LARS
Launch and Recovery System

Undergraduate Ocean Research Program
(Tech 697)

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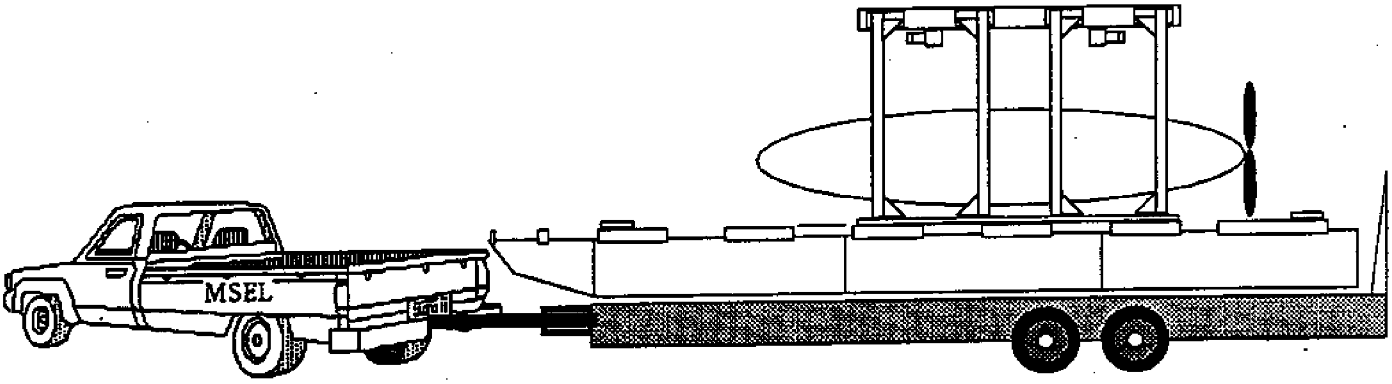

May 1992

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SUMMARY

A Launch and Recovery System (LARS) was designed and built to transport, launch, recover and support field maintenance of an Autonomous Underwater Vehicle (AUV) under development by the Marine Systems Engineering Laboratory (MSEL) of the University of New Hampshire. Figure 1 displays the AUV prototype currently under development by the MSEL design team.

The launch and recovery function is provided by a steel A-frame truss mounted on two large 28 foot, 22 inch diameter aluminum pontoons. To support the AUV, a cantilevered cradle system is attached to the steel frame. Hoists are also mounted to the frame for the purpose of raising and lowering the AUV from the water. For maneuvering on the water a small horsepower outboard motor is mounted to the stern of the pontoon assembly.

Transportation of the pontoon system to and from the test sight is accomplished using a 32 foot trailer modified to meet the system requirements. The trailer is equipped with a winch and rollers to facilitate loading and unloading of the pontoon barge. The trailer is also equipped with a cradle system to alleviate pontoon stress created by the AUV weight during road transit.

The pontoon assembly, loaded with the AUV, is placed on the trailer and transported to the desired boat launch.

MSEL Prototype AUV

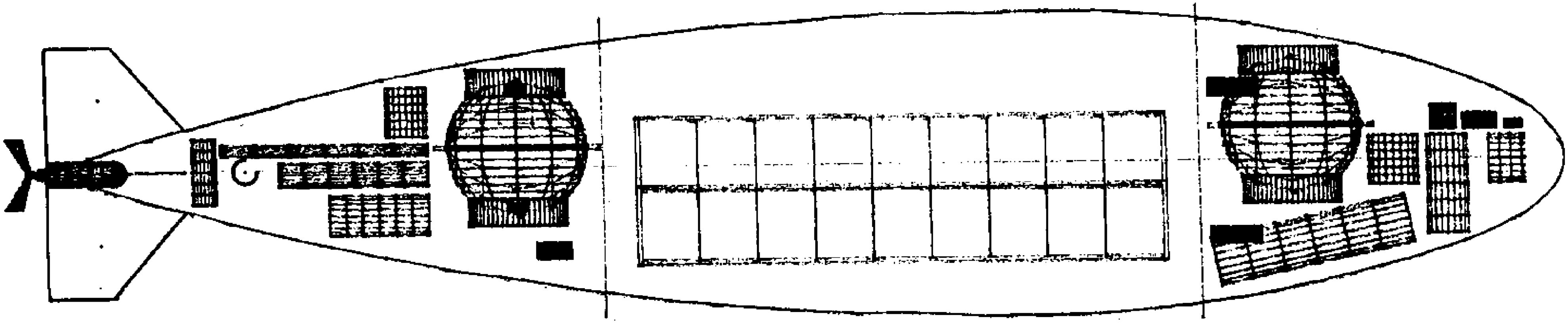


Figure 1

During transport the AUV is fastened to the trailer cradle system. At the boat launch the AUV is affixed to the A-frame cradle system prior to backing the trailer into the water to launch the pontoon barge. The barge is motored to the launch sight where the AUV is lifted off the cantilever cradle and lowered into the water to complete its mission. The process is reversed when retrieving the vehicle.

This project presented several challenges to the LARS project team which had to be overcome to meet the project objectives. One of these challenges included allocating a total budget of $3500, with estimated material costs in excess of $7000. A complete conceptual design and prototype had to be completed and tested in a nine month period ending in May 1992. A final challenge was to use readily available materials and manpower to create a prototype which will meet all the requirements necessary to launch and recover an Autonomous Underwater Vehicle.

LARS System Specifications:

Pontoon Barge:

Dimensions: 28 ft long, 7 ft wide

Weight: 2900 lbs fully loaded

Pontoons: Industry standard 28 ft, 22 in diameter aluminum composition party boat pontoons

Barge and Submersible weight: Estimated at 6100 lbs

Propulsion of Barge: 25 hp gasoline marine motor

Hoisting Mechanism: 4000 lbs vertical lifting

Hoisting Power: 2 DieHard Deep Cycle Marine Batteries

Work Platforms: Surround the Barge on 3 sides for working on AUV

A-Frame: Constructed from low carbon structural steel

Trailer Transportation System:

Dimensions: 32 ft long and 6 ft wide. Trailer is double axle

Load: Trailer is capable of transporting a 17,000 lb load

Hitch: A vehicle with a 2 5/16" Ball can transport the trailer

Loading Barge: 28 Rollers allow the barge to be loaded as a party boat on a lake

Winch: 3000 lb capacity for hauling barge system on and off the trailer

INTRODUCTION

An Autonomous Underwater Vehicle (AUV) is currently under development at the University of New Hampshire's Marine Systems Engineering Laboratory. This is a joint project with the Bermuda Biological Station for Research and the University of Hawaii at Manoa. The goal of these organizations is to develop and deploy a relatively low cost AUV to acquire ocean scientific data. This data is to be acquired using existing ocean science sensors and then compared to data previously attained with conventional ship board systems. To satisfy the needs of this project a Launch and Recovery System (LARS) is required to transport, launch and retrieve the AUV during its testing phase. This was accomplished through the Undergraduate Ocean Research Program, UNH course TECH 697, which provides limited support for such projects.

Three functional requirements had to be satisfied by the system. These included transportation of the AUV to and from the MSEL and the various test sites, launch and recovery of the AUV between the shore and water, including water transit, and support of all testing and field maintenance during the AUV operations. Figure 2 displays the LARS system prototype.

As with any project, there are many constraints and requirements to be addressed with in the design and production phases. Two of the main constraints were

Launch and Recovery System
The Conceptual Package

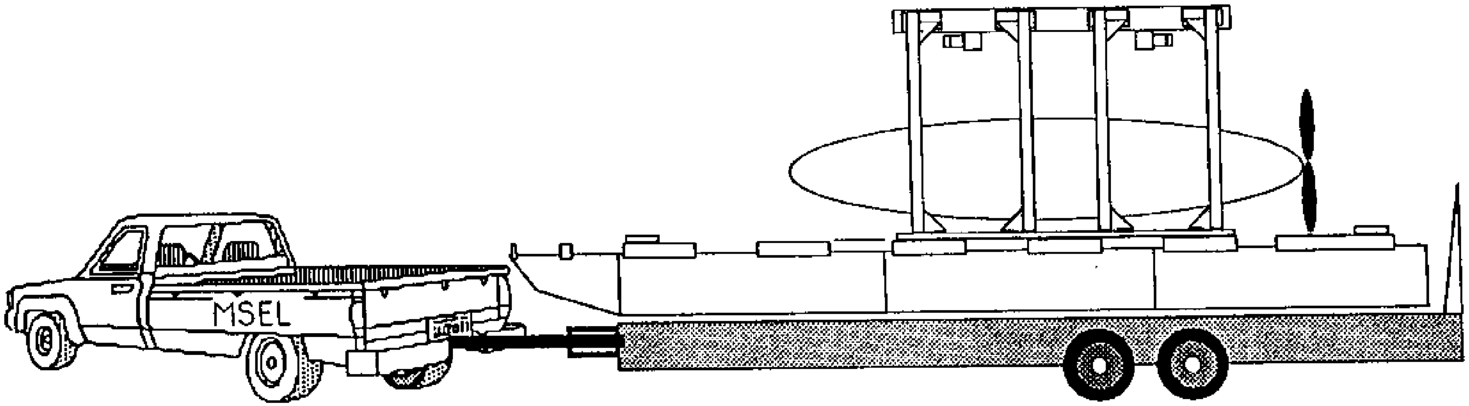


Figure 2

designing around a previously determined budget and completion with in the 1991/92 academic year time frame. These set limitations on the design, material selection and manufacturing processes. The LARS must accommodate size restrictions set by the AUV designers. This entails frequent interaction with AUV engineers due to changing AUV parameters as its design progresses. LARS was designed for stability in sea-state 2 conditions and an unbalanced condition for crew and equipment weights of up to 800lbs maximum. LARS was also designed around the availability of standard parts, use of standard boat launches, meet state and federal highway transportation codes and finally to keep the system as safe and simple as possible.

PROJECT TEAM MANAGEMENT

The project team consisted of six undergraduate UNH mechanical engineering students. The Fall semester of 1991 was devoted more to the initial conceptual design and gaining initial cost estimates for major system components and material. The initial organization of these six members centered around a formal weekly meeting with the project advisor and several informal team meetings. This proved adequate for the first semester. The fall semester was especially challenging for all six individuals. It was the first semester of senior year and the entire LARS project team was enrolled in Dr. Sedor's Naval Architecture course, OE-751, to gain some insight into naval architecture principles in order to accomplish the design.

During the early part of the spring semester the conceptual design was firmed up and detailed design work commenced. Materials were ordered and assembly started. The members opted to keep the once a week formal meeting with Dr. Sedor. The team was further broken down into sub teams of two to work on three of the major subsystems. Deadlines were established for specific accomplishments with each group. Individual efforts of these three teams would combine with the Monday meetings to tackle large system problems with the advisor.

These individual efforts seemed to work very well. The three teams could produce results independently from the larger unit, yet keep all efforts integrated. Individual Schedules were much more flexible in that respect. Whenever needed, the three teams would meet informally to discuss problems with the project. What seemed to work well was the fact that these groups of two would help each other out on occasion. Any slack in one group was picked up by another.

The project Advisor, Dr. Gerald Sedor, played a very important role in the successful completion of this project. He advised us on several different levels. These levels consisted of: Mechanical Design, Personnel Management, Project Troubleshooting, and Materials/Industry Acquisitions. Dr. Sedor helped the team by allowing the group to always make the first move, with advice on proper procedure soon to follow. Dr. Sedor was also instrumental in obtaining many pieces of equipment and various donated materials from the University and industry. His efforts were the main factor in keeping our team within its allotted budget.

Budget Considerations

One of the biggest challenges in the completion of the project was dealing with budget and constraints. The primary challenge with respect to the budget could be simply stated as constructing a system with estimated material cost of approximately $7,000.00 for only $3,500.00. This budget was raised from the original $3,000.00, to $3,500.00 based upon need and available funds. Obviously, this project could only be completed with the help and support of many people who donated not only money but time as well. Some of these are described below.

One major contributor was the local branch of Sears and Roebuck, who generously donated three 3000 lb. capacity winches, valued at a total of $731.00, and three deep cycle marine batteries ($375.00) to operate the winches. Another area which encountered costs larger than expected was the acquisition of pontoons. The project team originally planned to use pontoons currently owned by the University of New Hampshire, but this was not feasible. Playbouy Pontoon Inc., of Alma, Michigan, in conjunction with Green's Marine, of Hooksett New Hampshire, located a pair of suitable pontoons and shipped them for $875.00, which is significantly below market price. Since the project team originally planned to acquire the pontoons at no cost the $875.00 was not included in the budget. Through the efforts

Jere Chase, a gracious donation was received from the UNH classes of 1936 and 1937 to cover this added expense.

Two other contributors aided in reducing the cost of constructing the LARS. The trailer owner reduced the trailer price by $300.00 and Boat U.S. provided marine materials at wholesale price. See Figure 3 for detailed budget description.

Other costs incurred were labor, telephone, and copying expenses, gasoline reimbursements, rental charges for a truck, materials for the frame etc. All machining of parts was completed by the project team members at the UNH machine shop in Kingsbury Hall, under the direction of Robert Champlin. This saved hundreds of dollars in machine shop charges and was accomplished by project team members none of whom had any previous experience machining metal. All welding was completed by a UNH student at the rate of $15.00 per hour, a substantial rate below current shop charges which typically are in the $40.00 per hour range. All assembly of the trailer and pontoon frame system was completed by the project team members, including painting of the frame.

Another substantial contribution to this effect was made by the Henschel Company, of Newburyport, MA. When the aluminum pontoons arrived without much of the superstructure shown on the drawings, the expertise of Henschel Co. in welding aluminum was used to obtain and install the required

LARS System Working Budget

Description:	**Price:**	**Donated:**	**Expenditures:**
Trailer	$1,300	$300	$1,000
2--28 ft Pontoons	$2,400	$2,400	$0
3--2500 lb Pull Winches	$731	$731	$0
Steel for A-Frame	$806	$0	$806
Transport Sub-System	$421	$0	$421
Welding	$225	$0	$225
3--Marine Batteries	$375	$375	$0
Hoist Electronics	$60	$0	$60
Paint Materials	$120	$0	$120
McMaster-Carr	$110	$0	$110
Hoist Pulley Blocks	$70	$0	$70
Miscellaneous Materials	$300	$0	$300
Miscellaneous	$200	$0	$200
Totals:	**$7,118**	**$3,806**	**$3,312**
Total Allotted / Approved Budget :			**$3,500**

aluminum structure for mounting the hoist support frame to the pontoons.

Time Considerations

There was a substantial time constraint with the project. The LARS Team had to design and build the LARS System in two semesters. The completion date was to be May 20, 1992. The MSEL Group wanted to test their submersible in the summer months, which required the use of the LARS System for launch and recovery.

Figure 4 displays the predicted time schedule used at the start of the design phase. This figure also displays the deviation from this schedule. Various things contributed to not adhering to the original plan. The acquisition of parts through industry was one of the bigger set backs. This, and many other obstacles met in the two semesters contributed lag to the completion schedule.

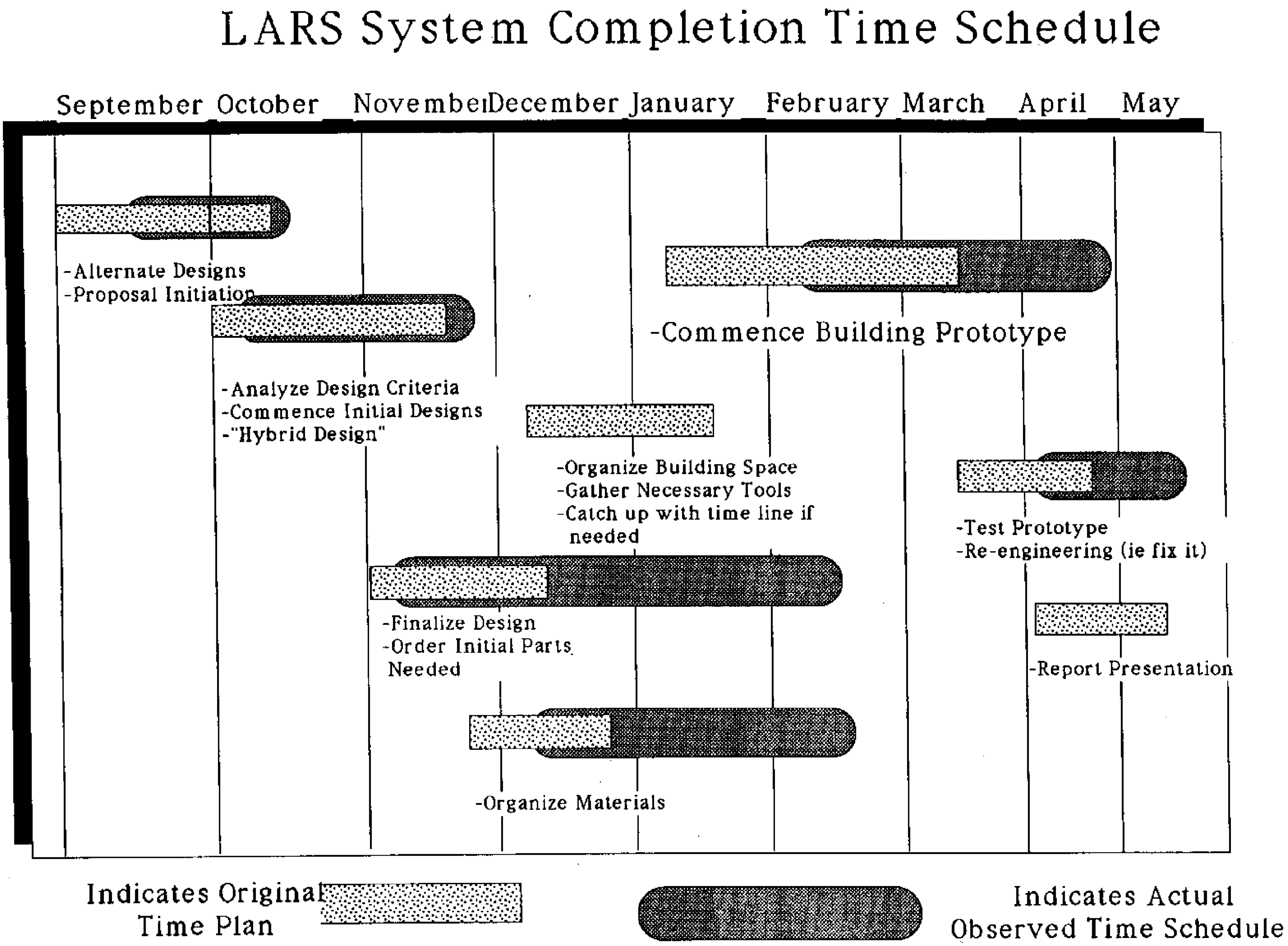

LARS System Completion Time Schedule
September
October
Novembe
December
January
February
March
April
May
-Alternate Designs
-Proposal Initiation
-Analyze Design Criteria
-Commence Initial Designs
-"Hybrid Design"
-Commence Building Prototype
-Organize Building Space
-Gather Necessary Tools
-Catch up with time line if needed
-Test Prototype
-Re-engineering (ie fix it)
-Finalize Design
-Order Initial Parts Needed
-Report Presentation
-Organize Materials
Indicates Original Time Plan
Indicates Actual Observed Time Schedule

Figure 4

LARS PONTOON BARGE

General Description

The Pontoon Barge assembly serves two major purposes: Buoyancy for flotation of the AUV and a structure for lifting the AUV. The Structure is designed to accommodate all of the LARS System's needs for functionality to meet the objectives of the project. Budget and time limitations dictated a structure that would be as simple as possible to build,and provide the necessary structural integrity.

An "A" Frame space truss was chosen for it's simplicity of design and ability to meet the performance requirements necessary. The "A" design would allow both pontoons to easily attach to the frame, give a top rail to mount a hoisting system, and accommodate the subsystems necessary to launch and recover the AUV.

The overall length of the frame was slightly longer than the sub itself for the first iteration. At seventeen feet long, this was quickly discarded because of material weight problems and fabrication problems. An eight foot frame was then chosen rather arbitrarily. As the group began to design around the frame size, this length seemed to work out perfectly.

A design problem related to the structure configuration was whether to have the outer four legs oriented at an angle (Figure 5) or vertically (Figure 6). Ideally, the legs off at an angle would be the best system for supporting sway

A- Frame Compound-Leg-Angle View

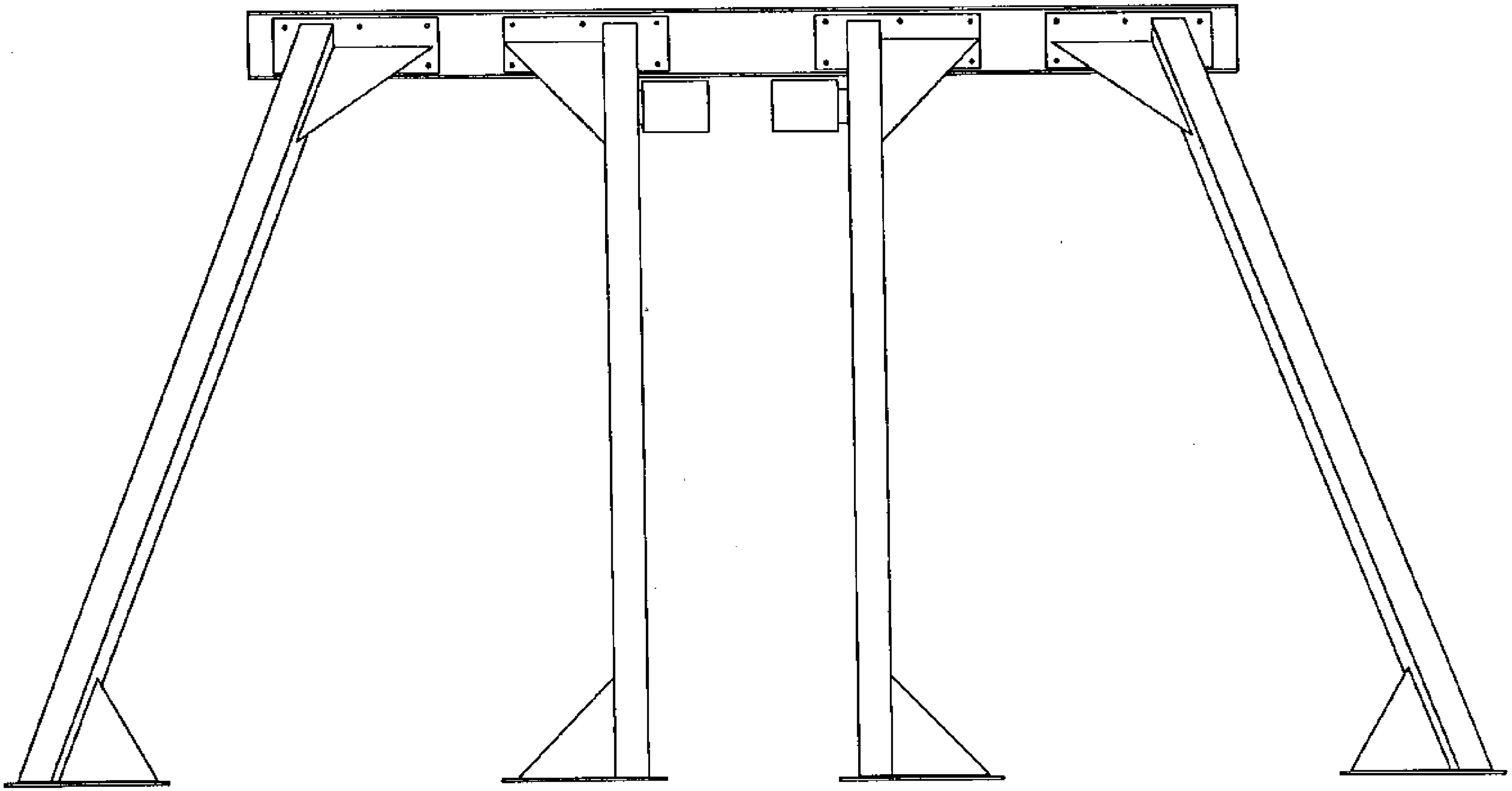


Figure 5

A-Frame Right Angle Leg View

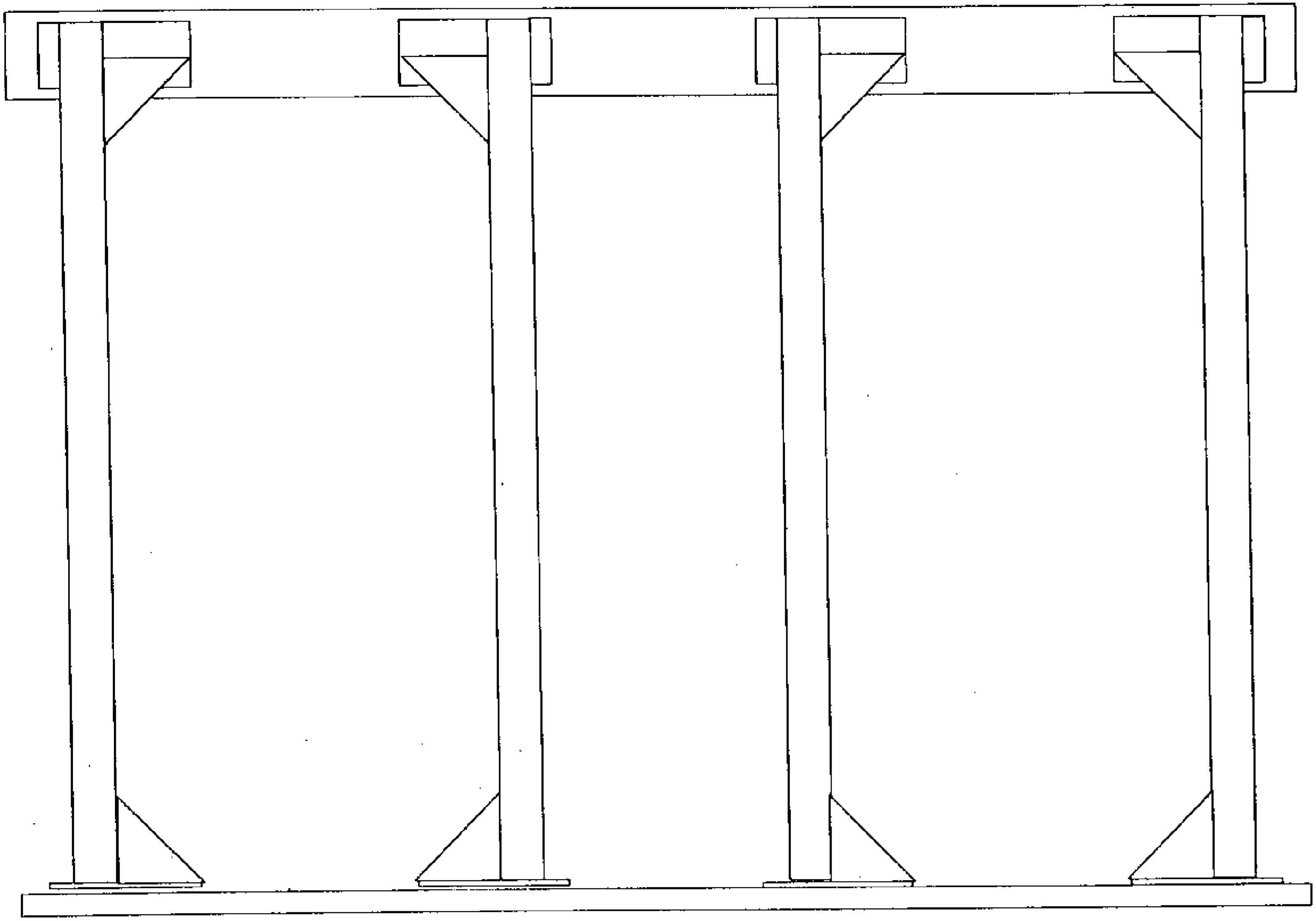


Figure 6

motion (bow to stern sway as opposed to port-starboard sway motion). The final iteration was a compromise between material efficiency and budget limitations. The vertical leg configuration was selected, since the angled legs would have cost hundreds of dollars more for machining expenses and would have exceeded the budget.

Frame Design

The frame width chosen was based on major highway regulations, which limits the total width of the LARS System to a maximum of eight feet. Figure 7 shows the frame width necessary for highway compliance.

Frame height was chosen to be 104 inches. This height was selected based on the need for sufficient height to allow lifting of the AUV out of the water while at the same time remaining as low as possible for the following reasons: highway codes dictate a certain height limit; standard machining angles could be used for the legs; and general instability would occur from having a weight placed high on a floating structure. The higher the top of the structure, the more material involved in the legs. This couples directly into weight, and cost of the frame.

Once the frame configuration was chosen, the next task was to select frame material. Three options were evaluated: steel, aluminum or polyvinyl chloride (PVC) tubing. Of the three, aluminum would have been the optimum choice given it's high strength to weight ratio, however it's cost was prohibitive. That left steel or PVC. Steel had the strength needed and machining properties that could be handled by the group at UNH. PVC was investigated to determine it's desirability in terms of cost, material properties and machineability.

The PVC option was seriously considered, but discarded after intensive consideration based on several factors. An efficient method for attaching the frame to aluminum pontoons could not be identified, which meant that the pontoons would have to be specially constructed from PVC piping. This would elevate the cost substantially as well as require some very complicated machining. When dealing with PVC, a large factor of safety (on the order of 10), needs to be used to help deal with the materials irregular properties, especially that of catastrophic brittle failure. For these reasons, PVC was eliminated and steel was selected for the frame.

Although a lighter weight frame would be more desirable, the 28 foot long pontoons, at 2 feet in diameter, provide plenty of buoyancy to support the heavier steel frame. Using steel simplified the machining, as welding steel is easier than welding aluminum. And perhaps most importantly, the steel could be acquired within the project's budget.

Structural Parts of Frame

Figures 7 and 8 show the physical layout of the frame. Several standard structural steel components were chosen and employed to build the frame. System testing includes various static and dynamic loads while in the water. A maximum sea state operating condition of Sea State 2 was selected as reasonable for the operating area and the design. The maximum "g" loadings that the frame must be able to endure under these conditions were obtained from reference one.

A structural "I" beam was chosen for the top member of the A-Frame. An I shape member is the best choice for bearing the two hoist loads that will lift the weight of the AUV. This type of a member is also very rigid and secure in the plane that the bending stresses will occur . A box beam was considered, but the I beam was determined to be technically adequate, less expensive and easier to use in the assembly.

"C" Channels are used for the bottom two running plates used to attach the legs of the frame to the pontoons. Channel is an excellent choice for this application because of good bending resistance in the plane experiencing the loads. The width of a channel will give ample contact area to properly secure the pontoons. The vertical weight forces will be spread out over the large area that the channel provides for this pontoon attachment. A box beam was considered, but channel was chosen for it's larger

LARS Pontoon Barge Front View

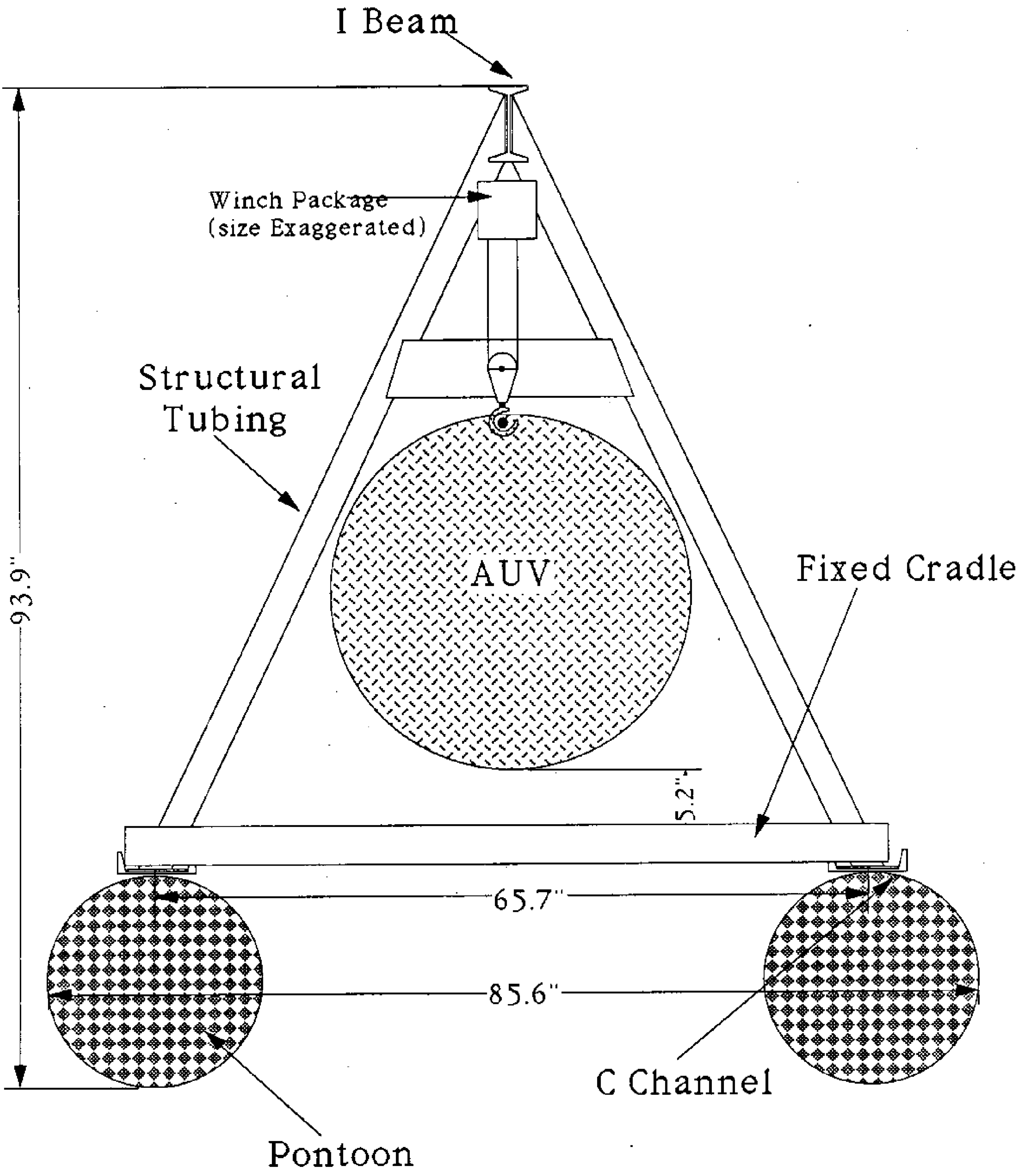


Figure 7

LARS Pontoon Barge Side View

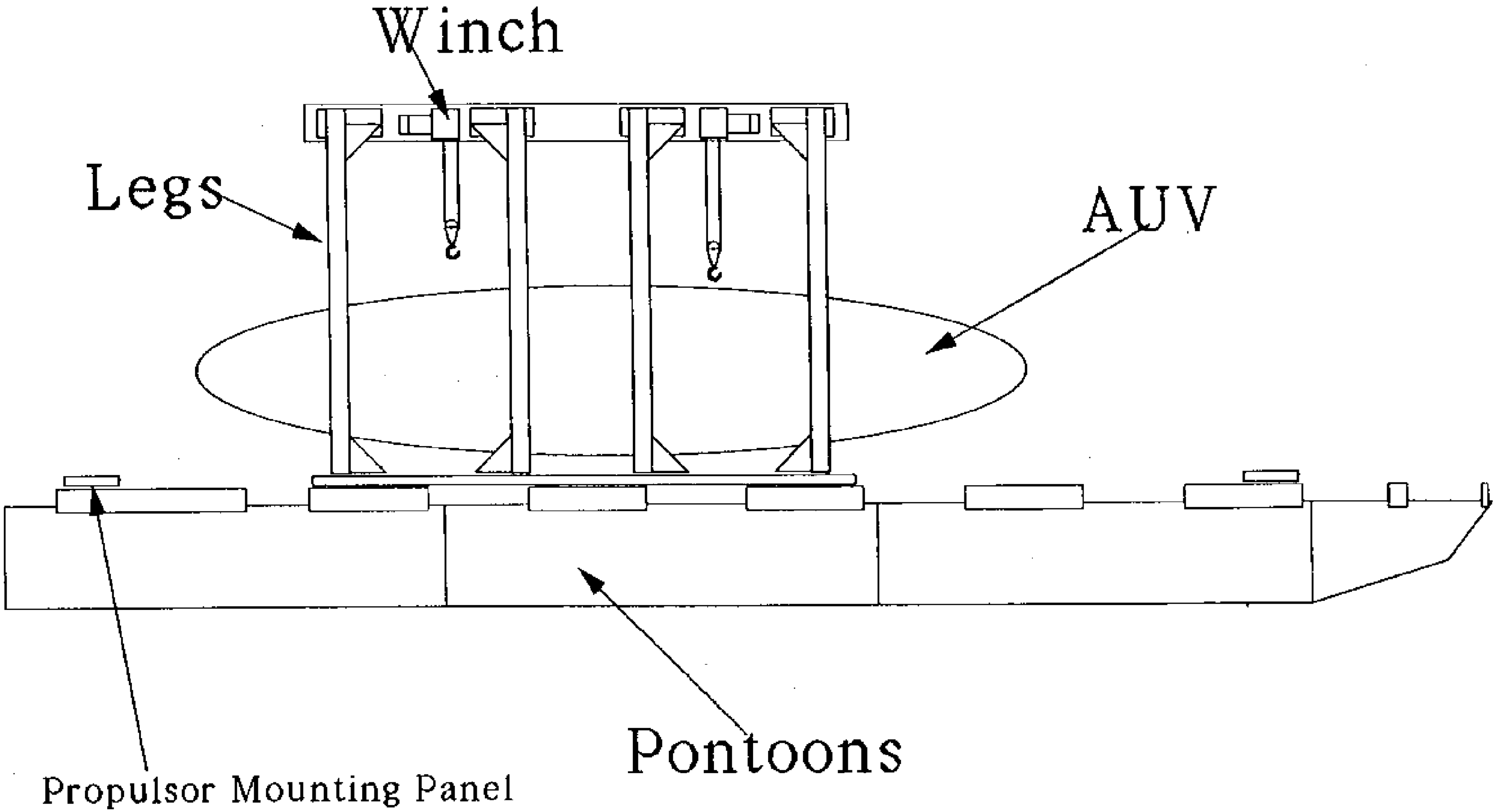


Figure 8

attachment area, better bending properties and lighter weight for the given application. Fastening the pontoons to the bottom of the frame would be very difficult with box beam materials.

The legs form the basic triangle of the A Frame. A material with superior bending resistance properties was needed to complete the frame legs. Structural I beam was the first choice, as it's bending properties would be excellent for the application. Machineability was the deciding factor for eliminating this choice however. Steel tubing was the next consideration. A large enough wall thickness and diameter would provide the necessary bending properties. However, machining odd angles on round tubing would be a difficult task for inexperienced students. Box beam was the next best and was selected for the legs.

All other materials associated with the frame were either small pieces of angle iron or flat bar steel stock. These materials were chosen for simplicity of completing miscellaneous parts needed for the full functionality of the pontoon barge.

Structural Analysis of Frame

In order to endure the violent loadings possible in sea state 2, the physical characteristics of the structural steel must be chosen fairly accurately. Physical redundancy means excessive weight, instability, and inflated costs. Physical inadequacy risks utter frame failure, and extremely hazardous operating conditions. The frame was modeled on a PC Based Stress-Strain Package called PC Stran.

The LARS Frame is a statically indeterminate structure. Using just shear and moment equations to determine the bending properties would not suffice. The group wanted to see the frame behave under a lot of different load conditions to simulate the varying severity of the sea environment on the barge. A PC-Based Stress/Strain Package "PC Stran" was employed to perform this analysis task.

PC Stran is a simplified version of Finite Element Software. The frame is modeled as a space frame (as seen in Figure 9). Geometry is employed to determine each node in an X, Y, Z space determined by letting the left pontoon front end represent 0, 0, 0. A node is where forces are located or physical elements of the frame come together. Node locations represent where lifting point forces or where legs attach (for two examples) in 3-Dimensional Space.

These node locations are entered into the Package. A graphical representation of the frame is can then be seen. The user simply enters in the locations of all the loads

Wireframe Representation for Stress Analysis

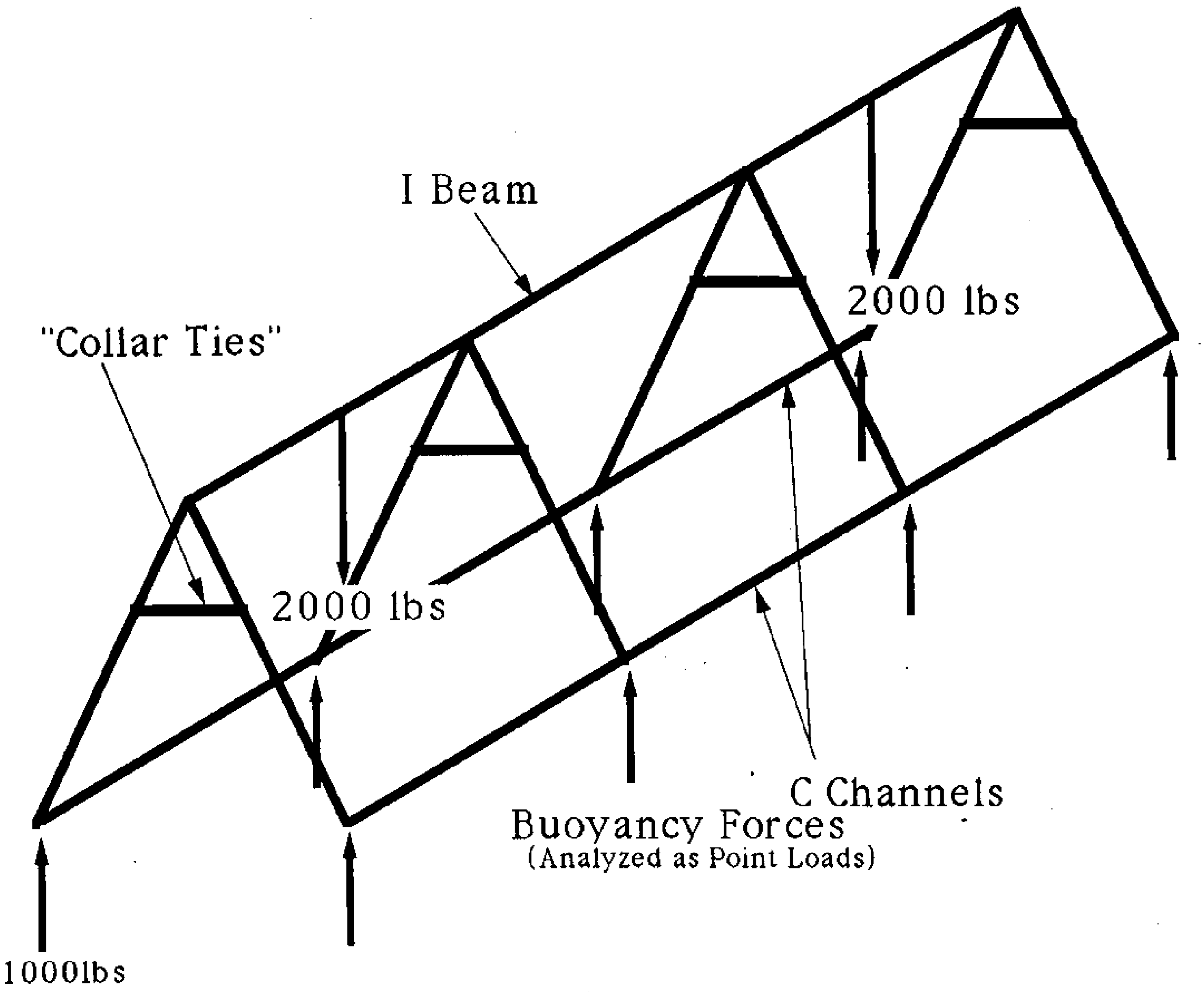


Figure 9

imposed on the frame. Different load cases are realized with this action. The appropriate values for the frame's structural materials are entered as well. (These properties include the weights, moment of inertias, etc.)

A graphical description and documentation is given for each load case after computation. Our group simply kept entering new structural material values and different load cases until a strong enough frame was realized. (A frame that would be reliable on the ocean sea state of 2 with a factor of safety of 2 at all times.) This software tool proved invaluable to the group in determining the proper steel materials to order for the frame. The appendix has an equipment list that details the choices made for all the materials and mechanisms chosen for the system.

Frame Modularity

One of the design constraints established during the conceptual design phase was that of modularity. Having a modular frame system allows the frame to be easily disassembled. Modularity has many advantages over a rigidly welded A Frame. This frame could be stored in a small area. Transportation of the pontoon barge system would be easier. The pontoon barge can be easily repaired in the event that one of the legs sustains damage. The frame and pontoons could be used for several different applications if they are easily separable. The frame could be a free standing hoist unit for working on large heavy equipment, for example. The pontoons could also be used for a different buoyancy application. At a university where recourses are limited, the need to support alternative projects or needs with the same material is a common practice. Hence, the emphasis on flexibility and modularity in design.

Figure 10 shows the layout of individual legs. The angles of the legs were cut, and flat bar stock was machined into plates that would be welded onto each end of the legs. The I beam and two C Channels were drilled to accept these legs. A bolted connection is used to complete the fastening of the frame. All other connections were standard welds completed by a qualified welder. Appendix D and E contains the bolt and weld size information and analysis.

Frame Construction

The complete frame system went through many design iterations until a final design was selected where the project team felt comfortable with proceeding to the construction phase. The frame was drawn up with every detail mapped out on Minicad+ CAD software. Working drawings were generated at this point.

There are only a few basic parts which make up the frame in order to keep it as simple and functional as possible. There are a couple of important pieces of the

Structural Connection of Legs to I Beam Configuration

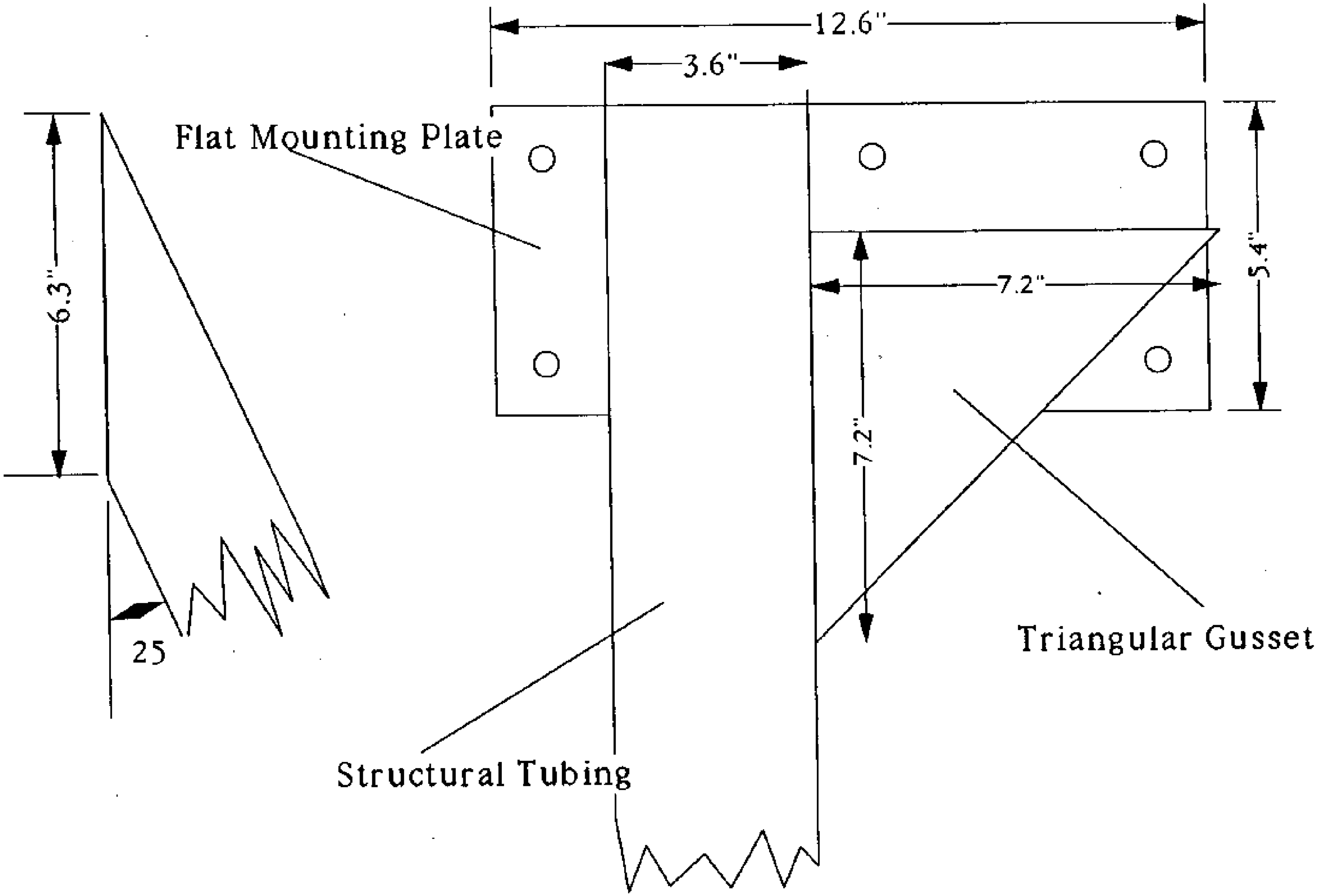


Figure 10

frame in addition to the I Beam, Channel and Box tubing previously mentioned. Flat bar stock was needed to make triangular gussets to compensate for any possible sway motion of the frame. Figures 8, 10 show this arrangement. Flat bar was also needed to make "Collar Tie" type reinforcements. Figure 7 displays this application. This reinforcement is analogous to construction collar ties in a roof application. If the frame was in a rigid application all the time (i.e. no wave motion or motion period) all the legs would be in pure compression. This fact makes these ties a redundant support with a theoretical associated zero force.

The frame was initially to be completed by a certified machinist (with the angled outer legs as represented in Figure 5) from raw stock to finish welding. The estimate for this service was approximately $700 higher than could be tolerated by the budget. Therefore the project team decided to take on the machining responsibility itself. With this change came the compromise of straightening the end legs, as opposed to the more desirable angled legs. Compound angles required of the angled end legs was well beyond the scope of any of the members machining skills. Cost estimates for structural steel were obtained from various steel yards and material was purchased. CV Machine was especially helpful in obtaining steel from Isaacson Steel Company in Berlin.

The initial construction phase involved cutting all material to the proper lengths, widths and angles. Figure

10 shows the leg/end plate system employed for modularity. The collar ties and gussets were then cut out on the steel band saw. The I beam and channel pieces were cut to length. All the pieces that needed angle cuts were then cut after cutting to length was completed.

Drilling was the next step. The end plates for each leg were all drilled at the same time. All sixteen plates were placed together and drilled simultaneously to insure proper placement of all eight holes in each plate. A master plate was chosen from this stack. This plate was placed on the Channel and I beam pieces. This plate was placed so that the same pattern of 9/16" holes could be drilled in each of the two channels and single I beam. The collar ties were then drilled.

The required 25 degree angle and height of the I beam in the frame resulted in a situation where the legs would interfere with the I beam flange. This was resolved by cutting a notch in the I beam where the legs would bind. This small part of the flange was removed with a cutting torch for each of the eight legs, and the rough edges smoothed over with a body surface grinder.

When the frame pieces were at the point where major pieces could be integrated together, all the plates were bolted into their respective positions on the Channel and I-beam pieces (ready to accept the legs). A wood jig was made to raise the I-beam up and hold it in a vertical equilibrium position. This jig also spaced the Channel pieces equally out to the sides. The I-beam and Channel were actually drywall-screwed into this jig for temporary rigidity. The legs were fastened to the frame once these three basic components were in place. Each leg was laid into place, observed for correct fit (to a tight tolerance for angle opening, and overall height) and spot welded in place, the top plate against the I-beam and the bottom plate against the channel. All eight legs were done this way, and only one needed slight re-machining in order to fit properly. This method was developed based on consultation with Charles Seavey, Jr. (of CV Machine). The advice was not to assemble each leg system independently but proceed as previously mentioned, since numerous problems could result from single leg system assembly. The legs might not all be exactly cut equally, for example. Another potential problem results from the heat added when spot welding. This heat would most likely have distorted the legs to the point where they would not go together properly on the I-beam and Channel.

The whole frame was then disassembled for the purpose of finishing the weld beads all around each leg system. The welding could not be done properly with the legs in a vertical position. This was most unfortunate, however, since the finish welding heat made the plates on each end of the leg bow to a considerable extent. Every leg had to be beaten at both ends to get the plates sufficiently straight for future frame assembly. The frame was subsequently assembled for installation of the shear gussets and collar tie plates.

Spot welding was done with the frame in a vertical position, then the frame was then disassembled to allow for finish welding to take place. The frame was now completed and ready for finishing.

Structural steel comes in a very rusty condition when acquired from steel yards. The finished frame assembly was very rusty at the time of structural completion. The project team was able to obtain sandblasting services from a local steel tank manufacturer (Fedco Industries, Inc.) at no cost. The sandblasting prepared the surface (down to shining, bare metal) for priming and finish paint. After sandblasting, the frame (shipped in pieces) was transported to a local autobody shop, who provided (again, at no cost) time, space and use of equipment to spray paint the frame. High quality car enamel paint and a special marine (red oxide) primer was used as a protective coating, as the sea environment is very corrosive. Galvanizing the entire frame would have been the best choice for corrosion protection from the sea, but the cost of doing so was prohibitive.

The frame was then complete and ready for the application of the various subsystems that make the system functional. These include the fixed AUV Cradle, Hoist System, Work Platforms, and Propulsor Systems.

Pontoon Description

A PVC structural pontoon was initially considered and evaluated for use on the LARS floatation vehicle. These PVC pontoons were to consist of a large diameter duct with end caps welded at each end. Circular reinforcing rings of PVC would be attached to modify the structure enabling it to bear heavy loads during use. PVC offered many desirable qualities when first analyzed. The physical properties of the material such as fatigue, corrosion resistance, and ease of manufacture were examined. With the PVC the length of the pontoon could be varied depending on the buoyancy needed. There were two main disadvantages with this structure: weight, and mode of engineering failure. The PVC's weight per foot of pontoon length made them fairly heavy for a floatation unit. The failure mechanism that the PVC would most likely encounter would be fracture without yielding, causing catastrophic failure in the pontoon. For these reasons the use of aluminum pontoons was investigated. The wide use of aluminum pontoons in "party boat" applications suggested its possible use in the LARS. The aluminum pontoon was chosen because of its light weight , ease of modification and availability.

The buoyancy requirements were calculated using a spreadsheet to total all equipment and material weights. This spreadsheet is located in Figure 11. The data displays the approximate weight of the pontoon barge of 2,696 pounds,

LARS Adaptability Specs

Approximate Weight of
Pontoon Barge (lbs)
2696.0

Total System Weight:
(lbs)
6196

Center of Gravity (Above Baseline)
(in)
44.31

Part Description:	Quantity (#, ft, etc.)	Unit Weight (lb)	Total Weight (lb)	Z Location (inches)
Structural Tubing	60	8.15	489	52
C Channel/Pontoon Support	20	11.50	230	22
Pontoons	2	150.00	300	11
Struct. Tubing/Sub Cradle	12	17.30	208	24
6" Flat Bar Stock	19	5.10	97	100
Triangular Gussets	5.5	6.81	37	52
"Collar Ties"	10	5.10	51	59
Winches (3000# pull)	2	25.00	50	100
Batteries (900 A Marine)	2	50.00	100	22
Crew (MSEL Personnel)	2	200.00	400	58
Main "I" Beam Support	10	18.40	184	100
Trolling Motor/Propulsion	1	100.00	100	22
Miscellaneous Materials	1	300.00	300	22
Miscellaneous (tools, etc.)	1	150.00	150	52

FIGURE 11

which, added to the estimated weight of the AUV of 3,500 pounds, results in an estimated total system weight of 6,196 pounds. For design and safety requirements the pontoons were to be kept at or below half draft under all loading conditions. Using the standard diameter for pontoons of this size (24 inches), a plot of the buoyancy force in pounds verses the draft in inches was developed. This plot is given in Figure 12 for two pontoon lengths, 24 ft and 28 ft, which are industrial standard sizes. Using the calculated required buoyancy, the curve for the 24 foot length yields a draft of almost 16 inches, compared to the 13 inch draft with the 28 foot length. The 28 foot pontoons met the maximum draft requirement and was selected for this design.

Pontoon Modifications

The 28 foot pontoons as received differed from the manufacturer's specifications and drawings. The plans received from the supplier in January showed the existence of inverted C Channel welded along the pontoons. The system design was based on having this channel to bolt up with the channel on the bottom of the frame. The pontoons as received did not have these continuous channel pieces present. Small, flimsy pieces of aluminum were fastened to the sides of the pontoons. This unexpected and unplanned for configuration was a major set back. Plans had been designed around the

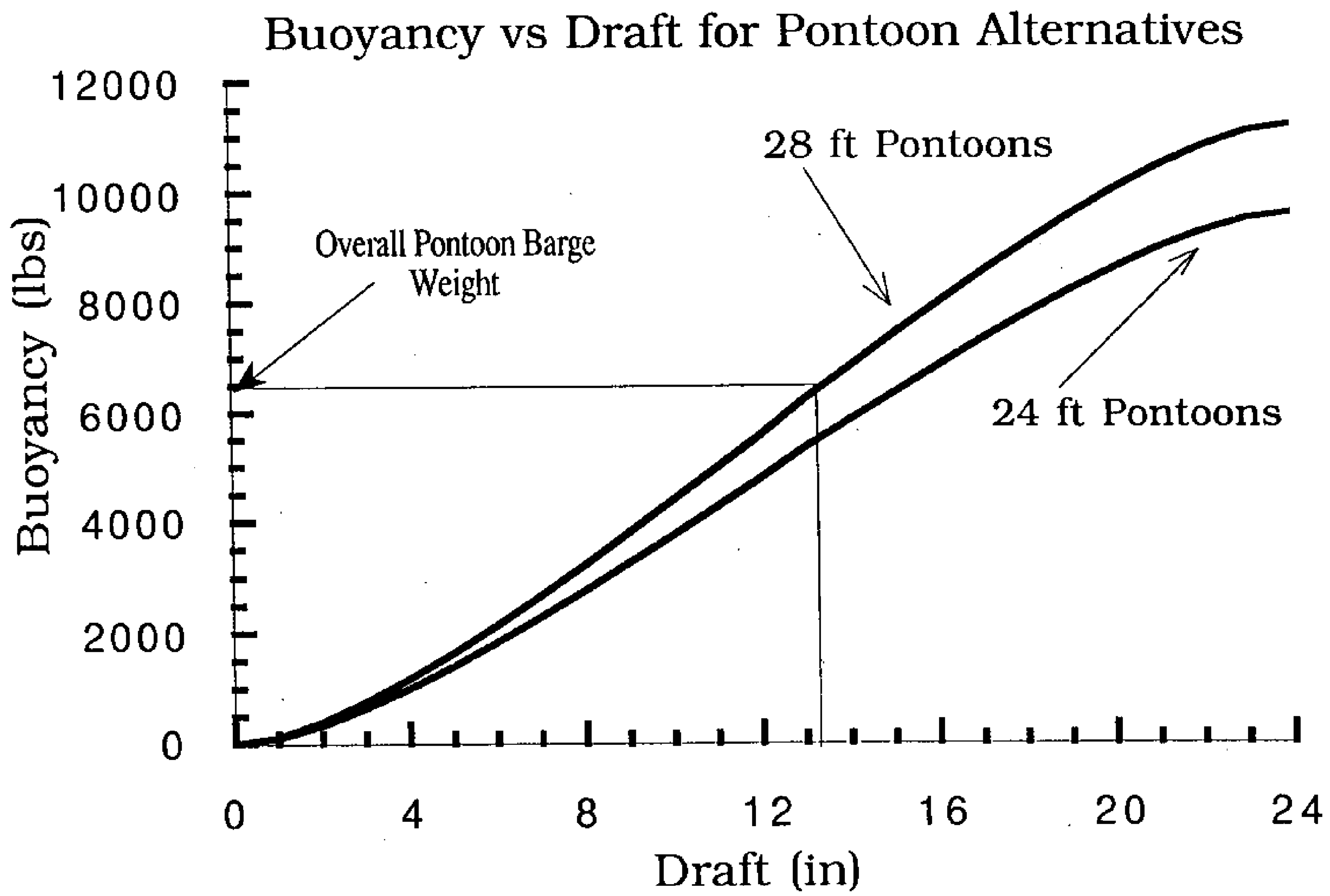

Buoyancy vs Draft for Pontoon Alternatives
Buoyancy (lbs)
12000
10000
8000
6000
4000
2000
0
Overall Pontoon Barge Weight
28 ft Pontoons
24 ft Pontoons
0
4
8
12
16
20
24
Draft (in)

Figure 12

configuration shown on the suppliers drawing and the frame prototype built accordingly. The as received condition presented a challenge in providing the necessary structural integrity for the pontoon barge. Rapid reengineering was required to meet schedules. The project team modified the design to include two twenty foot pieces of aluminum channel that could be welded to the pontoons. The channels present on the frame were bolted to these two channels to make the design work. Support by the Henschel Co. of Newburyport MA in obtaining the material and welding the channels to the thin pontoons helped save the day!

Since the frame is only ten feet long, a bending moment and shear are present at the locations on the pontoons where the frame ends (i.e., there will be seven feet of pontoon left out on each side of the frame. See Figure 8). The use of the 20 foot aluminum channels minimizes this problem while providing for an attachment between the pontoons and the frame. The twenty foot channel spreads the vertical weight load out over a large area, and the long length of each aluminum channel significantly reduces shear loading at the pontoon edges as well as the bending moment at any point on the pontoons.

Stability

The pontoon barge design incorporates an ability to operate safely under sea-state two conditions, as described in reference 1. This included choosing weld and bolt designations capable of bearing the loads. The standard analysis used to determine the necessary weld and bolt sizes was taken from reference 2. This analysis, which was done on the most highly stressed frame section, is shown in appendices D and E. Material specifications were chosen taking into account the safety factors necessary to meet sea-state two conditions.

It is highly desirable for the pontoon barge to operate with the pontoons not more than half submerged when the barge is loaded to its maximum design condition. The 28 foot pontoons used on this system experience a draft of eleven inches when fully loaded with the weight of equipment and crew totalling 6200 lbs. A graphical analysis was performed depicting drafts for various ranges of weights and is shown in Figure 12.

During some phases of operation, crew and equipment may be distributed unevenly on the pontoon barge. The wide catamaran configuration selected for this design provides great resistance to lists induced by transverse changes in the center of gravity. The equation shown below illustrates the effect a transverse change of the center of gravity has on list angle

$$\overline{GG}_{new}\,(\text{Transverse}) = \overline{GM}\,\tan\Phi$$

GG_{new} = The distance between the new center of gravity caused by a transverse addition and the original center of gravity

GM = The distance between the center of gravity and the metacenter

ϕ = Angle of list caused by the weight addition

The derivation of the above equation is shown in reference 3. Central to stability is the geometric locations of the center of gravity, center of buoyancy and the metacentric height in relation to the lowest point of the pontoons. This calculation as well as the calculations of the parameters included in the above equation are shown in appendices B, C, F and G. An off-center 800 lb load of crew and equipment located on one side of the pontoon barge causes an angle of list of approximately 1.5 degrees. This was considered a "worst case" off center load.

LARS SUB-SYSTEMS

Hoist System

The AUV is lifted and lowered out of the water with an electric hoisting system. The ideal system would consist of a single hoist located at the center of the I beam. This hoist would lift the AUV from two points to keep it stable. A hoist designed to accomplish this was identified, but its cost was more than 2/3 of the total project budget, precluding its use and presenting one more challenge to the design team.

The project team considered using winches similar to those used on Jeeps and other trucks. Sears and Roebuck at the Fox Run Mall were contacted and agreed to donate three winches and three deep cycle marine batteries. Although the winches could sustain the vertical weight of the AUV with no problem, winches are not designed to be used as hoisting mechanisms. The rotors on the motors are not designed to be locked. In a stall condition, the starter will heat up with a 180 Amp stall current, which would burn the winches out in seconds. This required that the AUV must always be in motion when the winches are running either up or down, and presents a problem with operating the fixed cradle subsystem. The AUV must somehow be lifted out of the water and held in a fixed position for an indefinite amount of time while the crew readies the fixed cradle.

A simple solution was chosen. The system design was modified to include two winches mounted to the main I beam of the frame. Figures 13 and 14 display this setup. Pulley blocks with appropriate hooks are employed to lift the AUV in two "hard points" located on the top of the sub. These pulley blocks will effectively cut each winch load approximately in half. I beam flange clamps are used to secure the end of the winch lines after going through the pulley block. These clamps are very useful in compensating for sway motion of the submersible bow to stern. Figure 14 displays this clearly.

Both winches are wired together into a single grip that one crewman can operate. The wiring in the grip is such that one gets optimum control over both winches. This control consists of individual control of lift/lower for each winch. The AUV position in the frame can be corrected if it starts to tilt (trim bow/stern). Either winch can be activated to lift or lower the submersible as needed to regain a level lifting position.

The electronic control was approached from several different angles. Electric relays and IGBT Power Transistors were looked at for power control of the winches. Power DPDT Toggle switches were used to switch the polarity of the battery voltage in the end. (Changing the battery polarity allows the winches to lift or lower a load.) The toggle switches were the simplest approach to the problem. Figure

Hoisting Mechanism

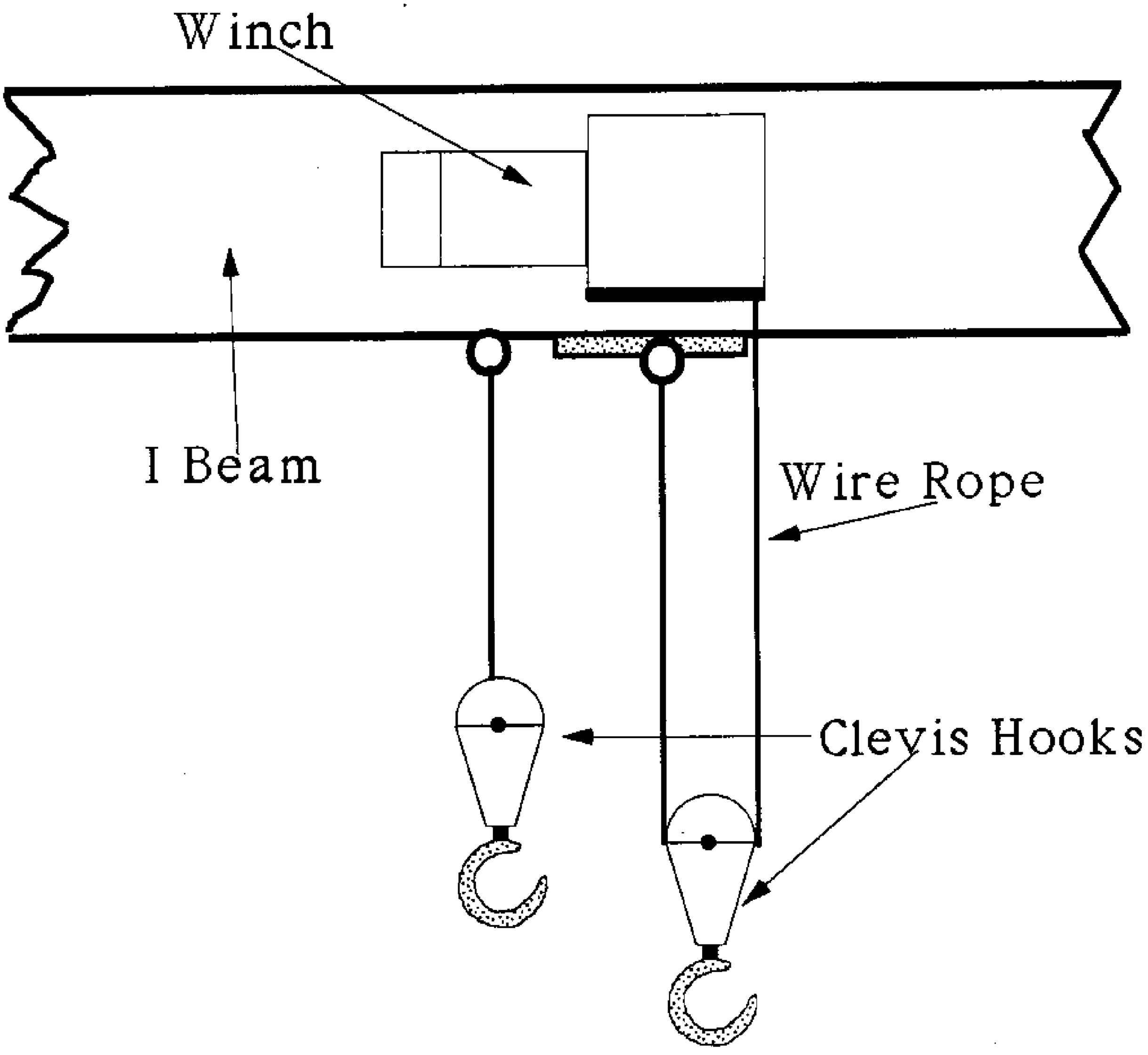


Figure 13

Hoist Subsystem Closeup Drawing

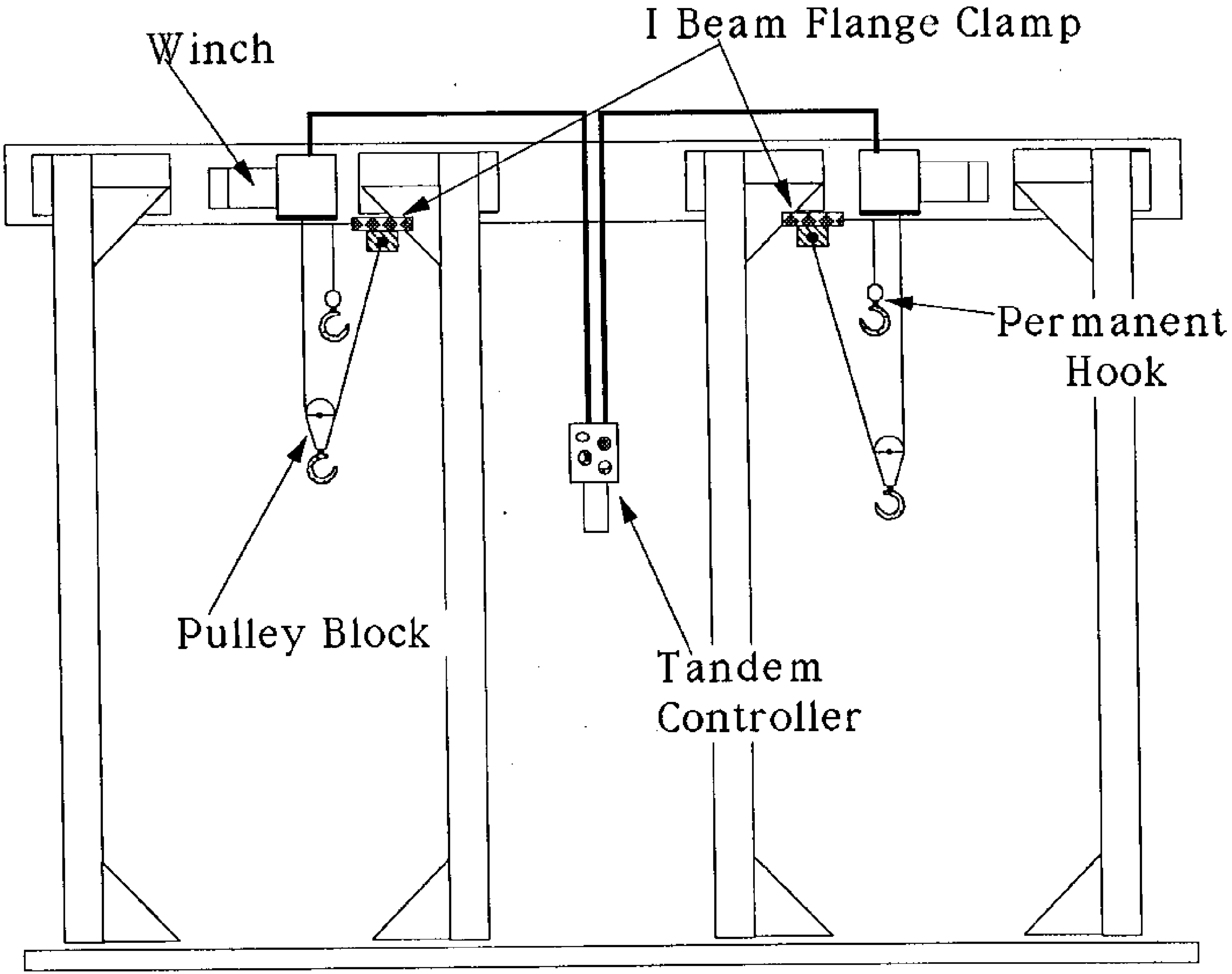


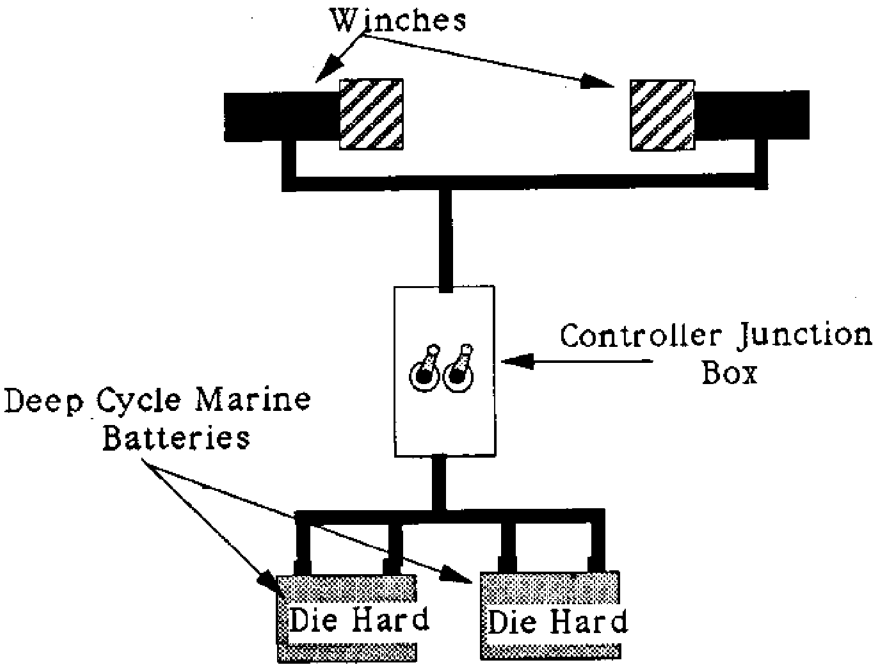
Figure 14

15 displays the wiring necessary to facilitate this control action.

The AUV recovery phase dictates that the submersible has to be held in place once it reaches its recovery height in the frame. Figure 7 displays the holding system. The submersible is effectively brought above its temporary equilibrium point for recovery. Slack in the permanent hook line will be present. The crewman simply slips the permanent hook into the hard point. The submersible is lowered in this same motion until the permanent hook's line becomes taught. The AUV will now rest on these two lines firmly attached to the I beam until it is ready to assume its transport position on the fixed cradle. Launching is just the opposite.

The batteries required to power these two winches are protected at all times. Each battery is placed in a separate watertight battery box. Both batteries are deep cycle marine batteries delivering 900 cold cranking amps when fully charged.

Winch Controller Diagram



Winch Wiring Diagram

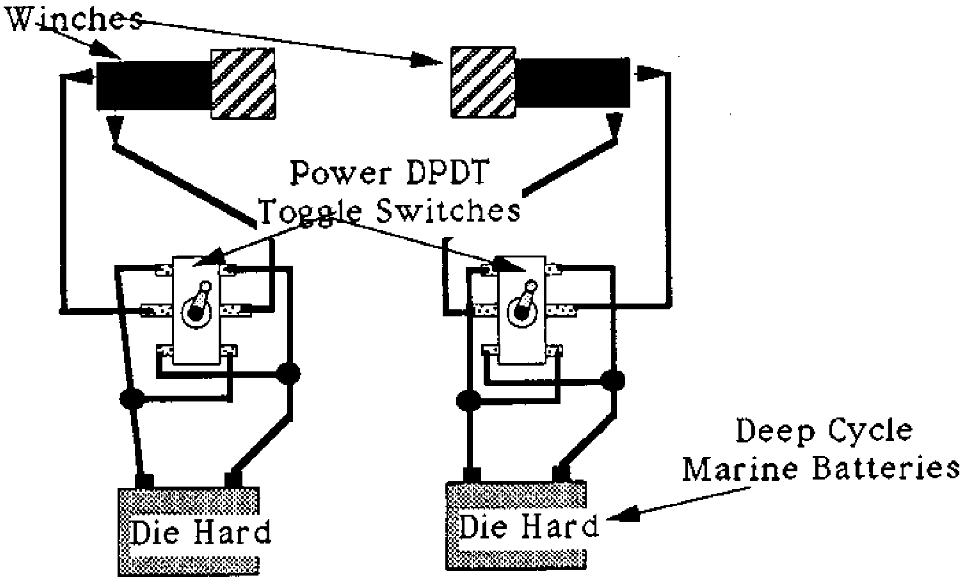


Figure 15

Propulsion System

For propulsion, the LARS system utilizes a gasoline engine of 25 hp. It is hand controlled from the back of the pontoons, much in the same way a small dingy is driven. The motor is of ample size to propel the loaded LARS vehicle through it's tasks, yet is modular in that it is easily removed for servicing or replacement.

The motor is a Mercury Marine type, mounted of the back of the system using clamps which are a part of the motor. A cross piece is mounted, an L shaped steel member to provide a base for mounting the motor as well as providing greater structural rigidity of the LARS vehicle.

The motor is operated in standard fashion. When in land transit, the motor tips up and locks, providing clearance for loading and unloading the vehicle. once in the water, the motor is tilted down such that the propeller is in the water. The operator stands on a platform that extends across the back of the vehicle between the pontoons and directs the movement of the vehicle.

On Board Cradle System

During some phases of operation the LARS vehicle motion is extreme. Rough seas as well as loading and unloading both have this potential. These conditions can induce large stresses in the frame and make it difficult for operators to perform basic maintenance on the AUV if it is supported only by its cables. The AUV would sway with the disturbing motion, creating a potential hazard for the operators.

For these reasons it was decided to devise a mechanism to affix the AUV rigidly to the LARS frame. An on board cradle system was devised which is essentially two simple cantilevered beams which swing underneath the AUV and allow it to be lowered onto them. The AUV is being designed with hard points under its battery compartments that will support the submarine weight, however the details of these hardpoints have not yet been finalized by the AUV designers. For this reason the cantilevered beams have no pins or receptacle devices designed to come into contact with the AUV surface. The cantilevered beam supports are being left unaltered to permit easy modification after the AUV hard point design has been finalized.

Trailer Assembly

To transport the pontoon system and AUV between MSEL and its field test site, some type of trailer was needed. A 32 foot, double axle steel frame trailer was located through a private sale. This trailer was chosen because of its load capacity and its ease of modification. The load capacity is rated at 17,000 pounds which is well above the LARS total system weight. The modifications to the trailer that were necessary would not cause problems because its simple I-beam open structure.

To relieve stress from the pontoons during road transit, a support system attached to the trailer was designed and installed. This system is similar to the cradle system explained earlier that is attached to the pontoon frame system. The main difference is that the trailer cradle system is permanently fixed to the main I-beams on each side of the trailer. A diagram of the transportation subsystem is given in figure 16.

Transportation Subsystem

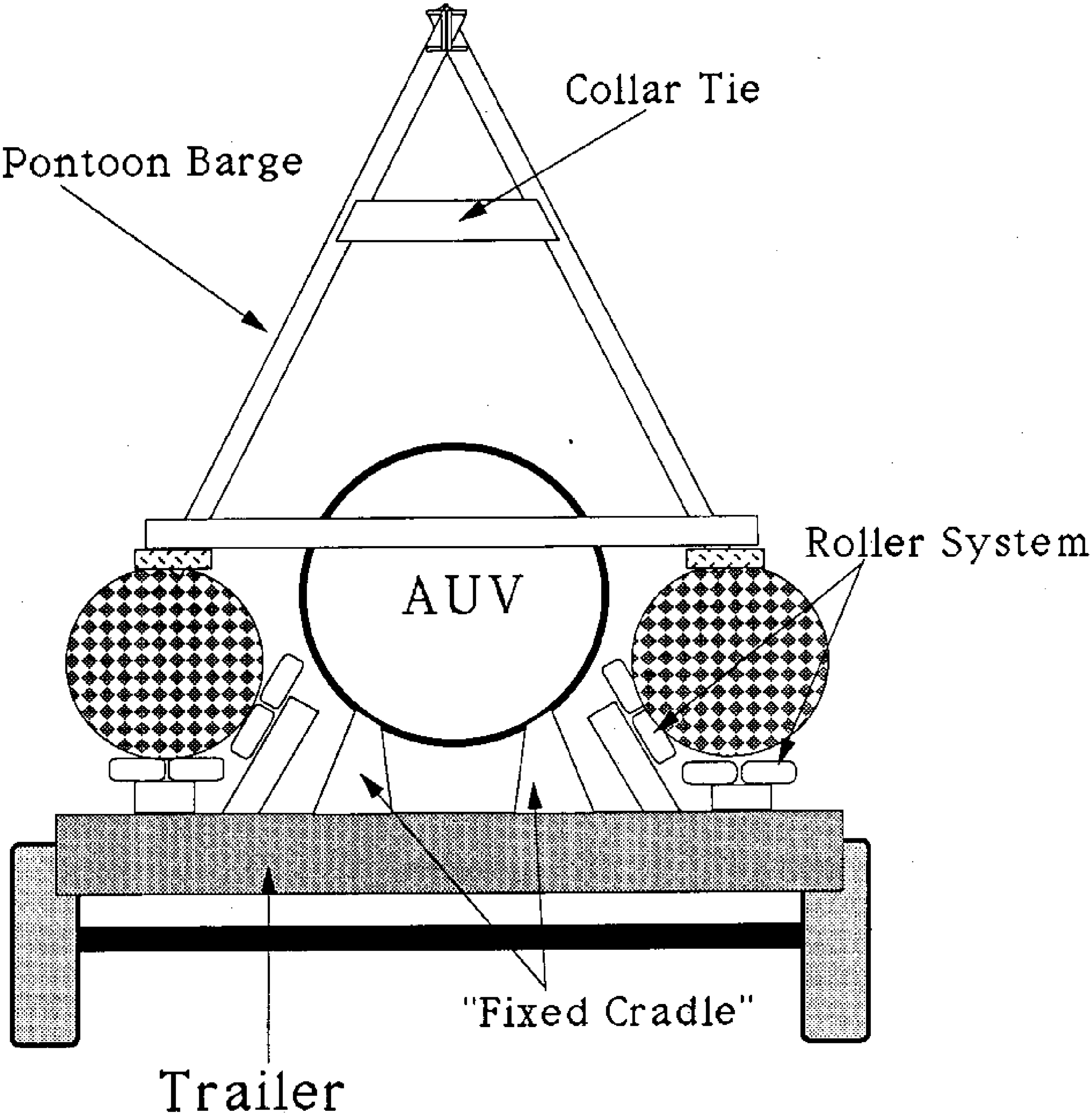


Figure 16

Trailer Launch and Recovery Operations

The process of launching the LARS pontoon / AUV system is similar to that of a regular boat. The system is designed for use with any standard boat launching ramp. This allows testing of the AUV at various testing sites. The process of launching the AUV starts with the transfer of the AUV from the trailer support cradle system to the pontoon and frame support system. The trailer should be stationary on a level surface during this transition. The AUV is raised off of the support system fixed to the trailer, while still in the up position, the second support system is swung and locked into place. The AUV is then lowered onto the support cross beams. At this point the LARS is ready to be backed down the boat ramp and into the water. The trailer is sufficiently long to enable it to be backed far enough into the water which will allow the pontoon barge system to begin to float off of the trailer. Once the pontoon barge system with the AUV are completely afloat and away from the trailer, the troller motor can be used to power the system to the testing site. At the test site the AUV is again raised to detach it from the support system. When the support system is cleared from the underside of the AUV, it is ready to be lowered into the water to start its mission. At the completion of its mission, the pontoon barge is positioned over the AUV in order to hoist it out of the water. Once the AUV is attached to the support system, the pontoon barge can be powered back to the boat launch site. To load the system back on the trailer, a winch system is used. The winch is attached to the front of the trailer which will latch onto the front of each pontoon. When the pontoon system is completely pulled onto the trailer it is securely fastened to the trailer frame for transportation.

TESTING PROGRAM

A test program was developed to validate the operability of the pontoon barge and the trailer system. There are several phases to the test program. First, the trailer system was initially tested to determine that it was fully functional and able to launch and recover the pontoon barge/AUV combination with relative ease using standard boat launches.

The pontoon barge was subject to several tests. Initially it was floated out into a lake to test for general seaworthiness. An inclining experiment was conducted to determine actual stability. The troller motor system was tested to determine its adequacy in maneuvering the heavily loaded pontoon barge around a lake. Finally, the hoist system will be tested to see if it is properly functioning.

Future test procedures would include an ocean trial. This would add the element of a hostile sea state and provide a more severe test of the adequacy of the system.

CONCLUSIONS

The LARS system provides a simple, reliable and effective means of transporting an AUV over a highway system, launching and recovering the AUV, and providing a field test and maintenance platform during AUV test operations. Although the LARS system as designed and built is functional, there are areas that could be improved with future refinement. For example, bumpers could be mounted around the pontoons to help protect both the system and those working around it. In the interest of safety, full working platforms could be fitted with lifelines running the length of both pontoons and across the back by the troller motor. For as long as the system is in use, constant development will insure that the system remains functional and up to date.

In terms of lessons learned, each group member would agree that this has been a worthwhile if hectic experience. Very few engineering classes available to undergraduates instill an appreciation for skills such as time management and group dynamics as this project did. Members received a taste of the real world and learned a great deal about problem solving techniques. One particularly important lesson involved financial recourses; almost anything can be accomplished with an unlimited budget, but real skill comes in producing a product on time and on a limited budget.

There are many people to thank for their assistance, and we refer the reader to the acknowledgement section in the appendix. But most of all we appreciate the time and dedication given to us by Dr. Sedor, who guided us, encouraged and kicked us as necessary. The Tech 697 course gave us the ability to take a concept from design to completion, and the lessons learned in doing so are things that can be learned no where else.

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[2] Shigley, Joseph and Mischke, Charles. Mechanical Engineering Design. Fifth Edition, 1989. McGraw-Hill Inc., New York.

[3] Gillmer, T. and Johnson, B. Introduction to Naval Architecture. Third Printing, 1987. Naval Institute Press, Annapolis Maryland.

Appendices:

Appendix A: System Parts List
Appendix B: Stability Figure
Appendix C: Stability Calculations
Appendix D: Weld Analysis
Appendix E: Bolt Analysis
Appendix F: Center of Gravity
Appendix G: Angle of List Calculations

Appendix A
LARS System Parts List

Pontoon Barge:

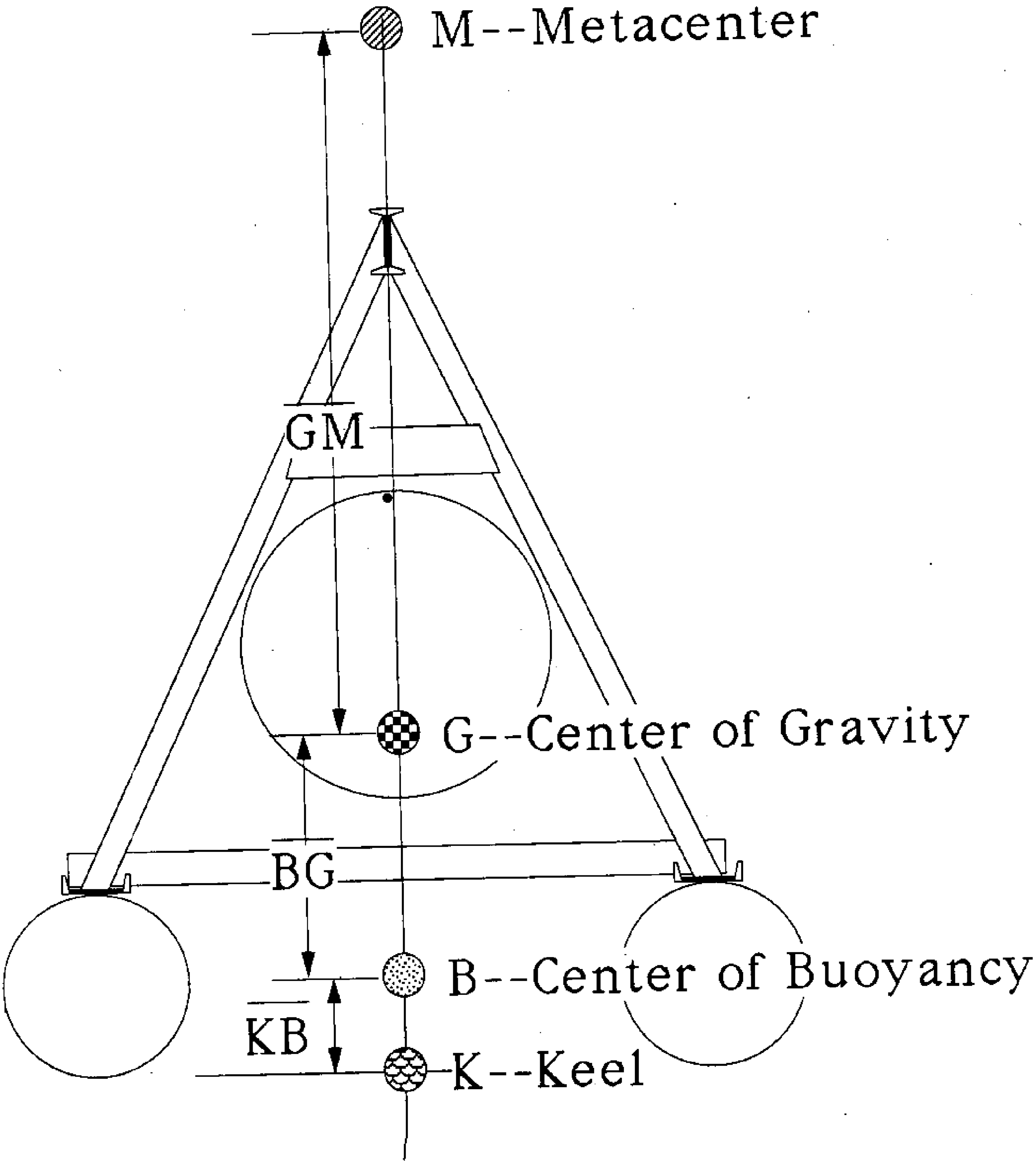
Part:	Description:	Quantity:
Legs	4"X3"X3/16" X 8' Steel Tubing	8
Top Frame Support	W8 X 18.4 X 10' Steel I Beam	1
Bottom Frame Support	C8 X 11.5 X 10' Steel Channel Iron	2
Triangular Gussets	8" X 1/4" Steel Flat Bar	16
"Collar Ties"	6" X 1/4" Steel Flat Bar	4
Leg Plates (Top/Bottom)	6" X 1/4" Steel Flat Bar	16
Pulley Block	Sears "Superwinch" Pulley Blocks	2
Winch	Sears "Superwinch X1"	2
Pontoon	22" X 28' PlayBuoy Pontoon	2
Front/Back Plates	2"X2"X3/16" Angle Iron	2
Fixed Cradle	4" X 4" X 3/8" X 6' Steel Tubing	2
Cradle Pivot Assembly	4" X 4" X 3/8" Angle Iron	2
Propulsor	25 Horsepower Trolling Motor (Gas)	1
Winch Battery	900 Amp Sears Deep Cycle Marine	2
Battery Case	Sears Die Hard Sealed Battery Box	2
Fasteners	1/2", 3/8" Grade 5 Bolts, Nuts, Washers	Many!
Electrical Wire	8 AWG Hookup Wire	30 ft
Toggle Switch/Winch	Newark Electronics Power Toggle DPDT	2

Trailer Transportation System:

Part:	Description:	Quantity:
Trailer	32' X 6' Trailer 17000# Load Capacity	1
Winch	Sears "Superwinch X1"	1
Barge Hoist Rope	25' wire rope extension w/clevis hooks	1
Winch Battery	900 Amp Sears Deep Cycle Marine	1
Battery Case	Sears Die Hard Sealed Battery Box	1
Lights	Lights Added for Brakes/Backing Up	1 set
Ball	2 5/16" Ball for Hitching/Trailer Tow	1
Roller	Boat America Pontoon Rollers	28
Roller Plates	4" X 1/4" Flat Bar Steel	28
Roller Channel	C4 X 5.5 Steel Channel Iron	14
Fasteners	1/2", 3/8" Grade 5 Bolts, Nuts, Washers	Many!

Appendix B

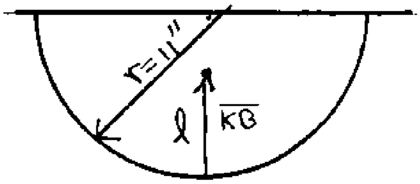
Pontoon Barge Stability Representation



Appendix C:

Calculation of $\overline{BG}$

$\overline{BG} \equiv$ Distance between centers of gravity and buoyancy
See fig.



Note:
Center of Buoyancy lies on centroid of submerged area

Cross section of pontoon at half draft

$$l = r - \frac{4}{3}\frac{r}{\pi} = .39' = \overline{KB}$$

$$\overline{BG} = \overline{KG} - \overline{KB}$$

location of center of gravity

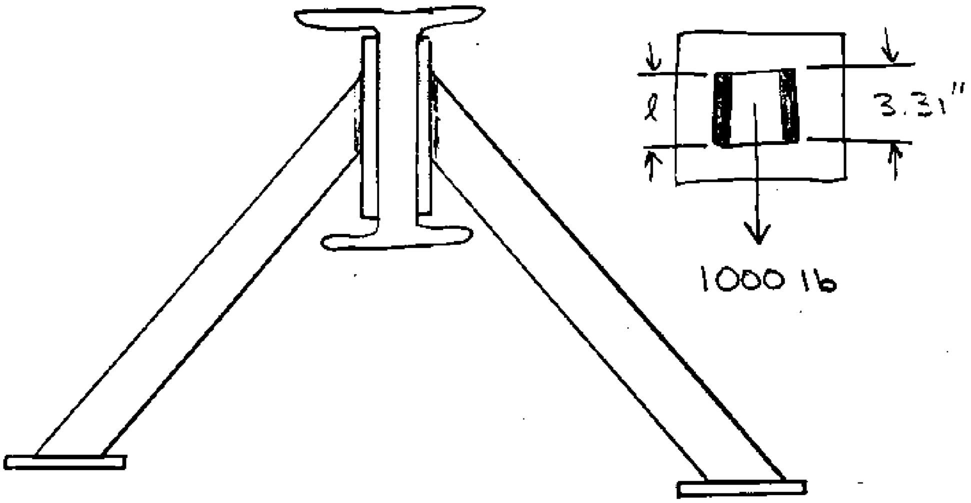
$$= 3.8 - .39 = 3.43 \text{ ft.}$$

$$\boxed{\overline{BG} = 3.4 \text{ ft}}$$

K = Lowest point of pontoons.
B = Center of Bouyancy
G = Center of Gravity
M = Metacenter
$\overline{KB}$ = Distance between K & B.
$\overline{KG}$ = Distance between K & G.
$\overline{GM}$ = Distance between G & M.

Appendix D:

Weld Analysis



$\sigma_y = 67$ KSI ← yield strength of weld material

$\tau_{permissible} = .4\sigma_y$ ← allowable shear stress in welds

$$\tau = \frac{F \leftarrow \text{load applied}}{\underbrace{.707 h l}_{\leftarrow \text{throat area of weld}}}$$

$$\boxed{h = .008''}$$

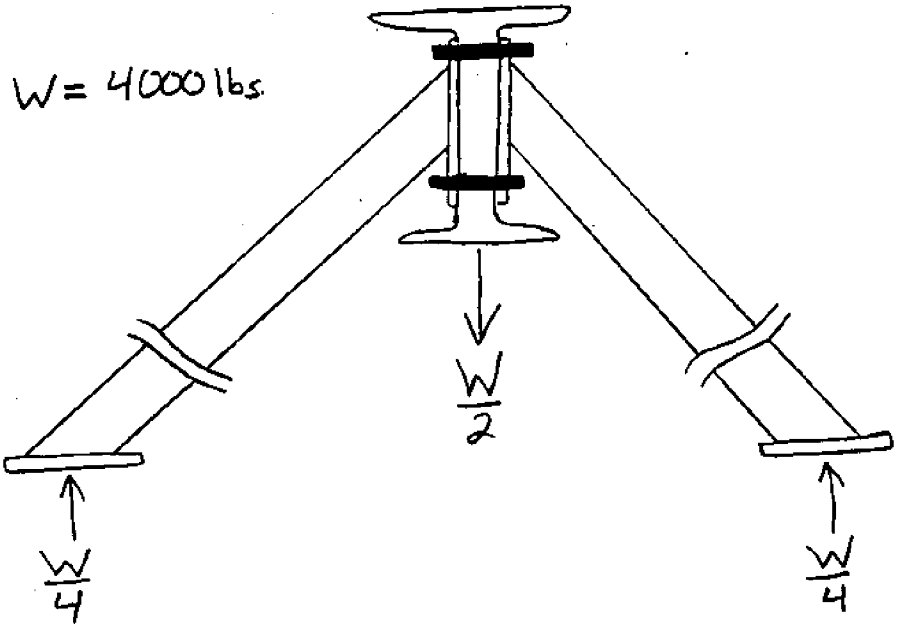
- tiny weld, impractical
- appied $h = .5''$

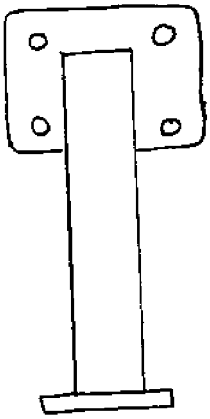
$$S.F. = \frac{.5}{.008} \cong 60$$

Appendix E:

Bolt Designation:

$W = 4000$ lbs.





<u>Desired Strength</u>

Grade 7 → $\sigma_y = 115$ ksi

<u>Shear Eqn.</u>

$\tau = \sigma_y = \frac{F}{A}$ For $F = \frac{W}{16}$

$$\sigma_y = \frac{\frac{W}{16}}{\frac{\pi D^2}{4}}$$

$$D = FS\sqrt{\frac{W}{4\pi\sigma_y}}$$

Using Factor of Safety (FS) = 7

Diameter of Bolt: $D_B = .368$ inches

$D_B \approx \frac{3}{8}$ inches

∴ Bolt Designation = $\frac{3}{8}$" Grade 7 Medium-Carbon All

<u>Note</u>: Assumed Weight Divided Between Two Inner Supports.

Appenendix F:

Center of Gravity Calculation:

$$\overline{CG} = \frac{\sum (Z \times W)_{each} \times N}{\sum W_{TOTAL} \times N}$$

$\overline{CG}$ ≡ center of Gravity (inches).

Z ≡ Height Between Bottom of Pontoon and Center of Gravity of each individual Part (inches).

W ≡ weight (lbs.)

N ≡ Number of units.

$$\overline{CG} = \frac{\left[\begin{gathered}(11'' \times 350 \times 2) + (24'' \times 70 \times 2) + (61.1'' \times 53.8 \times 8) + (100.4'' \times 184) \\ + (22'' \times 115 \times 2) + (92.4'' \times 22 \times 2) + (50.5'' \times 4000) + (24'' \times 100 \times 2)\end{gathered}\right]}{\left[(350 \times 2) + (70 \times 2) + (53.8 \times 8) + (115 \times 2) + (22 \times 2) + (100 \times 2) + 184 + 4000\right]}$$

$$\boxed{\overline{CG} = 45.8 \text{ inches}}$$

$$\overline{CG} = \overline{KG}$$

$\overline{KG}$ ≡ Distance Between Center of Gravity and Bottom of Pontoons.

Appendix G:

Stability: Calculating Angle of List

$$\overline{GG}_{new}(\text{transverse}) = \overline{GM}\tan\phi \qquad ①$$

$\phi \equiv$ list angle

$\overline{GM} \equiv$ distance between center of gravity and metacenter

$\overline{GG}_{new} \equiv$ distance between new center of gravity caused by weight addition and old center of gravity

Calculatating $\overline{GM}$:

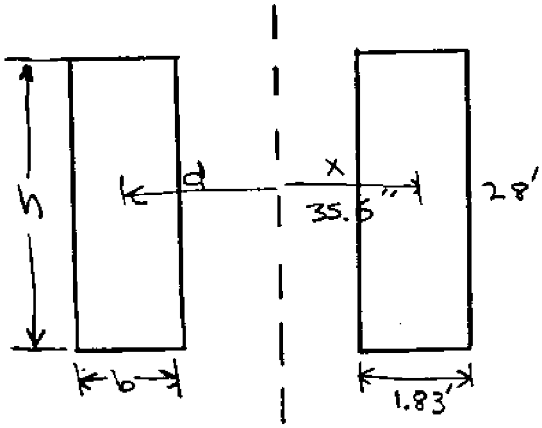
$$\overline{GM} = \overline{BM} - \overline{BG} \qquad \text{(see fig … for explanation)} \qquad ②$$

$\overline{BG}$ – Known

$$\overline{BM} = \frac{I}{\nabla} \qquad ③$$

$I \equiv$ inertia about waterplane area

$\nabla \equiv$ Volume displaced at half draft



Waterplane area of pontoons

Appendix G (cont):

$$I = \int x^2 \, dA$$

$$\bar{I} = \frac{bh^3}{12}$$

$\bar{I} \equiv$ Moment about pontoons centroid

$$I = 2(\bar{I} + d^2 A) \longleftarrow \text{from composite shapes}$$

$$= 2\left[\frac{(28)(1.83)^3}{12} + \frac{(35.6)^2}{144}(1.83)(28)\right] = 866 \text{ ft}^4$$

$$\nabla(\text{half draft}) = 2\left(\frac{11}{12}\right)(28) = 51.3 \text{ ft}^3$$

$$\overline{BM} = \frac{866}{51.3} = 16.9 \text{ ft}$$

$$\overline{GM} = \overline{BM} - \overline{BG} = 16.9 - 3.43 = 13.5'$$

- Assume a weight addition of 800lb on a pontoon edge
- Must calculate $\overline{GG}_{new}$ (transverse) and solve for list angle ϕ in equation ①

$$\overline{GG}_{new} = \frac{0(6200) + (3.04)(800)}{6200 + 800} = .347 \text{ ft} \qquad ④$$

$$\overline{GG}_{new} = \overline{GM} \tan \phi$$

$$\phi = \tan^{-1}\left[\frac{\overline{GG}_{new}}{\overline{GM}}\right] = 1.5^\circ \text{ list angle}$$

An unbalanced load of 800 lb on 1 pontoon edge causes a list angle of 1°

ACKNOWLEDGEMENTS

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Gerald Sedor Phd,PE Project Advisor/Professor,UNH Durham, NH
The LARS Group would like to express extra special thanks to Dr. Sedor at this time. Dr. Sedor's efforts in industry donations/acquisitions, project/problem management, and design consultation were unprecedented in a student project situation. These efforts were the deciding factor in the successful completion of this project.

Jere Chase, UNH Class of 1936
Mr. Chase coordinated support from the UNH Classes of 1936 and 1937 to provide funds for purchasing the pontoons.

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Mr. Seavey provided quick access to steel material for the group in times of need. He is also responsible for a substantial amount of assembly and machining consultation that proved valuable to the team.

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Mr. Ferraira provided the team with over $900 in hardware donations from the local Sears Store in Newington. All hoisting credits go to Mr Ferraira.

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Mr. Champlin aided the team by giving much needed guidance on all machining tasks required of the LARS System. His help allowed the group to perform over 90% of all machining tasks.

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Matt provided welding expertise to the group. He welded the entire Pontoon Barge's Frame together.

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Fedco donated sandblasting expertise. They completed sandblasting tasks necessary for paint preparation of the LARS Frame.

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Rocky donated space and equipment necessary to paint the entire LARS Pontoon Barge Frame.

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Playbuoy Pontoons provided a pair of pontoons at a wholesale price and covered shipping expenses.

Classes of '36,'37 UNH Durham, NH
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Mr. Parady, working with Mr. Arnold Green, located a source of pontoons and, working with Mr. Jere Chase, obtained funding for the pontoons from the UNH Classes of 1936 and 1937.

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Chris provided a lot of valuable machining skills, time, and consultation to the group during the construction and assembly of the Pontoon Barge Frame. He was our liaison to the MSEL AUV Design.

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Tom provided a liaison between Dr. Sedor and Henschel Industries. This company donated aluminum stock and welding skills necessary for the proper modifications of our Playbuoy Pontoons.

TECH 697 Course Administrators, UNH Durham, NH
The Technology 697 Course administrators allowed the group to design/Buy/Actually build this entire LARS System. The group was very cooperative with the team in terms of budget considerations.

Arnold Green, Green's Marina, Hooksett,NH
Green's Marine helped to locate pontoons and coordinate delivery from Michigan.