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Laboratory Memorandum

LM-2004-09

Design of a Yaw Restraining Heave Post

R. Shandera

April 2004



DOCUMENTATION PAGE

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SUMMARY <p>The Institute for Ocean Technology is a national research facility that specializes in the testing of scale models. In many cases they are models of vessels that may one day see production. The information gathered from the testing facilities will give the people who designed the vessel a sense of how the vessel will perform in the real world. Often the models are not self propelled, yet propulsion must come from the carriages above the tow tanks. Often the propulsion is transferred to the models through the use of a heave post. The current heave post does not have the ability to restrict the motion of the model about its own axis. Therefore another piece of equipment is used to accomplish this task. There are a number of problems associated with this device that are considered undesirable. To eliminate the use of this piece of equipment a new heave post was designed. In order to have a heave post which functioned properly a set of design criteria were established. The design criteria lead to the development of several designs, from which the best suited candidate was chosen. The new heave post, when it is manufactured will supplement the existing heave post, giving the facility the ability to operate more smoothly.</p>			
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Technology

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océaniques

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1.0 Introduction

The Institute for Ocean Technology (IOT) is a part of the National Research Council (NRC). The main component of their research is model testing. The models that are tested at IOT's facilities consist of virtually any structure that will interact with the ocean. Everything from the Hibernia platform to underwater vehicles has been tested in the facilities at IOT. A majority of the models tested at IOT are scale models of ships. These models are tested to determine their performance under various conditions. In most of these tests, models require some form of propulsion. Some models are self-propelled. However, more are propelled through the carriages situated over the various tanks. The clear water towing tank (CWTT) carriage is capable of reaching a top speed of 10m/s. The device employed to provide propulsion varies depending on the type of model being tested, many times a simple heave post is used. This post is designed to allow the model to move freely in the vertical direction (heave), and rotate freely about that axis of the post (yaw) and is used in conjunction with a gimble that allows the model to pitch and roll. However it is not always desirable to allow the model to yaw. If a large model is unstable it is possible for it to yaw until it breaks the gimble. The gimble has the ability to resist yaw moments but has no strength in that direction. Currently IOT does have the ability to keep a model from yawing. However, this will be discussed later. This was the driving force for the need of a yaw restraining heave post. This post is not a complete replacement of the existing heave post. It will instead be used to supplement the

existing post. This will allow both the ice tank and the fresh water tow tank to operate at the same time without equipment availability causing a problem.

2.0 Existing Design

There are several tow posts at IOT. They vary in both diameter and length. Currently the medium heave post and gimble are used more often for the purposes of experimentation. The dimensions of that post are:

- Outer Diameter 2.5"
- Inner Diameter 1.75"
- Weight 22.5 lbs
- Length 23"



Figure 1. The existing medium heave post

This post can be seen in figure 1. Also shown in this figure is the frame that supports the post. The post is allowed to move freely in both heave and yaw. It

is not allowed to move in the horizontal direction. This is obviously a necessity if the post is to transfer any force to the model. The heave post is strong enough to resist virtually any force applied via a model. The limiting factor of this design is the linear bearings that restrain the yaw of the model. The average model is accelerated at 0.4m/s^2 , and the operator of the carriage gradually accelerates large models to prevent the bearings from becoming overloaded. However the real danger of failure occurs when the operator must fully apply the brakes of the carriage. This results in an deceleration of 3 m/s^2 . Forces much greater in magnitude are generated at this acceleration. A quick inspection of Newton's second law shows that the same model will generate a force 7 times larger occurs during a sudden stop than under normal operating conditions.

$$F = ma \quad (1)$$

Where: F = force
m = mass
a = acceleration

The medium heave post does perform the job it was designed to do. However the need to restrict the motion of the model about the vertical axis presented itself.

The institute is currently able to restrict the motion of the model in yaw. This is done through application of a device known within the institute as "the grasshopper". The grasshopper can be seen in figure 2. The grasshopper

attaches to the bow of the model and the square post is used to resist the yaw. There are two major problems associated with the grasshopper. First, there is a counterweight that can be seen to the left of the figure 2. When the model has trimmed, the counterweight has no effect. However, when a model is pitching and heaving due to wave and wind interactions, the counterweight has a detrimental effect. When wave and wind are applied to a model the intention is to measure how the model responds.



Figure 2. The current yaw restricting "The Grasshopper".

The counterweight does not allow the true motion of the model to be observed. The counterweight actually has a dampening effect on the motion of the model. This reduces the accuracy of the data collected and does not allow for a good correlation between model motion and full scale motion. The second problem associated with the grasshopper is its length. The grasshopper is not always

long enough to reach the model and hold it at the appropriate angle. When this situation occurs a number of six-inch extensions are added. This reduces the flexural and torsional stiffness of the apparatus. The grasshopper acts like a cantilever beam. As the length of the cantilever beam increases, so does the amount the end of the beam will deflect under a given load. Also, as the length increases, so does the angle of twist that will be experienced. These phenomena are determined by the following equations:

$$\theta = \frac{TL}{GJ} \quad (2)$$

Where:
 θ = the angle of twist
T = the applied torque
L = the length of the member
G = the modulus of rigidity
J = the polar moment of inertia of the cross section

$$\delta = \frac{PL^3}{3EI} \quad (3)$$

Where:
 δ = the deflection of the end of the post
P = the applied load
L = the length of the post
E = the modulus of elasticity
I = the moment of inertia

3.0 Design Criteria

The design of the tow post is a classic design problem. The post is required to be longer, lighter, and stronger than the current post. This does not give any specific limit to the characteristics of the design. It was determined that the post must meet the following characteristics:

- Weight: 45Lbs.
- Heave: 27in. (amount of heave for long medium diameter post.)
- Model Size:
 - Length 7m
 - Mass 1000 kg
- Acceleration: 3m/s^2
- Post must mount to the large tow post shown in figure 3.
- The ability to resist yaw forces while being able to trim the yaw angle.
- The ability to lock the post in heave must be present.



Figure 3. Large tow post.

4.0 Design

There were a number of possible designs considered for the new heave post. There are several characteristics that are common among all the designs. First, the inclusion of a linear rail and bearing system is common to all designs. The linear rail and bearing insure that the post will heave properly. That is, the coefficient of friction will be lowered greatly, which will keep the heave post heaving freely. Also, the bearings will be used to counteract any yaw force acting on the model. The bearings chosen for the new heave post are THK SHS 15LC. These rails were chosen over the THK SHS 15C bearings because they have a higher critical load of 35kN. Under an applied load of 35kN the balls in the bearing will start to cause indentations on the rails that will decrease the

effectiveness of the rail system. Also, all the designs must be mounted in some way to the front of the existing tow post shown in figure 3. This will allow the cross-sectional area of the heave post to be increased in comparison to the existing design. An increase in cross-sectional area will increase the strength of the post in virtually all-loading conditions. This is important since the length of the post is also going to increase. The fact that the heave post is to be mounted away from the center of the tow post will allow for easy adjustment of the yaw angle of the model with respect to the tank wall. It is possible to simply have a pivot post with a treaded rod at another location to adjust the yaw angle with the heave post in this location. However, if the post were aligned with the center of the tow post, a much more complicated gearing system would likely be used.

4.1 Alternative Heave Post Designs

There were a number of alternative designs considered for the heave post. They consisted of different geometries and the use of different materials. The first design considered was simply an alteration of the current heave post. A 2.5" outer diameter hollow shaft was considered. The existing design is able to withstand any force applied to the model. Again the linear bearings are the limiting factor to the force that can be applied. This design would be difficult to fabricate. The post would need to be machined to allow for proper alignment of the linear rails. Even though it is possible for this to be done with the boring mill it would require more work and reduce the strength of the post. Then, a carbon fiber square post with external dimensions of 3" x 3" was tried. The use of a

carbon fiber post would have reduced the weight of the post and will not be sacrificing a great deal of strength. However, the technology is not present at IOT to manufacture such a post, purchasing a carbon fiber sail boom was considered. A closer inspection was made to the process that will be used to attach the linear rails. The process would be very complicated and greatly increase the price of the design. If this technology were more readily available at IOT then this material would have become a more viable option.

4.2 Chosen Design

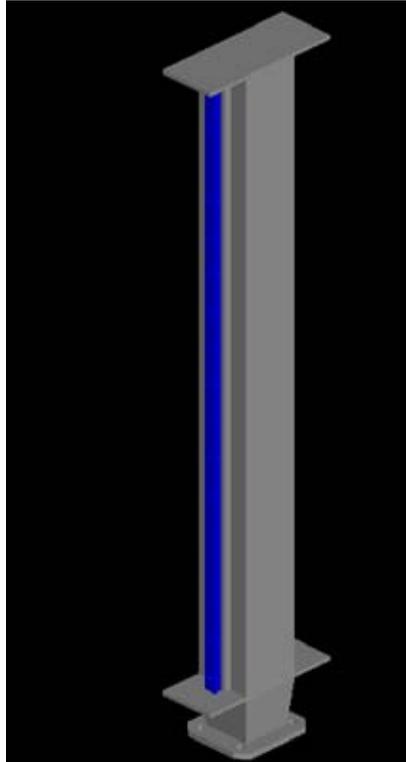


Figure 4. The design drawing for the yaw restraining heave post is shown above.

The chosen design is that of a 3" x 3" x 3/16" steel box tube with a length of 40".

The use of the box tube not only increased the moment of inertia but also

reduced the weight of the post. However, the addition of the linear rails and the mounting surfaces for those rails increased the weight to approximately 40lbs. The new design is heavier than the existing design, however for this is to be expected considering the new design is 17" longer than the current design. The weights of 40" length post are 23lb and 35lbs for the new and existing design respectively. This is before the addition of the linear rail. The maximum force that will be experienced when the post is in operation is determined by the maximum acceleration of the carriage. Under normal operating conditions an acceleration of 0.4m/s^2 will be experienced. However, it is possible that an acceleration of 3m/s^2 will be experienced when the carriage brakes are fully applied in an emergency. The post may be able to withstand large forces, but without a support system it is not able to propel a model.

4.3 Frame Design

The support system for the tow post underwent the most drastic changes from the beginning of the design process. The design of the frame of the post was an evolutionary process. When a new feature was identified the design of the support system changed. The major functions that the frame required to possess are:

- Allow the post to heave freely.
- Resist yaw forces.
- Allow for the attachment of the existing wake flow survey equipment.
- Have the ability adjust the model's yaw angle
- Have the ability to lock the post in heave

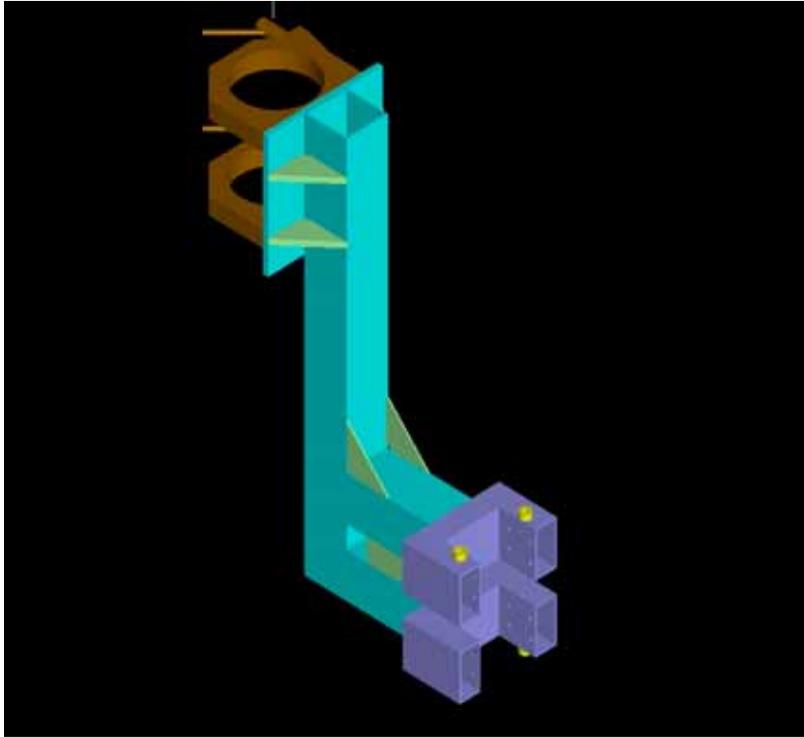


Figure 5. An early design of tow post support system.

The design for the frame started very simply. An early design for the post frame can be seen in figure 5. This design was very simple and very light. It is simply a number of pieces of 4" x 4" box tube welded together. This design was very strong, but there are a number of problems associated with the design. First, there is no way to preload the linear bearings. This is a technical problem that will affect the effectiveness of the device. During assembly the bearings position must be adjusted and pre-loaded until the post heaves freely. This is, of course, a major problem that has been eliminated in future iterations of the heave post frame. Another problem associated with this design is the spacing between the bearings. It is common practice to provide at least one bearing length between the bearings. This helps to reduce the amount of force acting on each bearing.

The frame is much too long, and will behave like a cantilever beam. Like all cantilever beams as the length increases the end of the post will deflect much more. Also this frame does not allow the yaw angle to be trimmed. This is a necessity to eliminate any error introduced during the installation of the frame.

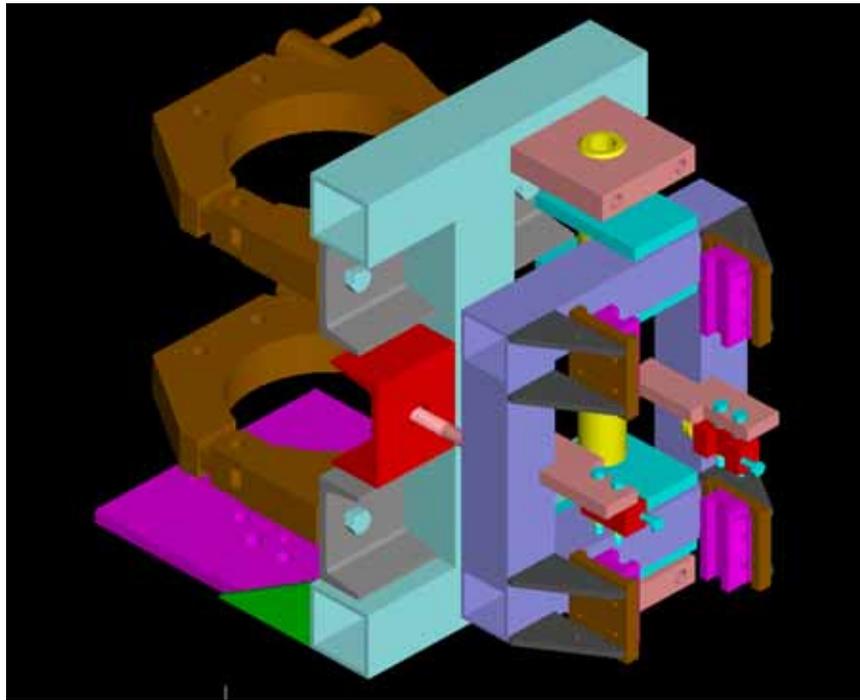


Figure 6. The final design of the frame.

The final design of the heave post frame is shown in figure 6. This design has incorporated all function that was necessary. This increased the number of components needed to full fill the design criteria. As the number of components increased so did the weight. However, for the components possessing the largest volume, the large tow post clamps are to be made of aluminum to reduce their weight. The weight is not a major problem as far as testing is concerned. The tow post will support the weight of the frame. The only weight that is of major concern is that of the heave post. The design of the frame is very

compact. It is not possible to see the scale of this design from figure 6. However, the frame is approximately 23" high and 12" wide. In fact, it will be possible to restrict the motion of heave post and crane the heave post into position while it is attached to the large tow post. This makes the job of the people setting up the models in the testing facilities easier. They will no longer need to move the post into position with a boat and have the risk of falling into the tow tank. There are a number of features that this frame possesses that the first design does not. It is now possible to adjust the yaw angle of the model. This will insure that the model will run straight down the tank. However, the amount of adjustment present is only one or two degrees in either direction. This all that is required to trim any error introduced due to the installation. Another option that needed to be designed is a system to restrain the post in heave. In the case of a wake flow survey the model is set at a certain level in the water and a certain pitch angle is also imposed. The axial loading on the post during claming must not be applied to the bearings. If either the weight of the model or the buoyant force is too great, then the bearings may fail. Therefore, it was decided to attach the heave restraint to the frame and clamp to the linear rails. The final frame design was also required to have one final feature that needed to be added. This was the ability to impose an angle on the model and it is also a necessity. There is equipment existing already for this purpose. After a number of potential designs it was determined that attaching the existing equipment would be simpler and more cost effective. This required a slight modification to the large clamps to accommodate two bolt holes. This will allow both tanks to

conduct testing at the same time without equipment being an issue. The new design of both the heave post and its corresponding frame are more complicated than the existing heave post. However, more options are available and the major problem associated with the grasshopper has been eliminated. Even though a number of improvements have been made over the existing post, the new post may need some improvements in the future. The final design can be seen in figure 7.

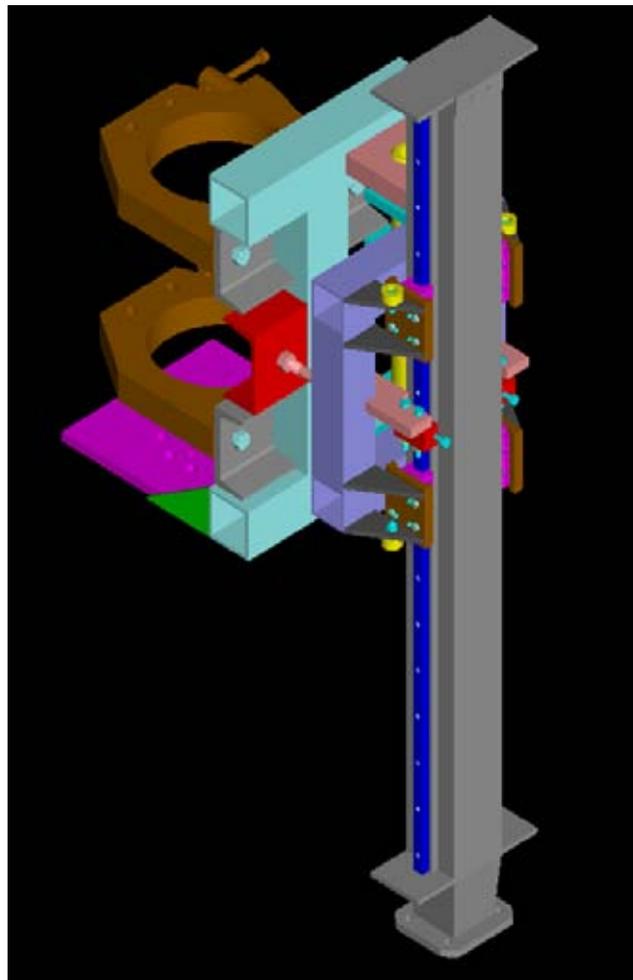


Figure 7. Final assembled design.

5.0 Future Considerations

There are a number of areas in which the heave post and its frame can be improved. As the frame is currently designed it is impossible to measure the amount of yaw force present in the model. This is due to the positioning of the pivot post in relation to the tow post. The pivot post is not in alignment with the tow post. This means that the treaded rod will carry a certain amount of the tow force. Since a portion of the tow force will always be present there will never be a time when there is no force acting on the bolt. This makes the ability to tune the yaw almost impossible. In the future this process can be automated. One possibility could be to use a ball screw that is able to pivot, and a stepper motor. A motor controller will adjust the angle of the post slightly by spinning in a given direction. Then a micro controller will compare the force experienced by the load cell to a previous measurement. If the force is lower then the screw will advance another step. However, if the measured force is greater then the previous it will reverse direction. This will continue to happen until the model is oriented in the proper position.

6.0 Conclusion

The design of the new heave post has been a success up to this point. The design passed the final design review and was approved for fabrication. The fabrication drawings can be seen in appendix A. The design exceeded the existing design in all areas. The only factor that is keeping this design on the

shelf will be funding. When funding is available this post will be fabricated and quickly put into use. This post will be a great asset to the Institute for Ocean Technology because it will help get more accurate readings on model runs. Also, the fact that IOT will now have two towing kits should decrease the likelihood that scheduling problems between the two tow tanks will be reduced. This piece of equipment will be an invaluable addition to IOT's current method of propelling models.

7.0 Appendix A

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421016101	Parts List	A3
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421016103	Sub Assembly 1	A2
421016104	Sub Assembly 2	A2
421016105	Sub Assembly 3	A3
421016106	Front Frame Parts	A3
421016107	Shaft Supports	A3
421016108	Pivot Shaft	A3
421016109	Pitch Adapter Parts	A2
421016110	Pitch Apoter assembly	A3
421016111	Large Clamps	A3
421016112	Clamp Parts	A3
421016113	Clamp Handle	A3
421016114	Heave Clamp Part	A3
421016115	Heave Clamp Parts	A3
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421016117	Back Frame Parts 2	A3
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421016119	Front Frame Fabrication	A3
421016120	Bearing Mount Machining	A3
421016121	Post Pieces	A3
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421016123	Toper Fabrication	A3
421016124	Bearing Mounting plates	A3
421016125	Post Fabrication	A3
421016125	Post Machining	A3

Notes:

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TOLERANCES
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 0.X ± 0.03
 0.XX ± 0.015
 0.XXX ± 0.005
 Angle +/- .5 deg.
 Fabrication +/- .04
 Fraction (5 inch 1/4-1/2)

List of Materials

#	Description	Size	Quantity
1	4"x4"x3/16" steel box tube	40" long	1
2	2"x2"x3/16" steel Box Tube	10.28" long	2
		8" long	2
3	2.5"x2.5"x3/16" Steel Box Tube	13.5" long	1
		10.1" Long	2
4	2" Steel Plate	4"x4.5"	1
5	1/2" Steel Plate	9.5" x 9.5"	1
		2.75" x 2.75"	2
		2.75" x 1.5"	2
		1.75" x 4"	3
6	1/4" Steel Plate	3" x 2.5"	16
		2.5" x 4"	2
		2.25" x 3"	2
7	3/16" Steel Plate	3" x 3"	4
8	1" Steel Plate	2" x 4"	4
9	C4 x 7.25 Steel Channel	3.375" Long	2
		3" Long	1
10	1.5" Alum plate	10.5" x 6"	1
		4.5" x 9.5"	1
11	1/2" dia steel rod	4" long	1
12	1.5" dia rod	5.5" long	1
		3" long	1
13	4" x 4" X1/4" steel box tube	20" long	1
14	2" dia Steel Shaft	16" long	1

List of Materials (cont'd)

#	Description	Size	Quantity
15	3/8" shaft	4" long	1
16	THK SHS 15LC Block		4
17	THK SHS 15 Rail	39.5" long	2

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DRWN R. Stander **CHKD** **APP'D** **DATE** 21-Apr-11-2004

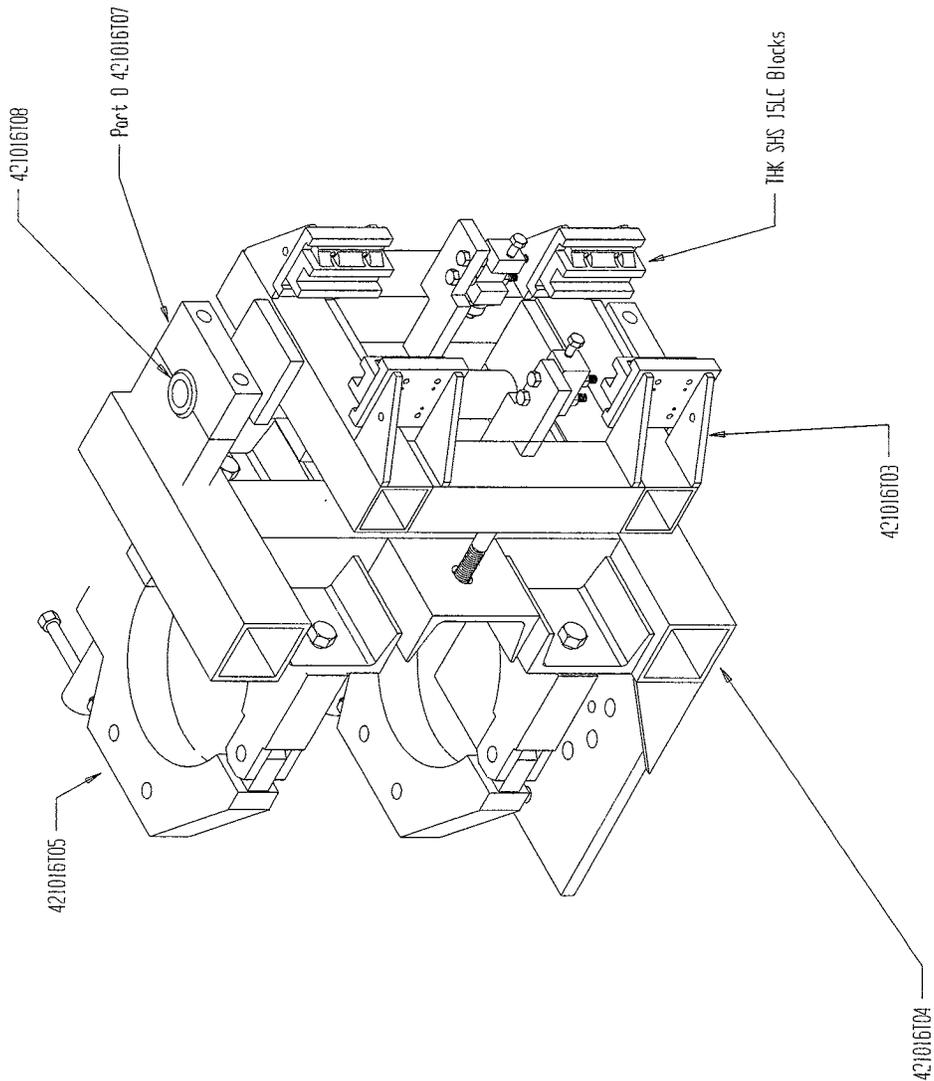
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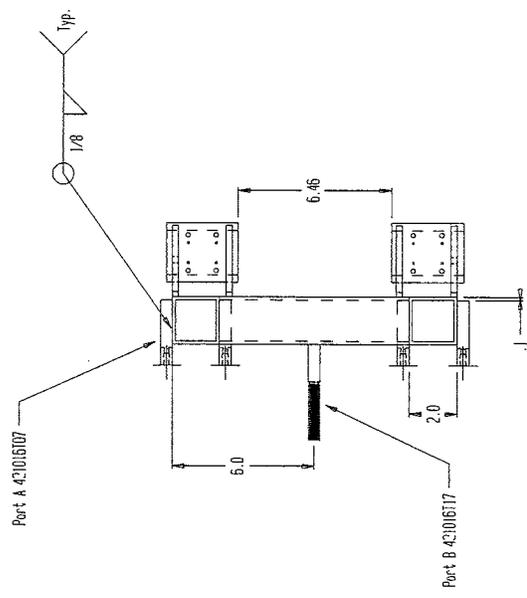
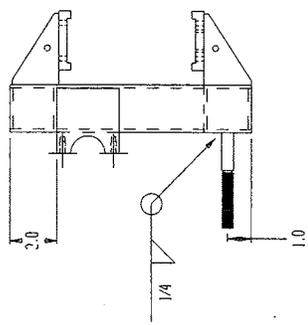
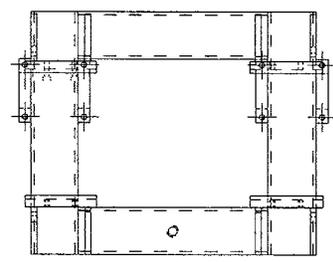
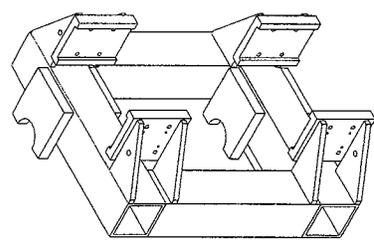
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St. John's, Newfoundland A1B 3T5		421016102
Part	421016	Sheet 1 of 1
Drawn	R. Shandera	
Quantity	1	

REV	DATE	BY	APPROVED
1	8/27/2005	8/27/2005	
2	8/27/2005	8/27/2005	
3	8/27/2005	8/27/2005	

Notes:
 Deburr - Remove All Sharp Edges
 Chip and Brush all welds
 Part File: 421016103

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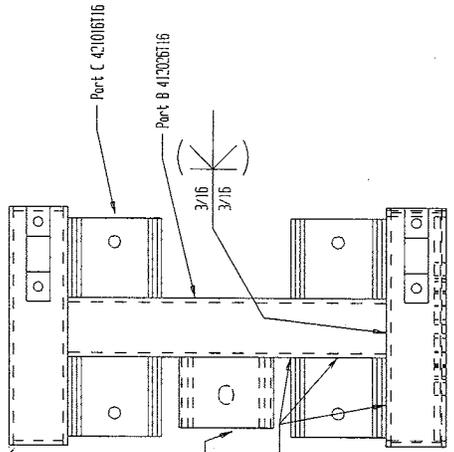
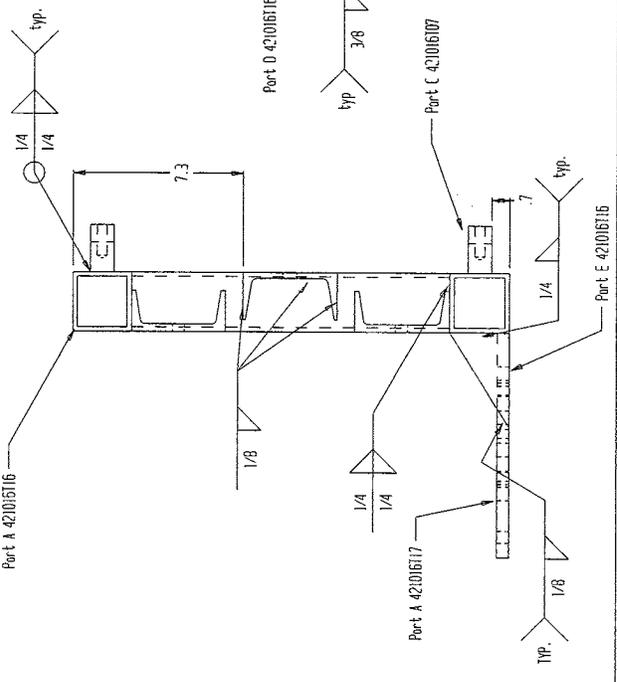
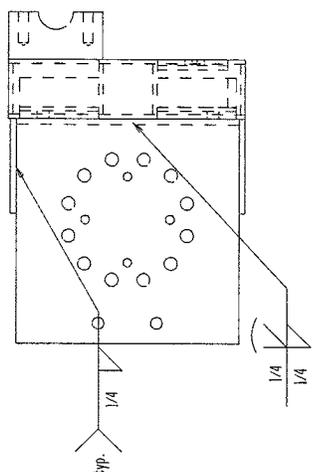
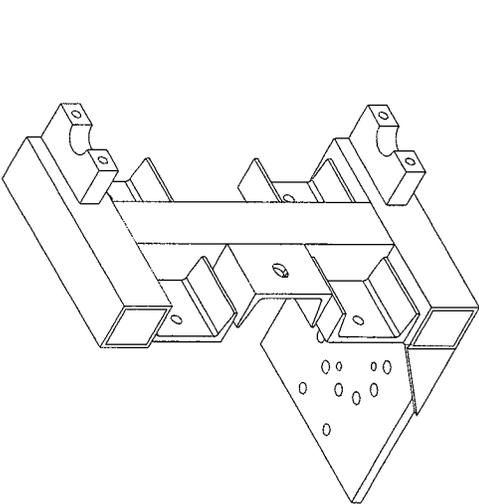
 National Research Council Canada Conseil national de recherches Canada	Material HSS Heat Treatment FINISH DIMENSIONS IN: INCHES <input checked="" type="checkbox"/> MILLIMETERS <input type="checkbox"/> APPROVED Quantity NA	TITLE 421016 Yaw Restraining tow post Sub Assembly	PART NUMBER 421016103
		INSTITUTE FOR OCEAN TECHNOLOGY Fermin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	SCALE 1:1
TOLERANCES (Unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction < 6 inch +/- 1/64 > 6 inch +/- 1/32	DRAWN R. Shondero	DATE 14-FEB-1995	SHEET 1 OF 1

1 2 3 4 5 6 7 8

REV	DATE	DESCRIPTION	BY	CHKD

Notes:
 Deburr - Remove All Sharp Edges
 Chip and Wire Brush all Weib's
 Part File 421016104

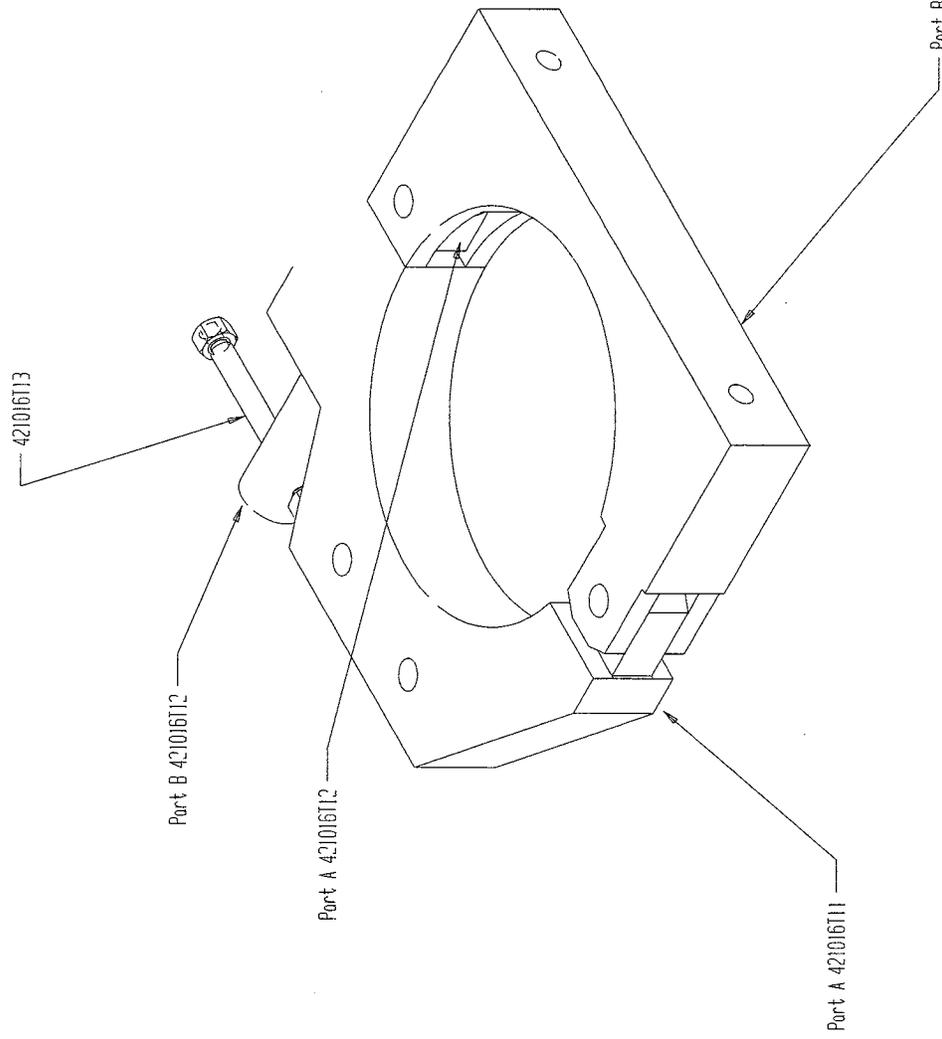
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National Research Council Canada Conseil national de recherches Canada	Material IRS Heat Treatment	FINISH DIMENSIONS IN: <input checked="" type="checkbox"/> JACKS <input checked="" type="checkbox"/> MILLIMETERS	TRN 421016	DATE 13-Apr-2004
			DRWN R. Shandera	REV 1-4
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication < 6 inch 1/4 VMA > 6 inch 1/2 VMA		Institute for Ocean Technology 421016 Yaw Restrainting Tow Post Rear Assembly		
APPROVED 		QUANTITY 1		
PART NUMBER 421016104		DATE 13-Apr-2004		

Conseil national de recherches Canada
 Institute for Ocean Technology
 421016
 Yaw Restrainting Tow Post
 Rear Assembly

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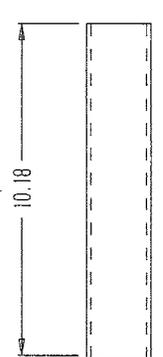
Notes:
 Deburr - Remove All Sharp Edges
 Part File 421016T05

NO.	DATE	DESCRIPTION	REVISED	DATE	APPROVED

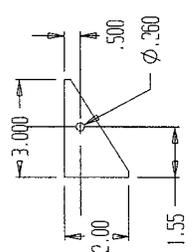
National Research Council of Canada Conseil national de recherches Canada		Institute for Ocean Technology Yerrin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction (< 6 inch 1/16 > 6 inch 1/32)		TITLE 421016 Yaw Restraining Tow Post Sub Assembly 3	
Material NO Heat Treatment		DRAWN R. Shandera	
FINISH DIMENSIONS IN: <input checked="" type="checkbox"/> INCHES <input type="checkbox"/> MILLIMETERS		APPROVED Quantity NO	
<input checked="" type="checkbox"/> DIMENSIONS AS SHOWN <input type="checkbox"/> DIMENSIONS AS NOTED <input type="checkbox"/> DIMENSIONS AS SPECIFIED		PART NO 421016T05	
TYPED NAME 1 : 10		DATE 19-Feb-1991	
SHEET NO 1		OF SHEETS 1	

REV	DATE	DESCRIPTION	BY	APPROVED

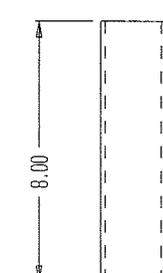
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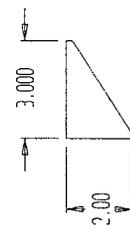
Part A
2 X 2 X 3/16 Box Tube
2 Needed



Part C
1/4 in Steel Plate
4 Needed



Part B
2 X 2 X 3/16 Box Tube
2 Needed



Part D
1/4 in Steel Plate
4 Needed

Notes:
Deburr - Remove All Sharp Edges
Part File 421016106

National Research Council Canada 		Conseil national de recherches Canada ATC-CATC	
Institute for Ocean Technology Ferwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5		Institut pour la Technologie Ferwin Place, P.O. Boite 12093, Station de Poste A St. John's, Nouvelle-Fondlande A1B 3T5	
PART 421016	TITLE Yow Restraining Tow Post	DRAWN R. Shandera	DATE 08-April-2004
REV A3	REVISED 421016106	APPROVED 	SHEET 1 OF 4
QUANTITY 05 noted		SCALE 1 : 4	

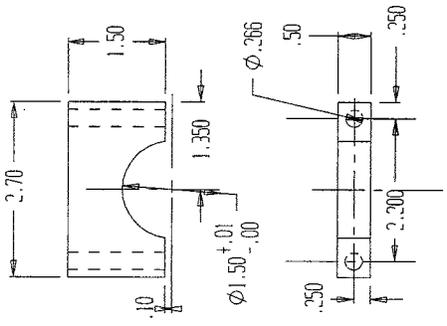
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction 1/8 inch 1/4 1/8 3/8 inch 1/2 1/2	Material 44W Steel Heat Treatment
<input checked="" type="checkbox"/> DIMENSIONS IN INCHES <input type="checkbox"/> ALL DIMENSIONS	FINISH
	HOLE SIZE

3	4	5	6	7	8	9	10	11	
NO. DRAW		REVISION		DATE		APPROVED			

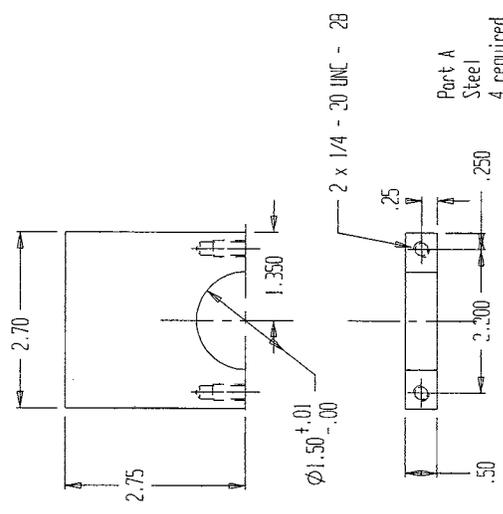
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Notes:

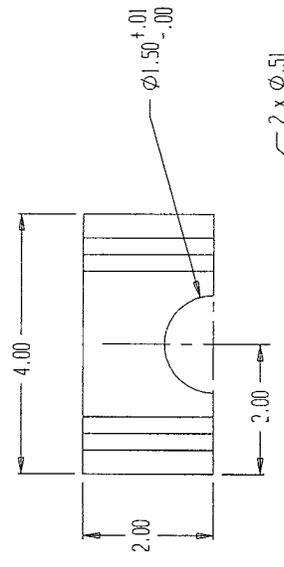
Deburr - Remove All Sharp Edges
Part File 421016107



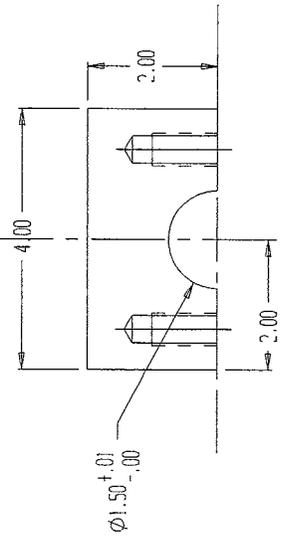
Part A
Steel
4 required



Part B
Steel
4 required



Part C
Steel
2 required



Part D
Steel
2 required

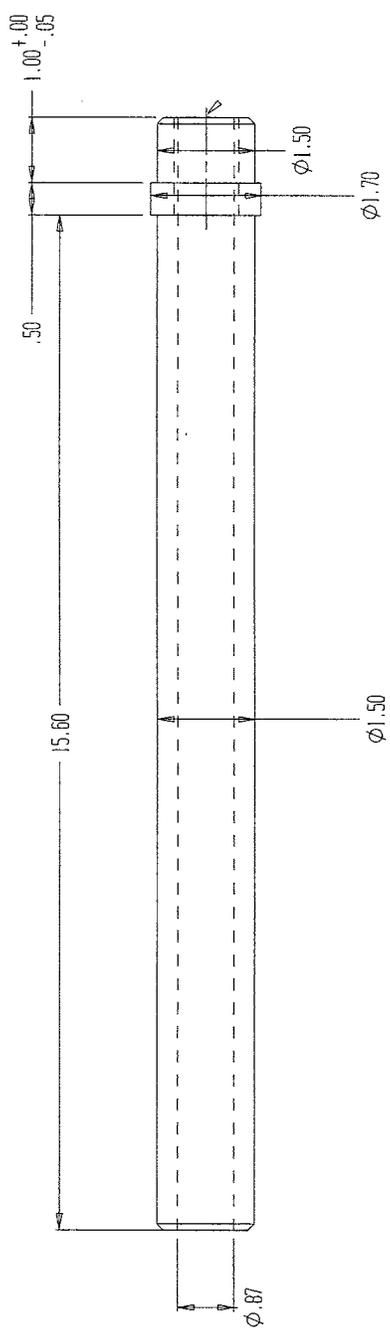
National Research Council of Canada Conseil national de recherches Canada		ATAC-CNRC	
Institute for Ocean Technology Kerwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5		Yaw Restraining Tow Post Shaft Supports	
Material 4140 Steel Heat Treatment		PART 421016	
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle ±/− .5 deg. Fabrication ±/− .04 Fraction < 6 inch 1/16 > 6 inch 1/32		DRAWN BY R. Shondera	
CHECKED BY <input checked="" type="checkbox"/> HILBERT <input type="checkbox"/> APPROVED		TITLE 421016	
QUANTITY 4		DATE 18-April-2004	
SCALE 1:10		SHEET 1 OF 1	

1 2 3 4 5 6 7 8

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NO.	DATE	REVISIONS	APPROVED

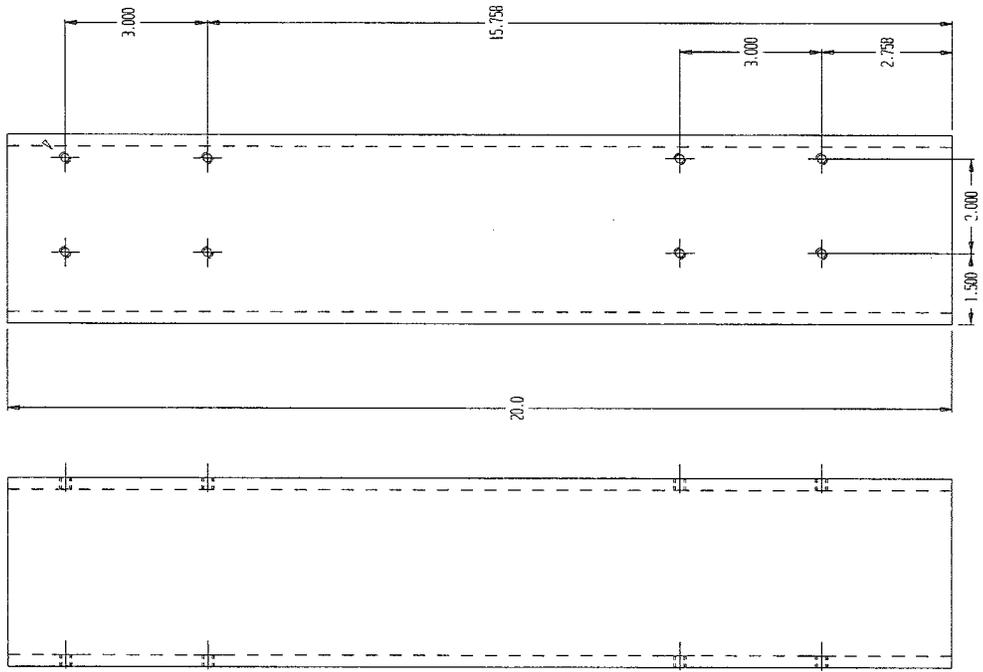
Notes:
 Bechurr - Remove All Sharp Edges
 Part File 421016T08



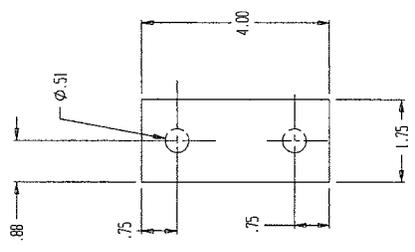
National Research Council of Canada Conseil national de recherches Canada	Material 44W Steel Heat treated	FINISH <input checked="" type="checkbox"/> DIMENSIONING IN INCHES <input type="checkbox"/> MILLIMETERS	TITLE 421016 Yaw Restraining Tow Post Frame Pivot Shaft
		TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 1/8 inch 1/16 1/8 inch 1/32	DRAWN R. Shandera
Quantity 1		SCALE 1:1	
DATE 6 April 2004		SHEET 1 of 1	

Conseil national de recherches Canada
 Institute for Ocean Technology
 Perwin Place, P.O. Box 12093, Postal Station A
 St. John's, Newfoundland A1B 3T5

16 1/4-30 UNC-3B



Part A
4' x 4' x 1/4" Steel Box Tube
1 Required



Part B
1/2" steel plate
3 Required

Notes:
Deburr - Remove All Sharp Edges
Part File 421016109

ALL DIMENSIONS ARE TO BE TAKEN FROM THE CENTERLINE UNLESS OTHERWISE SPECIFIED. DIMENSIONS ARE TO BE TAKEN FROM THE CENTERLINE UNLESS OTHERWISE SPECIFIED. DIMENSIONS ARE TO BE TAKEN FROM THE CENTERLINE UNLESS OTHERWISE SPECIFIED. DIMENSIONS ARE TO BE TAKEN FROM THE CENTERLINE UNLESS OTHERWISE SPECIFIED.

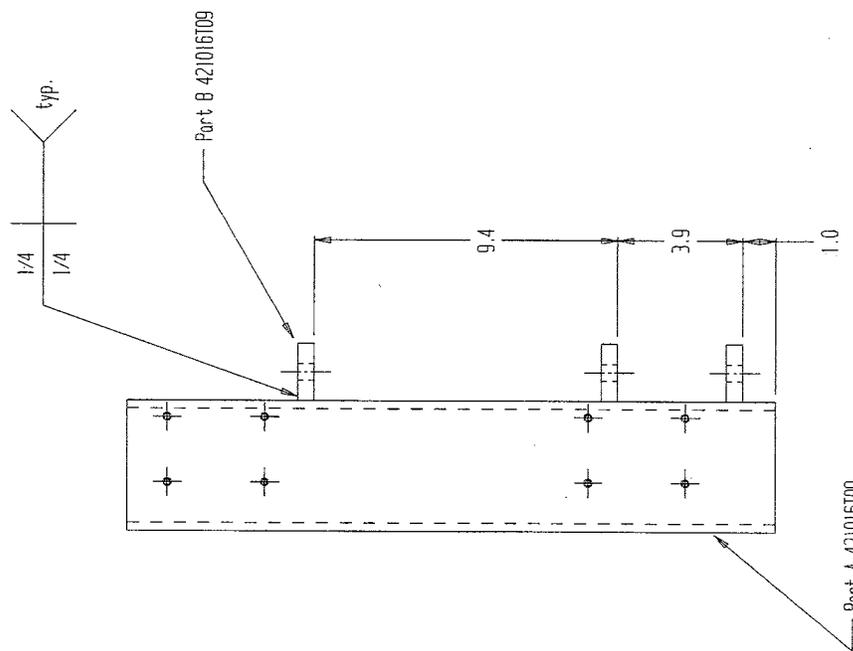
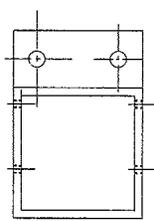
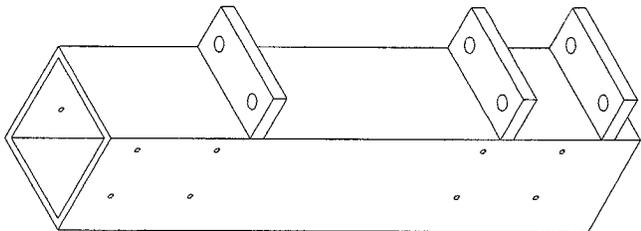
REV	DATE	BY	DESCRIPTION
1			ISSUED FOR CONSTRUCTION
2			REVISION

National Research Council Canada Conseil national de recherches Canada		ARC-CMRC	
Institute for Ocean Technology Kerwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5			
PART 421016 Yaw Restraining Tow Post		PART 421016109 Pitch Adapter Parts	
FINISH MATERIAL HSS Heat Treatment		QUANTITY 05 noted	
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction < 6 inch +/- 1/64 > 6 inch +/- 1/32		DRAWN R. Shandera	
FINISH MATERIAL HSS Heat Treatment		DATE 08-April-2004	

NO.	DATE	REVISION	BY	APPROVED

Notes:

Deburr - Remove All Sharp Edges
 Chip and Wire Brush all welds
 Part File 421016T10



National Research Council Canada Conseil national de recherches Canada		NRC-CNRC	
Institute for Ocean Technology Yerrin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5		Yaw Restraining Tow Post Pitch Control Adapter	
PART NO 421016	TITLE Yaw Restraining Tow Post Pitch Control Adapter	QUANTITY 1	PART NO 421016T10
MATERIAL 44W Steel Heat Treatment	FINISH <input checked="" type="checkbox"/> DIMENSIONS TO JACKS <input checked="" type="checkbox"/> MILL/VENT <input type="checkbox"/>	SCALE 1:1	DATE 13-April-2004
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction (6 inch +/- .004) 6 inch +/- .02	DRAWN R. Shandera	CHECKED A3	SHEET NO 1 of 1

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7
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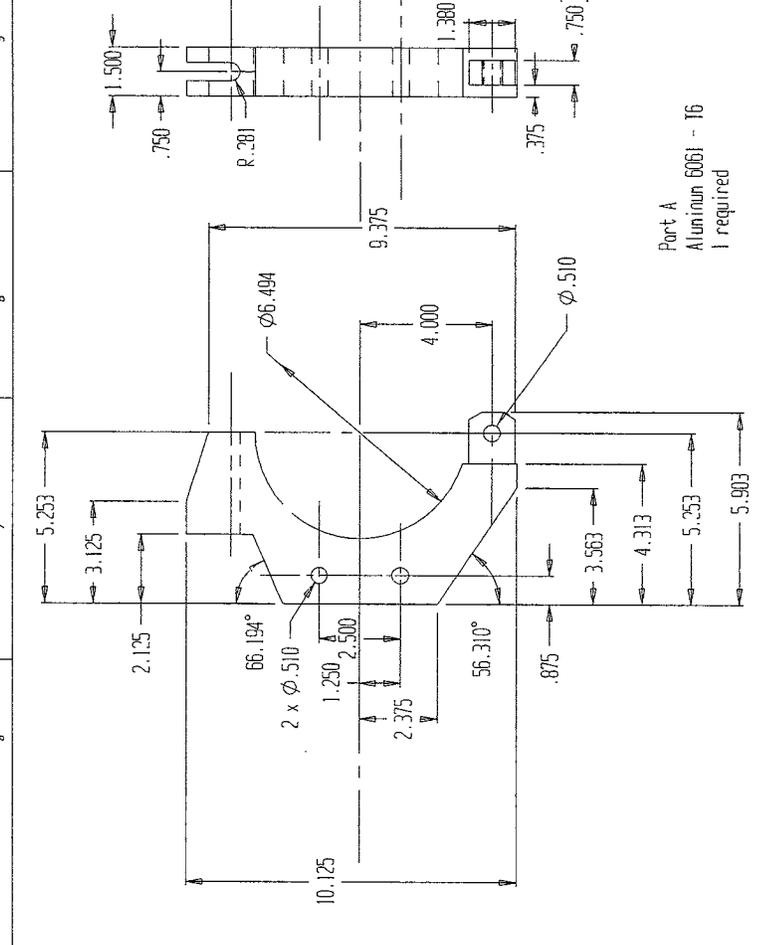
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NO.	DATE	DESCRIPTION	BY	APPROVED

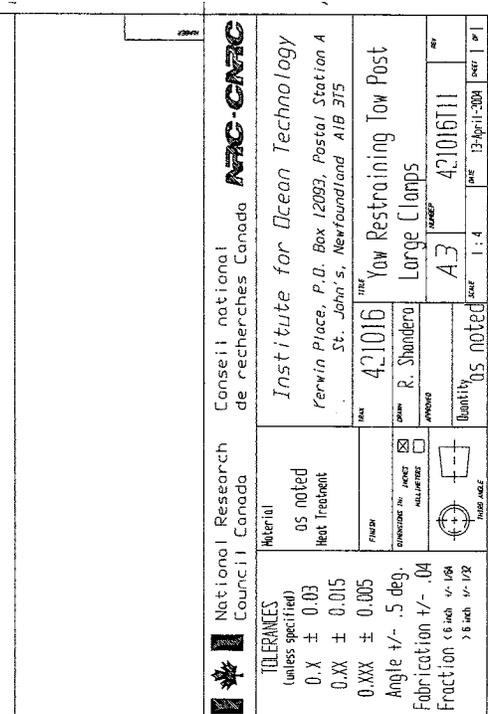
Notes:

Deburr - Remove All Sharp Edges

Part File 421016T11



Part A
Aluminum 6061 - T6
1 required

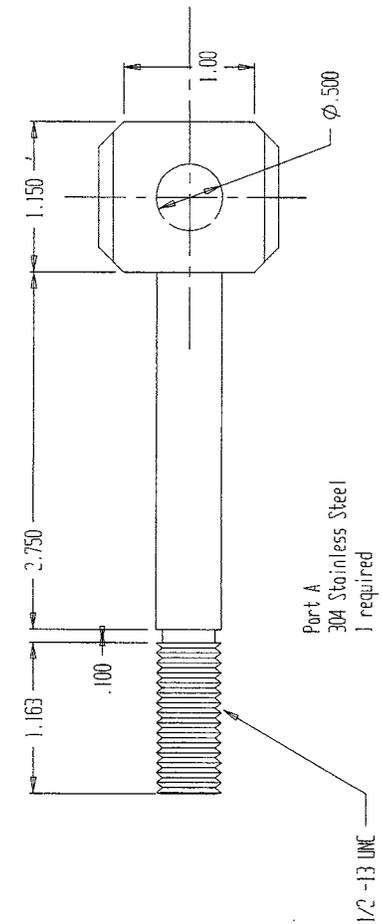
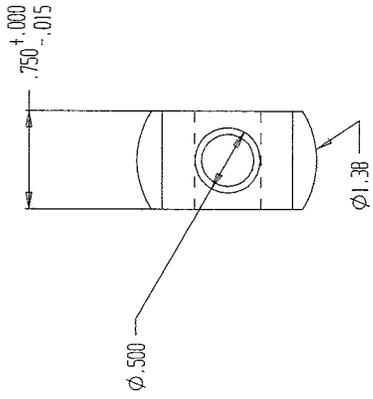


Part B
Aluminum 6061 - T6
1 required

NATIONAL RESEARCH COUNCIL OF CANADA Conseil national de recherches Canada INSTITUTE FOR OCEAN TECHNOLOGY Yaw Restraining Tower Clamps Large Clamps R. Shandera 421016 421016T11 13-Apr-11-2004 1:4 43 421016T11 13	Material OS noted Heat treatment	FINISH DIMENSIONS IN: <input type="checkbox"/> INCHES <input checked="" type="checkbox"/> MILLIMETERS APPROVALS DRAWN: <input type="checkbox"/> CHECKED: <input type="checkbox"/> DESIGNED: <input type="checkbox"/>	QUANTITY OS noted 43
	TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction (< 6 inch ^v .156 > 6 inch ^v .125)	NATIONAL RESEARCH COUNCIL OF CANADA Institut national de la recherche scientifique 1100 Avenue de la Recherche St. John's, Newfoundland A1B 3T5	Yaw Restraining Tower Clamps Large Clamps R. Shandera 421016 421016T11 13-Apr-11-2004 1:4 43 421016T11 13

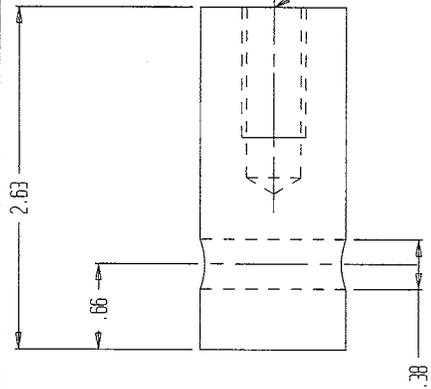
REV	DATE	DESCRIPTION	BY	APPROVED

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Part A
 304 Stainless Steel
 1 required

1/2 - 13 UNC



Part B
 304 Stainless Steel
 1 Required

1.0 1/2 - 13 UNC - 2B

Notes:
 Deburr - Remove All Sharp Edges
 Part File 421016T12

 National Research Council of Canada Conseil national de recherches Canada	Material OS noted Heat treatment	FINISH <input checked="" type="checkbox"/> ANODIZING IN ACES <input type="checkbox"/> MILL FINISH <input type="checkbox"/> POLISH	DIMENSIONS IN MILLIMETERS <input checked="" type="checkbox"/>	TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction < 8 inch +/- 1/64 > 8 inch +/- 1/32	NATIONAL RESEARCH COUNCIL OF CANADA INSTITUT NATIONAL DE RECHERCHES EN SCIENCE ET TECHNOLOGIE 1100 MAINTENANCE AVENUE OTTAWA, K1A 0S6	NATIONAL RESEARCH COUNCIL OF CANADA INSTITUT NATIONAL DE RECHERCHES EN SCIENCE ET TECHNOLOGIE 1100 MAINTENANCE AVENUE OTTAWA, K1A 0S6

Conseil national de recherches Canada
 NRC-CNRC
 Institute for Ocean Technology
 Kerwin Place, P.O. Box 12093, Postal Station A
 St. John's, Newfoundland A1B 3T5

421016
 Yaw Restraining Tow Post
 Clamp Pieces

R. Staudera

Quantity
 OS noted

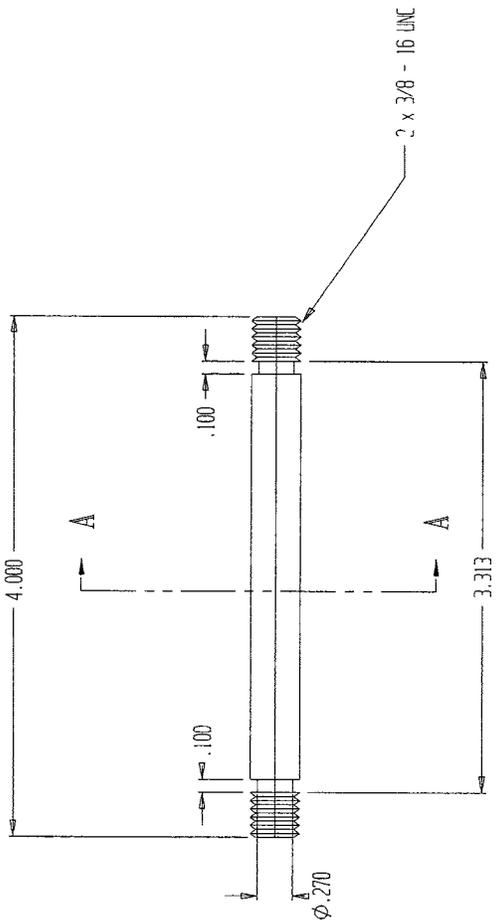
PART NUMBER
 421016T12

REV
 A3

DATE
 05-Apr-11-2004

SHEET
 1 of 1

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SECTION A-A

Notes:
 Deburr - Remove All Sharp Edges
 Part File 421016T13

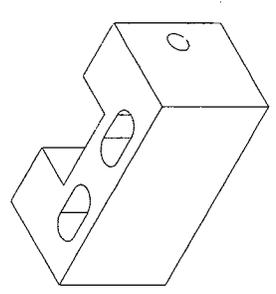
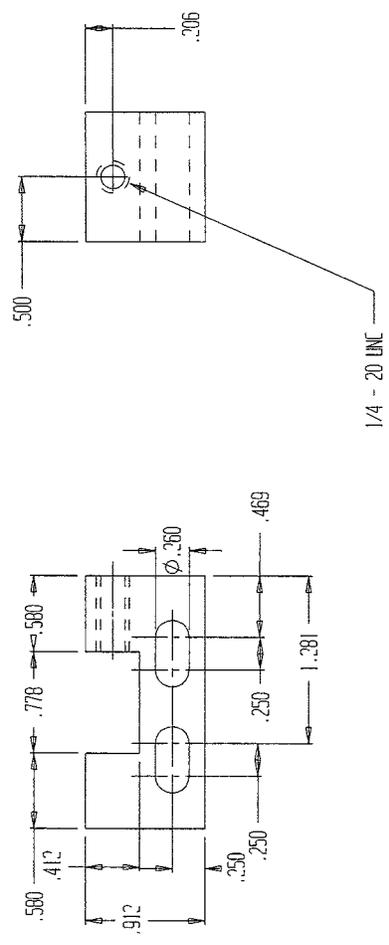
 National Research Council of Canada Conseil national de recherches Canada	Material Steel Heat treatment	FINISH <input checked="" type="checkbox"/> POLISHED <input type="checkbox"/> MILLFINISH <input type="checkbox"/> OTHER	QUANTITY 1	PART NO. 421016T13	TITLE Yaw Restraining Tow Post Clamp Handle	INSTITUTION FOR DECEAN TECHNOLOGY Fermin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	DRAWN BY R. Shandera	APPROVED 	DATE 13-Apr-1984	SHEET NO. 1 OF 1

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REV	DATE	DESCRIPTION	REVISIONS	DATE	DESCRIPTION	REVISIONS	DATE	DESCRIPTION	REVISIONS

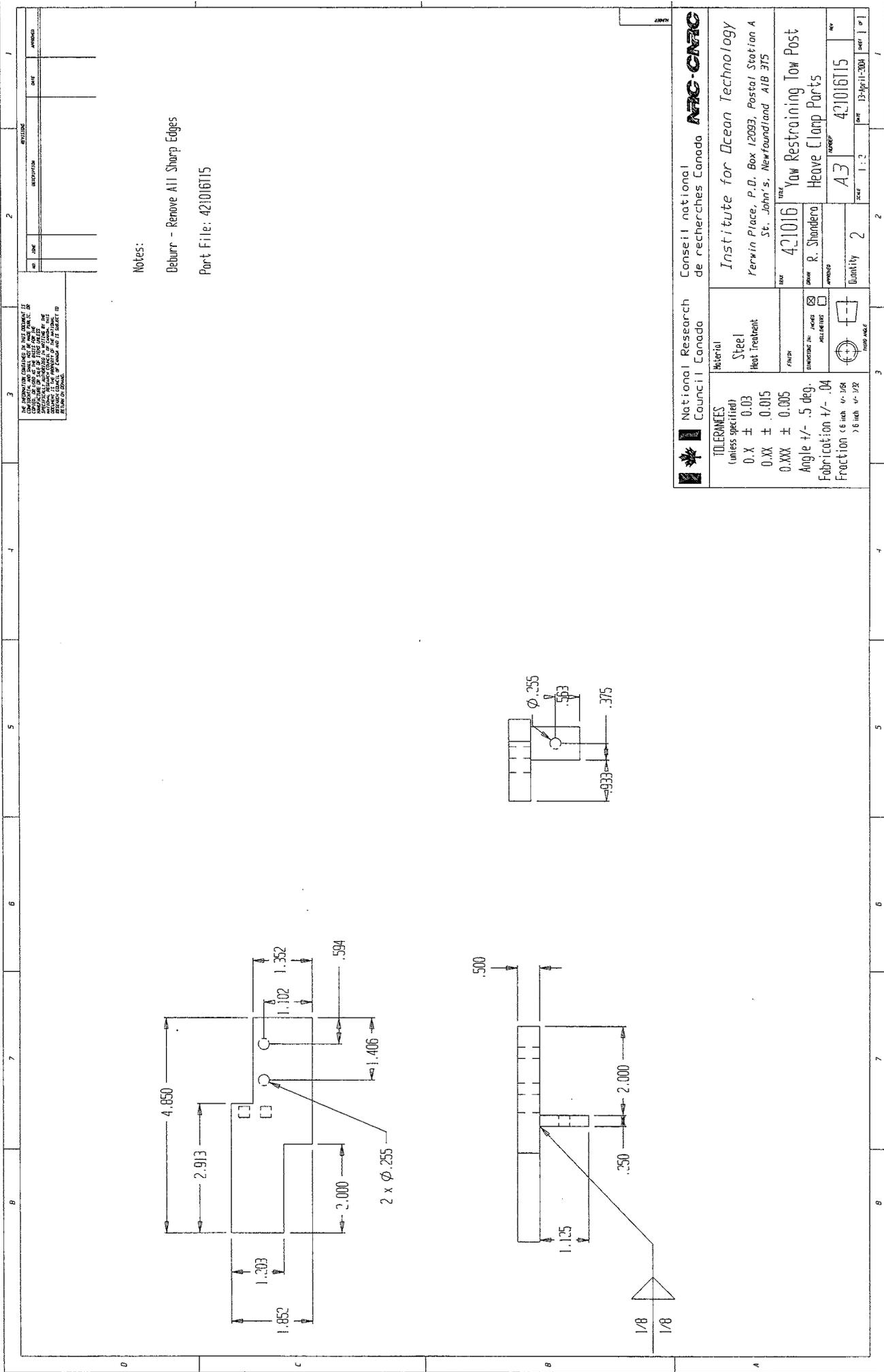
Notes:

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 Part File: 421016T14

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National Research Council Canada Conseil national de recherches Canada	Material Steel Heat Treatment	Part No. 878	Title Yaw Restraining Tow Post Heave Clamp Parts
		Designer R. Shandera	Date 13-April-2004
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication < 6 inch < 1/8 > 6 inch < 1/32	Finish <input checked="" type="checkbox"/> POLISHED <input type="checkbox"/> MILL FINISH <input type="checkbox"/> HONEY COMB	Quantity 2	Part No. 421016T14
Institute for Ocean Technology Perwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	Scale 1:1	Rev A3	Part of 1



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Notes:

Deburr - Remove All Sharp Edges
 Part File: 421016T15

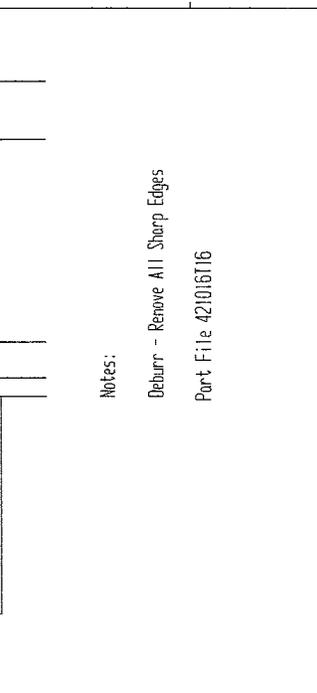
National Research Council Canada Conseil national de recherches Canada		ARC-CATC	
Institute for Ocean Technology 7800 University Ave., P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5		Institute for Ocean Technology 7800 University Ave., P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	
PART 421016	TITLE Yaw Restraining Tow Post Heave Clamp Parts	DRAWN R. Shandera	DATE 13-April-2004
FINISH STEEL Heat Treatment	DIMENSIONS IN MILLIMETERS <input checked="" type="checkbox"/> ANGLES <input type="checkbox"/> HOLLOW SHAFTS <input type="checkbox"/> HOLLOW SHAFTS	APPROVED Quantity 2	SHEET 1 OF 2
TOLERANCES (unless specified) D.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction 6 max 1/16 7.6 max 1/32	Material Steel Heat Treatment	PART NO. 421016T15	DATE 13-April-2004

0 1 2 3 4 5 6 7 8 9

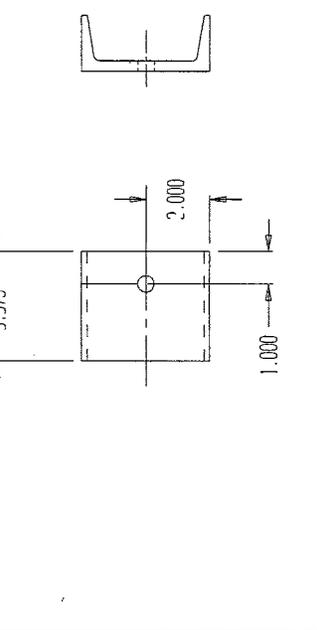
ALL DIMENSIONS CONTAINED IN THIS DOCUMENT IS TO BE CONSIDERED AS PART OF THE CONTRACT. THE CONTRACTOR SHALL BE RESPONSIBLE FOR VERIFYING THE ACCURACY OF ALL DIMENSIONS AND MATERIALS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY MATERIALS AND EQUIPMENT. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY LABOR AND SERVICES. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY TRANSPORTATION AND LOGISTICS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY INSURANCE AND BONDING. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY COMMUNICATIONS AND RECORDS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY UTILITIES AND SERVICES. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY MATERIALS AND EQUIPMENT. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY LABOR AND SERVICES. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY TRANSPORTATION AND LOGISTICS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY INSURANCE AND BONDING. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY COMMUNICATIONS AND RECORDS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY UTILITIES AND SERVICES.

REV.	DATE	DESCRIPTION	BY	APPROVED

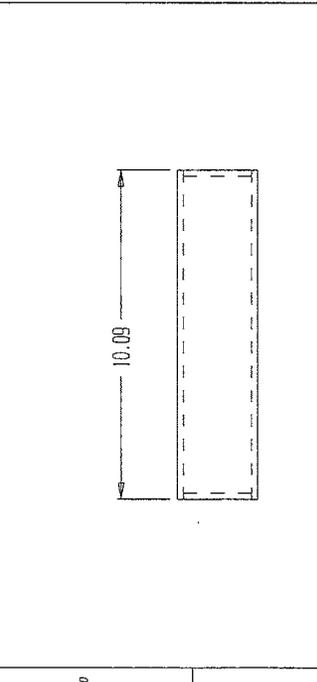
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 Deburr - Remove All Sharp Edges
 Part File 421016116



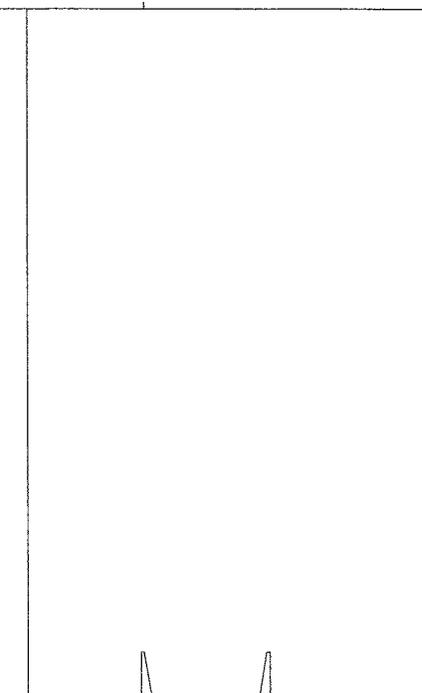
Part C
 C4 x 7.25 Steel Channel
 4 Required



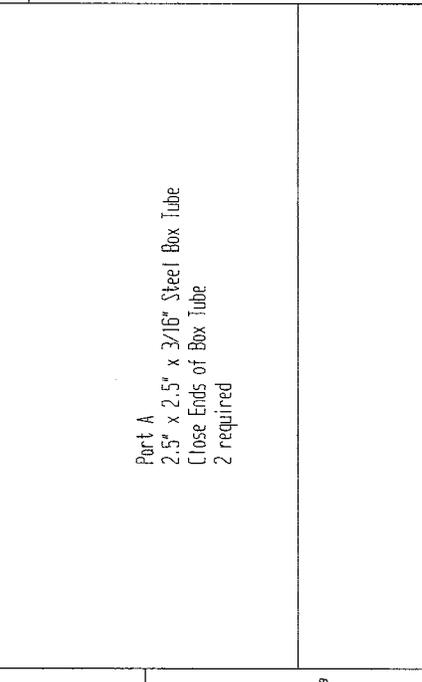
Part D
 C4 x 7.25 Steel Channel
 1 Required



Part E
 1/4" steel plate
 2 required



Part A
 2.5" x 2.5" x 3/16" Steel Box Tube
 Close Ends of Box Tube
 2 required



Part B
 2.5" x 2.5" x 3/16" Steel Box Tube
 1 required

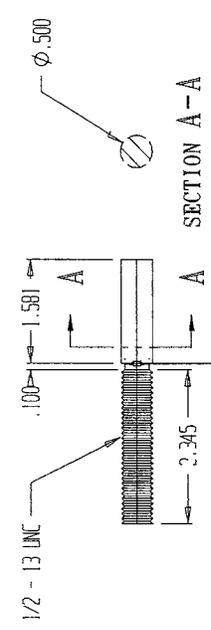
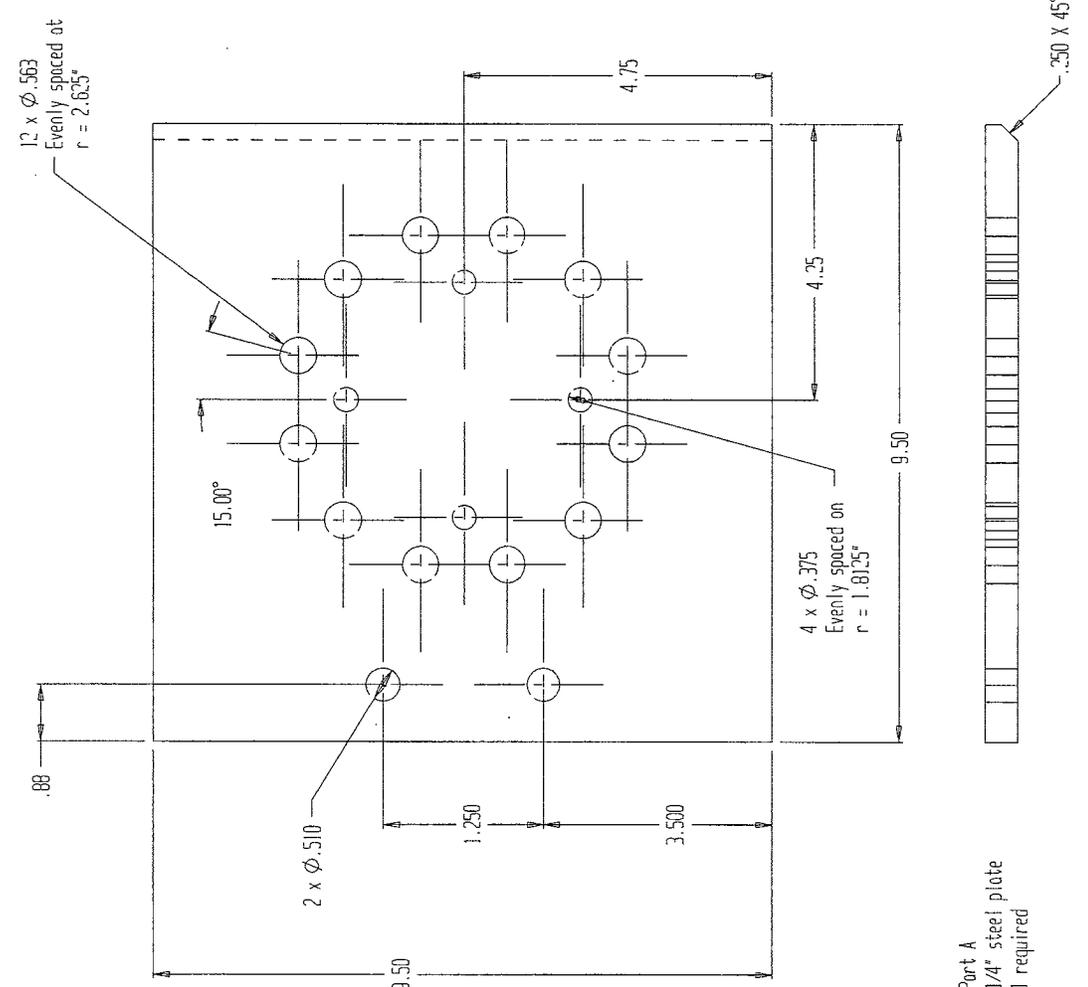
	National Research Council Canada Conseil national de recherches Canada	Institute for Ocean Technology Ferwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	Part No: 421016 Title: Yaw Restraining Tow Post Back From Parts	Date: 19-Feb-1999 Scale: 1:4
	Material: 44W Steel Heat treatment:	FINISH:	DIMENSIONS IN: <input checked="" type="checkbox"/> INCHES <input type="checkbox"/> MILLIMETERS	TOLERANCES (unless specified): 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle ±/- .5 deg. Fabrication ±/- .04 Fraction 1/16, 1/8, 1/4, 1/2
APPROVED: [Signature] Quantity: 1		DRAWN: R. Shandera Part No: 421016 Title: Yaw Restraining Tow Post Back From Parts		

National Research Council Canada
 Conseil national de recherches Canada
 Institute for Ocean Technology
 Ferwin Place, P.O. Box 12093, Postal Station A
 St. John's, Newfoundland A1B 3T5
 Part No: 421016
 Title: Yaw Restraining Tow Post Back From Parts
 Date: 19-Feb-1999
 Scale: 1:4
 Material: 44W Steel
 Heat treatment:
 FINISH:
 DIMENSIONS IN: INCHES MILLIMETERS
 TOLERANCES (unless specified):
 0.X ± 0.03
 0.XX ± 0.015
 0.XXX ± 0.005
 Angle ±/- .5 deg.
 Fabrication ±/- .04
 Fraction 1/16, 1/8, 1/4, 1/2
 APPROVED: [Signature]
 Quantity: 1
 DRAWN: R. Shandera
 Part No: 421016
 Title: Yaw Restraining Tow Post Back From Parts

REV	DATE	DESCRIPTION	BY/CHK

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Notes:
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 Part File 421016117



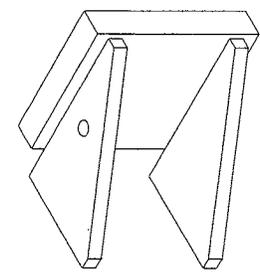
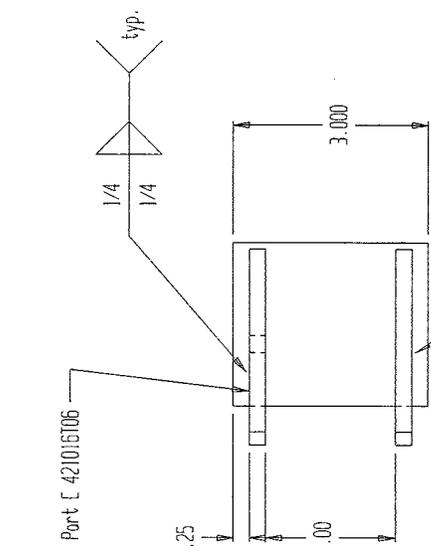
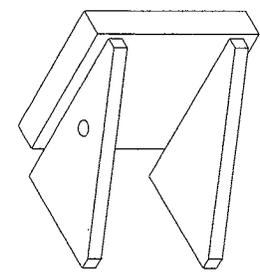
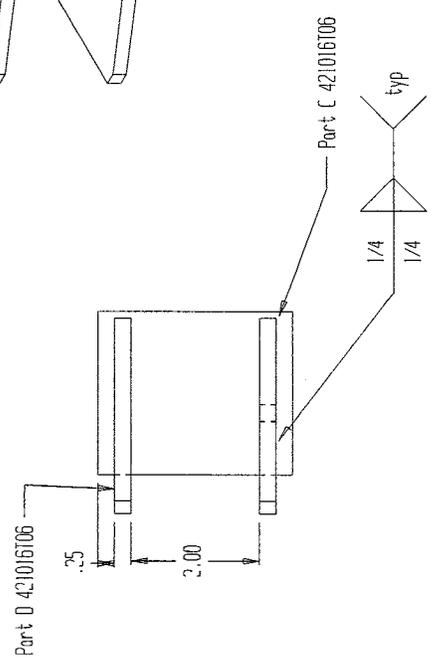
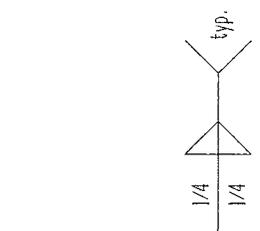
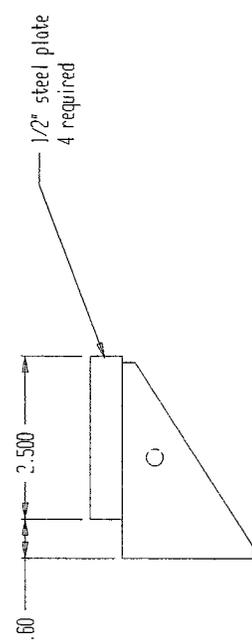
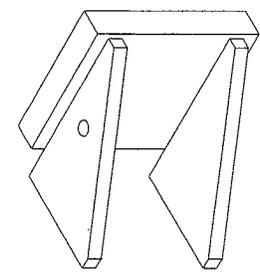
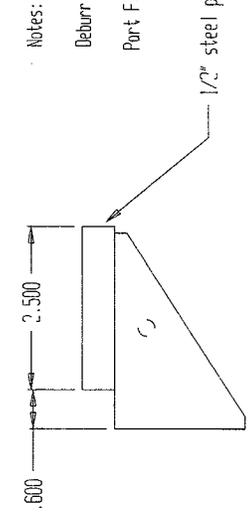
Part B
 Steel
 1 Required

Part A
 1/4" steel plate
 1 required

	National Research Council Canada Conseil national de recherches Canada	National Institute for Ocean Technology Institut national de technologie marine
	05 noted Heat Treatment	421016 Yaw Restraining Tow Post Back from parts 2
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction < 6 inch +/- 1/32 > 6 inch +/- 1/16	FINISH DIMENSIONS IN: <input checked="" type="checkbox"/> INCHES <input type="checkbox"/> MILLIMETERS QUANTITY: 05 noted DRAWN BY: R. Shandera APPROVED BY: A3 DATE: 13-April-2004 SHEET: 1 of 1	MATERIAL: 05 noted HEAT TREATMENT:

REV	DATE	DESCRIPTION	REVISED

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National Research Council of Canada **NRCC-CNRC**
 Conseil national de recherches Canada
 Institute for Ocean Technology
 Ferwin Place, P.O. Box 12093, Postal Station A
 St. John's, Newfoundland A1B 3T5

TOLERANCES
 (unless specified)
 0.X ± 0.03
 0.XX ± 0.015
 0.XXX ± 0.005
 Angle +/- .5 deg.
 Fabrication ± 1/8 inch ± 1/16

Material
 05 notched
 Heat Treatment

FINISH
 DIMENSIONS IN SQUARE MILLIMETERS
 SURFACE

DATE 421016
DESIGNER R. Shandera
APPROVED
QUANTITY 2
SCALE 1:2
DATE 13-April-2004
SHEET 1 of 1

Part B
 2 required

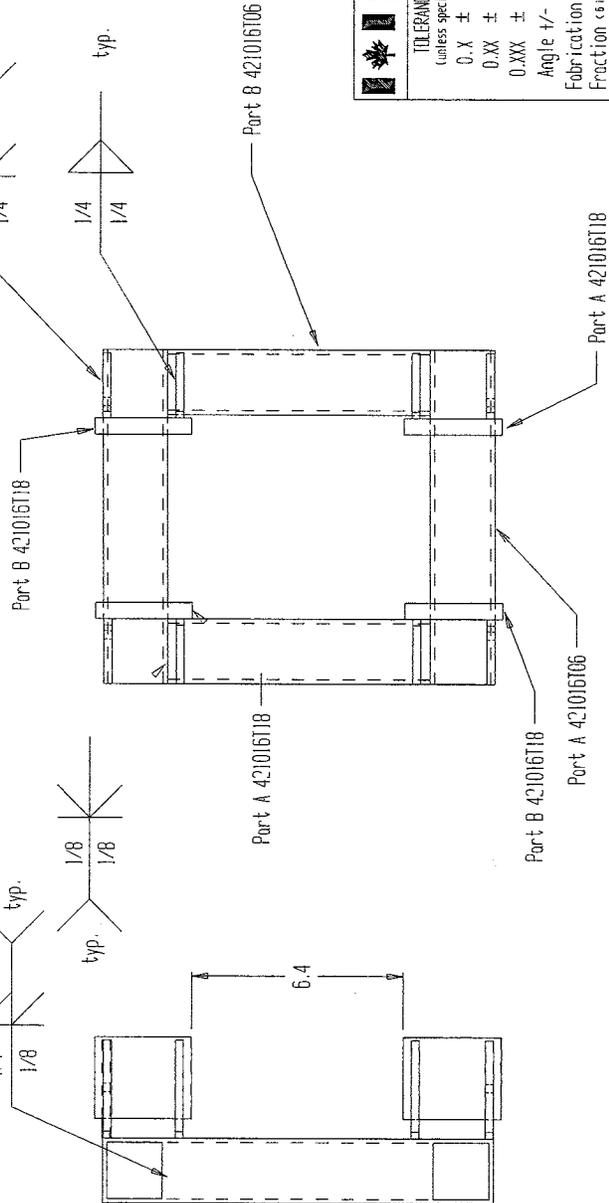
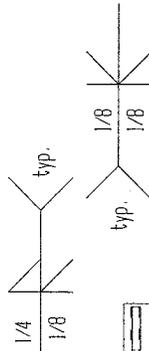
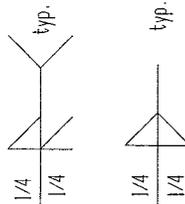
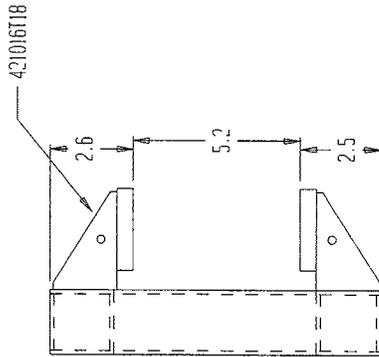
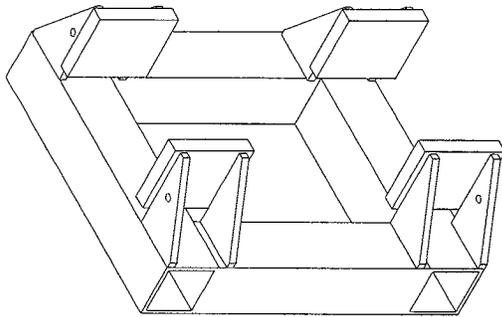
Part A
 2 required

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NO	DATE	DESCRIPTION	REVISIONS	BY	APPROVED

Notes:

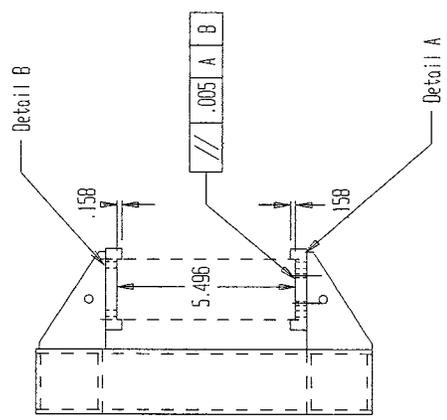
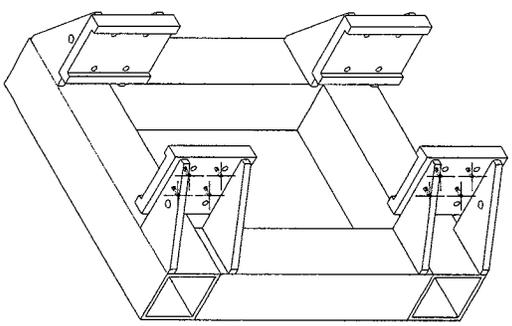
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Part File 421016T19



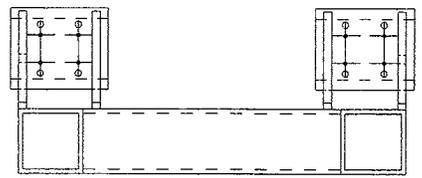
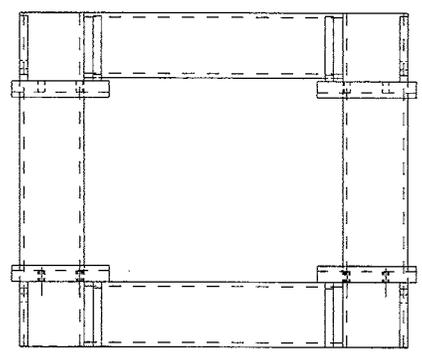
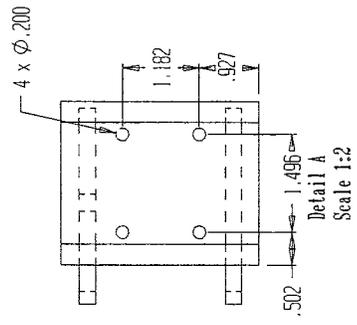
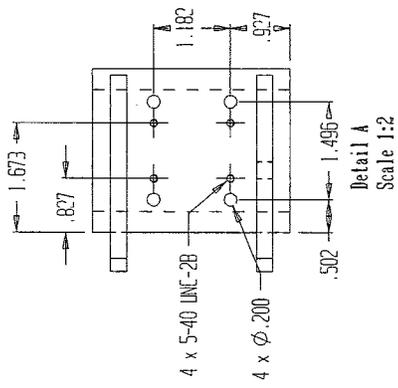
 National Research Council Canada Conseil national de recherches Canada	Material 44W Steel Heat treated	FINISH <input checked="" type="checkbox"/> POLISHED <input type="checkbox"/> MILLFINISH <input type="checkbox"/> OTHER	QUANTITY 1	PART NO. 421016	DRAWN BY R. Shandera	APPROVED 	DATE 19-Feb-1959

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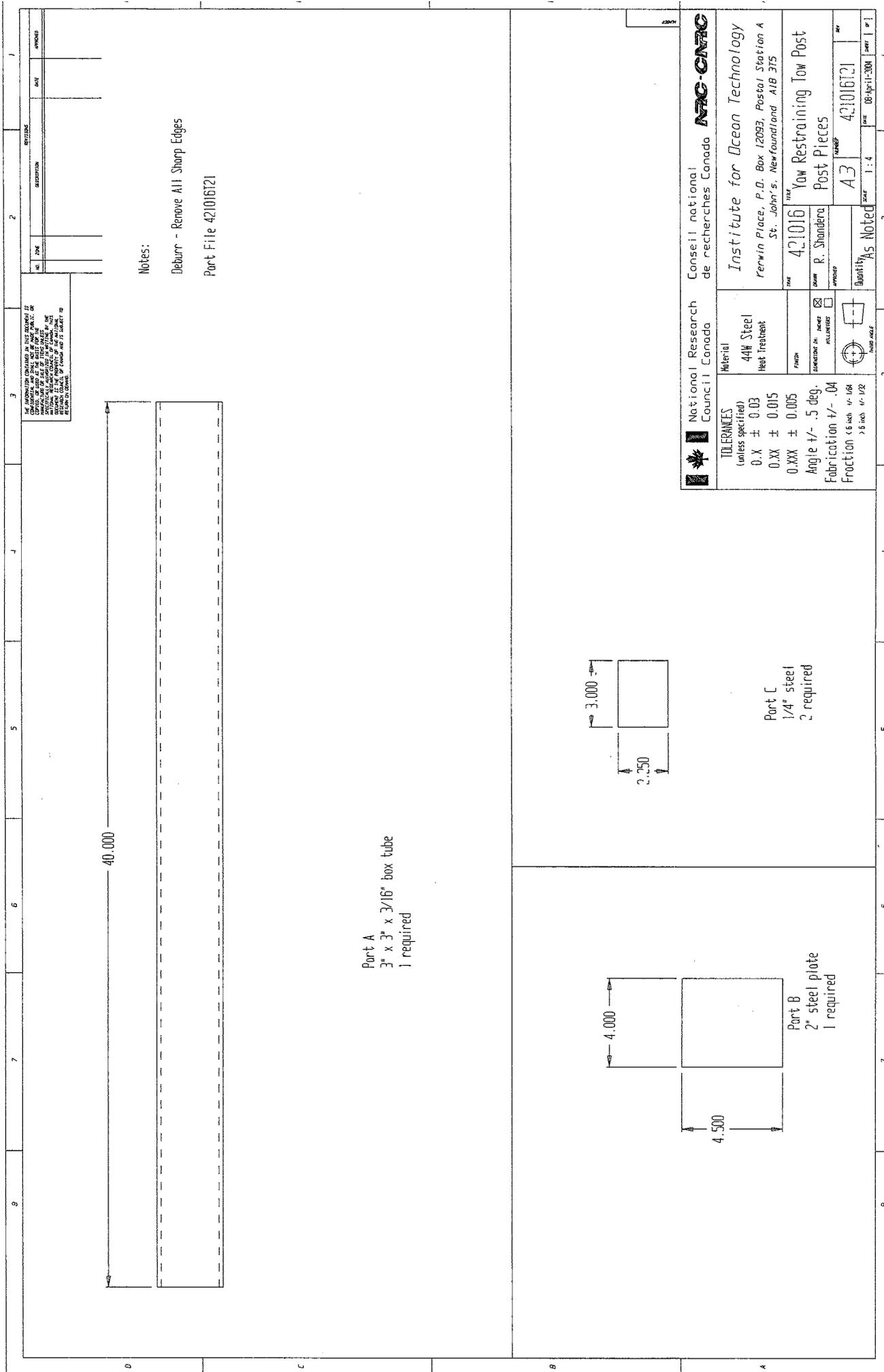
NO.	DATE	REVISIONS



Notes:
 Deburr - Remove All Sharp Edges
 Part File 421016T20



 National Research Council Canada	Conseil national de recherches Canada 	
	Institute for Marine Dynamics Kerwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	
TOLERANCES unless specified 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction 1/8 inch 1/16	Material 44W Steel Heat Treatment FINISH SPECIFIC IN: <input checked="" type="checkbox"/> HARP <input type="checkbox"/> MILL/REED APPROVED	Part No. 421016 Name T. Slade Quantity 1
Quantity 1		Part No. 421016T20 Date 15-Feb-1999 Scale 1:10



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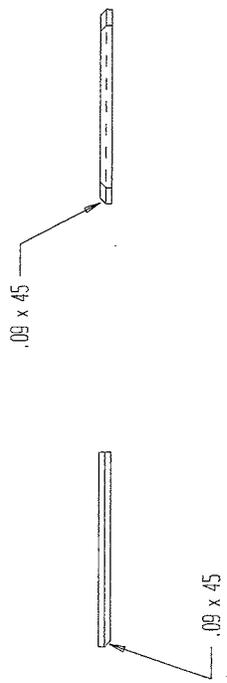
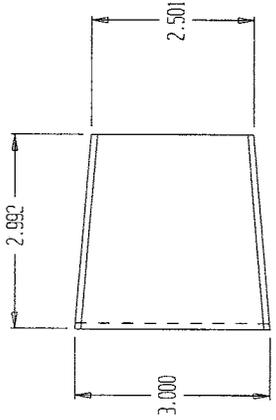
Notes:
 Deburr - Remove All Sharp Edges
 Part File 421016121

Part A
 3" x 3" x 3/16" box tube
 1 required

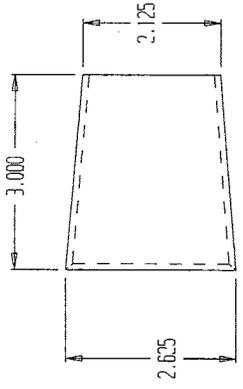
Part B
 2" steel plate
 1 required

Part C
 1/4" steel
 2 required

National Research Council Canada Conseil national de recherches Canada			
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle 1/4- .5 deg. Fabrication 1/4- .04 Fraction < 6 inch 1/16 > 6 inch 1/32		Material 4W Steel Heat Treatment	
FINISH DIMENSION ON JACKS <input checked="" type="checkbox"/> MILL/REB <input type="checkbox"/>		PART NO. 421016	
		TITLE Yaw Restraining Tow Post	
QUANTITY As Noted		DRAWN BY R. Shandera	
APPROVED [Signature]		DATE 421016121	
NATIONAL ARCHIVES 95 ELGIN STREET OTTAWA, ONTARIO K1A 0N6		INSTITUTION FOR OCEAN TECHNOLOGY Ferwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	



Part A
3/16" steel plate
2 required



Part B
3/16" steel plate
2 required

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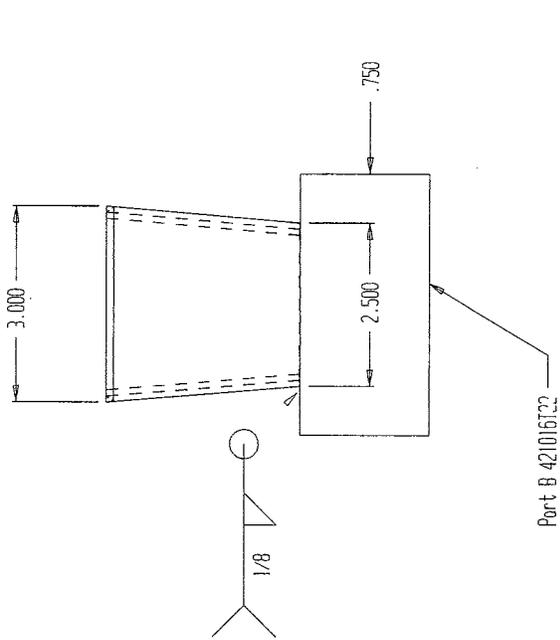
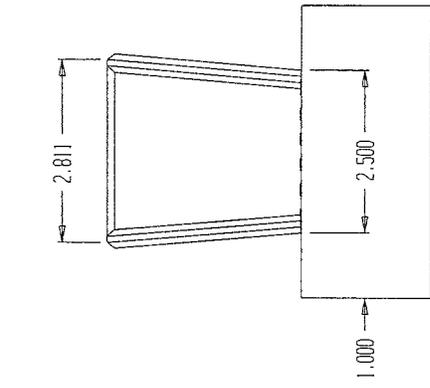
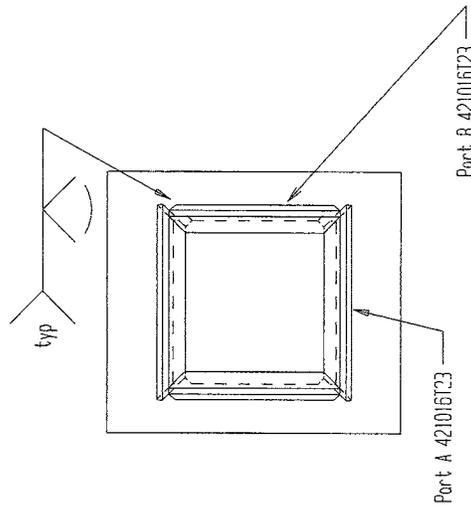
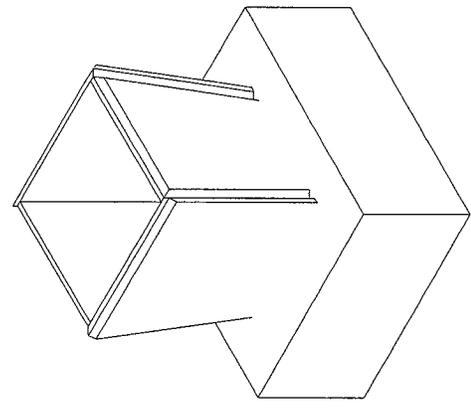
Notes:
Deburr - Remove All Sharp Edges
Part File 421016122

	National Research Council of Canada Conseil national de recherches Canada	National Institute for Ocean Technology Institut national de technologies océaniques
	Yerrwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	Yerrwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction 1/8 inch +/- .004 2/8 inch +/- .002	Material AS noted Heat treatment	Part 421016 Yaw Restraining Taper Pieces
FINISH DIMENSIONS IN INCHES <input checked="" type="checkbox"/> ALL INCHES <input type="checkbox"/> ALL METRIC	QUANTITY 05 noted	DRAWN BY R. Shandera
	PART NAME Yaw Restraining Taper Pieces	PART NUMBER 421016122
SHEET 1 OF 1	SCALE 1:1	DATE 21-April-2004

REV.	DATE	DESCRIPTION	BY	APPROVED

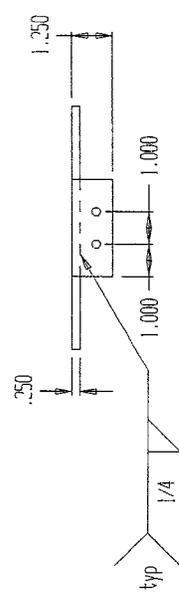
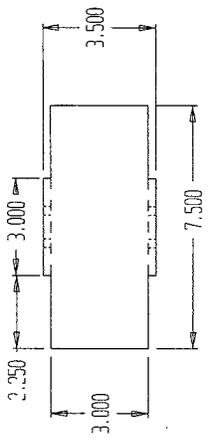
Notes:
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 Chip and brush all welds
 Part File 421016123

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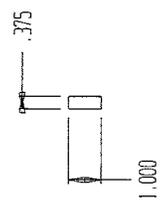
National Research Council Canada Conseil national de recherches Canada	Material 44W Steel Heat Treatment	Part No. 421016	Title Yaw Restraining Heave Post Taper Fabrication
	FINISH <input type="checkbox"/> JAWES <input type="checkbox"/> ALLIAGES <input type="checkbox"/> TYPING MARKS	Quantity 1	Date 21-April-2004
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication < 6 inch $1/8$ > 6 inch $1/16$	Institute for Ocean Technology Yervin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5	Author R. Shandera	Drawing No. 421016123

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Part A
Steel
1 Required

Notes:
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Part File 421016T24



39.700

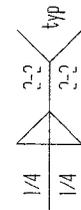
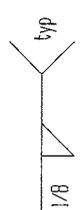
Part B
Steel
2 Required

	National Research Council Canada	Conseil national de recherches Canada	NRCC-CNRC
	<i>Institute for Ocean Technology</i> Perwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland A1B 3T5		
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 3.6 inch +/- 1/32 3.6 inch +/- 1/32	Material 44H Steel Heat Treatment	Part No. 421016	Title Yaw Restraining Tow Post Bearing Mounts
FINISH <input checked="" type="checkbox"/> ENGRAVING IN ANGLES <input type="checkbox"/> MILLING/DRILL	DRAWN BY R. Shandera	DATE 21-April-2004	SHEET NO. 1 of 1
THIRD ANGLE 	QUANTITY 1	SCALE 1 : 4	PART NO. 421016T24

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Notes:

Debur - Remove All Sharp Edges
Part File 421016125



Part C 421016121

Part B 421016124

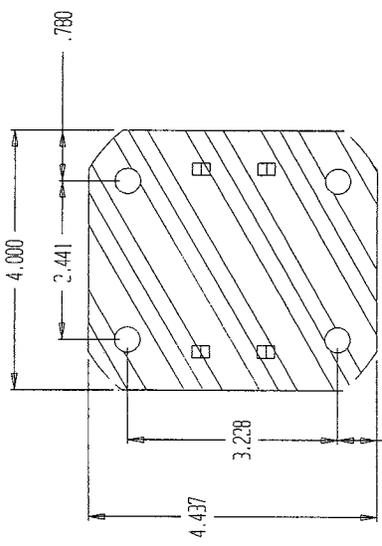
421016123

National Research Council of Canada Conseil national de recherches Canada NRC-CNRC		Institute for Ocean Technology Ferwin Place, P.O. Box 12093, Postal Station A St. John's, Newfoundland, A1B 3T5	
TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 Fraction 3/8 inch 1/4 1/8 1/16	Material 44W Steel Heat treatment F150	Part No. 421016 Part Name Yaw Restraining Tow Post Part Description Post Fabrication	Part No. 421016125 Part Name Yaw Restraining Tow Post Part Description Post Fabrication
Quantity 1	Drawing No. 421016	Date 18-Feb-1999	Scale 1:1

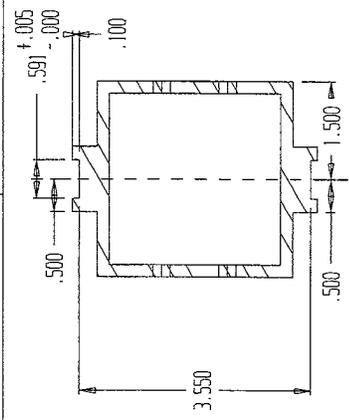
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 Part File 421016126

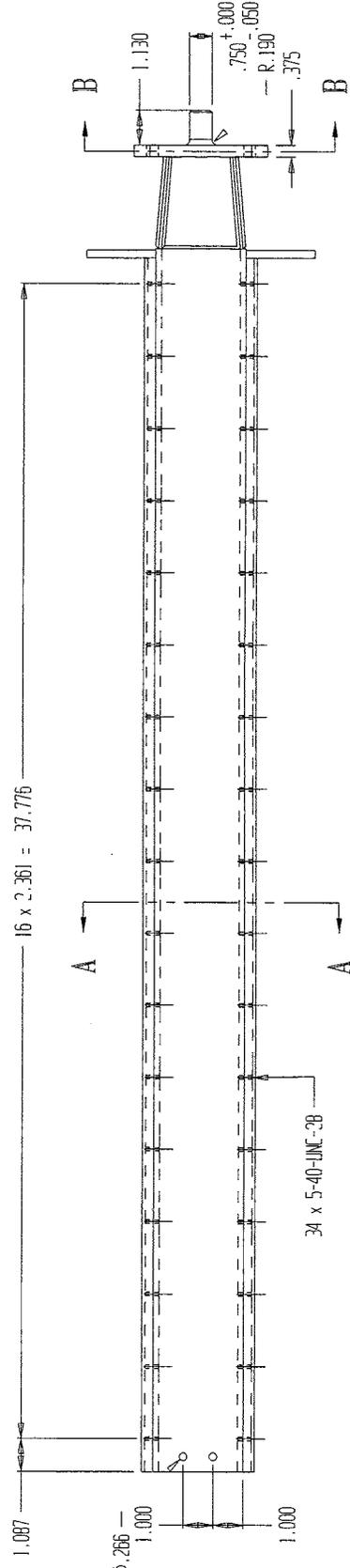
NO DIMENSIONS SHOWN ON THIS DRAWING IS TO BE CONSIDERED AS A BASIS FOR THE DESIGN OF ANY PART OR ASSEMBLY. THE DIMENSIONS SHOWN ON THIS DRAWING ARE THE DIMENSIONS TO WHICH THE PARTS ARE TO BE MANUFACTURED AND ASSEMBLED TO.



SECTION B-B
 SCALE 1:2



SECTION A-A
 SCALE 1:2



National Research Council Canada Conseil national de recherches Canada NTC-CMTC	Material 44W Steel Heat treatment	Part No. 421016	Title Yaw Restraining Tow Post Post Machining
	TOLERANCES (unless specified) 0.X ± 0.03 0.XX ± 0.015 0.XXX ± 0.005 Angle +/- .5 deg. Fabrication +/- .04 3/8 inch +/- 1/32	Drawing No. / INCH / MILLIMETER 421016 / 1:2	Date 27-Apr-1970
Quantity 1	Scale 1:2	Drawing No. 421016	Title Yaw Restraining Tow Post Post Machining

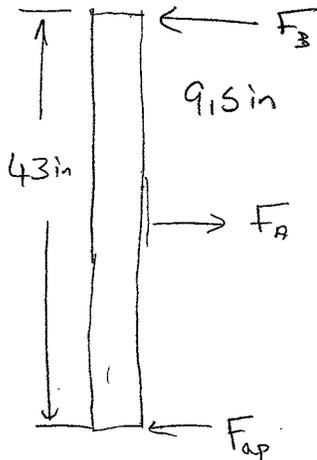
8.0 Appendix B



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$$F = ma$$

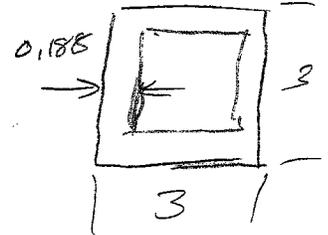
$$m = 2000 \text{ kg}$$

$$a = 3 \text{ m/s}^2$$

$$F = (2000 \text{ kg})(3 \text{ m/s}^2)$$

$$= 6 \text{ kN}$$

$$= 1348.9 \text{ lbs}$$



$$\sum M_B = 0 = -F_{AP}(43) + F_A(9.5)$$

$$F_A = \frac{F_{AP}(43)}{9.5}$$

$$= \frac{(1348.9 \text{ lb})(43)}{9.5}$$

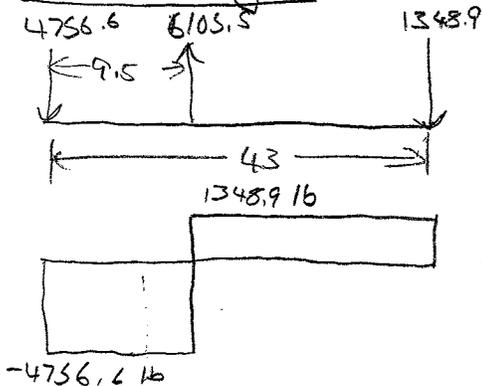
$$= 6105.5 \text{ lb} = 27.2 \text{ kN (Bearing OK)}$$

$$\sum F_x = 0 = -F_A + F_B - 1348.9 \text{ lb}$$

$$F_A = 6105.5 \text{ lb} - 1348.9 \text{ lb}$$

$$= 4756.6 \text{ lb} = 21.2 \text{ kN (Bearing OK)}$$

Beam Strength



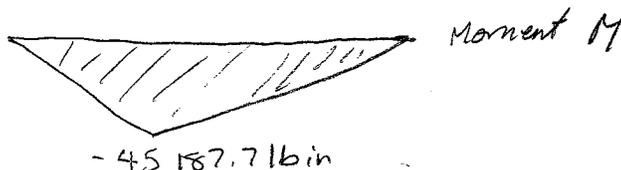
$$\sigma = \frac{M C}{I}$$

$$= \frac{(45187.7 \text{ lb in})(1.5 \text{ in})}{\frac{1}{12}(3^4 - 2.624^4)}$$

$$= 24213.8 \text{ PSI}$$

$$\Rightarrow FS = \frac{58 \times 10^3}{24 \times 10^3}$$

$$= 2.4$$

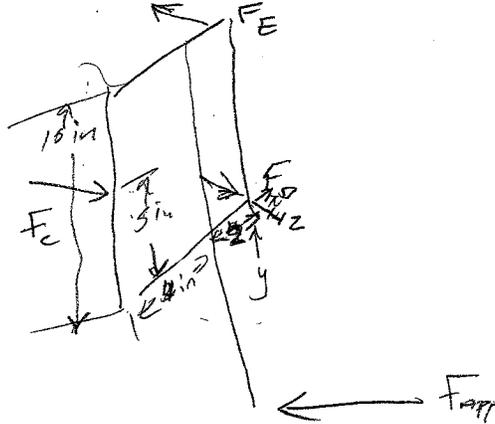




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$$\sum M_y = 0 = F_c(6) - F_{app}(4)$$

$$\begin{aligned} F_c &= \frac{2}{3} F_{app} \\ &= 2(1348.916) \\ &= 449.616 \end{aligned}$$

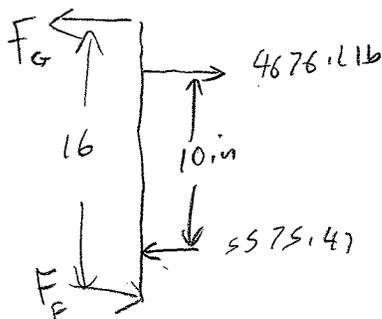
$$\sum M_x = 0 = -F_E(10) + 449.6(5) + 1348.9(33.16)$$

$$\begin{aligned} F_E &= \frac{(449.6)(5) + 1348.9(33.16)}{10} \\ &= 4676.216 \end{aligned}$$

$$\sum F_z = 0 = F_D - F_E + F_c - 1348.9$$

$$\begin{aligned} F_D &= F_E + 1348.9 - F_c \\ &= 4676.17 + 1348.9 - 449.6 \\ &= 5575.47 \end{aligned}$$

Pivot Post





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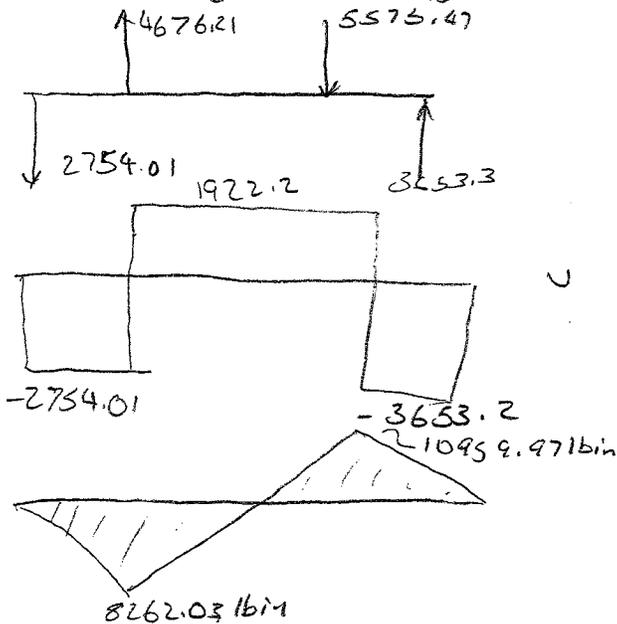
$$\sum M_G = 0 = 16 F_f + 4676.2(3) - 5575.47(13)$$

$$16 F_f = 58452.5116$$

$$F_f = 3653.3$$

$$\sum F_x = 0 = -F_G + 4676.2 - 5575.47 + 3653.3$$

$$F_G = 2754.0116$$



$$M = 10959.9716 \text{ in}$$

$$I = \frac{\pi}{4} (r_o^4 - r_i^4)$$

$$= \frac{\pi}{4} (0.75^4 - 0.15^4)$$

$$= 0.1994 \text{ in}^4$$

$$\sigma = \frac{M c}{I} = \frac{(10959.9716 \text{ in})(0.75)}{0.1994 \text{ in}^4}$$

$$= 41219 \text{ psi}$$

$$FS = \frac{58 \times 10^3}{41 \times 10^3}$$

$$= 1.4$$

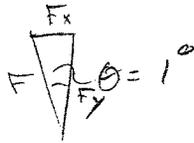


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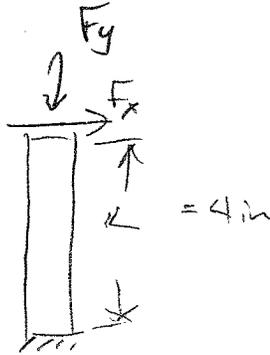
treaded rod



$$F = 500 \text{ lbs}$$

$$F \sin \theta = F_x$$

$$F_x = 8.7 \text{ lb.}$$



$$F_y = F \cos \theta$$

$$= 499.9$$

$$\sigma = \frac{P}{A} + \frac{M C}{I}$$

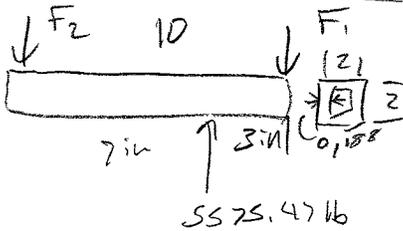
$$= \frac{499.9 \text{ lb}}{\pi (0.75)^2} + \frac{(8.7)(4 \text{ in})(0.25 \text{ in})}{\frac{\pi}{4} (0.75)^4}$$

$$= 5377 \text{ lb OK.}$$

Deflection of cantilever

$$\delta = \frac{PL^3}{3EI} = \frac{(500 \text{ lb})(33 \text{ in})^3}{3(29 \times 10^6 \text{ psi})(\frac{1}{2}(3^4 - 2.624^4))}$$

= 0.25 in of deflect at max load & length.



$$\sum M_1 = 0 = (-5575.47 \text{ lb})(3 \text{ in}) + F_2(10 \text{ in})$$

$$F_2 = 1672.6 \text{ lb}$$

$$F_i = (5575.47 - 1672.6) \text{ lb}$$

$$= 3902.8$$

$$M = 11708.4 = 3902.8(3)$$

$$\sigma = \frac{M C}{I} = \frac{(11708.4 \text{ lb in})(1)}{\frac{\pi}{12} (2^4 - 1.624^4)} = 15.5 \text{ ksi}$$

OK

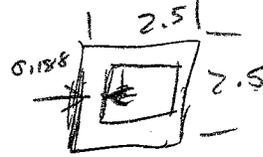
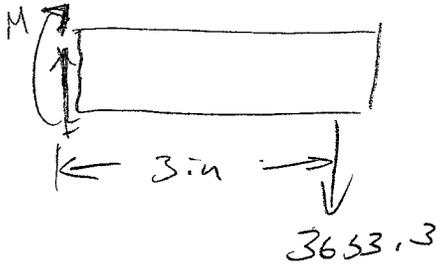
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$$M = -(3653.3)(3)$$

$$= -10959.9 \text{ bin}$$

$$\sigma = \frac{Mc}{I}$$

$$= \frac{(10959.9) \overset{\text{bin}}{(1.75 \text{ in})}}{\frac{1}{12} (2.5^4 - 2.124)}$$

$$= 8786 \text{ PSI} < 88000 \text{ PSI OK}$$