERTIAL MEASUREMENTS UNITS

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SUMMARY

Inertial Measurement Units (IMUs) are used to obtain data about an object’s motion. They contain three orthogonal accelerometers and three rate gyroscopes to measure linear accelerations and angular velocities. By integrating these data, the position and orientation of an object can be measured at all times.

These IMUs are used extensively at the Institute for Ocean Technology (IOT), and consequently there are a number of devices available on the premises. Selecting an IMU for a certain application is challenging, so to ease the process, a simultaneous and direct performance comparison of eight of the available units at IOT was proposed. As there was no available apparatus for completing these comparison tests, a suitable apparatus had to be designed and fabricated.

The concept selected for the test apparatus was a pendulum capable of swinging in two axis by means of a two degree-of-freedom universal joint. The pendulum arm itself was four meters in length such that the natural frequency of the apparatus was 0.25Hz. The pendulum arm assembly was supported by a four legged frame, similar in design to a tripod, with the universal joint joining the top of the frame to the top of the arm. Two angle encoders coupled to the universal joint measured the angle of the arm, and a platform that contained all of the IMUs was fastened to the bottom of the arm. Having all of the IMUs fastened to one platform ensured that the devices were experiencing the same motion, therefore a direct comparison of each unit’s performance was valid.

The apparatus was fabricated in IOT’s machine shop and assembled on the premises. Although a number of calibrations have to be performed on the apparatus before reliable results can be produced, preliminary tests were conducted as a “proof of concept”. Preliminary testing was successful, therefore a thorough assessment of the performance of each IMU will be performed using this apparatus in January 2011.

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Executive Summary

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1 Introduction

1.1 Inertial Measurement Units

Inertial Measurement Units (IMUs) are used in a variety of fields to obtain information about an object's motion. They usually measure linear accelerations and angular velocities, and integrate these data to calculate the position and orientation of a body. These devices incorporate three orthogonal accelerometers and three rate gyroscopes, with data analysis and filtering techniques to produce realtime motion information [1]. For example, all modern airplanes, submarines and spacecraft are equipped with at least one IMU that measures the pitch, roll, yaw and heading of the vehicle. Due to the large number of applications where an IMU plays a crucial role, these units must be very reliable, accurate and precise. Choosing a specific unit can also be challenging as the price, required accuracy, and durability must be taken into consideration [2].

1.2 Performance Comparison Testing

At the National Research Council's Institute for Ocean Technology (IOT), inertial navigation systems are used regularly when completing scale model tests of different vessels. IMU are also critical in the development of Autonomous Underwater Vehicles (AUVs), as there is no input from an operator to correct the heading of a vehicle when it's in the water, and using other navigation systems, such as GPS, is impossible. With such a large demand for these devices, IOT has accumulated a wide variety of IMUs. Although many of these units were purchased for a specific application with certain requirements in mind, there has not a been conclusive comparison test of the available IMUs to determine which units excel in certain environments. This is the underling purpose for constructing a test-apparatus that can simultaneously test all the available IMUs, the end result being a direct comparison of the performance of each unit.

2 Mechanical Design Process and Fabrication

2.1 Concept Selection

A testing platform that could perform the comparison tests was not available at IOT, therefore an apparatus had to be designed and fabricated, or a commercial product had to be purchased. The proposal to test all of the IMUs simultaneously required that all the units to be fastened to the same "platform." The platform had to be actuated in some way to achieve a desired motion, and the movement of the platform had to be accurately recorded in order to compare with the output of the IMUs.

There are a number of devices that are used in industry to calibrate IMUs, and a couple of them were considered for comparison testing purposes. The first device was a three degree of freedom (d.o.f) gyro table, as seen in Figure 1. The platform with all of the IMUs would be mounted to the center gyro, and would spin the IMUs in pitch, roll and yaw. Another option was to use a Stewart Platform, as seen in Figure 2. This device uses six hydraulic, pneumatic or electric actuators to move the top platform with 6 d.o.f; three linear translations in x, y and z, and rotations in pitch, roll and yaw.

Figure 1: Gyro table

Figure 2: Stewart platform

Both of these devices have adequate performance in terms of achieving the desired motion, however they are expensive and fairly complex units. To reduce cost and complexity, the concept selected for the testing apparatus was a simple pendulum with two d.o.f. This design required mounting the platform containing all of the IMUs to the end of a pendulum arm.

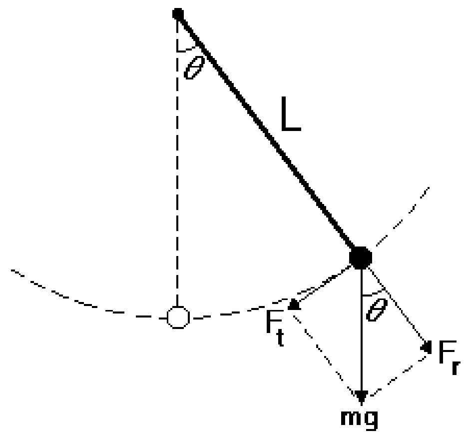


Figure 3: Simple pendulum

2.2 Apparatus Specifications

After the concept for a testing apparatus was selected, a list of specifications was produced. A detailed design that met these requirements was critical for a successful set of comparison tests. The apparatus was required to:

- be a free standing structure.
- have a pendulum arm 4 m in length, such that it had a period of approximately four seconds.
- have two independent, orthogonal axis about which the arm can swing.
- be able to complete at least ten cycles, or swings, before the motion decayed significantly.

- have two angular displacement encoders, one for each axis, to measure the position of the arm.
- have a "platform" at the end of the arm, to which six or seven inertial measurement units, a power source, data acquisition system, and any other required electronics would be mounted.
- have a three or four legged collapsable frame with "feet" for stability.
- be secured with sandbags or anchor bolts if required.
- utilize off-the-shelf components wherever possible.
- utilize in-stock materials wherever possible during construction.

One of the specifications above required the natural frequency of the pendulum to be 0.25 Hz [3]. The reason for this is that Marport Deep Sea Technologies Inc. is involved in the IMU comparison testing, and they wanted the natural frequency of the pendulum to correspond with the natural frequency of their AUV, the SQX-500, in pitch and roll. This ensured that the motion, and performance, of the IMUs during testing would be similar to what they would encounter during the regular operation of the AUV.

2.3 Mechanical Design

The specifications listed above guided both mechanical design of the apparatus and the design of the platform that contains all of the electronics. A model of the apparatus was created using SolidWorks CAD design software, as seen in Figure 4. This allowed not only an accurate visualization of the apparatus, but additional features available in SolidWorks, such as physical dynamics and interference detection, were valuable tools when refining the design.

The apparatus can be broken down into three main sections; the free-standing frame structure, the pendulum arm capable of swinging with two d.o.f, and the platform containing the electronics. Although the design of each section is not completely independent from the others, this modular design approach was still taken. The three modules were combined to complete the final assembly.

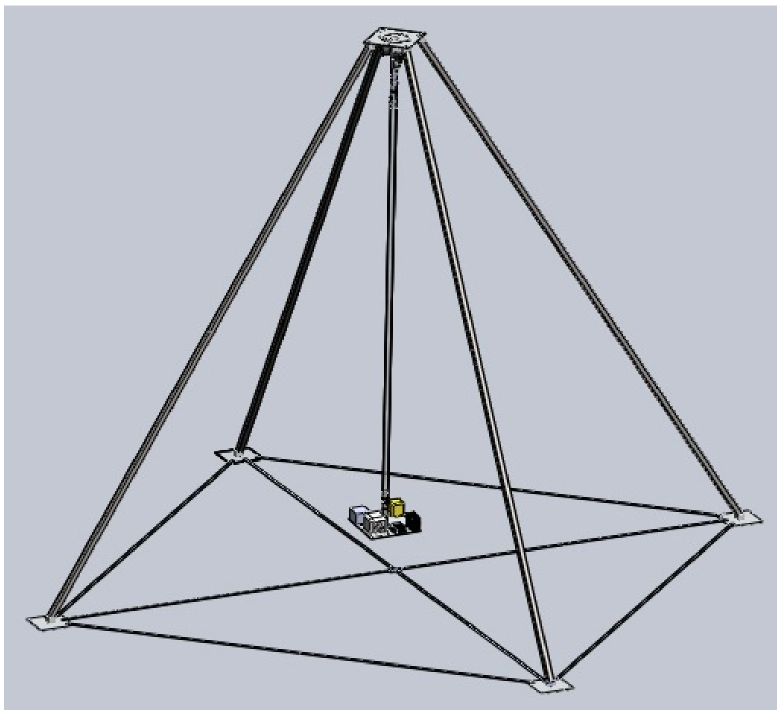


Figure 4: SolidWorks 3D model of the pendulum apparatus

2.3.1 Free-Standing Frame

The design of the frame structure was based on a simple tripod design. However, for extra stability when the pendulum arm was swinging, four "legs" were used instead of three. Also for stability, a "support pad" was also fastened to the end of each leg. To position the legs in a repeatable way every time the apparatus was assembled, four pieces of aluminum bar stock were fastened between the pads, forming a square floor-frame, seen in Figure 5. To keep this square frame from twisting, additional bar stock was added in a "X" configuration.

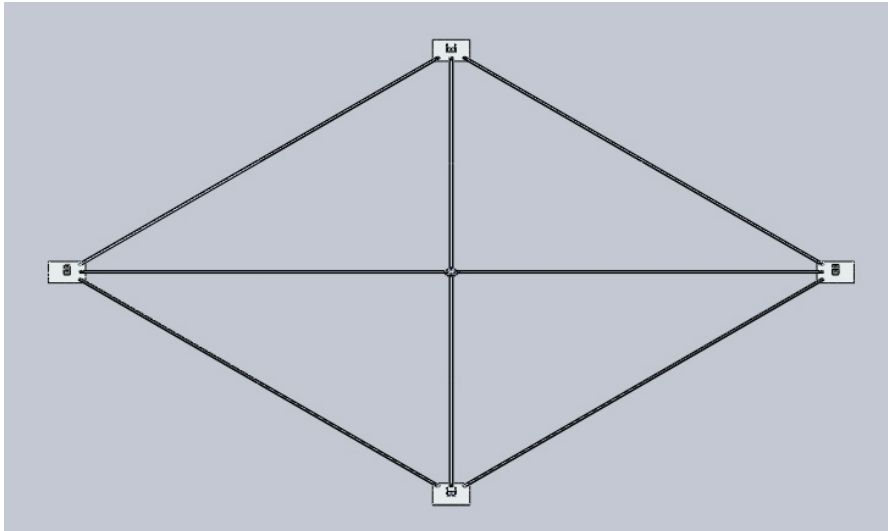


Figure 5: Floor frame made from aluminum flat bar

At the top of the frame, the four legs were fastened to a horizontal mounting plate. Mounting tabs made from pieces of aluminum channel were used to pin the legs to the support pads and top mounting plate.

The dimensions and geometry of the frame were restricted by the required length of the pendulum arm, and the fact that the arm must swing 30 degrees from the vertical without any interference. Therefore, each leg was angled away from the top plate at 35 degrees from the vertical for clearance. Also, the height of the frame was dimensioned to be 4.5 m, thus making the square footprint of the apparatus approximately 5 m by 5 m.

The entire frame structure was made from aluminum for its lightweight and good machining characteristics. The four support legs were made from 50.8 mm aluminum square tubing with 3.2 mm wall thickness. The support pads and top mounting plate were made from 6.35 mm aluminum plate, and the floor frame was made from 38.1 mm by 6.35 mm aluminum flat bar. As mentioned previously, the mounting tabs were made from sections of 76.2 mm x 50.8 mm channel with 9.5 mm wall thickness [4].

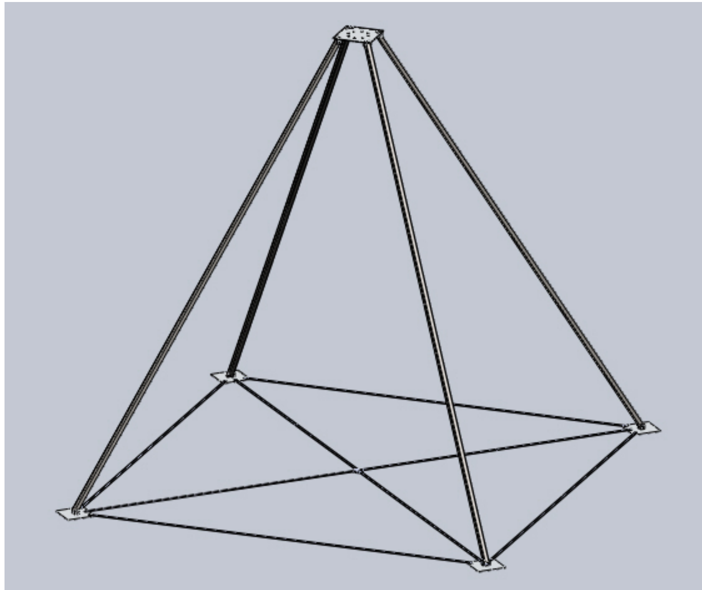


Figure 6: Assembled frame structure

2.3.2 Pendulum Arm Assembly

The design of the pendulum arm itself was quite simple, as it was only a 4 m long piece of 38.1 mm aluminum tubing with 5.08 mm wall thickness. Most of the design work for the arm assembly went into making the arm capable of swinging about two axes, and being able to measure the position of the arm at any given time.

To get the required two degrees of freedom of the pendulum arm, the design of the arm pivot was based on a simple universal joint, also known as a Cardan joint. These two d.o.f joints are based on the design of gimbals and are commonly used for power transmission between two shafts. With slight modifications to the standard design, a universal joint was the best option to achieve the required motion in the pendulum arm yet would allow the rotation about each axis to be separately measured.

As seen in Figures 7, 8 and 9, the design of the pivot for the pendulum consisted of two "yokes" that were positioned orthogonal to each other. A 12.7 mm shaft ran through each yoke and through a "gimbal block," which connected the two yokes together. The rotation of the shafts was coupled to the rotation of the gimbal block due to the dowel pins that were inserted through both parts. Each shaft was supported by two ball bearings, which were housed in the yokes, to reduce friction thus making the motion of the arm decay more slowly over time.

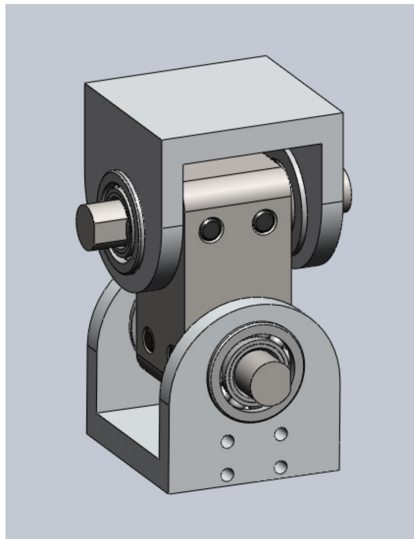


Figure 7: Universal joint design

The rotation of the shafts, and therefore the position of the arm, was measured with two Trans-Tek angle encoders with “infinite” resolution (depending on the analog to digital converters) . One of the encoders was fastened to the top mounting plate, and the encoder shaft was coupled to the shaft that ran though the top yoke. The second encoder was mounted to the pendulum arm itself, and the shaft of this encoder was coupled to the shaft that ran though the bottom yoke. By combining the outputs from the two encoders, and knowing the geometry of the arm assembly, the position, orientation and expected accelerations of any point along the arm or platform can be calculated.

As seen in Figure 9, the top yoke was welded to a piece of pipe, and the pipe was welded to another plate. This assembly gets bolted to the top mounting plate, seen in Figure 8. The bottom yoke was also welded to a piece of pipe, along with a bracket to mount the lower encoder. To ease assembly and disassembly of the apparatus, the 4 m arm was designed to be

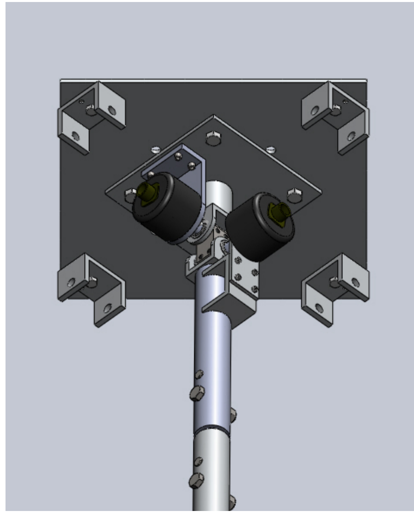


Figure 8: Angle encoders attached to universal joint

removable. To attach the arm to the universal joint, the pendulum arm pipe was placed over, and pinned to, a "spigot" that was also inserted and pinned to the piece of pipe on the universal joint.

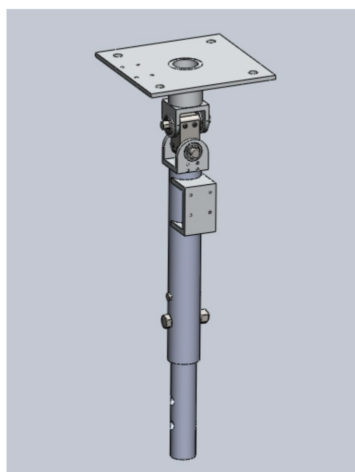


Figure 9: Universal joint assembly

2.3.3 Electronics Platform

The design of the platform that contained all of the IMUs units was constrained by two things; the platform had to be large enough so all of the IMUs could be mounted, and once the platform was assembled it had to be balanced so that the motion of the pendulum remained as natural as possible. A list of the IMUs that were selected for performance comparison testing can be seen in Table 1 below.

IMU	Manufacturer	Approx. Price
PHINS ™	IXsea	$100,000
Crossbow NAV440	Crossbow Technology Inc.	$35,000
Watson AHRS-E304	Watson Industries	$10,000
MotionPak II ™	Systron Donner	$5,000
Xsens MTi ™	Xsens	$3,000
Microstrain 3DM-GX1	Microstrain	$2,000
iSensor 16360	Analog Devices	$100
Mini MotionPak	IOT	$300

Table 1: Selected IMUs for comparison testing

Along with these nine units, a Data Acquisition System (DAS), six Lithium-ion batteries, two DC/DC converters, and some terminal blocks were required to be mounted to the platform. A 3D model of each IMU, along with the other electrical components, was produced so the platform could be laid out in the most efficient way possible. All of the electronics were weighed, and their mass properties were inserted into their respective SolidWorks models. The position of each model on the platform was decided by trial and error; a potential arrangement was decided upon, then the center of mass of the platform was calculated. If the center of mass was not close enough to the center of the plate, within tolerance, then the process was repeated.

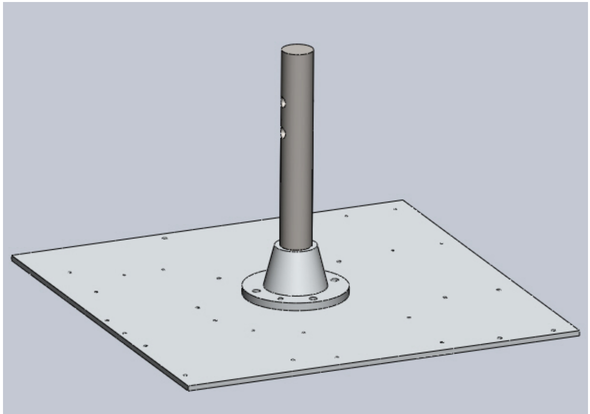


Figure 10: Platform with flange

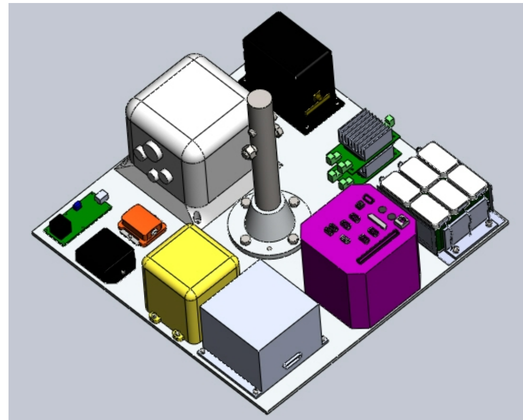


Figure 11: Platform with electronics

The platform itself was simply a square piece of 6.35 mm aluminum plate. A number of holes were drilled and tapped to secure the electronic components with threaded fasteners. The final dimensions of the platform to accommodate the electronics was 508 mm square. In order to fasten the platform to the bottom of the pendulum arm, a flange assembly was added, seen in Figure 10. This flange gets bolted to the platform with four fasteners, and pinned to the arm with a 12.7 mm dowel pin.

2.3.4 Final Assembly

After the initials designs for each of the three sections were complete, the individual assemblies were integrated into one final assembly. Any small issues with the design were quickly noticed and fixed. Once the assembly was problem free, engineering drawings were produced for each component for the fabrication process.

2.4 Fabrication

The fabrication of the pendulum apparatus was completed in IOT's machine shop. As previously mentioned, the design of the apparatus was kept as simple as possible to reduce fabrication time. Along with this, the majority of the components were machined from 6061 aluminum, which has very good machining characteristics, and thus reduced fabrication time.

Fabrication of the apparatus required the use of a manual milling machine and lathe. There was no computer numerical controlled machining required, which saved time and money. Examples of machining set-ups and procedures can be seen in the following images.

Figure 12: Machining the universal shafts

Figure 13: Bridgeport milling machine

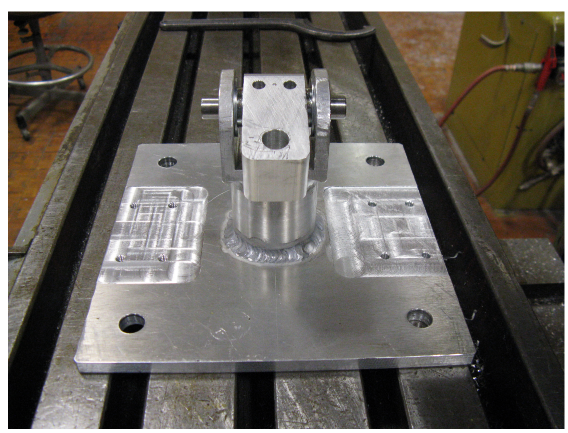


Figure 14: Top universal assembly

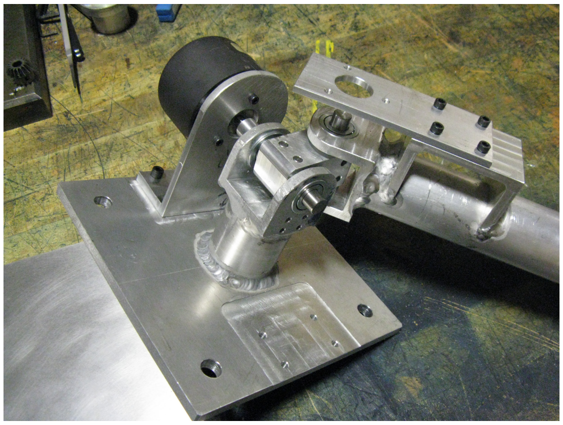


Figure 15: Universal assembly

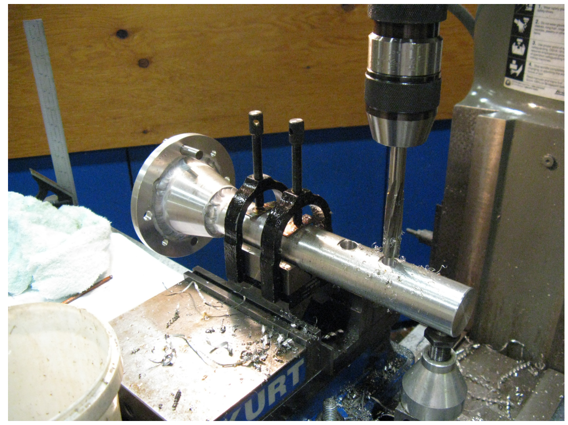


Figure 16: Machining the flange

3 Set-up Procedures and Calibration

3.1 Assembling the Apparatus

After fabrication was complete, the apparatus was assembled at the far end of the Clear Water Towing Tank in IOT. Due to the size of the pendulum apparatus, certain procedures had to be followed during set-up, and are summarized in the following list:

1. The floor frame, made from the aluminum flat bar and the support pads, was laid out and bolted together.
2. The mounting tabs were pinned and bolted to the four support pads.
3. The universal joint assembly and the pendulum arm were pinned together.
4. The four support legs, along the pendulum arm assembly, were laid horizontally on the floor.
5. Four mounting tabs were fastened to the top mounting plate, along with the four support legs and pendulum arm assembly.

6. The top mounting plate, support legs and arm assembly were then hoisted vertically using an overhead crane, and positioned in the center of the floor frame.

7. Each support leg was moved to its support pad at the corner of the frame and bolted to the mounting tabs.

8. The two angle encoders were installed onto the universal joint, and their cables were wrapped down the pendulum arm.

9. All the electronics were fastened to the platform, the flange assembly was installed, and then the platform was pinned to the bottom of the arm.

Figures 17 through 20 show the assembled appartus.

Figure 17: Installing the encoders

Figure 18: Arm swinging for first test

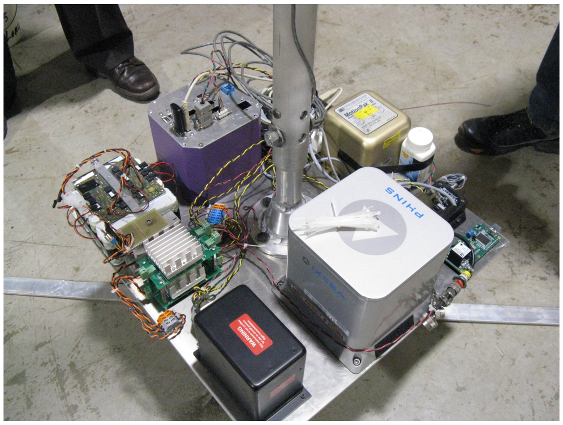


Figure 19: Installed electronics platform

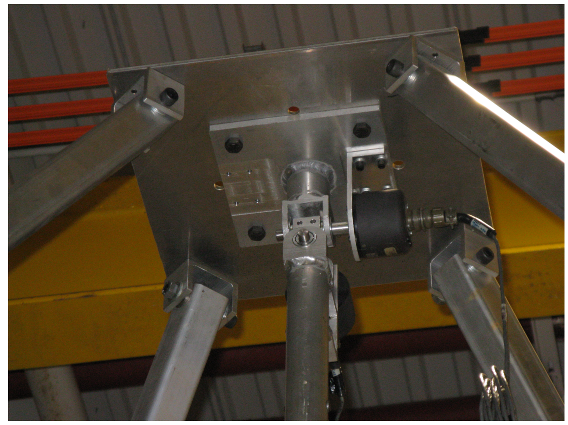


Figure 20: Top mounting plate

3.2 Calibration

Once the apparatus is assembled, certain calibrations have to be performed. For example, the angle encoders have a linear range in their output from -30 to +30 degrees. The design of the mounting brackets for the encoders required that a reference "notch" on the end of the encoder shafts be pointed straight down, inline with the axis of the pendulum arm. Therefore, if the shafts are not positioned correctly when they are coupled to the universal shafts, the output from the encoders will not give the true position of the pendulum arm, and a calibration is required.

Along with this, each of the IMUs has its own origin and coordinate system. For example, some of the units might follow the "left-hand rule" while others will use the "right-hand rule" when measuring accelerations. Also, the way the units are arranged on the platform, some devices may be measuring "pitch" while others will be measuring "roll" for the exact same motion. This is not an issue, however, because the IMUs use the same components to measure accelerations along each axis, so there will be no bias in that regard.

During data analysis, the different coordinate systems and positions of the devices on the platform will be accounted for. This will be achieved by choosing one origin and coordinate system on the platform itself, and the origins and coordinate systems of all the devices will be referenced from that by a simple translation and rotation. This will make a direct comparison of the performance of each unit much easier.

Other calibrations that will be required are due to inaccuracies during the machining process. For example, the two shafts going through the “gimbal block” may not be exactly orthogonal to each other. Also, there are multiple pinned connections from the universal joint down to the platform. Therefore, if the encoders output motion only in “pitch,” for example, the IMUs units on the platform may also be experiencing a small amount of “roll” as well due to small misalignments in the pinned connections.

4 Testing Procedures and Data Analysis

4.1 Testing Procedures

There will be two main types of tests performed using the pendulum apparatus. The first type of test is static in nature, and involves holding the pendulum arm at a specified angle for a period of time. The purpose of this test is to compare the performance of the IMUs in terms of integration “drift.” This is the phenomenon where small errors in acceleration measurements get integrated into larger errors in velocity, and even larger errors in position. All IMUs are subject to this type of unwanted behavior which can be detrimental for long duration applications. These tests will determine which IMUs are better suited for long mission times.

The second type of testing to be performed using the apparatus is dynamic, and involves allowing the pendulum arm to swing freely. The dynamic tests will include pure pitch and roll tests where the arm is swinging in a single plane, as well as tests with a combination of pitch and roll where the platform is moving in an elliptical path. The results from the dynamic tests will determine which units are better suited to applications where there are higher acceleration rates, and where short term accuracy is critical.

As mentioned previously, the pendulum apparatus only has two degrees of freedom, which means it can test the units in terms of pitch and roll, but not it yaw. To get around this, the platform containing the IMUs will be removed from the bottom of the pendulum arm, and placed on a rotary table available at IOT. This rotary table will be able to complete any yaw tests that are required. Combining the results from the static, dynamic and rotary table tests will give a thorough performance comparison of the available IMUs.

4.2 Sources of Error

One possible source of error in the results could come from improper calibrations during set-up. An error such as this would show up as a constant offset throughout the entire data set. Another source of error that would be harder to notice is that the pendulum arm may deflect over its 4 m length. This would result in the measured angle from the INS units to be different from that measured from the encoders at the top of the arm.

The platform containing the INS units could also deflect a small amount under load. Consequently, certain regions on the platform might deflect to different angles, causing discrepancies in the outputs from the devices. Seeing as how the platform is well balanced, this effect should be kept to a minimum.

Another possible source of error, or unwanted "noise" in the data, was observed during assembly. If the pendulum arm was subjected to a "hit" or impact, this induced a high frequency vibration along its length and in the platform, and these accelerations would be picked up by the IMUs. This would appear in the results as a high frequency signal from the vibrations overlaid on the low frequency signal from the motion of the pendulum. If this is the case for some of the tests, a simple filter could be applied to remove the unwanted "noise."

4.3 Preliminary Results

Initial testing was performed on five of the IMUs. The data were recorded using the PC-104 DAS that was located on the platform along with the other electronics. The two angle encoders were not used for the first test because an analog to digital converter was not available.

The five units that were tested for the initial run were the PHINS, Watson, Xsens, Microstrain and MotionPak II devices. Three dynamic tests were performed; one test attempted pure "roll" in the pendulum arm, one test was pure "pitch," and the final test was a combination of the two whereby the platform travelled along a "circular" or "elliptical" path.

Figure 21 shows the output from the PHINS in pitch and roll. The green line is roll, and red is the pitch, the horizontal axis shows the time in seconds and the vertical axis shows the measured angle from the unit in degrees. As seen on the image, this test was not purely in roll as intended. The pendulum arm was not pulled back exactly on the roll plane when it was released. Therefore, as the arm began to swing back and forth, it also began to "walk" around the frame in a similar fashion to precession in a Focault pendulum. As the roll began to decay, the pitch was increasing in amplitude indicating precession in the motion.

The second test was intended to be purely in pitch, and the result was much more successful than the previous attempt. Once again, Figure 22 shows the output from the PHINS unit in pitch and roll. One observation that can be noted from this graph is the exponential decay in the motion of the pendulum arm. By fitting a curve to these data, damping coefficients can be determined that include air resistance and friction within the bearings. Also, seen in Figure 23, which is a close up view of two of the peak amplitudes, the period of this swing if very close to 4 seconds, indicating a frequency of approximately 0.25 Hz.

The final dynamic test that was performed was a combination of pitch and roll, i.e the platform was swinging around in a circular fashion. Figure 24 shows the output from the PHINS. This

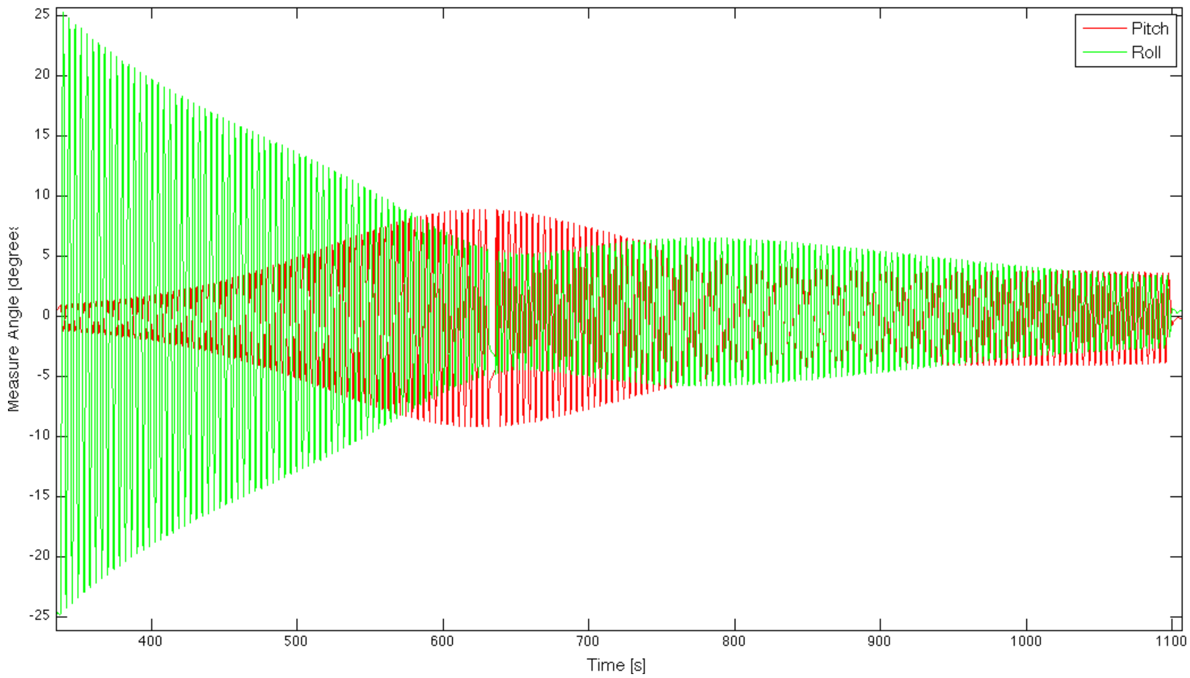


Figure 21: PHINS output in pitch and roll during the first test

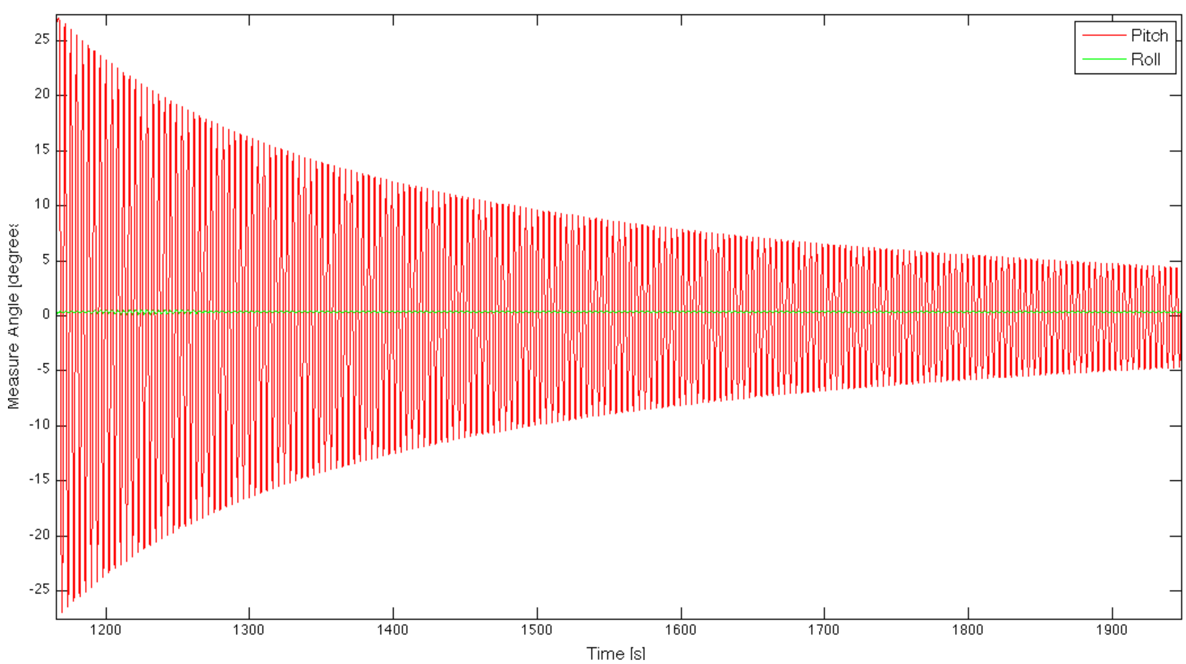


Figure 22: PHINS output in pitch and roll during the second test

graph demonstrates that the platform was swinging with an elliptical path, and along with this, the fact that the larger amplitudes are changing from pitch to roll indicate that there was

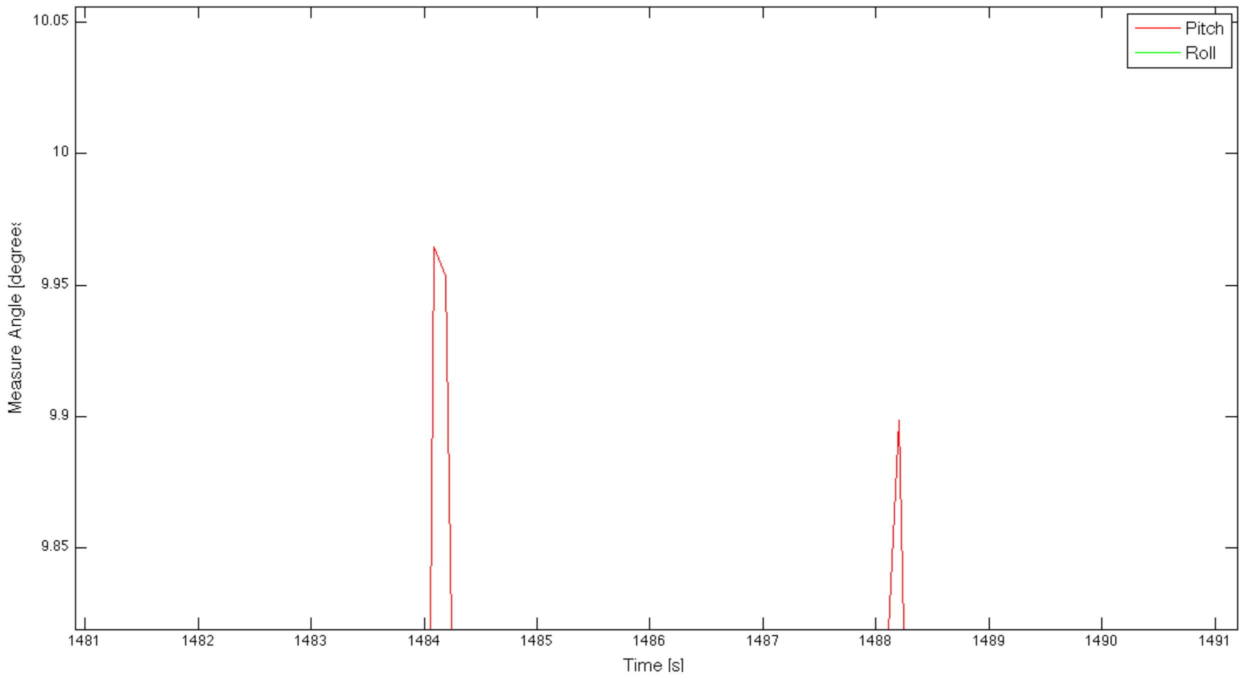


Figure 23: Peak to peak period is approximately four seconds

precession occurring in this test as well.

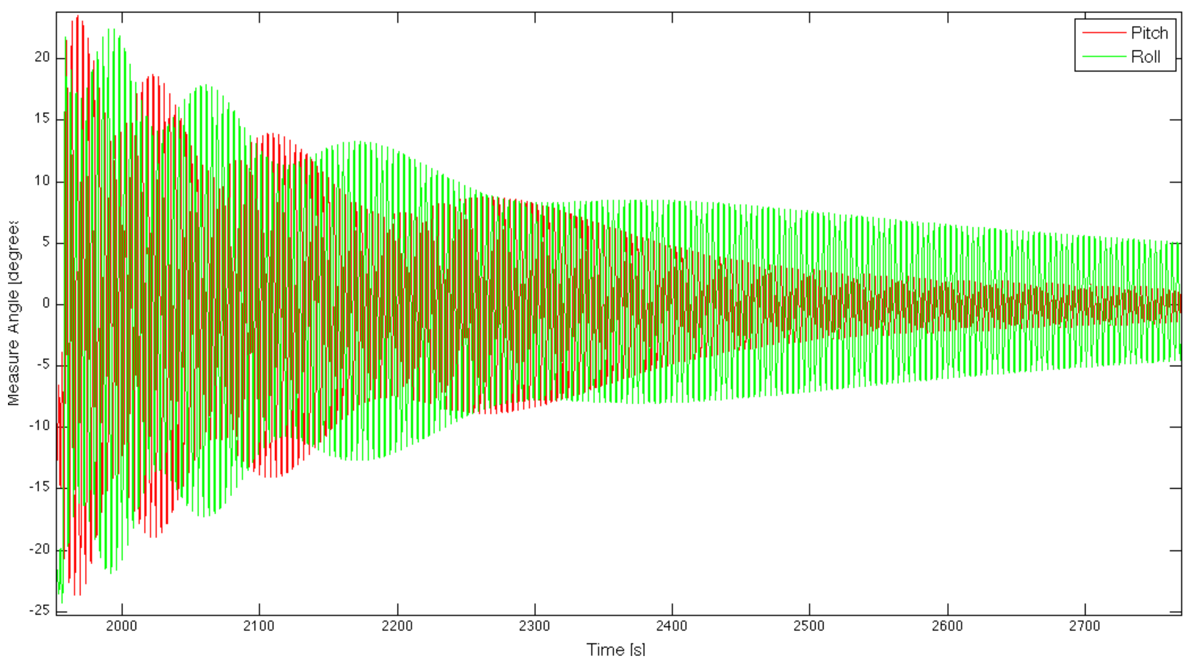


Figure 24: PHINS output in pitch and roll during the third test

The real purpose for testing is to be able to make direct comparisons, and an example of this is seen in Figure 25. This graph compares the output from the PHINS and Watson units in pitch during the second dynamic test that was performed. Their outputs are very similar, however the PHINS measured a larger peak than the Watson. If the angle encoders were available for this test, these results could be compared to the output from the encoders. This would determine which unit was more accurate.

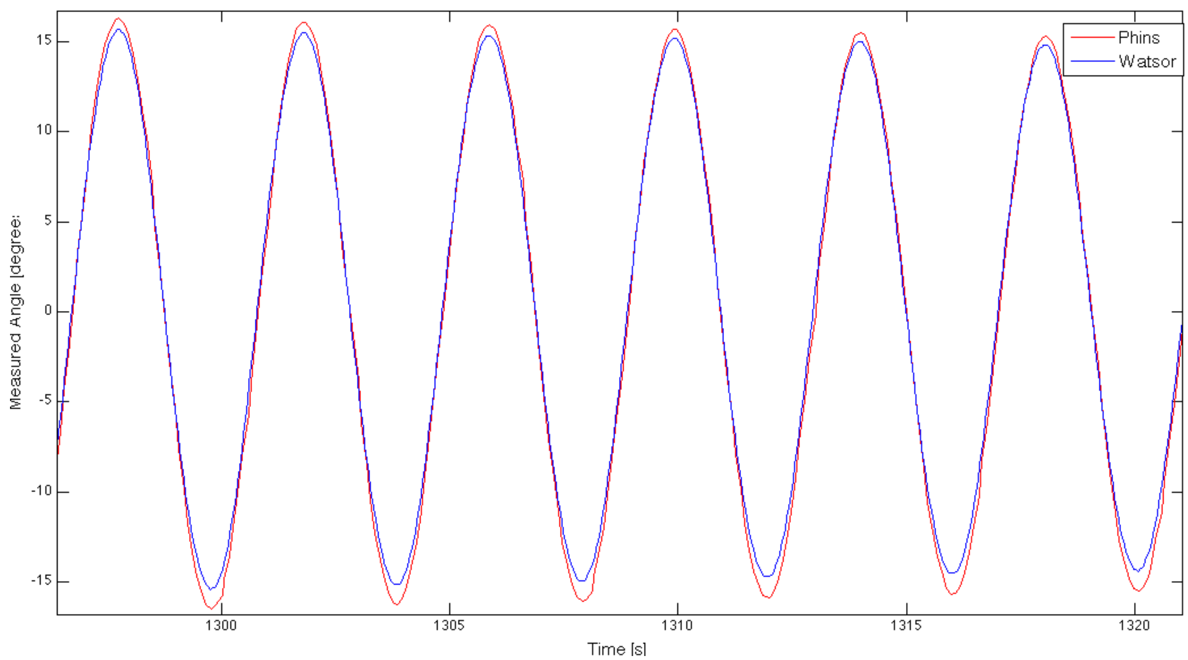


Figure 25: PHINS vs. Watson in pitch during the second test

The previous type of graph is the desired result once complete testing and data analysis are finished. Graphs for pitch, roll, yaw and accelerations will be produced that compare all of the INS. These preliminary tests can not be used for comparison purposes as no calibrations were performed on the apparatus.

5 Conclusions

A direct and simultaneous comparison of several IMUs has never been conducted previously, giving motivation for this type of test at IOT. Comparing the performance of the IMUs available at IOT will provide a reliable reference for researchers when choosing an IMU for a specific application in the future. The following list summarizes the design process and validation of the testing apparatus.

1. A free-standing pendulum was selected as the testing apparatus for its simplicity and low cost.

2. Specifications for the apparatus were defined, for example, the arm must be 4 m in length, be able to swing with two degrees of freedom, and an electronics platform with all of the IMUs would mount to the bottom of the arm.

3. A 3D model of the apparatus was created using SolidWorks software and engineering drawings were produced once the design was finalized.

4. The apparatus was fabricated in IOT's machine shop and assembled on the premises .

5. Preliminary tests verified that the apparatus was fully functional and suitable for comparing the performance of each IMU.

The initial tests that were performed using the apparatus are a "proof of concept," however, no conclusions regarding the performance of each unit can be drawn from the present results. Additional tests will be performed in January 2011 and the assessment will then be completed.

6 Recommendations

The following work should be performed in the future to get reliable and useful results from the performance comparison tests:

- All of the IMUs and the angle encoders should be set up for the actual testing.
- The apparatus should be calibrated as discussed previously.
- During data analysis, determine if any sources of error from the apparatus are invalidating the results, and address them as necessary.
- Perform "yaw" tests on the entire IMU platform on the rotary table available at NRC-IOT.
- Analyze all of the data and compare the relative performance of each IMU.

7 References

[1] A. D. King,“Inertial Navigation - Forty Years of Evolution”. Gec Review, Vol. 13, pp, July 1998, 140-149

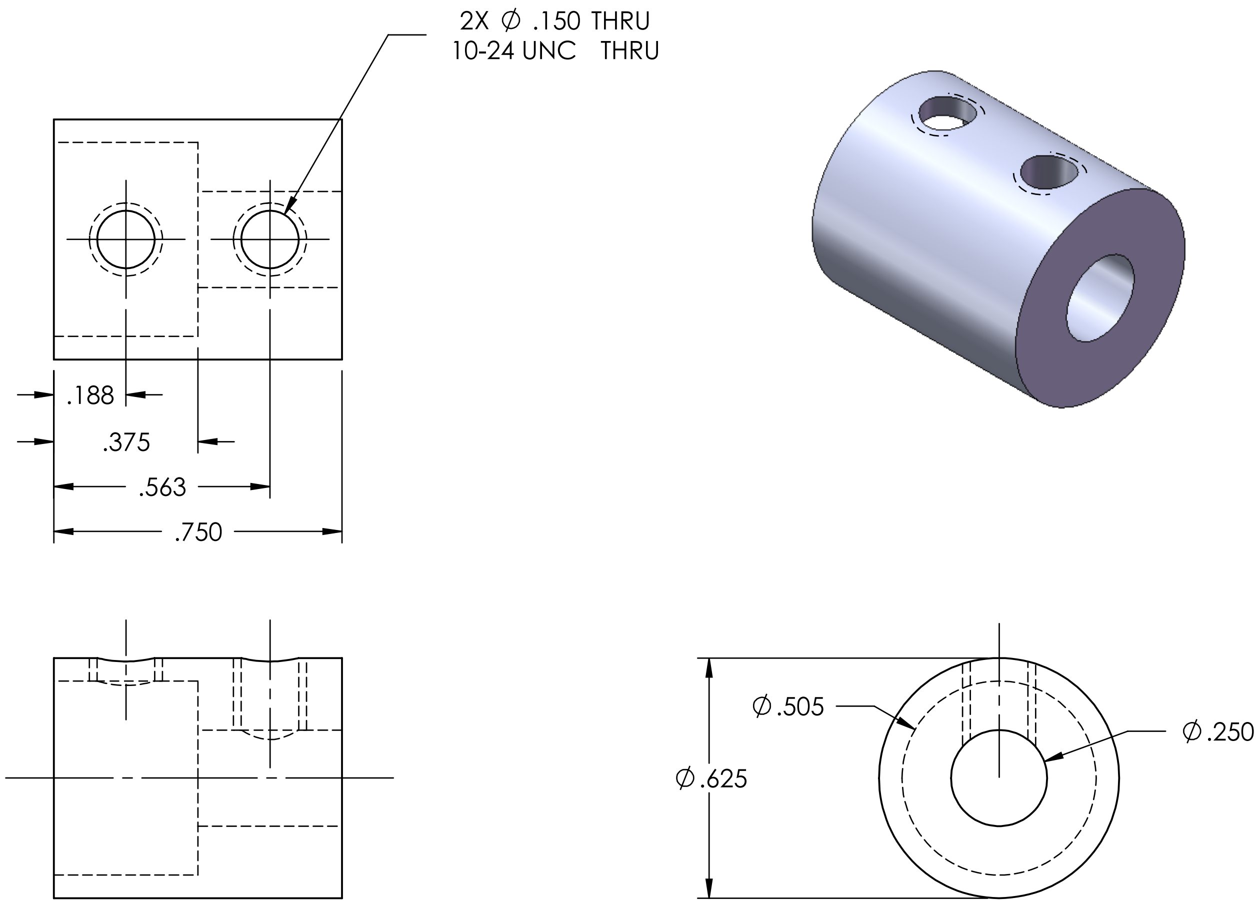
[2] S. G. Smith, “Modern Inertial Technology”. Journal of Navigation, Vol. 46, 1993, p 449

[3] Weisstein, Eric W. (2007). ”Simple Pendulum”. Eric Weisstein’s world of science. Wolfram Research.

[4] Russel Metals,“Tube and Pipe”, p 58, “www.russelmetals.com”

Appendix A

Detailed Drawings



NOTES:

1) QUANTITY: 2

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

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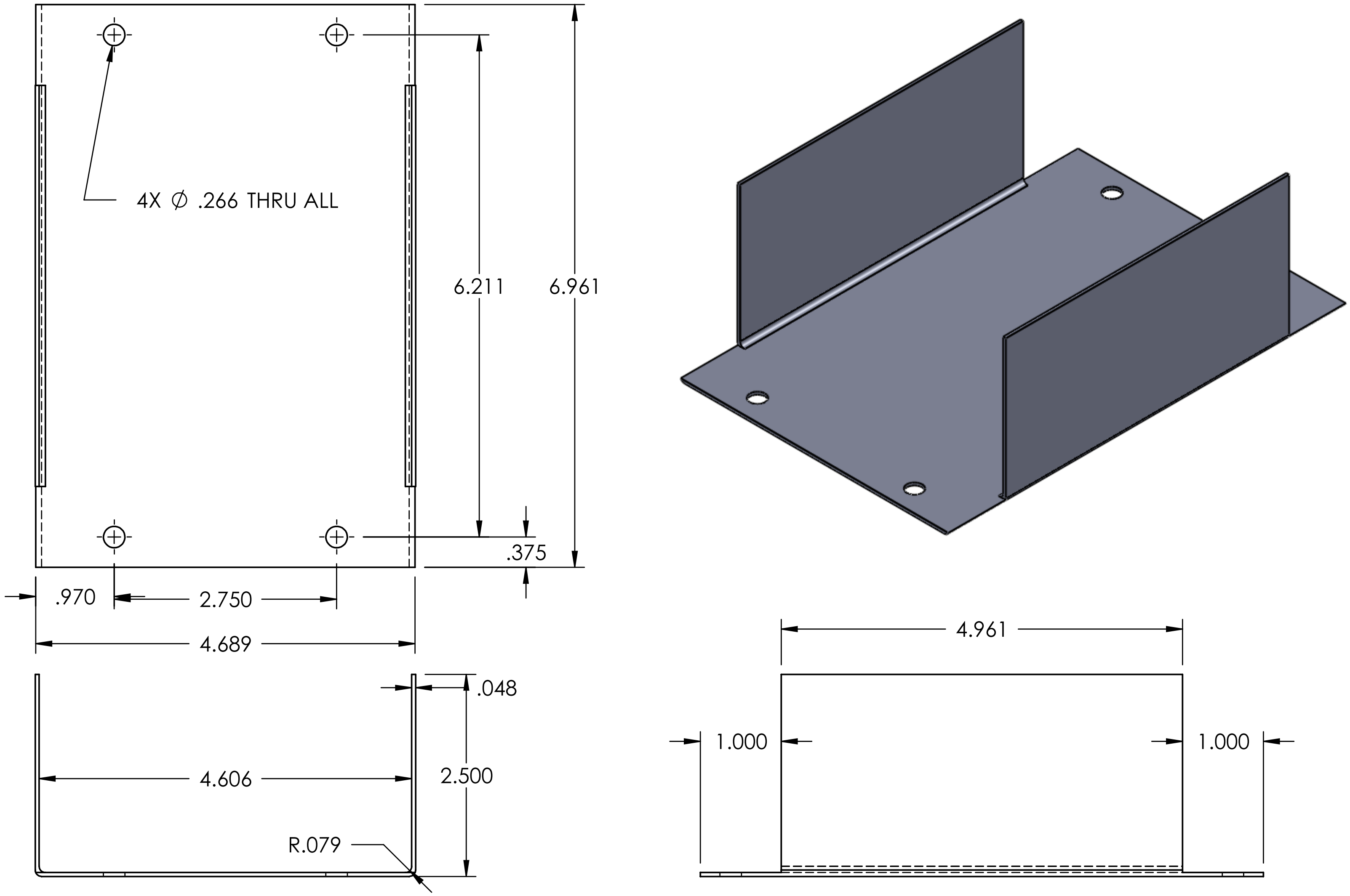
DIMENSIONS IN: INCHES	CHECKED BY:	THE INFORMATION CONTAINED IN THIS DOCUMENT IS CONFIDENTIAL AND SHALL NOT BE MADE PUBLIC, OR COPIED, OR USED AS THE BASIS FOR THE MANUFACTURE, OR SALE OF ITEMS UNLESS SPECIFICALLY AUTHORIZED IN WRITING BY MARPORT CANADA INC. THIS DOCUMENT IS THE PROPERTY OF MARPORT CANADA INC. AND IS SUBJECT TO RETURN ON DEMAND.
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY:	PROJECT TITLE: / ASSEMBLY REFERENCE:
INCHES: X.X ± 0.06; X.XX ± 0.02; X.XXX ± 0.005	DATE: 12/10/2010	DESCRIPTION: ADT SHAFT COUPLING
MILLIMETERS: X ± 1; X.X ± 0.5; X.XX ± 0.1	THIRD ANGLE PROJECTION; DO NOT SCALE DRAWING	PART / DRAWING NUMBER:
ANGLES ± 0.5°	SCALE: 2:1; SHEET SIZE: A	REV LETTER: A; SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY:

2) MATERIAL:

3) FINISH:

4) WEIGHT:

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY DB	MARPORT	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
DIMENSIONS IN MILLIMETERS	CHECKED BY CB		
TOLERANCES UNLESS OTHERWISE SPECIFIED INCHES X.X ± 0.06 X.XX ± 0.02 X.XXX ± 0.005 MILLIMETERS X ± 1 X.X ± .5 X.XX ± 0.1 ANGLES ± 0.5°	APPROVED BY A	PROJECT TITLE	ASSEMBLY REFERENCE
	DATE 31/12/2010	DESCRIPTION	
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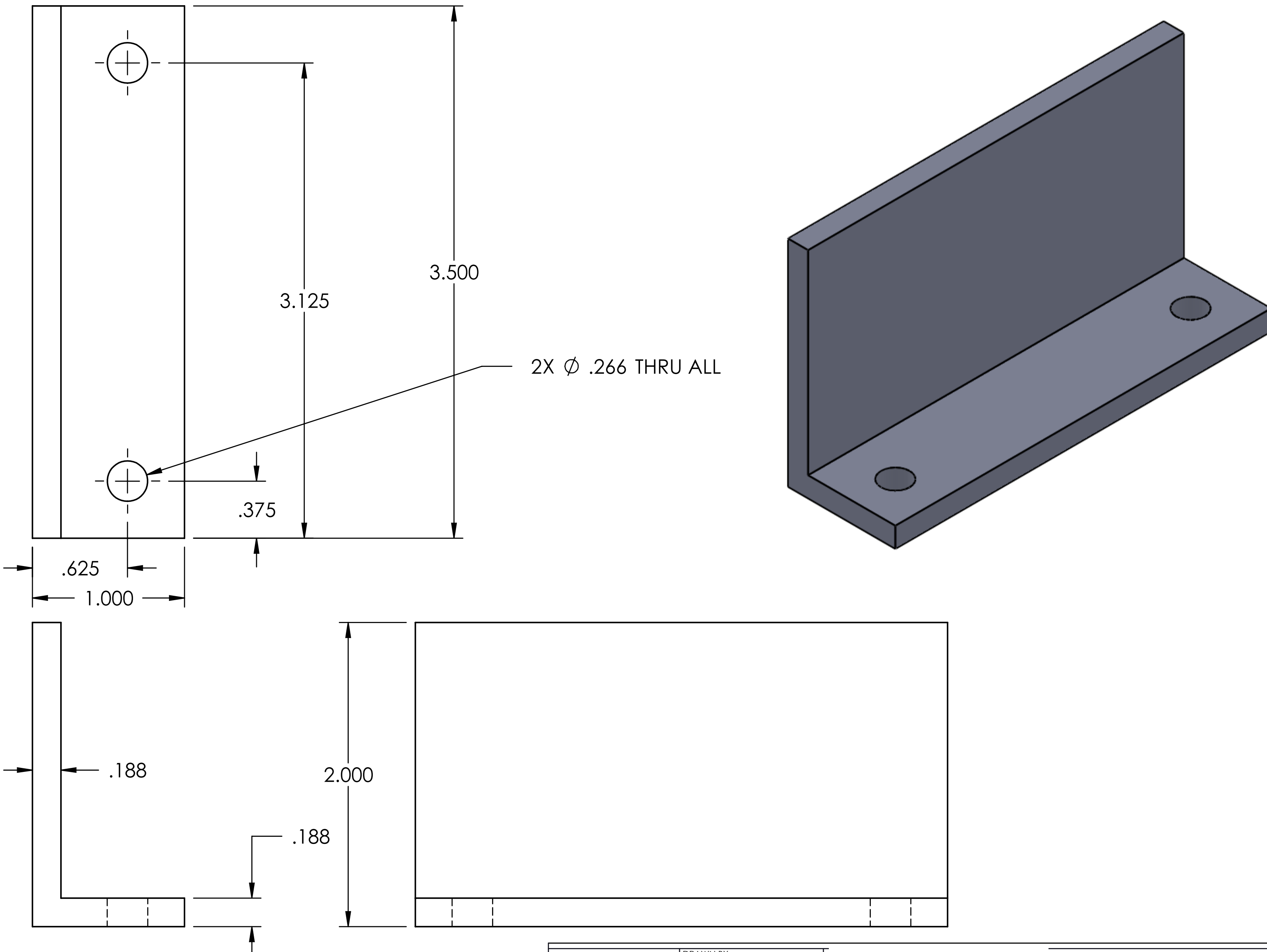
	SCALE 1:5 / SHEET SIZE A		SHEET NUMBER 1 OF 1



NOTES:

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2) MATERIAL: Aluminum Angle

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY T. HOUSE	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
DIMENSIONS IN INCHES	CHECKED BY	
TOLERANCES UNLESS OTHERWISE SPECIFIED INCHES X.X ± 0.06 X.XX ± 0.02 X.XXX ± 0.005 MILLIMETERS X ± X.X ± .5 X.XX ± 0.1 ANGLES ± 0.5°	APPROVED BY	PROJECT TITLE / ASSEMBLY REFERENCE
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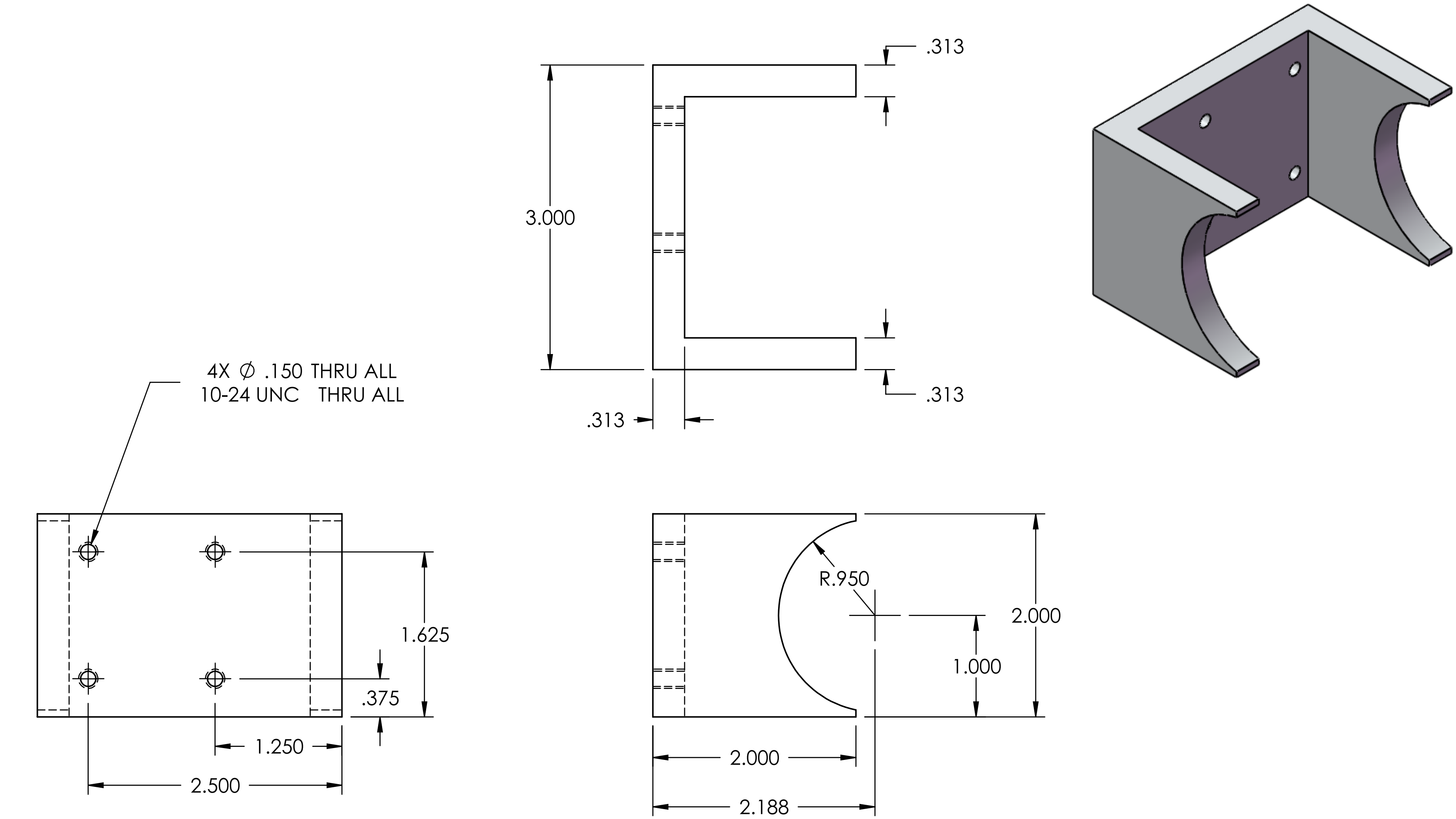

NOTES:

1) QUANTITY: 1

2) MATERIAL: ALUMINUM U - CHANNEL

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 25/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 2:3

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.
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PROJECT TITLE:

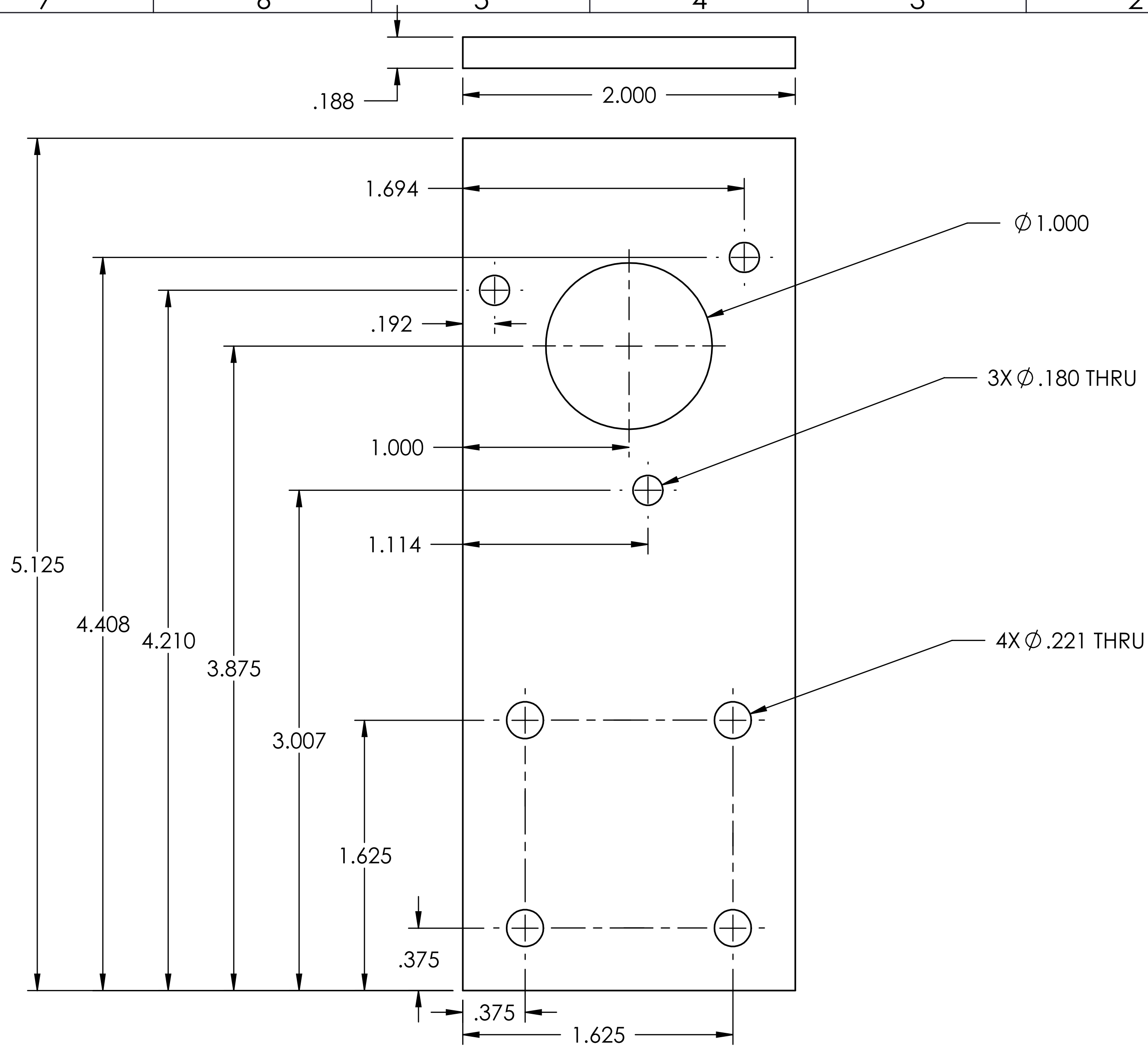
ASSEMBLY REFERENCE:

DESCRIPTION: BOTTOM ADT ARM MOUNT

PART / DRAWING NUMBER:

REV LETTER: B

SHEET NUMBER: 1 OF 1



NOTES:

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2) MATERIAL: 3/16" X 2" ALUMINUM BAR

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY TH	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
DIMENSIONS IN INCHES	CHECKED BY	THE INFORMATION CONTAINED IN THIS DOCUMENT IS CONFIDENTIAL AND SHALL NOT BE MADE PUBLIC, OR COPIED, OR USED AS THE BASIS FOR THE MANUFACTURE, OR SALE OF ITEMS UNLESS SPECIFICALLY AUTHORIZED IN WRITING BY MARPORT CANADA INC. THIS DOCUMENT IS THE PROPERTY OF MARPORT CANADA INC. AND IS SUBJECT TO RETURN ON DEMAND.
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY	PROJECT TITLE / ASSEMBLY REFERENCE
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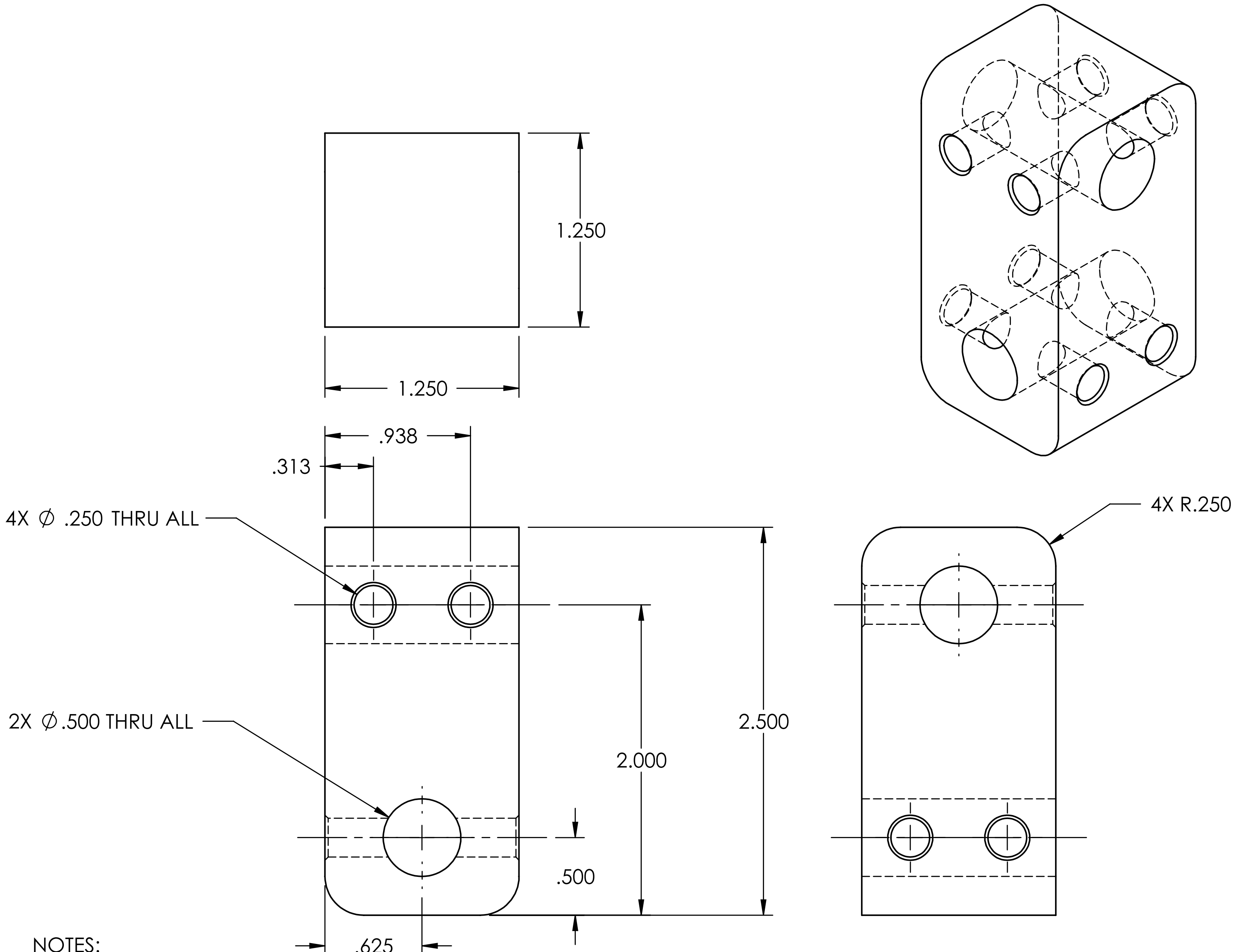

NOTES:

1) QUANTITY: 1

2) MATERIAL: ALUMINUM

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4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

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X.XX	± 0.02
X.XXX	± 0.005

MILLIMETERS

X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 08/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:1

SHEET SIZE: A

MARPORT

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ASSEMBLY REFERENCE:

DESCRIPTION: CENTER BLOCK

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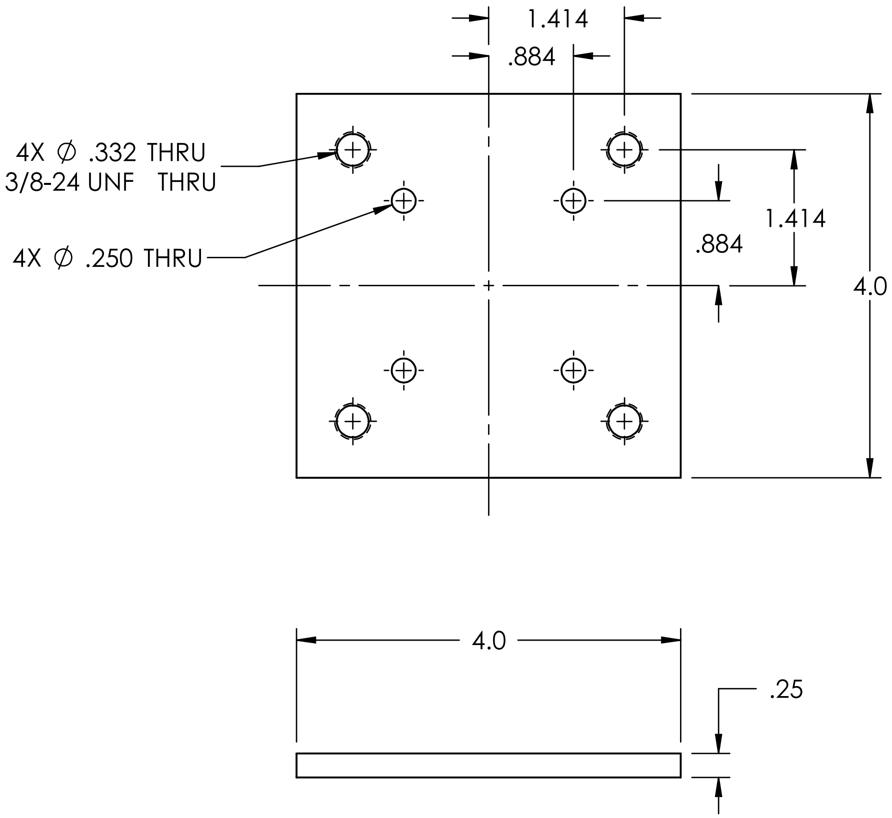
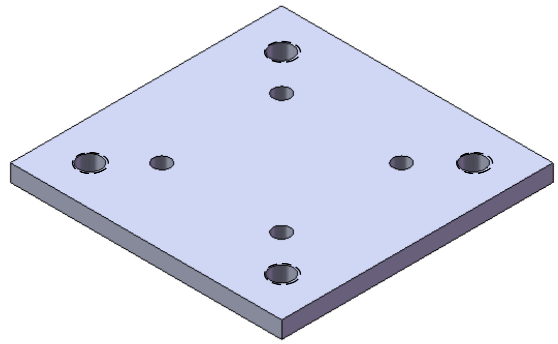
SHEET NUMBER: 1 OF 1





NOTES:

1) QUANTITY: 1

2) MATERIAL: ALUMINUM PLATE

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

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X.XXX	± 0.005
MILLIMETERS	
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X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 08/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:2

SHEET SIZE: A

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

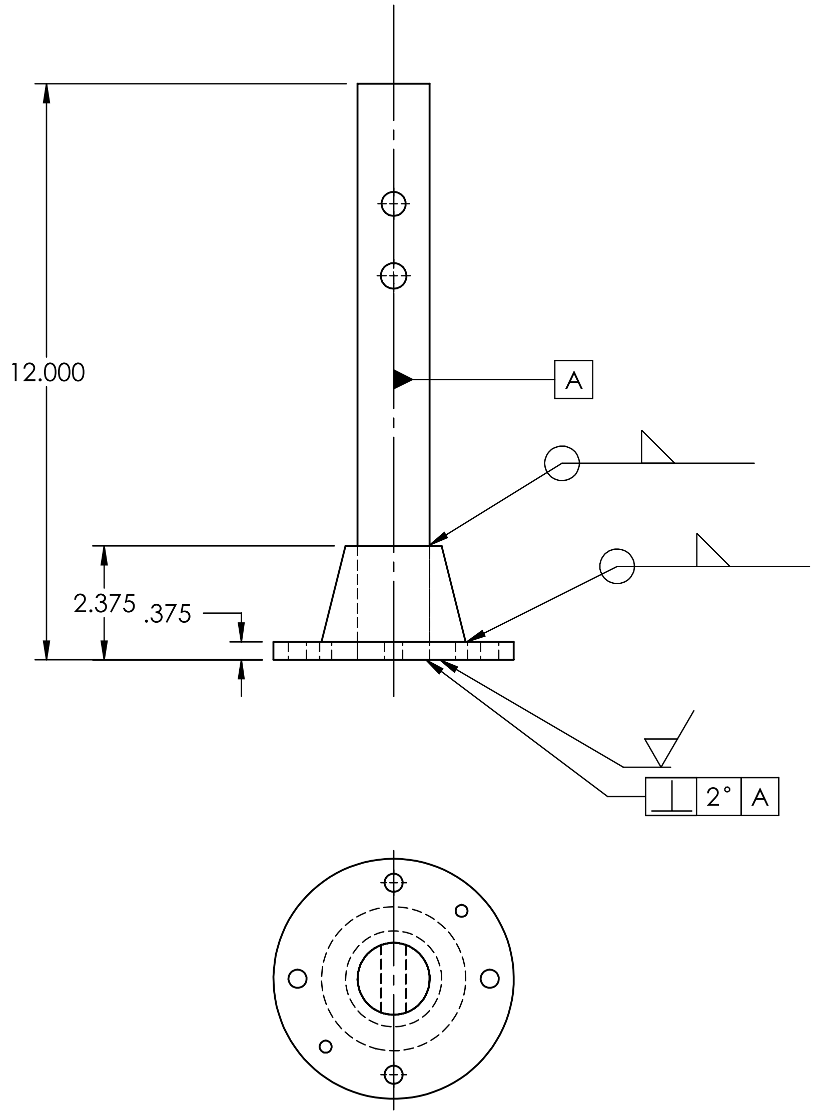
ASSEMBLY REFERENCE:

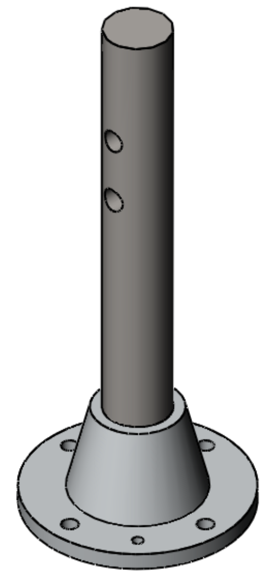
DESCRIPTION: CENTER PAD

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1





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1) QUANTITY: 1

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

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DIMENSIONS IN: INCHES	CHECKED BY		
TOLERANCES UNLESS OTHERWISE SPECIFIED INCHES X.X ± 0.06 X.XX ± 0.02 X.XXX ± 0.005 MILLIMETERS X ± 1 X.X ± 0.5 X.XX ± 0.1 ANGLES ± 0.5°	APPROVED BY	PROJECT TITLE	ASSEMBLY REFERENCE
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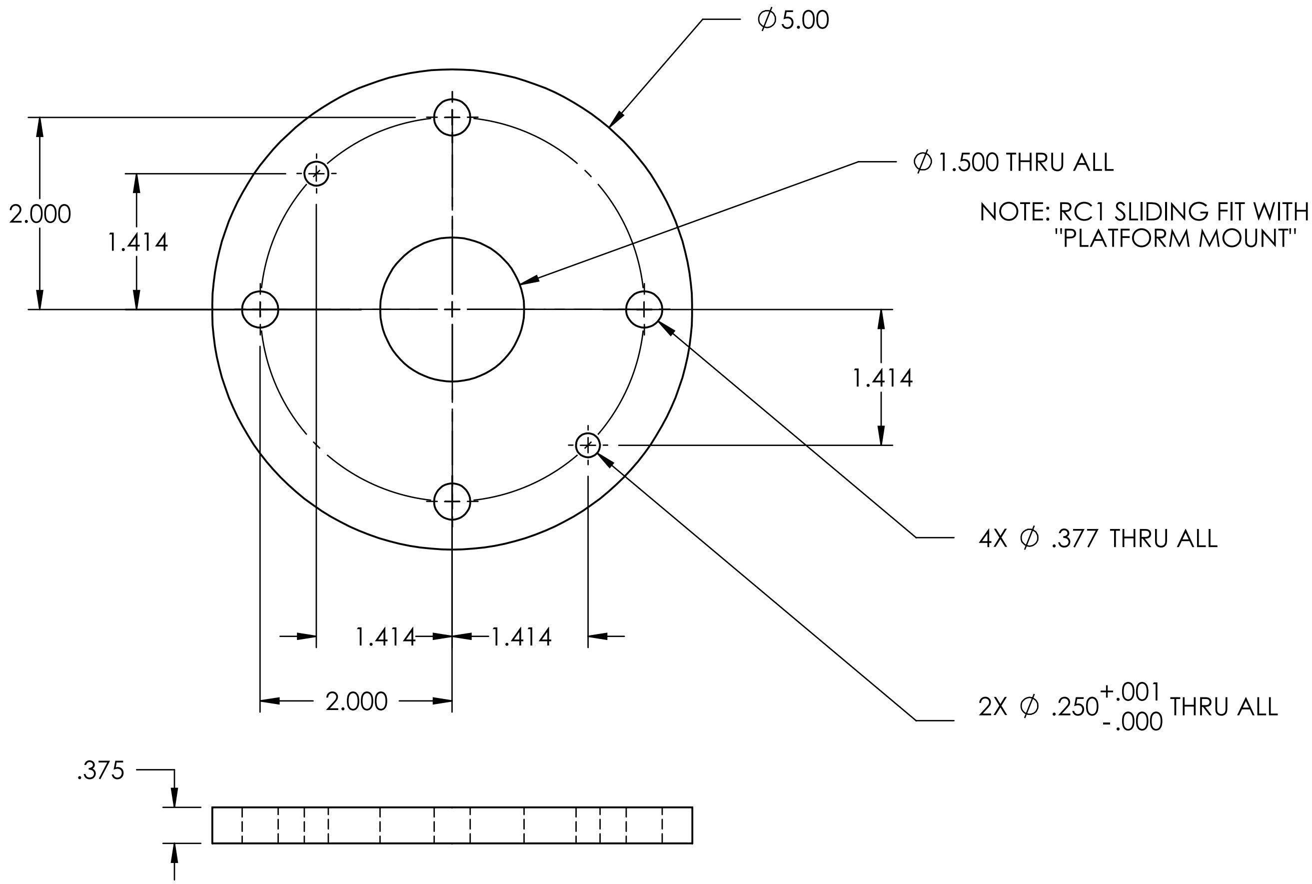
MARPORT

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4



NOTES:

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2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

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X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 17/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:2

SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

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ASSEMBLY REFERENCE:

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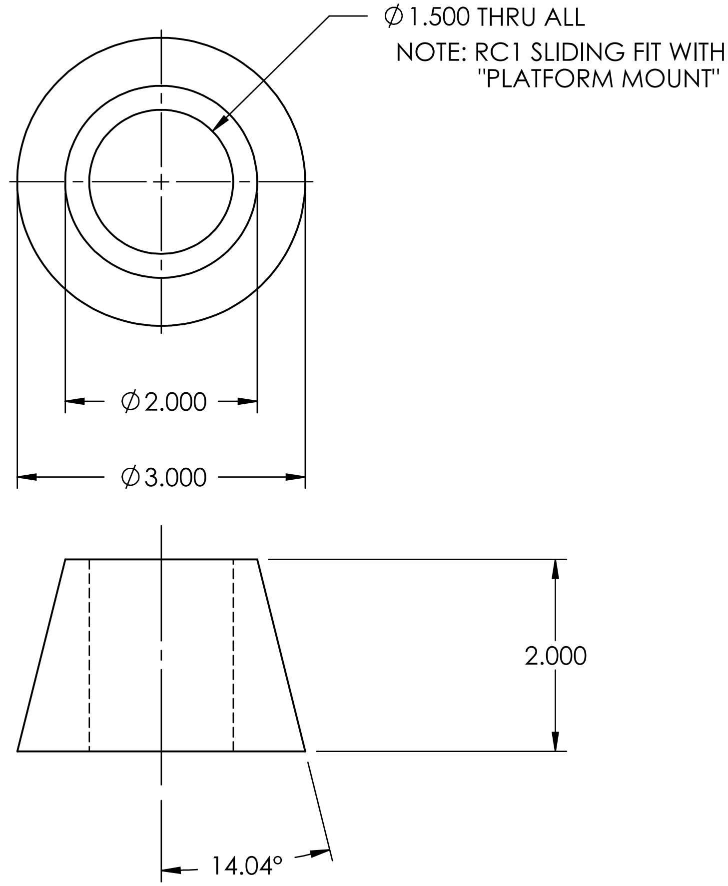

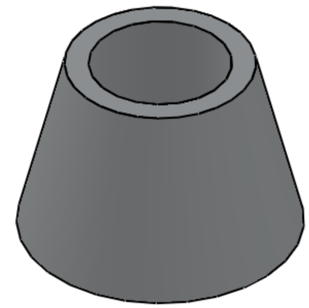

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3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN: INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

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X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 17/11/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:2

SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

ASSEMBLY REFERENCE:

DESCRIPTION: FLANGE

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1

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A2	-9.500	-6.149	1/4-20 UNC THRU ALL
A3	-3.289	-8.899	1/4-20 UNC THRU ALL
A4	-3.289	-6.149	1/4-20 UNC THRU ALL
B1	-9.004	-3.430	∅ .154 THRU ALL
B2	-9.004	1.953	∅ .154 THRU ALL
B3	-5.246	-3.430	∅ .154 THRU ALL
B4	-5.246	1.953	∅ .154 THRU ALL
C1	-8.569	4.000	10-32 UNF THRU ALL
C2	-8.569	9.500	10-32 UNF THRU ALL
C3	-4.069	4.000	10-32 UNF THRU ALL
C4	-4.069	9.500	10-32 UNF THRU ALL
C5	-2.082	5.050	10-32 UNF THRU ALL
C6	-2.082	9.670	10-32 UNF THRU ALL
C7	-.102	5.050	10-32 UNF THRU ALL
C8	-.102	9.670	10-32 UNF THRU ALL
D1	-2.000	.000	∅ .377 THRU ALL
D2	.000	-2.000	∅ .377 THRU ALL
D3	.000	2.000	∅ .377 THRU ALL
D4	2.000	.000	∅ .377 THRU ALL
E1	-1.41	1.41	∅ $.250^{+.001}_{-.000}$ THRU ALL
E2	1.41	-1.41	∅ $.250^{+.001}_{-.000}$ THRU ALL
F1	3.261	-3.307	1/4-28 UNF THRU ALL
F2	3.261	2.835	1/4-28 UNF THRU ALL
F3	9.403	-3.307	1/4-28 UNF THRU ALL
F4	9.403	2.835	1/4-28 UNF THRU ALL
G1	3.698	-9.138	6-32 UNC THRU ALL
G2	3.698	-6.638	6-32 UNC THRU ALL
G3	5.413	4.325	6-32 UNC THRU ALL
G4	5.413	6.313	6-32 UNC THRU ALL
G5	8.948	-9.138	6-32 UNC THRU ALL
G6	8.948	-6.638	6-32 UNC THRU ALL
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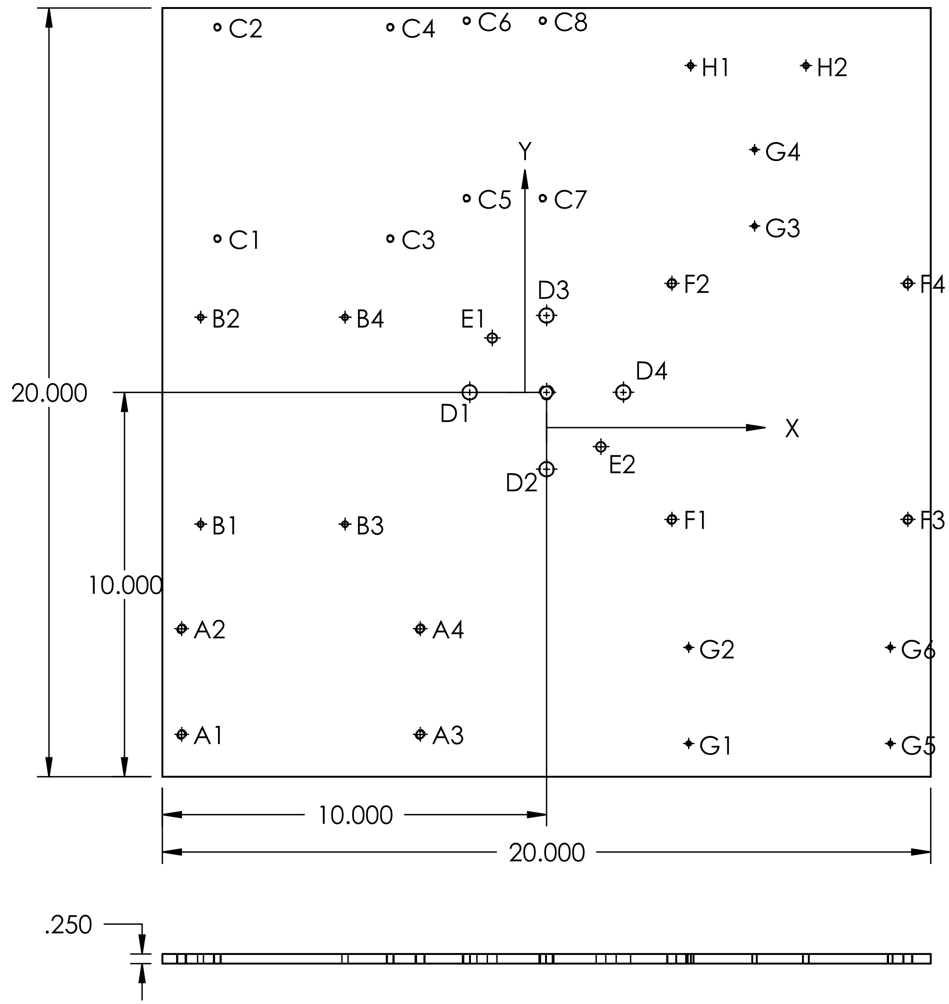

NOTES:

1) QUANTITY: 1

2) MATERIAL: 1/4" ALUMINUM PLATE

3) FINISH: N/A

4) WEIGHT: N/A

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DIMENSIONS IN: INCHES	CHECKED BY:
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MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

ASSEMBLY REFERENCE:

DESCRIPTION: IMU PLATFORM

PART / DRAWING NUMBER:

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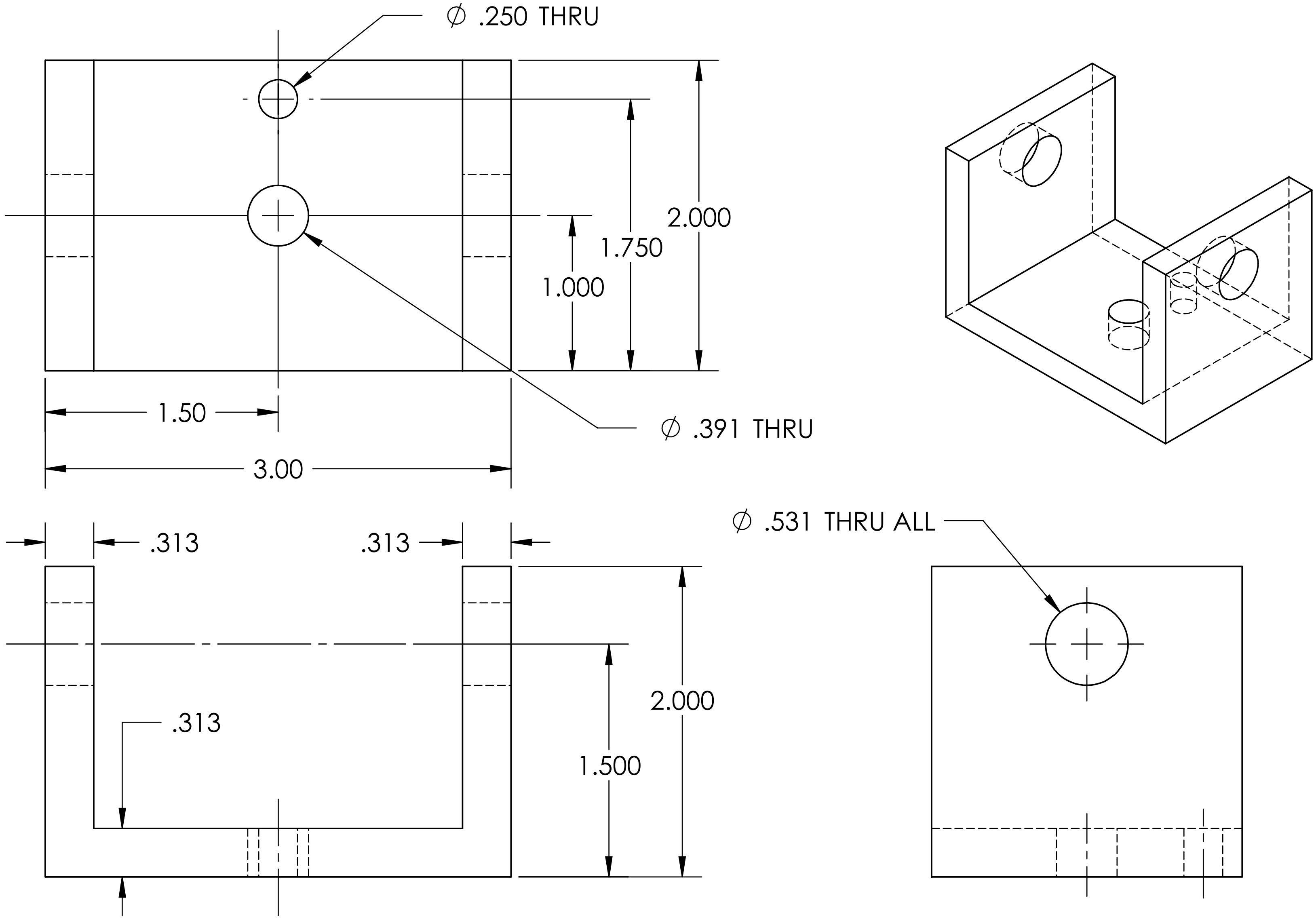
SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 8

2) MATERIAL: Aluminum U - Channel

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 10/04/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:1

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

ASSEMBLY REFERENCE:

DESCRIPTION: MOUNTING TABS

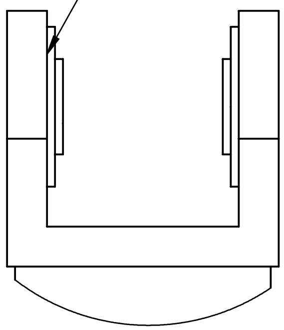
PART / DRAWING NUMBER:

REV LETTER: -

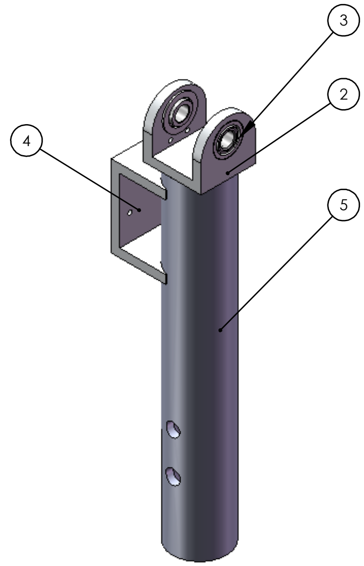
SHEET NUMBER: 1 OF 1

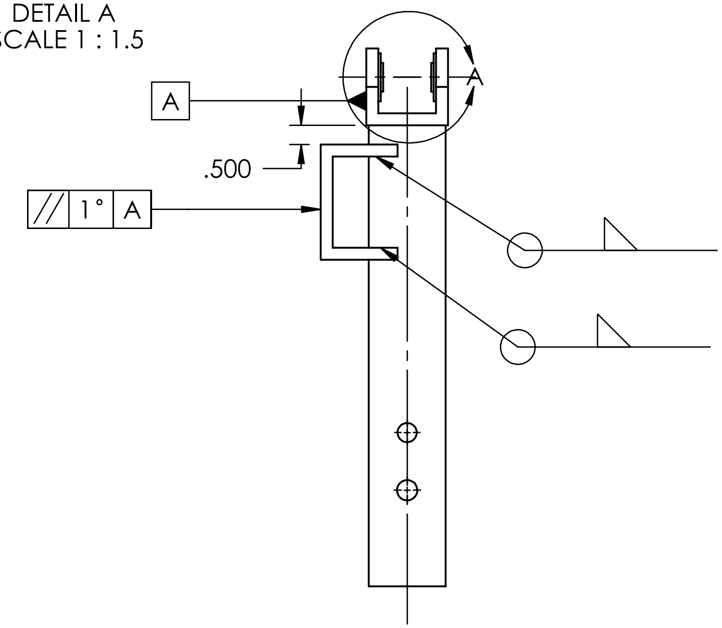
ITEM NO.	PART NUMBER	QTY.
2	Yoke	1
3	Bearings 6383K234	2
4	Bottom ADT arm mount	1
5	Top Pendulum Arm	1

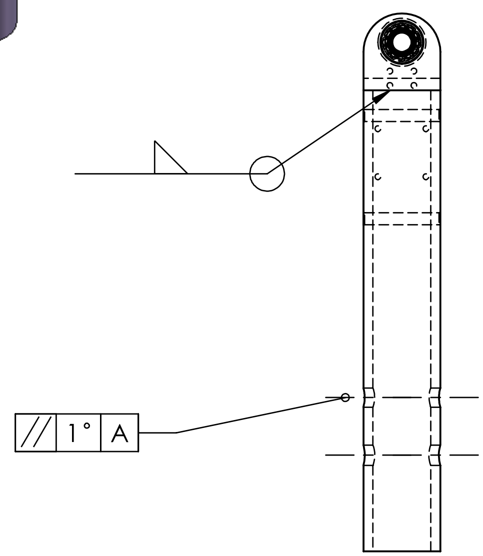
NOTE: PRESS FIT BEARINGS SO FLANGE IS ON INSIDE FACE



DETAIL A
SCALE 1 : 1.5







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2) MATERIAL: N/A

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 12/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:5

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

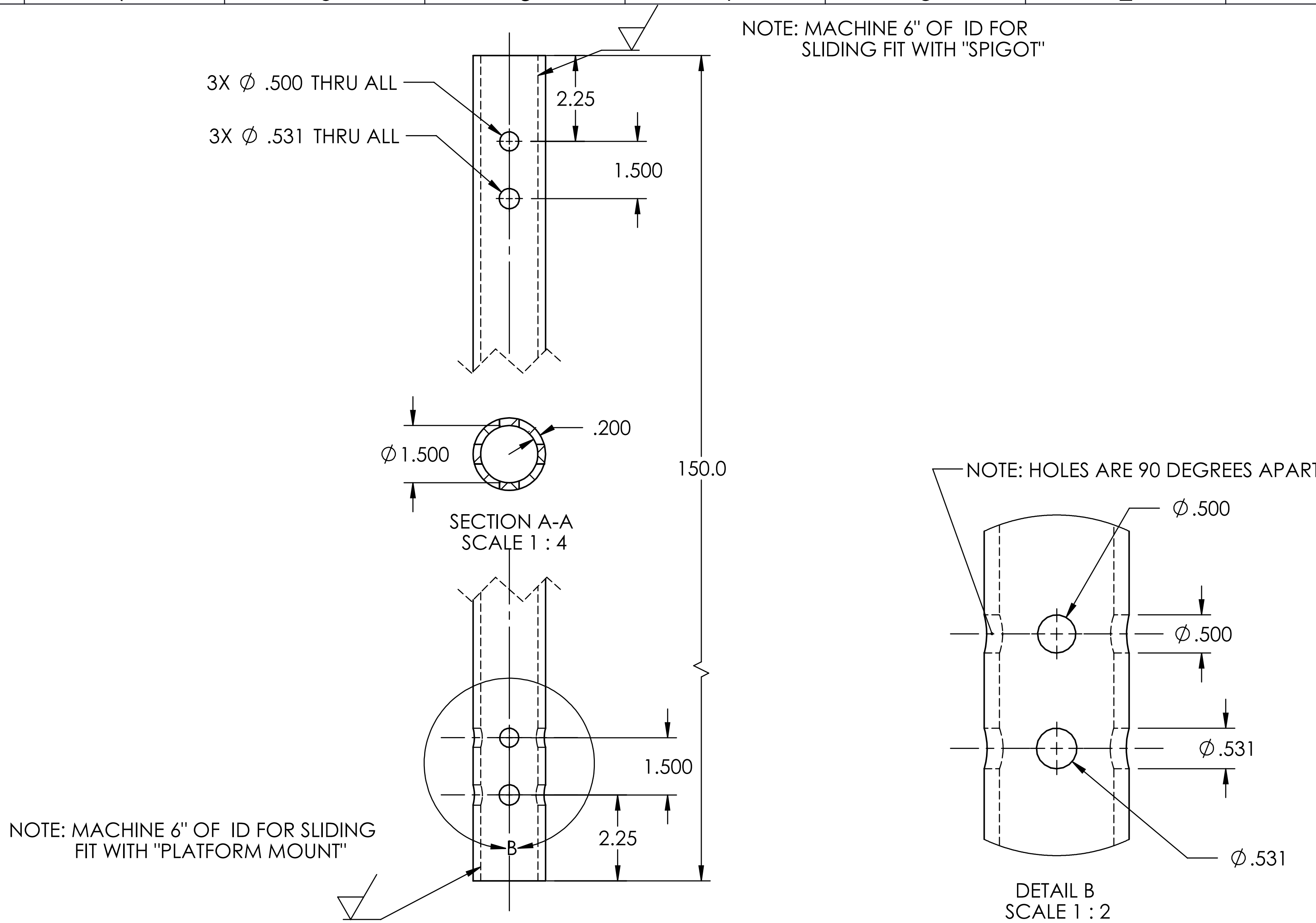
ASSEMBLY REFERENCE:

DESCRIPTION: PENDULUM ARM ASSEMBLY

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

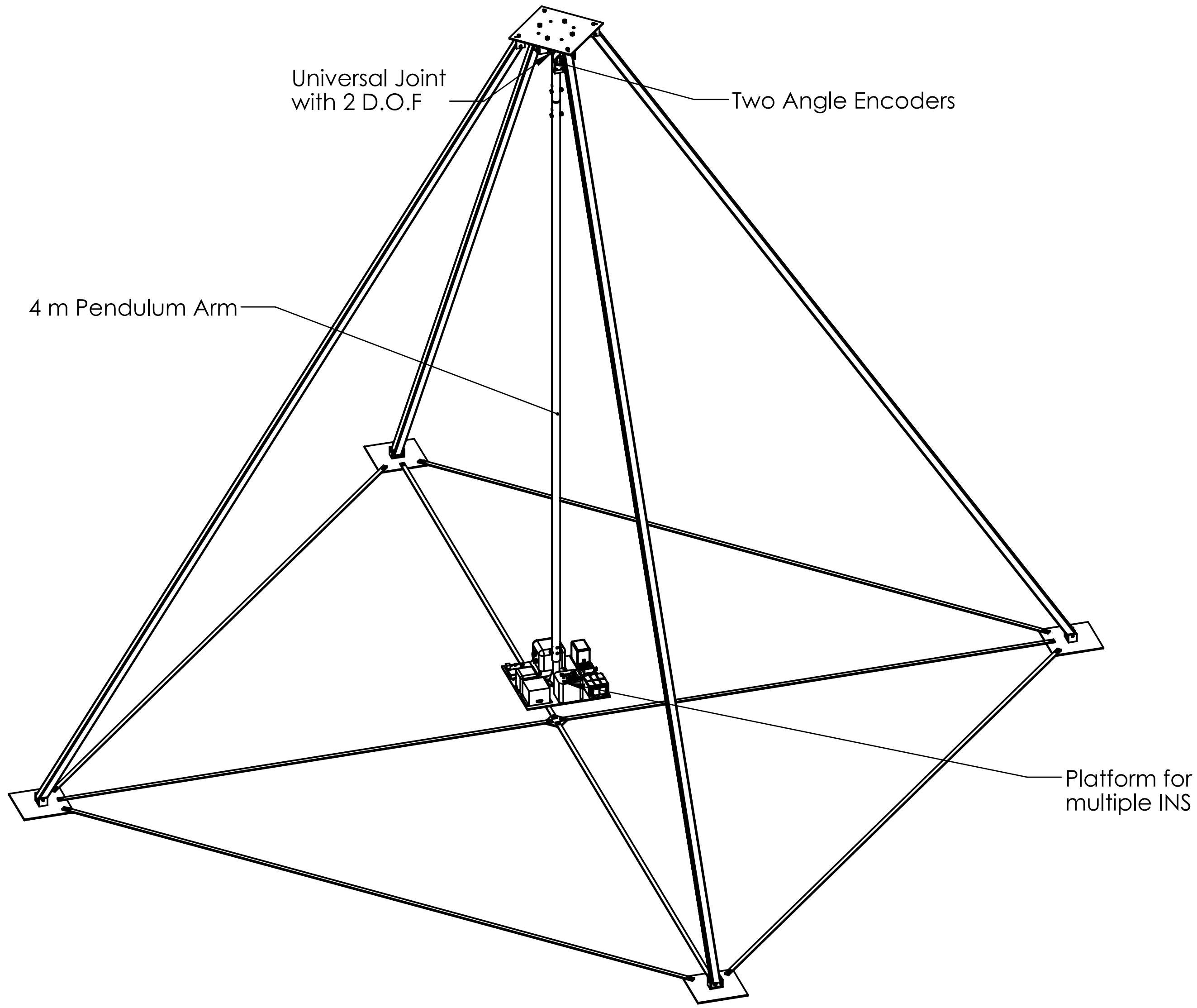
1) QUANTITY: 1

2) MATERIAL: ALUMINUM PIPE - SCHEDULE 80

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY: TH	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
DIMENSIONS IN: INCHES	CHECKED BY:	
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY:	PROJECT TITLE: / ASSEMBLY REFERENCE:
INCHES X.X ± 0.06; X.XX ± 0.02; X.XXX ± 0.005	DATE: 25/10/2010	DESCRIPTION: PENDULUM ARM
MILLIMETERS X ± 1; X.X ± 0.5; X.XX ± 0.1	THIRD ANGLE PROJECTION; DO NOT SCALE DRAWING	PART / DRAWING NUMBER:
ANGLES ± 0.5°	SCALE: 1:33.3; SHEET SIZE: A	REV LETTER: B; SHEET NUMBER: 1 OF 1



DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN

TOLERANCES
UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: T. House

CHECKED BY:

APPROVED BY:

DATE: 24/11/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:1

SHEET SIZE: A

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

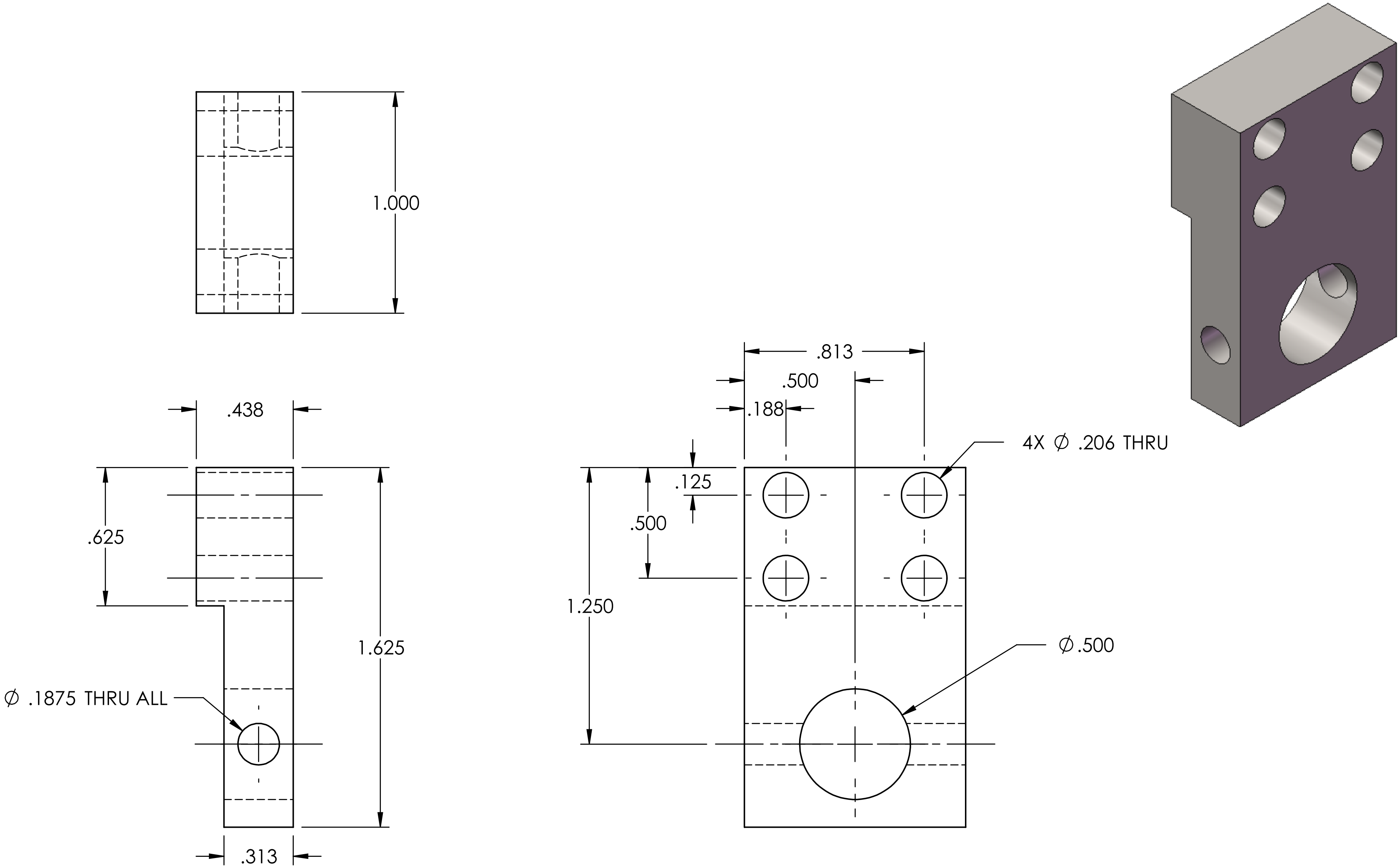
ASSEMBLY REFERENCE:

DESCRIPTION: INS Testing - Pendulum Apparatus

PART / DRAWING NUMBER:

REV LETTER: -

SHEET NUMBER: 1 OF 1



NOTES:

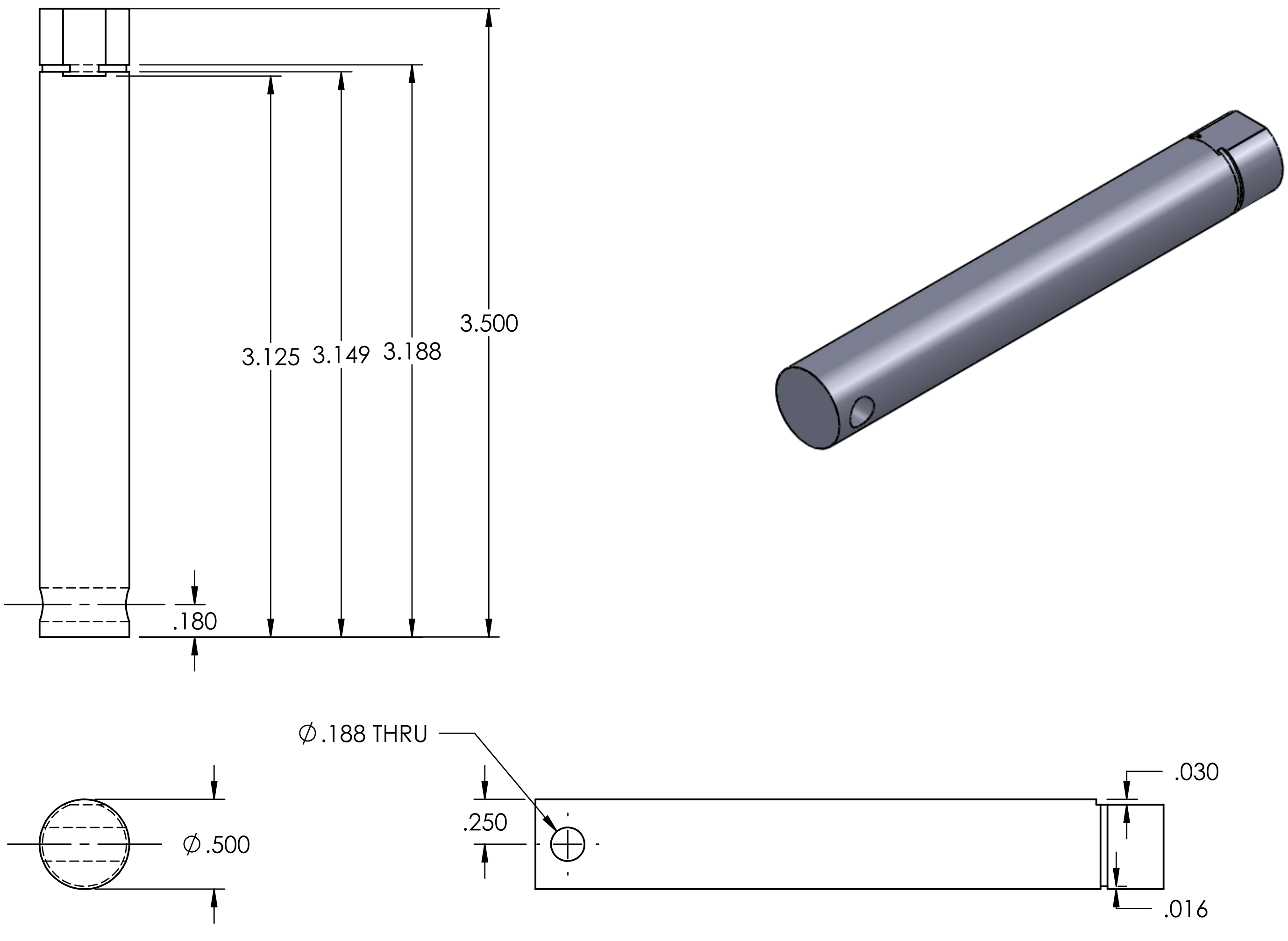
1) QUANTITY: 1

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY TH	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4	
DIMENSIONS IN INCHES	CHECKED BY	THE INFORMATION CONTAINED IN THIS DOCUMENT IS CONFIDENTIAL AND SHALL NOT BE MADE PUBLIC, OR COPIED, OR USED AS THE BASIS FOR THE MANUFACTURE, OR SALE OF ITEMS UNLESS SPECIFICALLY AUTHORIZED IN WRITING BY MARPORT CANADA INC. THIS DOCUMENT IS THE PROPERTY OF MARPORT CANADA INC. AND IS SUBJECT TO RETURN ON DEMAND.	
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY	PROJECT TITLE	ASSEMBLY REFERENCE
INCHES X.X ± 0.06; X.XX ± 0.02; X.XXX ± 0.005	DATE 31/12/2010	DESCRIPTION PITCH/ROLL LOCK	
MILLIMETERS X ± 1; X.X ± 0.5; X.XX ± 0.1	THIRD ANGLE PROJECTION; DO NOT SCALE DRAWING	PART / DRAWING NUMBER	REV LETTER A
ANGLES ± 0.5°	SCALE 1:1; SHEET SIZE A		SHEET NUMBER 1 OF 1



NOTES:

1) QUANTITY: 1

2) MATERIAL: GROUND STEEL ROD

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES

X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005

MILLIMETERS

X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: T. HOUSE

CHECKED BY:

APPROVED BY:

DATE: 26/11/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:1

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

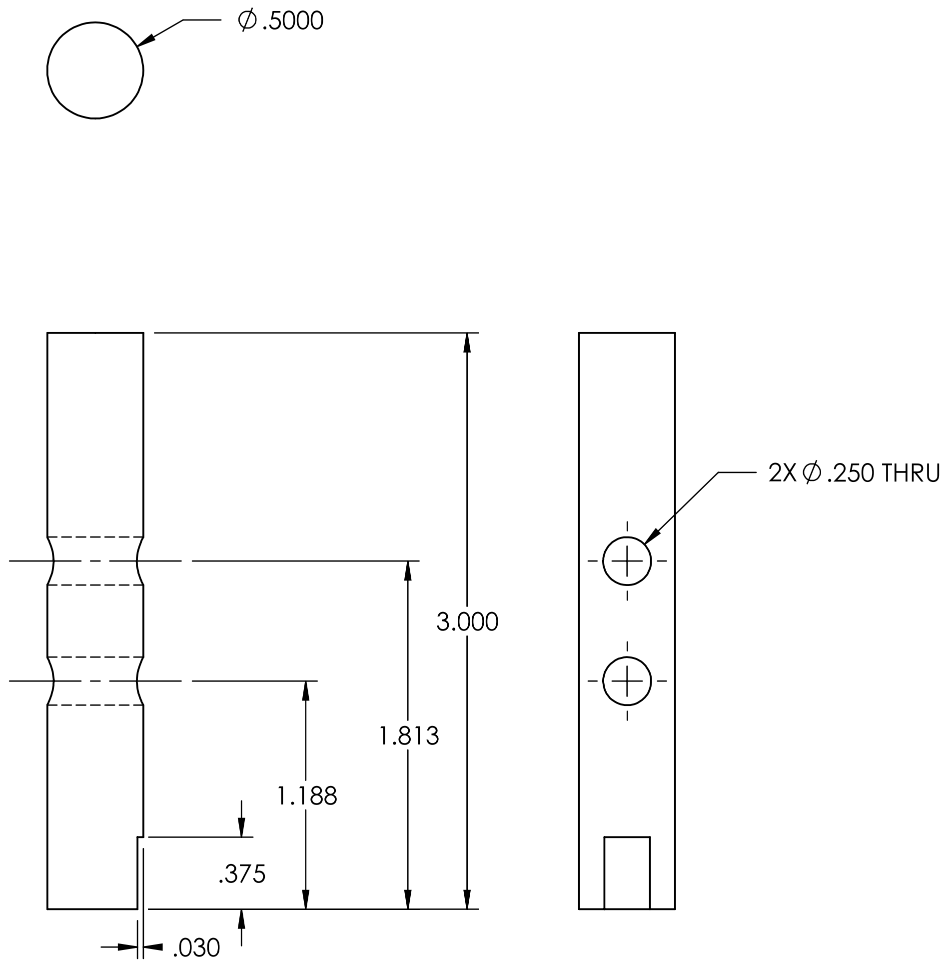
ASSEMBLY REFERENCE:

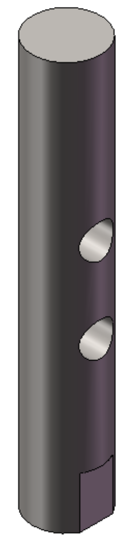
DESCRIPTION: PIVOT ROD 2

PART / DRAWING NUMBER:

REV LETTER: B

SHEET NUMBER: 1 OF 1





NOTES:

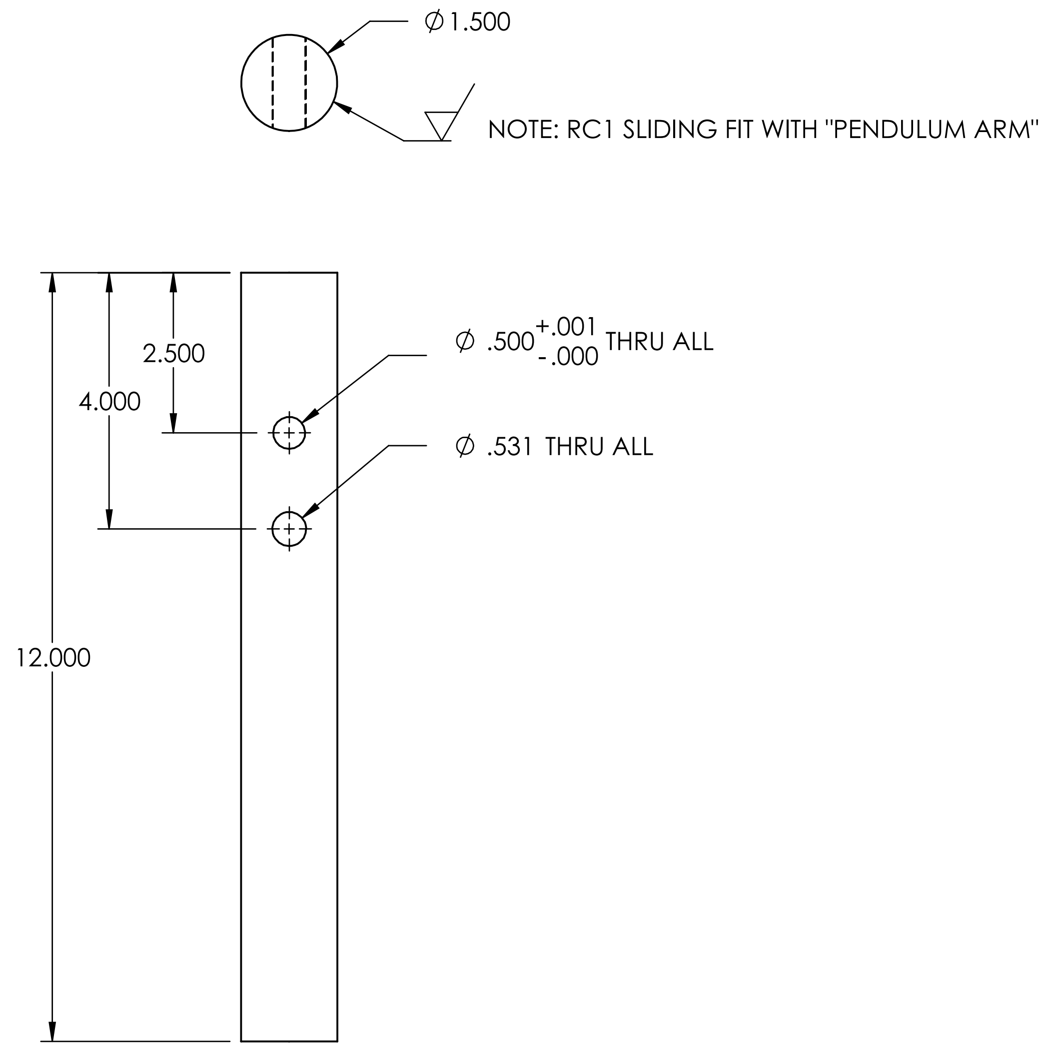
1) QUANTITY: 2

2) MATERIAL: GROUND ROD - STEEL

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY TH	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
DIMENSIONS IN INCHES	CHECKED BY	THE INFORMATION CONTAINED IN THIS DOCUMENT IS CONFIDENTIAL AND SHALL NOT BE MADE PUBLIC, OR COPIED, OR USED AS THE BASIS FOR THE MANUFACTURE, OR SALE OF ITEMS UNLESS SPECIFICALLY AUTHORIZED IN WRITING BY MARPORT CANADA INC. THIS DOCUMENT IS THE PROPERTY OF MARPORT CANADA INC. AND IS SUBJECT TO RETURN ON DEMAND.
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY	PROJECT TITLE / ASSEMBLY REFERENCE
INCHES X.X ± 0.06 X.XX ± 0.02 X.XXX ± 0.005	DATE 08/10/2010	DESCRIPTION PIVOT ROD
MILLIMETERS X ± 1 X.X ± 0.5 X.XX ± 0.1	THIRD ANGLE PROJECTION DO NOT SCALE DRAWING	PART / DRAWING NUMBER
ANGLES ± 0.5°	SCALE 1:1 / SHEET SIZE A	REV LETTER A / SHEET NUMBER 1 OF 1



NOTES:

1) QUANTITY: 1

2) MATERIAL: 6061 ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES

X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005

MILLIMETERS

X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 17/11/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:3

SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

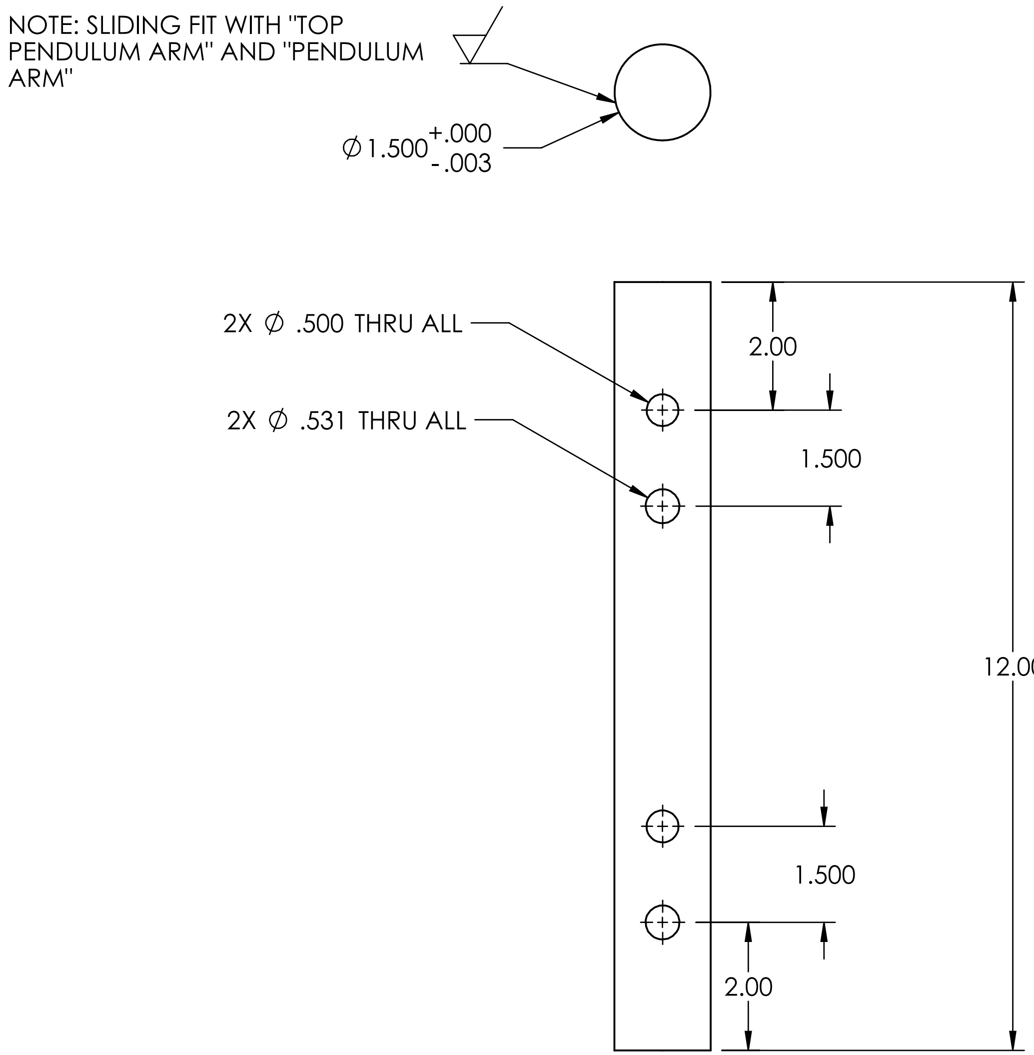
ASSEMBLY REFERENCE:

DESCRIPTION: PLATFORM MOUNT

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY:1

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 08/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:5 | SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

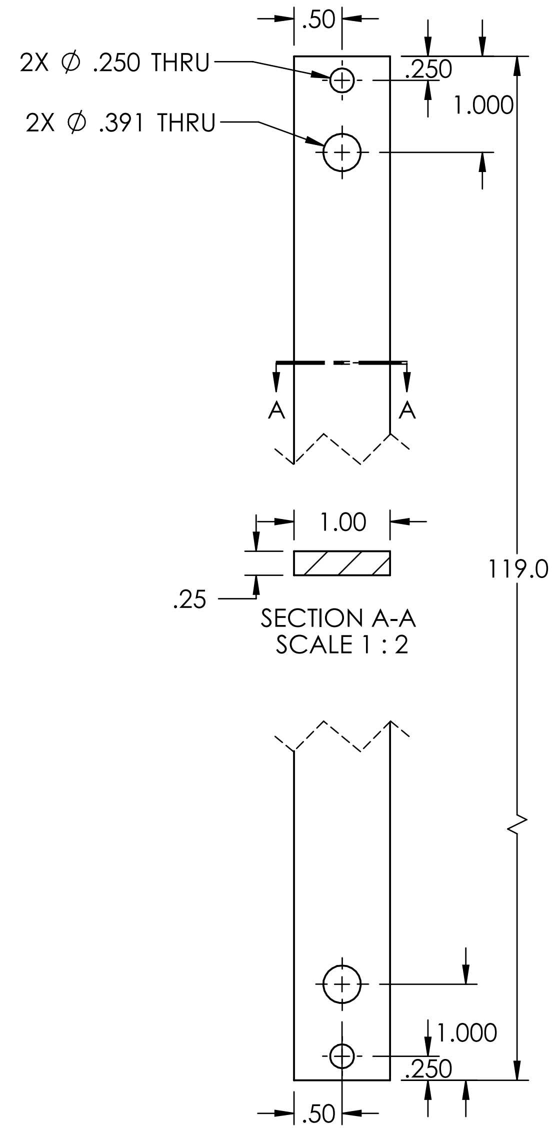
ASSEMBLY REFERENCE:

DESCRIPTION: SPIGOT

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 4

2) MATERIAL: ALUMINUM BAR

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 08/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:33.3

SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

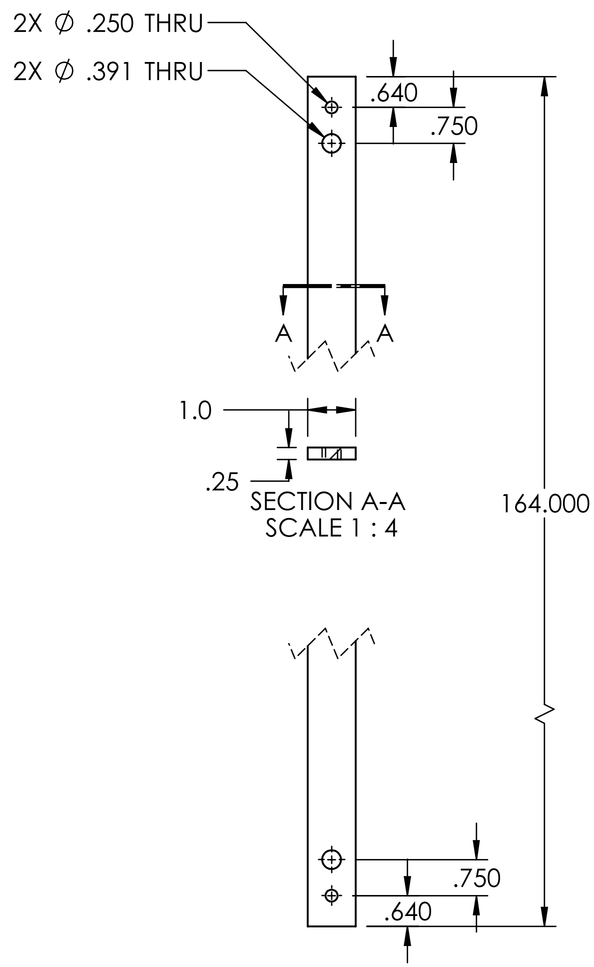
ASSEMBLY REFERENCE:

DESCRIPTION: SUPPORT BRACES

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY:4

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 12/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:50

SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

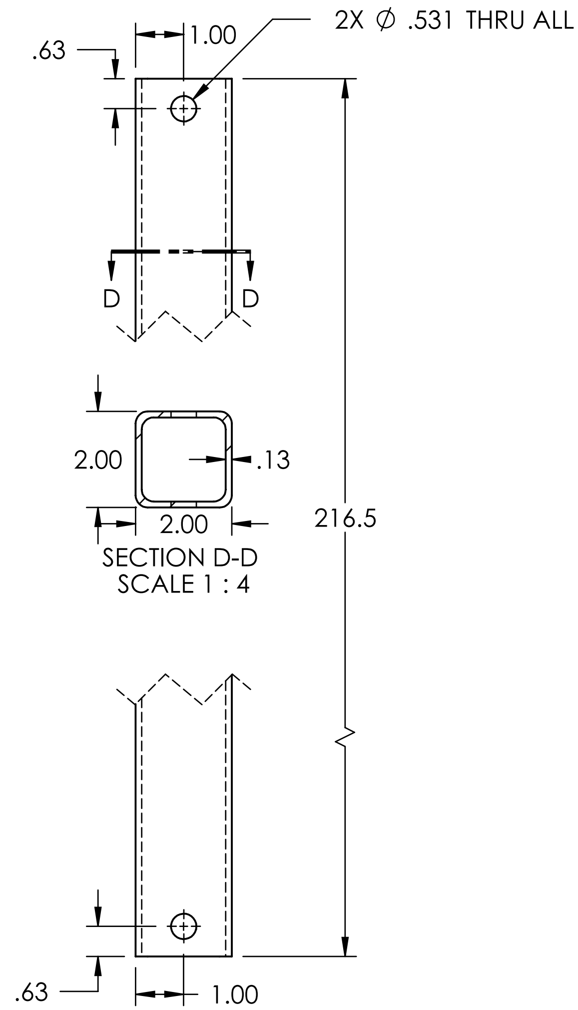
ASSEMBLY REFERENCE:

DESCRIPTION: SUPPORT BRACE

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 4

2) MATERIAL: ALUMNINUM SQUARE TUBE

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN: INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 08/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:50

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

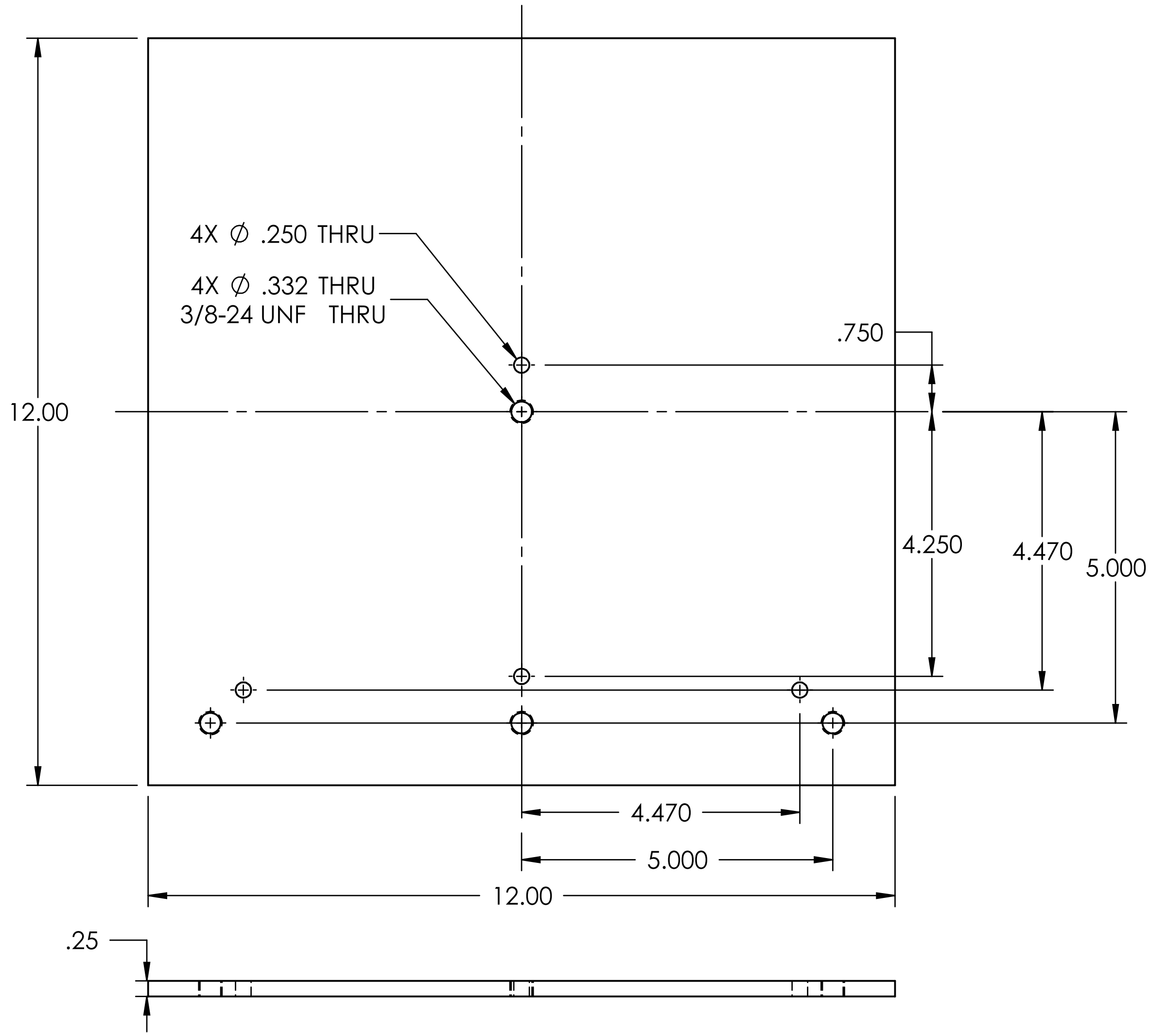
ASSEMBLY REFERENCE:

DESCRIPTION: SUPPORT LEGS

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

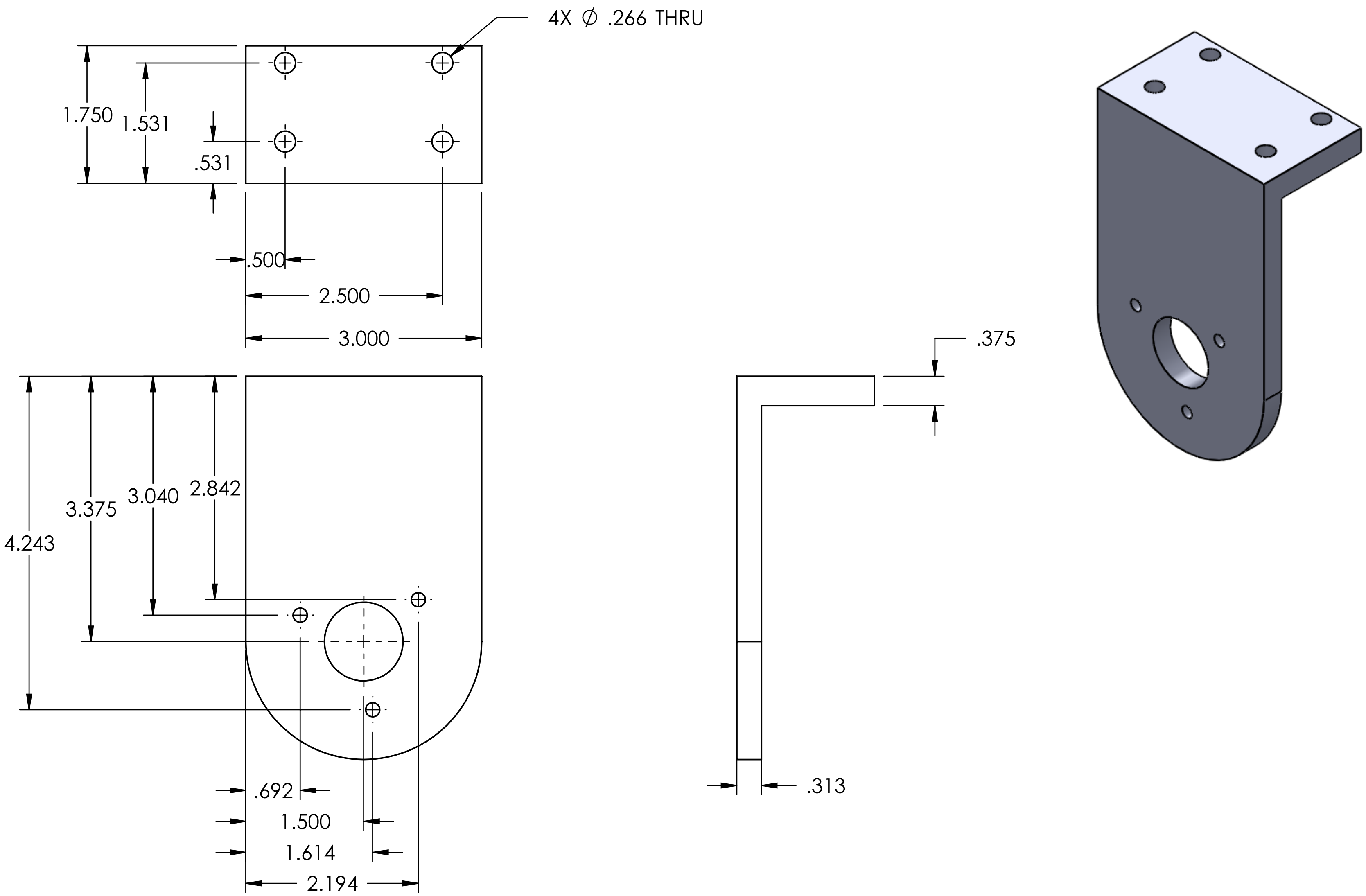
1) QUANTITY: 4

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY: TH	MARPORT CANADA INC.
DIMENSIONS IN: INCHES	CHECKED BY	50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY	PROJECT TITLE / ASSEMBLY REFERENCE
INCHES: X.X ± 0.06; X.XX ± 0.02; X.XXX ± 0.005	DATE: 10/04/2010	DESCRIPTION: SUPPORT PAD
MILLIMETERS: X ± 1; X.X ± 0.5; X.XX ± 0.1	THIRD ANGLE PROJECTION; DO NOT SCALE DRAWING	PART / DRAWING NUMBER
ANGLES ± 0.5°	SCALE: 1:3; SHEET SIZE: A	REV LETTER: A; SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 1

2) MATERIAL: 6" ALUMINUM U-CHANNEL

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES

X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005

MILLIMETERS

X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 17/11/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:2

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

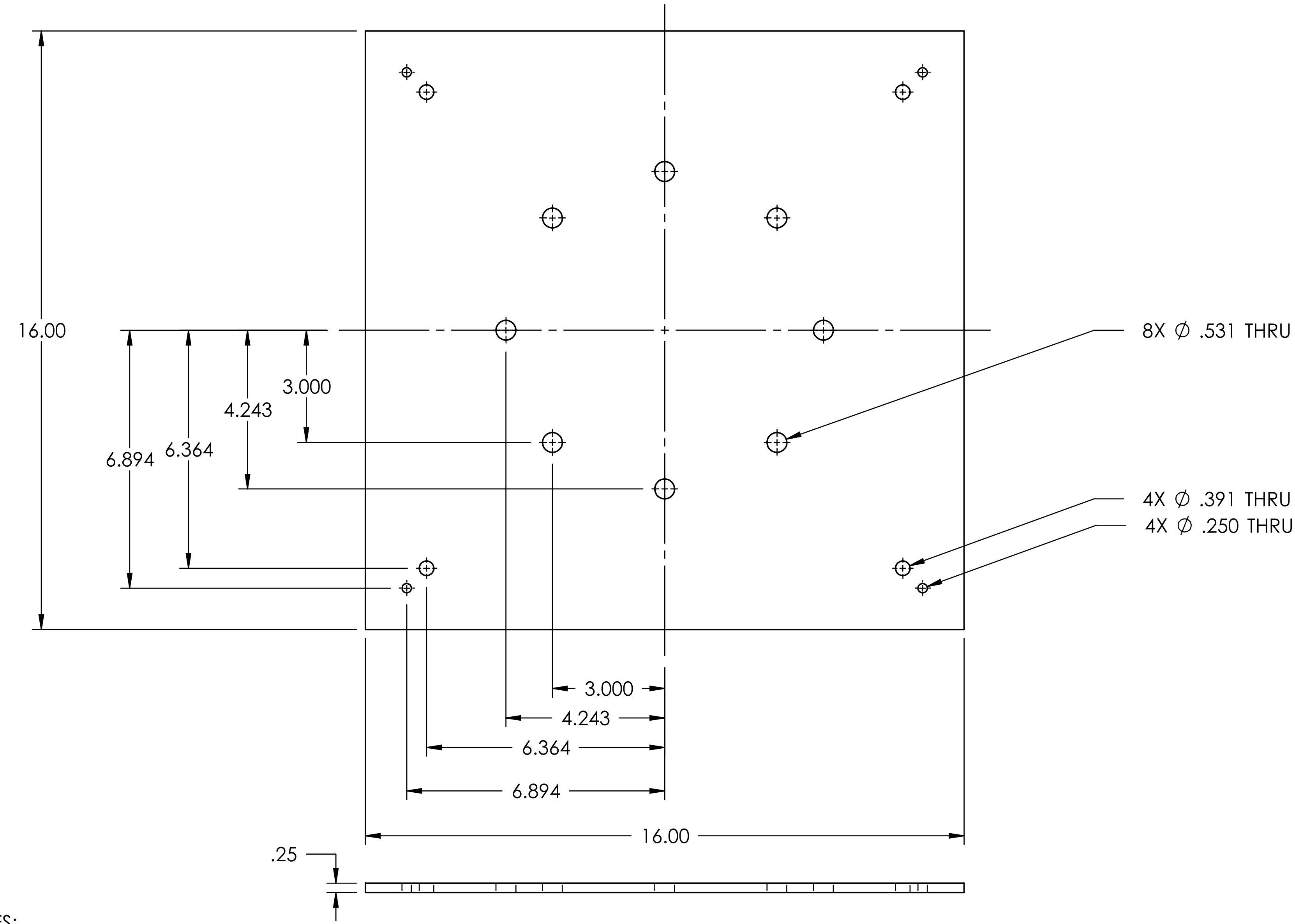
ASSEMBLY REFERENCE:

DESCRIPTION: TOP ADT MOUNT

PART / DRAWING NUMBER:

REV LETTER: C

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 1

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 05/10/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:4

SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

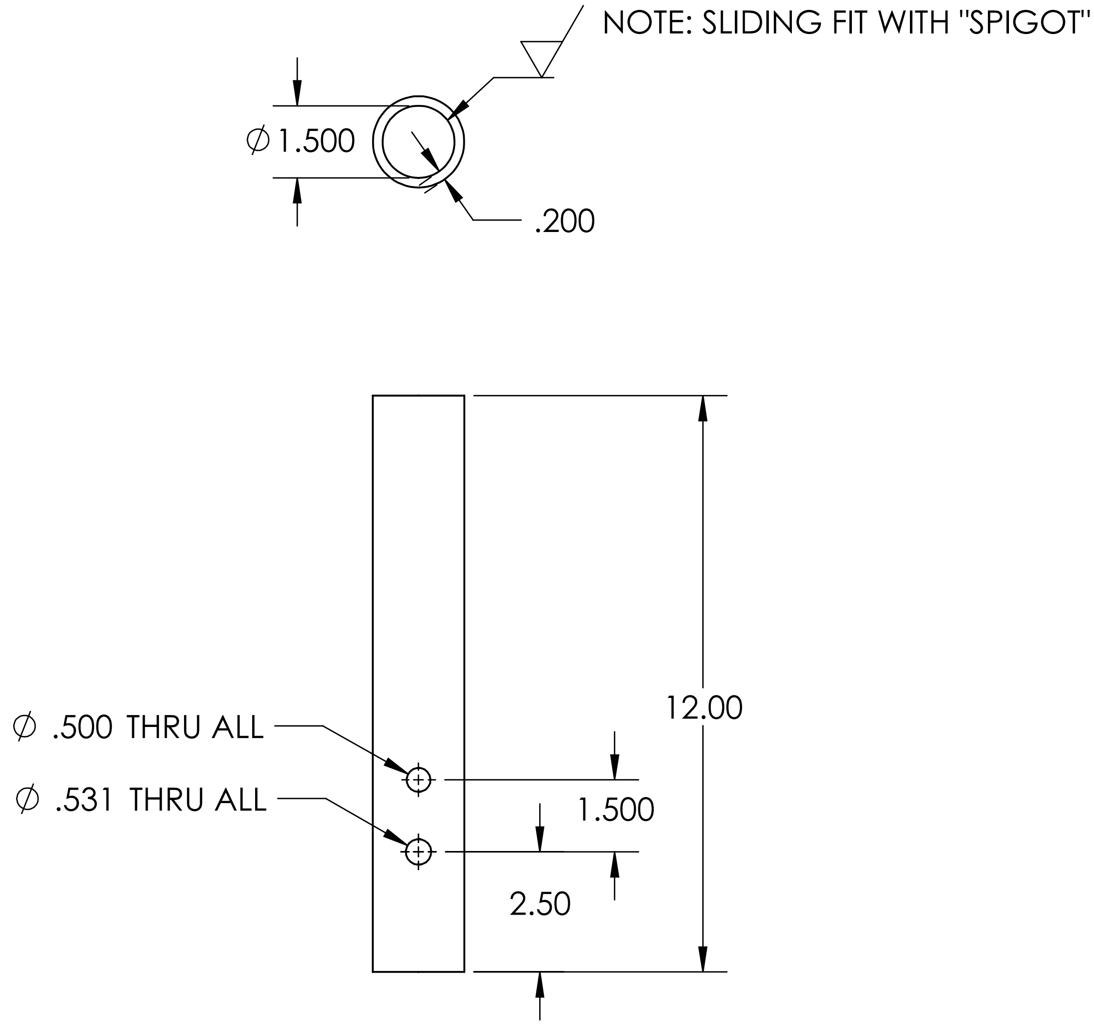
ASSEMBLY REFERENCE:

DESCRIPTION: TOP MOUNTING PLATE

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 1

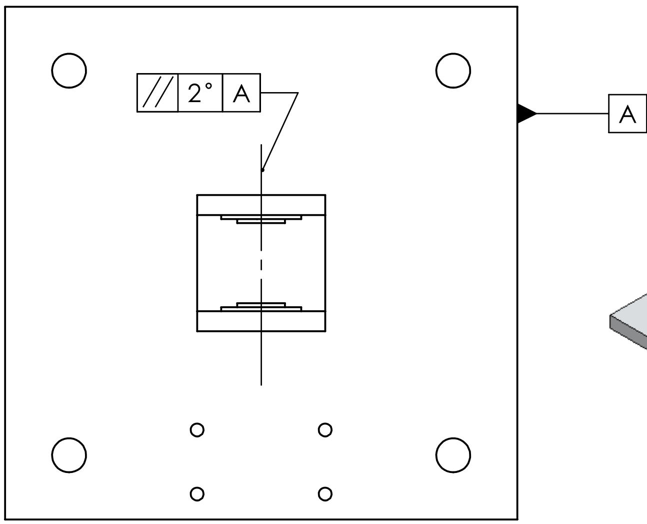
2) MATERIAL: ALUMINUM PIPE - SCHEDULE 80

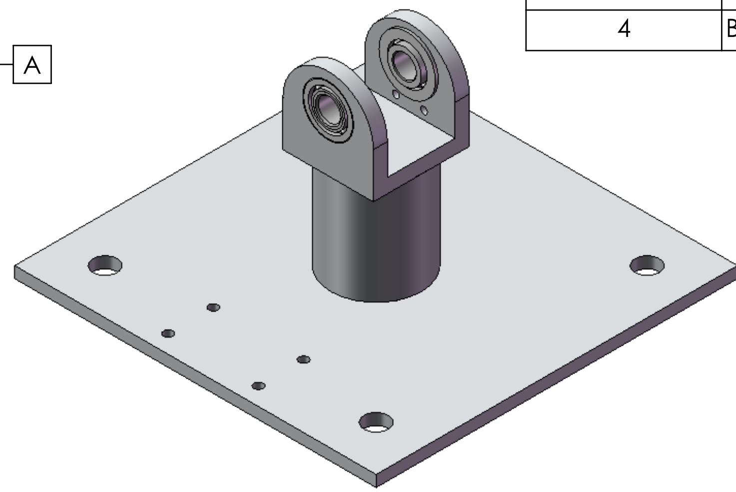
3) FINISH: N/A

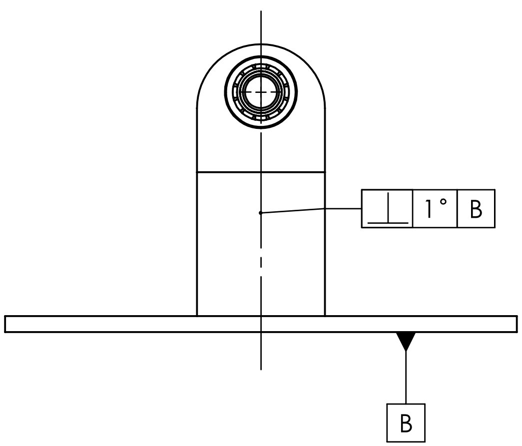
4) WEIGHT: N/A

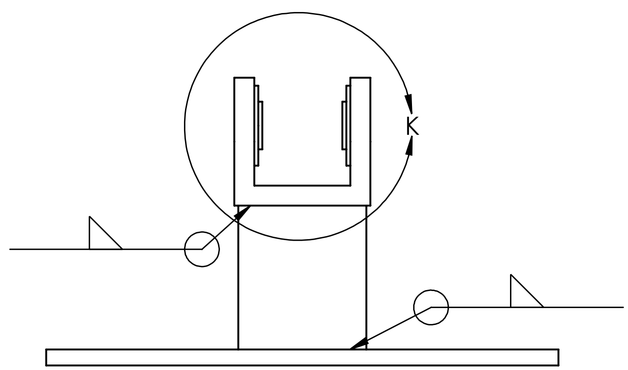
DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY: TH	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4
DIMENSIONS IN: INCHES	CHECKED BY:	
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY:	PROJECT TITLE: / ASSEMBLY REFERENCE:
INCHES: X.X ± 0.06; X.XX ± 0.02; X.XXX ± 0.005	DATE: 25/10/2010	DESCRIPTION: TOP PENDULUM ARM
MILLIMETERS: X ± 1; X.X ± 0.5; X.XX ± 0.1	THIRD ANGLE PROJECTION; DO NOT SCALE DRAWING	PART / DRAWING NUMBER:
ANGLES ± 0.5°	SCALE: 1:5; SHEET SIZE: A	REV LETTER: B; SHEET NUMBER: 1 OF 1

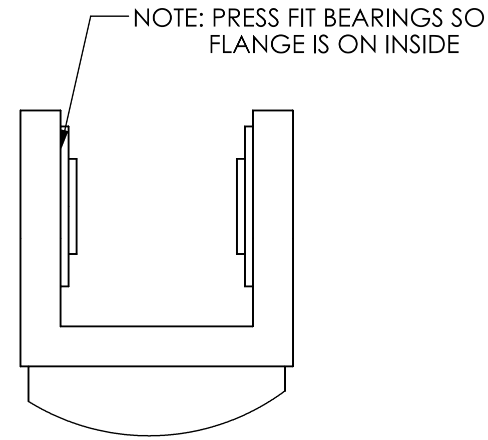
ITEM NO.	PART NUMBER	QTY.
1	UJ Base Mount	1
2	UJ Top Mount	1
3	Yoke	1
4	Bearings 6383K234	2











DETAIL K
SCALE 2 : 3

NOTES:

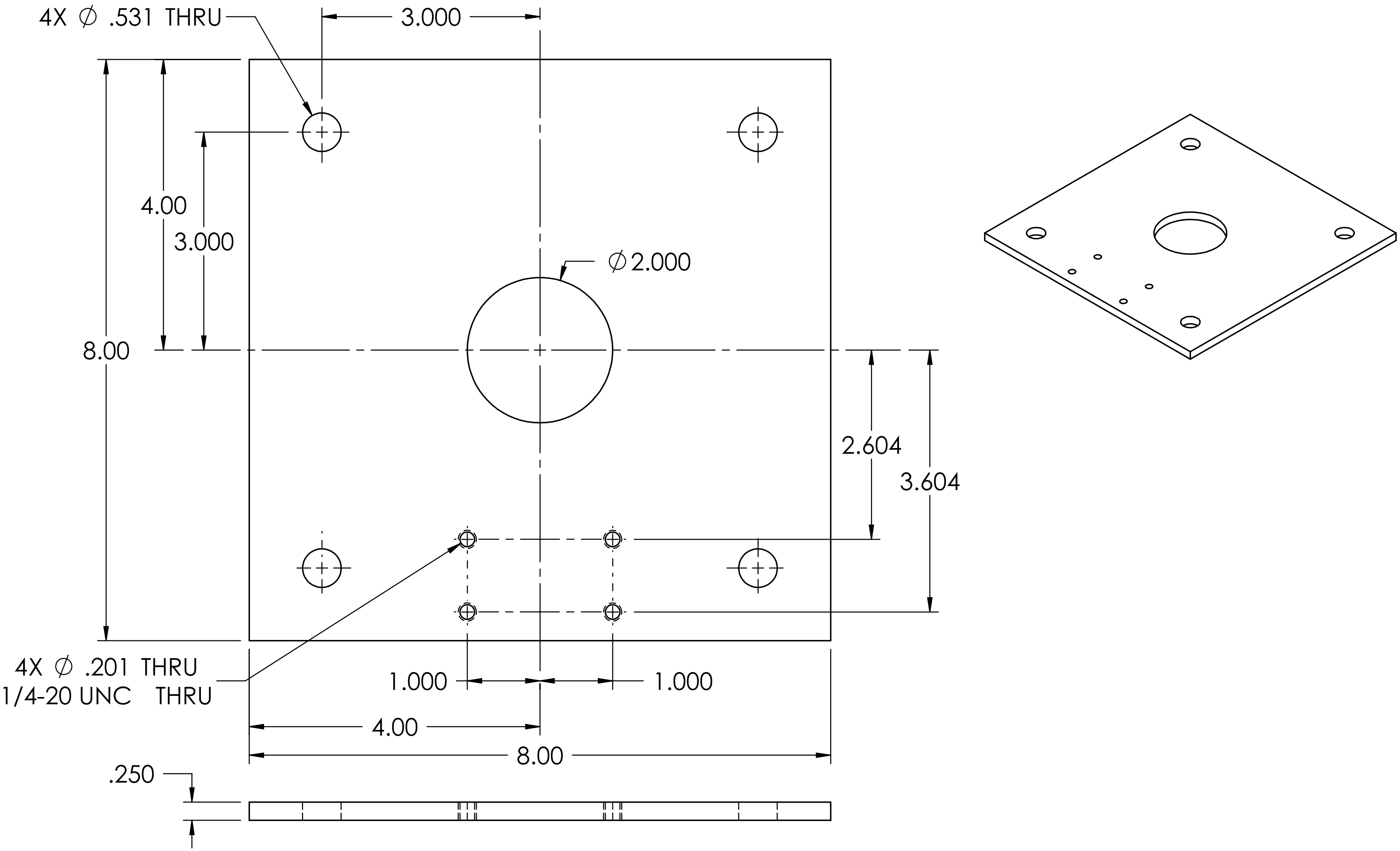
1) QUANTITY: 1

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY TH	MARPORT CANADA INC. 50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4	
DIMENSIONS IN INCHES	CHECKED BY		
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY	PROJECT TITLE	ASSEMBLY REFERENCE
INCHES X.X ± 0.06, X.XX ± 0.02, X.XXX ± 0.005	DATE 10/04/2010	DESCRIPTION TOP UNIVERSAL ASSEMBLY	
MILLIMETERS X ± 1, X.X ± 0.5, X.XX ± 0.1	THIRD ANGLE PROJECTION; DO NOT SCALE DRAWING	PART / DRAWING NUMBER	REV LETTER A
ANGLES ± 0.5°	SCALE 1:5; SHEET SIZE A		SHEET NUMBER 1 OF 1



NOTES:

1) QUANTITY: 1

2) MATERIAL: 1/4" ALUMINUM PLATE

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 10/04/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:5

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

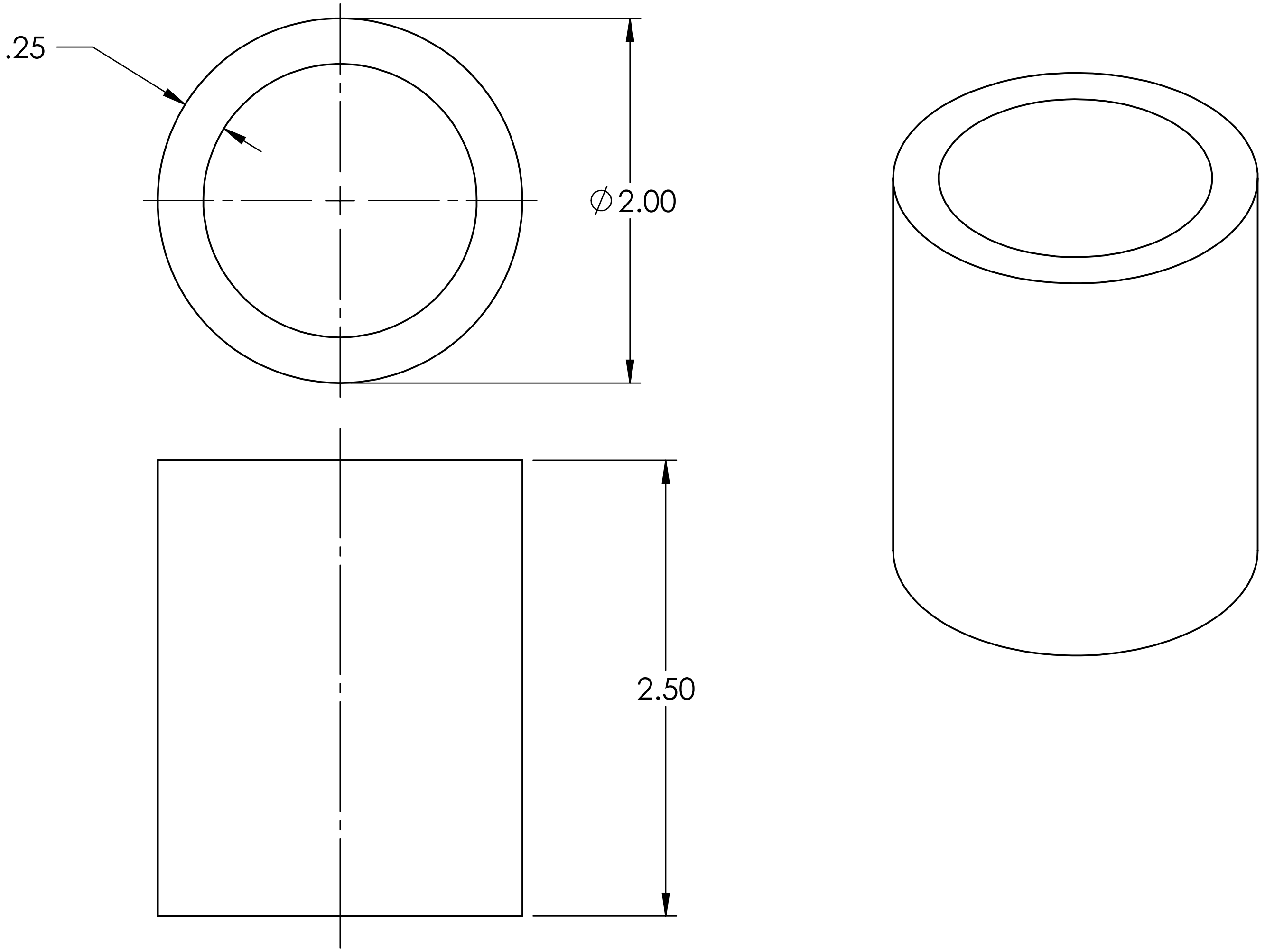
ASSEMBLY REFERENCE:

DESCRIPTION: UJ BASE

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 1

2) MATERIAL: 6061 ALUMINUM

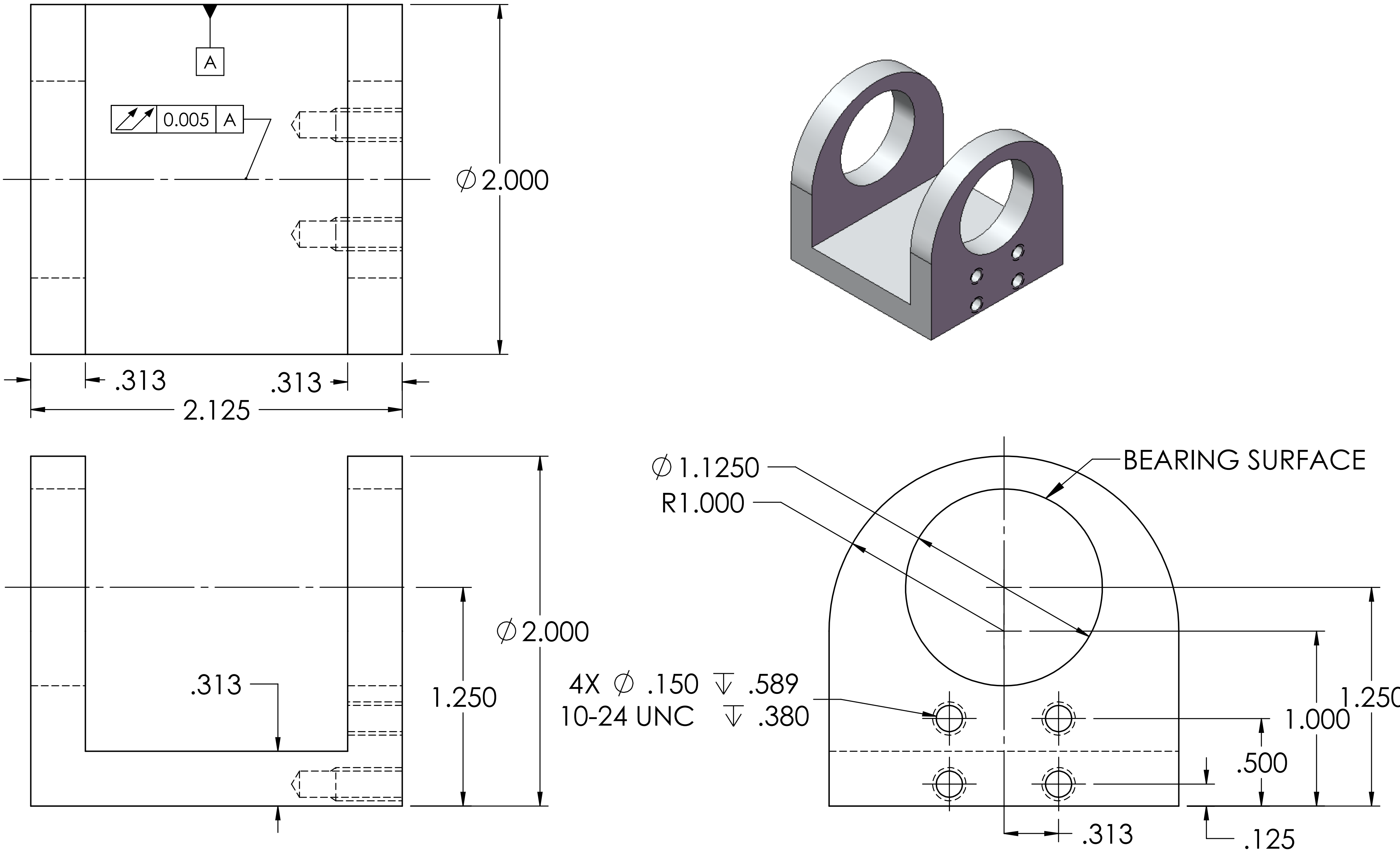
3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994	DRAWN BY: TH
DIMENSIONS IN: INCHES	CHECKED BY:
TOLERANCES UNLESS OTHERWISE SPECIFIED	APPROVED BY:
INCHES X.X ± 0.06, X.XX ± 0.02, X.XXX ± 0.005	DATE: 10/04/2010
MILLIMETERS X ± 1, X.X ± 0.5, X.XX ± 0.1	THIRD ANGLE PROJECTION / DO NOT SCALE DRAWING
ANGLES ± 0.5°	SCALE: 1:1 / SHEET SIZE: A

MARPORT CANADA INC.
50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:	ASSEMBLY REFERENCE:
DESCRIPTION: UJ TOP MOUNT	
PART / DRAWING NUMBER:	REV LETTER: - / SHEET NUMBER: 1 OF 1



NOTES:

1) QUANTITY: 2

2) MATERIAL: ALUMINUM

3) FINISH: N/A

4) WEIGHT: N/A

DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

DIMENSIONS IN INCHES

TOLERANCES UNLESS OTHERWISE SPECIFIED

INCHES	
X.X	± 0.06
X.XX	± 0.02
X.XXX	± 0.005
MILLIMETERS	
X	± 1
X.X	± 0.5
X.XX	± 0.1
ANGLES	± 0.5°

DRAWN BY: TH

CHECKED BY:

APPROVED BY:

DATE: 10/04/2010

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

SCALE: 1:1

SHEET SIZE: A

MARPORT

MARPORT CANADA INC.

50 HARBOUR DRIVE, ST. JOHN'S, NEWFOUNDLAND, A1C 6J4

PROJECT TITLE:

ASSEMBLY REFERENCE:

DESCRIPTION: YOKE

PART / DRAWING NUMBER:

REV LETTER: A

SHEET NUMBER: 1 OF 1

Appendix B

IMU Data Sheets

Four Degrees of Freedom Inertial Sensor

ADIS16300

FEATURES

14-bit digital gyroscope with digital range scaling
±75°/sec, ±150°/sec, ±300°/sec settings
Tri-axis, 14-bit digital accelerometer
±3 *g* measurement range
13-bit pitch and roll incline calculations
330 Hz bandwidth
150 ms start-up time
Factory-calibrated sensitivity, bias, and axial alignment
Digitally controlled bias calibration
Digitally controlled sample rate, up to 819.2 SPS
External clock input enables sample rates up to 1200 SPS
Digitally controlled filtering
Programmable condition monitoring
Auxiliary digital input/output
Digitally activated self-test
Programmable power management
Embedded temperature sensor
SPI-compatible serial interface
Auxiliary, 12-bit ADC input and DAC output
Single-supply operation: 4.75 V to 5.25 V
2000 *g* shock survivability
Operating temperature range: −40°C to +85°C

APPLICATIONS

Medical instrumentation
Robotics
Platform control
Navigation

FUNCTIONAL BLOCK DIAGRAM

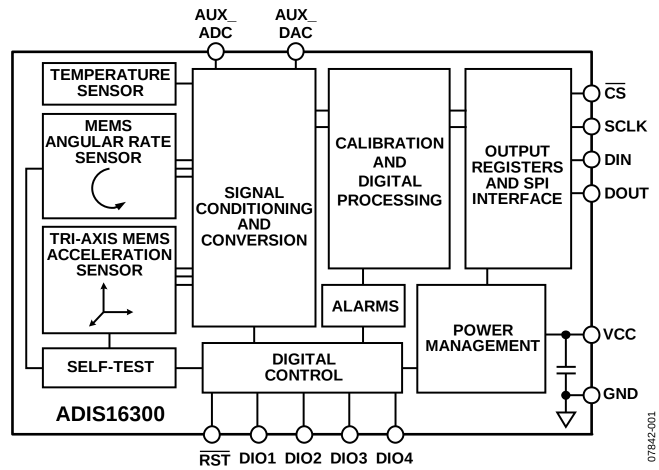


Figure 1.

GENERAL DESCRIPTION

The ADIS16300 *i*Sensor® is a complete inertial system that includes a yaw rate gyroscope and tri-axis accelerometer. Each sensor in the ADIS16300 combines industry-leading *i*MEMS® technology with signal conditioning that optimizes dynamic performance. The factory calibration characterizes each sensor for sensitivity, bias, alignment, and linear acceleration (gyro bias). As a result, each sensor has its own dynamic compensation for correction formulas that provide accurate sensor measurements over the specified power supply range of +4.75 V to +5.25 V. The ADIS16300 provides a simple, cost-effective method for integrating accurate, multi-axis, inertial sensing into industrial systems, especially when compared with the complexity and investment associated with discrete designs. All necessary motion testing and calibration are part of the production process at the factory, greatly reducing system integration time. Tight orthogonal alignment simplifies inertial frame alignment in navigation systems. An improved SPI interface and register structure provide faster data collection and configuration control.

The ADIS16300, along with a flex interface, drops into current systems that use the ADIS1635x family, providing the opportunity to scale cost for systems that only require four degrees of freedom inertial sensing. This compact module is approximately 23 mm × 31 mm × 7.5 mm and provides a standard connector interface, which enables horizontal or vertical mounting.

Rev. A

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SPECIFICATIONS

T_A = −40°C to +85°C, VCC = 5.0 V, angular rate = 0°/sec, dynamic range = ±300°/sec, ±1 *g*, unless otherwise noted.

Table 1.

Parameter	Test Conditions	Min	Typ	Max	Unit
GYROSCOPE					
Dynamic Range		±300	±375		°/sec
Initial Sensitivity	T_A = 25°C, dynamic range = ±300°/sec	0.0495	0.05	0.0505	°/sec/LSB
	T_A = 25°C, dynamic range = ±150°/sec		0.025		°/sec/LSB
	T_A = 25°C, dynamic range = ±75°/sec		0.0125		°/sec/LSB
Sensitivity Temperature Coefficient			400		ppm/°C
Misalignment	Reference to z-axis accelerometer, T_A = 25°C		0.1		Degrees
	Axis-to-frame (package), T_A = 25°C		±0.5		Degrees
Nonlinearity	Best fit straight line		0.1		% of FS
Initial Bias Error	T_A = 25°C, ±1 σ		±3		°/sec
In-Run Bias Stability	T_A = 25°C, 1 σ, SMPL_PRD = 0x01		0.007		°/sec
Angular Random Walk	T_A = 25°C, 1 σ, SMPL_PRD = 0x01		1.9		°/√hr
Bias Temperature Coefficient			0.1		°/sec/°C
Linear Acceleration Effect on Bias	Any axis, 1 σ (MSC_CTRL Bit [7] = 1)		0.05		°/sec/*g*
Voltage Sensitivity	VCC = 4.75 V to 5.25 V		0.25		°/sec/V
Output Noise	T_A = 25°C, ±300°/sec range, no filtering		1.1		°/sec rms
Rate Noise Density	T_A = 25°C, f = 25 Hz, ±300°/sec, no filtering		0.038		°/sec/√Hz rms
3 dB Bandwidth			330		Hz
Sensor Resonant Frequency			14.5		kHz
Self-Test Change in Output Response	±300°/sec range setting	±696	±1400	±2449	LSB
ACCELEROMETERS	Each axis				
Dynamic Range		±3	±3.6		*g*
Initial Sensitivity	25°C	0.594	0.6	0.606	m*g*/LSB
Sensitivity Temperature Coefficient	X axis and Y axis		250		ppm/°C
	Z axis		300		ppm/°C
Misalignment	Axis-to-axis, T_A = 25°C, Δ = 90° ideal		±0.25		Degrees
	Axis-to-frame (package), T_A = 25°C		±0.5		Degrees
Nonlinearity	Best fit straight line		±0.3		% of FS
Initial Bias Error	T_A = 25°C, ±1 σ, X axis and Y axis		±60		m*g*
	T_A = 25°C, ±1 σ, Z axis		±110		m*g*
In-Run Bias Stability	T_A = 25°C, 1 σ, X axis and Y axis		0.048		m*g*
	T_A = 25°C, 1 σ, Z axis		0.054		m*g*
Velocity Random Walk	T_A = 25°C, 1 σ, X axis and Y axis		0.118		m/sec/√hr
	T_A = 25°C, 1 σ, Z axis		0.164		m/sec/√hr
Bias Temperature Coefficient	X axis and Y axis		2.5		m*g*/°C
	Z axis		4.5		m*g*/°C
Output Noise	T_A = 25°C, no filtering, X axis and Y axis		5		m*g* rms
	T_A = 25°C, no filtering, Z axis		7.5		m*g* rms
Noise Density	T_A = 25°C, no filtering, X axis and Y axis		0.2		m*g*/√Hz rms
	T_A = 25°C, no filtering, Z axis		0.3		m*g*/√Hz rms
3 dB Bandwidth			330		Hz
Sensor Resonant Frequency			5.5		kHz
Self-Test Change in Output Response	X axis and Y axis	500	1100	1700	LSB
	Z axis	90	450	860	LSB
INCLINOMETER					
Sensitivity			0.044		°/LSB
TEMPERATURE SENSOR					
Scale Factor	T_A = 25°C output = 0x0000		0.14		°C/LSB

Parameter	Conditions	Min	Typ	Max	Unit
ADC INPUT					
Resolution			12		Bits
Integral Nonlinearity			±2		LSB
Differential Nonlinearity			±1		LSB
Offset Error			±4		LSB
Gain Error			±2		LSB
Input Range		0		+3.3	V
Input Capacitance	During acquisition		20		pF
DAC OUTPUT	5 kΩ/100 pF to GND				
Resolution			12		Bits
Relative Accuracy	For Code 101 to Code 4095		±4		LSB
Differential Nonlinearity			±1		LSB
Offset Error			±5		mV
Gain Error			±0.5		%
Output Range		0		+3.3	V
Output Impedance			2		Ω
Output Settling Time			10		µs
LOGIC INPUTS[1]					
Input High Voltage, V_{INH}		2.0			V
Input Low Voltage, V_{INL}				0.8	V
	$\overline{CS}$ signal to wake up from sleep mode			0.55	V
$\overline{CS}$ Wake-Up Pulse Width		20			µs
Logic 1 Input Current, I_{INH}	V_{IH} = 3.3 V		±0.2	±10	µA
Logic 0 Input Current, I_{INL}	V_{IL} = 0 V				
All Pins Except $\overline{RST}$			−40	−60	µA
$\overline{RST}$ Pin			−1		mA
Input Capacitance, C_{IN}			10		pF
DIGITAL OUTPUTS[1]					
Output High Voltage, V_{OH}	I_{SOURCE} = 1.6 mA	2.4			V
Output Low Voltage, V_{OL}	I_{SINK} = 1.6 mA			0.4	V
FLASH MEMORY	Endurance[2]	10,000			Cycles
Data Retention[3]	T_J = 85°C	20			Years
FUNCTIONAL TIMES[4]	Time until data is available				
Power-On Start-up Time	Normal mode, SMPL_PRD ≤ 0x09		180		ms
	Low power mode, SMPL_PRD ≥ 0x0A		245		ms
Reset Recovery Time	Normal mode, SMPL_PRD ≤ 0x09		55		ms
	Low power mode, SMPL_PRD ≥ 0x0A		120		ms
Sleep Mode Recovery Time			2.5		ms
Flash Memory Test Time	Normal mode, SMPL_PRD ≤ 0x09		17		ms
	Low power mode, SMPL_PRD ≥ 0x0A		90		ms
Automatic Self-Test Time			12		ms
CONVERSION RATE	SMPL_PRD = 0x01 to 0xFF	0.413		819.2	SPS
Clock Accuracy				±3	%
Sync Input Clock				1.2	kHz
POWER SUPPLY	Operating voltage range, VCC	4.75	5.0	5.25	V
Power Supply Current	Low power mode at 25°C		18		mA
	Normal mode at 25°C		42		mA
	Sleep mode at 25°C		500		µA

[1] The digital I/O signals are driven by an internal 3.3 V supply, and the inputs are 5 V tolerant.
[2] Endurance is qualified as per JEDEC Standard 22, Method A117, and measured at −40°C, +25°C, +85°C, and +125°C.
[3] The retention lifetime equivalent is at a junction temperature (T_J) of 85°C as per JEDEC Standard 22, Method A117. Retention lifetime decreases with junction temperature.
[4] These times do not include thermal settling and internal filter response times (330 Hz bandwidth), which may impact overall accuracy.

TIMING SPECIFICATIONS

T_A = 25°C, VCC = 5 V, unless otherwise noted.

Table 2.

Parameter	Description	Normal Mode (SMPL_PRD ≤ 0x09) Min[1]	Typ	Max	Low Power Mode (SMPL_PRD ≥ 0x0A) Min[1]	Typ	Max	Burst Mode Min[1]	Typ	Max	Unit
f_{SCLK}		0.01		2.0	0.01		0.3	0.01		1.0	MHz
t_{STALL}	Stall period between data	9			75			$1/f_{SCLK}$			µs
$t_{READRATE}$	Read rate	40			100						us
t_{CS}	Chip select to clock edge	48.8			48.8			48.8			ns
t_{DAV}	DOUT valid after SCLK edge			100			100			100	ns
t_{DSU}	DIN setup time before SCLK rising edge	24.4			24.4			24.4			ns
t_{DHD}	DIN hold time after SCLK rising edge	48.8			48.8			48.8			ns
t_{SCLKR}, t_{SCLKF}	SCLK rise/fall times		5	12.5		5	12.5		5	12.5	ns
t_{DF}, t_{DR}	DOUT rise/fall times		5	12.5		5	12.5		5	12.5	ns
t_{SFS}	$\overline{CS}$ high after SCLK edge	5			5			5			ns
t_1	Input sync pulse width		5								µs
t_2	Input sync to data ready output		600								µs
t_3	Input sync period	833									µs

[1]Guaranteed by design and characterization, but not tested in production.

TIMING DIAGRAMS

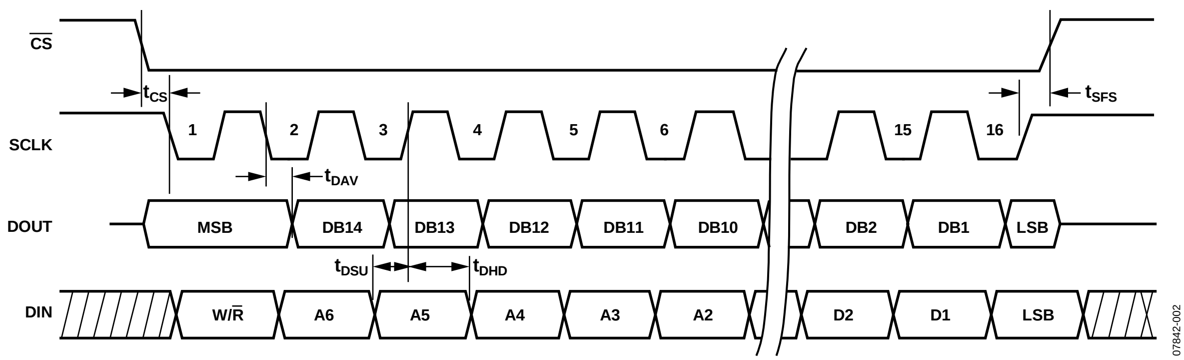


Figure 2. SPI Timing and Sequence

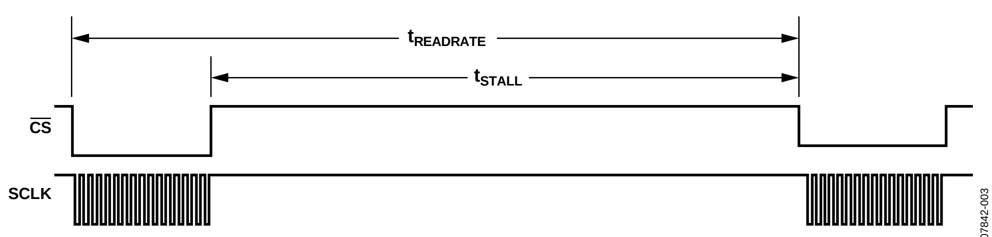


Figure 3. Stall Time and Data Rate

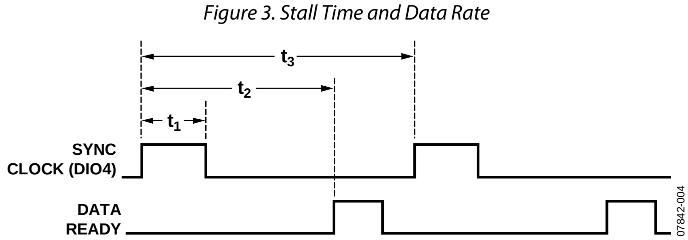


Figure 4. Input Clock Timing Diagram

Attitude & Heading Reference System

AHRS-E304

Description:

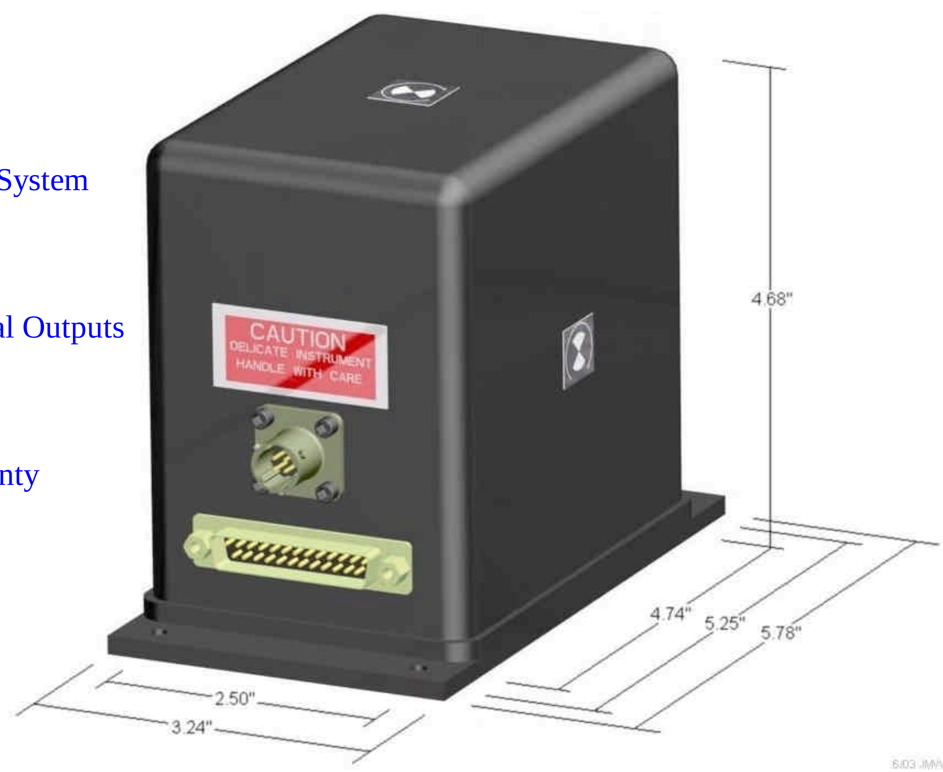
The signals from three solid state angular rate sensors are coordinate transformed and then integrated to produce attitude and heading outputs that reflect normal aircraft attitude coordinates. These attitude and heading signals are compared against a triaxial accelerometer and a triaxial fluxgate magnetometer to derive gyro drift error. These errors are filtered over a long time constant and are used to adjust biases in the system so that the long-term convergence of the system is to the vertical references and the magnetic heading. A velocity input is used to calculate compensations for centrifugal forces and velocity changes on the vertical reference to improve overall stability and accuracy.

This is a microprocessor-based system using a 16 bit A/D converter, a 12 bit D/A converter and an RS-232 interface. The microprocessor has stored parameters for all the sensor inputs to correct bias, scale factor, axis alignment, and others. The analog attitude and heading outputs are updated 71.11 times per second. The serial interface is highly configurable and provides access to almost all operational parameters.

Applications:

The AHRS-E304 has been used on the land, in the sea and in the air for instrumentation, remote pilot display, stabilization, control and dead-reckoning navigation.

- Solid State, Strap Down System
- Low Cost, Low Power
- Rugged, High Reliability
- Vibration Resistant
- Analog and RS-232 Serial Outputs
- Interface Software
- PC Heading Calibration
- Display Software
- One Year Limited Warranty
- Engineering Support



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AHRS-E304 Specifications*

Pitch Rate	±100°/s (10°/s/V) Positive for nose up
Roll Rate	±100°/s (10°/s/V) Positive for roll right
Yaw Rate	±100°/s (10°/s/V) Positive for right turn
Heading Rate	±100°/s (10°/s/V) Positive for right turn
Bank	±180° (18°/V) Positive right bank
Elevation	±90° (18°/V) Positive for nose up
South Heading	0 to 360° (18°/V) (North = ±10V; East = -5V; South = 0V; West = +5V)
North Heading	0 to 360° (18°/V) (South = ±10V; West = -5V; North = 0V; East = +5V)
Rate Accuracy	Static ±0.2°/sec; Dynamic ±2% Digital, ±6% Analog
Attitude Accuracy	Static ±0.5°; Dynamic ±2%**
Heading Accuracy	Static ±1°; Dynamic ±2%**
Digital Output	RS-232 serial communications (adjustable baud rate)
Velocity Input	±400 KPH (±10V) forward velocity
Weight	32 oz.
Power	+12 / +24VDC (10 to 30 VDC) < 5 Watts

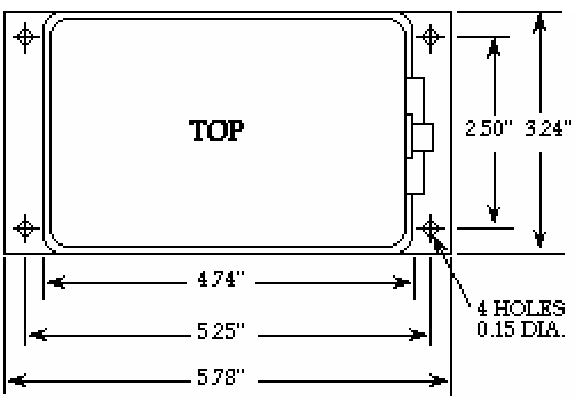
Error correction time constant is about 15 seconds

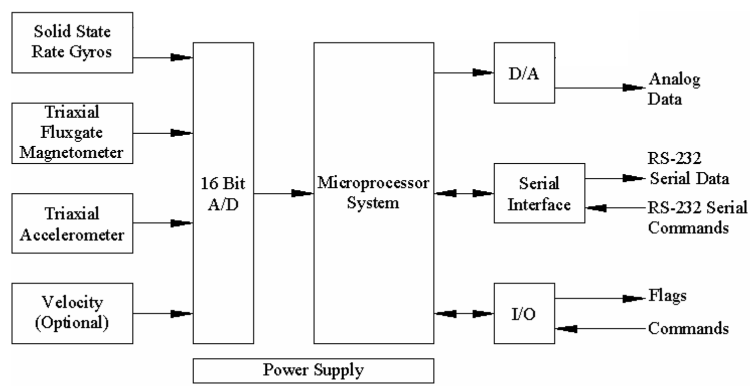
Error growth without error correction is approximately 0.03?/sec.

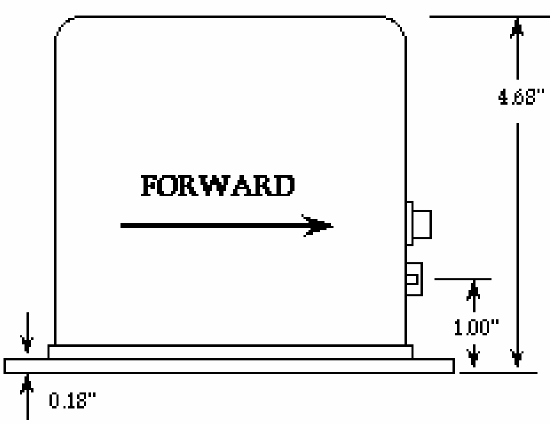
No attitude limits (however, errors are likely to grow rapidly within 5? of vertical in elevation).

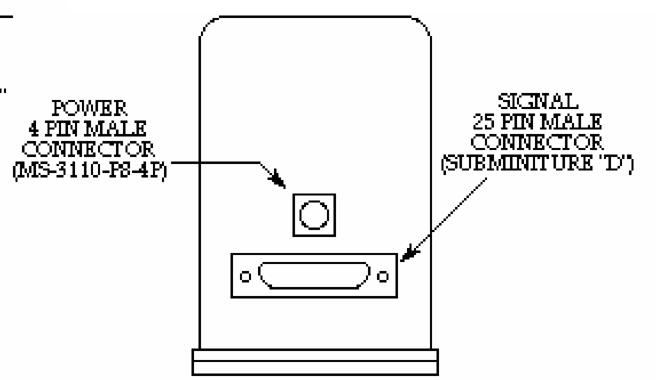
* Subject to change without notice.

** Assumes accurate velocity data.









7/03 JMW

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3DM-GX1®

Gyro Enhanced Orientation Sensor

Introduction

3DM-GX1® combines three angular rate gyros with three orthogonal DC accelerometers, three orthogonal magnetometers, multiplexer, 16 bit A/D converter, and embedded microcontroller to output its orientation in dynamic and static environments.

Operating over the full 360 degrees of angular motion on all three axes, 3DM-GX1®provides orientation in matrix, quaternion, and Euler formats. The digital serial output can also provide temperature compensated, calibrated data from all nine orthogonal sensors at update rates of 350 Hz.

Networks of 3DM-GX1® nodes can be deployed by using the built-in RS-485 network protocol. Embedded microcontrollers relieve the host system from the burden of orientation calculations, allowing deployment of dozens of 3DM-GX1® nodes with no significant decrease in system throughput.

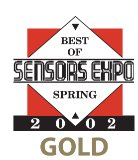
Output modes and software filter parameters are user programmable. Programmed parameters and calibration data are stored in nonvolatile memory.

Features & Benefits

- on-board processing/filtering of accelerometer, gyro and magnetometer output
- fully compensated over wide temperature range
- calibrated for sensor misalignment and gyro G-sensitivity
- supports hard-iron field calibration
- outputs Euler angles, quaternion, orientation matrix, attitude and heading (azimuth/yaw) or raw sensor data
- standard RS-232, RS-485 outputs, optional analog output
- small, lightweight and low power
- AHRS, IMU and vertical gyro modes

Applications

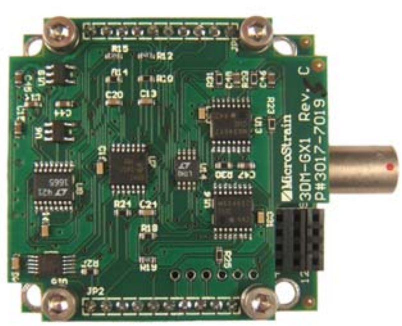
- unmanned aerial / underwater vehicles, robotics – navigation, artificial horizon
- computer science, biomedical – animation, linkage free tracking/control
- mobile cameras, sonar scanners – image reconstruction
- mobile radio antennas – aiming optimization, dynamic correction, antenna shaping
- manufacturing – container handling, hydraulic lift systems, machine tools



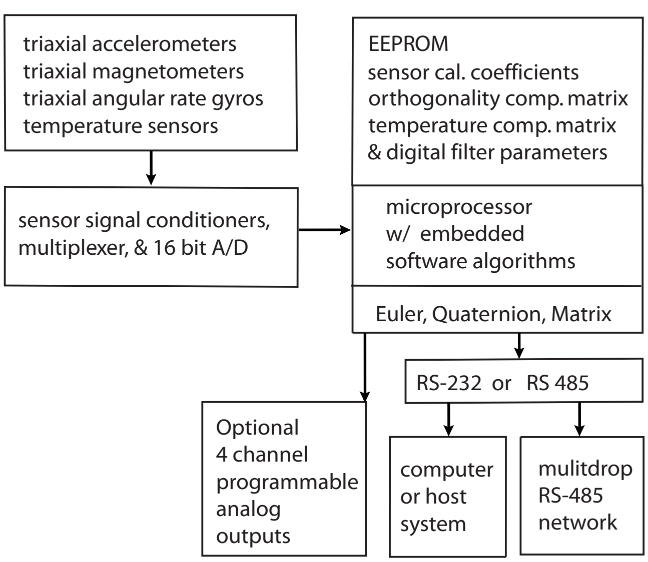
3DM-GX1® utilizes the triaxial gyros to track dynamic orientation and the triaxial DC accelerometers along with the triaxial magnetometers to track static orientation. The embedded microprocessor contains a unique programmable filter algorithm, which blends these static & dynamic responses in real time.

This provides a fast response in the face of vibration and rapid movement while eliminating drift. The stabilized output is provided in an easy-to-use digital format. Analog output voltages proportional to the Euler angles can be ordered as an option.

Full temperature compensation is provided for all nine orthogonal sensors to insure performance over a wide operating temperature range.



3DM-GX1's® small size is ideal for OEM applications.



Specifications

Orientation range (pitch, roll, yaw)	360° all axes (orientation matrix, quaternion) ± 90°, ± 180°,± 180° (Euler angles)
Sensor range	gyros: ± 300°/sec FS accelerometers: ± 5 g FS magnetometers: ± 1.2 Gauss FS
A/D resolution	16 bits
Accelerometer nonlinearity Accelerometer bias stability*	0.2% 0.010 g
Gyro nonlinearity Gyro bias stability*	0.2% 0.7°/sec
Magnetometer nonlinearity Magnetometer bias stability*	0.4% 0.010 Gauss
Orientation resolution	<0.1° minimum
Repeatability	0.20°
Accuracy	± 0.5° typical for static test conditions ± 2.0° typical for dynamic (cyclic) test conditions & for arbitrary orientation angles
Output modes	matrix, quaternion, Euler angles, & nine scaled sensors with temperature
Digital outputs	serial RS-232 & RS-485 optional with software programming
Analog output option	4 channel, 0–5 volts full scale programmable analog outputs
Digital output rates	100 Hz for Euler, Matrix, Quaternion 350 Hz for nine orthogonal sensors only
Serial data rate	19.2/38.4/115.2 kbaud, software programmable
Supply voltage	5.2 VDC minimum, 12 VDC maximum
Supply current	65 mA
Connectors	one keyed LEMO, two for RS-485 option
Operating temp.	-40 to +70°C with enclosure -40 to +85°C without enclosure
Enclosure (w/tabs)	64 mm x 90 mm x 25 mm
Weight (grams)	75 grams with enclosure, 30 grams without enclosure
Shock limit	1000 g (unpowered), 500g (powered)

*Accuracy and stability specifications obtained over operating temperatures of -40 to 70°C with known sine and step inputs, including angular rates of ± 300° per second.

For additional information, please refer to "3DM-GX1 - Detailed Specifications", available online at www.microstrain.com.

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Patent Pending

SYSTRON DONNER INERTIAL

MEMS Multi-Axis Inertial Sensing System

MotionPak® II

Applications

- **Vehicle Instrumentation**
- **Robotics**
- **Remotely Piloted Vehicles**
- **Attitude Reference Systems**
- **Industrial Control Systems**
- **Navigation Aiding GPS**
- **Marine Instrumentation**
- **Flight Testing**

Description

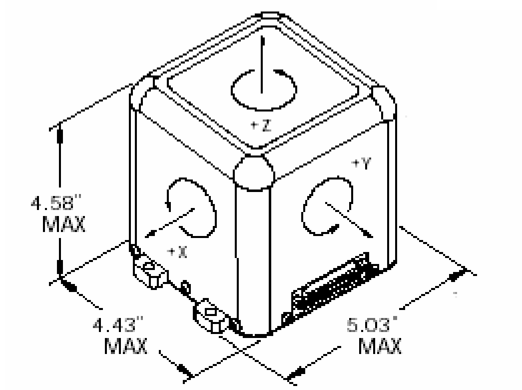
The MotionPak® II is a "solid-state" MEMS six degree of freedom inertial sensing system used for measuring linear accelerations and angular rates in instrumentation and control applications. It is a highly reliable, compact, and rugged package providing both analog and digital (RS-232) outputs. With three orthogonally mounted micromachined quartz angular rate sensors and three silicon based accelerometers, the MotionPak II is a fully self-contained motion measurement package utilizing internal power regulation and signal conditioning electronics.

Key Performance Features

- **"Solid-State" Sensors**
- **Dual Level Analog Outputs**
- **RS-232 Digital Output**
- **Single Supply Feature**
- **Compact, Rugged Package**
- **Wide Bandwidth**
- **Long Operating Life**
- **Fast Start-Up**
- **Low Cost**
- **Fully Self-Contained System**

MEMS Multi-Axis Inertial Sensing System

www.systron.com



Part Number:	MP2K-CCC-666-100			
	STANDARD OUTPUTS		SINGLE SUPPLY FEATURE	
	(High, low & RS-232 outputs)		(Low Output & RS-232 only)	
Input Power	Dual Supply (bipolar)		Single supply	
Input Voltage	+ and - 15 Vdc ±1 Vdc		+ 11.0 Vdc +16.0 Vdc	
Input Current	Plus Supply <125 milliampere		<125 milliampere	
	Minus Supply <35 milliampere			
Performance	**Rate Channels**	**Accelerometer Channels**	**Rate Channels**	**Accelerometer Channels**
Standard ranges	±75°/sec	±1.5g	±75°/sec	±1.5g
Full Scale HIGH Analog Output	±10 Vdc	±10 Vdc	--	--
Full Scale LOW Analog Output	+0.5/+4.5 Vdc	+0.5/+4.5 Vdc	+0.5/+4.5 Vdc	+0.5/+4.5 Vdc
Scale Factor HIGH-nominal	0.133 V/°/sec	6.66 V/g	--	--
Scale Factor LOW-nominal	0.027 V/°/sec	1.2 V/g	0.027 V/°/sec	1.2 V/g
Sensitivity (Error) -40 to +85°C	±6% (1)	±5%	±6% (1)	±5%
Offset HIGH-nominal	0 Vdc	0 Vdc	--	--
Offset low-NOMINAL	2.5 Vdc	2.5 Vdc	2.5 Vdc	2.5 Vdc
Offset (-40 to +85°C)	±5.0°/sec (2)	±125 mg	±5.0°/sec	±125 mg
Output noise High Analog	28 mV RMS	28 mV RMS	--	--
Output noise Low Analog	6 mV RMS	5 mV RMS	6 mV RMS	5 mV RMS
Start-up time	1.0 Second	1.0 Second	1.0 Second	1.0 Second
Bandwidth	DC to >30 Hz	DC to >250 Hz	DC to >30 Hz	DC to > 250 Hz
Non-linearity (% Full Range)	<3%	±40 mg	<3%	±40 mg
Environments				
Operating temperature	-40 TO +85°C		-40 TO +85°C	
Storage temperature	-40 TO +85°C		-40 TO +85°C	
Vibration survival	4 g RMS (20 – 2 KHz)		4 g RMS (20 – 2 KHz)	
Shock	200 g PK 2 mSec ½ sine pulse		200 g PK 2 mSec ½ sine pulse	
(1) Sum of 3% Set and 3% Linearity, worst case				
(2) Sum of 1.8°/sec Set and 3.2°/sec TC, worst case				
RS-232 Feature				
	Data Transfer Rate: 32 Hz maximum (measuring 7 “12 BIT” WORDS)			
	LSB = 1.2 millivolt (Least Significant BIT)			
Temperature Sensor				
	10 millivolt/°K	-40°C (233.15°K) = +2.33 Vdc	+85°C (358.15°K) = +3.58 Vdc	

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965769-1 Rev. C

The MTi is a miniature size and low weight 3DOF Attitude and Heading Reference System (AHRS).The MTi contains accelerometers, gyroscopes and magnetometers in 3D, and as such is an Inertial Measurement Unit (IMU) as well. Its internal low-power signal processor provides real-time and drift-free 3D orientation as well as calibrated 3D acceleration, 3D rate of turn and 3D earth-magnetic field data.

The MTi is an excellent measurement unit for stabilization and control of cameras, robots, vehicles and other (un)manned equipment.

Highlights

- Real-time computed attitude/heading and inertial dynamic data
- 360º orientation referenced by gravity and earth magnetic field
- Integrated 3D gyroscopes, accelerometers and magnetometers
- On board DSP with realtime sensor fusion algorithm
- Gyroscopes enable high-frequency orientation tracking
- High update rate (256 Hz), inertial data at max 512 Hz
- Individually calibrated for temperature, 3D misalignment and sensor cross-sensitivity
- Accepts and generates synchronization pulses

Compact Design

- Compact and robust design
- Easy integration in any system or application (OEM)
- Low weight, ultra-low power consumption

High performance

The MTi uses gyroscopes, accelerometers and magnetometers in order to determine the orientation. The sophisticated Xsens sensor fusion algorithm copes with temporary magnetic disturbances and short-term accelerations, resulting in a reliable real-time orientation estimate. Additionally, the MTi SDK incorporates a magnetic field mapping routine to correct for hard and soft iron effects.

Application-specific settings for optimal accuracy

As the MTi is used in a wide range of applications, the embedded sensor fusion filter algorithm should be adapted to the specific application to ensure the best achievable accuracy. Xsens has tested and tuned the sensor fusion filter settings for a range of common motion scenarios. The unique sets of parameters are provided in user-settable Scenarios. Using the correct scenario for your application ensures highest attainable accuracy for the application at hand, tested by Xsens, without the need for lengthy extensive tuning with uncertain results. Just set and go.

Maximum flexibility

The MTi can be software or hardware synchronized (both SyncIn and SyncOut). The extensive SDK ensures full control of the MTi and makes interfacing to the MTi easy. The SDK provides interfaces at multiple levels: intuitive Windows GUI software, API binary libraries (Windows, Linux) as well as supplying source code implementing the MTi binary communication protocol for easy integration on any platform. With the MTi, your preferred solution is easy and fast to realize.

Output

- 3D orientation (360°)
- 3D acceleration
- 3D rate of turn
- 3D magnetic field

MTi TECHNICAL SPECIFICATIONS

Attitude and Heading

Static accuracy (roll/pitch)	<0.5 deg
Static accuracy (heading)[1]	<1 deg
Dynamic accuracy[2]	2 deg RMS
Angular resolution[3]	0.05 deg
Dynamic range:	
- Pitch	± 90 deg
- Roll/Heading	± 180 deg
Maximum update rate:	
- Onboard processing	256 Hz
- External processing	512 Hz
Specified performance operating range[4]	0...+55 °C

Interfacing

Digital interface	RS-232, RS-485, RS-422 (max 921k6 bps) and USB (ext. converter)
Operating voltage	4,5 - 30V
Power consumption	350 mW
Interface options I/O	SyncOut, AnalogIn, SyncIn (depends on digital interface)

Maximum operational limits

Ambient temperature operating range[4]	-40...+85 °C

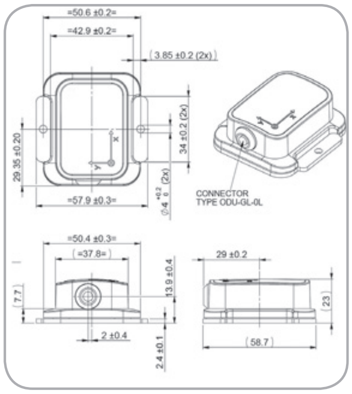
INDIVIDUAL SENSOR SPECIFICATIONS

Sensor performance	Rate of turn	Acceleration	Magnetic field
Dimensions	3 axes	3 axes	3 axes
Full Scale (standard)	± 300 deg/s	± 50 m/s²	± 750 mGauss
Linearity	0.1% of FS	0.2% of FS	0.2% of FS
Bias stability[5]	1 deg/s	0.02 m/s²	0.1 mGauss
Scale Factor stability[5]	-	0.03%	0.5%
Noise	0.05 deg/s/√Hz	0.002 m/s²/√Hz	0.5 mGauss
Alignment error	0.1 deg	0.1 deg	0.1 deg
Bandwidth	40 Hz	30 Hz	10 Hz
Max update rate	512 Hz	512 Hz	512 Hz

HARDWARE SPECIFICATIONS

Housing

Dimensions (WxLxH)	58x58x22 mm
Weight	50 g



Options

Interface:		Full scale acceleration:		Full scale rate of turn:	
RS-232	28			150 deg/s	G15
RS-485	48	5g (50 m/s²)	A53	300 deg/s	G35
RS-422	68	18g (180 m/s²)	A83	1200 deg/s	G25

Product code: MTi-## A## G##

Standard version: MTi-28 A53 G35

The MTi is RoHS compliant

Note: Specifications subject to change without notice

1 in homogeneous magnetic environment
2 under condition of a stabilized Xsens sensor fusion algorithm
3 1 standard deviation of zero-mean angular random walk
4 non-condensing environment
5 deviation over operating temperature range 1σ

xsens

NAV440

GPS-Aided MEMS Inertial System

Crossbow® TECHNOLOGY / INC.

The Crossbow NAV440 is a fully-integrated combined GPS navigation and GPS-aided Attitude & Heading Reference System (AHRS) solution. The NAV440 provides full inertial data (angles, rates, accels) and GPS position, along with inertially computed velocity that provides significant improvement in stability and higher data rates compared with stand-alone GPS velocity measurements.

The NAV440 integrates highly reliable MEMS sensors (gyros and accelerometers), 3-axis magnetometer, and a WAAS/EGNOS-enabled GPS receiver all in a compact and rugged environmentally sealed enclosure. The NAV440 provides consistent performance in challenging operating environments, and is user-configurable for a wide variety of applications such as unmanned vehicle control, land vehicle guidance, avionics systems, and platform stabilization.

KEY FEATURES

- **Pitch and roll accuracy of <0.4°**
- **Output data rate up to 100 Hz**
- **High-range sensor options (400°/sec, 10g)**
- **WAAS and EGNOS enable GPS**
- **Low power < 4W at 28 VDC**
- **High reliability, MTBF >25,000 hours**
- **Rugged sealed enclosure**
- **Certified for DO-160D environments**

SPECIFICATIONS

Environment

Operating Temperature	-40° to +71°C
Enclosure	IP66 compliant

Electrical

Input Voltage	9 to 42 VDC
Power Consumption	< 4 W
Digital Interface	RS-232

Physical

Size	3.0"w x 3.75"l x 3.0"h
Weight	1.3 lbs (0.58 kg)
Interface Connector	DB15, D-sub 15-pin Male
GPS Antenna Connector	SMA Male

PERFORMANCE

Position/Velocity

Position Accuracy	<3.0 m CEP
1PPS Accuracy	±50 ns

Heading

Accuracy	<1.0° rms (magnetic)
	<0.75° rms (with GPS aiding)

Attitude

Range: Roll, Pitch	±180°, ±90°
Accuracy	<0.4°

Angular Rate

Range: Roll, Pitch, Yaw	±200° or ±400° [1]
Bias Stability in run	<10°/hr
Bias Stability over temp	<0.02°/sec

Acceleration

Input Range	±4 g or ±10 g [1]
Bias Stability in run	<1 mg
Bias Stability over temp	<4 mg

1 Option available

For more information:

Phone: 1-408-965-3300
Email: info@xbow.com
www.xbow.com

Crossbow Technology, Inc.
1421 McCarthy Blvd.
Milpitas, CA 95035

Photo Credit: Matt Morgan
6020-0159-01 Rev A

PHINS

TECHNICAL SPECIFICATIONS

IMO Certified
N° 19110/A1 EC
N° 19183/A1 EC

PERFORMANCE

Position accuracy (1)	
With GPS	Three times better than GPS accuracy
With USBL/LBL (Subsea Applications)	Three times better than USBL/LBL accuracy
With DVL	0.1% of travelled distance
No aiding for 2 minutes	3 m
No aiding for 5 minutes	20 m
Pure inertial mode	0.6 Nm/hr
Heading accuracy (2) (3)	
With GPS	0.01 deg secant latitude
With USBL/LBL/ DVL (Subsea Applications)	0.02 deg secant latitude
Roll and Pitch dynamic accuracy (2)	0.01 deg
Heave accuracy	5 cm or 5% (whichever is greater)

OPERATING RANGE / ENVIRONMENT

Operating / Storage Temperature	-20 to 55 °C / -40 to 80 °C
Rotation rate dynamic range	Up to 750 deg/s
Acceleration dynamic range	± 15 g
Heading / Roll / Pitch	0 to +360 deg / ±180 deg / ±90 deg
MTBF (computed/observed)	40,000 hours / 80,000 hours
No warm-up effects	
Shock and Vibration proof	

PHYSICAL CHARACTERISTICS

Dimensions (L x W x H)	180 x 180 x 160 mm
Weight in air	4.5 kg
Water proof	IP66
Material	Aluminium

INTERFACES

Serial RS232/RS422 port	5 inputs / 5 outputs / 1 configuration port
Ethernet port (4)	UDP / TCP Client / TCP server
Pulse port (5)	4 inputs and 2 outputs
Sensors supported	GPS, USBL, RAMSES, LBL, DVL, DEPTH, CTD/SVP
Intput/Output formats	Industry standards: NMEA0183, ASCII, BINARY
Baud rates	600 bauds to 115.2 kbaud
Data output rate	0.1 Hz to 200 Hz
Power supply	24 VDC
Power consumption	15 W

(1) CEP: 50 % circular Error Probability. DVL aiding position accuracy is dependent on DVL performances.
(2) RMS values
(3) Secant latitude = 1 / cosine latitude
(4) All input /output serial ports are available and can be duplicated on Ethernet ports
(5) Use GPS PPS pulse for accurate time synchronization of PHINS

Specifications subject to change without notice

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2010-02-PS-PHI

Appendix C

Angular Encoder Data Sheets

Series 600

High Accuracy ADTs

The Series 600 Angular Displacement Transducers (ADT's) are precision differential capacitors. These transducers do not have the edge effects and dimensional instability characteristic of traditional capacitive devices. The sensing element is coupled to a solid state oscillator, demodulator, and amplifier to yield DC input — DC output performance.

These transducers deliver a high level analog DC voltage directly proportional to shaft angular displacement with a high degree of conformity. Rotation is continuous and there is no reactive torque. Reliable performance is assured by the absence of any high speed rubbing contacts.

KEY FEATURES

- **Ranges from ±30º to ±60º**
- **Non-linearity < 0.05%**
- **Absolute Measurement**
- **DC Voltage Operation**

SPECIFICATIONS

MODEL NO.	DISPL. RANGE +CW, -CCW	LINEARITY*	MAX. USABLE RANGE	LINEARITY USABLE RANGE	OUTPUT VDC	INPUT/ OUTPUT CURVE	TYPICAL TEMP. COEF. SPAN/°F
0600-0000	±30°	±0.05%	±40°	±0.10%	100 mV/°	1	-0.01%
0601-0000	10° -70° CW	±0.05%	0° -80° CW	±0.10%	100 mV/°	2	-0.015%
0602-0000	10° -70° CCW	±0.05%	0° -80° CCW	±0.10%	100 mV/°	3	-0.01%
0603-0000	±60°	±0.10%	±80°	±0.15%	100 mV/°	4	-0.01%
0603-0001	±60°	±0.05%	±80°	±0.10%	100 mV/°	4	-0.01%
0603-0002	20° -140° CW	±0.10%	0° -160° CW	±0.15%	50 mV/°	5	-0.015%
0603-0003	20° -140° CW	±0.05%	0° -160° CW	±0.10%	50 mV/°	5	-0.015%
0603-0004	20° -140° CCW	±0.10%	0° -160° CCW	±0.15%	50 mV/°	6	-0.01%
0603-0005	20° -140° CCW	±0.05%	0° -160° CCW	±0.10%	50 mV/°	6	-0.01%

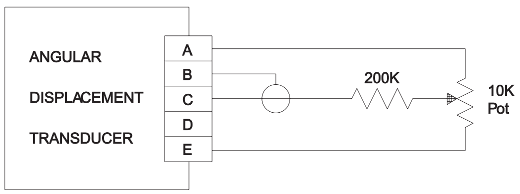
*Definition: Zero Base Terminal Average, expressed as a max % deviation of total range.

CW defined as clockwise direction of shaft rotation, when viewed from shaft end.

COMMON ELECTRICAL SPECIFICATIONS

REPEATABILITY	< .01%	**INTERNAL CARRIER FREQUENCY**	400 KHz
RESOLUTION	Infinite	**RIPPLE, MAX.**	20 mV P/P 400 KHz
CURRENT, INPUT	30 mA Max.	**ZERO ADJUSTMENT**	±3°
IMPEDANCE, OUTPUT	< 2 Ohms	**ZERO POSITIONS**	See Output Curves
MAX. ANGULAR VELOCITY	1,440°/sec	**FREQUENCY RESPONSE**	> 1500 Hz
MAX. ANGULAR VELOCITY with output down < 2%	18,000°/sec available (see "Ordering Information", pg. 53)	**EXCITATION VOLTAGE** Input > 18 VDC may damage unit	15.00 VDC (see options, pg. 53)
INPUT POLARITY PROTECTED		**OUTPUT SHORT CIRCUIT PROTECTED**	

REMOTE ZERO OPERATION

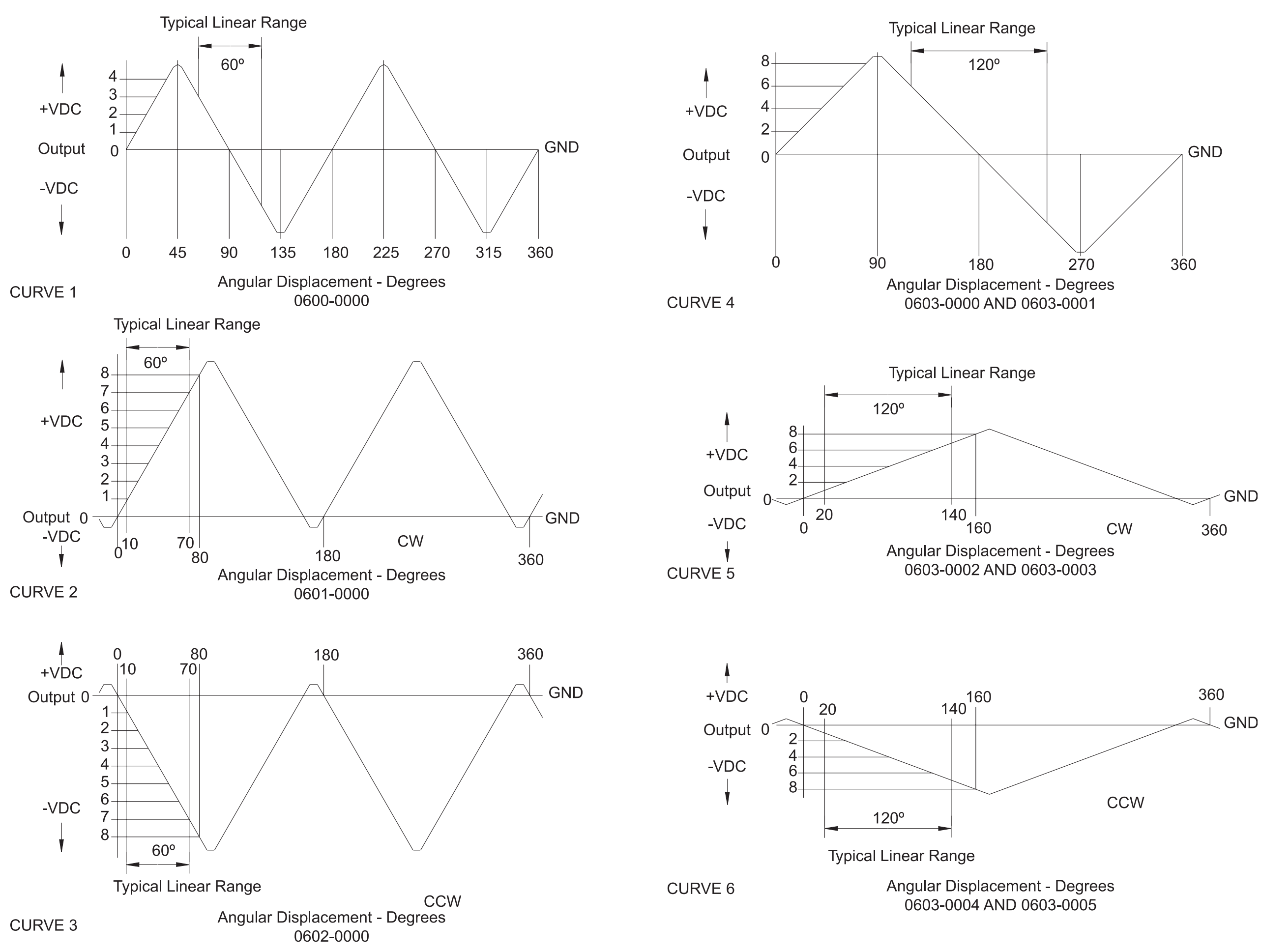


Connector Pin Legend	Pin
Input +	A
Input Ground	B
Remote Zero Control	C
Output +	D
Output Ground	E

REMOTE ZERO CONNECTIONS

Unless operating in a noise free environment, the lead to pin C must be shielded, as shown. The existing zero adjust potentiometer in the Angular Displacement Transducer must be rotated fully clockwise before the remote zero control can function correctly. This remote function is useful in applications where it is inconvenient to access the adjustment screw on the transducer housing.

INPUT - OUTPUT CURVES

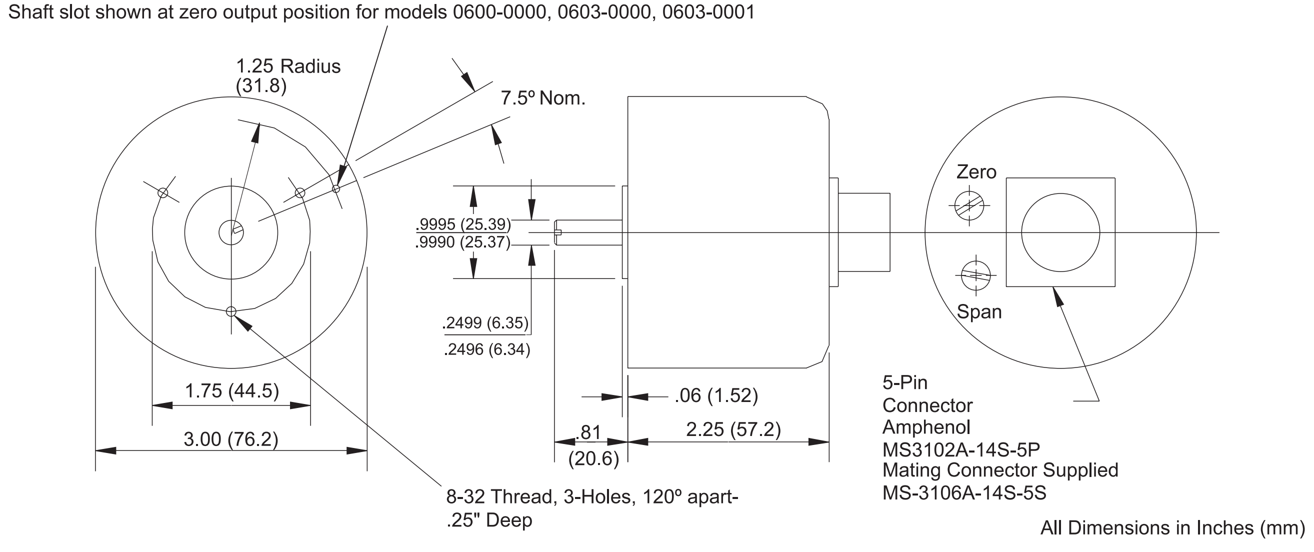


Series 600
Mechanical Specifications

MECHANICAL SPECIFICATIONS

DISPLACEMENT RANGE	Continuous	**NOMINAL WEIGHT**	12.5 oz., 352 gm.
TORQUE, MAX. STARTING (0.5 GM. CM. AVAILABLE)	5.0 gm. cm.	**LIFE: LIMITED BY BEARINGS, EG.**	10 lbs. radial load at 10 RPM; bearing life - 17,000 hours
TORQUE, MAX. RUNNING	3.5 gm. cm.	**OPERATING TEMP. RANGE**	+32°F to +167°F (0°C to +75°C)
MOMENT OF INERTIA, ROTOR	6 gm. cm.^{2}	**OPERATING TEMP. RANGE (EXPANDED)**	-67°F to +257°F (-55°C to +125°C) available (see "Ordering Information", next pg.)
MAX. RADIAL LOAD, AT SHAFT END	10 lbs.	**STORAGE TEMP. RANGE**	-67°F to +257°F (-55°C to +125°C)
MAX. AXIAL LOAD	7 lbs.	**MOUNTING**	Any position, gravity insensitive

DIMENSIONAL DIAGRAM



SLOT - ANGLE POSITION

MODEL	SLOT-ANGLE POSITION	MODEL	SLOT-ANGLE POSITION
0600-0000	0° ±3°	**0603-0000, 0603-0001**	0° ±3°
0601-0000	40° CW ±3°	**0603-0002, 0603-0003**	80° CW ±3°
0602-0000	40° CCW ±3°	**0603-0004, 0603-0005**	80° CCW ±3°

As seen in the output curves graph on the previous page, there is more than one linear range throughout one complete shaft revolution. Only one of these ranges is calibrated. To find the calibrated range, line up the slot in the shaft to the drill hole in the face of the unit. The output voltage at this position corresponds to the angular position within the linear range. For Models 0600-0000, 0603-0000, and 0603-0001, this is the zero position.

INSTALLATION

There are no installation restrictions; the transducer can be mounted in any position. Three tapped holes are provided in the mounting surface. The close toleranced stainless steel pilot when fitted into a properly machined bore will predetermine the shaft position. Aligning the shaft slot with the drill spot on the transducer face will approximate the center of the working range. Refer to the physical diagram for mounting dimensions.

ORDERING INFORMATION

Model # — S-Number Description

060_ - 000_ — S - 0 _ 0 _ 0 _

TEMPERATURE
1 +32°F to +167°F
2 -67°F to +257°F[1]

ANGULAR VELOCITY/ STARTING TORQUE
1 Standard
2 Max Angular Velocity: 18,000°/sec
3 Max Angular Velocity: 18,000°/sec; Starting torque: 0.5 gm. cm[2].

SEALING
1 General Purpose
2 Splashproof

Notes: 1. When expanded temperature range is selected, option 2 or 3 must be selected under Angular Velocity.
2. The shaft OD is reduced to 0.125 Inches (3.18 mm).

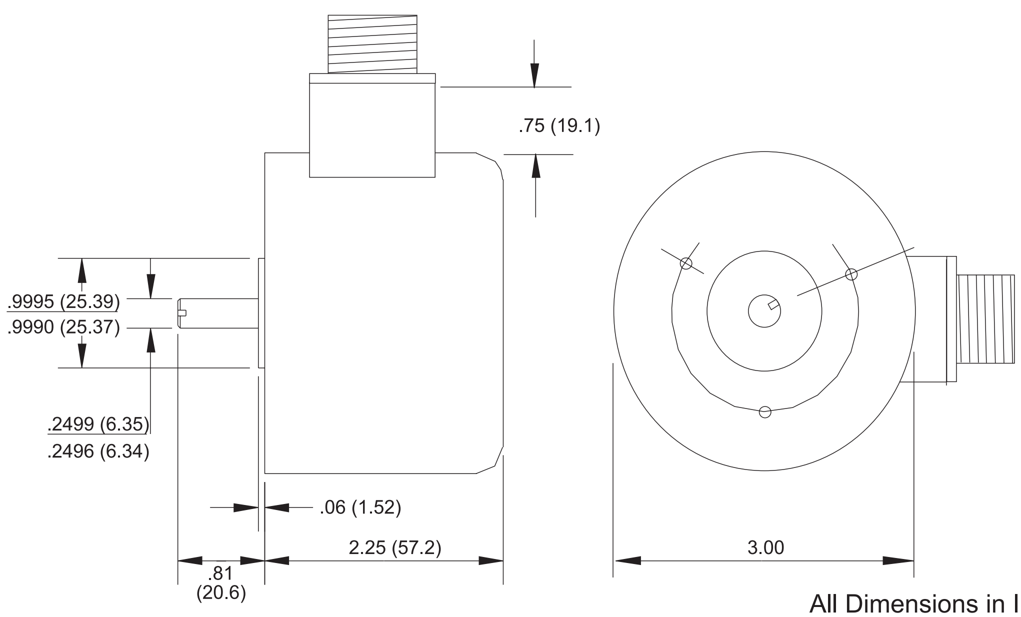
For an additional charge, the following options are available at the time of purchase:

- Units can be factory calibrated to your specified excitation voltage, ranging from 12 to 16 VDC to provide an output as stated in the electrical specifications per listed model number. The standard is 15 VDC.
- Units can be factory calibrated to your specified sensitivity; available sensitivity values will vary with the particular model selected, the input voltage and other factors. Please contact factory for details.
- Zero offset other than the standard models listed ranging from 0° to ±30° (0600-0000) to 0 to ±60° (0603-0000) can be ordered providing that the maximum output voltage is 4 VDC less than the supply voltage (12 to 16 VDC).

SALES OPTIONS

Option #	Description
X0016:	Vibration Protection - Internal electronics are encapsulated in RTV to prevent free movement during high vibration and/or shock
X0033:	Material modification for operation in a vacuum environment; Span and Zero pots are replaced by fixed resistors
X0035:	Increase axial load tolerance to 14 pounds; not available with high speed option
X0042:	Optional side connector configuration; replaces axial connector; see diagram below

DIMENSIONAL DRAWING



All Dimensions in Inches (mm)

TRANS-TEK INCORPORATED