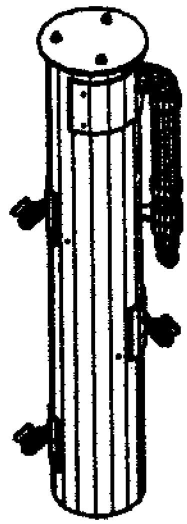
WINNOW

A Self-Contained, Autonomous Plankton Collection, Sorting, and Storage System



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WINNOW *vb*, to separate the desirable from the undesirable; to filter

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I Introduction

One of the most important species for commercial fishing in New England, the Atlantic Cod (*Gadus morhua*), has seen a decline in numbers in the 1990's. In 1991, 92.2 million pounds of Atlantic Cod were landed, but 1992 evidenced a catch of only 61.2 million pounds; a decrease of 33%. These numbers pertain to Atlantic Cod, however, they are representative of many other species' populations which have shown a decline as well. Catch numbers recorded by the North American trawl fishery indicate a drastic reduction in the amount of fish that are being landed as a peak of almost 500 million pounds in 1983 has given way to total landings of 219 million pounds in 1992. This decline in landings is even more remarkable when one considers that fishing effort increased over the same period of time (Anonymous, 1993). Landing statistics make it clear that cod, and several other commercially exploited species, are at record low levels. While there are fishery management plans designed to help rebuild these population, there is presently a scarcity of product selling at high prices to the consumer. Compounding the lack of supply is an increase in consumer demand for fresh seafood. Thus we have a wide, and growing, gap between supply and demand.

One way to bridge the gap between supply and demand is to produce more fish through aquaculture. This practice, which is essentially the aquatic equivalent of agriculture, involves growing the fish in captivity under controlled conditions. While aquaculture has been practiced on small scales for several centuries, over the last 25 years it has matured into an important industry. This has occurred through improvements in science and technology that now make it possible to grow several species cost effectively. Continued growth of the industry, particularly through the domestication of additional species, will depend on further research and on reducing production costs even further.

There are several steps involved with raising a marine fish species. The process begins with the collection of eggs and sperm, either from captive broodstock or from wild caught fish. Fertilized eggs are incubated for several days depending on species and incubation temperature. Newly hatched larvae exist on an endogenous source of nutrients (yolk-sac) for several days, but once this is exhausted they must begin feeding on small food particles. As the fish grow beyond this first-feeding stage, the size of food particles increases in proportion to their body size. After a period of time ranging from months to years, depending on the species, the fish are ready for harvest. For most species, the most technologically difficult and expensive stages in aquaculture is supplying the appropriate first feeding diets. Unlike freshwater species, most first-feeding marine fish larvae have poorly developed digestive systems that are incapable of digesting formulated (man-made) diets (Bisbal and Bengsten, 1995). For this reason, it is essential that live prey be provided. These are typically small zooplankton including rotifers and brine shrimp nauplii. Thus, most commercial marine fish hatcheries must culture zooplankton in addition to the fish. This is further compounded by having to produce phytoplankton to feed the zooplankton. Thus the requirement of live larval foods adds a substantial amount to overall production costs. While some of the increased cost is associated with additional labor, some are associated with improving the nutritional quality of the live, cultured prey. Both rotifers and brine shrimp are deficient in fatty acids, which are essential for cell membrane formation and function, as precursors for hormones, and as activators for certain enzyme systems (Watanabe et al., 1983; Kanazawa, 1985; Watanabe, 1993; van der Meeren, 1993). To improve fatty acid content, they are typically enriched with commercially available emulsions of fish oils (Watanabe et al., 1983). These add high amounts of highly unsaturated fatty acids making the prey more nutritious, but they also add to the overall cost of hatchery operation.

An alternative to the production of live food, and its associated cost, is to use wild zooplankton as a first-feeding diet. It is far superior to cultured food in its nutritional profile (Nass et al., 1987; van der Meeren, 1991; LeRuyet et al., 1993), and is essentially "free for the taking". Unfortunately, collecting sufficient amounts of wild zooplankton to support a commercial scale hatchery is presently not cost effective, since the traditional means of collection with towed plankton nets would require enormous amounts of time. Additional time would be spent sorting (sieving) the prey to sizes appropriate for different sized larvae.

The overall goal of this project was to design and test a system capable of autonomously collecting, sorting, and storing large amounts of wild zooplankton. It was hoped that the development of such a system would enable wild zooplankton to be used in commercial scale marine fish aquaculture operations.

II Project Outline

A list of desired parameters were developed which the system must meet. Each parameter will be thoroughly explained as to its relevance, importance, and need. These requirements were determined from the existing cod hatchery and extrapolated to meet the desired level of cod development in the future. This system will need to be able to collect sufficient amounts of plankton to adequately supply food to a desired amount of cod to be raised in the hatcheries.

Three size ranges of plankton are desired: 80 - 250 microns, 250 - 500 microns, and greater than 500 microns, for three stages of cod larvae growth. The plankton need to be collected, sorted and stored in such a manner that they can be easily accessed for research or to feed the cod when necessary. Ideally, the system will be modular. This will make it easy to maintain and adjust as well as allow it to have interchangeable parts which can accommodate several desired applications. This will make it easy to maintain for routine cleaning in case a screen is clogged or torn and needs to be rinsed or removed. Interchangeability allows the system to be adjusted to provide alternative uses. Essentially, these features make the system user friendly.

Safety is also very important, therefor simplicity is an important factor. This will improve the reliability of the system as well. The number of moving parts will also play an important roll in safety, reliability, and user friendliness.

An efficient system is desired. The reason for this is that the power will be supplied from a remote source; generator, battery, solar power, etc..., and required power will need to be kept to a minimum. The effectiveness of the system will be a major contributor to the efficiency of the system. The more accurate the sampling and sorting processes, the less water will be required to collect the desired proportions of plankton. Also, contributing to the effectiveness is the notion of being plankton friendly. The plankton are desired to be living in order to attract the attention of the larvae. The higher percentage of plankton which survive intact, the more effective and efficient the system is. The Winnow System should also be environmentally friendly, otherwise it would be counter productive for the purpose which it is intended.

The overall cost of the unit must be considered. Depending upon the final design, the cost of individual parts will be distributed to benefit the continuous operation and maintenance of the system over time. At the same time, the system will need to be corrosion resistant. It will operate in a materially harsh environment. The lifetime of the system needs to be sufficient enough to justify its production.

The mechanical stability of the system also needs to be considered. It is anticipated that the filtration system may be subjected to swaying through a sixty degree arc due to waves from inclement weather and nearby passing transportation vehicles. The durability is also an important factor. The atmosphere around the system requires that it be able to withstand some abuse during maintenance and operation. Finally, the overall size of the system will be considered to best accommodate the desired factors listed, the space limitations determined by its final location of operation, and feasibility for human interaction.

III Objectives

There are several desired parameters which need to be addressed by the project team designing the plankton filtration, sorting, and storage system (Winnow). Each of these factors will be thoroughly evaluated to produce several methods which will accommodate the design requirements. These requirements can be divided into three separate categories: cod rearing, biological, and engineering objectives. Each set of objectives are tightly linked and dependant upon each other. The cod rearing objectives are presented within the project outline. The biological objectives are the desired applications for the system. The engineering objectives are the desired goals determined from the cod rearing and biological parameters.

The main objective for the biological aspect of the Winnow is to run tests and observe the efficiency of the Winnow once it is built. This includes tests of both a prototype and final model. The number of organisms passing through the screens as well as the size of each will be recorded. From these numbers, it will be possible to observe the efficiency of each sized screen by seeing which organisms should be there and which should not, according to their measured sizes. Furthermore, the collected plankton can be used for further study, or can be fed directly to the cod. The overall efficiency of the Winnow will be determined and will be modified as deemed necessary to increase its efficiency. Finally, data will be analyzed for both the Winnow and plankton tows. The data will be compared to see if the Winnow does in fact do its job of being more efficient.

Secondary goals include educating ourselves about plankton characteristics, including diurnal movements, population numbers, and vertical migrations. This would enable us to make a more efficient Winnow system that would be able to optimize the number collected. This will be achieved through various collection at: different times of day, different depths, and different locations. Not only would this information optimize how much is collected, but also where at what location it would give the best results.

The first design parameter to be evaluated will be to determine the volume of water required to collect sufficient plankton to sustain the quantity of cod larvae to be cultured. The pump and intake system can then be determined to most effectively collect the plankton without harming them. The most efficient method of filtering and sorting the plankton can then be determined. An appropriate storage facility can then be administered. Finally, the required power can be determined to operate the Winnow System.

- Intake Requirements

  The intake requirements are dependant upon two primary parameters: plankton density and desired number of plankton. The Winnow System will need to be operational only during the seasons during which plankton are reasonably abundant. This period, late spring through early autumn, corresponds to the cod larvae growth cycle which is of interest. The plankton density varies greatly during this period. At times, the desired number of plankton will require several hours of collecting, while at other times, it will only require several minutes. It is important that the intake system be sufficient to accommodate the maximum case of these possible situations.

- Pump

The significant limiting constraints for the pump are its corrosion resistance and its effects on the plankton as they pass through the impeller. Research determined that pump lifetimes are significantly lower than required for cast iron pumps used in the ocean environment. Also, pumps specifically designed for use in these elements, made of titanium, stainless steel, plastic, or other non-corrosive material, were either too expensive or were not designed for the desired flow rates determined for this application.

- Filtering

The filtering process is the most delicate operation in the system. The plankton are so highly concentrated at times that clogged screens are a highly probable occurrence. At other times, the lack of plankton density may cause severe run-off of smaller plankton into the larger collection areas. Also, the filtering process is possibly the most abusive to the plankton because this is where they are being caught. In the pump it is important for the plankton to pass unmolested, however during filtering they will be traveling at an accelerated pace and need to be redirected without harm. There are several possible methods of filtering using different screen orientations and geometries to insure the safety of the plankton.

- Sorting

Separating the plankton into desired size ranges is the most important feature of the Winnow Project. Single size plankton collectors are currently available on the market, however it is desired to have three size categories for filtered plankton. The desired range of sizes may change for different applications. For this reason, it is desired to have a system which is adaptable or even interchangeable. This may be accomplished in one of two general methods. One way is to collect all sizes of plankton together, as current systems do, and develop an apparatus to sort the concentrated plankton. The other way is to filter the plankton multiple times, in a series of decreasing mesh size filters, and distribute them individually.

- Storage

Storing the plankton locally has several advantages. Without storage ability, the hatchery administrators will need to predict the plankton density in the ocean to determine the appropriate length of time the collection system will need to operate to adequately supply the larvae with food. The cod larvae will be fed following a strict time schedule, therefor it is necessary to determine alternative solutions to help balance the plankton supply throughout the season. The simple solution to this problem is to store plankton locally and use this consistently replenished supply of fresh, live plankton to feed the larvae.

- Power

The power for the Winnow System is determined primarily be the pump requirements. There are some possible subsystems such as a back wash or other applications which may also need to be powered. These requirements will be negligible in comparison to the pump. The power supply will need to be remote to allow flexibility in the location where the system will be implemented. It will also need to be housed to protect it from the harsh environment.

IV Preliminary Design Alternatives

A series of design possibilities were developed to perform the desired operations described previously. From the initial sketches, five designs were determined to be applicable and were further developed into possible working models to be judged for the final design. The designs which were not further developed were determined to be inappropriate and did not qualify for further investigation. The five designs selected were given names, a fully detailed sketch, and a description of their mechanical process. A decision matrix was developed by the Winnow Team to evaluate the performance of each design with regards to the desired operational standards presented earlier.

1. Discfilter

The discfilter (Figure 1) is so named because it is made up of a series of rotating discs. The concentrated sea water would enter on the right hand side of the apparatus. The larger plankton would be collected with the first screen, and each decreasing size thereafter. The screens would rotate using friction and pressure to lift the plankton out of the water. At the top of the screen, the plankton would be back washed onto trays which would carry the concentrated, sorted plankton to a desired location. The back wash would be provided by the filtered water exiting the system so that the particulate matter would be minimal to prevent clogging the screens and contaminating the system with unfiltered water.

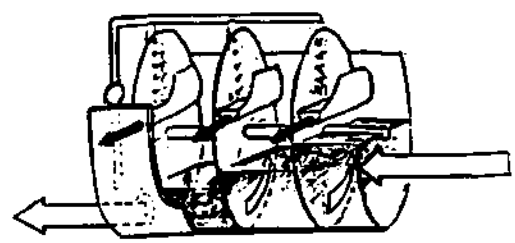


Figure 1. Discfilter

2. Funnel Filter

The gravity funnel filter (Figure 2) simulates the operation of the tow filtration which is currently used for plankton collection. The tow filtration system uses a conical mesh with a cup at the apex to collect the plankton. In this system, the water is pumped to the top and falls through a series of filters. The plankton are collected by tubes at the bottom of the filtering mesh while the smaller particles and filtered water continue to the next filter. To prevent the water from funneling straight to the bottom of the filter and out the distribution tubes, a plastic cap will be located above the collection area to distribute the water horizontally and through the screen. The concentrated plankton can be distributed as desired.

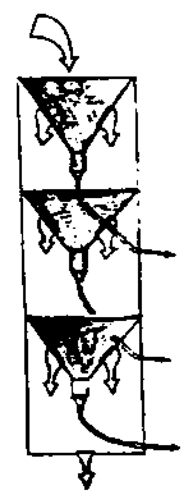


Figure 2. Funnel Filter

3. <u>Valve Controlled Filter</u>

The valve controlled filter (Figure 3) is a simpler series of filters place at the intersection of crossing pipes. When the valves are in the first position, the water flows in the left hand side and is filtered three times. At determined time intervals, the valves switch and the back wash is pumped perpendicular to the original flow. This water removes the collected plankton and disperses it to desired storage locations. The valves are then rotated back to their original positions to filter again. The valves will be controlled by a microprocessor located on board the system.

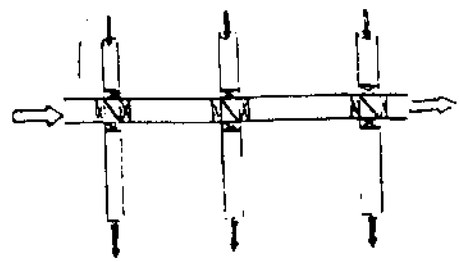


Figure 3. Valve Controlled Filter

4. <u>Drumfilter</u>

The drumfilter (Figure 4) is also commercially available for single size collection. It consists of three concentric drums made of the desired mesh sizes. The water enters the system in the center and falls through each rotating filter. Each drum screen rotates and carries the plankton to the top where the screen is back washed onto a channel. The plankton can then be distributed as desired. Similar to the discfilter, the back wash is provided by the filtered water. Recycling this water is more effective and prevents clogging and contamination within the system.

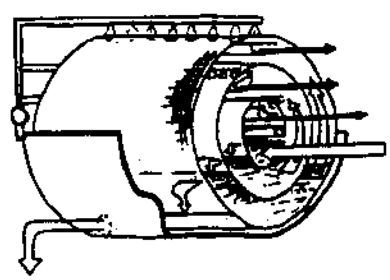


Figure 4. Drumfilter

5. <u>Belt Filter</u>

The belt filter (Figure 5) is a series of scoops made of desired screen sizes attached to a belt. Each scoop carries the plankton to a channel where it is removed and distributed as desired. The tray of plankton is back washed to ensure full removal of all the plankton. The water enters the system at the left and passes through each section. In addition to the scoop filters, the water is filtered between sections to ensure only the proper size plankton are collected and distributed to a desired location.

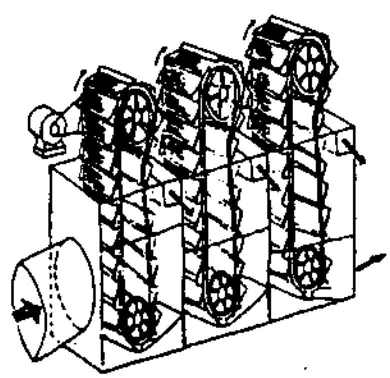


Figure 5. Belt Filter

To compare and analyze the five initial designs, a decision matrix (Table 1) was created. Initially, a series of objectives and parameters were determined to be important factors to be considered in the design and operation of the system. They were determined from requirements established by the cod hatchery and from features desired by the Winnow Team and its advisors. Each of these parameters were rated individually using a scale from one to ten; one being of little importance and ten being most important. The final rank of each objective was determined by averaging the score from the team members. Next, each of the preliminary designs were evaluated by each team member and were rated as to how effectively that design met the desired standards determined previously. Again, a scale from one to ten was used and then averaging the rating of all team members. The overall value for the category was determined by multiplying the rank of the parameter to the rating it achieved. The sum of all category ratings constructed the total score of the design.

		Discfilter	Funnel	Valve	Drumfilter	Belt
0.87	Corrosion Resistance	7.22	8.38	6.93	7.51	7.51
0.83	Cost	4.17	8.06	5.28	3.61	3.61
0.80	Durability	5.33	6.93	4.53	5.87	4.00
0.93	Effectiveness	8.71	7.47	4.67	8.40	5.91
0.83	Efficiency	7.22	7.50	6.39	6.67	4.72
0.73	Environmentally Friendly	6.36	7.09	6.60	6.11	5.87
0.83	Maintainability	4.72	7.78	5.28	4.72	4.17
0.73	Minimal Moving Parts	3.67	7.33	3.67	3.18	2.20
0.90	Plankton Friendly	7.50	8.40	7.50	7.20	7.20
0.87	Reliability	7.22	7.22	4.91	5.78	5.20
0.87	Safety	7.80	8.09	7.80	6.64	6.36
0.57	Size	4.16	4.34	5.10	3.59	3.40
0.73	Stability	5.87	5.38	7.09	6.11	5.62
0.90	User Friendly	7.20	8.10	6.00	7.50	6.60
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1. Decision Matrix

The rank of each parameter is listed to the left of its name. The best possible score for a design would be 11.4 if a system was rated with a ten for each parameter by each team member. It can be seen from the data in Table 1 that the funnel filter best fulfills the requirements determined for the operation of the system. Its score of 8.95 is clearly better than any of the other design options. The funnel filter will be critically evaluated to determine if the design will be successful. A scale model will be constructed and tested to perform the evaluation. This model will take into consideration any design changes which may make the system more applicable. Should the design fail to successfully meet the desired criteria, the second choice, the discfilter, will be evaluated. A similar design is currently marketed, therefor the Winnow Team is confident of its ability to perform the necessary functions adequately.

V Design Selection and Optimization

The design selection process has determined that the funnel filter design most completely satisfies the desired attributes outlined previously. A complete analysis of the feasibility of this design was performed to determine the optimum design for both collecting and sorting the plankton.

The initial design was altered slightly during the optimization process. The first change was related to the filters. It was determined to be impractical to use conical sections for each filter. These were determined to be the source of several problems. First, the tubes which collect and distribute the plankton need to have access to the exterior of the system to distribute the plankton. This became difficult because the three proposed solutions were all determined to be unreasonable. The first possible solution was to run each plankton removal tube through the following tube. This would be difficult to do if the system should need to be disassembled for maintenance. The next solution was to send the tube through the side of the following funnel section by cutting a hole in the filter and sealing around the exiting tube. This is impractical because of the difficulty in maintaining a reasonable seal and because of the added difficulty in maintenance. Finally, the third solution was to stack the filters far enough apart to allow the run off tubes enough space to exit the system without interrupting the next filter. This is unacceptable due to the steep angle of the funnels. One of the initial features which made this system so accommodating was its ability to stack the funnels within each other to conserve space. To stack the funnels atop one another would make the system very tall which would hinder its stability.

The solution to this first problem was to change the funnel design to a flat screen which would be placed at an angle to the vertical which would allow the water to filtered while the plankton would run off the end and be collected outside the filter system. Each screen would act similar to a portion of the funnel design filter. Instead of having a full 360° conical section, the screen would be comparable to a small angle of that filter. This new design was determined to be more feasible and practical as well as more adaptable for future considerations. This design was used for the scale test model to determine several parameters including: flow rate, frame size, screen angle, and collection tube size.

All of these parameters are dependant upon each other, therefor it would be very difficult and time consuming to attempt to perform a series of tests varying a single variable and holding the others constant. Instead, limits were placed on each parameter which the Winnow Team deemed to be competent estimations for the final design. Reynold's Scaling was used to compare the results from the scale model to determine the final model design parameters. Initially, to determine the scale model size, a desired flow rate was estimated. This was performed using estimated data from several plankton tows. The volume of water needed to be filtered was determined by estimating the volume which was actually filtered, the number of plankton collected, and the desired number of plankton for a specific feeding (Appendix B: Reynold's Scaling). The model flow rate was determined to be greater than 17.5 gallons per minute (66.25 liters per minute) for a four inch diameter frame size. The model was constructed with screen angles at 45° and standard ½ inch flexible tubing was used for the collection and distribution.

Pepper was used to model the plankton due to the lack of plankton available in the local waters during the winter months. Pepper was selected due to its availability, flexibility, buoyancy, and visibility. Pepper is very common and can be ground into any desired particle size. It is light and was determined to have similar characteristics to plankton when subjected to water. Also, the pepper is very visible in water to assist in the test procedures. Being able to visualize the processes was very helpful to alter parameters and see the effects immediately without full analysis. Initially, micro balloons were desired to model the plankton. This was recommended for the same reasons that the pepper was a good model. The advantage to the micro balloons is their uniformity. The sizes are known to be within a certain range. Also, they are available in several colors to increase the effects of visualization for testing as well as for demonstration purposes. This option was discarded when it was determined that the sizes required were not available from a single manufacturer. The cost and complication of purchasing through multiple vendors was determined to be greater than the benefits.

The initial tests were comprised of three measured samples of the pepper in its three different sizes. They were combined in a volume of water which was poured into the top of the model at approximately the calculated rate determined from the Reynold's Scaling. The three filtered sections were analyzed to assess the concentration and accuracy of the filtering. The results were positive but did not meet the desired standards. It was determined that too much of the smaller particulate was bing filtered prior to reaching its final destination at the bottom of the model. It is believed that this may be due to a film of water creating a barrier along the top of the filter screen and redirecting the flow along the mesh and not through it. One possible solution for this problem was to decrease the screen angle to keep the water from rushing out the collection outlet directly. Another solution was to reduce the exiting flow with smaller outlet tubes and give gravity more opportunity to overcome this action. The third solution was to control the incoming flow and force it to begin near the top of each filtering screen so that the entire mesh would be utilized. Finally, because the occurrence was observed primarily at the first screen, the flow may be dispersed upon entering the system so that it does not have as much momentum down along the screen.

To test the effects of varying screen angle, a sample of the largest filter screen (500 μm) was placed over a wire mesh for stability. The pump was run and the flow was directed across the mesh. The angle was varied while the effects on the flow direction and filtering were viewed. The results showed that the optimum screen angle was at 50° from the horizontal. At this angle and the large flow rate, the water was filtered effectively with just enough run-off to keep the plankton from building up and clogging the screen.

Varying the collection tube diameter was not possible with the test model. The initial exit holes had been made, and the previous tests showed that the exit diameter should be reduced. There are no means to reduce the size of the holes which were already present which would produce confident results. To allow for variability in the final model, the exit collection tubes will be fitted with valves which can vary the flow resistance. Testing of the final model will determined the optimum setting for each individual valve to create the most effective system.

Another possible solution to control the excess flow from the first collection tube was to control the flow as it approaches each screen. This was accomplished by inserting diverters after each filter which redirects the flow towards the top of the next filter. This helps the filtering process by insuring that the entire screen is utilized. Also, the flow is being dispersed horizontally so that it has less tendency to flow in a laminar fashion along the screen. Instead, it will fall chaotically which is more suitable for filtering.

Finally, as the water enters the system at the top, it can be dispersed using a diffuser. This apparatus is comprised of a fibrous poly-mesh held between two solid plates. The bottom plate has three holes which allow the water to flow out over the top of the first screen in the same manner as the diverters. At the same time, the diffuser aerates the water which is better for the plankton and also benefits the filtering.

	Mesh Size		
	80	250	500
March 7			
Mean Size	176.50	259.00	476.50
# Copepods	0.65	2.68	1.55
# Barnacles	0.33	6.94	3.10
Efficiency	**100%**	**50%**	**60%**

	Mesh Size		
	80	250	500
April 4			
Mean Size	205.50	339.75	1504.00
# Copepods	0.87	0.67	0.15
# Barnacles	1.23	1.87	0.06
Efficiency	**100%**	**95%**	**100%**

April 4			
Mean Size	204.50	378.50	1555.00
# Copepods	0.45	1.05	0.23
# Barnacles	0.53	0.58	0.15
Efficiency	**100%**	**95%**	**100%**

April 4			
Mean Size	200.00	308.50	N/A
# Copepods	0.18	0.74	N/A
# Barnacles	0.12	0.95	N/A
Efficiency	**100%**	**100%**	**N/A**

Table 2. Scale model test results: Plankton densities (values are plankton per liter)

Further testing of the scale model (Table 3) produced more favorable results. For this set of tests, the model was used at the Coastal Lab and filtered plankton instead of pepper. The March 7 test shows the greatest deviation. This is expected due to the lack of plankton available during this time of year. The April 4 test was performed without the presence of the 500μ filter to analyze the effect of the first screen efficiency. The mean size was determined for each test as well as the approximate plankton density (Appendix B, Plankton Density). The density is measured in plankton per liter.

The plankton was collected and a sample was taken from each size storage container. The efficiency was determined by counting the number of plankton which should be found in a different collection container. For example, plankton from 80μ to 250μ should be found in the smallest collection. If a larger plankton was discovered, it should have been filtered previously, and therefor, is considered an error. The sample sizes for each test varied, but the overall efficiency was nearly 80%. This marked improvement was enough evidence to proceed with the final model.

VI System Components

The final model (Figure 9) incorporates several of the design modifications suggested previously. To simplify the process and design of the Winnow System it is divided into several subsystems. Each of these are listed below with an explanation of the function. All designed subsystems include a detailed assembly drawing (Appendix A) and instructions.

Filtering and sorting are the primary processes of the system. These are composed of several individual components. These begin with the pre-pump filter which eliminates the possibility of massive debris affecting the system. The pump, the inlet, the diffuser, which aerates the water and removes energy from the incoming water to protect the filters, are other important components. The filter screens, the frame, a supporting base, the storage containers, and the power supply are the rest of the components which complete the system. Each of these parts ware built or determined around the primary filtering section to create the optimum design for efficiency while fulfilling all the requirements derived earlier.

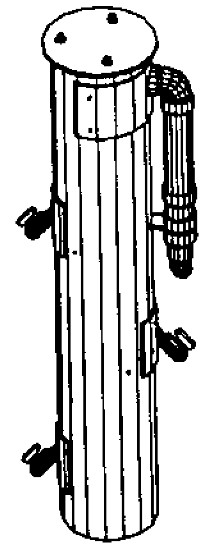


Figure 6. Final Winnow Design

Pre-pump Filter

The water entering the pump is initially filtered to keep any excessive debris from entering the system. Anything too large could be potentially dangerous to the system and harm the pump impeller or filter screens. To alleviate this problem, the pump is surrounded by a nylon mesh which is sealed around the pump using plastic ties to hold it in place. The mesh is approximately ¼ inch. This is open enough to keep from negatively effecting the pump performance without becoming clogged with debris while filtering out any substance which may be damaging to the system.

Pump

The pump was chosen using several design requirements to narrow the possibilities. A flow rate of 100 gallons per minute was determined to be the minimum required flow rate necessary from experimental data (Appendix B) from the scale model as well as research on the population dynamics of plankton. The limitations imposed upon the pump selection, flow rate, corrosion resistance, cost, etc., made the search for an accommodating pump very difficult. The Winnow Team finally decided to select a Goulds Submersible Sewage Pump, model 3887. The pump is rated to 100 gallons per minute at fourteen feet of head and 160 gallons per minute at only 5 five feet of head. This is more than adequate to meet the desired needs of the system. The power requirements are minimal for the single phase motor. The pump requires ½ horsepower and 115 volts of output for operation. The casing is made of cast iron and the impeller is also cast iron. These are not the most corrosion resistant materials, however the lifetime of the pump is estimated at over five years in the ocean environment. This was determined to be an acceptable for the application. The cost of the pump (Appendix D) was above the anticipated, budgeted amount, however, again, this was determined to be acceptable considering the total budget limitations.

Inlet

The inlet section was designed to accommodate the extensive volume of water entering the system while reducing the velocity of the flow to protect both the plankton and the mesh screens. The pump outlet is two inches in diameter. The filtering system has a one foot diameter. To slow the incoming flow, the inlet pipe was diverged twice. The first diverging section changed to a three inch diameter section and the second section changed to a four inch diameter section. This reduced the velocity by a factor of four. One hundred gallons per minute traveling in a two inch diameter section of pipe travels at 10.20 ft/sec [122.55 in/sec]. This would undoubtedly tear through the screens. The reduced flow resulted in a flow rate of 2.55 ft/sec [30.64 in/sec] which is more realistic for this application. The inlet is fitted with a quick release connection to allow the cover to be easily removed for maintenance. It is also fitted with a standard y-valve to connect a hose which feeds from the pump and can be used for area maintenance or as desired.

Diffuser

The diffuser is another means to divert the flow and protect the filter screens. This is located at the top of the Winnow System and also acts as a cover to the mechanism. The mesh removes energy from incoming flow as well as aerating the water. This is also beneficial to filtering process by helping to disperse the plankton and keep them from forming large concentrated globs which may potentially harm or clog the filtering screens. The water falls out of the diffuser through three holes located above the top of the first filter to ensure that the entire screen is used to filter the plankton and increase the accuracy of the filtering screens. The flow rate from the diffuser is far smaller than it would be if the flow was corrected by simply diverging the inlet to the final frame size of one foot diameter. This flow adjustment would result in a rate of 0.28 ft/sec [3.40 in/sec]. The flow rate from this unit is only 0.23 ft/sec [2.77 in/sec]. This is a more efficient and effective method of reducing the flow rate.

Filter Screens

The size and shape of the filter screens are determined from the frame size and the optimum screen angle. The three sizes of screen mesh used for the cod hatcheries are: 80μ, 160μ , and 250μ. The screen assembly is removable from within the system for easy cleaning, maintenance, and replacement. This feature makes the Winnow System more versatile while reducing the cost of maintaining minor failures within the system. The Winnow System is adaptable because the filter screen assembly can be made with any size mesh available on the market. If the size requirements are different for a similar application, the Winnow System can be modified by simply changing screens and leaving all other parts the same. This is more cost effective than having a tool with only one use.

Also, it is expected that there will be occasional tearing of the screens for a variety of reasons. The ability to replace a filter allows the user more freedom by not having to wait as long for a new system, or having to use valuable storage for large, bulky replacement parts. It is also more cost effective because it saves on materials and construction.

Frame

The test apparatus was constructed of a frame which was modular. This was the initial solution thought to make maintenance and versatility a feasible option. It was determined during testing that this method was not optimum due to the number of leaks which were observed. The frame was constructed of PVC and was cut at the desired screen angle and clamped with the screen in place. The leaks were primarily due to thermal expansion. Due to this occurrence, it was determined that the frame should be of solid construction. This allows it to be used to mount the internal and external features. Having a rigid frame also increases the structural integrity and stability of the system.

VII Methods

There are two distinct methods to analyze the effectiveness of the Winnow System. The first way is to determine its efficiency at sorting the various size plankton, and the second is to compare the accuracy of the results to the tow collection method. The efficiency of the Winnow System was determined by comparing the sizes of the plankton in each collection to the expected size range of the filtering. Any observance which was outside the expected size range was considered an error. Comparing the Winnow effectiveness to that of the tow is slightly more complicated. This is performed by comparing efficiencies or , in this case, the mean size of each collection. Analysis of variance (ANOVA) tests were performed to evaluate the comparison. A p-value greater than 0.05 is representative of similar or equal means for a two sample test. Otherwise, it needs to be determined which method is more effective. This is easily determined by inspection of the data.

When a tow was performed, a standard 0.5m diameter, 80μ plankton tow net was dragged for 0.2 miles and analysis was conducted in the same manner as discussed above. The tow distance is used to approximate the filtered volume to compare to the Winnow System tests. The plankton was collected in a bucket and sorted using hand sieves to analyze each size distribution independently. The three sizes of sieves correspond to the filters for the Winnow System: 80μ, 250μ, and 500μ.

When testing the Winnow, the flow of the water through the system was 100 gallons per minute. As water passed through the system, it was filtered through 80, 250, and 500 micron screens and collected in 17 gallon containers.

Each sample was analyzed by adding 1 to 2 drops of 10% Formalin to a 1 milliliter sample from each container. The number of organisms were then counted using an Olympus dissecting scope, model S240, and then plankton were measured using an ocular micrometer where 0.10 cpu = 1 mm at zoom 1.0. The specimens were counted using a hand counter.

A series of tests were performed for the aforementioned purposes. Four species of zooplankton were found to be more abundant than all others and were counted independently. Two of these types, copepod nauplii and adult copepod, are of significant importance due to there nutritional value to the cod larvae.

On April 10, the Winnow System was run for 30 minutes. This same test was conducted on April 16 and 17. The system was run for 60 minute durations on these days. To simplify the results and discussion, these will be referred to collectively as Trial 1. The tests were performed to determine the efficiency of the Winnow System and determine if it meets the desired efficiency.

Trial 2 was performed on April 23. The intention of these tests were to determine the relative effectiveness of the Winnow System as compared to the existing tow collection method. The Winnow System was run for 120 minutes for these tests. This is approximately the same volume of water which was filtered by the tow. The data was analyzed by performing the ANOVA tests. The goal of the tests is to determine if the use of the Winnow System is sufficiently better or worse than the existing tow method.

The third set of tests (Trial 3), conducted April 29, followed the same format as the second trial. This set of tests were performed to determine the effects of changing the outlet resistance for the 500μ filter. This test was conducted to determine if the efficiency of the Winnow System could be further optimized by controlling the out flow from the filter screens. Again, the Winnow System was run for two hours, and the tow was 0.2 miles.

VIII Results

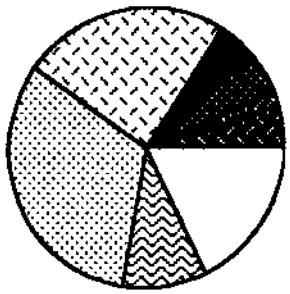
Trial 1 was an attempt to determine the efficiency of the Winnow System. These tests were conducted on three separate days, April 10, 16, and 17. The results (Table 4) were somewhat random from date to date and size to size. The table shows the densities (plankton per liter) of the four most abundant species of zooplankton filtered. Also shown are the mean size (microns) of the plankton collected. The efficiency of the filtering is highlighted at the bottom. A more discrete breakdown of the collected plankton for the entire set of tests (Figure 7) describes an overall effectiveness. The size distributions which should be filtered in the smallest section (80μ - 250μ) are primarily in white with little cross-hatching. The middle size range (250μ - 500μ) are cross-hatched in blue. Anything larger than 500μ is heavily cross-hatched in black. The percentages of each size collected by that filter are listed to help show the effectiveness of the filtering.

Trial 1	Mesh Size (microns)		
	80	250	500
a) April 10			
Copepod Nauplii	1.618	0.344	0.000
Copepod	1.165	0.115	0.365
Barnacle Nauplii	0.129	1.147	0.041
Barnacle Cyprid	2.066	0.057	0.041
Mean Size (microns)	178.50	284.00	346.50
Efficiency	**85.0%**	**75.0%**	**10.0%**
b) April 16			
Copepod Nauplii	1.417	0.218	0.000
Copepod	1.667	0.131	0.033
Barnacle Nauplii	0.083	0.174	0.000
Barnacle Cyprid	0.166	0.044	0.200
Mean Size (microns)	163.00	292.75	468.25
Efficiency	**92.5%**	**70.0%**	**57.5%**
c) April 17			
Copepod Nauplii	0.360	0.065	0.000
Copepod	0.090	0.974	0.064
Barnacle Nauplii	0.000	0.195	0.000
Barnacle Cyprid	0.090	0.065	0.000
Mean Size (microns)	279.75	433.50	463.25
Efficiency	**55.0%**	**70.0%**	**43.0%**

Table 4. Trial 1 Test Results: Winnow Efficiency.

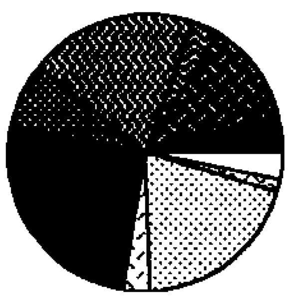
Results of Trial 1 (Winnow) Size Class Break-Down

80 micron screen



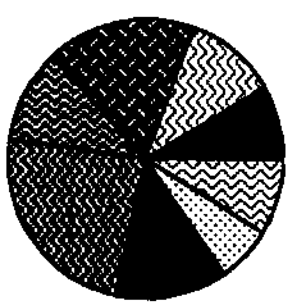
%<250 =84%
% >250, <500=16%
% >500 =0%

250 micron screen



%<250 =24%
% >250, <500=71%
% >500 =5%

500 micron screen



%<250 =15%
% >250, <500=65%
% >500 =20%

On April 23, the Winnow System was run to compare it to the conventional tow method for filtering accuracy (Trial 2). Again, the density of the four most common species were recorded individually (Table 5). The measurements were taken for similar size samples from both collection methods; Winnow and conventional plankton tow. The mean plankton size for each can be compared to give an idea of the relative effectiveness of the two collection methods. Analyzing the efficiencies of the two methods is a more complete comparison.

Trial #2a	Screen Size (microns)					
	80		250		500	
	Winnow	Tow	Winnow	Tow	Winnow	Tow
Copepod nauplii	0.1540	0.0100	0.0120	0.0003	0.0090	0.0000
Adult Copepods	0.1450	0.0060	0.3130	0.0020	0.0270	0.0002
Barnacle larvae	0.1380	0.0001	0.0230	0.0005	0.0090	0.0000
Barnacle cyprids	0.0080	0.0000	0.0230	0.0000	0.0220	0.0000
Mean size (microns)	178.0	159.5	290.5	239.5	246.0	307.5
Efficiency	**85.0%**	**100.0%**	**80.0%**	**60.0%**	**0.0%**	**0.0%**

Trial #2b	Screen Size (microns)					
	80		250		500	
	Winnow	Tow	Winnow	Tow	Winnow	Tow
Copepod nauplii	0.0940	0.0030	0.0560	0.0020	0.0000	0.0000
Adult Copepods	0.0580	0.0020	0.1300	0.0040	0.0080	0.0002
Barnacle larvae	0.0020	0.0001	0.0060	0.0002	0.0000	0.0000
Barnacle cyprids	0.0000	0.0000	0.0370	0.0010	0.0000	0.0000
Mean size (microns)	188.0	154.0	293.5	253.5	468.5	355.5
Efficiency	**80.0%**	**100.0%**	**80.0%**	**50.0%**	**50.0%**	**0.0%**

Table 4. Trial 2 Test Results: Comparing the Winnow and conventional tow collection methods.

A statistical analysis is the most complete method to compare the data. The data for both runs was combined (Table 5a) to perform the ANOVA Test. The appropriate method for comparing the means of data sets is to use a p-test. This is a test to determine if one method of filtering is significantly more effective than the other. The results of these tests are also listed (Table 5b). Similar to Figure 7, the data collected for both tests of Trial 2 are described (Figure 8) showing the size distribution and the accuracy of plankton collected for each method.

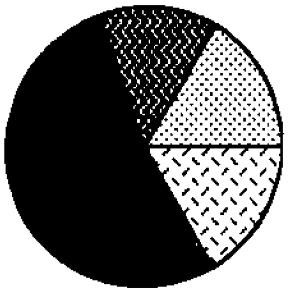
a) mean densities	Screen Size (microns)					
	80		250		500	
	Winnow	Tow	Winnow	Tow	Winnow	Tow
Total Zooplankton	0.1020	0.0040	0.2210	0.0030	0.0170	0.0010
Adult Copepods	0.1020	0.0040	0.2210	0.0030	0.0170	0.0010
Copepod Nauplii	0.1240	0.0060	0.0340	0.0010	0.0040	0.0000

b) p-values	Screen Size (microns)		
	80	250	500
Total Zooplankton	0.157	0.14	0.227
Adult Copepods	0.157	0.14	0.227
Copepod Nauplii	0.059	0.277	0.423

Tale 5. ANOVA Test: a) Mean densities b) p-test results

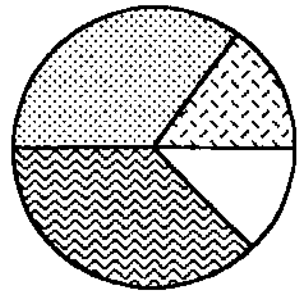
Comparison of Size groups Collected by Winnow and Plankton Tow (Trial 2)

80 micron Winnow



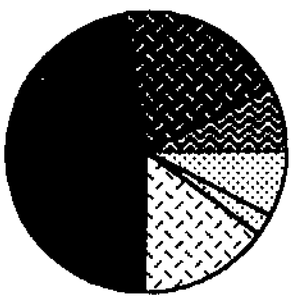
% <250 =83%
% >250, <500=17%
% >500 =0%

80 micron Tow



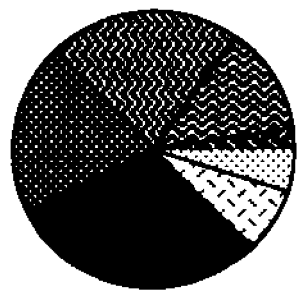
% <250 =100%
% >250, <500=0%
% >500 =0%

250 micron Winnow



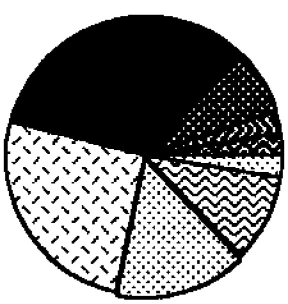
% <250 =25%
% >250, <500=75%
% >500 =0%

250 micron Tow



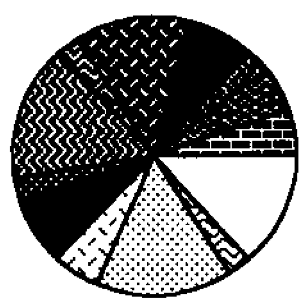
% <250 =54%
% >250, <500=46%
% >500 =0%

500 micron Winnow



% <250 =34%
% >250, <500=46%
% >500 =19%

500 micron Tow
winnow data



% <250 =14%
% >250, <500=86%
% >500 =0%

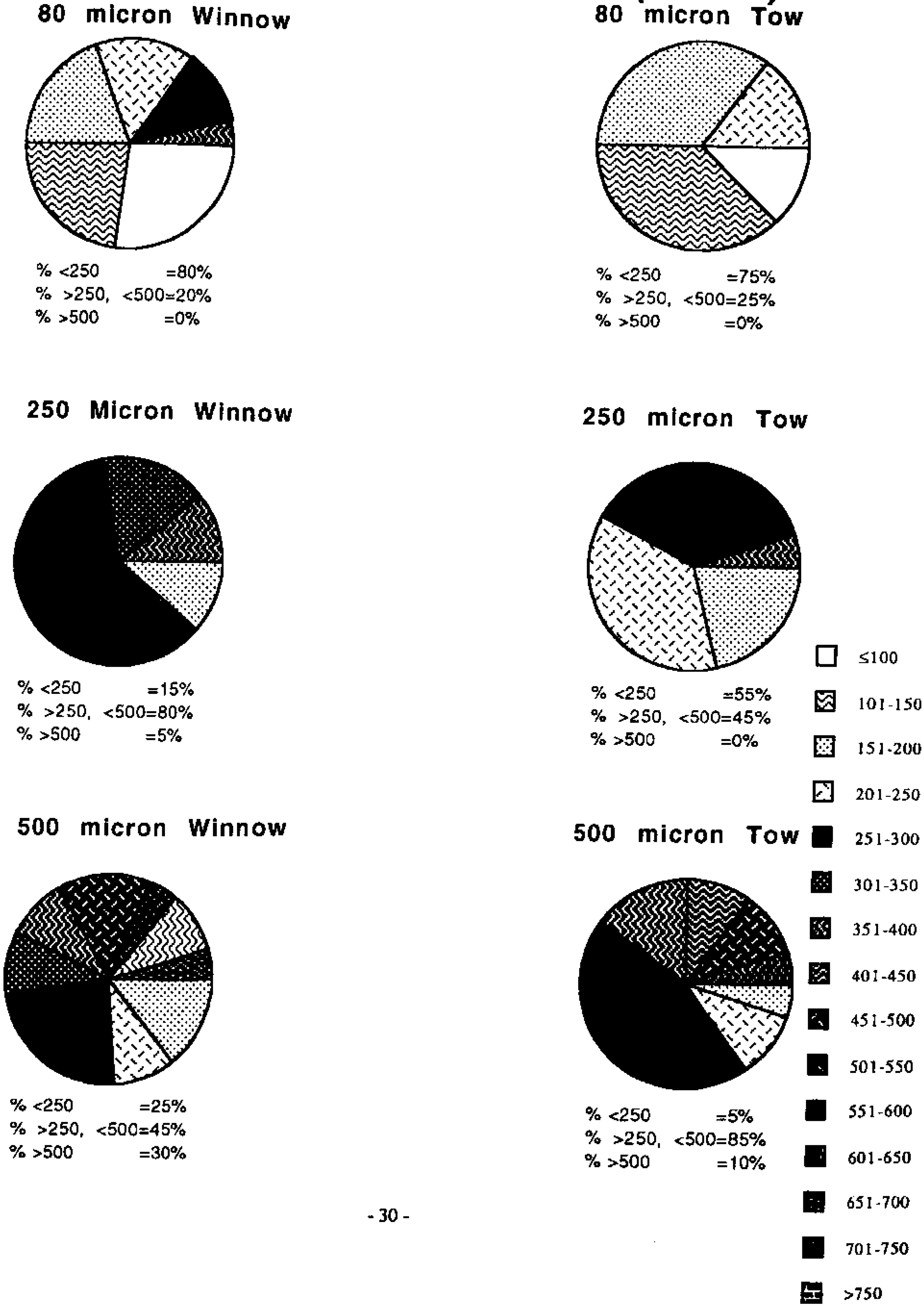
The third set of tests, Trial 3, was performed on April 29. The tests were similar to those conducted in Trial 2. The mean densities were determined (Table 7) for the two collection methods. The ANOVA Test was again used to compare the two methods for collecting Copepods. The size distributions (Figure 9) are also show using the same format as the previous trial data.

Zooplankton Mean Densities	Winnow	Tow	p-value
80 microns	0.0850	0.0040	0.1500
250 microns	0.0900	0.0010	0.1700
500 microns	0.0370	0.0009	0.0400

	Winnow	Tow	p-value
Copepods	0.1929	0.0043	0.0300
C. nauplii	0.0251	0.0020	0.4107

Table . ANOVA Test: Comparing the Winnow and conventional tow collection methods.

Comparison of Size groups Collected by Winnow and Plankton Tow (Trial 3)



IX Discussion

There are two standards by which the success of the project is measured. The first is the ability of the Winnow System to perform its primary function; effectively filtering and sorting plankton for research or aquaculture. The means for determining the success of the project is the analysis of the testing which has been performed over the past few weeks. The second standard to which the project is evaluated is the completeness to which it meets all desired objectives presented when the project was initially proposed. The method for determining the systems fulfillment of these parameters is less analytical. There are no tests which can be performed to determine the modularity or cost-effectiveness of the system. These types of objectives can only be compared to process desires or constraints presented to the project.

The initial tests of the Winnow System show positive signs. The results do not seem to meet the standards set at the beginning of the project, however the testing is still in a beginning stage. The project set forth with two objectives: to collect plankton for research and for cod hatcheries. The research has been initiated. The first research the Winnow will assist is to determine its own effectiveness. Following the results of this testing, the Winnow System may be used for further research, unless it is deemed to be ineffective in collecting and sorting plankton to the standards desired for the research intended. The cod hatcheries are not yet operational; they are still in the experimental phase. Results from this desired operation will be determined when the hatcheries are in place. This may be as early as this summer (June, 1997). The significant difference in the two applications are: the research needs a higher degree of accuracy for determining plankton densities, and the aquaculture needs live, healthy plankton. Determining the survival rate of the plankton is very difficult due to the measurement process. The plankton are measured on a microscope slide. To place them on the slide, they are taken from a mixture of 10% Formalin. This compound kills the plankton to keep them from swimming around while being observed under the microscope. Moving plankton would make measurments very difficult to perform.

After each test was performed, the system was checked for any mechanical problems which may have occurred during testing. This was done to see that the system was mechanically stabile and to see if there may be any problems with the system which may skew results. Any problems which arose were analyzed and discussed by the Winnow Team to determine the source of the problem and the optimum solution.

Trial One

The first tests of the Winnow System were performed on April 10 and continued to April 16 and 17. The values obtained for efficiencies were rather variable. These efficiencies were most likely due to a few unexpected flaws found in the Winnow. Some of the initial problems the Winnow Team encountered had to do with the screen plates and the diverters.

The first, and most damaging flaw, was that the clearance between the screen plates and the frame was greater than desired. The cause of this variance may be attributed to the thermal properties of the PVC they are constructed from. Large thermal expansions had been observed with the scale model when it was first constructed. The result of the poor tolerance was that plankton were able to slip between the screen plate and the frame. The impact this has on the effectiveness of the Winnow is tremendous. Flow was allowed to pass through a section of the Winnow without passing through a filter. This was observed in the April 10 tests as evidenced by the low mean plankton and efficiency size collected by the 500μ screen. The solution to this problem was to simply add a seal, or gasket, around the screen plates. The gasket is flexible and compensates for any variability due to thermal expansion or compression. The effects of this correction were immediately noticed from the results of the tests performed on April 16, 17. These results show a significant increase in the mean plankton size as well as the overall efficiency of the Winnow System.

The next flaw discovered was that the diverters and the screens were not sufficiently held in place. After the test on April 16 the first diverter had fallen off of the stop and was found leaning against the frame on top of the 250μ screen. This did not seem to make a difference in the efficiencies of the 250μ and the 80μ, however it was still a source of error. On April 17, again after the test was complete, it was observed that the 80μ screen had partially come off its stop. The flow of the filtered plankton was severely hindered as they were to be swept through the exit valve. This source of error was reflected in the efficiency of the 80μ screen. Previously, this screen had consistently performed better than the other two filters. The results of this test show that the efficiency of the 80μ filter was significantly below its standard. The solution to the problems of the insecure screen frames and diverters turned out to be an instillation problem. When the individual screens were re-assembled within the frame, no problems with stability were observed.

Trial Two

The effects of the adjustments made after the first trial were immediately evident in the results of the second trial. The efficiency of the Winnow was more consistent. The performance of the system was compared to that of the tow collection technique. The results were generally positive except for the accuracy of the 500μ filter.

The results from Trial 2 show that the system was filtering more accurately than in Trial 1. This was determined by the increased efficiency. The reduced screen clearance and increased mechanical stability of the system both had positive effects on the performance of the Winnow System.

In general, the Winnow performed better and more accurately than the tow method of collecting plankton. It is possible that the reason for this is due to the tow mesh having to be as small as the smallest particle to be collected. In this case, the tow mesh was 80μ. Mesh this small has a tendency to become clogged with larger plankton or even foreign debris. This creates added resistance to the incoming water which results in a smaller filtered volume of water than expected.

The proof of the Winnow's superior performance is evidenced by the ANOVA Test. The test shows that for every sample size and species, the mean plankton sizes between the Winnow and tow techniques are significantly dissimilar. Reviewing the mean plankton sizes from Table 5, the Winnow consistently collected plankton within the appropriate range more successfully. This can also be observed in Figure 8. The relative accuracy can be seen by the color distinction. Ideally, the 80μ sample would be all white with light cross-hatching, the 250μ sample would be all blue, and the 500μ sample would be black with white cross-hatching. The Winnow is only less efficient for the 80μ filter.

The most disturbing statistic is the inability of the Winnow System to collect only large plankton in the 500μ section. It is evident by the mean plankton size that too many smaller plankton are being collected here. This was a problem also noticed from the scale model. Three of the possible solutions, changing screen angles, diverters, and the diffuser, have all been implemented. The fourth proposed solution was altering the outlet. This can be performed by adjusting the exit valves. The data suggests that the flow resistance from the 500μ screen is too small. This may be compensated for by partially closing the valve.

Trial Three:

The third set of tests were conducted in an attempt to optimize the Winnow System. The results were compared to tow results as they were for Trial 2. Again, as expected, the Winnow performed far better than the tow method. The data which is most significant, is in Figure 9. Adjusting the out flow from the screens had a positive effect on the results. The efficiency of the 500μ filter was increased as hoped. When the data is compared to the tow results, it can be seen that some of the increase in efficiency is due to an increase in the availability of larger plankton. However, the Winnow results show a more complete efficiency. The tow data suggests that plankton were abundant in the 250μ - 500μ size range. The Winnow data supports this observance. When the two sets of data are compared, the Winnow System was more successful at collecting the plankton into the appropriate size categories.

Trial Summary

Some of the problems or errors in the results were beyond our control. Some of these variables include: plankton density, plankton migration, and tides. These are natural events which the Winnow System can only hope to limit the extent to which they affect performance.

The plankton density varies throughout the year. They are most abundant during the summer months and rather scarce during winter. The Winnow System was developed to operate primarily during the summer. The tests performed thus far have been conducted in less than ideal conditions for analyzing the performance of the system. The plankton densities observed were very low. This is evident in the data of all the results. The densities varied from nearly nothing to as many as two plankton per liter of water. The densities during the abundant months are anticipated to be several times greater. Also, the plankton sizes are smaller at this time of year. This can be seen best from the results of Trials 2 and 3. The efficiency of the larger screen was severely lower than the other two. The primary reason for this is the lack of plankton greater than 500μ.

There has been little research on the migration habits of plankton. Their location in the water column as well as their location relative to shore varies widely from day to day, and even hour to hour. There migration is influence by several factors including water temperature and the amount of light present. This effects the results by adding an unknown element between tests. It complicates comparisons between tests conducted on different days, or even different times of the same day.

The other major factor effecting the results are the ocean tides. The plankton are carried by these natural movements as well as local currents. The tides effect the depth of the water and, therefor, the migration of the plankton. The tide levels vary slightly as well as their timing from day to day.

Altogether, these factors make repeatability and comparability very difficult, if not impossible. There is no way to account for the uncertainty introduced by these factors.

Engineering Analysis

At the start of the project, the Winnow Team was confronted with a set of objectives which needed to be met to consider the project a success. These parameters were outlined previously and are discussed here to determine the extent to which they have been met.

The first parameter discussed was user friendliness. The collection and distribution process is very simple and does not require any human interaction. The Winnow System has proven, thus far, to be very simple to operate. This includes any alterations or maintenance which has been necessary. Some minor modifications have already been implemented in the early stages of testing. The accessibility of the system was very convenient and made the adjustments easy to perform. The modularity of the system is presented by the removable screens and diverters. These also aid in the maintainability of the system. The Winnow System has been very safe to work with to this point. There are no moving parts other than the pump which was also a desired feature. This has made the project very reliable so far.

The efficiency of the system has not yet been fully determined. The initial results have been positive, however, only time will tell if the system will meet the desired levels outlined in the timeline. The system can not be measured to determine how plankton friendly it is. The best way to determine this will be to analyze the aquaculture. The ability of the system to collect live, healthy plankton will be determined, in part, by the success of the cod rearing when it is implemented. The system is definitely environmentally friendly. The only power currently used is electric. This is minimal for a ½ horsepower pump. The cost of running the pump for several hours is comparable to watching television for an equal duration.

The system can be considered cost effective. The initial budget proposed ($3150) was granted by the TECH 797 projects committee. The cost of the Winnow, to this point, is just below $2000. This total does not include a generator which was proposed as the eventual source of power for the system. This budget was met by constructing the system primarily of PVC. This makes the system very corrosion resistant. The pump was the most significant expense ($450) and is also expected to have the shortest lifetime of all the parts of the system. The anticipated lifetime is nearly five years which justifies its purchase.

The Winnow is mechanically stabile. It has been proposed that is can be made more stable by constructing a base. This may be performed at a later date, but was not included in the original design due to time constraints. The most delicate part of the system has been the filters. They needed to be durable enough to handle the accelerated flow rates which they experience. The results to this point have been positive. It is expected, with regular maintenance, the filters will need to fixed or replaced very infrequently. The expected lifetime for the screens is one year. New frames and filters can be constructed at minimal costs.

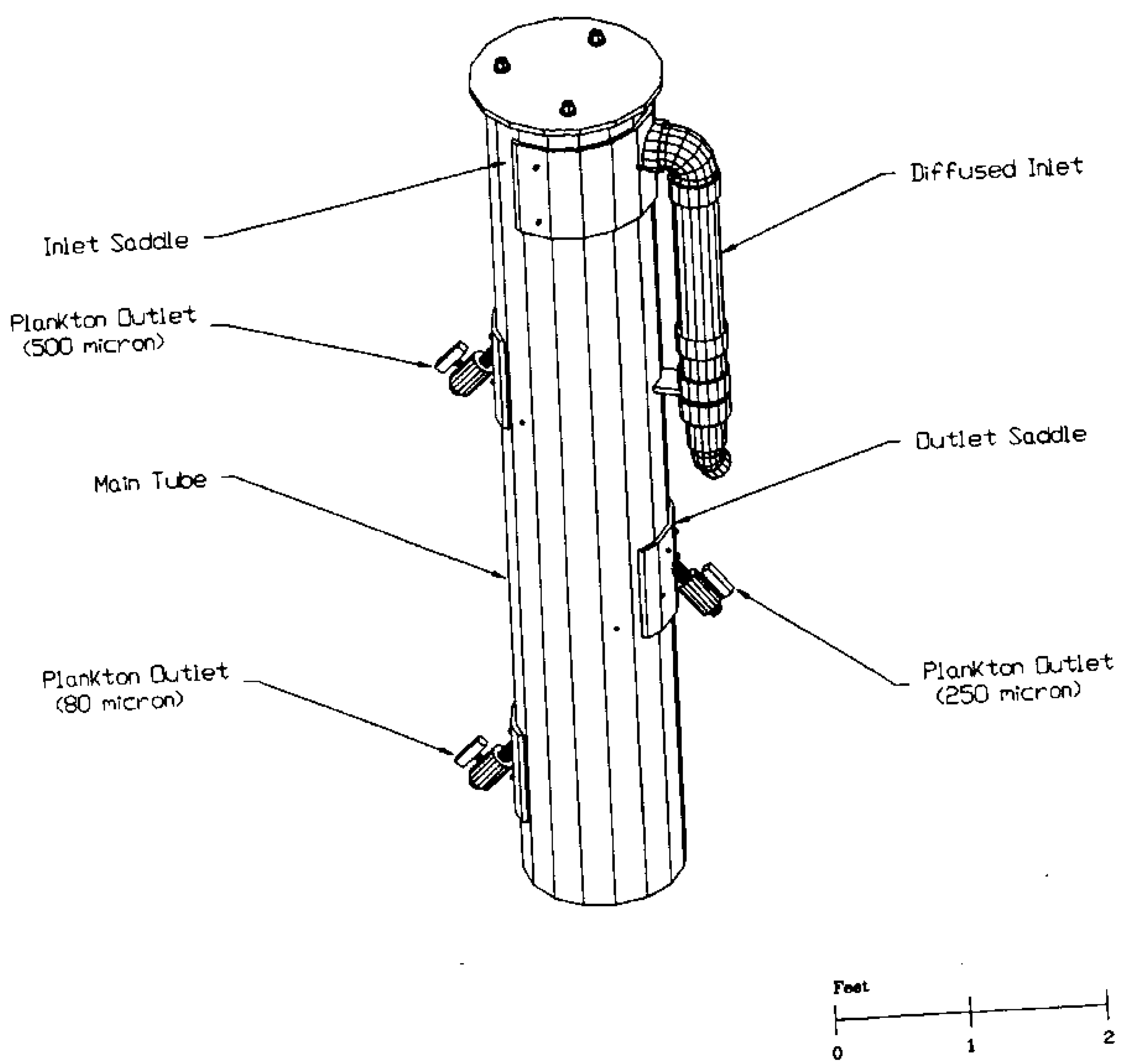
Finally, the size of the Winnow is such that is makes use of vertical space and requires little area to operate. The system can be mounted on a small raft (8ft x 8ft) with comfortable stability and plenty of room for operators to maneuver about.

As a whole, the Winnow System meets the desired parameters presented at the beginning of the project. Most goals were met, however some performance characteristics fell slightly short of the expected output. It is difficult to analyze the Winnow System completely at this time due to the season. A complete analysis would require testing throughout the summer when the plankton density is dramatically increased, as well as the traffic in the location where the system resides. These two factors will have a great impact upon the performance of the system in several ways. The tests performed thus far do provide an indication of the anticipated success of the project. The Winnow Team is excited about the potential for further use of the system. There are several possible alternative uses for the Winnow System in addition to the research and aquaculture which has been thoroughly discussed here.

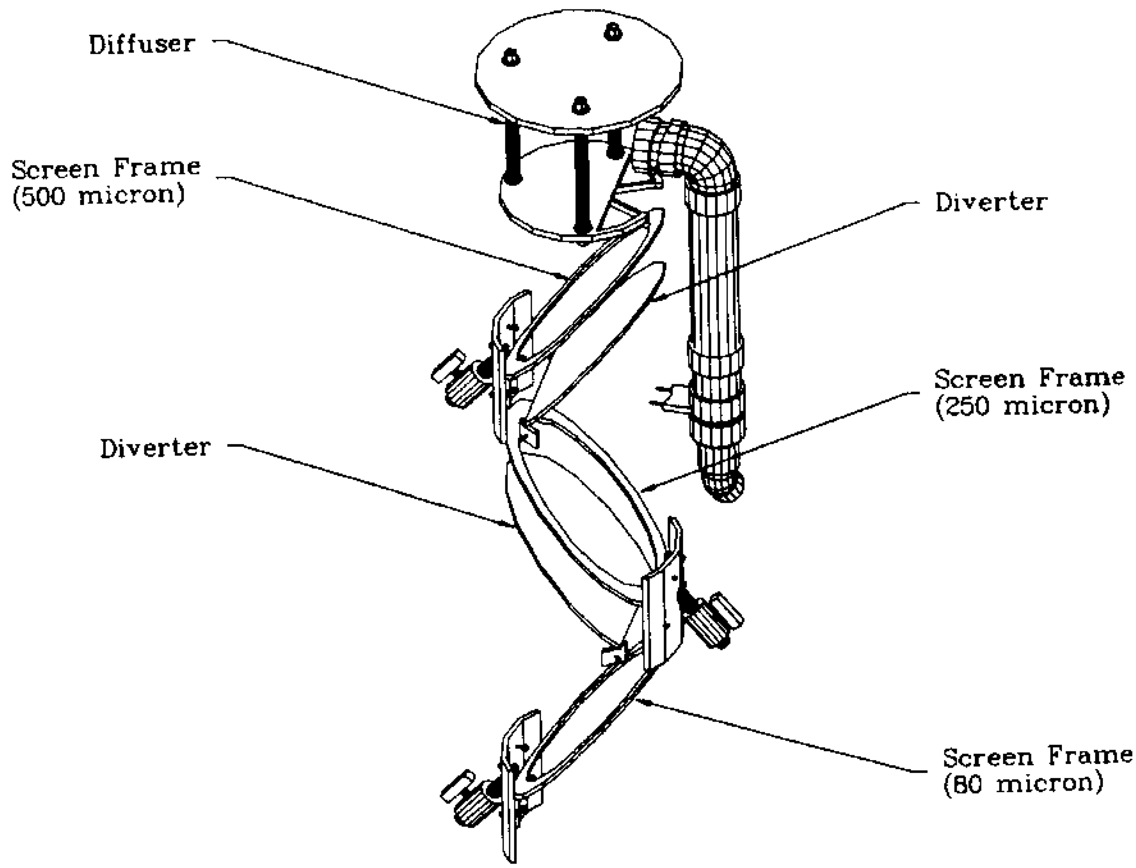
Appendix

Appendix A. Design Layout

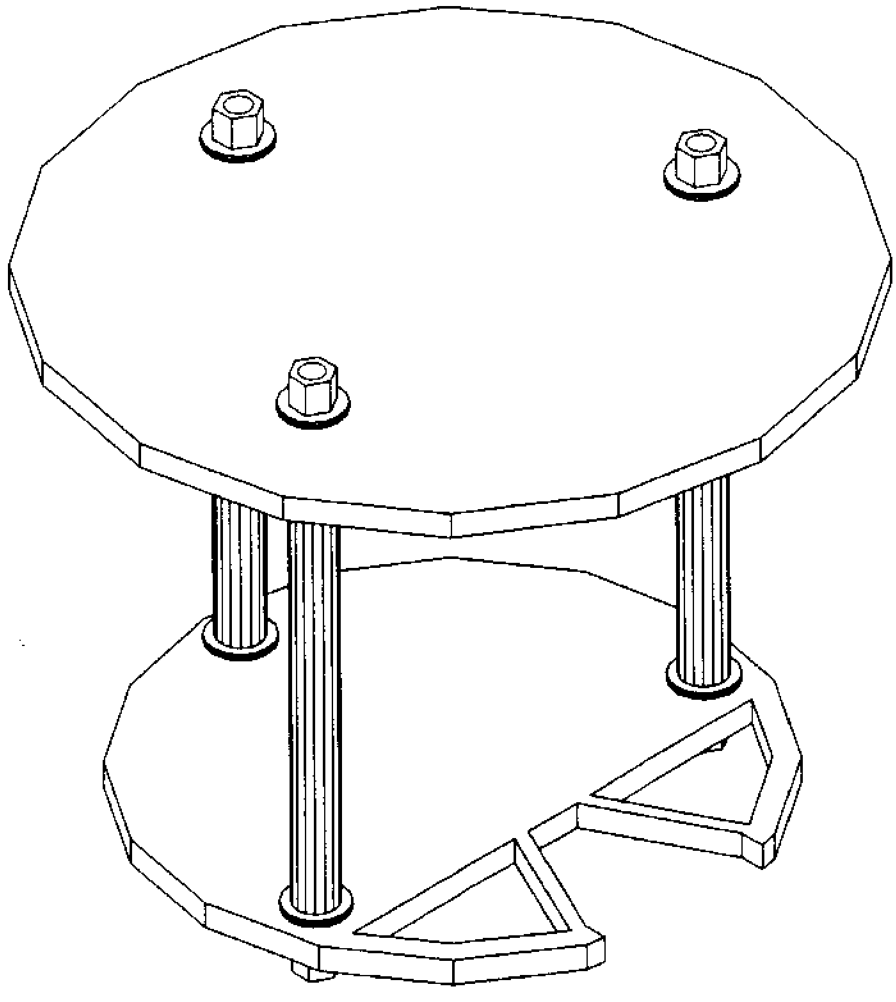
The following section contains detailed assembly drawing of the Winnow System. Each drawing includes standard hardware specifications and necessary dimensioning.



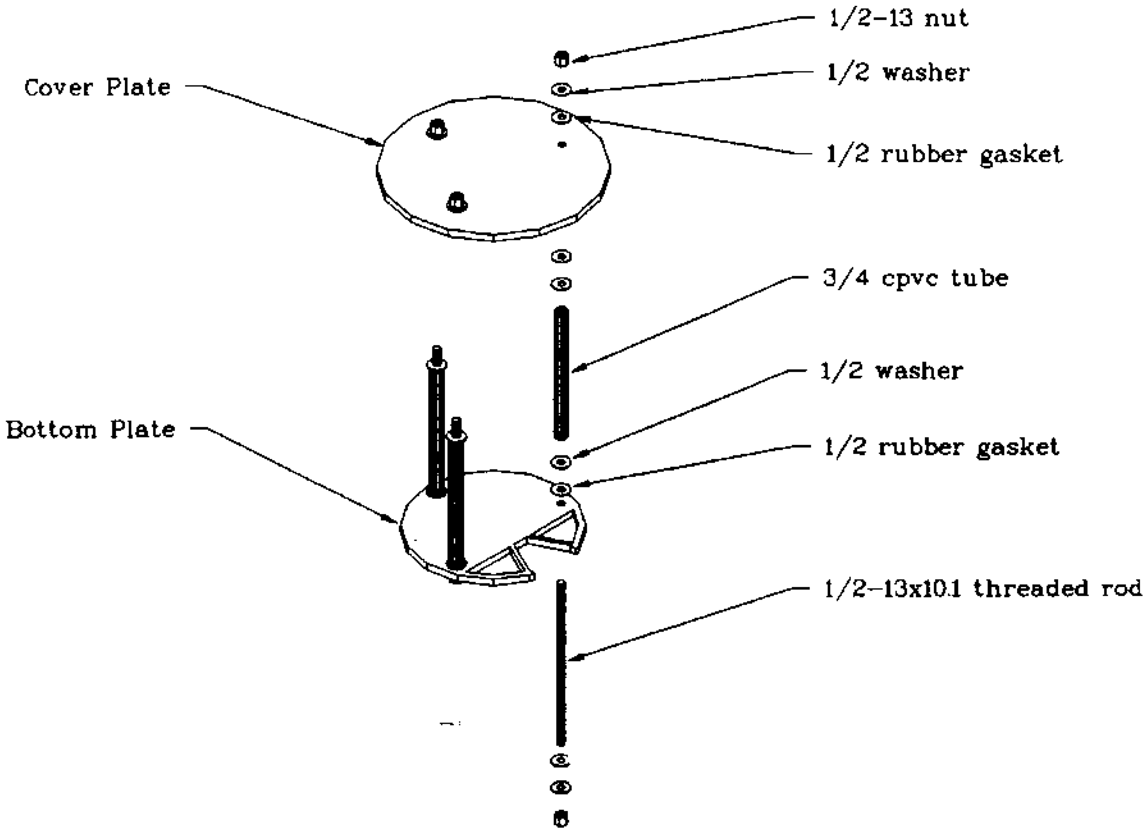
Winnow	Title: Isometric View of System	
	Figure A1	Date: 4/27/97



Winnow	Title: Isometric Inside Main Tube	
	Figure A2	Date: 4/27/97

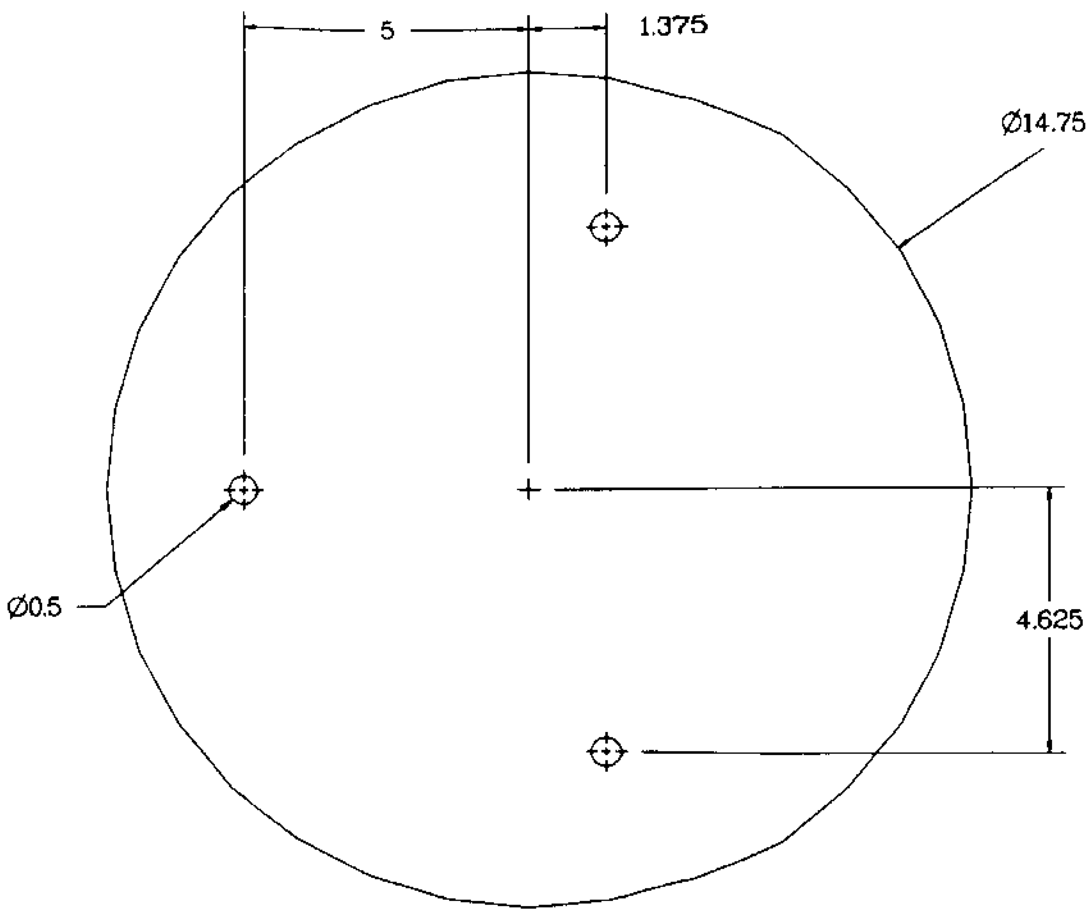


Winnow	Title: Isometric of Diffuser
	Figure A3 Date: 4/27/97



Units = inches

Winnow	Title: Exploded Isometric of Diffuser
	Figure A4 Date: 4/27/97



thickness = 1/2

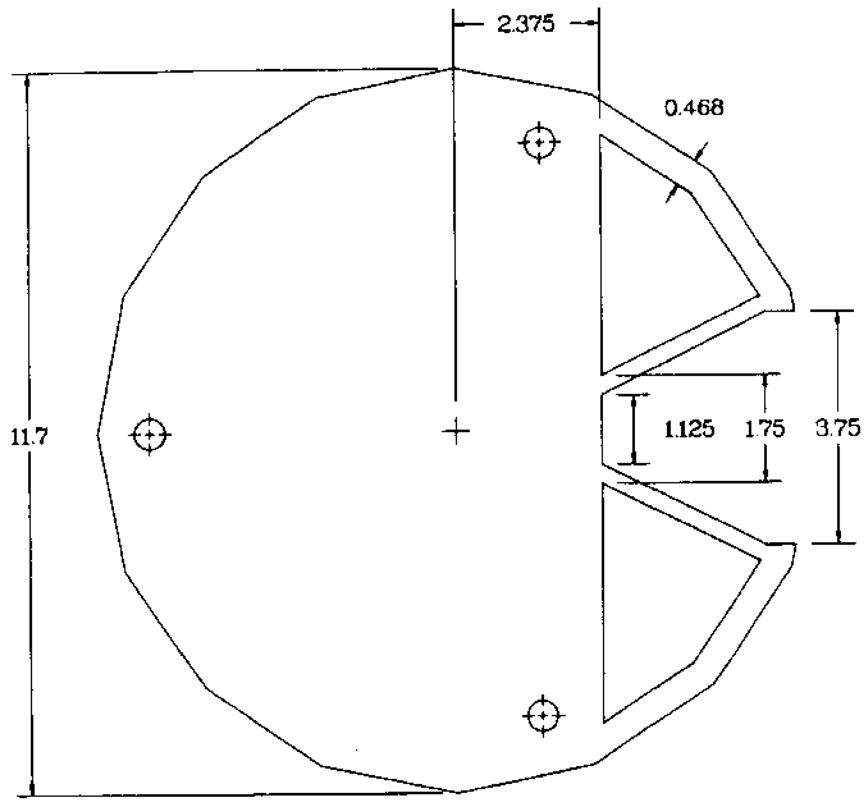
Units = inches

Winnow

Title: Top View of Cover Plate

Figure A5

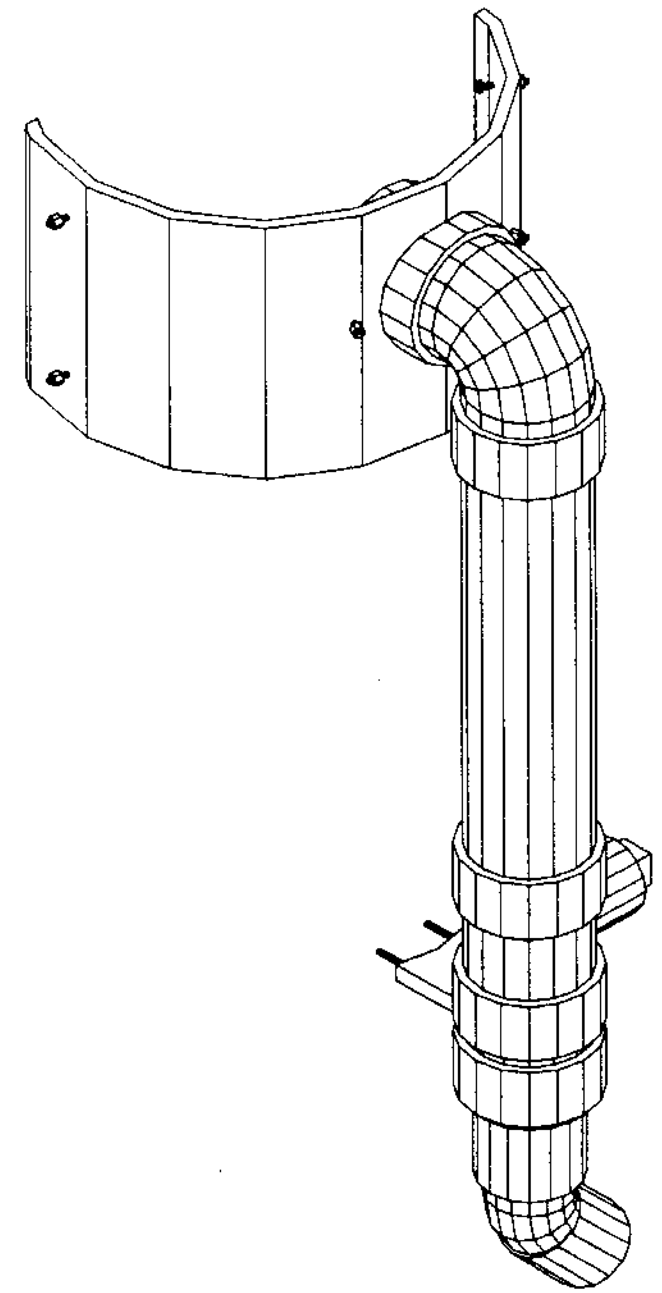
Date: 4/27/97



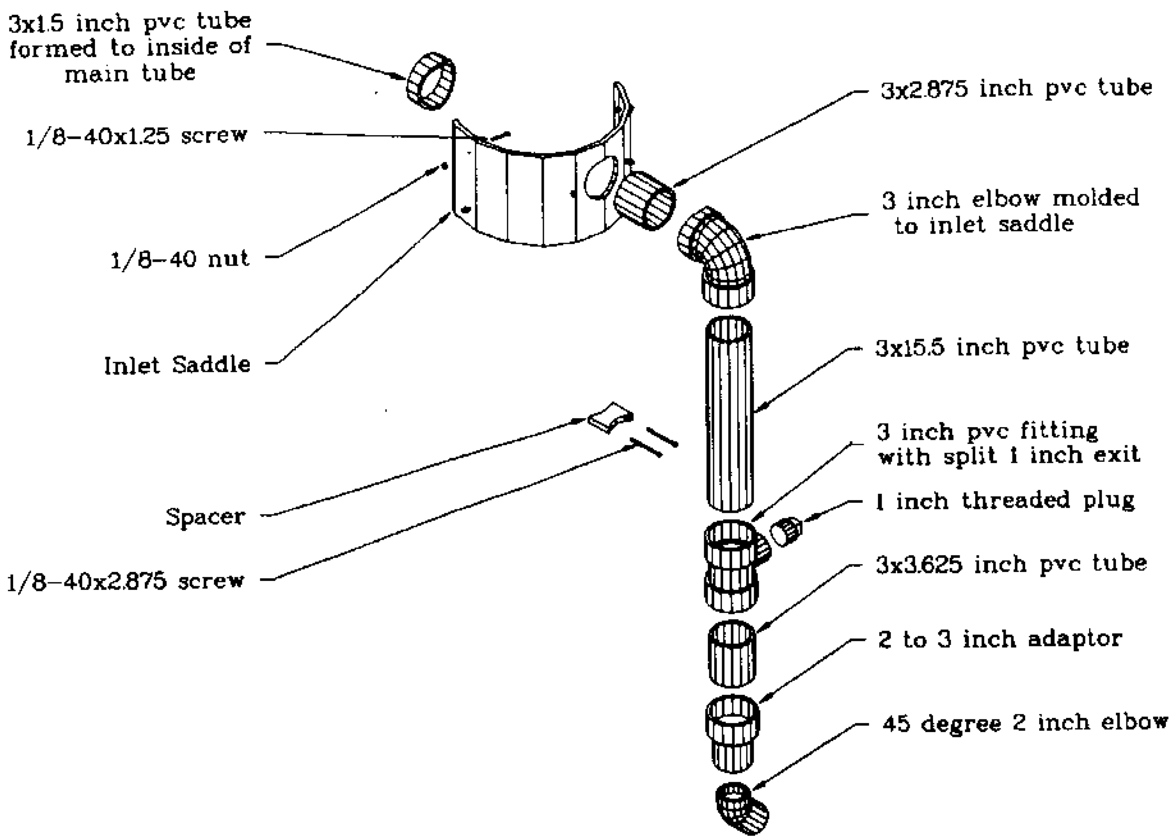
thickness = 1/2

Units = inches

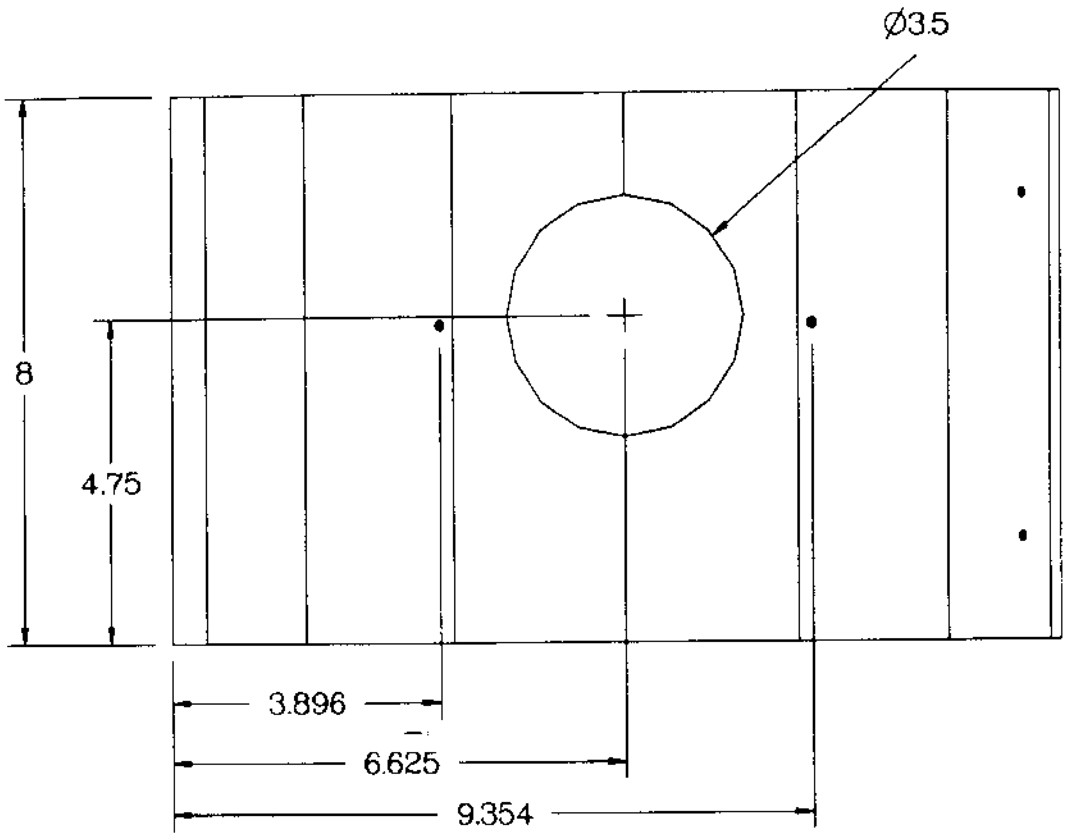
Winnow	Title: Top View of Bottom Plate
	Figure A6 Date: 4/27/97



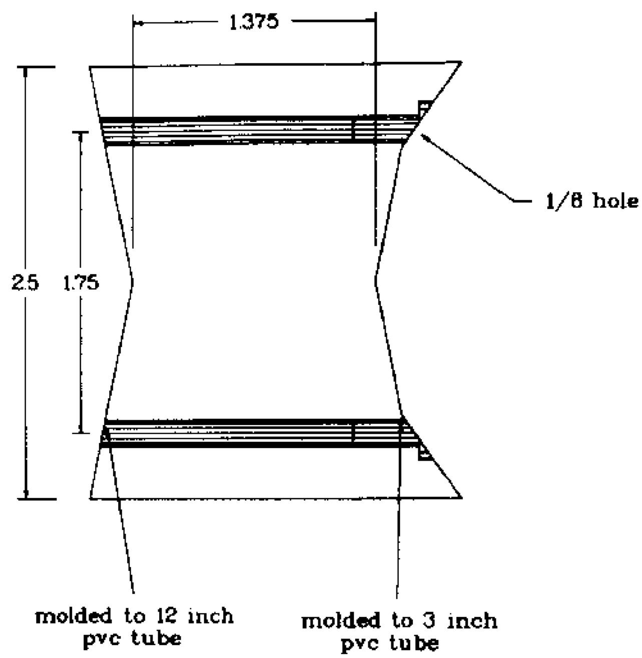
Winnow	Title: Isometric View of Diffused Inlet and Saddle
	Figure A7 Date: 4/27/97



Winnow	Title: Exploded View of Diffused Inlet and Saddle	
	Figure A8	Date: 4/27/97



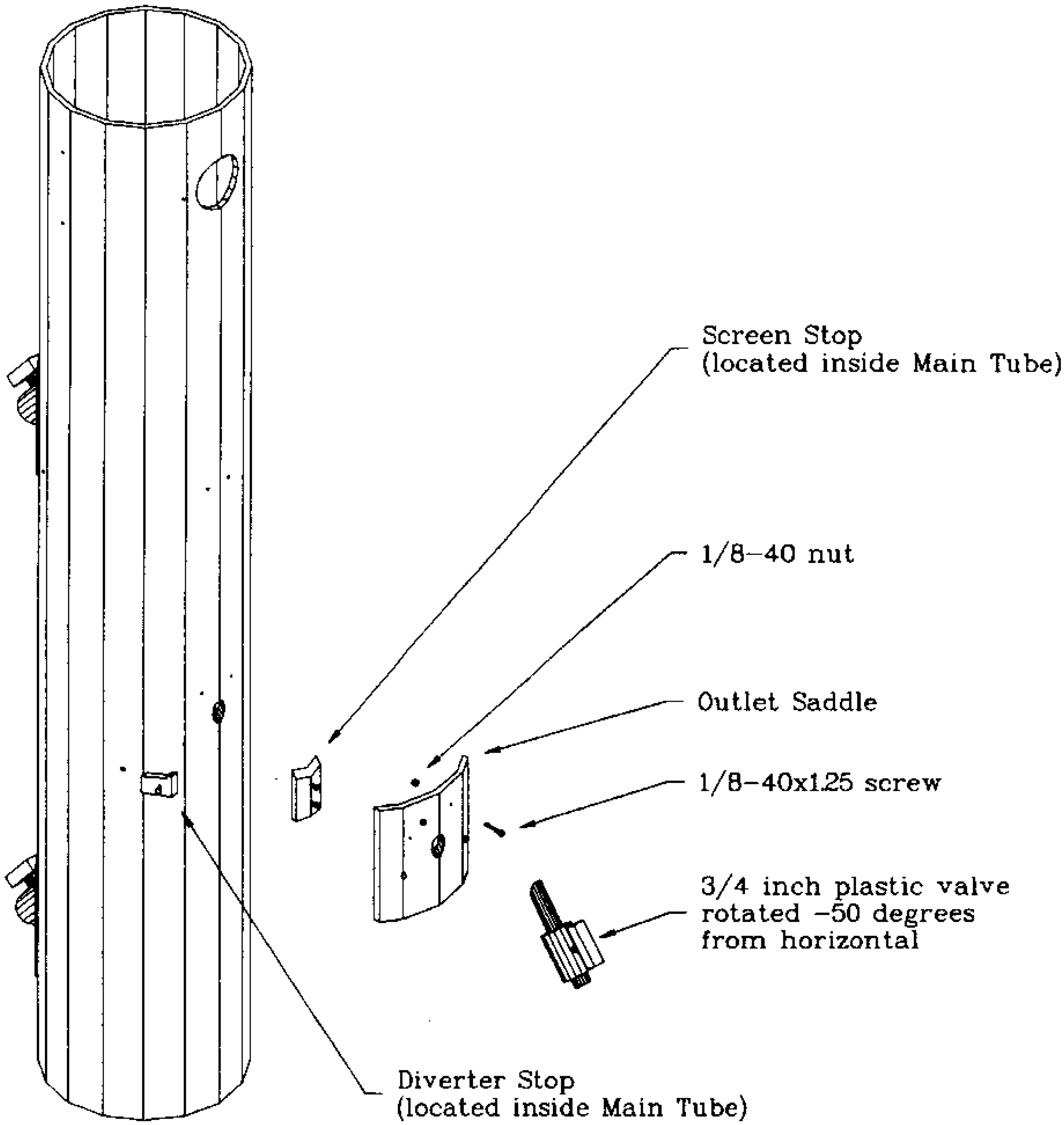
Winnow	Title: Right Side of Inlet Saddle
	Figure A9 Date: 4/27/97



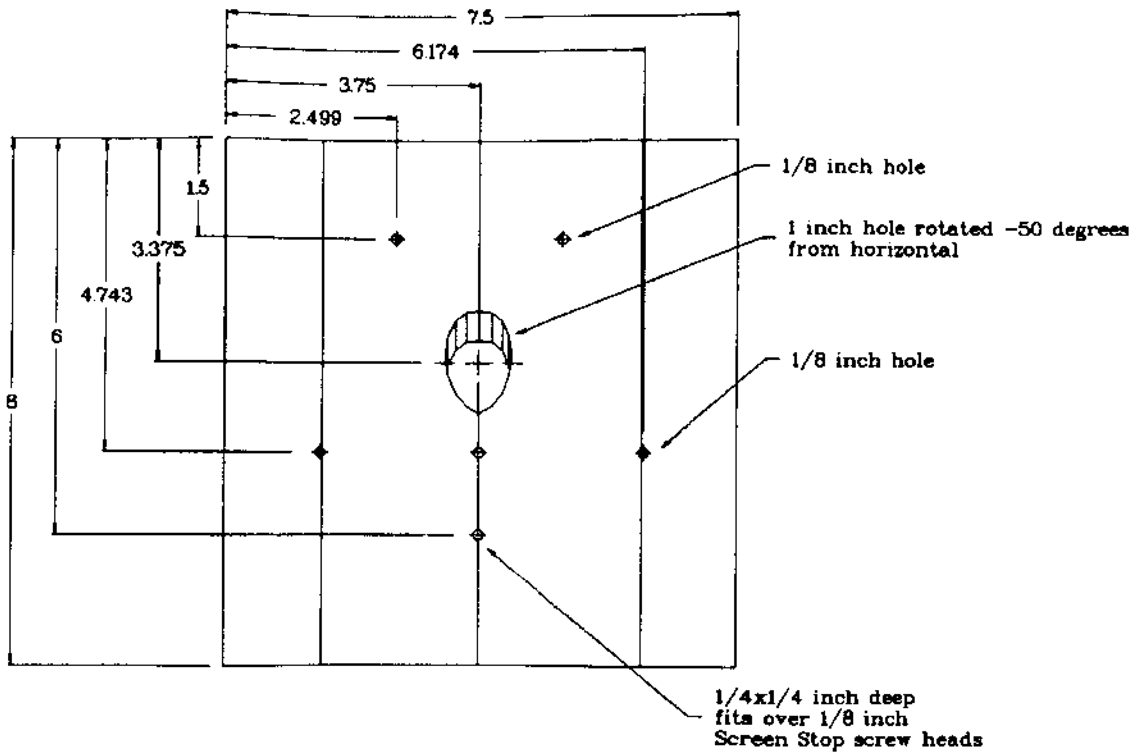
thickness = 1/2

Units = inches

Winnow	Title: Top View of Spacer	
	Figure A10	Date: 4/27/97



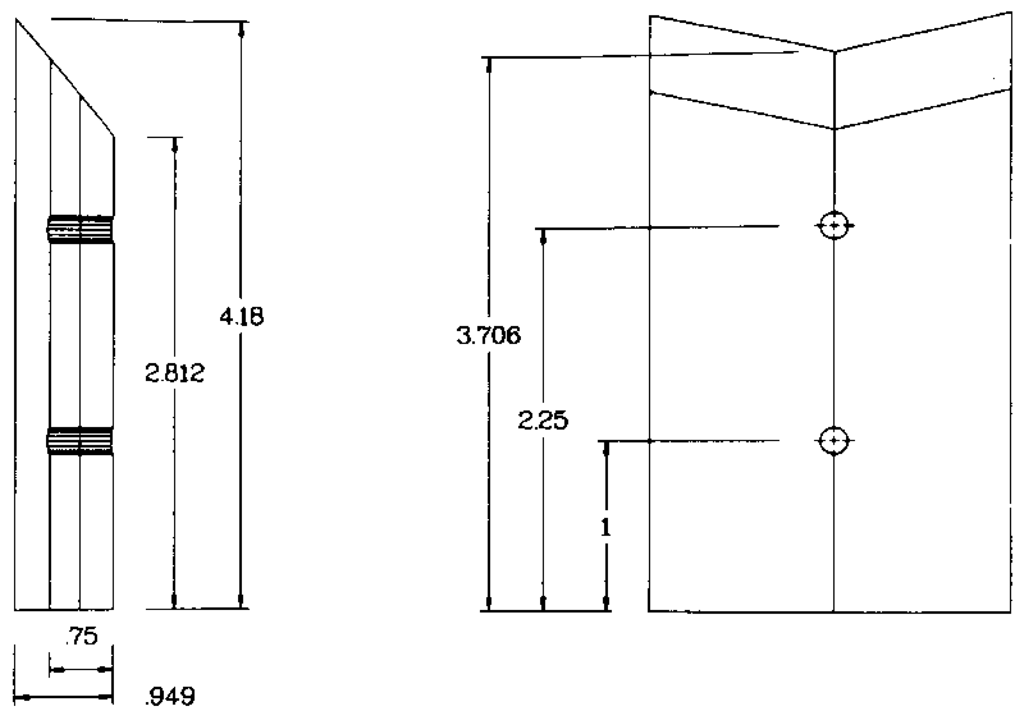
Winnow	Title: Exploded Main Tube and Plankton Outlet	
	Figure A11	Date: 4/27/97



thickness = 3/8

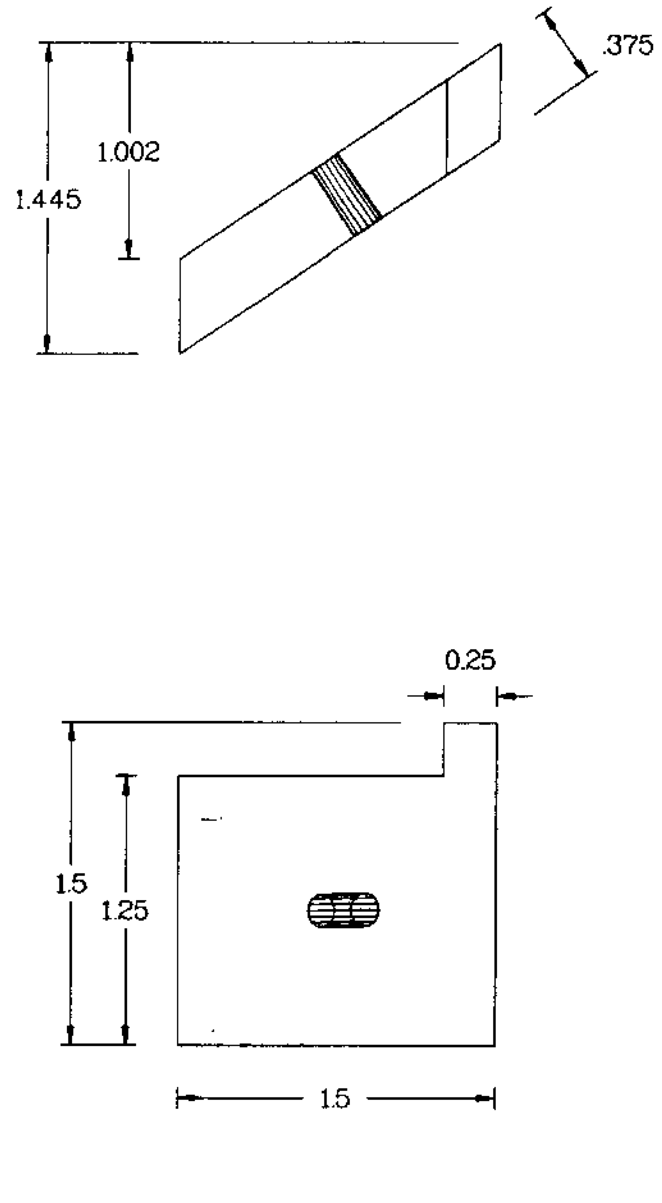
Units = inches

Winnow	Title: Left View of Outlet Saddle	
	Figure A12	Date: 4/27/97

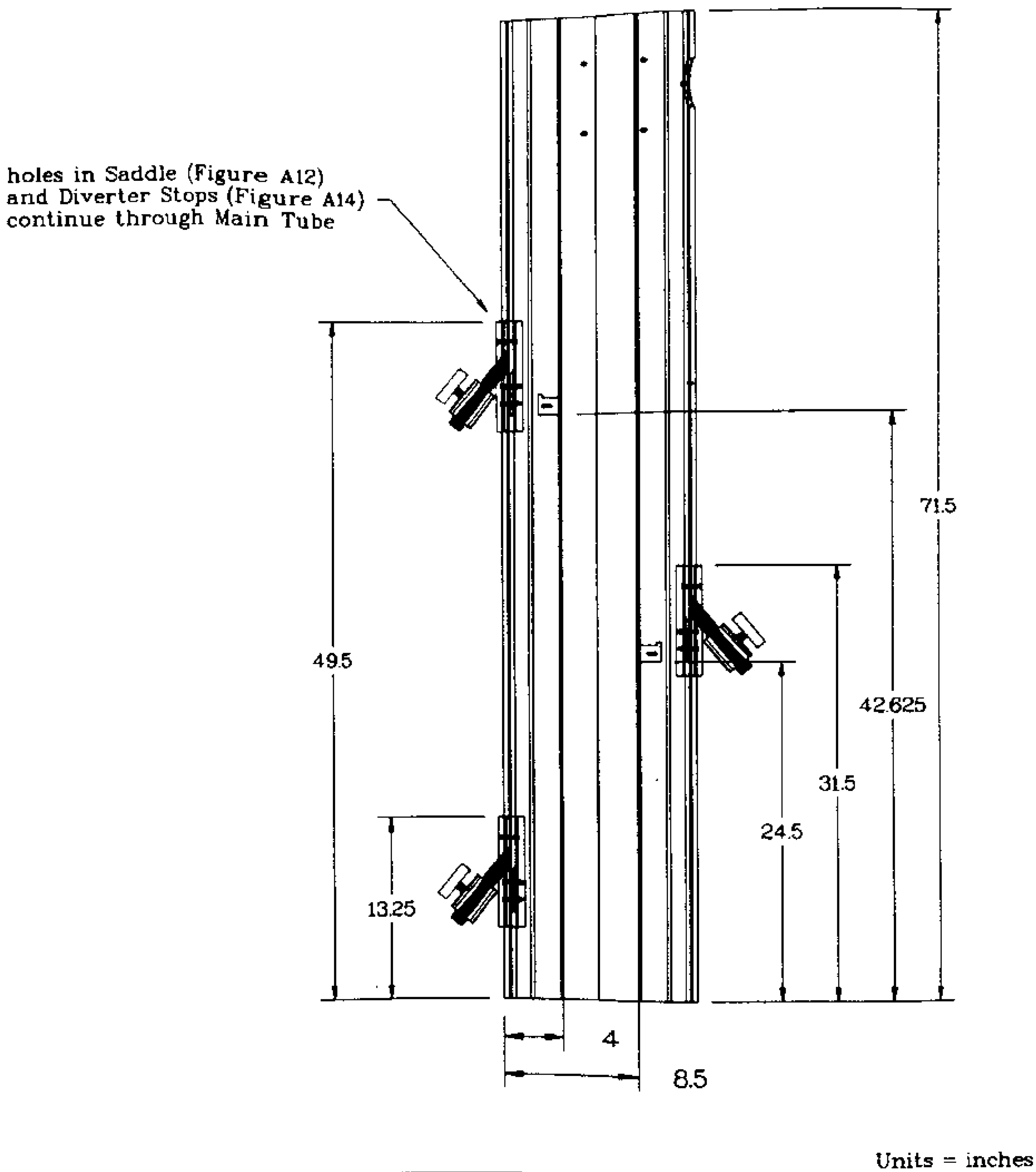


Units = inches

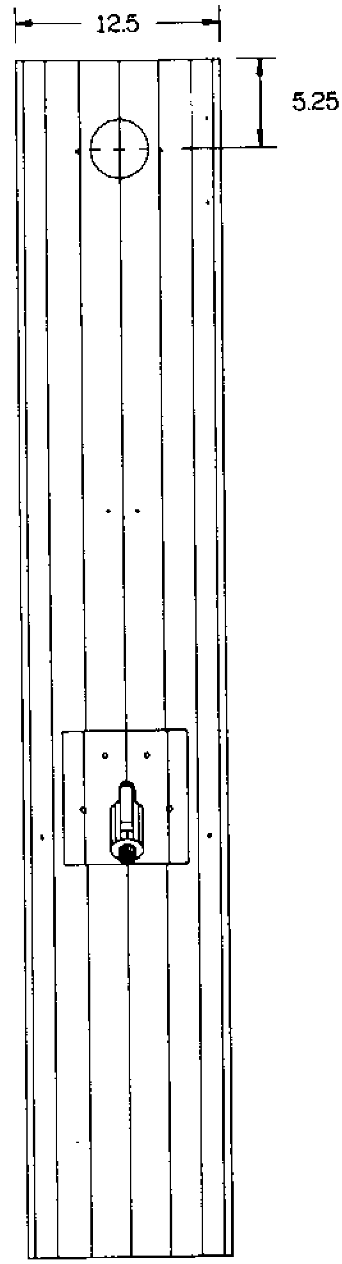
Winnow	Title: Front and Side View of Screen Stop	
	Figure A13	Date: 4/27/97



Winnow	Title: Front and Top View of Diverter Stop	
	Figure A14	Date: 4/27/97

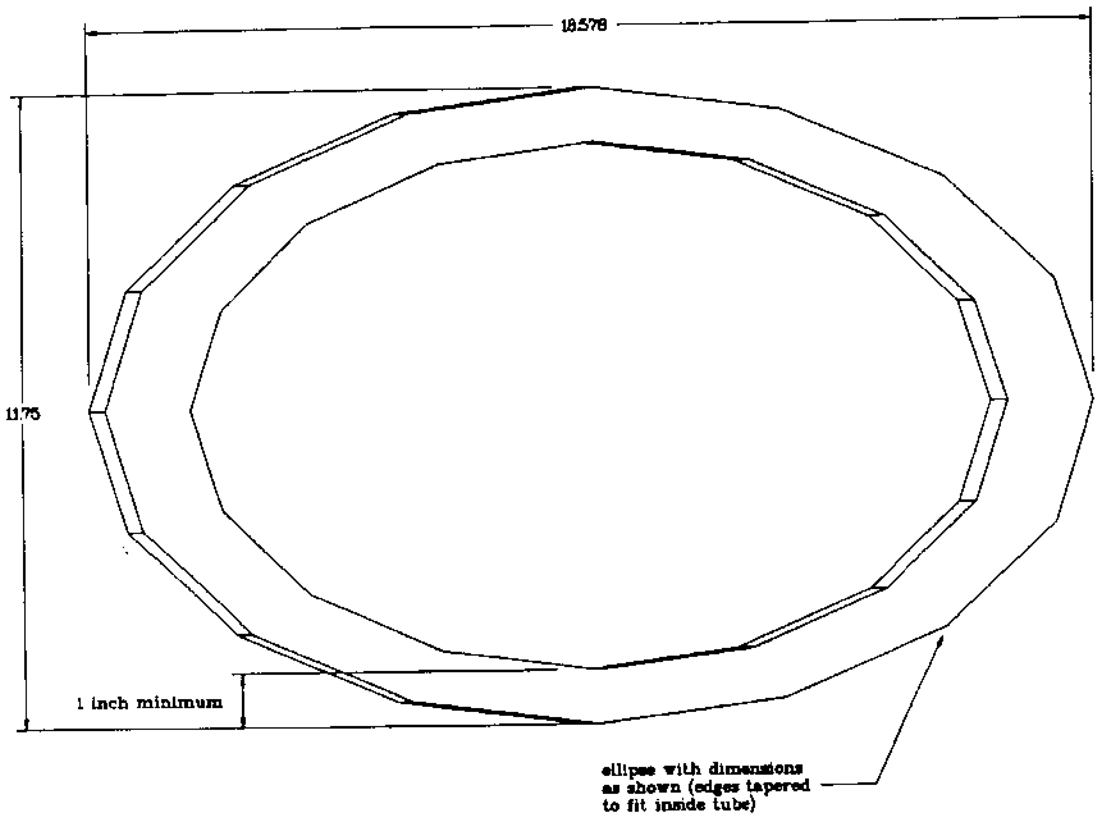


Winnow	Title: Front View of Main Tube	
	Figure A15	Date: 4/27/97



Units = inches

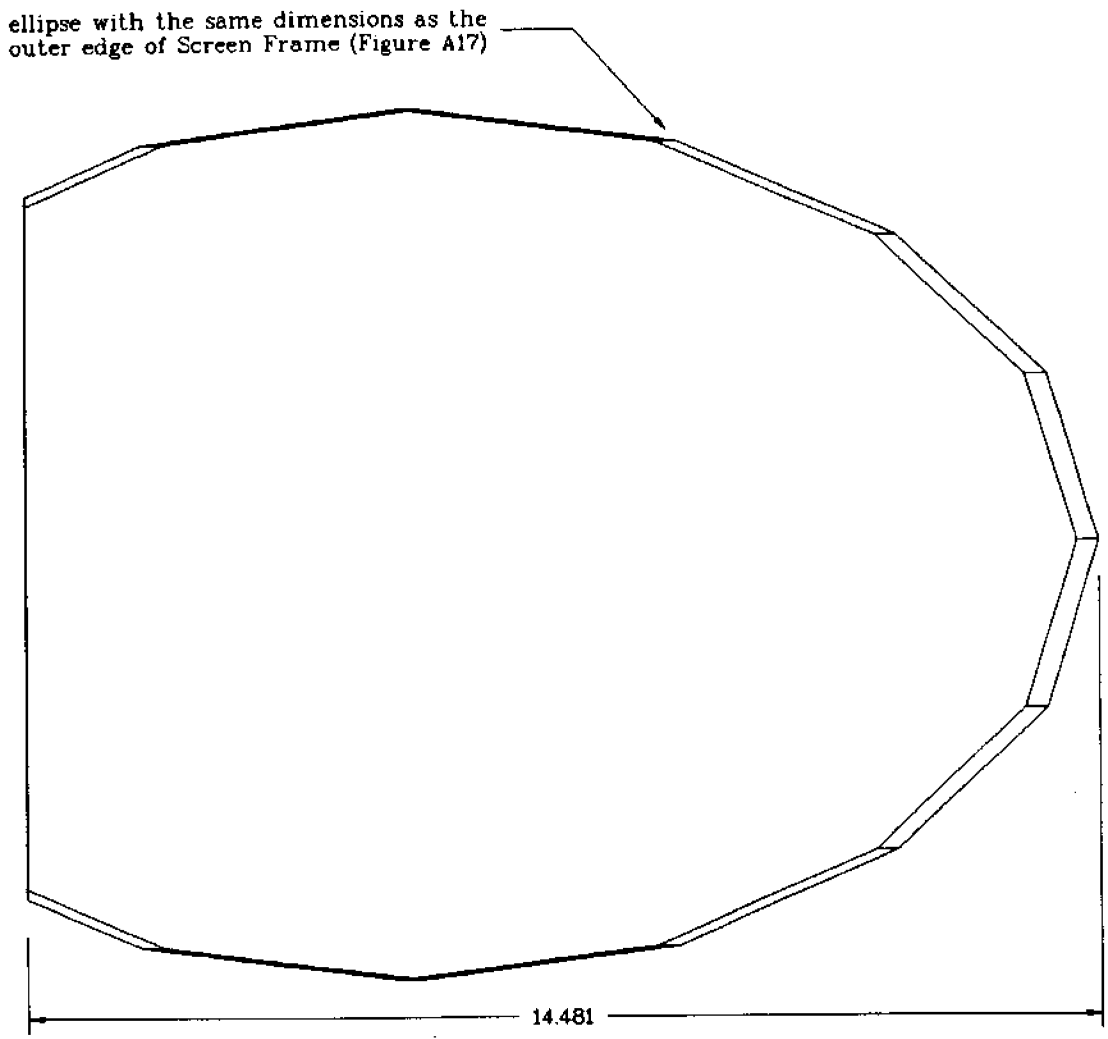
Winnow	Title: Right View of Main Tube	
	Figure A16	Date: 4/27/97



thickness = 1/4

Units = inches

Winnow	Title: Top View of Screen Frame
	Figure A17 Date: 4/27/97



thickness = 1/4

Units = inches

Winnow	Title: Top View of Diverter
	Figure A18 Date: 4/27/97

Appendix B. Sample Calculations

The following section is comprised of a set of sample calculations to verify the assumptions and data from the text. The plankton density calculations were performed several times. Shown below is a sample of the process which was followed to estimate the plankton density in the ocean at the time of the testing. The Reynolds Scaling uses dimensionless parameters to compare like objects of unlike size. This section is verification for the design selection and optimization of the final Winnow System.

- Plankton Density

▸ Reynold's Scaling

Dimensionless Parameters: Model Scaling

Model dimensions

diameter of model tube	$Dmod := 4 \cdot in$	$Dmod = 0.333 \cdot ft$
diameter of model outlets	$dmodout := \frac{3}{16} \cdot in$	$dmodout = 0.016 \cdot ft$
area of model tube	$Amod := \frac{\pi \cdot Dmod^2}{4}$	$Amod = 0.087 \cdot ft^2$

Winnow dimensions

diameter of Winnow tube	$Dwin := 11.75 \cdot in$	$Dwin = 0.979 \cdot ft$
diameter of Winnow outlets	$dwinout := \frac{13}{16} \cdot in$	$dwinout = 0.068 \cdot ft$
area of Winnow tube	$Awin := \frac{\pi \cdot Dwin^2}{4}$	$Awin = 0.753 \cdot ft^2$

Scaling constants

viscosity of seawater $\mu := 0.0015 \cdot \frac{newton \cdot sec}{m^2}$ $\mu = 1.008 \cdot 10^{-3} \cdot \frac{lb}{ft \cdot sec}$

density of seawater $\rho := 61.7 \cdot \frac{lb}{ft^3}$

mesh size $mesh := \begin{pmatrix} 80 \\ 250 \\ 500 \end{pmatrix} \cdot 1 \cdot 10^{-6} \cdot m$ $mesh = \begin{bmatrix} 2.6247 \cdot 10^{-4} \\ 8.2021 \cdot 10^{-4} \\ 1.6404 \cdot 10^{-3} \end{bmatrix} \cdot ft$

Model

Flow Rates

The model was tested three times with three different flow rates, q1in, q2in, and q3in.

1. $q1in := \frac{9 \cdot liter}{8.11 \cdot sec}$ $\quad q1in = 17.59 \cdot \frac{gal}{min}$

2. $q2in := \frac{9 \cdot liter}{16.8 \cdot sec}$ $\quad q2in = 8.491 \cdot \frac{gal}{min}$

3. $q3in := \frac{9 \cdot liter}{44.05 \cdot sec}$ $\quad q3in = 3.238 \cdot \frac{gal}{min}$

Tests performed

Nine liters were poured through the model at three different rates. The flow rates at the outlets, 80μ, 250μ, and 500μ, respectively, are given by q1out, q2out, and q3out, respectively.

A. q1in

$$time1 := 8.11 \cdot sec \quad trial1 := \begin{pmatrix} 0.185 \\ 0.145 \\ 0.080 \end{pmatrix} \cdot liter \quad q1out := \frac{trial1}{time1} \quad q1out = \begin{pmatrix} 0.362 \\ 0.283 \\ 0.156 \end{pmatrix} \cdot \frac{gal}{min}$$

B. q2in

$$time2 := 16.8 \cdot sec \quad trial2 := \begin{pmatrix} 0.205 \\ 0.225 \\ 0.070 \end{pmatrix} \cdot liter \quad q2out := \frac{trial2}{time2} \quad q2out = \begin{pmatrix} 0.193 \\ 0.212 \\ 0.066 \end{pmatrix} \cdot \frac{gal}{min}$$

C. q3in

$$time3 := 44.05 \cdot sec \quad trial3 := \begin{pmatrix} 0.560 \\ 0.420 \\ 0.115 \end{pmatrix} \cdot liter \quad q3out := \frac{trial3}{time3} \quad q3out = \begin{pmatrix} 0.202 \\ 0.151 \\ 0.041 \end{pmatrix} \cdot \frac{gal}{min}$$

The flow rate to each successive screen is slowed due to the flow rate out the exit. Therefore, the flow rates in to the second and third screens are adjusted by subtracting the flow rate of the previous outlet from the flow rate in. (This calculation proves significant mainly for the flow rates of the Winnow and is included for completeness).

A. 1. Flow rate to second screen $q1in1 := q1in - q1out_2$ $q1in1 = 17.433 \cdot \frac{gal}{min}$

2. Flow rate to third screen $q1in2 := q1in1 - q1out_1$ $q1in2 = 17.15 \cdot \frac{gal}{min}$

3. Flow exiting the model $q1exit := q1in2 - q1out_0$ $q1exit = 16.788 \cdot \frac{gal}{min}$

B. 1. Flow rate to second screen $q2in1 := q2in - q2out_2$ $q2in1 = 8.425 \cdot \frac{gal}{min}$

2. Flow rate to third screen $q2in2 := q2in1 - q2out_1$ $q2in2 = 8.213 \cdot \frac{gal}{min}$

3. Flow exiting the model $q2exit := q2in2 - q2out_0$ $q2exit = 8.02 \cdot \frac{gal}{min}$

C. 1. Flow rate to second screen $q3in1 := q3in - q3out_2$ $q3in1 = 3.197 \cdot \frac{gal}{min}$

2. Flow rate to third screen $q3in2 := q3in1 - q3out_1$ $q3in2 = 3.046 \cdot \frac{gal}{min}$

3. Flow exiting the model $q3exit := q3in2 - q3out_0$ $q3exit = 2.844 \cdot \frac{gal}{min}$

The ratio of the flow rate at the mesh to the flow rate out the outlet is calculated below. This ratio
is a function of the tube diameter to outlet diameter ratio D/d, the mesh size to outlet diameter mesh/d, and the Reynolds number, Re(ρ, flow rate out, D, viscosity, area).

Test 1

$flowratioq1500 := \frac{q1in}{q1out_2}$ $flowratioq1250 := \frac{q1in1}{q1out_1}$ $flowratioq180 := \frac{q1in2}{q1out_0}$

$flowratioq1500 = 112.5$ $flowratioq1250 = 61.517$ $flowratioq180 = 47.432$

Test 2

$flowratioq2500 := \frac{q2in}{q2out_2}$ $flowratioq2250 := \frac{q2in1}{q2out_1}$ $flowratioq280 := \frac{q2in2}{q2out_0}$

$flowratioq2500 = 128.571$ $flowratioq2250 = 39.689$ $flowratioq280 = 42.463$

Test 3

$flowratioq3500 := \frac{q3in}{q3out_2}$ $flowratioq3250 := \frac{q3in1}{q3out_1}$ $flowratioq380 := \frac{q3in2}{q3out_0}$

$flowratioq3500 = 78.261$ $flowratioq3250 = 21.155$ $flowratioq380 = 15.116$

Dimensionless Parameters

Model

flow rate in / flow rate out = f(D/d, mesh/d, Re (ρ, flow rate out, D, viscosity, area))

D/d Tube diameter/outlet diameter $\frac{Dmod}{dmodout} = 21.333$

mesh/d 80 μ $\frac{mesh_0}{dmodout} = 0.017$

mesh/d 250 μ $\frac{mesh_1}{dmodout} = 0.1$

mesh/d 500 μ $\frac{mesh_2}{dmodout} = 0.105$

For each test, three Reynolds numbers are calculated, one for each flow rate from each outlet.

Test 1

80 μ outlet $Req180 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q1out_0$ $Req180 = 188.357$

250 μ outlet $Req1250 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q1out_1$ $Req1250 = 147.631$

500 μ outlet $Req1500 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q1out_2$ $Req1500 = 81.452$

Test 2

80 μ outlet $Req280 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q2out_0$ $Req280 = 100.757$

250 μ outlet $Req2250 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q2out_1$ $Req2250 = 110.587$

500 μ outlet $Req2500 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q2out_2$ $Req2500 = 34.405$

Test 3

80 μ outlet $Req380 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q3out_0$ $Req380 = 104.972$

250 μ outlet $Req3250 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q3out_1$ $Req3250 = 78.729$

500 μ outlet $Req3500 := \frac{\rho \cdot Dmod}{Amod \cdot \mu} \cdot q3out_2$ $Req3500 = 21.557$

Winnow

Flow rates

1. Q1in is the flow rate to the Winnow. (this is the actual flow rate at 5 feet of head)

$$Q1in := \frac{168 \cdot liter}{22.5 \cdot sec} \qquad Q1in = 118.349 \cdot \frac{gal}{min}$$

Cflow is the flow rate out of the intake and is subtracted from Aflow. (valve opened at 3 inch intake to slow flow into the Winnow)

$$Cflow := \frac{24.5 \cdot liter}{8.53 \cdot sec} \qquad Cflow = 45.526 \cdot \frac{gal}{min}$$

2. Q2in is the slowed flow rate to the Winnow.

$$Q2in := Q1in - Cflow \quad Q2in = 72.824 \cdot \frac{gal}{min}$$

Tests performed

(the matrix values are the filtered outlets ordered by size: 80μ, 250μ, 500μ)

A. Q1in with mesh installed in the diffuser

$$t1 := 16.51 \cdot sec \qquad Q1 := \begin{pmatrix} 3.0 \\ 4.0 \\ 9.8 \end{pmatrix} \cdot liter \quad Q1out := \frac{Q1}{t1} \quad Q1out = \begin{pmatrix} 2.88 \\ 3.84 \\ 9.408 \end{pmatrix} \cdot \frac{gal}{min}$$

B. Q1in without mesh installed in the diffuser

$$t2 := 15.95 \cdot sec \qquad Q2 := \begin{pmatrix} 2.2 \\ 3.6 \\ 8.4 \end{pmatrix} \cdot liter \quad Q2out := \frac{Q2}{t2} \quad Q2out = \begin{pmatrix} 2.186 \\ 3.578 \\ 8.348 \end{pmatrix} \cdot \frac{gal}{min}$$

C. Q2in with mesh installed in the diffuser

$$t3 := 16.54 \cdot sec \qquad Q3 := \begin{pmatrix} 2.5 \\ 2.65 \\ 8.5 \end{pmatrix} \cdot liter \quad Q3out := \frac{Q3}{t3} \quad Q3out = \begin{pmatrix} 2.396 \\ 2.54 \\ 8.146 \end{pmatrix} \cdot \frac{gal}{min}$$

D. Q2in without mesh installed in the diffuser

$$t4 := 14.19 \cdot sec \qquad Q4 := \begin{pmatrix} 2.2 \\ 2.3 \\ 6.0 \end{pmatrix} \cdot liter \quad Q4out := \frac{Q4}{t4} \quad Q4out = \begin{pmatrix} 2.457 \\ 2.569 \\ 6.702 \end{pmatrix} \cdot \frac{gal}{min}$$

The flow rates for each successive screen are calculated, as were calculated for the model.

A. Q1in with mesh installed in the diffuser.

1. Flow rate to second screen $Q1in1 := Q1in - Q1out_2$ $Q1in1 = 108.941 \cdot \frac{gal}{min}$

2. Flow rate to third screen $Q1in2 := Q1in1 - Q1out_1$ $Q1in2 = 105.1 \cdot \frac{gal}{min}$

3. Flow exiting the model $Q1exit := Q1in2 - Q1out_0$ $Q1exit = 102.22 \cdot \frac{gal}{min}$

B. Q1in without mesh installed in the diffuser.

1. Flow rate to second screen $Q2in1 := Q1in - Q2out_2$ $Q2in1 = 110.002 \cdot \frac{gal}{min}$

2. Flow rate to third screen $Q2in2 := Q2in1 - Q2out_1$ $Q2in2 = 106.424 \cdot \frac{gal}{min}$

3. Flow exiting the model $Q2exit := Q2in2 - Q2out_0$ $Q2exit = 104.238 \cdot \frac{gal}{min}$

C. Q2in with mesh installed in the diffuser.

1. Flow rate to second screen $Q3in1 := Q2in - Q3out_2$ $Q3in1 = 64.678 \cdot \frac{gal}{min}$

2. Flow rate to third screen $Q3in2 := Q3in1 - Q3out_1$ $Q3in2 = 62.138 \cdot \frac{gal}{min}$

3. Flow exiting the model $Q3exit := Q3in2 - Q3out_0$ $Q3exit = 59.743 \cdot \frac{gal}{min}$

D. Q2in without mesh installed in the diffuser.

1. Flow rate to second screen $Q4in1 := Q2in - Q4out_2$ $Q4in1 = 66.121 \cdot \frac{gal}{min}$

2. Flow rate to third screen $Q4in2 := Q4in1 - Q4out_1$ $Q4in2 = 63.552 \cdot \frac{gal}{min}$

3. Flow exiting the model $Q4exit := Q4in2 - Q4out_0$ $Q4exit = 61.095 \cdot \frac{gal}{min}$

The ratio of the flow rate at the mesh to the flow rate out the outlet is calculated below. This ratio
is a function of the tube diameter to outlet diameter ratio D/d, the mesh size to outlet diameter mesh/d, and the Reynolds number, Re(ρ, flow rate out, D, viscosity, area).

Test 1

$$flowratioQ500 := \frac{Q1in}{Q1out_2} \qquad flowratioQ250 := \frac{Q1in1}{Q1out_1} \qquad flowratioQ80 := \frac{Q1in2}{Q1out_0}$$

$flowratioQ500 = 12.579$ $\qquad flowratioQ250 = 28.369$ $\qquad flowratioQ80 = 36.492$

Test 2

$$flowratioQ1500 := \frac{Q1in}{Q2out_2} \qquad flowratioQ1250 := \frac{Q2in1}{Q2out_1} \qquad flowratioQ180 := \frac{Q2in2}{Q2out_0}$$

$flowratioQ1500 = 14.178$ $\qquad flowratioQ1250 = 30.748$ $\qquad flowratioQ180 = 48.679$

Test 3

$$flowratioQ500 := \frac{Q2in}{Q3out_2} \qquad flowratioQ250 := \frac{Q3in1}{Q3out_1} \qquad flowratioQ80 := \frac{Q3in2}{Q3out_0}$$

$flowratioQ500 = 8.94$ $\qquad flowratioQ250 = 25.469$ $\qquad flowratioQ80 = 25.937$

Test 4

$$flowratioQ2500 := \frac{Q2in}{Q4out_2} \qquad flowratioQ2250 := \frac{Q4in1}{Q4out_1} \qquad flowratioQ280 := \frac{Q4in2}{Q4out_0}$$

$flowratioQ2500 = 10.866$ $\qquad flowratioQ2250 = 25.737$ $\qquad flowratioQ280 = 25.861$

Dimensionless Parameters

Winnow

$$\frac{Dwin}{dwinout} = 14.462$$

D/d Tube diameter/outlet diameter

mesh/d 80 μ $\frac{mesh_0}{dwinout} = 3.876 \cdot 10^{-3}$

mesh/d 250 μ $\frac{mesh_1}{dwinout} = 0.012$

mesh/d 500 μ $\frac{mesh_2}{dwinout} = 0.024$

Reynolds Number

For each test, three Reynolds numbers are calculated, one for each flow rate at each outlet.

Test 1

80 μ outlet $ReQ180 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q1out_0$ $ReQ180 = 510.772$

250 μ outlet $ReQ1250 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q1out_1$ $ReQ1250 = 681.03$

500 μ outlet $ReQ1500 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q1out_2$ $ReQ1500 = 1.669 \cdot 10^3$

Test 2

80 μ outlet $ReQ280 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q2out_0$ $ReQ280 = 387.717$

250 μ outlet $ReQ2250 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q2out_1$ $ReQ2250 = 634.447$

500 μ outlet $ReQ2500 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q2out_2$ $ReQ2500 = 1.48 \cdot 10^3$

Test 3

80 μ outlet $ReQ380 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q3out_0$ $ReQ380 = 424.872$

250 μ outlet $ReQ3250 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q3out_1$ $ReQ3250 = 450.364$

500 μ outlet $ReQ3500 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q3out_2$ $ReQ3500 = 1.445 \cdot 10^3$

Test 4

80 μ outlet $ReQ480 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q4out_0$ $ReQ480 = 435.806$

250 μ outlet $ReQ4250 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q4out_1$ $ReQ4250 = 455.616$

500 μ outlet $ReQ4500 := \frac{\rho \cdot Dwin}{Awin \cdot \mu} \cdot Q4out_2$ $ReQ4500 = 1.189 \cdot 10^3$

From Dimensional analysis, the ratio of the flow rate into the tube (Qin) to the flow rate exiting the plankton outlets (Qout) is a function of the following dimensionless parameters: ratio of the screen mesh size to the exit diameter (m/d), ratio of the tube diameter to the exit diameter (D/d), and the Reynolds number (Re). With these relationships, the model can be easily scaled to full size. This approach requires that all the terms in every governing equation be dimensionally consistent. The calculations beginning on page A21 in Appendix B examine the validity of this assumption.

Three different flow rates were run through the model and the three corresponding Reynolds numbers for each of the three outlets were calculated and plotted (Figure A19). Four similar tests were run on the Winnow and those results were plotted (Figure A20). An apparent trend of a decreasing flow rate ratio with an increasing Reynolds number for both setups is observable. The entire set of data points was plotted on the same scale and an exponential relationship related the two groups of data points (Figure A21). The log scale was implemented on both axes, and a linear fit with an R-squared equal to 0.612 results in an equation that relates flow rate to Reynolds number. The results of this analysis provide the means to determine geometries for corresponding flow rates, and flow rates for certain geometries.

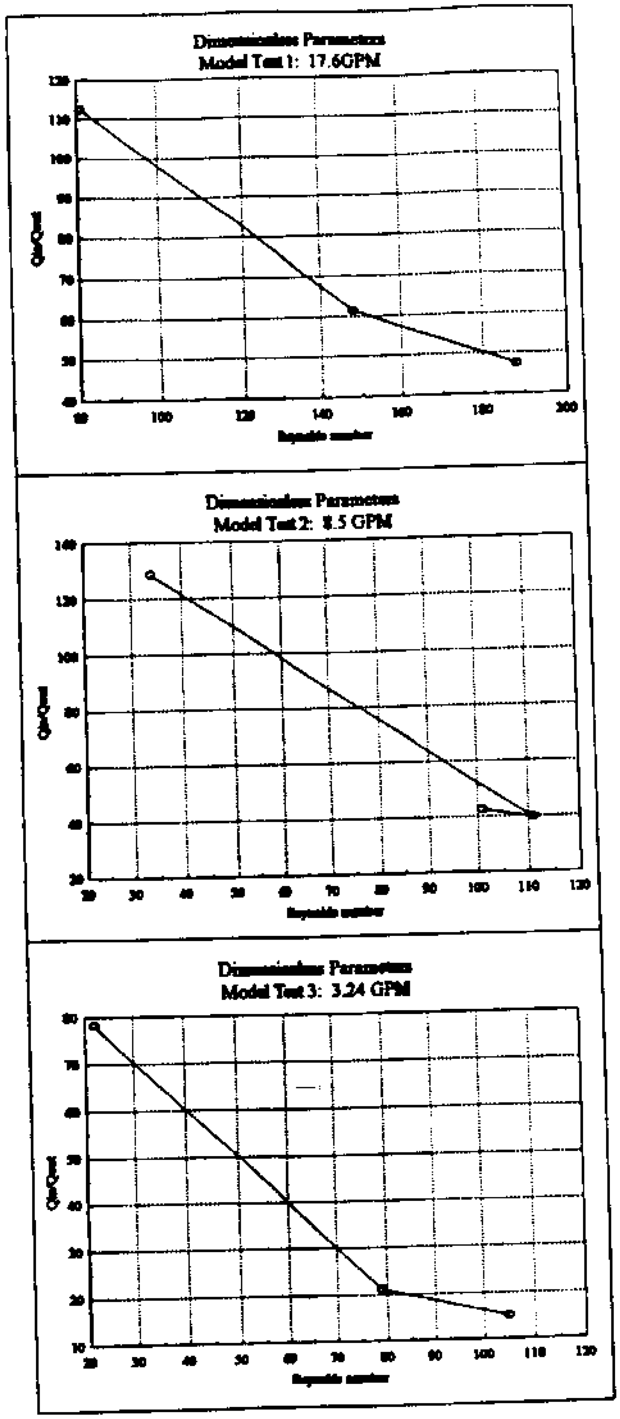


Figure A19 Reynolds Scaling: Model Tests A)17.6 GPM
B) 8.5 GPM
C) 3.24 GPM

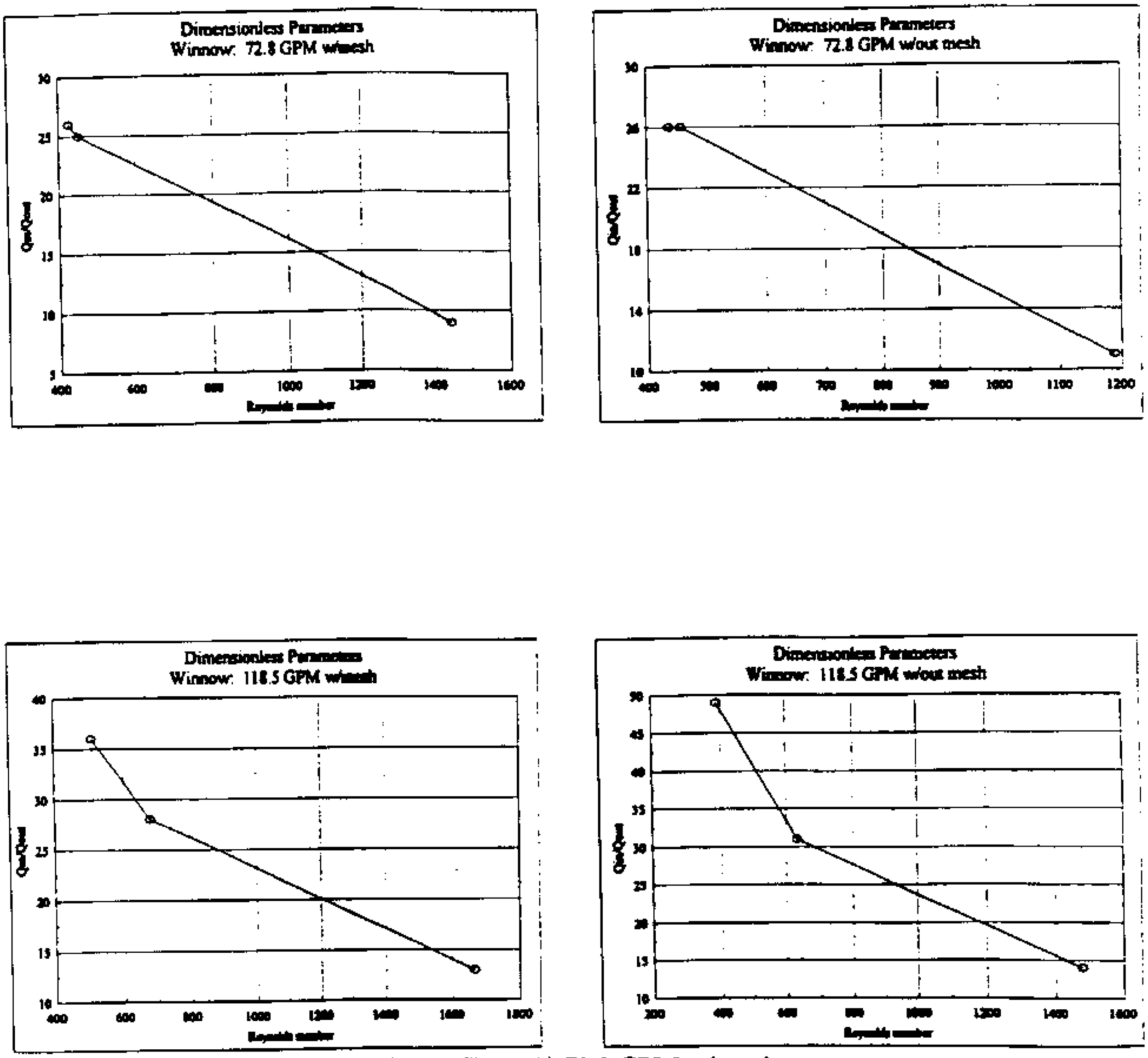


Figure A20 Reynolds Scaling: Winnow Tests A) 72.8 GPM w/ mesh
B) 72.8 GPM w/out mesh
C) 118.5 GPM w/ mesh
D) 118.5 GPM w/out mesh

Dimensionless Scaling

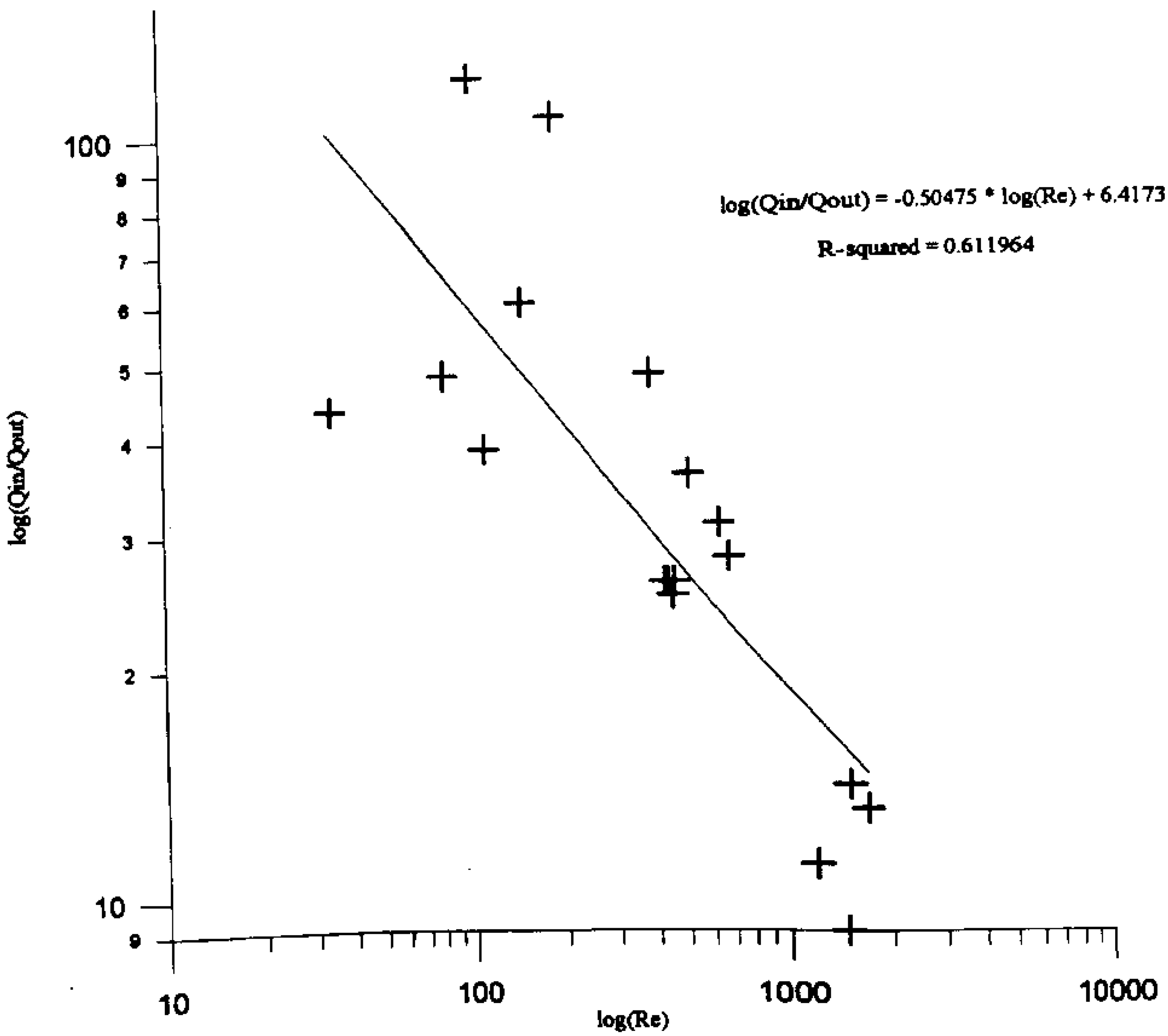


Figure A21 Dimensionless Parameters: Determining the accuracy of the scaling

Appendix C. Timeline

A timeline was constructed (Figure A8) to help assist the Winnow Team keep on schedule throughout the project. Deadlines were set throughout the process to ensure that the project would be completed on time. Several hurdles were met along the way. Some delays were incurred, however in some instances, the progress was accelerated. The following pages illustrate the outlined schedule and actual progress of the Winnow Project as the year passed.

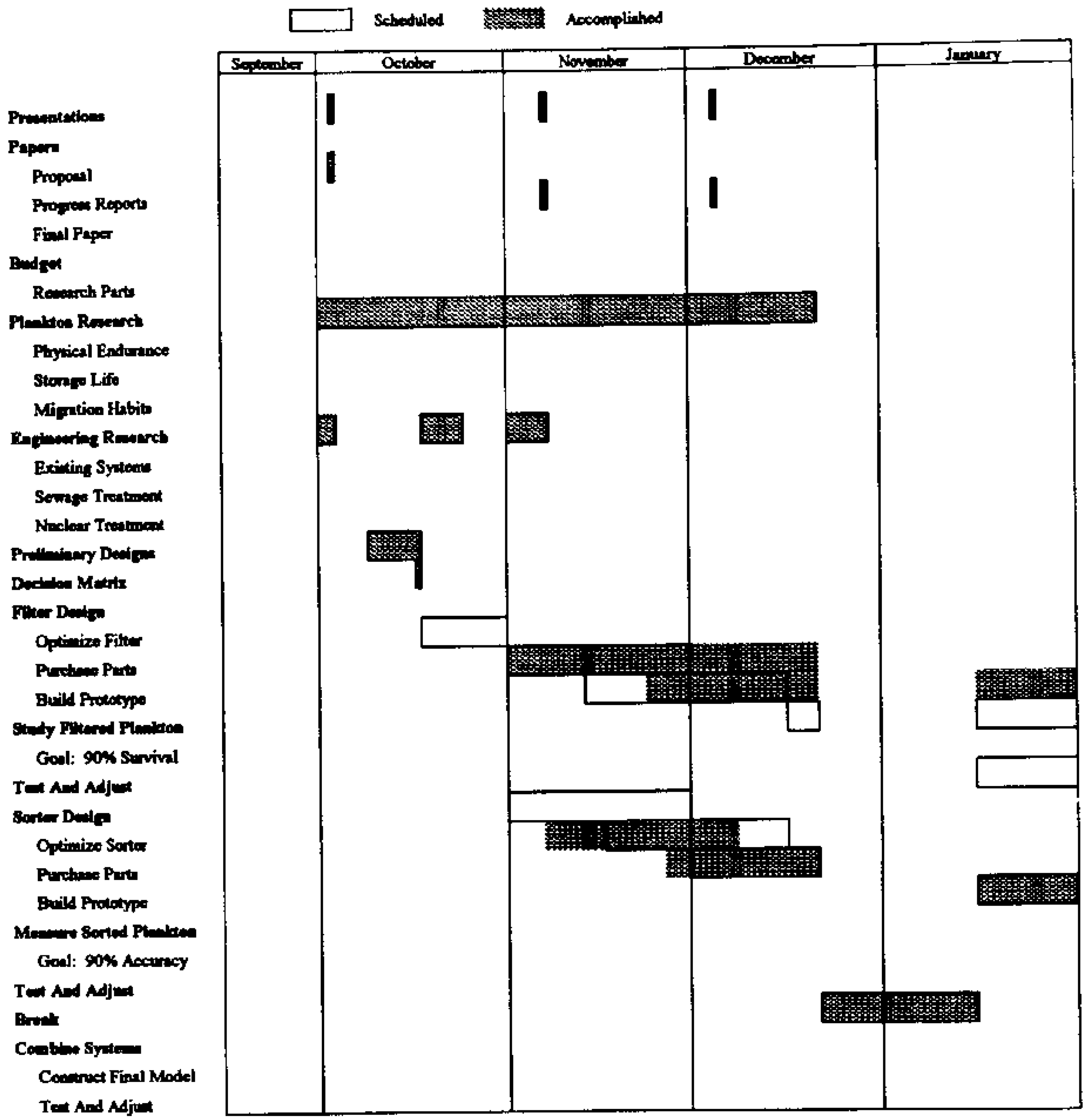


Figure A21(a). Winnow Timeline: Semester I

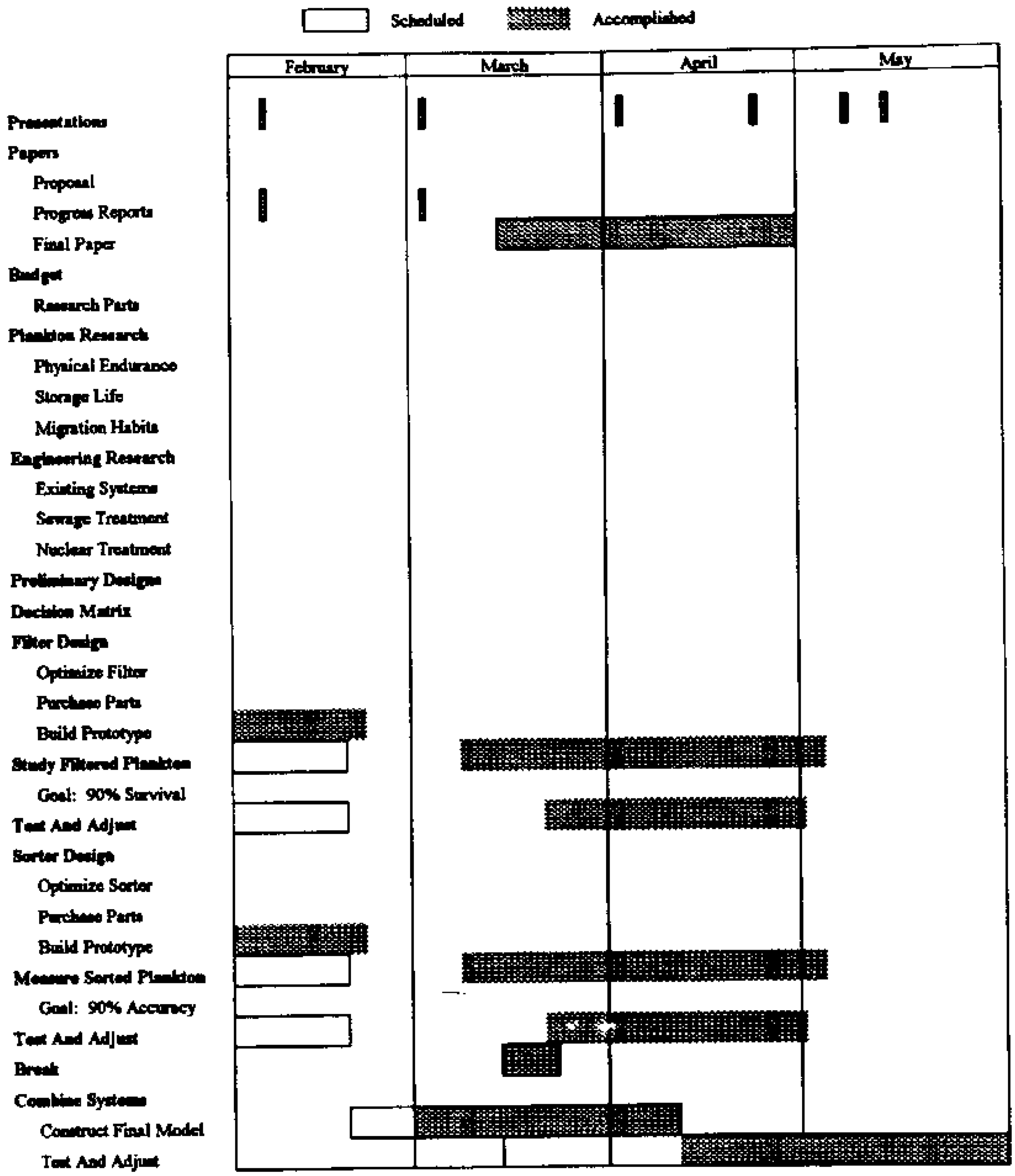


Figure A21(b). Winnow Timeline: Semester II

Appendix D. References

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