A PMM Balance for C Scout

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/8896174
Laboratory Memorandum; no. LM-2004-35, 2004

National Research Council Canada
Institute for Ocean Technology

Conseil national de recherches Canada
Institut des technologies océaniques

Laboratory Memorandum

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DOCUMENTATION PAGE

REPORT NUMBER	NRC REPORT NUMBER	DATE
LM-2004-35		December 2004

REPORT SECURITY CLASSIFICATION	DISTRIBUTION
Unclassified	Unlimited

TITLE

A PMM BALANCE FOR C SCOUT

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PUBLICATION

SPONSORING AGENCY(S)

Institute for Ocean Technology, National Research Council, St. John's, NL

IMD PROJECT NUMBER	NRC FILE NUMBER

KEY WORDS	PAGES	FIGS.	TABLES
PMM Balance Upper Frame, C Scout model	iv, 13, App. A	20	

SUMMARY

The Design and Fabrication Group was asked to design a balance for C Scout. The C Scout model is a full scale under water vehicle prototype intended for near surface observations. The purpose for the balance was to measure the underwater forces in drag and sway and the yaw moments generated by the model during maneuvers in the horizontal plane. The balance was placed internal to the model so that it would not measure the forces induced in the mounting apparatus.

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INTRODUCTION

The Design and Fabrication Group was asked to design a balance for C Scout. The C Scout model is a full scale under water vehicle prototype intended for near surface observations. The purpose for the balance was to measure the underwater forces in drag and sway and the yaw moments generated by the model during maneuvers in the horizontal plane. The balance was placed internal to the model so that it would not measure the forces induced in the mounting apparatus.

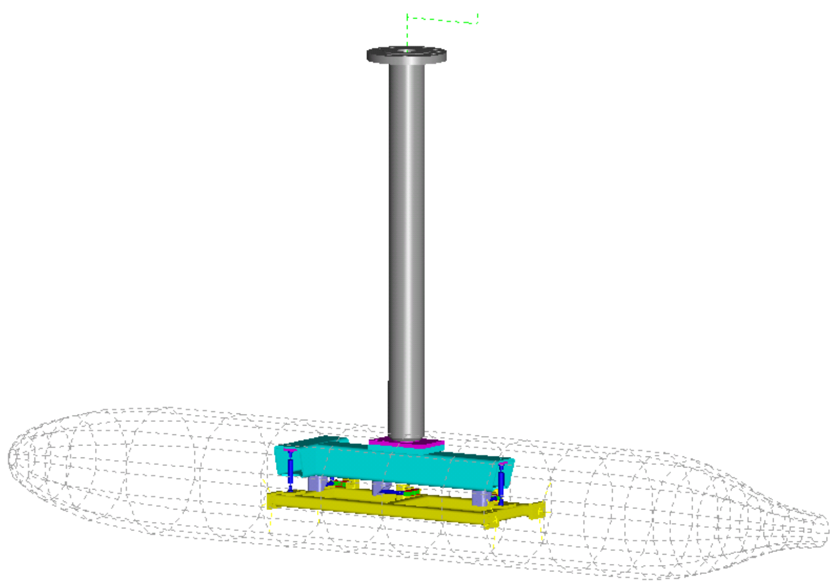

Figure 1 C Scout Internal Balance

As can be seen from Figure 1 this balance consists of three basic pieces a post (in gray) a groundside frame (in blue) and a model frame (in yellow). The model frame attaches to the internal structure of the model and the post attaches to an adaptor plate welded to the PMM Balance Upper Frame.

BALANCE CAPACITY

The balance was configured with a 50 lb load cell in drag and two 100 lbs load cells in sway. The balance was not fitted with vertical load cells. The vertical flexible links were sized for 250 lbs breaking load.

Single Component Capacities

Maximum Drag Force	50 lbs.	measured
Maximum Sway Force	200 lbs.	measured
Maximum Heave Force	750 lbs.	not measured
Maximum Pitch Moment	10,500 in-lbs	not measured
Maximum Yaw Moment	2,400 in-lbs	measured
Maximum Roll Moment	2,400 in-lbs	not measured

Note that combinations of forces and moments cannot result in loads that exceed the single load cell or flexible link capacities.

This balance was designed around the Interface SSB-50, 100, 250 cantilever style load cells. All three of these load cells sizes have a common bolt pattern and the balance can be fitted with any of these load cells in any of the six locations. Accommodation for three load cells in the vertical direction was made so that the balance could be configured to measure 3 forces and 3 moments. The vertical load cells were not required for this test series and were not fitted. In their place three longer flexible links were designed and fitted. Future reconfiguration of the balance to accommodate 250 lbs load cells will require the design and fabrication of suitable flexible links.

BACKGROUND

Planning Phase Finite Element Models

During the planning phase of this project a number of finite element models were run to determine the general configuration of the support structure and the load cell capacity required. See the memo entitled “Options For Mounting the C Scout Captive Model on the PMM” in Appendix A. The design of the support structure and the choice of load cells followed the recommendations contained in the memo.

Flexible Links

The planning phase work also identified the need for flexible links of smaller capacity than had previously been accepted practice at IOT. The machine shop at the Faculty of Engineering at MUN had recently purchased a new turning center. The staff in the machine shop was approached with a design for a simplified flexible link section of the required size and a successful procedure for producing the links was arrived at.

Load Cells

The load cells chosen during the planning phase were cantilever load cells. These load cells were chosen because of availability and cost considerations. The under water model configuration with a flooded interior meant that the load cells would have to be water proofed at IOT and thus after the factory calibration. A single load cell was waterproofed and then the load vs deflection characteristics of the load cell were physically measured. This was done so that an accurate finite element model of the load cell could be used for the natural frequency predications. Some hysteresis and zero drift due to the potting were noted during the measurement process. The waterproofing altered the mechanical dimensions of the load cell. Stand off washers and a sleeve to waterproof the cable was fitted to allow room for the potting compound and cable sealant. The effect of changing the ambient pressure on the load cells was not checked.

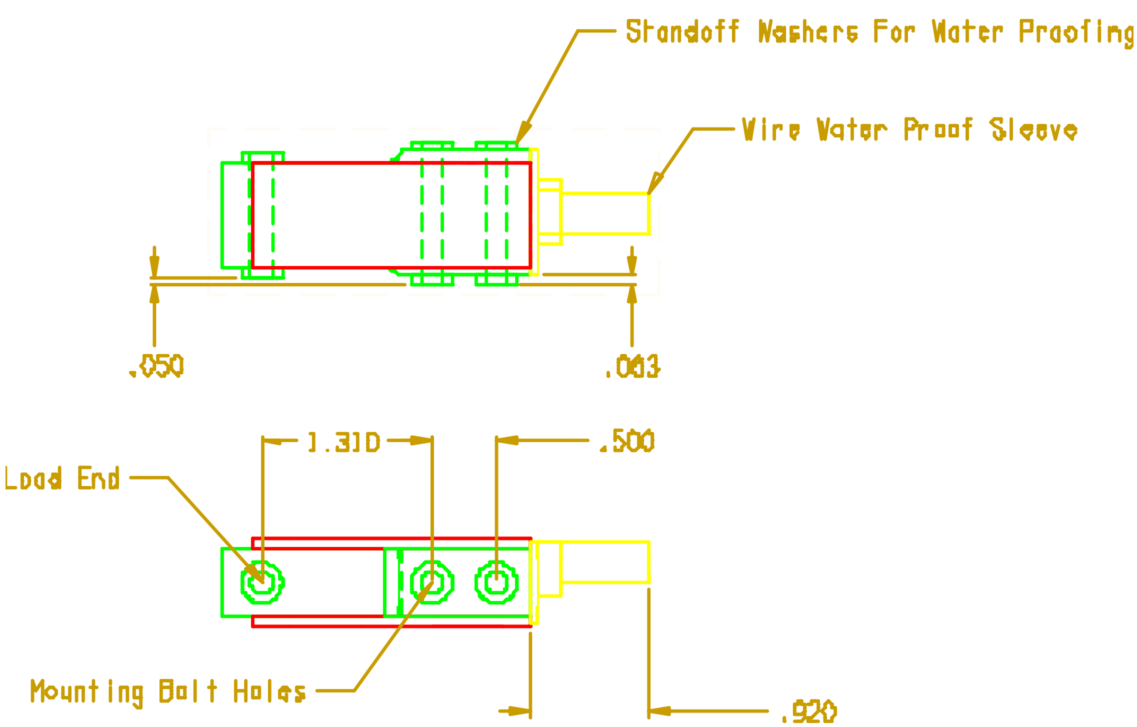

Figure 2 Typical Load Cell (shown without potting material)

Existing Model

One of the two existing C Scout models had an empty parallel middle body that consisted of a space frame with a thin aluminum skin over the outside. The upper half of the skin hinged open to provide access to the interior. The space framing consisted of two ring frames forward and two ring frames aft of the central interior cavity. Three small rectangular longitudinal stringers joined the ring frames.

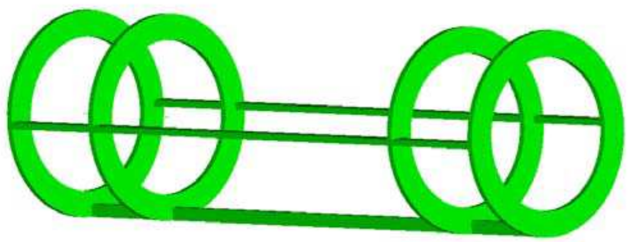

Figure 3 Cscout Framing

The outside diameter of the ring frames was measured as 15.75 inches with a molded depth of 2 inches and a siding of .5 inches. The length of the interior cavity was measured at 32.69 inches. These dimensions defined the available space and support points for an interior balance.

Attachment to the PMM or MDTF

During the planning phase it was assumed that the balance could be removed from the PMM and that the C Scout mounting post could be attached to the bull gear. The concept was to remove the bull gear and shaft, set the assembly up in the medium lathe and turn a mating surface for the C Scout mounting post. This proved impractical during the design phase when it was realized that the bull gear shaft was welded to the upper PMM balance frame. The balance frame had no spare material provided that could be machined to provide a true surface for mounting the C Scout balance. And disassembly of the bull gear, bull shaft, bearings and PMM upper balance frame was time consuming and difficult due to the mechanical arrangement.

A design layout for a new PMM bull shaft and gear was ruled out when the quote for replacing the bull gear was received. An alternative design layout for attaching the C Scout balance to the MDTF was also drawn but ruled out because access to the MDTF could not be secured.

Thus a compromise mounting to the PMM was arrived at with the fitting of an “as welded” flange centered below the PMM bull shaft and welded to the upper PMM balance frame. Errors associated with this were anticipated and accepted.

Design Analysis

Design Loads

The scientific authority defined the ranges for the design loads as;

Drag Force from 0 to 11.7 lbs.

Sway Force from 2.3 to 112.4 lbs.

Heave Force from 10.8 to 27.6 lbs.

Roll Moment from 5.3 to 54.9 in-lbs.

Pitch Moment from 327.5 to 832 in-lbs.

Yaw Moment from 71 to 1,655 in-lbs.

Finite Element Model

A detailed design layout for the balance and support post was drawn following from the planning phase analysis. This detailed layout was then used to refine the finite element model of the balance itself, the load cells and the flexible links.

Load Cell FEA Model

The spring constants for the 50 and 100 lbs capacity load cells after water proofing were measured using a dial indicator to measure deflection and dead weights to apply known loads. The load procedure followed the ASTM A73 - 2000 standard for calibration of load measuring devices. The 50 lbs load cell had a spring constant of 9,135 lbs per inch and the 100 lbs load cell had a spring constant of 10,810 lbs per inch. Round rods of equivalent spring stiffness for the given dimensions in the FEA model were calculated and used to model the load cells.

Added Mass for C Scout Model

The FEA natural frequency solver assumes the model is in air. The submarine model is an essentially closed body, which is flooded when submerged. The weight of this water is accounted for by artificially adding mass to the model. The added mass due to the entrained water inside submerged body was estimated at 1 times the submerged volume.

The volume was measured 18,700 cubic inches or 675 lbs of water. This was modeled by defining the model skin as .5-inch thick steel plate elements.

Stress Results

Two load cases for stress were run to confirm the flexible link sizes, the capacity of the load cells and define the influence of sway and yaw combined on drag.

Load Case 1 – 12 lbs Drag

Predicted maximum stress was 9,470 psi - drag flexible link – OK

Measured Axial Force was 11.93 lbs – or 99.4 % of applied – OK

Load Case 2 – 112 lbs of Sway and 1655 in-lbs of Yaw – Combined Load

Predicted maximum stress was 50,850 psi – forward side force flexible link – OK

Influence on Drag – Drag measured .074 lbs with the full combined yaw and sway. Assuming an applied drag force of 12 lbs this would be 6% and indicates the need for calibration of the assembled balance.

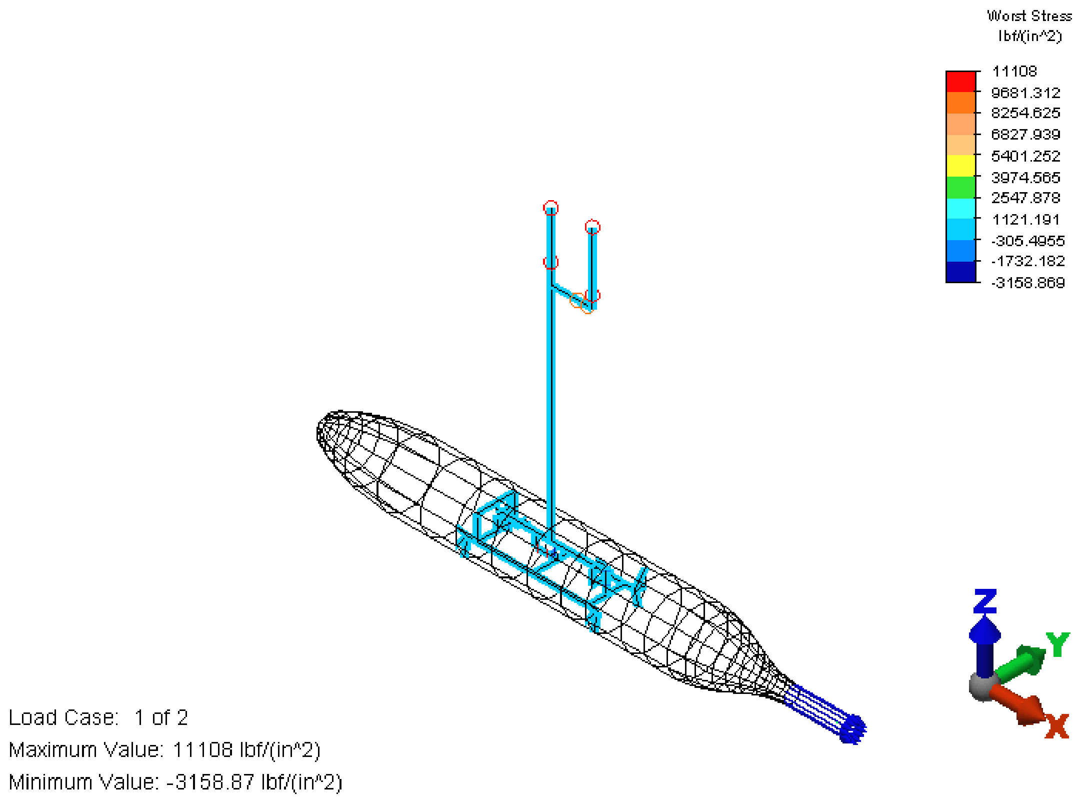

Figure 4 Stress Due to Drag (maximum stress on drag link)

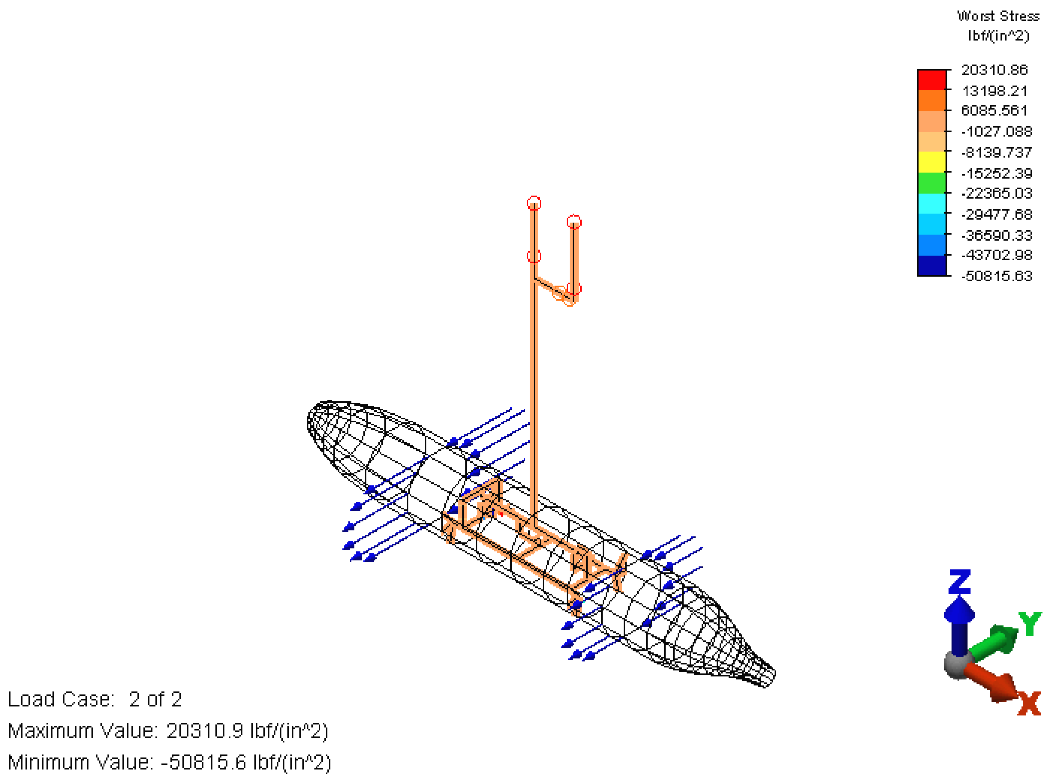

Figure 5 Stress due to Side Force (maximum stress on side force links)

Natural Frequency Predictions

The model was also run using the natural frequency prediction processor. The first predicted mode was in Yaw at 3.74 Hrz. The second predicted mode was in pitch at 3.99 Hrz. The third predicted mode was in sway at 4.73 Hrz.

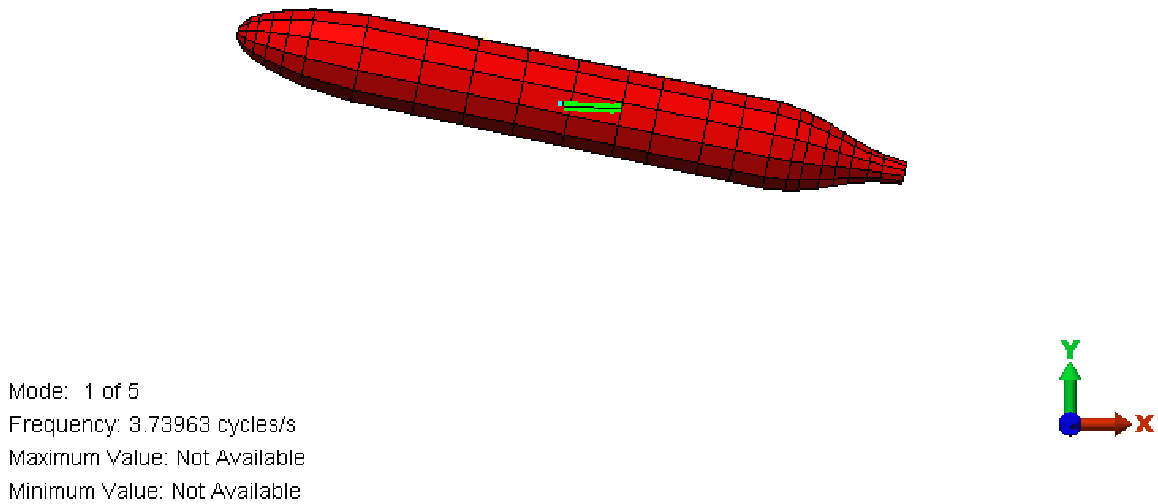

Figure 6 Yaw Natural Frequency Deflected Shape

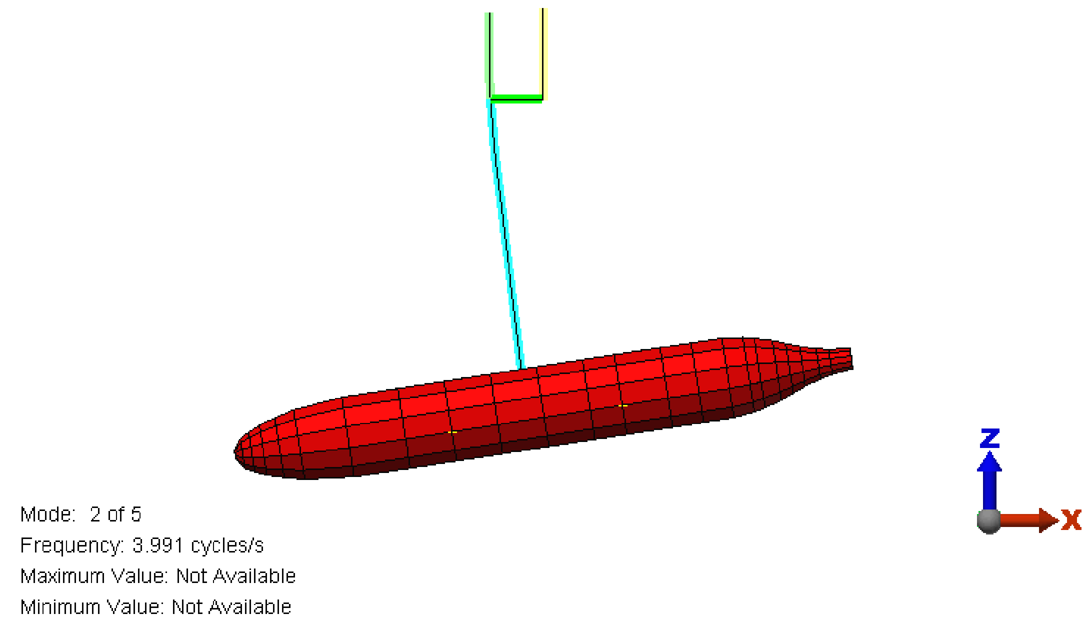

Figure 7 Pitch Natural Frequency Deflected Shape

DETAILED PART DESCRIPTION

PMM Adaptor Flange

The connection to the PMM was detailed as an "as welded" flange. To help reduce the distortion due to welding the flange was specified oversize on thickness as 1.25" steel plate.

The flange was provided with a counter bore to help center the post and a 12 bolt pattern to allow ample opportunity for shimming the post into alignment.

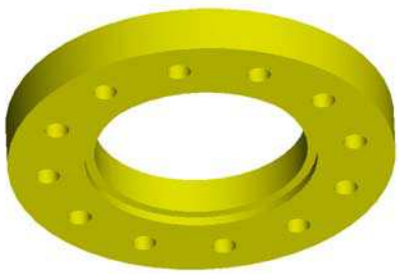

Figure 8 PMM Flange

Model Post

The cantilevered configuration of this apparatus was inherently soft and susceptible to vibration. To counter this the wall thickness of the mounting tube was increased to the maximum size that could be easily obtained. Russel Metals provided a quote for 4.500" outside diameter x .500" wall thickness seamless steel tubing with a 2-week delivery time.

The upper end of the model post was configured to match the PMM adaptor flange and the lower end was provided with bossed and keyed plate to connect to the balance ground frame. The lower end plate boss and keyway were designed to resist the drag, sway and yaw forces in shear. This reduced the size required for the bolts in this connection and thus reduced the torque forces generated during fastening. This low connection force arrangement was used to reduce the risk of over loading the drag load cell during model installation.

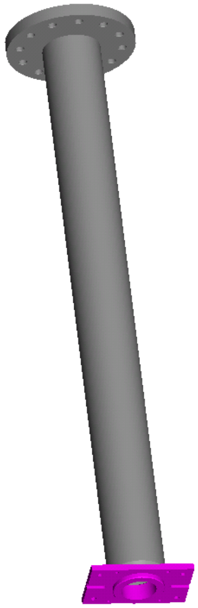

Figure 9 Model Post

Balance Ground Frame

The ground frame was designed using standard steel box tube and plate sections. The box tube was used because the shape is stiff in torsion and bending and has balanced properties about both the X and Y axis. The balance of properties helps to reduce unwanted modes of deflection and cross talk in the balance.

The ground frame was also provided with sight holes for locating the vertical sight of the surveyor's transit during setup for calibration. The sight holes were located in line with the side force flexible links and on the top of the frame.

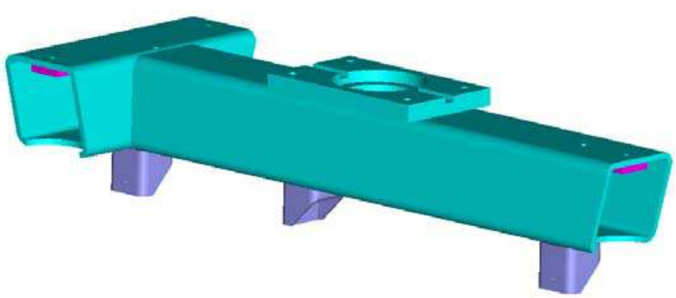

Figure 10 Ground Frame

Balance Model Frame

The model balance frame had to be provided with connection points to the model framing. This framing was inside the model where machine tools would not have been able to reach. Thus the model frame had to be provided with a connection technique that could be done with a hand held drill. The model balance frame was detailed using stock box tube sizes that were comparable to the model framing. This was done because a heavier frame would not have resulted in a stiffer setup overall when fastened to a slight model. Machined pads and clearance holes were provided for the future mounting of vertical load cells for a six-component balance configuration. The mounting arrangements were intended for the same type of load cell as used for the horizontal force measurement.

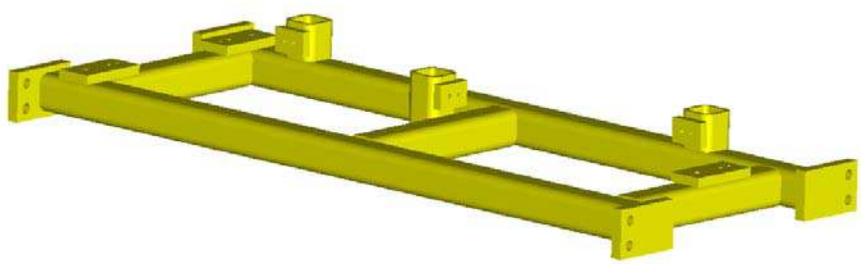

Figure 11 Balance Model Frame

Calibration Arm

The project plan called for calibrating the balance in the model prep shop. To do this a dedicated bracket to mount the balance to the existing calibration post in the model prep shop was needed. The orientation of the balance in the shop was arranged to measure drag in the direction between the calibration post and the cold room wall. The configuration of the balance pad on the model post allowed the balance direction to be reversed for calibration of load in both directions.

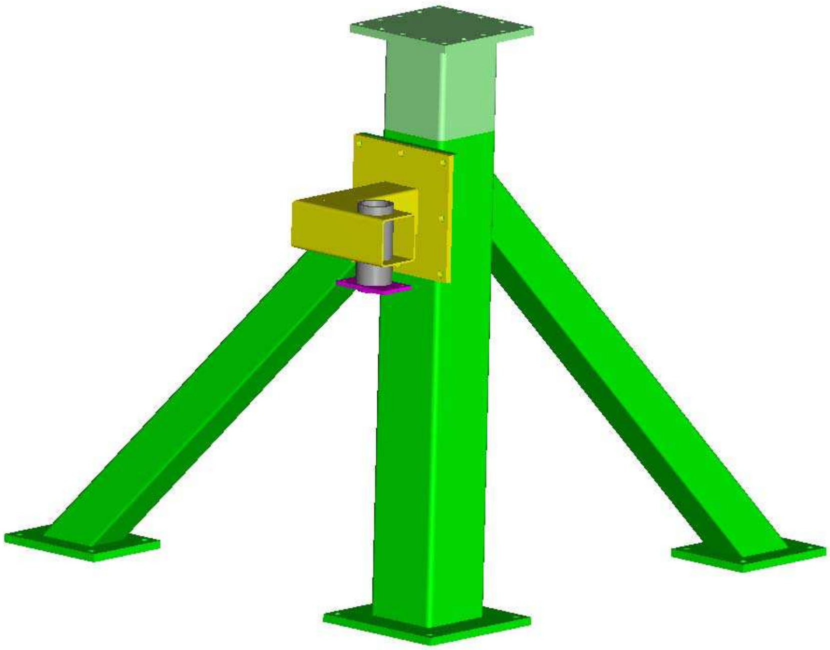

Figure 12Calibration Post and Arm

PMM Configuration

A layout of the model, balance and PMM was done to allow for the planning of an installation procedure.

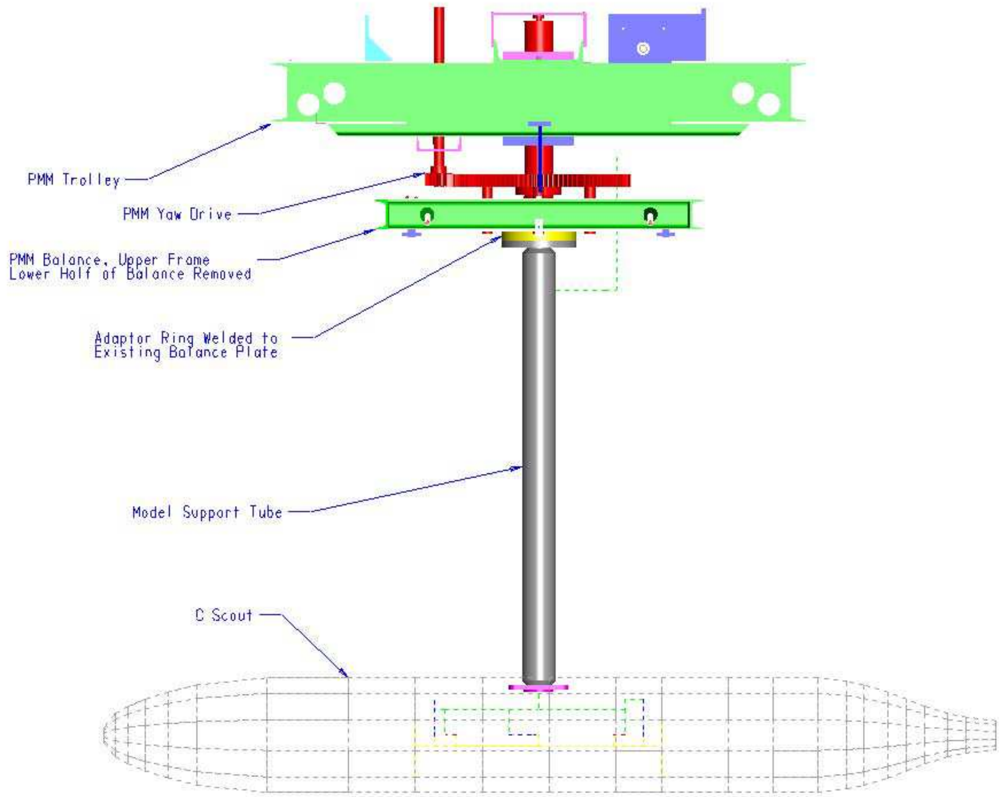

Figure 13 PMM Configurations

Drawing List

Source File CadUser\projects\891 auv controll cscout\jbell\Cscout balance 1

891J11	prt	jbell	model frame fab	model frame welding drawing
891J12	prt	jbell	ground frame fab	ground frame welding drawing
891J13	prt	jbell	GF Machining	ground frame machining drawing
891J14	prt	jbell	mf machining	model frame machining drawing
891J15	prt	jbell	Vertical Link	No Load Cell Vertical Links
891J16	prt	jbell	Side Force Link	
891J17	prt	jbell	Drag Link	
891J18	prt	jbell	Post Model Pad	Post lower plate fabricatioin
891J19	prt	jbell	Post upper Pad	
891J20	prt	jbell	Post fabricating	
891J21	prt	jbell	Post machining	
891J22	prt	jbell	fairing insert	fairing insert for model post connection
891J23	prt	jbell	Pmm Flange	
891J24	prt	jbell	Cal Arm Weld	
891J25	prt	jbell	Cal Arm Machine	

Appendix A Feasibility Report for C Scout Balance

To: Chris Williams / Tony Randell

From: John Bell

Date: 18 March 2004

Re: Options For Mounting the C Scout Captive Model on the PMM

The objective of this investigation was to identify a basic concept and estimate the effort and expenses involved in mounting the C Scout captive model on the PMM for testing in the Ice Tank.

The test objectives were laid out during the design concept meeting.

This investigation looked at three aspects of the apparatus for this experiment. The first was the basic structural component configuration and it's stiffness when related to the PMM components. The second aspect was the stress level induced in the PMM components by the experiment. The third aspect was the load cells and their capacity, acquisition and what configuration of balance best suited the testing contemplated.

Structural Component Configuration

The large bull gear for the yaw drive of the PMM was identified as the desired attachment point for the C scout model. This would require the removal of the PMM balance and would eliminate the large moments inherent with using the PMM balance as is for this type of testing.

The bull gear is mounted on a 4 inch OD x 3.375 ID pipe which is supported by two flange mounted ball bearing units. The bull gear is rotated and restrained in yaw by a 3.5 inch OD pinion gear. The pinion gear is in turn mounted on a 1.5 inch OD shaft which is @ 18 inches long. This pinion shaft acts as a torsion spring and significantly influences the rigidity of the bull gear and anything attached to it in yaw.

A finite element model was made which included the bull gear web, the bull gear shaft, the pinion gear, and the pinion shaft. Thus the effect of the pinion shaft as a spring in torsion was included. Three configurations for mounting the model to the bull gear were then investigated.

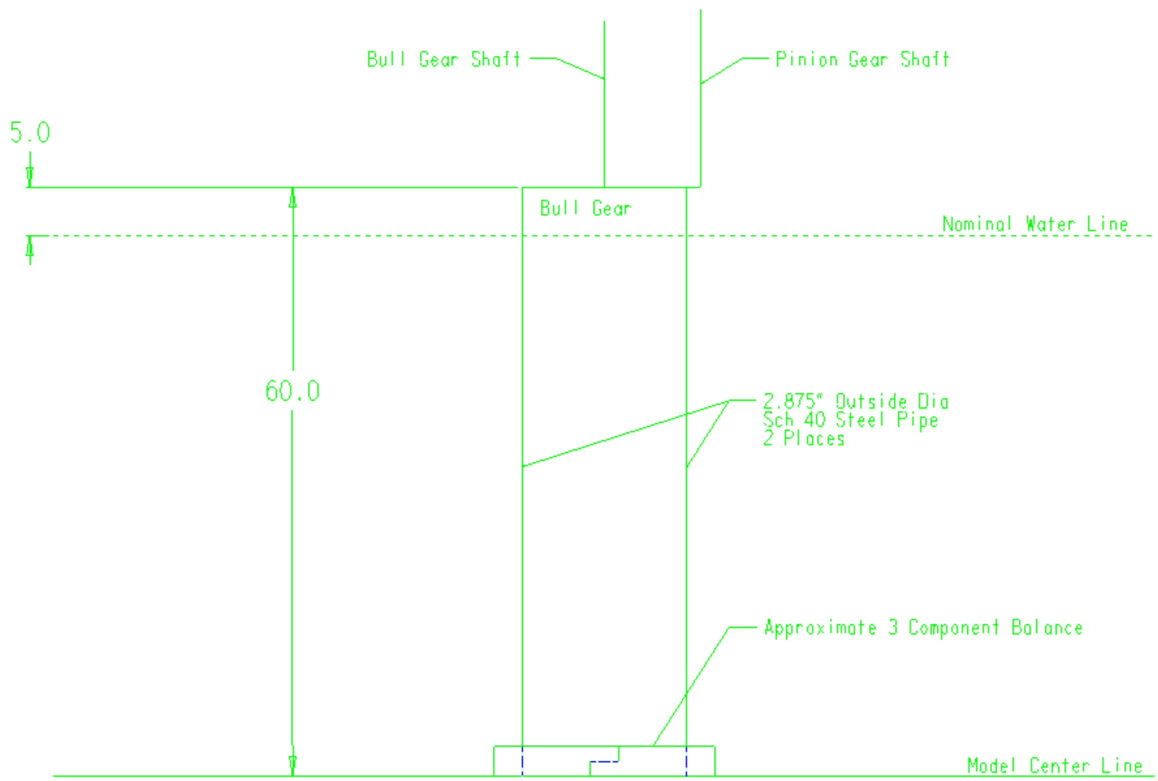

Figure 14 Approximate Model / PMM Configuration

Two Post Model

The first configuration investigated consisted of two vertical pipes extending down to the model from the bull gear. The two pipes would then pass through the model skin and attach to the groundside of the model balance.

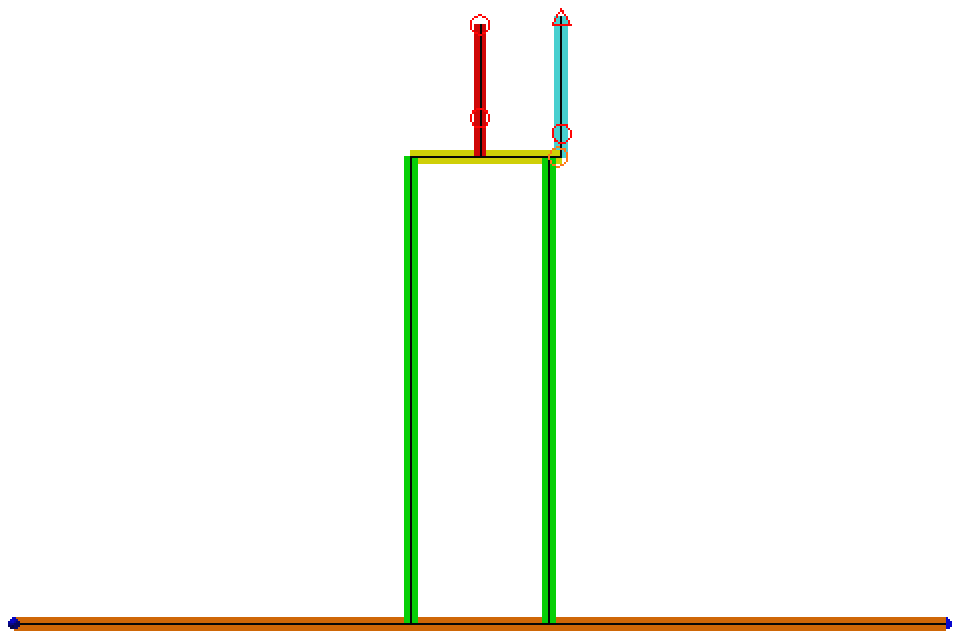

Figure 15 Two-Post Model

The model in figure 1 shows the bull gear shaft in red, the bull gear in yellow and the pinion shaft in blue. The associated bearings are modeled as boundary conditions and show as circles and triangles depending on the exact configuration. The two pipes extending down from the bull gear are given properties of 2 ½ inch Sch 40 steel pipe which has an outside diameter of 3 inches. The model was represented as a single line and given the properties of a 10 x 10 x 3/8 wall steel box tube weighing 48 pounds per foot.

Single Post Model

The author felt that the bull gear and shaft arrangement would largely negate the benefits of having two shafts. Therefore a simplified arrangement, which used only a single shaft, was tried. The single shaft would need to be 4 inch Sch 40 pipe - larger than the 3 inches specified or could be made of an asymmetrical section such as 3 x 6 x 3/8 wall box tube. The results reflect the 3 x 6 box tube section.

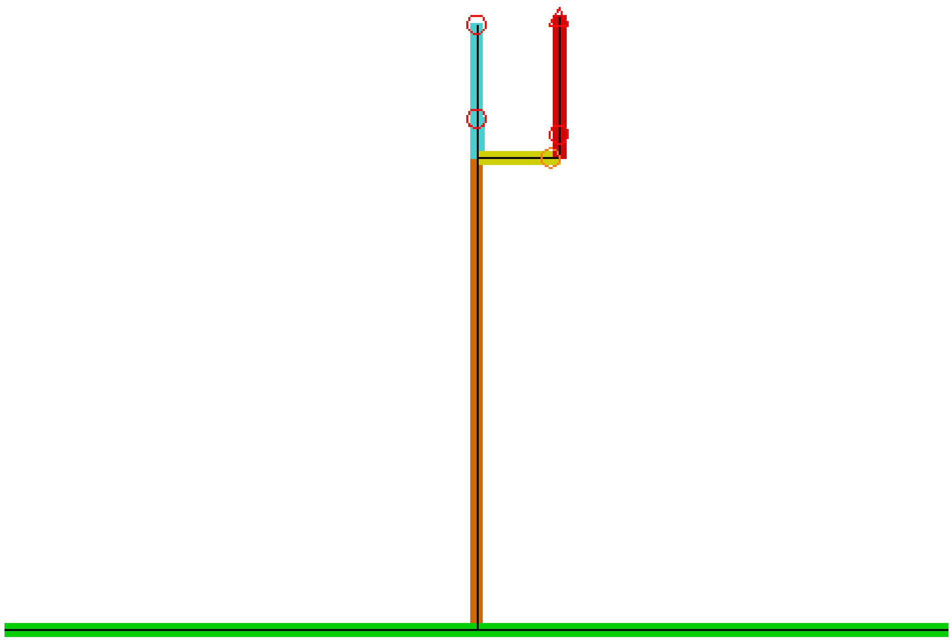

Figure 16 One Post Arrangement

C Frame Model

A third configuration which would maintain the model centrally below the yaw axis and support the model from behind to eliminate the flow disturbance created by a shaft entering from the side of the model was also tried.

In this model the C frame is shown above the model because the FEA cannot deal with one beam element inside another. Therefore one is shown close beside the other. The bull gear shaft, bull gear, pinion shaft and bearings are copies of the model elements from the other two models.

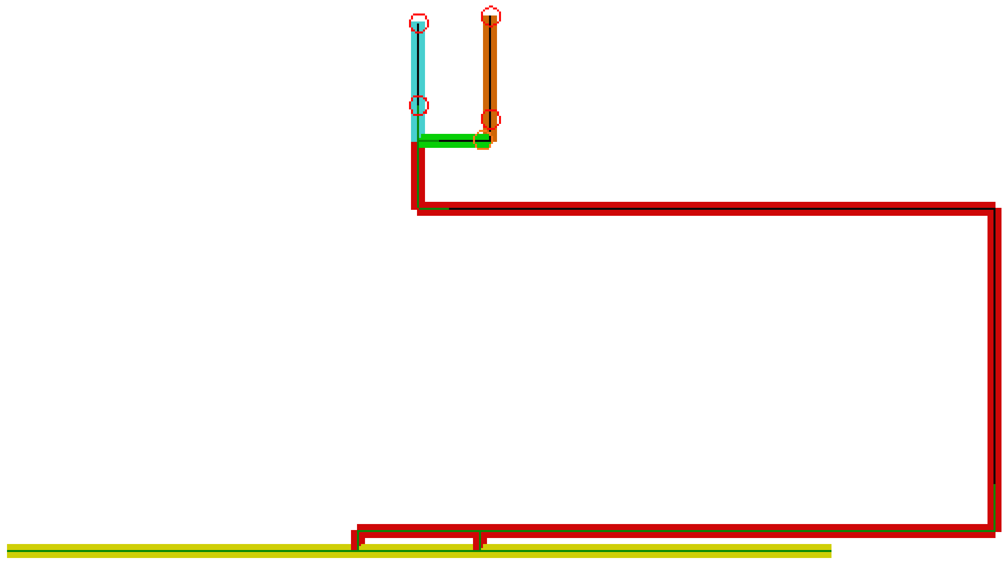

Figure 17 C Post Arrangement

Model Results

A 1 pound load was placed on all three models in drag and sway and equal and opposite 1 pound loads were placed on the ends of the C scout model to simulate pitch and yaw. The displacement of the model was then measured to show how soft the mounting was. A second analysis was run with all three models to calculate the 1st mode of natural frequency in air.

The results are shown in the table below.

Model Results

	Drag	Sway	Pitch	Yaw	1st Mode Natural Frequency
2 Post Model	0.0067	0.0052	0.0055	0.0067	1.53 Hrz
1 Post Model	0.0005	0.0006	0.0012	0.0039	3.86 Hrz
C Post Model	0.0029	0.007	0.012	0.014	1.47 Hrz

The single post arrangement shows considerable benefit in both stiffness and simplicity. The natural frequency predictions of the model could be expected to drop by half when immersed in water and therefore the two post and c post arrangements would be slightly below 1 Hrz.

Stress Predictions

The model experimental loads provided were used to predict the stresses that would be applied to the PMM components. The experimental maximum loads were predicted to be 12 pounds in drag, 36 lbs in sway and 717 in-lbs of yaw moment.

A rough approximation of a 3 component balance with 6 flexible links was modeled and added to the single post model from the previous work.

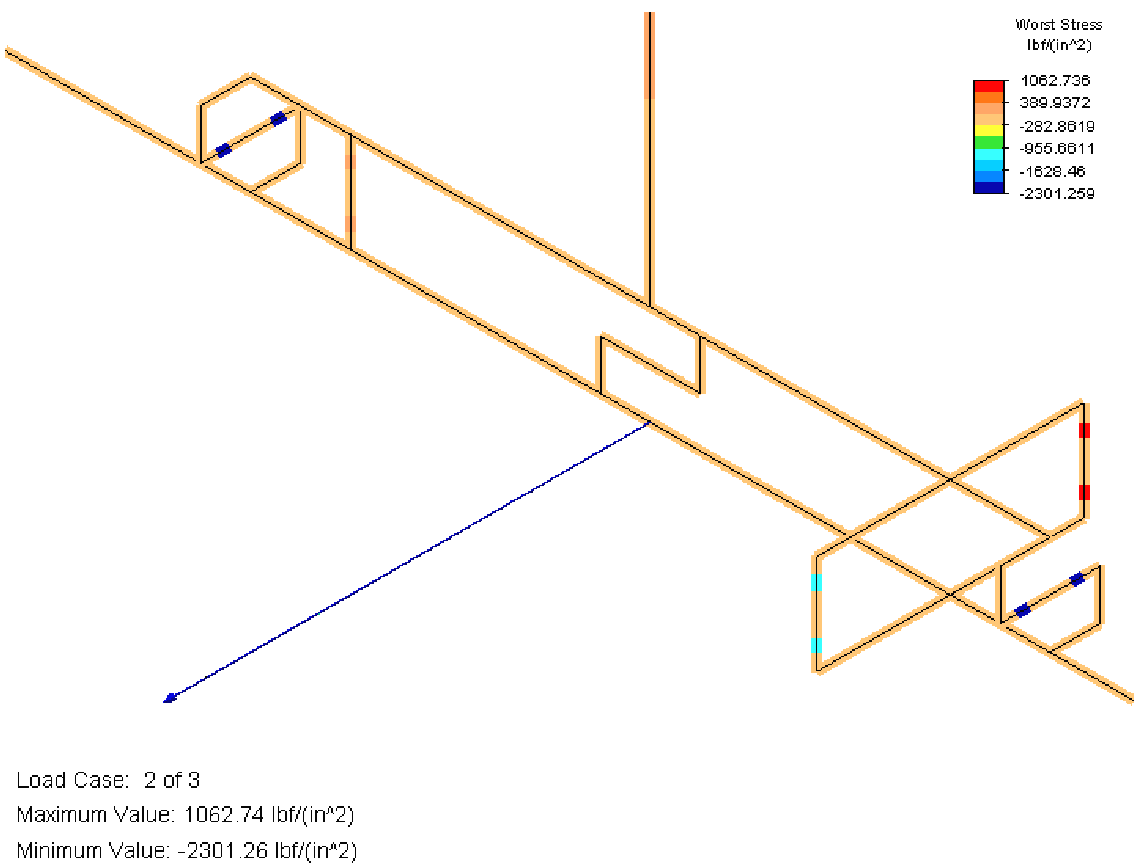

Figure 18 Balance Model Added to the 1 Post Model

The model included flexible links made form high strength aluminum and a heavy 16 x 16 x 3/8 wall box tube for C Scout. The predicted loads were then placed on the model and the model was then analysised for stress and natural frequency.

The stresses placed on the PMM bull gear shaft were then checked and the maximum predicted stress was 1062 psi. which was well within the limit of the shaft material. The vertical flexible links, which support the weigth of C Scout, were highly stressed when bearing the weight of the model. This indicated that the model should be neutrally buoyant to achieve accurate force measurement and that efforts to protect the load cells during assembly and outfit would be required. The first natural frequency of the model setup only slightly dropped to 3.77 Hrz in yaw.

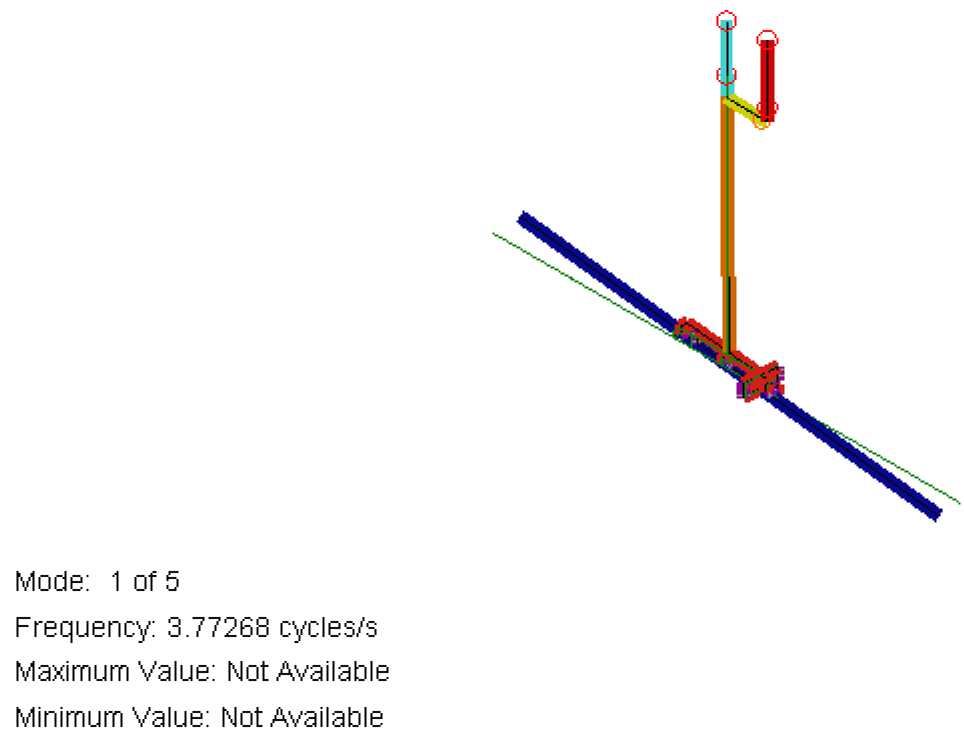

Figure 19 Natural Frequency 1st Mode – Yaw

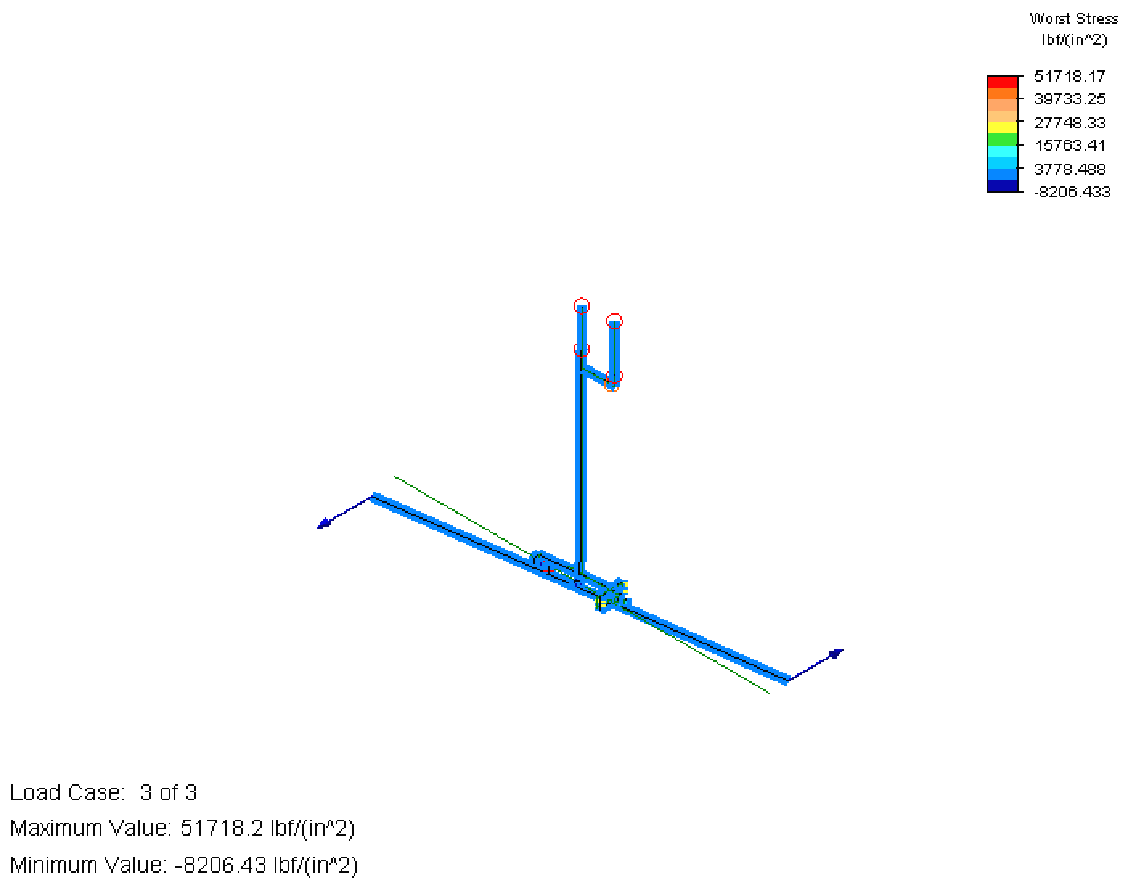

Figure 20 Stress Dither - Yaw

Balance and Load Cells

The balance only need measure drag, sway, and yaw forces and thus this requirement can be accommodated with a 3-component balance arranged in the X-Y tank axis plane. The balance would be fitted with 3 flexible links in the vertical direction and allowance could be made for future fitting of load cells in the vertical for a full 6-component balance if required. The structural concept required a balance within the model cavity.

This configuration of balance is already in use at IOT and the concept is well understood.

The finite element analysis done here indicated that the drag force load cell should have a capacity of 25 to 50 lbs tension/compression. The two side force load cells should have a capacity of 50 to 100 lbs.

Individual miniature waterproof button load cells would be ideal for this application, however we don't have anything below 250 lbs capacity and these cells are difficult to obtain and expensive.

Thus we are left with cantilever load cells, which have been potted, in house, to waterproof them. These cells have large deflections to measure load and will negatively influence the yaw natural frequency.

An alternative to the cantilever load cells would be a single 6-component load cell. A check of the AMTI catalogue showed that we would need a MC6 load cell to measure the yaw moment and it would have drag and sway capacities of 1000 lbs. This would mean that the load cell capacity in the drag and sway directions would be far too high had that it would be unable to measure the drag or sway forces in the range anticipated.

Possible Sources for Future Difficulties

The combination of model size and small forces will represent a design, fabrication, alignment, and calibration challenge for D&Fab. At a minimum this model setup will require special handling and if repeated use is to be made of the apparatus then overload stops, special dollies and dedicated signal conditioners may be justified. There may also be significant hurdles to get over in mounting this model under the carriage without damaging the load cells.