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TURBINE FLOW METER AND CALIBRATION FACILITY STUDY

FACILITIES ENGINEERING DIVISION
of THE MARQUARDT CORPORATION
Van Nuys, California

Item IV - Final Report
FE-269-3

Contract No. AF 04(611)-7548

AUGUST 1962

Rocket Research Laboratory
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Edwards Air Force Base, California

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THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

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FOREWORD

Small errors in liquid propellant metering can result in extremely costly penalties in rocket and missile development programs. To carry out a successful mission, the residual fuel mass of an aerospace vehicle during flight or when parked in a coasting or rendezvous orbit, must be continually known with extreme precision. Propellant consumption errors can lead to failure of the mission. Accurate airborne flow meters will diminish this error better than level gaging, because the latter is inapplicable to zero-G flight where the propellant interfaces in the tank are discontinuous.

Of equal importance is propellant loading accuracy, both to provide a lift-off total liquid mass, and to verify density/mass computations when volume tanking to fixed liquid-level probes. Thus, both airborne and ground support flow metering are involved.

The importance of accurately measuring mass quantities of liquids into space vehicles ranks in importance with thrust and guidance capability.

It was startling, therefore, during this study to discover that a paucity of dependable flow meter calibration correlation data existed. Almost without exception, meters for storable propellants are calibrated with water and utilized on the propellants without corrections. While facilities for correlating water calibrations against cryogenic propellants are operated by NASA, industrial laboratories and aerospace corporations, only extremely limited data and correlation facilities are available for storable propellants.

The accuracies obtained by storable propellant flow meters are then a matter of opinion and are not actually known. Even based on expert opinion, these accuracies are far from sufficient to meet current aerospace needs.

This report outlines current practice in the aerospace and turbine flow meter industries and discusses a new concept recently introduced by the petroleum pipeline transmission industries which incorporates on-stream calibration and could reduce flow measuring errors by a full order of magnitude.

ACKNOWLEDGEMENT

We wish to acknowledge the valuable assistance of many people in industry and government without whose help this report could not have been prepared.

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ABSTRACT

Turbine meter theory and practice are reviewed. Current practices in calibrating turbine-type flow meters using water or a standard hydrocarbon to determine K factors for application to storable propellants are examined and found unsuitable for accurate work. Correlation data in literature and private files are inadequate. Criteria are provided for the design of calibration facilities to provide direct calibration on propellants.

An unusual technique recently developed in the petroleum industry may greatly increase both accuracy and reliability.

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Addendum III - Instrument Society of America Tentative Recommended Practice, RP31.3 - "Recommended Calibration Procedures for Turbine-Type Flow Transducers"

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SECTION I

I. DEFINITION OF TERMS AND ABBREVIATIONS (Ref. ISA RP31.1 and RP37.1)

Readout: The instrument which monitors (displays or records) the "flow rate" and/or "total flow."

Examples: Pulse counter
Digital voltmeter
EPUT-meter

Flow Transducer: The FLOW METER. "A turbine-type flow transducer with an electrical output is a measuring device in which the action of the entire fluid stream turns a bladed rotor at a speed nominally proportional to the volume rate of flow, and which generates or modulates an output signal with a frequency proportional to the rotor speed." (ISA Recommended Practice RP31.1)
In this report, the flow transducer may be referred to as the "meter" and "flow meter."

Counter: An electronic frequency (cycles/sec. or total cycles) readout arranged decade-wise. A common form of frequency counter for reading-out flow is the EPUT-meter (Events-per-Unit-Time).

Load Cell: An electronic force or weight-measuring transducer, usually employing a strain-gaged tension or compression member hermetically encased in a sealed capsule.

Propellant: In this report, a liquid burned as a "fuel" or "oxidizer" to provide propulsive force to a missile or other aerospace vehicle.
Examples: RP-1, liquid hydrogen, pentaborane, etc.

Storable: A propellant which is easily stored without excessive evaporative loss such as occurs with cryogenic fluids.

Cryogenic: Pertaining to liquefied gases, particularly oxygen, nitrogen, hydrogen, helium, and fluorine.

Pulse: Synonymous with cycle, pip, count.

Fuel: In this report the fuels are:

Hydrazine	(N_2H_4-Monopropellant)
Unsymmetrical Dimethyl Hydrazine	(UDMH)
50-50 Blend	(Mixture of 50% N_2H_4 and 50% UDMH)
Pentaborane	(B_5H_9)
RP-1	(Refined Kerosene)
Liquid Hydrogen	(LH_2) a cryogenic liquid

Oxidizer: In this report the oxidizers are:

Nitrogen Tetroxide	(N_2O_4)
Chlorine Trifluoride	(ClF_3)
Liquid Oxygen	(LO_2)
Liquid Fluorine	(LF_2)

Cycle: The preferred term, a "cycle" is one of a series of electrical waves which constitute the output signal of a turbine-type flow transducer. Each cycle represents a discreet unit volume (or "mass" in some cases) of the fluid being measured, and is usually generated by each blade of the rotor.

Frequency: The repetition-rate of the transducer output signal, usually expressed in cycles per second.

Abbreviations

NASA	National Aeronautics and Space Administration
DOD	Department of Defense
MSFC	Marshall Space Flight Center
AEC	Atomic Energy Commission

SECTION II

II. [illegible]

this rep[illegible] was to provide special engineering studies of [illegible] turbine f[illegible] ansducers, accuracies obtainable and methods [illegible] criteria [illegible] design and construction of propellant calibration [illegible] were to be [illegible]ed. The studies and criteria apply to flow trans-[illegible] to 2-1/2-inches in size and to the following propellants:

[illegible]	Fuels
[illegible]	UDMH
[illegible]	N_2H_4
	50-50 Blend (N_2H_4 and UDMH)
	B_5H_9
	RP-1

Literature and industry surveys were to be included and the ability of private industry to accept propellant calibrations contracts evaluated. Cryogenic liquid flow correlations, when available from literature and industry, were also to be evaluated for liquefied gases of oxygen, nitrogen, hydrogen and fluorine

SECTION III

III. DISCUSSION

A. History of Turbine Flow Meters

The use of a bladed rotor, turned by the force of fluid flow, is not in itself a very recent development. Known as the "anemometer," a delicately-balanced windmill-type velocity meter has been in popular usage for many years to measure low-velocity, low-pressure air streams such as found in fan and blower performance studies, ventilation ducts, air-conditioning systems, etc.

Cup-shaped, as well as flat-bladed, velocity-sensing devices have also been used for gaging open-channel flows as seen in irrigation works, and for logging ship speed.

In closed conduits under pressure: - pipes, there have been used (and still are found) many thousands of what are called "propeller" meters. These are usually combined with a "positive-displacement" element which measures main flow, while the propeller or turbine measures the smaller bypass or shunt flow.

As a result of the widespread acceptance of the term "propeller-meter," it has often been applied to any flow meter which has a vaned rotor. Lately, the term "turbine-meter" or "turbine flow meter" has come to be associated more and more with those earlier models which actually metered only a fraction of the total stream.

In order to clarify the terms, the Instrument Society of America in its Recommended Practice RP31.1 established the definition of a turbine-type flow transducer (flow meter) as one which measures the entire fluid stream, not just part of it. This definition eliminates from this report any consideration of "propeller" types operating on only a portion of the total flow.

It may be pertinent to also point out that the word "turbine" is always associated in engineering circles with a fluid-driven member, whereas "propeller" connotes a fluid-driving member. The American Society of Mechanical Engineers, in "Fluid Meters - Their Theory and Application" is not in accord with this interpretation, but the aerospace industry has generally aligned itself with it. Therefore, we will use the generic word "turbine" in this report.

The aerospace industry has almost universally adopted the turbine-type flow transducer for flow-rate, as well as total flow measurements of all types of fluids -- liquids and gases, used in airborne or in ground systems.

Probably the salient feature of the turbine transducer, compared with other flow meter types, is its distinctly advantageous form of output signal: AC frequency. Frequency in turn is proportional to volume flow-rate. Although the signal amplitude (voltage) drops off at low flows, along with frequency, this disadvantage is of minor importance to most users.

Another strong advantage of the turbine meter over other types lies in its inherent long-term precision and repeatability coupled with fast response, relatively low cost, low weight and size, as well as low pressure-drop. Thinking in terms of P/D (positive-displacement) meters, all of these factors favor the turbine-type in addition to its preferred output signal mentioned above.

The P/D meter manufacturers, in order to combat the swelling sales of turbine meters, have been adding pulse-generators to their meters. Thus, one revolution of the P/D register drive-shaft can stand for 100 or any desired number of electrical pulses per unit volume. With the addition of pulse generators, the P/D-type meters have overcome only one of the advantages of the turbine-type; i.e., frequency proportional to flow, but the P/D meters still are bulkier and offer more flow resistance than turbine-types.

However, authorities agree that the limitations of the turbine meter in respect to pressure-loss, sensitivity to upstream disturbance, and inability to endure over-speeding with gas, will soon bring into more frequent

use several smooth-bore flow meters. With no parts in the flow stream, this new generation of meters will in time be more common than any other type. However, their development has been slow and they are far from practical in their present state.

It is not hard to visualize the dynamic forces that produce, in a turbine meter, a rotational speed nominally proportional to volume flow. The torque producing a change in rotor speed is, according to Dr. Jerry Grey:[14]

$$T = I \frac{d^2\theta}{dt^2}$$

Where: T = hydrodynamic torque on rotor blades
I = axial moment of inertia of rotor
θ = angular displacement of rotor
t = elapsed time

This relationship merely shows that the hydrodynamic torque T acts on each blade through some discreet swept angle θ, and that the heavier the rotor (higher I values), the longer time t it will take to accomplish the change in speed.

If, then, we start off with zero flow (with rotor at rest) and gradually increase flow, the rotor speed will increase in proportion to the moment of inertia if we neglect frictional losses. In practice, this is not possible. Therefore, rotor acceleration occurs until a state of equilibrium is reached where the driving torque exactly equals resistive torque, and the rotor then travels at the speed where this state of equilibrium exists.

Due to the complex relationship between rotor geometry, and viscous forces of the fluid acting on the blades and hub of rotor, and as this complex relationship varies from one make of meter to another (and between meters of the same make), it becomes only of academic interest to algebraically express the equation for rotor speed. Dr. Grey,[14] Hochreiter,[23] and others have developed such an expression. Suffice to say, the K-factor (cycles per

gallon) of each individual transducer is the means by which we relate rotor speed to linear velocity. Since the output frequency f is the same as rotor speed (by an even factor), and linear velocity is equated to volume flow, we see that:

$$K = \frac{\text{rotor speed}}{\text{volume flow}} = \frac{f\,(\text{cycles/sec})}{Q\,(\text{gals/sec})} = \frac{\text{cycles}}{\text{gals}}$$

A closer analytical study would bring out the logical deduction that at only one point in each blade is there exactly the same relative velocity between the blade and a particle of fluid at that spot. At other points on the blade the fluid is either being driven by the rotor or the rotor is being driven by the fluid. This is true because the flow is turbulent in the plane of the rotor, and velocity distribution along the length of the blade is not ideal. Research in blade shapes by each manufacturer has resulted in some preferring flat blades and some preferring twisted blades; the ideal shape is governed to a large extent by the geometry of the flow passage. The end result toward which all have strived is, of course, a compromise between linear range, pressure loss, and viscosity immunity.

One of the earliest aircraft models to be used was one developed by Mr. David M. Potter while employed by the Navy during World War II. It was first manufactured about 1945 by the Breeze Company, later by Potter Aeronautical Corporation. Other early models similar to Potter's were later produced by such firms as Cox, Fischer & Porter, and Waugh. Today the aerospace industry has the choice of eight U.S.A. sources of turbine-type flow transducers and at least one foreign brand. These are:

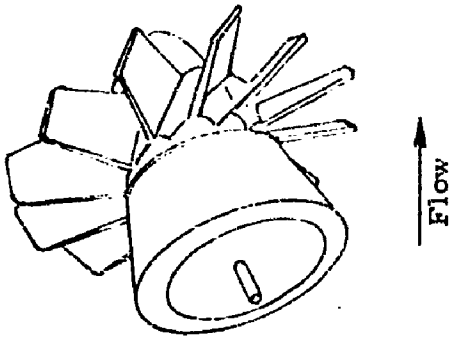
1. Cox Instruments, Detroit, Michigan
2. Fischer & Porter Company, Warminster, Pennsylvania
3. Hydropoise, Inc., Scottsdale, Arizona (a Division of Brooks Instrument Corporation, Philadelphia)
4. Potter Aeronautical Corporation, Union, New Jersey
5. Quantomics Inc., Tarzana, California
6. Revere Corporation of America, Wallingford, Connecticut
7. Space Instrumentation Company, Santa Monica, California
8. Waugh Engineering Division, Van Nuys, California
9. Meterflow Ltd., 606 N. Feltham Trading Estate, Feltham, Middlesex, England (Represented in U.S.A. by Communication Control Corporation, Van Nuys, California)

With no exception, these transducers all measure flow rate and total flow by generating or modulating an electrical signal proportional to the volume of flow passing through it. In some cases it is also possible to infer gravimetric or mass units (pounds or kilograms) by compensating for the known or inferred specific weight of the fluid. Some types of mass flow meters can even measure directly in gravimetric units by proper design.

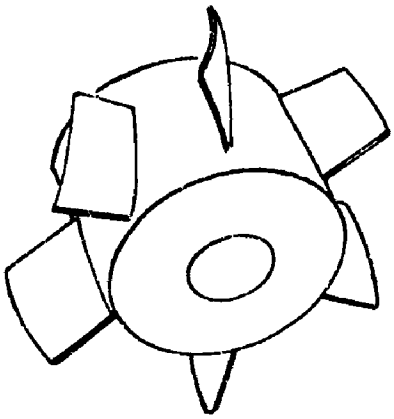
In the majority today are those designs which generate one electrical cycle with each blade that sweeps through the magnetic field present in the fluid passage. A permanent magnet stationed within the windings of the pickoff coil produces the field. This principle of transduction is called "reluctance," and the coil is known as an active coil. Alternately, some designs feature a perforated or serrated shroud ring surrounding the blades and revolving with them. Each hole or "tooth" generates a cycle, making it possible to generate relatively high signal frequencies with just a few blades, or at low rotary speeds.

In the earlier models a cylindrical permanent magnet was embedded in the rotor hub; or, in large-size meters, magnets were emplaced in the blade tips. In either case, the magnet swept past a stationary "passive" pickoff coil on the exterior of the meter housing, inducing a pulse for each pole-piece that swept under the winding. These are known as "inductance" types.

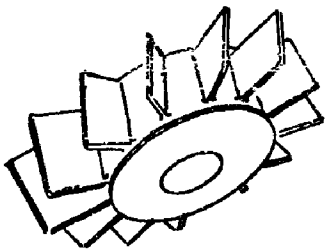
TYPICAL ROTOR GEOMETRY



Tapered blades;
Conical shaped hub
(Potter)



Curved, stubby blades;
Symmetrical shape
(Cox, Fischer & Porter,
Hydropoise, etc.)



Straight, stubby blades;
Symmetrical shape
(Spaco, Waugh, etc.)

Figure 1

TYPICAL INTERNAL GEOMETRY

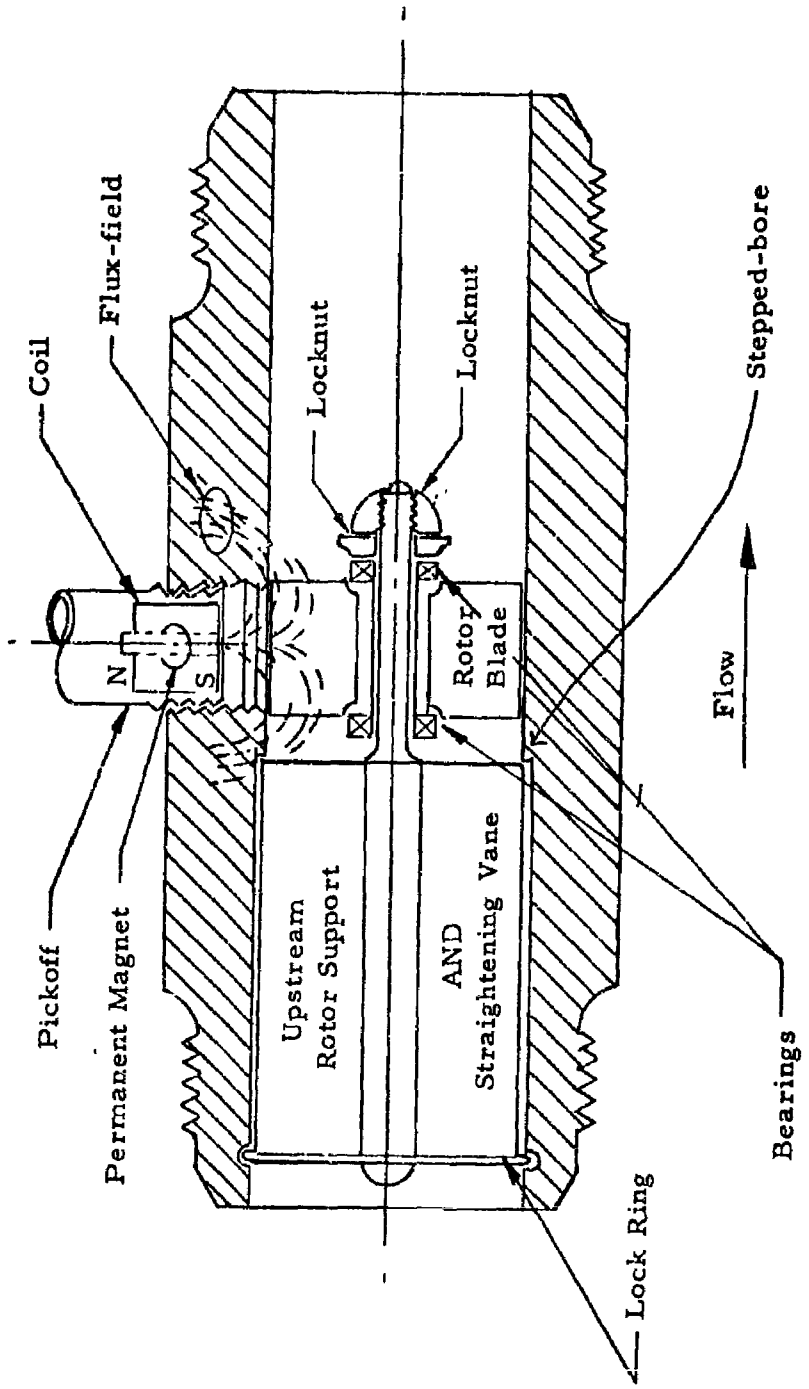


Figure 2

To avoid severe weight and response penalties the reluctive type element with active coil is used almost exclusively today. The transducer housing must be made of a non-conductor to eliminate eddy currents that otherwise would vitiate the signal.

It is equally important to so design the flow meter that the torque driving the rotor is strong enough at low velocities to overcome bearing and viscous drag, as well as the electrical drag of the magnet. To do this and yet avoid excessive pressure drop through the unit requires a judicious balance between rotor design and signal strength.

Future turbine flow meter designs are expected which will improve performance in these ways:

a. Lessen the unit's sensitivity to viscous effects.

b. Increase the unit's linear range.

c. Enhance reliability and long-life through better craftsmanship and materials, as well as through design improvements.

d. Lower first cost by closer quality control, resulting in a diminishing need to individually flow-test or calibrate each transducer.

e. Permit sensing mass-flow directly rather than inferentially.

It is generally felt throughout the aerospace industry that the ultimate in flow measurement is a transducer which has no moving parts in the stream, or better than this, one with no internal parts. Several "smooth-bore" designs are now in the development stage but are not ready for widespread use. Typical of these smooth-bore types are:

a. Decker's gyroscopic-loop mass flow meter

b. Gulton's ultrasonic mass flow meter

c. Dr. John Laub's boundary-layer thermal or electro-caloric mass flow meter, licensed to several companies.

These are not recommended at this time as a replacement for turbine-type flow meters.

To help overcome the problem of rotor overspeed resulting from gas purging or cryogenic (boil-off) gassing, turbine flow meters are sometimes equipped with an electromagnetic brake. Potter and Waugh offer these models complete with a small transistorized frequency switch, which, sensing the rotor speed, energizes the externally-mounted brake coils at some preselected value. The rotor can then be arrested or held to a safe speed.

B. An Analysis of Volumetric Turbine Flow Meter Differences

The essential construction and generic differences, easily recognizable, to help distinguish between various makes of volumetric turbine-type flow transducers, are these:

1. Electrical. - There is no readily distinguishable or characteristic difference between the pickoff-coil on various makes. Except that the threads may be different, or the method of locking or safety-wiring the pick-off may vary, any of the flow meters may have a connector containing from one pin to four pins. This much is almost uniform: they all have the pin-half of the connector on the flow meter. This practice is common to most electronic transducers: the pin-half being on the transducer and the socket-half on the cable or leads.

Potter's original flow meter design (circa 1948) used a one-pin connector, the winding being grounded at one end to the flow meter which in turn was grounded to earth or vehicle-frame (airplane) through the piping system. However, in time, Potter's customers found it much preferable to "float" the coil. This calls for two pins, and today most of the connectors have at least two-pins, or, a two-screw terminal in commercial models.

Some users have gone to three-pin and four-pin pickoffs. The Instrument Society of America's standard RP31.1 recommends three pins arranged thus:

Figure 3. Pickoff Wiring

Type I Type II

It can be seen from above figures that in the Type I coil the winding "floats," while the "C" pin can be used to ground the circuit or the cable shield as desired. In the Type II three-pin connector there is no ground to the flow meter, the "C" pin being used to carry the center-tap of the winding. This technique helps to reduce noise pickup and is preferred by some users.

In the four-pin pickoff A, B, and C pins are used as in a three-pin arrangement, while the "D" pin is "dead." The only reason for four pins is to facilitate standardization of connectors between flow transducers and other transducer types like pressure, force, etc. which employ four active conductors.

Other electrical differences between makes are found in the nature of the output signal. These differences, not always visually apparent, are:

a. Quantomics employs a photocell pickoff principle rather than the electromagnetic (self-generating) principle, to avoid low-flow nonlinearity.

b. Potter, Waugh, and Fischer & Porter can furnish transducers which, instead of generating a frequency signal, modulate an FM-carrier signal supplied to the transducer by an external oscillator. This technique improves flow meter performance by extending low flow linearity, because of

lessened electromagnetic drag. The reason for this is that generating electrical energy in the flow meter takes work out of the liquid in order to turn the rotor. If no work is performed, there is no electromagnetic drag and hence, the rotor spins with less drag. Thus, at low flow rates, the speed (hence K-factor) is higher.

c. Cox has traditionally favored high-frequency output signals, accomplished by a combination of more blades and/or high rotor speeds. Higher rotor speeds, of course, come from sharper blade angles, but this creates more pressure-drop.

d. To develop greater signal strength (volts instead of millivolts) Potter has used special "high-mu" magnetic straps on some of their transducers. This is not done, however, without considerable sacrifice in linear range, because at lower flows, the added work load performed by the rotor in generating more electricity can only result in fewer cycles per gallon (K is smaller).

2. Mechanical. - To better explain major mechanical differences in transducers, it may help to briefly chronicle the lineage or ancestry of the various makers.

It has been stated that the Pottermeter was among the first, if not the first, to make a start in the field. At about this same time (World War II), with the upsurge in aircraft engine development and testing, there was a booming market for test flow meters for use in engine run-in cells. The variable-area flow meter (known as a "rotameter") had become very popular for precisely measuring fuel consumption rates.

But the glass-tube rotameter -- glass so that the operator could read the float position by eye -- was unsafe. If the glass cracked or broke, fuel spillage would create an extreme hazard. (In fact, at least one catastrophic explosion and fire at a large eastern aircraft engine plant was traced to a glass-tube rotameter failure.)

So, the rotameter people -- mainly Fischer & Porter, Cox, and Schutte-Koerting -- developed all-metal rotameters. In this type, float position was sensed electronically for indicated or recorded readout. Going to higher and higher working pressures, these all-metal rotameters became bulky, heavy, and expensive. The natural evolution was to use a turbine meter. This brought two rotameter firms: Cox and Fischer & Porter, into the turbine flow meter field in the early 1950's.

About 1953, a former Rocketdyne engineering supervisor, Mr. Charles C. Waugh, decided to bring out a new turbine meter based on a radical design innovation: his rotor would be cantilever-supported from the inlet straightening vanes. Result: elimination of downstream bearing supports, longer inlet vanes, a shorter meter. Rotor end-thrust would be absorbed on a small "washer." (Cox and Spaco now use this construction, also.)

About this same time, Revere's turbine flow meter appeared. Revere's, like Cox and Fischer & Porter, were initially longer than the Potter and Waugh units due to bearing supports at both inlet and outlet ends.

Two more turbine flow meter firms were recently brought into existence by former Potter engineers: the "SPACO" transducer, built by Space Instrumentation Corporation, and the "HYDROPOISE" unit designed by Mr. Edward Francisco. Generally, in external appearance the Spaco and Hydropoise flow meters look pretty much like the Potter. Principally, internal construction differs in that the conventional Potter rotor has the characteristic conical shape, while Spaco and Hydropoise use rotors with small hubs (see Figure 1).

One other geometric design feature distinguishing Potter transducers from others is their use of a three-lobe rotor support. Until recently, all Potter meters had this distinctive geometry; now Potter offers optional construction with flat-shaped straightening vanes.

Various methods of locking the "internals" in the housing are employed. From a reliability standpoint it is felt that those designs are safer

which feature retention of the internal assembly by means of an integral step-diameter machined in the housing bore. This design appears to be preferable to the use of locking rings set in machined grooves. In the stepped-bore design, the entire rotor-and-vane assembly is "loaded" into the housing from the inlet end (see Figure 2).

Generally, each manufacturer would naturally claim design novelty for the sake of improved performance and reliability. This report makes no distinction between makes as to these important factors. Our recommendations are based on the probability that any and all of the various design types will be calibrated. The analysis of available N_2O_4 correlation data, while based on only one vendor source, Potter (because it just happened to be the one used), does not infer that this make is preferred. In this report all makes are considered acceptable for correlation studies.

C. An Analysis of Commercial Calibrators

The following tabulation shows the type of liquid calibrator normally used by each manufacturer. With few exceptions, these calibrators are also offered for sale by the flow meter manufacturer:

Flow Meter Mfr.	Volumetric			Gravimetric		
	Prover (Ball or Piston)	Static	Dynamic	Standpipe and Manom'r.	Static Weigh System	Dynamic Weigh System
Cox						X
F & P	X			X		
Hydropoise					X	
Meterflo	Not known					
Potter						X
Quantomics					X	
Revere		X			X	
Spaco					X	
Waugh	X	X	X		X	

Meter provers are available from several non-flow meter manufacturers. Two suggested sources are:

1. J. A. Halpine & Son, Inc., P. O. Box 6147, Tulsa 17, Oklahoma, Telephone: LU 7-4173

   Represented in Los Angeles area by:

   Vernon Tool Co., Ltd., 1101 Meridian Avenue Alhambra, California, Telephone: CU 3-1206

2. F. H. Maloney Co., P. O. Box 1777, Houston 1, Texas Telephone: FA 3-3161

   Represented in Los Angeles area by:

   Frost Engineering Service Co., P. O. Box 767 Huntington Park, California, Telephone: LU 7-1133

D. Factors Affecting Accuracy and Calibration

1. Geometric Factors

a. Meter Size. - Small-size turbine flow meters are more difficult to calibrate than large ones. Since this report deals more with the smaller sizes (1/2-inch through 2-1/2 inches), it is appropriate to discuss at some length the reasons why this is so, and how to minimize the effects.

(1) Weight or Volume Measurements. - Theoretically, it could be said, a certain per cent error yields the same degree of precision regardless of batch size. Thus, with large meters, an 0.01 per cent weighing error on a 1,000-pound batch is 0.1 pound. With small meters, the same per cent weighing error on a 100-pound batch is, of course, 0.01 pound. However, certain extraneous errors are constant regardless of batch size. Examples are:

(a) Human error in reading or recording data. This can be minimized by automating the data acquisition system.

(b) Effect of dirt, rust, wind, etc. on weigh scales. Minimize by such precautionary measures as maintenance and wind-break.

(c) Vertical restraint vector force on weigh scales due to connecting pipes. Minimize by proper piping design (horizontal loops, flexible connections).

(d) Density measurement, used to convert data from gravimetric to volumetric (or vice versa). A discreet error in looking up handbook figures, or in the temperature measurement, results in a larger per cent error on small batches than large ones. Minimize by exercising care on part of operator(s).

(2) Batch Size. - It is fundamental that at low flow rates on a large-size calibrator, the batch-size should be proportionately larger to attain the same degree of precision as with high flow rates. Often there is a sense of urgency in calibrating a flow meter, and there is a tendency on the part of the operator to cut the batch size to too small an amount.

(3) Hydrokinetic Effects. - In this area of error there can be pronounced effects depending on the flow-passage geometry of the particular transducer under test. The more experienced designers have minimized these potential errors by observing these basic tenets:

(a) Boundary-layer flow. - In smaller-size flow meters, particularly with the more viscous liquids, the velocity profile across the flow passage is more parabolic than flat because the boundary-layer flow is larger (percentage-wise) than in large meters. This effect will be treated later under "Viscosity."

(b) Rotor Drag. - In a rotor, blade aspect ratio, number of blades, blade L/D ratio, thickness and sharpness of blade effects

are more pronounced in small-size flow meters because viscous and electromagnetic drag can be a higher percentage of available driving torque. Of course, the linear range of the meter suffers and the operator sees the effect in low-flow K factor. The point here is that more care must be exercised in calibrating small meters than large ones, merely because the particular make of meter could have been improperly designed, or, the meter could have been designed for another liquid or another flow range.

(c) Rotor-support/straightening vanes. - In smaller meters it could happen that the area of free passage through the vanes is a smaller per cent of pipe area, due to structural strength requirements. The main effect of smaller area is higher velocity, with a side effect of altering velocity distribution. Thus, the flow pattern approaching the rotor is more apt to vary from one make to another, making correlation between water and other liquids more difficult.

b. Manufacturing Tolerances. - If a certain manufacturer's shop quality control is substandard, correlation between water and propellants will suffer from meter to meter of like size and geometry. The fit of the bearings, and particularly the imprecise machining or hand-filing of the critical blade-edges, will govern the calibration parameters.

c. Transducer Location in Usage Configuration. - It is generally recognized that the turbine-type flow transducer is as sensitive to flow phenomena as are other generic classes of flow meters, such as orifice meters. Two-phase flow (as encountered in cryogenic applications), transient flow (sudden rate changes), swirl or helicity due to adjacent elbows, valves and other components, all tend to bias the flow meter data. There are two approaches to a solution or at least a lessening of the severity of the effect:

(1) The best and simplest solution, but one not always feasible, is to install straightening vanes and/or to provide a sufficient straight inlet run. Under the "CRITERIA" section of this report recommendations are made as to the minimum length of straight run and the straightening vanes for the calibrator. These same criteria, if followed for the transducer's installation in usage configuration, will help to assure best accuracy.

(2) An alternate plan, if vanes are not used or if insufficient straight runs are impractical, is to actually calibrate using the identical piping configuration. The design criteria for the calibrators provides for clearances in the test meter area to permit installing all but the most complicated metering sections.

2. Physical Properties

a. Viscosity. - The literature is relatively lean in contemporary correlation data between water and quasi-viscous liquids. Private data are available from only two or three flow meter manufacturers; Fischer & Porter leads in this field, Cox and Potter also have data. In the bibliography, references No. 9 (Shafer), No. 21 (Lee and Karlby), No. 22 (Yard) and No. 23 (Hochreiter) are cited, with special emphasis on the postdelivery comments printed at the close of Shafer's paper. The concensus of expert opinion is that when K-factor is plotted against a Reynolds-Number-type parameter expressed as f/v (frequency divided by kinematic viscosity), the calibrations of not only one specific flow meter in various liquids, but also, correlations from one size to another, become meaningful.

Considered judgment prior to this present USAF study was that the propellants discussed in this report are of sufficiently low viscosity as to permit using water calibrations. (The propellant viscosities of interest are all less than 2 centistokes.) Wyle Laboratories' data (see Chart Nos. 1 and 2, Section III) indicate good correlations between water and N_2O_4. With only these few bits of data, however, one cannot make generalized conclusions concerning other sizes and makes of transducers or other propellants.

Viscosity will change almost every time that density changes, and temperature is the governing factor in this whole relationship. It matters little if viscosity decreases, if density also decreases by the same order of magnitude. That this is true can be appreciated by considering that viscous drag slows the rotor speed, while low-density liquids also slow it down.

Unfortunately, liquid viscosity variations almost always outweigh density changes. The manner in which viscous flow slows the rotor speed is three-fold: (1) the blades have to sweep through an almost stationary boundary-layer film at the pipe-wall; (2) bearing friction is higher: and (3) viscous flow produces a velocity profile not ideally suited to the shape of the blade. (The manufacturer can only shape the blade for one specific velocity-profile; this is why some use a plain paddle-shaped blade.) This non-ideal blade then finds itself having to push some liquid aside in turning, except at one exact combination of viscosity and velocity.

A complete study of this problem is probably best found in Hochreiter's paper (No. 23). ISA Recommended Practice RP31.2 also treats the subject adequately.

b. Density. - Density (also called "specific weight") affects the usage accuracy and the calibration of a volumetric turbine flow meter in two ways: (1) the power or torque available to spin the rotor can be mathematically shown to be linearly proportional to the liquid density. In several papers mentioned in the bibliography (notably Head's comments on No. 9), density "rho" (ρ) of the liquid is included in the parametric relationship $T/\rho n^2 D^5$, where T is the non-fluid friction torque. Essentially, this says that low-density liquids have less driving torque to overcome retarding bearing-friction, as well as viscous-drag forces. It is sufficient to point out, as Head has done, that "the general problem of water versus liquid hydrogen has loomed large in many informal discussions." Liquid hydrogen is an extreme example of a low-density liquid.

The other manner in which density affects the conventional volumetric turbine flow meter is in accurately knowing its exact numerical value when converting from volume to gravimetric units. If the calibrator is a true volumetric device (meter prover, stand-pipe, or other known volume) and the calibration constant K is desired in cycles per pound instead of cycles per gallon, a high order of precision is necessary. Because the propellant's density can vary even from batch to batch of the same manufacture, it is always prudent to run a representative sample through the laboratory for each specific lot of propellant. The temperature/density gradient can then be established without question, and used to convert temperature readings of the stream into densities. As an alternate, it is strongly recommended than an in-line densimeter be built into the calibrator. Precise in-line densimeters are presently available from Cox and Potter, as well as from non-flow meter manufacturers.

Laboratory-type densimeters of the pycnometer or Westphal type are recommended for batch sampling.

A word of precaution regarding liquid samples: it is quite possible that in draining the system to change from one propellant to another, the new liquid may become adulterated by small amounts of flushing liquid (water) or by the previous propellant. This possibility further emphasizes the desirability of continuous measurement of density by an in-line densimeter. The allowable error in density measurement must be in the fourth

significant figure if total calibration error is to be minimized. For example, the density of pentaborane (B_5H_9) which is the lightest of any of the propellants studied, should be accurate to 39.00 ± .02 (at 70°F) to be within 0.05 per cent. It is mandatory that this order of precision be assured if overall system accuracy on a gravimetric basis is to attain the desired level.

c. Temperature and Pressure. - The ISA Recommended Practice (RP31.2) on "Installation and Operation of Turbine-Type Flow Transducers -- Volumetric" covers the effects of temperature and pressure. Abstracting from that document, pressure changes the density of a liquid very slightly, and can also have a very small effect on the diameter of the flow meter housing. These effects are felt only at extremely high operating pressures (usually above 1000 psig), and are negligible at ordinary calibrating pressures.

Temperature, however, has two pronounced effects: (1) mechanical shrinkage or expansion of the transducer housing, and (2) changes to the physical properties of the measured liquid. The latter include its viscosity, density and vapor pressure. The first two property changes were covered earlier in this report, while the effect of vapor pressure is explained in RP31.2 (Addendum I).

E. Error Analysis

As an introduction to the treatment of error analysis, it is appropriate to review the philosophies underlying this subject. We should want to consider these questions concerning flow meter errors:

1. What is the difference between accuracy, precision, error, repeatability, and linearity?

2. How accurate is a new meter?

3. When does a meter start to lose accuracy, and how does one detect this?

4. How often should a flow meter be recalibrated?

5. What are the sources of error in calibrating?

6. What are the statistical approaches to error analysis?

7. What are the errors in converting volume flow to mass flow?

Taking up the above questions one at a time:

1. The Instrument Society of America, in its forthcoming Recommended Practice No. RP37.1, gives the following definitions for all aerospace test transducers except flow meters:

"Accuracy - The ratio of the ERROR to the FULL-SCALE OUTPUT (expressed as "within ± _____ per cent of FULL-SCALE OUTPUT), or the ratio of the ERROR to the OUTPUT, expressed in per cent."

"Error - The algebraic difference between the indicated value and the true value of the MEASURAND, usually expressed in per cent of the FULL-SCALE OUTPUT, sometimes expressed in per cent of the OUTPUT reading of the TRANSDUCER."

To all errors which apply to the meter must be added the errors of the calibrating stand, and these do vary because of the complication added by the variable calibration stand error.

The ISA's Recommended Practice on flow transducer terminology (RP31.1) does not attempt to define the precision of a turbine-type flow transducer as its "accuracy" or "error"; but assesses its performance instead in terms of its "repeatability" and "linearity," which are more meaningful.

The ISA definitions of "repeatability" and "linearity" as found in RP31.1 (see Addendum I) are already in accord, generally, with

industry usage. (In the next section of this report, "Data Presentation Methods," typical graphs are presented to illustrate these definitions.) A cursory review of several flow meter catalogs reveals these guaranteed performances:

	Repeatability	Linearity
Manufacturer A	± 0.1%	± 0.3%
Manufacturer B	± 0.5%	± 1.0%
Manufacturer C*	± 0.02%	± 0.5%
Manufacturer D**	± 0.1%	± 0.2%

*NOTE: Manufacturer C says:

> "ULTIMATE ACCURACY -- The precision of the meter equals or surpasses the current state-of-the-art in calibration equipment. The absolute precision can only be guessed until the ability to measure this is developed. It is probably on the order of .02 per cent, or better."

**NOTE: Manufacturer D says:

> "Precision equipment design and continuous quality control permit calibration to an accuracy within 0.2 per cent of the true flow and repeatability within ± 0.1 per cent."

Observe, from above excerpts, a difference of opinion among four manufacturers on definitions; i.e., saying "precision" and "accuracy" for "linearity" or "repeatability." However, there seems to be a general pattern of quoting a linearity figure of about twice the repeatability. In other words, the flow meters are twice as good in repeatability as in linearity.

2. How accurate is a new meter? This question was answered in the foregoing discussion on the meaning of accuracy, error, etc. Recall, too, the catalog statements of Manufacturer "C" and Manufacturer "D" to the

effect that their flow meters are accurate only to the extent that the calibration facility is accurate. Manufacturer "C" even infers that his product is more accurate than his own calibration equipment affords. It can be categorically stated, then, that: "a new flow meter is as accurate as the manufacturer's calibration." They are all better than ± 1.0 per cent linear and repeatable.

3. When does a meter start to lose accuracy? The factors affecting loss precision are mechanical (bearings, rotor) and electromagnetic (coil). Deterioration of either of these effects, other than causes external to the flow meter, can lead to gross errors. Usually, the result of bearing and/or rotor wear are manifest in an oscilloscope display of the output signal. Comparing the waveshape with that of a new meter can reveal, to a trained eye, loose bearings or a rotor rubbing the internal housing wall or other mechanical symtoms. A weak coil (loss of magnetism) can also be recognized on the grid of an oscilloscope by knowing the new meter's true signal strength. Of course, anyone familiar with the program or project in which the flow meter is used can detect malfunction through knowledge of what the true flow data should be.

4. How often should a flow meter be recalibrated? One philosophy is that the flow meter can be used until it is suspected of being in error by more than a preselected amount. A more sophisticated approach is to keep recycling freshly recalibrated or new meters into usage on a periodic basis. A suggested interval is six months or 100 tests, whichever occurs first. Of course, this will vary depending on the amount of abusive use (i.e., overspeeding, excessive temperature shocks, etc.). A flow meter with teflon or other type of plastic sleeve bearing can deteriorate "on the shelf," and these should be recycled on about a 12-month basis.

If the built-in meter prover described in Section V below is used, however, there will be no need to recalibrate. The flow meter would actually be recalibrated each time it is used.

5. What error sources occur in calibrating? Aside from human error, the equipment errors are either of a mechanical nature (tank dimensions changing), or instrumentation in character. These can both be periodically

verified against established NBS-certified standards as set forth in ISA-RP31.3. Only the owner's long experience with the idiosyncrasies of his particular calibrator can guide in the selection of a safe rechecking interval. It is safe to say that this period should never exceed one year. In fact, most state laws require annual resealing of a volume or weight measuring device.

6. What are the statistical approaches to error analysis? Probably the most erudite treatise specifically written on turbine flow meter calibrating errors is ASME Paper #57-A70 by Shafer and Ruegg of the NBS: "Liquid-Flowmeter Calibration Techniques." (No 24 in the bibliography.) Rather than quote from that paper, for an expanded study of the statistical methods in use today, it is preferable that textbooks on this subject be consulted.

In ISA-RP31.1, the definition of repeatability is:

> "..... ability to reproduce its calibration factor under the same conditions. Statistically, it is the product of the coefficient of variation of a number of calibration data, at nominally the same flow rate, and a statistical factor accounting for sample size at a stated confidence level."

If a flow meter is repeatedly calibrated without changing a single condition, one can compute by well-known methods the standard deviation. If, then, this standard deviation (sigma, or σ) is divided by the average calibration factor (K_{av}) for all these runs, this is known as the coefficient of variation (C_v), expressed as a per cent:

$$C_v = \frac{\sigma}{K_{av}} \times 100$$

Thus, for example, suppose the average K for a certain flow meter calibrated (without changing a single condition) one hundred times, is 105.7 cycles per gallon, and the standard deviation for these 100 runs is computed as 0.139. The coefficient of variation, then, is:

$$C_v = \frac{0.139}{105.7} \times 100 = 0.131 \text{ per cent}$$

If the coefficient of variation is based on a large sample size, 68 per cent of all calibration factors will deviate from the mean by an amount less than the coefficient of variation. The confidence level (probability) that any one calibration factor will be within this tolerance is said to be 68 per cent. Higher confidence levels may be established by multiplying the coefficient by a mathematically determined probability factor larger than 1. Likewise, compensation for small sample size may be made by increasing this factor. Tables of this factor, called "t," have been prepared for various confidence levels over a range of sample sizes down to 2. This provides the basis for a statistical expression of the repeatability characteristic of a measuring system called precision. It is the product of the factor "t" and the coefficient of variation.

$$\text{Precision (at a stated or implied confidence level)} = tC_v$$

The accuracy of a measuring system may be expressed in terms of its precision with respect to a calibration standard and the accuracy of that standard (A_s). The accuracy of the standard is usually combined with the coefficient of variation in a square-root-of-the sum-of-the-squares manner before the "t" factor is applied.

$$\text{Accuracy} = t\sqrt{A_s^2 + C_v^2}$$

The foregoing discussion of one statistical approach, upon which the ISA definition for "repeatability" is founded, helps to explain how an ideal comparison of flow meter and calibration stand precision may be made. A typical error analysis of a specific flow meter being calibrated on a specific stand might be performed as follows:

Assume, as an example, that we are calibrating a 2-1/2 inch flow meter with a capacity of 400 gpm at a frequency of 500 cps. The K-factor will then be about 75 cycles per gallon, if we divide the (500 x 60) cycles per minute by 400 gpm. Let us assume that at the maximum flow rate of 400 gpm we are limited by our 300-gallon tank to a 30-second run, and our net "batch" is therefore 200 gallons.

Error in measuring volume by meter prover:

Minimum detectable increment:

At beginning of measured volume = ± 0.02 gallons
At end of measured volume = ± 0.02 gallons

$$\text{Possible error in volume} = \frac{.02 + .02}{200} \times 100 = \pm 0.02 \text{ per cent}$$

Error in counting flow meter pulses:

Least count error at beginning = 1 count
Least count error at end of run = 1 count

$$\text{Possible counting error} = \frac{2 \text{ counts}}{(500 \times 30)\text{cts}} \times 100 = \pm .013 \text{ per cent}$$

Total calibration error:

(Volume error) + (counting error)
$\pm .02\% + \pm .013\% = \pm .033$ per cent

7. What are the errors in converting volume flow to mass flow?

One pitfall concerning mass flow determination is failure to measure directly the density of the liquid being processed. While temperature-density conversions obtained from literature are relatively accurate for pure chemicals (such as N_2O_4), they are not accurate for most organic fuels. The latter are composed of a great many chemical variations which differ from batch to batch. In the manufacturing and storage of these liquids, they occasionally stratify into layers of differing densities. It is also possible that insufficient blending of fuel mixtures such as UDMH and hydrazine will result in density variations.

The military specifications are not sufficiently specific to allow accurate temperature-density conversions as illustrated by the following:

Mil Spec.	Liquid	Density GM/cc Max.	Min.	% Variation (Max.-Min/min) 100
MIL-R-25576B	RP-1	0.815	0.80	1.75
MIL-D-25604B	UDMH	0.786	0.783	0.38
MIL-P-26536A	Hydrazine	1.006	1.002	0.20
MIL-P-27402	50% N_2H_4-50% UDMH	0.903	0.894	1.08

For accurate volume-mass conversion, density should be determined from well-mixed batches or from continuous indicating density meters.

F. Data Presentation Methods

It is considered more meaningful, in the flow meter industry, to judge performance by the ability of the flow meter to repeat; that is, always to produce X cycles for Y gallons at one specific flow rate. The number of cycles produced by a flow meter for each gallon that passed through it is called the "calibration factor" -- represented by "K." A graph of K-values over the flow range is generally regarded as the most meaningful picture of a flow meter's performance. The straightness of this plot is the transducer's "linearity," while the dispersion of test points above and below this straight line is its "repeatability." (See curve on following page.)

A well-designed flow meter in good condition, when calibrated with water, will result in a linear flow range of about ten-to-one and a repeatability of ± 0.1 per cent. In addition, if it is properly calibrated on a high-precision flow-stand, its "accuracy" can be expected to be about ± 0.25 per cent. As discussed above, however, this "accuracy" depends on so many other factors that it must be quoted with due caution.

Another manner of presenting a flow meter's calibration data, preferred by some, is shown on Page III-28.

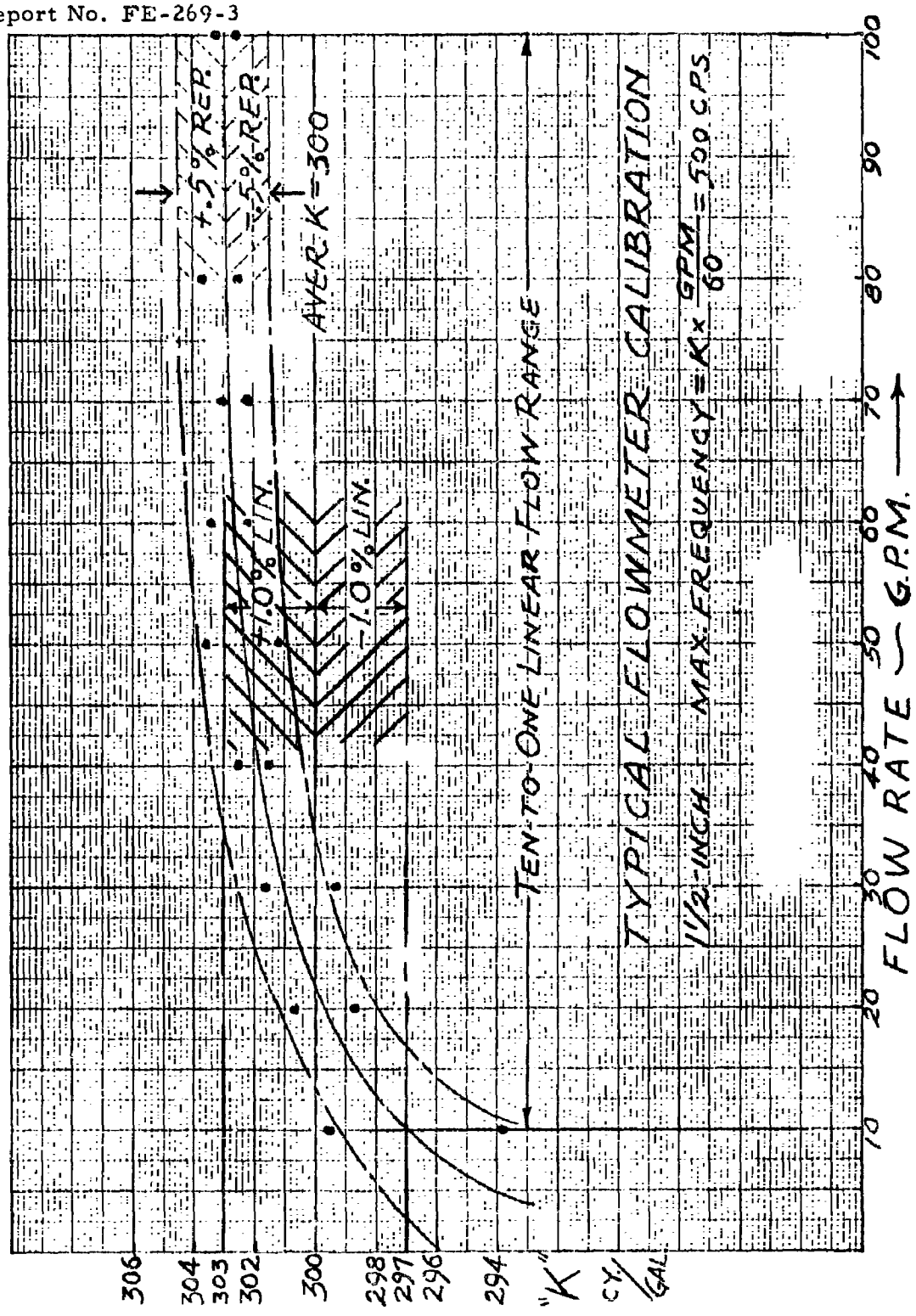

TYPICAL FLOWMETER CALIBRATION
1 1/2-INCH MAX. FREQUENCY = K × GPM/60 = 500 C.P.S.
TEN-TO-ONE LINEAR FLOW RANGE
AVER. K = 300
+.5% REP.
-.5% REP.
+1.0% LIN.
-1.0% LIN.
FLOW RATE — G.P.M.
10
20
30
40
50
60
70
80
90
100
"K" CY/GAL
306
304
303
302
300
298
297
296
294

Figure 4

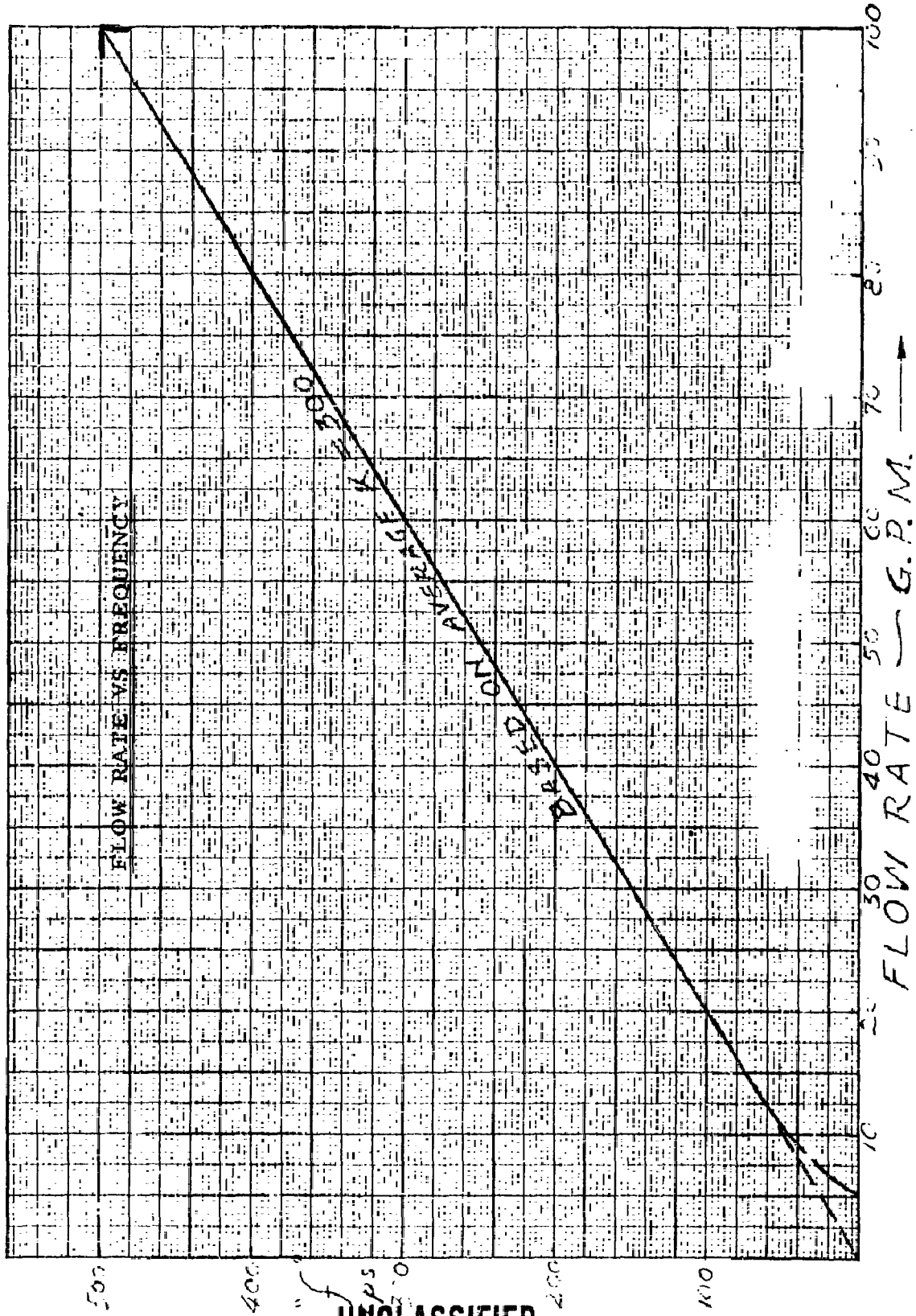

FLOW RATE VS FREQUENCY
BASED ON AVERAGE K = 200
FLOW RATE — G.P.M.
10
20
30
40
50
60
70
80
100
500
400
300
200
100

Figure 5

Note that the preceding curve does not intercept at 0/0, because at very low flow rates the rotor will not be turning (due to bearing friction and/or electromagnetic drag). Also, because the output signal at low rotor speed is sometimes too weak to trigger a pulse counter, so the output frequency often reads zero with low flow rates.

G. Instrumentation

It hardly seems necessary to point out the obvious, that no flow meter is any better (any more accurate) than the instruments used to monitor its performance. So it follows, that any and all instruments used for "reading-out" or "displaying" the discreet measurements sought after during calibration runs of a flow meter, must be of a higher order of accuracy than the flow meter itself.

Regardless of the type of volume or weight system used on the calibration-stand, no doubt the most important instrument is that which detects the flow meter's pulses and displays a digital number representing the total cycles, counts, or pulses generated by the flow meter for each gallon of liquid passing through the line. It is variously described as a "counter," "timer," "EPUT-meter," or simply "EPUT," and contains a decade-type of readout that electronically converts a chain of pulses into a digital display of decimal numbers.

"EPUT" is a familiar term meaning "Events Per Unit Time." There are several firms making EPUT-meters. A few are: Berkeley, Hewlett-Packard, General Radio, NLS, etc. This type of instrument receives a train of pulses and counts them. In a preselected time interval (usually ten seconds), it will count the total number of pulses which it receives. Thus, if it receives a 60-cycle ac power signal, it will count for ten seconds and read 600.00; then after displaying this figure for an instant, it automatically clears itself and reads it again as 599.99 or 600.01 cycles (or 60 cps).

A more useful form of the "EPUT-meter" for flow meters is perhaps the "counter." A "counter" is a first cousin of the EPUT-meter.

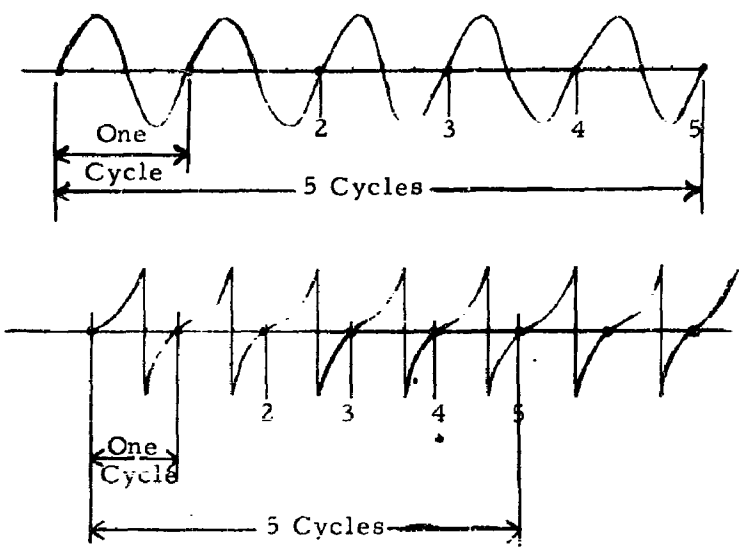
Instead of merely adding the total pulses it receives in a "unit-of-time" (1 second, 1 minute, etc.), it just keeps on counting until switched off manually or automatically. The "gate" which opens to start the count and closes to stop the count, in flow meter calibration work, is usually a contact activated by a liquid-level switch, a scale-beam, or the "position" of a displacement member as in a meter prover.

In calibrating a flow meter we desire to equate a certain volume or weight of liquid to a certain total number of pulses. It is very convenient to select a pulse-counter whose "gate" can be remotely and electrically turned ON and OFF by any type of switch actuated by the initial and final attainment of desired "batch" of liquid.

Some calibrators utilize a delicate magnetically-operated reed-switch on the balance-beam of a weigh scale. Others employ liquid-level switches to actuate the counter. Still others, whose calibration facility depends on the displacement of a measured volume (as in a "Meter Prover"), use a linear movement of "position" switch to trigger the counting process.

Some emphasis should be placed on the ability of the pulse-counter to faithfully count only true flow meter pulses, and to reject fraudulent pulses. What is a "fraudulent" pulse? This is any reversal of polarity not actually representing a flow meter-measured chunk of liquid. It may be more easily understood by an illustration:

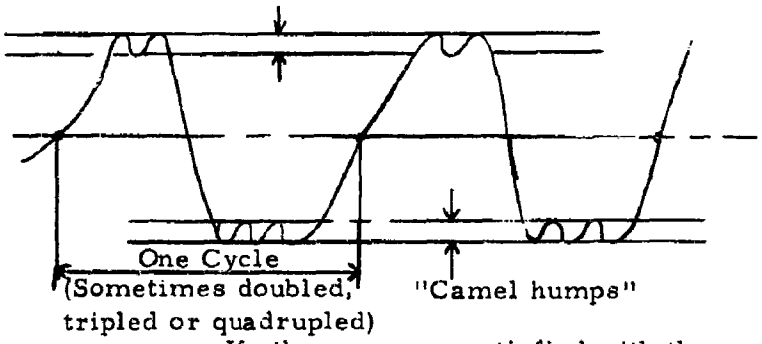
Figure 6. Natural Flow Meter Pulses:



A "sine-wave" normally generated by a flow meter with a magnetic, bi-polar rotor and a passive (non-magnetic) coil.

A "saw-tooth" wave normally generated by a flow meter with an active magnetic coil, and a rotor made of highly permeable material. Each blade of the rotor generates one pulse; one revolution of a 6-bladed rotor generates six pulses.

Figure 7. Fraudulent Pulses



Unusual bearing wear results in "camel-hump" waves that often double the count; always cause sporadic counting.

A double-count depends on trigger (threshold) level of counter, voltage-wise.

If, then, we are satisfied with the purity of the flow meter signal (by watching it on an oscilloscope), we may rest assured that two pulse counters will agree to within four counts. (One count possible error at the beginning and one at end of counting period, times 2.) That is, we will if the counters themselves are in good condition and are properly shielded and grounded, for otherwise they may also count spurious signals (such as 60-cycle from the power supply). Most counters have a built-in self-check, usually a 1-kc crystal source.

Individual preference dictates choice of decade display: the vertical or the circular zero-through-nine lighted readout. Flow meter manufacturers themselves use (and sell) both types; they are equally accurate.

If the time period (elapsed time) of a run is desired, for accurate flow-rate measurement, a seconds timer may be used. This instrument is very similar to the EPUT-type counter.

It is always prudent to view the wave-form of the flow meter on an oscilloscope throughout the calibration to insure that a reliable wave is always present.

The pulse-counters should have a minimum threshold, or should "trigger," at a voltage-level below that corresponding to the weakest signal expected. Most counters start counting when the voltage-level reaches 100 mv.

Therefore, if the flow meter to be calibrated has a peak-to-peak output of 1.0 volt at maximum flow, and a proportionate strength of 0.10 volt at 10 per cent flow, this 100-mv minimum signal should be ample to assure accurate counting. Otherwise, a preamplifier must be used.

The meter-prover (described later) provides "start" and "stop" impulses to open and close the gate on the EPUT or pulse-counter. Likewise, any scale-beam or liquid-level contact can do the same.

It is very important to observe these basic recommendations:

1. Redundancy in pulse-counting is cheap insurance; always use two counters connected in parallel to the flow meter under test; if they always agree within four pulses, you may rest assured that the count is accurate.

2. It is almost as important to keep a "reference" or "back-up" flow meter in the line in series with the flow meter under test. This second flow meter can be switched to the counters to verify the other flow meter's readings.

3. Have an oscilloscope (with camera attachment) on constant duty, and use it to verify the wave-form. If the "camel-humps" start showing up, you know you will have inaccuracies. Take a "picture" of the wave-form produced by a new flow meter. File this with the calibration data as a check on the wave-form produced by the same flow meter with worn bearings.

4. To provide a history for future flow meter calibration correlation, it is quite appropriate to maintain, as a minimum requirement, a log of the density and viscosity of the media (test-liquids) used. In-line densimeters and viscosimeters are available from the flow meter manufacturers, or can be recommended by any of them. Alternatively, a sample of the test medium can be analyzed in the laboratory.

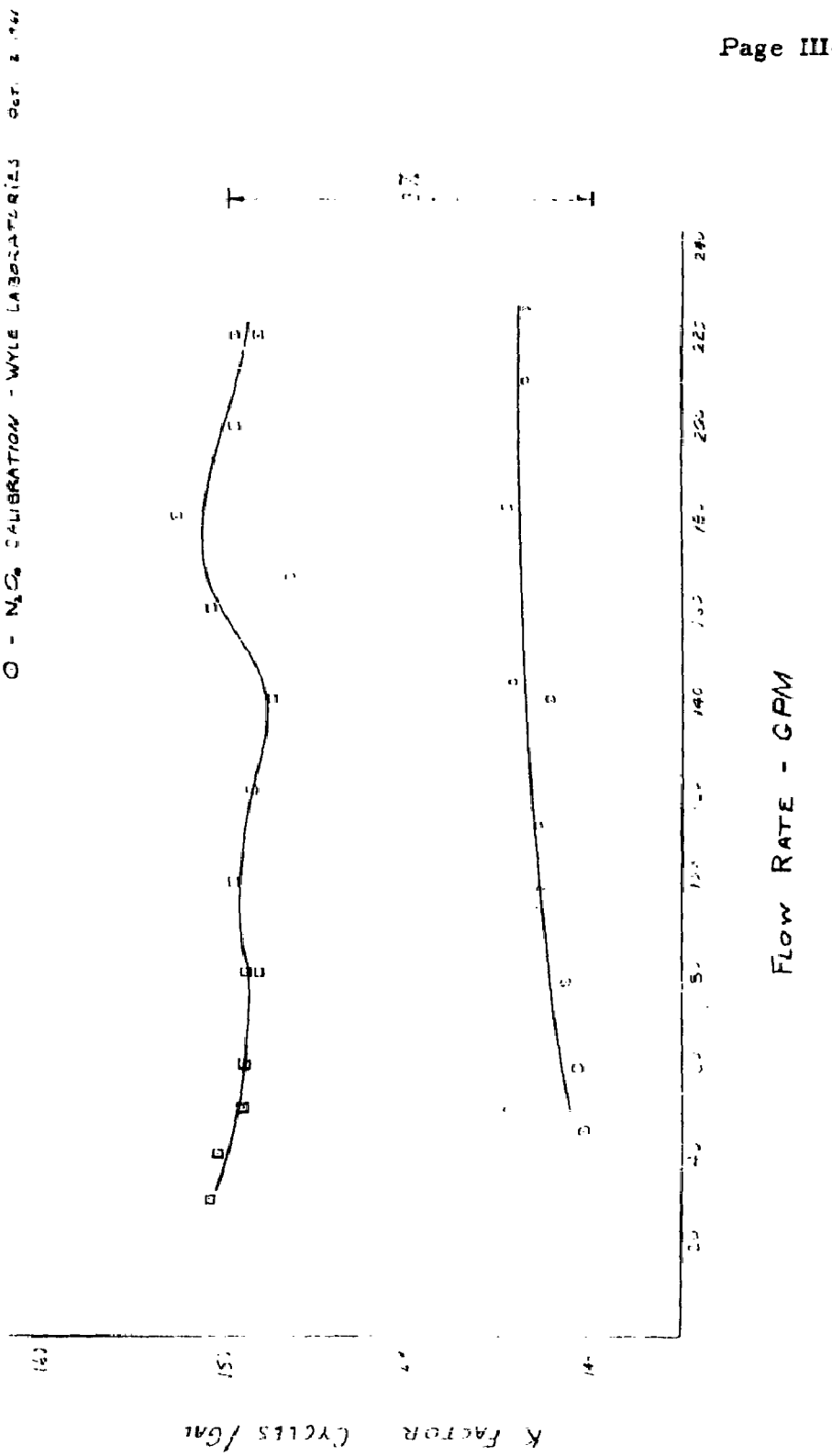
5. Have an accurate resistance-type or thermocouple-type temperature probe in the test line four diameters downstream from the flow meter (see ISA - RP31.1, 31.2, 31.3). A bourdon-spring pressure gauge with remote dial on the operator's console is also desirable, to monitor line pressure.

H. Correlations

1. Generalized Correlations. - Generalized correlations which predict turbine meter behavior based on fluid properties and meter size have been presented in the literature by Shafer, Lee and Karlby, Yard, Hochreiter, and others (bibliography A-9, 21, 22, 23). In one correlation the ratio of frequency divided by kinematic viscosity is plotted as a function of pulses per unit volume of flow. Thus, families of curves can be developed for fluids of differing voscosities. One manufacturer designs all its meters, regardless of size, to fall on a single curve. Shafer analyzed many makes of meters at the National Bureau of Standards and states, "... a curve is exactly true only for the particular meter calibrated as manufacturing tolerances are not sufficiently accurate to predict the exact performance of any turbine meter .... Summarizing the viscosity-rate tests it has been observed that the lower rates, smaller meter sizes and higher viscosities all tend to decrease the range of linear operation ... for meters of the same nominal flow range, the linear range differs considerably among the various makes, sometimes from a minimum of 5 to 1 to a maximum of 50 to 1." (See bibliography No. A-9.)

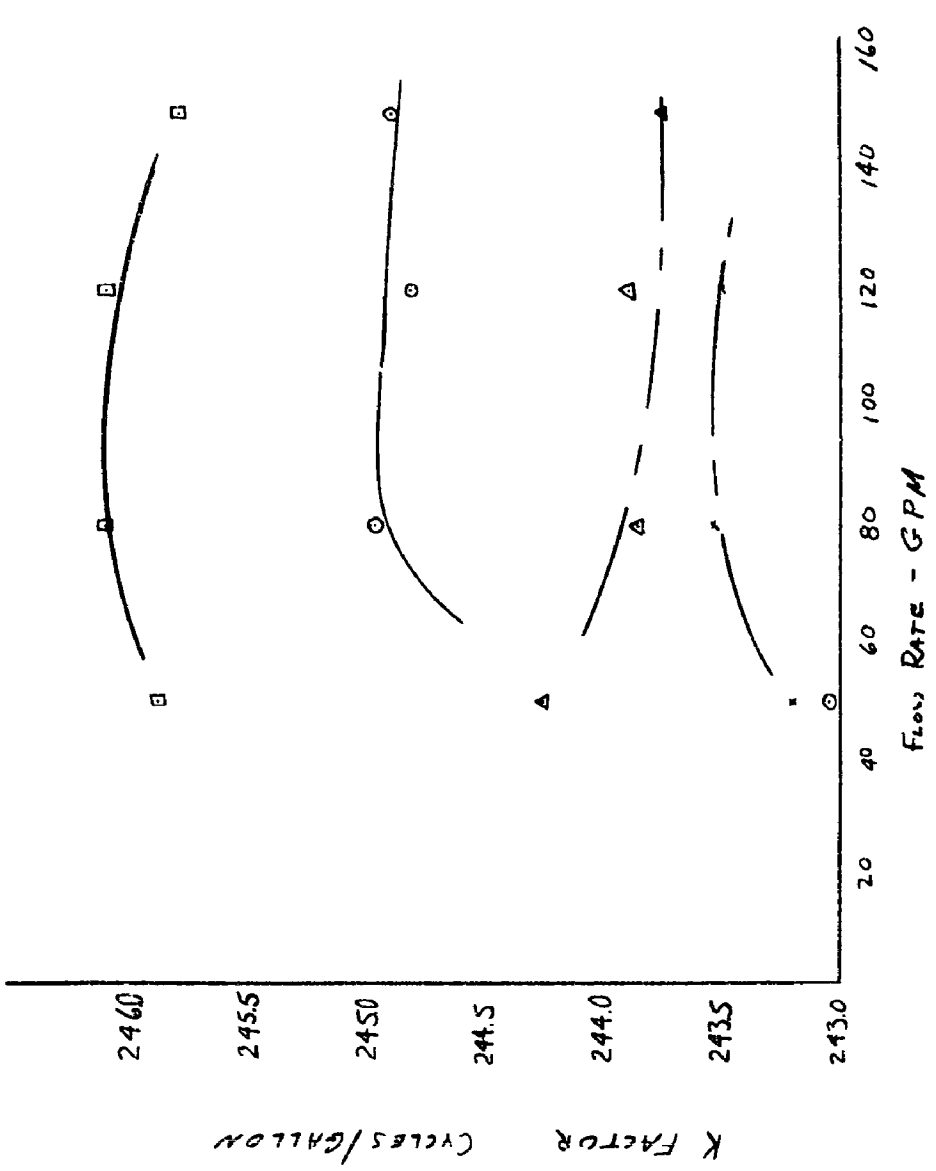
2. Storable Propellants. - With the exception of RP-1 fuel, correlations between water and storable propellants are nearly non-existent. The only calibration facility located with capability of utilizing storable propellants is that of Wyle Laboratories at Norco, California. Wyle's data, though, has been limited to only a few runs on N_2O_4 and 50-50 UDMH/Hydrazine on 2-inch and 2-1/2 inch size flow transducers. Kerosene (RP-1 fuel) correlation data are available in the literature (bibliography reference A-23), and in private files of meter manufacturers.

Figure 8. N_2O_4 vs. Water Flow Calibration
Potter Meter Model 2½A-2061



0.5%

Figure 9. N_2O_4 vs. WATER FLOW CALIBRATION



N_2O_4 - WATER FLOW CALIBRATION CORRELATIONS

Source: Telecon, Lee Mortenson of Wyle Laboratories on June 7, 1962

Potter 2-1/2 A 2061 (See Figure 8)

gpm N_2O_4 Flow	(0.01103 ft^3/# at 58°F)	$K_{N_2O_4}$ Cycles/gal.	Water gpm	K_{water} Cycles/gal.
167		149.657	220	149.84
226		148.373	220	149.96
144		148.433	200	149.96
98		148.276	180	150.28
182		148.458	160	150.09
78		148.142	140	149.75
50		148.446	120	149.85
112		148.276	100	149.96
45		148.033	80	149.83
59		148.058	80	149.88
140		148.215	60	149.90
210		148.373	50	149.91
			40	150.46
			30	150.92

Potter 2" Ser. No. 68 (See Figure 9)

gpm	$K_{N_2O_4}$ cycles/gal. sp.gr. 1.457	K_{water} cycles/gal.
50	243.05	245.88
80	244.97	246.10
120	244.82	246.10
150	244.90	245.80

Potter 2" Ser. No. 69

$K_{N_2O_4}$ cycles/gal. sp.gr. 1.457	K_{water} cycles/gal.
243.20	244.36
243.54	243.86
243.51	243.90
241.90	243.76

Figure 10 **VICOSITY EFFECTS ON POTTERMETER PERFORMANCE**

(MODEL NO. 2-2305, SERIAL NO. GELM-8)
POTTER AERONAUTICAL CO. - UNION, NEW JERSEY

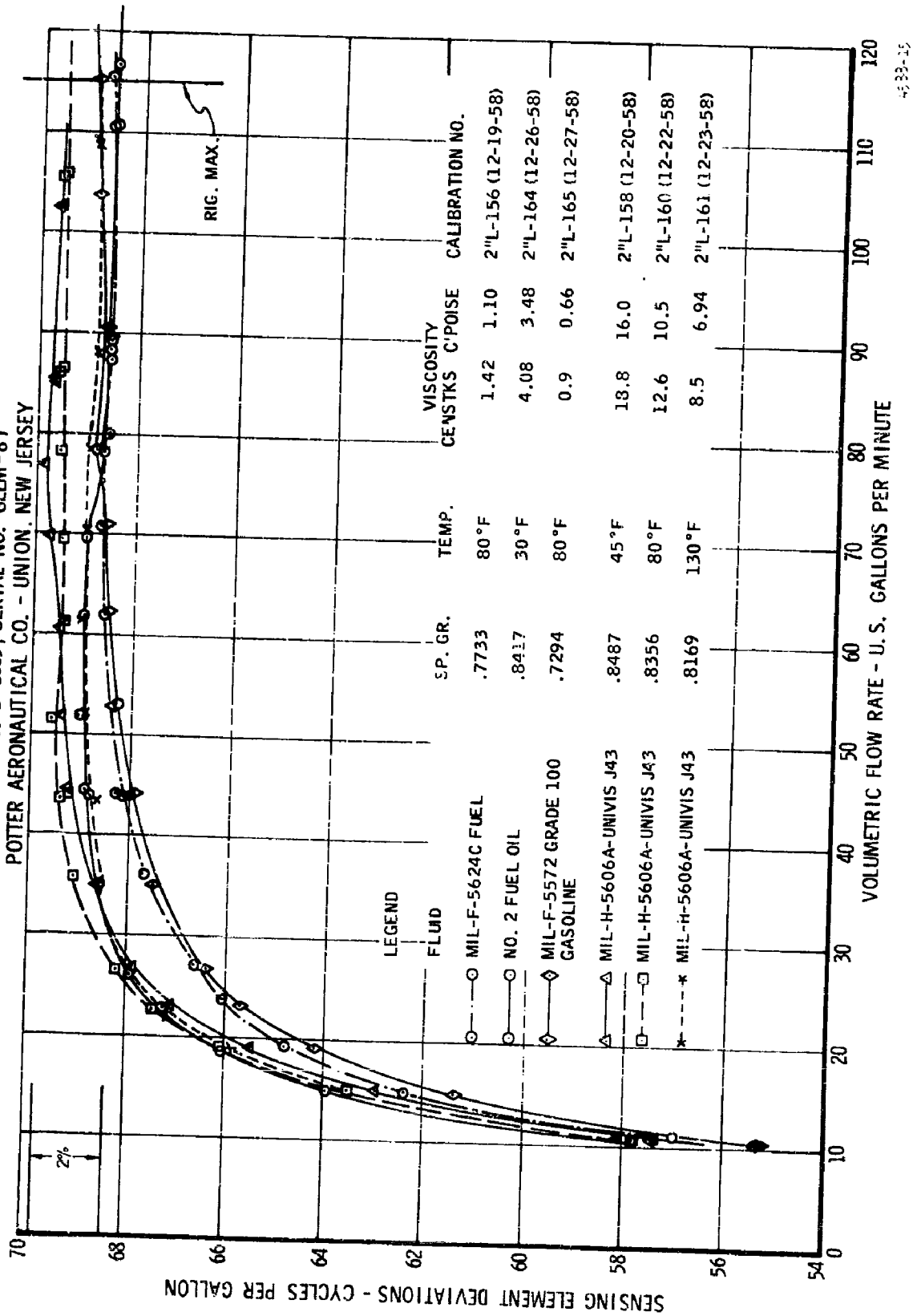


Figure 11 **PERFORMANCE CURVES ON THREE FLUIDS**

(THREE FLUIDS - INDEPENDENT OF LUBRICATION)

POTTER AERONAUTICAL CO. - UNION, NEW JERSEY

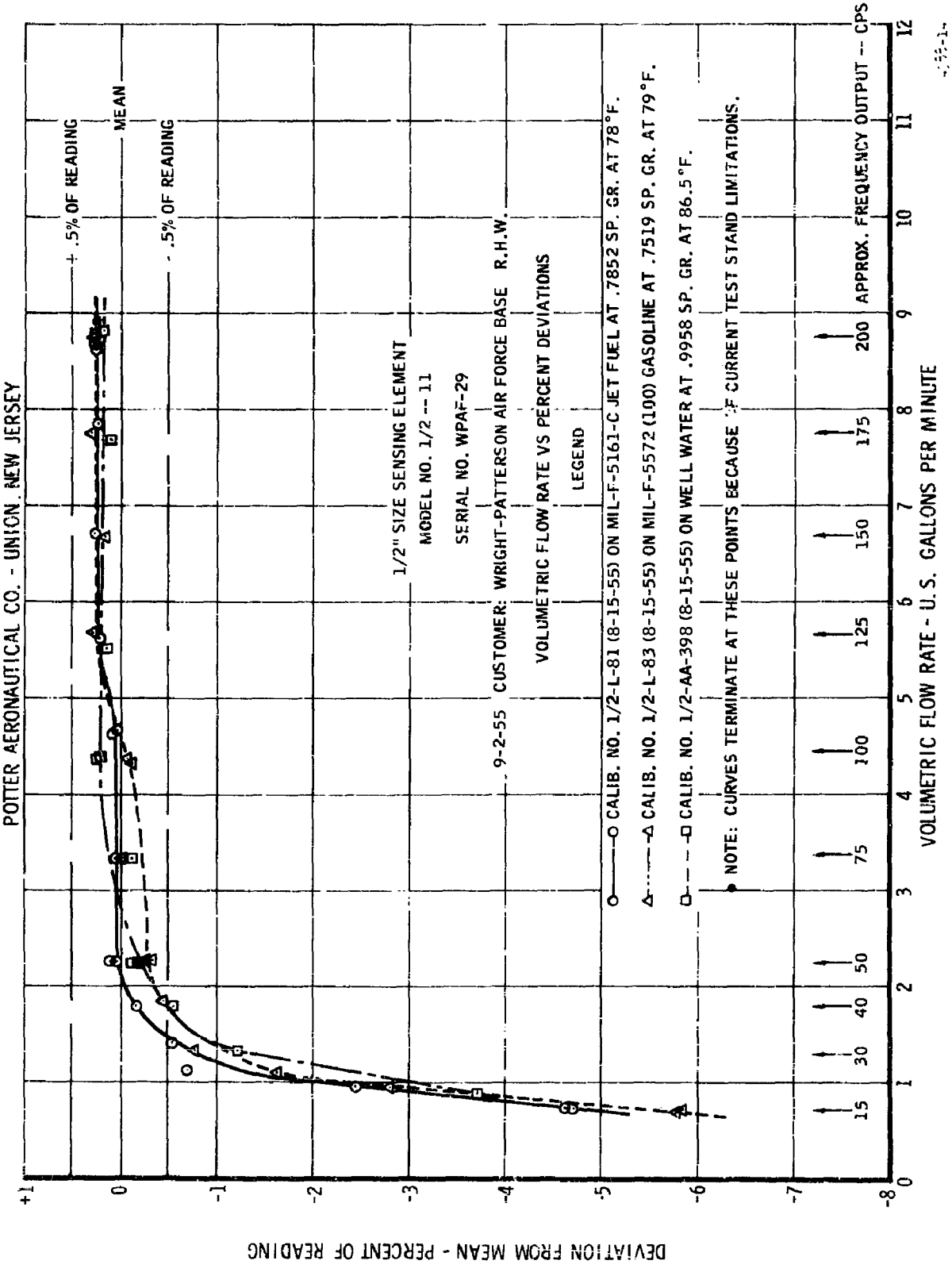


Figure 12. **PERFORMANCE CURVES ON THREE FLUIDS**
(THREE FLUIDS - INDEPENDENT OF LUBRICATION)
POTTER AERONAUTICAL CO. - UNION, NEW JERSEY

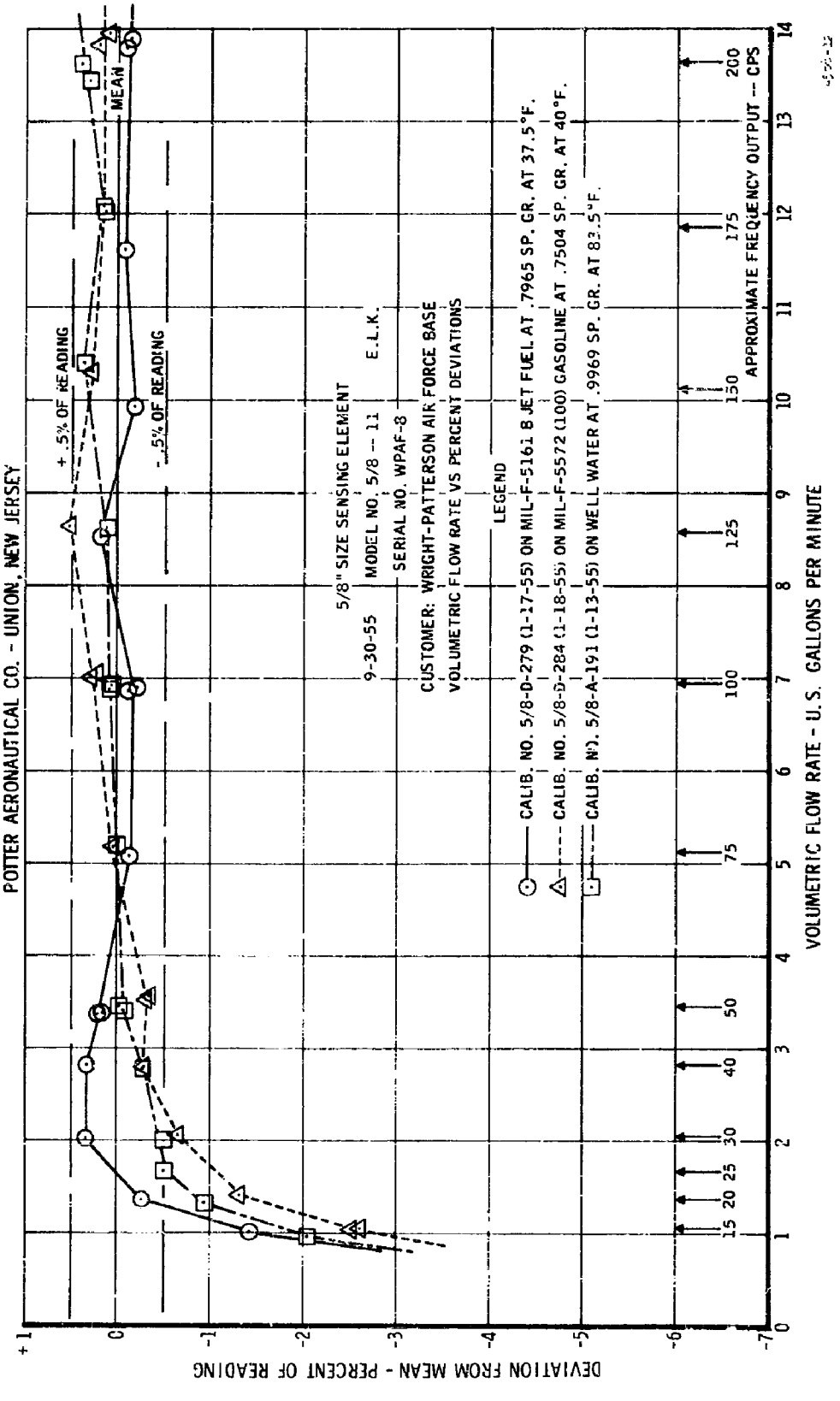
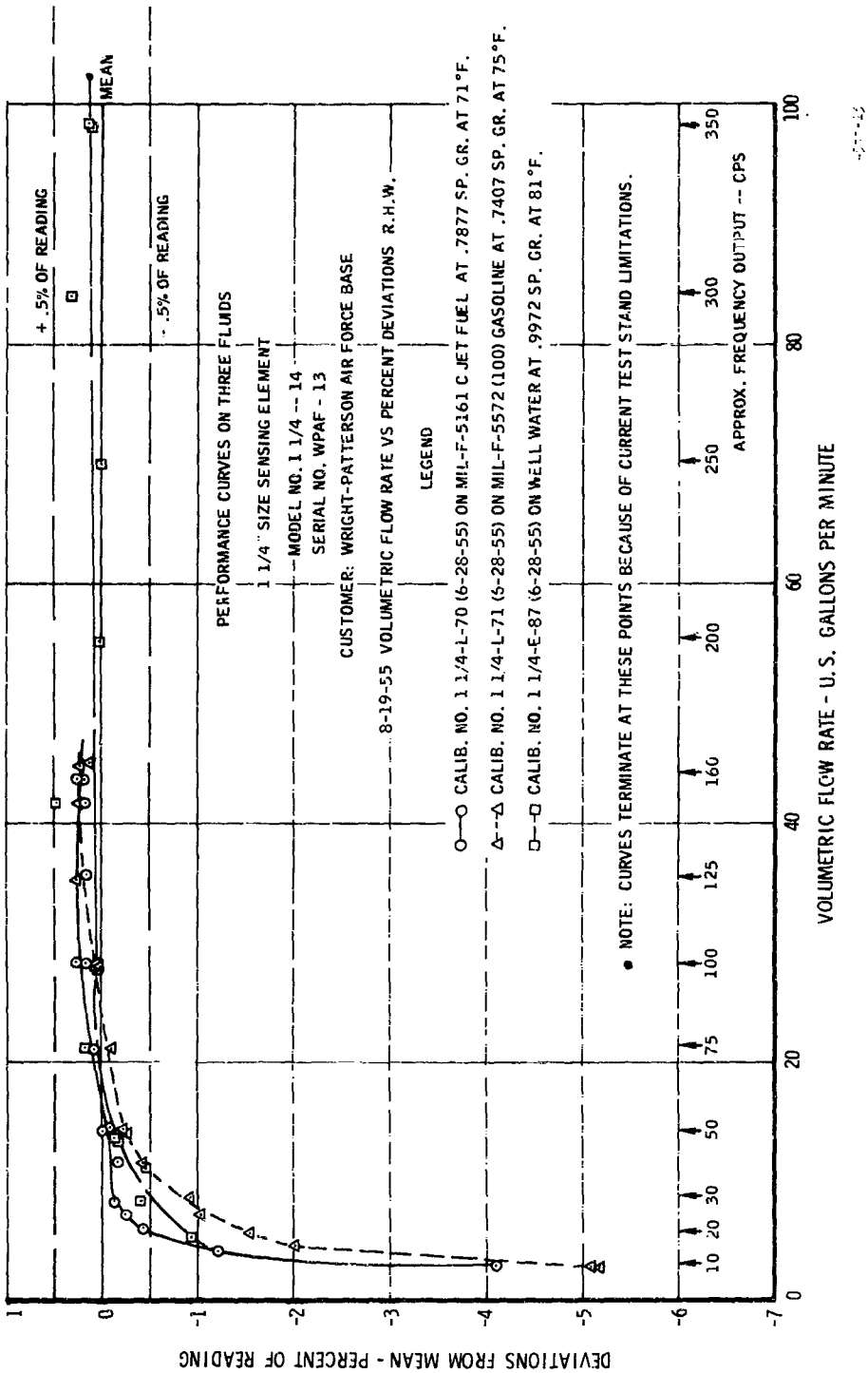


Figure 13 **PERFORMANCE CURVES ON THREE FLUIDS**

(THREE FLUIDS - INDEPENDENT OF LUBRICATION)
POTTER AERONAUTICAL CO. - UNION, NEW JERSEY



3. Cryogenic Propellants. - The users of turbine-type flow transducers for measuring cryogenic liquids, specifically liquid oxygen, nitrogen, and hydrogen, have developed a lack of confidence over the past decade in the predictable relationship between a water-calibrated K-factor and its cryogenic equivalent. In the aerospace industry this water-to-cryogenic correlation has been receiving much attention, and deservedly so, because it is particularly difficult to accurately calibrate a flow transducer with a cryogenic liquid. The reason for this is that both volume and weight determinations are precisely made only by the most careful attention to special techniques. However, pulse-counting is not a difficult measurement in cryogenic applications. Among the measurement problems peculiar to cryogenic volumes and weights are:

a. Boil-off losses, which have to be either minimized by maintaining high system pressure, or actually determined by differential level or weight measurement of the supply or receiving vessel, or by metering the gas.

b. True density values are almost always questionable. A temperature measurement immediately downstream (ISA recommends four pipe diameters) is usually used as the basis for assuming a density or specific weight. Some users actually determine both the volume and weight of liquid passed through the meter, thus avoid the inaccuracy of an assumed density.

c. Cavitation or two-phase flow must be avoided at all costs. This phenomenon easily occurs in a cryogenic system if too low a pressure is maintained at the flow meter. A turbine-type flow meter is especially prone to cavitation error by virtue of the tendency of the rotor blades to produce local incipient cavitation through their very shape: they are hydraulically inefficient.

d. Dimensional changes in the transducer parts due to thermal shrinkage can produce incalculable errors if uneven geometry results. The bearings can also become sluggish, adding to the low-flow friction unbalance. The rotor and housing geometry can change disproportionately if differentially contracting materials are used. And they almost always are: the housing if of a non-magnetic metal, the rotor is magnetic, and they usually have different coefficients of thermal expansion. Therefore, a calculated difference between a water K and a cryogenic K, using a thermal coefficient of expansion (contraction) is not usually sufficient. (See Addendum I, ISA Recommended Practice RP31.2.)

e. Liquid hydrogen, more than liquid oxygen and nitrogen, presents a special problem not only because it is much colder (over 100°F colder), but because its viscosity and density are so low. Users of LH_2 flow meters, therefore, have found it impossible to correlate by inferential techniques and always have had to rely on an actual LH_2 calibration.

As a practical necessity, most cryogenic flow meters have traditionally been flow-calibrated in the actual cryogenic liquid, and in the using configuration. For, the great majority of cryogenic flow metering installations in the aerospace industry have not been free from error-producing inlet conditions, nor has it always been possible to eliminate these errors by using straightening vanes ahead of the meter.

There are, of course, two approaches to the "in-use" calibration problem: one is to calibrate during actual filling or draining of a tank through the flow meter during a regular system test or engine run. The dewar tank, equipped with liquid-level and/or weight transducers, serves as a volume or weight standard by appropriate density translation as may be necessary. The other approach is to deliberately set up a flow meter test facility. The latter solution to the cryogenic calibration problem is preferred by most users because it is possible to instrument to a higher degree of perfection, and it is usually easier to schedule series of runs at varying flow rates.

However, it is noteworthy to observe at this point that there are in this country no more than half-a-dozen or so cryogenic flow meter calibration facilities especially designed for this purpose. It is a known fact that the Wyle Laboratories facility at Norco, California has the only commercial cryogenic flow meter test stands. Some valuable mass flow meter comparison studies for NASA are presently underway at Norco. The other cryogenic flow meter calibration facilities, strangely enough, are not owned by flow meter manufacturers, but are jointly owned and operated by DOD contractors and the Federal Government. In this category we find:

a. NASA's Lewis Laboratory, Cleveland, Ohio
b. NASA's Marshall Space Flight Center, Huntsville, Ala.
c. Aerojet-General, Sacramento, California
d. Rocketdyne Division, Canoga Park, California
e. Pratt & Whitney, West Palm Beach, Florida
f. Air Products & Chemicals, Inc., West Palm Beach, Fla.

From the above has come a wealth of cryogenic flow meter calibration information, among which we find in our bibliography these examples:

2) Minkin & Hobart "LH_2 Calibration Facility"
11) Bucknell "LH_2 Flow Measurement & Calibration"
12) Dow "The Cost of Instrumentation Error"
13) Grey "The Turbine Flowmeter for Cryogenic Liquids"
16) Smith "Accuracies & Calibration Techniques of Turbine-Type Flowmeters"
17) McElroy "Measuring Accuracies of the JUPITER Missile Flowmeters"
18) Minkin & Hobart "LH_2 Flowmeter Calibration Facility; Preliminary Calibration on Some Head-Type and Turbine-Type Flowmeters"
19) Favero, Mandell, and Yoder "Hydrogen Mass Flowmeter Development"
20) Wyle Laboratories "LH_2 Mass Flowmeter Evaluation and Development"

However, not all of the above-listed works treat water-to-cryogenic correlation. From those that do, we find these specific data of interest:

11) "..... up to 2 per cent non-predictability of (liquid) hydrogen calibration from water calibration." Sizes to 3-inch.

12) "One would assume that the calibration factor of a turbine-type flow meter would vary about 0.5 per cent from water to liquid oxygen. The Aerojet-General Corporation ..... has established that the actual variation from water calibration will vary from 0.2 per cent to 2.0 per cent ..... thus establishing the requirement to calibrate flow meters intended for cryogenic service in a cryogenic fluid if data inaccuracies below 1 per cent are anticipated."

13) "The only errors introduced uniquely by cryogenic-liquid operation of turbine flow meters are those of cavitation, dimensional change due to temperature, and viscosity. The latter two result from the application of calibrations utilizing a different fluid (usually water)." "It is essential to point out that the composite error lies within a ± 1/4 per cent repeatability band without an correction whatsoever for all meter pipeline sizes greater than two inches. For better accuracies than ± 1/4 per cent, or smaller pipeline sizes than two inches, corrections similar to those indicated by Figure 14 must be made." (See Page III-45.)

16) "In order to meter LOX (LO_2) flow accurately using a flow meter that has been calibrated with water, it has been found necessary at ABMA* to correct for the following:

"1) Shrinkage of flow meter housing caused by extreme low temperature of LOX.

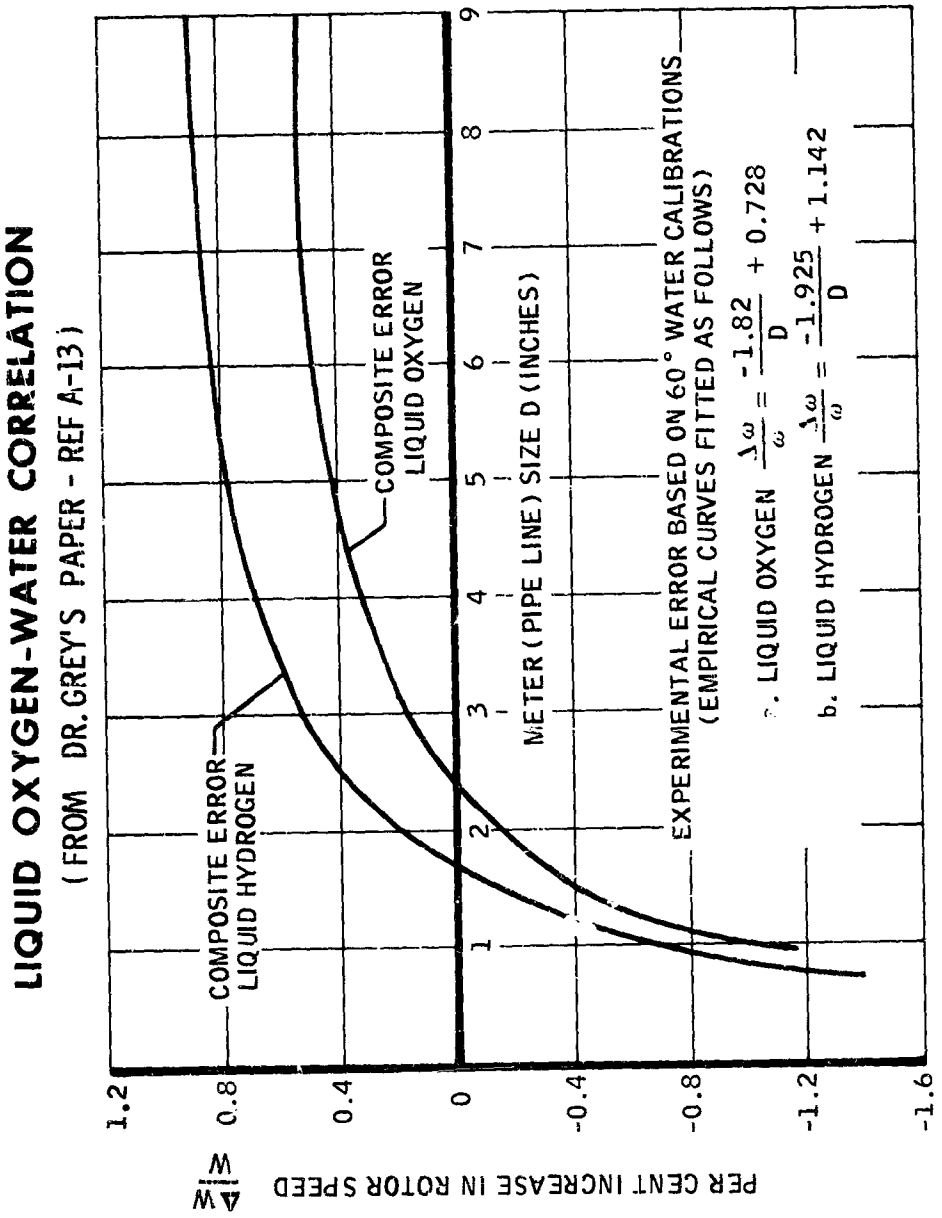
2) Viscosity difference between LOX and water.

"The two above factors, shrinkage and viscosity, cause errors of opposite polarity, with the shrinkage error predominating in large meters. A correction factor of one-half of one per cent is applied to all LOX meters at ABMA.* That is, the water calibration constant is multiplied by 0.995 to arrive at the correct calibration constant to be used for the LOX flow meters." (Seven-inch size.)

17) "Conversion factors, to be applied when flow meters are calibrated with water and used with other flow media, are determined by the size and material of the flow meter, and by temperature and viscosity of the flow media. For the JUPITER flow meters, with the calibration constant expressed in gal/cy, constants determined with water should be multiplied by a factor of 0.995 for LOX use ....."

*ABMA, Army Ballistic Missile Agency; is now MSFC.

(NOTE: References 16 and 17 were based on the same test program at Marshall Space Flight Center.)



4538-2

Figure 14

18) "Preliminary tests of several commercially available turbine-type meters show that the calibration constant (pulses per unit volume) for liquid hydrogen will differ, on the average, about 1.0 per cent from the value for water; the difference is not of the same sign for different meters."

From the foregoing referenced quotations, it is seen that the authors differ as to the degree of predictability of water-to-cryogenic correlation factors, but generally agree on the causes of this non-predictability, viz: thermal shrinkage and viscosity. They also agree on the influence of pipe-size, in that the larger size meters are more predictable (as one would expect).

As a result of this study, it is recommended that water calibration factors not be used for cryogenic turbine flow meters.

FOOTNOTE:

The formula for thermal shrinkage of a turbine flow meter, as found in ISA Recommended Practice RP31.2, is:

$$K_o = \frac{K_c}{1 + 3\alpha (T_o - T_c)}$$

Where: K_o = calibration constant (cy/gal) at operative temperature
K_c = calibration constant (cy/gal) at calibration temperature
T_o = operating temperature
T_c = calibrating temperature
α = thermal linear coefficient of expansion

Note that K_o increases as operating temperature decreases, and that the correction applies only when housing and rotor have the same thermal coefficient α (alpha).

SECTION IV

IV. SUMMARY OF INTERVIEWS AND CORRESPONDENCE WITH SPECIALISTS IN THE MANUFACTURE, DESIGN, APPLICATION AND CALIBRATION OF TURBINE FLOW METER SYSTEMS

A. Specialist Opinions*

Specialists in the field of turbine flow meter design, manufacture, and calibration were interviewed to determine the potential accuracy of turbine meters for volumetric flow measurement of RP-1, N_2H_4, UDMH, 50-50 N_2H_4/UDMH, B_5H_9, N_2O_4 and ClF_3. They were asked to discuss design parameters of a propellant flow calibration stand and to present data on tests for propellants. To provide a common denominator in discussion, all the specialists were asked the question, "Is it possible to calibrate turbine meters on water and expect $\pm$ 1/2 per cent accuracy when used on propellants?"

Answers to this question were all negative or uncertain with a few minor exceptions (for certain meter sizes where the manufacturer had limited experience on one of the propellants).

Specialists all agreed that correction K factors for converting flow calibration data based on water or other standards to propellant fluids cannot be calculated accurately from theoretical considerations alone.

B. Conclusions

Opinions of attainable accuracies for K factors based on water calibration and applied to propellants vary between 0.25 per cent to 2.0 per cent, depending on transducer size and application. Most thought it advisable to calibrate flow meters on the propellant rather than rely on water or standard organic oil calibrations.

With the exceptions of RP-1 and N_2O_4, no correlation data was found available for flow meters in the size range 1/2 inch to 2-1/2 inches.

*Interviews with specialists were by Bernard Basse. Opinions expressed were those of the individual interviewed -- not necessarily those of his employer.

Data on RP-1 indicates that water calibrations will result in errors of less than $\pm 0.5\%$ for some types of meters. Since the physical configurations developed by various meter manufacturers affect the calibration, one must qualify this by stating the limits of flow ratios over which the calibrations hold.

Lack of data on other propellants precludes more than an intelligent guess of attainable accuracy.

Most specialists favored their own pet method of calibration. These methods included standard balance arm weigh scales and calibrated volumetric tanks, used either 1) dynamically (measuring weight or volume while liquid flows into or out of tank), 2) statically (measurement before and after flow), and 3) calibrated volume tubes. Interest was also shown for the volumetric flow prover used in the petroleum industry.

C. Interview No. 1

Waugh Engineering Division
The Foxboro Company
Van Nuys, California

April 17, 1962

E. W. Miller - Chief Engineer

Waugh Engineering manufactures turbine flow meters and auxiliary readout equipment.

Mr. Miller has written for the literature (Refer to Bibliography Item 26) and is an authority on turbine meter design and application. He recommended calibration using the actual propellants, and emphasized the importance of this for small meters less than 1 inch in size. Mr. Miller discussed the turbine meter applications and made the following observations.

1. High density fluids extend low end calibration linearity.

2. Water calibration of turbine meters can be assured under special circumstances (i.e., 50-50 UDMH/N_2H_4 accuracy in 2 inch meter), but cannot be generalized for all sizes and fluids.

3. Meters are sized by equivalent ρV^2 factor; i.e., use smaller meter and higher velocity for LH_2 than for water (ρ is density, V velocity).

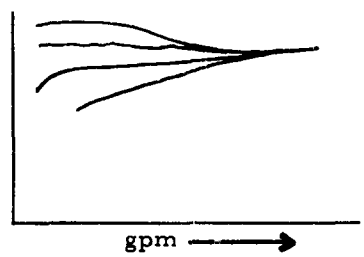
4. Correlation accuracy of metering various propellants based on water calibrations may have errors in excess of 1 per cent added to the water calibration error. The correlation error is larger for small meters.

5. Bearing life for continuous service in petroleum is about two years. The ball bearings are manufactured from 400 series steel. Useful life in water for continuous duty is less, probably six months to one year.

6. Effects of Meter Geometry

Figure 15

$K = \frac{\text{Cycles}}{\text{gal.}}$



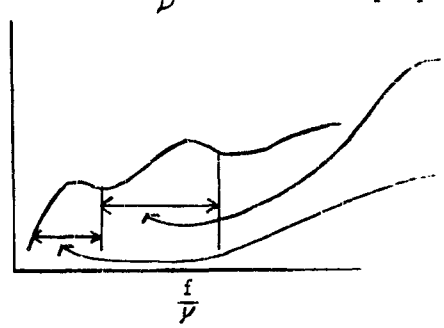
The same make, model and size can vary in flow characteristics because of differences in bearings and manufacturing tolerances (turbine clearance and blade surfaces)

7. Effects of Fluid Properties

Plot K vs $\frac{f}{\nu}$ since latter is proportional to the Reynolds Number.

Figure 16

K, $\frac{\text{Cycles}}{\text{gal.}}$



Transition region from viscous flow to turbulent flow

Region of low flow where magnetic and bearing drag (due to friction) become major factor in rotor spin rate

f = Frequency

ν = Viscosity in centistokes

8. Factors affecting shape of curve at low end:

a. Viscosity	Fluid Property Effects
b. Lubricity	
c. Bearing Drag	Geometric Properties
d. Shape of Rotor Blades	
e. Electromagnetic Load	

D. Interview No. 2

Fluid Flow Calibration Facilities April 25, 1962
Wyle Laboratories
Norco, California

Roland Clark

Wyle Laboratories has two cryogenic liquid flow test stands in operable condition, and one N_2O_4 system partially disassembled. One cryogenic system is designed to handle LO_2 and LN_2 and the other handles LH_2. All systems are designed to calibrate turbine flow meters against a balanced beam scale utilizing calibrated weights. The N_2O_4 calibration is statically determined, while the others are dynamically determined.

1. The Liquid Oxygen System consists of a 500 gallon calibration tank and a helium pressurization system mounted on a weigh platform, calibrated weights, a receiving tank and interconnecting piping, valves and fittings. In operation, the helium pressurizes the oxygen in the weigh tank and initiates transfer. Equilibrium conditions are attained after approximately ten seconds of flow. As the balance beam moves through its initial balance point, a capacitance switch which senses beam movement actuates a synchronous clock which furnishes a time base. Simultaneously, recording instrumentation is energized.

Calibrated weights which correspond to the selected weight of fluid to be transferred are then lowered to the weigh platform by pneumatic cylinders. The run is terminated when the capacitance switch again senses beam movement.

Maximum flow rate is approximately 50 pps.

The maximum gravimetric system error is calculated to be $\pm$ 0.127 per cent rms, and the maximum volumetric system error is calculated to be $\pm$ 0.213 per cent rms.

2. The Liquid Hydrogen System is similar to the oxygen system except for capacity, 8 pps, and details of system design (vacuum-jacketed lines and redundant recording equipment). Its rms errors for gravimetric and volumetric measurements are $\pm$ 0.140 per cent and $\pm$ 0.244 per cent respectively.

3. The Nitrogen Tetroxide flow calibration system has not been used for approximately six months, and is in a state of disrepair. The system appears to be cruder than the cryogenic systems. Pressurizing gas is stored off the weigh platform and corrected for by calculations based on the temperature and pressure in the ullage space before and after transfer. The weigh system is static (measures initial and final weight and is not initiated under dynamic equilibrium conditions).

Mr. Roland Clark estimated that Wyle could rebuild the N_2O_4 system for use on either storable oxidizers or fuels within one week. He thought the system could be used for calibrating with N_2H_4, UDMH, 50-50 N_2H_4/UDMH, N_2O_4 or RP-1, but could not be sure of compatibility with B_5H_9 or ClF_3 without further study.

Mr. Clark provided error analyses of the cryogenic systems Basic elements considered were:

a. Fundamental accuracy of weigh scale

b. Extraneous loading on scale (mass of piping)

c. Dynamic lag (inertia of balance arm weigh system)

d. Repeatability of the capacitance triggering switch

e. Accuracy of calibrated drop weights

f. Precision of fluid temperature measurement

E. Interview No. 3

Colorado State University
Fort Collins, Colorado

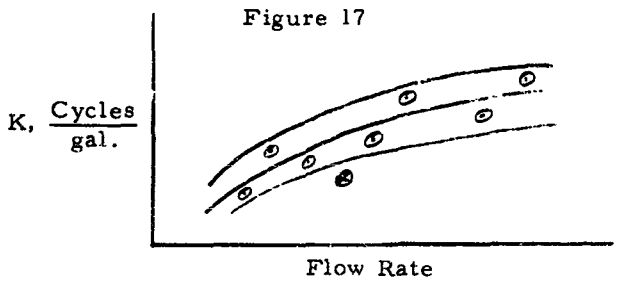
April 30, 1962

S. Karaki

Mr. Karaki, who is now studying for his Doctorate, supervises special studies in the area of hydrodynamics. He recently completed eleven research and test studies for The Martin Company on characteristics of turbine meters, determined from water and oil calibrations.

Unlike most other specialists interviewed, Mr. Karaki believes that long term turbine transducer reliability is limited to minimum errors of + 1 per cent regardless of the liquid being handled. Errors less than ± 0.5 per cent are readily obtained for a meter on a particular calibration run. When calibrations were repeated at intervals of one month or greater, however, almost invariably one or two data points would fall outside the ± 1 per cent error curve. This was characteristic of all the many makes and sizes of transducers tested.

Figure 17



Mr. Karaki is of the opinion that calibration with propellants is preferable, but not mandatory. He feels that, for low viscosity liquids, errors arising from rust deposits on turbine blades, evaporation deposits on bearings, and other random errors intrinsic to the turbine transducer operation and readout systems are large enough in magnitude so that added correlation errors (from calibration based on a different liquid) do not substantially change the overall accuracy. (The propellants under consideration have low viscosities, all less than 2 centistokes.)

Over the linear operating range of the flow meter, specific gravity variations in the range of interest, 0.6 to 2, have little effect on meter K factors.

Mr. Karaki found only minor effects resulting from bearing wear when transducers were re-calibrated after each 100 hour's use.

For calibration of small transducers, 2-1/2 inch size and less, Colorado State University utilizes a static weight system. Density is corrected for by temperature measurement

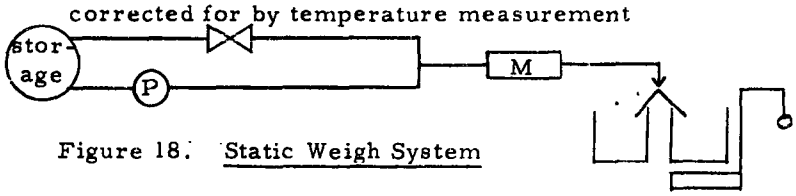


Figure 18. Static Weigh System

and calibration runs are monitored by an oscilloscope trace to assure constant flow.

F. Interview No. 4

Cox Instrument Division May 1, 1962
George L. Nankervis Co.
Detroit, Michigan

E. J. Dahn Sales Manager
A. W. Brueckner Chief Engineer

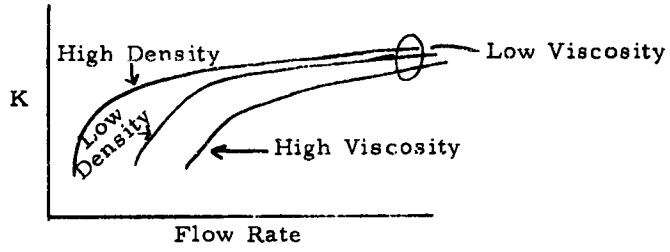
Cox Instrument manufactures turbine type flow transducers, digital and analog indicators, other instruments, flow meter calibration

stands, and load cell weigh systems.

For correlation errors less than 1 per cent, they believe it is mandatory that the transducer be calibrated on the use liquid and not on a reference liquid. When this is done, system errors of less than + 0.25 per cent are commonplace and easily obtainable, both for digital and analog readout.

Meters 1 inch and larger have relatively large maximum to minimum flow ratios in which the K factor is constant. Below 1 inch in size, viscosity and density effects result in decreased linear range.

Figure 19.



It was suggested that if non-toxic fluids with viscosities, lubricities and densities similar to the propellants could be found, they might be substituted for them during calibration. Cox has the following flow calibration capability for gases and liquids.

I Gas: Air

1. 5 cc/min - 2000 cc/min
2. 0-3000 scfm, (up to 1750 scfm traceable to the National Bureau of Standards)

II Liquids: Water and Hydrocarbons

0.4 pph - 12,000 gpm
50 pps - 150,000 pph, traceable to NBS
Counters are accurate to 3 counts in 7500 (0.04%)
1000 lb. weights are accurate to 0.003 per cent

Cox Calibrators use the dynamic balance arm system. Initial movement of the balance arm is picked up by a proximity switch (± .001 inch). To refine the proximity switch drift error, a photoelectric cell pickup will soon be substituted.

Cox flow calibrators feature course and fine flow control valves, liquid temperature controls, and readout for a digital timer, pulse counter, oscilloscope monitor, pump pressure and back pressure.

G. Interview No. 5 May 2, 1962

National Bureau of Standards
Washington, D. C.

M. R. Shafer

Mr. Shafer is a nationally recognized authority in the field of turbine type flow transducers and calibration facilities. He supervises flow calibrations at NBS and has written extensively on this subject.

Mr. Shafer pointed out that in tests on a large variety of smaller turbine transducers, the effect of mechanical drag may cause differences of 1 to 2 per cent between calibrations on the use liquid, although all the meters might agree on the test liquid.

Where ± 1 per cent accuracy is satisfactory, water calibration is reliable for meters 1 inch and larger in size provided the K (cycles/gal) constant is within ± 0.5 per cent over the range of interest and the use viscosity is less than 3 centistokes.

An equation which describes the relative magnitude of parameters affecting meter operation was analyzed:

$$\frac{Q}{ND^3} = f\left\{\frac{N\rho D^2}{\mu}, \frac{T}{N^2\rho D^5}\right\}$$

Q = Flow Rate
N = Rotor Speed
D = Diameter
ρ = Fluid Density (rho)
μ = Absolute Viscosity (mu)
T = Mechanical and Magnetic Drag
(above expressed in consistent units)

The function $\frac{N \rho D^2}{\mu}$ is dependent on the fluid properties. The larger this factor, the more turbulent the flow and the greater the range of flow over which the K-factor is constant. $\frac{T}{N^2 \rho D^5}$ is dependent on the geometry of the meter, mechanical and magnetic drag factors, and the momentum of the fluid. Obviously, low values of $\frac{T}{N^2 \rho D^5}$ result in low drag and constant K-factors. This function varies inversely with D^5 and becomes small for transducers 1 inch in size and larger.

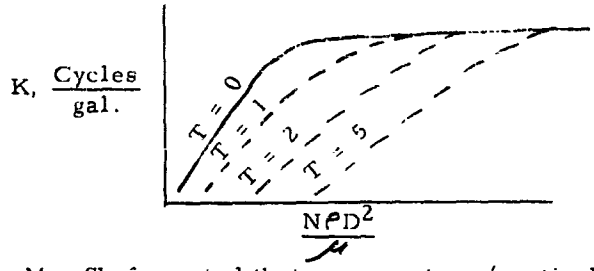


Figure 20.

Mr. Shafer noted that some meters (particularly small sizes) are sensitive to pickoff coil location and should be installed with their pickoff coil in the same orientation as when calibrated.

In discussing the design of a propellant fluid flow calibration facility, Mr. Shafer suggested that the test stand be designed for at least 4-5 times the accuracy of the transducers or $\pm$ 0.1 to 0.15 per cent. He favors the balance arm static weigh system over the dynamic system and either of these over a load cell system. He feels that the static system is far easier to troubleshoot. Depending on the diligence of the operators, dynamic systems take from a few months to a few years to eliminate errors from inertia, switching, etc. He also cautioned that flexible connections to the weigh tank must be placed in a horizontal plane to reduce weigh effects and that these are liable to be the weakest point in a design.

The National Bureau of Standards uses a modified Cox flow stand for its calibrations. For meters with low amplitude signal outputs, amplifiers (decade amplifier), Ballantine Laboratories in Boonton, New Jersey, and Kin-Tel, San Diego, California are used.

Mr. Shafer thought that meter provers of the type used in the petroleum industry might be quite practical for calibrating with toxic propellants.

H. Interview No. 6

Fischer & Porter Company
Warminster, Pennsylvania

May 3, 1962

John Kopp — Sales Engineer
A. W. Hernandez — Supervisor, Calibration Facilities

Fischer & Porter manufactures turbine type flow transducers, digital indicators, flow rate indicators and controllers, variable area flow meters, and flow calibration facilities.

Their personnel have written excellent flow meter articles for the Instrument Society of America and the American Society of Mechanical Engineers.

Regarding accuracy, they estimated ± 0.25 per cent maximum error using RP-1, and a similar accuracy for the other propellants if a substitute fluid which could simulate the viscosity, lubricity, and density could be used for calibration. For liquids with low viscosity (such as the propellants), they felt that 1/2 per cent error could be obtained using water calibration so long as the meter ranges were limited to linear portions of the flow vs K-factor curve. Their relative confidence in water calibration systems for F & P meters used on propellants is indicated below.

Meter Size	Max. Flow (gpm)	Flow Ratio Max. Flow - Min. Flow	Relative Confidence in Obtaining ± 1/2 per cent Error
3"	500	15-1	10 (Max.)
1-1/2"	100	15-1	7
		10-1	10
3/4"	20	15-1	5
		10-1	7
		5-1	10
1/2"	4	15-1	0
		10-1	1
		5-1	7
		3-1	10

if the use of the meters were limited to linear flow ranges in smaller sizes, and the maximum allowable error was ± 0.5 per cent, then a propellant calibration facility would not be needed for Fischer & Porter meters.

Fischer & Porter manufactures fluid flow calibration facilities for high flow rates based on precision bored volume cylinders and manometer column head indicators.

Mr. Hernandez emphasized the importance of operator training and maintenance of the calibration equipment, and thought that these were the most important factors in obtaining accurate calibrations. He noted that it takes the experts at Fischer & Porter from several months to in excess of one year to work the "bugs" out of a new calibration stand and constant attention is required to maintain accuracy.

In some circumstances more accuracy is obtained by calibrating one turbine meter against another standard meter rather than against the test stand. The reasoning behind this is that because of digital readout, repeatability of the turbine meter is greater than that of the calibration stand. The standard meter would be calibrated a great many times and a statistical curve obtained which averaged out the repeatability errors of the test stand. He then reasoned that for a single curve calibration check on a production meter the greater repeatability of the standard meter results in less than the random errors in the test stand. In practice, Fischer & Porter calibrated simultaneously against a test stand and a test meter.

He pointed out that neglect of air entrainment when calibrating at high flow rates, using pressurized gas, is a common error.

Fischer & Porter manufactures most designs with ball bearings, but also makes sleeve bearings for some applications. Ball bearings are 440C material which is compatible with N_2O_4 for short periods so long as the water content is less than 0.1 per cent.

I. Interview No. 7 May 3, 1962

Brooks Instrument Company
Philadelphia, Pennsylvania

Seymour Blechman Vice President

Brooks Instrument Company manufactures turbine meters in Scottsdale, Arizona and variable area meters in Philadelphia. Calibrations utilize water and standard hydrocarbons in methods similar to those of Fischer & Porter.

Mr. Blechman recommended that calibrations be performed utilizing the propellants rather than rely on water calibrations. Like Mr. Shafer, Mr. Blechman thought that meter provers of the type used in the petroleum industry could be economically utilized for direct calibration of propellant meters.

J. Interview No. 8 May 4, 1962

Potter Aeronautical Corporation
Union, New Jersey

W. F. Smith

The Potter Aeronautical Company pioneered the modern turbine meter utilizing magnetic pickup and digital counting. In addition to turbine meters, they manufacture a digital readout density recorder (Potter Densimeter) and a line of electronic flow recording and controlling devices.

Like most specialists, Mr. Smith recommended calibration with the actual propellant. He noted that in calibration of a Potter 3-inch meter on water, the linearity fell off rapidly at flows of less than 25 gpm. When calibrated with liquid hydrogen, the linearity fell rapidly below 75 gpm.

Mr. Smith provided curves showing comparison calibrations on gasoline, jet fuel and well-water for meters ranging from 1/2 inch, 5/8 inch, 1-1/4 inches, 1-1/2 inches, and 2 inches in size. In all these, the gasoline and jet fuel calibrations agreed with the water calibration within 1/2 per cent. (See Pages III-37 to III-40.)

Potter performs its calibrations using water or hydrocarbon liquids. Calibrations are carried out on dynamic balance arm weigh systems using magnetic proximity switches mounted on the balance arm to trigger timing and pulse counting equipment. In discussing flow calibration stands for toxic propellants, Mr. Smith suggested investigation of petroleum type meter provers.

K. Interview No. 9 May 16, 1962

Quantum Dynamics
Tarzana, California

Dr. F. F. Liu

According to Dr. Liu, Quantum Dynamics is primarily a research organization. The company specializes in measurement of transient phenomena.

Dr. Liu's turbine meter has several unique features. Each meter has two turbine rotors. The downstream rotor, called the slave turbine, is attached to the shaft and is driven by the fluid. The upstream rotor is the measuring turbine and rides "piggy-back" on a bearing mounted on the shaft. By this means the relative motion between the measuring turbine and its bearing becomes small, and frictional resistance, which tends to control the rpm at low flows, becomes very small. In addition to eliminating low flow friction, Dr. Liu claims that the use of two rotors at fixed distances produces a standing wave over the measuring turbine during transient flow (he described this as analogous to an electrical impedance match), providing accurate and instantaneous response. The pickoff is also unique and works from turbine blade-effected modulation of a 4 megacycle carrier, thus eliminating magnetic drag. Special light-beam consideration to the hydrodynamic lift and drag effects of the fluid on the blade reduce pressure drop and increase response. The overall effect, he claims, is a more accurate, high response meter with an extended linear flow range.

In some applications, transient (millisecond) responses are more important than long-term calibrations. Dr. Liu suggested a research project to study transient effects on signal strength and on accuracy during response.

Quantum Dynamics manufactures its turbine meters (other than prototypes) through subcontracts.

L. Interview No. 10 June 11, 1962

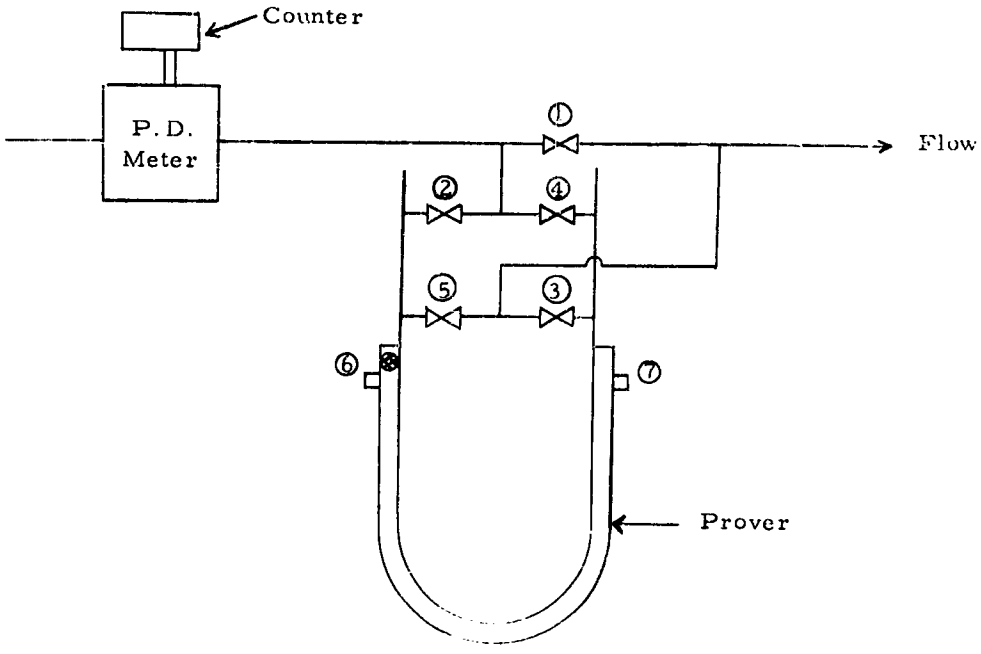
Calnev Pipe Line Company
Colton, California

C. D. Murphy and Ivan Ricketts

Calnev utilizes positive displacement meters (and not turbine meters) in its liquid transmission lines. This interview is included here, however, because Calnev calibrates its meters volumetrically with a "meter prover" which has an error of less than 0.02 per cent. The meters are calibrated while on-stream under normal operating conditions to provide an on-stream flow measurement error of 0.05 per cent by volume. While modifications are required to revise the materials of construction suitable for propellant handling, the meter prover system appears to have the potential to greatly diminish flow measurement errors if applied in the aerospace industries.

The Calnev meter prover is installed in its Colton, California pump station. It is manually valved onto the main line for meter calibration approximately once a week as illustrated on the following page.

Figure 24. Meter Prover



By closing valve (1) the flow can be made to go through the prover either left to right (valves (2) and (3) open) or from right to left (valves (4) and (5) open). A spherical ball (shaded) starts and stops the meter counting mechanism as it passes the mechanical switches (6) and (7). The meter is not considered satisfactory unless the error on 10 double runs (one run from left to right and one right to left) is within 0.05 per cent of the prover.

The meter prover is superior to previous calibrators used in the petroleum industry (i.e., volumetric tanks). Because it requires essentially no operator skill it is readily adaptable to remote control and can calibrate without interfering with on-stream flow conditions.

M. Interview No. 11 June 11, 1962

Southern Pacific Pipe Lines, Inc.
Los Angeles, California

M. J. Hogan

Mr. Hogan stated the meter prover is the first major advancement in flow measurement in pipe transmission in 30 years. Southern Pacific is placing them in all new lines and will eventually replace all existing volume tanks. The meters, spread over hundreds of miles distance, can be calibrated locally or remotely at the Los Angeles central office.

N. Telephone Consultations

1. Aerojet-General April 20, 1962
Sacramento, California

Mr. Jim McWilliams
Mr. John Close

Water-to-propellant correlation (except for cryogencis) is of negligible magnitude. Water-to-cryogenics correlation factors are of considerable magnitude. Storable propellant calibrations are not performed by Aerojet-General.

2. Rocketdyne Division April 20, 1962
Canoga Park, California

Lawrence H. Groeper

Rocketdyne does not calibrate turbine meters using storable propellants. Use of strain gage load cells for flow meter calibrating in water is a reasonable approach. Rocketdyne measures engine thrust by strain gages and the manufacturer's claim of errors of about 0.15 per cent are fair when used in conjunction with techniques which electrically balance the readout instrumentation for each run.

SECTION V

V. METER PROVERS

A. Discussion

With only minor modifications for aerospace usage, meter provers appear to have potential to reduce flow measurement errors by an order of magnitude of ten.

Meter provers are a relatively new development in the petroleum transmission pipeline industries. They have proven very accurate (± .02 per cent error magnitude) and reliable in use; and a tentative draft of a design standard for the American Petroleum Institute (see Addenda) has been prepared.

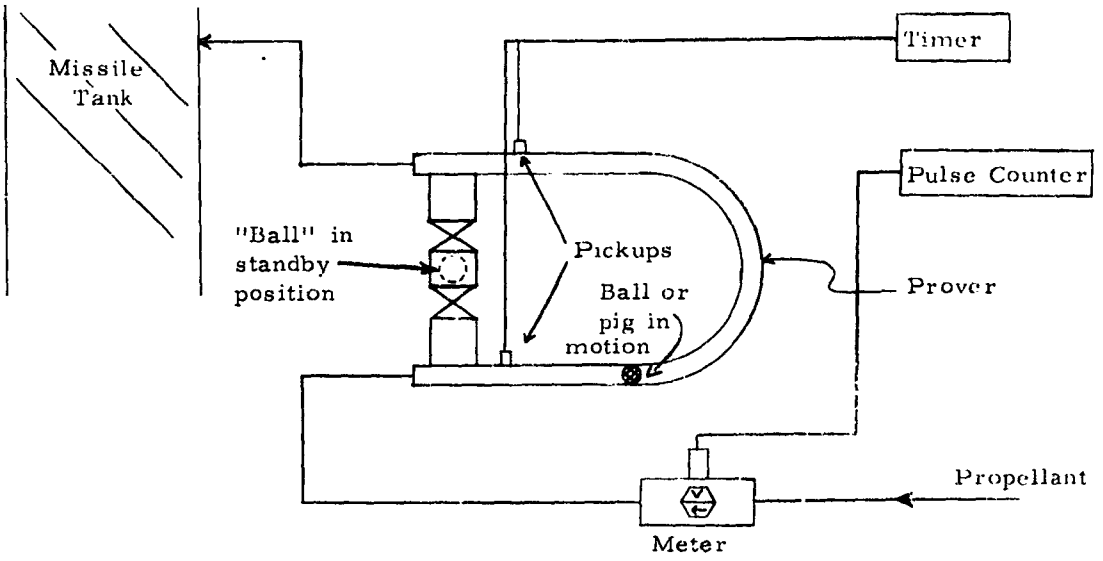
Simple in operation, the prover consists of a precision-bored tube and a fluid-driven piston which forms a leak-tight seal against the tube wall. Liquid flow forces the piston to travel between two contacts which are separated by an accurately known volume. Electronic measurement of time for the known volume displacement provides volumetric flow rate. In actual operation the piston is a plastic ball, or a cylinder with end seals (called a pig). These are illustrated in the API Standard.

In current practice, turbine-type flow meters are calibrated on water to determine the K factor (in cycles/gal.) and this factor is applied to the meters in use on propellants. Such a technique results in a probable error of approximately ± 1 per cnet in propellant to-water correlation, to which must be added the imprecision of the flow meter itself: another ± .2 to 1.0 per cent.

If, instead, the meters were calibrated on the propellants, this error might be reduced to, say, ± 0.5 per cent. (The residual error is due to physical changes in the bearings, to temperature variations, to variations in piping configuration between calibration and usage, and to physical and chemical variations allowable within military specification for propellants.) This would be true whether the meter were calibrated on a weigh scale or volumetric meter prover.

Quoting from the API Standard introduction: "The chief advantage of most of these mechanical displacement type provers is that during proving, the flow of the liquid through the meter being proved is not interrupted. This permits the meter to be proved on a continuous flow without starting or stopping the meter." This principle could be applied as propellant is transferred to a missile in a manner shown in the following sketch.

Figure 22. Meter Prover Applied to Propellant Loading System



In operation, the prover ball would be retained in a standby position (dotted) until a calibration is initiated. By opening the bottom valve, the ball is injected into the stream, passes between the two pickups, thereby calibrating the meter. It then returns by gravity to its standby position between the valves (bottom closed and top open).

Since variations in piping configuration, temperature, and liquid properties between a calibration run and loading run no longer exist, the only remaining errors are the repeatability of the meter and the absolute accuracy of the prover. These are of an order of magnitude of 0.05 per cent and 0.02

per cent respectively. If a continuous recording densimeter with an error of less than 0.05 per cent is used in conjunction with the prover, then it would be possible to determine absolute mass flow with an error of less than 0.15 per cent (prover 0.02 + meter repeatability .05 + densimeter .05 = .12 per cent, and r.m.s. value is .07 per cent). Such a system could prove very effective in the notoriously "difficult-to-calibrate" small meters under 1-inch size.

Summarizing, the approximate magnitudes of errors of the various systems are:

Calibration System	Magnitude of Volumetric Error
Water Calibration (applied to propellant)	± 1.0 per cent*
Propellant Calibration	± 0.5 per cent*
Meter Prover (in operating line)	± 0.07 per cent

*Errors can be much larger for meters under 1 inch in size for these two systems.

The meter prover also has potential use as an airborne component. For long duration flights in which the propellants are fed at slow rates, meter provers could be installed in series with the turbine meter to provide in-flight calibration and greatly improved reliability.

Details of design and operation are described in the attached Tentative API Standard 1101.

Whether installed directly in the operating line or used only as a calibrating device, the meter prover appears to have several advantages over other types.

a. It has a smaller absolute error than other commercial systems.

b. It calibrates directly in terms of volume, eliminating the necessity for density, viscosity and other corrections.

c. Except for extremes in temperature, it is not affected by ambient conditions.

d. It is likely to be less costly to purchase and install than other systems.

e. It is simple in design and concept.

f. It eliminates operator error, is easy to operate, and lends itself most readily to remote control.

g. It is more versatile and can be used over a greater maximum-to-minimum flow range.

h. It is easy to clean, flush, dry and maintain.

i. It is rugged and can be inexpensively designed with a wide safety margin.

Meter provers have a possible disadvantage in that it may be more difficult to make the seals leak-free on storable propellants than on hydrocarbons. The velocity between sealing surfaces is relatively slow, however, and the seals are readily replaced (since leaks are easily detected). The problem, if it should develop, could be confidently handled by a seal development study and by scheduled maintenance and seal replacement. The Martin Company at Denver, Colorado is currently performing compatability tests on meter prover seals with Titan II propellants (nitrogen tetroxide and 50-50 UDMH/hydrazine).

By addition of vacuum insulation, meter provers may also prove adaptable to use for cryogenic liquid calibrations. In this case, the advantages outlined above are amplified as is the potential problem of seal leakage.

SECTION VI

VI. COMMERCIAL CALIBRATION FACILITIES

In order to determine where facilities are available in private industry, The Marquardt Corporation addressed the following letter to the companies listed below.

"Gentlemen:

The Marquardt Corporation is currently performing a study for a missile propellant fluid flow calibration facility for the United States Air Force. One of the objectives of the study is the determination of available calibration facilities in private industry which can utilize one or more of the propellants listed below for direct calibration of turbine type flow meters in the size range 1/2 inch to 2-1/2 inches. Desired flow rates range from 1 to 450 gpm.

We would appreciate information regarding which of the propellants you can handle, a description of your system(s), (weight, volumetric, etc.) including accuracy, capacity and other pertinent data.

This information will be utilized to determine where and to what extent the Air Force can supplement its existing water calibration equipment without construction of new facilities.

Cryogenic Liquids

Oxygen	Hydrogen
Nitrogen	Fluorine

Storable Propellant Liquids

Nitrogen Tetroxide
Unsymmetrical Dimethyl Hydrazine
Hydrazine
50-50 Blend (N_2H_4 and UDMH)
Pentaborane
RP-1
Chlorine Trifluoride

Water

Very truly yours,"

Letters were sent to:

Douglas Aircraft Company, Sacramento Missile Field Station,
Sacramento, California

United Technology Corporation, Development and Test Site,
Coyote, California

Aerojet-General Corporation
Sacramento, California

General Dynamics/Convair, Electro-Mechanical Standard Lab
San Diego, California

General Dynamics/Ft. Worth, Fluid Dynamics Test Lab
Ft. Worth, Texas

Rocketdyne Division of North American Aviation
Canoga Park, California

Aerojet-General Corporation
Azusa, California

Lockheed Aircraft Corporation
Burbank, California

Wyle Laboratories
El Segundo, California

Air Products Company
Trexlertown, Pennsylvania

General Electric Company, Evendale Plant, Flight Propulsion Lab Dept.
Cincinnati, Ohio

Foxboro Company
Foxboro, Massachusetts

Bailey Meter Company
Wickliffe, Ohio

Taylor Instrument Companies
Rochester, New York

Brown Instruments Division
Philadephia, Pennsylvania

National Bureau of Standards, Cryogenic Engineering Lab
Boulder, Colorado

National Bureau of Standards
Washington 25, D. C.

Stellardyne Laboratories
El Cajon, California

Potter Aeronautical Corporation
Union, New Jersey

Waugh Engineering Division
Van Nuys, California

Cox Instruments
Detroit, Michigan

Brooks Instrument Company
Hatfield, Pennsylvania

Revere Corporation of America
Wallingford, Connecticut

Space Instrumentation Company
Santa Monica, California

Plantation Pipe Line Company
Atlanta, Georgia

Fischer & Porter Company
Warminster, Pennsylvania

Aro, Inc., AEDC
Arnold Air Force Station, Tennessee

Hamilton Standard
Windsor Locks, Connecticut

Pratt & Whitney Aircraft
East Hartford, Connecticut

Hydropoise, Inc.
Scottsdale, Arizona

Sixteen replies were received. Only one company (Wyle Laboratories) reported facilities for calibrating with storable propellants. Four reported facilities for calibrating with cryogenics (Aerojet-General Corporation, Rocketdyne, Wyle Laboratories, and Air Products for AEC), and many reported the capability to calibrate with hydrocarbons and water. (Rocketdyne performs storable propellant calibrations during loading at test stands, but these would not be applicable to this study.

A. Summary of Replies to Letter of Inquiry Regarding Liquid Flow Calibration Capability

Source	Capability
Aerojet-General	Liquid oxygen, liquid nitrogen and water Water Capacity -- 1000 lb/sec. Storage Capacity -- 300 ft^3 plus startup and after flow tank Pressurization -- 150 psi Line Diameter -- 10 inches Repeatability --- $\pm$ 0.05 per cent

Source	Capability
Rocketdyne	In-place calibration of propellants during transfer operations; water-oil and water-glycerine mixtures.
Potter Aeronautical	Water, hydrocarbons and freon.
Air Products & Chemicals, Inc.	None - Described LH_2 system in West Palm Beach constructed and operated for AEC. 1000 gpm Gilmore load cell weigh system.
Taylor Instrument Companies	Water only.
National Bureau of Standards Boulder, Colorado	None
Minneapolis-Honeywell	No facilities for propellants.
Foxboro Co., Massachusetts	Water and other non-volatile fluids; too small for commercial test work.
Fixcher & Porter Company	Water and hydrocarbons.
Bailey Meter Company	No facilities for propellants.
Hamilton Standard	No facilities for propellants.
Stellardyne Laboratories	10,000 gpm water system designed to calibrate gas flow by volumetric water displacement.
Cox Instruments	Hydrocarbons and water.
Aro, Inc. Arnold Air Force Station, Tennessee	No facilities for propellants.
Wyle Laboratories	See chart on following page.

WYLE LABORATORIES

System	Calibration Tank Capacity	Fluids	Pressure (psig)	Design Flow Range	Maximum Flow Rate	System Mass (%)	Accuracy Volumetric (%)	Comments
A	650	LH_2	50	0.5 - 5.0 (lb/sec)	10 lb/sec	0.15	0.25	Dynamic Time-Weight
		LN_2	50	0.5 - 5.0 (lb/sec)	10 lb/sec	0.15	0.25	
B	500	LOX	50	25 - 500 gpm	800 gpm	0.15	0.25	Dynamic Time-Weight
		LN_2	50	25 - 500 gpm	800 gpm	0.15	0.25	
		H_2O	50	25 - 500 gpm	800 gpm	0.15	0.20	
C	4100	LOX	50	500 - 3500 gpm	4000 gpm	0.15	0.25	Dynamic Time-Weight
		LN_2	50	500 - 3500 gpm	4000 gpm	0.15	0.25	
		H_2O	50	500 - 3500 gpm	4000 gpm	0.15	0.20	
D*	500	N_2O_4	50	25 - 500 gpm	800 gpm	0.15	0.20	Static Weight
E*	500	UDMH/N_2H_4	50	25 - 500 gpm	800 gpm	0.15	0.20	Static Weight
		UDMH	50	25 - 500 gpm	800 gpm	0.15	0.20	
		N_2H_4	50	25 - 500 gpm	800 gpm	0.15	0.20	

*Currently Non-Operative

SECTION VII

VII. CRITERIA FOR TURBINE FLOW TRANSDUCER CALIBRATION FACILITIES

The calibration facilities will be operated by the United States Air Force at Edwards Air Force Base, California. They should be suitable for the calibration of up to four various-size transducers in an eight-hour day, based on thirteen point calibrations. Facilities shall be designed for fixed outdoor installation on a concrete pad provided by others. (Refer to Figure 28, Page VII-17.)

A. Operating Conditions

Two independent systems shall be provided, one for calibration utilizing storable oxidizer propellants N_2O_4 and ClF_3 and the other for calibration utilizing storable fuels, RP-1, hydrazine, Unsymmetrical DiMethyl Hydrazine, 50-50 blend of hydrazine and Unsymmetrical DiMethyl Hydrazine and pentaborane. (For properties and recommended handling practices refer to attached charts and to references in Section B of the Bibliography.) The facilities shall be designed to handle any combination of the following transducer sizes and flowing conditions.

	Oxidizers	Fuels
Transducer Sizes (in.)	1/2 to 2-1/2	1/2 to 2-1/2
Flow Rate (gpm)	1 to 500	1 to 500
Pressure (psig)	0 to 100	0 to 50

Provisions shall be made to control the liquid temperature between 60°F and 100°F by hot water heating, using electrical energy for water-heating. (Cooling is not required for conditions when the liquid temperature is in excess of 60°F.)

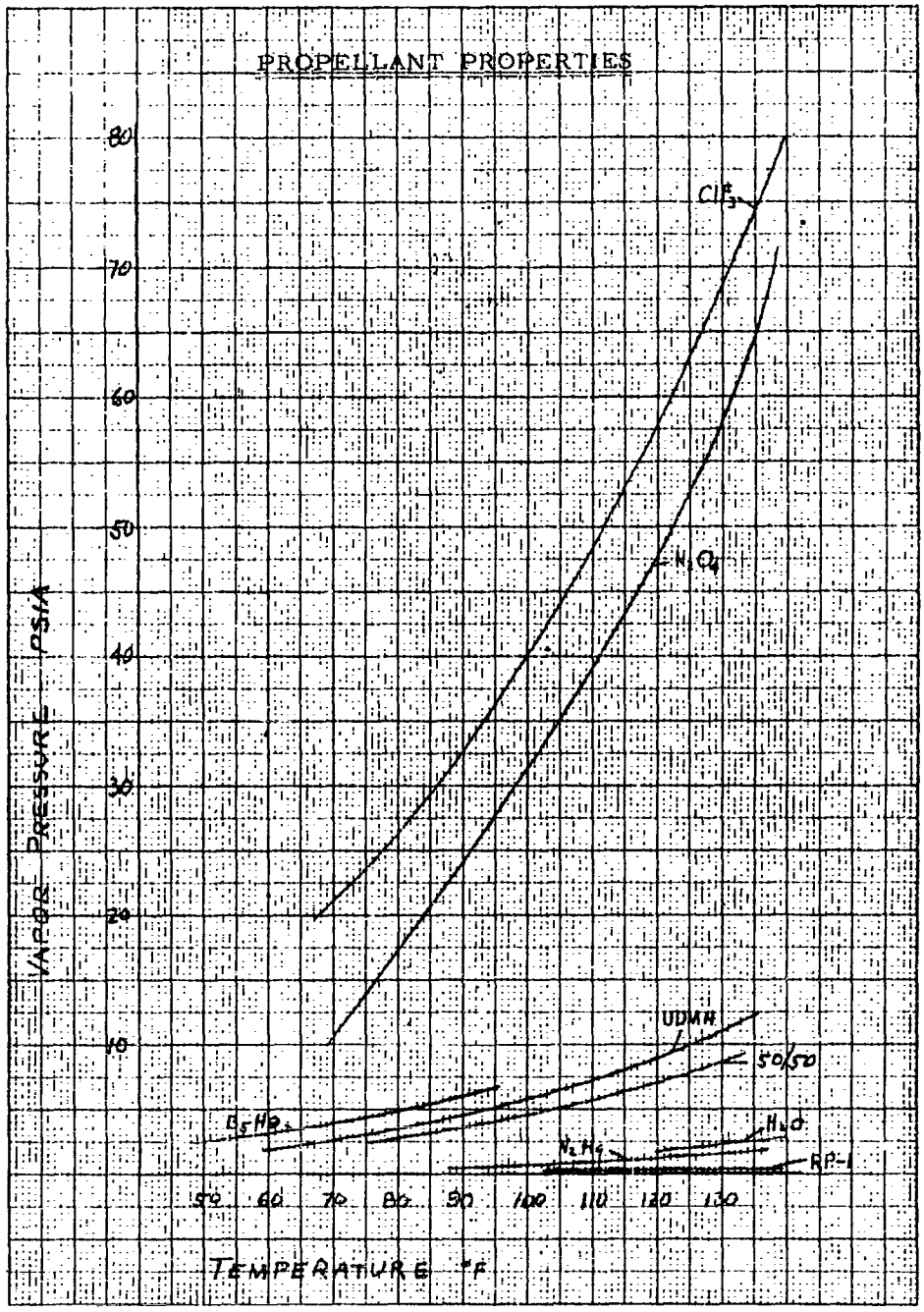
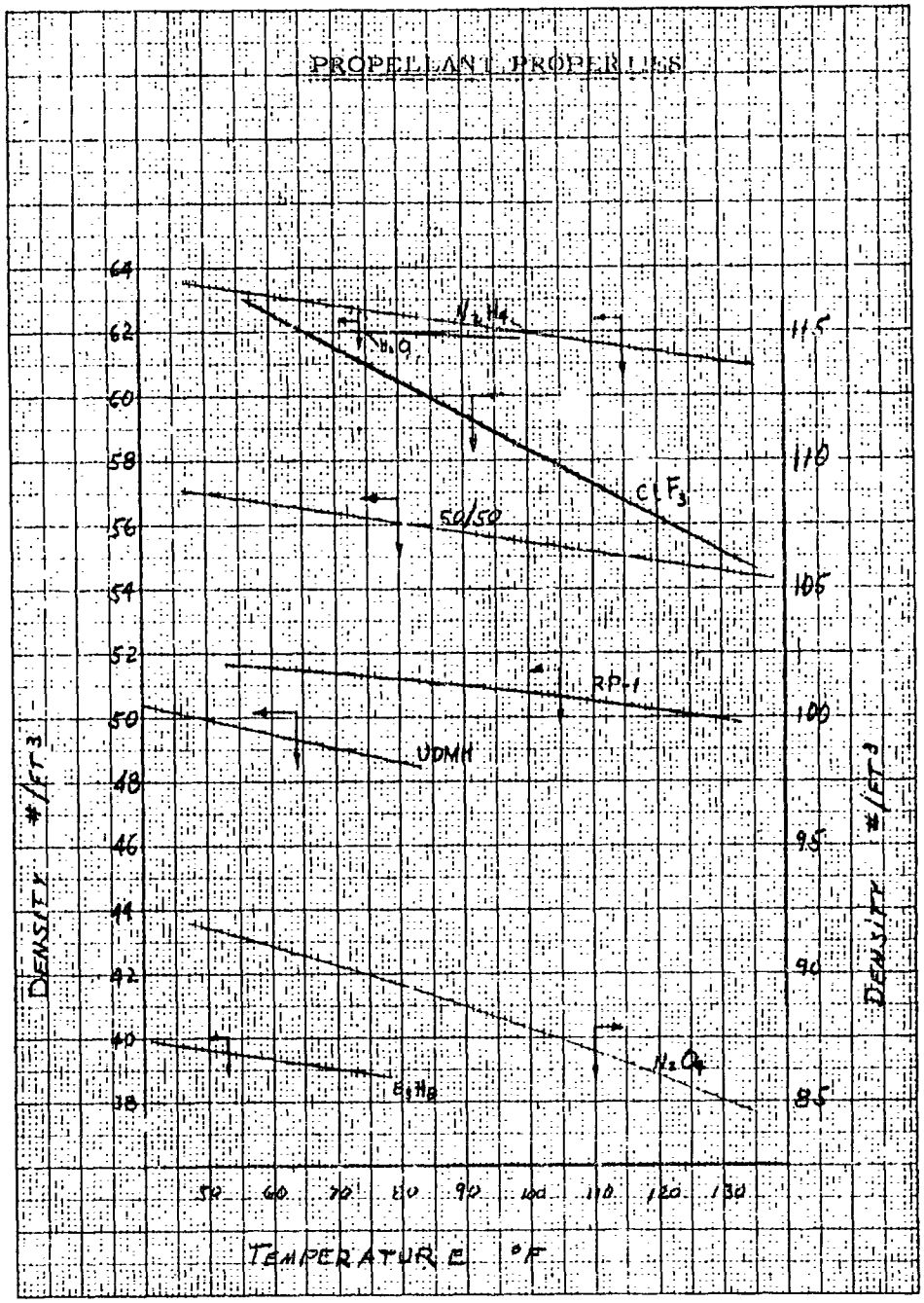

PROPELLANT PROPERTIES
VAPOR PRESSURE PSIA
80
70
60
50
40
30
20
10
ClF_3
N_2O_4
UDMH
50/50
B_5H_9
N_2H_4
H_2O
RP-1
50
60
70
80
90
100
110
120
130
TEMPERATURE °F

Figure 23


PROPELLANT PROPERTIES
N_2H_4
N_2O_4
ClF_3
50/50
RP-1
UDMH
B_5H_9
H_2O_2
DENSITY #/FT³
64
62
60
58
56
54
52
50
48
46
44
42
40
38
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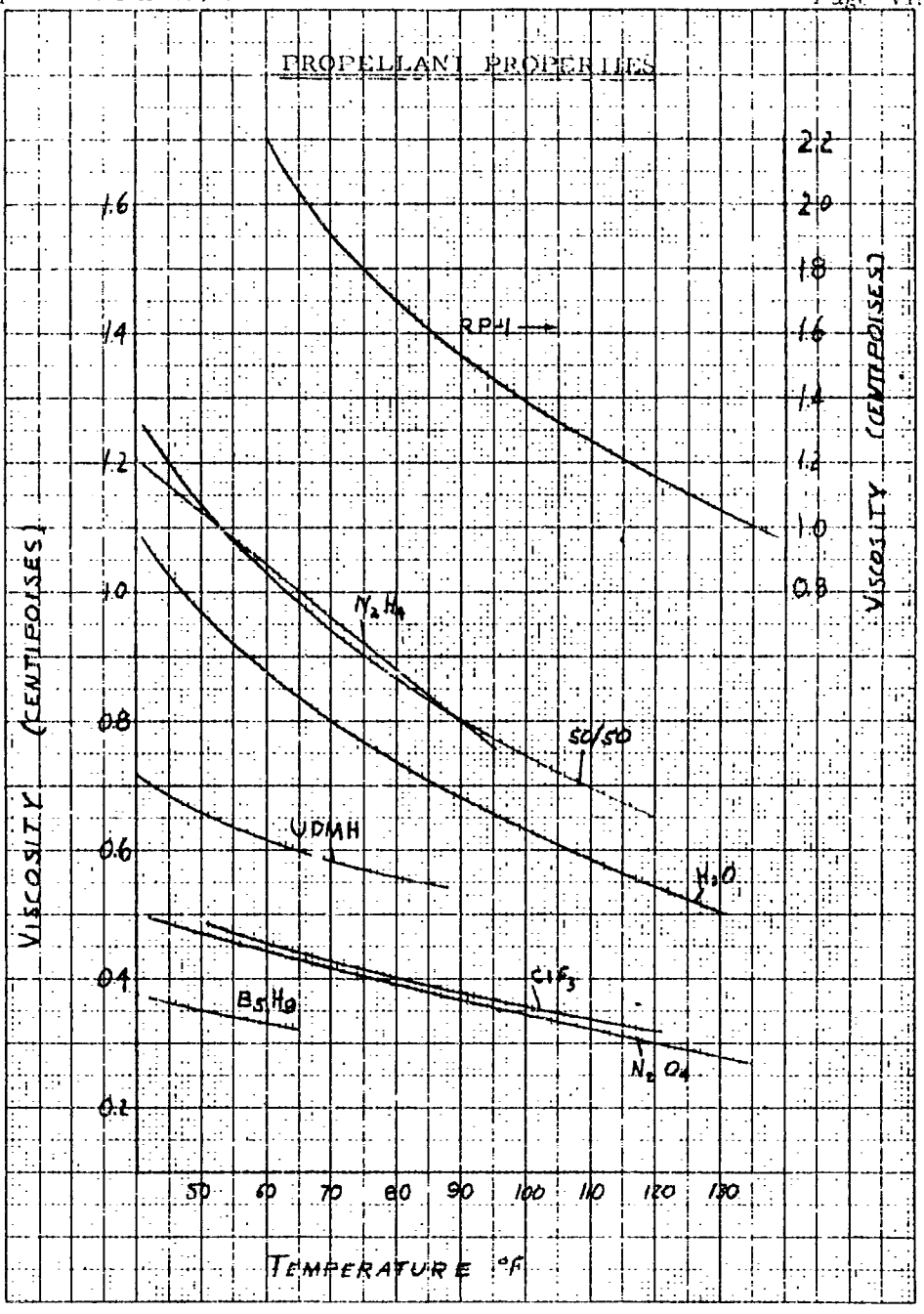
100
110
120
130
TEMPERATURE °F


PROPELLANT PROPERTIES
RP-1
N_2H_4
50/50
UDMH
H_2O
ClF_3
B_5H_9
N_2O_4
VISCOSITY (CENTIPOISES)
VISCOSITY (CENTIPOISES)
TEMPERATURE °F
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
50
60
70
80
90
100
110
120
130

B. Ambient Conditions

The facilities shall be suitable for operation in ambient conditions which vary from 0°F to 120°F, wind 50 mph, dust, sand and freezing rain. The local altitude at the site is 2,635 feet, and local gravity* is 32.15 ft/sec^2

C. Operability

Due to the hazard, the systems shall be capable of remote operation and instrumentation readout for multiple point calibrations of a transducer from the control panel without operator attendance to propellant handling equipment or instruments. Minimum readout instrumentation shall provide digital transducer pulse counts, digital millisecond timing, propellant density and temperature, and weight or volume of liquid transferred.

D. Minimum Acceptable Standards of Measurement

1. Reference to National Bureau of Standards. - Digital counting and timing equipment shall be traceable to standards which have been calibrated against Bureau of Standards Station WWV.

Scale counterpoise weights for the gravimetric calibrators shall conform to the tolerances for Class C Commercial Test Weights as stated in Circular 3 appearing in Volume III, Handbook 77 of the National Bureau of Standards, the acceptance tolerances (applicable to new or newly adjusted weights) being one-half the tabular tolerances. Calibration of counterpoise weights shall be by comparison at regular intervals with laboratory reference standards traceable to the National Bureau of Standards.

The weights shall be made of a non-magnetic, free-turning, stainless steel similar to AISI Type 303, shall be of one-piece construction and suitably slotted, when necessary, to permit centering of the weights about the counterpoise hanger; they shall not be plated or lacquered and the only adjustment permitted will be by removal of material. Surfaces of the weights, including those exposed by adjustment operations, shall be smooth and all corners and edges obviously rounded. Each weight larger

*The value of local gravity may be useful in the near future if and when the aerospace industry converts to absolute gravity units or if a force weigh system (load cell) is used.

than 0.1 pound shall be engraved with its nominal weight and its counterpoise value when used in connection with a scale of proper ratio; die-impressed figures are not acceptable.

Systems based on precision bored volumetric containers shall also be calibrated against Class C Commercial Test Weights, by measurement against distilled or de-ionized water, at known temperature or against NBS volumetric standards.

2. Other Measurements. - Density measuring devices shall be accurate to $\pm$ 0.0005 specific gravity.

Temperature indicators shall have a maximum error of $\pm$ 1°F.

E. Flushing and Drying

The system shall be designed for convenient and safe filling and draining of the propellants. Provisions shall be made for water or solvent flushing all surfaces which contact propellant liquids and all surfaces on which propellant vapor condensate may collect. Drains with manual valves shall be placed at all low points where liquids cannot be readily drained.

Provisions shall be made for vacuum drying the flushed system without disassembling it.

F. Overspeed Protection

For systems in which liquid transfer is accomplished by pressurized gas, provisions must be made which will assure that the gas will not enter the transducers and cause overspeed.

G. Errors

The systems, including instrumentation, shall have a maximum calibration error of $\pm$ 0.15 per cent of actual flow and a maximum repeatability error of $\pm$ 0.1 per cent of actual flow for all test fluid conditions and

rates of flow, and run times of between one and ten minutes. These errors shall be demonstrated mathematically taking into consideration as a minimum those errors outlined in Section VII. O, "Special Requirements for Calibration Systems." It is likely that to attain these accuracies, a minimum of two systems each for the oxidizer and fuel calibrations will be necessary.

H. Materials of Construction

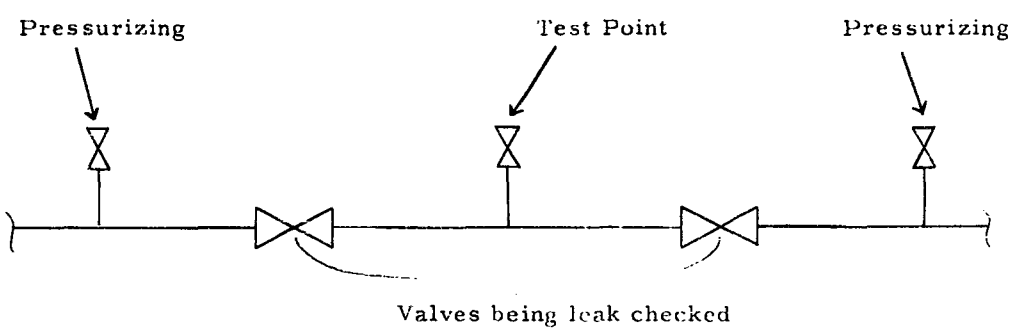
All metal surfaces which might contact the propellants shall be austenitic stainless steel, Type 304, 304L, 316, 316L, 321 or 346. Gaskets shall be 1/8 inch thick teflon. Gas, water or solvent handling equipment on the downstream side of filters shall be constructed of copper or austenitic stainless steel.

Thread lubricants shall be compatible with the fluids contained (see Bibliography - Safety and Propellant Handling Guides).

I. Valve Leaks

A method of leak detection shall be included at all valves where liquid can bypass the weight or volume measuring equipment. An acceptable method of leak checking is to provide double valves with a leak test point located between them. With both valves closed and pressurized, any leakage will flow out the test point.

Figure 26. LEAK CHECK



J. Safety

With only one exception (RP-1), the propellants are extremely toxic and will result in serious harm if allowed to contact the eyes or skin.

The facility shall be provided with suitable leak detectors and audible and visible alarm systems. Care shall be exercised to exclude from the design all low point enclosures where toxic fumes may collect.

Exhaust gases containing propellants and/or propellant vapors shall flow to fume scrubbers and be vented in a manner that will prevent accumulation of the stack gases in the operating area.

All lines and equipment carrying fuels shall be electrically grounded.

Lines containing propellants or with pressures in excess of 200 ps. shall not be piped into the control building.

In addition, the facilities shall comply with the recommendations of technical manual T. O. 11C-1-6, "General Safety Precautions for Missile Liquid Propellants." Other recommended reference guides are listed in the Bibliography, Section X. B.

The control panel shall be located in a control building equipped with safety view glass and constructed in accordance with Group G of the Uniform Building Code.

K. Weather Protection

Weigh system components which may be affected shall be protected from wind or drafts. This includes, as a minimum, weigh tanks, connecting pipe and scale beams. Balance pivots and other critical components shall be protected from weather erosion and corrosion, as well as from spillages.

L. Applicable Codes and Standards

Equipment shall be designed and constructed in accordance with the latest editions of the following codes.

1. Vessels. - American Society of Mechanical Engineers, Section VIII.

2. Pipe. - American Standards Association B 31.1.

3. Welding. - American Society of Mechanical Engineers, Section IX.

4. Electrical. - National Electrical Manufacturers' Association

5. National Board of Fire Underwriters, National Electrical Code

6. Joint Industry Conference
   Hydraulic Standards for Industrial Equipment
   Pneumatic Standards for Industrial Equipment

7. Instrument Society of America RP31.1, RP31.2, RP31.3

8. American Petroleum Institute, Standard 1101, Part I, Mechanical Displacement Meter Provers.

M. Scope of Work

This criteria applies to weight or volume measuring systems consisting of tanks, interconnecting piping, valves and fittings, pump (and motor) or gas transfer and storage systems, solvent storage and flushing equipment, vacuum drying equipment, safety devices such as gas analysis and relief valves, instruments, remote control consoles and interconnecting pipes and transmission lines.

N. Piping Configurations (Refer to Figure 29)

Straight piping runs on the inlets and outlets of transducers shall be a minimum of ten pipe diameters on the upstream side and five pipe diameters on the downstream side. Straightening vanes consisting of thin-wall tubes a maximum of one-third the diameter of the containing pipe and five pipe diameters long shall be assembled, welded and placed ten pipe diameters upstream of transducer locations. Transducer connection shall provide leak-tight seals, provide smooth inside surfaces without diameter steps and shall have no breaks along the wall in excess of 1/16 inch.

The test section shall be horizontal, and arranged to accept both a test transducer and a standard reference transducer in series, with straightening vanes between.

Readout equipment shall be capable of counting pulses from both transducers simultaneously.

The test transducer and its straightening vanes shall be readily removable. The space remaining shall be large enough so that a section duplicating the actual use configuration (maximum size 2-1/2 inches) can be substituted.

All non-propellant lines, except vacuum lines, which enter a propellant line or propellant tank shall be protected by double check valves; i.e., two check valves in series.

O. Special Requirements for Calibration Systems

1. Weigh Systems. - Weigh systems shall be balance arm systems, or load cell systems and shall be static or dynamic systems. (Refer to Figures 30 and 31.)

a. Static System. - In the static weigh system, the liquid shall be recirculated in a closed loop and diverted to the weigh tank by means of a fast-acting diverter valve. The weight of the storage vessel shall be determined before and after the run, under static conditions.

Error analysis shall include minimum of following:

Scale	Load Cell(s)
(1) Accuracy of weights	(1) Accuracy
Sensibility of scale	Sensibility
Repeatability of scale	Repeatability
	Readout error
	Drift effect
	Temperature compensation

Scale & Load Cell(s)

(2) Extraneous loads from connecting lines and liquid retained in lines

Effect of scale displacement on extraneous loads

(3) Dynamic lag (Lag in diverter valve; time in opening and closing)

(4) Density measurement error

(5) Timer and pulse-counter errors

(Errors shall be reported as $\pm$ the sum of the individual errors (and not as rms).)

b. Dynamic Weigh System. - In the dynamic weigh system, the initial and final weights are measured at a precisely determined time increment while liquid is flowing out of (or into) the weigh tank. After initiation of the calibration time cycle, calibrated weights are added to (or removed from) a platform on the weigh scale, and the run is terminated when the final weight is the same as the initial weight (i.e., the weight of liquid transferred equals the calibrated weights). A load-cell weigh system may be substituted for the scale. In this case, the timing device is initiated by a pushbutton and electronically terminated when the final load cell signal is equal to the initial signal.

Error Analysis

Scale	Load Cell(s)	
(1) Accuracy of weights	(1) Accuracy	) on increasing
Sensibility of scale	Sensibility	) weight and
Repeatability of scale	Repeatability	) on decreasing weight
	Readout error	
	Drift effect	
	Temperature compensation	

(2) Extraneous loads from connecting lines and liquid retained in lines

(3) Effect of scale displacement on extraneous loads

(4) Inertia error by the method of Shafer and Ruegg (ASME paper 57-A-70, 1957, "Liquid Flow Meter Calibration Techniques")

(5) Density Measurement error

(6) Timer and pulse counter error

(7) Photo-cell or magnetic pickup repeatability and lag errors

(8) The correction due to a varying amount of liquid in the falling column within the weigh tank by the changing level in the tank, and kinetic effects of the falling column

(9) Time for acceleration of scale and indicating mechanism to constant velocity prior to starting timer

2. Volumetric Systems. - The volumetric flow calibration system measures liquid displacement in a precision-bore tube. In a vertical tube (or "standpipe"), the displacement is commonly measured by a mercury manometer; in a horizontal prover by a ball or piston in the tube which is moved by the liquid. Timer stop and start are initiated by an instrument which precisely measures the height of the mercury column, or the position of the displacer ball or piston.

Mercury is commonly used as the manometer liquid because of its excellent electrical conductivity, high specific weight, and stability. It is not compatible with the propellants, however, and another manometric liquid would have to be found. The propellant itself might be satisfactory for fuel calibrations, in which case the manometer would become a liquid level gage. Unless both legs of the manometer are pressurized, the high vapor pressure of the oxidizers makes them unsuitable for manometer liquids.

If a volumetric calibrator of the type commonly referred to as a meter prover in the petroleum industry is provided, it shall be bidirectional and means shall be provided for determining leaks across the ball or piston seals. (Refer to Figure 32.)

Error Analysis

a. Static Systems

(1) Repeatability of volumetric measurement

(2) Precision of tube dimensions and effects of temperature and pressure

(3) Lag in diverter

(4) Density measurement error

(5) Timer and pulse counter errors

(6) Precision in readout of manometer

b. Dynamic Systems

(1) Repeatability of volumetric measurement

(2) Precision of tube dimensions and effects of temperature and pressure

(3) Lag, precision and repeatability of mechanical or proximity counter and timer start and stop switches

(4) Density measurement error

(5) Timer and pulse counter errors

(6) Precision in readout of manometer

(7) Incomplete drainage of walls

(8) Assurance that the pressure measuring device has completed its acceleration prior to starting timer

P. Instrument Society of America

The Instrument Society of America is about to publish Recommended Practice RP31.2 covering the proper installation and operation of a turbine-type flow transducer. This so thoroughly treats the subject of influential inaccuracy factors that it is attached in its preliminary form as an addendum.

Q. Preliminary Estimate

With only criteria upon which to base an estimate, it is, of course, impossible to provide accurate figures for the cost of the calibration facilities. This is especially true since the criteria allows a wide selection of gravimetric and volumetric calibrators.

As a rough guide, however, and based on a volumetric type calibrator and support equipment, the cost should be in the range of $120,000 to $140,000.

These figures include costs for supply and installation of two calibrator systems, one oxidizer and one fuel, each similar to that shown in the following illustration and complete with vessels, valves, piping, exhaust stacks, calibrators, vacuum drying systems, vapor leak detectors, instrumentation, and a small control building.

They do not include Contractor fees and markup, and design costs; and they assume that all utilities, electricity, water and gaseous nitrogen are available at the site.

If a more elaborate facility were provided, with individual storage for each propellant, the cost may be expected to be in the range of $170,000 to $200,000. Individual storage, of course, reduces the amount of flushing and drying to be performed when changing propellants and facilitates fluid handling and simplifies logistics problems.

SYMBOLS

MANUAL VALVE

CYLINDER OR SOLENOID OPERATED VALVE

CONTROL VALVE DIAPHRAGM OR MOTOR OPERATED

CHECK VALVE (ARROW SHOWS DIRECTION OF FLOW)

SAFETY VALVE

DENSITY INDICATOR

LIQUID LEVEL TRANSMITTER

LIQUID LEVEL INDICATOR

TEMPERATURE TRANSMITTER

PRESSURE TRANSMITTER

PRESSURE INDICATOR

TEMPERATURE INDICATOR

Figure 27
4532-1

VIEW FROM CONTROL ROOM WINDOW

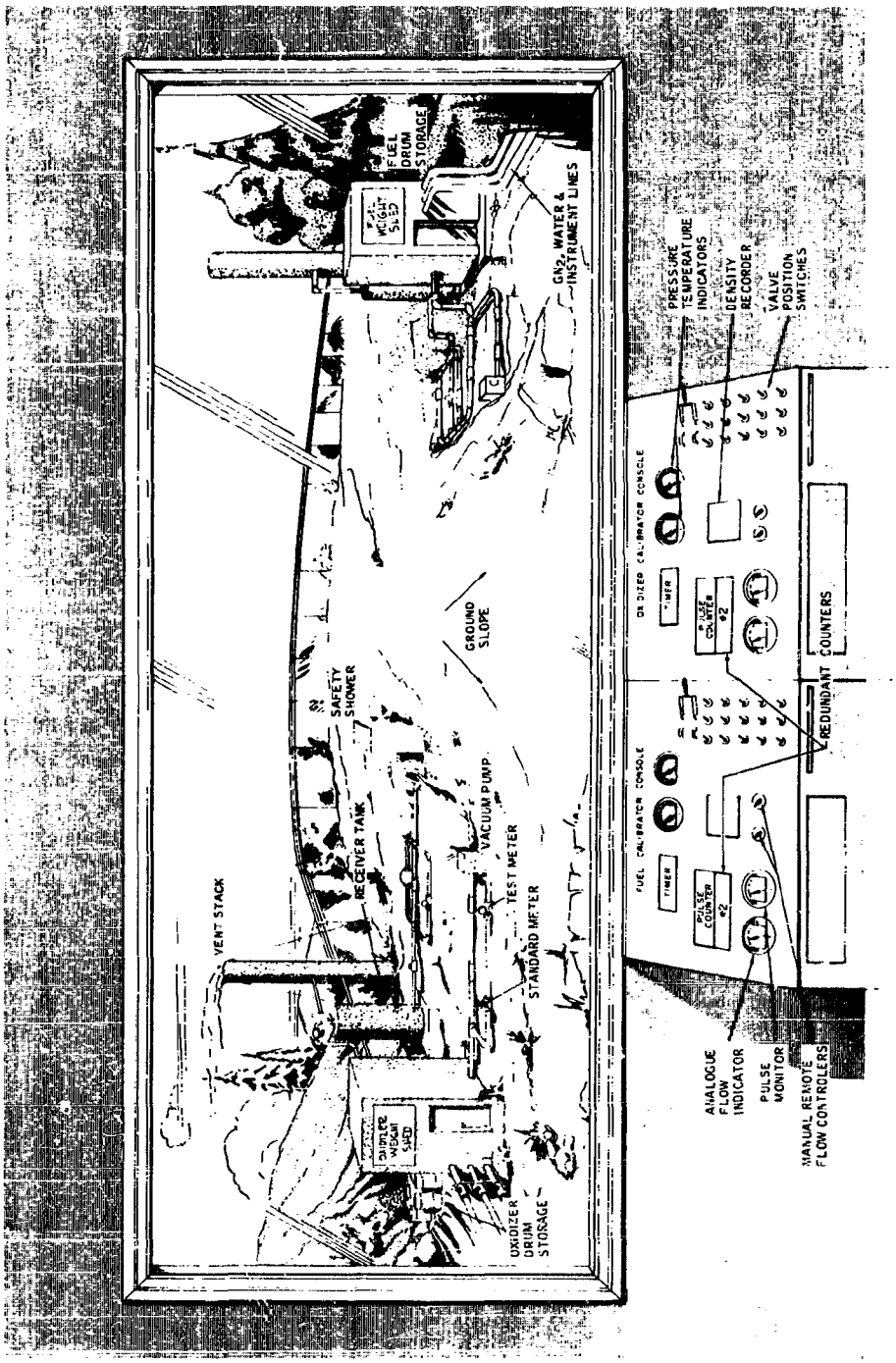
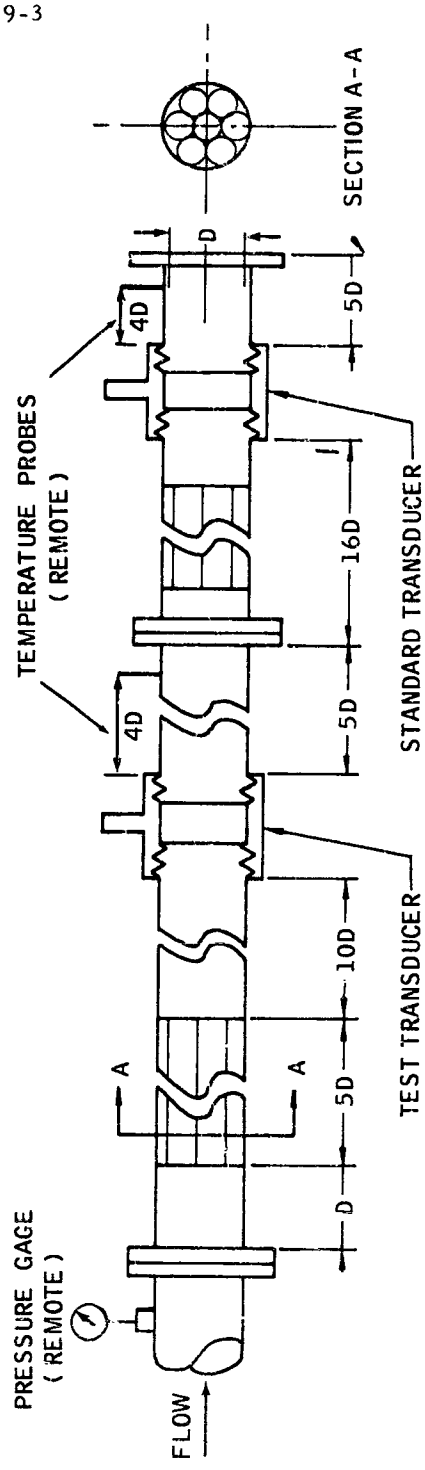


Figure 28

4535-4

CRITICAL TRANSDUCER INSTALLATION DIMENSIONS



NOTES:

1. ALL DIMENSIONS ARE FUNCTIONS OF PIPE INSIDE DIAMETER (D) & ARE MINIMUM VALUES
2. THE CONNECTING LINES SHALL MATCH THE TRANSDUCER SIZE

Figure 29

SUGGESTED FLOW SHEET FOR STATIC WEIGH CALIBRATION FACILITY-PUMPED SYSTEM

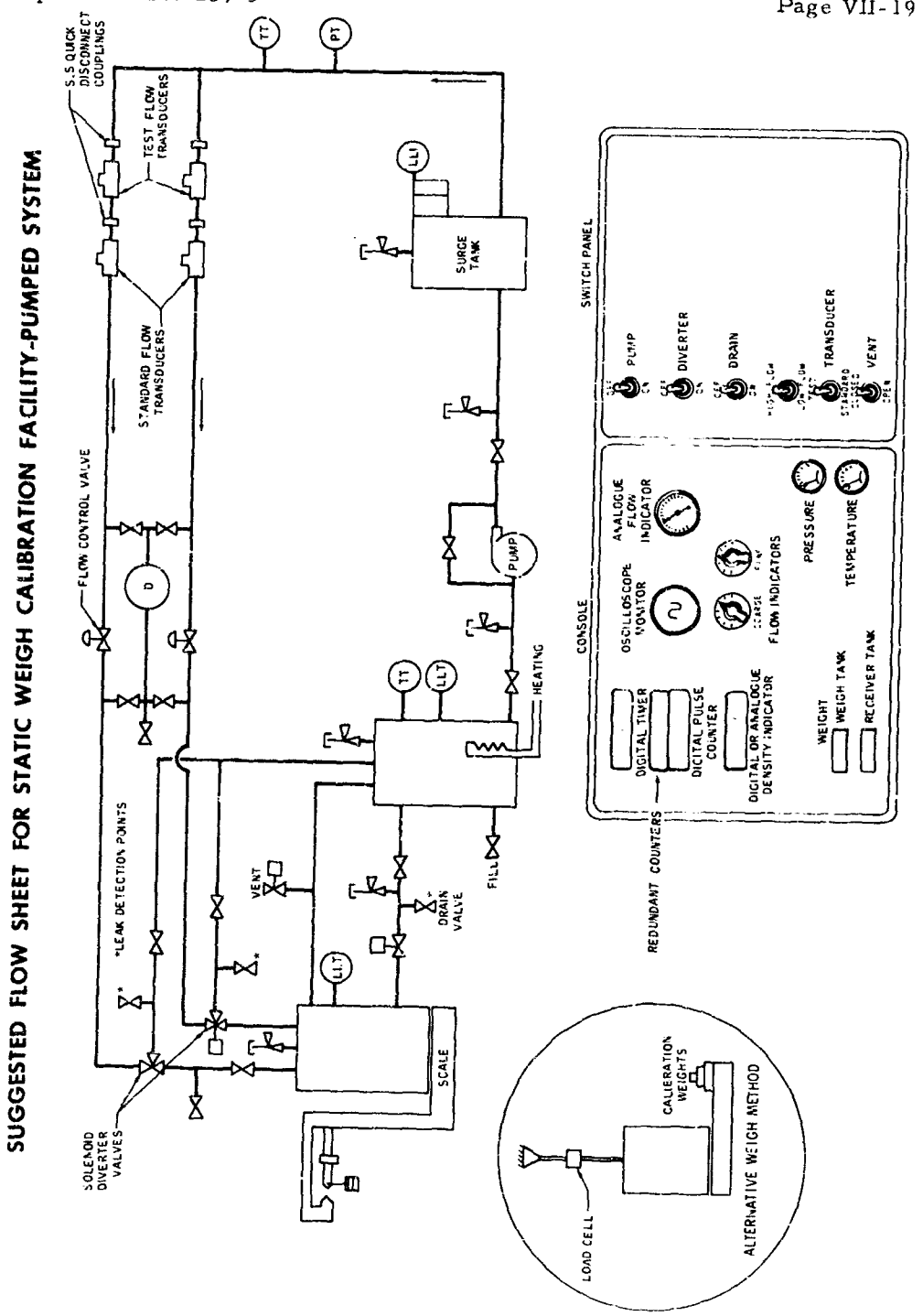


Figure 30

SUGGESTED FLOW SHEET FOR DYNAMIC WEIGH CALIBRATION FACILITY UTILIZING GAS TRANSFER

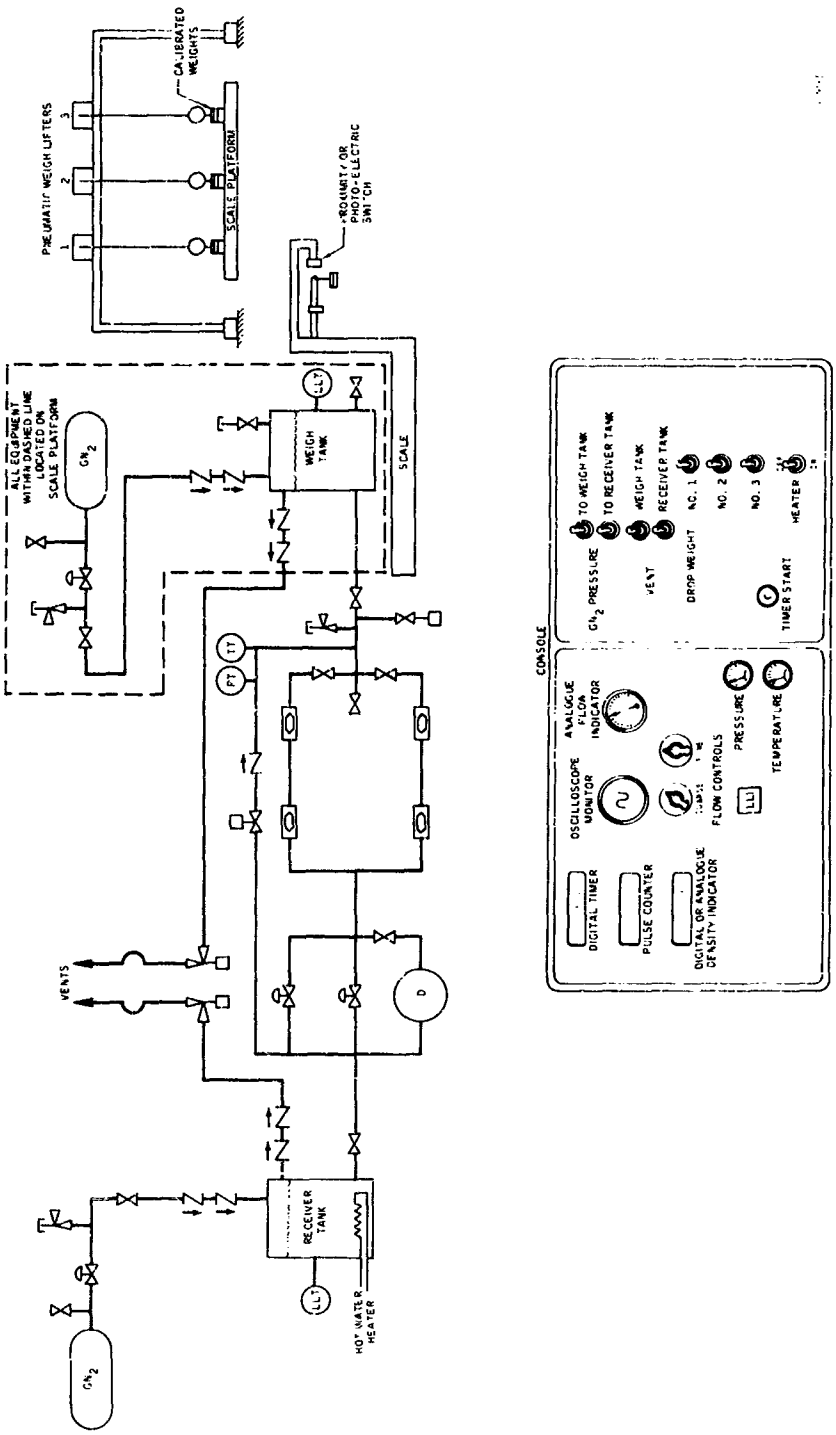


Figure 31

BIDIRECTIONAL METER PROVER FLOW SHEET

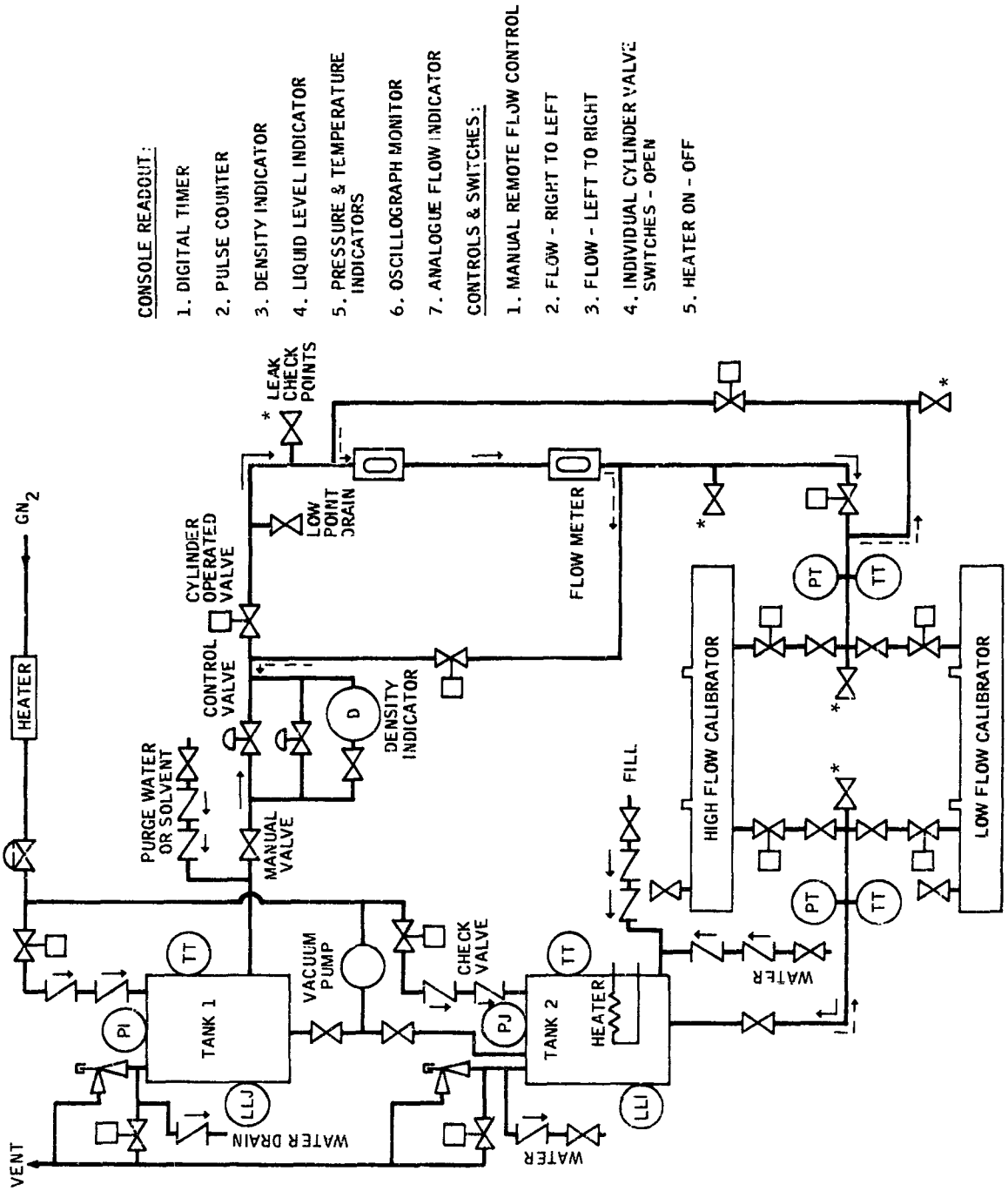


Figure 32

BIDIRECTIONAL VOLUMETRIC PROPELLANT FLOW METER CALIBRATOR

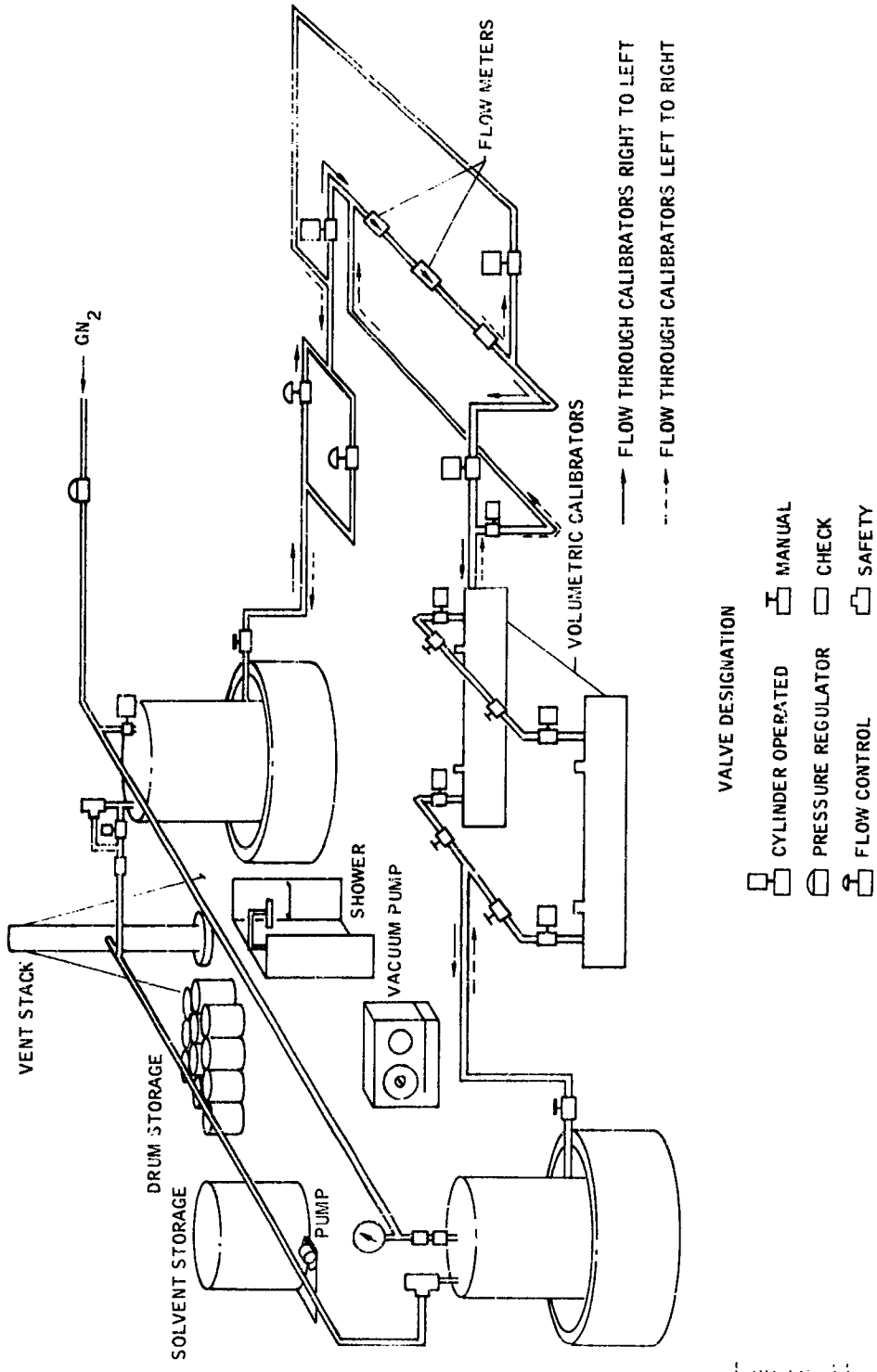
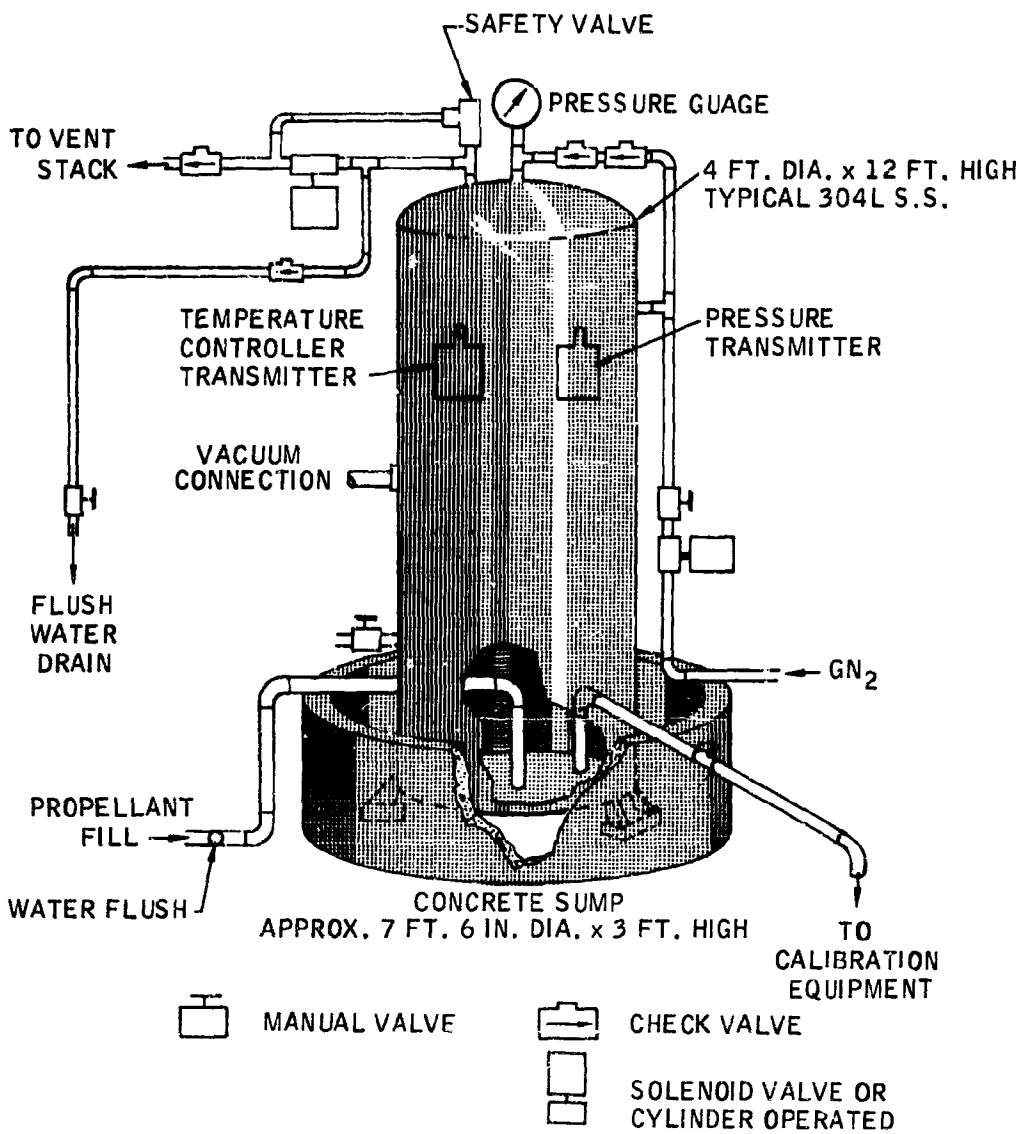


Figure 33

TYPICAL PROPELLANT STORAGE VESSEL



4588-5

Figure 34

SECTION VIII

VIII. CONCLUSIONS

With the exception of RP-1 fuel, empirical data illustrating flow correlations between water and storable propellants is very nearly non-existent.

Correlations developed in theory and proven in practice on hydrocarbon liquids (such as RP-1) indicate that for transducers above 1 inch in size and water, calibrations are accurate to within approximately $\pm$ 0.5%. The probable magnitude of error with these sizes, when water calibrations are applied to transducers for use on other propellants, is about $\pm$ 1 per cent.

Further generalizations about turbine transducer accuracies cannot be made because of radical differences in geometries between manufacturers, model differences of one manufacturer, and quality controls and maintenance differences between models of a given make and size.

An on-stream meter prover of the type used in the petroleum industry could reduce metering errors to about $\pm$ 0.1%.

Despite extensive correspondence and interviews with experts in the field, only one location was found which could calibrate turbine transducers with propellants: Wyle Laboratories at Norco (Los Angeles area), California.

SECTION IX

IX. RECOMMENDATIONS

A. It is recommended that on stream calibrations as performed by use of meter provers in the petroleum industry be adapted to aerospace test stands to reduce the probable error of ± 1 per cent of current water calibration practice to a demonstratable error of ± 0.1 per cent. To accomplish this, it would be prudent to establish a development program to assure that components of t prover can be made leak tight against storable propellants. (The Martin Company is now running such tests on N_2O_4 and 50-50 N_2H_4/UDMH).

B. It is recommended that the prover be adapted to use on cryogenic liquids.

C. It is recommended that a storable propellant calibration facility of the caliber of the National Bureau of Standards be established at Edwards Air Force Base or elsewhere to increase the reliability of calibrations and fill the void on water-propellant correlation data.

D. It is recommended that the existing Potter-Pacific water flow calibrator at Edwards Air Force Base, Laboratory Service Building #8451, be retained in its present configuration, and not converted to use on storable propellants. The reason for this is that it is highly desirable to maintain a "referee" or water-standard calibrator to provide a local facility for water-to-propellant correlations. Then, if our previous recommendation is followed, the flow meter (preferably assembled in its usage pipe-section) can be first water-calibrated on the existing Potter-Pacific rig in Building 8451 and then propellant-calibrated in the new calibrator. The resulting correlation errors can then be statistically accumulated to build a case history that will also aid others in this field.

SECTION X

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SECTION XI

XI. ADDENDA

As of the writing of this report, Instrument Society of America Standards RP31.2 and RP31.3 and American Petroleum Institute Standard 1101 (Tentative) are in preliminary draft form and may require some revisions before acceptance for publication.

ISA – RP31.1

1961

Report No. FE-269-3

SECTION XI
Addendum I

TENTATIVE
RECOMMENDED PRACTICE

TERMINOLOGY AND SPECIFICATIONS FOR TURBINE-TYPE FLOW TRANSDUCERS (VOLUMETRIC)

Sponsor
INSTRUMENT SOCIETY OF AMERICA
Penn Sheraton Hotel, 530 William Penn Place
Pittsburgh 19, Pa.
Published August, 1961

PRICE: $ .50 ISA MEMBERS
$ .75 OTHERS

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FOREWORD

This Tentative Recommended Practice has been prepared as a part of the service of the Instrument Society of America toward a goal of uniformity in the field of instrumentation. To be of real value this report should not be static, but should be subject to periodic review. Toward this end the Society welcomes all comments and criticism, and asks that they be addressed to the Standards & Practices Board Secretary, Instrument Society of America, Penn Sheraton Hotel, 530 Wm. Penn Place, Pittsburgh 19, Pa.

This report was prepared by the 8A-RP31 Committee on Flow Measurement in the Aero-Space Industry.

Robert L. Galley - Chairman, General Dynamics/Astronautics
Henry F. Eichenberger - Vice Chairman, General Dynamics/Convair
Clifford R. Benzel - Recorder, General Dynamics/Astronautics
Keith C. Campbell - Douglas Aircraft Company, Inc.
Lawrence H. Groeper - North American Aviation Corp./Rocketdyne
Frank Larango - Marquardt Corp.
Frank G. Klock, Jr. - Bureau of Naval Weapons
Robert Siev - General Tire and Rubber Company/Aerojet General
Francis J. Stockemer - Lockheed Aircraft Corp.

The assistance of those who aided in the preparation of this Recommended Practice by answering questionnaires, offering suggestions, and in other ways is gratefully acknowledged.

The following have reviewed the Report and served as a Board of Review:

Thurlow M. Morrow - General Metrics Co., (formerly with Aeroscience, Inc.)
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Joel Ferrell, Jr. - Aro, Inc.,
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Montgomery R. Shafer - U. S. Department of Commerce (NBS)
Charles C. Waugh - Waugh Engineering Co.

Approved for Tentative Publication by the Standards and Practices Board on June 19, 1961.

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CONTENTS

1. PURPOSE

1.1 This Recommended Practice establishes:

1.1.1 Uniform terminology for components and performance characteristics.

1.1.2 Uniform installation dimensions.

1.1.3 Uniform electrical output.

2. SCOPE

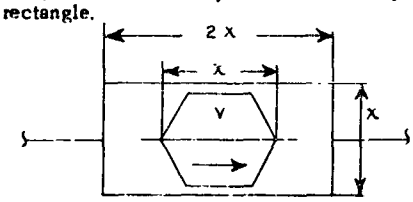
2.1 This Recommended Practice covers volumetric turbine-type flow transducers having an electrical output. They are used for either rate measurement or totalization, and are either self-generating or modulating.

3. TERMINOLOGY

3.1 A turbine-type flow transducer with an electrical output is a measuring device in which the action of the entire fluid stream turns a bladed rotor at a speed nominally proportional to the volume rate of flow, and which generates or modulates an output signal with a frequency proportional to the rotor speed.

3.2 Rotor, rotor support(s), housing, and pick-off are the preferred names for the major parts of a turbine-type flow transducer.

3.3 The drawing symbol for a turbine-type flow transducer is a hexagon with a major diagonal of X dimension centered on, and coincident with, the indicated major axis of an X by 2X rectangle.



A letter "V" is inserted in the hexagon to designate "volumetric", and a flow-direction arrow (one head for uni-directional, two heads for bi-directional) is inserted as shown.

3.4 The pressure drop of a turbine-type flow transducer is the differential pressure in psi at maximum linear flow measured between points four diameters upstream and four diameters downstream from its ends, using water at 60°F.

3.5 The calibration factor of a turbine-type flow transducer is designated by the letter "K" and is expressed in cycles per gallon (U.S.) or cycles per cubic foot, under the following specified conditions:

3.5.1 Calibration fluid.

3.5.1.1 Specific weight (lbs/gal or lbs/cu ft)

3.5.1.2 Viscosity (centistokes)

3.5.1.3 Downstream temperature (°F)

3.5.1.4 Downstream pressure (psia)

3.5.1.5 Flow rate (gal/min or cu ft/min)

3.5.2 Line configuration.

3.5.2.1 Length of straight line upstream

3.5.2.2 Length of straight line downstream

3.5.2.3 Type of flow straightner

3.6 The repeatability of a turbine-type flow transducer is its ability to reproduce its calibration factor under the same conditions. Statistically, it is the product of the "coefficient of variation" of a number of calibration data, at nominally the same flow rate, and a "statistical factor" accounting for sample size at a stated confidence level.

3.7 The linearity of a turbine-type flow transducer is the maximum percentage deviation from a stated calibration factor, of a number of mean calibration factors approximately equally spaced over a flow range.

3.8 The linear range of a turbine-type flow transducer is the flow range upon which the evaluation of linearity is based.

4. SPECIFICATIONS

4.1 Housing Dimensions

4.1.1 For flared tubing (MS 33656) the standard turbine-type flow transducer lengths are:

Nominal Tube Diam (Inches)	Transducer Length (Inches)	Equivalent Fitting
3/8	2.219(2 7/32)	AN 832-6
1/2	2.453(2 29/64)	AN 832-8
3/4	3.250(3 1/4)	AN 824-12
1	3.563(3 9/16)	AN 824-16
1-1/2	4.594(4 19/32)	AN 824-24
2	6.063(6 1/16)	AN 824-32

4.1.2 For flanged pipe (all flange types and all pressure ratings) the standard turbine-type flow transducer lengths are:

Nominal Pipe Diam (Inches)	Transducer Length (Inches)
1	8
1 1/2	9
2	9
3	10
4	12
6	14
8	16
10	20
12	24

4.1.3 For male-end threaded transducers the lengths are the same as for flanged transducers.

4.2 Electrical Connector

4.2.1 For self-generating turbine-type flow transducers the standard connector is a 3-pin MS 3102A-10SL-3P. The "A" pin is positive.

4.2.2 For those installations requiring explosion-proof or ruggedized connector, use an approved screw-type terminal.

4.3 Electrical Output

4.3.1 For all turbine-type flow transducers the standard output characteristics are:

4.3.1.1 Voltage into a 10,000 ohm load at minimum linear flow shall be not less than 30 millivolts, peak-to-peak.

4.3.1.2 Frequency at maximum linear flow shall be nominally 250, 500, 1000, or 2000 cycles per second.

4.3.1.3 Impedance at maximum linear flow shall not exceed 10,000 ohms.

4.4 Identification Symbols

The following information shall be permanently marked on the transducer housing.

4.4.1 Manufacturer

4.4.2 Part or Model No.

4.4.3 Serial No.

4.4.4 Flow Direction

4.4.5 Nominal Tube or Pipe Size

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Report No. FE-269-3

SECTION XI
Addendum II

TENTATIVE RECOMMENDED PRACTICE

INSTALLATION AND OPERATION

FOR

TURBINE-TYPE FLOW TRANSDUCERS

(VOLUMETRIC)

ISA RP 31.2

SPONSOR

Instrument Society of America
Penn-Sheraton Hotel
530 William Penn Place
Pittsburgh 19, Pennsylvania

FOREWORD

This Tentative Recommended Practice has been prepared as a part of the service of the Instrument Society of America toward a goal of uniformity in the field of instrumentation. To be of real value this report should not be static, but should be subject to periodic review. Toward this end the Society welcomes all comments and criticism, and asks that they be addressed to the Standards and Practice Board Secretary, Instrument Society of America, Penn-Sheraton Hotel, 530 Wm. Penn Place, Pittsburgh 19, Pennsylvania.

Robert L. Galley - Chairman, General Dynamics/Astronautics, San Diego, California

Henry F. Eichenberger - Vice Chairman, General Dynamics/Convair, San Diego, California

Keith C. Campbell - Douglas Aircraft Co., Inc., Santa Monica, California

Edgar L. Zwieback - Douglas Aircraft Co., Inc., Long Beach, California

Lawrence H. Groeper - Rocketdyne, A Division of North American Aviation Corporation, Canoga Park, California

Walter L. Sterling - Marquardt Corporation, Van Nuys, California

Robert Siev - Aerojet General, A Division of General Tire and Rubber Company, Azusa, California

Francis J. Stockemer - Lockheed Aircraft Corporation, California Division, Burbank, California

1. PURPOSE

1.1 This Recommended Practice establishes:

1.1.1 Installation (Section 3)

1.1.2 Check-Out (Section 4)

1.1.3 Data Acquisition (Section 5)

1.1.4 Data Interpretation (Section 6)

2. SCOPE

2.1 This Recommended Practice covers installation and operation of volumetric turbine-type flow transducers as described in RP31.1.

3. INSTALLATION

3.1 Environmental Considerations

A number of environmental conditions may affect the operation of a turbine-type flow transducer. Of these, moisture is the most common cause for malfunction. Electrical pick-off and connector must be waterproof to eliminate trouble from this source. Temperature of the transducer is largely determined by the temperature of the flowing fluid. However, the temperature of the pick-off and connector may be influenced by the environment. Low temperatures do not usually cause malfunction, but high temperature may result in failure of the insulation. Mechanical vibration will shorten the service life of a transducer and may also bias the data obtained. Magnetic fields in the proximity of the transducer or transmission cable may introduce spurious signals, or may attenuate the output if the circuit is not adequately shielded. The possibility of such signals vitiating data is greater when automatic frequency counting equipment is used.

3.2 Line Configuration

The turbine-type flow transducer is affected by upstream and downstream line configuration. The condition which produces this effect is primarily swirl of the flowing fluid and therefore upstream configuration is much more influential than downstream. Rules specifying a certain number of diameters of straight line upstream and downstream, which have been determined for orifice type flowmeters, are not applicable to the turbine type. A flow straightener is effective in eliminating swirl, and the upstream rotor support of a turbine type transducer acts to some extent as a straightener. However, because of differences in the effectiveness of the various rotor supports as straighteners, it is not possible to generalize on minimum length of upstream and downstream line. Suffice to say that the turbine-type flow transducer should be located with most of the available straight line upstream. Unusual downstream disturbances, such as a pump inlet may require a reduction in this ratio or in extreme cases a downstream straightener may be necessary.

Care should be taken not to allow piping to impose excessive stresses on the transducer housing.

3.3 Flow Straighteners

When it is not practical to provide a long straight flow path upstream of a turbine-type flow transducer or when maximum accuracy is desired, a flow straightener should be installed. Various designs of straighteners have been proposed. Tube bundles and sections of honeycomb have been found effective. In addition to effectiveness, the pressure drop and durability should be considered. For maximum accuracy, the transducer should be calibrated with the straightener installed upstream in the same manner as during operation.

3.4 Attitude of Transducer

Turbine-type flow transducers are usually calibrated on a flow bench in a horizontal position. In a majority of cases they are installed in the same attitude. However, when installed in a position other than horizontal, a difference in axial thrust balance may cause a change in the calibration factor. For maximum accuracy this effect should be known to be negligible for the design of transducer being used or the unit should be calibrated in the attitude in which it will be installed. For small transducers the angular position of the pick-off should be similarly considered.

3.5 Minimum Operating Pressure (Absolute)

A minimum operating pressure for any particular flow transducer installation should be maintained to preclude a change in the calibration factor due to various types of two-phase phenomena. The minimum operating pressure is a function of the vapor pressure of the fluid and the presence of other dissolved gases. The minimum operating pressure must be experimentally determined under actual test conditions and is defined as the line pressure at which the calibration factor at 125 per cent of the nominal maximum flow rate increases 1/2 per cent over the corresponding calibration factor obtained at the same flow rate but with a 10 psi higher pressure. The minimum operating pressure shall be measured four diameters downstream of the flow transducer.

3.6 Prevention of Overspeeding

A number of conditions may cause the rotor of a turbine-type flow transducer to turn at a speed higher than its rated value. Whether such overspeeding causes damage to the transducer depends upon the degree and duration. Improper selection of the transducer or excessive flow rate due to failure of some other component of the system can both cause overspeeding. Depletion of the metered

liquid in a pressurized feed system will usually cause ruinous overspeeding as the gas passes through the turbine-type flow transducer. Perhaps the most frequent cause of severe overspeeding of a liquid turbine-type flow transducer is gas in the line. Gas may be introduced during assembly of the system or may result from a change of state of the metered liquid under certain conditions of temperature and pressure. Overspeeding can be prevented by care in design and operation of the system. Careful assessment of the applicability of the above possible causes of overspeed to a given system is the first step. Proper location of the transducer with respect to valves can minimize risk. Finally, provision and use of a means for limiting flow or bleeding gas from a liquid system is essential. Different types of overspeed protection devices are available for specific application, including mechanical and electromagnetic brakes.

3.7 Filtration

For proper transducer operation the measured fluid should not contain solid particles having a maximum dimension more than half the clearance between rotor blade tip and bore of the housing. The service life of the transducer will be extended by filtering the measured fluid.

As a guide, the following U. S. standard sieve mesh sizes are recommended:

Transducer Size	Mesh Size	Particle Size
3/8-inch	170	88 microns
1/2-inch	120	125 microns
3/4-inch	45	350 microns
1-inch	45	350 microns
1-1/2-inch and up	18	1000 microns

3.8 Flow Direction

When installing a turbine-type flow transducer in a system, observe the flow direction arrow, or wording, marked on the transducer, regarding inlet and outlet ends.

3.9 Electrical Installation

3.9.1 A two-conductor or three-conductor shielded cable should be used for the electrical output. Wire size should be based on allowable signal attentuation. Avoid installation in a conduit containing power cables. (See Section 5.2.1)

3.9.2 The positive lead of the cable is connected to the "A" pin of the transducer connector.

3.9.3 For grounded piping, cable shield is to be ungrounded at the transducer end. It should be grounded at the instrument end only.

4. CHECKOUT

4.1 System Check

The type of checkout procedure will depend largely upon the flow transducer application. In some instances it may be possible and most expedient to establish test flow to functionally check the complete measuring system, with no serious consequences if proper operation is not obtained on first attempt. In other instances it may be of paramount importance that proper operation is obtained each and every time test flow is established, so that one or more of the following pre-test checks may be justified.

4.2 Rotor Spin Check

The most comprehensive check that may be made of a turbine-type flow transducer, associated circuitry and readout equipment, short of actually establishing flow, is to spin the rotor by tangential impingement of a jet of fluid. When such a check is desired, a pressure connection for this purpose must be provided on the housing. Any fluid that will not contaminate the system may be used. Extreme care must be exercised in making a spin check to avoid over-speeding. Even if excessive speeds are avoided, bearing lubrication may be inadequate so that prolonged checks should be avoided.

4.3 Induced Signal Check

The pick-off, associated circuitry and readout equipment of a self-generating flow transducer may be checked by an induced signal. A small coil, connected to an A.C. power source, is held in the proximity of the pick-off so as to effect an energy transfer. This functionally checks the circuit without breaking any connections and can be used to facilitate proper attentuation adjustment.

4.4 Applied Signal Check

The associated circuitry and readout equipment of a self-generating flow transducer may also be checked by applying the signal directly. Provision is made for connecting an oscillator in parallel with the pick-off to accomplish a check similar to that of Para. 4.3. Note, however, that the pick-off is not checked by this method. Care must be exercised to make sure that circuit characteristics are not altered or continuity disturbed by connection and disconnection of the oscillator.

4.5 Component Check

If any of the above checks indicate some malfunction, the circuit should be separated into two parts for additional checks.

4.5.1 Pick-Off Check

The resistance of the pick-off and resistance to ground should conform to the manufacturer's values plus allowance for any additional lead that may be included.

4.5.2 Readout Equipment Check

The readout equipment and associated circuitry should be checked by applying an oscillator signal of approximately 30 mv, peak-to-peak, at a frequency corresponding to that of the transducer at minimum linear flow.

5. DATA ACQUISITION

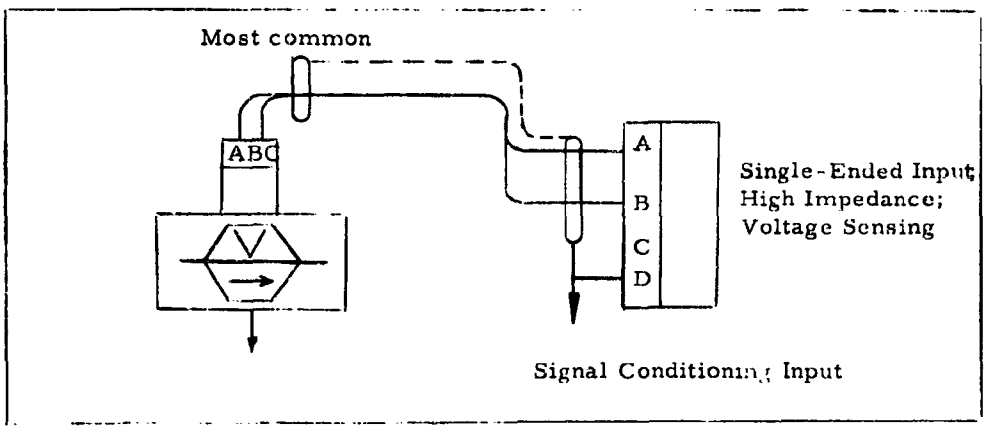
"Data acquisition" as used herein includes any treatment of the transducer output signal necessary for converting it into a form convenient for interpretation.

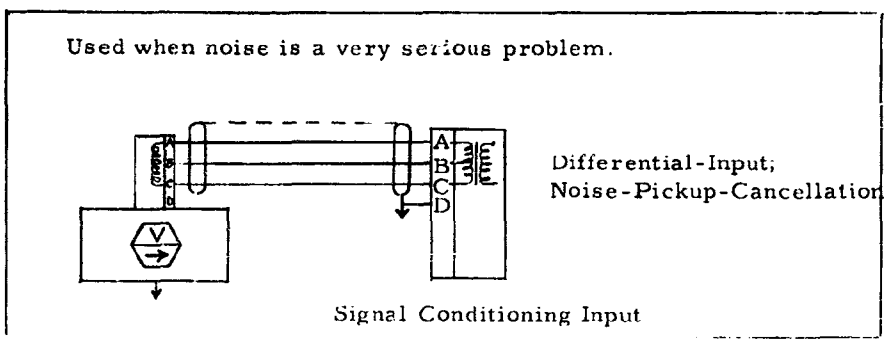
The data signal is transferred and converted in the following general manner. The electrical output from the flow transducer is sent to the signal conditioning equipment by means of a signal transmission system. After the signal has been properly conditioned, it is sent to a data presentation system, which consists of a monitor display or recording system. The display and recording can be a combination of analog and digital readouts.

The various recording systems shown below are meant only as a guide since there are many possible variations and combinations.

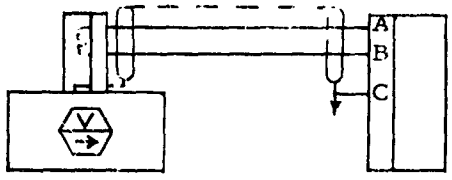
5.1 Signal Transmission

The common methods of transmitting electrical signals generated by the flow transducer to the signal conditioning equipment are as follows:



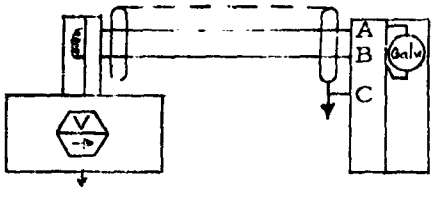


Used for ungrounded transducer.



Single-Ended-Input;
Low-Impedance;
Current-Measuring.

Used when high accuracy is the most important consideration.



Single-Ended-Input;
Low-Impedance;
Current-Measuring.

5.2 Signal Conditioning

In addition to the basic operations of amplification or attenuation, certain signal conditioning may be done to obtain data in a different form.

5.2.1 A rate-type signal conditioner counts, for repetitive short time intervals, the number of cycles of transducer signal produced in each of those time intervals. By the choice of a suitable time interval, desired units of volumetric flow rate may be indicated. Flow rate may be indicated even in gravimetric units if specific weight is constant.

5.2.2 A "totalization-type" signal conditioner is the process of accumulating the number of cycles proportional to the total volumetric flow which has passed through the transducer during any preselected time interval.

5.2.3 An integration-type signal conditioner provides a dc voltage level proportional to the signal frequency.

5.2.4 A "scaling-type" signal conditioner multiplies or divides the transducer output frequency by some selected factor. It is generally used to facilitate presentation and reduction of data.

5.3 Data Presentation

5.3.1 Monitor Display

Display is divided into two general categories, digital and analog. Both rate and totalization data are easily displayed digitally, while rate can also be displayed in analog form.

5.3.2 Recorded Data

To obtain a permanent record of the data, it is usually recorded by means of an electric typewriter, counter printer, graphic recorder, oscillograph or magnetic tape system. There are numerous combinations of recording systems, the detailed discussion of which would be beyond the scope of this Recommended Practice.

5.4 Supplemental Data

In many applications, the measurement of one or more additional variables may be necessary for complete interpretation of the flow data. Such supplemental data are generally limited to the following:

5.4.1 Temperature

Temperature of the measured fluid often has an effect on the performance of a turbine-type flow transducer. Any one or more of the following effects may produce errors and must be considered. There is a mechanical effect caused by thermal expansion or contraction of the transducer housing and rotor when the operating temperature materially differs from calibration temperature. (See Paragraph 6.1.1) An elevated or depressed operating temperature changes the physical properties of the fluid being measured, specifically, its vapor pressure, viscosity and specific weight. (See Paragraphs 3.5, 5.4.2 and 5.4.3)

5.4.2 Viscosity

Kinematic viscosity measurement is desirable when operating over a wide temperature range or near the low end of the transducer's flow range, and when high accuracy is

important. Fluid viscosity is usually determined indirectly by measuring the fluid temperature at a point four diameters downstream of the flow transducer. The measured temperature information is used to obtain the fluid's viscosity from known temperature vs viscosity data for the particular fluid being measured. Available data on the viscosity-temperature relationship of the fluid being measured may be supplemented by analysis of samples from the actual batch to determine the viscosity at operating temperature. Alternatively, a viscosimeter can be used for direct measurement.

5.4.3 Specific Weight

It is necessary to know the specific weight of the fluid at the flow transducer when gravimetric flow data are desired. This may be determined from a temperature measurement in the same manner as is described for viscosity. Alternatively, a densitometer may be used. In some systems the densitometer is arranged to compensate automatically the volumetric flow measurement so that flow rate and flow totalization are presented in gravimetric units. This approach often entails some loss of accuracy.

5.4.4 Pressure

Where compressibility is an important factor, fluid pressure is measured. The pressure should be measured four diameters downstream of the flow transducer (see Paragraph 3.5).

6. DATA INTERPRETATION

This section deals only with the analytical factors which affect the flow data acquired. It is presumed that factors such as two-phase flow, pulsation and electrical interference have been minimized to a degree consistent with the accuracy desired.

6.1 Volumetric Flow Measurement

Regardless of whether the signal conditioning equipment provides a measurement of flow rate or total flow, the readings must be divided by the calibration factor, "K" (defined in paragraph 3.5 of RP31.1), to obtain volumetric data. As noted in that paragraph, the factor is a function of several independent variables for which corrections may be applied according to accuracy requirements. For totalization, a mean effective calibration factor must be determined based on representative values of these variables. If the signal conditioning equipment introduces a scaling factor, it must also be applied to the data at this time. The flow through a turbine-type flow transducer is torsionally deflected by the rotor due to bearing friction and signal generation torque. In a properly functioning transducer this effect is small and is incorporated in the calibration factor. The magnitude of the effect, however, varies inversely with the specific weight of the flowing fluid, and size of transducer. Consequently, if the specific weight of the operating fluid differs from that of the calibrating fluid, an error is introduced. Even a change in specific weight, due to temperature or pressure variation, affects the factor. Because the magnitude of this error is related to the transducer design, no generalized correction can be given. Fortunately, the error is small, but even so it is desirable to calibrate with a fluid of approximately the same specific weight as the operating fluid, and at the same temperature and pressure in the case of a gas or compressible liquid.

Corrections, if applied at all, are usually for one or more of the following:

6.1.1 Temperature

Transducer temperature is usually assumed to be that of the flowing fluid. When operating temperature differs from that noted during calibration, an error is introduced

due to dimensional changes of the housing and rotor. A correction based on the thermal coefficient of expansion ( ) may be approximated as follows:

$$K_o = \frac{K_c}{1 + 3 \quad (T_o - T_c)}$$

Note that K_o decreases as operating temperature increases and that the correction applies only when housing and rotor have the same thermal coefficient.

6.1.2 Flowrate

The calibration factor "K" is usually expressed as a constant. When a range of flow rates is to be covered, error can usually be reduced by expressing the factor as a linear function of flowrate* either with or without temperature correction. In some cases a non-linear expression of calibration factor may be justified.

6.1.3 Viscosity

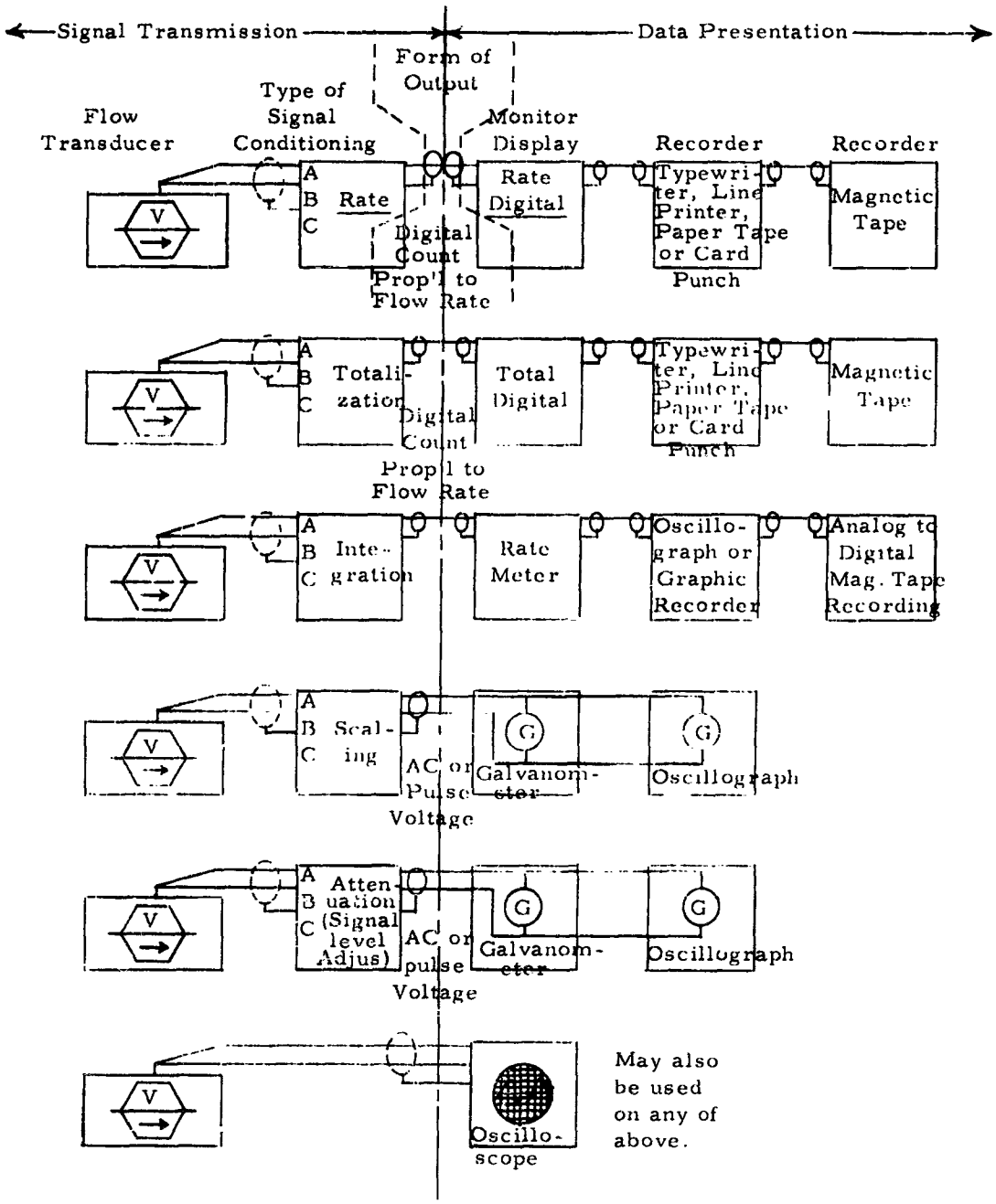
If viscosity of the operating fluid differs from that of the calibrating fluid, or if it varies during operation due to temperature change, it may be necessary to obtain calibration data at more than one viscosity. These data are best utilized as a single relationship of K factor vs Reynolds Number if transducer characteristics enable such a presentation. For simplification, the quantity f/ (output signal divided by Kinematic viscosity) which is approximately proportional to Reynolds Number, may be used instead. If transducer characteristics are such that a single relationship is not obtained the data must be utilized as a family of constant viscosity relationships of K factor vs flowrate.* In either case these relationships may be expressed as linear or non-linear functions.

*Either flowrate or frequency (of output signal) can be plotted, as they are essentially proportional one to the other.

6.2 Gravimetric Flow Measurement

When flow data obtained with a turbine-type transducer are desired in gravimetric units, the volumetric rate or total flow must be multiplied by the specific weight of the metered fluid at operating conditions. See paragraph 5.4.3.

RECOMMENDED DATA DISPLAY AND RECORDING SYSTEMS



Report No. FE-269-3

SECTION XI
Addendum III

TENTATIVE RECOMMENDED PRACTICE

RECOMMENDED CALIBRATION PROCEDURES

FOR

TURBINE-TYPE FLOW TRANSDUCERS

ISA RP 31.3

SPONSOR

Instrument Society of America
Penn-Sheraton Hotel
530 William Penn Place
Pittsburgh 19, Pennsylvania

1. Purpose

This Recommended Practice has been prepared to serve as a guide in the accurate calibration of turbine-type flow transducers for non-cryogenic liquid service.

2. Scope

This Recommended Practice covers the techniques involved in the calibration of volumetric turbine-type flow transducers as described in RP31.1.

3. Calibration Methods

Methods suitable for the calibration of turbine-type flow transducers may be classified as:

a) Direct Gravimetric
b) Indirect Gravimetric
c) Volumetric

Each of these methods has advantages and disadvantages depending upon the liquid being metered and the type of operation. The gravimetric methods require that the specific weight of the liquid be determined accurately to provide a basis for converting weight to volume, and, the effect of the buoyancy of the air must also be considered. The volumetric method is advantageous where specific weight determinations are difficult to perform, and is more direct in that conversions from weight to volume are not required.

The calibrator may be either of the open-type for use with low vapor pressure liquids only, or of the closed-type in which a pressure greater than atmospheric is maintained to prevent liquid loss from the measuring vessel by evaporation. The calibration methods are further classified as Static or Dynamic.

3.1 Static Method

In this method, weighing or measurement of volume occurs only while the liquid is not flowing into or out of the measurement vessel. This method is capable of high accuracy under properly controlled conditions and is conveniently traceable to the National Standards through static checks with reference units of weight or volume.

3.2 Dynamic Method

In this method, the measurement of volume or weight occurs while the liquid is flowing into or out of the measuring vessel. Although more suitable for many applications, it may involve dynamic errors which cannot be detected through static checks with reference units of mass of volume. Therefore, it is important that each new dynamic calibrator of a different type or size be checked carefully to prove that significant dynamic errors do not exist.

4. Calibration Procedures

Two procedures for conducting a turbine-type flow transducer are the running start-and-stop and the standing start-and-stop. The procedure which more closely duplicates the type of service anticipated in the application of the transducer should be selected whenever possible.

4.1 Running Start-and-Stop

The running start-and-stop requires that a reasonably constant flow rate be maintained through the transducer prior to, during, and immediately after the collection of the liquid in the measurement vessel. This duplicates the type of service encountered when the transducer is used for the measurement of flow rate or for totalization of large throughputs of long time-interval duration.

4.2 Standing Start-and-Stop

The standing start-and-stop more closely duplicates applications involving totalization of small throughputs of a short time-interval duration. This procedure requires that a "no-flow" condition exist at the transducer prior to the beginning and at the end of the calibration run.

5. General Precautions

General precautions which should be considered in the design of a calibration system for turbine-type flow transducers include the following:

5.1 System Piping

The piping between the transducer and the measurement vessel should be short, of small volume compared to the volume collected during the calibration interval, and especially designed for the convenient elimination of all air and vapor. It should be so constructed to assure that all of the liquid and only that liquid passing through the transducer is collected in the measurement vessel during the calibration interval.

5.2 Throttling or Flow Control

Throttling or flow control valves should be located downstream of the transducer to reduce the possibility of two phase flow occurring within the transducer under test. When this is not practical, a back-pressure regulator or similar device should be installed downstream to maintain the required back pressure.

5.3 Leak Indicators

Positive methods, visual if possible, should be provided to assure that no leakage occurs through the emptying mechanism of the measurement vessel during the calibration interval.

5.4 Measurement Vessel Capacity

The capacity of the measurement vessel should be not less than the volume delivered in one minute by the transducer operating at its maximum flow rate. Use of considerably smaller capacities may involve an appreciable sacrifice in the accuracy of the calibration procedure.

6. Calibration Systems

6.1 Direct Gravimetric, Open, Static, Calibrator

This system as shown in Figure 1 is applicable to the running start-and-stop procedure of calibration and can be used only with liquids of low vapor pressure. It utilizes a diverter to direct the flow as desired to storage or to the measurement vessel (weigh tank) without disturbing the rate of flow. The diverter actuates the electronic counter at the midpoint of its traverse, diverts the flow quickly, and has approximately equal traversing speeds in each direction.

Prior to a calibration run, the diverter is positioned for return to storage, the flow rate adjusted to the desired value, the dump valve closed and the tare weight of the weigh tank determined. The diverter is then operated to divert the liquid into the weigh tank, automatically starting the counter. After collection of the appropriate amount of liquid, the diverter is repositioned to return to storage, automatically stopping the counter. The total cycles accumulated and the liquid temperature at the transducer are recorded, gross weight measured and net weight determined. The volume of liquid corresponding to this net weight is calculated from the specific weight of the liquid at the temperature of the liquid passed through the transducer during the run. Considerations are included for the effect of air buoyancy.

The modification of this system as shown in Figure 2 is applicable to the standing start-and-stop procedure of calibration. In this method,

the diverter is replaced by an on-off valve located near the end of the line discharging into the weigh tank. Prior to a standing start-and-stop calibration, the on-off valve is opened and the flow rate adjusted by means of other valves to the desired value. The on-off and dump valves are then closed, the tare weight measured, and the counter reset to zero. The on-off valve is opened and the counter automatically totalizes cycles from the transducer without external actuation. When an appropriate amount of liquid has been collected, the on-off valve is closed, liquid flow stops, and readings of gross weight and total cycles are obtained.

6.2 Direct Gravimetric, Open, Dynamic, Calibrator

This method is used only for the running start-and-stop procedure of calibration. The electronic counter is actuated by the counterpoise beam of the weigh-scale. The principal components of a dynamic calibrator are shown in Figure 3.

Dynamic factors which may influence the accuracy of calibration by this method may include: change in inertia of the weigh system with the resultant change in time required to accelerate the counterpoise beam past the counter actuation point; the change in impact force of the falling liquid between the initial and final weigh points; the collection of an extra amount of liquid from the falling column by the rising level in the weigh-tank; and surging of the liquid in the weigh-tank at the instant the weighing is performed.

Prior to a calibration by this procedure, the weigh-tank dump valve is opened, the flow rate adjusted to the desired value, the counter reset to zero, and an appropriate counterpoise tare-weight selected. This weight should be sufficiently large to prevent the counterpoise beam from rising until forces resulting from the closing of the dump valve have subsided and significant drip-off from the dump valve has ceased. Generally, the tare time should be of 10 or more seconds in duration, but shorter intervals are sometimes adequate when operating near the maximum capacity of the system.

The counter is triggered when the weight of liquid in the weigh-tank increases to the point where it balances the counterpoise tare weight. An additional weight, equivalent to the preselected number of pounds of calibrating liquid, is then added to the pan depressing the counterpoise beam. When the mass of liquid in the weigh-tank balances this weight, the counter is automatically stopped. Data recorded for the run include total cycles, net weight of liquid collected, and the temperature of the liquid at the transducer.

6.3 Direct Gravimetric, Closed, Calibrator

This calibrator provides a method of maintaining sufficient back pressure in the weigh-tank to prevent significant evaporation of high vapor pressure liquids during the calibration interval. As a dynamic calibrator, it is used with the running start-and-stop procedure. The standing start-and-stop procedure can be used when it is operated as a static calibrator.

The schematic diagram, Figure 4, shows liquid flow out of the weigh tank through the transducer during the calibration run. The pressurizing gas provides the necessary pressure level to prevent evaporation and to cause the liquid to flow through the system. The method is equally suitable for applications in which flow into the weigh-tank is desired during the calibration run. In this case, the test section of flow straightener, transducer, and flow control is reversed from that illustrated.

The procedures followed and data recorded in conducting a calibration run with this calibrator are similar to those previously described for the open-type gravimetric calibrators. However, in this closed system, the weight of pressurizing gas entering or leaving the weigh-tank during a calibration run is significant. Thus, adequate supplementary instrumentation must be supplied to determine accurately the weight of pressurizing gas transferred to or from the weigh-tank during the run.

6.4 Indirect Gravimetric, Open, Calibrator

This method is used only for the running start-and-stop procedure of calibration. The principal component of the system, Figure 5, is a vertical standpipe whose height is very large compared to its diameter. The large L/D ratio is necessary to minimize the surface area at which evaporation may occur and to produce measurable changes in pressure at the bottom of the standpipe as the liquid level rises. Incremental increases in pressure are measured by means of a mercury manometer equipped with electrical contacts or by any other suitable pressure measuring instrument which can be set to start and stop a counter at preselected pressure increments. The weight of liquid added to the standpipe is then the product of the standpipe cross-section area and the measured change in pressure, and is independent of the density of the calibrating liquid to the same extent that any other weighing procedure is independent of the density of the liquid being weighed. As in the case of other weighing procedures a correction must be made for the effect of buoyancy of the atmosphere on the liquid. For a system using a single leg mercury manometer as the pressure sensing instrument, corrections are also made for the weight of liquid entering the manometer well and the change in elevation of the mercury level in the well. The basic equation for exact head balance and liquid weight is as follows:

$$W = .03613\left(\frac{Pl}{Pl - Pa}\right) Al \cdot H_{hg} \quad P_{hg}\left(1 + \frac{At}{Aw}\right) - Pa\left(1 + \frac{At}{Al}\right) - Pl\left(\frac{At}{Aw} - \frac{At}{Al}\right)$$

Where W = weight of liquid discharging from transducer being calibrated, which is the sum of that entering the standpipe and that entering the mercury manometer as mercury is displaced.

H_{hg} = Change in elevation of mercury meniscus; i.e., distance between contacts used in inches.

P_{hg} = Mercury density at manometer temperature, grams/cc.

Pl = Density of calibrating liquid, grams/cc.

Pa = Density of atmospheric air, which is assumed constant at .0012 grams/cc.

Al = Cross-section area of standpipe, in square inches.

At = Cross-section area of manometer tube, in square inches.

Aw = Cross-section area of manometer well, in square inches.

The procedures followed and the data recorded are essentially the same as those for the direct gravimetric calibrators.

Dynamic considerations applicable to this system are: (1) ascertain that the pressure-measuring device has completed its acceleration and attained a constant velocity before the weigh-time interval is commenced, (2) oscillations resulting from the natural frequency of the pressure indicator must not exist and, (3) air compression in the standpipe, especially at high flow rates, can result when restrictions such as flame arrestors are placed in the vent. It is readily seen that errors indicating higher than actual flow can result when such restrictions exist. Other important considerations are: Effects of thermal expansion on

the standpipe cross-sectional area and on the density of the manometer fluid, and incomplete drainage of the standpipe walls before starting the weigh-time determination, a particularly significant factor when high viscosity liquids are used.

6.5 Volumetric Calibrators

This method of calibration may be subdivided into the same system types as the gravimetric calibrators. Volumetric calibrators may be designed as static or dynamic systems and for open or closed operation. The liquid level in the measurement vessel may be determined continuously by employing a buoyant force technique or incrementally using liquid level probes.

In using a volumetric calibrator, the true volume passed through the transducer is that volume registered by the measurement container with corrections applied to include allowances for the change in:

a) Measurement container dimensions with change in pressure, C_{mp}.
b) Measurement container dimensions with change in temperature, C_{mt}.
c) Volume of liquid as a result of pressure differences existing between the transducer and the measurement container, C_{lp}.
d) Volume of test liquid as a result of temperature differences existing between the transducer and the measurement container, C_{lt}.

The calibration factor is then computed:

$$\text{cycles/gallon} = \frac{\text{Total Count}}{V\,(\text{Trans } T, P)} - \frac{\text{Total Count}}{V_{Ind} \cdot C_{mp} \cdot C_{lp} \cdot C_{lt}}$$

Where: $V_{(Trans\ T, P)}$ = true volume at transducer temperature and pressure in gallons.

V_{Ind} = volume indicated by the volumetric measuring container.

7. Component Accuracy

7.1 Weights

Scale counterpoise weights for the gravimetric calibrators shall conform to the tolerances for Class C Commercial Test Weights as stated in Circular 3 appearing in volume III, Handbook 77 of the National Bureau of Standards, the acceptance tolerances (applicable to new or newly adjust weights) being one-half the tabular tolerances. Calibration of counterpoise weights shall be by comparison at regular intervals with laboratory reference standards traceable to the National Bureau of Standards.

It is recommended that scale counterpoise weights procured in the future for use on lever-type weighing systems of gravimetric calibrators shall be made of a non-magnetic, free-turning, stainless steel similar to AISI Type 303, shall be of one piece construction and suitably slotted, when necessary, to permit centering of the weights about the counterpoise hanger; they shall not be plated or laquered and the only adjustment permitted will be by removal of material. Surfaces of the weights, including those exposed by adjustment operations, shall be smooth and all corners and edges obviously rounded. Each weight larger than 0.1 pound shall be engraved with its nominal weight and its counterpoise value when used in connection with a scale of proper ratio; die-impressed figures are not acceptable.

7.2 Pressure Sensing Devices

The intervals between electrical contacts in the mercury manometer type pressure sensing instrument shall be measured by means of a Shadograph, Cathetometer, or other optical techniques. Consideration must be given in the application of these techniques to the possibility of error introduced by image distortion when viewing the contacts through the glass manometer wall. The measurements shall be made in a

temperature controlled area, and at the same temperature as that to which the manometer is normally exposed. Other pressure sensing devices such as differential pressure transducers shall be calibrated with precision dead weight testers, the accuracy of which is traceable to the National Bureau of Standards. Further, they shall be temperature compensated or temperature controlled.

8. Calibration Liquids

8.1 The liquid used in performing a calibration should, whenever possible, be the same as that for which the transducer is to be used in service, and the operating conditions should be duplicated.

8.2 A substitute calibrating medium may be employed when it is impractical to use the operating liquid. When this is done, the kinematic viscosity and specific gravity of the calibrating liquid should be within 10 per cent of that of the operating liquid. The lubricity of a liquid cannot be as accurately defined as viscosity and specific gravity, but this parameter should be considered when using operating liquid simulants and should be matched as closely as possible.

8.3 Filtration shall be provided to protect the transducer against damage and/or malfunction from solid particles or other materials such as lint. As shown in RP31.2, the degree of filtration required is a function of meter size. For general usage on a calibration stand where various size meters are to be calibrated, a 50 micron or finer filter shall be employed.

9. Installation Procedure

9.1 When installing the transducer in the calibration rig, observe the flow direction arrow, or wording, marked on the transducer regarding inlet and outlet ends.

9.2 If flow straighteners or straight sections of pipe are used as an integral part of the transducer service installation, then the calibration shall be performed with the same configuration. Under those circumstances where the transducer must be used immediately downstream of pipe elbows or other swirl producing pipe fittings, it is recommended that the calibration be performed with the same plumbing configuration, but this technique does not guarantee a good calibration.

9.3 The transducer shall be calibrated in a horizontal position with the pick-off vertically upward since this is the normal attitude for most service installations. However, when the service installation is other than horizontal, a difference in axial thrust balance may cause a change in the calibration factor. Pick-off orientation may also cause an error due to the relationship of magnetic drag and gravitational forces in some types of transducers. For maximum accuracy, these effects should be known to be negligible for the design of the transducer being used or the unit should be calibrated in the attitude in which it will be installed. When a transducer is equipped with two or more pick-offs, the transducer is to be calibrated with all pick-offs installed.

10. Calibration Procedure

10.1 The meter shall be "run-in" for a period of at least five minutes prior to calibration to insure good operation of the transducer during calibration.

10.2 During the run-in period, the rms millivolt output of the pick-off shall be measured and recorded at the rated minimum and maximum flow rates. The wave shape of the output signal shall also be observed on a cathode-ray oscilloscope to check for transducer malfunctions.

10.3 The pressure drop across the transducer shall be measured at maximum rated flow (Ref. RP31.1).

10.4 The operating pressure shall be measured and should be such as to preclude a change in the calibration factor due to various types of two-phase phenomena. The pressure shall be measured four diameters downstream of the flow transducer (Ref. RP31.1). The required back pressure may be determined by specific tests, but in the absence of exact data it may be set at a pressure equal to the sum of the vapor pressure of the liquid at the operating temperature plus three times the measured pressure drop across the transducer.

10.5 The temperature of the calibrating liquid shall be measured with a thermocouple or other temperature sensor four diameters downstream of the transducer. If it is necessary to install the temperature sensor upstream of the transducer, because of installation considerations, make certain that the sensor does not introduce swirl in the liquid. In all installations, the sensor must be immersed to a sufficient depth to minimize thermal conduction error.

10.6 The total number of pulses (or cycles) accumulated for each calibration point shall be dictated by the flow measurement accuracy requirement. Since the usual electronic counter has an inherent accuracy of $\pm$ 1 pulse (or cycle), it is apparent that a sufficient number of pulses (or cycles) should be accumulated to make that error negligible.

10.7 The total count method does not require that flow rate be maintained absolutely constant when calibrating in the region in which the calibration factor is essentially independent of flow rate. Variations in flow rate of not more than 4 per cent should not introduce significant errors. However, in the laminar and transition regions, the calibration factor is affected significantly by both flow rate and liquid viscosity. Thus, in calibrating in these regions, flow rate should be maintained constant to 1 per cent or better or the duration of the calibration run, as well as the total pulse count, should be measured. These data then provide means of determining the exact average frequency existing during the run.

10.8 All gravimetric calibration methods require an accurate basis for converting weight to volume. Thus, the specific weight of the liquid in pounds per gallon at the transducer temperature and pressure should be determined to an accuracy of 0.05 per cent or better. Considerations must also be included for the effect of air buoyancy. Suitable instruments for the determination of specific gravity include the hydrometer, Westphal balance, and pycnometer.

The conversion from specific gravity to specific weight should take into consideration the effect of temperature on both the liquid and the specific gravity measuring instrument. This may amount to as much as 0.5 per cent per 10°F for the liquid and .01 per cent per 10°F for the instrument in working with typical hydrocarbons. Applicable tables to provide for these corrections are sometimes available. ASTM D-125° Petroleum Measurement Tables for use with liquid hydrocarbons and soft glass 60°F hydrometers are an example.

Specific weight may also be computed directly when specific gravity is measured with a 60°F hydrometer at the transducer calibration temperature (t) by the relation:

$W_{uv(t)} = 8.3372\ (SG_i + C)$ = pounds per gallon in vacuo at temperature, (t).

where: 8.3372 = weight in pounds of a gallon of water in vacuo at 60°F.

SG_i = true specific gravity as indicated by a soft glass 60/60°F hydrometer at the temperature t °F.

$C = 0.000025\ (\frac{5}{9})\ SG_i\ (60 - t)$ = a correction for the expansion or contraction of the hydrometer from the reference temperature of 60°F. For liquid hydrocarbons having a specific gravity range 0.7 to 0.9 the approximate value, C = 0.0001 per 10°F, is usually accurate.

Similar corrections to compensate for temperature effects on other specific gravity and density measuring instruments are usually available from the instrument manufacturer. A plot of specific gravity versus temperature for the calibrating liquid in use is required for this direct computation method when calibration temperature is not constant or specific gravity cannot be determined at the exact calibration temperature.

11. Data Handling

11.1 The total number of pulses (or cycles) accumulated on the counter during a test run divided by the number of gallons passed through the transducer gives the basic calibration in cycles per gallon.

11.2 The number of calibration points shall not be less than five and should include the minimum and maximum flow rates as specified by manufacturer.

11.3 The number of runs at each calibration point shall be not less than two and shall be taken with the flow rate increasing and decreasing to determine the effect of hysteresis on repeatability. Successive runs should have repeatability within $\pm$ .1 per cent.

12. Data Presentation

12.1 Since the turbine type flow transducer is a volumetric device, the calibration data should be presented in volume units. The standard format should be a plot or cycles/gallon versus frequency. Cycles/gallons is designated by the letter "K" (Ref. RP31.1). For convenience to the user, it is also correct to present the data in a number of other ways such as: gallons/cycle, or pounds/cycle. When a transducer is calibrated with a number of liquids with various kinematic viscosities, it is useful to plot the data as cycles/gallon ("K") versus frequency divided by the viscosity in centistokes. This in essence shows the effect of Reynolds Number on transducer performance.

12.2 The volumetric data are convertible to gravimetric units by the following relationship:

$$\text{lb/hr} = \frac{f \times 3600 \times W_{uv}\ (\text{Trans T, P})}{K}$$

Where: K = cycles per gallon at a given frequency

f = cycles per second (meter output)

W_{uv} = Weight per unit volume in vacuo of the test liquid at transducer temperature and pressure.

13. Correlation with NBS

13.1 It is recommended that flow rate correlation checks shall be made with the National Bureau of Standards at two-year intervals.

13.2 The correlation checks shall be made using turbine type transducers of proven repeatability as transfer standards. The transducers so used shall be termed "Reference Transducers."

13.3 The liquid used shall be Mil-Spec. 7024 A Type-2 which is the liquid used in the NBS calibrator.

13.4 A minimum of five points covering the full range of the transducer shall be taken in the calibration of the Reference Transducers.

13.5 The number of test runs at each calibration point shall be 8 to 10 and the standard deviation shall be no greater than .06.

13.6 The Reference Transducer shall be calibrated by the users on a monthly basis to maintain surveillance of the accuracy of the calibration facility.

14. Comparison Calibrations

14.1 In-place calibrations of turbine type flow transducers may be performed when it is impractical to remove them from the operating system or when it is desirable to determine the effect of pulsation or swirl which may be present in the system.

14.2 In-place calibrations are performed using turbine type flow transducers which shall be termed "Master Transducers."

14.3 The Master Transducer shall be installed in series with the transducer to be calibrated and the proper steps taken to reduce pulsation and swirl at the inlet to the Master Transducer.

14.4 A five-point calibration shall be made covering the rated range of the transducer. The flow rate points are set by the frequency output of the Master Transducer and the flow rate is held constant using a frequency meter, electronic counter, or cathode-ray oscilloscope for indication of flow variation. Cycles per gallon shall be used as the basis for the comparison of indicated flow rates as follows:

$$K_2 = K_1 \times \frac{CPS_2}{CPS_1}$$

Where: K_1 = Cycles per gallon of Master Transducer.
K_2 = Cycles per gallon of transducer being calibrated.
CPS_1 = Cycles per second of Master Transducer.
CPS_2 = Cycles per second of transducer being calibrated.

This simple method can be used only if the temperature of the operating liquid is the same at both meters. If the temperature of the liquid is different at the two locations, then a correction must be made for the difference in specific gravity.

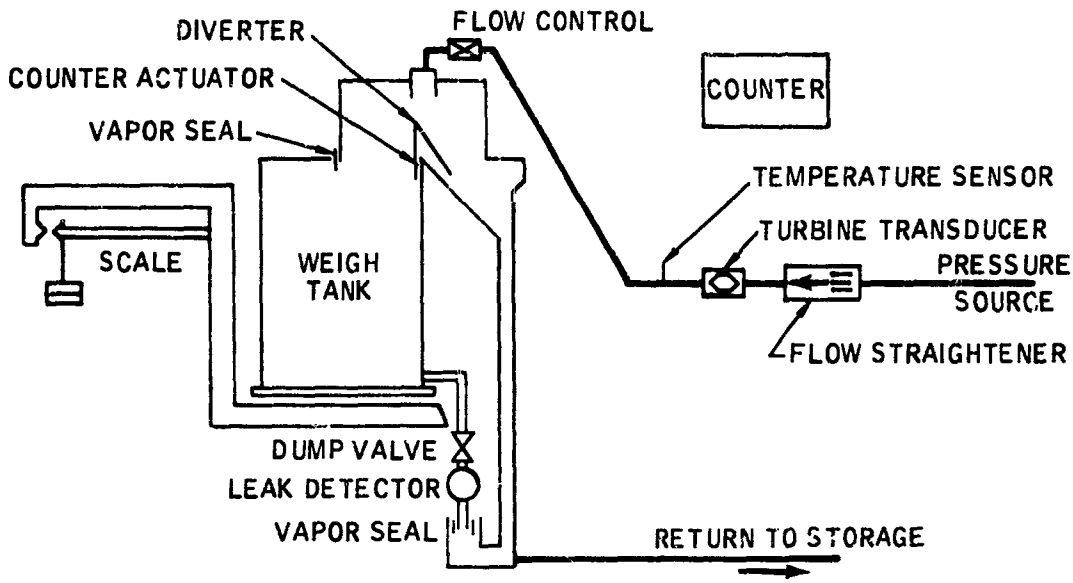
Then: $K_2 = K_1 \times \frac{CPS_2}{CPS_1} \times \frac{SP \circ Gr_2}{SP \circ Gr_1}$

Where: $SP \circ Gr_1$ = Specific Gravity at the Master Transducer

$SP \circ Gr_2$ = Specific Gravity at transducer being calibrated.

DIRECT GRAVIMETRIC

OPEN STATIC CALIBRATOR
RUNNING START & STOP



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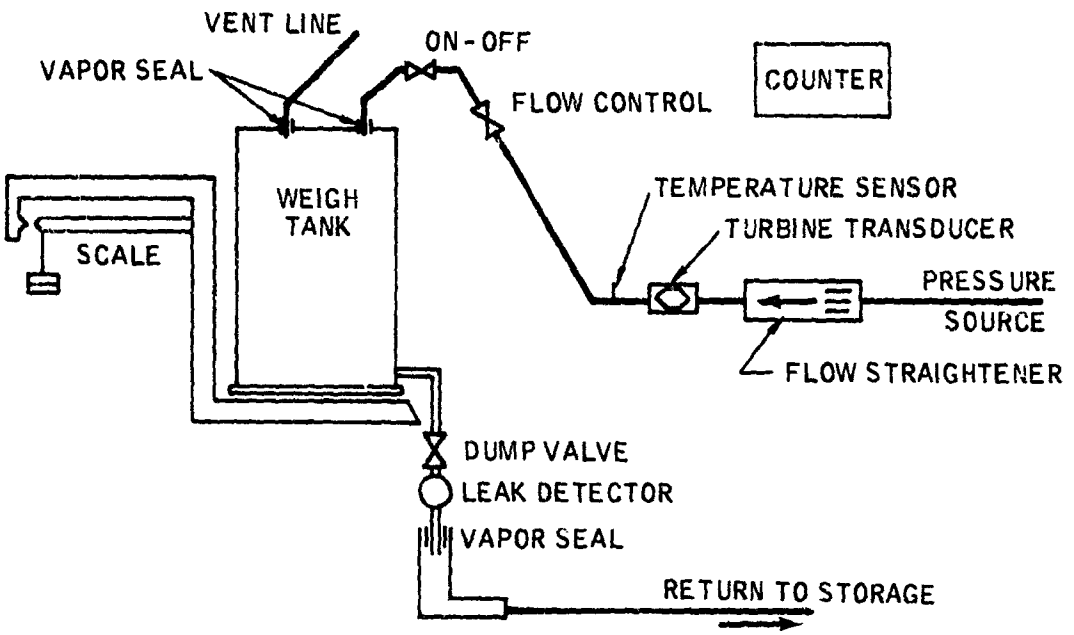
DIRECT GRAVIMETRIC

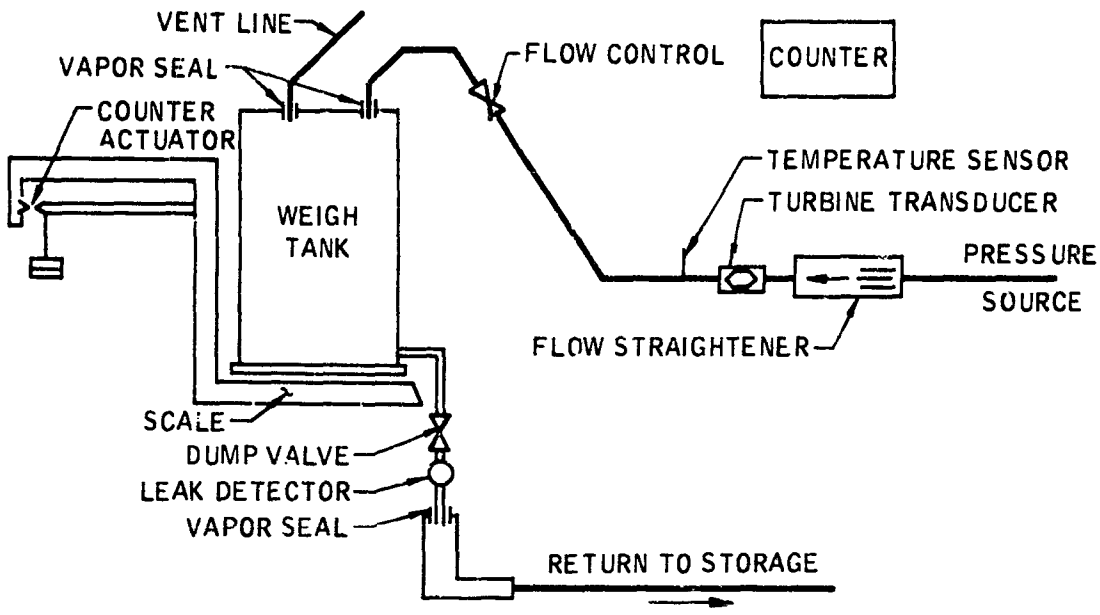
OPEN STATIC CALIBRATOR

STANDING START & STOP



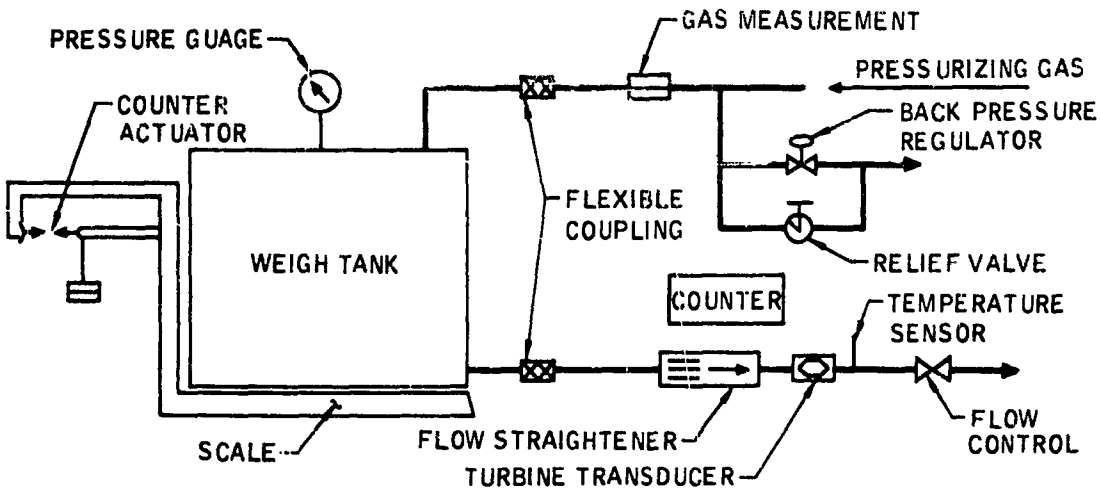
4535-10

DIRECT GRAVIMETRIC OPEN DYNAMIC CALIBRATOR

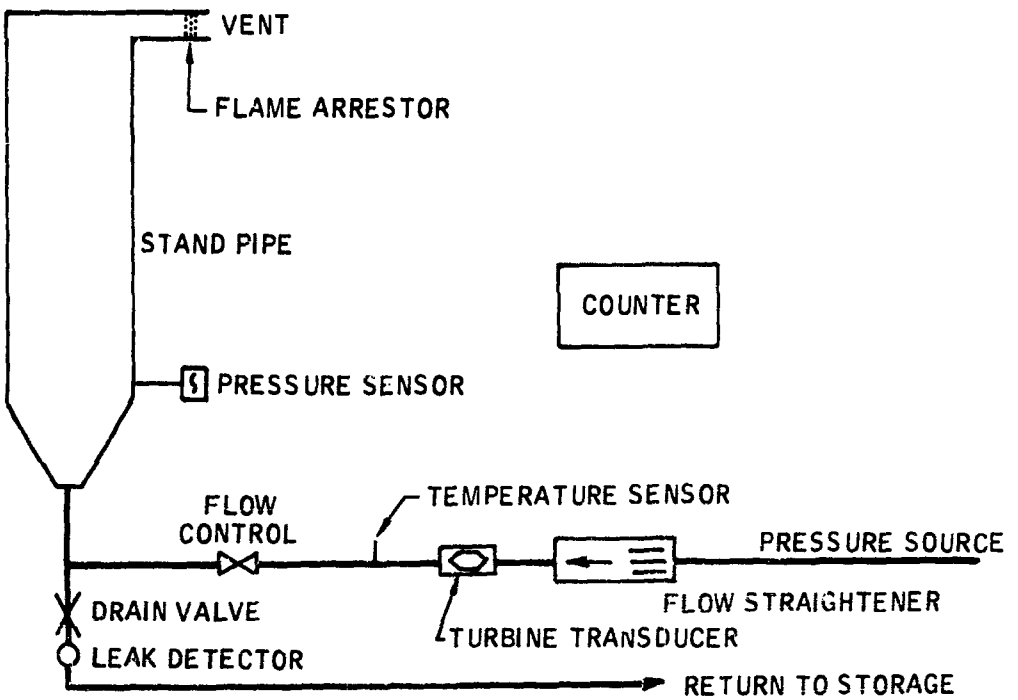


-533-17

DIRECT GRAVIMETRIC CLOSED CALIBRATOR



INDIRECT GRAVIMETRIC OPEN DYNAMIC CALIBRATOR



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Report No. FE-269-3

SECTION XI
Addendum IV

PROPOSED

1962 SUPPLEMENT

API STANDARD 1101

(DRAFT OF JANUARY 31, 1962)

MECHANICAL DISPLACEMENT METER PROVERS

AMERICAN PETROLEUM INSTITUTE

1271 AVENUE OF THE AMERICAS

NEW YORK 20, NEW YORK

Price _____

In the May 1962 meeting of the A.P.I. Committee in Denver, there were numerous changes made in the draft of January 31, 1962 PROPOSED 1962 SUPPLEMENT - API STANDARD 1101 - MECHANICAL DISPLACEMENT METER PROVERS. These changes are for the most part revisions of grammar. The only changes of any consequence are those which pertain to Section 7 - The Water Draw Method of Calibration. Discussion of this method may be found on page 30 and Appendix E.

It was agreed that for water draw pressures of 75 pounds and higher, the water compressibility correction factor would be 0.0000032. For water pressure of 25 pounds to 75 pounds the correction factor would be 0.0000042 and for water pressure up to 25 pounds the factor would be 0.0000055.

It was further agreed that the formula to be used to account for changes in volume of a prover due to internal pressure would be

$$1 - \frac{\text{Pressure} \times \text{Prover Diameter}}{23.2 \times 10^6 \times \text{Prover Wall Thickness}}$$

J. Charles Halpine
A.P.I. Committeeman

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PART I
MECHANICAL DISPLACEMENT METER PROVERS

I. INTRODUCTION

During the preparation of the 1960 revision to API Standard 1101, general developments were being made in the techniques of proving meters by Mechanical Displacement provers. These developments are now sufficiently advanced to warrant standardization and are covered in this supplement.

Improvement in the techniques of meter proving has progressed to the extent that mechanical displacement provers reduce the expense and difficulty of proving large capacity meters and makes more practical the application of these meters in large pipe line, tanker and barge metering operations. Yet these techniques apply equally well to smaller size meters, as for instance those being used in LACT operations.

The 1960 Revision of API Standard 1101 includes a brief description of some of the "Mechanical Displacement" provers in paragraphs 2026 and 2027. It is in this field that most of the new developments have occurred and with which this Supplement is chiefly concerned. Mechanical displacement provers have been developed for pipe line use which utilize a calibrated portion of the pipe line itself as the prover. Auxiliary sections of piping, constructed specifically as prover sections, are also widely used and these may be straight sections of piping of "folded" and laid in the form of a loop. Both portable and stationary provers may be constructed on these principles. Some provers are so arranged that liquid can be displaced in either direction, viz., the reciprocating or bidirectional types.

The chief advantage of most of these mechanical displacement type provers is that during proving, the flow of liquid through a meter being

proved is not interrupted. This permits the meter to be proved on a continuous flow without starting or stopping the meter.

When a meter is being proved while it is running under normal operating conditions, such as is possible with mechanical displacement provers, the volume required to be displaced from the prover by the displacing device is dependent upon (1) the resolution with which the meter register can be read and (2) the resolution with which the position of the displacing device can be located at the extremities of the prover section. The application of high rate pulse generators on the meters and precision displacer detectors in the prover section, combined with the elimination of errors arising from the start-stop method, have enabled the use of considerably smaller provers than previously described in API Standard 1101, paragraphs 2026, 3034 and 3035.

II. DESCRIPTION OF SYSTEMS

The continuous flow technique of meter proving is accomplished by several types of mechanical devices, all of which are relatively simple and commercially available. Each type, however, is dependent upon a common basic principle of operation; accurately and repetitively displacing a precalibrated and known volume of liquid from a cylindrical container with a mechanical sealing displacing device driven through the container by fluid energy from the stream being metered. Simultaneously, the corresponding metered volume is indicated. A ratio is determined between the known volume displaced and the meter registration to determine the meter factor.

A meter being proved on a continuous flow basis must be equipped at the time of proof with two registers. The first may be either the mechanical or electronic, driven by the meter continuously and is the meter's totalizing register. The second may be of the electronic pulse counting, although not restricted to this type, and is gated on and off by the passage of the displacing device across detectors at the extremities of the prover section; and is employed as the proving register.

In order to reduce the physical dimensions of these provers to a convenient and economic size, a high resolution of the meter's proving register and detector device is necessary. High register resolution may be accomplished by attaching a pulse generating device to the meter to provide a high number of pulses relative to the rotation of the meter. These pulses are counted by a proving register. High resolution of the detectors can reduce the length of the prover.

When proving by mechanical displacement provers only those pulses received during the proving run must be counted and the limits of the prover volume must be defined by detecting or sensing devices which are actuated by the displacer. These detectors are utilized to start and stop the proving counter at the limits of the displaced volume so that pulses created by the meter during the proving run only are counted. Such detectors must have the ability to detect and signal the location of the displacer with a resolution comparable to that of the pulse generating and counting system.

There are two basic methods or designs of the continuous flow, mechanical prover, namely, unidirectional and bidirectional. As their names imply, the unidirectional prover allows the displacer to travel in only one direction through the proving section, while the bidirectional type allows the displacer to move in either direction, for it incorporates a means of reversing the flow through the prover section.

Both unidirectional and bidirectional provers may be constructed so that the full flow stream of the meter or meter battery being proved may pass through the prover. Mechanical displacement provers can be manually or automatically operated.

The following describes details to each type of prover.

UNIDIRECTIONAL PROVERS

Unidirectional provers may be divided into two categories; (1) the non-return in-line type, commonly referred to as the "measured mile" and (2) the return or circulating type often called the "endless loop."

(1) Non-Return Unidirectional Prover

This type prover is an in-line prover which utilizes a section of a pipe line as the prover section and is

described in API Standard 1101, Paragraphs 3034 and 3035. The system is usually most condusive to the proving of a battery of meters operating on a common stream and the entire metered stream flows continuously through the in-line prover. Detectors are placed at selected points which define the calibrated volume of the prover section. This volume is usually determined by the master meter method described in Section VII. A displacer launching device is placed up-stream of the prover section, and receiving facilities are installed at some point downstream of the prover section. Often conventional scraper traps already installed may be used. To make a proving run, a displacer (scraper, piston, or spheroid) launched upstream is allowed to displace the prover volume and then received downstream.

(2) Return Unidirectional ("Endless Loop")

The calibrated continuous prover loop technique is a variation of the in-line proving described in the above paragraph and is shown in Figures 4 and 5. This type prover involves the passage of circulation of the displacer, usually a spheroid, around a prover section consisting of a closed loop of pipe in which a central control interchange unit (special ball type valve modified to handle spheroid Figure 4) acts as a common launching and receiving device. In the "endless loop" technique, the piping is arranged so that the downstream end of a loop of pipe crosses over the up-stream end of the looped section. The central interchange also

sometimes employs two valves which permits the displacer to be launched through the prover without the necessity of removing the displacer from the proving system and reinserting it at the upstream end of the prover. Such continuous or "end less" calibrated prover loops may be manually operated or may be power operated and automated to enable the proof of a meter by actuation of a push button. The metered stream is usually permitted to run through the loop section of pipe in a normal operation and consequently need not be isolated from the carrier line unless desired. This enables the movement of a multiplicity of liquids through the prover section affording a self flushing action and minimizing intermixing between different liquids.

BIDIRECTIONAL PROVERS

These provers may be divided into two categories; (1) "Running Start-Stop," (Figures 1, 2, and 3), and (2) "Standing Start-Stop" (API Standard 1101, Paragraph 3033 and Figures 21 and 22.

(1) Bidirectional "Running Start-Stop"

These are of the type which consist of a prover section in which the displacer travels back and forth. Suitable manifolding and valves either manually or automatically operated enables the reversal of the flow through the prover. The prover section is often a straight piece of pipe, and normally employs a cylindrical displacer, or it may be contoured or folded. The straight or the folded

type can be designed in such a way as to fit into limited space or enable its portability. A spheroid is normally used in the "folded" or "contoured" type. The direction of flow through the prover section, and consequently the direction of movement of the displacer, is alternated by manipulation of the prover's manifold or directing valves. At the end of each stroke, the liquid by-passes the displacer until the valves are reversed. A meter proof run usually consists of a round trip of the displacer for greatest accuracy and consequently the volume displaced from this type prover is expressed as the sum of the displaced volume in two directions.

(2) Bidirectional, "Standing Start-Stop"

This type prover is built in relatively small sizes for relatively small flow rates and is particularly condusive to proving meters which make intermittent deliveries of high vapor pressure liquids, such as LP Gas. Because this type prover does not have the advantage of allowing the meter to be proved on the "Running Start-Stop" basis its volume must conform to volume specification described in Standard 1101 for such type provers. The prover requires no special high speed read-out equipment on the meter for resolution, for the meter is operated and read in much the same manner as with a conventional prover tank. After recording the opening meter reading, and with the displacer against the stop at one end of the calibrated section, the

valve or valves are operated to reverse the stream through the prover. The prover volume used is that displaced by one stroke of the piston in either direction and a round trip is not necessary for a proof run. Meters proved by this type prover should be equipped with a totalizing register having a least reading compatible with the displaced volume.

III - EQUIPMENT FOR MECHANICAL PROVERS

CONSTRUCTION DETAILS COMMON TO ALL MECHANICAL PROVERS

The materials selected for a prover should conform with the applicable codes for the pressure rating and area designation of the system at the point at which the prover is to be located. Proper corrosion allowances and the usual design considerations for pressure piping should be made. Suggested minimum material standards for any system are Grade B, carbon steel pipe and fittings, and Grade 1, A181 carbon steel flanges. Pipe should be selected for roundness, smoothness, and only the best lengths employed.

In the fabrication of provers, care must be exercised to assure proper alignment and concentricity of pipe joints and this should be made as neat as practicable. All welding should be in accordance with applicable codes. Care should be taken to prevent burn through, icicles, high-lows and the like when applying the stringer bead in prover section welds. For the lower ASA ratings it is often advantageous to butt the ends of pipe and welding fittings together to reduce burn-through. Should flanged joints be required, dowel pins for precise alignment of the joints should be employed and gasket concentricity should be assured.

Internal coating of the prover section with a suitable coating material which will provide a hard, smooth, long lasting finish will reduce corrosion and prolong the life of the displacer and prover. It appears that internal coatings are most useful when the prover is used with liquids having little or no lubricity, such as aviation and motor gasolines, LPG, etc. Generally, the more impervious the elastomer is to petroleum liquids, the more desirable internal coating becomes. The

impervious elastomers generally have the least wear resistance. However, excellent results and satisfactory longevity of the elastomer have been experienced by using common mill finished pipe without coating.

Insulation of provers, when installed above ground may contribute to better temperature stabilization. Proper temperature stabilization of the proving system is normally accomplished by the continuous circulation of liquid through the prover section.

It is recommended that industrial thermometers having a suitable range be used, graduated in single degrees or less and accurate to 1 degree F. or better. They shall be installed at the meter and at the prover inlet. (A.P.I. Standard 2500)

Pressure gauges are required in closed Prover Systems. These gauges shall be reliable and of suitable range, calibrated to an accuracy of 1% of full-scale reading. (Refer to Par. #2018 in A.P.I. Code #1101.)

EQUIPMENT COMMON TO ALL DISPLACEMENT PROVERS

Displacing Devices

One type of displacing device commonly used in mechanical provers is the elastomer spheroid which is hydrostatically filled with water or glycol-and-water under pressure, and expanded so that its minimum diameter is slightly larger than the inside diameter of the prover section. Expansion to between one and two per cent greater than pipe I.D. is considered satisfactory for the operating diameter of the spheroid. This allows it to act as a squeegee and leave only a minute consistent film on the wall of the prover section. Care must be exercised to assure that no air remains inside the spheroid during its expansion. The elastomer must be impervious to the operating liquids.

A second type of displacing device is the cylindrical mechanical piston with cups. It is made so that standard pipe line scraper cups can be fastened to each end in such a way that the lip of the cup is facing away from the piston. This forces the lip of the cup out against the inside wall of the pipe when a pressure differential is exerted across the cup. This allows the cups to act also as a squeegee and leave only a minute consistent film on the wall of the prover.

A third type of displacing device, somewhat similar in nature to the cylindrical piston, is the "dumbbell scraper". This usually consists of a solid steel shaft, of appropriate length with respect to the pipe diameter, to each end of which is attached one or more elastomer pipe line scraper discs or cups. Steel back-up plates may be used on each side of the discs for rigidity. The discs are normally considerably larger in diameter than the inside diameter of the pipe and hence fit the wall of the pipe tightly to effect the squeegee action.

Other displacers will be acceptable if they give the same reproducibility and accuracy as the three types described above.

Valves

All valves used in mechanical prover systems must be bubble tight on low differential pressure tests. It is highly advisable to provide a method for checking valve leakage in the system design. Full positioning of flow reversing valves in bidirectional provers must be completed before the displacer actuates the first detector to assure that liquid does not by-pass the prover while the displacer is making its trip between detectors.

Detection Devices and Switches

For any given direction of the displacer, detection devices and

switches must detect the position of the displacer at the same point within close tolerance each time it passes the detector. They must initiate a signal to properly start or stop the proving register. They must be actuated only by the passage of the displacer. Displacers composed entirely of an elastomer normally employ or require detectors of the mechanically actuated switch type. For displacers composed of both magnetic and elastomer materials, detectors may be of the mechanical, electronic proximity, or induction pickup types. The tolerance to which the detectors in a prover section can signal the position of the displacer is one of the governing factors in determining the length of the prover section.

Meter Pulse Generators

A meter should be equipped with a pulsing device which will generate electrical pulses of satisfactory characteristics for the type of proving register employed. It should generate a sufficient number of pulses per unit volume to provide the required resolution. For positive displacement meters, these units may consist of a gear increaser mounted on, and driven by, the meter. On the output shaft of the gear increaser is mounted some type of pulse generating device. There are several types of pulse generating devices which may be used.

1. The reluctance type meter pulse generator uses a reluctance coil which is mounted a fixed distance from the teeth, grooves or blades of a rotating wheel. As this wheel is rotated by the meter, the passage of the teeth, grooves or blades in close proximity to the reluctance pickup coil produces electrical pulses, of an amplitude proportional to meter speed. These pulses are transmitted to the proving counter. These devices have a minimum speed at which they should be operated. Below this minimum speed

they will not generate pulses of sufficient amplitude to be counted by the electronic counter. Many turbine type meters employ pulse generators operating on this principle. The reluctance coils are wound on a permanent magnet core. The teeth, grooves or blades of the rotating wheel or rotor must be constructed of a magnetically-permeable metal. This method is described as "variable reluctance".

2. The inductance type meter pulse generator is similar to the reluctance type, except that inductance coils are wound on a core of magnetically-permeable metal. The rotating wheel or rotor either has a magnet in the hub or magnets in the blade tips or wheel tips.

3. The photoelectric type meter pulse generator uses a photoelectric cell and fixed light source between which is interposed a marked, toothed or perforated rotating wheel or disc driven by the meter. The markings, teeth or perforations on the wheel are concentric with the center of the rotating wheel and arranged so that rotation of the wheel causes interruptions in the light beam to the cell. Manufacturers supply each devices with various numbers of teeth or perforations on the rotating wheel to give the desired number of interruptions per revolution. These interruptions of the light to the photocell produce short duration pulses of equal amplitude regardless of speed of rotation. These pulses are transmitted to the electronic counter.

Other types of pulse generators may be considered acceptable if they operate with satisfactory reproducibility and accuracy.

Excessive or variable torque load on the output shaft of a meter can effect the meters performance. Any pulse generating device, if permanently installed on a meter, should create an absolute minimum torque load on the

output shaft. Any pulse generating device intended for installation on a meter only during its proof shall be sufficiently torque free to produce the same meter factor with and without the pulse generator being installed.

Uniformity of rotation of the pulse generating device with respect to flow rate, is mandatory. Since the pulse generating device usually delivers a relatively large number of pulses per revolution, the angular travel of the pulse generating wheel for one pulse is extremely small. For this reason, extreme care must be exercised in the design of pulse generator driving systems to prevent a loping, jumping or erratic action of this wheel. Wear on gear, back lash in gears, torsion in drive shafting of mechanical accumulating systems and other mechanical faults must be eliminated. Where employed, the type of meter calibrator, adjuster or temperature compensator employing a continuous integrating mechanism is preferable and will usually provide greater accuracy than the cyclic integrating or cyclic rotation boosting type.

Electronic Pulse Counters

Usually an electronic pulse counter is employed as the meter proving counter to effect high resolution and ease of remote indication. These may be simple pulse counting devices, and may be equipped with a built-in start-stop electronic switching circuit operated from the prover section detectors. Solid state counters are rugged and adaptable for field use. Any such counters may display the count by nixie tubes, decimal counting units, decade counting tubes and others. The manufacturer's requirements for grounding circuits, use of proper shielded cable and its adequate isolation, proper plugs and receptacles for cables, etc. must be strictly followed.

Transients pulses must not be picked up by electronic counters. Where remote proving of meters is contemplated, electronic counters having binary coded output for remote transmission of each counter digit are available.

Connections should be provided on these Prover Systems to allow water calibration or master meter calibration at a later date. (Refer to connections shown on Fig. #1, Fig. #2, Fig. #3 of this manual.)

EQUIPMENT FOR UNIDIRECTIONAL PROVERS

The equipment necessary for the proper operation of the return type or "endless loop" unidirectional prover is centered around the spheroid interchange unit. It is within this unit that the spheroid is removed from the flowing stream at the downstream end of the meter prover section and caused to be passed through the interchange conduit by gravity and reinserted at the upstream end of the prover section.

Spheroid interchange unit valving may be accomplished with several different combinations of valves. Each of these comprises a system of valves located in the interchange conduit for "locking" or passing the spheroid vertically downward through the conduit, yet at the same time preventing flow through the conduit which would by-pass the prover section. Typical combinations of valves are:

1. Dual clapper type check valve assembly, with power operated clappers opening vertically downward, as illustrated in Figure 5.
2. Dual through conduit type valve assembly with or without power operators as illustrated in Figure 5.
3. Single special ball valve modified for spheroid handling, insertion and removal, as illustrated in Figure 4.

The controls and power operators employed in connection with the "endless" type loop valves, etc., will be dependent primarily upon the degree of automation with which it is desired to operate the unit.

All of the above "endless loop" units utilize special oversized launching and separating tee assemblies as follows:

1. Separator Tees - Should be sized at least one pipe size larger then the nominal sphere, or loop size. By the use of fluid dynamics formulas, the required size of the separator may be computed by properly considering rate of flow and density of the inflated sphere. Sizing of the tee is very critical to assure dependable separation of the spheroid from the stream. It is often necessary to size the tee several pipe sizes larger at the higher flow rates. For practical purposes, the liquid velocity through this tee should not exceed 2-3/4 feet per second unless special baffling is employed within the tee to remove the spheroid. Smooth flow transition fittings are important on both ends of the run of the tee. Bars should be welded across the outlet end of the run to prevent the sphere from leaving the tee unit. Care should be taken in designing the bars to assure that they will not be damaged by the sphere. Fig. 4 shows details of the separator tee.
2. Launching Tees - are generally only one pipe size larger than the sphere, and have smooth transition fittings leading into the prover section. The launching tee should have a sight inclination toward the prover section to assure proper

movement of the spheroid into prover during periods of low flow such as might occur during a calibration by the water displacement method. A typical example of operation is that of the special ball valve of Figure 4, with a blanked-off bore that forms a cavity to hold the sphere, and prevents fluid communication across the valve. The valve should be sized one pipe size larger than the sphere. This allows the sphere to drop into and out of the bore of the valve. The valve may also have provisions for a side outlet and closure to facilitate easy insertion or removal of the sphere when the ball plug is in the 90° position (cavity horizontal.) The interchange unit must have bubble-tight seals at low differential pressure.

Launching and receiving facilities for the non-return "measured mile" provers shown in Figure 23 of API Standard 1101 may be of almost any type varying from simple hand operated scraper barrels to fully automated units. Launchers should be provided with means to isolate the barrel from line pressure when loading the displacer and provisions should be made for the release of only one displacer at a time when desired. Receivers usually consist of an over sized barrel with pressure isolation means and a suitable closure. Side outlets or other through flow means must be provided on such receivers and when spheroids are being used as the displacing device, such side outlets should be barred or shielded to prevent the spheroid from entering or blocking the outlet. This is usually most safely accomplished by installing an oversized, perforated sleeve permanently fixed in the receiving barrel to receive and confine the spheroids in line while permitting the liquid to flow through and around the sleeve.

EQUIPMENT FOR BIDIRECTIONAL PROVERS

Components used on Bidirectional Prover systems are identified in Figures 1, 2, and 3 of this supplement. The outlets on the prover barrel to the check valve should be drilled holes or slots. The openings should be deburred and should have a total area equal to or greater than the check valve size. The total area of the drilled holes is usually $1\frac{1}{2}$ times the area of the outlet on the end of the prover barrel. (see Figure 1)

Multi-port or four separate valves with linkage are usually employed for reversing the direction of the displacer. All valves must provide continuous flow through meter during proving.

IV. APPLICATION AND USES OF MECHANICAL DISPLACEMENT PROVERS

Mechanical Displacement type meter provers are applicable to any liquid which can be metered provided that the liquid does not have a deleterious effect on any of the components of the prover system, and provided the proving operations simulate the normal meter operating conditions.

These meter proving systems are useful in oil industry metering because:

1. They lend themselves to a high degree of automation.
2. Errors resulting from evaporation of liquid during a proof run are reduced.
3. The effects of temperature on previously known meter proving techniques are reduced.
4. They provide a means of rapidly proving meters under actual operating conditions of flow rate, pressure, and temperature.
5. They eliminate observation errors in quantity gauging.
6. They are suitable for proving properly equipped positive displacement and turbine meters of virtually any size.
7. They are highly advantageous in their ability to prove a meter under the meters actual undisturbed flowing conditions without the necessity of shutting off flow through the meter which allows the meter to perform its normal measurement function.
8. Need of stand-by meter and pertinent switching of valves during proving is eliminated.

9. They eliminate problems associated with high viscosity liquids and the tendency for such liquids to cling to the prover surface.

10. Problem of wax deposition or incrustation is effectively eliminated with the use of mechanical displacement provers in that the repeated passage of the displacer through the meter prover section precludes the possibility of wax buildup which might otherwise effect the volume of the prover.

V. DESIGN OF MECHANICAL DISPLACEMENT METER PROVERS

Choice of Prover Type

In approaching the design of a mechanical prover it is necessary to establish the type of prover required for an installation and the manner in which it will be interconnected with the meter piping. Common types include the unidirectional (Figures 4 & 5) and the bidirectional (Figures 1, 2, & 3). From a study of the application, usage, and space limitations, it will be possible to establish the following:

(a) That the system be portable or permanent.

(b) The number of meters to be proved at a site and whether they are to be proved individually or as a battery on a common stream.

(c) That portions of the prover are desired above or below ground level.

(d) The degree of automation to be incorporated in the proving operation.

(e) If the prover is to be continuously kept in series with the meter or isolated from the metered stream when not in use.

Design of Prover and Related Piping

A - Effect of flow rate through system

In determining the diameter of the pipe to be used in the prover section, the hydraulic loss through the mechanical prover should be compatible with the head loss considered tolerable in the metering installation. Generally speaking, the diameter of the prover section should not be less than the outlet diameter of any single meter to be proved. It may be larger, and this will

usually be necessary where a battery of meters is to be proved as a unit on a common liquid stream. The inlet and outlet lines including valves and connections to the prover should be sufficiently large to prevent a significant change in flow rate through the meter when flow is directed through the prover.

Economical utilization of materials, space considerations, and prover selection will usually indicate the displacer velocity. The displacer velocity for a bidirectional system may be approximately 2.5 ft/sec. as a typical design specification. For a unidirectional system, this may be 10 ft/sec. Velocities of up to 10 ft/sec. are considered to be tolerable for both systems if the prover system incorporates means of reducing surges and the velocity of the displacer before it completes its stroke.

B - Design of volume displaced in prover

One approach to the design of the system would be to provide that the volume between the detector switches be approximately 0.5 per cent of the maximum flow rate through the prover system. With this, other items that are considered in determining the prover volume are:

(a) Reproducibility of the proving system.

(b) Repeatibility of detector switches to provide the required resolution.

(c) Resolution of meter proving counter.

The reproducibility of the proving system will be dependent upon the sum total of the reproducibility limits of the system components. This refers particularly to the resolution action of the detectors and the meter proving register. Therefore, if the designer seeks high reproducibility he must select the components and establish dimensions accordingly.

The repeatibility of detector switches to provide the required resolution can be illustrated as follows:

The length of any mechanical displacement prover from detector to detector is established mathematically as a function of the resolution with which the detector switches are able to locate the displacer and the desired reproducibility of the system to indicate the quantity of liquid displaced from between the detectors. To illustrate, assume that a prover is to be designed which will have the ability to repeatedly displace a quantity of liquid which has a maximum variation of 0.02%, i.e., plus or minus 0.01%. This represents a reproducibility of quantity displacement of plus or minus 1 part in 10,000. To obtain this reproducibility, the length of the prover from detector to detector must be 10,000 times the lineal range or tolerance within which the displacer detector can repeatedly signal the location of the displacer. For the sake

of illustration, assume that each of the two detector switches chosen for a prover has the ability to signal the location of a displacer somewhere within the range of 1/32" or 0.0312". This means that the length of one trip of the displacer can vary from the length of another trip of the displacer by a maximum of 1/16" or 0.0625". To have a reproducibility of displacement of 1 part in 10,000, the prover would have to be 10,000 (0.0312") = 312 = 26' long from detector to detector. It should be specifically noted that there are numerous kinds of detectors available and numerous conditions under which they may be operated in conjunction with a displacer and that the theoretical reproducibility of a prover is dependent on the practical reproducibility of its detector signals with respect to prover length. If a lesser degree of accuracy is required, the prover section may be made proportionately shorter. If a higher degree of accuracy is required, the prover may be made longer or the detectors more resolute.

The resolution of the meter proving counter is illustrated as follows:

Any type of meter proving register which can be started and stopped by the first and second detectors respectively and which has a least reading compatible with the reproducibility desired of the system may be used with a mechanical displacement prover. To obtain

high resolution of meter reading, it is usually expedient to use a pulse generator on the meter and an electronic counter as the meter proving register. Electronic counters have the ability to indicate pulse intervals to within ± 1 interval in any number of intervals counted.

Therefore, if it is again desired, as in the above, to have a reproducibility of ± 1 part in 10,000, it is necessary to generate a minimum of 10,000 pulses (counts or least reading units) on a meter proving counter during a proof of a meter. This may be accomplished by properly designing the tachometer so that the product of the tachometer pulse output per unit of volume and the displaced volume of the prover will equal the desired number of pulse intervals or least reading units. Caution is suggested, however, in the use of gear driven tachometers on positive displacement meters, to assure backlash, drive shaft torsion, cyclic effects, etc., are not allowed in any manner to effect the pulse generation. Such effects are usually most successfully eliminated by limiting the pulse generation rate to approximately 1000 pulses per revolution of the meter output drive shaft and at the same time adjusting the displaced volume of the prover to produce the total number of pulses required during a proof.

A typical approach to the design of a mechanical displacement meter prover is cited in the following example for a six inch meter operating at a 1200 B/H.

ASSUMPTIONS:

1 - Prover volume to be ½% of maximum flow through prover system.

2 - A desired repetition of prover system is within ± .025%

3 - A pulse generator to be employed on the meter will generate 1000 pulses per barrel and this will be fed into a digital counter having an indicating ability of ± one count for any number of pulse intervals counted.

4 - Resolution of each of the detector switches will be assumed to be ± .030 inch meaning that there could be a maximum undetected difference in length of the prover section from one meter proof run to the next of 0.12 inch.

5 - Maximum displacer velocity up to 10 feet per second.

DESIGN

By assumption one, the volume between the detector switches would be 0.005 x 1200 = 6.0 barrels.

By the second assumption, a series of proof runs must be produced with the largest variation not more than .05%.

By the third assumption the total variation of two counts that may exist between proof runs. To satisfy assumption #2, the total number of pulses required is obtained by $\frac{2 \text{ pulses/run}}{.05\%}$ =4000 pulses. This means that the volume of the meter proof must be $\frac{4000 \text{ pulses/run}}{1000 \text{ pulse/barrel}}$ = 4 barrels.

Treating the fourth assumption, the minimum length of the prover section would be governed by the resolution of detector switches. As it is required to calibrate provers within a total difference of 0.02 percent between calibration runs, the length between detector switches would be 0.12 inch/0.0002

equals 600 inches or 50 feet. If the resolution in assumption four had been ± .015, the length between detectors would have been 25 feet.

OTHER DESIGN FEATURES

The designer should refer to Section III for details on equipment that are applicable to the type of prover that is being considered.

It is recommended for the reciprocating type prover and others where applicable that the inlet connections to the prover section be located on the bottom side to prevent accumulation of foreign material.

All valves associated with any type prover system must be designed to provide bubble tight shut-off. The locations of thermometers, pressure gauges, valves and other appurtenances are recommended on Figures 1, 2, and 3.

VI. INSTALLATION OF MECHANICAL PROVERS

Mechanical Features

All components of the prover installation, including connecting piping, valves, manifolds, etc., shall be in accordance with applicable pressure codes. Once the prover is on stream, it becomes a part of the pressure system. The prover section and related components, if installed above ground, shall have suitable hangers and supports as prescribed by applicable codes and sound engineering principles. Adequate provisions should be made for expansion and contraction, vibration, reaction to pressure surges, etc. Consideration should be given to the installation of suitable valving to isolate the prover unit from line pressure when not on stream, for maintenance, removal of the displacer, etc. All units should be equipped with suitable vent and drain connections. Provisions should be made for the disposal of liquids or vapors drained or vented from the prover section, by pumping back into the system, or by diverting it to some collecting point. Thermometers and pressure gauges shall be installed at or near the inlet and outlet of every mechanical prover in order to accurately determine the average temperature and pressure of the liquid between the detectors. It is usually advisable and expedient to provide permanently blinded flanges or valve connections on either side of a bubble tight block valve in the carrier stream which can serve as a permanent connection for proving portable meters, or as a means such as required for calibration of the prover by the master meter procedure or the waterdraw procedure. (See Figures 6 and 7).

Electrical Features

All wiring and controls shall conform to applicable codes. Explosion proof components shall conform to the appropriate class and group applicable

to the location and operation. All electrical controls and components should be placed in a convenient location for operation and maintenance. Manufacturer's instructions for installation and grounding of such items as tachometers, electronic counters, signal cables, etc., should be strictly followed.

Safety Features

Safety relief valves with adequate discharge piping and suitable for the control of thermal expansion and contraction of the liquid in the prover section, while isolated from the main stream, shall be installed. Power controls and remote controls should be suitably protected with lock out switches and/or circuits between remote and adjacent panel locations to prevent accidental remote operation while a unit is being controlled locally. Suitable safety devices and locks should be installed to prevent inadvertent operation, or unauthorized tampering. All automated or power operated meter proving systems may have emergency manual operators for use in the event of failure of the power source or in the event of an accident.

VII. THE CALIBRATION OF MECHANICAL DISPLACEMENT METER PROVERS

Introduction

Any mechanical prover must be calibrated before being placed in meter proving service to determine the quantity of liquid which will be displaced from it during a meter proof. This volume shall be known as the "Base Volume" of the prover and will be the volume displaced during a proof when the prover is at 60 degrees F and the liquid at atmospheric pressure. It should be clearly established that the proof of a meter with a unidirectional prover will comprise a single trip of the displacer between the two detectors while the proof of a meter with a bidirectional prover will comprise a complete round trip of the displacer between detectors. For this reason the base volume of a unidirectional prover is the calibrated volume displaced between detectors whereas the base volume of a bidirectional prover is the sum of the calibrated volumes displaced between detectors for a round trip of the displacer.

Two general methods for the calibration of mechanical displacement meter provers are recognized. These are: (a) Calibration by means of NBS certified test measures and water and (b) calibration by means of master meters. Appendix II describes another method of calibration using precise dimensional measurements and subsequent calculations and conversion to the desired liquid measure units of barrels or gallons. This method has been found to be suitable in certain cases, and may be used where mutually agreeable to all parties concerned.

CALIBRATION OF PROVER USING WATER DRAW METHOD

General

The calibration of provers may be simplified, when possible, by placing the prover, test measures, and test liquid in a constant-temperature enclosure to allow the equipment and test liquid to reach an equilibrium temperature. The displacer will have to be moved through the prover section several times. This will provide for reaching equilibrium temperature conditions and eliminate any air pockets. The temperature and pressure of the water at each end of the prover should be observed and the average considered as the temperature and pressure in the prover at the start of the calibration. When a temperature change occurs in the measures withdrawn during a calibration, corrections must be made in accordance with Paragraph 2123 through 2125 of API Standard 1101.

It is recognized that some provers will be calibrated outside under extreme hot or cold temperature conditions. In these cases, the prover should be temporarily isolated and sheltered to reduce the extreme temperature effects.

Test measures for the calibration of the prover using the waterdraw method are to be in accordance with Paragraph 2041 through 2047 of API Standard 1101.

Preparation of Prover for Calibration

The prover can be calibrated by using temporary small diameter water lines and valves as shown in Figures 6 and 7 or by using the valves and piping that will be part of the field installation. This is shown in Figures 1, 2 and 3. In both cases, the prover, including all valves and fittings, shall be tested for leaks. A suitable means is to be provided

for precisely locating the position of the displacer when the displacer causes the detector to react. Figures 6 and 7 show a suggested method employing signal lights. Solenoid valves activated by the detector switches have been successfully used.

Calibrating Procedure

The following paragraphs describe the method of calibrating a mechanical displacement meter prover by water withdrawal. A volume in either direction must be either an "off to off" switch (light) indication or an "on to on" switch (light) indication. The procedure described below involves an "on to on" switch light indication.

After the displacer has been moved back and forth in both directions several times and a trial run has been made to determine the approximate volume so as to closely anticipate the final switch operation, the displacer is driven past one of the switches into the dead space just outside the prover volume on either end of the prover. Observe when the switch goes "on" and then stop the water while driving the displacer across the detector toward the dead space, just as the switch goes "off". Reverse the valves so the displacer travels toward the prover section, wasting water. Waste the water slowly through the slow-rate bleed or if the adjustment is sensitive enough, through the nozzle. Stop the waste just as the switch indication is in the "on" position. The water is then directed into test measures of suitable size. Continue these measure withdrawals until the last several gallons of the approximate volume. Reduce the withdrawal to a slow bleed rate until the "on" switch indication is observed, whereupon the water to the measure is stopped. The condition of the drain hose and other withdrawal equipment shall be the same at the

end of the last withdrawal as it was at the beginning of the first withdrawal. A displacer trip is now made in the opposite direction, repeating the above procedure. These two trips do not necessarily have to agree in observed displaced volume since the switching action may be different for each direction, but the total round trip volume is considered the observed volume of the prover at this point.

Repeat the above described round trip procedure until two consecutive round trip volumes are determined which, after correction, agree with each other within 0.02 per cent. The average of two such round trip corrected volumes is considered the "base" round trip volume for the prover at 60 degrees F. and atmospheric pressure.

The corrected volume for two consecutive trips in the same direction should also agree within 0.02 per cent.

The procedure for water calibrating a unidirectional type of prover is substantially identical to the procedure described above for a single stroke or trip of the displacer in the bidirectional prover after proper consideration of the difference in method of manipulating the displacer.

In the above discussion, the volumes observed as the sum of the test measure volumes for each trip of the displacer must first be corrected for temperature effects on the observed volume by the procedure described in Paragraphs 2123-2125 of API Standard 1101 and this temperature corrected volume in turn corrected for water compressibility using the factor F = 0.0000032 per psi shown in Paragraph 2122 of API Standard 1101 from the calibrated pressure to atmospheric pressure. Then a reduction must be made because of the increased size of the prover under pressure by applying the proper factor for the calibrating pressure as described and shown in

Table 2. The observed volume for each trip should be corrected individually to get the base trip volume displaced at 60 degrees F. and atmospheric pressure.

At the completion of a calibration, the data sheets should be used to prepare a suitable certificate for the prover and these should be signed by all parties witnessing the calibration. A sample data sheet and certificate is shown in Figures 10 and 11.

CALIBRATION OF PROVER USING MASTER METER METHOD

General

The procedure for determining the displaced volume of a mechanical displacement type prover by the master meter method involves essentially (1) the very accurate determination of the performance of a suitable single master meter or of each of a battery of several meters comprising a master meter calibration unit by proving them against some acceptable standard in accordance with techniques described in API Standard 1101 using preferrably a liquid of low volatility which can subsequently be flowed at normal operating conditions through the prover to be calibrated, (2) the connecting of this precalibrated master meter unit in series with the prover section to be calibrated in such a way that the total flow through the prover section must also pass through the master meter unit, (3) the connecting of the mechanical displacer signals at the extremities of the prover section to suitable meter proving registers on the master meters, (4) the launching of the mechanical displacer through the meter prover section and (5) the assignment of the corrected volume indicated by the master meters as the displaced volume of the prover, (6) the master meter should be proved again after the calibration of the mechanical prover.

For precise calibration, it is recommended that the master meter be non-temperature compensated, and be equipped with a direct drive shaft between meter measuring element and proving register, thus eliminating all cyclic corrections by the meter.

Procedure

Select a master meter calibration unit, either one meter or a suitable battery of meters in parallel if the flow rate is too high for one meter, wherein the meters are in the best of repair and operating condition and have a history of consistent performance. Each is equipped with a suitable high resolution meter proving register which can be gated "on" and "off" by the displacer detectors. In addition this master meter calibration unit should have the normal totalizing registers producing the necessary resolution, if these registers are to be used in proving the unit. The meters should be protected with suitable strainers or filters. Air vents should be installed at their high points and at the high points of their associated piping.

Each master meter is first connected individually between a suitable source of supply of liquid and a meter prover. The prover used shall be one that has been calibrated by use of NBS certified test measures.

After making a suitable number of preliminary meter proofs to assure that all the air is out of the meters and associated piping and that equipment and liquid temperatures are stabilized, a series of meter proofs is made to accurately determine the performance of the master meter over the range of flow rates which will encompass the flow rate anticipated through the meter when it is subsequently used to calibrate the prover. Usually it is expedient to make an accuracy curve for the meter, plotting meter

factor vs. flow rate, and at the same time showing the observed meter and prover temperatures and pressures. Sufficient runs of this nature should be made to assure that consistent and reproducible factors are being obtained and that the average results are accurate and reproducible. The meters' proving registers may or may not be used in these curve determinations depending on the proving method but will subsequently be used in the calibration of the mechanical prover section. Because of this, it is mandatory that the operation of the meter proving registers do not in any way effect the meter performance. Data for these meter proofs may be kept on a form similar to Figure 12.

When the proof of the master meter unit is complete and the curves for each meter known, the unit is connected in series with the mechanical displacement prover to be calibrated, making certain that no liquid can bypass the master meter unit. The unit may be connected at either the upstream or downstream end of the proving section. The master meter proving registers are connected to the displacer detectors in the same manner as the proving registers of the normally installed operating meters.

Flow of liquid of the type used in the proof of the master meters is started through the meter prover section and master meters at a rate not to exceed the capacity of the master meters and not less than 25 per cent of the expected normal operating rate for the mechanical prover. The rate must be within the range for which the master meter was proved. This flow is continued until it is certain that all vapor is out of the meters, associated piping, meter prover section, etc., and temperature observations show that temperatures in the system have stabilized. When such conditions prevail, the mechanical displacing device is launched through the meter

prover section and allowed to move through the section to its normal point of stoppage. The mechanical displacer must be identical to that which will be used in future normal operation of the prover. During such a run, the temperature and pressure of the stream at the master meters should be observed just after the displacer has passed the first detector, again when it is approximately half way through the section and finally just before it encounters the second detector. These observations are averaged and recorded as the temperature and pressure of the stream at the master meter during the run. Similarly, the temperature and pressure at or near both detectors should be observed immediately before the displacing device passes the first detector and these observations averaged and recorded to give the average temperature and pressure of the liquid displaced between the detectors during the run. The quantity indicated by each proving register should be recorded for each run made.

A suggested form, "Report of Calibration of Unidirectional Meter Prover Section by Master Meter Method", Figure 8, shows the manner in which the prover volume is calculated, including the manner in which pressure corrections may be made to a master meter factor when it's case pressure is not the same during its use as it was when it was proved. This form is shown for a master meter unit having three meters, viz, A, B and C, in parallel when a prover section is calibrated. A form similar to Figure 8 or 9 may be used for recording and calculating the prover volume of a bidirectional prover.

It is usual practice to make a reasonable number of repetitive runs in this calibration procedure, for once the master meter and other equipment is located and operating, it is relatively simple and quick to make test runs. Acceptable practice is to average the results of a number or

obviously consistent test runs to get the final prover section displaced volume. However, the average of two consecutive runs which are within 0.02 per cent are similarly acceptable.

VIII. OPERATION OF MECHANICAL PROVERS

General

The basic principles of meter operation and proving as outlined in Standard 1101 definitely apply to mechanical displacement proving systems except as described in this supplement. Attention is called to Appendix C of Standard 1101, "General Information of Meter Operation", as well as individual paragraphs describing displacement provers. This section presents some additional basic operating fundamentals applicable to mechanical displacement provers, particularly of the "on stream" or "running start-stop" type, which are unique to the technique.

Preparation for Proving

Equipment checking prior to proving should include inspection of all valves where leakage could effect results, the attachment of any accessories used for proving, and the energizing of any electrical circuits required. Thermometers and pressure gauges should be checked as frequently as required to maintain accurate temperature and pressure measurement.

The entire stream from the meter or battery of meters to be proved is diverted to flow through the prover. In most unidirectional permanently installed provers the flow through the meters is normally continuous through the prover section as well. Flow is maintained through the meters and prover section until stable conditions of temperature are reached. Vent connections must be checked to insure that the meter and prover section are completely purged, and that no pockets of air or vapor remain in the system.

A trial proving run is frequently conducted as a final check before commencing the recorded meter proving. This is good practice, and is recom-

mended, particularly on those type provers where this readily accomplished with little loss of time. The trial runs should include checking of the electronic or other read-out equipment. Observation of the readings from the trial run will often indicate equipment maladjustment not otherwise apparent.

Conducting Proving Runs

The physical operations necessary to conduct proving runs will vary with specific installations, these installations ranging from complete manual operation to fully automatic. Basically, however, the operation will consist of operating a valve or combination of valves that cause the metered stream to move the displacing device through the calibrated section of the prover. The proving counter reading is recorded prior to the start of every run, or if so equipped, it may be reset to zero.

In the case of manually operated provers, it is desirable to perform the valve switching with deliberate, uniform speed, completing the operation well before the displacement device enters the calibrated section of the prover. In automated systems, a push button normally initiates a complete meter proof cycle and the timing of the operation is a matter of adjustment of the valve operators and the proper sequencing of the control system.

In unidirectional provers, a proving run consists of one trip of the displacement device through the calibrated section.

In bidirectional provers, a proving run usually consists of a round trip of the displacing device.

Upon completion of each proving run, the data is recorded, the initial counter reading again determined and additional proving runs are made as

required. The data for each direction may also be recorded for bidirectional provers. Sufficient runs should be made to verify the accuracy of the measurement. A suitable meter proving report should be prepared upon which to indicate the data and final meter factor as described in Appendix C. A sample report is illustrated in Figure 12 for liquids with vapor pressures at or below atmospheric pressure. Figure 13 is a suggested report for liquids with vapor pressure above atmospheric pressure.

Special Techniques for Specific Types of Provers

Proving A Battery of Meters With Any Mechanical Prover:

Most of the operating procedures described herein have been for the proving of a single meter, the simplest case. If the meter to be proved is part of a battery of meters handling a common stream, it is merely necessary to divert the stream from the meter to be proved through the prover. The flow is then adjusted to the desired rate.

A battery consisting of two or more meters operating in parallel on a common stream may be substantially the same during proof as during normal measurement. The prover must, of course, be sized for the total flow through the battery. Each meter may be equipped with its own proving register or a combining or summing system may be employed to accumulate the registration of two or more meters into a common output which is in turn transmitted to a single proving register. If such mechanical or electronic totalizing equipment is employed, extreme care must be exercised in the selection and use of such equipment to prevent the introduction of errors. The proving operation is the same as that for proving a single

meter. The registration recorded on the proving report is the combined total of that for the individual meters. The meter factor thus obtained is applied to the combined observed readings of the meters in the battery.

AWJanekijan
January 31, 1962

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Figure 1 Typical Layput of Bidirectional Straight Type Piston Prover System

Figure 2 Typical Layout of Bidirectional "Folded" Type Prover System With Inclined Ends

Figure 3 Typical Layout of Bidirectional "Folded" Type Prover System With Spring Bumper Ends

Figure 4 Schematic of Single Valve Type Unidirectional "Endless" Spheroid Prover System

Figure 5 Schematic of Dual Valve Used With the Unidirectional Prover System

Figure 6 Layout for Water Calibration of Bidirectional Prover

Figure 7 Layout for Water Calibration of Unidirectional Prover

APPENDIX B - TYPICAL CALIBRATION DATA SHEETS

Figure 8 Report of Calibration of Unidirectional Meter Prover by Master Meter Method

Figure 9 Report of Calibration of Bidirectional Prover by Master Meter

Figure 10 Report of Calibration of Bidirectional Meter Prover by Water Draw Method

Figure 11 Sample Certificate for Bidirectional Prover

APPENDIX C - DESCRIPTION OF METER PROVING REPORT

Figure 12 Meter Proving Report for Liquids with Vapor Pressure Less than Atmospheric Pressure
Explanation of Meter Proving Report Figure 12

Figure 13 Meter Proving Report for Liquids with Vapor Pressure Greater than Atmospheric Pressure

APPENDIX D

Correction factor for change in dimension of pipe volume with change in temperature. Table 1

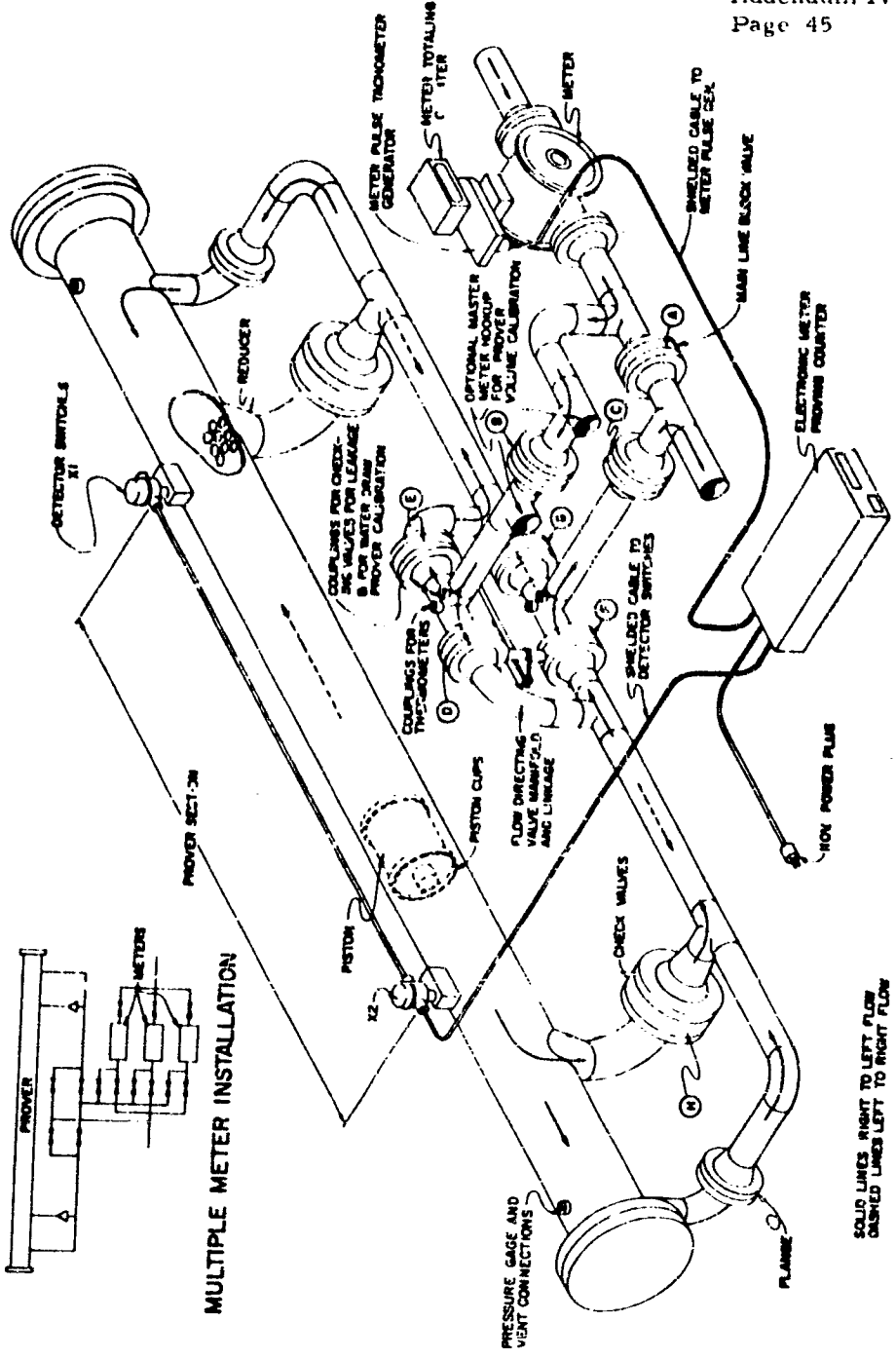
APPENDIX E - PRESSURE CORRECTION FACTOR FOR STEEL PIPE AND WATER

Table 2 - Pressure correction factors C_{ps} for change in dimensions of pipe volume with change in pressure.

Derviation of Formula for C_{ps}

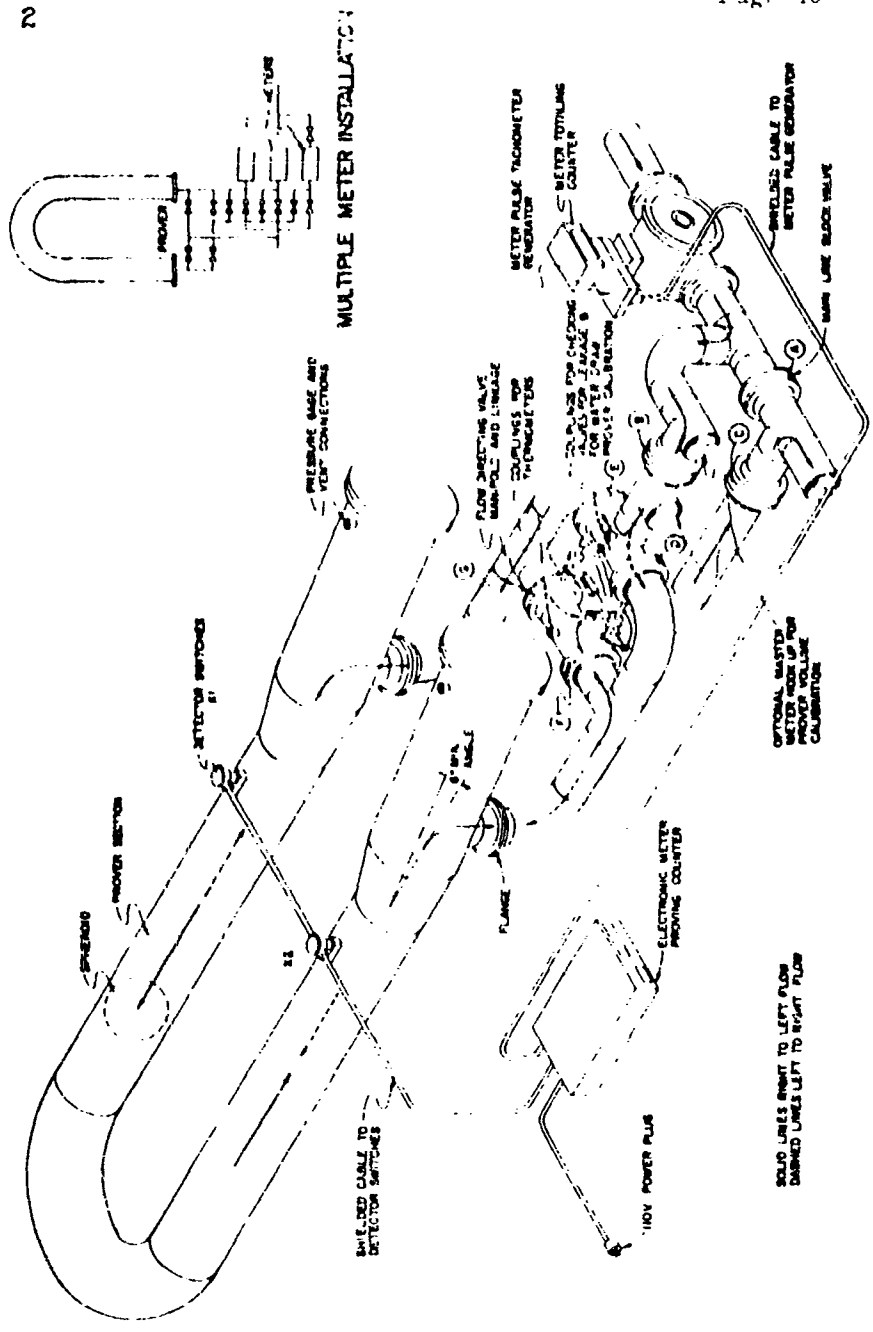
APPENDIX F

Calibration of Pipe Prover (Use of Dimensional Measurements).

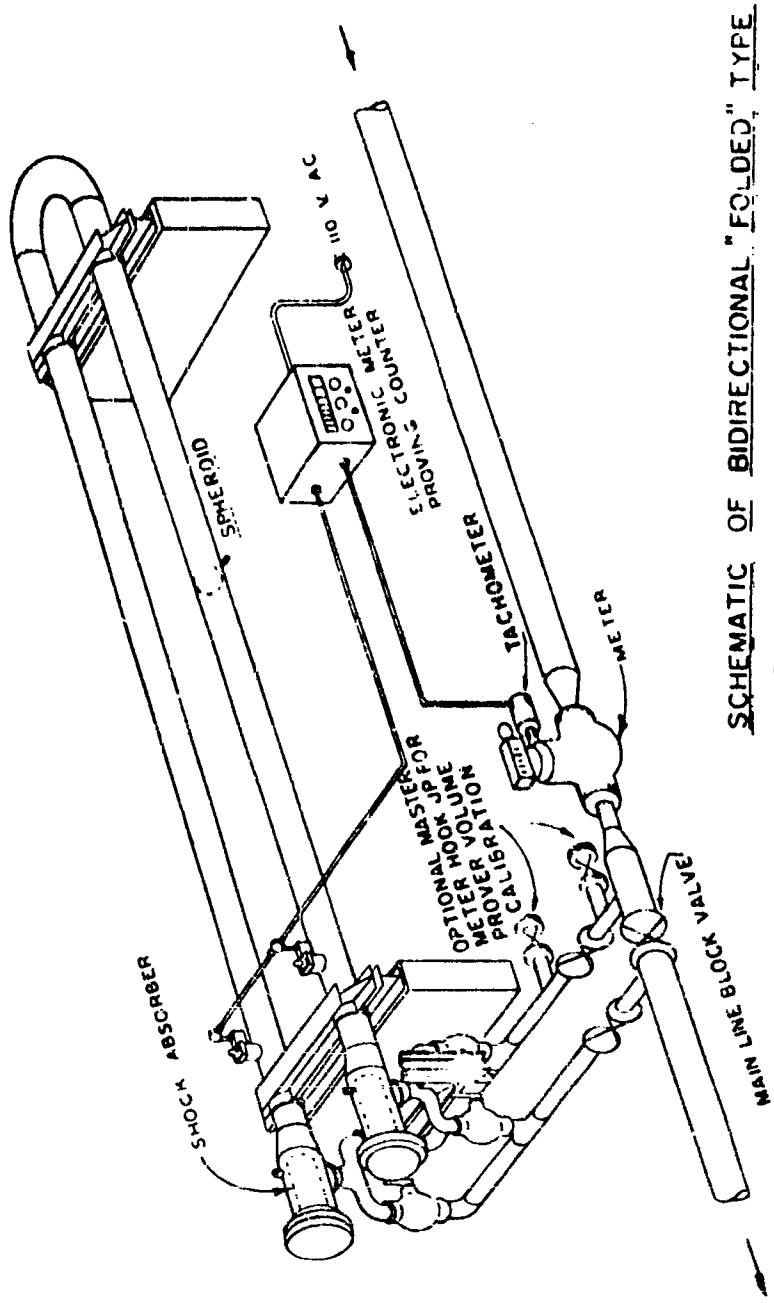


SCHEMATIC OF BI-DIRECTIONAL
STRAIGHT TYPE PISTON PROVER SYSTEM
FIG. 1

2

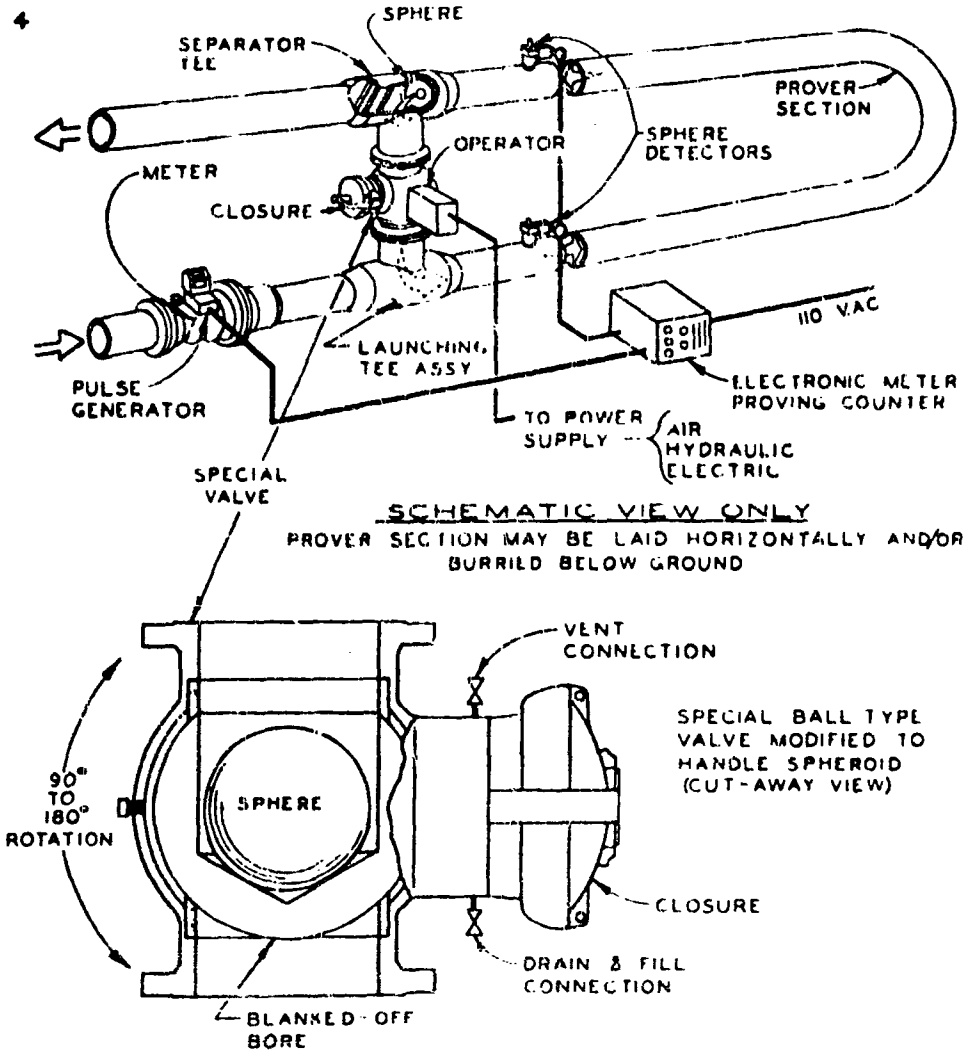


SCHEMATIC OF BI-DIRECTIONAL "FOLDED" TYPE SPHEROID PROVER-SLOPING ENDS
FIG. 2



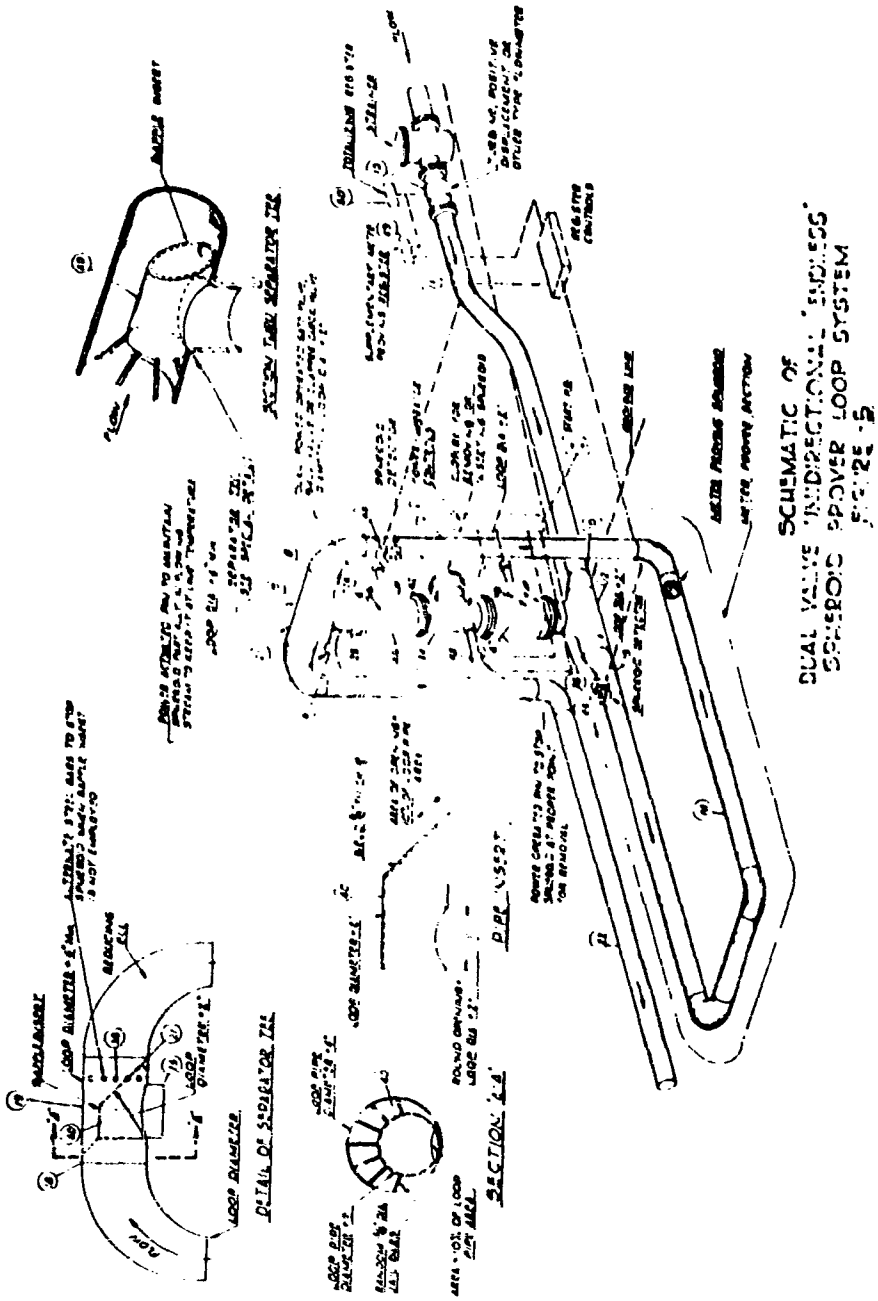
SCHEMATIC OF BIDIRECTIONAL "FOLDED" TYPE SPHEROID PROVER-SHOCK ABSORBER ENDS

FIG. 3



TYPICAL UNIDIRECTIONAL RETURN TYPE PROVER SYSTEM
FIG. 4

APPENDIX A


DETAIL OF SEPARATOR TEE
SECTION 'A-A'
PIPE WEST
SCHEMATIC OF
DUAL VALVE 'INDIRECTIONAL' BROOKS'
SPHEROID PROVER LOOP SYSTEM
FIGURE 5

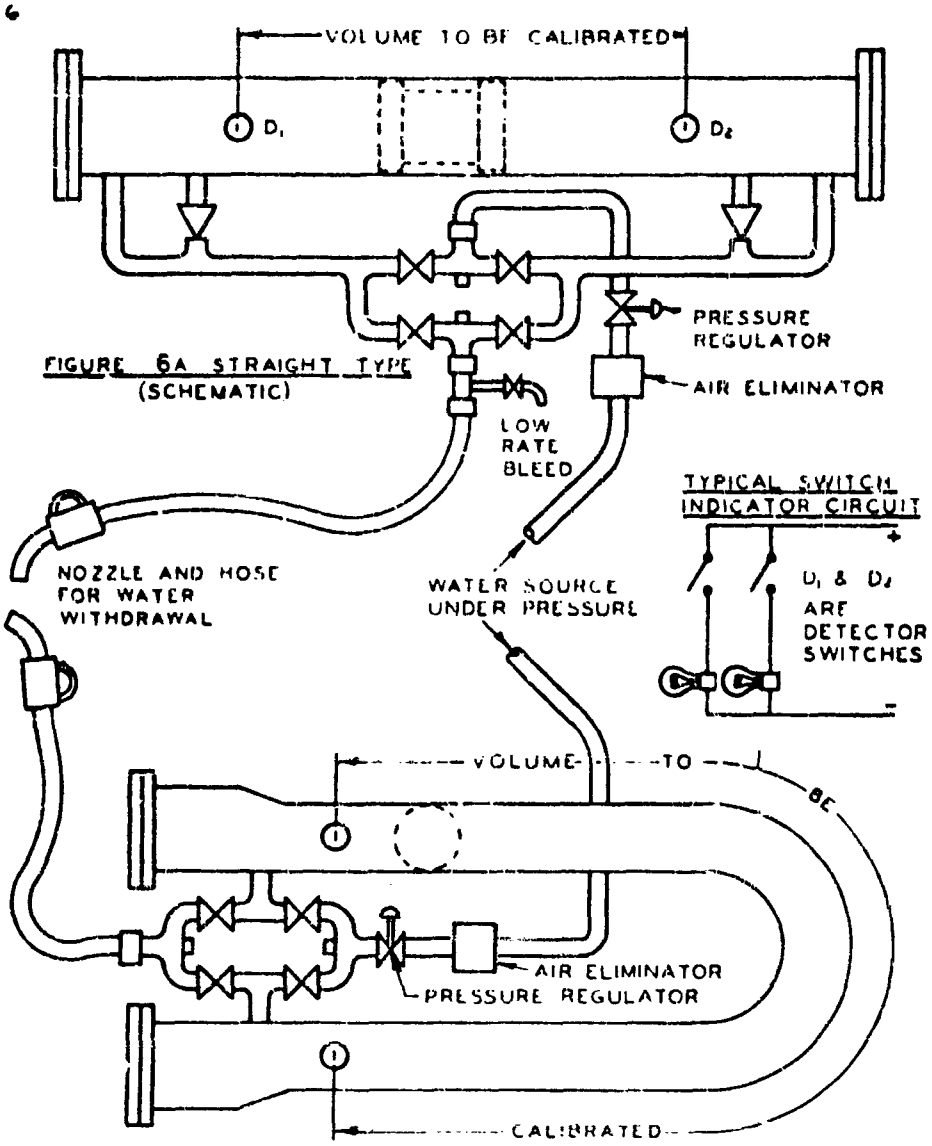


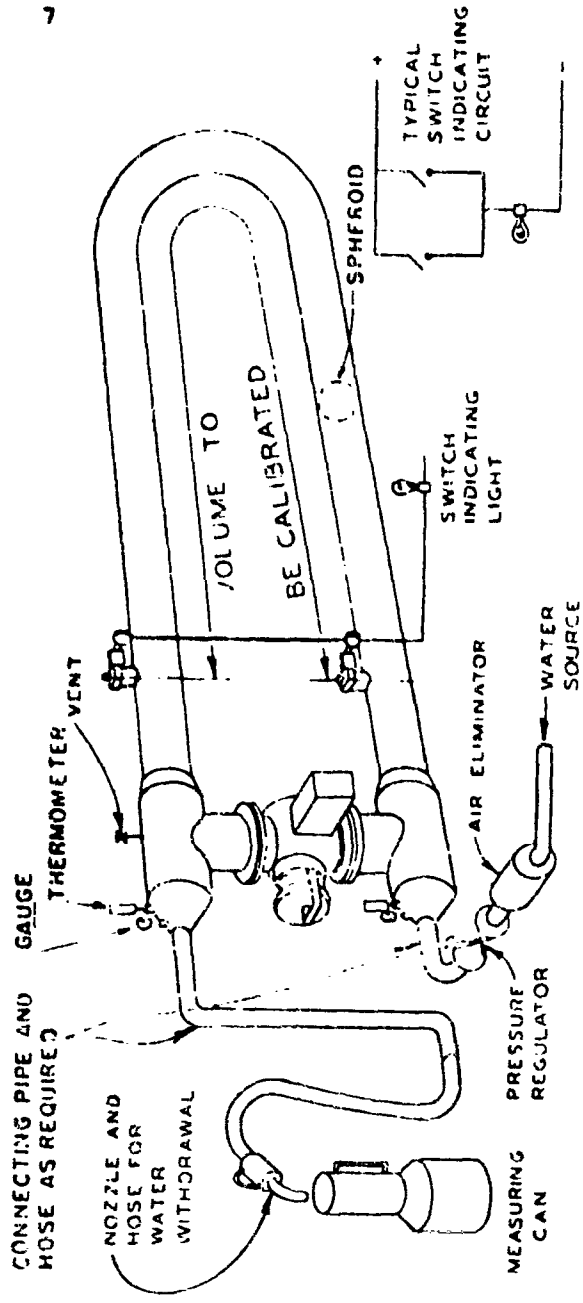
FIGURE 6A STRAIGHT TYPE (SCHEMATIC)

FIGURE 6B "U-BEND" TYPE (SCHEMATIC)

WATER CALIBRATION OF TWO TYPES OF BIDIRECTIONAL PROVERS

FIG. 6

7



WATER CALIBRATION OF A UNIDIRECTIONAL PROVER
FIG. 7

Sheet 1 of 1

8

Arizona Oil Company

REPORT OF CALIBRATION OF UNIDIRECTIONAL PROVER
(MASTER METHOD)

Section Calibrated: Four Rivers Terminal
Test No. 2 Date Made 10/25/61
Calibrated By: John Hancock & Henry Moran
Base Volume By Prior Test
Date 8/1/60 & Product Used For Prior Test Furnace Oil

Product Used: Furnace Oil
API GRAVITY @ 60° F 33.1
Pipe Dia ____ Length ____
Wall Thickness ____
Type of Displacer: 43 Barometer Natural Rubber Spherical

Description of meter meters Employed: Portable Smith
Calib Unit #2999 where Last Proved: Chicago Term
Meter Performances Taken From Test Meter Curves No. 18
(Attach Test Meter Curves Hereto)
Remarks: Chicago - Rain - Cold

DESCRIPTION OF QUANTITIES	Run No. 1 Meter "A"	Meter "B"	Meter "C"	Totals All Meters	Run No. 2 Meter "A"	Meter "B"	Meter "C"	Totals All Meters	Run No. 3 Meter "A"	Meter "B"	Meter "C"	Totals All Meters
1 - Final meter reading - Acco Register												
2 - Initial meter reading - Acco Register												
3 - Registration by meter - Acco Register												
4 - Final meter reading - Calib. Register	10547.2	9833.7	8849.6		1509.0	10778.3	6811.7		2551.3	1520.8	7805.6	
5 - Initial meter reading - Calib. Register	9616.8	8851.7	7846.0		507.2	9833.8	5849.6		1509.0	775.3	6811.7	
6 - Registration by meter - Calib. Register	910.4	979.1	999.6	2879.1	994.8	944.9	962.1	2878.8	942.3	945.5	993.7	2878.7
7 - Time Displacer received	hrs.	min.	sec		hrs.	min.	sec		hrs.	min.	sec	
8 - Time Displacer launched	hrs. 1402	min.	sec		hrs. 1410	min.	sec		hrs. 1432	min.	sec	
9 - Elapsed time for Displacer run - min.	hrs.	min. 2	sec 30	= 2.05 min	hrs.	min. 2	sec 30	= 2.05 min	hrs.	min. 2	sec 30	= 2.05 min
10 - Rate of flow during run - GPM 5 & 6	444	475	485		459	461	489		485	460	485	
11 - Meter factor from factor vs. Rate curve	.9975	.9927	.9987		.9986	.9989	.9991		.9986	.9991	.9979	
12 - Registration corr. by meter factor (all)	909.03	973.07	993.51	2875.57	944.98	943.86	991.01	2879.85	944.98	941.96	992.81	2875.75
13 - Meter pressure during this run				58				58				58
14 - Meter pressure during proof				15				15				15
15 - Diff. in meter operating press. 13-14				43				43				43
16 - Factor for press. diff. Table E, API 101				1.0002				1.0002				1.0002
17 - Temp. @ meter during this run				61.6°				61.6°				61.6°
18 - Factor for meter temp. Table 6, D-1250				.9993				.9993				.9993
19 - Registration @ 60° & 0 psig (12 x 16 x 18)				2873.13				2873.81				2873.81
20 - Prover pressures @ Detectors 1 & 2	at min. 1 104	at min. 2 102	average 103		at min. 1 104	at min. 2 102	average 103		at min. 1 104	at min. 2 102	average 103	
21 - Prover temp. @ Detectors 1 & 2	at min. 1 61.2°	at min. 2 61.2°	average 61.2°		at min. 1 61.2°	at min. 2 61.2°	average 61.2°		at min. 1 61.2°	at min. 2 61.2°	average 61.2°	
22 - Factor for prover pressure Table 2				1.0002				1.0002				1.0002
23 - Factor for prover temp. Table 1				1.0000				1.0000				1.0000
24 - Factor for liquid pressure Table E API 101				1.00077				1.00077				1.00077
25 - Factor for liquid temp. Table 5				.9995				.9995				.9995
26 - Base prover volume-bbls @ 60° & 0 psi			1.000697	2873.42			1.000697	2873.42			1.000697	2873.32
27 - Base prover volume-Bbls @ 60° & 0 psi				68.420				68.415				68.412

Formulas: 9 = (min. + 60) + (sec. ÷ 60)
16 = (1.0000 + (19)(F)), where F is from Table E, API 101
19 = 12 × 16 × 18
26 = 19 × 22 × 23 × 24 × 25
27 = 26 ÷ (42.00)

Signed by: [illegible] For [illegible] S.O.Co
Signed by: [illegible] For Wallace Pet Co
Witnessed by: [illegible] For Rich Fuels Co.
Checked O.K. by: [illegible] For Rich Fuels Co

Base volume from Run #1 - 68.420
Base volume from Run #2 - 68.415
Base volume from Run #3 - 68.412
Average B.V. to be used 205.247 ÷ 3 = 68.4157 Bbls. @ 60° & 0 psig

FIGURE - 8

APPENDIX B

CALIBRATION DATA SHEET
FOR PISTON DISPLACEMENT METER PROVER

FOR _____ DATE _____ SHEET ____ OF ____

LOCATION _____ PRODUCT USED _____

SIZE _____ DIA. " _____ BETWEEN DETECTOR SWITCHES. MFGRS. SERIAL NO. _____

REF. DWG. NO. _____ MANIFOLD SIZE _____ WORKING PRESSURE _____ PSI

CALIBRATED BY MASTER METER SEE P.D. METER PROVING REPORT SHEET _____, ATTACHED

RUN NO.	ELECTRONIC COUNTER REGISTRATION		NET TIME ROUND TRIP	PRESSURE PSI		TEMPERATURE °F		
	ONE WAY	ROUND TRIP		METER	PROVER	METER	PROVER NORTH END	PROVER SOUTH END
AVG.								

RATE OF FLOW IN _____

REMARKS _____

WITNESSES

SIGNATURE	DATE	REPRESENTING

FIGURE - 9

Owner:								CALIBRATION REPORT				File:	
								Meter Prover Serial No.					
								Certified Containers Used yes					
								Nom. Size Gal.		100	1		
Water-Draw Calibration of Displaced Vol.				10" Pipe .375" Wall				Volume Cu. In.		23100	231		
Type of Prover Design: UNIDIRECTIONAL				Date: 12 Mar 1961				Serial No.		M-13	M-2		
Fill No.	Dir. of Run	Average Prover Press. Psig.	Can Volume Cu. In.	Scale Reading Above Zero + Cu. In.	Scale Reading Below Zero - Cu. In.	Actual Quantity Read Cu. In.	Averg. Temp. Prover	Averg. Temp. Liquid Drawn	Temp. Diff.	X Temp. Correction Factor	Vol. Adj. to 60° @ Calibration Pressure Left Dir.	Vol. Adj. to 60° @ Calibration Pressure Right Dir.	
1	100	25	23100	10		23110	54°F	56°F	+2	.99964	23102		
	100	25	23100	16		23116	54	57	+3	.99945	23104		
	1	26	231		1	230	55	55	0	1.00000	230	Avg 46436	
2	100	24	23100	5		23105	55	56	+1	.99951	23101		
	100	26	23100	17		23117	56	59	+3	.99945	23105		
	1	25	231	1		232	55	55	-3	.99947	232	Avg 46438	
3	100	26	23100	15		23115	55	55	+3	.99947	23103		
	100	25	23100	5		23105	56	57	+1	.99953	23101		
	1	24	231	0		231	56	57	+1	.99953	231	Avg 46435	

I Certify that this Calibration was done in accordance with the latest API Standards.

A. Total average volume @ 60°F and calibrating pressure (Not corrected for pressure effects)			46436.3
B. Water compressability reduction factor from calibrating pressure to atmospheric C_{pw} Table 2	46436.3x .99956	=	46429.8
C. Pressure correction factor for steel calibrating pressure to atmospheric C_{ps} Table 1	$\frac{46429.8}{1.0000}$	=	46429.8
D. Final total average prover volume to deliver at 60°F and atmospheric pressure (in Cal. or BBL.)		Gallons	200.9948

Witness	Title	Company

SEAL

FIGURE 10 APPENDIX B

APPENDIX B

CERTIFICATE OF CALIBRATION OF MECHANICAL DISPLACEMENT METER PROVER

OCTOBER 6, 1961

CERTIFICATE NO. 1

TO WHOM IT MAY CONCERN

SUBJECT - METER PROVER
SERIAL NO. 101
OWNER - JOHN DOE COMPANY
MANUFACTURER - X COMPANY
LOCATION - HOUSTON, TEXAS

This is to certify that on October 6, 1961, we the undersigned calibrated subject prover and established the atmospheric volume at 60° F. which would be displaced for a round trip of the displacer using water as a calibrating medium.

VOLUME DISPLACED LEFT TO RIGHT	VOLUME DISPLACED RIGHT TO LEFT	VOLUME DISPLACED ROUND TRIP
120.6162 gallons	120.6670 gallons	241.2832 gallons
120.6160 gallons	120.6668 gallons	241.2828 gallons
Average volume displaced per round trip of displacer at atmospheric pressure and 60° F.		241.2830 gallons or 5.7448 barrels

The following NBS certified test measures were used in establishing the volume displaced between the detector switches per round trip of the displacer.

NBS No. 4455 Certified to Deliver 1 US Gallon at 60° F
NBS No. 455 Certified to Deliver 5 US Gallons at 60° F
NBS No. 456 Certified to Deliver 50 US Gallons at 60° F

The calibration was conducted according to the latest edition of API Standard 1101 and its Supplements, and was witnessed by the undersigned. All parties concerned were satisfied with the procedure followed and the volume established.

Signed_____ Signed_____

For _____ For _____

FIGURE 11

APPENDIX C

12

METER PROVING REPORT - PROVER SECTION METHOD

(For meters with or without temperature compensators)

Station or Terminal Some Oil Company Report No. 22

Meter No. 2 and 3 Serial No. Date 7/24/61

Meter Make Any Size 6" Batch No. N-45-22

Initial Totalizer Reading Product Gasoline

Date Meters Last Repaired API Gravity 60.7

DESCRIPTION OF QUANTITY	RUN NO. 1 METER 2	RUN NO. 1 METER 3	RUN NO. 2 METER	RUN NO. 2 METER
METER REGISTRATION DATA				
1. Final Meter Reading: Total Pulses ÷ Pulses/bbl.	24.550	24.562		
2. Initial Meter Reading: Total Pulses ÷ Pulses/bbl.	00.000	00.000		
3. Registration by Meter Bbls. 1 - 2	24.550	24.562		
4. Total Registration for Run Bbls. Sum of 3	49.112			
5. Temp. of Stream at Meter °F	74.4			
6. Factor for Meter Temp. D-1250 (from Table 6)	0.9910			
7. Corrected Meter Registration 4 x 6	48.670			
8. Meter Case Pressure Inlet & Outlet	53 51 av. 52		av.	
PROVER SECTION VOLUME DATA				
9. Pressures at Trip No. 1 & Trip No. 2	51	49		
10. Average Prover Pressure Sum of 9 ÷ 2	50			
11. Temps. at Trip No. 1 & Trip No. 2	74.4	74.4		
12. Average Prover Temp. Sum of 11 ÷ 2	74.4			
13. Base Prover Volume - Bbls.	49.362			
14. Factor for Prover Pressure C_{ps} (Table 2)	1.0001			
15. Factor for Prover Temp. C_{ts} (Table 1)	1.0003			
16. Factor for Liquid Pressure (Table II, API 1101)	1.0004			
17. Factor for Liquid Temp. D-1250 (Table 6)	0.9910			
18. Net Prover Volume - Bbls. 13x14x15x16x17	48.957			
PERFORMANCE COMPUTATIONS				
19. Time Scraper Launched				
20. Elapsed Time for Run - Mins. & Secs.	1:28			
21. Elapsed Time for Run - Hrs. (60 x min.) + sec. / 3600	0.0244			
22. Rate of Flow During Run - BPH 4 ÷ 24 ÷ 21	2025			
23. Meter Factor (with compensator) 18 ÷ 8				
24. Meter Factor (without compensator) 18 ÷ 7	1.0059			
25. Amt. Corr. for Factor 1.0000 (1.0000) - 24				

SIGNED BY Henry Smith FACTOR TO BE APPLIED 1.0059 @ 2025 BPH

CHECKED BY Harry Jones @ 52 PSI METER CASE PRESSURE

FIGURE - 12

APPENDIX C

EXPLANATION OF PROVING REPORT OF FIGURE 12

Line 1. Final Meter Reading
Meter proving counter reading taken at completion of run = total pulses ÷ pulses per barrel.

Line 2. Initial Meter Reading
Meter proving counter reading taken before start of run = total pulses ÷ pulses per barrel.

Line 3. Registration by Meter - Barrels
Gross meter registration during run. Line 1 minus Line 2.

Line 4. Total Registration for Run
Sum of all meters operating on a common stream.

Line 5. Temperature of Registration °F.
Average temperature of product at meter from temperatures taken at start and completion of the proof run.

Line 6. Factor For Meter Temperature (Fmt)
Temperature correction factor for temperature recorded in Line 5 to convert gross volume in Line 4 to a 60.0° F. volume. This factor may be obtained from the ASTM-IP Petroleum Measurement Tables - D-1250, Table 6, Reduction of Volume to 60° F. against API Gravity at 60° F.

Line 7. Corrected Meter Registration
Meter registration corrected to 60.0° F. barrels. Line 4 multiplied by Line 6.

Line 8. Meter Case Pressure - Inlet and Outlet
Average of pressures observed on inlet and outlet sides of meter.

Line 9. Pressure at Detector No. 1 and Detector No. 2.
Read just before displacer hits detector No. 1.

Line 10. Average Prover Pressure
Sum of No. 1 and No. 2 detector pressures ÷ 2.

Line 11. Temperature at Detector No. 1 and Detector No. 2.
Read just before displacer hits detector No. 1.

Line 12. Average Prover Temperature
Sum of No. 1 and No. 2 detector temperatures ÷ 2.

Line 13. Base Prover Volume
Displaced volume of meter prover section with pipe temperature of 60.0° F. and internal pressure of 0 psig. This volume has been accurately determined by special calibration and will remain fixed for any given prover.

Line 14. Factor for Prover Pressure C_{ps}
The circumference of the prover pipe stretches with increasing pressure; thus the base volume of the prover changes with internal pressure. This correction factor (C_{ps}) is used to adjust the base volume of the prover pipe to the volume it will contain when completely full of liquid under pressure. The factor is obtained by entering Table 2 of the Appendix E with the average prover pressure, Line 10, and picking the factor for the proper size prover pipe.

Line 15. Factor For Prover Temperature C_{ts}
The volume of a steel vessel increases with increasing temperature; thus the base volume of the prover changes with pipe line temperature. This correction factor (C_{ts}) is used to adjust the base volume of the prover pipe to the volume it will contain at its average observed temperature. The factor is obtained by entering Table 1 of the Appendix D with the average temperature, Line 12, and selecting the proper factor.

Line 16. Factor For Liquid Pressure F_{pl}
This factor (F_{pl}) is used to convert the base prover liquid volume at the observed pressure of Line 10 to its equivalent volume at standard pressure conditions. The factor is obtained by solving the equation shown in API Standard 1101, Table II.

Line 17. Factor For Liquid Temperature
Temperature correction factor (F_{lt}) to convert base prover liquid volume at its average temperature, Line 12, to its equivalent volume at 60° F. Use ASTM-IP Petroleum Measurement Tables - D-1250, Table 6.

Line 18. Net Prover Volume - Barrels
Volume of liquid displaced from prover section during proof run at standard reference conditions of pressure and temperature. Equal to Line 13 X Line 14 X Line 15 X Line 16 X Line 17.

Line 20. Elapsed Time Run
Measured with stopwatch to nearest second. Read in minutes and seconds.

Line 21. Elapsed Time for Run - Hours

Line 22. Rate of Flow - BPH
Line 4 times Line 24 divided by Line 21.

Line 23. Meter Factor (With temperature compensator)
Line 18 divided by Line 4.

Line 24. Meter Factor (Without temperature compensator)
Line 18 divided by Line 7. Fill in factor to be used and rate In BPH at bottom of sheet and sign report. Check report and make sure all items are properly filled in.

FORMULA USED FOR CALCULATIONS

Formula for Line 18: $V_1 = K \times C_{ps} \times C_{ts} \times F_{pl} \times F_{lt}$ (1)

Where:

V_1 = Net prover volume displaced @ 60° F. and standard pressure

K = Base prover volume when prover is at 60° F. and 0 psig.

C_{ps} = Correction factor for change in pipe volume (dimensions) with change in pressure. (Appendix E - Table 2).

C_{ts} = Correction factor for change in pipe volume (dimensions) with change in temperature. (Appendix D - Table 1)

F_{pl} = Correction factor for change in liquid volume with change in pressure. (API-1101-Table II)

F_{lt} = Correction factor for change in liquid volume with change in temperature (ASTM Tables D-1250 - Table 6)

Formula for Line 7: $V_2 = G\ (F_{mt})$ (2)

Where:

V_2 = Net meter registration @ 60° F. and operating pressure.

G = Gross meter registration (observed)

F_{mt} = Correction factor for change in meter registration with change in temperature (Line 6)

Formula for Line 24: $f = \frac{V_1}{V_2} = \frac{\text{Net Prover Volume}}{\text{Net Meter Registration}}$ (3)

Where:

f = Meter Factor for meter without temperature compensator.

<u>SAMPLE CALCULATION</u>

Product = 60.7° API Gasoline

P = 50 psig Average Prover Pressure

T = 74.4° F. Average Prover Temperature

G = 49.112 Bbls. Gross Meter Registration

T_m = 74.4° F. Meter Temperature

K = 49.362 Base Volume

P_s = 0 psig Standard Pressure for Product being pumped.

C_{ps} = 1.0001 from Table 1, Appendix E.

C_{ts} = 1.0003 from Table 3, Appendix D.

Solving for "F" from Standard 1101, Table II, the average prover temperature of 74.4° F. is closest to 74.0° F. and the API gravity of 60.7 is closest to 61° API. From Table II, Standard 1101 Compressibility Factors per PSI for Liquid Hydrocarbons, the compressibility F per lb. is found to be 0.0000082.

$F_{pl} = 1 + (P-P_s)\ (F)$ from Standard 1101, Table II.

$= 1 + (50-0)\ (.0000082)$

$= 1 + 0.0004$

$F_{pl} = 1.0004$

$F_{lt} = 0.9910$ (ASTM-IP Table 6)

$V_1 = K \times F_{pp} \times F_{pt} \times F_{lp} \times F_{lt}$

$= 49.362 \times 1.0001 \times 1.0003 \times 1.0004 \times 0.9910$

$V_1 = 48.957$

$$F_{mt} = 0.9910 \text{ (ASTM-IP Table 6)}$$

$$V_2 = G\ (F_{mt})$$

$$= 49.112 \times 0.9910$$

$$V_2 = 48.670$$

$$f = \frac{V_1}{V_2} = \frac{48.957}{48.670} = 1.0059$$

USE OF METER FACTOR

The meter factor as shown on Line 24 of report is multiplied by the observed meter registration, obtained from meter totalizer counter, to give the gross meter volume at standard (atmospheric) pressure conditions and meter operating temperature. This volume may then be corrected to give net 60° F. barrels, if desired.

Meter factors obtained as above are accurate only so long as the internal meter operating pressure existent during the proof is maintained during its routine operation.

Where electronic registers are employed as proving counters, the formulas used above are unchanged but the pulses per indicated barrel must be considered.

APPENDIX C - FIGURE 13

METER PROVING REPORT - PROVER SECTION METHOD
(For Meters With or Without Temperature Compensators)

Station or Terminal SAME OIL COMPANY Report No. 26
Meter No. 3 Serial No. 728391 Date 1/18/68
Meter Make ANY Size 6" Batch No. H-12-62
Initial Totalizer Reading 43689 Product PROPANE
Date Meters Last Repaired 8-16-61 Specific Gravity @ 60F .503 Vapor Pressure @ 100F 205

DESCRIPTION OF QUANTITY	RUN NO. 1	RUN NO. 2
METER REGISTRATION DATA		
1. Final Meter Reading - Total Pulses ÷ Pulses/Bbl.	49.112	
2. Initial Meter Reading Total Pulses ÷ Pulses/Bbl.	0	
3. Registration by Meter - Bbls. (line 1 - line 2	49.112	
4. Temp. of stream at meter - F	74.4	
5. Meter Case Pressure	248	
6. Factor for compressibility of liquid phases	1.004672	
7. Factor for meter liquid temp. (From ASTM D-1250)	.975	
8. Net Bbls. through meter (reduced to std. conditions***) (line 3 x line 6 x line 7)	48.1079	
PROVER SECTION VOLUME DATA		
9. Pressure at Trip No. 1 & Trip No. 2	251 & 249	
10. Average Prover Pressure sum of line 1&2	250	
11. Temp. at Trip No. 1 & Trip No. 2	74.4 & 74.4	
12. Average Prover Temp. sum of line 1&2	74.4	
13. Base Prover Volume - Bbls. (From calibration)	49.362	
14. Factor for Prover Pressure (CPS from calibration)	1.0020	
15. Factor for Prover Temp. CTS	1.0012	
16. Factor for compressibility of liquid phase**	1.00490	
17. Factor for liquid temp. (from ASTM D-1250)	.975	
18. Net volume in prover (reduced to standard conditions***) (line 13 x line 14 x line 15 x line 16 x line 17)	48.47504266	
PERFORMANCE COMPUTATIONS		
19. Elapsed time for run - min. & sec.	1:30	
20. Rate flow Bbl./Hr. (line 18÷Line 19 in Sec.)x3600	1939.0017	
21. Meter factor (line 18 ÷ line 8	1.00763	
Note: This meter factor converts meter reading to metered volume at metered conditions. To convert to standard conditions see Section IV of API Std. 1101.		

* line 6 = 1÷1-(Pressure @ meter - equilibrium vapor pressure)F
** line 16 = 1÷1-(Pressure @ prover - equilibrium vapor pressure)F
Where F is the liquid compressibility factor from appendix of API Standard 1101.

*** Volume reduced to standard conditions means the volume the liquid would occupy if it were at 60F and at equilibrium pressure at 60F.

Signed by _____ Checked by _____

APPENDIX D

STEEL CORRECTION FACTOR C_{ts} - TEMPERATURE

(See Paragraph 3045, API Standard 1101)

A volumetric correction factor must be applied to the base prover volume to account for the change in volume of the prover with change in its steel temperature.

C_{ts} = Correction factor for converting the volume of the prover at 60° F. (base volume) to its volume at some observed average temperature
= 1 + (Tp - 60) (Em)

Where:

Tp = average temperature of the steel comprising the prover section, usually assumed to be the same as the average liquid temperature in the prover section, in degrees fahrenheit, as indicated at Detectors No. 1 and No. 2.

Em = coefficient of cubical expansion of 0.0000182 per degree fahrenheit for a mild steel vessel as recommended in ASA Standard B 31.3-1959: Petroleum Refinery Piping.

The following is a convenient tabular form" of values of Fpt from -3.3° F. to 150.1°F.:

TABLE 1

Tp (Observed Temperature)	Fpt
-3.3 - 2.1	.9989
2.2 - 7.6	.9990
7.7 - 13.1	.9991
13.2 - 18.7	.9992
18.8 - 24.2	.9993
24.3 - 2917	.9994
29.8 - 35.2	.9995
35.3 - 40.7	.9996
40.8 - 46.2	.9997
46.3 - 51.7	.9998
51.8 - 57.2	.9999
57.3 - 62.6	1.0000
62.7 - 68.1	1.0001
68.2 - 73.5	1.0002
73.6 - 79.0	1.0003
79.1 - 84.5	1.0004
84.6 - 90.0	1.0005
90.1 - 95.5	1.0006
95.6 - 101.0	1.0007

(Cont'd.) Tp (Observed Temperature)	Fpt
101.1 - 106.5	1.0008
106.6 - 111.9	1.0009
112.0 - 117.4	1.0010
117.5 - 122.9	1.0011
123.0 - 128.3	1.0012
128.4 - 133.8	1.0013
133.9 - 139.2	1.0014
139.3 - 144.6	1.0015
144.7 - 150.1	1.0016

APPENDIX E

DERIVATION OF FORMULA FOR C_{ps} - FORMULAE FOR CHANGE IN VOLUME OF PROVER WITH CHANGE IN PRESSURE

Paragraph 2116 - 2122 - API Standard 1101 describes a method for determining experimentally the volume of a prover under pressure. However because it is sometime more convenient to calculate the change in volume with change in pressure, the following derives a formulae for this calculation.

There are several approaches to the derivation of the formula for determining the change in volume of a cylinder with change in pressure one derivation follows:

Nomenclature —

Cps = the factor for determining the increase in prover volume with increase in pressure.
D = internal diameter in inches of prover section at zero gage pressure.
L = length in inches of prover section at zero gage pressure.
C = internal circumference in inches of the prover section at zero gage pressure.
V = internal volume in cubic inches of prover section at zero gage pressure.
P = increase in pressure in pounds per square inch of the prover section.
ΔD = increase in prover internal diameter in inches with increase in pressure P.
ΔL = increase in prover length in inches with increase in pressure P.
ΔC = increase in prover internal circumference in inches with increase in pressure P.
ΔV = increase in prover volume in cubic inches with increase in pressure P.
E = modulus of elasticity in pounds per square inch.
t = prover wall thickness in inches.
s = hoop stress in pounds per square inch in prover wall due to pressure P.
u = Poisson's ratio.

Then: $$Cps = \frac{V+\Delta V}{V}$$

As: $$V = .7854\ D^2L$$

And: $$V+\Delta V = .7854\ (D+\Delta D)^2\ (L+\Delta L)$$

$$Cps = \frac{.7854\ (D+\Delta D)^2\ (L+\Delta L)}{.7854\ D^2L}$$

$$= 1 + \frac{(2.5 - 2u)\ P(0.5D + 0.6t)}{Et}$$

If we assume E = 30,000,000 and u = .25

$$\text{Then:} \quad Cps = 1 + \frac{P(0.5D + 0.6t)}{15 \times 10^6 t} \qquad (4)$$

If we assume that a buried pipe prover will be restrained so that the internal pressure causes no longitudinal stress but does cause hoop stress, then ΔL becomes zero and ΔD is not affected by Poisson's ratio. Thus, from equation (1)

$$Cps = 1 + \frac{2DL\ \Delta D}{D^2 L}$$

And from equation (2)

$$\Delta D = \frac{DS}{E}$$

$$\text{Then:} \quad Cps = 1 + \frac{2S}{E}$$

Substituting from equation (3)

$$Cps = 1 + \frac{2P(\frac{D}{2} + 0.6t)}{Et}$$

If E is 30,000,000

$$\text{Then:} \quad Cps = 1 + \frac{P(0.5D + 0.6t)}{15 \times 10^6 t} \qquad (5)$$

It will be noted that the equation for a free end prover, equation (4) and for a buried prover, equation (5) are the same. It will also be noted that if a value other than 0.25 is used for Poisson's ratio the two equations will not be the same.

Because the term (0.6t) is insignificant in equation (5), it can be eliminated and the final formula simplified as follows:

$$Cps = 1 + \frac{P0.5D}{15 \times 10^6 t} = 1 + \frac{PD}{30 \times 10^6 t}$$

Where: P = (Pp − Pa)

Pp = Operating or observed pressure psig

Pa = Pressure, psig at which base volume of prover was determined (usually 0 psig)

$$Cps = \frac{D^2L + 2DL\Delta D + L\Delta D^2 + D^2\Delta L + 2D\Delta D\Delta L + \Delta L\Delta D^2}{D^2L}$$

Inasmuch as ΔD and ΔL are quite small, ΔD^2, $\Delta D\ \Delta L$, and $\Delta L\ \Delta D^2$ are extremely small and may be neglected.

$$\text{Then:} \quad Cps = 1 + \frac{2DL\Delta D + D^2\Delta L}{D^2L} \qquad (1)$$

If a material has stress in only one plane, the strain will be equal to the length of the segment multiplied by the stress over the modulus of elasticity. However, if the material is stressed in two directions, the strain will be reduced by an amount equal the stress in the perpendicular direction divided by the modulus of elasticity and multiplied by the considered length and a factor known as Poisson's ratio. A pipe prover with free ends will have a longitudinal stress equal to one half that in a circumferential direction. Thus, the changes in diameter (D) and length L of a prover can be written in terms of either circumferential or longitudinal stress.

$$\text{As:} \quad \Delta C = C\left(\frac{S}{E} - u\frac{S}{2E}\right)$$

$$\text{And:} \quad \frac{\Delta D}{D} = \frac{\Delta C}{C}$$

$$\text{Then:} \quad \Delta D = D\left(\frac{S}{E} - u\frac{S}{2E}\right) \qquad (2)$$

$$\text{And:} \quad \Delta L = L\left(\frac{S}{2E} - u\frac{S}{E}\right)$$

$$\text{Then:} \quad Cps = 1 + \frac{2D^2L\left(\frac{S}{E} - u\frac{S}{2E}\right) + D^2L\left(\frac{S}{2E} - u\frac{S}{E}\right)}{D^2L}$$

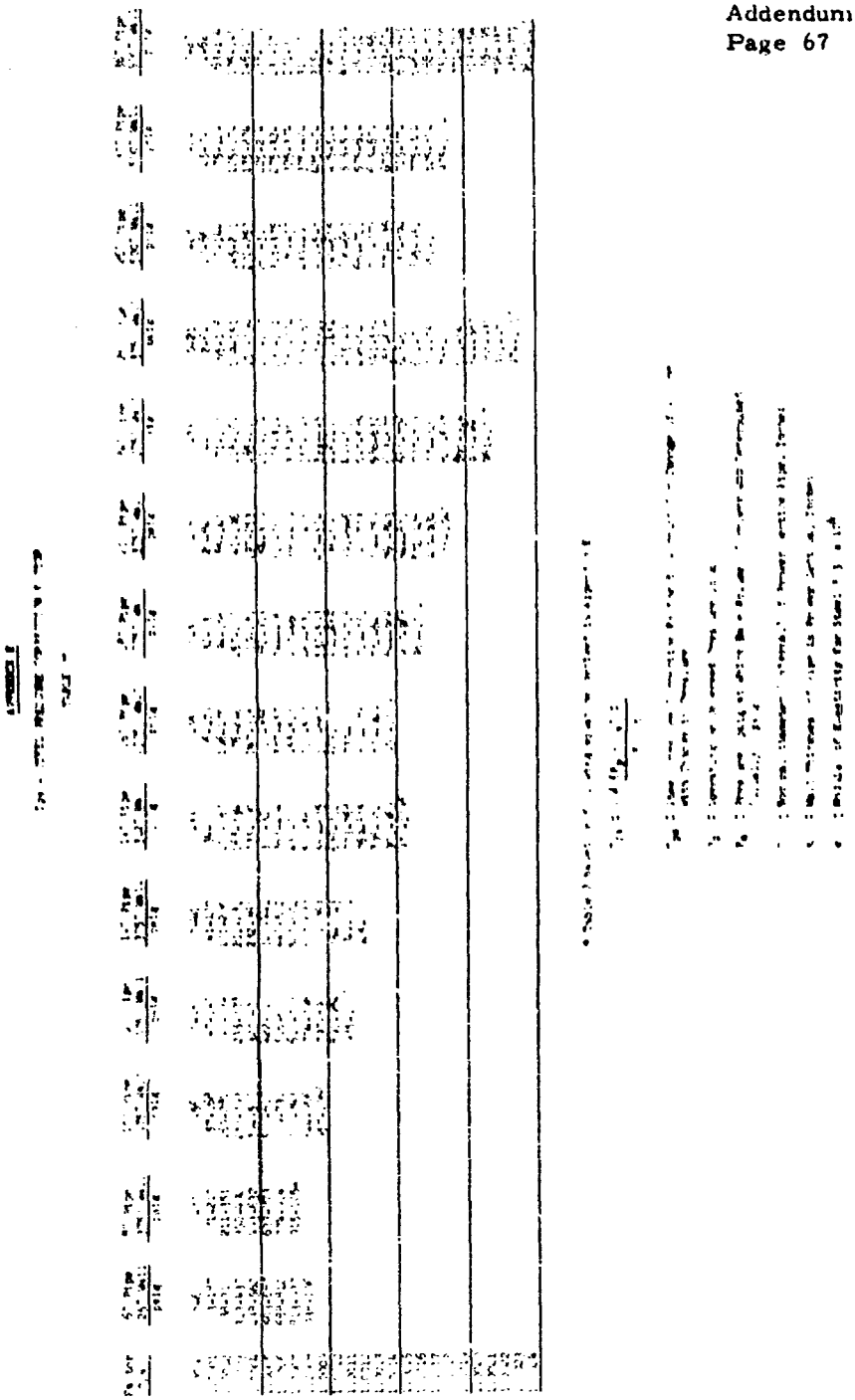
$$= 1 + \left(\frac{2S}{E} - u\frac{S}{E} + \frac{.5S}{E} - u\frac{S}{E}\right)$$

$$= 1 + \frac{2.5S - u2S}{E}$$

As the hoop stress (reference, Section VIII, ASME Boiler and Pressure Vessel Code) is:

$$S = \frac{P\left(\frac{D}{2} + 0.6t\right)}{t} \qquad (3)$$

$$Cps = 1 + \frac{(2.5 - 2u)\,\frac{P\left(\frac{D}{2} + 0.6t\right)}{t}}{E}$$



APPENDIX F

CALIBRATION OF PIPE PROVERS

(use of dimensional measurements)

The following outline describes the methods used in determining the actual volume of the calibrated pipe prover by means of accurate dimensional measurement and subsequent calculation and conversion to liquid measure, barrels or gallons.

The prover pipes on which this procedure has been used and the accuracy actually established have been internally honed. It is not the intent in this honing to achieve a perfect cylinder, rather to provide a polished surface free of burrs and roughness. Also careful pre-selection of the pipe is essential to assure it is free of dents, flattening or internal fissures that would create extreme diametric variations.

METHOD NO. 1 - DIAMETRIC MICROMETER MEASUREMENTS

This can only be carried out where the pipe I.D. is large enough to permit a person to work inside taking measurements. It has been accomplished in provers as small as 16".

1. For diametric measurements an inside micrometer calibrated to 68°F is used. It is left in contact with the pipe at all times except when in use so that it will be at pipe temperature. Further, it is equipped with a handle insulated from it to reduce any expansion effect due to manual handling.

2. A cylindrical jig covered on the outside with felt, for thermal insulation, marked at 45° intervals and having a level attached to it is used to determine the measurement points and is pulled through the pipe ahead of the person making the measurements. The person making the measurements lies on a felt pad to insulate his body heat from the pipe. The jig is moved forward through the pipe in even increments, usually 4, 5 or 6 inches and 4 diametric measurements are made at each position.

3. Every fourth set of measurements is subsequently re-checked.

4. All measurements are recorded as to longitudinal location and also to each radial position. First and last longitudinal locations are just outside the calibrated section.

5. The longitudinal measurement is made with an accurately calibrated steel tape (68°F) from centre to centre of detection switch holes, the final part increment on the tape being measured by calipers. This measurement is made inside the pipe with the pipe rolled so that the detection switch holes are vertically downward.

6. From the recorded measurements calculations are made of the precise volume in this manner:

   (a) Arithmetic average of 4 diameters is worked out.

   (b) The RMS value (standard deviation) of these 4 diameters is also calculated to establish the difference between this and the arithmetic average.

   (c) Using (a) or (b) (generally the difference is negligible and the arithmetic average can be used) the average cross sectional area is established and the volume can then be accurately worked out.

   (d) As a further check the maximum probable error is calculated for all the measurements taken.

7. Using the change of volume coefficient (0.0000182) of the pipe for temperature deviation from that at the calibration temperature a graph and a table is set up for the actual volume at all oil temperatures encountered.

METHOD NO. 2 - CIRCUMFERENTIAL MEASUREMENTS

This method has been used in small and large diameter pipes (as small as 8" nominal pipe).

1. A jig is made up to take internal circumferential measurements at even increments (4, 5 or 6 inches) along the pipe. A brief description of one such jig is as follows:

   (a) A heavy metal shoe resting on the pipe bottom has anchored to it and resting on the pipe the fixed end of a flexible steel tape(about 1/2" wide). It also holds a very strong spring device and a dial gauge reading in thousandths.

   (b) The above tape is attached to the jig by flexible fingers to maintain it in the precise vertical and horizontal planes.

   (c) From the fixed end in the jig the tape is held very tightly against the pipe internal circumference by the free-end being under the pressure of the spring in (a) above. Any movement of this free end is linked to the dial gauge.

2. At some point near the end of the pipe where the person making the measurements can reach, a tape of similar material which has been made up just slightly shorter than the internal circum-

ference of the pipe and with its ends machined square, is positioned. Using a blued wedge this tape is forced against the pipe wall and the true length is established with the tape removed and held flat. This length is that of the tape held flat, plus wedge (reason for bluing). The true length of the tape in its curved state is then calculated since the true neutral of a tape moves from centre to 44% from the inside and 56% from the outside when it is formed into a circle.

3. Now the jig is set up at this same point and the dial gauge is zeroed. All subsequent readings of the dial gauge as it moves down the pipe are referred plus or minus of this datum. Readings can be taken by looking down the pipe through a magnifying sight glass.

4. If pipe size permits, diametric measurements as in Method No. 1 are done at some locations as a cross check.

5. As a further cross check a piece of pipe is set up and machined to a circumference equal to that established in (d) above. The tape and wedge procedure is repeated to determine any deviation of the pipe internal circumference from that of a true circle. No significant difference has yet been found.

6. Longitudinal measurement is made similarly to that in Method No. 1. To assist in fixing the centre of the detection switch holes, a very sharply pointed conical piece is machined so that its point is flush with the pipe interior when it is held into the ball recess by a plug screwed into the detection switch coupling on the pipe.

7. From the average of each of the circumferences "C" squared the average cross sectional area is calculated using $\frac{C^2}{4\pi}$

8. As in method No. 1, the volume in cubic feet and barrels is then calculated. Also temperature coefficient is similarly applied. The mathematics of probable error can also be applied if so desired.

It is felt that use of either of the above methods will achieve a very accurate true volume of the prover pipe, this volume being capable of verification by the mathematics. Also, in either method (particularly No. 2 as it is much faster) a number of calibration runs can be made and compared.

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