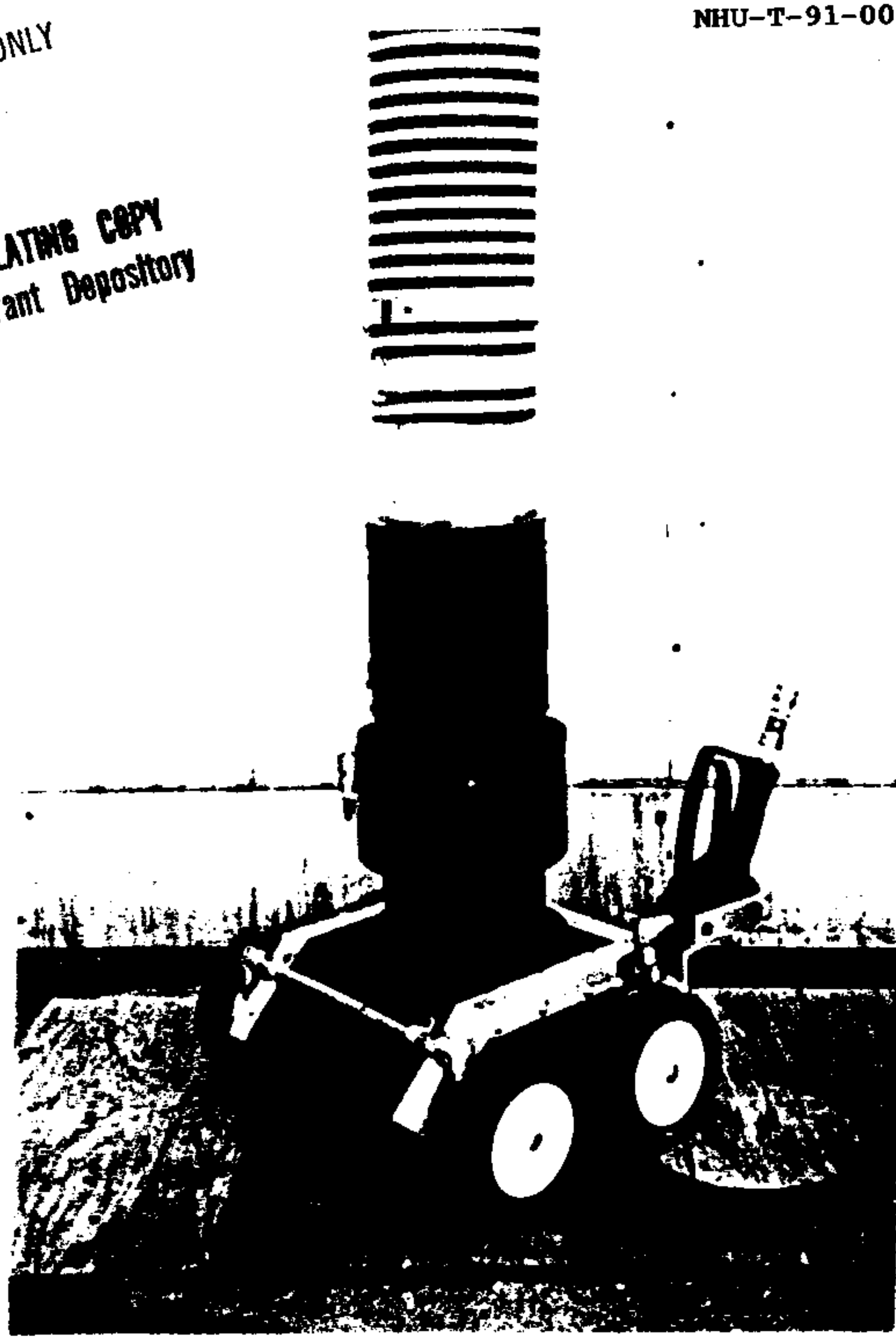

R O M B O

REMOVAL OF MARINE BIOFOULING ORGANISMS MACHINE

UNIVERSITY OF NEW HAMPSHIRE

OCEAN PROJECTS

MAY 1991

ROMBO

The Design and Construction for the

Removal Of Marine Biofouling Organisms Machine

UNIVERSITY OF NEW HAMPSHIRE

UNDERGRADUATE OCEAN PROJECTS

1990-1991

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ABSTRACT

A diver operated machine was developed to remove and collect biofouling materials and marine specimens. The machine consists of two major components: The water jets and the air lift. The jets "blast" the biofouling materials from their habitat, while the lift evacuates the loosened debris.

Two high pressure water jets are symmetrically angled on the outer edge of the machine to counteract all reaction forces and keep the removed biomass just below the lift intake. The lift is attached to the intake hood on the machine and removes any loosened biofouling from the water jets. The lift consists of a 10 foot long, 6 inch diameter hose coupled to a PVC air diffuser. By pumping compressed air through the diffuser, a pressure differential forms inside the lift hose when submerged in water. This differential creates suction which evacuates loosened biomass above the jet target area. Both water jet and air lift flows are controlled manually by the diver.

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INTRODUCTION

An increasing problem for nuclear and hydro power plants is the accumulation of mussels and sediment in their intake tunnels. Underwater structures and surfaces act as artificial reefs which attract marine life and provide them with an environment to live and multiply in. Mussels and similar shellfish force the overhaul of water facilities and cause damage to fisheries that experts estimate could cost up to $4 billion in the Great Lakes region alone. Biofouling accumulation in underwater intake pipes and cooling tunnels restrict water flow which decreases plant productivity and efficiency. As a result, these facilities have sincere interest in possible solutions to the problem.

Besides manual removal there exist water blasting systems which use a single jet to remove biofouling growth. Although effective for dislodgement, these systems scatter the biomass which either reattach in unwanted places (see Power Plant Intake Figure 1) or restrict the operator's visibility, thus making the task unsafe. Many jet cleaning systems exert unmanageable reaction forces on the operator which limit control and efficiency. One other type of debris removal system is the air lift. This device uses compressed air to form a pressure differential inside a long vertical pipe. The differential creates a vacuum effect which lifts loose particles and debris from the cleaning area. Currently, air lifts aren't used with any type of biofouling removal system because they require an additional operator which is costly as well as dangerous.

The Removal Of Marine Biofouling Organisms (ROMBO) is an effective solution to the problems associated with existing submersible cleaning systems (cost, safety, control) by incorporating the air lift and water jets into one unit. The integration of these systems creates a safe, inexpensive, and manageable method of biofouling removal and collection.

COLLECTED DEBRIS AT BOTTOM OF INTAKE

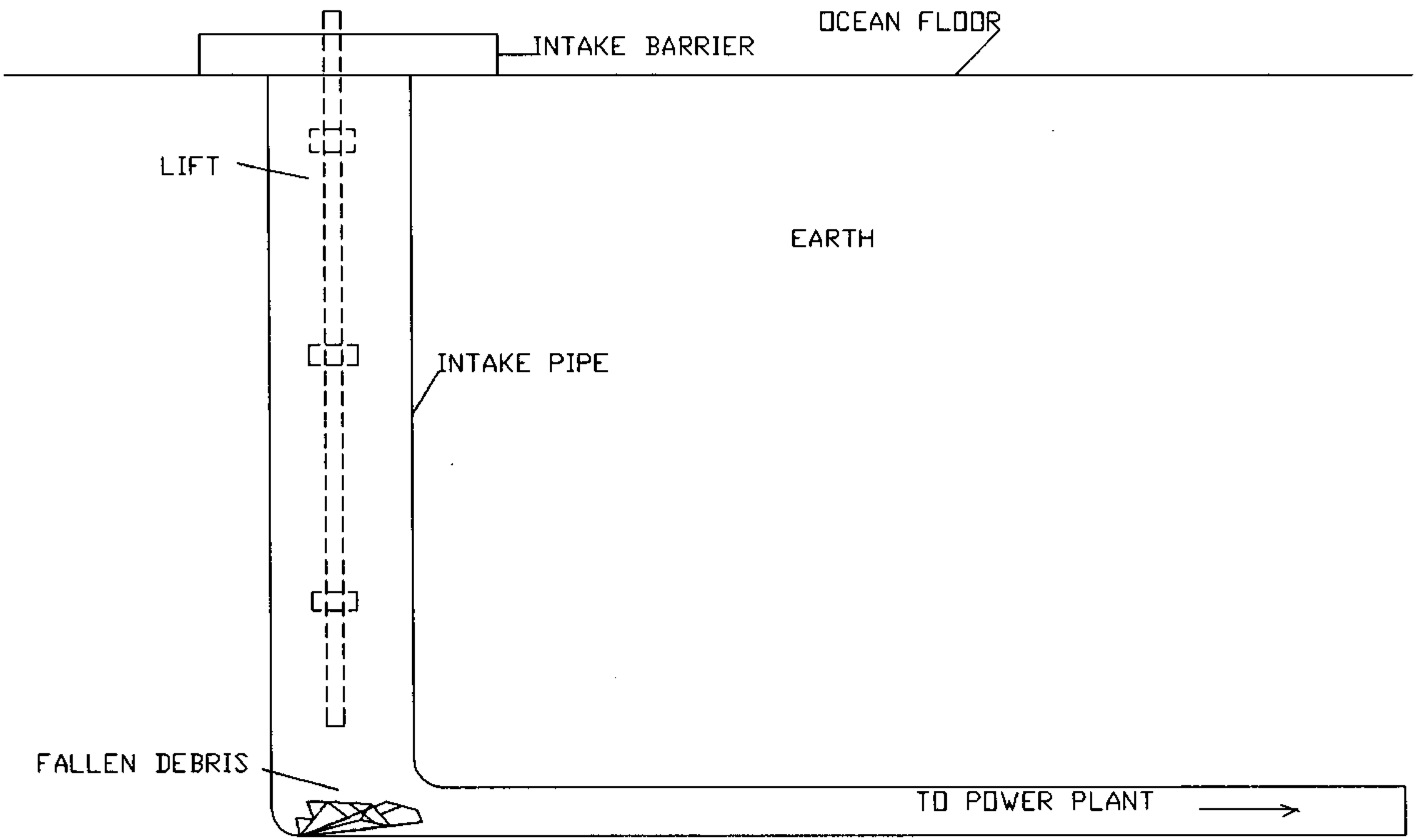


FIGURE 1

OBJECTIVES

The three objectives of the ROMBO project were to design, build, and test a state of the art biofouling removal machine that was manageable, safe, and efficient.

1) Manageability was a key factor in designing an air lift-water jet integrated system for solo operation. Reaction forces created by the high pressure water would have to be balanced so that diver maneuverability wasn't restricted by excessive weighting or tethering, as with existing systems.

2) Safety is also an important factor in the design process due to previous problems with diver visibility when using high flow rates and pressures.

3) The last objective required the design of a machine that was efficient. One that minimized diver work time and maximized biomass removal rates. The greater the removal rate the less costly the job.

DESIGN CRITERIA

The design process incorporated the following steps in the following order:

(1) Obtain research material on horse and blue mussels and other types of shell fish. Research and observe environmental habits, characteristics, and surface attachment forces.

(2) Obtain information concerning diver (operator) limitations and restrictions.

(3) Observe, analyze, and test existing blasting and lift systems or alternate systems. Learn how components of the system are integrated.

(4) Determine the maximum obtainable force from the nozzles.

(5) Calculate the rate at which the jet force has dissipated from the nozzle exit to the target surface at various depths.

(6) Do a jet configuration analysis. Determine the optimal configuration of the jets including diameter, positioning, and quantity.

(7) Determine a required mass flow distribution for the jets and design a manifold to distribute adequate flow to each jet.

(8) Design and determine placement of handles. The placement of the handles will determine ease of operation as well as play a role in qualitatively determining machine reaction forces.

(9) Determine an optimal method of balancing reaction forces.

(10) Design and analyze the air lift. Incorporate it into the hull without interfering with machine operator.

(11) Analyze the lift and how it will affect the machine reactions. Size, shape, and suction power are all important considerations.

(12) Design controls to vary and restrict air and water outlet flows.

(13) Final machining and assembly.

(14) Test the machine in salt water on various surfaces, at various depths.

(15) Modify: Correct malfunctions in machine components.

(16) Present results.

LITERATURE SURVEY

The first phase of our project was to conduct a literature search on the characteristics of mussels; types, sizes, habitats, etc. We were interested in removing three types; the blue, the horse, and the zebra from horizontal wood and concrete surfaces.

We discovered an experiment that had been done on mussels and their dislodgement forces. In short the procedure entailed tying mussels to a force transducer which was placed underwater. After several days the mussels attached their byssal threads to the transducer and drag forces caused by the water current were measured. This did not help us since our goal was to shear the mussels byssal threads with a high pressure water blasting gun. Unfortunately nothing of this nature was found since mussel removal with water blasting systems is fairly unfamiliar.

Next we needed to locate information on underwater high pressure jet impingement to help us determine what size water compressor to purchase. The size of the compressor would have to compensate for the quantity of jets and their target area size. Since very little literature was located we decided to search through different industries and even compressor sales people to gather any information we could. We received some information from the Portsmouth Naval Ship Yard in Kittery, Maine. An interview with project engineers and ship hull maintenance employees gave us insight on just how strong these mussels attached to their ships, piers, and buoys. For removal they use large compressors with single nozzle blasting wands which are somewhat effective but very inefficient. We received information on their compressor system but it was out of the range of our budget.

After further searching we decided that if we cut down on the number of jets and decreased the hull size we could afford an adequate compressor.

No literature was found on any type of removal system integrated with an airlift because such a system had not yet been devised. The next best information we found was that on the operation of the submersible airlift which has been around since the late nineteenth century. Information gathered on airlifts were helpful with some respects but for the most part did not apply to biofouling removal systems. The lifts evaluated in the article were short in length (up to 8 feet long) and small in diameter (I.D. max. was 4"). The application of diffuser literature ranged from aeration in processing plants to sludge tanks and conventional airlifts used a direct line of air into the hose entrance instead. Since we wanted uniform flow with adequate suction we came up with our own diffuser design which was inexpensive to build and highly efficient.

TEST METHODS

The purpose of the testing was to demonstrate that the ROMBO prototype would meet the aforementioned objectives and design criteria. The testing was done in two parts: 1) Pool test 2) Operational feasibility test.

1) Pool test:

The air lift was tested independently in the University swimming pool. The lift hose and diffuser were connected and submerged to 14 feet. While the hose was supported upright, a SCUBA air cylinder (simulating an air compressor) was attached to the diffuser inlet air port. Compressed air was released from the cylinder into the diffuser for a full five minutes. During this period observations for bursting and leaking of the diffuser were made. Lift suction power and lift maneuverability were also noted. Along with the diffuser test, a jet analysis was performed to evaluate various jet parameters for optimal jet configuration design (See Jet Analysis).

2) Operational Feasibility Test:

After the pool test and design analysis were completed an ocean test was devised to observe how well ROMBO could perform under actual conditions. The test took place on a fairly smooth, horizontal surface which was covered by a layer of algae and mussels. Due to a lack of underwater light the test depth was limited to 25 feet so that video footage of the event could be recorded. One diver operated ROMBO and qualitatively observed machine characteristics such as maneuverability, visibility, and reaction forces on the hull and lift. Also, removal effectiveness and efficiency were compared with a single nozzle water blasting wand. System deployment and retrieval were rated by on board observers.

(see SUMMARY OF RESULTS for machine characteristics).

JET ANALYSIS

Due to the lack of information available on the dispersion forces of a submerged water jet we devised our own inexpensive testing apparatus to correlate the effects of distance on submerged jet power. The test system schematic is shown in Figure 2 . The setup enabled us to effectively measure jet impingement forces as a function of distance by way of a voltage output reading.

The force transducer (Omega LCDA-25) converts a strain to a voltage by the resistive changes in the strain gages mounted inside. The resistance change on the gage causes a proportionate change in voltage which is monitored by the digital Fluke multimeter. To convert the output signal from mv to lbs we constructed a calibration plot (Figure 3) by pre-weighting the load cell. Preparation of the strain gage for submersible operation entailed removing the existing neoprene rubber sleeve (this sleeve made the transducer water resistant not submergible) and coating the strain gages and lead wires with resin solvent and microcrystalline wax M-coat W-1. Once coated a new thicker rubber hose was put over the gages and sealed with silicon rubber (Dow Corning RTV Silicon Rubber) and 1 inch hose clamps. See Figure 4 for transducer and electronic system schematic.

To accurately determine the effects of impingement distance, nozzle type, and nozzle quantity, we constructed the PVC stand and steel manifold. The test frame in Figure 2 is made of 2" PVC schedule 40 piping and PVC cement. As shown in Figure 2, the frame has 4 pin holes in the top tube so that jet impact distance from the nozzle to the transducer could be altered from 4-7 inches. Directly across from the transducer the aluminum test jet manifold is mounted. The manifold (Figure 5) has 4 nozzle holes allowing us to determine the effects of two versus four nozzle flow with respect to impingement force on the transducer plate. The manifold itself was bolted onto a solid steel pipe which was pinned into the PVC tube as shown in

WATER JET TEST DEVICE

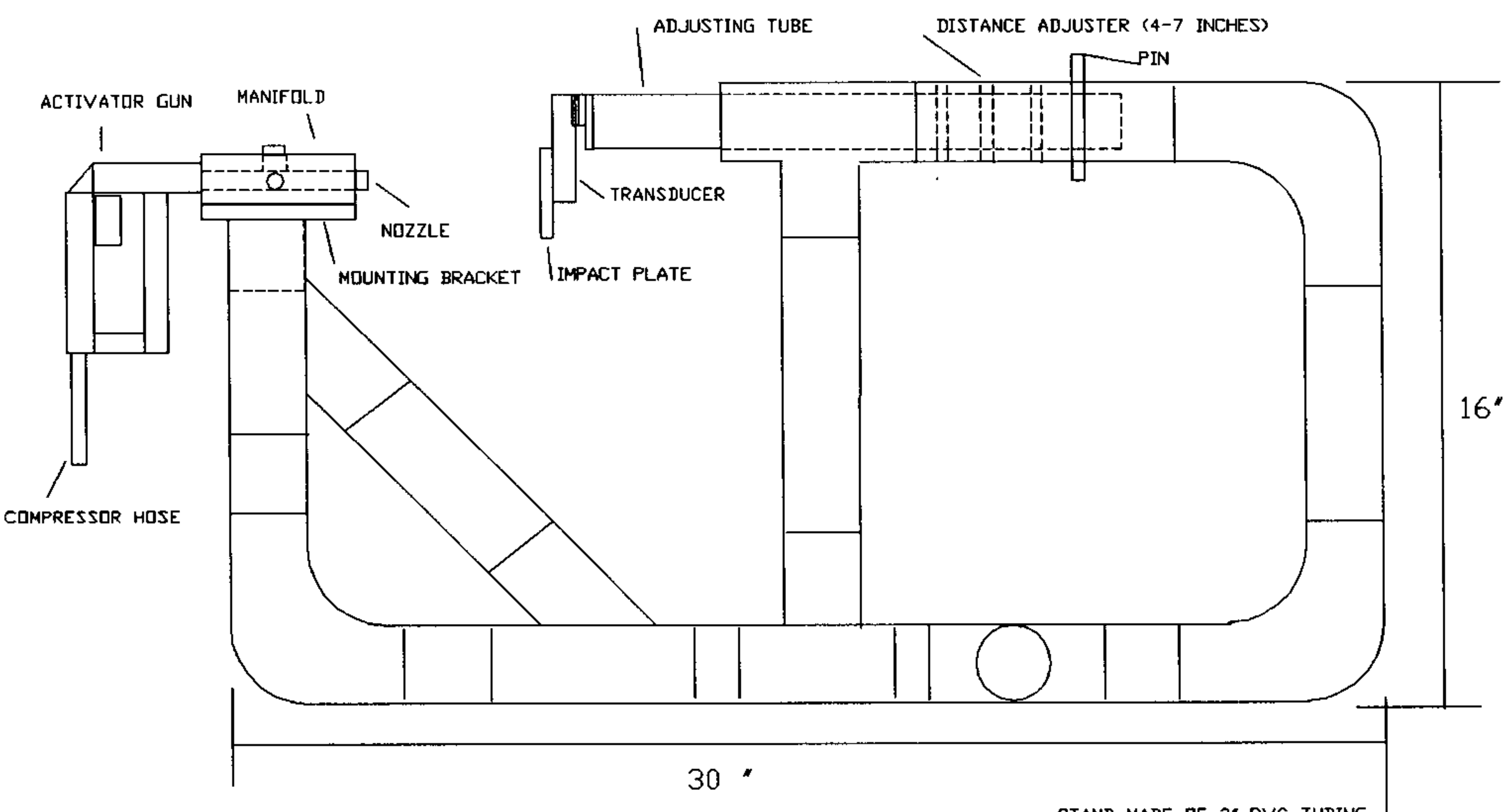


FIGURE 2

FORCE TRANSDUCER CALIBRATION GRAPH
LBS VS. MILLIVOLTS

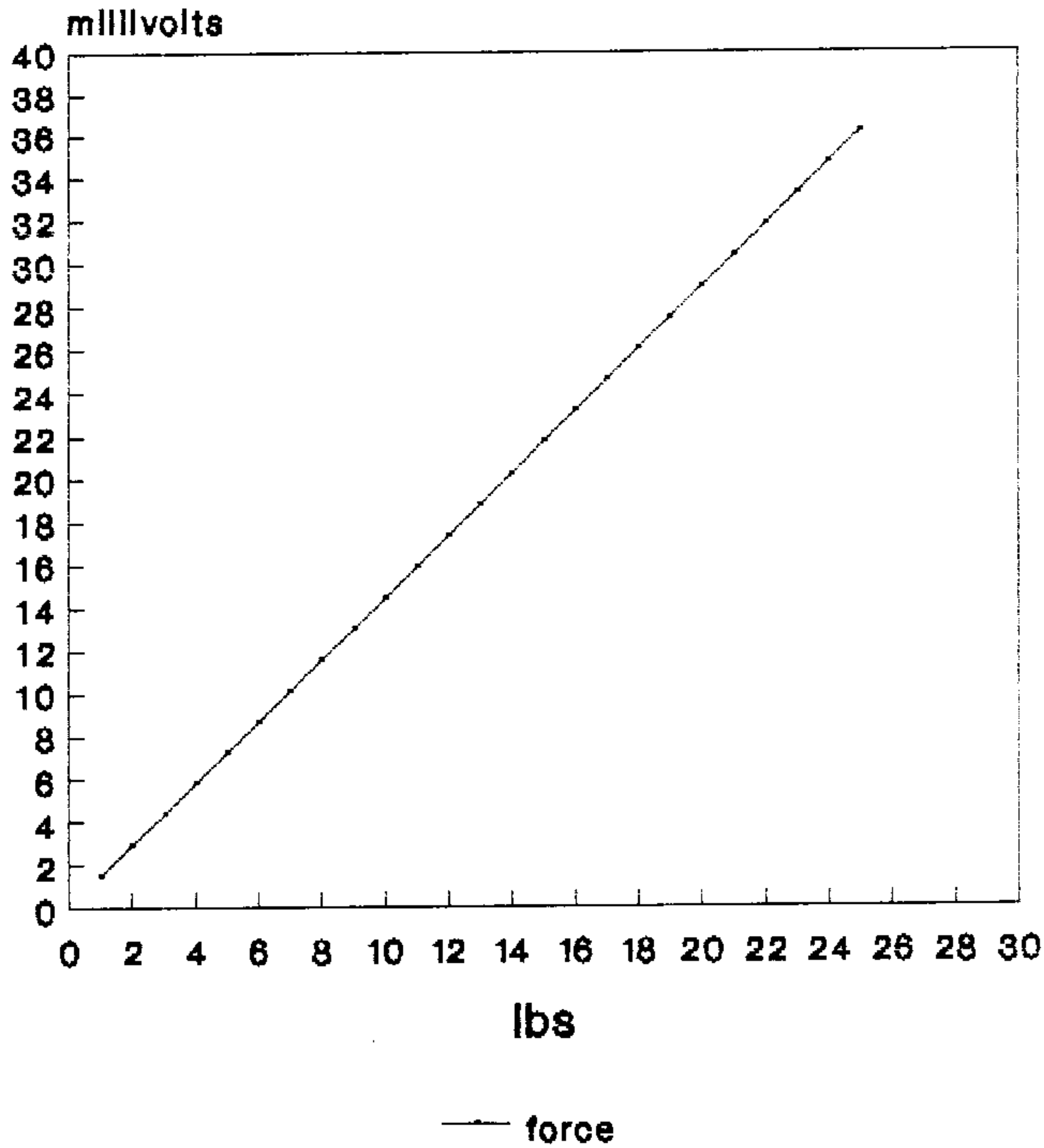


FIGURE 3

TRANSDUCER MOUNTING SYSTEM WITH ELECTRONICS

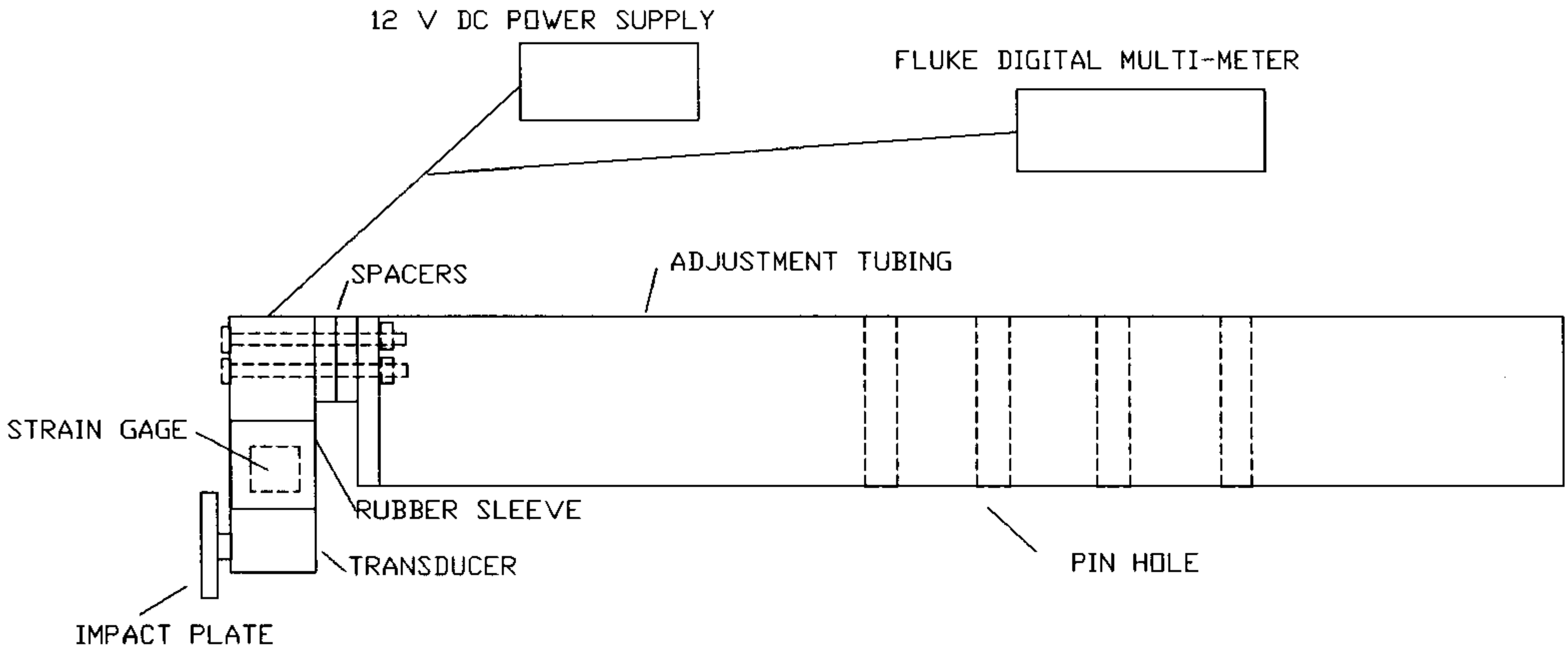


FIGURE 4

TEST MANIFOLD DESIGN

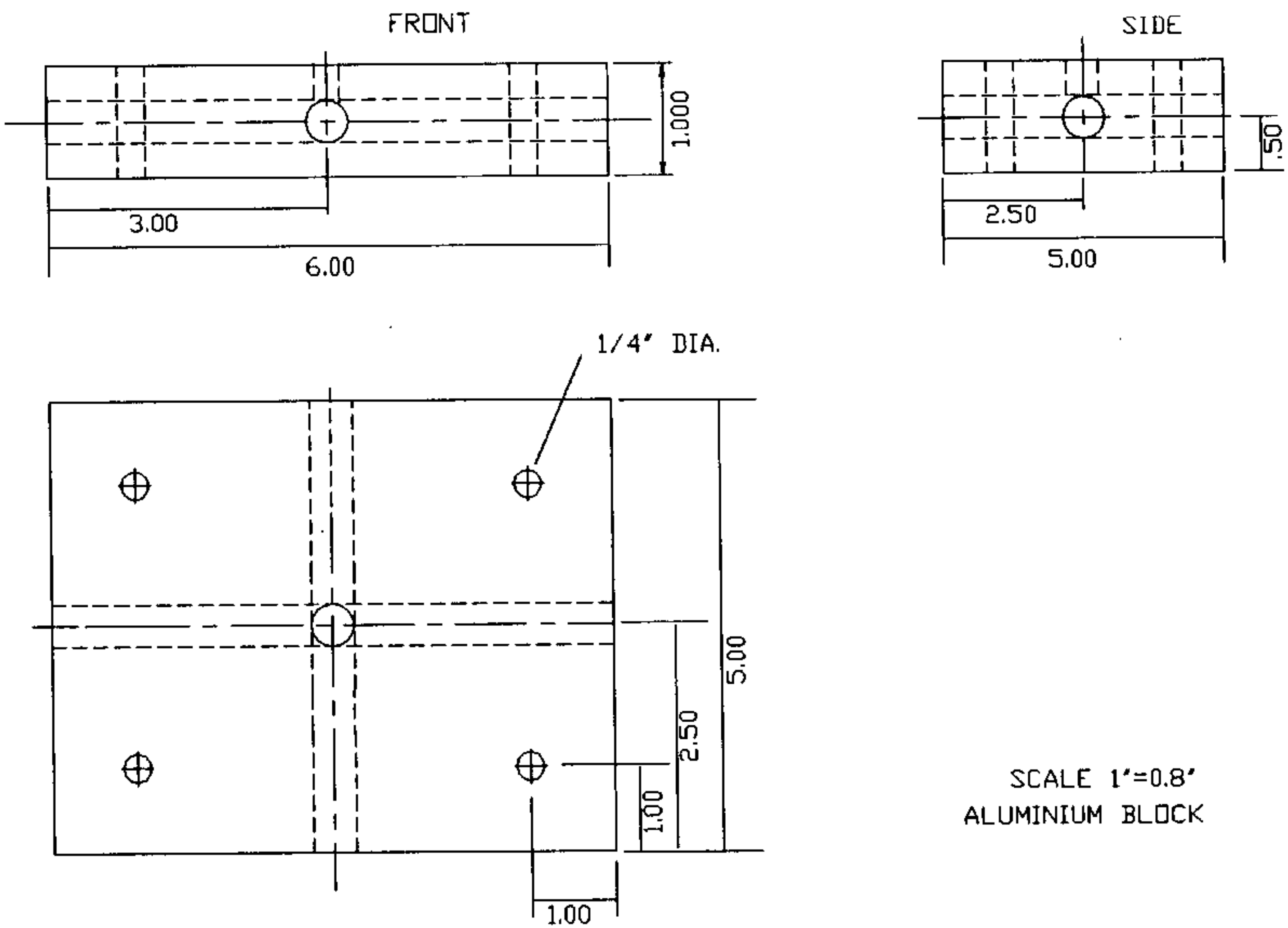


FIGURE 5

Figure 2. The original jet gun and wand (supplied with the purchased water compressor) screws into the back of the manifold for better control and personal safety. Only one jet actually impacts the transducer test plate whether 2 or 4 nozzles are used. When tested with 2 nozzles the other 2 manifold port holes are plugged with brass plug screws.

The transducer test system described above was used to collect force data based on impact distance, number of nozzles, and nozzle type (0^{o}, 15^{o} fan, etc.). Experiments were done in both air and 14 feet of water in the University swimming pool. Tables 1 and 2 show the results of the two tests based on nozzle parameters and impingement distances.

FORCES OF ZERO DEGREE NOZZLES IN WATER

NOZZLE	TRIAL	MILLIVOLTS 4"	5"	6"	7"
2/0 DEG	1	5.3	4.6	4.4	4.3
	2	5.3	4.6	4.4	4.3
	3	5.3	4.6	4.4	4.3

NOZZLE	TRIAL	LBS FORCE 4"	5"	6"	7"
2/0 DEG	1	3.54	3.07	2.94	2.87
	2	3.54	3.07	2.94	2.87
	3	3.54	3.07	2.94	2.87

DUE TO THE RESULTS OF THE AIR TEST, ONLY TWO ZERO DEGREE NOZZLES WERE TESTED UNDERWATER. IN AIR, THE 4 NOZZLE CONFIGURATION SHOWED A CONSIDERABLE DROP IN FORCE, THEREFORE TO SAVE TIME THIS WAS ELIMINATED FROM THE UNDERWATER TEST.

TABLE 1

FORCES OF VARIOUS NOZZLE CONFIGURATIONS IN AIR

NOZZLES	TRIAL	MILLIVOLTS 4"	5"	6"	7"
2/0 DEG	1	8.45	8.4	8.3	8.2
	2	8.45	8.4	8.3	8.2
	3	8.45	8.4	8.3	8.2
2/15 DEG	1	8.21	8.1	7.8	7.5
	2	8.21	8.1	7.8	7.5
	3	8.21	8.1	7.8	7.5
4/0 DEG	1	2.17	2.15	2.05	1.98
	2	2.17	2.15	2.05	1.98
	3	2.17	2.15	2.05	1.98

NOZZLES	TRIAL	LBS FORCE 4"	5"	6"	7"
2/0 DEG	1	5.71	5.63	5.57	5.4
	2	5.71	5.63	5.57	5.4
	3	5.71	5.63	5.57	5.4
2/15 DEG	1	5.49	5.41	5.21	5.02
	2	5.49	5.41	5.21	5.02
	3	5.49	5.41	5.21	5.02
4/0 DEG	1	1.45	1.43	1.37	1.32
	2	1.45	1.43	1.37	1.32
	3	1.45	1.43	1.37	1.32

TABLE 2

MATERIAL SELECTION

Due to the corrosiveness of salt water the following materials were selected for ROMBO. The machine frame, air diffuser, and reinforcements are made of PVC plating, piping, and aluminum angle iron, respectively. The (Kanaflex) lift hose is constructed of reinforced rubber hose with helically wound plastic bands for hose rigidity. The high pressure piping and Swagelok fittings as well as all the bolts, nuts, and washers are stainless steel. The quick disconnect fittings and the quarter turn ball valve for the air lines are brass. All materials chosen are resistant to the effects of sea water and will prevent any type of future failure due to corrosion.

In addition to being noncorrosive the PVC schedule 40 piping and plating offer sufficient properties of strength and durability for our application. The air diffuser (PVC piping) operating pressures range from 90-140 psig. This range is easily accommodated without failure due to the PVC pipes 180 psig burst rating. The 1/2" PVC plating used for the machine walls has an impact rating of 1.75-2.0 ft. lbs./in^2, which is strong and tough enough to support any operating loads that may be experienced (suction force, jet impact, reaction forces).

The lift hose was selected because of its compressive wall strengths as well as its overall flexibility. Once operating, the hose must resist compressive (collapse) stress due to the pressure differential between the bubbles inside and the water outside. Although compressively strong, it can be flexed to a 40" bend radius, if needed. One other benefit of the Kanaflex hose is that it behaves neutrally buoyant when submerged. Being weightless enhances diver maneuverability and deployment of the system.

Due to operating pressures of 3000 psi, 1/2" O.D. stainless steel piping rated at 5000 psi, was used for the jetting system. All fittings for the piping are stainless steel Swagelok, which are rated at 6000 psi. Swagelok uses internal feral nuts that lock down on the pipe when tightened.

This creates a water tight seal which is stronger than a threaded coupling as well as more convenient. They can be loosened and tightened any number of times and still remain burst proof when refastened. Swagelok fittings for the nozzles allow impingement angles to be easily adjusted.

AIR LIFT DESIGN

The air lift was designed so that it could be easily maneuverable under water and remain efficient for evacuating mussels up to 5 inches in diameter. We decided that the inside diameter of the lift hose should be 6 in. to prevent clogging and maximize flow. The most difficult part in designing the lift was to determine what kind of flow rate was needed for effective evacuation at any depth. No applicable literature was found for large, tall air lifts so we decided to come up with our own diffuser design and method of machine-lift coupling. To optimize lift efficiency while preventing slug (pulsating) flow, we utilized moderate air flow rates. As Figure 6 shows, increasing the air flow rate beyond the uniform flow regime won't increase suction . It will only cause slug flow. In the slug flow region, large bubbles of air are separated by an annular film of liquid in contact with the pipe wall. These air bubbles are separated by slugs of liquid which may contain a few smaller air bubbles. The problem with slug flow is that it creates an uneven distribution of bubbles and bubble sizes which can cause vibrations in the entire system. This results in arduous handling for the operator of the system.

To maintain smooth and evenly distributed flow the diffuser needs very fine bubble diameters (less than 0.09") and multiple diffuser holes equally spaced around the diffuser pipe cross section. The design shown in Figures 7, 8 consist of schedule 40 PVC pipe and collars. Two rows of 21 air ports (3/64" diameter) each were drilled at 45 through the 6 inch diameter pipe cross section. Two PVC collars (6" I.D., 8" O.D.) were glued to the 6 inch pipe. One placed 1.5 inches above the top row of diffuser holes and the other collar 1.5 inches below the lower row of diffuser holes. Sandwiched between the diffuser collars, while concentric with the six inch pipe, is a 5 inch section of 8 inch I.D. PVC piping. A brass 90 elbow air inlet was mounted to the side of the 8 inch pipe.

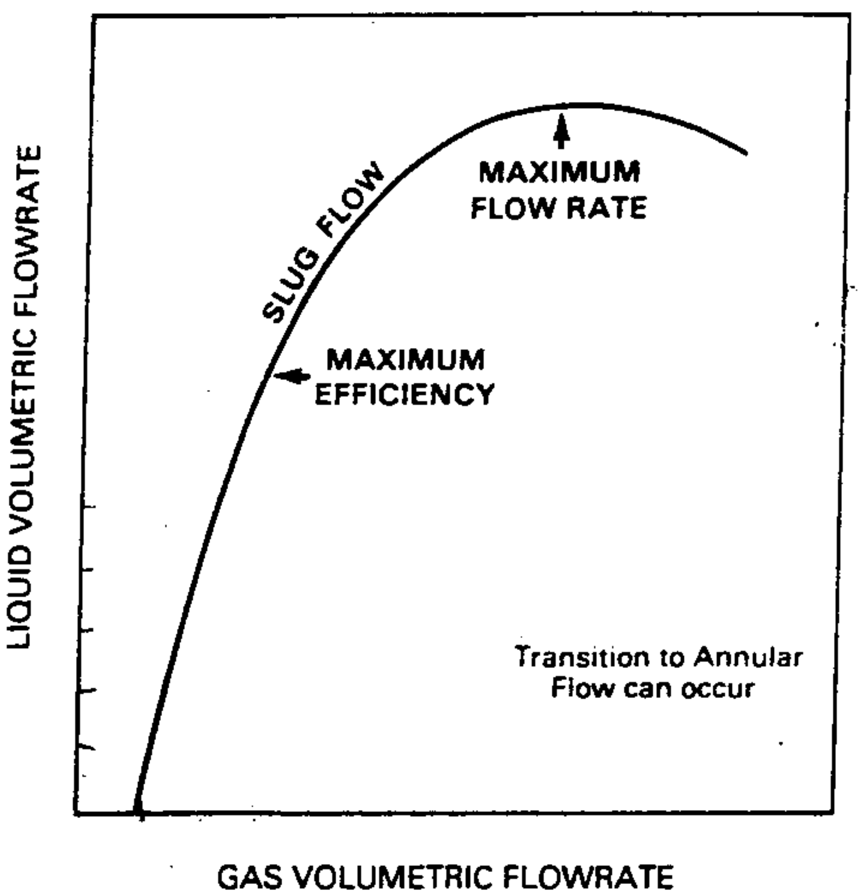


Figure 2. Typical air lift pump operating curve. Equation 15 is valid for the ascending portion of the curve, up to the maximum liquid flow rate.

FIGURE 6

DIFFUSER X-SECTION WITH MOUNTING FLANGE

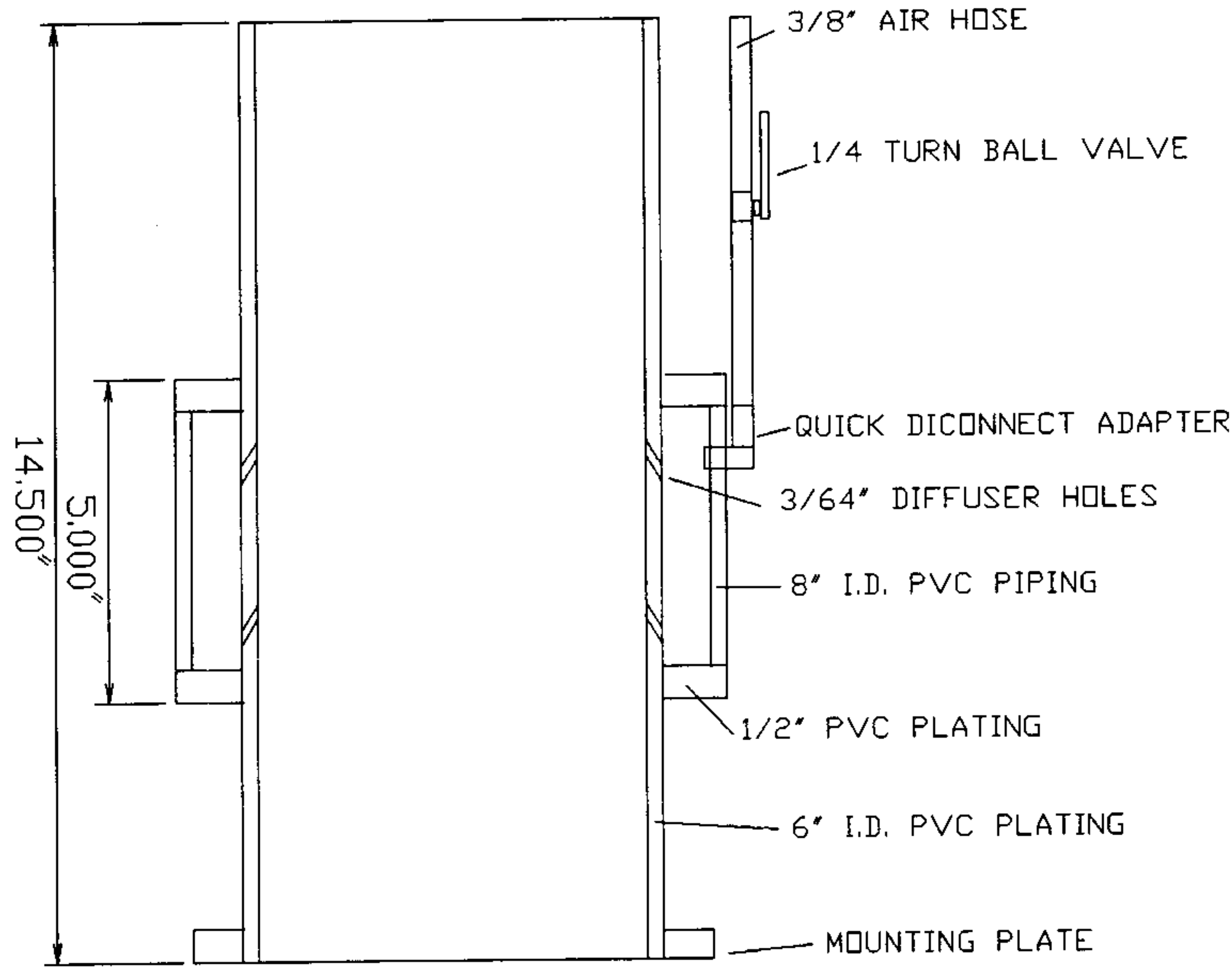


FIGURE 7

DIFFUSER X-SECTION

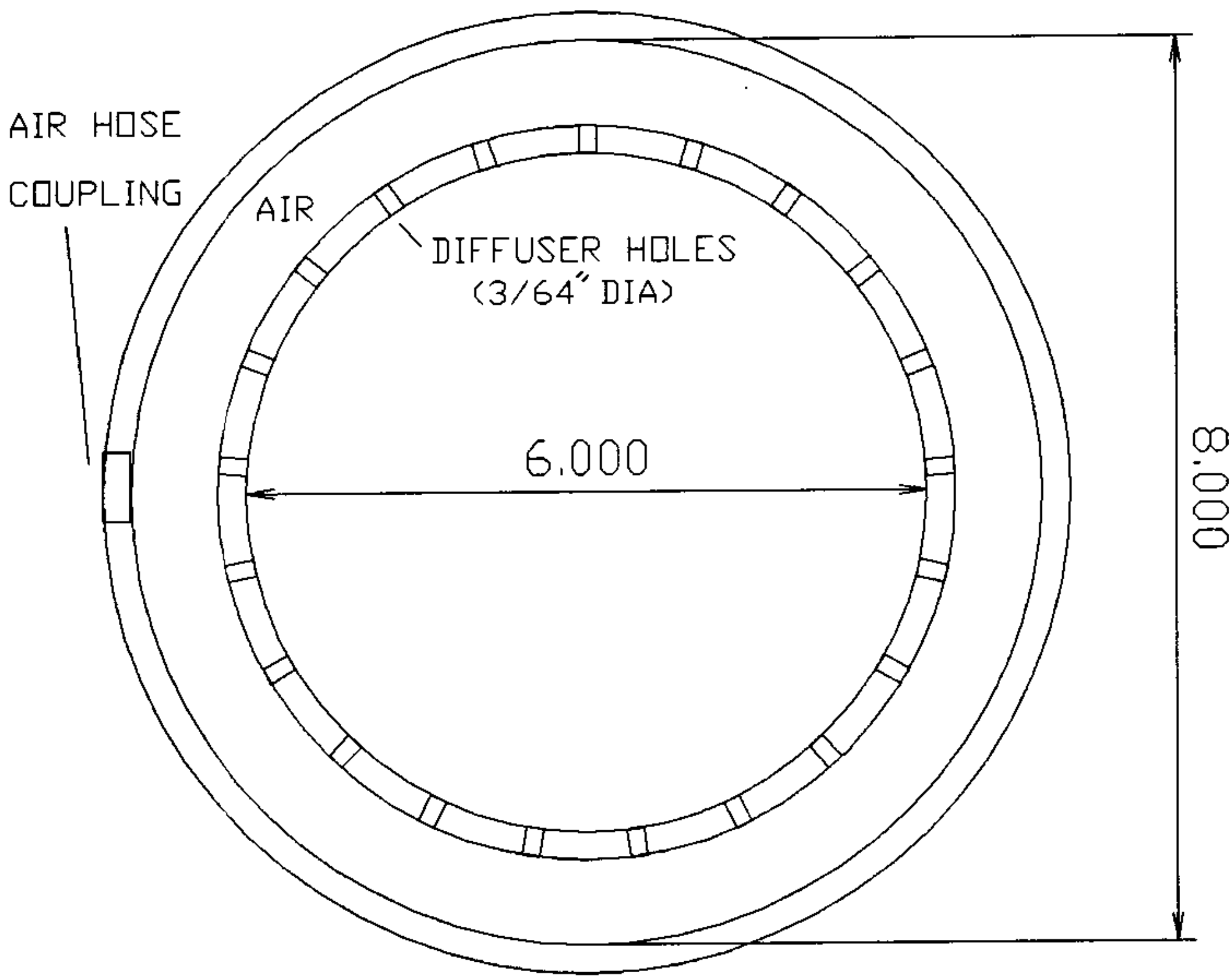


FIGURE 8

The selection of the lift hose was based on flexibility, lightness, and economical feasibility. The Kanaflex series 300 EPDM all weather suction hose was chosen because it contained these characteristics plus it was rugged and remained neutrally buoyant under water. The hose is 10 feet long and has an inside diameter of 6 inches. The helically wound plastic on the outside keeps it somewhat rigid and prevents collapsing. The hose has a smooth inside wall that prevents biofouling from clogging the lift. Another beneficial feature is that the rubber maintains a certain stiffness throughout a broad temperature range. Specifications and characteristics are shown in the Appendix.

At one end of the hose an aluminum male connector was machine banded inside the Kanaflex diameter. The connector weighs 5 lbs. and has the same internal diameter as the Kanaflex. Since the diffuser-hose coupling has standard pipe thread, the connector allows the diffuser to attach to the hose by simply screwing it on. With the attachment of an aluminum female coupling on the other end of the Kanaflex hose, additional hose length may be connected.

The ROMBO air lift system uses a 128 psig, 25 GPM air compressor designed and built by team advisor Paul Lavoie. The compressor is gas driven and a quick disconnect fitting allows for the air inlet hose to be directly attached. The other end of the air inlet hose is attached with brass quick disconnects to the quarter turn ball valve. When the compressor is running, the ball valve allows the operator to regulate airflow into the diffuser.

The air lift system is attached to the machine by an 8 inch O.D. mounting collar (the collar is glued to the 6 inch diffuser tube) by seven 10/24 inch bolts that screw directly into the top of the machine's hull.

HULL AND PIPING DESIGN

To effectively design the machine hull, set parameters were determined, such as material selection and size. Factors affecting material selection were already discussed in "Material Selection" page 17. Other parameters in our design consideration were ease of machining, availability, weight, and cost. The material we chose that satisfied all of these constraints was 1/2" PVC plating.

Size constraints: The air lift mounting collar presented a minimum size constraint on the hood panel due to it's outside diameter of 8 inches.There was also a maximum size constraint due to the the effects of distance on jet force. We determined from the jet data that beyond 5 inches the jets would have little or no effect on the target area. Other important considerations on frame design were piping layout, and reaction forces caused by the jet and piping configuration. We determined that the jet configuration constraints had to be solved before hull/frame design could begin. In order to logically design the frame, jet configuration, and controls, we devised the flow chart in Figure 9.

The primary factors in hull dimensioning were the 8" minimum diameter size due to the mounting collar on the diffuser. Before the exact dimensions and shape were chosen we decided to use opposing jets aimed perpendicular (see Figure 10) to the machines forward path of motion so that all reaction forces would be negated. We decided that a square shape would be most effective for containing blasted material and pipe/jet mounting. The piping and coupling was specifically chosen to handle high pressure, be noncorrosive, and easy to modify. Swagelok satisfied those criteria. With the final piping layout complete, revisions on the frame were made to accommodate the jets, wheels, and nozzles.

The handles were designed from 1.25" aluminum angle iron and 1" diameter piping. They were welded to 1.5" x 3" aluminum plates that screwed onto the back

DESIGN FLOW CHART

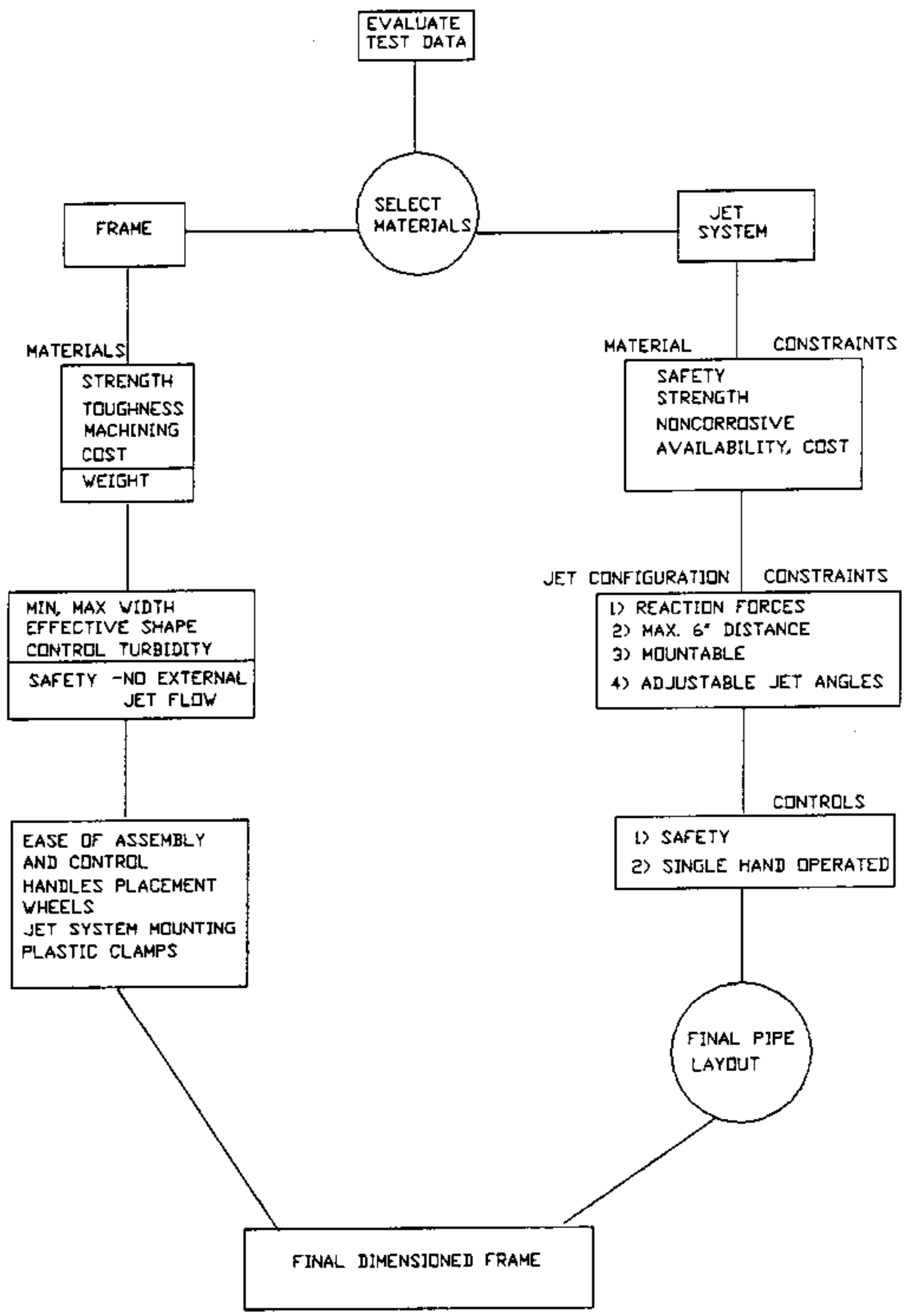


FIGURE 9

PIPING CONFIGURATION

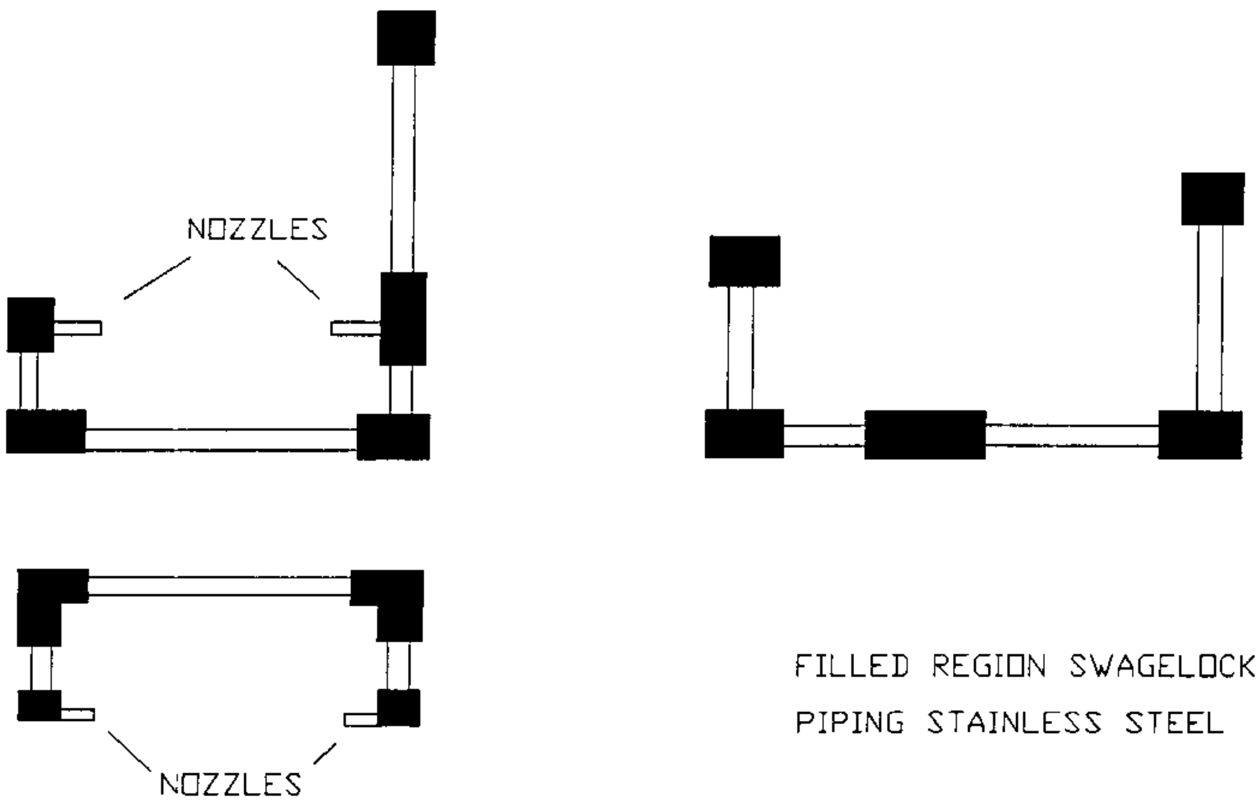
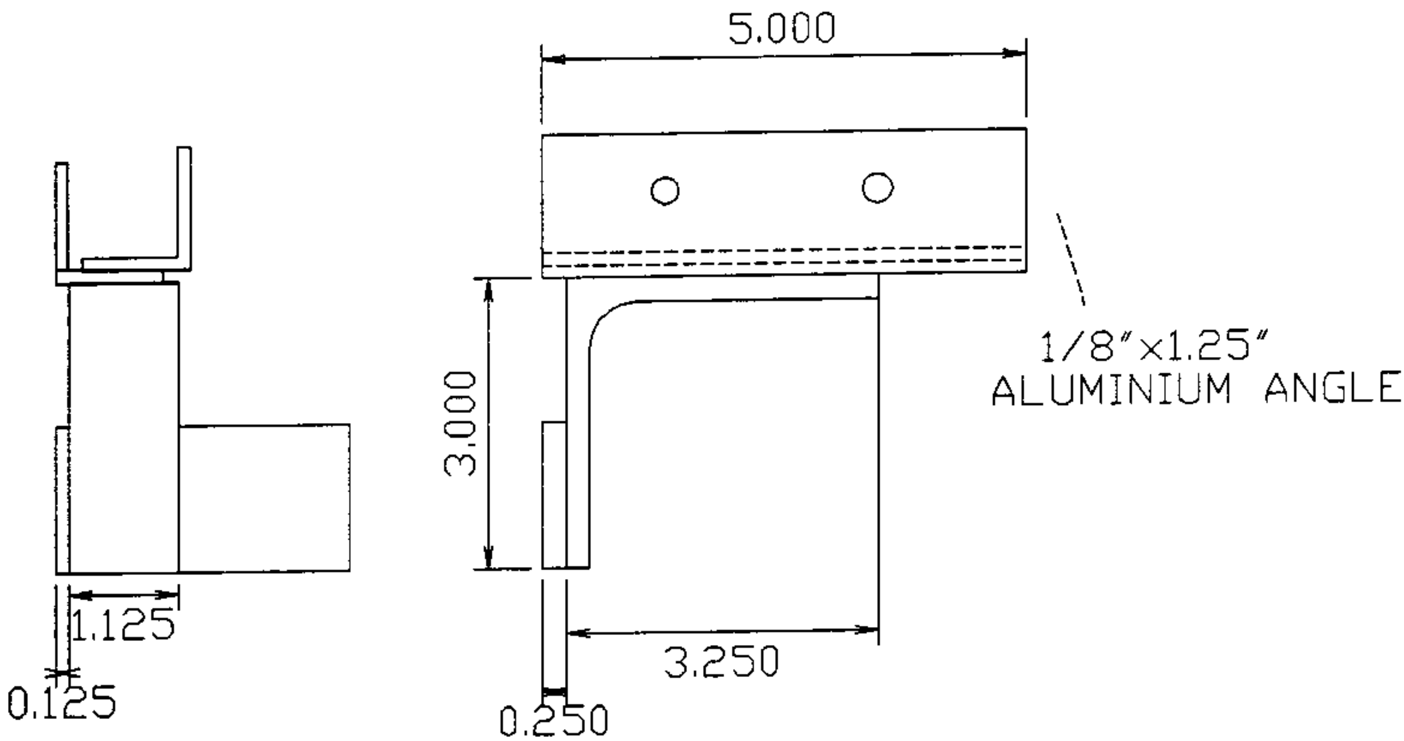


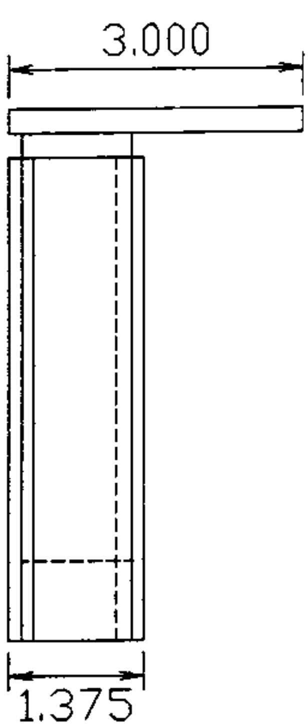
FIGURE 10

of the machine to facilitate the piping design as well as diver control. See Figures 11 & 12 for handle design. To improve manual control while minimizing cost and complexity, we decided to use the handle (jet gun) from the original single wand set up. This allowed single handed control of the jetting system and provided a safe and effective apparatus for machine control.

The rubber wheels (6 inch O.D.) were chosen so that they were large enough to avoid being stuck on uneven surfaces while small enough to mount on the machine frame. We mounted them so that the frame had one inch of clearance between itself and the cleaning area so that the jets could maximize their target area. The entire frame was reinforced with 1.25 inch aluminum angle iron along all of the wall joints. See Figure 13 for overall machine dimensions and part placement.

GUN HANDLE MOUNT





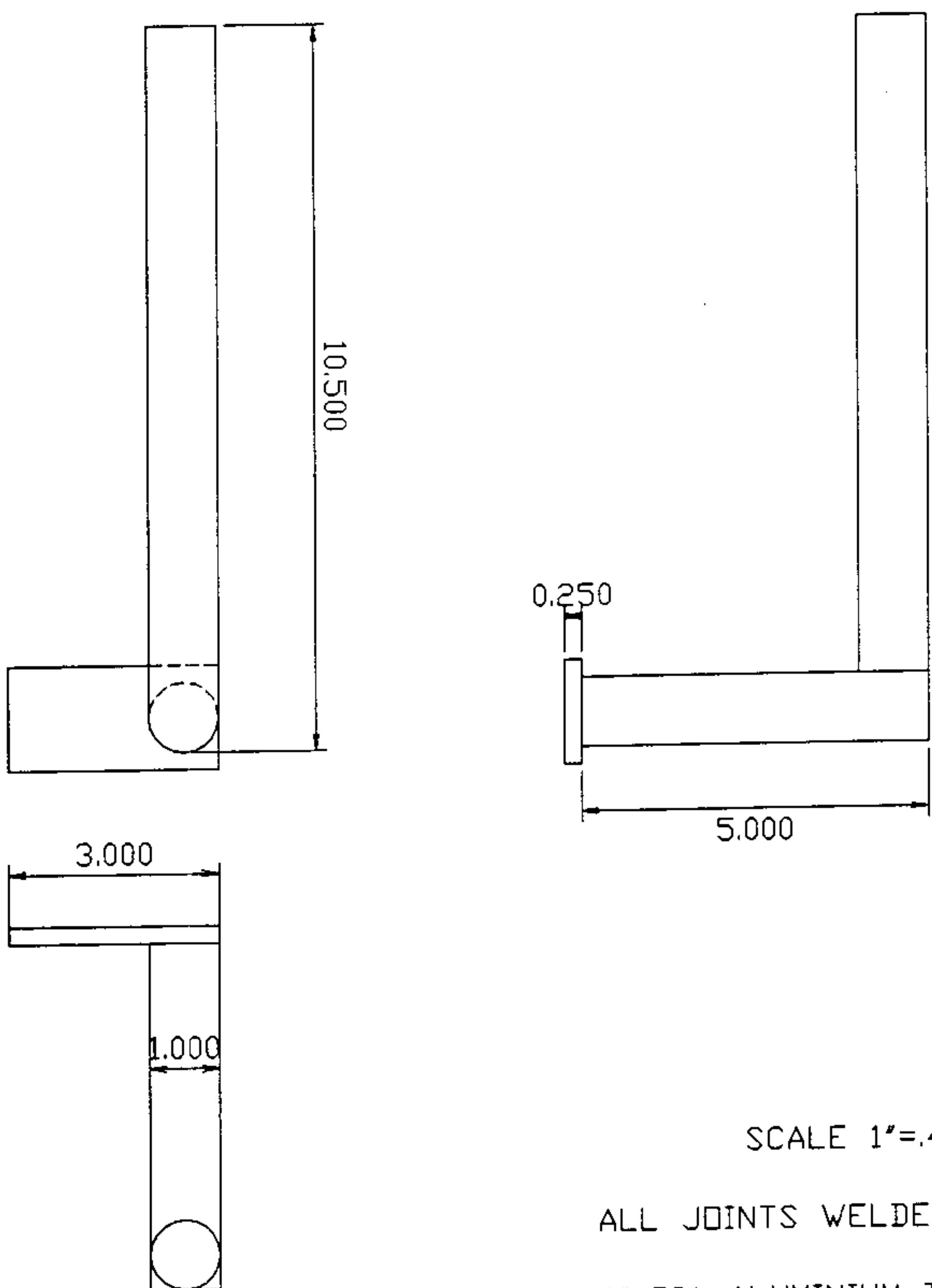
ALL JOINTS WELDED

ALL MATERIALS ALUMINIUM

ALL DIMENSIONS IN INCHES

FIGURE 11

AUXILIARY HANDLE



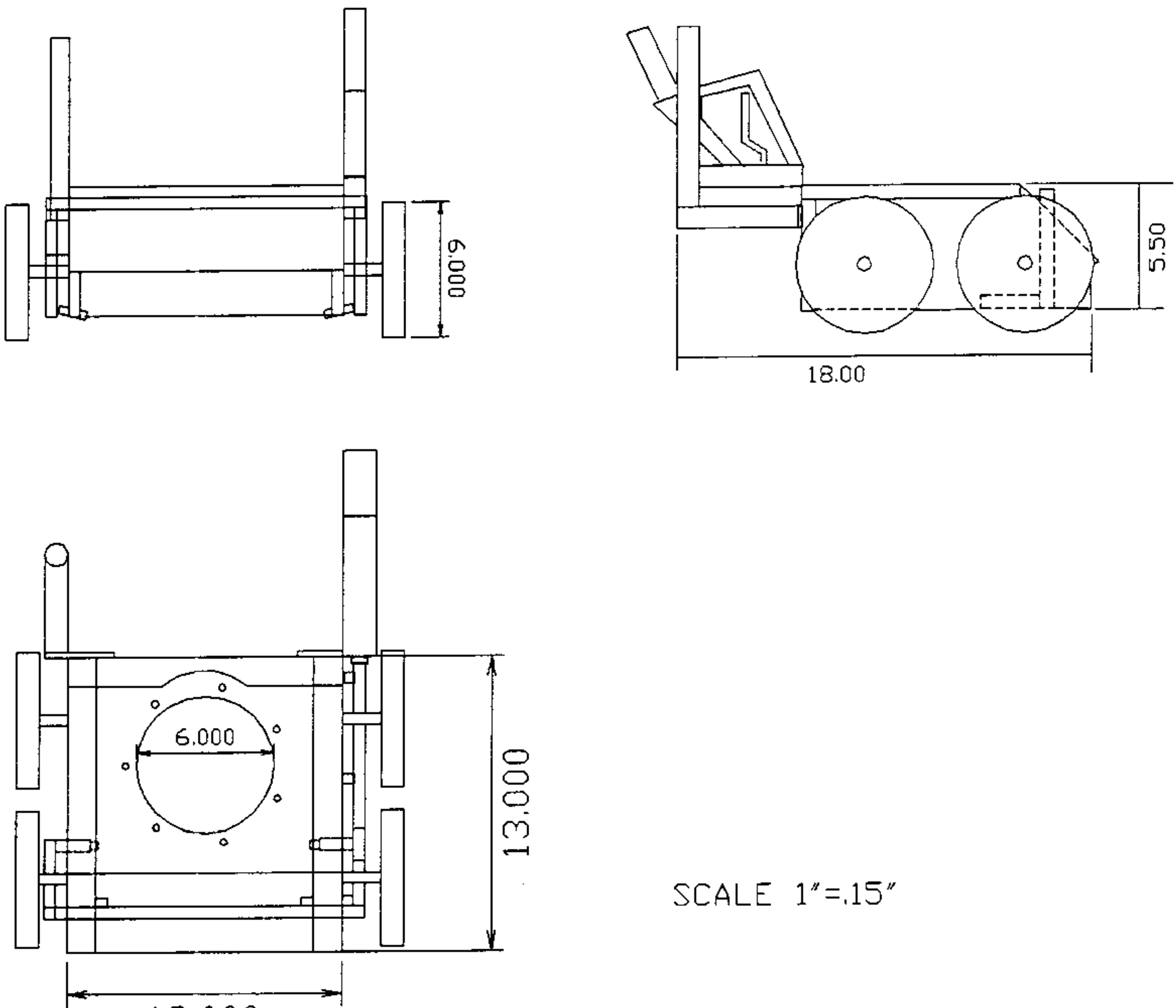
SCALE 1"=.4"

ALL JOINTS WELDED

1" DIA ALUMINIUM TUBING

FIGURE 12

ASSEMBLED MAIN MACHINE FRAME



SCALE 1"=.15"

FIGURE 13

SUMMARY OF RESULTS

In the pool, the air lift operated successfully with no visible leaks through the seams or couplings. It was determined that 120 psi air pressure was enough to generate lifting in 10 feet of water.

The results obtained from our first field test were both informative and promising. The ROMBO machine satisfied all but one of the design's objectives; efficiency. The jetting system did not provide adequate cutting force to dislodge the mussels from their habitat.

The 3000 psi water compressor supplied a maximum force of 4 lbs in water from the test performed in the pool. This force was not enough to dislodge the mussels that were subjects of the field test. Due to the time and location factors, this particular bed was the only accessible test site. Had more time been available, a test on smaller, weaker mussels could have been performed and ROMBO may have been more successful.

The removal and control aspects of the system performed superbly. ROMBO diver/operator Paul Lavoie evaluated it's performance. He stated that the machine did not twist or roll because of the hose. When the air lift was operating the moving water inside the the lift hose kept the system upright (vertical) and neutrally buoyant, which eased manageability. No reaction forces were experienced and the visibility remained unaffected by jet impact.

The lift worked effectively and efficiently. The air compressor/diffuser system provided enough air so that sufficient suction was created to evacuate dislodged debris. After lift exit the bubbles provided additional momentum to carry away the debris and prevent it from falling onto the work area. The lift bubbles created by the diffuser were uniform and no slug or pulsating flows were experienced during operation.

One of the most impressive qualities of the machine was it's ability to maintain good visibility in the work area. During our test the visibility remained very clear and allowed the diver to operate the machine safely and effectively. The ROMBO hull enclosed any flying debris and the lift swiftly removed it.

There were no material failures or leaky seals on ROMBO during the test. The diffuser seams did not leak air while under pressure. The hull and piping remained rigid during operation and the wheels effectively provided easy movement for the operator.

The reaction forces associated with submerged jet flow were balanced so that there was no resultant force on the diver. Thus, the diver didn't have to expel extra energy to maneuver the system.

As a comparison to the ROMBO machine, a hand wand was tested with the 3000 psi compressor using a single zero degree nozzle. The single jet did remove mussels from the rock, however, the diver became exhausted after five minutes of use due to the large reaction force of the wand. The single wand also hindered diver visibility thus increasing the risk of injury.

Deployment and retrieval of ROMBO was an easy task for one person on board the Jere Chase (U.N.H. boat), because the lift hose is neutrally buoyant. Once off the boat it took about a minute to move the assembled system down to 25 feet.

FEASIBLE ALTERNATIVES

After evaluating the ROMBO machine as an entire working unit, it is evident that some modifications must be made. The major problem with the system is the lack of force supplied by the compressor. Due to its size and maximum flow rate (3000 psi, 4.5 GPM) the jet force is limited to about 4 lbs. The only mechanical improvement would be to obtain a compressor with a larger maximum pressure and flow rate. Due to the cost of such a compressor this may not be the best solution.

Another simple modification is to redesign the jetting system on the machine. The system was tested with the jets 11" apart and angled at 20° to the horizontal. Effective and efficient removal did not occur because the water jets were too far apart and targeted over too large an area. If the nozzles concentrated on a smaller target area, better results would have been obtained. This may be possible by reducing the size of the hull from 12" to 6", where the jets are positioned.

A modification which may prove even more effective than scaling ROMBO, is to add a fine sand dispersion device that attaches to the water compressor. The device consists of a pressure vat that draws sand into the water line after compression. Sand in the water would result in a more abrasive and powerful cutting stream to dislocate target specimens (mussels, sea urchins, etc.).

An alternative is to do away with the entire hull and mount the jets directly onto the lift hose/diffuser. Without the hull, the lift and jets would be closer to the target area thus decreasing the target area to the diameter of the lift (i.e. 6"). This may produce a greater combined effort of "blasting" and evacuating biofouling. With the addition of handles and a flow trigger, this may be considered a suitable alternative. With the aid of a remotely operated vehicle (ROV) the design could offer another application. Many nuclear and hydro power plants have tall, narrow upright cooling tunnels which collect mussels and starfish on their inner walls.

Without an air lift, any material manually removed will fall into the cooling tunnel and accumulate (Figure 1). With the revised ROMBO machine, and sufficient lift length and air diffusers, loose biofouling could be evacuated from the tunnel. The ROV maybe necessary to maneuver ROMBO since deep tunnel diving is dangerous.

Another possible system that could be integrated with the air lift includes adding a mechanical cutter or rotor that is powered by hydraulic pressure. The cutter may accomplish the jetting system or replace it entirely. Although more complex than our jetting system mechanical interaction with the mussels may be the most effective removal method if some type of revolving blade were designed to shear the organism's byssal threads.

ALTERNATIVE APPLICATION

An alternative application to biofouling removal would be harvesting. There is an increasing interest in the harvesting of small sea animals for both consumption and research. There is a large market in Japan for sea urchins, as they are considered a delicacy there. Divers are actively collecting sea urchins, by hand, off the coast of Maine. This is a very slow and expensive method. ROMBO could be used to harvest the shellfish to decrease harvesting time. An inexpensive net could be attached to the top of the lift to collect the larger urchins. This net would allow the smaller sea urchins to fall through, thereby screening for size. This application is not limited to sea urchins, any small sea animal could be collected.

CONCLUSIONS

The ROMBO machine has a promising future in the applications of mussel removal and shellfish harvesting. It's compact size makes it ideal for hard to reach places while it's airlift collects biomass safely and effectively.

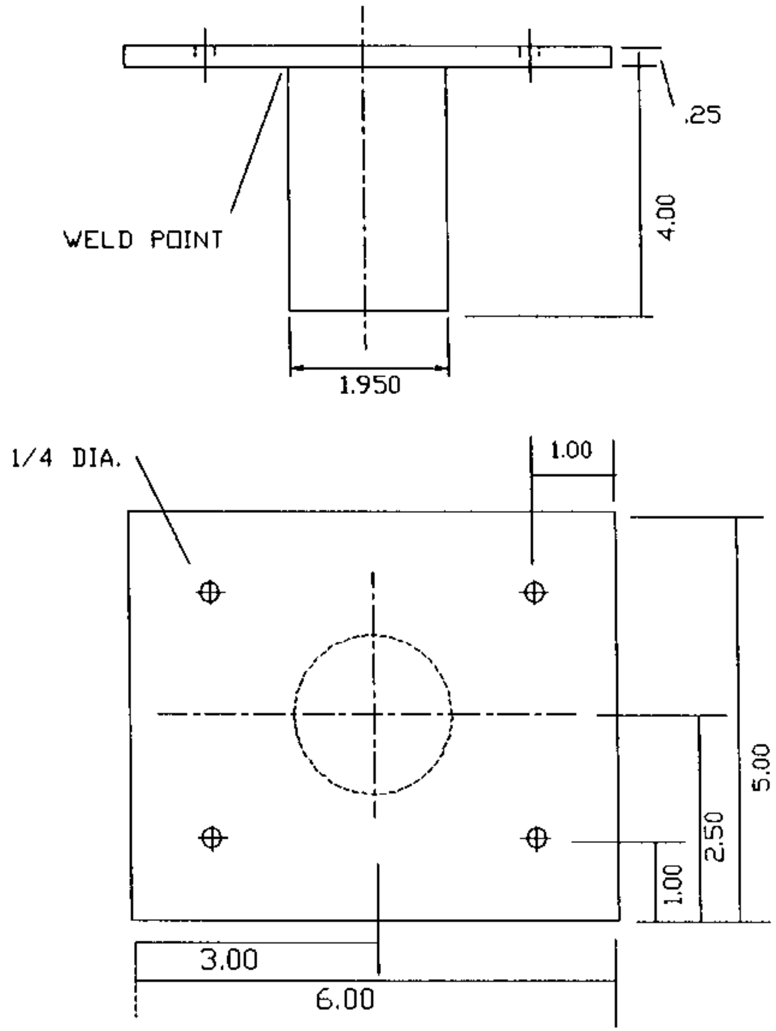
The fault of ineffective removal may have been in our underestimating the forces needed to dislocate the mussels from their attachment surface.

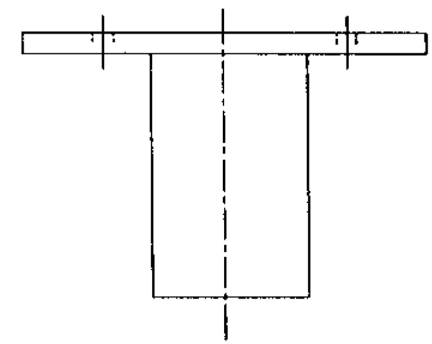
Mechanically the jets and the lift operated as planned.

We designed and constructed our own diffuser and jet impingement test to save money and these systems present an effective solution for biomass removal and harvesting through further modifications with the ROMBO machine.

APPENDIX

TEST MANIFOLD MOUNTING BRACKET

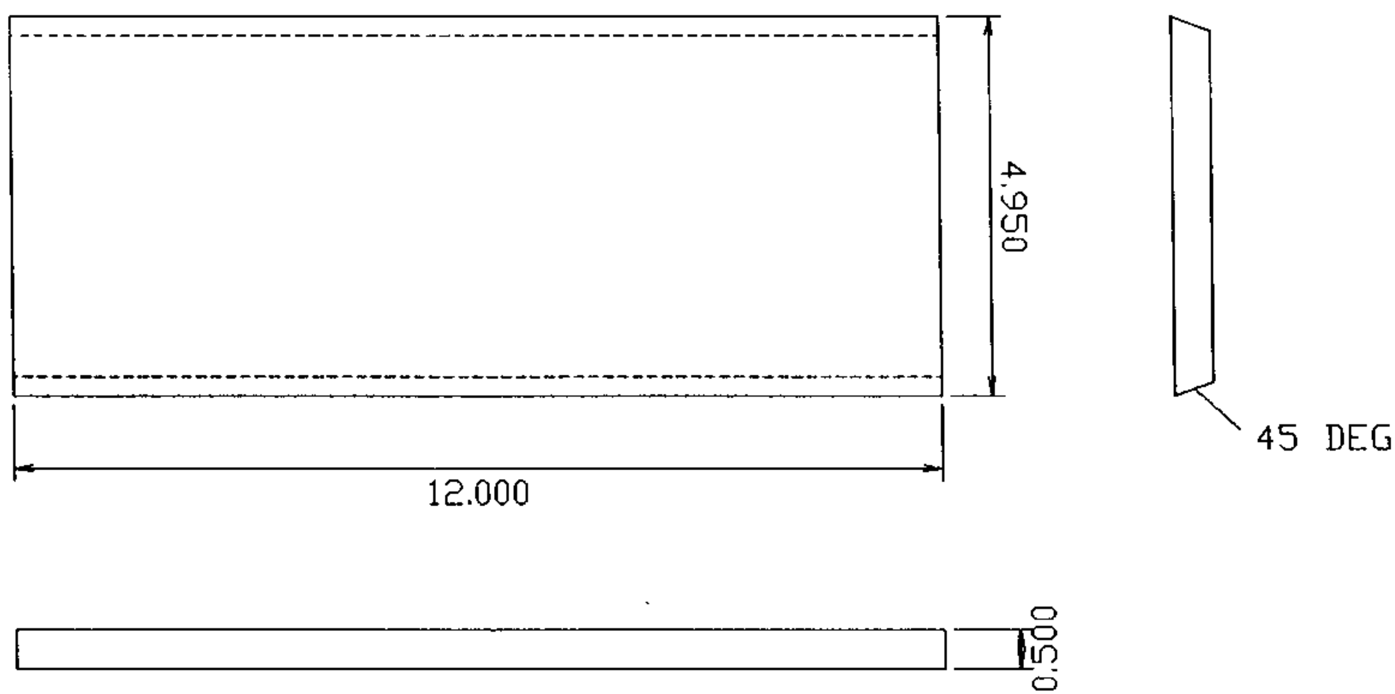




SCALE 1"= .54"

ALL DIMENSIONS IN INCHES

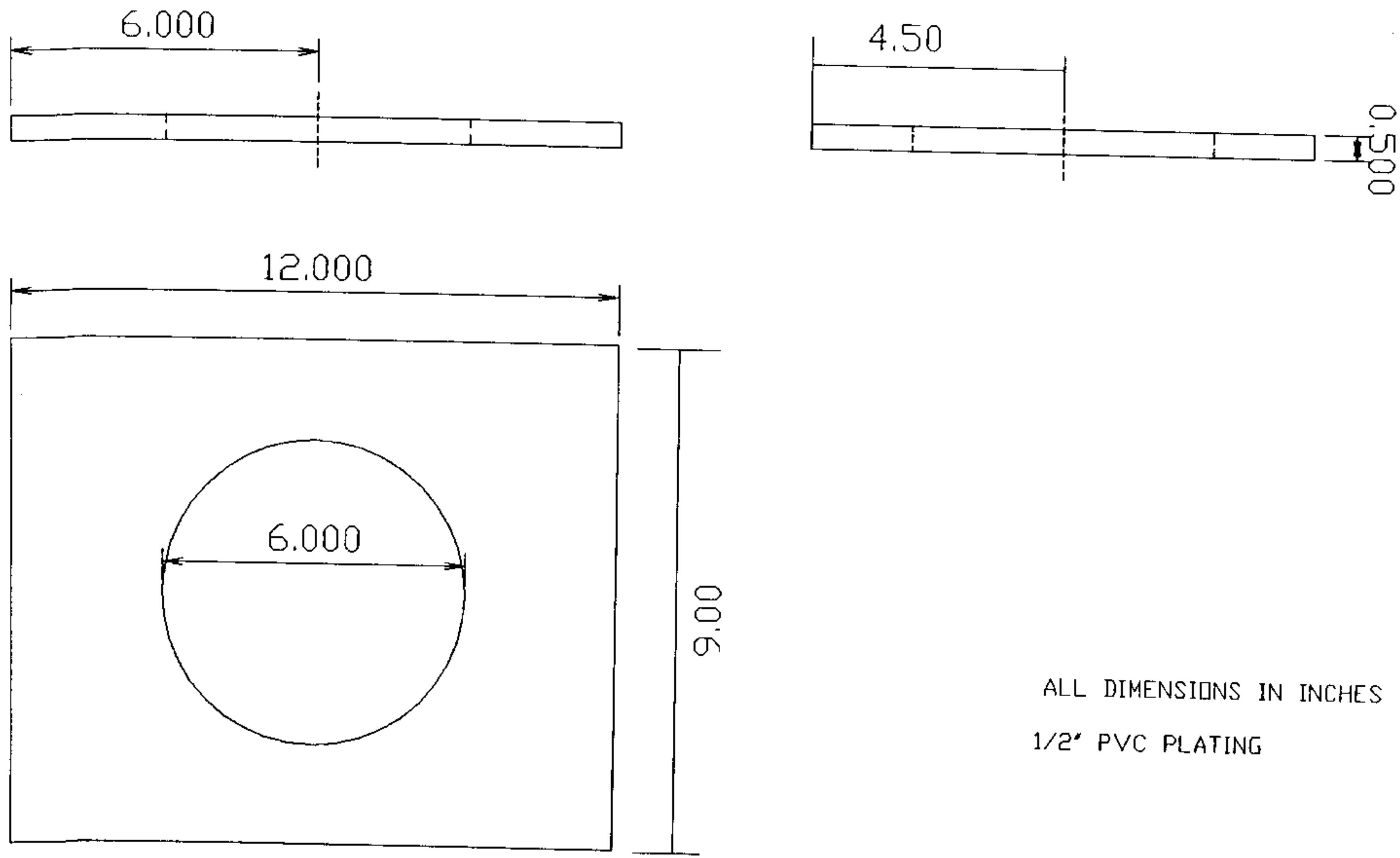
FRONT PLATE



SCALE 1"=.5"
ALL DIMENSIONS IN INCHES

1/2" PVC PLATING

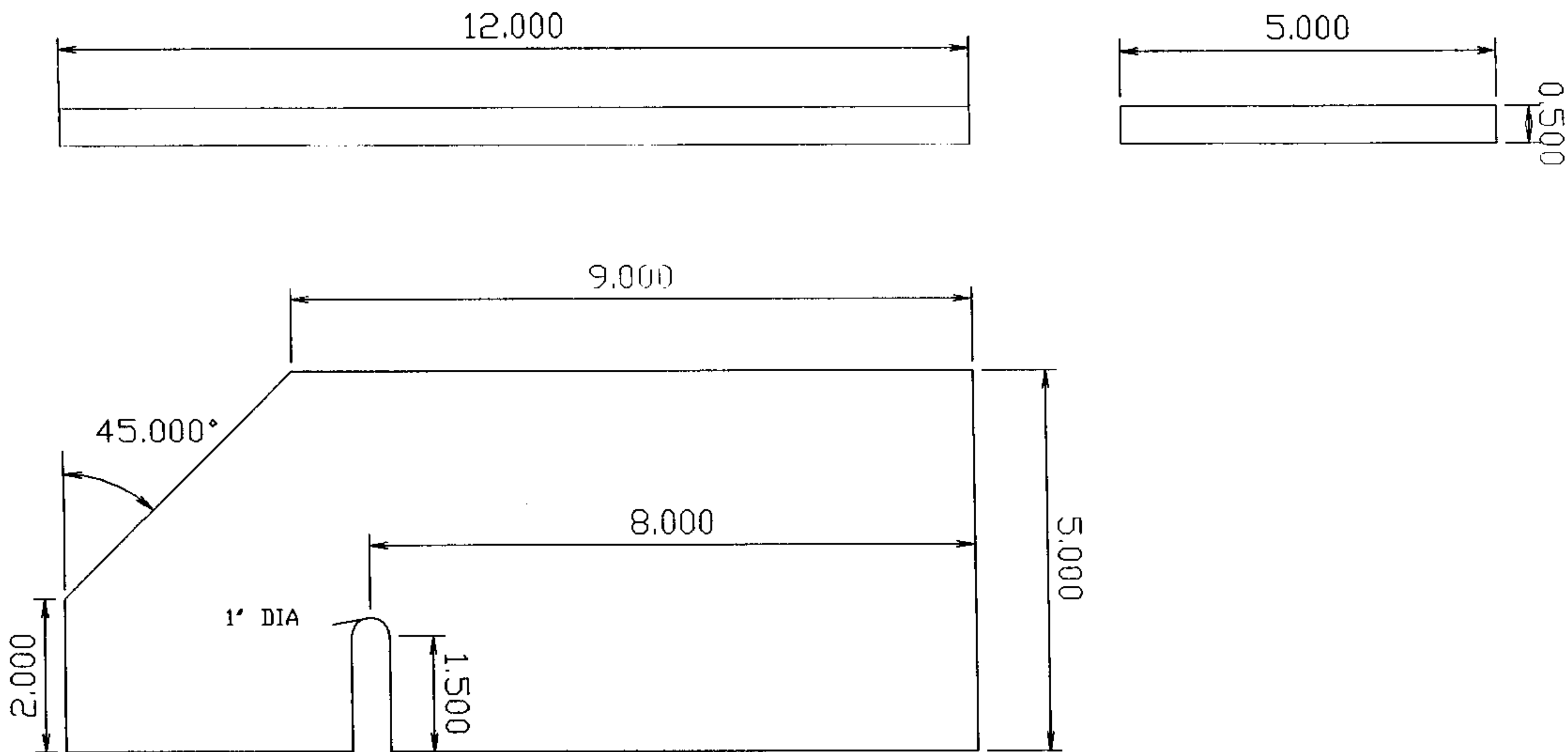
TOP PLATE



ALL DIMENSIONS IN INCHES

1/2" PVC PLATING

SIDE PLATES

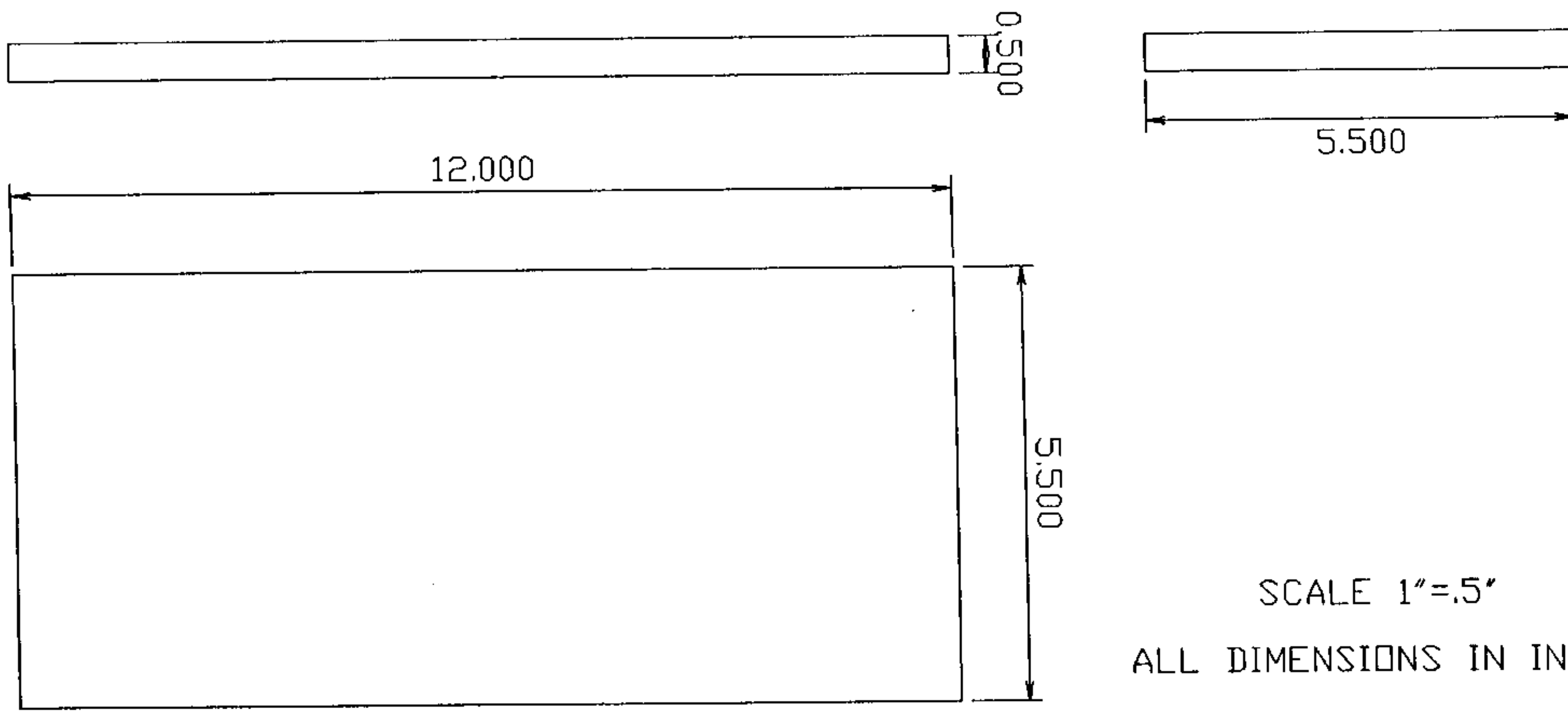


SCALE 1"=.5"

ALL DIMENSIONS IN INCHES

1/2" PVC PLATING

BACK PLATE



SCALE 1"=.5"

ALL DIMENSIONS IN INCHES

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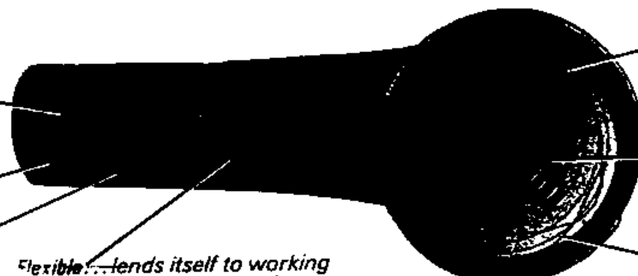

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***Economical**... initial cost is low, and Kanaflex is almost maintenance-free, to save you money in the long run.*

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1	1.34	0.30	1.9	50	220	29.8	0.23
1¼	1.65	0.33	3.2	50	220	29.8	0.34
1½	1.84	0.35	3.2	50	220	29.8	0.40
2	2.43	0.39	5.2	50	190	29.8	0.67
2½	2.94	0.56	5.6	50	190	29.8	0.92
3	3.52	0.59	7.1	43	150	29.8	1.10
4	4.61	0.65	11.0	38	140	29.8	1.84
5							
6	6.69	0.87	20.0	23	100	28.0	3.07

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SPECIFICATIONS:

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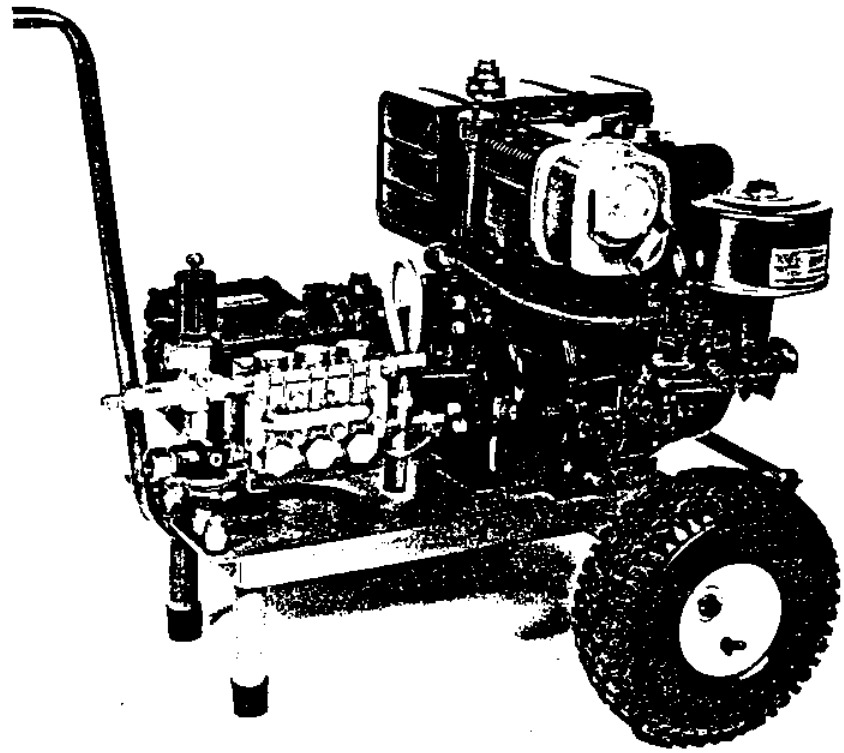
DISCHARGE CAPACITY	GPM	5 GPM	4 GPM	4.5 GPM
OPERATING PRESSURE	PSI	2,200 PSI	2,200 PSI	3,000 PSI
ENGINE:		BRIGGS AND STRATTON INDUSTRIAL COMMERCIAL		
RATED HORSEPOWER	HP	11	8	11
ENGINE WARRANTY		2 YEARS	2 YEARS	2 YEARS
LOW OIL PROTECTION		OIL GUARD	OIL GUARD	OIL GUARD
FUEL:		REGULAR OR UNLEADED		
FUEL TANK CAPACITY	GAL.	1.50	1.50	1.50
STARTING:		RECOIL ROPE START		
PUMP:		GENERAL TRIPLEC CERAMIC PLUNGER H.D. OIL BATH GEAR DRIVEN 2:2 TO 1 RATIO		
UNLOADER VALVE:		PRESSURE REGULATING, VARIABLE P.S.I.		
HEAT/INLET RELIEF VALVE:		RELIEVES HEATED WATER DURING BYPASS		
WATER STRAINER:		80 MESH STAINLESS STEEL IN LINE		
HIGH PRESSURE HOSE:		3/8" I.D. X 50' STEEL WIRE BRAIDED, OIL & CHEMICAL RESISTANT 3,000 PSI WORKING		
GUN:		TRIGGER CONTROLLED, 4,000 PSI RATED INSULATED W/ SAFETY LOCK OFF 36" WAND		
NOZZLES:		FOUR (4) 0 DEG. 15 DEG. 25 DEG. 40 DEG.		
BASE PLATE:		3/16" HIGH STRENGTH STEEL. ENAMEL PAINT		
WHEELS:		410 / 350-4 2 PLY PNEUMATIC		
HANDLES:		FRONT AND REAR LIFTING		
WARRANTY:		TWO YEARS ENGINE AND PUMP		
DIMENSIONS:	L X W X H	41" L X 24" W X 27" H		
NET WEIGHT:	LBS.			
SHIPPING WEIGHT:	LBS.			
OPTIONAL:		ELECTRIC START, STATIONARY (SKID) MOUNT		



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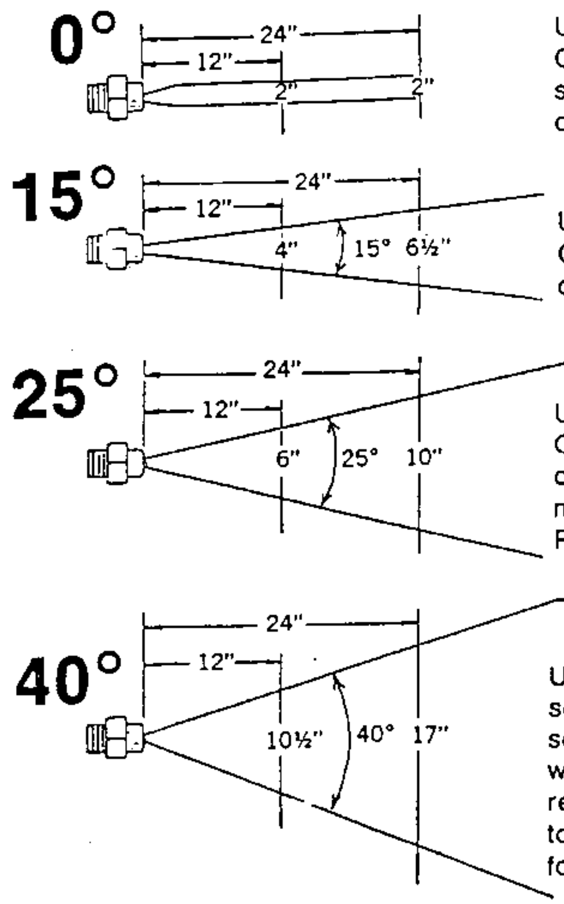
HIGH PRESSURE SPRAY TIPS

Width of spray pattern's at a distance of 12" and 24" from the tip.



0° — Used primarily for blasting. Gives highest impact per square inch surface area covered.

15° — Used for heavy duty cleaning. Gives high impact with good coverage.

25° — Used for general type cleaning Gives high impact with maximum coverage. Most popular washing nozzle. Fits the natural Pattern of most washers.

40° — Used for application of chemical solutions and/or cleaning moderately soiled surfaces. The best washing nozzle. However, requires practice to learn to use. Not for the novice.

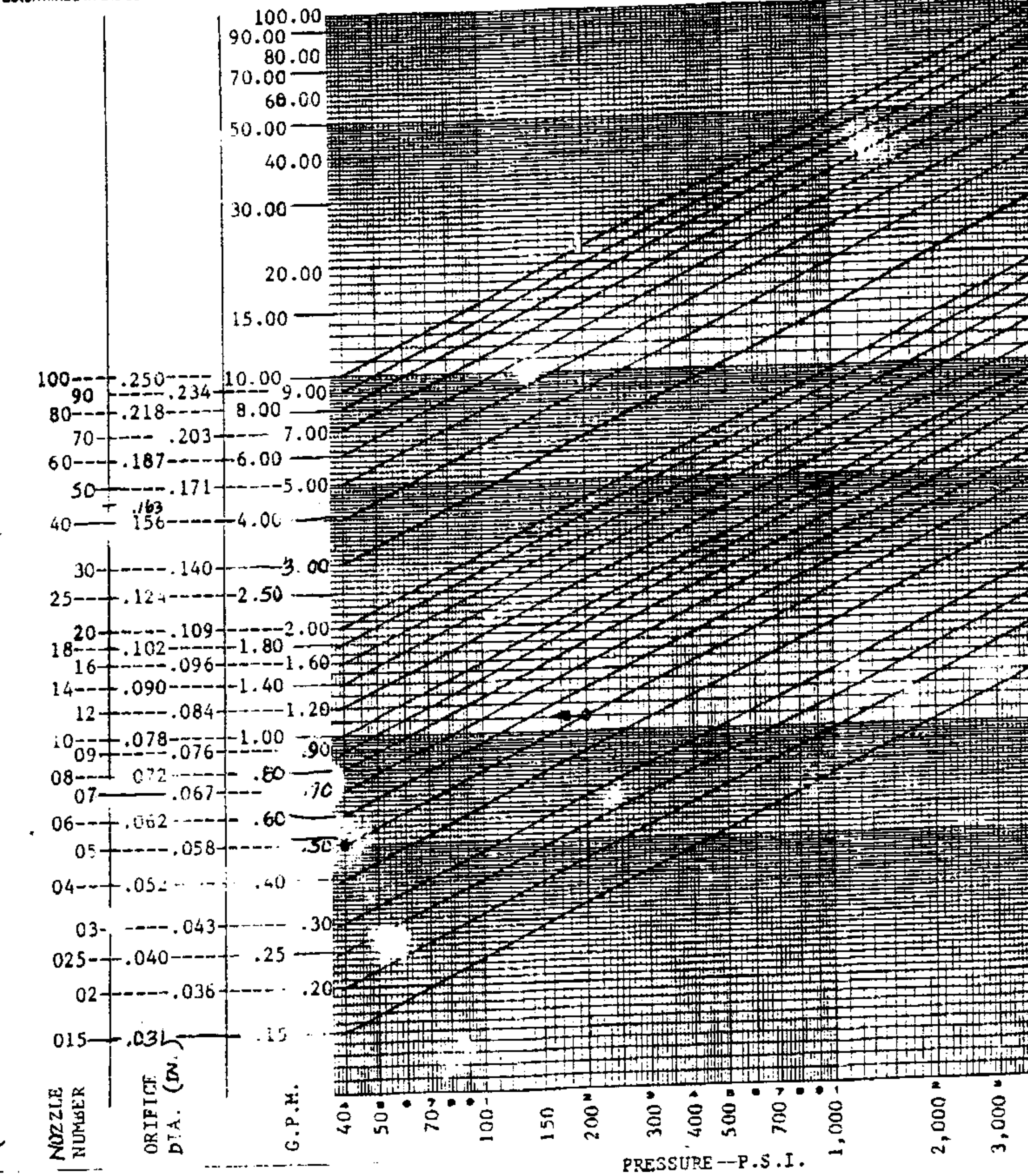
NOZZLE PERFORMANCE CHART

For quick determination of NOZZLE (TIP) capacities in gallons per minute (GPM) at various pressures (PSI)

HOW TO USE:

This chart begins at 40 PSI, the most common standard at which nozzles are calibrated. Slanted lines indicate nozzle performance at pressures to 5,000 PSI. The correct slanted line is chosen by orifice number, orifice diameter, or GPM rating appearing in left vertical columns.

EXAMPLE: Your nozzle is rated 0.5 GPM at 40 PSI and you desire to find its output capacity at 200 PSI. Follow the slanted line which intersects 0.5 GPM 40 PSI vertical axis to 200 PSI vertical axis. Read left across horizontal axis to GPM scale. The capacity of this nozzle at 200 PSI is 1.10 GPM. Performance determined in the same manner for a known nozzle orifice number or orifice diameter.



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