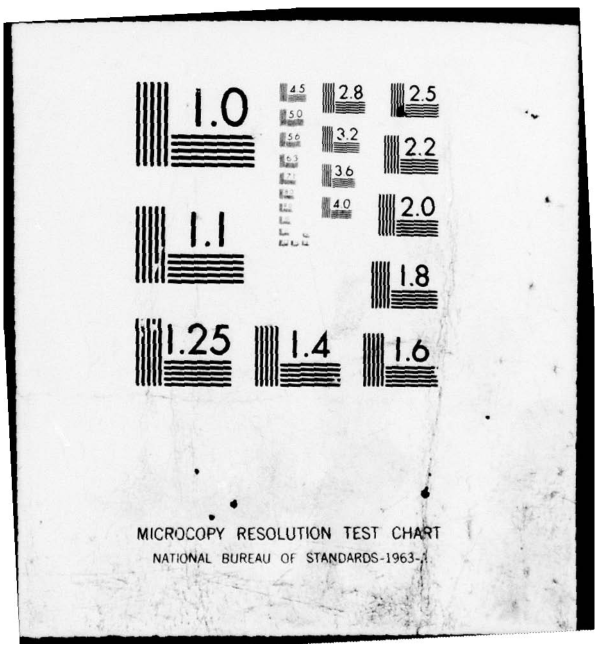
AD-A073 905 DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 20/4
SHIPBOARD, WATER AND OIL, HIGH PERFORMANCE FLOWMETER NEEDS IN T--ETC(U)
AUG 79 J G DIMMICK, H K WHITESEL

UNCLASSIFIED DTNSRDC/PAS-78-27 NL

| OF |

AD
A073905

END
DATE
FILMED
10-79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL

12

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

DTNSRDC PAS-78-27

AD A073905

SHIPBOARD, WATER AND OIL, HIGH PERFORMANCE FLOWMETER NEEDS IN THE UNITED STATES NAVY

Joseph G. Dimmick
Henry K. Whitesel

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED.

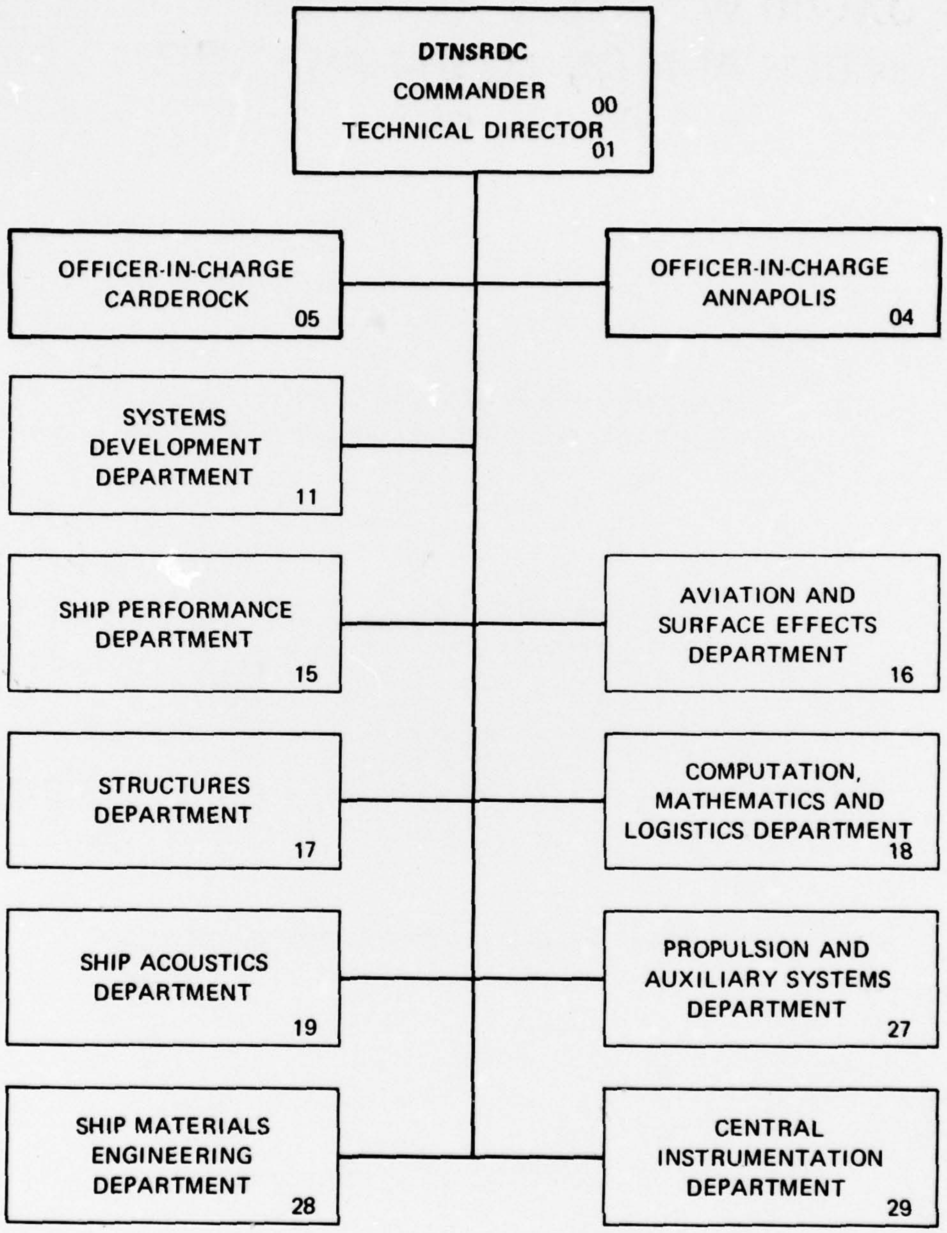
PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT

RESEARCH AND DEVELOPMENT REPORT

August 1979 DTNSRDC PAS-78-27

SHIPBOARD, WATER AND OIL, HIGH PERFORMANCE FLOWMETER NEEDS IN THE UNITED STATES NAVY

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



NDW-DTNSRDC 3960/43b (Rev. 3-78)
GPO 928 740

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: DTNSRDC/PAS-78-27
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): SHIPBOARD, WATER AND OIL, HIGH PERFORMANCE FLOWMETER NEEDS IN THE UNITED STATES NAVY
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): Joseph G. Dimmick and Henry K. Whitesel

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS: David W. Taylor Naval Ship R&D Center, Annapolis, Maryland 21402

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NAVSEA Project F43-433; Task Area 433-302; Work Unit 1-2730-100

11. CONTROLLING OFFICE NAME AND ADDRESS: David W. Taylor Naval Ship R&D Center, Bethesda, Maryland 20084

12. REPORT DATE: August 1979

13. NUMBER OF PAGES: 29

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flowmeters
Shipboard applications
Performance requirements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of a study of present and future Navy shipboard flowmeter needs and applications are presented. Required and desirable performance characteristics are compared with existing Military Specifications, commercially available equipment, and the state of the art. Existing and potential applications are described. Applications described in this report are restricted to water and fuel oils except for a brief discussion of the need

(Continue on reverse page)

Item 20 (Continued)

for two-phase and steam flowmeters. It is concluded that a universal or general-purpose flowmeter is highly desirable. It should measure mass flow rates with an accuracy of ±1 percent over the entire range of flow rates encountered on Navy ships. It should be compatible with all pipe sizes, pipe materials, fluids, temperatures, pressures, and flowstream characteristics. It should be obstructionless, reliable, repeatable, easily calibrated, and easily maintained. It should have output signals linear with flow rate and be compatible with automatic control systems, remote gages, alarms, loggers, and computer-based monitoring systems. Lightweight, small volume, low cost, easy installation, and low power consumption are highly desirable.

Unfortunately, there is no flowmeter or family of flowmeters available which meet the above requirements. The most likely candidate is an acoustic sensor to measure both flow velocity and fluid density from which mass flow rate could be computed. The most serious unknown is the capability of acoustic techniques involving the transmission of sound through low-density fluids such as steam.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

^{o}C	Degree Celsius
^{o}F	Degree Fahrenheit
FS	Full scale
cm	Centimeter
cm/sec	Centimeter per second
ft/sec	Foot per second
gpm	Gallons per minute
kg/cm^2	Kilogram per centimeter squared
lpm	Liter per minute
max	Maximum
min	Minimum
kPa	Kilopascal
in.	Inch
m^2/sec	Meter squared per second
ft^2/sec	Foot squared per second

ABSTRACT

The results of a study of present and future Navy shipboard flowmeter needs and applications are presented. Required and desirable performance characteristics are compared with existing Military Specifications, commercially available equipment, and the state of the art. Existing and potential applications are described. Applications described in this report are restricted to water and fuel oils except for a brief discussion of the need for two-phase and steam flowmeters. It is concluded that a universal or general-purpose flowmeter is highly desirable. It should measure mass flow rates with an accuracy of ±1 percent over the entire range of flow rates encountered on Navy ships. It should be compatible with all pipe sizes, pipe materials, fluids, temperatures, pressures, and flowstream characteristics. It should be obstructionless, reliable, repeatable, easily calibrated, and easily maintained. It should have output signals linear with flow rate and be compatible with automatic control systems, remote gages, alarms, loggers, and computer-based monitoring systems. Lightweight, small volume, low cost, easy installation, and low power consumption are highly desirable.

Unfortunately, there is no flowmeter or family of flowmeters available which meet the above requirements. The most likely candidate is an acoustic sensor to measure both flow velocity and fluid density from which mass flow rate could be computed. The most serious unknown is the capability of acoustic techniques involving the transmission of sound through low-density fluids such as steam.

ADMINISTRATIVE INFORMATION

This report completes one milestone of the Shipboard Machinery and Control-Monitoring and Automation project, Task C, funded under NAVSEA project F43-433, Task Area 433-302, Work Unit 1-2730-100.

INTRODUCTION

OBJECTIVE

The overall objective program of the shipboard machinery and control monitoring and automation is to improve the continuity of ship control and machinery operation while permitting more effective use of available manning through increased automation, better maintenance, and improved shipboard instrumentation. One aspect of the program is the definition and development of universal or general-purpose shipboard flowmeters. The objectives of this report are to present the results of a study of Navy flowmeter applications and needs and to identify areas in which improvements are required or desirable. Within the scope of this effort, flowmeter applications described are generally restricted to water and fuel oils, except for a brief discussion of two-phase and steam flowmeter needs.

BACKGROUND

The operation of modern naval vessels requires the transfer, storage, and use of more than 50 different liquids and gases. To control the flows of fluids, the flows or some effects of the flows must be measured. Manning reduction and increasing levels of automation tend to increase the need for direct measurement of fluid flow. In some cases, improved flowmeter performance characteristics are required. As the state of the art advances, new flowmeters which have potential Navy applications become available from commercial sources. These must be considered with respect to realistic requirements to ensure that specified performance characteristics represent actual application requirements rather than merely the best available at the current state of the art. Flowmeter requirements which cannot be met by currently available instrumentation are possible subjects for research and development programs.

APPROACH

This report presents: (1) a review of present and potential flowmeter applications in the Navy in terms of required performance characteristics, (2) a survey of the flowmeter measurement concepts, and (3) an examination of Navy flowmeter needs. It should be noted that the decision to use a flowmeter in some particular application depends to a very large extent on the cost and maintainability of the flowmeter. The information gained by use of the flowmeter must be of sufficient value to warrant the cost of purchase, installation, and maintenance. Thus, Navy flowmeter needs and future applications depend strongly on flowmeter characteristics. The information presented here is intended to aid the allocation of research and development funds required to meet the Navy's flowmeter needs and to provide an overview of possible Navy flowmeter applications for manufacturers who are potential suppliers.

FLOWMETER CONCEPTS

In comparing flowmeters, the many flowmeter choices available may be classified by basic concepts and operating principles.

IDEAL FLOWMETER

Some of the characteristics that are desirable in a flowmeter are listed below:

1. Output signal is linear with flow rate.
2. Capable of measuring mass flow and/or volume flow.
3. Obstructionless flow path (pressure drop the same as for an equal length of pipe).
4. Can be used at all fluid temperatures encountered on ships.
5. Can be used in all pipe sizes encountered as ships.
6. Not affected by upstream and downstream conditions (very important on submarines).
7. Wide dynamic range (at least 100:1)
8. Low initial cost.
9. Reliable and easily maintained.
10. Accurate and repeatable.
11. Can meter all fluids used in Navy.

The many types of flowmeters available were developed because each type has some inherent shortcoming or special advantage. Furthermore, desirable characteristics are not necessarily requirements. These must be quantified to avoid making specifications too stringent and to avoid increasing costs. It is possible to select a variety of meters to satisfy most shipboard flow measurement needs, but with the accompanying penalties of a wide variety of spare parts, maintenance, and training requirements.

MEASUREMENT CONCEPTS

Measurements of fluid flow may be divided into two general categories: volumetric flow measurements and mass flow measurements. For either volumetric or mass flow measurements, the quantity of interest may be the flow rate or the total quantity transferred over some time period. While it may appear relatively simple to convert between volumetric and mass flow, this conversion depends on knowing the fluid density during the volumetric or mass flow measurement. The fluid density depends on the pressure, temperature, and composition of the fluid. It can vary over several orders of magnitude throughout some flow systems.

Flowmeters may be classified into three categories, depending on the fluid stream characteristic that influences the sensing element. First are volumetric meters which sense the volume flow rate or fluid velocity. (If the "average" velocity is sensed, volumetric flow rate can be computed as the product of the average velocity and the appropriate cross-section area.) Second are velocity-pressure meters based on Bernoulli's law relating the kinetic energy and pressure drop. The fluid density must be known to determine either volume or mass flow rate. Third are mass flowmeters in which the sensing element responds to the stream momentum.

These classifications of the different types of flowmeters are not mutually exclusive, as some particular flowmeters fall in more than one category. The classification helps to illustrate some operation characteristics of different flowmeters. For example, velocity-pressure meters generally have lower dynamic range capability because the measured parameter, pressure, is proportional to the square of the velocity. For more complete discussions of measurement concepts see references 1-10.*

Volumetric or Fluid Velocity Flowmeters

The sensing element responds to the volume flow rate or velocity of the fluid stream.

1. Positive Displacement Flowmeters. The stream is divided into discrete known volumes and counted as it passes through the meter. These are mechanical meters with one or more moving parts in the fluid stream that physically separate the fluid into volumetric increments. Examples are nutating disk, sliding vane, and oscillating piston flowmeters.

*A complete listing of references can be found on page 23.

2. <u>Velocity Flowmeters</u>. The sensing element responds to the velocity of the fluid stream. The volumetric flow rate is computed by multiplying the sensed average velocity with the cross-sectional area of the conduit. Sensing elements are classified into three types: "point-velocity" sensors measure flow velocity at a single point or volume which is small relative to the pipe size; the average velocity is computed from a knowledge of the flow distribution and the measured point velocity. Examples of "point-velocity" flowmeters are the acoustic and laser doppler flowmeters. "Line-velocity" sensors measure flow velocity along a line, usually across the pipe diameter; the average velocity is then computed from a knowledge of the flow distribution and the measured line velocity. An example of a "line-velocity" flowmeter is the acoustic transit time flowmeter. "Volume-velocity" sensors measure flow velocity over the entire volume of the conduit and usually require no "a priori" knowledge and are usually independent of the flow distribution. Examples of "volume-velocity" flow sensors are the turbine and electromagnetic flowmeter.

3. <u>Time-of-flight or Tracer Flowmeters</u>. The sensing element determines the time interval required for the fluid flow to carry a "tagged" volume of fluid a specified distance downstream. Time-of-flight flowmeters are a special kind of velocity flowmeters; they require estimations or measurements of the amount of mixing that occurs within the fluid during flow between the tagging location and the detection location. Tagging schemes may involve seeding the fluid with a tracer material or remotely identifying (magnetically, for example) a fluid volume. Examples of time-of-flight flowmeters are transit-time nuclear magnetic resonance (NMR) flowmeters and acoustic correlation flowmeters.

4. <u>Velocity Pressure Flowmeters</u>. The sensing element responds to the kinetic energy of the stream, therefore the signal is, in general, proportional to the product of the flowstream density and the square of the velocity.

5. <u>Head Flowmeters</u>. The flow path is restricted to cause a change in velocity creating a measurable differential pressure or "pressure-head" (Bernoulli's Law), proportional to the fluid velocity squared. Fluid density must be known to determine either volume or mass flow rate. Examples of head flowmeters are: the pitot tube, venturi, orifice, and flow nozzle.

6. Force or Drag Flowmeters. The force or drag on a probe configuration in the fluid stream is directly proportional to the kinetic energy of the stream; hence, the density times the velocity squared. Examples are: target and drag flowmeters.

7. Variable Area Flowmeters. The area through which the stream passes is varied (usually by changing pipe diameter) to maintain a constant pressure differential across the restriction. The flow rate is directly proportional to the area. One example is a Rotameter® (a tapered tube and float mounted vertically).

8. Weirs. Apertures in the top of a dam or across an open channel or in the side of an open tank or storage vessel. The volumetric flow rate is proportional to a power of the head as measured from the level of the still water to the bottom of the weir. Weirs are often field-made; one example of Navy use is a slotted weir pipe used to measure the brine overflow rate in the Model "S" distilling plant.

Mass Flowmeters

The reaction of the sensing element to the fluid stream is nominally proportional to the mass rate of flow. Two common categories of mass flowmeter are:

1. Angular Momentum Flowmeters. An angular momentum is introduced into the fluid stream and the corresponding torque is measured to provide the mass flow rate. If the torque is constant, the mass flow rate is inversely proportional to the angular velocity. If the angular speed is held constant the torque is directly proportional to the mass flow rate. Examples are: twin turbine, axial-flow mass flowmeter, and gyroscopic mass flowmeters.

2. Inferential Mass Flowmeter. This type consists of a density transducer and a volumetric flowmeter combined to produce an output proportional to mass flow rate.

® Fisher and Porter Company.

FLOWSTREAM CHARACTERISTICS

The physical and dynamic properties of the fluid flowstream are critical parameters in the performance of flowmeters. Ideally, the flowmeter should respond only to the mass or volume flow rate. However, in practice, the meter output will vary to some extent with fluid temperature, viscosity, density, Reynolds number, flow profile, and whether the flow is a gas, liquid or slurry. The more significant effects are discussed below.

Reynolds Number

The Reynolds number is a dimensionless parameter, for any consistent system of units, defined as the ratio of inertial forces to viscous forces:

$$\frac{\text{Inertial Forces}}{\text{Viscous Forces}} = \frac{VD\rho}{\mu} = R_e$$

where V = flow velocity

D = characteristic diameter or length

ρ = fluid density

μ = absolute viscosity

For large Reynolds numbers ($R_e > 10{,}000$) the flow is generally turbulent, and for small Reynolds numbers ($R_e < 2{,}000$) the flow is laminar. In laminar flow, the velocity distribution across a diameter in a pipe is parabolic with the peak velocity occurring on the center line. In turbulent flow the velocity distribution is nearly uniform along a diameter until very near the wall. There is a transition region generally regarded as occurring between $10{,}000 < R_e < 2{,}000$, where flow may be laminar, turbulent or some combination thereof. For those flowmeters that measure the flow velocity at a point rather than averaging over the enclosed volume the change between turbulent and laminar flow will cause significant change in the meter calibration.

Viscosity

The fluid viscosity is a measure of the fluid's resistance to shear or angular deformation. Thus, the pressure drop across a flowmeter will increase as the fluid viscosity increases. The differential pressure changes due to changes in viscosity will be greater in flowmeters with narrow, complex passages than in ones that are as open as a pipe (example: positive displacement nutating disc meter versus an electromagnetic meter).

Density

The fluid density affects the relationship between volumetric and mass flow rates. For those flowmeters based on Bernoulli's Law (orifice, venturi, and nozzles) the density is a direct factor in the relationship between the measured quantity and the flow rate. For liquids, the possible density change in the flow system due to any cause is of the order of several percent, but, for gases, the density changes may be several hundred percent due to differing temperatures and pressures in the flow system. For two-phase flows, the density changes may be several orders of magnitude.

Temperature

The fluid temperature affects the flowmeter measurement primarily through the temperature dependence of the fluid viscosity and density. Secondary effects are dimensional changes in the flowmeter because of the fluid temperature.

Pressure

The fluid pressure affects a flowmeter performance primarily through density changes, for example, in compressible gases or two-phase flows. Of course, the flowmeter must be able to withstand the fluid pressure. Secondary effects are dimensional changes in the flowmeter because of pressure changes.

Fluid Composition

The fluid being metered may consist of various mixtures of gases, liquids, and solids. Such fluids may damage or clog flowmeter mechanisms.

The lack of a uniform characteristic may affect the meter calibration. For example, an electromagnetic flowmeter will measure gas bubbles in liquid as liquid volume up to the bubble concentration where the fluid conductivity is decreased below about 10 micromhos.

Fluid Corrosiveness

The materials from which the flowmeter is constructed must be compatible with the fluid and piping system that contacts it. This must always include both the metered fluid and pipe cleaning fluids.

NAVY FLOWMETER APPLICATIONS AND NEEDS

This section of the report describes in qualitative and quantitative terms some of the present and future Navy applications and needs for shipboard flowmeters. Current military specifications for shipboard flowmeters are summarized. Both commercially available and developmental flowmeters which have potential Navy shipboard applications are discussed.

The operation of modern naval vessels involves the use, handling, and storage of a variety of liquids and gases. Table 1 illustrates the variety of fluids used in today's Navy. Of the fluids listed, water and fuels dominate by far in the quantity handled and are the primary fluids for which flowmeters are used by the Navy. Many of the lubricants and gases have specialized uses, are not common shipboard items, and are seldom measured with flowmeters. One notable exception is the use of flowmeters to monitor the oxygen and carbon dioxide flows on submarines.

Examples of systems using flowmeters aboard ship are given in Table 2, which emphasizes that fuel, water, and air are the primary fluids that require flow metering onboard ships. These systems are critical elements in the operation and habitability of Navy ships. The management of shipboard fluids is an essential but complex task, involving the propulsion, life support, and mission-related systems of every ship.

Although Table 1 lists almost 50 fluids used in the Navy, resource limitations dictated that this report be concentrated on the predominant fluids - fuel and water. This section describes some current flowmeter applications in fuel and water piping systems and delineates the accuracy, repeatability, capacity, serviceability, fluid compatibility, and flowstream requirements of flowmeters used in those systems.

TABLE 1 - FLUIDS USED IN THE NAVY

Liquids				Gases
Fuels	Water	Lubricants	Miscellaneous	
Diesel Fuel Marine (MIL-F-16884G)	Potable (drinking water quality)	Forced-feed oils (Symbols 2075 to 2250 inclusive)	Amine	Acetylene (C_2H_2)
				Air
JP5 (MIL-T-5624K)	Feedwater (boiler water quality)	Hydraulic oils, noncorrosive (2075H and 2110H)	Lithium Bromide solution	Ammonia (NH_2)
Aviation Gasoline (MIL-G-5572E)			Liquid Refrigerants	Argon (A)
	Condensate	Nonrusting turbine oil (2190 TEP)		Carbon Dioxide (CO_2)
Automotive Gasoline (MIL-G-3056D)	Seawater	Forced-feed oils (Symbols 3042 to 3150 inclusive)		Chlorine (Cl_2)
	Brine (from distilling plants)			Refrigerant 12 (CCl_2F)
	Contaminated water, drains	Compounded marine-engine oils (4065)		Refrigerant 22 ($CHClF_2$)
		Compounded steam cylinder oils (6135, 7105)		Ethyl Chloride (C_2H_5Cl)
				Ethylene oxide (C_2H_4O)
		Compounded air cylinder oils (8190)		Helium (He)
				Hydrogen (H_2)
		Mineral marine-engine and cylinder oil (5150, 5180, and 4230)		Inert gas
				Methyl chloride (CH_3Cl)
				Nitrogen (N_2)
		Aviation engine oils (1065, 1100)		Nitrous oxide (N_2O)
				Oxygen (O_2)
		Internal combustion lubricating oils (9110, 9170, 9250, and 9500)		Propane (C_3H_8)
				Sulfur dioxide (SO_2)
				Butane (C_4H_{10})
				Steam (H_2O)

TABLE 2 - EXAMPLES OF SHIPBOARD SYSTEMS USING FLOWMETERS

System Type	System	Fluid
Propulsion	Conventional oil boiler - steam turbine	Fuel oil service Boiler feedwater/condensate Steam flow Airflow
	Gas turbines	Fuel oil service Airflow
	Electric battery motor	Airflow; ventilation of battery space, agitation of electrolyte Water flow - battery cooling system
	Diesel engine	Fuel oil service
Auxiliary	Distilling plants	Feedwater in Brine flow out Freshwater out
	Ventilating, heating, air conditioning	Chilled water flow
	Atmospheric control	Oxygen output
	Trim and drain systems	Trim pump discharge Drain pump discharge
	Electronic equipment cooling systems	Coolant flow
Fuel Handling	Ship fuel system	Fill and transfer main, fueling stations Service
	Cargo fuel oil	Fill and discharge risers
	Gasoline/JP-5 "Cargo"	Replenishment station (to and from ship) Service station (to and from vehicles, aircraft)

FUEL FILLING AND TRANSFER SYSTEMS

Since most Navy ships use fuel oil for propulsion, the handling and storage of fuel oil aboard ships is a major task. The capability to refuel at sea is a standard requirement for combat ships where all can receive fuel from oilers and where the larger combatants such as carriers and cruisers can refuel escorts such as destroyers. Ships that are required to transfer fuel to other ships must have fuel oil systems that are capable of maintaining 7.03 kg/cm^2* (100 psi) at the deck connections. Those portions of the fuel oil filling and transfer systems which can be subjected to replenishment ship cargo pump shutoff pressures must have a minimum system design pressure of 14.06 kg/cm^2 (200 psi). The filling mains incorporate venturi flowmeters capable of reading flow in either direction.

The cargo fuel oil systems of oilers (AO, AOE, AOR classes) are arranged for receiving bulk oil from shore or from ships alongside and for discharging oil through a replenishing hose to other ships alongside. A propeller or turbine meter is provided in each discharge riser and is capable of reading flow in either direction. Discussions with operating personnel indicate that the flowmeters are usually used to determine if flow has actually started or stopped and to estimate the length of time required to complete the transfer. Tank level indicators or sounding are used to measure the total quantity transferred for accountability purposes.

FUEL OIL SERVICE SYSTEMS

Fuel oil service flowmeters for nonnuclear steam or gas turbine driven ships should be designed for 24.61 kg/cm^2 (350 psi) operating pressure, 0 to 114 lpm (30 gpm) flow rates, and bearings and materials compatible with JP-5 or Marine Diesel Fuel. The maximum temperature of the fuel metered is 57.2° C (135° F).

---

*A list of abbreviations appears on page v.

FUEL OIL STRIPPING SYSTEMS

At the present time, naval ships have no effective means of measuring the amount of fuel oil wasted when the fuel oil storage and service tanks are stripped of water prior to drawing fuel from the tank for use. The stripping operation consists of pumping a small quantity (about 8 percent of the total) of liquid from the bottom of the fuel oil tanks. The initial liquid pumped is water, followed by a mixture of water and fuel oil; pure fuel oil is pumped last. The ship's operators need to know when the mixture becomes pure fuel oil. The present approach is to pump a sufficiently large quantity so that the operators are sure (without benefit of instrumentation) that there is pure fuel oil present prior to transfer. The measurements desired are the total amounts of water and fuel oil transferred and a knowledge of when the liquid flowing becomes pure oil. Almost all existing ships require some means for making these determinations. A flowmeter, ideally of the clamp-on type, is needed to measure both water and fuel oil flow through the fuel oil stripping systems and to differentiate between the two.

DISTILLING SYSTEMS

For proper and efficient use of Navy distilling plants it is necessary to measure the freshwater output with a flowmeter. The largest distilling plants provide 189,000 lpm (50,000 gpm) or about (132.5 lpm (35 gpm)). Positive displacement flowmeters for fresh and potable water are purchased under MIL-M-2082. There are two classes of shipboard positive displacement water meters depending on the temperature of the water flow; Class A - cold water, for volume measurement of water up to 37.8^{o} C (100^{o} F) and Class B - hot water, for volume measurements of water above 37.8^{o} C (100^{o} F).

FEEDWATER CONTROL SYSTEM

Three-element feedwater control systems maintain constant boiler drum water level through use of three signals; (1) steam flow, (2) feedwater flow, and (3) boiler drum water level. Steam and feedwater flow are measured by sensing pressure drops across appropriate orifices or flow obstructions (headmeters). Such automatic control systems do not require accurate measurement of flow but do require precise response to changes in the controlled variable. Very repeatable and reliable flow sensors with adequate resolution and speed of response are needed rather than accurate flowmeters. The required flow sensors are usually provided as integral components of the feedwater control system.

TRIM AND DRAIN SYSTEMS

To maintain the proper trim of submarines, the flows in the trim and drain systems are measured. Waste water containing various contaminants in widely varying proportions is pumped from internal tanks through a drain system flowmeter to the waste oil collecting tank external to the pressure hull. Under normal operating conditions, the trim system contains only seawater, and every effort is made to avoid contaminating it with anything else. Under casualty conditions, where either a trim or drain pump has failed, the trim and drain systems can be cross-connected to use the pump and meter from one system in the other system, and the trim system may become contaminated with drain system contents. Normal pumping rates for each system range from about 378.5 to 908.5 lpm (100 to 240 gpm).

DEEP SUBMERGENCE BALLAST CONTROL

On the deep-diving vehicles, such as the ALVIN, ballast is controlled by pumping seawater in and out of a series of high-pressure tanks. The ballast status is determined by knowing the tank capacity, the approximate pumping rates, and the amount of ballast onboard at the beginning of the dive. A better control system would be to use an accurate flowmeter on the connecting lines between ballast tanks, in combination with level sensors to monitor the amount of ballast in each tank. This application requires an accurate, low cost, small, high-pressure flowmeter. It should be clamp-on and be capable of operation within (wetted) a high-pressure medium. Flowmeter operation on small diameter (3/8-inch minimum) pipes is needed. No satisfactory flowmeter has yet been found for this application.

COMBUSTION CONTROL SYSTEMS

Automation combustion control systems maintain constant steam pressure at the steam drum or superheater outlet through use of five signals: (1) steam pressure, (2) fuel oil supply flow, (3) fuel oil return flow, (4) combustion airflow, and (5) steam flow. Steam and airflows are measured by sensing pressure drops across appropriate orifices or flow obstructions (headmeters). The fuel flows are measured by a variety of means, including variable area flowmeters.

STEAM PLANT HEAT BALANCE MEASUREMENT

With the advent of energy consciousness, stimulated by the rising cost and scarcity of energy supplies, several research and development programs have begun with the objective of quantifying the efficiency with which ships are operated. One of these programs involves determining the operational status of the steam distribution system on destroyer power plants. The approach is to determine what machinery components use how much steam over an extended period of time. Monitoring of steam flow and condensate flow is desired. It is also desired that the pipelines not be opened for installation of special instrumentation. Present flowmeter technology can be used to measure the condensate flow, utilizing a clamp-on acoustic flowmeter that is accurate to ±5 percent of reading without in situ calibration.[8] A clamp-on steam flowmeter is not available but is needed.

SHIPBOARD MACHINERY PERFORMANCE MONITORING

The Shipboard Machinery Performance Monitoring (SMPM) program is aimed at developing equipment for determining the operational status and maintenance needs for auxiliary machinery on surface ships. The system will monitor machinery performance parameters on a long-term, on-line basis and will use trend analyses to determine maintenance requirements. Clamp-on operation is not required but is desirable and might be justified on an economic basis when the cost of ship alterations are considered. The SMPM program needs flowmeters accurate to ±1 percent of reading and capable of operating about 5000 hours without recalibration. In-line flowmeters are presently available with claimed accuracies to ±1 percent of reading.

However, the combination of accuracy and long-term operation of available flowmeters is doubtful. Reliability experiments and evaluations of available flowmeters by independent laboratories are needed.

MAINTENANCE MONITORING

The Navy's Shipsystem Maintenance Monitoring and Support Office (SMMSO) is currently using a clamp-on acoustic flowmeter[8] to measure flow rates in pipes. The requirement is for a portable flowmeter to be carried aboard any ship, attached to any diameter pipe containing a liquid, and used for measuring the flow rate inside the pipeline. Present technology allows this to be accomplished with an accuracy of about ±5 percent of reading in the turbulent flow regime. High accuracy is needed because the flow information is used to trend machinery performance degradation and to help determine when maintenance is required. A need exists for a portable, clamp-on flowmeter that is more accurate than ±5 percent of reading.

An additional requirement of SMMSO is for a nonintrusive instrument to measure flows through leaking shipboard valves. The fluids involved are high-pressure air, water, steam, and hydraulic oil. It has been found that it is feasible to develop an instrument or instruments capable of measuring hydraulic, steam, and high-pressure air valve leakage acoustically with useful range, accuracy resolution, and repeatability. In the case of water and hydraulic oil, it has been found necessary to control the differential and the downstream pressures to make the measurements. The quantitative leakage measurement investigation makes use of previously developed technology,[10] principally the Acoustic Valve Leak Detector (AVLD), which measures the ultrasonic acoustic emissions characteristic of internal valve leakage.

Some of the current needs for the valve leakage measurement program are:

1. Increased sensitivity.
2. Reduced dependence on valve geometry.
3. Better understanding of the acoustic emissions of two-phase flows.
4. Better separation of signal from background noise.

ACCURACY AND FLOWSTREAM REQUIREMENTS

Existing military specifications list many of the flowmeter requirements for the Navy applications listed in the previous section on Application and Needs. These are summarized in Table 3. Many of the accuracy requirements in Table 3 are probably dictated more by available technology rather than by actual system flow measurement needs. If more accurate flowmeters were available from industry, ship designers would probably begin using them, and new or revised military specifications would be issued requiring the improved accuracies.

TABLE 3 - SUMMARY OF FLOWMETER MILITARY SPECIFICATIONS

(Actual performance specifications for particular flowmeter applications are generally specified separately with purchase order)

Military Specification	Flowmeter Type	Fluids	Flow Range for Specified Accuracy	Accuracy	Working Pressure Kg/cm^2(psi)
MIL-M-2082B(SHIPS) 17 October 1959	Volumetric Positive Displacement				
	Class A:	Cold Water: to 37.8° C (100°F)	5-100% max rate	±2% of actual flow (0.1% full scale)	7.031 (100)
	Class B:	Hot Water: 37.8° to 82.2° C (100° to 180°F)	25-100% max rate	±3% of actual flow (0.75% full scale)	3.515 (50)
MIL-F-24259(SHIPS) 17 October 1966	Fluid Volume Velocity (turbine, vortex velocity, drag)	Freshwater, seawater, fuels, and oils	Ratio max/min flow rate 10:1 20:1	Linearity: ±0.5% Linearity: ±1.0%	As Specified. otherwise 49.21 (700) saltwater 35.15 (500) cargo fluids
MIL-F-24291B(SHIPS) 10 August 1971	Electromagnetic Fluid Flowmeter	Fresh- or seawater or any fluid with conductivity as low as 10^{-4} mhos/cm	30.48 to 91.44 cm/sec(1 to 3 ft/sec) 91.44 to 457.2 cm/sec (3 to 15 ft/sec)	±3.05 cm/sec (±0.1 ft/sec) ±2.285 cm/sec (±0.075 ft/sec)	49.21 (700) 49.21 (700)

Two examples of applications for which no flowmeters are available will illustrate this point:

1. On the ALVIN and other planned deep-diving vehicles, an accurate flowmeter is needed in combination with level sensors to monitor the amount of ballast onboard. If an accurate, low cost, small, high-pressure flowmeter was available from industry, it could be used in this application. The Center is currently evaluating flowmeters for this application.

2. An accurate clamp-on flowmeter was needed on another program to monitor the flow of steam and condensate in a destroyer power plant, the objective of the program being to determine the steam system energy distribution over an extended period of time without opening the pipeline for installation of special instrumentation. A clamp-on, ultrasonic flowmeter has recently been developed which may suffice for the condensate measurement, but a clamp-on steam flowmeter is not available.

In general, the flowmeters used for Navy applications up to 700 psi are the electromagnetic, acoustic transit time, turbine, and propeller or vane types. Industry frequently uses differential pressure flowmeters for pressures up to 700 psi. In general, both Navy and industry use differential pressure flowmeters for pressures higher than 700 psi.

Flowstream parameters, other than pressure, of interest in Navy applications include pipe diameter, fluid temperature, fluid viscosity, velocity ranges, and Reynolds number ranges as shown in Table 4. This listing shows the wide range of values for fluid parameters in Navy applications. Of particular interest is the column listing and maximum Reynolds numbers, as this value indicates whether flow is laminar or turbulent. Table 4 shows that Navy flowmeter applications sometimes require operation in both laminar and turbulent flow regimes. Most applications fall in the turbulent flow regime.

Table 4 lists flowstream parameter variations that span the range of Navy liquid flowmeter applications. Thus, one might infer the need for a "universal" or general-purpose flowmeter to cover the full span or parameter variations listed. For each specific application, there is a much smaller range of parameter variation than that given in Table 4, especially in the flow velocity variation. Therefore, a flowmeter frequently can be purchased that will meet the requirement of an individual application but will not meet the requirements for all Navy shipboard applications.

TABLE 4 - SUMMARY OF NAVY FLOWMETER LIQUID PARAMETER RANGES

Fluid Type	Pipe Diameter Min/Max(1) cm (in.)	Flow Velocity Min/Max(1) lpm (gpm)	Flow Velocity Min/Max(1) m/sec (ft/sec)(4)	Fluid Temperature Min/Max °C (°F)	Kinematic Viscosity Min/Max 10^{-6} m²/sec (10^{-6} ft²/sec)	Reynolds No. Min/Max	Pressure(3) Maximum kPa	Pressure(3) Maximum (Psi)
Freshwater	1.2/40 (0.5/16)(2)	1/76,000 (0.25/20,000)(4)	0.1/7 (0.4/30)(4)	4/95 (40/200)	0.30/1.6 (3.2/17)	1,000/ 12×10^6	10,500	1,500
Seawater	1.0/40 (0.375/16)(2)	1/76,000 (0.25/20,000)(4)	0.1/7 (0.4/30)(4)	4/95 (40/200)	0.30/1.6 (3.2/17)	700/ 12×10^6	62,000	9,000
JP-5	2.5/40 (1/8)	10/24,000 (2.5/6,000)	0.3/15 (1/50)	10/65 (50/150)	1.4/3.4 (15/37)	2,000/ 2×10^6	7,000	1,000
Aviation Gasoline	2.5/40 (1/8)	10/24,000 (2.5/6,000)	0.3/15 (1/50)	10/65 (50/150)	0.53/0.93 (5.7/10)	8,000/ 6×10^6	7,000	1,000
Diesel Fuel Marine	2.5/40 (1/8)	10/24,000 (2.5/6,000)	0.3/15 (1/50)	10/65 (50/150)	1.9/14.0 (20/150)	600/ 1.7×10^6	7,000	1,000
Contaminated Water, Drains	2.5/8 (1/3)	10/900 (2.5/240)	0.3/4 (1/12)	4/95 (40/200)	0.30/1.6 (3.2/17)(6)	5,000/ 1×10^6(6)	5,000	700
Hydraulic Oils	0.6/8 (0.25/3)	(5)	(5)	(5)	(5)	(5)	21,000	3,000
Lubricating Oils	0.6/8 (0.25/3)	(5)	(5)	10/65 (50/150)	14.0/560 (150/6,000)	(5)	1,000	150

(1) Minimum and maximum values for pipe diameter and flow velocity are intended to bracket most Navy applications. A few applications will occur with values lying outside these ranges. This table shows the span at typical values for fluid parameters in most Navy applications. Single flowmeter applications will not be required to operate over the ranges shown. In many applications, the minimum velocity will be zero, but the minimum velocity required for measurement is listed.

(2) Maximum diameters might be as high as 2.5 times the value shown if water jet applications were included.

(3) A comprehensive search was not completed on the maximum pressure for Navy applications. Values given are estimated from a general knowledge of piping system design.

(4) Maximum flow rates are estimated from a general knowledge of standard practice in industrial process design.

(5) Information was not available at the time of publication.

(6) This is the value for the viscosity of water. Contamination will generally cause higher viscosity values and lower Reynolds numbers.

CALIBRATION REQUIREMENTS

Calibration of flowmeters has traditionally been accomplished using weighing systems in a metrology laboratory with the transfer of that calibration to the field installation depending on the use of proper engineering practice by the cognizant applications engineer. The availability of a flowmeter that is easy to calibrate in situ or that is intrinsically self-calibrated would save time and money while improving flowmeter performance aboard ship. There are at least two flowmeters, electromagnetic and acoustic transit time, for which paratial on-site calibration capabilities have been developed. A calibrated signal is connected in place of the primary sensing unit, thereby allowing precise adjustment (calibration) of the secondary unit (electronic processor). There is a need to develop flowmeters that have full self-calibration capabilities while being useful in the shipboard environment.

CONCLUSIONS

The majority of present and future Navy applications of flowmeters involve oil, water or steam. Flowstream characteristics such as pressure, temperature, flow regime, phase, and pipe size cover wide ranges. There is at present no single type of flowmeter which can be used in every Navy application involving oil and water.

Accuracy and flow rate range requirements also exceed the capabilities of a single type of flowmeter. For some potential applications, accuracy requirements exceed the state-of-the-art for flowmeters which are otherwise acceptable. Some present applications, particularly those which use flowmeters to measure the total quantity of fluid transferred, would benefit from increased accuracies. Good accuracy and repeatability are also requirements for the various performance and maintenance monitoring applications, particularly those that employ long-term trend analyses.

Navy flowmeter applications may be classified by function as follows:

1. Automatic controls.
2. Remote manual controls.
3. Performance and maintenance monitoring.
4. Alarm systems.

Flowmeters for application to automatic control systems are not specified separately, since they must function as an integral part of the overall system. Most past and current Navy shipboard applications of flowmeters to automatic control systems need high reliability, maintainability, and repeatability because they operate continuously and contribute to the fighting effectiveness of the ship. For instance, high-performance boilers can be operated without automatic feedwater controls but at a sacrifice of manuverability.

Applications of flowmeters to remote manual control systems almost always involve intermittent operations such as refueling at sea. Flowmeter accuracy is required, commensurate with the accuracy of tank level measuring systems, but flowmeters of that accuracy are not presently installed. This requirement applies particularly to flow rates much less than full scale. The fuel filling and transfer application is very similar to cargo control applications in modern commercial tankers, and commercial practices should be further investigated.

Performance and maintenance monitoring applications require long-term stability and accuracy in the range of ± 1 percent. A particularly important application for which no suitable flowmeter is available is steam flow measurement. The few flowmeters presently installed are for automatic boiler controls and are not adequate for performance and maintenance monitoring. Installation is expensive because of the high-pressure, lagged piping. Clamp-on flowmeters for steam are not yet available. The potential benefits are improved material condition, better maintenance planning, and the ability to identify energy losses in the majority of Navy ships.

Flowmeters used as sensors in alarm systems require high reliability and low false alarm rates. They are vital for protection of systems and equipment which depend on water for cooling. Alarm functions could also be added to appropriate flowmeters installed for performance and maintenance monitoring.

Obstructionless flowmeters are highly desirable but have several operational disadvantages. Electromagnetic flowmeters are not capable of measuring oily flows. Acoustic clamp-on meters have relatively low accuracy.

Mass flow measurement of bi-phase fluids is very desirable, but no suitable flowmeter is available. Potential applications include steam systems, water jet propulsion, and valve leakage. A potential solution is to use acoustic techniques to measure both flow velocity and fluid density. If successful, such an instrument could be wetted or clamp-on, and could be used on fluids comprising gases, single liquids, liquid mixtures such as oil and water, and gas-liquid mixtures such as air-water, steam-water, and air-oil.

A universal or general purpose flowmeter is highly desirable. It should measure mass flow rates with an accuracy of ± 1 percent over the entire range of flow rates encountered on Navy ships. It should be compatible with all pipe sizes, pipe materials, fluids, temperatures, pressures, and flowstream characteristics. It should be obstructionless, reliable, repeatable, easily calibrated, and easily maintained. It should have output signals linear with flow rate and compatible with automatic control systems, remote gages, alarms, loggers, and computer-based monitoring systems. Lightweight, small volume, low cost, easy installation, and low power consumption are highly desirable.

Unfortunately, there is no flowmeter or family of flowmeters available which meet the above requirements. The most likely candidate is an acoustic sensor to measure both flow velocity and fluid density from which mass flow rate could be computed. The most serious unknown is the capability of acoustic techniques involving the transmission of sound through low-density fluids such as steam.

If a universal or general purpose flowmeter was developed to meet the above applications, it would likely be a high-cost instrument relative to other flowmeters, and, therefore, would not be used in all Navy applications where ideal performance is not essential. Thus, there will continue to be a need in the Navy for low-cost, nonuniversal flowmeters, such as PD meters, orifices, and venturi meters.

RECOMMENDATIONS

The total research and development effort for flow sensors in the U. S. Navy must encompass developments by private industry and other government and nonprofit agencies. As flowmeters become available from these other sources they should be tested and evaluated for operation in the shipboard environment. The Naval Ship Engineering Center, Philadelphia, has traditionally handled this test and evaluation effort, and should continue to do so in the future.

In addition to test and evaluation of nonuniversal flowmeters, in-house applied development efforts should be concentrated on applications involving oil and water, with the objective of producing a single flowmeter or family of flowmeters capable of meeting all or most present and future shipboard requirements. Specific problem areas which should be addressed are:

1. Mass flow measurement of bi-phase fluids.

2. Obstructionless flow measurement.

3. Nonintrusive (clamp-on) flowmeters.

4. Extended dynamic ranges.

5. Accuracy and repeatability of ± 1 percent.

6. Fluid and pipe compatibility.

7. Reliability and maintainability.

8. Obstructionless, nonintrusive, mass flow measurement of gases.

It is recommended that acoustic techniques be investigated and developed to provide a possible solution to the above listed problem areas. Four recommended objectives are:

1. Improve the accuracy of clamp-on acoustic flowmeters to ± 1 percent over their entire flow rate measurement range.

2. Determine the feasibility of using acoustic techniques to measure the mass flow of gases, particularly steam, with the required accuracy.

3. Develop means to use acoustic techniques to measure fluid velocity and fluid density simultaneously.

4. Develop means to use acoustic techniques for on-site flowmeter calibration.

REFERENCES

1. Doebelin, Ernest O., Measurement Systems Application and Design, McGraw-Hill, New York (1975)

2. Harvey, Glenn F., Ed., ISA Transducer Compendium, 2nd ed., Part I, Instrument Society of America, Pittsburgh (1969)

3. Soisson, Harold E., Instrumentation, John Wiley & Sons, New York (1975)

4. Norton, Harry N., Handbook of Transducers for Electronic Measuring Systems, Prentice-Hall, Englewood Cliffs (1969)

5. Liptak, Bela G., Ed., Instrument Engineers Handbook, Vol. 1, Chilton, New York (1969)

6. Durrani, Tariq S., and Clive A. Greated, Laser Systems in Flow Measurements, Plenum Press, New York (1977)

7. Dowdell, Rodger B., ed., Flow: Its Measurement and Control in Science and Industry, Vol. 1-3, Instrument Society of America, Pittsburg (1971)

8. Irwin, Lafayette K., ed., Flow Measurement in Open Channels and Closed Conduits, Vol. 1-2, U.S. Dept of Commerce, National Bureau of Standards, Washington (1977)

9. Lomas, D. J., Instrumentation Technology, "Selecting the Right Flowmeter," Parts I & II (May and June 1977)

10. Dickey, J. W., et al, "Acoustic Measurement of Valve Leakage Rates," Materials Evaluation (Jan 1978)

INITIAL DISTRIBUTION

COPIES	
8	NAVSEA
	1 SEA 05D
	2 SEA 05R
	2 SEA 532 (Levine & Karsch)
	1 SEA 613 (Steckley)
	2 SEA 99612
3	NAVSECPHILADIV
	1 SEC 6732/J. Foti
	1 SEC 6761/J. Castorina
	1 SEC 6772/J. Donnelly
12	DDC

CENTER DISTRIBUTION

Copies	Code
2	(273)
1	(2731/W. McWhirter)
10	(2732/H. Whitesel)
1	(522.2)
1	(5231)

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.