Report No. CG-D-10-97

Feasibility of Using Composite Materials to Reduce the Weight of the CCN-150 Transfer Pump

H. K. Telegadas

Carderock Division
Naval Surface Warfare Center
Bethesda, MD 20084-5000

Final Report
November 1996

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Marine Safety and Environmental Protection, (G-M)
Washington, DC 20593-0001

and

United States Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

NOTICE

Marc B. Mandler
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-10-97	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Feasibility of Using Composite Materials to Reduce the Weight of the CCN-150 Transfer Pump	5. Report Date November 1996 6. Performing Organization Code Project No. 4120
7. Author(s) H. K. Telegadas	8. Performing Organization Report No. R&DC 32/96
9. Performing Organization Name and Address Carderock Division Naval Surface Warfare Center Bethesda, MD 20084-5000	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Marine Safety and Environmental Protection (G-M) Washington, DC 20593-0001 U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code Commandant (G-MOR) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Kenneth Bitting, 860-441-2733.

16. Abstract

A Phase I study was initiated by the Coast Guard R&D Center to determine the feasibility of using composite materials to reduce the weight of the National Strike Force cargo transfer pumps. The Carderock Division of the Naval Surface Warfare Center (CDNSWC) was tasked to carry out Phase I. Initially all of the pumps in the Coast Guard's inventory were investigated. The study eventually focused on one particular pump at the Coast Guard's request, the CCN-150. A CCN-150 was obtained and disassembled by CDNSWC. Each of the major components was assessed as to the feasibility of fabricating it out of composite materials. A test plan for strain gaging and running the CNN-150 at a variety of operating conditions was proposed. Actual testing of the CCN-150 would provide an understanding of the operational strain levels in the pump. Three options were presented for a composite CCN-150. The risk and potential weight savings for each option were presented. CDNSWC recommended that a composite CCN-150 be pursued in two separate stages. First, the suction bell and pump bowl would be replaced by a composite version. This pump would then be evaluated. If the performance of the CCN-150 was not degraded by these new composite components and significant weight savings were demonstrated, work on a composite motor housing would be initiated. A CCN-150 with a composite suction bell, pump bowl, and motor housing has the potential for reducing the weight of a state-of-the-art stainless steel CCN-150 by 36%.

17. Key Words oil spill equipment transfer pumps composite material pumps	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) UNCLASSIFIED	20. SECURITY CLASSIF. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

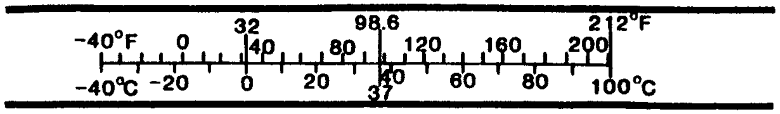
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares(10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Contents

Page

Contents (continued)

Figures

Figures (continued)

Tables

Nomenclature

AST	Atlantic Strike Team.
ASTM	American Society for Testing and Materials.
CAD	Computer Aided Design.
CDNSWC	Carderock Division Naval Surface Warfare Center.
E	modulus of elasticity.
E_c	modulus of elasticity of composite.
E_s	modulus of elasticity of steel.
FOSC	Federal On-Scene Coordinators.
gpm	gallons per minute.
GRP	glass-reinforced polymeric.
GST	Gulf Strike Team.
ID	inner diameter.
in	inch
ksi	thousand pounds per square inch.
lb	pound.
Msi	million pounds per square inch.
NAVSEA	Naval Sea Systems Command.
NCP	National Contingency Plan.
Ni-Al-Bz	nickel-aluminum-bronze.
NSFCC	National Strike Force Coordination Center.
NSF	National Strike Force.
OD	outer diameter.
OWOCRS	Open Water Oil Containment and Recovery System.
psi	pounds per square inch.
PST	Pacific Strike Team.
r	radius.
RTM	resin transfer molding.
t_c	wall thickness of composite.
t_s	wall thickness of steel.
VOSS	Vessel of Opportunity Skimming System.
δ_r	change in radius.
ε	strain.
σ	stress.

EXECUTIVE SUMMARY

Objective

The objective of this study was to determine the feasibility of using composite materials to reduce the weight of the National Strike Force cargo transfer pumps.

Technical Approach

All the pumps in the Coast Guard's inventory were investigated. The study eventually focused on the CCN-150 transfer pump.

In phase one of the project, this pump was tested at a variety of operating conditions to determine the operational strain levels within the pump. The results of these tests may be found in CG-D-10-97.

In phase two of the project, a composite pump bowl and suction bell were designed and fitted to the existing CCN-150. Subsequent tests showed that the composite parts performed as well as their metallic counterparts. The results of these tests may be found in CG-D-11-97.

Findings

Tests showed that the performance of the pump was not degraded with the composite parts. The use of the composite material reduced the weight of the stainless steel pump by 28%.

Recommendations

The report offers three options for future pump development: a) perform additional testing to refine the current composite suction bell and pump bowl, b) fabricate additional parts of composite to reduce weight further, and c) design an all new joint Navy/Coast Guard transfer pump that would minimize weight and optimize the strength advantages of composites.

Introduction

In 1973 the National Contingency Plan (NCP), which establishes contingency planning procedures and a standardized spill response organization for the United States, created the National Strike Force. The National Strike Force (NSF) is a Coast Guard *special force* consisting of trained personnel and specialized equipment available to provide necessary services to carry out the NCP. The NSF works directly for Federal On-Scene Coordinators (FOSC) which are the focal points for oil and hazardous spill response. The National Strike Force may be best understood by its mission statement: [1]

> *"The NSF is a unique, highly-trained cadre of Coast Guard professionals who maintain and rapidly deploy with specialized equipment in support of Federal On-Scene Coordinators preparing for and responding to oil and chemical incidents in order to prevent adverse impact to the public and reduce environmental damage."*

The National Strike Force consists of three strike teams, the Atlantic Strike Team (AST), the Gulf Strike Team (GST), and the Pacific Strike Team (PST), and the National Strike Force Coordination Center (NSFCC). The location of each of these organizations and its area of command is shown in Fig. 1. The strike teams operate under the control of the NSFCC which provides support and standardization guidance. Each of the teams' activities are broken into seven major mission areas: response; equipment; preparedness; training; marketing / liaison; research and development; and overhead, with "response" being the most well-known mission. In FY93, the NSF responded to 139 cases. [2] In each of these cases, the strike teams provided the FOSCs with communications support, expert advice, and assistance.

As was indicated in the mission statement, the national strike teams must be ready to rapidly respond to spills. In order to maintain their readiness, the strike teams' inventory of response equipment is typically prepackaged and stored on trailers as *ready loads* for quick transport by truck or air. A typical ready load is shown in Fig. 2 and may include any or all of the following pollution response equipment:

- Open Water Oil Containment and Recovery System (OWOCRS).
- Vessel of Opportunity Skimmimg System (VOSS).
- Oil-containment barriers.
- Temporary storage tanks.
- Mobil command posts.
- Air monitoring equipment.
- Communications equipment.
- Level 'A' response personal protection equipment.
- Photographic equipment.
- Small boat(s).
- Diesel-driven hydraulic power pack.
- Portable pumping systems.

Included in the portable pumping systems are the submersible pump systems which are used to off load cargo from stranded tank vessels. The systems include the hydraulically-operated cargo transfer pumps themselves, diesel-engine-driven hydraulic prime movers, hydraulic lines, cargo hoses, and various mechanical handling equipment. Most of the components in these systems are heavy and cumbersome. Moving the pumps, cargo hoses, hydraulic hoses, and associated equipment around the deck of a stranded vessel can be difficult and slow. Valuable time and opportunity can be lost in addition to the potential generation of many personal injuries. It is anticipated that the NSF off-loading mission would greatly benefit if the weight of existing transfer equipment could be reduced without sacrifice to pumping capacity or ruggedness. One such approach is by making use of composite materials. The high specific strength and specific stiffness of composites, as compared to other engineering materials, makes them attractive alternatives when reducing weight is a priority.

In order to begin the investigation into lightweight transfer equipment, the Carderock Division of the Naval Surface Warfare Center (CDNSWC) was tasked by the Coast Guard Research and Development Center to review the design and performance of the various transfer pumps in the NSF inventory and to conduct a preliminary investigation into the feasibility of using composite materials in an effort to reduce the weight of these pumps. CDNSWC has been the lead agency for the Navy on conducting research into the use of composites in pumping systems. In the 1980's, CDNSWC completed an investigation for development of a Navy standard family of composite centrifugal pumps. [3] The investigation included hydraulic performance, endurance, cavitation, high-velocity seawater erosion, high-impact shock, vibration, mechanical loading, and inclined operational evaluation with composite pumps supplied by five U.S. manufacturers. At-sea evaluations were also completed with composite brine and feed pumps aboard two DD-963 class destroyers. The results of these investigations provided the Naval Sea Systems Command (NAVSEA) with the basis for specifying the material, performance, and construction criteria for a Navy-design family of composite centrifugal pumps for general surface fleet applications. Detailed design of this standardized family of Navy composite centrifugal pumps has recently been completed and the manufacture of preproduction prototype units is now underway.

This Phase I feasibility report focuses on taking advantage of the high specific strength and stiffness of composites in an effort to reduce the weight of NSF cargo transfer pumps with no loss in performance capabilities.

Background

Pump Inventory

CDNSWC visited the Gulf Strike Team in April 1993 in order to become familiar with the NSF cargo pump inventory. Six pumps were examined:

- Stripper
- Single Stage
- Double Stage
- Thune Eureka
- Sloan
- TK-5

A brief description of the six pumps is given below followed by a summary of the pertinent characteristics in Table 1.

Stripper

The Stripper pump is an 8 inch diameter, submersible, single-stage, mixed-flow pump. It measures 61 inches in length. Its steel case makes this pump quite heavy, approximately 330 lb. The Stripper is able to pump at rates up to 1330 gallons per minute (gpm). Its suction intake is at the bottom of the pump which enables it to remove a tank's cargo to within several inches from the bottom. The Stripper pump is primarily used to pump petroleum products. The Stripper pump is shown in Fig. 3.

Single Stage

The Single Stage is also a one stage, mixed flow pump. It measures 8 inches in diameter and 53 inches in length. The Single Stage's case is steel and the pump weighs approximately 265 lb. This pump is able to pump at rates up to 1500 gpm and is primarily used to off load petroleum products. The Single Stage pump is shown in Fig. 4.

Double Stage

The Double Stage pump is a two stage mixed-flow pump. The Double Stage is shown hanging in Fig. 5. This pump weighs approximately 500 lb., has a diameter of 10 inches, and is 87 inches long. The Double Stage, like the Single Stage and Stripper pumps, is primarily made out of steel. The Double Stage is able to pump at rates up to 1645 gpm. It is used to move petroleum cargo at high rates.

Thune Eureka

The Thune Eureka is a mixed flow pump weighing 280 lbs. It has a 12 inch diameter and is 41 inches in length. The Thune Eureka is capable of pumping at rates up to 1800 gpm. It suction location is at the bottom of the pump and, like the Stripper pump, is able to remove a tank's cargo to within a few inches of the bottom. This pump is used to transfer petroleum products. The Thune Eureka is primarily made of nickel-aluminum-bronze. The pump is shown in Fig. 6.

Sloan

The Sloan "trash pump" (Fig. 7) is used to transfer light-weight petroleum products and water. It's suction location is located at the bottom of the pump and thus, it can remove these products to within a few inches of the tank's bottom. The Sloan weighs 140 lb., is 23.5 inches long, and has a 20 inch diameter. The Sloan is able to pump these lightweight products at rates up to 1147 gpm. It is primarily made of aluminum.

TK-5

The TK-5 is a stainless steel, one stage pump. It is primarily used to handle corrosive chemical but can also be used for viscous oils and high temperature fluids. It has a 12 inch diameter, is 36 inches long, and weighs approximately 172 lb. The TK-5 is capable of pumping fluids at rates up to 2200 gpm.

Table 1. Summary of the NSF submersible, hydraulic transfer pumps. [4]

Pump	Pump Rate (gpm)	Diameter (in)	Length (in)	Weight (lb)	Product
Stripper	1330	8	61	330	Petroleum
Single Stage	1500	8	53	265	Petroleum
Double Stage	1645	10	87	500	Petroleum
Thune Eureka	1800	12	41	280	Petroleum
Sloan	1147	20	23.5	140	Light Petroleum
TK-5	2200	12	36	172	Corrosive Chemicals

Further Investigation

In addition to visiting the GST, CDNSWC was able to obtain the Stripper and Single Stage pumps for a more detailed investigation. Each of these pumps was examined, disassembled, and the primary components weighed.

An excess-inventory Stripper pump was received at CDNSWC from the Coast Guard partly disassembled, damaged, and missing various parts. Never-the-less, the major components of this pump, marked as #1, #2, #3, and #4 in Fig. 8, were intact and their individual weights measured. The individual weights are shown in Fig. 8. The weight of the hydraulic motor , 29.8 lb., is also noted in the figure. The balance of the weight of the stripper pump is comprised of smaller parts such as the shaft, seals, sling, fittings, etc.

The Stripper is shown disassembled in Fig. 9. Again the various major components are marked and their weights included in the figure. It is obvious from this figure that the Stripper pump is comprised of a few, very heavy components. These components are good candidates for composites technology.

The Stripper pump was reassembled. During that process, several actions were taken to try and restore the missing and/or damaged components. The actions included: installing a missing allen key on the shaft; cleaning the pump housing of all rust; coating all threads with an anti-seize product; fabricating new gaskets; and renewing a broken pipe nipple.

The Single Stage pump arrived at CDNSWC essentially intact. This pump is shown in Fig. 10 assembled and disassembled in Fig. 11. In each figure, the major components are numbered and their weights noted. As in the case of the Stripper pump discussed above, the Single Stage pump is comprised of relatively heavy, thick-walled steel components which did not appear to be optimized from a design standpoint for portability, corrosion resistance, nor structural efficiency.

Recommendation

After examining the six pumps listed above, it became apparent that the first three listed in Table 1, Stripper, Single Stage, and Double Stage, are the most likely pumps to readily benefit through upgrading with composites. The three pumps are all very heavy and have steel as the primary construction material. The casings are thick and initially appear to be over designed. The pumps themselves are essentially axisymmetric bodies of revolution housing an impeller and motor. Axisymetric bodies are easily fabricated with composites using filament winding techniques.

In addition to being heavy, the Stripper, Single, and Double Stage pumps all have diameters less than 12 inches which facilitates the application of composite materials. Typically, a one-for-one replacement of a composite material for a metal is not possible, especially when trying to replace steel.

Composites are commonly more compliant and less strong than their metal counterparts. When a composite material is used to replace a metal in an existing "metal" design, the part is usually thickened in order to recover the strength and stiffness as needed. Since all Coast Guard transfer pumps must have outside diameters of less than 12.5 inches (to pass through existing deck openings for tank cleaning machines), [5] and since the diameter of these three pumps are less than 12 inches, the casing thickness of each of these pumps (Stripper, Single Stage, Double Stage) can be increased in critical locations in order to reduce stress and/or increase sectional stiffness.

Although the Thune Eureka is also a heavy pump, 280 lb., applying composites technology to this pump would be more difficult than with either of the first three pumps listed in Table 1. The housing for this pump is non-axisymmetric with the hydraulic input/output lines penetrating the side of the housing. This is shown clearly in Figs. 12 and 13. In addition, the Thune Eureka's diameter is already at 12 inches leaving little room to increase the wall thickness of the casing. Trying to replace this non-axisymmetric metal case with sealed penetrations and little tolerance for increasing the wall thickness (especially in the region surrounding the penetrations) would be a very challenging and probably a costly undertaking. The chance for successfully fabricating this pump out of composites is small compared to fabricating one of the other three pumps already mentioned.

The last two pumps listed in Table 1, the Sloan and TK-5, should not be considered candidates for composites at this time. Both pumps are already lightweight as compared to any of the others. In fact, the Sloan pump is made of aluminum. Very little could be done to lighten this pump by switching to composites.

The TK-5, although not aluminum, is also light as compared to the first four pumps listed. Its stainless steel construction is necessary to prevent it from being attacked by corrosive chemicals. Several factors prevent this pump from being an likely first choice for fabrication with composites. First, any composite material chosen would need to withstand attack by the many corrosive chemicals this pump experiences in service. A number of chemical compatibility, chemical corrosion, and chemical erosion tests would need to be performed in order to confidently identify a suitable material for substitution.

These test may become costly and are not necessary with any of the other pumps. Second, the TK-5 is relatively lightweight. The effect composites would have in reducing this weight further would be minimal. Finally, the TK-5's diameter is already 12 inches. The same problems which were described for the Thune Eureka apply to this pump, i.e., there is little room to increase its wall thickness in order to compensate for the difference in mechanical properties of composites as compared to the stainless steel.

Following this discussion, CDNSWC initially recommended that the Double Stage pump be targeted for further study. The Double Stage has a fairly simple design with a straight, axisymmetric housing. It is the heaviest pump and thus would profit the most by using composite materials to reduce weight. It has a diameter less than 12 inches which would allow flexibility in its redesign. Finally, any technology developed for this pump could easily be adapted to the Single Stage and Stripper pumps, since all of these pumps are very similar in design. The payoffs in redesigning this pump with composites are relatively great while the technical risks involved are relatively small.

Approach

The approach to reducing the weight of the Double Stage pump is outlined in Fig. 14. The first step is to continue to determine physical, mechanical, and environmental requirements of the Double Stage pump and to accurately obtain the loading conditions during operation. This will be accomplished by reviewing the manufacture's drawings and specification sheets and through discussions with the various NSF strike teams. Once the loading conditions are established, a finite element model of the Double Stage pump will be built and analyzed. By analyzing the original pump, a baseline is established for direct comparison with a composite design. Once a baseline is established, the same model will be analyzed using candidate composite properties substituted for the baseline metal properties of the casing and other major metal components. The results from this model will be compared with the original results. If a direct substitution of composite properties does not yield an acceptable design, the composite model will be modified accordingly. Essentially an iterative process is set up using the baseline results as feedback. The process will continue until either a satisfactory composites design is established or not. If this approach is deemed not feasible, a new composite pump meeting all of the structural and environmental requirements of the Double Stage pump will have to be designed from the ground up.

Literature Review

The literature review for this report is broken into two parts. The first is a review of current state-of-the-art (SOA) pumps manufactured in the US which might meet the Coast Guard's requirements for a submersible, hydraulically-driven composite pump. Using the Thomas Register [6], a list was made of possible companies by searching the following subheadings:

Pumps: Axial Flow
Pumps: Ballast
Pumps: Barge Unloading
Pumps: Centrifugal Screw
Pumps: Chemical
Pumps: Chemical Feed
Pumps: Chemical Plant
Pumps: Corrosion Resistant
Pumps: Hydraulic
Pumps: Plastic
Pumps: Propeller
Pumps: Submersible
Pumps: Transfer

The completed list is given alphabetically in Appendix A. The companies are being contacted and if there are candidate pumps which seem to match the Coast Guard's requirements with little or no modification, the pumps will be obtained for specific evaluation to be determined by the Coast Guard and CDNSWC. At this time approximately half of the companies listed in Appendix A have been contacted with no success in matching the Coast Guard's requirements.

The second part of the literature review consists of a more conventional search of possible papers, articles, books etc. on the broad topic of composite pumps. The Technical Information Center at CDNSWC was contacted and a search was initiated using the key words *Composite* and *Pump*. A total of 248 matches were made. The complete list of citations is given in Appendix B. Out of this list, twelve papers were requested for review, six of which have been obtained. The remaining are being sought. No foreign language papers were requested even though some of these were very interesting. A brief summary follows.

An overview of non-metallic, corrosion resistant pumps as compared to their metal counterparts is provided in two technical papers by the Ingersoll-Rand Company. Both articles are written by the same author, Frederic Buse of the Ingersoll-Rand Company. [7,8] The author describes the development of the non-metallic pump as a solution to costly, corrosion resistant metal alloys. Buse discusses material selection, manufacturing techniques, and design considerations for non-metallic pumps. The focus is on centrifugal pumps.

The design and development of a centrifugal composite pump from the ground up is described by Banerjee. [9] The pump was developed as a substitute for metallic pumps in the chemical process industry. The goal of the project was to develop a pump whose components would be made from a single glass-reinforced polymeric (GRP) material and whose structural integrity would be the same as its metallic counterpart. The GRP would provide superior corrosion resistance. An iterative process involving the design, testing, and analysis of actual pumps was used to optimize the material choice and final configuration. Tests included coupon testing for mechanical properties and weight gain, casing pressurization, fatigue endurance, long term hot-loop exposure, nozzle loading, and field installation performance. The final pump was made of compression molded, glass reinforced, vinyl ester.

An interesting presentation on a specific secondary advantage of using composite materials in lieu of metals for corrosion resistant pumps is presented by Petersen. [10] He postulates that an energy savings will be realized by the increased efficiency and lower energy consumption of non-metallic molded pumps as compared to metal castings due to the smoother surface finish of the non-metallic pump. Petersen outlines a theoretical method for calculating this savings. Actual tests were then performed by changing the surface finish of a molded centrifugal pump. The efficiency did decrease with increase surface roughness although there was some discrepancy between the actual data and predicted results. Petersen points out that the savings is minimal and represents a secondary benefit.

Two papers were reviewed which discussed the advantages of using a specific material, PYROITE, for pumps which need to be resistant to corrosive fluids. [11,12] PYROITE is essentially an epoxy with three separate and distinct zones. The first zone is an inner layer consisting of the polymer with a diamond filler for maximum protection against chemical attack. The second zone is the middle layer consisting of the polymer filled with oriented chopped glass fibers for maximum strength. The last zone is the outer layer consisting of random short glass fibers and the PYROITE resin forming a protective coating. Included in each paper was a thorough discussion comparing the different material choices and construction techniques for chemical pumps. The PYROITE material is compared with stainless steel, various thermoplastic materials, lined construction techniques, cast thermosets, and reinforced thermosets. More information on PYROITE is being sought.

Amerglass of the Netherlands is currently using the resin transfer molding (RTM) technique to fabricate enclosures for vacuum pumps. [13] The RTM method was chosen because it is able to produce a large number of complex-shaped parts economically. The parts are made to final shape with finishing operations, such as making grooves and holes, done by computer controlled machining.

Finally, a interesting article was found entitled *The Effects of Vertical Pump Materials of Construction on Design and Performance.* [14] At first it was thought that this article would be very helpful since the NSF transfer pumps fall into this category of pumps. However, the paper never mentions non-metallic materials as alternatives for the construction of these pumps. The paper goes into some detail about the common vertical pump configurations. For each, configuration, the pump is broken into its parts list and the recommended material for each part is given. Common materials for the pipe column, suction bowl, and discharge bowl are steel, stainless steel, and cast iron depending on the fluid being pumped.

It is apparent from the limited review above, that the use of polymeric composites in the pump industry has been limited to those applications where good corrosion resistance is needed. The driver for this technology has been the demand for greater corrosion resistance than is offered by the stainless steels and nickel-based alloys, but at a lower cost than some of the more expensive, highly corrosion resistant alloys, such as titanium, zirconium, and Hastelloys. No information was found on using composites to reduce weight as a primary goal. However, much of the technology developed on composite pumps for the chemical and chemical processing industry can be borrowed for this project.

Redirection

The pump inventory described above consists of older pumps which have been in the Coast Guard's inventory for some time now. Recently, the Coast Guard acquired a newer pump, the CCN-150. The CCN-150, shown in Fig. 15, is a mixed-flow, submersible pump made of stainless steel. It is a more modern pump than any if those listed in Table 1. Subsequent discussions with NSF personnel indicate that the CCN-150's characteristics in terms of weight, size, and hydraulic performance are generally "preferred" over those of the Stripper, Single Stage, Double Stage, and other transfer pumps previously described in this report. The Coast Guard and CDNSWC decided to focus primarily on this pump since it is more likely to play a more important role in future NSF response actions. That is, CDNSWC was now to determine the feasibility of using composite materials in an effort to reduce the weight of the CCN-150. The remainder of this report is dedicated to this effort.

CCN-150

Background

The CCN-150 is a submersible pump supplied by Marine Pollution Control Corporation for NAVSEA and the Coast Guard. It was designed initially for use by the Supervisor of Salvage for emergency off loading stranded Navy oilers. The CCN-150 (Fig. 15) operates like the other submersible pumps in the NSF inventory. Hydraulic and discharge lines are attached to the pump which is then lowered into the tank to be drained. The output rate of the pump is controlled by the flow rate of the hydraulic fluid from the prime mover.

The CCN-150 is an all stainless steel pump weighing 187 lb. It is 28 inches long and has a 12 inch diameter. Because its suction intake is at the bottom of the pump, the CCN-150 is able to remove a tank's cargo to within a few inches of the bottom. The CCN-150, being stainless steel, is able to pump chemicals as well as petroleum products.

Comparing the CCN-150 with the Thune Eureka, Fig. 15 with Fig. 6, we see that the two pumps are very similar in design. As it turns out, both pumps belong to a family of pumps, all with the designation CCN-150. The pump shown in Fig. 6 is the CCN-150-1C Thune Eureka. That shown in Fig. 15 is the CCN-150-5C Kvaerner Eureka. There is also a pump designated CCN-150-3C Kvaerner Eureka. The CCN-150-1C was the original design followed later by the CCN-150-3C. The CCN-150-5C is the most recent design. The three pumps are compared in Table 2. [15] The Coast Guard has requested that CDNSWC focus on the CCN-150-5C only since this is the most modern pump of the three. In order to avoid confusion, from here on out the CCN-150-5C will be referred to as the CCN-150 while the original shown in Fig. 6 will be known as the Thune Eureka.

Table 2. Comparison of the CCN-150 family of pumps. [15]

Pump	Construction Material	Pump Rate (gpm)	Diameter (in)	Length (in)	Weight (lb)	Product
CCN-150-1C Thune Eureka	Ni-Al-Bz	1800	12	41	280	Petroleum
CCN-150-3C Kvaerner Eureka	Ni-Al-Bz / Stainless	2200	12	28	187	Petroleum
CCN-150-5C Kvaerner Eureka	All Stainless	2200	12	28	187	Petroleum / Chemicals

Approach

Applying composites technology to the CCN-150 in an effort to reduce weight is a challenging task. The CCN-150 has a diameter of 12 inches. There is very little room to increase its diameter if a thicker casing is required to reduce stress levels in the composite. The weight of the CCN-150 is relatively low. Composites will not have the impact on weight reduction for this pump as compared to some of the other older pumps (Single Stage, Double Stage, Stripper). However, unlike the Thune Eureka, the body of the CCN-150 is axisymmetric. The hydraulic fittings penetrating the motor housing on the top of the pump instead of its side allowing the body of the motor housing to remain cylindrical. Axisymmetric bodies lend themselves to a variety of fabrication techniques without the cost of complicated molds.

An approach similar to the one shown in Fig. 14 for the Double Stage was to be used for the CCN-150. The literature search of state-of-the-art pumps would continue. Loading conditions and design philosophy for the CCN-150 were to be obtained from discussions with the various strike teams and the pump's supplier, Marine Pollution Control Corporation. Detailed drawings of the pump were also to be obtained in order to accurately build the finite element models. However, contact with Marine Pollution Control Corporation yielded no information about the design requirements. In addition, the design drawings were not available. At this time it was deemed infeasible to pursue the finite element method as a design tool without the detailed drawings and an understanding of the boundary conditions. A different approach was needed.

CDNSWC decided to try and obtain a CCN-150 for further inspection. A brand new CCN-150 was made available via the Coast Guard R&D Center and delivered to CDNSWC. The pump was disassembled in order to study its construction. The disassemble CCN-150 is shown in Fig. 16. The pump consists of six primary parts listed in Table 3. Missing from this pump was a coupling flange which is used to join two CCN-150 pumps in series.

Table 3. Major components of the CCN-150.

Component	Wt. (lb.)
motor housing	42.6
hydraulic motor	63.2
pump bowl	31.8
impeller	11.0
suction bell	46.2
strainer	4.6

The pump is essentially put together as follows. The motor and impeller are internal components to the pump. The motor attaches to the motor housing through the hydraulic line fittings and to the pump bowl through four bolts. The impeller attaches to the end of the motor via a stub shaft. The suction bell and motor housing are bolted together around their circumferences. The bolts pass through the outer ring of the pump bowl, sandwiching it between the suction bell and housing and holding it stationary during operation. The strainer is bolted to the end of the suction bell, also around their circumferences. If the coupling flange were to be used to attach two CCN-150 pumps in series, the flange would be bolted to the suction bell. The strainer would be then attached to the end of the second CCN-150. A schematic of the assembly of the Thune Eureka is shown in Fig. 17 for clarification (since the assembly for the CCN-150 is very similar). The major differences is that the CCN-150 does not have a shaft line and its associated components and the fittings for the hydraulic lines pass through the motor housing at its top, not its side as is shown for the Thune Eureka.

Each of the major components listed above was then assessed independently as to the feasibility of fabricating it using composite materials. (The total weight of the components listed above, 199.4 lb., is more than the weight listed in Table 2., 187 lb. It is not known why there is a discrepancy in these numbers. For consistency, all weight savings calculations will be based on the weights of the individual components).

Motor Housing

Observations and Analysis

A photograph and schematic of the motor housing is shown in Figs. 18 and 19 respectively. Included in Fig. 19 is a sectional view showing nominal dimensions and thicknesses. The housing consist of five primary parts, the discharge tube, rigging handles, top plate, center cylinder section, and a bolting ring. All the parts are connected by welding. The bolting ring contains eight threaded holes for attaching to the suction bell.

After examining the housing, it becomes apparent that the wall thickness of the center cylinder is very thin. Without a knowledge of the stress levels and operating conditions of the pump, replacing this section with a weaker, more compliant composite of the same thickness would be very risky. The wall thickness should be increased in an effort to reduce stresses and increase the stiffness. If we use an equivalent deformation criteria, a rough order-ofmagnitude for the required wall thickness can be calculated. Using simple strength-of-materials equations, the change in diameter of a straight cylindrical section subjected to internal pressure is given by [16]

$$\delta_r = \frac{r\sigma}{E} \quad , \tag{1}$$

where: δ_r = change in radius of the cylinder,
r = radius,
σ = circumferential stress,
E = modulus of elasticity.

Therefore, the equivalent wall thickness of a composite cylinder that has the same change in radius due to internal pressure as a steel cylinder is given by

$$t_c = \frac{E_s}{E_c} t_s \quad , \tag{2}$$

where: t_c = equivalent wall thickness of composite,
t_s = wall thickness of steel cylinder,
E_s = modulus of elasticity of steel,
E_c = modulus of elasticity of composite.

Using these equations to size a composite cylinder midsection for the CCN-150 motor housing, the wall thickness of a glass/polyester and carbon/epoxy were calculated. A glass/polyester housing would have a wall thickness of 1.5625 inches while a carbon/epoxy housing would have a wall thickness of 0.625 inches. The calculations are based on the original 5/32 inch wall thickness of the CCN-150's cylindrical midsection and the following material properties: [17]

$Es = 30 \times 10^6$ psi,
$Ec = 3.0 \times 10^6$ psi (glass/polyester),
$Ec = 7.5 \times 10^6$ psi (carbon/epoxy).

Although the analysis performed above is crude, it never-the-less illustrates the point that when replacing metallic components with composites, the composite typically needs to be thickened in order to match the performance requirements of the original structure. Only with a complete knowledge of the exact loading conditions and with the use of intricate analysis techniques (such as the finite element method) can a one-for-one replacement of a metal structure with a composite material be performed with any degree of safety and confidence.

Another area of concern in using composites for this component of the pump is the discharge tube, rigging handles, and their attachment to the top plate. It is unlikely that bonding operations can sustain the bending moment fatigue loads that these components experience during service.

Finally, the assembly of the motor housing to the suction bell is an area of concern. The bolting ring's wall thickness (1/2 inches) is considered thin and presents several problems if a one-for-one replacement with composites is necessary. First, drilling and tapping a blind hole in composites can result in weak joints that can become damaged after several assembly / disassembly operations. The sections should be joined via through-bolting. Second, the bolts used to assemble the pump are M8 x 1.25 metric bolts. This size bolt leaves very little edge (less than 3/32 inches from the edge of the hole to the edge of the bolting ring). This amount of material seems insufficient to prevent high stress levels and premature failure when a composite is used in lieu of the original steel.

Two out of the three problems mentioned above are due to the fact that there is a constraint on the outside diameter of the NSF transfer pumps. This size constraint is due to the requirement that the pumps must fit through the standard 12 1/2 inch diameter deck openings for tank cleaning machines. [5] Consequently, the NSF transfer pumps must have must have maximum outside diameters less than 12 1/2 inches for unimpaired admission to a tank. However, a potential composite motor housing design was developed with the assumption that the wall thickness could be increased. The approach is presented below for completeness and to document its planning.

Composite Motor Housing

A plan for fabricating a composite motor housing is shown in Fig. 20. The wall thickness would be increased from the original steel housing by decreasing the inner diameter (ID) and increasing the outer diameter (OD). In the original design, the bolting ring has a smaller ID than the rest of the housing in order to accommodate the bolt holes. The ID of the composite housing would be equivalent along its entire length in this new design and equal to the original ID of the bolting ring. This alone increases the wall thickness to 1/2 inches. The remainder of the required thickness would be obtained by increasing the OD as needed. The top plate would remain steel so that the rigging handles and discharge tube can be attached by welding.

The plan consists of five stages. First, the housing section would be filament wound on a mandrel of the appropriate diameter. The winding would continue until most of the wall thickness was achieved. At that point, grooves would be machined in the wall of the housing, step 2. Stainless steel tubes would then be bonded into these grooves along the length of the housing, step 3. The tubes provide a straight channel for threaded rods which will eventually be used to assemble the pump. In step 4, the housing is placed back on the filament winder and the remaining composite applied. This final winding operation not only builds up the necessary wall thickness, it provides a stabilizing covering for the tubing. Finally, the housing is machined to length and the pump is assembled. The long threaded rods can be attached directly to the steel top plate sandwiching the housing between the top plate and the suction bell.

As was pointed out, this plan may be difficult to carry out further because the OD of the pump must remain less than or equal to 12 1/2 inches. In addition, there are also ID constraints that complicate modifications. For example, when the CCN-150 is assembled, the existing hydraulic drive motor sits right up against the inner wall of the housing midsection. Any decrease in the ID of this section would misalign the motor along the axis of the pump and prevent the pump from operating. Consequently, replacement and/or redesign of the hydraulic drive motor itself may be required in order to achieve the desired composite wall thickness. A new / redesigned hydraulic drive motor which permits increasing the wall thickness of a composite motor housing is one area of possible future work. However, the goal of this study was to determine the feasibility of replacing the CCN-150 pump components using existing internal drive hardware and thus, any composites used in the motor housing must replace the metal directly on a 1-to-1 basis.

A direct replacement of the housing with a composite is risky. However, two scenarios come to mind. First, the center midsection could be fabricated out of composites leaving the top plate and bolting ring steel. The three pieces would be assembled by bonding. The second scenario is having the entire housing except the bolting ring fabricated out of composites. The bolting ring should remain steel and would be bonded to the composite midsection. In both of these scenarios, carbon/epoxy should be used in lieu of a glass reinforced composite because of the higher strength and stiffness of carbon as compared to glass. In ether case, a significant amount of design and testing needs to be completed. A summary of composite motor housing options is presented in Table 4.

Table 4. CCN-150 composite motor housing options.

Option	Weight (lb)	Risk	Comment
Oversized carbon/epoxy midsection containing stainless steel tubing. Stainless steel top plate. Bolted construction.	36.5	low-medium	Minimal weight savings. Desirable mechanical assembly via threaded rods. Not an option due to the constrains on ID and OD. May become feasible with a redesigned hydraulic drive motor.
Carbon/epoxy midsection. Stainless steel top plate and bolting ring. Bonded construction.	32.6	medium-high	Thin midsection. Risk borders on high due to the direct replacement of steel w/ composite. Bonded assembly needs detailed analysis.
Carbon/epoxy midsection and top plate. Stainless steel bolting ring. Bonded construction.	23.1	high-very high	High-very high risk due to direct replacement w/ composite and problems of connecting rigging handles/discharge tube to top plate. Bonded construction and top plate attachments needs extensive analysis.

Hydraulic Motor

Although the hydraulic motor is the heaviest of all of the CCN-150 components, there is no current plan to try and replace/redesign this motor using polymer matrix composites. There is a possibility of replacing the case of the motor with an advanced metal matrix composite, however, that undertaking was not addressed at this time. A photograph of the motor is shown in Fig. 21.

Pump Bowl

The pump bowl, shown in Fig. 22, is comprised of three main parts, a center hub, five vanes, and an outer ring. The outer ring contains the through holes which allows it to be sandwiched between the suction bell and motor housing during assembly. This sandwiching holds the pump bowl stationary during operation. The vanes act to recover the energy from the flow as it leaves the rotating impeller. The rotating impeller is immediately upstream of the pump bowl. The hydraulic motor attaches to the center hub. The bolt holes used to attach the motor can be seen from the downstream view of the pump bowl shown in Fig. 23. Thus the hub acts to support and anchor the motor. In addition, the shape of the pump bowl helps to direct the flow around the motor.

The pump bowl is a heavy component and appears to be over designed. It is a primary and very likely candidate for composites. However, the complicated shape and geometry of this piece make it a costly item for molding, especially when only one item is needed. Therefore, machining the pump bowl from a thick block of composites becomes the only economical and practical method of fabrication. The Sims Pump Valve Company has been fabricating composite impellers in just this fashion since 1961. They are one of the few companies known that can not only fabricate composite blocks to the thickness required, but also have the machining capability and practical experience necessary to fabricate a composite pump bowl for this project.

Composite Pump Bowl

Sims manufactures and uses their own proprietary materials. Very little information about the three-dimensional mechanical properties of these materials is known. For that reason, CDNSWC has begun to characterize the mechanical properties of two of the Sims materials most commonly used in composite impellers, SMS 375 and SMS 302. Measuring the actual properties of these materials will help us decide which material is best suited for this application.

SMS 302 is essentially a phenolic/organic composite while SMS 375 is essentially a epoxy/glass composite. The complete formulation of these materials is proprietary. In order to completely characterize the three dimensional properties, we had asked Sims for both a thin, 1/4" laminate (to measure inplane properties), and a 1/4" slice from a thick block of material. This slice will enable us to generate the through-the-thickness or interlaminar properties of these materials. A schematic of the two different panels is shown in Fig. 24. We were not able to obtain a thick slice of the SMS 302 material. The company, however, sent us a thick slice from a SMS 300 panel. The difference between SMS 300 and SMS 302 is that SMS 300 has all the warp fiber directions laying in the same direction (parallel) while SMS 302 has the warp direction of every other layer turned 90° in order to obtain more uniform properties in the plane of the laminate. The constituents of SMS 300 and SMS 302 are identical and thus, the interlaminar properties of the two materials, for all intents and purposes, should be identical.

Sims was contacted about fabricating the pump bowl out of SMS 375. The cost estimate for fabricating this component out of SMS 375 is $8750.00. The composite pump bowl is expected to weigh approximately 9.25 lb. This is a savings of 22.5 lb. or 71% over the original steel pump bowl.

Material Tests

The test methods used were all ASTM standards. All testing was performed on a Satec Baldwin 60,000 lb. hydraulic test frame. The load, and either strain or deflection was recorded continually on a PC based data acquisition system (depending on which tests was being performed).

The shear tests were performed according to ASTM D5379/D5379M entitled Standard Test Method for Shear properties of Composite Materials by the V-Notched Beam Method.

The tensile tests were performed according to ASTM D638. Each specimen was instrumented with a 0/90 strain gage rosette. This enabled both the transverse as well as the longitudinal strain to be recorded. Modulus, strength, Poisson's ratio, and strain to failure were measured.

Compression tests were done according to ASTM D695. Each specimen was instrumented with a unidirectional strain gage aligned with the testing axis. Modulus, strength , and strain to failure were measured.

Flexural properties were measured using ASTM method D790. A Satec deflectometer was used to record the mid span displacement during the flexural tests. Modulus and strength were measured.

Our original Iosipescu fixture was not operational at this time. We have just obtained a new fixture and testing of the shear properties are in progress.

The inplane and interlaminar results are listed in Tables 5 and 6 respectively. Because the laminates are made of impregnated woven fabric, inplane test were conducted in both the warp and fill directions. This has no meaning for the interlaminar tests, thus, only one column of data is reported in the table. Some observations are listed below:

- The inplane properties of the SMS 302 material is essentially identical in the warp and fill directions. This was expected since the every other layer of this material is rotated 90°.
- The inplane compressive behavior of SMS 302 was nonlinear resulting in a large strain to failure. The tensile behavior was somewhat brittle, resulting in a relatively low strain to failure.
- The interlaminar compressive response of SMS 302 resulted in large strains without failure. The strength reported is the stress in the material at 5% strain.
- SMS 375 had different inplane properties in the warp and fill directions. This material is fabricated with all warps parallel.
- SMS 375 had, overall, better mechanical response than the SMS 302 material.
- Both materials are weak in the through-the-thickness direction. This comes as no surprise as this is typically the "weak link" for composite laminates.

After reviewing this data, SMS 375 is recommended for the pump bowl. This material has significantly better mechanical properties than SMS 302. Since the actual loading conditions of the pump bowl are not known at this time, the material with the better mechanical performance is the obvious choice.

Table 5. Inplane properties of SMS 302 and SMS 375.

Property	SMS 302		SMS 375	
	Warp	Fill	Warp	Fill
tensile modulus (Msi)	1.4	1.4	3.3	2.9
tensile strength (ksi)	12.5	12.4	54.5	45.1
tensile elongation (% ε)	0.810	0.804	2.03	1.97
Poisson's ratio	0.30	0.30	0.15	0.14
compressive modulus (Msi)	1.5	1.5	3.5	3.2
compressive strength (ksi)	37.6	37.3	68.3	60.2
compressive elongation (% ε)	5.85	5.57	2.02	1.79
shear modulus (Msi)				
shear strength (ksi)				
flexural modulus (Msi)	1.4	1.3	3.1	2.7
flexural strength (ksi)	25.2	21.5	67.7	56.1

Table 6. Interlaminar properties of SMS 300 and SMS 375.

Property	SMS 300	SMS 375
tensile modulus (Msi)	0.68	1.3
tensile strength (ksi)	1.40	6.74
tensile elongation (% ε)	0.212	0.539
Poisson's ratio	0.23	0.19
compressive modulus (Msi)	0.75	1.3
compressive strength (ksi)	29.0*	67.7
compressive elongation (% ε)	NA*	5.16
shear modulus (Msi)		
shear strength (ksi)		

* No failure occurred due to displacement limit of fixture. Strength is the stress in the sample @ 5% ε.

Impeller

The CCN-150's impeller is shown in Fig. 25. At first it was assumed that the impeller, like the pump bowl, could be fabricated out of SMS 375. Again, Sims Pump Valve Company has a tremendous experience base in fabricating impellers very similar to this one. However, the impeller itself combines with a set of chopping blades attached to the struts of the suction bell to form a pulping mechanism for any foreign objects that might enter the pump. It is not known whether the composite impeller could stand up to this pulping and chopping task without chipping and significant damage developing. A composite impeller would weigh approximately 3.2 lb. and cost $5500.00 to fabricate.

An alternative would be to fabricate the impeller out of titanium. Titanium would decrease the weight of the impeller and have comparable resistance to damage as the original steel impeller. The cost for fabricating a titanium impeller is $8130.00. However, the total pump weight savings obtained by switching the impeller material from steel to titanium is minimal because the weight of the original steel impeller is small compared to the other pump components. Both alternatives are summarized in Table 7.

Table 7. Impeller material choices and comparison.

Material	Wt. (lb)	Savings	Cost	Comment
SMS 375	3.2	71%	$5500.00	Probable problem with impeller damaging during operation.
Titanium	6.4	42%	$8130.00	Minimal impact in reducing the weight of the CCN-150.

Suction Bell

The suction bell is probably the best candidate for composites out of all the pump components listed in Table 3. With the exception of the hydraulic motor itself, the suction bell is the heaviest of all the CCN-150-s components. It appears to be over designed and primarily a lightly loaded structure. The majority of the suction bell's profile is less than 12 inches in diameter leaving room to thicken a composite version as needed.

Photographs of the suction bell are shown in Figs. 26 and 27. The inlet side is stiffened with a set of three radial ribs. The ribs seem to be a hold over from earlier designs of the CCN-150. These earlier designs used a shaft line in stead of a short stub shaft, and the ribs provided a bearing support for the end of the shaft (see Fig. 17). The ribs now appear to be used to secure the chopping blades that were discussed in the previous section. A chopping blade attaches to each of these ribs via four bolts. This is clearly shown in both Figs. 26 and 27. The chopping blades seem to be an after thought of the CCN-150 since they appear nowhere in the maintenance manual.

The most obvious fabrication method for a composite suction bell would be an open male mold process using a room temperature curing resin reinforced with glass fibers. A room temperature curing resin is beneficial for two reasons. First, ovens and/or autoclaves are not needed, reducing fabrication costs. Second, inexpensive and easily machined syntactic tooling can be used, also reducing cost. Glass fibers should be used because the application does not warrant the added expense of using carbon fibers. The suction bell does not appear to be a highly loaded structure and any stress concentrations can be reduced through thickening the composite in the necessary regions (most of the suction bell is less than 12 inches in diameter). And finally, a male mold is proposed because the inlet geometry is critical to the flow of the fluid being pumped into the impeller. A male mold machined exactly to the inlet profile required transfers this profile to the inside of the composite part during fabrication.

A local composites design fabricator was contacted about building a composite suction bell. The company, Marine Design and Composites, is a custom job shop, with over 24 years of experience in the composites industry. They specialize in one-of-a-kind composite prototypes and short run parts. Several meetings with Marine Design and Composites led to the following fabrication scenario:

> The proposed material for this application is glass/vinyl ester. Tooling would be machined from a suitable syntactic tooling board and surface coated to provide proper surface finish for the inside profile of the suction bell. The part would be constructed in two

> stages. The inlet side containing the three radial ribs would be molded in thirds around an appropriate mold. After each was removed from the mold, the three pieces would be machined and bonded together along the center axis forming the inlet part of the housing integral with the three radial ribs. This now single piece would then be inserted into a second tool around which the remainder of the body would be molded. During this final operation, the two parts thus form an integral one piece composite suction bell.

The cost for fabricating the suction bell according to the directions above is $6000.00. The estimated finished weight is 15.6 lb., a savings of 66%.

Obviously, a detailed drawing of the original suction bell is needed to begin fabricating the mold for this part. In fact, drawings for all of the CCN-150's components listed in Table 3 are needed before any detailed analysis or fabrication can begin. However, CDNSWC has not been able to obtain the drawings for this pump. In an effort to begin the process of producing our own set of drawings, CDNSWC approached its own Design and Engineering Group. The Design and Engineering Group at CDNSWC provides engineering and design services in support of research projects and facilities at the Center. The group consist of mostly mechanical engineers and CAD designers performing mechanical design and structural analysis of test equipment and models needed by researchers to verify R&D concepts. The group often generates conceptual solutions but will also translate researcher's ideas into viable designs, producing engineering drawings. The suction bowl was sent to this group in order for them to produce a set of detailed drawings. The group used a combination of hand-tool measurements and those of a Browne and Sharpe Coordinate Measuring Machine to determine the detail dimensions and surface curvatures of the suction bell. A preliminary engineering drawing was completed and is included in Appendix C. The inside profile of the suction bell is also stored digitally on a computer. The appropriate dimensions and level of detail required for fabricating a mold can now be recalled at any time and the information provided to Marine Design and Composites.

Strainer

The strainer, shown in Fig. 28, is the lightest component of those listed in Table 3. There doesn't seem to be much benefit in making this part composite. In fact, the strainers that have been observed by CDNSWC have all been slightly bent to some degree. This is primarily due to the pump being rested on the strainer when set upright and from the strainer impacting the bottom of tanks during operation. The ductile properties of steel make it a better material for this application, especially when very little, if any, weight savings would be realized by switching to composites.

Test Set-up

As was pointed out several times in this report, very little information concerning the loading conditions and stress levels in the CCN-150 during operation is known. CDNSWC approached the Coast Guard and suggested that strain gages be attached to the CCN-150 and the pump run over a range of operating conditions. The strain levels measured would provide real magnitudes of the strains and principal stresses at these locations. With these stress/strain levels known, CDNSWC can begin to understand how the CCN--150 (and thus its components) respond during operation. In addition to measuring the strain levels in the CCN-150, it was decided that the head/capacity curve would also be measured during operation. This information is important for matching the level of strain in the pump to an actual operating condition and provides a baseline for future testing of a composite pump.

It was recommended that the test should be conducted at the AST at Ft. Dix, New Jersey. The AST has a test tank suitable for running the CCN-150. All of the necessary auxiliary equipment needed to run the test such as the prime mover, hydraulic lines, discharge hoses, etc. and the personnel trained in operating all of the equipment are also available at the strike team. Having all necessary personnel and equipment on hand at the test site greatly reduces the chance of a situation occurring which could significantly delay or cancel the test. It also eliminates the need for shipping all of the necessary equipment and a trained person to another location.

A list of equipment needed to conduct the test of the CCN-150 was supplied to the Coast Guard. The list included:

- Weather-proof enclosure with adequate power for data acquisition equipment.
- Handling and rigging equipment for supporting and lowering the CCN-150 into the test tank.
- Cargo hose assemblies.
- Diesel engine hydraulic prime mover and hydraulic input/output lines.
- Single phase power at the test tank.

A schematic of the proposed test loop was also supplied to the Coast Guard. This schematic is shown in Fig. 29.

Numerous strain gages were attached to the CCN-150. A 0/45/90 strain gage rosette was applied to the outside of the suction bell, pump bowl ring, and housing at four equally spaced locations around the circumference of each component. The relative locations are shown in the schematic, Fig. 30. A three gage rosette was used in each of these locations so that the principal strains are measured and thus the principal stresses could be calculated. It is generally necessary to measure the strain in three different locations at a point in a body to completely define the strain field. [18]

Two of the vanes of the pump bowl were also gaged in an effort to determine the strain in these parts during operation. On each of the vanes, three 0/45/90 rosettes were attached along the length of the vane where the vane connects to the hub. It was hoped that a measure of the bending forces along this vane could be estimated from the strain levels recorded. The gages can be seen in Figs. 31 and 23.

Unidirectional gages were attached to the rigging handles and around the base of the discharge tube where it intersects the top plate of the motor housing. The gages on the handle would hopefully give an indication of the amount of stress put on these components as the pump is moved around and lowered into a tank. The discharge tube was strain gaged in an effort to measure the bending loads on the discharge tube due to the weight and movement of the cargo hoses as the pump is being lowered and as the hoses themselves become full during operation. The strain levels in the rigging handles, discharge tube, and motor housing are extremely important in order to begin the design of a composite motor housing. Recall that it is this component which has the lowest probability of being successfully fabricated with composites without an understanding of the operational loads.

A summary of the gages attached to the pump is given in Table 8. All of the gages were manufactured by the Micro-Measurements Corporation. A PC-based data acquisition system will be used to scan the gages and record the strain levels during operation. A schematic of the data acquisition set-up is shown in Fig. 32. A complete summary of the test results will be presented in a future report following this one.

Table 8. Summary of strain gages for the CCN-150 test.

Pump Component	No. Gages	Gage Type	Micromeasurement Designation
Suction Bell	4	0/45/90 rosette	CEA-06-250UR-350
Pump Bowl (outside ring)	4	0/45/90 rosette	CEA-06-062UR-120
Pump Bowl Vane	6 (3 ea. vane)	0/45/90 rosette	CEA-06-062UR-120
Motor Housing	4	0/45/90 rosette	CEA-06-250UR-350
Rigging Handles	4 (2 ea. handle)	unidirectional	CEA-06-125UW-350
Discharge Tube	4	unidirectional	CEA-06-062UW-350

Recommendation

After reviewing the information gained about the CCN-150 presented above, there appears to be three options in fabricating a composite CCN-150. The options are listed below in order of risk.

Option 1. The option presenting the least risk would have a composite pump bowl manufactured by the Sims Pump Valve Company and a composite suction bell manufactured by Marine Design and Composite. The rest of the components would remain stainless steel. The estimated weight of this pump is 146.3 lb. resulting in a 27% weight savings over the original, all stainless steel CCN-150.

<u>Option 2.</u> The next option would also have a composite pump bowl and suction bell as in option 1. In addition, the motor housing would be fabricated to have a carbon/epoxy midsection with a stainless steel top plate and bolting ring as was described in Table 4. The estimated weight of this pump is 136.3 lb. resulting in a 32% weight savings over the original, all stainless steel CCN-150.

<u>Option 3.</u> The third option, like the first two, would have a composite pump bowl and suction bell. The motor housing would be all carbon/epoxy except for the bolting ring which would remain stainless steel. The motor, impeller and strainer would also remain stainless steel. The estimated weight of this pump is 126.8 lb. resulting in a 36% weight savings over the original, all stainless steel CCN-150.

The three options reviewing the weight of each individual component is summarized in Table 9. The risk associated with each option tends to follow the risk associated in fabrication the different motor housing options described in Table 4. There appears to be very little risk involved with a composite pump bowl and suction bell, so the risk presented in Table 9 is tied directly to the risk in developing and fabricating a composite motor housing.

A composite impeller is not recommended because of the added role of chopping foreign objects this component must perform. The risk of damage developing during the chopping operation is considered too great for the minimal weight savings that would be obtained. The titanium impeller is also not considered to be an option because of the minimal impact on the total weight savings associated with switching from steel to titanium. However, to be complete, a titanium impeller would increase the weight saving of each of the three options listed in Table 9 by 2%.

CDNSWC would recommend that a composite CCN-150 be fabricated in two separate stages. First, a composite pump bowl and suction bell would be fabricated as was described in option 1. The risk is low and would result in a majority of the possible weight savings being realized. The CCN-150 could then be reassembled with these composite parts. This hybrid pump could then be taken to the Atlantic Strike Team's test facility and tested. The results of this test could then be compared to the results from the original test described in the section entitled **Test Set-up**. If the performance of the hybrid pump is similar to that of the original, all stainless steel pump, work could begin on the design of a new composite motor housing including the possibility of a redesigned hydraulic drive motor.

Table 9. Summary of CCN-150 composite options.

Option	Risk	Motor Housing	Hydraulic Motor	Pump Bowl	Impeller	Suction Bell	Strainer	Total Wt. (lb.)	Wt. Savings
Baseline	----	42.6 lb	63.2 lb	31.8 lb	11.0 lb	46.2 lb	4.6 lb	199.4 lb	----
1	low	42.6	63.2	9.25	11.0	15.6	4.6	146.3	27 %
2	medium-high	32.6	63.2	9.25	11.0	15.6	4.6	136.3	32 %
3	high-very high	23.1	63.2	9.25	11.0	15.6	4.6	126.8	36 %

Administrative Information

This Phase I feasibility investigation was sponsored by the U.S. Coast Guard R&D Center, Groton, CT., and directed by LT. Michael J. Roer of the Marine Environmental Safety Division. Work was executed under sponsor order No. Z51100-3-E00608. Technical coordination was provided through Mr. George Wilhelmi of CDNSWC Code 823.

Appendix A
List of Pump Manufacturers

Abel Pumps Corp.	412-741-3222	Chemical
ABO Industries , Inc.	619-453-9515	Chemical
Accutek Filling Equipment Co.	800-989-1828	Chemical
ACME Products & Engineering, Inc.	718-851-4200	Corrosion Resistant
ACME Pumps & Wellpoints, Inc.	813-752-3137	Submersible
AFS/Pump Express	800-231-8602	Chemical
Air Dimensions, Inc.	800-423-6464	Chemical
Aisco, Inc.	817-335-4467	Hydraulic
Allied signal, Inc.	201-455-2000	Hydraulic
Amatech Corp.	718-392-7575	Chemical
American Industrial Pump, Inc.	800-231-0590	Axial Flow
American Lewa, Inc.	508-429-7403	Chemical
American-Marsh Pumps, Inc.	517-484-2100	Hydraulic
Ampco Pumps Co.	800-959-0831	Chemical
Ansimag, Inc.	708-290-0482	Chemical
Application Associates, Inc.	908-753-1155	Centrifugal Screw
Ash Pump	800-453-9216	Chemical
Atlas Pumps	708-757-7170	Chemical
Aurora Pump	708-859-7000	Chemical
B.J.M. Corp.	203-399-5937	Corrosion Resistant
Balcrank Products, Inc.	800-747-5300	Chemical
Barnant Co.	800-637-3739	Chemical
Barnes Pumps, Inc.	419-774-1511	Submersible
Barnes, John S. Corp.	815-398-4400	Hydraulic
Blackmer	800-759-4067	Chemical
Blue White Industries	714-893-8529	Chemical
Bran & Luebbe, Inc.	708-520-0700	Chemical
BSM Pump Corp.	800-283-3600	Corrosion Resistant
Burks Pumps	513-773-2442	Submersible
Butterworth Jetting Systems	713-644-3636	Ballast
Cat Pumps	612-788-6318	Chemical
Caterpillar Industrial Products, Inc.	309-675-1000	Hydraulic
CEF Industries, Inc.	800-888-6419	Submersible
Chem-Tech	813-575-2900	Chemical Feed
Chemac, Inc.	201-592-0970	Chemical Plant
Chempump	215-343-6000	Chemical Feed
Chicago Industrial Pump Co.	312-587-1777	Chemical
Chicago Pump Co.	708-344-4960	Submersible
Clearwater Engineering, Inc.	713-371-9200	Chemical Feed
Complete Dewatering , Inc.	800-800-9562	Submersible
Componenta International	203-459-5007	Axial Flow
Composite High Pressure Technologies, Inc.	302-645-4314	Corrosion Resistant
Cooper Industries	217-222-5400	Corrosion Resistant

Corr Tech, Inc.	800-752-7054	Chemical
Crisafulli Pump Co., Inc.	800-442-7867	Hydraulic
Crown Glass Corp.	312-666-2000	Plastic
Crown Tech. Corp.	708-367-8700	Chemical
Dana Corp.	803-234-4615	Hydraulic
Danfloss Fluid Power	414-633-3511	Hydraulic
Delta Power Hydraulic Co.	815-397-6628	Hydraulic
Deming Div., Crane Co.	216-337-7861	Chemical Plant
Donnelly, R. W., Fluid Power, Inc.	800-497-4502	Hydraulic
Dorr-Oliver Inc.	800-547-7809	Chemical
Dresser Pumps	908-647-6800	Barge Unloading
Dynalab Corp.	800-828-6595	Chemical
Dynapower/Stratopower	803-760-5700	Hydraulic
Eastern	716-292-8000	Chemical Plant
Eaton Corp.	612-937-9800	Hydraulic
ECO	716-292-8000	Chemical
Edson International	508-995-9711	Corrosion Resistant
Edwards Mfg., Inc.	800-959-2136	Chemical
Elastec, Inc.	800-359-3627	Submersible
Eldex Laboratories, Inc.	800-969-3533	Chemical
Envirotech Molded Products Co.	801-526-2600	Plastic
EPG Companies, Inc.	800-443-7426	Corrosion Resistant
Evsco, Inc.	708-362-7066	Chemical
Filter Pump Industries	818-504-2391	Chemical
Fleming, L. J. LTD	519-326-4496	Axial Flow
FloJet Corp.	714-859-4945	Chemical
Flowtronex International	800-959-7867	Centrifugal Screw
Fluitron, Inc.	215-355-9970	Hydraulic
FMC Fluid Control	713-591-4000	Corrosion Resistant
Franklin Research	800-531-9018	Chemical Plant
Franklin Research	800-531-9018	Submersible
Galigher Pump	800-453-9216	Chemical
Galileo Vacuum Systems	203-653-5911	Chemical
Gator Pump Co.	800-256-6365	Hydraulic
Gelber Industries	708-965-1300	Chemical
General Pump/U.S., Inc.	612-454-6500	Chemical Feed
Godwin Pumps of America	609-467-363-	Chemical
Gormann-Rupp Industries	419-755-1011	Axial Flow
Graco, Inc.	800-367-4023	Chemical
Graymills Corp.	312-248-6825	Chemical
Great Lakes Hydraulics, Inc.	800-968-0188	Hydraulic
Greylor Co.	708-741-1707	Plastic
Grindex Pumps	708-957-9988	Corrosion Resistant
Grover Manufacturing Corp.	213-724-3444	Corrosion Resistant
Guzzler Manufacturing Inc.	800-822-8785	Axial Flow
H&H Pump and Dredge Co,	601-627-9631	Barge Unloading
Hagglunds Denison Corp.	800-551-5956	Hydraulic

Haight Pump Div.	414-784-3293	Chemical
Halsted & Hoggan, Inc.	213-632-1248	Chemical
Hammelmann Corp.	513-233-3487	Chemical Plant
Hardwood Engineering Co.	508-668-3600	Corrosion Resistant
Hartell Div., Milton Roy Co.	215-322-0730	Plastic
Hastings Pipe Co.	402-463-6633	Axial Flow
Hayward Tyler	802-655-4444	Chemical Plant
Holland Pump Mfg., Inc.	407-697-3333	Hydraulic
Homa Pump Corp.	203-327-6365	Axial Flow
Hydra-Tech Pumps, Inc.	609-267-5393	Axial Flow
Hydraulic Power Units, Inc.	708-595-4680	Hydraulic
Hydro Power, Inc.	812-232-0156	Barge Unloading
Hydro-Pac, Inc.	800-394-1511	Corrosion Resistant
Hydro-Services	713-499-8611	Hydraulic
Hydroperfect International, Inc.	416-791-3388	Hydraulic
Hypac, Inc.	606-849-2447	Hydraulic
Hypro Corp.	612-633-9300	Chemical
IFP Hydraulics	708-678-5795	Hydraulic
IMO Industries, Inc.	800-925-2466	Axial Flow
Imtra Corp.	508-995-7000	Corrosion Resistant
Ingersoll-Rand Co.	800-257-9530	Axial Flow
Innovative Material Systems, Inc.	800-800-4010	Hydraulic
Instech Laboratories, Inc.	800-443-4227	Chemical
International Pump Mfg., Inc.	305-471-7998	Chemical
Iris Engineering, Inc.	508-429-5902	Chemical
Itt Jabsco	714-545-8251	Axial Flow
Jaeco Pump Co.	215-822-6000	Chemical Feed
Karbate Vicarb, Inc.	216-572-3600	Chemical Plant
Kemlon Products & Development Corp.	713-747-5020	Chemical Feed
Ketema, Inc.	215-639-0900	Chemical
Keystone Engineering Co.	713-747-5020	Hydraulic
Kontro Co., Inc.	508-544-2536	Chemical
La Bour Pump Co.	219-293-0653	Chemical
Lawrence Pumps, Inc.	508-682-5248	Axial Flow
Leistritz Corp.	201-934-8262	Chemical
Lewis, Chas. S., & Co., Inc.	314-843-4437	Chemical
Lightning Industries, Inc.	816-842-3800	Barge Unloading
Liquiflo Equipment Co.	908-754-1336	Chemical
Litco	512-444-3555	Chemical Plant
M&W Pump Corp.	305-426-1500	Axial Flow
M.C. Aerospace Corp.	800-448-9140	Hydraulic
Madden	800-369-6233	Chemical Feed
March Mfg., Inc.	708-729-5300	Chemical
McFarland	713-864-3366	Chemical Feed
Megator Corp.	412-963-9200	Chemical Plant
Moyno Industrial Products	513-327-3553	Chemical Feed
MP Pumps Inc.	313-293-8240	Ballast

MTE Hydraulics, Inc.	815-397-4701	Hydraulic
MTH Pumps	708-552-4115	Chemical Plant
Muli-Duti Mfg., Inc.	800-447-8342	Corrosion Resistant
Mulko Hydraulics	708-449-1770	Chemical Feed
Nagle Pumps, Inc.	708-754-2940	Corrosion Resistant
Neptune Pump Mfg. Co., Inc.	800-828-5488	Chemical
Netzsch, Inc.	215-363-8010	Chemical
Nu Con Corp.	800-779-8770	Propeller
Oberdorfer Pumps, Inc.	315-437-0316	Chemical
Ohler Machinery Co.	319-987-2121	Barge Unloading
Oildyne	800-394-1654	Hydraulic
Pacer Pumps	800-233-3861	Chemical
Paco Pumps, Inc.	713-391-6000	Submersible
Pantex Valve Actuators & Systems, Inc.	800-879-8179	Hydraulic
Parker Hannifin Corp.	800-272-7537	Chemical
Peerless Pump	213-726-1232	Axial Flow
Petro Boom Environmental, Inc.	800-243-7455	Submersible
Plastic Engineered Products, Inc.	908-534-6111	Plastic
Plenty Products, Inc.	800-554-4225	Barge Unloading
Precision Powered Products, Inc.	713-466-6751	Axial Flow
Price Pump Co.	707-938-8441	Chemical
Procon Products	615-890-5710	Corrosion Resistant
Pump Rentals Inc	609-267-6740	Axial Flow
Pumpex, Inc.	908-730-7004	Corrosion Resistant
Pumpsall, Inc.	609-273-8693	Chemical
QED Environmental Systems, Inc.	800-394-2647	Chemical
Randolph Austin Co.	512-282-1590	Chemical Feed
Reidville Hydraulics & Mfg., Inc.	203-754-9040	Hydraulic
Rexroth Corp.	215-694-8300	Chemical
Roper Pump Co.	706-335-5551	Chemical
Roth Pump Co.	309-787-1791	Chemical
RS Corcoran Co.	800-637-1067	Chemical
Ruthman Pump & Engineering, Inc.	513-559-1900	Chemical
S C Hydraulic Engineering Corp.	213-321-4536	Hydraulic
SCC Pumps, Inc.	708-593-8495	Chemical
Scientific Technology, Inc.	800-343-9679	Submersible
Seepex US, Inc.	800-695-3659	Barge Unloading
Serfilco, Ltd.	800-323-5431	Chemical
Sethco Pumps	516-435-0530	Chemical
Shanley Pump & Equipment	708-439-9200	Chemical
Sherwood Div., Hypro Corp.	313-259-2095	Chemical
Smart Products, Inc.	800-338-0404	Chemical
Squire-Cogswell Co.	708-272-8900	Corrosion Resistant
Stancor, Inc.	203-268-7513	Chemical
Star Hydraulics, Inc.	708-453-3238	Corrosion Resistant
Stemmerich, Inc.	800-325-9528	Chemical Plant
Stow Manufacturing Co.	607-723-6411	Submersible

Sykes Pumps	813-752-3137	Chemical Plant
TAT Engineering Corp.	800-243-2526	Chemical
Technical Innovators	800-373-6396	Chemical Plant
Templeton, Kenly & Co.	800-323-9114	Hydraulic
Thomas Industries, Inc.	414-457-4891	Corrosion Resistant
Thomsen, L. C., Inc.	800-394-3692	Chemical
Toomey Associates, Inc.	508-668-3600	Hydraulic
Tradewinds Power Corp.	305-592-9745	Centrifugal Screw
Travaini Pumps USA, Inc.	800-535-4243	Chemical Plant
Treatment Technologies	800-733-RVII	Chemical
Tri-Rotor, Inc.	800-782-4477	Chemical
Turn 1 Engineering, Inc.	202-362-0944	Corrosion Resistant
Tuthill Pump Co.	800-777-2706	Chemical
Ultra Hydraulics	800-959-1323	Hydraulic
United States Plastic Corp.	419-228-2242	Plastic
Utilities Supply Co.	800-343-7555	Chemical
VantonPump & Equipment Corp.	908-688-4216	Chemical
Vertiflo Pump Co.	800-338-1917	Chemical
Vickers, Inc.	800-547-7805	Hydraulic
Viking Pump Inc.	319-266-1741	Barge Unloading
Voith Hydro, Inc.	717-792-7000	Axial Flow
Wanner Engineering, Inc.	800-369-4172	Chemical
Warman International, Inc.	608-221-2261	Chemical
Warren Pumps Inc.	413-436-7711	Barge Unloading
Warren Rupp, Inc.	419-524-8388	Chemical
Warrender, Ltd.	800-24-FLUID	Chemical
Water Cooling Corp.	718-528-4000	Chemical Feed
Water Cooling Corp.	718-528-4000	Submersible
Watson-Marlow, Inc.	508-658-6186	Chemical Feed
Waukesha Fluid Handling	800-252-1090	Chemical
Weil Pump Co.	312-637-8844	Submersible
Weinman-AMW Industries	501-329-9811	Submersible
Wessels Co.	313-875-5000	Submersible
Westcoast Rotor, Inc.	800-356-6080	Chemical Plant
Wilden Pump & Engineering Co.	909-422-1700	Barge Unloading
Williams Instrument Co.	800-899-2250	Chemical
Winpro, Inc.	516-420-0066	Chemical Plant
Worldwide Marine	800-394-2029	Hydraulic
Xolox Corp.	800-348-0744	Chemical
Yamada America	800-235-1886	Chemical
Yeomans Chicago Corp.	708-344-9600	Corrosion Resistant
Zenith Pumps	800-277-8969	Chemical
Zoeller Co.	502-778-2731	Submersible

Appendix B
Literature Survey Citations

Citations from CA Search - APPLIED: APP

1. NDN 044-0218-6387-4: COMPOSITE MATERIALS AND MANUFACTURING OF BLADES FOR TRANSFER PUMPS
2. NDN 044-0218-5741-2: ADVANCED MATERIALS FOR TURBOMACHINERY. TECHNICAL MEMO NUMBER 2. ADVANCED MATERIALS COMPATIBILITY WITH STORABLE PROPELLANTS (MONOMETHYL HYDRAZINE AND NITROGEN TETROXIDE)
3. NDN 044-0214-2810-0: UTILIZATION OF CERAMICS IN SLURRY PUMPS
4. NDN 044-0213-4872-4: THERMAL CONDUCTIVITY OF NATURAL ZEOLITE-PTFE COMPOSITES
5. NDN 044-0213-4203-5: COMPOSITE CASTING OF COPPER-STEEL ROTOR CASTINGS FOR PLUNGER HYDRAULIC PUMP
6. NDN 044-0210-7485-5: STUDY AND APPLICATION OF COMPOSITE CORES IN INVESTMENT CASTING
7. NDN 044-0204-4586-2: MANUFACTURE OF COMPOSITE MATERIAL FOR VANE OF VANE PUMP
8. NDN 044-0202-1290-9: LIGHT METAL ALLOY COMPOSITES WITH LOW THERMAL EXPANSION FOR PUMP ROTOR
9. NDN 044-0196-2893-2: MANUFACTURE OF CARBON-METAL STRUCTURAL COMPOSITES
10. NDN 044-0159-0741-3: HARD ALLOYS FOR AXIAL SLEEVES AND BEARINGS OF PUMPS
11. NDN 044-0159-0731-0: SINTERED TUNGSTEN CARBIDE COMPOSITE ALLOY RESISTANT TO CORROSION
12. NDN 044-0158-2301-1: COMPOSITE BEARING PARTS FOR PUMPS
13. NDN 044-0157-1707-7: FIBER-REINFORCED ALUMINUM ALLOY FOR HIGH-SPEED ROTATING PARTS
14. NDN 044-0155-8715-7: SILICON CARBIDE COMPOSITE OF EXCELLENT CORROSION AND WEAR RESISTANCE FOR PUMP
15. NDN 044-0150-2136-8: TUNGSTEN CARBIDE ALLOY FOR COMPOSITE CYLINDER
16. NDN 044-0147-9417-9: METAL POWDER FOR BEARING SURFACES
17. NDN 044-0145-5569-0: FABRICATION OF STEEL CYLINDER BLOCKS COVERED WITH AN ANTIFRICTION ALLOY
18. NDN 044-0140-4430-0: FIBER-REINFORCED METAL COMPOSITE
19. NDN 044-0139-1508-0: EXPLOSIVE COMPACTION OF P-M COMPOSITE SEAL MATERIALS
20. NDN 044-0138-0832-8: DEVELOPMENT OF A POLYMER-COMPOSITE INDUSTRIAL MACHINE
21. NDN 044-0136-3559-8: CHARACTERISTICS OF SPUTTER ION PUMP WITH ZIRCONIUM-ALUMINUM COMPOSITE CATHODE
22. NDN 044-0135-3673-0: COMPOSITE BEARING MATERIALS
23. NDN 044-0134-5272-6: DETERMINATION OF THE PARAMETERS OF TURBOMOLECULAR VACUUM PUMPS WITH A COMPOSITE FLOW-THROUGH SECTION
24. NDN 044-0115-4931-9: SLIDING ALUMINUM-CARBON FILAMENT COMPOSITE FOR COMPRESSOR VANES
25. NDN 044-0106-5576-8: COMPOSITE MATERIALS AS AN IMPORTANT RESERVE FOR INCREASING THE LIFE OF GAS AND PETROLEUM EQUIPMENT
26. NDN 044-0106-2021-3: SELECTION OF ANTIFRICTION MATERIAL OF HIGH WEAR RESISTANCE

FOR END SEALS

27. NDN 044-0089-8634-0: COMPOSITE POLYMERIC MATERIALS: EVALUATION OF CROSSLINKED GEL PROTEIN SURFACES

28. NDN 044-0088-6458-1: USE OF A COMPOSITE BIOMER-BUTYL RUBBER-BIOMER MATERIAL TO PREVENT TRANSDIAPHRAGMATIC WATER PERMEATION DURING LONG-TERM, ELECTRICALLY-ACTUATED LEFT VENTRICULAR ASSIST DEVICE (LVAD) PUMPING

29. NDN 044-0085-5122-0: CORROSION- AND ABRASION-RESISTANT COMPOSITE ALLOYS FOR CENTRIFUGALLY CAST LININGS

30. NDN 044-0075-2964-4: STUDY OF COMPOSITE MATERIAL BEHAVIOR IN FRICTION NODES IN THE PRESENCE OF CORROSIVE MEDIUM

Citations from ENERGY SCIENCE AND TECHNOLOGY (DOE): EDB

31. NDN 108-0578-2737-4: How to reduce weight of castings

32. NDN 108-0577-3235-1: A survey on technical problems in designing high-speed rotors with developing materials

33. NDN 108-0568-1126-7: Corrosion resistance in sulfuric acid of composite materials based on chromium oxide

34. NDN 108-0566-6879-3: Centrifugal pumps design and application. Second edition

35. NDN 108-0526-0003-1: Advances in power transmission using filament wound composites

Citations from Engineering Index: EIX

36. NDN 017-0192-1552-0: Polymeric composite materials used in pump equipment of chemical plants

37. NDN 017-0191-4434-2: Heat transfer intensification in fixed bed adsorbers

38. NDN 017-0191-0755-2: Subsea processing system ready for Gulf of Mexico field

39. NDN 017-0190-3910-8: Experimental study of absorption and gain by two-level atoms in a time-delayed non-Markovian optical field

40. NDN 017-0190-1754-0: Derived thermodynamic design data for refrigeration and heat pump systems operating on HCFC-123

41. NDN 017-0184-8681-6: Ceramic matrix composites for rocket engine turbine applications.

42. NDN 017-0184-8680-4: Ceramic matrix composite applications in advanced liquid fuel rocket engine turbomachinery.

43. NDN 017-0180-0620-0: Erbium-doped composite glass waveguide amplifier.

44. NDN 017-0179-3905-0: Evaluation of abrasive particle trajectories in a slurry jet during erosion of metal matrix composites.

45. NDN 017-0178-9568-0: Energy integration of mechanical heat pumps with process fluid as working fluid.

46. NDN 017-0178-1207-4: Tribological characteristics of elastomeric and elastomeric/thermoplastic contacts under conformal sliding conditions.

47. NDN 017-0176-5922-3: Numerical model for the left ventricle pump: From the excitation of the fibers to the contraction of the whole heart.

48. NDN 017-0175-9353-4: Investigation of feed coefficient of high-pressure piston pumps for cryogenic liquids.

49. NDN 017-0172-5023-0: Corrosion behaviour of a porous iron-silicate material.

50. NDN 017-0167-0875-5: Integrated artificial heart-lung device.

51. NDN 017-0166-9427-6: Selection of mutual angular displacement of rotor wheels and nozzle guide vanes.

52. NDN 017-0166-5690-1: Ceramics for rocket engine components.

53. NDN 017-0163-6382-0: Derived thermodynamic design data for heat pump systems operating on R23.

54. NDN 017-0163-6381-8: Derived thermodynamic design data for heat pump systems operating on R1270.

55. NDN 017-0163-6380-6: Derived thermodynamic design data for heat pump systems operating on R503.

56. NDN 017-0162-9915-6: Utilisation of ceramics in slurry pumps.

57. NDN 017-0162-9901-6: Electrodes for fuel cells and oxygen pumps. A test procedure.

58. NDN 017-0161-0803-0: Note on the lubrication of composite slippers in water-based axial piston pumps and motors.

59. NDN 017-0156-5824-0: Derived thermodynamic design data for heat pump systems operating on R744.

60. NDN 017-0156-5823-9: Derived thermodynamic design data for heat pump systems operating on R13.

61. NDN 017-0156-5822-7: Derived thermodynamic design data for heat pump systems operating on R170.

62. NDN 017-0154-5959-0: Coupled rod and fluid dynamic model for predicting the behavior of sucker-rod pumping systems.

63. NDN 017-0154-4063-5: Machinery selection factors for resin transfer molding of epoxies.

64. NDN 017-0153-6497-9: Composite driving system for LVAS and IABP. Practical and effective driving and weaning.

65. NDN 017-0153-0834-4: Heat integration of distillation columns with heat pumps.

66. NDN 017-0152-5524-8: Method for designing fiberglass sucker-rod strings with API RP 11L.

67. NDN 017-0146-6087-1: Heat pumps in industrial processes. An optimization methodology.

68. NDN 017-0146-6083-4: Heat pumps and pinch technology.

69. NDN 017-0144-9344-9: Compressed air-driven duplex membrane pumps. Presentation of a new generation.

70. NDN 017-0144-8099-6: Composite piston cuts friction loss.

71. NDN 017-0136-0895-6: Fiber reinforced superalloys for rocket engines.

72. NDN 017-0136-0574-8: Rational contours for the dynamic-transport surfaces of the flow channels in hydraulic machines.

73. NDN 017-0135-3975-2: Vacuum furnace brazing large segments of heat exchanger for nuclear fusion reactor.

74. NDN 017-0134-7534-8: Increasing the wear and corrosion resistance of fuel pump plunger pairs.

75. NDN 017-0134-3719-0: Advances in power transmission using filament wound composites.

76. NDN 017-0134-3269-6: Development, testing and the economics of a composite/plastic seawater reverse osmosis pump.

77 NDN 017-0129-5573-9: Method for designing fiberglass sucker rod strings using API RP 11L.

78. NDN 017-0129-2159-6: Peristaltic dosing pumps in water treatment.

79. NDN 017-0129-2157-2: Pumps in impregnated graphite for corrosive duties.

80. NDN 017-0129-2146-8: Magnetic drive chemical pumps of tomorrow.

81. NDN 017-0129-2145-6: Non-metallic pumps.

82. NDN 017-0129-2144-4: Sodium pumps for fast breeder reactors.

83. NDN 017-0124-7610-2: Experimental study of wear resistance of mineral-polymer composites in hydroabrasive media.

84. NDN 017-0122-2474-5: Metallurgical magnetohydrodynamic applications.

85. NDN 017-0120-2550-5: Potential application of composite materials to future gas turbine engines.

Citations from Engineering Index: EI1

86. NDN 007-0098-8411-0: POLYMER-BASED MATERIALS FOR PUMPS TO HANDLE CORROSIVE & AGGRESSIVE FLUIDS.

87. NDN 007-0094-5307-0: POLYMER-BASED MATERIALS FOR PUMPS IN THE PROCESS AND CHEMICAL INDUSTRIES.

88. NDN 007-0080-5727-1: HIGH-SPEED SEAL DEVELOPMENT SALTWATER AND AMMONIA SERVICE SEM DASHS WHAT CUSTOMERS WANT TODAY.

89. NDN 007-0075-7092-6: SOLAR WATER PUMP.

90. NDN 007-0067-4657-7: CRYOCONDENSATION PUMPING OF TRITIUM AND ITS MIXTURES WITH D//2 AND H//2.

91. NDN 007-0009-0403-3: OLD WOOD BOTTOM, NEW CONCRETE TOP MAKE COMPOSITE PILE

92. NDN 007-0004-0133-3: CAPROLONE PLASTIC PUMP IMPELLERS

Citations from CA Search - MACRO: MAC

93. NDN 043-0093-4192-1: ABRASION-RESISTANT FIBER-RUBBER COMPOSITE ROTARY SEALS

94. NDN 043-0091-6715-5: FLEXIBLE GRAPHITE - PTFE COMPOSITE SEALS

95. NDN 043-0091-5407-0: FLEXIBLE GRAPHITE-CARBON FIBER BRAIDED COMPOSITE SEALS

96. NDN 043-0085-9709-9: A COMPOSITE RUTHENIUM-PLATINUM CATALYST FOR 2-PROPANOL DEHYDROGENATION ADOPTABLE TO THE CHEMICAL HEAT PUMP SYSTEM

97. NDN 043-0083-3219-5: SLIDING PARTS OF PISTON PUMPS FOR SEAWATER

98. NDN 043-0083-2021-1: STUDIES IN MODIFIED POLYBISMALEIMIDE RESINS AND ITS COMPOSITE MATERIALS

99. NDN 043-0080-7921-0: MOLDING COMPOSITIONS WITH HIGH WEAR RESISTANCE FOR PACKING RINGS AND SEALS

100. NDN 043-0077-4078-2: ASBESTOS-PHENOPLAST COMPOSITES FOR ROTARY VANES IN VACUUM PUMP

101. NDN 043-0075-4431-2: PARA-ARAMID REINFORCED COMPOSITES FOR WEAR-RESISTANT BLADES

102. NDN 043-0070-0804-9: ABRASION-RESISTANT MATERIALS

103. NDN 043-0069-7292-2: ABRASION-RESISTANT MATERIALS

104. NDN 043-0069-0629-9: ABRASION-RESISTANT CERAMIC-RUBBER COMPOSITES

105. NDN 043-0058-5725-6: CAVITATION EROSION RESISTANCE OF POLYMER COMPOSITE COATINGS IN SALT SOLUTIONS

106. NDN 043-0030-9099-9: MIXTURE FOR MANUFACTURE OF COMPOSITES

107. NDN 043-0025-2648-4: SELECTION OF MATERIALS FOR SEALING RINGS OF THE END PACKING OF PETROLEUM PUMPS

108. NDN 043-0016-6196-3: CARBON FIBER AND COMPOSITE MATERIALS OF CARBON FIBER AND POLY(TETRAFLUOROETHYLENE)

109. NDN 043-0005-3601-2: STEEL-GRAPHITE FRICTION PAIRS IN PUMP END SEALS

110. NDN 095-0195-9493-3: Hydraulically controlled diaphragm pump for high pressures

111. NDN 095-0195-7187-8: Cryogenic vane pump

112. NDN 095-0193-9272-8: Method for processing composite water pump seal ring

113. NDN 095-0191-6591-8: Pump apparatus for biomedical use

114. NDN 095-0190-5055-6: Method for producing inner stators for electromagnetic pumps

115. NDN 095-0189-0227-9: Rotary vane pump with carbon/carbon vanes

116. NDN 095-0185-5959-7: Prestressed composite concrete tank with improved pump joint and method for constructing the same

117. NDN 095-0184-5810-0: Plunger for a downhole reciprocating oil well pump and the method of manufacture thereof

118. NDN 095-0180-2281-4: Adjustable flow-combining restrictor for hydraulic excavator dual pump circuit

119. NDN 095-0179-2543-0: Composite vacuum pump

120. NDN 095-0172-5868-1: Heat transfer apparatus for heat pumps

121. NDN 095-0151-8776-2: OTR safety urinal pumps

122. NDN 095-0147-2361-5: Self-aligning sealing means for pumps and other machinery, including rotating shafts

123. NDN 095-0146-0171-6: Self-contained rotary fuel pump

124. NDN 095-0144-4380-1: Rotary vane pump with floating rotor side plates

125. NDN 095-0140-6794-3: Pump

126. NDN 095-0138-5203-1: Magnetically coupled pump with a bipartite separating pot

127. NDN 095-0137-7758-6: Gear pump or motor with hard layer in interior casing surface

128. NDN 095-0137-5719-8: Absorption refrigeration and heat pump system

129. NDN 095-0136-5572-9: Turbomolecular pump

130. NDN 095-0135-2825-2: Absorption refrigeration and heat pump system

131. NDN 095-0130-8116-6: Rotor for rotary fluid pump

132. NDN 095-0128-7682-9: Reciprocating down-hole sand pump

133. NDN 095-0121-9087-7: Control improvements in deep well pumps

134. NDN 095-0119-0392-8: Method for manufacturing a rotor for a rotary fluid pump

135. NDN 095-0115-9664-3: Vane-type rotary pump having two-piece side housings

136. NDN 095-0105-5654-6: Self-contained rotary fuel pump

137. NDN 095-0103-7222-8: Composite centrifugal impeller for slurry pumps

138. NDN 095-0095-0613-0: Self-contained rotary fuel pump

139. NDN 095-0090-8132-5: Manually operated, trigger actuated diaphragm pump dispenser

140. NDN 095-0080-3360-8: Turbine-impeller pump for use in geothermal energy recovery systems

141. NDN 095-0076-0040-4: Centrifugal pump

142. NDN 095-0070-1290-7: SEALING SYSTEM FOR USE IN COMPOSITE MULTI-STAGE PUMP

143. NDN 095-0069-4487-0: CENTRIFUGAL PUMP

144. NDN 095-0062-5867-6: DRY AIR ROTARY PUMP OR COMPRESSOR

145. NDN 095-0060-4029-4: INJECTION PUMP FOR INJECTING MOLTEN METAL

146. NDN 095-0052-3014-2: METHOD AND MEANS FOR ACCURATELY ALIGNING THE AXES OF SHAFTS IN PUMP ASSEMBLIES OR THE LIKE

147. NDN 095-0050-6690-1: VERTICAL CANTILEVER PUMP

148. NDN 095-0040-0086-4: COMPOSITE KNOCKDOWN PUMP

Citations from Rubber & Plastics Research Abstracts: RPA

149. NDN 131-0102-7729-8: FORTIFY METALS AGAINST CORROSION

150. NDN 131-0102-4960-6: DESIGN FOR FAILURE

151. NDN 131-0102-1216-4: CONTROLLING A GEAR PUMP ASSISTED DEGASSING EXTRUDER VIA DUAL PRESSURE SENSING

152. NDN 131-0101-9615-8: GEAR PUMPS IN COMPOUNDING APPLICATIONS

153. NDN 131-0101-8984-1: MEDICINE AND PLASTICS

154. NDN 131-0101-8978-6: COMPOUNDING: LET'S BE MODULAR

155. NDN 131-0101-8969-5: NEW PIC PROCESS FOR PRECISION COMPONENTS

156. NDN 131-0101-8021-7: PLASTICS AND THE ENVIRONMENT. SAVING ENERGY IN PROFILE EXTRUSION

157. NDN 131-0101-7971-9: FOR HOME AND LEISURE ACTIVITIES

158. NDN 131-0101-7429-1: PHENOLICS MEET DEMANDING UNDERBONNET NEEDS

159. NDN 131-0101-7425-4: RESIN TRANSFER MOULDING - AN EVOLVING TECHNOLOGY

160. NDN 131-0101-7350-0: LIQUID RESIN CASTING FILLS THE GAP BETWEEN MACHINING AND INJECTION MOULDING

161. NDN 131-0101-5568-5: PRO SERIES OFFERS PRECISION INJECTION

162. NDN 131-0101-5566-1: OPTIONS CAN BE TAILORED TO MATCH PROCESS

163. NDN 131-0101-5565-0: RAM ALLOWS RTM OF AEROSPACE COMPOSITES

164. NDN 131-0101-3163-2: ADDITIVES CASEBOOK: PLASTIC APPLICATIONS STARRING ADDITIVES

165. NDN 131-0101-2981-9: POWER TRANSMISSION. POLYMERS. CONVEYOR BELTING. FLUID POWER

166. NDN 131-0101-1697-7: WHAT CHOICES FOR SCREWS?

167. NDN 131-0101-0297-8: AT K'92: THE LOST-CORE TECHNOLOGY. FULLY AUTOMATIC TECHNOLOGY OUT OF ONE SOURCE

168. NDN 131-0100-9344-8: MIXING IN CONTINUOUS INTERNAL MIXERS

169. NDN 131-0100-7508-2: MORE ULTRAS FROM BASF

170. NDN 131-0100-7485-5: GUYSON FOR QUALITY SANDING

171 NDN 131-0100-1496-2: SAFETY AND MAINTENANCE IN HIGH PRESSURE POLYETHYLENE PLANT

172. NDN 131-0085-5305-1: ANGUS MECHANICAL SEALS. DESIGN MANUAL

173. NDN 131-0085-3760-4: NEW METERING UNITS FOR PU ELASTOMERS

174. NDN 131-0085-3016-6: DESIGNED FOR EXCELLENCE

175. NDN 131-0085-1416-1: ARLON HIGH PERFORMANCE THERMOPLASTIC

176. NDN 131-0085-0922-0: CIBA'S DIE IS CAST FOR FURTHER GROWTH IN NICHE MARKETS

177. NDN 131-0085-0272-9: CRITICAL PARTS GUARANTEED TO WORK

178. NDN 131-0084-9405-8: NEW POLYMER HAS PROMISING MEDICAL FUTURE

179. NDN 131-0084-8539-2: INJECTION MOULDING WITH NEAR-PTFE CHEMICAL RESISTANCE

180. NDN 131-0084-8475-2: ROD AND PLATE

181. NDN 131-0084-7769-3: FLOW METERS FOR AGGRESSIVE MEDIA

182. NDN 131-0084-7209-9: IXEF POLYARYLAMIDE HIGH PERFORMANCE REINFORCED ENGINEERING THERMOPLASTIC

183. NDN 131-0084-5555-7: GEAR PUMP IS EXTERNALLY LUBRICATED

184. NDN 131-0084-3781-6: VACUUM BAGGING: A VERSATILE PROCESSING TOOL

185. NDN 131-0084-3780-4: LABELLING SYSTEM PASSES AIRBUS TEST

186. NDN 131-0084-3603-4: PUMPS - DEMAND FOR SOLUTIONS

187. NDN 131-0084-3534-0: INDUSTRIAL RTM NEW DEVELOPMENTS IN MOULDING AND PREFORMING TECHNOLOGIES

188. NDN 131-0084-1782-9: EXTRUSION COMPOUNDING WITH GEAR PUMPS

189. NDN 131-0083-9821-5: COMPRESSION PRESS OPERATES WITHOUT OIL

190. NDN 131-0083-9737-5: LATEST NEWS FROM THE MACHINERY MANUFACTURERS

191. NDN 131-0083-9605-0: PUMPS GET ENCLOSURES MADE BY RTM

192. NDN 131-0083-7336-0: GRAPHITE WHISKER-REINFORCED MATERIALS

193. NDN 131-0083-6329-8: DEVELOPMENTS IN MATERIALS AND PROCESSING

194. NDN 131-0083-5424-8: VACUUM - DISTRIBUTION, PUMP DESIGN, ADJUSTMENT AND PROTECTION

195. NDN 131-0083-4666-5: BUSS NEW GENERATION ASSETS

196. NDN 131-0083-2196-6: GREAT FUTURE OF PPS

197. NDN 131-0083-1552-8: CORROSION-FREE RESINS

198. NDN 131-0083-0830-5: CONTINUOUS FRP SHEET PRODUCTION

Citations from USG/NTIS: USG

199. NDN 033-0154-6555-7: Sntp Propellant Management System.

200. NDN 033-0152-5220-3: Evolution des Materiaux Utilises en Propulsion Fusee a Ergols Liquides (Evolution of Materials Used in Liquid Propellant Rocket Engines).

201. NDN 033-0151-5535-0: HM7 Turbopump CMC Stator Trials.

202. NDN 033-0151-1470-0: Repair, Evaluation, Maintenance, and Rehabilitation Research Program. Evaluation of the Rehabilitation Program for Relief Wells at Leesville Dam, Ohio.

203. NDN 033-0150-5592-6: Progress Toward a Tungsten Alloy Wire/High Temperature Alloy Composite Turbine Blade.

204. NDN 033-0144-9644-3: Composite Load Spectra for Select Space Propulsion Structural Components.

205. NDN 033-0143-1475-4: Automation of Cutting and Drilling of Composite Components.

206. NDN 033-0142-7394-6: Mitsubishi Juko Giho. Vol. 28. No. 2. 1991. Special Issue: Air Conditioning and Refrigeration.

207. NDN 033-0141-9218-1: Propulsion System Needs.

208. NDN 033-0139-2707-0: Probabilistic Design Analysis Using Composite Loads Spectra (CLS) Coupled with Probabilistic Structural Analysis Methodologies (PSAM).

209.	NDN 033-0137-7556-7:	Ceramic Composites for Rocket Engine Turbines.
210.	NDN 033-0136-7959-1:	Fiber-Reinforced Ceramic Composites for Earth-to-Orbit Rocket Engine Turbines.
211.	NDN 033-0133-9559-0:	Composite Load Spectra Project.
212.	NDN 033-0126-6262-5:	PROBABILISTIC STRUCTURAL ANALYSIS METHODS OF HOT ENGINE STRUCTURES.
213.	NDN 033-0124-9814-0:	FIBER REINFORCED SUPERALLOYS FOR ROCKET ENGINES.
214.	NDN 033-0116-7188-6:	PNEUMATIC INDUCTION FIBER SPREADER WITH LATERAL VENTURI RESTRICTORS.
215.	NDN 033-0115-8770-0:	SURFACE SHIP MACHINERY - A SURVEY OF PROPULSION ELECTRICAL AND AUXILIARY SYSTEM DEVELOPMENT
216.	NDN 033-0114-8958-0:	STAEBL/GENERAL COMPOSITES WITH HYGROTHERMAL EFFECTS (STAEBL/GENCOM):
217.	NDN 033-0111-1206-0:	PROBABILISTIC STRUCTURAL ANALYSIS TO EVALUATE THE STRUCTURAL DURABILITY OF SSME(SPACE SHUTTLE MAIN ENGINE) CRITICAL COMPONENTS.
218.	NDN 033-0110-2787-0:	HEAT RADIATORS FOR ELECTROMAGNETIC PUMPS: CARBON/CARBON COMPOSITE RADIATORS WITHSTAND HIGH TEMPERATURES.
219.	NDN 033-0107-8923-3:	PROBABILISTIC STRUCTURAL ANALYSIS METHODS FOR SPACE PROPULSION SYSTEM COMPONENTS.
220.	NDN 033-0099-1249-3:	NBS (NATIONAL BUREAU OF STANDARDS) RESEARCH REPORTS.
221.	NDN 033-0098-4425-6:	ADVANCED HIGH PRESSURE O2/H2 TECHNOLOGY.
222.	NDN 033-0097-5127-8:	DESIGN PROCEDURES FOR LOW SPEED WATERJETS SUITABLE FOR APPLICATION IN AMPHIBIOUS VEHICLES.
223.	NDN 033-0090-7734-8:	FLUID SLURRY PUMP AND CONTROL APPARATUS - DEVELOPMENT. FINAL REPORT.
224.	NDN 033-0087-2942-3:	DEVELOPMENT OF PERCUTANEOUS ENERGY TRANSMISSION SYSTEMS.
225.	NDN 033-0084-6849-4:	GEOTHERMAL ENERGY: CORROSION AND EQUIPMENT. MAY 1976-1981 (CITATIONS FROM THE NTIS DATA BASE).
226.	NDN 033-0084-6848-2:	GEOTHERMAL ENERGY: CORROSION AND EQUIPMENT. 1982-JUN 83 (CITATIONS FROM THE NTIS DATA BASE).
227.	NDN 033-0083-4315-6:	COSTS AND INDEXES FOR DOMESTIC OIL- AND GAS FIELD EQUIPMENT AND PRODUCTION OPERATIONS 1982.
228.	NDN 033-0081-6039-6:	STUDY OF VACUUM SYSTEMS FOR A HEAT ENGINE/FLYWHEEL AUTOMOTIVE PROPULSION SYSTEM. FINAL REPORT.
229.	NDN 033-0077-6459-2:	PACKING DESIGN AND MATERIALS FOR COAL LIQUEFACTION SLURRY FEED PUMPS. INTERIM TECHNICAL REPORT NO. 2.
230.	NDN 033-0075-7553-9:	DEVELOPMENT OF PERCUTANEOUS ENERGY TRANSMISSION SYSTEMS.
231.	NDN 033-0075-3701-0:	STUDY OF ACCUMULATOR PASSENGER CARS BASED ON THE IFIELD HYDROSTATIC PUMP/MOTOR UNIT.
232.	NDN 033-0074-7337-8:	GEOTHERMAL ENERGY: CORROSION AND EQUIPMENT. MAY 1976-DECEMBER 1981 (CITATIONS FROM THE NTIS DATA BASE).
233.	NDN 033-0071-4201-5:	DEVELOPMENT OF ELECTRICAL ENERGY CONVERTERS TO POWER AND CONTROL LEFT HEART ASSIST DEVICES.
234.	NDN 033-0068-6969-2:	DEVELOPMENT OF A PERCUTANEOUS ENERGY TRANSMISSION SYSTEM.
235.	NDN 033-0064-6036-4:	MANUFACTURE AND PROPERTIES OF A GLASS FABRIC/EPOXY COMPOSITE BELLOWS.
236.	NDN 033-0064-5870-9:	GEOTHERMAL ENERGY: CORROSION AND EQUIPMENT. MAY 1976-JULY 1980 (CITATIONS FROM THE NTIS DATA BASE).

237. NDN 033-0062-1966-1: LONG-TERM SUPPLY CURVES FOR GEOTHERMAL ENERGY: THE IMPACTS OF TECHNOLOGY.

238. NDN 033-0059-8212-6: NEW HEAT TRANSFER GEOMETRY FOR HYDRIDE HEAT ENGINES AND HEAT PUMPS.

239. NDN 033-0058-4522-9: TESTING AND EVALUATION OF POTENTIAL HAZARDS FROM A TEFLON IMPREGNATED PACKING.

240. NDN 033-0057-6580-5: DEVELOPMENT OF PERCUTANEOUS ENERGY TRANSMISSION.

241. NDN 033-0056-2242-3: GEOTHERMAL ENERGY. PART 2. CORROSION AND EQUIPMENT. VOLUME 3. MAY 1976-JULY 1979 (CITATIONS FROM THE NTIS DATA BASE).

242. NDN 033-0050-4962-0: GEOTHERMAL ENERGY. PART 2. CORROSION AND EQUIPMENT. VOLUME 3. MAY 1976-JULY 1978 (CITATIONS FROM THE NTIS DATA BASE).

243. NDN 033-0045-0528-9: GEOTHERMAL ENERGY. PART 2. CORROSION AND EQUIPMENT. VOLUME 3. MAY 1976-JULY 1977 (CITATIONS FROM THE NTIS DATA BASE).

244. NDN 033-0040-8248-2: NITROSO RUBBER EXPULSION BLADDERS FOR NITROGEN TETROXIDE APPLICATION.

245. NDN 033-0040-6637-3: COMPOSITE SAMPLING METHOD AND SYSTEM.

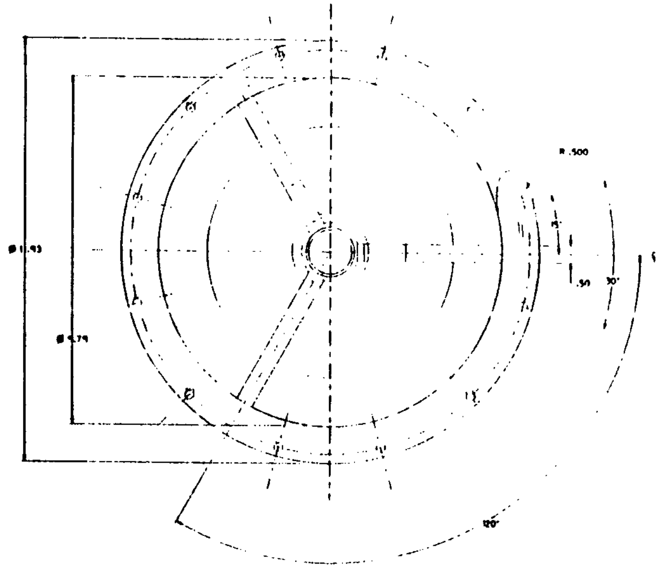
246. NDN 033-0040-4096-7: ENGINEERING MECHANICS AT THE TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY.

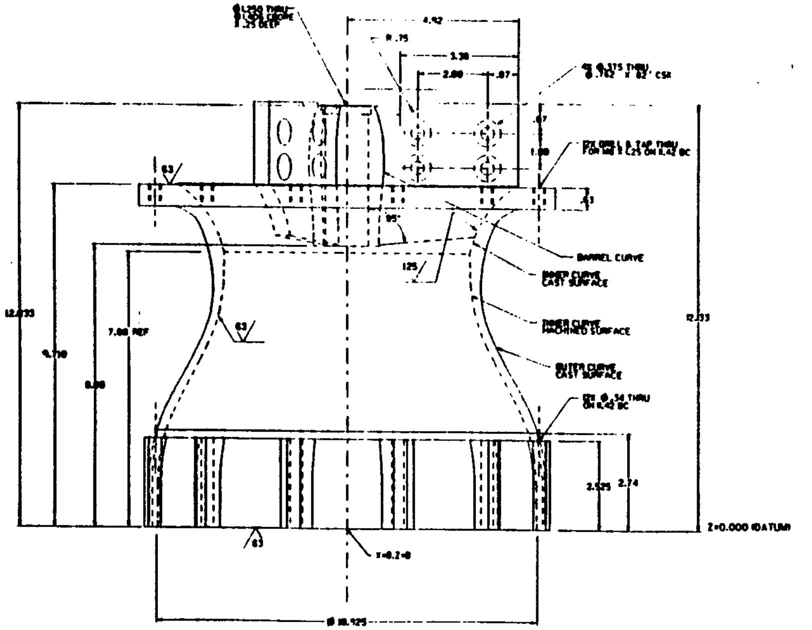
247. NDN 033-0037-9003-1: MICROFIBER MATERIALS FOR GROWTH OF INTIMAL LININGS IN CIRCULATORY ASSIST DEVICES.

248. NDN 033-0037-1503-3: FIELD EVALUATION TESTING OF REVERSE OSMOSIS HIGH PRESSURE PUMPS AND ENERGY RECOVERY TURBINES ROSWELL NEW MEXICO.

Appendix C

Preliminary Engineering Drawing of the Suction Bell





130 √ EXCEPT AS NOTED

INNER CURVE	
X	Z
5.436	0.000
5.436	0.250
5.436	0.500
5.436	0.750
5.436	1.000
5.436	1.250
5.420	1.500
5.409	1.750
5.376	2.000
5.330	2.250
5.271	2.500
5.190	2.750
5.109	3.000
5.003	3.250
4.884	3.500
4.756	3.750
4.625	4.000
4.493	4.250
4.362	4.500
4.231	4.750
4.103	5.000
3.983	5.250
3.878	5.500
3.789	5.750
3.716	6.000
3.657	6.250
3.611	6.500
3.578	6.750
3.558	7.000
3.552	7.250
3.546	7.500
3.539	7.750
3.602	8.000
3.684	8.250
3.779	8.500
3.914	8.750
4.086	9.000
4.293	9.250
4.548	9.500
4.950	9.750

OUTER CURVE	
X	Z
5.686	0.000
5.686	0.250
5.686	0.500
5.686	0.750
5.686	1.000
5.686	1.250
5.679	1.500
5.660	1.750
5.629	2.000
5.586	2.250
5.529	2.500
5.460	2.750
5.376	3.000
5.270	3.250
5.162	3.500
5.034	3.750
4.903	4.000
4.760	4.250
4.619	4.500
4.487	4.750
4.364	5.000
4.244	5.250
4.130	5.500
4.036	5.750
3.957	6.000
3.906	6.250
3.870	6.500
3.852	6.750
3.861	7.000
3.886	7.250
3.919	7.500
3.969	7.750
4.028	8.000
4.104	8.250
4.207	8.500
4.344	8.750
4.707	9.000

BARREL CURVE	
X	Z
0.965	8.000
0.962	8.250
0.977	8.500
0.982	8.750
1.000	9.000
1.026	9.250
1.043	9.500
1.060	9.750
1.090	10.000
1.103	10.250
1.102	10.500
1.089	10.750
1.070	11.000
1.046	11.250
1.003	11.500
0.939	11.750
0.847	12.000

LIST OF MATERIALS

PC. NO.	NAME OF PIECE	REQ.	MATERIAL OR NOTE
1	IMPELLER HOUSING	1	COMPOSITE

NOTES:

1. THE DIMENSIONS AS SHOWN WERE OBTAINED FROM THE EXISTING PART, BY MEASUREMENTS TAKEN AT THE CARDEROCK MACHINE SHOP (BLD 9.

DRAWING TO BE REVIEWED BY
HARRY TELEGADAS CODE 644
PHONE 267-2165

PRELIMINARY

REV.	ZONE	DESCRIPTION	BY	APP'D	DATE

REVISIONS

REFERENCES

DATE 12/17/93
DRAWN HLR
CHECKED
DESIGNED
APPROVED
DATE

COAST GUARD
NFS PUMP SUCTION BOWL
REVERSE ENGINEERING
SCALE 1/4

DEPARTMENT OF THE NAVY
NAVAL SURFACE WARFARE CENTER

E84-4230-1

References

1. NSFCC, "Serving America: The U.S. Coast Guard NSF," NSFCC, North Carolina (1993).
2. NSFCC, "The National Strike Force Year in Review," NSFCC, North Carolina (1993).
3. Suitt, D. W., "Composite Pumps for Shipboard Use Final Summary Report," David Taylor R&D Report, DTRC-PAS-88-25 (August 1988).
4. Roer, Michael, LT USCG, and Whipple, Frank, CDR AST, *Private Communications,* (April 1993).
5. Ingram, Thomas, Government Services Unit, ABS Americas, *Private Communications,* (March 1994).
6. Thomas Register
7. Buse, Frederic W., "Non-Metallic Pumps," *World Pumps,* No. 272, pp. 142-145 (May 1989).
8. Buse, Frederic W., "Chemical Pumps Metallic and Nonmetallic," *Centrifugal Pumps Design and Applications,* Ch. 15, Gulf Publishing, Texas, pp. 283-329 (1992).
9. Banerjee, Bani R., Gray, Brian E., and Anderson, Thomas F., "Development of a Polymer Industrial Machine," *Northwest Branch Symposium Paper,* Institute of Chemical Engineers, Vol. 104, No. 6, pp. 2.1-2.10 (1985).
10. Petersen, R. R., "Auxiliary Benefits Derived From the Use of Reinforced Plastics in Centrifugal Pump Applications," *Materials of Construction of Fluid Machinery and Their Relationship to Design and Performance,* American Society of Mechanical Engineers, New York, pp. 39-47 (1981).
11. No Author, "Polymer-based Materials for Pumps in the Process and Chemical Industries," *South African Mining and Engineering Journal,* Vol. 91, No. 4168, pp. 45-53 (November 1980).
12. No Author, "Polymer-based Materials for Pumps to Handle Corrosive and Aggressive Fluids," *The Certificated Engineer,* Vol. 54, No. 2, pp. 855-857 (February 1981).
13. No Author, "Pumps Get Enclosures Made by RTM," *Reinforced Plastics,* Vol. 36, No. 3, p. 6 (March 1992).

14. Greutink, H. A. J., "The Effects of Vertical Pump Materials of Construction on Design and Performance," *Materials of Construction of Fluid Machinery and Their Relationship to Design and Performance,* American Society of Mechanical Engineers, New York, pp. 19-27 (1981).
15. Whipple, Frank, CDR AST, *Private Communications,* (February 1994).
16. Cook, Nathan H. "Axially Loaded Members and Structures," *Mechanics and Materials for Design,* Ch. 3, McGraw-Hill, New York, pp. 57-107 (1984).
17. Leslie, James C., "Properties and Performance Requirements," *Advanced Thermoset Composites,* Ch. 3, Van Nostrand, New York, pp. 74-109 (!986).
18. Dally, J. W., and Riley, W. F., "Experimental Stress Analysis," *Analysis of Strain-Gage Data,* Ch. 10, McGraw-Hill, New York, pp. 318-336 (1978).

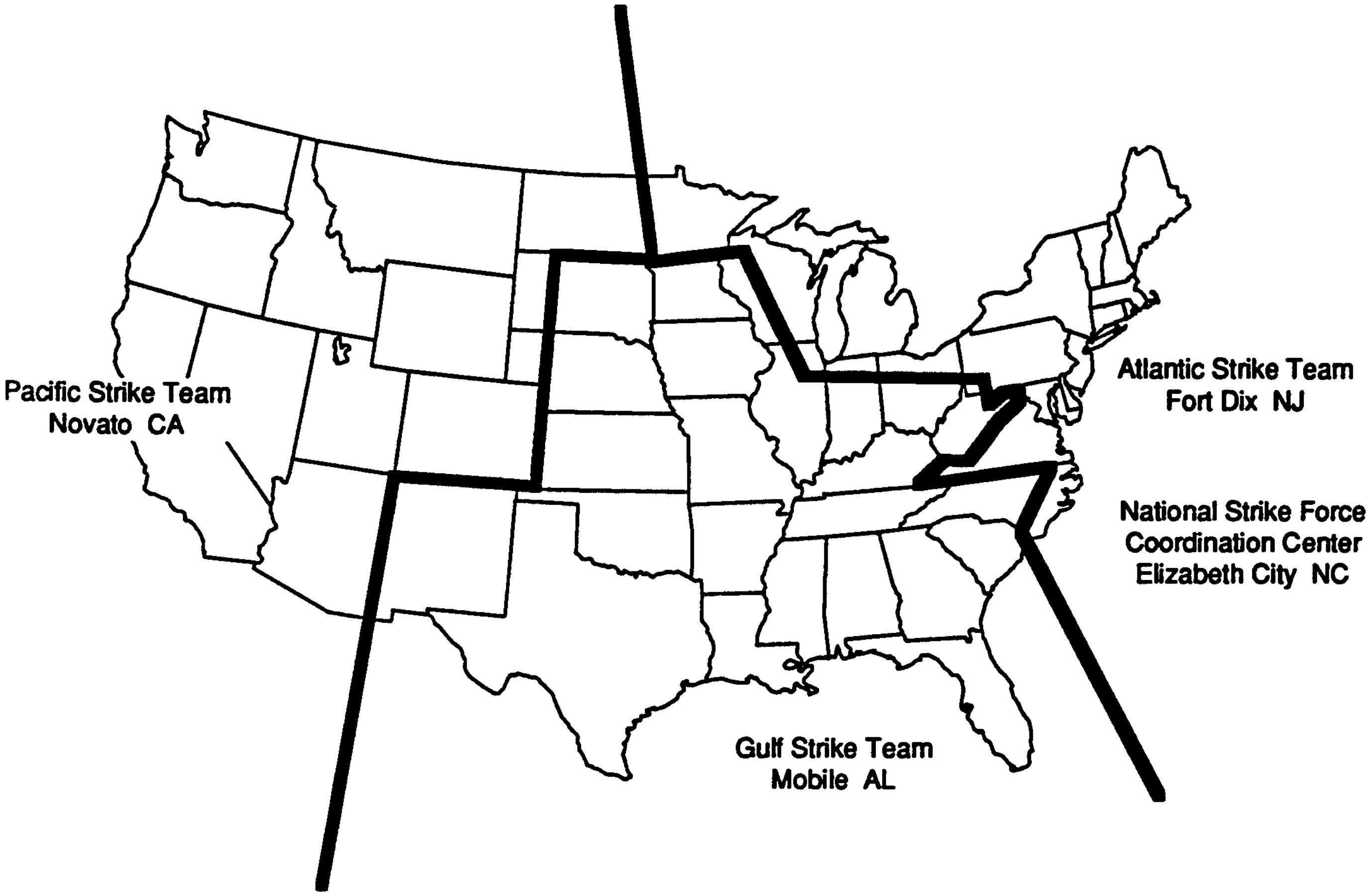


Fig. 1. Location and area of command of the National Strike Teams.

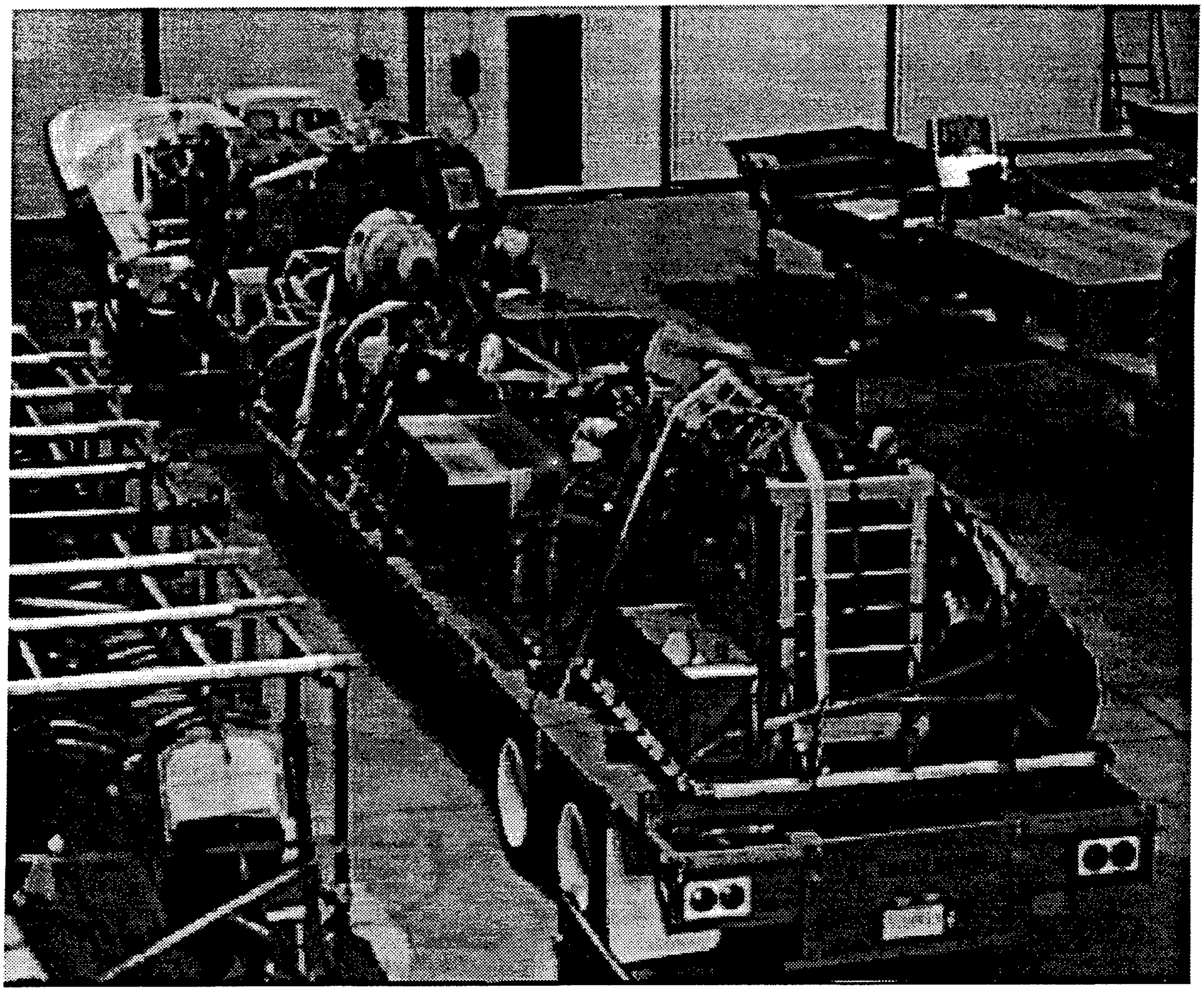


Fig. 2. Gulf Strike Team ready load.

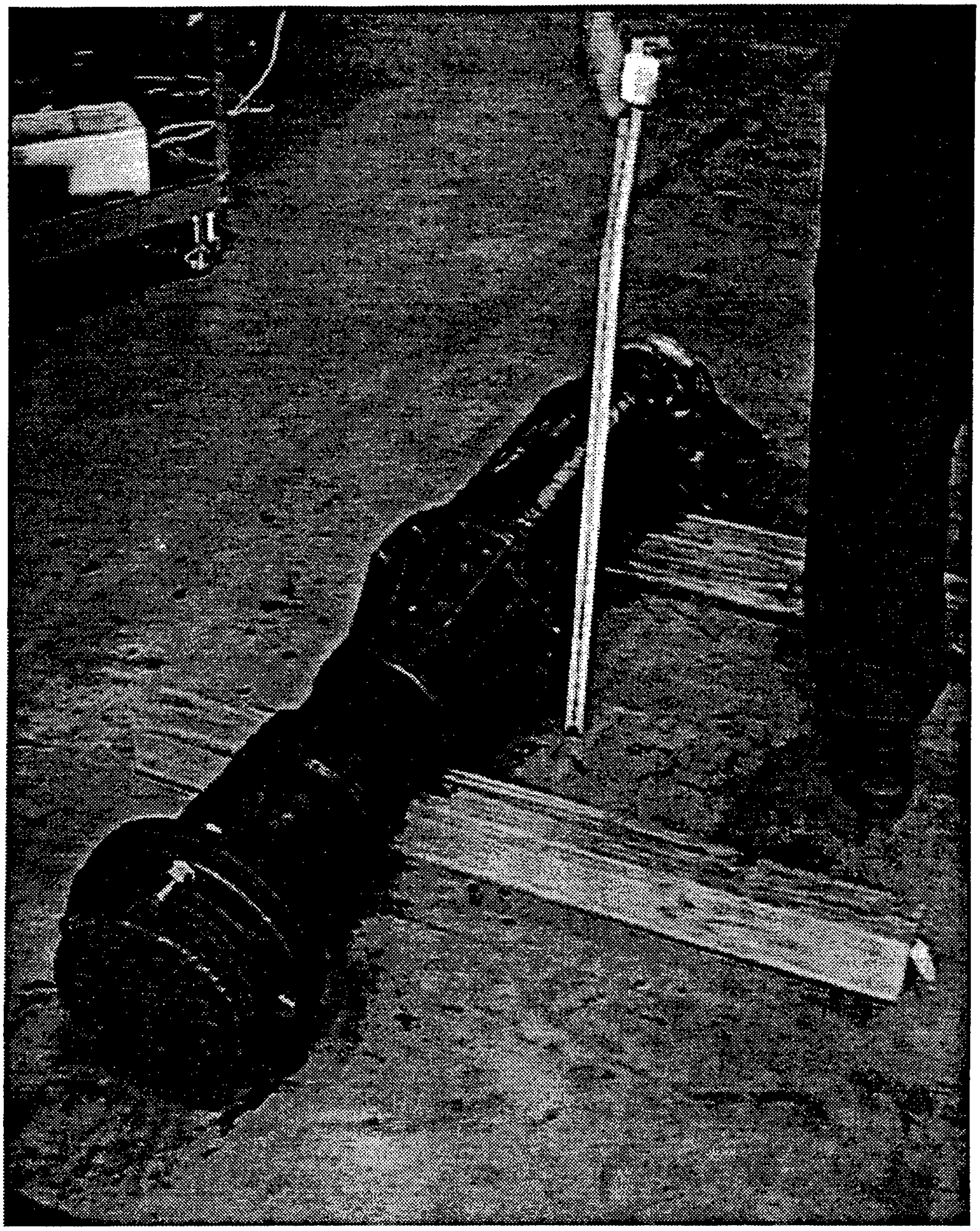


Fig. 3. Stripper pump.

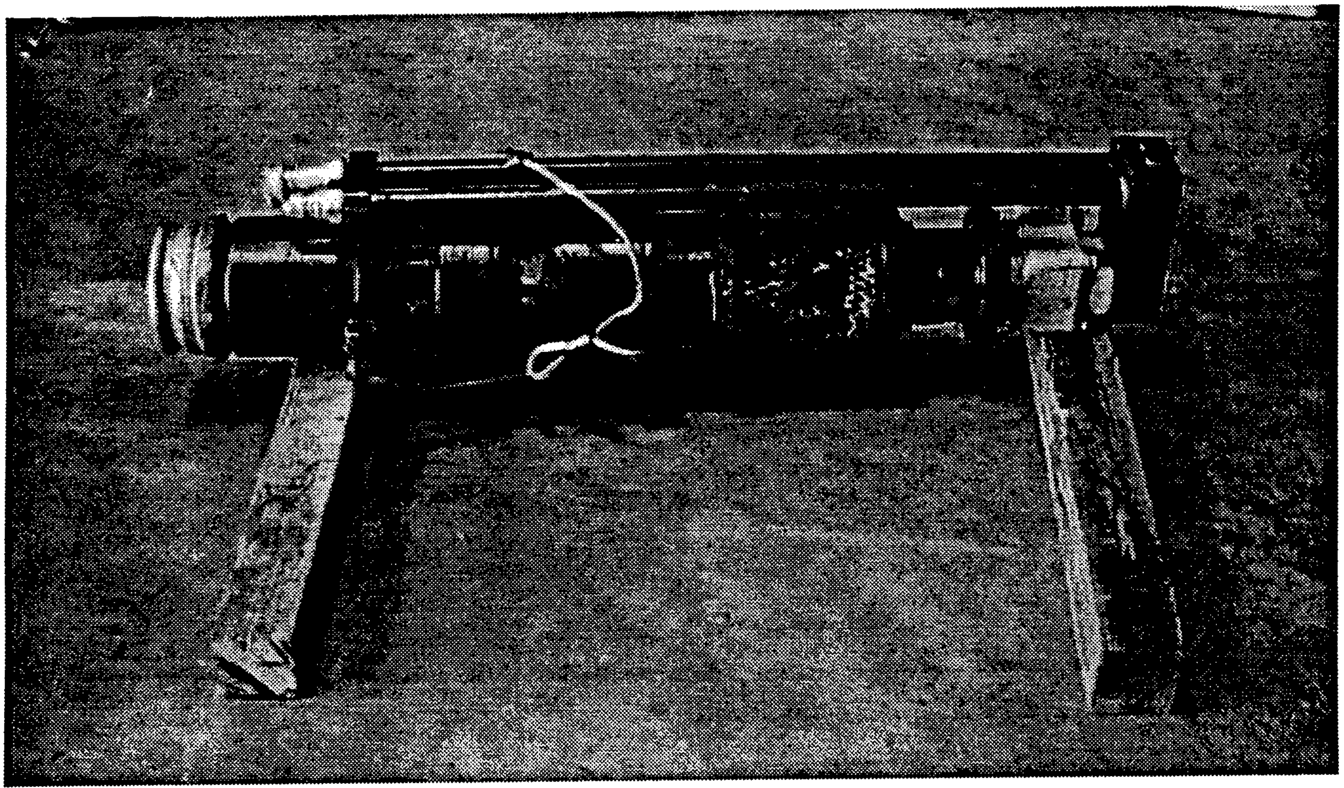


Fig. 4. Single Stage pump.

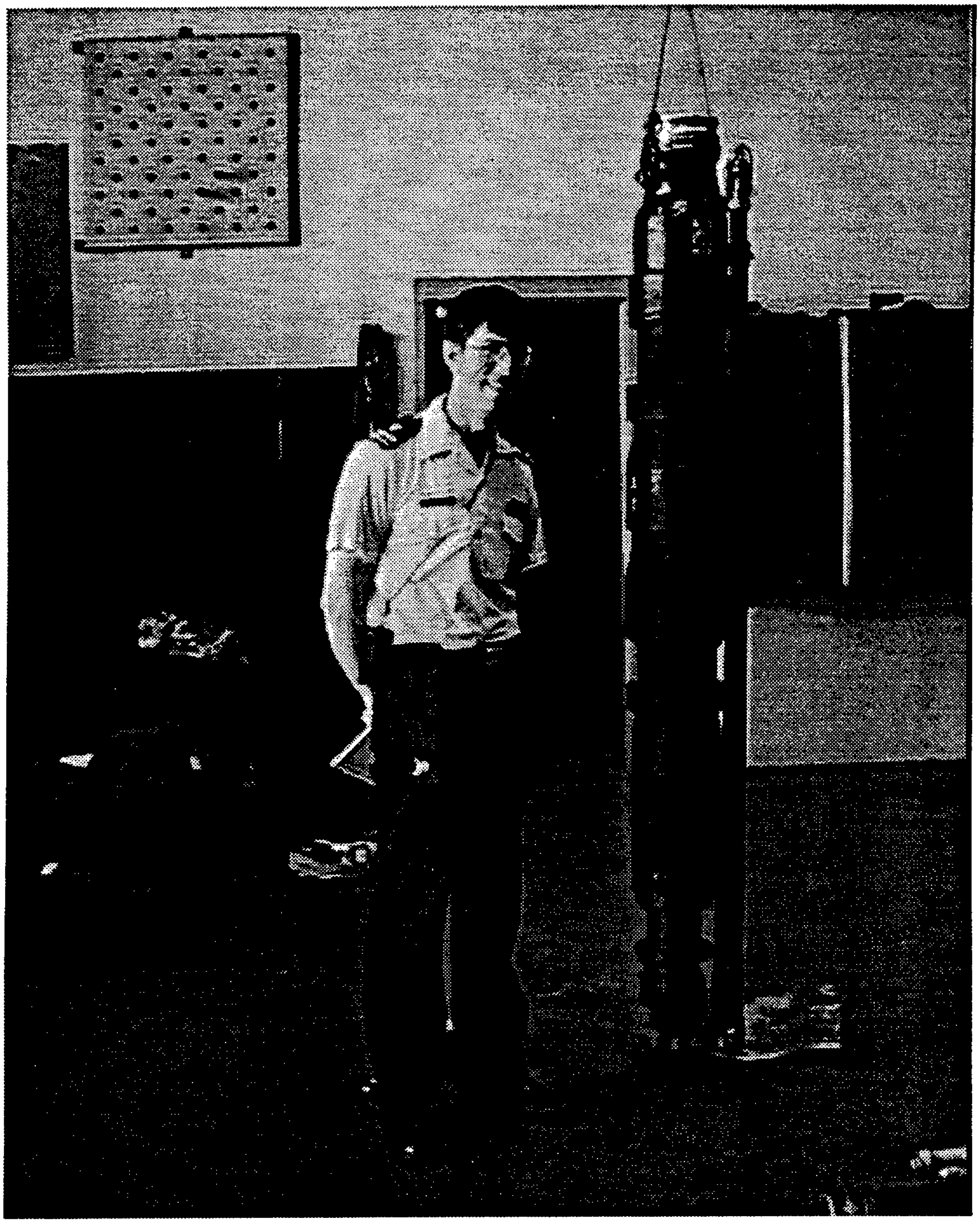


Fig. 5. Double Stage pump.

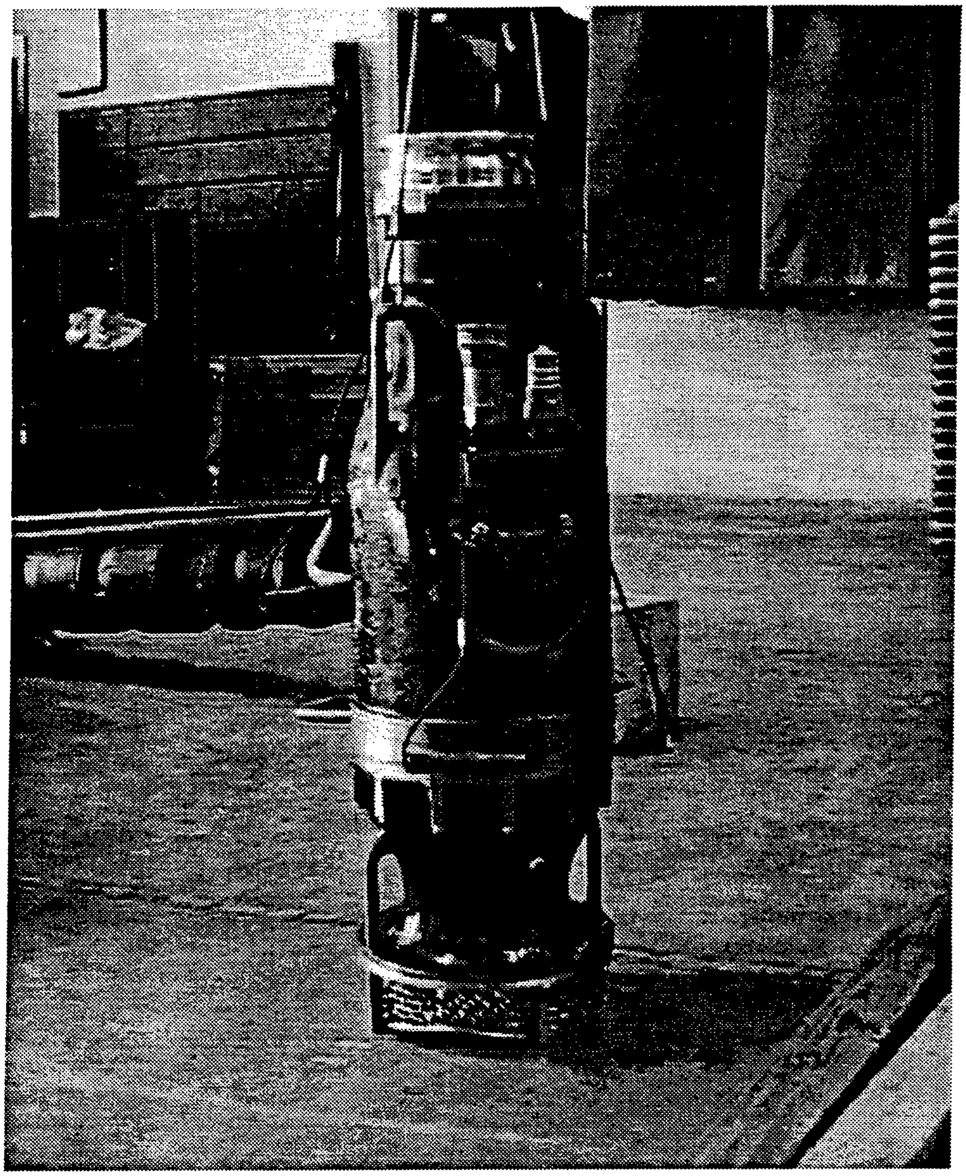


Fig. 6. Thune Eureka pump.

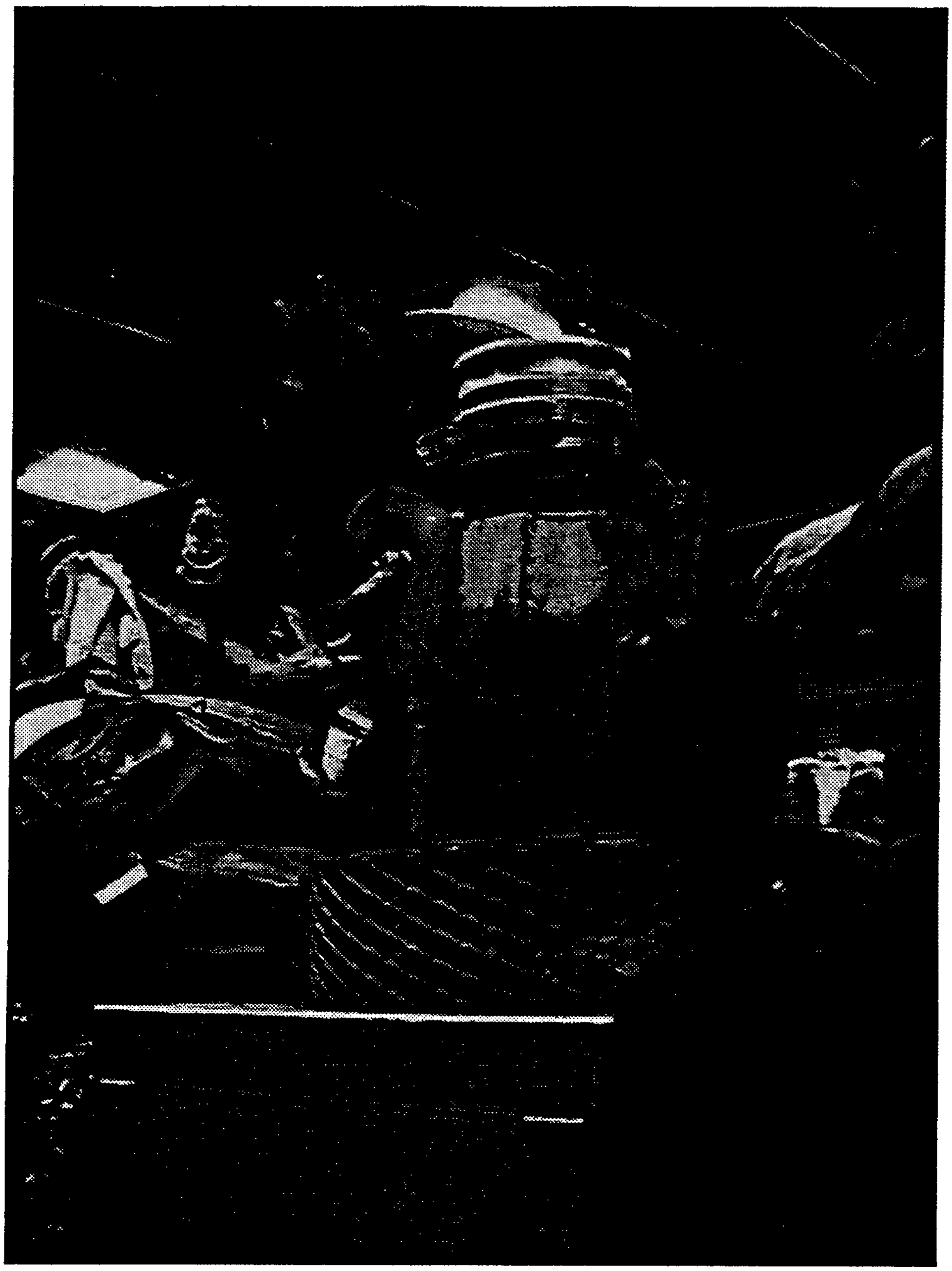
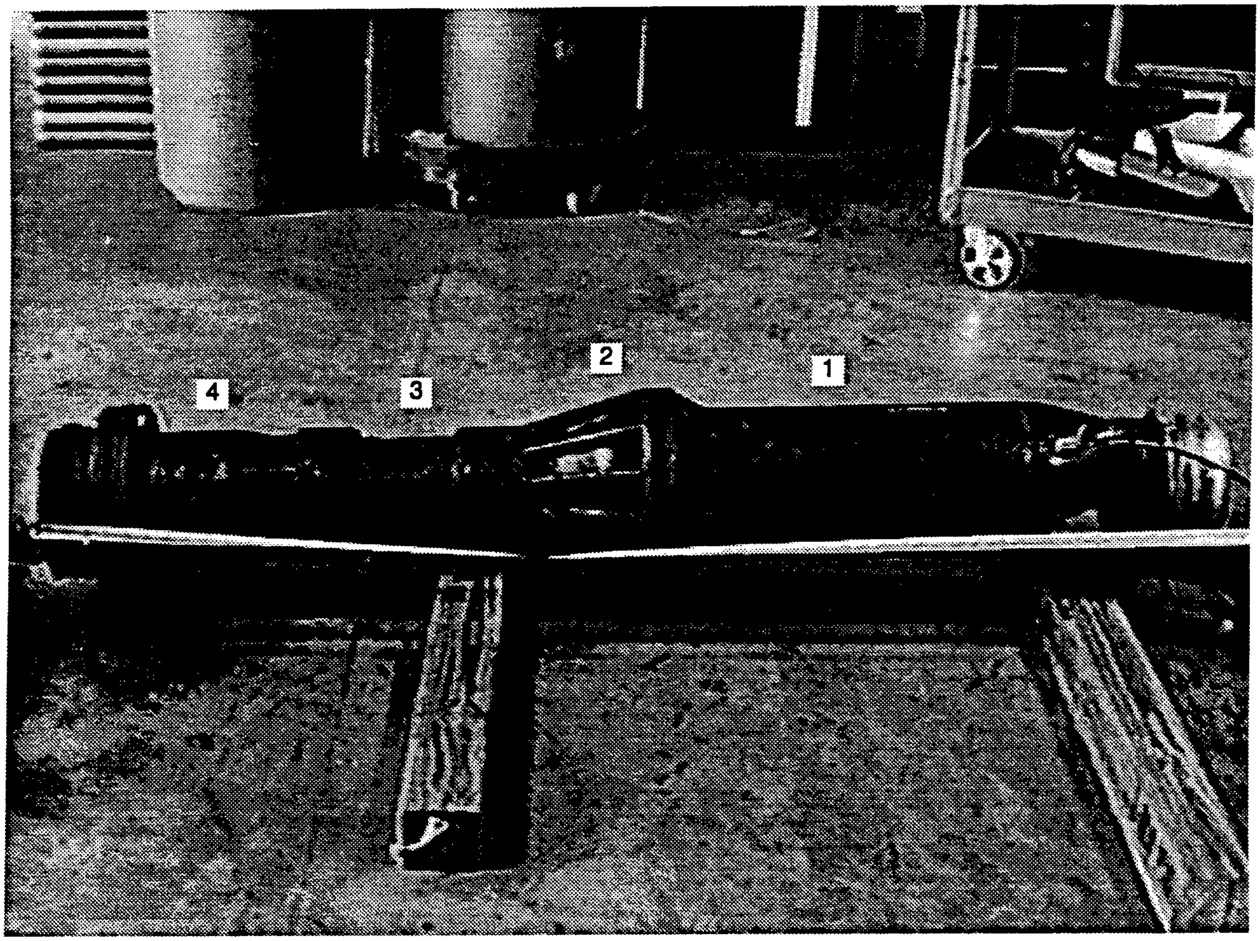
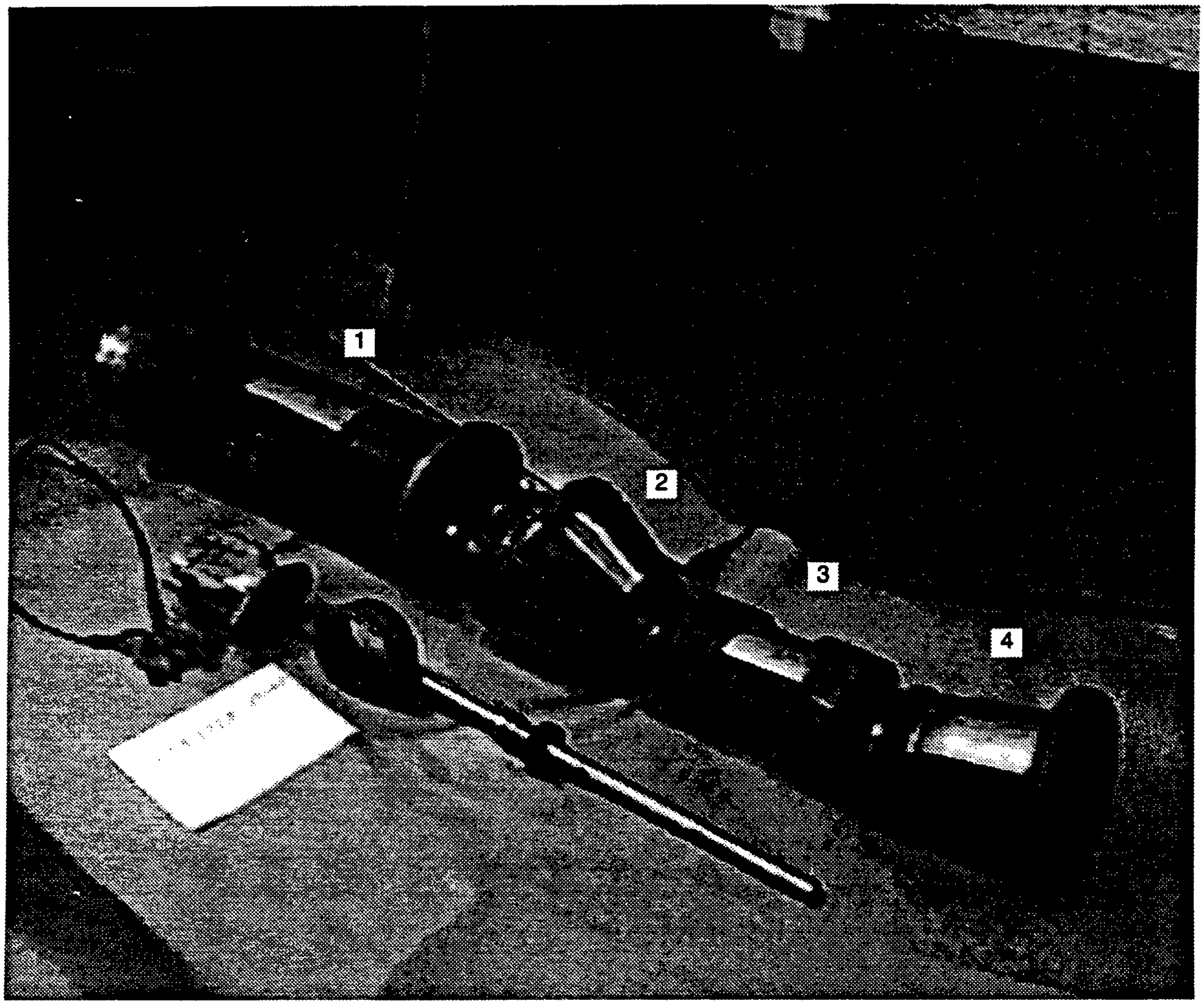


Fig. 7. Sloan pump.



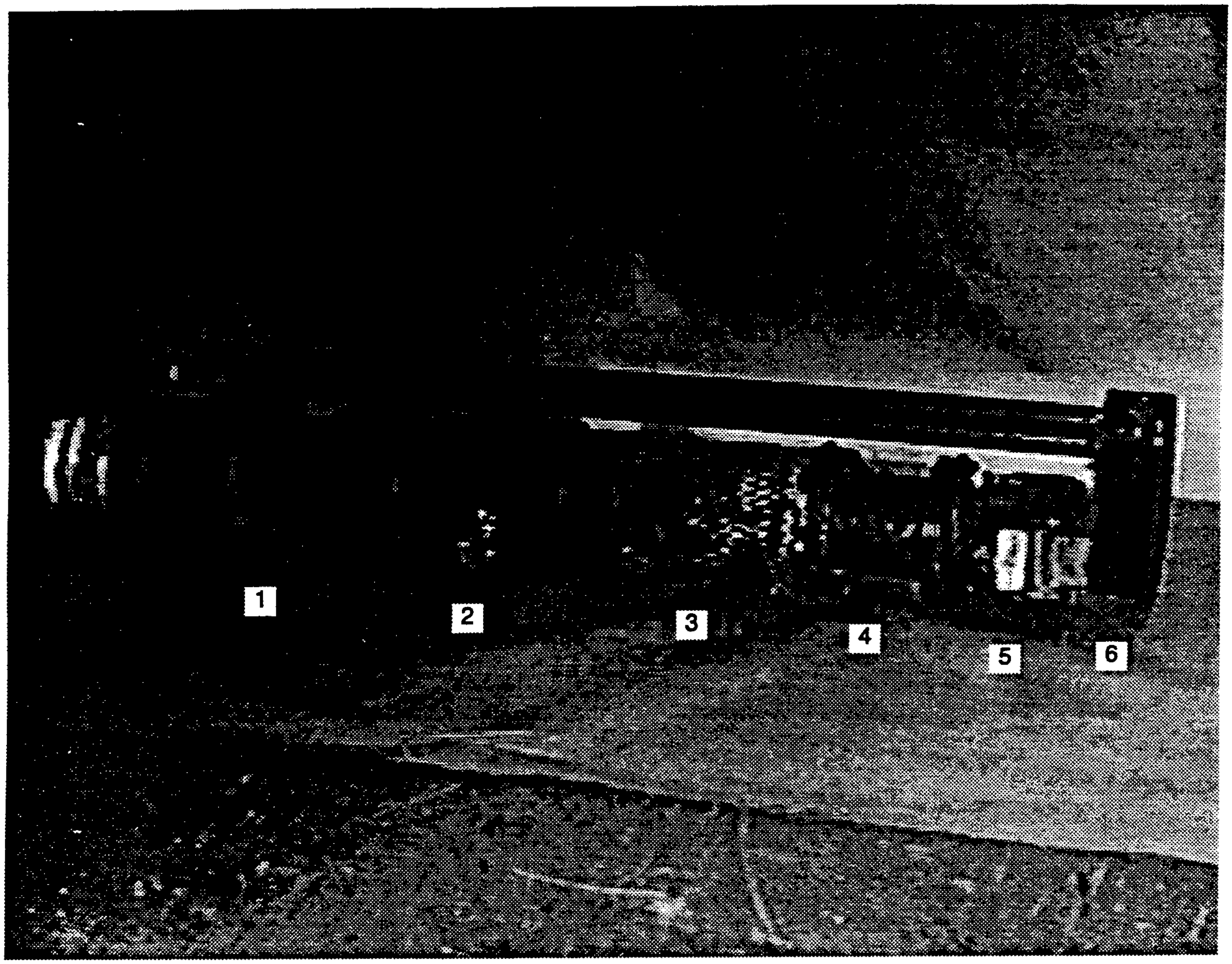
Part No.	Weight
1	93.2 lb.
2	70.2 lb.
3	31.8 lb.
4	58.4 lb.
Motor	29.8 lb.

Fig. 8. Assembled Stripper pump identifying and listing the weights of the major components.



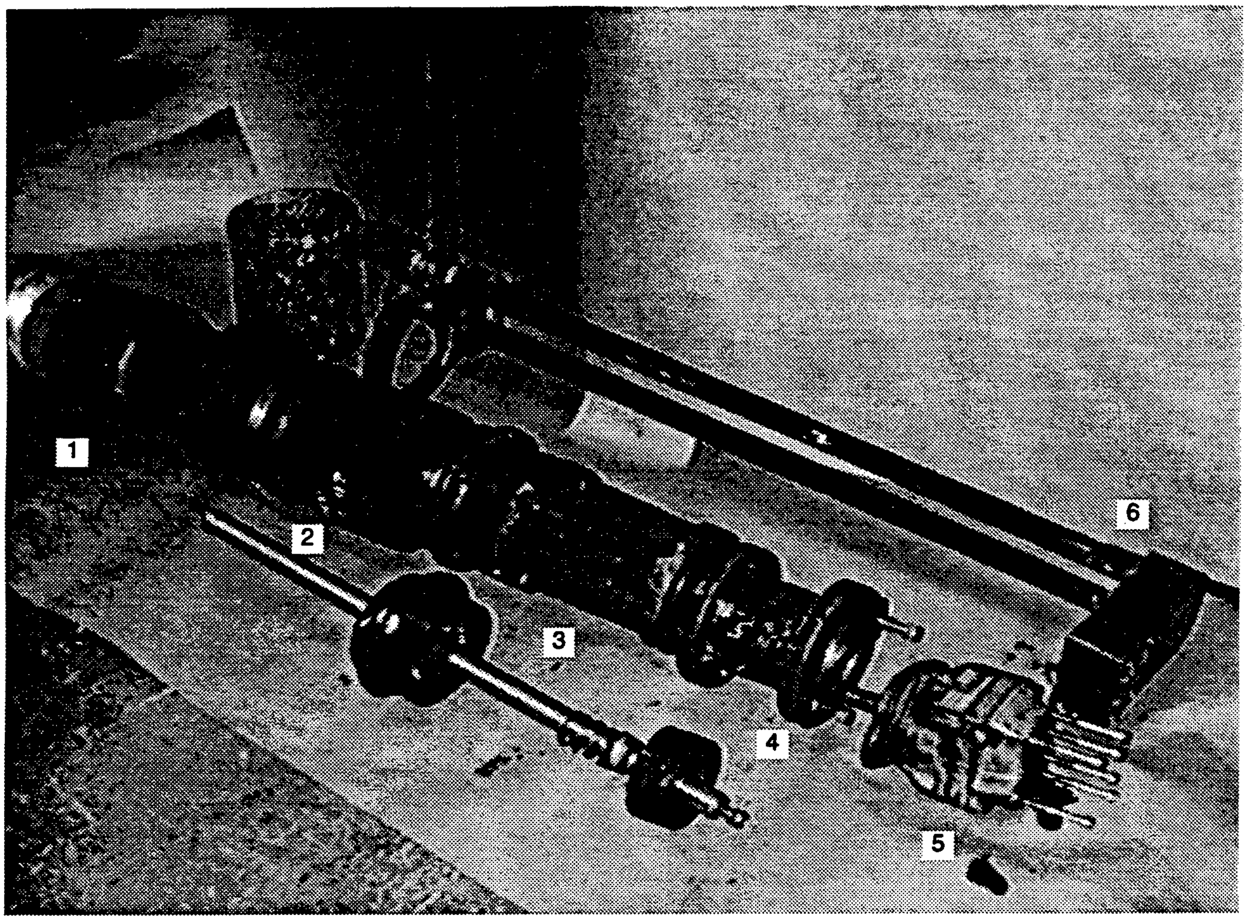
Part No.	Weight
1	93.2 lb.
2	70.2 lb.
3	31.8 lb.
4	58.4 lb.
Motor	29.8 lb.

Fig. 9. **Disassembled Stripper identifying and listing the weights of the major components.**



Part No.	Weight
1	48.2 lb.
2	33.2 lb.
3	41.2 lb.
4	29.4 lb.
5	29.8 lb.
6	45.8 lb.
Shaft/Impeller	20.2 lb.

Fig. 10. Assembled Single Stage identifying and listing the weights of the major components.



Part No.	Weight
1	48.2 lb.
2	33.2 lb.
3	41.2 lb.
4	29.4 lb.
5	29.8 lb.
6	45.8 lb.
Shaft/Impeller	20.2 lb.

Fig. 11. Disassembled Single Stage identifying and listing the weights of the major components.

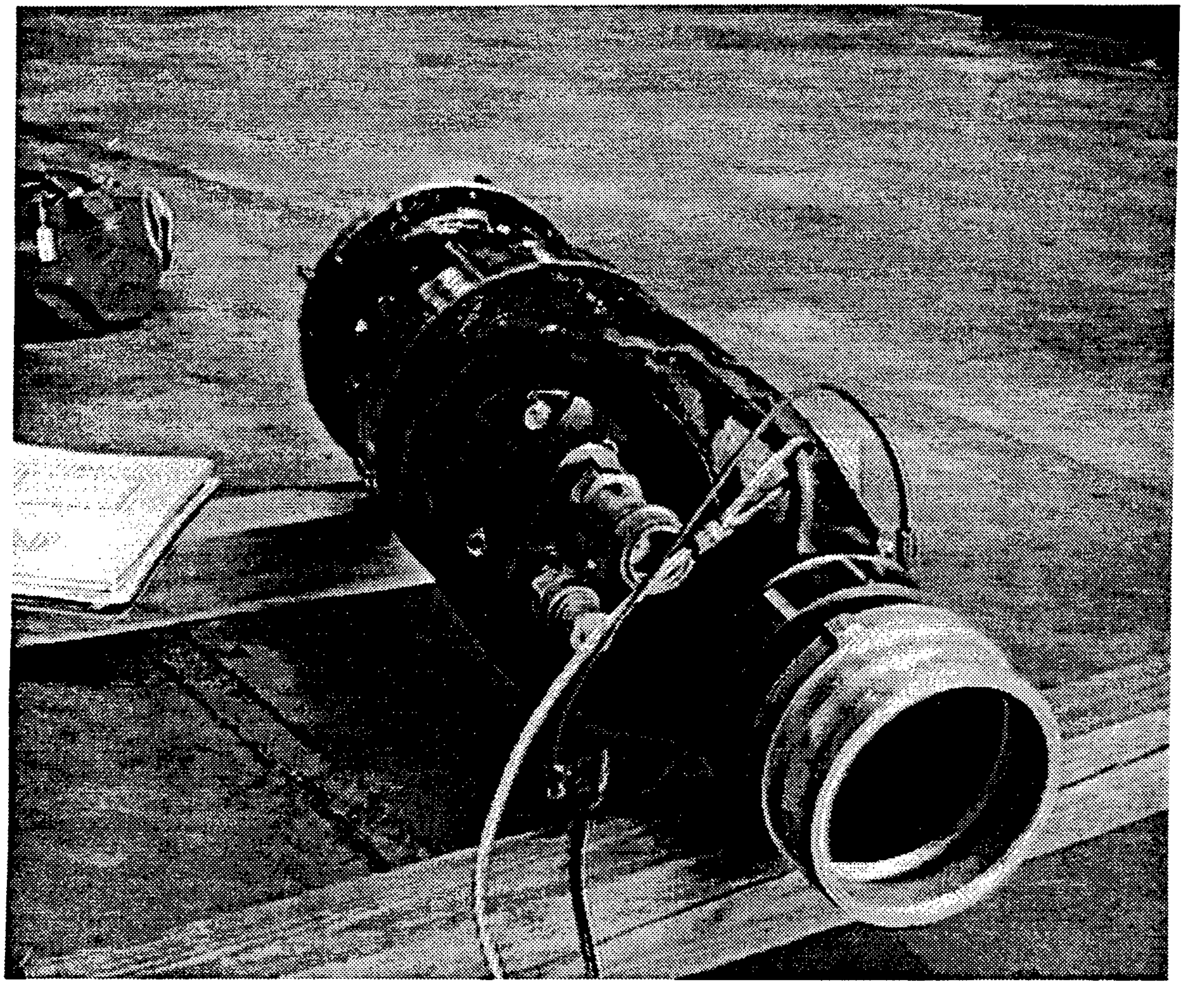


Fig. 12. Thune Eureka pump showing the penetration of the hydraulic motor with the side of the motor housing.

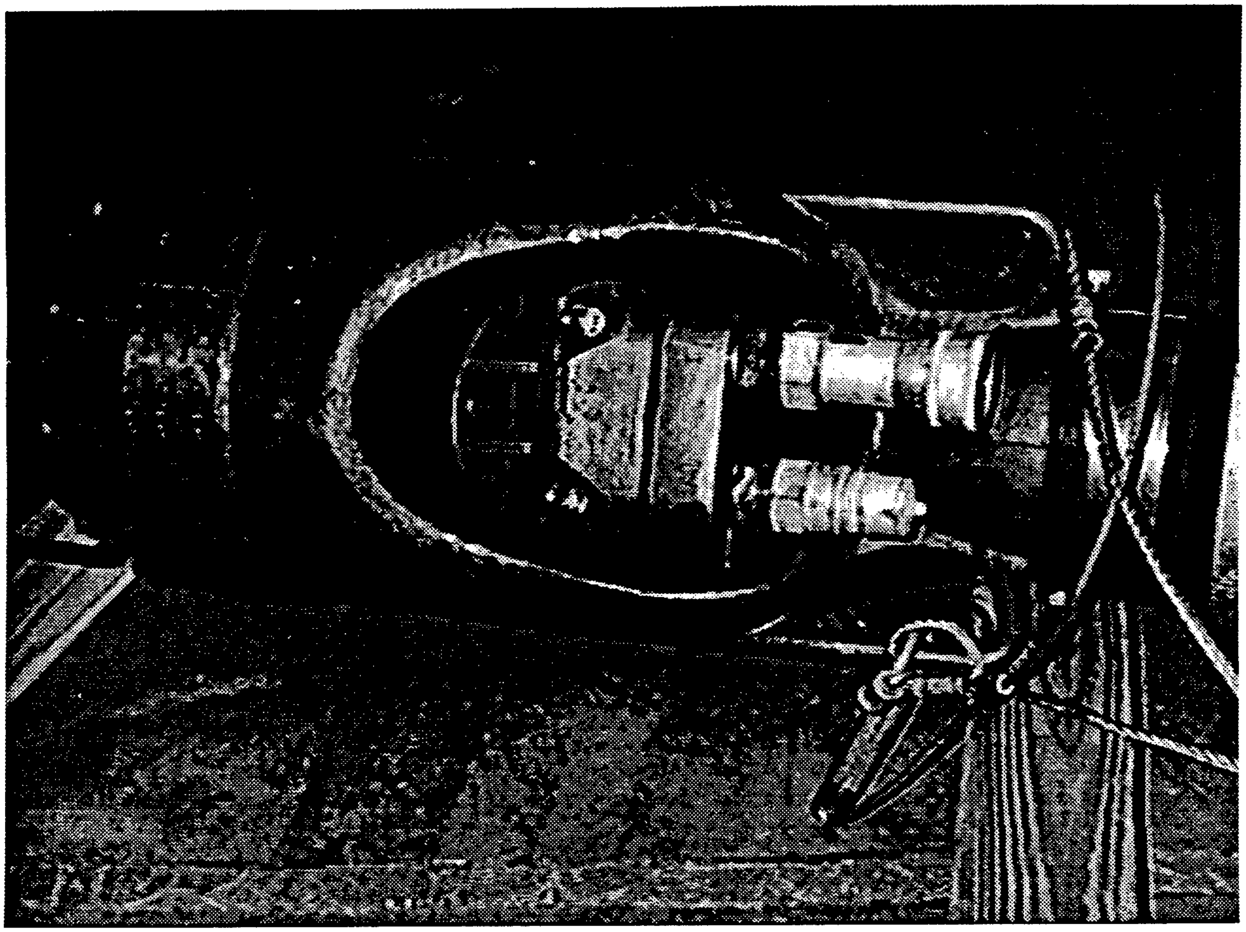


Fig. 13. Thune Eureka pump showing the penetration of the hydraulic motor with the side of the motor housing (alternate view).

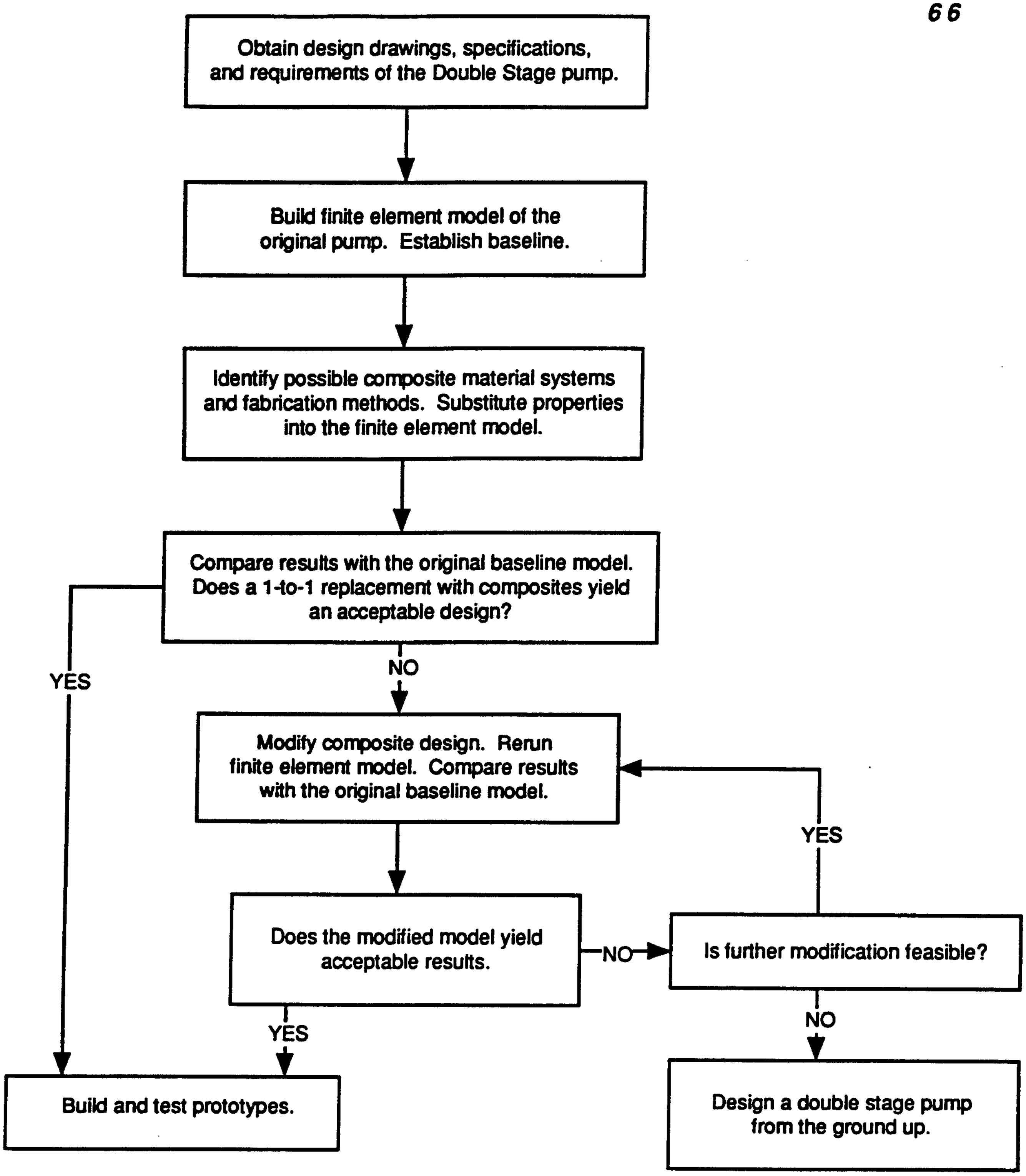


Fig. 14. Flow diagram of the approach for reducing the weight of the Double Stage pump.

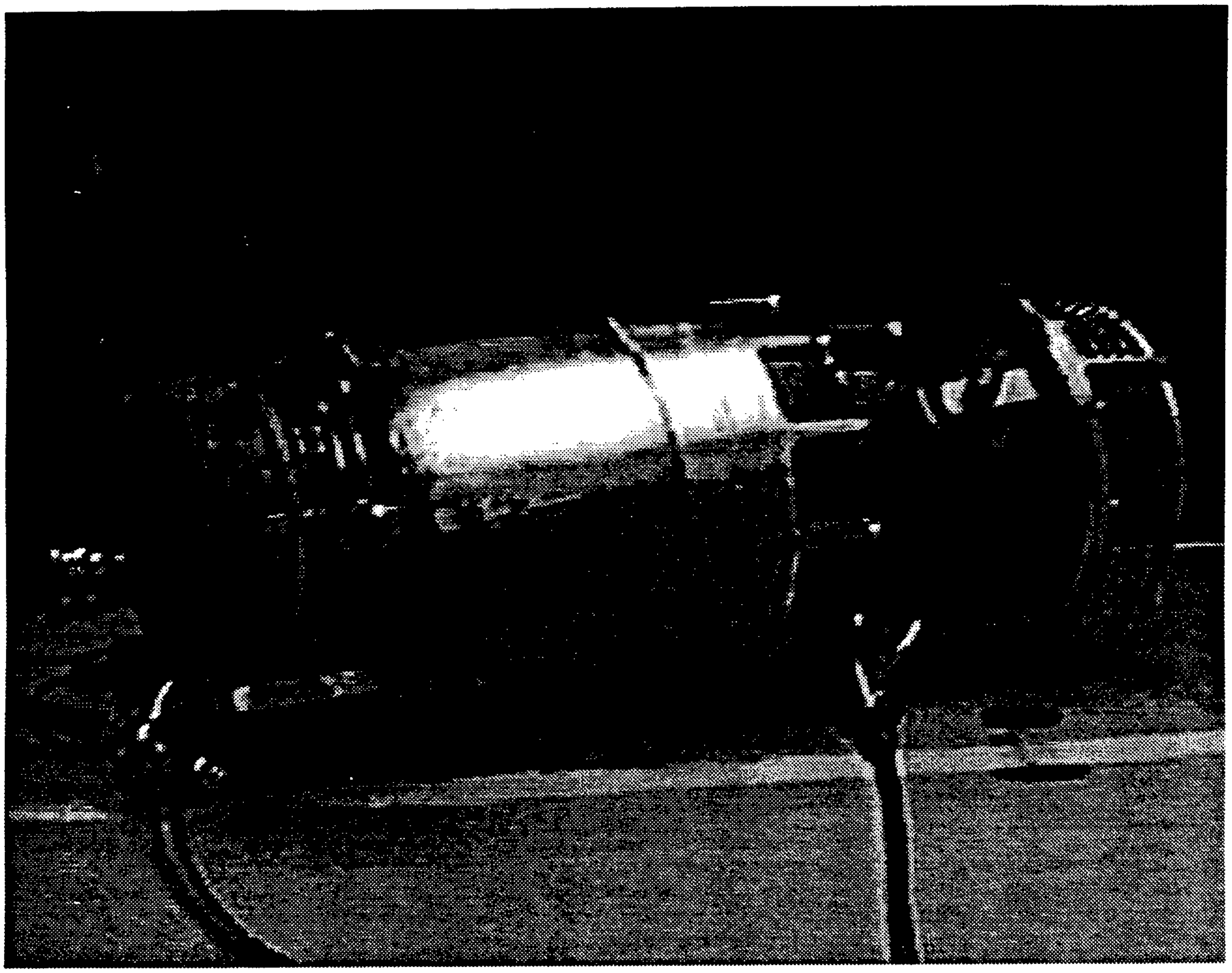


Fig. 15. CCN-150 pump.

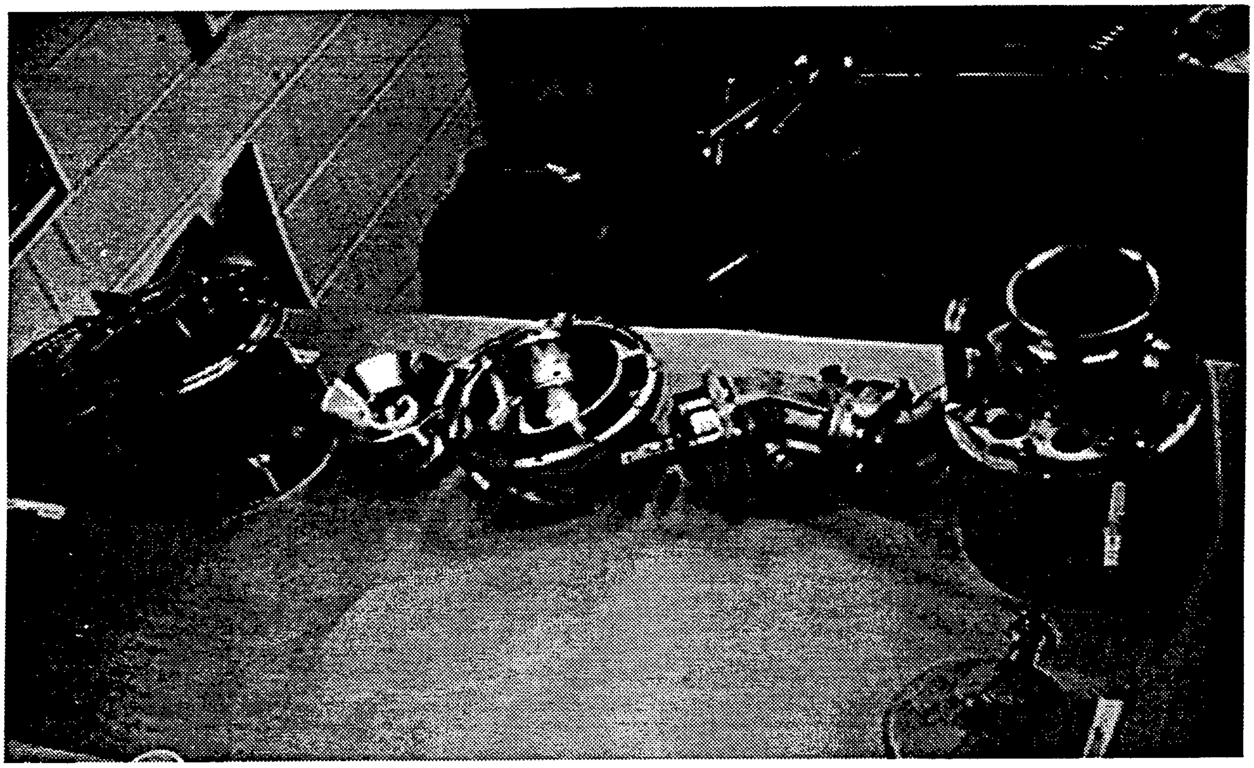


Fig. 16. Disassembled CCN-150.

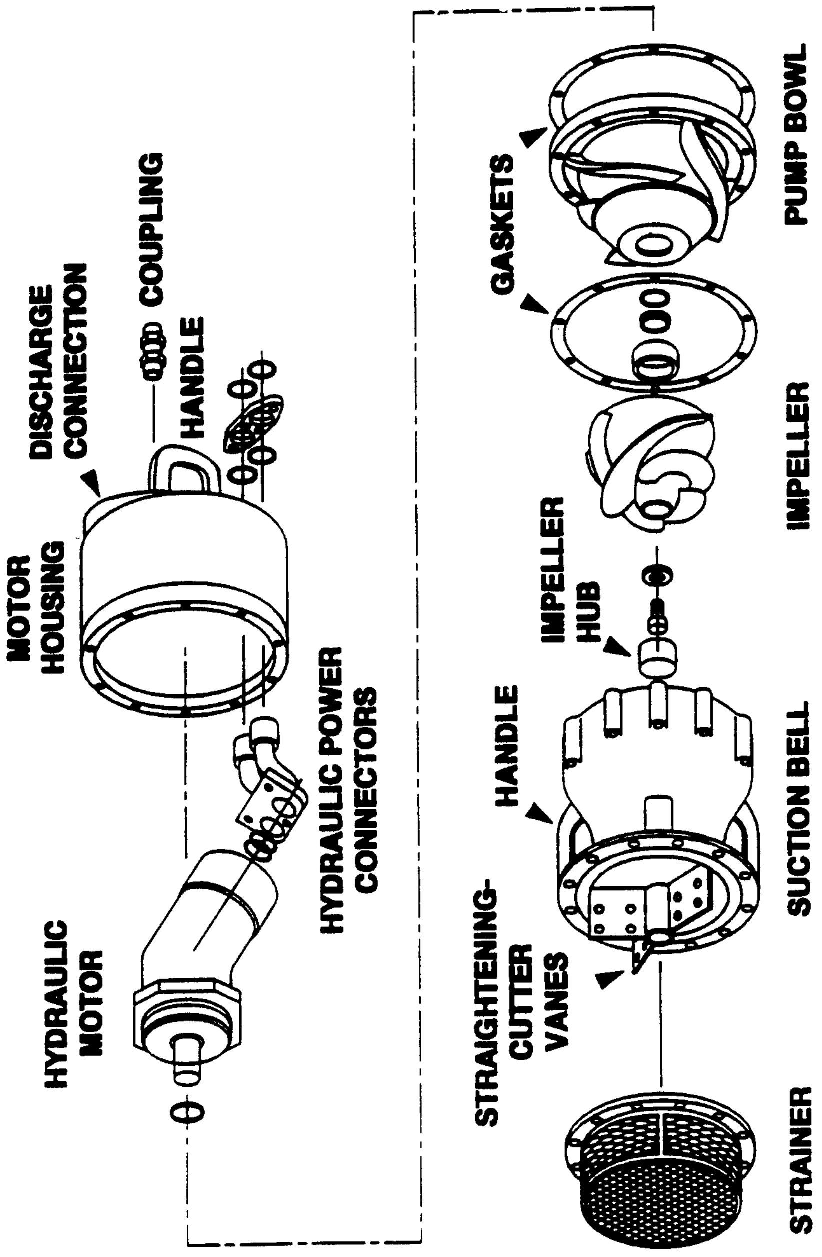


Fig. 17. Assembly drawing of the Thune Eureka.

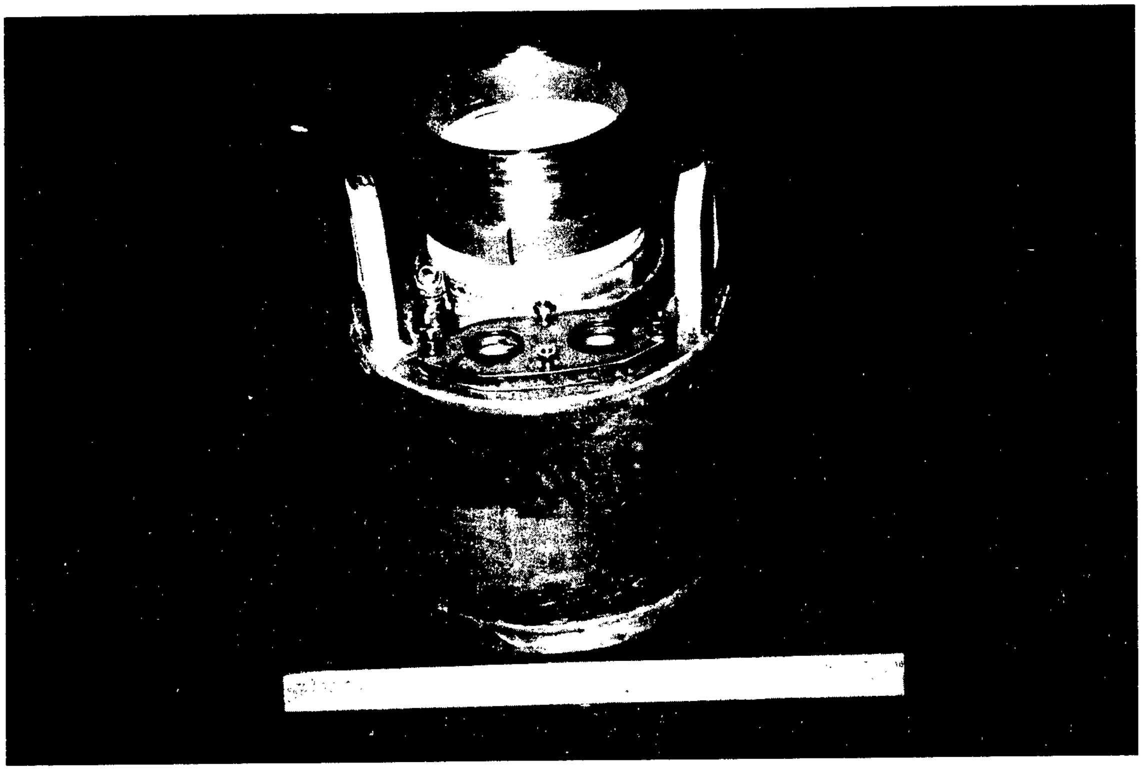


Fig. 18. CCN-150 motor housing.

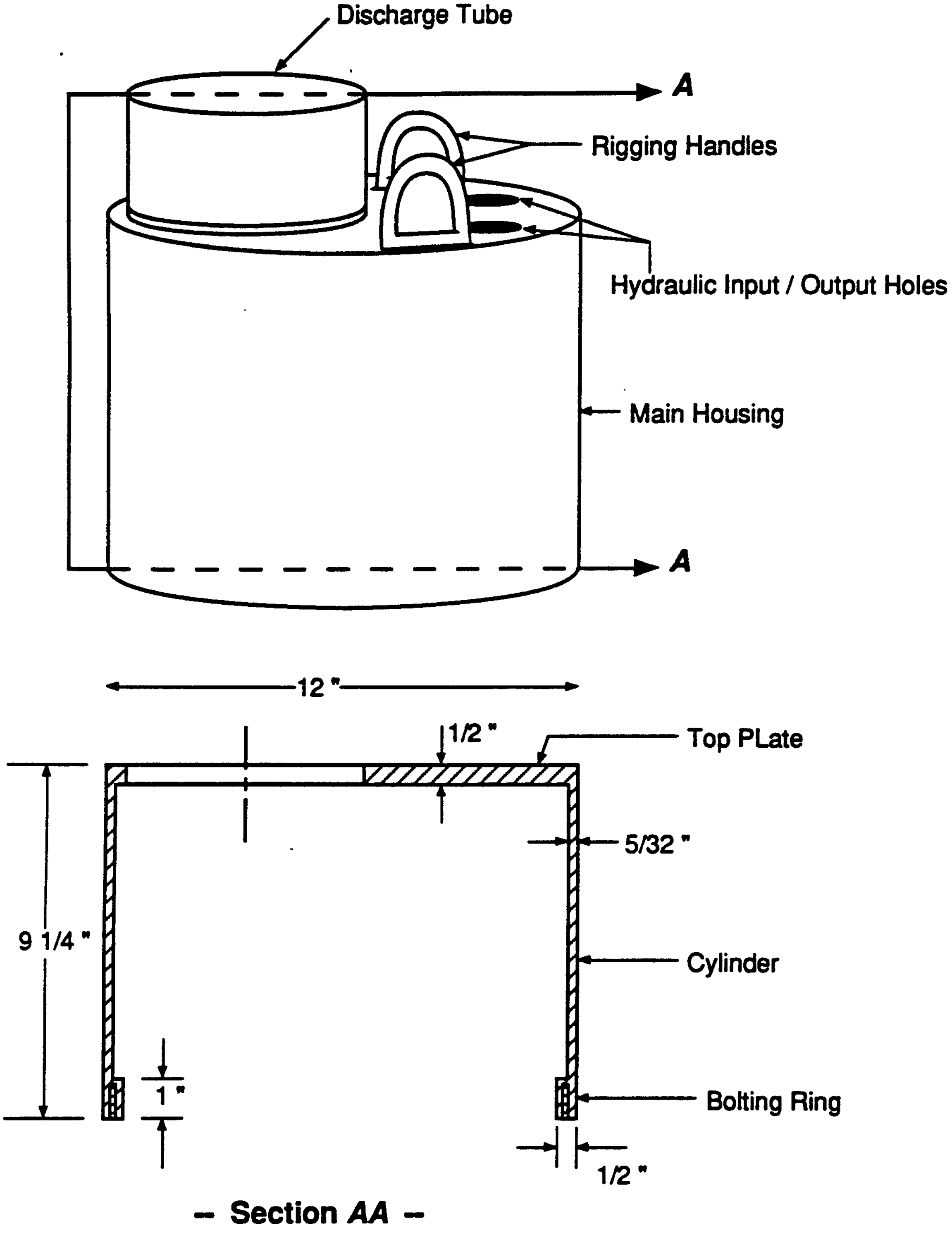


Fig. 19. CCN-150 motor housing schematic.

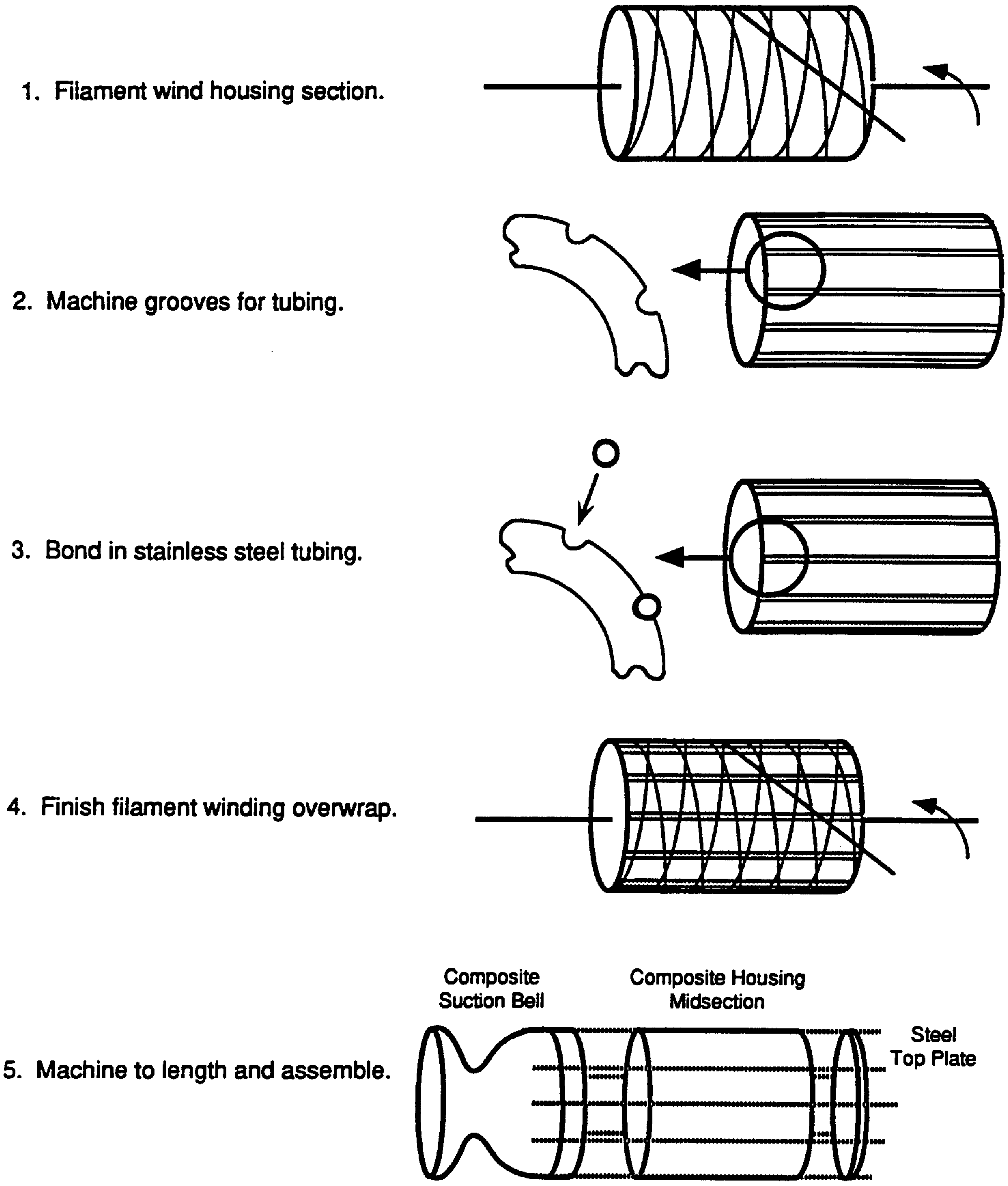


Fig. 20 Schematic of a plan for fabricating a composite CCN-150 motor housing.

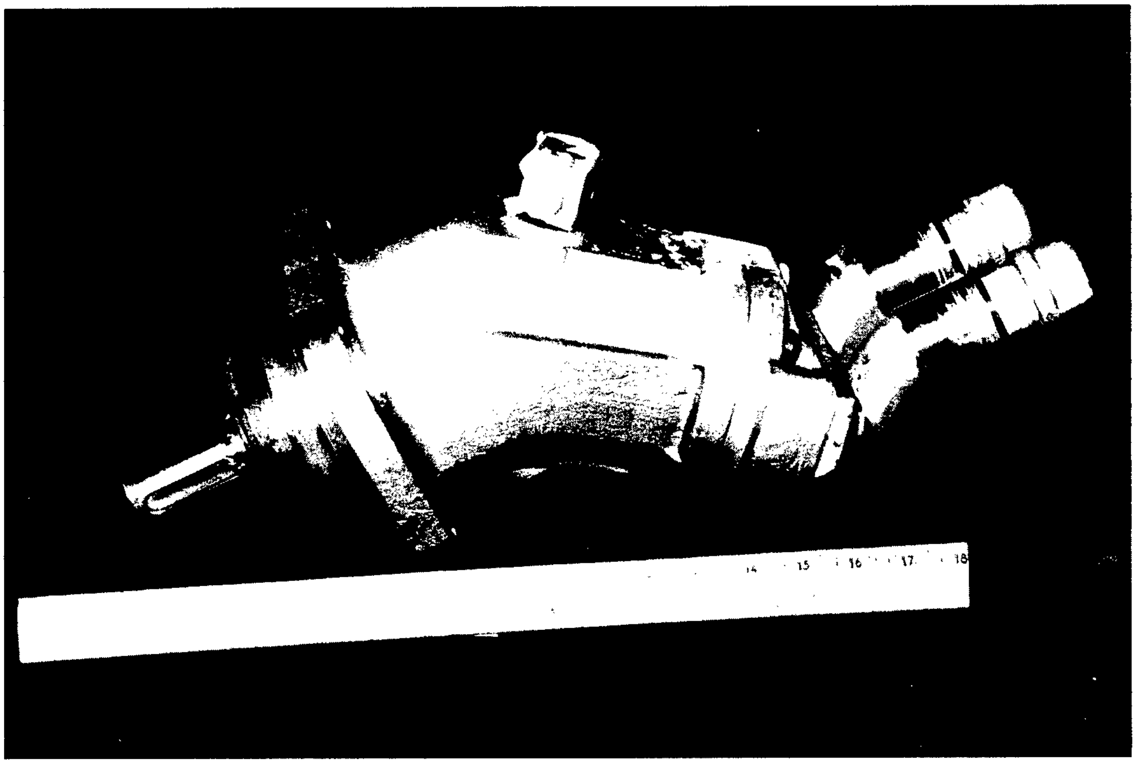


Fig. 21. CCN-150 hydraulic motor.

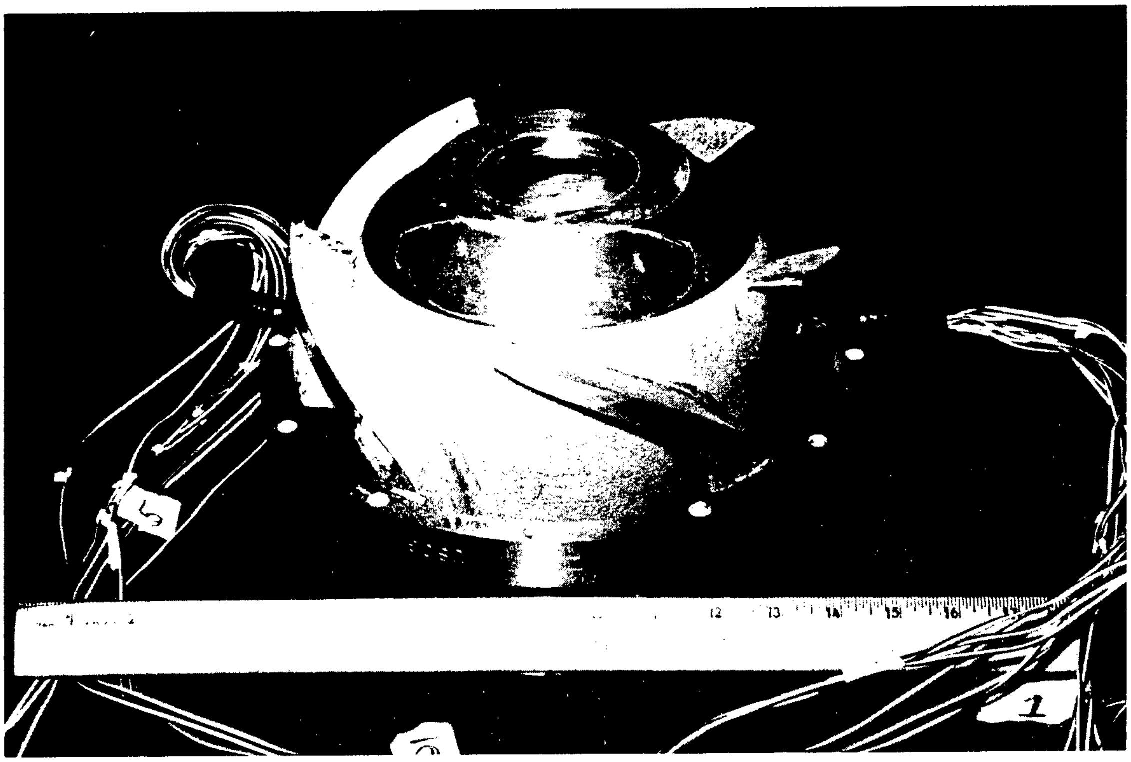


Fig. 22. CCN-150 pump bowl.

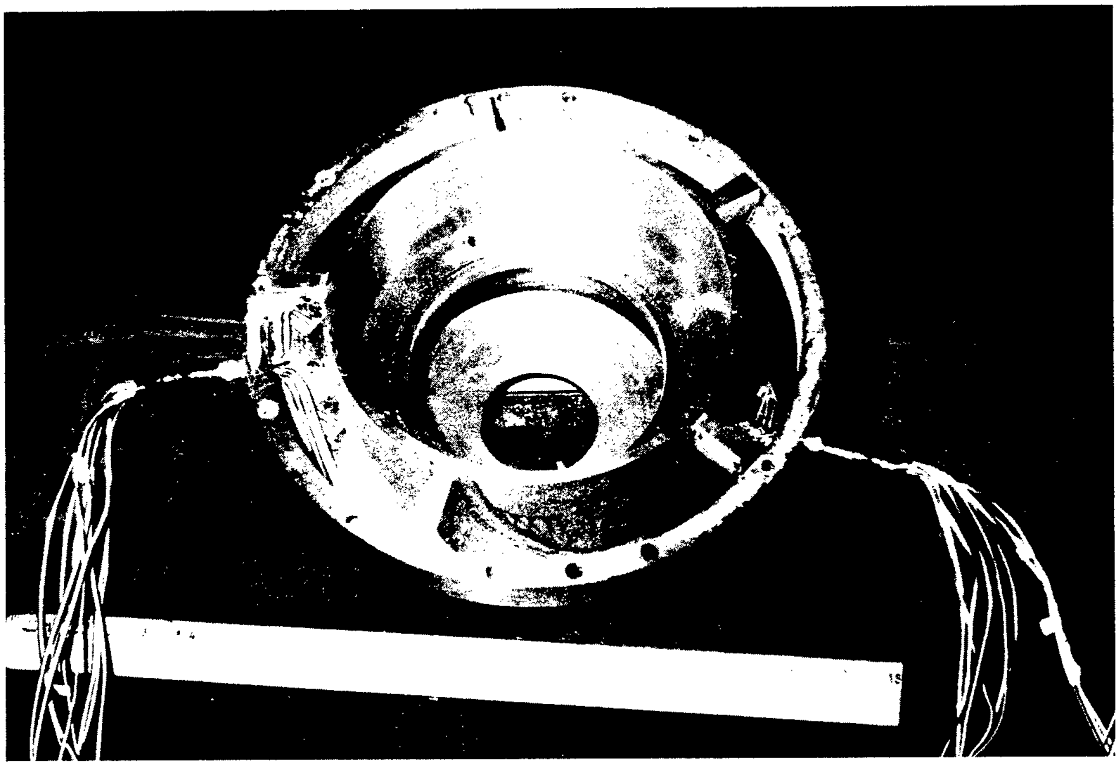
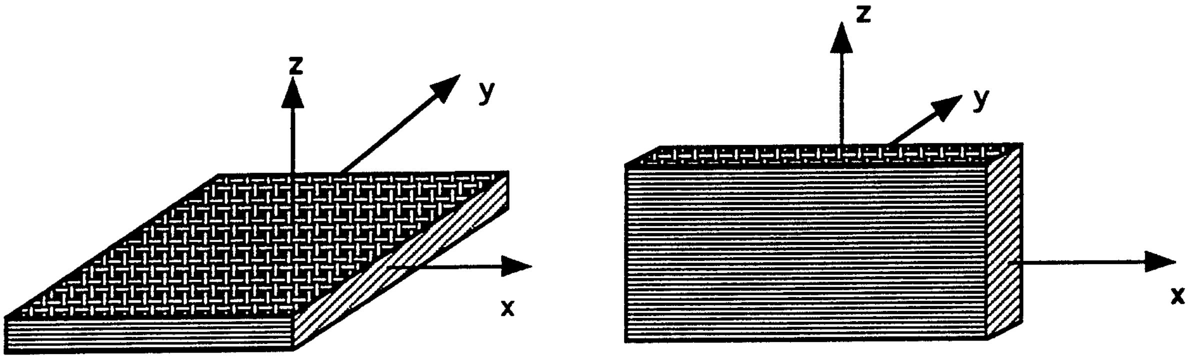


Fig. 23. CCN-150 pump bowl (downstream view).



Thin panel to measure inplane properties.

Thick "slice" to measure interlaminar properties.

Fig. 24. Schematic of the two type of panels needed to obtain the three-dimensional properties of Sims' materials.

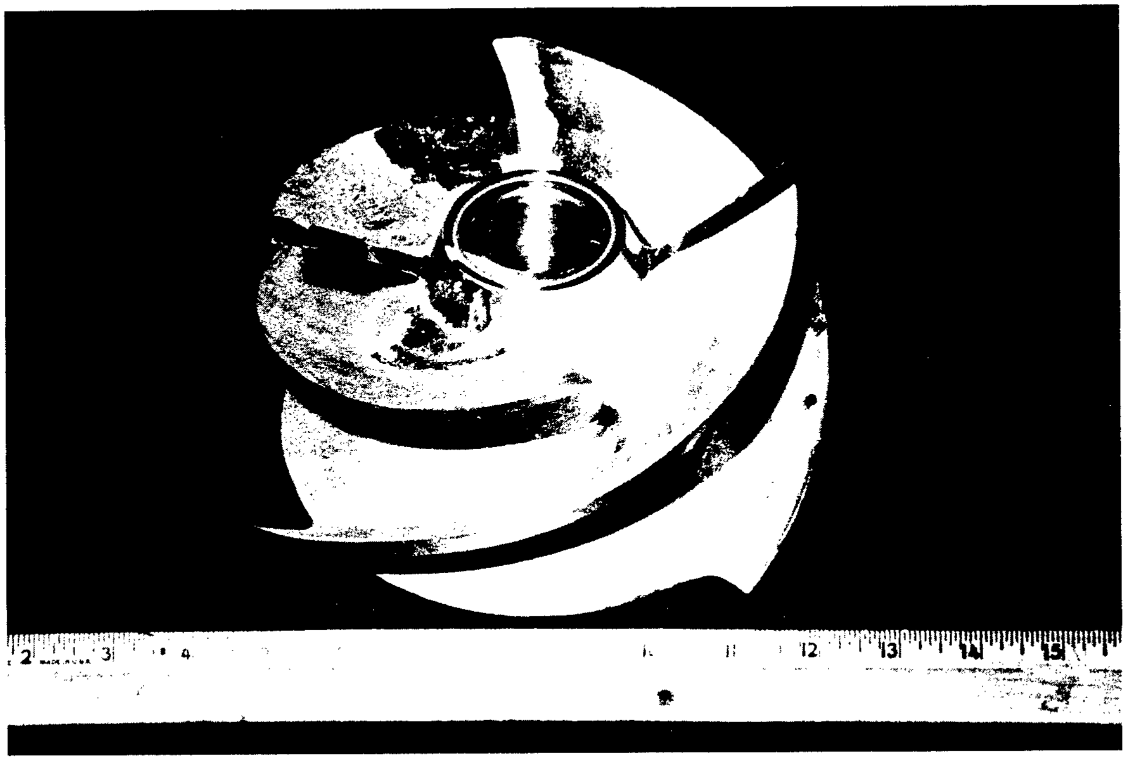


Fig. 25. CCN-150 impeller.

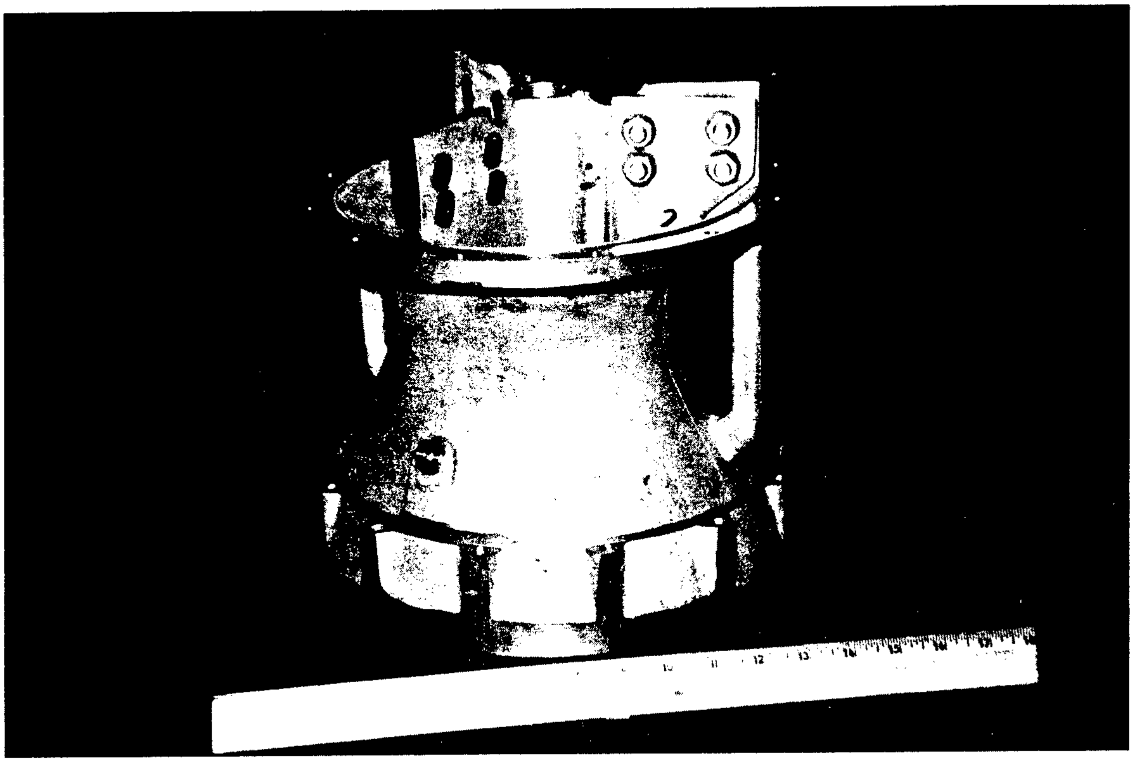


Fig. 26. CCN-150 suction bell.

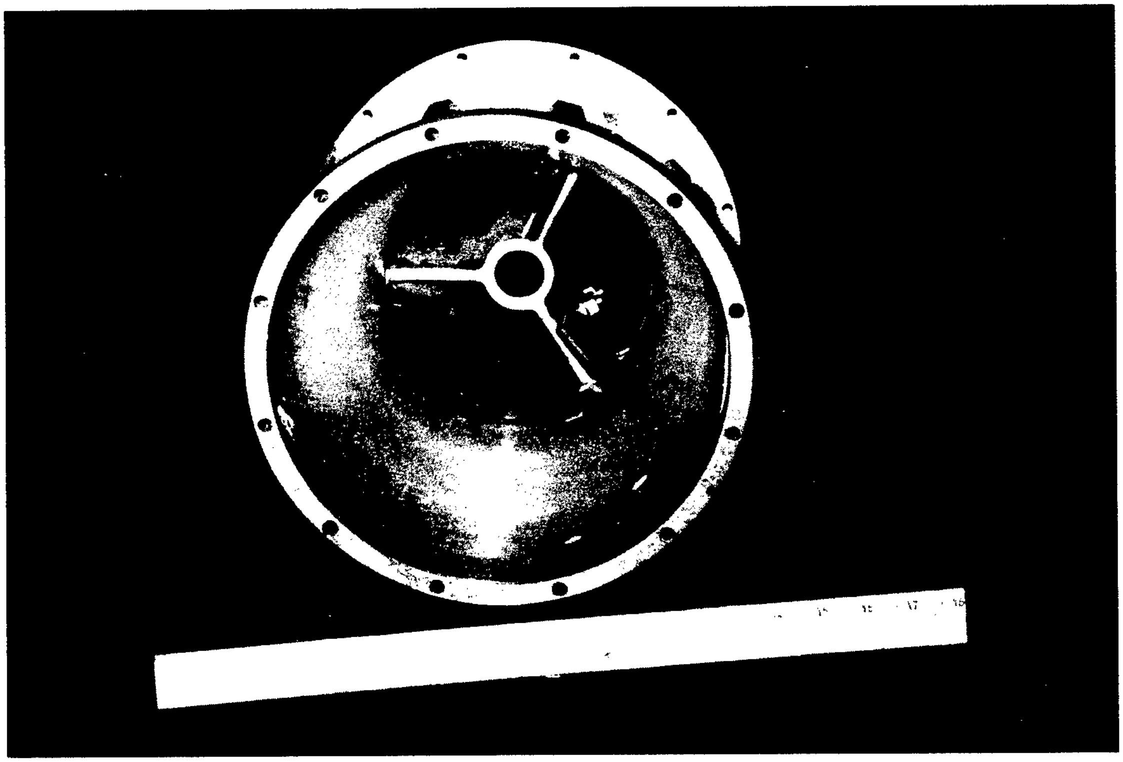


Fig. 27. CCN-150 suction bell (alternate view).

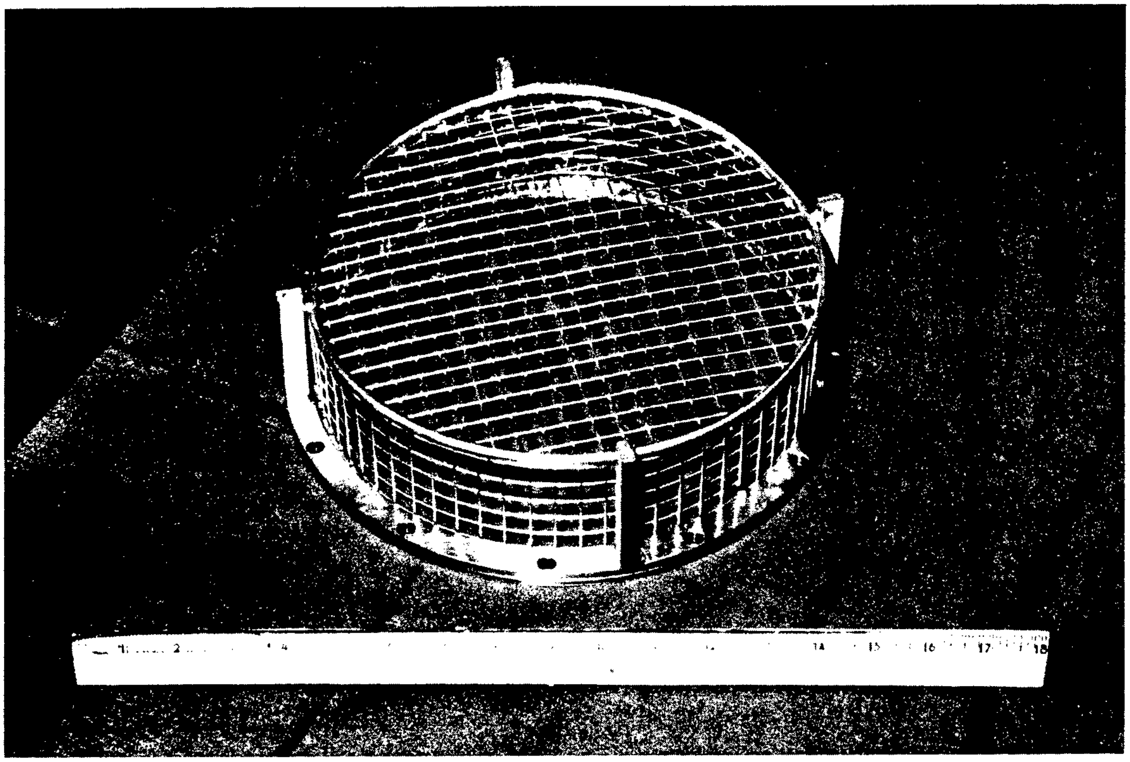


Fig. 28. CCN-150 strainer.

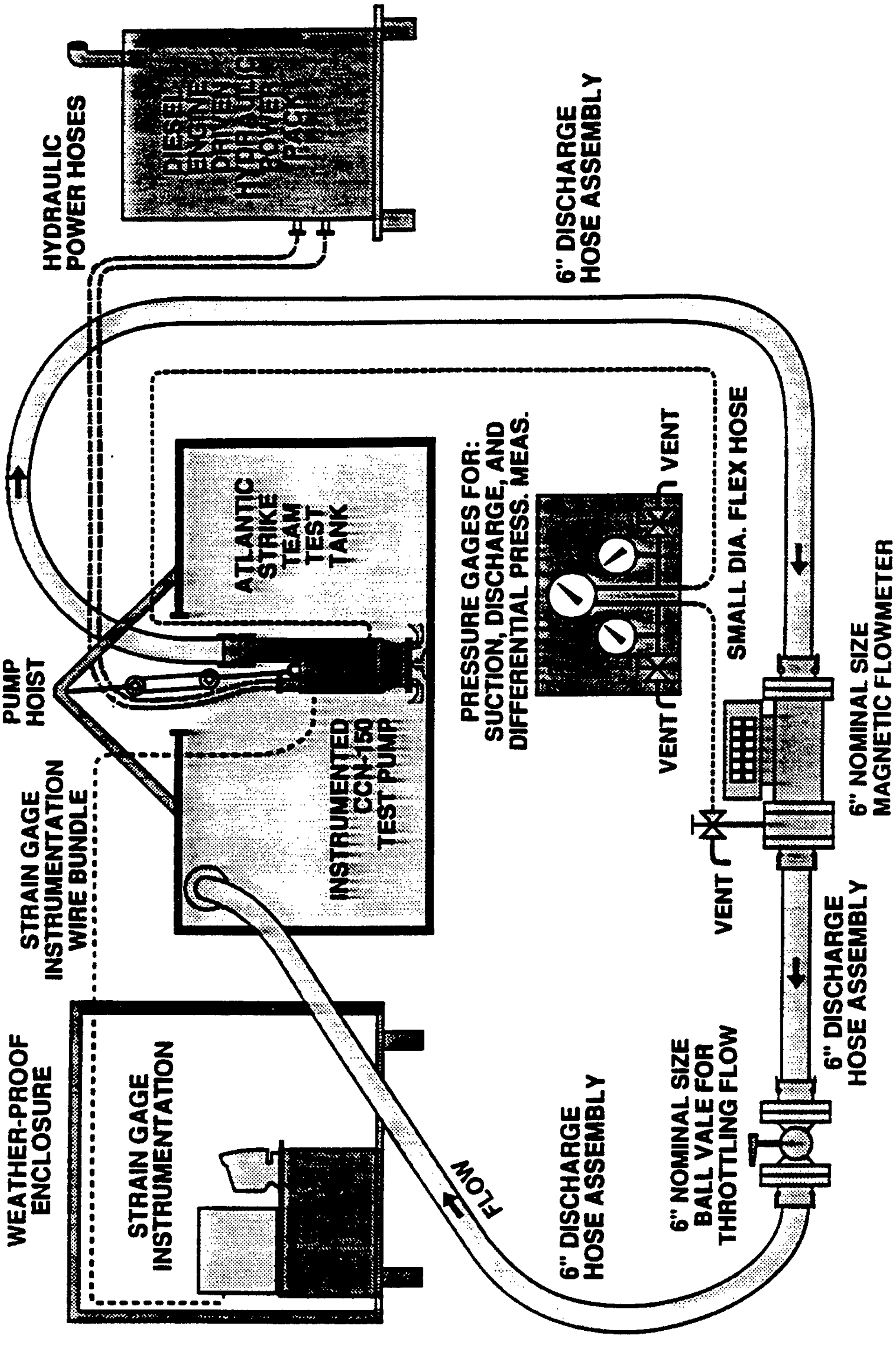
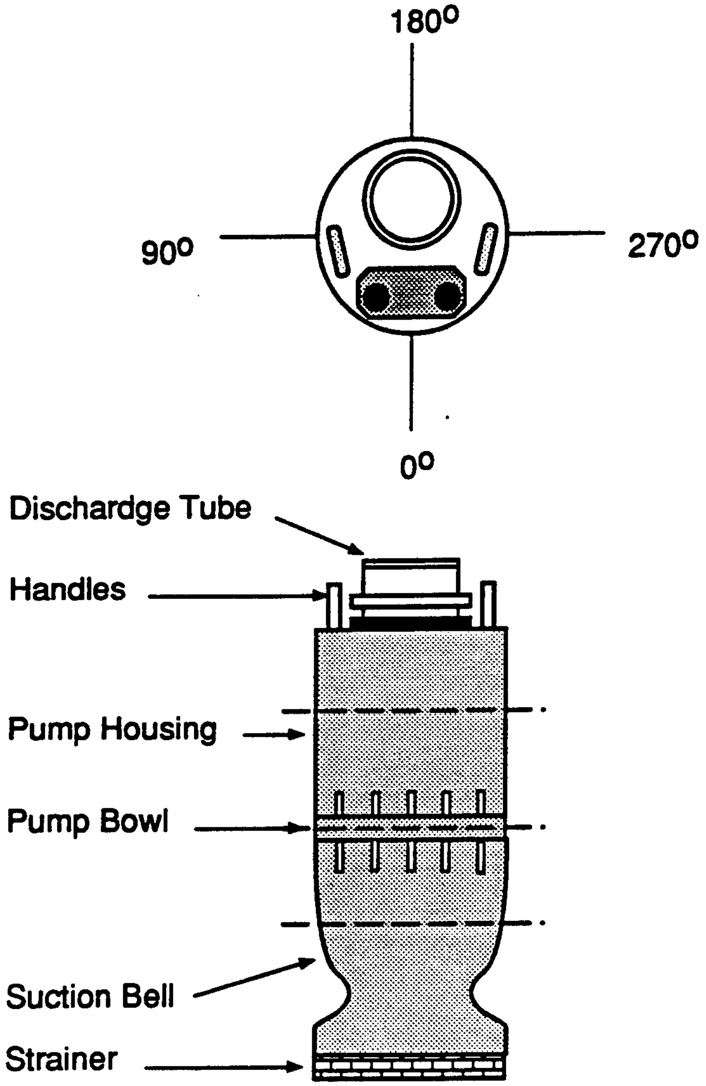


Fig. 29. Schematic of the proposed test loop for evaluating the performance of the CCN-150.



— — — Dotted line marks the approximate location of strain gages along the length of the pump. At each of these locations, a stain gage rosette was applied at 0°, 90°, 180°, and 270°.

Fig. 30. **Schematic showing relative locations of strain gage attached to the CCN-150.**

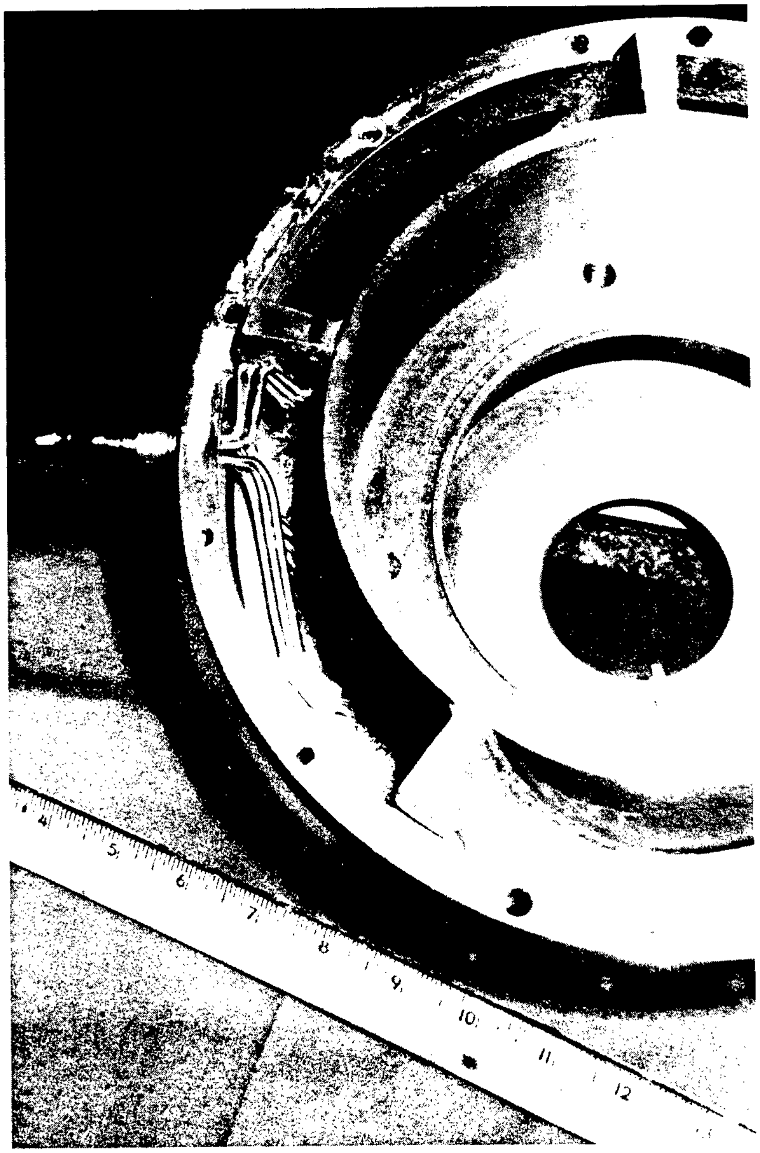


Fig. 31. Strain gages on the vane of the pump bowl.

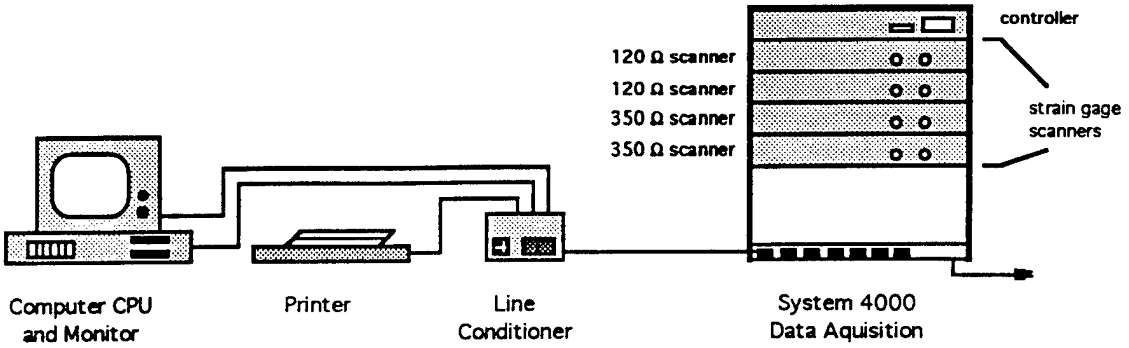


Fig. 32. Schematic of the data acquisition equipment.