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Engine Laboratory

Technical Report

1988 / 08

Laboratoire des moteurs

Rapport technique

TR-ENG-002
NRC NO. 29847

CALIBRATION OF AN FTI OMNITRAK BALLISTIC FLOW CALIBRATOR SYSTEM

W. Grabe and J. Carvish

Division of
Mechanical Engineering

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CALIBRATION OF AN FTI OMNITRAK BALLISTIC FLOW CALIBRATOR SYSTEM

ETALONNAGE D'UN SYSTÈME DE CALIBRAGE BALISTIQUE (FTI OMNITRAK) DE DÉBITMÈTRES

W. Grabe, J. Carvish

Technical Report
1988/08

Rapport technique
TR-ENG-002
NRC NO. 29847

D.M. Rudnitski, Head/Chef
Engine Laboatory/
Laboratoire des moteurs

J. Ploeg
Director/Directeur

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ABSTRACT

In 1983, the Engine Laboratory acquired an Omnitrak ballistic calibrator for calibrating its own turbine fuel flowmeters, and, eventually, those of other Canadian users, as a national facility. Initially, the manufacturer's calibration had been used. In the spring of 1987, the Omnitrak was calibrated by Engine Laboratory personnel for the first time. The report documents all aspects of this calibration for future reference and, more importantly, for traceability of the calibration accuracy. Very close agreement was established between the manufacturer's and NRC's calibration factors, when compared on the basis of identical correction procedures. The original oversight of a small balance correction by the manufacturer was identified and taken in account.

RÉSUMÉ

En 1983, le Laboratoire des moteurs a acquis un calibrateur balistique Omnitrak pour faire l'étalonnage de ses propres débitmètres à turbine (pour carburant) et, éventuellement, ceux d'autres utilisateurs canadiens. A l'origine, on se servait des étalonnages effectués par le fabricant. Au printemps 1987, le personnel du Laboratoire des moteurs a effectué l'étalonnage de l'Omnitrak pour la première fois. Le présent rapport documente tous les aspects de cet étalonnage pour fins de référence ultérieure et, plus important encore, pour assurer la possibilité de traçage de la précision d'étalonnage. Un rapprochement très étroit a été établi entre les facteurs d'étalonnage du fabricant et ceux du CNRC lorsque ceux-ci ont été comparés en utilisant des méthodes de correction identiques. Une petite correction de l'équilibrage effectuée par le fabricant et que l'on avait pas saisi à l'origine a été identifiée et prise en compte.

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1.0 INTRODUCTION

In 1983, the Engine Laboratory, Division of Mechanical Engineering, purchased an Omnitrak ballistic flow calibrator, Model OT-150, S/N 83110022, from Flow Technology Inc., Phoenix, AZ. It serves to calibrate periodically the in-house volume flowmeters, used in gas turbine operation. Furthermore, it may be utilized, in the near future, to provide a calibration service to other Canadian flowmeter users, on a to-be-determined fee basis.

With the purchase came a factory calibration, which has been applied ever since [Appendix A]. As a check of the existing calibration, and in preparation for documented client meter calibrations, it was decided to re-calibrate the ballistic flow calibrator. This report deals with the preparation and execution of this calibration.

2.0 DESCRIPTION OF OMNITRAK CALIBRATOR

The Flow Technology, Inc. Omnitrak calibrator is a very precise volumetric calibration device (FTI, 1982). It uses a piston, within a smooth-bore cylinder, to provide accurate displacements of the test liquid along its travel [Fig. 1]. The piston is actuated by a compressed gas, usually air. Attached to the piston shaft is a photoelectric sensor (encoder) which generates pulses as it slides along a finely-etched glass rule. Each pulse represents an extremely small, but precise, volume of fluid (approximately 0.06 cm^3). The displaced volume is virtually unaffected by the liquid's viscosity, density, and compressibility. As the piston travels at a preset rate along the cylinder, the test fluid is pushed through the flowmeter under test. The data control console receives the pulse count from the encoder/translator and the pulse accumulation from the flowmeter, which, together with their appropriate times, provide the basis for the necessary arithmetic. A typical data output sheet is given in Appendix B.

The characteristic of a flowmeter is defined by its K-factor, which gives the meter pulses per unit volume passed through, as a function of the meter output frequency divided by the fluid's viscosity. The frequency is thus proportional to the flowrate. Ideally, the K-factor is constant over the meter's operating range. In reality it varies slightly with flowrate, with strong excursions at the low flows. A typical example is given in Figure 2. A good description of turbine flowmeter technology can be found in Zimmerman R. et al. (1977).

3.0 CALIBRATION EQUIPMENT

3.1 Omnitrak Calibrator

The calibrator was prepared for calibration according to instructions (FTI 1982; Maurey 1985) and verbal communications with the manufacturer. The following comments relate primarily to those parts of the procedure not found in the manual.

With two end tubes installed, a dummy meter was placed in the test transducer section (FTI 1982). The normally-used test fluid, JP4 turbofuel, was drained from the calibrator system through the fill drain line (V7), [Fig. 3], and the flow tube drain (V6) into containers placed in an existing recess in the floor. Subsequently, the JP4-soaked filter element was removed, and the system was left to drain overnight. A new filter element was installed, and 40 liters of heptane, a hydrocarbon of the methane series, recommended by FTI, was poured by gravity feed into the calibrator, from the top of an adjacent cabinet. For better rinsing of the surge tank, it is recommended to use 60 liters for the next calibration. The heptane was put in with the piston in the retracted position, and the system was flushed thoroughly by moving the piston back and forth about six times. The top bleed valves (V10 and V10') were opened to facilitate complete flushing. Also, the three throttling valves (V3, V4, and V5) were opened for thorough rinsing of all piping. It should be noted that, with the piston fully in the downstream position, the surge tank was one quarter to one third filled with the solvent.

When it was felt that the whole calibrator system had been properly flushed, the heptane was drained, first from the fill drain valve (V7) and then from the flow tube drain valve (V6). Next, the heptane-soaked filter element, the dummy meter, and the two end tubes were removed, and the water draw tube arrangement was installed at bleed valve V10' (opposite from valve V10). This tube had been fashioned from 1/4" copper tubing, as per FTI drawing 03-85486 (FTI, 1985), a general diagram of the water draw test setup.

While the system was left to drain the heptane for about two hours, some air was also blown through to assist the heptane removal. The dummy meter and the two end tubes were reinstalled. As indicated in the FTI diagram referred to above, the calibrator end at the drain side was propped up by a length of 2"×4" wood. A fresh filter element was placed into its housing. Subsequently, the calibrator system was filled by gravity feed, with 70 liters of fresh, distilled water, through the fill drain valve (V7). The water was run through the calibrator system, between the flow tube and the surge tank, about ten times. During these water circulations the top bleeds were cracked open to permit the escape of any trapped air. With the flow tube piston in the return position (RHS), the dummy meter and the end tubes were removed, in preparation for the calibration process. The end, left open by the removal of the left hand side end tube, was capped off with a modified plug, which had a bleed added. With the operating handle in the run position, any remaining air was bled from bleed valves V10' and V9. The calibrator system was ready for a water draw calibration.

3.2 Water Draw Vessel

On account of some conflicting information, the initial calibration runs were carried out with a 2000 ml volumetric flask. While a flask of this size was recommended in the calibration procedure (FTI 1982), the original FTI calibration runs used a volume of one US gallon (1 US gal = 3.785 dm^3) per draw, or nearly twice the recommended amount.

Reasoning that larger draws would yield more accurate results, it was decided to switch to a 4000 ml vessel for the official calibration draws. Two narrow-mouth Erlenmeyer flasks, Pyrex brand, with reinforced beaded top, (Fisher Scientific catalogue number 10-040P), were purchased. It proved to be a judicious choice in that the gross weight per draw came to within 6% of the balance's full range of 5500 g. The flask used in the calibration has been marked as "1", for future reference.

3.3 Calibration Weights

A complete set of solid stainless steel weights, class S, was purchased. They follow the 5-3-2-1 series and range from 10 mg to 2000 g. The weights were calibrated by the Physics Division, NRC; the calibration report is attached as Appendix C. Excellent agreement was established between the weights' nominal values and true masses. While the greatest percent difference existed with the 10 mg weight, the smallest of the set, viz 0.2%, for practical purposes the 0.01 g deviation of one of the 2000 g weights (0.0005%) had the greatest impact on the weighing (sheets S7 to S22). However, by using the calibration values, the true mass of any weight could be established, subject to calibration tolerances and to buoyancy corrections.

3.4 Weighing Balance

A new toploading balance was purchased in preparation for the calibration. It was a Sartorius E5500S electronic balance, S/N 36 100 090, with a stated standard deviation of ≤±0.01 g and a maximum linearity deviation of ±0.02 g. The balance's weighing range was 5500 g, which included any subtracted tare.

It was found that the great sensitivity of the scale demanded a solid surface for its support, and a hood for keeping air movements away. In the absence of a proper balance table, the toploader was set on the concrete floor of the calibrator room, and levelled by adjusting the three feet/levelling screws.

The Sartorius toploader was provided with an internal and a external calibration. The internal calibration did not require any weights, and it supposedly calibrated the balance electronically/ mechanically over its full range. For the external calibration, an accurate weight of 5000 g was required. Such a standard weight, made of solid stainless steel, was purchased with the balance. Its mass was established by the Laboratory for Basic Standards, Physics Division, as 5000.03 ± 0.03 g [Appendix C].

Initial weighing of the 5000 g standard weight gave balance readings of 4999.81 g, which was between the true mass of 5000.03 g and the apparent weight of 4999.21 g, if the weight's buoyancy in air was taken into consideration. It was decided to adjust the calibration internally, following instructions transmitted by telephone from the vendor's representative, to read 5000.03 g ±0.01 with the standard weight placed on the pan. Hence, the balance was calibrated to read the true mass of a stainless-steel artifact in air.

3.5 Calibration of Accessories

In order to assure traceability to recognized national standards, it was of great importance that all elements involved in the calibration process were compared with these standards. In Canada, the Division of Physics, NRC, is the custodian of physical standards, such as mass, time, temperature, and frequency. In turn, Canadian standards are compared with those of the National Bureau of Standards, Washington, D.C., and other countries.

The calibration of the weights, used in the weighing of the water draws, has been discussed in Section 3.3 and Appendix C.

The prescribed frequency check on the Omnitrak was carried out with a Fluke Model 2161A frequency counter, S/N 379 5003 [Appendix D]. A single-point calibration verification by the Physics Division's Standards Laboratory showed an actual frequency of 999.9999 ± 0.0001 kHz for an indicated frequency of 1 MHz, a deviation of 0.1 ppm. This infinitesimal deviation constitutes a zero error for all practical purposes.

The temperature measuring arrangement for the calibration fluid and room temperatures was calibrated in-house with a JOFRA oven/calibrator [Appendix E]. At room temperature 21.1°C (70°F) the deviation from the true temperature was found to be less than 0.2°C (0.3°F). A precision of ±0.3°C (±0.5°F) is considered to be excellent.

The JOFRA calibrator had previously been checked by the Division of Physics [Appendix E] and the calibration was taken into account.

4.0 CALIBRATION PROCEDURE

4.1 General

The calibration described in this report was the first in-house calibration since the Omnitrak calibrator was acquired, some three years ago. Instructions given in the manual (FTI, 1982), and by telephone communication with the supplier, were closely followed. The preliminary results were based on weighing water draws on an electronic toploading balance, which had been calibrated immediately prior to the calibration process. The results were subsequently checked by comparative balancing with calibrated weights, which were not available at the time of the Omnitrak calibration. The comparative balancing provided direct traceability to Canadian mass standards at the National Research Council.

4.2 Water Draws

Two series of water draws (C87-1 and C87-2) were carried out for familiarization with the calibration procedure and for assurance that all equipment involved worked properly. Generally, the procedure outlined by FTI (1982, p. 12) was followed. While the first series consisted entirely of 2000 ml draws, water draws in the second series were alternated between 2000 ml and 4000 ml; with the latter the flask was filled twice for a single pulse count. Since it was felt that errors could possibly be introduced by this method, a 4000 ml flask was obtained for the two official calibration draw series (C87-3 and C87-4) [Section 3.2].

Before commencement of water draw series C87-3, the 4000 ml Erlenmeyer flask was thoroughly cleaned and dried. Then the weight of the flask was tared on the calibrated balance, and the tare was recorded for future reference. The balance allowed taring out the flask weight, so that the net water weight could be read directly. About 1000 ml of water was drawn off, at the beginning of the piston stroke and discarded to eliminate any flow tube end effects and small amounts of trapped air. Subsequently, the first draw commenced.

With the operating pressure at about 8 psig (55 kPa), the bleed was slowly opened to allow a steady water stream into the flask, at a rate of between 35 and 65 Hz on the calibrator. It was found that the recommended rate of 100 Hz corresponded to a flow that caused some splashing. A room temperature reading was taken approximately midway through the draw, which was terminated slightly above the 4000 ml mark. Since the calibration was chosen to be by mass, rather then by volume determination, an exact draw volume was not required. The indicated weight of the sample was recorded, together with the number of pulses collected during the draw, as was the water temperature, and the water was poured into a clean water container for future use. The wet container was tared, the Omnitrak was reset, and the process was repeated for the second draw, and subsequent ones. After eight water draws, the translator was about 6 in from the flow tube end plate, which was considered to be a safe distance for avoiding tube end effects.

Out of interest, one further draw was taken in series C87-4, until the piston came to the end of its travel. The draw was approximately 3500 ml and showed a significantly increased K-factor [Fig. 4]. This point confirmed the presence of some earlier referred to end effects. Otherwise, all points fell within a band of 0.08%; the inner five points were within 0.016% of each other. For highest calibation accuracy, the Omnitrak operation should be restricted to the middle 50% of travel.

4.3 Computation of K-Factor

4.3.1 General

The objective of the Omnitrak calibration was the establishment, or check, of a specific relationship between a volume displaced by the flow piston in the flow tube and the pulses counted by the encoder/ translator. It is expressed as the K-factor, in "pulses per unit volume", in our case US gallons, as a function of corrected flow, expressed as "frequency divided by viscosity", in units of hertz per centistoke.

The K-factor was obtained by NRC in two ways, which differed only in the sample weighing method, and by an FTI reduction program [Section 4.3.4]. All methods yielded virtually identical results, which provided confidence in the calibration process and the quality and precision of the equipment used.

4.3.2 NRC method 1

Water draw samples taken were weighed with a toploading electronic balance [Section 3.4], which had been calibrated to indicate 5000.03 g with a stainless steel weight of 5000.03 (±0.03) g placed on its pan. Within the weight's calibration accuracy, the balance showed the true mass of the weight.

As a first step in data reduction, the indicated weights of the individual water draws were corrected for buoyancy (Data Sheets S1 and S2). The correction took into account the buoyancies in air of the water draw, as well as the stainless steel weight. A detailed description of buoyancy effects on weighing is given in Appendix F. Subsequently, the pulses per mass (gram) and pulses per volume (US gallon) were computed. The mass-to-volume conversion is described in Appendix G. Finally, the pulses per US gallon (MT/OT) were averaged for each of the two series.

In order to ensure that the individual draws formed a reasonable pattern and also showed good repeatability, the MT/OT values were plotted in sequential order in Figure 4. It was found that the pulses per volume increased along the flow tube by about 0.08%, within the manufacturer's declared limit of 0.1%, see Data Sheet S3 ("Maximum variation of A_x"). The same trend existed with the original FTI calibration. However, repeatability between the two NRC calibration series was excellent, viz. within 0.0024%.

The effects of temperature and pressure on the displaced volume must be accounted for when performing a volume calibration (water draw), as well as a flowmeter calibration (FTI 1982; Appendix C). The corrections followed the layout on the "FTI Calibrator Constant Determination Data Sheet" (Data Sheet S3). In the case of the two calibration series, C87-3 and C87-4, the corrections to standard conditions increased the MT/OT constants by 4.3 and 3.4 pulses/US gal, about 0.006%, respectively (Data Sheets S3 and S4). Rounded off to the nearest pulse, both corrected constants were 62213 pulses/US gal.

4.3.3 NRC method 2

In discussions with researchers at the Laboratory for Basic Standards, Physics Division, it was learned that the true mass of a body, such as a water draw, can only be established by comparative balancing [Appendix F]. In this process, the electronic balance is merely used for comparing the unknown mass, e.g. water, with a known mass, the calibrated weights, taking into account the buoyancies of both.

The newly acquired set of weights [Section 3.3] was calibrated by the Physics Division [Appendix C]. In order to establish the true mass of each water draw, weights were placed on the balance pan to duplicate the balance reading of a draw. The nominal values of the weights, as well as the true values, obtained from calibration, were recorded and added (Data Sheets S7 to S22). Finally the true mass of the water draws was entered in Data Sheets S23 and S24. Subsequent calculations followed the same pattern as that of method 1.

Inspection of the weights' calibrations in Appendix C shows that the true masses of the weights were very close to the nominal ones. The deviation of greatest impact on the total weight was 0.01 g (0.0005%) for one of the 2000 g weights. Because of its relative magnitude, it overshadowed all other deviations from nominal in the final sum total.

Using the Sartorius balance as a comparator rather than a weighing apparatus, did not alter the previous test results [Section 4.3.2] to any noticeable degree. Comparing the equivalent data sheets of the two NRC weighing methods, S23 with S1 and S24 with S2, it can be seen that the averaged calibration constants were within 0.2 pulses/US gal (0.0003%) for the two series.

Since the correction to standard conditions used the same factors as those of method 1, the averaged calibration constant, rounded off to the nearest pulse, remained 62213 pulses per/US gal (Data Sheets S25 and S26).

While the final results showed that an accurate Omnitrak calibration could be obtained with the Sartorius precision balance alone, the use of calibrated weights confirmed that fact and provided traceability to prime standards at NRC's Physics Division.

4.3.4 FTI reduction program

As part of Flow Technology's customer service, a calibration reduction program, called "DRAW 5-87", was provided on a mini-floppy disk. The program was run on an IBM-compatible, personal computer. The raw data of test series C87-3 and C87-4 were entered and processed. The results are given in Data Sheets S5 and S6.

The calibration constants C_{SS}, at standard conditions, of 62213.5 and 62211.8, respectively, came within 1 pulse/US gal of NRC's hand-calculated pulses, a deviation of 0.0016%, or 16 ppm. This can be considered as complete agreement.

It should be pointed out that both, the NRC and FTI, reduction methods were based on the same principles; although the computational arrangements differed slightly.

4.3.5 Comparison with original calibration

The original FTI calibration, which accompanied the Omnitrak, had a C_{SS} factor of 62202 pulses/US gal [Appendix A]. This was 11 pulses lower than the new NRC-obtained factor. There is reason to believe that the difference was not caused by a change in the calibrator's system but rather by the omission of the balance calibration factor, also referred to as scale factor. The balance calibration factor accounts for the balance weights' buoyancy in air. If this factor were multiplied out of the corrections on Data Sheets S5 and S6, the constants would become 62204 and 62202 pulses/US gal, respectively. The above reasoning is supported by the fact that the FTI reduction program originally supplied did not include the balance calibration factor.

5.0 SUMMARY

(i) This report describes the calibration of the FTI Omnitrak ballistic flowmeter calibrator, Model OT-150, S/N 83110022. Its purpose is to document the calibration and its traceability to primary standards and to provide a guide for future calibrations.

(ii) In preparation for the calibration, a precision balance with 5000 g range and 0.01 g resolution, and a stainless steel, Class S, set of weights were purchased. The set of weights was calibrated by the Physics Division, NRC.

(iii) The calibration comprised two series of eight water draws each. The data were reduced manually by two slightly differing NRC methods and by an FTI supplied computerized program. All methods followed the same principles.

(iv) The two NRC methods differed in the way the water draw weights were established. In the first one, the balance readings were taken as the mass values. In the second one, the balance was used as a comparator between the draw masses and stainless steel weights.

(v) The FTI reduction program was supplied with balance readings of the water draws, as used in the first NRC method.

(vi) The calibration factors of the two series, calculated by the three described approaches, agreed within 1.7 pulses/US gal, or 0.0027%. This excellent agreement is an indication of the careful approaches taken by supplier and user in reducing the data accurately and of the high quality of the calibration equipment used.

(vii) The new Omnitrak calibration factor, rounded to the nearest pulse, is 62213 pulses/US gal.

(viii) The calibration factor provided by FTI with the delivery of the calibrator was 62202 pulses/US gal. It is believed that the lower value, by 11 pulses, was on account of the omission of a balance calibration factor. The error introduced by this difference was 0.018%.

6.0 RECOMMENCATIONS

(a) Periodic recalibrations of the Omnitak ballistic calibrator are required. The interval between calibrations depends very much on the work load, the frequency of fluid changes, and indications of systematic shifts in meter calibrations. Furthermore, participation in external calibration programs, such as the NBS round robin one, would render an internal recalibration unnecessasry. As a general guideline, the time between calibrations should not exceed five years.

(b) At the time of a recalibration, the calibrations of ancillary equipment should be reviewed, i.e. the frequency counter, temperature measuring devices, the weighing scale, and the weight set. Depending on usage, the Laboratory for Basic Standards, Physics Division, recommends an initial calibration check of the weights after five years, unless visible damage has taken place.

(c) The in-house calibration could be delayed, or replaced, by participation in an external calibration procedure, such as the recent round robin calibration program of the National Bureau of Standards, (NBS), Gaithersburg, MD. A program of this kind compares one's complete calibration system with those of NBS and other participants, which yields traceable bias as well as precision estimates. Continued participation in this NBS-led activity is strongly recommended.

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FTI, 1982. Installation, Operation and Maintenance Manual Omnitrak. Flow Technology, Inc., 4250 East Broadway Road, Phoenix, Arizona, 85040.

FTI, 1985. Installation, Operation and Maintenance Manual Omnitrak. Flow Technology, Inc., 4250 East Broadway Road, Phoenix, Arizona, 85040.

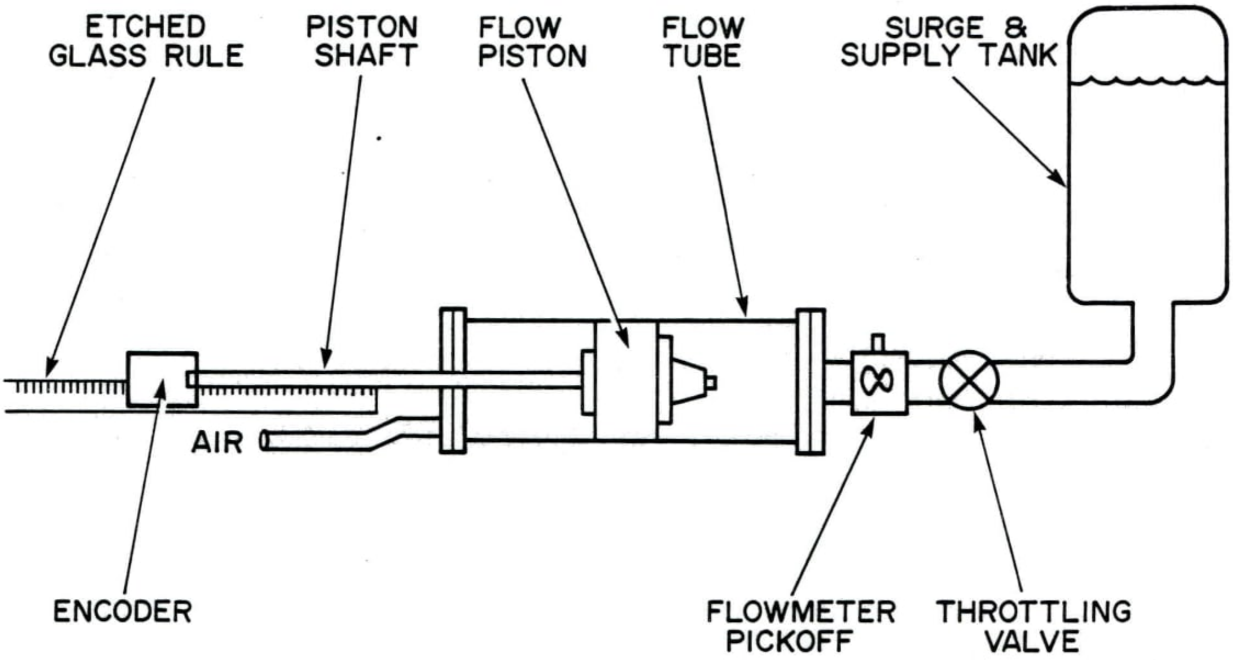


FIG. 1 BASIC OMNITRAK MECHANICAL LAYOUT
REF. FTI, 1982

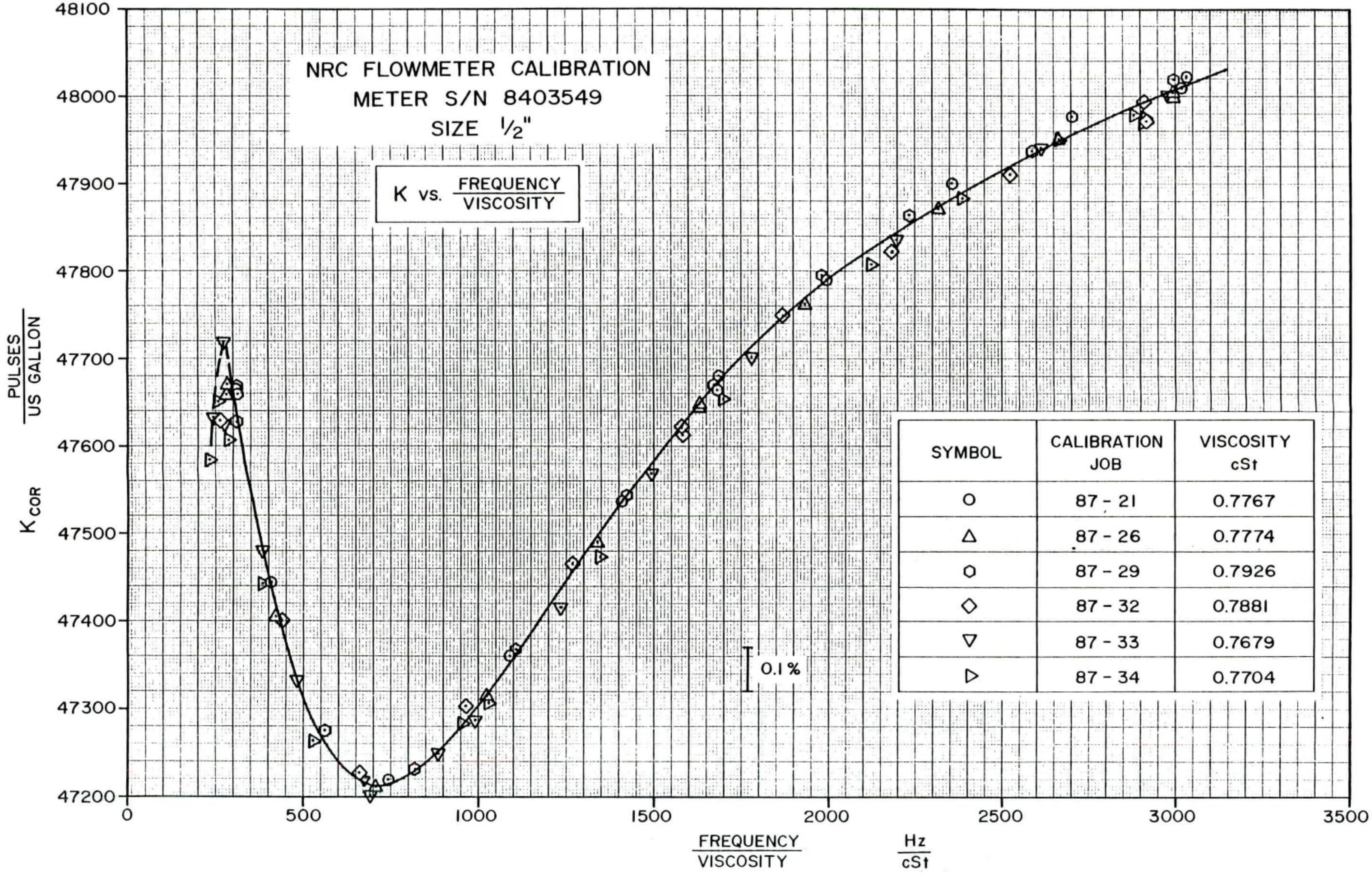


FIGURE 2: TYPICAL CALIBRATION OF A TURBINE FLOWMETER

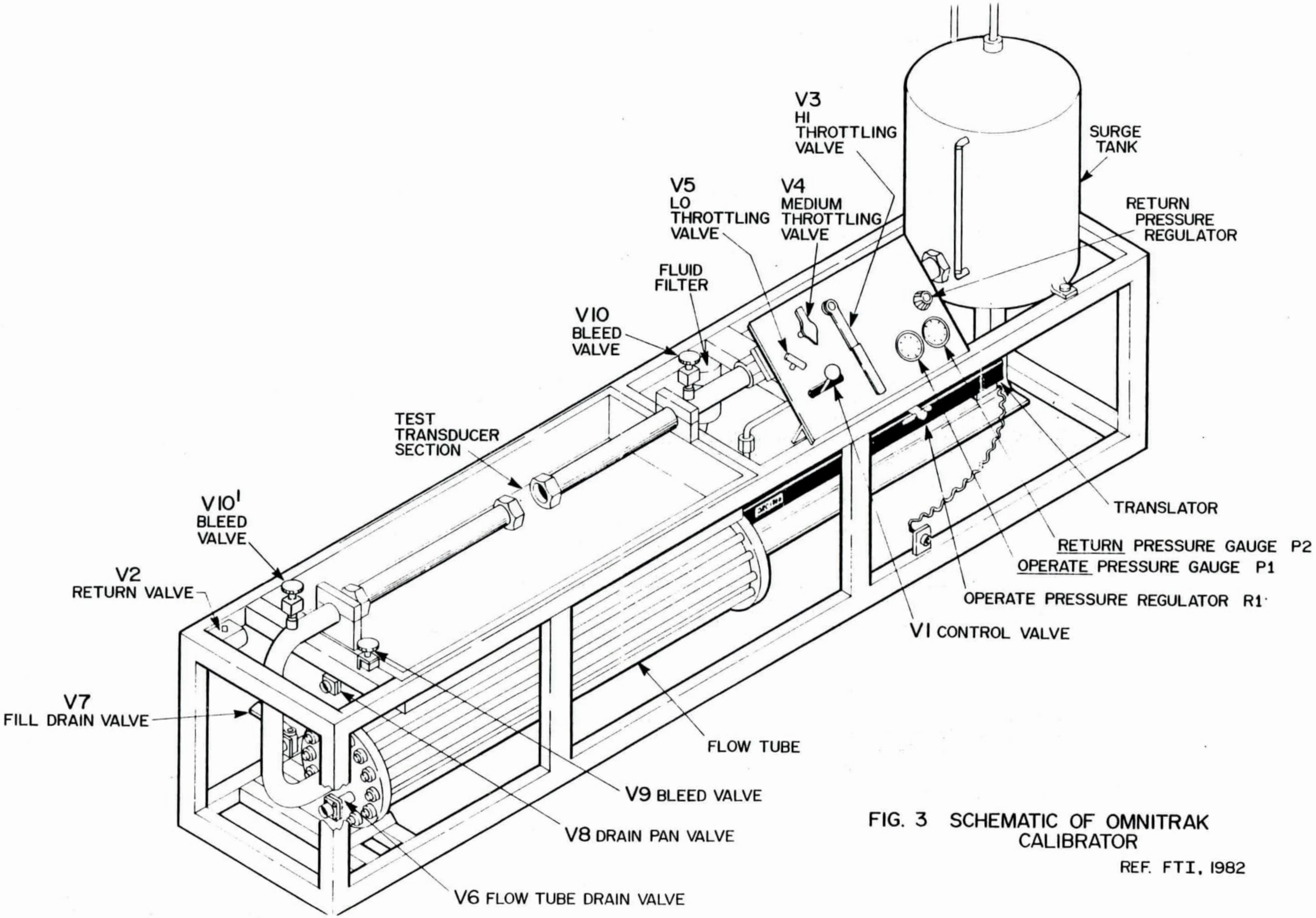
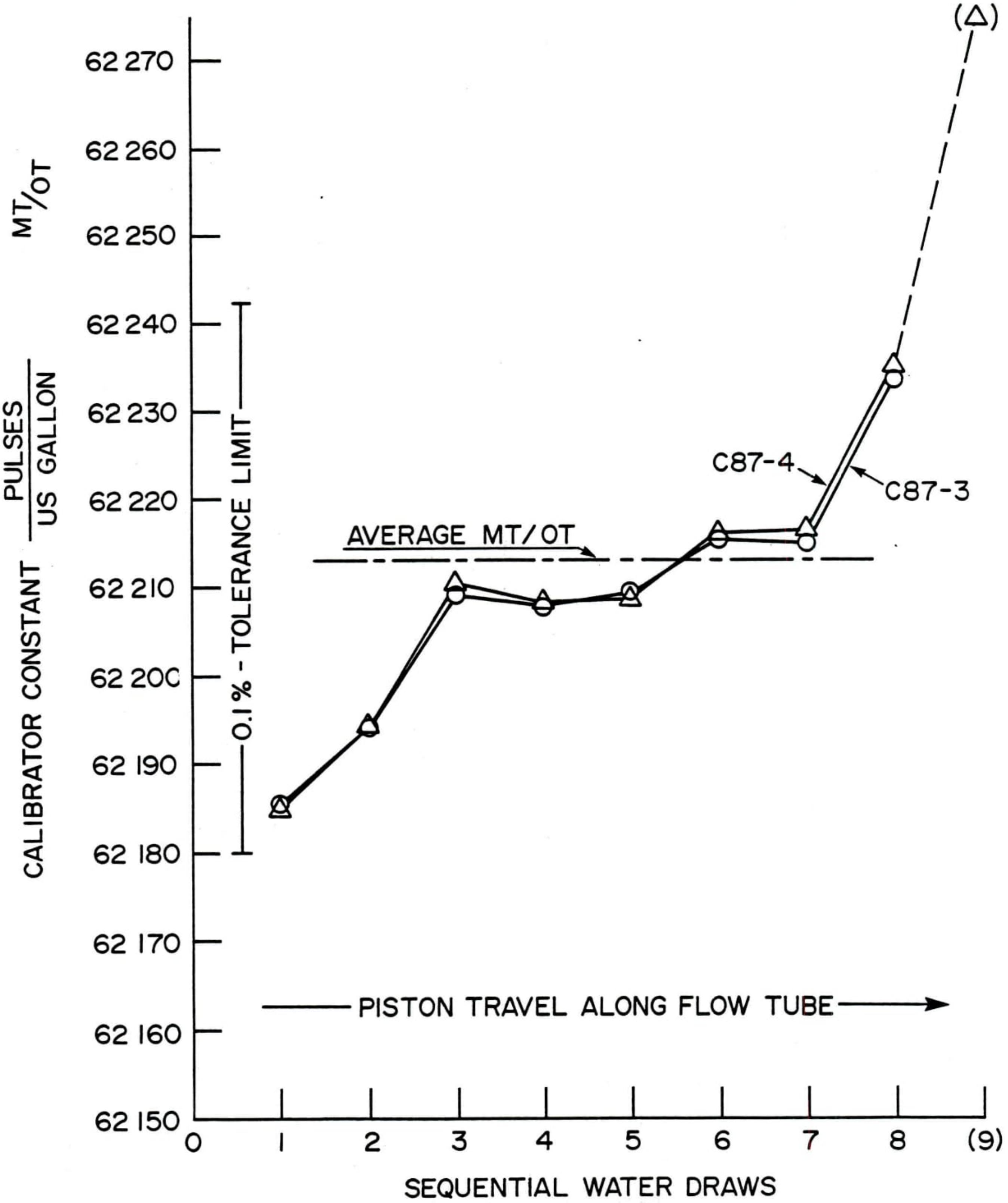


FIG. 3 SCHEMATIC OF OMNITRAK CALIBRATOR

REF. FTI, 1982

FIG. 4 OMNITRAK CALIBRATOR CONSTANTS ALONG PISTON TRAVEL IN FLOWTUBE



FTI CALIBRATOR CONSTANT DETERMINATION SHEET

S1

DATA - NRC METHOD 1

NRC/DME Engine Laboratory

Job No.: C87-3

Model No.: OT 150

Serial No.: MT 83110022

Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g

Accuracy: ± 0.02 g

Weight Set:

TEST	T_r °F	T_w °F	#MT/OT Pulses (x)	Mass g as weighed	Mass g * corrected for buoyancy Y	MT/OT Pulses/g (Z)	MT/OT Pulses/gal. (A_x)
1	71.5	69.7	66056	4009.06	4013.13	16.4600	62185.4
2	72.5	69.4	66152	4014.32	4018.39	16.4623	62194.2
3	67.4	69.5	66121	4011.47	4015.54	16.4663	62209.2
4	72.9	69.5	66128	4011.98	4016.05	16.4659	62207.9
5	67.8	69.5	66229	4018.01	4022.09	16.4663	62209.4
6	72.1	69.4	66152	4012.95	4017.02	16.4679	62215.4
7	66.6	69.6	66340	4024.39	4028.47	16.4678	62214.9
8	72.0	69.4	66240	4017.11	4021.19	16.4727	62233.7
AVE:	70.3	69.5				AVERAGE:	62208.8

* SEE APP. F

$Z = X/Y$

$A_x = Z \times W$

W = 3777.98 g/US GAL

NOTE: The weight of 1 US gallon of water (W) in air, at a given water temperature ($T_{W_{AVE}}$), is obtained from development in Appendix G.

FTI CALIBRATOR CONSTANT DETERMINATION SHEET

S2

DATA - NRC METHOD 1

NRC/DME Engine Laboratory Job No.: C87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ±0.02 g

Weight Set:

TEST	T_r °F	T_w °F	#MT/OT Pulses (x)	Mass g		MT/OT Pulses/g (Z)	MT/OT Pulses/gal. (A_x)
				as weighed	* corrected for buoyancy Y		
1	68.1	69.0	66214	4018.96	4023.11	16.4584	62184.8
2	72.4	68.6	66099	4011.38	4015.52	16.4609	62194.2
3	67.4	68.9	66208	4016.95	4021.10	16.4651	62210.3
4	72.5	68.6	66172	4014.90	4019.04	16.4646	62208.3
5	66.4	68.9	66228	4018.27	4022.42	16.4647	62208.7
6	72.5	68.7	66148	4012.93	4017.07	16.4667	62216.3
7	67.1	68.9	66173	4014.43	4018.57	16.4668	62216.5
8	71.8	68.6	66197	4014.68	4018.82	16.4717	62235.2
*(9)	(70.5)	(69.0)	(58355)	(3536.79)	(3540.44)	(16.4824)	(62275.5)
AVE.:	69.8	68.8				AVERAGE:	62209.3

* SEE APP. F

$Z = X/Y$ W = 3778.30 g/US GAL $A_x = Z \times W$

NOTE: The weight of 1 US gallon of water (W) in air, at a given water temperature ($T_{W_{AVE}}$), is obtained from development in Appendix G.

S3

FTI CALIBRATOR CONSTANT DETERMINATION DATA SHEET
(Calibrators with Translators)

CORRECTION TO STANDARD CONDITIONS

Customer: NATIONAL RESEARCH COUNCIL CANADA Job No: C87-3

Model No: OT 150 Serial No: MT 83110022 Date: 31/3/87

- -

Certified Test Measure Data:

Identification No:__________ Certified Vol.(V)__________ ☐ liter ☐ gallon

Certification temp (T_c)______°F Cubical expansion coeff(γ_m)__________/°F

Volume Draw data (using distilled water):

Run No. (x)	MT/OT Pulses (A_x)	Water Temp (T_x) °F	Note: Maximum variation of A_x and T_x as follows:
1			$\frac{A_{Max} - A_{Min}}{A\ avg.} \times 100 \le 0.1$ (%)
2			$T_{Max} - T_{Min} \le 1°F$
3			
4			
5			

T_d= 70.3 °F = translator temp(room temp.).

P = 8 psig=Volume draw pressure (operate pressure).

T_w= 69.5 °F = $\frac{T_1 + T_2 + \cdots . T_5}{5}$ = Avg. temp of draw water and flow tube.

A = 62208.8 = $\frac{A_1 + A_2 + \cdot \cdot \cdot A_5}{5}$ = Average MT/OT pulses collected/US gallon.

C_{tm}= N/A = $1+(T_w-T_c)\gamma_m$=correction for thermal expansion of the test measure.

F = 0.0000032/psig = compressibility factor for water.

C_{p1}= 1.000026 = $\frac{1}{1-PF}$ = Correction for compressibility of the water.

T_s = 68 °F=Temperature Standard (usually 68°F).

β_p= 19.2×10^{-6}/°F ✓(304 SST)
 = 17.8×10^{-6}/°F (316 SST) } = Coefficient of square expansion for flow tube.

C_{ts}= 1.000029 = $1 + (T_w-T_s)\beta_p$ = Correction for thermal expansion of flow tube.

α_d= 4.5×10^{-6}/°F = Coefficient of linear-expansion of translator material.

C_{td}= 1.000010 = $1 + (T_d-T_s)\alpha_d$= Correction for thermal expansion of translator.

E = $28 \times 10^{+6}$ psi = Modulus of elasticity for flow tube material (304 or 316 SST).

D = 7.749 Inch = Internal diameter of flow tube.

t = 0.438 Inch = Flow tube wall thickness.

C_{ps}= 1.000005 =$1 + \frac{PD}{Et}$ = Correction for expansion of flow tube due to pressure.

Vm = ——— ☐ lit ☐ gal = V (converted to appropriate units, 3.785412 liters=1 gallon).

$CS_u = \frac{A}{\cancel{Vm}}$ = __________ Pulses/Unit Vol. ☐ Liter ☒ Gallon uncorrected.

$CS_S = CS_u \times \frac{C_{p1} C_{ts} C_{td} C_{ps}}{C_{tm}}$ = 62213.1 Pulses/US gallon Microtrak/Omnitrak Constant (Corrected to temp T_s and 0 psig)

FTI CALIBRATOR CONSTANT DETERMINATION DATA SHEET

(Calibrators with Translators)

S4

CORRECTION TO STANDARD CONDITIONS

Customer: NATIONAL RESEARCH COUNCIL CANADA Job No: C87-4

Model No: OT 150 Serial No: MT 83110022 Date: 1/4/87

- -

Certified Test Measure Data:

Identification No:________ Certified Vol.(V)________ ☐ liter ☐ gallon

Certification temp (T_c)________°F Cubical expansion coeff(γ_m)________/°F

Volume Draw data (using distilled water):

Run No. (x)	MT/OT Pulses (A_x)	Water Temp (T_x) °F	Note: Maximum variation of A_x and T_x as follows: $\frac{A_{Max} - A_{Min}}{A\ avg.} \times 100 \leq 0.1$ (%) $T_{Max} - T_{Min} \leq 1$°F
1			
2			
3			
4			
5			

T_d= 69.8 °F = translator temp(room temp.).

P = 8 psig=Volume draw pressure (operate pressure).

T_w= 68.8°F = $\frac{T_1 + T_2 + \cdots\ T_5}{5}$ = Avg. temp of draw water and flow tube.

A = 62209.3 = $\frac{A_1 + A_2 + \cdots A_5}{5}$ = Average MT/OT pulses collected/US gallon.

C_{tm}= N/A = $1+(T_w-T_c)\gamma_m$=correction for thermal expansion of the test measure.

F = 0.0000032/psig = compressibility factor for water.

C_{p1}= 1.000026 = $\frac{1}{1-PF}$ = Correction for compressibility of the water.

T_s = 68 °F=Temperature Standard (usually 68°F).

β_p= 19.2 x 10^{-6}/°F (304 SST) = Coefficient of square expansion for flow tube.
= 17.8 x 10^{-6}/°F (316 SST)

C_{ts}= 1.000015 = $1 + (T_w-T_s)\beta_p$ = Correction for thermal expansion of flow tube.

α_d= 4.5 x 10^{-6}/°F = Coefficient of linear-expansion of translator material.

C_{td}= 1.000008 = $1 + (T_d-T_s)\alpha_d$= Correction for thermal expansion of translator.

E = 28 x 10^{+6} psi = Modulus of elasticity for flow tube material (304 or 316 SST).

D = 7.749 Inch = Internal diameter of flow tube.

t = 0.438 Inch = Flow tube wall thickness.

C_{ps}= 1.000005 =$1 + \frac{PD}{Et}$ = Correction for expansion of flow tube due to pressure.

Vm = ________ ☐ lit ☐ gal = V (converted to appropriate units, 3.785412 liters=1 gallon).

$CS_u = \frac{A}{Vm}$ = ________ Pulses/Unit Vol. ☐ Liter ☒ Gallon uncorrected.

$CS_S = CS_u \times \frac{C_{p1}C_{ts}C_{td}C_{ps}}{C_{tm}}$ = 62212.7 Pulses/US gallon Microtrak/Omnitrak Constant (Corrected to temp T_s and 0 psig)

S5

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                          VOLUME CONSTANT DETERMINATION

NATIONAL RESEARCH COUNCIL CANADA                            DATE: 04-09-1987
================================================================================
FLOW TECHNOLOGY CALIBRATOR                                  GRAVIMETRIC METHOD

MODEL NUMBER OT15             Test No. C87-3                SERIAL NUMBER 83110022
================================================================================
 RUN   TRANSLATOR   WATER          AIR       WATER DRAW   WEIGHT     PULSES PER
NUMBER   PULSES   TEMPERATURE  TEMPERATURE    PRESSURE   (GRAMS)    KG APPARENT
================================================================================
 1       66056      69.7          71.5           8        4009.06     16476.7
 2       66152      69.4          72.5           8        4014.32     16479.0
 3       66121      69.5          67.4           8        4011.47     16483.0
 4       66128      69.5          72.9           8        4011.98     16482.6
 5       66229      69.5          67.8           8        4018.01     16483.0
 6       66152      69.4          72.1           8        4012.95     16484.6
 7       66340      69.6          66.6           8        4024.39     16484.5
 8       66240      69.4          72.0           8        4017.11     16489.5
         ------     ----          ----          --                    -------
         66177      69.5          70.3           8        4014.91     16482.9
================================================================================

    FLOW TUBE MATERIAL ----------------304 STAINLESS STEEL
    FLOW TUBE I.D.--------------------- 7.75  INCHES
    FLOW TUBE WALL THICKNESS----------- .4375  INCHES

    BAROMETRIC PRESSURE 28.9 INCHES Hg.(734.1 MM Hg.)  RELATIVE HUMIDITY 50%
    AIR DENSITY .00115  g/cm^3   WATER DENSITY .998033 g/cm^3
    STANDARD WEIGHTS DENSITY 7.8  g/cm^3
    BALANCE CALIBRATION FACTOR  0.999853

                 0.999853 X 4014.91                       mass of water
 mass     = ----------------------            volume   = -------------
of water       1 -(.00115/.998033)            of water       .998033


Cp1 =  CORRECTION FOR COMPRESSIBILITY OF WATER 1.000026

Cts =  CORRECTION FOR THERMAL EXPANSION OF THE FLOW TUBE 1.000029

Ctd =  CORRECTION FOR THERMAL EXPANSION OF TRANSLATOR 1.000011

Cps =  CORRECTION FOR EXPANSION OF FLOW TUBE-PRESSURE 1.000005

          pulses x Cp1 x Cts x Ctd x Cps
Css =  ------------------------------------
                 vol / 3785.412

Css =     62213.5 PULSES PER U.S. GALLON AT  68 DEGREES F AND 0 PSIG
  r =     16435.1 PULSES PER LITER AT 20 DEGREES C AND 0 PSIG

================================================================================
TRACEABILITY OF MASS STANDARDS:
INVENTORY NO._______________   NBS NO._______________

CALIBRATED BY________________                        APPROVED BY _____________
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S6

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                        VOLUME CONSTANT DETERMINATION

NATIONAL RESEARCH COUNCIL CANADA                         DATE: 04-07-1987
==============================================================================
FLOW TECHNOLOGY CALIBRATOR                               GRAVIMETRIC METHOD

MODEL NUMBER OT15            Test No. C87-4              SERIAL NUMBER 83110022
==============================================================================
 RUN   TRANSLATOR   WATER          AIR       WATER DRAW   WEIGHT    PULSES PER
NUMBER   PULSES   TEMPERATURE  TEMPERATURE    PRESSURE   (GRAMS)    KG APPARENT
==============================================================================
 1        66214      69.0          68.1           8       4018.96     16475.4
 2        66099      68.6          72.4           8       4011.38     16477.9
 3        66208      68.9          67.4           8       4016.95     16482.2
 4        66172      68.6          72.5           8       4014.90     16481.6
 5        66228      68.9          66.4           8       4018.27     16481.7
 6        66148      68.7          72.5           8       4012.93     16483.7
 7        66173      68.9          67.1           8       4014.43     16483.8
 8        66197      68.6          71.8           8       4014.68     16488.7
        ------       ----          ----          --                   ------
          66180      68.8          69.8           8       4015.31     16481.9
==============================================================================

    FLOW TUBE MATERIAL ----------------304 STAINLESS STEEL
    FLOW TUBE I.D.--------------------- 7.75  INCHES
    FLOW TUBE WALL THICKNESS----------- .4375  INCHES

    BAROMETRIC PRESSURE 29.6 INCHES Hg.(751.8 MM Hg.)  RELATIVE HUMIDITY 50%
    AIR DENSITY .00119  g/cm^3   WATER DENSITY .998118 g/cm^3
    STANDARD WEIGHTS DENSITY 7.8  g/cm^3
    BALANCE CALIBRATION FACTOR  0.999847

                0.999847 X 4015.31                        mass of water
 mass     =  ---------------------           volume   =  -------------
of water       1 -(.00119/.998118)          of water        .998118


Cp1 =  CORRECTION FOR COMPRESSIBILITY OF WATER 1.000026

Cts =  CORRECTION FOR THERMAL EXPANSION OF THE FLOW TUBE 1.000015

Ctd =  CORRECTION FOR THERMAL EXPANSION OF TRANSLATOR 1.000008

Cps =  CORRECTION FOR EXPANSION OF FLOW TUBE-PRESSURE 1.000005

         pulses x Cp1 x Cts x Ctd x Cps
Css =  --------------------------------------
                 vol / 3785.412


Css =    62211.8 PULSES PER U.S. GALLON AT  68 DEGREES F AND 0 PSIG
  r =    16434.6 PULSES PER LITER AT 20 DEGREES C AND 0 PSIG

==============================================================================
TRACEABILITY OF MASS STANDARDS:
INVENTORY NO._______________   NBS NO._________________

CALIBRATED BY___________________                     APPROVED BY ______________
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S7

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87 -3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg – 10 mg

TEST : 1

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4009.06	2000	2000.01			
	2000	2000.00			
	5	5,0000			
	3	3,00001			
	1	1,00002			
	0.05	0,05000			
4009.06	4009.05	4009.06003	+0.00003	0,00000	TOTAL

S8

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2kg - 10mg

TEST : 2

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4014.32	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	3	3.00001			
	1	1.00002			
	0.3	0.30000			
	0.02	0.01999			
4014.32	4014.32	4014.33012	+ 0.01012	+0.00025	TOTAL

S9

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0,02 g

Weight Set: Troemner 2kg - 10mg

TEST: 3

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4011.47	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	1	1.00002			
	0.3	0.30000			
	0.1	0.10000			
	0.05	0.05000			
	0.02	0.01999			
4011.47	4011.47	4011.48011	+ 0.01011	+0,00025	TOTAL

S10

TRUEMASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius ES500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02

Weight Set: Troemner 2 kg - 10 mg

Test : 4

BALANCE INDICATION OF WATER DRAW g	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION g	TRUE MASS OF WEIGHTS g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
			g	%	
4011.98	2000	2000.01			
	2000	2000.00			
	10	10,0001			
	1	1.00002			
	0.5	0.49997			
	0.3	0.30000			
	0.1	0.10000			
	0.05	0.05000			
	0.02	0.01999			
	0.01	0.00998			
4011.98	4011.98	4011.99006	+ 0.01006	+0.00025	TOTAL

S11

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E 5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02

Weight Set: Troemner 2 kg - 10 mg

TEST: 5

BALANCE INDICATION OF WATER DRAW g	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION g	TRUE MASS OF WEIGHTS g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
			g	%	
4018.01	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	5	5.0000			
	3	3.00001			
	0.01	0.00998			
4018.01	4018.01	4018.02009	0.01009	0.00025	TOTAL

S12

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: SARTORIUS E5500S S/N: 36100090

Range: 5500 g Accuracy: ± 0,02g

Weight Set: Troemner 2 kg - 10 mg

TEST : 6

BALANCE INDICATION OF WATER DRAW g	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION g	TRUE MASS OF WEIGHTS g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION %	
4012,95	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	2	2,00001			
	0.5	0,49997			
	0.3	0.30000			
	0.1	0.10000			
	0.05	0.05000			
4012,95	4012.95	4012,96008	+0,01008	+0.00025	TOTAL

TRUE MASS DETERMINATION OF WATER DRAWS (NOT CORRECTED FOR BUOYANCY)

S13

NRC/DME Engine Laboratory Job No.: C87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST 17

BALANCE INDICATION OF WATER DRAW g	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION g	TRUE MASS OF WEIGHTS g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
			g	%	
4024.39	2000	2000.01			
	2000	2000.00			
	20	20.0001			
	3	3.00001			
	1	1.00002			
	0.3	0.30000			
	0.05	0.05000			
	0.03	0.03001			
4024.39	4024.380	4024.39014	+ 0.00014	+0.00000	TOTAL

TRUE MASS DETERMINATION OF WATER DRAWS (NOT CORRECTED FOR BUOYANCY)

S14

NRC/DME Engine Laboratory Job No.: C 87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E 5500 S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10mg

TEST : 8

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4017.11	2000	2000.01			
	2000	2000.00			
	10	10,0001			
	5	5,0000			
	2	2,00001			
	0,1	0.10000			
	0,01	0,00998			
4017.11	4017,11	4017.12009	+0.01009	+0.00025	TOTAL

TRUE MASS DETERMINATION OF WATER DRAWS (NOT CORRECTED FOR BUOYANCY)

S15

NRC/DME Engine Laboratory Job No.: C 87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ±0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST : 1

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4018.96	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	5	5.0000			
	3	3.00001			
	0.5	0.49997			
	0.3	0.30000			
	0.1	0.10000			
	0.05	0.05000			
	0.01	0.00998			
4018.96	4018.96	4018.97006	+0.01006	+0.00025	TOTAL

S16

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory

Job No.: C 87-4

Model No.: OT 150

Serial No.: MT 83110022

Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g

Accuracy: ± 0.02g

Weight Set: Troemner 2 kg - 10 mg

TEST : 2

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4011.38	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	1	1.00002			
	0.3	0.30000			
	0.05	0.05000			
	0.03	0.03001			
4011.38	4011.38	4011.39013	+ 0.01013	+ 0.00025	TOTAL

S17

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST : 3

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4016.95	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	5	5.0000			
	1	1.00002			
	0.5	0.49997			
	0.3	0.30000			
	0.1	0.10000			
	0.05	0.05000			
4016.95	4016.95	4016.96009	+ 0.01009	0.00025	TOTAL

S18

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST : 4

BALANCE INDICATION OF WATER DRAW g	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION g	TRUE MASS OF WEIGHTS g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
			g	%	
4014.90	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	3	3.00001			
	1	1.00002			
	0.5	0.49997			
	0.3	0.30000			
	0.1	0.10000			
4014.90	4014.90	4014.91010	+0.01010	+0.00025	TOTAL

S19

TRUE MASS DETERMINATION OF WATER DRAWS
(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

Test : 5

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4018.27	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	5	5.0000			
	3	3.00001			
	0.2	0.19998			
	0.05	0.05000			
	0.02	0.01999			
4018.27	4018.27	4018.28008	+0.01008	+0.00025	TOTAL

TRUE MASS DETERMINATION OF WATER DRAWS (NOT CORRECTED FOR BUOYANCY)

S20

NRC/DME Engine Laboratory

Job No.: C87-4

Model No.: OT 150

Serial No.: MT 83110022

Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g

Accuracy: ±0.02g

Weight Set: Troemner 2 kg - 10 mg

TEST : 6

BALANCE INDICATION OF WATER DRAW g	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION g	TRUE MASS OF WEIGHTS g	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
			g	%	
4012.93	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	2	2.00001			
	0.5	0.49997			
	0.3	0.30000			
	0.1	0.10000			
	0.03	0.03001			
4012.93	4012.93	4012.94009	+0.01009	+0.00025	TOTAL

TRUE MASS DETERMINATION OF WATER DRAWS

S21

(NOT CORRECTED FOR BUOYANCY)

NRC/DME Engine Laboratory Job No.: C 87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0,02 g

Weight Set: Troemner 2 kg - 10 mg

TEST : 7

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4014,43	2000	2000.01			
	2000	2000,00			
	10	10,0001			
	3	3,00001			
	1	1,00002			
	0,3	0,30000			
	0,1	0,10000			
	0.03	0.03001			
4014,43	4014,43	4014.44005	+0,01005	+0,00025	TOTAL

TRUE MASS DETERMINATION OF WATER DRAWS (NOT CORRECTED FOR BUOYANCY)

S22

NRC/DME Engine Laboratory Job No.: C 87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E 5500 S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST : 8

BALANCE INDICATION OF WATER DRAW	WEIGHTS USED FOR DUPLICATING BALANCE INDICATION	TRUE MASS OF WEIGHTS	DIFFERENCE BETWEEN TRUE MASS AND BALANCE INDICATION		
g	g	g	g	%	
4014.68	2000	2000.01			
	2000	2000.00			
	10	10.0001			
	3	3.00001			
	1	1.00002			
	0.5	0.49997			
	0.1	0.10000			
	0.05	0.05000			
	0.03	0.03001			
4014.68	4014.68	4014.69011	+0.01011	+0.00025	TOTAL

S23

FTI CALIBRATOR CONSTANT DETERMINATION SHEET

DATA - NRC METHOD 2

NRC/DME Engine Laboratory Job No.: C 87-3

Model No.: OT 150 Serial No.: MT 83110022 Date: 31/3/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST	T_W AVE °F / T_r AVE °F	#MT/OT Pulses (x)	Mass g			MT/OT Pulses/g (Z)	MT/OT Pulses/gal. (A_x)
			as indicated by balance	from calibrated weights	* corrected for buoyancy Y		
1	69.5	66056	4009.06	4009.0600	4013.1282	16.45998	62185.47
2	70.3	66152	4014.32	4014.3301	4018.4036	16.46226	62194.08
3		66121	4011.47	4011.4801	4015.5507	16.46623	62209.10
4		66128	4011.98	4011.9901	4016.0612	16.46588	62207.78
5		66229	4018.01	4018.0201	4022.0973	16.46628	62209.29
6		66152	4012.95	4012.9601	4017.0322	16.46788	62215.32
7		66340	4024.39	4024.3901	4028.4738	16.46777	62214.92
8		66240	4017.11	4017.1201	4021.1964	16.47271	62233.57
						AVERAGE:	62208.69

$Z = X/Y$ * SEE APP. F $A_x = Z \times W$

W = 3777.98 g/US GAL.

NOTE: The weight of 1 US gallon of water (W) in air, at a given water temperature ($T_{W_{AVE}}$), is obtained from development in Appendix G

FTI CALIBRATOR CONSTANT DETERMINATION SHEET

S24

DATA - NRC METHOD 2

NRC/DME Engine Laboratory Job No.: C 87-4

Model No.: OT 150 Serial No.: MT 83110022 Date: 1/4/87

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Sartorius E5500S S/N: 36 100 090

Range: 5500 g Accuracy: ± 0.02 g

Weight Set: Troemner 2 kg - 10 mg

TEST	T_{W} AVE °F T_{r} AVE °F	#MT/OT Pulses (x)	Mass g			MT/OT Pulses/g (Z)	MT/OT Pulses/gal. (A_x)
			as indicated by balance	from calibrated weights	corrected * for buoyancy Y		
1	68.8	66214	4018.96	4018.9701	4023.1183	16.45838	62184.72
2	69.8	66099	4011.38	4011.3901	4015.5305	16.46084	62194.02
3		66208	4016.95	4016.9601	4021.1062	16.46512	62210.20
4		66172	4014.90	4014.9101	4019.0541	16.46457	62208.12
5		66228	4018.27	4018.2801	4022.4276	16.46468	62208.55
6		66148	4012.93	4012.9401	4017.0821	16.46668	62216.08
7		66173	4014.43	4014.4400	4018.5835	16.46675	62216.34
8		66197	4014.68	4014.6901	4018.8339	16.47169	62235.03
						AVERAGE:	62209.13

* SEE APP. F

$Z = X/Y$ $A_x = Z \times W$

W = 3778.30 g/US GAL.

NOTE: The weight of 1 US gallon of water (W) in air, at a given water temperature ($T_{W_{AVE}}$), is obtained from development in Appendix G

S25

FTI CALIBRATOR CONSTANT DETERMINATION DATA SHEET

(Calibrators with Translators)

CORRECTION TO STANDARD CONDITIONS

Customer: NATIONAL RESEARCH COUNCIL CANADA Job No: C87-3

Model No: OT 150 Serial No: MT 83 11 00 22 Date: 31/3/87

Certified Test Measure Data:

Identification No: ______ Certified Vol.(V) ______ ☐ liter ☐ gallon

Certification temp (T_c) ______ °F Cubical expansion coeff(γ_m) ______ /°F

Volume Draw data (using distilled water):

Run No. (x)	MT/OT Pulses (A_x)	Water Temp (T_x) °F	Note:
1			Maximum variation of A_x and T_x as follows: $\frac{A_{Max} - A_{Min}}{A\ avg.} \times 100 \le 0.1$ (%) $T_{Max} - T_{Min} \le 1$°F
2			
3			
4			
5			

T_d = 70.3 °F = translator temp(room temp.).

P = 8 psig=Volume draw pressure (operate pressure).

T_w = 69.5 °F = $\frac{T_1 + T_2 + \ldots\ T_5}{5}$ = Avg. temp of draw water and flow tube.

A = 62208.69 = $\frac{A_1 + A_2 + \cdot \cdot \cdot\ A_5}{5}$ = Average MT/OT pulses collected/US gallon.

C_{tm} = N/A = $1+(T_w-T_c)\gamma_m$=correction for thermal expansion of the test measure.

F = 0.0000032/psig = compressibility factor for water.

C_{p1} = 1.000026 = $\frac{1}{1-PF}$ = Correction for compressibility of the water.

T_s = 68 °F=Temperature Standard (usually 68°F).

β_p = 19.2 x 10^{-6}/°F ✓(304 SST)
= 17.8 x 10^{-6}/°F (316 SST) = Coefficient of square expansion for flow tube.

C_{ts} = 1.000029 = $1 + (T_w-T_s)\beta_p$ = Correction for thermal expansion of flow tube.

α_d = 4.5 x 10^{-6}/°F = Coefficient of linear-expansion of translator material.

C_{td} = 1.000010 = $1 + (T_d-T_s)\alpha_d$ = Correction for thermal expansion of translator.

E = 28 x 10^{+6} psi = Modulus of elasticity for flow tube material (304 or 316 SST).

D = 7.749 Inch = Internal diameter of flow tube.

t = 0.438 Inch = Flow tube wall thickness.

C_{ps} = 1.000005 = $1 + \frac{PD}{Et}$ = Correction for expansion of flow tube due to pressure.

Vm = ______ ☐ lit ☐ gal = V (converted to appropriate units, 3.785412 liters=1 gallon).

$CS_u = \frac{A}{\cancel{Vm}}$ = ______ Pulses/Unit Vol. ☐ Liter ☒ Gallon uncorrected.

$CS_S = CS_u \times \frac{C_{p1}C_{ts}C_{td}C_{ps}}{C_{tm}}$ = 62213.0 Pulses/US gallon Microtrak/Omnitrak Constant (Corrected to temp T_s and 0 psig)

S26

FTI CALIBRATOR CONSTANT DETERMINATION DATA SHEET

(Calibrators with Translators)

CORRECTION TO STANDARD CONDITIONS

Customer: NATIONAL RESEARCH COUNCIL CANADA Job No: C87-4

Model No: OT150 Serial No: MT 83110022 Date: 1/4/87

- -

Certified Test Measure Data:

Identification No: ________ Certified Vol.(V) ________ ☐ liter ☐ gallon

Certification temp (T_c) ________ °F Cubical expansion coeff(γ_m) ________ /°F

Volume Draw data (using distilled water):

Run No. (x)	MT/OT Pulses (A_x)	Water Temp (T_x) °F	Note: Maximum variation of A_x and T_x as follows:
1			$\frac{A_{Max} - A_{Min}}{A\ avg.} \times 100 \le 0.1$ (%)
2			$T_{Max} - T_{Min} \le 1$°F
3			
4			
5			

T_d = 69.8 °F = translator temp(room temp.).

P = 8 psig=Volume draw pressure (operate pressure).

T_w = 68.8 °F = $\frac{T_1 + T_2 + \cdots T_5}{5}$ = Avg. temp of draw water and flow tube.

A = 62209.13 = $\frac{A_1 + A_2 + \cdots A_5}{5}$ = Average MT/OT pulses collected/US gallon.

C_{tm} = N/A = $1+(T_w-T_c)\gamma_m$=correction for thermal expansion of the test measure.

F = 0.0000032/psig = compressibility factor for water.

C_{p1} = 1.000026 = $\frac{1}{1-PF}$ = Correction for compressibility of the water.

T_s = 68 °F=Temperature Standard (usually 68°F).

$\beta_p = 19.2 \times 10^{-6}$/°F ✓ (304 SST) = Coefficient of square expansion for flow tube.

$= 17.8 \times 10^{-6}$/°F (316 SST)

C_{ts} = 1.000015 = $1 + (T_w-T_s)\beta_p$ = Correction for thermal expansion of flow tube.

$\alpha_d = 4.5 \times 10^{-6}$/°F = Coefficient of linear-expansion of translator material.

C_{td} = 1.000008 = $1 + (T_d-T_s)\alpha_d$ = Correction for thermal expansion of translator.

E = $28 \times 10^{+6}$ psi = Modulus of elasticity for flow tube material (304 or 316 SST).

D = 7.749 Inch = Internal diameter of flow tube.

t = 0.438 Inch = Flow tube wall thickness.

C_{ps} = 1.000005 = $1 + \frac{PD}{Et}$ = Correction for expansion of flow tube due to pressure.

Vm = ________ ☐ lit ☐ gal = V (converted to appropriate units, 3.785412 liters=1 gallon).

$CS_u = \frac{A}{\cancel{Vm}}$ = ________ Pulses/Unit Vol. ☐ Liter ☒ Gallon uncorrected.

$CS_S = CS_u \times \frac{C_{p1}C_{ts}C_{td}C_{ps}}{C_{tm}}$ = 62212.5 Pulses/US gallon Microtrak/Omnitrak Constant (Corrected to temp T_s and 0 psig)

APPENDIX A

FTI OMNITRAK ACCEPTANCE TEST AND CALIBRATION

APPENDIX A: FTI OMNITRAK ACCEPTANCE TEST AND CALIBRATION

Title: CALIBRATOR ACCEPTANCE TEST (w/Translator)	**Flow Technology, Inc.**		
Prepared by: Tom Blankenship			Operating Procedures
Approved by: Walter Wunsch			OPN: 20-03A
Approved by: Cecil Cole	**Date:** Jan. 1983		**Page** 1 **of** 4

1. PURPOSE: TO ESTABLISH A STANDARD ACCEPTANCE TEST FOR FTI CALIBRATOR SYSTEMS.

2. CRITERIA:

Each Calibrator shall meet the following criteria:

a. Satisfactorily withstand, without leaks or distortion, a hydrostatic pressure test of 250 PSIG for 30 minutes. Acceptance certification is documented per page 2. Refer to Flow Technology Operating Procedure 20-01.

b. Establish a Calibrator constant (pulse/unit volume) with ±.05% repeatability using water. Data and calculations are shown on Page 3. Acceptance certification is documented per Page 2. Refer to Calibration Procedure in the Calibrator Manual.

c. Satisfactorily demonstrate a meter factor repeatability to within ±.05% based on 5 runs for each flow rate. Three flow rates shall be used (Lower, Middle, and Upper end of the flow range of the Calibrator). Data is recorded on Page 4. Acceptance certification is documented per Page 2. Refer to operating instructions in the Calibrator manual.

3. CONDUCT AND WITNESS OF TEST:

a. Each of the tests (pressure, volume and constant) will be conducted by the Project Engineer and/or a Mechanical Technician and witnessed and certified by the Quality Assurance Manager or his designated representative.

b. If a Source Inspection is specified in the Purchase Contract, the Source Inspector will also sign each certificate.

REVISIONS

No.	Revised by:	Date	No.	Revised by:	Date	No.	Revised by:	Date
1	Ron Jackson	9/30/83						

OPN 20-03A
2 of 4

CALIBRATOR PERFORMANCE CERTIFICATE

Customer: Fielding Crossman & Associates Ltd Job No: 20750 E

Model No: OT 150 Serial No: MT 83110022 Date: 12/28/83

We Hereby Certify the above mentioned Calibrator has been Pressure tested in accordance with FTI Specifications:

Tested To: 275 PSIG

Duration: 30 Minutes

We Hereby Certify the above mentioned equipment was calibrated on the date indicated, using a certified test measure traceable to NBS, at atmospheric pressure and 68 °F. **The Calibrator Constant was determined to be:** 62202

We Hereby Certify the above mentioned Calibrator was performance tested and demonstrated proper functioning under actual operating conditions.

Five (5) runs at three (3) selected flowrates were used:

1) 180 GPM with ± .014% Repeatability,
2) 54 GPM with ± .010% Repeatability,
3) 0.21 GPM with ± .043% Repeatability,

Operator Alfred J. Friedevich Date 12-28-83

Quality Assurance Date 12-28-83

Source Inspector N/A Date

OPN 20-03A
3 of 4

FTI CALIBRATOR CONSTANT DETERMINATION DATA SHEET
(Calibrators with Translators)

Customer: Fielding Crossman & Associates LTD Job No: 20750 E

Model No: OT 150 Serial No: MT 83110022 Date: 12/28/83

- -

Certified Test Measure Data:

Identification No: N/A Accuracy ± ____ % Certified Volume (V) ________ ☐ liter ☐ gallon

Certification temp (T_c) ____ °F Cubical expansion coeff(γ_m) ________________ /°F

Volume Draw data (using distilled water):

Run No. (x)	MT/OT Pulses (A_x)	Water Temp (T_x) °F	Note: Maximum variation of A_x and T_x as follows: $\frac{A_{Max} - A_{Min}}{A\ avg.} \times 100 \le 0.1$ (%) $T_{Max} - T_{Min} \le 1$°F
1			
2			
3			
4			
5			

T_d = 70 °F = translator temp(room temp.).

P = 10 psig=Volume draw pressure (operate pressure).

T_w = 69 °F = $\frac{T_1 + T_2 + \cdots\ T_5}{5}$ = Avg. temp of draw water and flow tube.

A = 62197.918 = $\frac{A_1 + A_2 + \cdots\ A_5}{5}$ = Average MT/OT pulses collected.

C_{tm} = N/A = $1+(T_w-T_c)\gamma_m$ = correction for thermal expansion of the test measure.

F = 0.0000032/psig = compressibility factor for water.

C_{p1} = 1.000032 = $\frac{1}{1-PF}$ = Correction for compressibility of the water.

T_s = 68 °F=Temperature Standard (usually 68°F).

β_p = 19.2×10^{-6}/°F* (304 SST)
= 17.8×10^{-6}/°F (316 SST) } = Coefficient of square expansion for flow tube.

C_{ts} = 1.0000192 = $1 + (T_w - T_s)\beta_p$ = Correction for thermal expansion of flow tube.

α_d = 4.5×10^{-6}/°F = Coefficient of linear-expansion of translator material.

C_{td} = 1.000009 = $1 + (T_d - T_s)\alpha_d$ = Correction for thermal expansion of translator.

E = $28 \times 10^{\overset{+6}{\boxed{-6}}}$ psi = Modulus of elasticity for flow tube material (304 or 316 SST).

D = 7.749 Inch = Internal diameter of flow tube.

t = .438 Inch = Flow tube wall thickness.

C_{ps} = 1.0000063 = $1 + \frac{PD}{Et}$ = Correction for expansion of flow tube due to pressure.

Vm = 1.0000 ☐ lit ☐ gal = V (converted to appropriate units, 3.785412 liters=1 gallon).

$CS_u = \frac{A}{V_m}$ = 62197.918 Pulses/Unit Vol. ☐ Liter ☒ Gallon uncorrected.

$CS_S = CS_u \times \frac{C_{p1} C_{ts} C_{td} C_{ps}}{C_{tm}}$ = 62202. Pulses/ gallon Microtrak/Omnitrak Constant
(Corrected to temp T_s and 0 psig)

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ADDENDUM
to
F T I Calibrator Constant Determination Sheet

Customer: Fielding Crossman & Associates LTD Job No: 20750 E

Model No: OT 150 Serial No: MT 83110022 Date: 12/28/83

Volume collected during "water draw" determined by mass measurement.

Balance: Make & Model: Arbor 7506 S/N 50422 (FTI)

Range: 7500 gm Accuracy: ± .01 gm

Weight Set: Class P FTI # 50307

Data:

	T_w °F	#MT/OT Pulses (X)	Mass gm (Y)	MT/OT Pulse/gm (Z)	MT/OT Pulse/gal. (A_x)
1	69	61657	3742.11	16.476533 ✓	62186.357
2	69	61912	3757.37	16.477483	62189.942
3	69	62010	3763.11	16.478392	62193.373
4	69	61954	3759.16	16.48081	62202.499
	69	61911	3755.65	16.484763	62217.419

$Z = X/Y$ $A_x = Z \times W$

(US)

Weight of 1 gallon of water in air at various temperatures:

T_w		(W)	T_w		(W)
°C	°F	Weight gm	°C	°F	Weight gm
20	68	3774.630	26	78.8	3769.341
20.5	68.9	3774.238	26.5	79.7	3768.835
21	69.8	3773.845	27	80.6	3768.329
21.5	70.7	3773.433	27.5	81.5	3767.806
22	71.6	3773.021	28	82.4	3767.283
22.5	72.5	3772.589	28.5	83.3	3766.742
23	73.4	3772.157	29	84.2	3766.201
23.5	74.3	3771.707	29.5	85.1	3765.644
24	75.2	3771.256	30.0	86.0	3765.086
24.5	76.1	3770.787	30.5	86.9	3764.512
25	77.0	3770.317	31.0	87.8	3763.938
25.5	77.9	3769.816	31.5	88.7	3763.348

CALIBRATOR PERFORMANCE DATA SHEET

OPN 20-03A
4 of 4

Customer: Fielding Crossman & Associates LTD Job No: 20750 E

Model No: OT 150 Serial No: MT 83110022 Date: 12/28/83

Calibration Fluid: Distilled Water Specific Gravity N/A Viscosity N/A cks

RUN NO.	FREQ (HERTZ)	FLOW RATE	"K" PULSES/GAL	A SEC T VOL	B SEC T FMP	C # FMP	VOLUME

Flow Meter Model No: Serial No: Size:

Pickoff Model No: Type

1							
2		Refer to attached data sheets.					
3							
4							
5							

Flow Meter Model No: Serial No: Size:

Pickoff Model No: Type:

6							
7							
8							
9							
10							

Flow Meter Model No: Serial No: Size:

Pickoff Model No: Type:

11							
12							
13							
14							
15							

A = Volume (D) Displacement Time in Sec.
B = Exact Period For Pulses (C) in Sec.
C = Whole Pulses Generated During (D) Displacement
D = Displacement Volume Selected in Gallons

Hertz = $\frac{C}{B}$ GPM = $\frac{D}{A}$ 60 Gallon/Minute "K" = $\frac{C \times A}{D \times B}$ Pulses/Gallon

CALIBRATION BY: Alfred J Friedrich Q.A.

CALIBRATION DATE: 12/29/83

FLOW TECHNOLOGY INC.
FLOWMETER
DATA SHEET

CUSTOMER: FIELDING.CROSSMAN & ASSOCIATES LTD. JOB: ....20750 E.....

Model #: ..FT-24-LJC..... Flowmeter size: 1½... Serial #: ...N/A...

Pickoff Type: ....Mag.... Pickoff P/N: 30880...... Bearing Type: Journal Graphite

Calibration fluid: ...Distilled Water Fluid Viscosity: ....N/A.........

Specific Gravity: ....N/A.. Temp.: ..70°F... Calibration Date: Dec. 29, 83

Microtrak Constant: ...62202 pulse/gal........ Units: .....GPM......

FREQ	F RATE	K	T VOL	T FMP	# FMP	# MTFUL	VOL
1595.4	172.4	555.16	000.6959	000.6963	001111	0124404	2.0
1668.0	180.2	555.16	000.6656	000.6654	001110	0124404	2.0
1657.1	179.0	555.28	000.6701	000.6704	001111	0124404	2.0
1626.4	175.7	555.31	000.6828	000.6824	001110	0124404	2.0
1633.9	176.5	555.30	000.6797	000.6799	001111	0124404	2.0
8.87	53.93	555.00	002.2250	002.2250	001110	0124404	2.0
497.22	53.75	555.02	002.2325	002.2323	001110	0124404	2.0
502.36	54.30	555.04	002.2097	002.2095	001110	0124404	2.0
495.14	53.53	554.97	002.2416	002.2417	001110	0124404	2.0
494.63	53.48	554.93	002.2438	002.2440	001110	0124404	2.0

FLOW TECHNOLOGY INC.
FLOWMETER
DATA SHEET

CUSTOMER: FIELDING CROSSMAN & ASSOCIATES LTD. JOB: 20750 E

Model #: FT-6-8LB Flowmeter size: .370" Serial #: 860265

Pickoff Type: RF Pickoff P/N: 31199 Bearing Type: Ball

Calibration fluid: Distilled Water Fluid Viscosity: N/A

Specific Gravity: N/A Temp.: 70°F Calibration Date: Dec. 29, 1983

Microtrak Constant: 62202 Units: GPM

FREQ	F RATE	K	T VOL	T FMP	# FMP	# MTFUL	VOL
98.343	.2188	26961.	137.0801	137.0804	013481	0031101	0.5
98.137	.2183	26971.	137.4138	137.4085	013485	0031101	0.5
98.049	.2180	26974.	137.5564	137.5531	013487	0031101	0.5
97.869	.2176	26980.	137.8384	137.8371	013490	0031101	0.5
97.409	.2165	26984.	138.5091	138.5073	013492	0031101	0.5

APPENDIX B

CALIBRATOR OUTPUT SHEET

APPENDIX B: CALIBRATOR OUTPUT SHEET

NATIONAL RESEARCH COUNCIL CANADA
DIVISION OF MECHANICAL ENGINEERING

TURBINE FLOWMETER CALIBRATION

ustomer: NRC-ENGINE LABORATORY
Date: 12-NOV-87 Job #: 87-34

CALIBRATOR DATA

Make: Flow Technology Omnitrak Calibrator System Model: OT-150 S/N: 83110022
Microtrak Constant: 62213 Volume Unit: U.S. Gallon
Calibration Fluid: JP4 Aviation Turbine Fuel
Specific Gravity(15.56/15.56 Deg.C): 0.7527
Fluid Temperature (Average)[Deg. C]: 22.90
Viscosity [cSt] : 0.7704
Room Temperature (Average)[Deg. C]: 23.50 Operating Pressure [Psig]: 80.00

FLOWMETER DATA

Make/Model : FT-4-8A3-LB
S/N : 8403549
Pickoff P/N: 27B 31199-101
Size : 1/2 IN.
Pickoff Type: R.F.
Bearing Type: BALL

****

RUN	T VOL	T FMP	# FMP	VOL	FREQ	F RATE	Kcor	FREQ/VISC
1	2.3331	2.3336	4797.0	0.1	2055.6	2.5717	47951.	2668.1
2	2.1577	2.1577	4799.0	0.1	2224.1	2.7807	47981.	2886.8
3	2.9212	2.9214	4782.0	0.1	1636.9	2.0540	47808.	2124.6
	2.6038	2.6042	4790.0	0.1	1839.3	2.3043	47884.	2387.4
5	3.6404	3.6401	4766.0	0.1	1309.3	1.6482	47655.	1699.4
6	4.5719	4.5716	4748.0	0.1	1038.6	1.3124	47475.	1348.0
7	6.4228	6.4222	4729.0	0.1	736.35	0.93417	47286.	955.74
8	5.9561	5.9553	4731.0	0.1	794.42	1.0074	47308.	1031.1
9	8.8675	8.8675	4722.0	0.1	532.51	0.67663	47212.	691.16
10	11.588	11.587	4727.0	0.1	407.94	0.51779	47263.	529.49
11	15.905	15.905	4745.0	0.1	298.34	0.37724	47442.	387.23
12	21.265	21.267	4762.0	0.1	223.92	0.28215	47608.	290.63
13	26.005	26.003	4759.0	0.1	183.02	0.23072	47585.	237.54
14	23.874	23.873	4766.0	0.1	199.64	0.25132	47653.	259.12
15	2.1400	2.1401	4798.0	0.1	2242.0	2.8037	47969.	2909.9
16	2.1361	2.1360	4798.0	0.1	2246.3	2.8089	47974.	2915.5

T VOL=Time for Displaced Volume [Sec.]
T FMP=Time for Flowmeter Pulses [Sec.]
# FMP=Number of Flowmeter Pulses [ ]
VOL=Volume of Fluid Displaced [U.S. Gal.]
FREQ=Frequency of the Flowmeter [Pulses/Sec.]
F RATE=Flowrate [U.S. Gal./Min.]
Kcor=K-Factor of the Flowmeter Corrected to Standard Conditions [Pulses/U.S. Gal.]
FREQ/VISC=Frequency Divided by the Viscosity of the Fluid at the Temperature of the Run [Pulses/Sec.*cSt

Calibrated by:__________________ Certified by:__________________

APPENDIX C

CALIBRATION OF WEIGHTS

This appendix comprises two parts. The first contains the calibration documentation of a single 5000 g weight, purchased from the supplier of the toploading balance, which was used in the Omnitrak calibration process. The second part consists of the calibration report by the Physics Division, NRC, of the weight set acquired for the correct mass establishment of the water draws.

As the reports show, all weights were extremely accurate. The 5000 g weight was within ±0.03 g, or ±0.0006%. The Class S set from Troemner Inc., Philadelphia, PA, showed only very small deviations from the nominal values. With the exception of the three smallest weights, 10, 20 and 30 mg, which would have very little influence on any weighing anyway, deviations were less than 0.01% for all the other weights.

National Research
Council Canada

Conseil national
de recherches Canada

PHYSICS DIVISION

DIVISION DE PHYSIQUE

CALIBRATION OF A WEIGHT

AMS-020

OTTAWA

DATE April 27, 1987

REPORT NO. AMS-020
RAPPORT NO.

CALIBRATION OF A WEIGHT

for/pour
NATIONAL RESEARCH COUNCIL
MECHANICAL ENGINEERING
ATT: MR. J. CARVISH

AUTHOR D.G. KEARNEY
AUTEUR

APPROVED
APPROUVÉ for Director/pour le directeur

DESCRIPTION: One Sartorius 5000 gram weight.

The above described weight has been compared with the Standards of the National Research Council of Canada and the results of the calibration at this date are given below:

NOMINAL MASS (g)	MASS (g)	UNCERTAINTY (g)
5000	5000.03	±0.03

National Research Council Canada
Division of Physics

Conseil national de recherches Canada
Division de physique

Laboratory for Basic Standards

Laboratoire des étalons fondamentaux

Canada

The primary responsibility of the Laboratory for Basic Standards is to develop and maintain the national base for the system of measurement units used in Canada (Systeme International d'Unites: SI), and to ensure that there can be direct traceability to this national base throughout the country.

The Laboratory develops and improves primary standards and techniques for physical measurements in accordance with the evolving definitions of the SI units and improvements in technology, disseminates technical information and expertise to the Canadian measurement community, provides consultative services and makes equipment and facilities available to interested organizations.

The Laboratory maintains primary measurement capabilities for the basic physical quantities: length, mass, time, electricity, temperature, and light intensity. It also provides a first order calibration service for suitable instruments or reference standards associated with these basic quantities or with a number of derived physical quantities. Typical such derived quantities are in the fields of photometry, colorimetry, acoustics, microwaves, ionizing radiation, pressure, and various dimensional measurements.

A major interest of the Laboratory is the cooperative development and the coordination of the Systeme International d'Unites. This requires active and continuous collaboration with the Bureau International des Poids et Mesures (BIPM), certain other international organizations, and with the national standards laboratories of other industrialized countries.

La principale responsabilité du Laboratoire des étalons fondamentaux est d'élaborer et de conserver la base nationale du système d'unités de mesure employé au Canada (Système international d'unités : SI), tout en permettant de remonter directement à cette base nationale partout au pays.

Le Laboratoire prépare et améliore des étalons primaires et des techniques de mesure physiques conformément aux définitions courantes des unités SI et aux progrès de la technologie, assure la diffusion d'informations techniques et de savoir-faire au sein de la communauté métrologique canadienne, offre des services de consultation et met de l'équipement et des installations à la disposition d'organismes intéressés.

Le laboratoire conserve des modalités de mesure primaire pour les quantités physiques fondamentales : longueur, masse, temps, électricité, température et intensité lumineuse. Il offre également un service d'étalonnage de premier ordre pour des étalons de référence et des instruments appropriés associés à ces quantités fondamentales ou à des quantités physiques dérivées. Ces dernières relèvent typiquement de la photométrie, de la colorimétrie, de l'acoustique, des micro-ondes, des rayonnements ionisants, de la pression et de diverses mesures dimensionnelles.

Le Laboratoire porte un intérêt majeur à l'élaboration coopérative et à la coordination du Système international d'unités. Cela exige une collaboration active et permanente avec le Bureau International des Poids et Mesures (BIPM), avec d'autres organismes internationaux et avec les laboratoires d'etalonnage nationaux d'autres pays industrialisés.

DATE 23 February 1988

REPORT NO. AMS-078
RAPPORT NO.

CALIBRATION OF A SET OF WEIGHTS

for/pour

MR. J. CARVISH
ENGINE LAB M-7
NATIONAL RESEARCH COUNCIL

AUTHOR D. KEARNEY
AUTEUR

George Chapman

APPROVED
APPROUVÉ for Director/
pour le directeur

DESCRIPTION: A set of TROEMNER weights ranging in nominal mass from 2000 grams to 10 milligrams contained in a wooden case.

The above described weights have been compared with the Standards of the National Research Council of Canada and the results of the calibration at this date are given below:

NOMINAL MASS (g)	MASS (g)	UNCERTAINTY (g)
2000 (2kg)	2000.01	±0.04
•2000 (2kg)	2000.00	±0.04
500	500.00	±0.01
300	300.004	±0.006
200	200.002	±0.004
100	100.000	±0.002
50	50.000	±0.001
30	30.000 0	±0.000 6
20	20.000 1	±0.000 4
10	10.000 1	±0.000 2
5	5.000 0	±0.000 1
3	3.000 01	±0.000 06
2	2.000 01	±0.000 04
1	1.000 02	±0.000 02

NOMINAL MASS (mg)	MASS (gm)	UNCERTAINTY (mg)
500	499.97	±0.01
300	300.00	±0.01
200	199.98	±0.01
100	100.00	±0.01
50	50.00	±0.01
30	30.01	±0.01
20	19.99	±0.01
10	9.98	±0.01

APPENDIX D

CALIBRATION OF FREQUENCY COUNTER

APPENDIX D

CALIBRATION OF FREQUENCY COUNTER

DATE 17 October 1986

REPORT NO. TLS-019
RAPPORT NO.

CALIBRATION OF A FLUKE UNIVERSAL COUNTER TIMER
MODEL 7261-A, SERIAL NUMBER 375-5003

for/pour

Engine Laboratory
Division of Mechanical Engineering
National Research Council of Canada

AUTHOR R.J. Douglas
AUTEUR

APPROVED ....
APPROVÉ for Director/
pour le directeur

The unit under test was operating on its internal batteries when it arrived, hand carried, at the time laboratory. The unit was connected to a 115 VAC source for the duration of the calibration. No special measurements were taken on the temperature of the instrument under test. The ambient temperature in the time laboratory is normally 21 +/- 1 °C.

A 1 MHz square wave derived from the primary cesium clock Cs VI-C was connected to channel A of the unit under test. A 50 Ω coaxial cable was used, terminated at the channel A input of the unit under test with a 50 Ω terminator, giving a peak-to-peak amplitude of 1.6 volts for the calibrating 1 MHz signal. The reading displayed by the unit under test was 999.9999 +/- 0.0001 kHz.

The unit under test was then unplugged and returned to its owners.

APPENDIX E

CALIBRATION OF TEMPERATURE CALIBRATOR AND THERMOCOUPLE

Prior to the Omnitrak calibration process, two JOFRA ovens/calibrators, Models 6005 and EVJ-D-50RC were checked by NRC's Physics Division. The calibration report No. APH 2738 is attached.

Model EVJ-D-50RC was used to calibrate the temperature measuring arrangement used to monitor the calibrator fluid and the room temperatures. In both cases, home-made precision-wire thermocouples were utilized, in conjunction with the DIGITAL II ANALOGIC AN6520 temperature readout/calibrator, S/N 068-30005.

A check of the thermocouples/DIGITAL II assembly by the JOFRA calibrator yielded the following results:

- JOFRA demand setting: 70°F
- JOFRA indicated temperature: 70.1/70.0 70.05°F (Avg.)
- Calibration correction for 20°C (68°F)
  (Report No. APH 2738) 20.22-20.10°C = 0.12°C = 0.22°F
- JOFRA actual temperature: 70.27°F
- DIGITAL II readout: 70.55°F
- DIGITAL II error: (High) 0.28°F

DATE April 21, 1986

REPORT NO.
RAPPORT NO. APH 2738

Calibration of Two JOFRA Temperature Calibrators

for/pour

Division of Mechanical Engineering
Engine Lab
Attn: J. Carvish

AUTHOR
AUTEUR Don Lawlor

APPROVED
APPROUVÉ for Director/pour le directeur

The JOFRA temperature calibrators were monitored by a standard platinum resistance thermometer as indicated in the table below.

Model 6005 Serial No. 55123			Model EVJ-D-50RC Serial No. 54230		
Temperature	Set	Read	Temperature	Set	Read
49.97°C	50°C	50°C	-22.14°C	-50.0°	-22.3°C
99.56°	100°	100°	-19.36°	-20.0°	-19.5°
149.26°	150°	150°	- 9.91°	-10.0°	-10.0°
199.82°	200°	201°	0.15°	0.0°	0.1°
250.29°	250°	251°	10.22°	10.0°	10.1°
299.31°	300°	301°	20.22°	20.0°	20.1°
349.74°	350°	351°	30.31°	30.0°	30.1°
399.15°	400°	401°	40.31°	40.0°	40.1°
448.90°	450°	451°	50.41°	50.0°	50.1°
499.01°	500°	501°	60.51°	60.0°	60.1°
548.22°	550°	550°			

APPENDIX F

BUOYANCY EFFECTS IN WEIGHING

Archimedes' Principle states that "a body floating or submerged in a liquid is buoyed up by a force equal to the weight of the liquid displaced". This principle applies equally to liquids immersed in a gas, e.g. water in air.

Using water immersed in air as an example:

Apparent weight of water, $m'_{H_2O} = m_{H_2O} - m_{AIR}$

or

$$m'_{H_2O} = \rho_{H_2O} V_{H_2O} - \rho_{AIR} V_{AIR}$$

where ρ = density of the fluids, and
V = volume of the fluids.

Since the water is completely immersed in air:

$$V_{AIR} = V_{H_2O}$$

and

$$m'_{H_2O} = \rho_{H_2O} V_{H_2O} - \rho_{AIR} V_{H_2O}$$

$$m'_{H_2O} = \rho_{H_2O} V_{H_2O} \left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right]$$

$$m'_{H_2O} = m_{H_2O} \left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right]$$

Correction for buoyancy is often found in the form: $\left(1 - \frac{\rho_1}{\rho_2}\right)$

Hence, in order to find the true mass of a water draw sample, the correction is:

$$m_{H_2O} = \frac{m'_{H_2O}}{\left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right]}$$

where m_{H_2O} = true mass of water sample,

m'_{H_2O} = balance reading of water sample,

ρ_{AIR} = density of air,

ρ_{H_2O} = density of water.

With an approximate air density of 1.2 kg/m^3 and a water density of 998 kg/m^3, at room temperature, the correction quotient for buoyancy is 0.9988, or 0.12%.

If the balance has been calibrated by means of stainless steel weights, their buoyancy effects must also be taken into consideration. From the above development:

$$m'_{SS} = m_{SS}\left[1 - \frac{\rho_{AIR}}{\rho_{SS}}\right]$$

where m_{SS} = true mass of stainless steel weight(s),

m'_{SS} = balance reading of stainless steel weight(s), and

ρ_{SS} = density of stainless steel, often taken as between 7600 and 7800 kg/m^3,

The buoyancy effects on stainless steel is about 0.99985, or 0.015%.

For a given water draw weighing on a toploader one can write the equivalence:

$$m_{H_2O}\left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right] = m_{SS}\left[1 - \frac{\rho_{AIR}}{\rho_{SS}}\right]$$

However, prior to the weighing process, the balance had been calibrated to read the true mass of the stainless steel weight of 5000 g. Thus m_{SS} is also the balance reading, and:

$$m_{H_2O} = (\text{balance reading})\,\frac{\left[1 - \frac{\rho_{AIR}}{\rho_{SS}}\right]}{\left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right]}$$

This expression assumes linearity of the balance between the calibration weight and the sample weight. In the case of the water draws, the values were close enough to support that assumption, i.e. 5000,03 g calibration weight and about 5200 g gross of water and flask.

Sample calculation for this method (1):

Job No.: C87-3, Test: 1

- balance reading: 4009.06 g
- density of air, ρ_{AIR}, at T_r = 70.3°F: 1.16 kg/m^3,
- density of weight, ρ_{SS}: 7800 kg/m^3,
- density of water, ρ_{H_2O}, at T_w = 69.5°F: 998.0368 kg/m^3, [App. G],

then

$$m_{H_2O} = 4009.06 \frac{\left(1 - \frac{1.16}{7800}\right)}{\left(1 - \frac{1.16}{998.0368}\right)}$$

$$m_{H_2O} = 4013.128 \text{ g}$$

For highly accurate mass establishment, the electronic toploader should be used as a true "balance". An item, say a water draw sample, is weighed and the indicated weight is recorded. This balance reading is then reestablished with calibrated weights of known material, e.g. solid stainless steel. The weights used are recorded, their true masses are added, and the buoyancy corrections are applied as before.

$$m_{H_2O} \left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right] = m_{SS} \left[1 - \frac{\rho_{AIR}}{\rho_{SS}}\right]$$

and

$$m_{H_2O} = m_{SS} \frac{\left[1 - \frac{\rho_{AIR}}{\rho_{SS}}\right]}{\left[1 - \frac{\rho_{AIR}}{\rho_{H_2O}}\right]}$$

where m_{H_2O} = true mass of the water draw,

m_{SS} = true mass of the calibrated weight(s)

and densities as defined before.

Sample calculation for this method (2):

Job No.: C87-4, Test: 1

- balance reading: 4018.96 g
- true mass of weights: 4018.9701
- density of air, ρ_{AIR}, at T_r = 69.8°F: 1.18 kg/m^3
- density of weights, ρ_{SS}: 7800 kg/m^3
- density of water, ρ_{H_2O}, at T_w = 68.8°F: 998.1219 kg/m^3, [App. G.],

then

$$m_{H_2O} = 4018.97 \frac{\left(1 - \frac{1.18}{7800}\right)}{\left(1 - \frac{1.18}{998.1219}\right)}$$

$$m_{H_2O} = 4023.1183 \text{ g}$$

Note that the balance indication is now eliminated from the process. It is used only for the comparison of two masses of different substances. In practice it will be found that, under the above described circumstances, the balance reading will be very close to the total mass of the weights, m_{SS}.

APPENDIX G

CONVERSION OF WATER MASS TO VOLUME

The conversion of water mass to volume was based on the work by Menaché and Girard (1973) and the conversion tables by Zimmerman and Lavine (1961).

From Zimmerman and Lavine:

$$1 \text{ US Gallon} = 3785.4118 \text{ cm}^3 = 3.785412 \text{ dm}^3$$

From Menaché and Girard:

Maximum density of water, at 4°C:

$$\rho_{MAX} = 999.975 \frac{\text{kg}}{\text{m}^3} = 999.975 \frac{\text{g}}{\text{dm}^3}$$

Relative density, d, of water at temperature T:

$$d = \frac{\text{density at temperature T}}{\text{maximum density, at } 4^\circ\text{C}} = \frac{\rho_T}{999.975}$$

Combining:

$$1 \text{ US Gallon of water at temperature T} = 3.785412 \cdot \rho_{MAX} \cdot d \left[\frac{\cancel{\text{dm}^3} \cdot \text{g} \cdot \cancel{\text{g}} \cdot \cancel{\text{dm}^3}}{\cancel{\text{dm}^3} \cdot \cancel{\text{dm}^3} \cdot \cancel{\text{g}}}\right]$$

For series C87-3:

$$T_{W_{AVG}} = 69.5^\circ\text{F} = 20.8^\circ\text{C}$$

from Table G1 (Menaché, Girard, 1973)

$$d_{20.8^\circ\text{C}} = 0.9980618$$

and

$$1 \text{ US Gallon water } (20.8^\circ\text{C}) = 3.785412 \cdot 999.975 \cdot 0.9980618 = 3777.98 \text{ g}$$

For series C87-4:

$$T_{W_{AVG}} = 68.8^\circ\text{F} = 20.4^\circ\text{C}$$

$$d_{20.4^\circ\text{C}} = 0.9981469$$

and

$$1 \text{ US Gallon water } (20.4^\circ\text{C}) = 3.785412 \cdot 999.975 \cdot 0.9981469 = 3778.30 \text{ g}$$

Note: From the FTI - supplied conversion table (not included in this report):

For $T_w = 20.8^\circ\text{C}$: $3774.002 \frac{\text{g}}{\text{US Gallon}}$ (by interpolation)

For $T_w = 20.4^\circ\text{C}$: $3774.316 \frac{\text{g}}{\text{US Gallon}}$

REFERENCES

MENACHÉ, M., GIRARD, G. 1973. Concerning the Different Tables of the Thermal Expansion of Water between 0 and 40°C, Institut Océanographique, 195, rue Saint-Jacques, F-75005 Paris, and Bureau International des Poids et Mesures, Pavillion de Breteuil, F-92310 Sèvres, France Metrologia 9, 62-68, by Springer Verlag 1973.

ZIMMERMAN, O.T., LAVINE, I. 1961. Industrial Research Service's Conversion Factors and Tables, Industrial Research Service Inc., Dover, New Hampshire.

Thiesen, Scheel, Diesselhorst

	0	1	2	3	4	5	6	7	8	9
0	0,999 8676	8744	8809	8872	8934	8994	9052	9108	9163	9215
1	9266	9315	9363	9409	9452	9495	9535	9574	9611	9646
2	9680	9712	9742	9770	9797	9822	9845	9867	9887	9906
3	9922	9937	9951	9963	9973	9981	9988	9994	9997	9999
4	1,000 0000	*9999	*9996	*9992	*9986	*9978	*9969	*9959	*9947	*9933
5	0,999 9918	9901	9882	9863	9841	9818	9794	9768	9740	9711
6	9680	9648	9615	9580	9543	9505	9466	9425	9382	9338
7	9293	9246	9198	9148	9097	9044	8990	8934	8877	8819
8	8759	8698	8635	8571	8506	8439	8371	8301	8230	8158
9	8084	8009	7932	7854	7775	7694	7612	7529	7444	7358
10	7271	7182	7092	7001	6908	6814	6718	6622	6524	6424
11	6324	6222	6118	6014	5908	5801	5692	5583	5472	5360
12	5246	5131	5015	4898	4779	4659	4538	4416	4292	4167
13	4041	3914	3785	3656	3525	3392	3259	3124	2988	2851
14	2713	2573	2433	2291	2148	2003	1858	1711	1563	1414
15	1264	1112	0960	0806	0651	0495	0337	0179	0019	*9858
16	0,998 9697	9533	9369	9204	9037	8870	8701	8531	8360	8188
17	8014	7840	7664	7488	7310	7131	6951	6770	6588	6404
18	6220	6034	5848	5660	5471	5281	5090	4898	4705	4511
19	4315	4119	3921	3723	3523	3323	3121	2918	2714	2509
20	2303	2096	1888	1679	1469	1258	1045	0832	0618	0403
21	0186	*9969	*9750	*9531	*9310	*9089	*8866	*8643	*8418	*8193
22	0,997 7966	7738	7510	7280	7050	6818	6585	6352	6117	5882
23	5645	5407	5169	4929	4689	4447	4205	3961	3717	3472
24	3225	2978	2730	2480	2230	1979	1727	1474	1219	0964
25	0708	0451	0194	*9935	*9675	*9414	*9153	*8890	*8626	*8362
26	0,996 8097	7830	7563	7295	7026	6755	6484	6213	5940	5666
27	5391	5116	4839	4562	4283	4004	3724	3443	3161	2878
28	2594	2310	2024	1738	1450	1162	0873	0583	0292	0000
29	0,995 9708	9414	9120	8824	8528	8231	7933	7634	7334	7034
30	6732	6430	6127	5823	5518	5212	4905	4598	4289	3980
31	3670	3359	3047	2734	2421	2106	1791	1475	1158	0841
32	0522	0202	*9882	*9561	*9239	*8916	*8593	*8268	*7943	*7617
33	0,994 7290	6962	6633	6304	5974	5643	5311	4978	4644	4310
34	3975	3639	3302	2964	2626	2287	1947	1606	1264	0922
35	0578	0234	*9889	*9544	*9197	*8850	*8502	*8153	*7803	*7453
36	0,993 7101	6749	6396	6043	5688	5333	4977	4620	4263	3904
37	3545	3185	2825	2463	2101	1738	1374	1009	0644	0278
38	0,992 9911	9543	9175	8806	8436	8065	7693	7321	6948	6574
39	6200	5824	5448	5071	4694	4315	3936	3556	3176	2795
40	2412	2030	1646	1262	0876	0491	0104	*9717	*9329	*8940
41	0,991 8550	8160	7769	7377	6985	6591	6197	5803	5407	5011
42	4614									

Table G1: **Relative Density Values for Pure Water of Natural Origin, Free of Dissolved Gases, Under One Standard Atmosphere, in Tenths of a Degree Celsius**

Ref: Thiesen, M.: Phsik. Tech. Reichs, Wiss. Abhandl. 3, (1900) (Table p. 68).

Reproduced in Menaché and Girard, 1973

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4 Calibration of an FTI Omnitrak Ballistic Flow Calibrator System

AUTHOR(S)/AUTEUR(S)

5 W. Grabe, J. Carvish

SERIES/SÉRIE

6

CORPORATE AUTHOR/PERFORMING AGENCY/AUTEUR D'ENTREPRISE/AGENCE D'EXÉCUTION

National Research Council Canada Engine Laboratory
7 Division of Mechanical Engineering

SPONSORING AGENCY/AGENCE DE SUBVENTION

8

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NOTES

13

DESCRIPTORS(KEY WORDS)/MOTS-CLÉS

14 Calibration, turbine flowmeter; liquid flow

SUMMARY/SOMMAIRE

15 Describes the calibration of an Omnitrak ballistic flow calibrator in detail, giving traceability of measuring devices.

ADDRESS/ADRESSE

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