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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

An Accuracy Statement for a Facility Used to Calibrate Static Pressure Transducers and Differential Pressure Transducers at High Base Pressure

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An Accuracy Statement for a Facility Used to Calibrate Static Pressure Transducers and Differential Pressure Transducers at High Base Pressure

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A facility has been developed to calibrate pressure transducers that are used in the NBS Gas Mass Flow Facility. Both static and differential pressure transducers can be calibrated. An air dead weight tester is the standard for static transducers in the range from 3.8 to 4.5 MPa. An air dead weight tester is also the standard for the differential pressure transducers in the range of 2.5 kPa to 50 kPa; a cistern manometer provides the transfer for the standard to a base operating pressure of 4.1 MPa. The calibration of the air dead weight gage by NBS-Washington contributes ±65 ppm to the uncertainty of the calibration of the static pressure transducers. The calibration of the air dead weight gage adds ±69 ppm to the calibration of the cistern manometer. This, plus the uncertainties in the high pressure corrections to the cistern manometer and our measurement of the mercury temperature, contributes ±690 ppm to the uncertainty of the differential pressure transducer calibrations.

Key Words: calibration; differential manometer; piston gage; pressure difference; pressure transducer; standards.

1. Introduction

This accuracy statement describes the equipment used for differential and static pressure transducer calibrations and the tracibility of the accuracy of this equipment to the National Bureau of Standards. The purpose of the pressure calibration facility is to calibrate both the static pressure transducers and the differential pressure transducers used in the Gas Mass Flow Reference Facility. The calibration facility is designed to calibrate the transducers in place using the transducer signal conditioning equipment as used for data gathering in the flow facility. The equipment included in the calibration of the transducer and its signal conditioning system is a transducer, an electrical power supply for the transducer, an analog-to-digital voltage converter, a channel multiplexer and a mini-computer.

The pressure range of the calibration facility to calibrate the static pressure transducers is 3.8 (550 psi) to 4.27 MPa (620 psi), and an air dead weight tester provides the calibration standard. The differential pressure transducers are calibrated with a mercury manometer which can be used at base pressures as high as 34 MPa. For our use, the base pressure at 4.1 MPa (600 psi) is applied to both sides of the mercury manometer and the differential pressure transducer, then the desired differential is added to the base pressure. These differential pressure transducers are calibrated in the range of 2.5 kPa (10 in. H_2O) to 50 kPa (200 in. H_2O). We have examined experimentally the accuracy to which this manometer can calibrate these transducers.

2. Summary

By using an air dead weight gage as the transfer standard between NBS-Washington and NBS-Boulder, we have been able to establish a calibration facility that contributes no more than $\pm$ 690 ppm of systematic error to the total uncertainty of the calibration of differential pressure transducers at 50 kPa and no more than $\pm$ 65 ppm to that of the static pressure transducers. The total uncertainty of measurements made with a pressure transducer also contains the uncertainty in the correction relationship between readings made on the transducer and the corresponding readings of the standard, plus the random imprecision of the pressure transducer. In examples given in the text of actual calibrations of pressure transducers, a static pressure transducer is calibrated with a total uncertainty of $\pm$ 570 ppm at 4.1 MPa, and a differential pressure transducer is calibrated with a total uncertainty of $\pm$ 1254 ppm at 50 kPa. The differential pressure transducer calibration uses a cistern-type mercury manometer, which is calibrated with the air dead weight gage. The direct calibration of the cistern manometer is made at ambient pressure; the correction at the base pressure of 4.1 MPa has been verified by using two air dead weight gages, one as a reference and the calibrated gage as the measuring device.

3. Static Pressure Transducer Calibration Facility

Some early work was done using Bourdon tube gages to calibrate the static pressure transducers, however, these gages were deemed inadequate and have been replaced by an air dead weight tester.

The dead weight gage uses a precision ground piston in a mating cylinder as the pressure measuring device. Weights are added to the piston for measurement of various pressures. The piston has an extended stem at the top end to accommodate the weights. The bottom end of the cylinder connects via a tube to the instrument that is to be calibrated. Gas is introduced into the dead weight gage from a clean gas source until the piston rises in the cylinder. As a minute amount of gas flows past the piston it drops slowly with time, but the pressure is maintained as the piston falls. The piston is rotated either manually or via a built-in motor drive. Rotation of the piston eliminates static friction between the piston and cylinder, so the piston is floating on a gas column and is lubricated at the cylinder walls with a gas film. The level of pressure measured is set by the weight of the piston and the weights added to it. The dead weight gage thereby uses the basic measurement units of mass and piston area to measure pressure. The air dead weight gage used for our calibrations has two piston-cylinder sizes. The smaller piston has a pressure range to 4.27 MPa (620 psi). The larger piston measures pressure to 107 kPa (15.5 psi). The smaller piston is used to calibrate the static pressure transducers before each day of tests. The larger piston is used at ambient base pressure to calibrate the cistern manometer. This in turn is used to calibrate the differential pressure transducers before each day's tests.

Both of the piston-cylinder assemblies were calibrated by the National Bureau of Standards' National Measurement Laboratory at Gaithersburg, MD. The calibrations determine the effective area of each piston at the specified test conditions. The specified conditions and the calibrations are included as Appendix A. As described in Appendix A, a number of models were fit to the calibration data. The model

$$\text{Force} = \text{Area} \times \text{Pressure}$$

has been selected as adequate for both piston assemblies to determine the effective piston area. Also note that the ranges reported in Appendix A are slightly less than we have available on our gage. This discrepancy resulted because NBS-Gaithersburg did not calibrate the weight set and, therefore, was not aware of the weights available in our set. Our weight set was calibrated at the State of Colorado Metrology Laboratory, Denver, CO. The report of this calibration is included as Appendix B. Note that the masses are reported as apparent mass versus brass. This calibration technique of using apparent mass versus brass corrects for the air buoyancy of weights of unknown density, provided we use this mass and the air buoyancy correction for brass to calculate the force on the piston of the air dead weight gage. The air buoyancy correction is then

$$1 - \frac{a}{b}$$

where a is the local air density and b is the density of the standard brass weight which is 8.4 g/cm^3.

Besides the air bouyancy correction for the weights, several other corrections must be considered for each data point for accurate pressure measurement using the dead weight gage. They include corrections for the thermal expansion of the piston and cylinder, corrections for local gravity, and corrections for the elasticity of the piston and cylinder. As noted in Appendix A, these corrections have been applied to the calibrations at NBS-Gaithersburg. The thermal expansion correction is made for each gage reading by measuring the gage temperature using a built in thermometer and applying the correction using the coefficient of thermal expansion of the piston and cylinder material. The gravity correction is constant and is applied to each reading using the local acceleration of gravity. The piston and cylinder were calibrated at NBS at pressure so any elastic deformation is, in effect, included in the calibration. Table I gives the error uncertainties for these corrections.

Having calibrated a pressure transducer at, say, a fixed set of conditions against the air dead weight gage, the total uncertainty of the average of n measurements made with the calibrated transducer at this same set of conditions is defined here as:

$$\text{Total Uncertainty Limit} = SE_s + 2.576 \left(\sigma_\beta + \sigma_c/\sqrt{n}\right)$$

where SE_s is the systematic error limit for the standard, σ_β is the standard deviation of the correction of the readings of the calibrated meter to those of the standard, σ_c is the standard deviation for readings made with the calibrated gage, n is the number of readings made at the fixed set of conditions and 2.576 is the 99.5 percentile of the standard normal distribution. The σ_β and σ_c are not added in quadrature because the correction is now fixed and its uncertainty becomes a systematic error for future measurements using the calibrated gage.

Most often σ_β and σ_c are unknown and must be estimated from the data, that is, σ_β is estimated from the data used to calibrate the transducer and

σ_C is estimated from pressure measurements made with the transducer. Then the total uncertainty limit (T.U.L.) for an average of n measurements made with the calibrated tranducer is defined as:

$$\text{T.U.L.} = SE_S + 2.576\ (A\,\widehat{\sigma_\beta} + B\,\widehat{\sigma_C}/\sqrt{n})$$

where $\widehat{\sigma_\beta}$ and $\widehat{\sigma_C}$ are the estimated standard deviations, and A and B are factors greater than 1 which increase the limit in proportion to our uncertainty of the estimates. These values of A and B decrease toward 1 as the number of observations used in making each of the estimates increases. The value of 2.576A is taken from the table of the 99.5 percentiles of the student-t statistics and B is derived using the table of the 0.01 percentiles of the chi-square distribution. Both A and B are functions of the number of observations used. See NBS Handbook 91 [1].

For the high pressure piston, SE_S equals 57 ppm for the piston area, plus 3 ppm uncertainty for the weights, plus 5 ppm uncertainty for the gage corrections (65 ppm). The two flow system static pressure transducers are calibrated using a first degree least squares fit to six replicated pressure values (12 points). The same values, to a close approximation, are used for each calibration, and the values are in the range of 3.8 MPa to 4.27 MPa. From our experience with the two static pressure transducers in over a dozen calibrations, we can ascribe for our example the nominal values of 100 ppm and 200 ppm to the estimates of σ_β and σ_C, respectively. We use the value A = 1.2 because of using 12 points in each calibration, and the value B = 1.2 because we have over a dozen such calibrations (i.e. over 100 points). In our example of how these numbers are used, we consider an average of n=10 values, then

$$\text{T.U.L} = [65 + 2.576\ (1.2 * 100 + 1.2 * 200/\sqrt{10})]\ \text{ppm}$$

$$= 570\ \text{ppm}\ (.057\%\ \text{at}\ 600\ \text{psi})$$

The estimates of $\widehat{\sigma_\beta}$ and $\widehat{\sigma_C}$ were obtained from linear least squares fits of the transducer data to the corresponding air dead weight data. The uncertainty in the calibration of the air dead weight gage, SE_S=65 ppm, adds little to the T.U.L.

4. Differential Pressure Transducer Calibration Facility

We are using a high-base-pressure cistern-type mercury manometer to calibrate the transducers used to measure pressure drop across orifice plates. Using this manometer, the transducers can be calibrated at the base pressures used during gas flow tests. The range of the differential pressure transducers are 25 kPa (100 in. H_2O) and 50 kPa (200 in. H_2O). They are both calibrated using a base pressure of 4.1 MPa (600 psi).

A mercury height sensing element is incorporated on the low pressure side (tube side) of the cistern manometer. The manometer is constructed of stainless steel so that the sensing element must detect a magnetic float on the mercury surface by sensing the change in inductance in a wire coil. The coil sensing unit is driven by an electrical servo system, and it tracks the float and is attached to a perforated metal band which pulls around a cog wheel. The wheel drives a counter that displays the column height in inches. The ratio of the cistern volume change to the low pressure side or column volume change is 20 to 1; the cistern level change is included in column height display through the choice of gear ratios in the gear train between the cog wheel and the readout counter.

Early in the program the manometer became erratic, especially at zero differential pressure. After experimenting with several configurations of floats, a steel ball 3.2 mm smaller in diameter than the inside diameter of the manometer tube was selected. All data in the report were obtained using this float.

When measuring mercury height at high base pressures, corrections must be applied to the manometer readings relative to low base pressure conditions. A head correction to the mercury column is required to account for the difference in density in the two gas columns from the top of the mercury column to the pressure transducer level. For the maximum mercury displacement used, 387 mm (207 in. H_2O), the correction is -0.03 mm (-0.016 in. H_2O). This correction is linear with height and independent of base pressure if we assume perfect gas laws apply. At high base pressure, the pressure acting on the manometer tube expands it slightly. The ratio of wall thickness to the inside diameter of the cistern is similar to that of the tube and presumably expands a commensurate amount. At the high base pressures, the gas column in the high pressure side of the manometer contributes significantly to the mercury column height. This requires a correction if the true mercury height corresponding to the differential pressure across the manometer is desired. The corrected mercury column height h_{cor} is

$$h_{cor} = h_{obs} (1-\rho_N/\rho_{Hg})$$

where h_{obs} is the column height read, and ρ_N and ρ_{Hg} are the nitrogen gas and mercury liquid densities, respectively, at the temperature and pressure of the measurement. At the base pressure at which the transducers will be calibrated, 4.1 MPa, the correction amounts to 0.4% or 1.6 mm (0.86 in. H_2O) for a 400 mm Hg column height.

Compressibility of the mercury, which increases density, must also be considered when using a mercury manometer at elevated pressure. From NBS Monograph 8 [2], the density of mercury increases 0.02% at 4.1 MPa. Table 2 gives the uncertainties of the errors associated with these corrections to the cistern manometer.

The cistern manometer has no redundancy to test for proper operation of the readout machinery. Therefore, the air dead weight gage with the low pressure piston is included in the calibration system to provide a means of monitoring the performance of the cistern manometer.

Use of the air dead weight gage and the low pressure piston does not permit us to check the high pressure corrections to the cistern manometer at the desired base pressure. Therefore, we elected to perform a limited number of calibrations of the cistern manometer at high base pressure by using two air dead weight gages. When using two air dead weight testers for calibrating a differential pressure device, one instrument is used as the reference or base pressure measurement and the other instrument measures the base pressure plus the differential. Since both instruments are first balanced at the base pressure the reference instrument does not need to be calibrated. Therefore, we used the calibrated instrument for the base plus differential pressure. Because the instrument must operate at the base plus the desired differential pressure the high pressure piston must be used in this calibrating scheme. This means that the precision for this calibration is limited to the precision of the high pressure piston and not the low pressure piston as is the case for ambient base pressure calibration.

The method using two air dead weight gages required a null device for zero differential to determine when both gages are at equal pressures, since porting two gages together produces an unstable condition allowing one gage to fall and the other to rise. The minuscule difference in pressure produced by elevation etc. is not enough to produce a stable condition. By using a null device to separate the two gages, one can experimentally balance both gages at the same pressure. To control the pressures at various gage settings and at the null, several gas displacers are required. A schematic of the system is shown in figure 1. Each time one displacer is adjusted the other must also be adjusted since the mercury in the manometer transfers pressure.

To determine the absolute sensitivity of the dual piston method, we first raised the system pressure to about 4.1 MPa with the cross-over valve open. We then determined the null reading for the null measuring transducer. We selected a base pressure so that the calibrating gage and not the reference gage was balanced using preselected gage weights. Next we closed the crossover valve and added weights to the reference gage and adjusted the displacers until both gages were floating and the null device read the same as its previous null point. We then added an additional 20 mg weight to the reference gage. This was easily discernable by the null device. Twenty mg weight on the piston gage is equivalent to 23.4 Pa (0.09 in. H_2O) so the balance method should be able to detect 23.4 Pa, which is 0.05% of the range of the 50 kPa transducer.

The problem with using the dual piston method for high base pressure is that the random variation over a number of days of measurements made at a nominal pressure is four or five times that for similar measurements made at atmospheric pressure. This allows us to only check for relatively gross errors in the high pressure corrections. The random uncertainty for a correction at 41.3 kPa (166 in. H_2O), for example, is 55 Pa ($\pm$0.22 in. H_2O). The number of days at which measurements were made at high base pressure is five, and some of the uncertainty is likely due to learning the new procedures. Within this limitation, however, we see no need for changes in the high pressure corrections for the cistern manometer.

The cistern manometer is calibrated at ambient base pressure against the air dead weight tester using nine specified pressure values; these values range from 2.8 kPa (11 in. H_2O) to 52 kPa (207 in. H_2O). This ambient base pressure calibration is performed in the same manner as the static pressure calibration described in section 3, except that the low pressure piston is used. All correction to the air dead weight gage values still apply and are considered.

The two differential pressure transducers are in turn calibrated against the cistern manometer at 4.1 MPa base pressure using the same differential pressure values; only six of the pressures are used for each transducer (see Tables 3 and 4). Before each day's use on the Gas Mass Flow Facility, each transducer is checked using the cistern manometer. During this operation, each of the six differential pressure values is used twice for a total of 12 points. If the calibration of a transducer has not changed significantly in the last n checks, then all 12 n experimental values can be used for the calibration. A first degree least squares fit is made to the 2 n replicated six pressure values, and this linear relationship is the new calibration. In computing the total uncertainty limit of the average of k differential pressure transducer readings, we have

$$\text{T.U.L.} = SE_p + SE_c + 2.576(A\hat{\sigma}_\beta + B\ \hat{\sigma}_c/\sqrt{k}),$$

where SE_p is 60 ppm systematic error for the low pressure piston plus 5 ppm for corrections, plus 4 ppm uncertainty for the weights used, plus 400 ppm uncertainty for high pressure and temperature corrections to cistern manometer (469 ppm) and $SE_c = 2.576A'\hat{\sigma m}$, where $\hat{\sigma m}$ is our estimated standard deviation for this correction to the cistern manometer reading and A' is as A is described in the section 3 and depends on the number of readings that have gone into the estimate $\hat{\sigma m}$. The values for $\hat{\sigma}_\beta$, A, $\hat{\sigma}_c$, and B are as described in section 3 and are based on the fit to the n calibrations as mentioned above.

Table 3 presents these values for the 100 in. meter and Table 4 does the same for the 200 in. meter. A large part of the systematic error of the facility is due to the uncertainty in the temperature correction for the mercury in the cistern manometer. We expect to improve our accuracy of this measurement in the future.

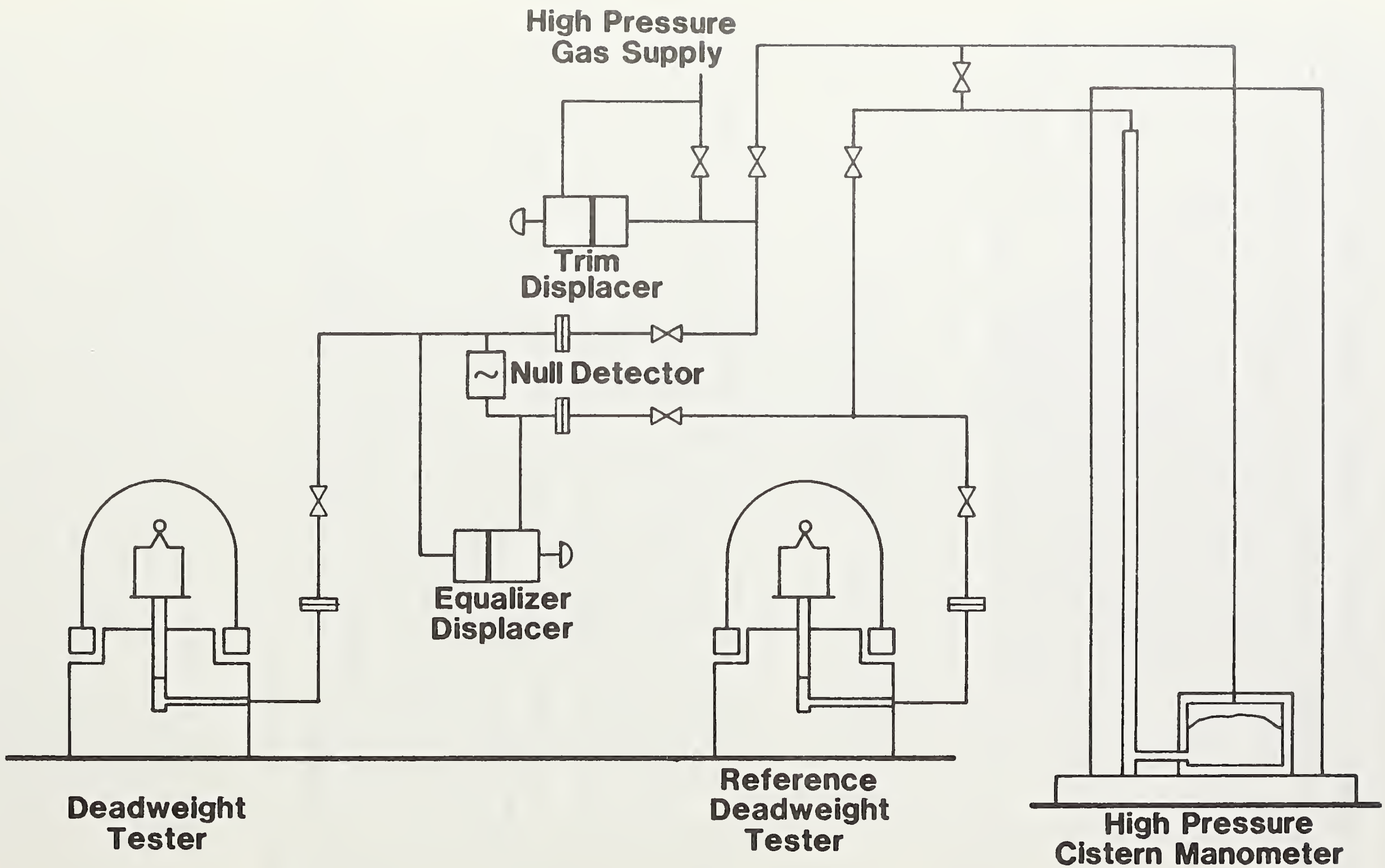


Figure 1. System schematic for calibration of the cistern manometer.

Table 1. Uncertainties of Corrections for Air Dead Weight Gage

	Uncertainty in Measurement	% Error
Temperature	± 0.25 K	± 0.0004
Gravity	± 0.001 cm/s^2	± 0.0001
Buoyancy in air	± $2.0 \times 10^{-5} g/cm^3$	± 0.0002
Error in quadrature		± 0.0005

Table 2. Uncertainties of High Pressure Corrections for Cistern Manometer

	Uncertainty in Measurement	% Error
Relative compressibility of Hg	± 1.6×10^{-4}	± 1.6×10^{-2}
Temperature correction for Hg	± 2°C	± 0.036
Tube expansion		± 5×10^{-5}
Base pressure reading	± 69 kPa	± 0.0047
Error in quadrature		± 0.040

Table 3a. Cistern Manometer Corrections and Total Uncertainty Limit for 100 in. meter (inches of water)

ΔP	Correction (added)	SE_p	A'	$\hat{\sigma}_m$	A	$\hat{\sigma}_\beta$	B	$\hat{\sigma}_c$	SE_p+SE_c	T.U.L.
11.0	.049	.0051	1.36	.0043	1.79	.023	1.37	.020	.021	.15
19.6	.054	.0091	1.36	.011	1.79	.020	1.37	.020	.048	.16
41.4	-.029	.0192	1.30	.0024	1.79	.015	1.37	.020	.028	.12
60.8	.073	.0282	1.36	.0098	1.79	.014	1.37	.020	.063	.15
82.5	.122	.0382	1.14	.0060	1.79	.019	1.37	.020	.056	.16
102.7	.049	.0477	1.36	.0071	1.79	.025	1.37	.020	.073	.21

Table 4a. Cistern Manometer Corrections and Total Uncertainty Limit for 200 in. meter (inches of water)

ΔP	Correction (added)	SE_p	A'	$\hat{\sigma}_m$	A	$\hat{\sigma}_\beta$	B	$\hat{\sigma}_c$	SE_p+SE_c	T.U.L.
11.0	.049	.0051	1.36	.0043	1.79	.015	1.31	.043	.021	.14
41.4	-.029	.0192	1.30	.0024	1.79	.010	1.31	.043	.028	.12
82.5	.122	.0382	1.14	.0060	1.79	.011	1.31	.043	.056	.15
124.7	.038	.0579	1.44	.032	1.79	.011	1.31	.043	.176	.27
166.0	.096	.0770	1.14	.0053	1.79	.010	1.31	.043	.093	.19
207.4	.142	.0962	1.21	.015	1.79	.016	1.31	.043	.143	.26

Table 3b. Cistern Manometer Corrections and Total Uncertainty Limit for 100 in. meter (kPa)

ΔP	Correction (added)	SE_p	A'	$\widehat{\sigma m}$	A	$\widehat{\sigma_\beta}$	B	$\widehat{\sigma_c}$	SE_p+SE_c	T.U.L.
2.73	.012	.0013	1.36	.0011	1.79	.0057	1.37	.0050	.0052	.037
4.88	.013	.0023	1.36	.0027	1.79	.0050	1.37	.0050	.0119	.040
10.30	-.007	.0048	1.30	.0006	1.79	.0037	1.37	.0050	.0070	.030
15.13	.018	.0070	1.36	.0024	1.79	.0035	1.37	.0050	.0157	.037
20.53	.030	.0095	1.14	.0015	1.79	.0047	1.37	.0050	.0139	.040
25.56	.012	.0119	1.36	.0018	1.79	.0062	1.37	.0050	.0182	.052

Table 4b. Cistern Manometer Corrections and Total Uncertainty Limit for 200 in. meter (kPa)

ΔP	Correction (added)	SE_p	A'	$\widehat{\sigma m}$	A	$\widehat{\sigma_\beta}$	B	$\widehat{\sigma_c}$	SE_p+SE_c	T.U.L.
2.73	.012	.0013	1.36	.0011	1.79	.0037	1.31	.011	.0052	.035
10.30	-.007	.0048	1.30	.0006	1.79	.0025	1.31	.011	.0070	.030
20.53	.030	.0095	1.14	.0015	1.79	.0027	1.31	.011	.0139	.037
31.03	.009	.0144	1.44	.0080	1.79	.0027	1.31	.011	.0438	.067
41.31	.023	.0192	1.14	.0013	1.79	.0025	1.31	.011	.0231	.047
51.61	.035	.0239	1.21	.0037	1.79	.0040	1.31	.011	.0356	.065

5. References

[1] Natrella, M. G.; Experimental Statistics. Nat. Bur. Stand. (U.S.) Handb. 91;- January 1963.

[2] Brombacker, W. G.; Johnson, D. P.; Cross, J. L.; Mercury Barometers and Manometers. Nat. Bur. Stand. (U.S.) Monogr. 8; May 1960.

APPENDIX A (Part 1)

APPENDIX A (Part 2)

APPENDIX B

RGD
P-7772
52200/5220607

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
NATIONAL MEASUREMENT LABORATORY
WASHINGTION, D.C. 20234

R E P O R T O F C A L I B R A T I O N

ONE DOUBLE -RANGE DEAD WEIGHT PISTON GAGE
SUBMITTED BY

NBS-BOULDER

INSTRUMENT RECEIVED:MAY 18,1981 TEST COMPLETED:JUNE 5,1981
REFERENCE: COST CENTER
NO.7732571

DESCRIPTION

NBS IDENTIFICATION NO.: P-7772B
MANUFACTURER: RUSKA
MANUFACTURER'S SERIAL NO.: NONE
MANUFACTURER'S TYPE NO.: NONE
WEIGHTS WERE NOT RECEIVED WITH THE INSTRUMENT.

PISTON NO.: V-601 PRESSURE RANGE: 13.7 TO 4137 KPA
CYLINDER NO.: V-601 CYLINDER TYPE: SIMPLE
NOMINAL SIZE: 8E-6 SQ. METER

REFERENCE TEMPERATURE, T(S) = 23.0 DEGREES C.

THE INSTRUMENT WAS LEVELED SO THAT THE AXIS OF ROTATION OF THE PISTON WAS VERTICAL.

OBSERVATIONS WERE MADE WITH MANUAL ROTATION OF THE WEIGHTS ON THE TEST GAGE.

THE TEMPERATURE WAS MAINTAINED NEAR 23 DEGREES C AND CORRECTIONS WERE BASED ON READINGS OF AN ATTACHED THERMOMETER.

NBS WEIGHTS WERE USED IN THE CALIBRATION.

REFERENCE LEVEL AND PISTON POSITION, THE REFERENCE LEVEL IS 0.003 METER BELOW THE LOWER EDGE OF THE WEIGHT HANGER.
THE GAGE WAS OPERATED WITH THE LOWER EDGE OF THE WEIGHT HANGER AT THE LEVEL OF THE INDEX LINE MARKED ON THE PISTON/CYLINDER HEAD ASSEMBLY.

THE INSTRUMENT WAS CALIBRATED WITH NITROGEN USED AS THE PRESSURE TRANSMITTING FLUID.

IF A TARE ERROR IS INDICATED,IT SHOULD BE ADDED ALGEBRAICALLY, IN PA, TO THE PRESSURE DEVELOPED BY THE GAGE.

VALUES OF CHARACTERISTIC PARAMETERS OF THE INSTRUMENT WITH THE ESTIMATED UNCERTAINTY OF THE DETERMINATION ARE GIVEN IN THE FOLLOWING TABLE(S). EXPLANATORY INFORMATION IS GIVEN IN THE ENCLOSED ''SUPPLEMENT FOR REPORTS ON DEAD WEIGHT PISTON GAGES''.

TO FACILITATE THE DETECTION OF ERRORS THE WEIGHT NUMBERS, GAGE TEMPERATURES, DIRECTION OF ROTATION (1.=CW, -1.=CCW) AND JACKET PRESSURE P-J ARE LISTED FOR ALL OBSERVATIONS. OBSERVATION NUMBERS 101 TO 199 REFER TO THE STANDARD, AND 201 TO 299 REFER TO THE TEST INSTRUMENT. MASS AND DENSITY OF THE WEIGHTS ARE LISTED IN THE WEIGHT TABLE.

OBS. NO.	TEMP(C)	ROT	P-J(PA)	WEIGHT NUMBERS				
101.	23.54	1.	0.	400.	428.	526.	527.	529.
				530.	531.	488.	489.	294.
				296.	298.	299.	301.	
102.	23.55	1.	0.	400.	428.	526.	527.	529.
				530.	531.	488.	489.	294.
				295.	298.	299.	300.	301.
103.	23.53	1.	0.	400.	428.	521.	522.	526.
				527.	529.	530.	531.	488.
				490.	493.	494.	294.	295.
				298.				
104.	23.56	1.	0.	400.	428.	521.	522.	523.
				524.	526.	527.	529.	530.
				531.	488.	491.	493.	494.
				295.	297.			
105.	23.43	1.	0.	400.	428.	521.	522.	523.
				524.	525.	526.	527.	529.
				530.	531.	488.	491.	495.
				294.				
106.	23.43	1.	0.	400.	428.	521.	522.	523.
				524.	525.	526.	527.	529.
				530.	531.	488.	491.	495.
				294.				
107.	23.42	1.	0.	400.	428.	521.	522.	523.
				526.	527.	529.	530.	531.
				488.	490.	494.	294.	297.
				298.				
108.	23.44	1.	0.	400.	428.	521.	526.	527.
				529.	530.	531.	488.	490.
				492.	493.	295.		
201.	23.32	1.	0.	600.	552.			
202.	23.39	-1.	0.	600.	552.			
203.	23.39	1.	0.	600.	552.	553.	554.	
204.	23.42	1.	0.	600.	552.	553.	554.	555.
				556.				
205.	23.27	1.	0.	600.	552.	553.	554.	555.
				556.	557.	558.	559.	
206.	23.28	-1.	0.	600.	552.	553.	554.	555.
				556.	557.	558.	559.	
207.	23.30	1.	0.	600.	552.	553.	554.	555.
208.	23.31	1.	0.	600.	552.	553.		

WEIGHTS NOT LISTED IN THE WEIGHT TABLE ARE ASSIGNED NUMBERS 600 TO 699. THOSE USED IN THIS RUN ARE LISTED ON THIS PAGE. THEY INCLUDE PISTON, WEIGHT HANGERS ETC OF THE INSTURMENT UNDER TEST. ALSO LISTED ARE THE CHARACTERISTICS OF THE STANDARD USED IN THIS TEST AND AVAILABLE DATA FOR THE INSTRUMENT UNDER TEST.

NUMBER	MASS	DENSITY
600.	.011796456	10.240

CHARACTERISTICS OF THE STANDARD

1.1300000+02	STANDARD
8.3893592-06	AREA IN M**2
0.0000000	PRESSURE COEFFICIENT B IN PA(-1)
0.0000000	
0.0000000	
0.0000000	CIRCUMFERENCE OF PISTON IN M
0.0000000	OIL BUOYANCY (VOLUMN) CORRECTION ABOVE CYLINDER
5.0000000-06	THERMAL EXPANSIVITY OF PISTON /DEG C
5.0000000-06	THERMAL EXPANSIVITY OF CYLINDER /DEG C
0.0000000	
2.3000000+01	REFERENCE TEMPERATURE OF STANDARD DEG C
0.0000000	PZ (PA)
0.0000000	SZ ZERO CLEARANCE JACKET PRESSURE COEFFS. PA/N
0.0000000	QZ (PA/N**2)
0.0000000	D (1/PA)
0.0000000	E JACKET PRESSURE COEFFICIENTS
0.0000000	F
5.4000000-05	3 SIGMA A/A
0.0000000	3 SIGMA B1
0.0000000	3 SIGMA B2

2.0000000+02	INSTRUMENT UNDER TEST
8.0000000-06	AREA IN M**2
0.0000000	PRESSURE COEFFICIENT B FROM PREVIOUS CALIBRATION IN PA-1
0.0000000	
0.0000000	
0.0000000	CIRCUMFERENCE OF PISTON IN M
0.0000000	
5.0000000-06	THERMAL EXPANSIVITY OF PISTON /DEG C
5.0000000-06	THERMAL EXPANSIVITY OF CYLINDER /DEG C
-6.0000000-03	DIFFERENCE IN REFERENCE LEVELS IN M
2.3000000+01	REFERENCE TEMPERATURE OF THE INSTRUMENT UNDER TEST
1.1810000-03	DENSITY OF PRESSURE FLUID IN G/CM**3
9.8579999-06	PRESSURE COEFFICIENT OF DENSITY IN PA-1
0.0000000	SURFACE TENSION OF PRESSURE FLUID IN N/M

THIS TABLE LISTS THE FORCE GENERATED BY THE LOAD ON THE STANDARD INSTRUMENT. AN AIR BUOANCY CORRECTION HAS BEEN APPLIED. ALSO LISTED ARE THE CORRECTIONS FOR SURFACE TENSION, TEMPERATURE, JACKET PRESSURE AND PRESSURE COEFFICIENT OF THE STANDARD.

NO.	FORCE STD (N)	FLUID BUO. STD	SURF. T. (N)	TEMP. STD	JACKET PRESSURE	PRESS. COEFF.
101.	5.89496+00	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
102.	5.89508+00	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
103.	1.74534+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
104.	2.90120+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
105.	3.47912+01	0.00000	0.00000	1.00000+00	1.00000+00	1.00000+00
106.	3.47912+01	0.00000	0.00000	1.00000+00	1.00000+00	1.00000+00
107.	2.32326+01	0.00000	0.00000	1.00000+00	1.00000+00	1.00000+00
108.	1.16741+01	0.00000	0.00000	1.00000+00	1.00000+00	1.00000+00

THIS TABLE LISTS THE FORCE GENERATED BY THE LOAD ON THE INSTRUMENT UNDER TEST. AN AIR BUOANCY CORRECTION HAS BEEN APPLIED. ALSO LISTED ARE THE CORRECTIONS FOR SURFACE TENSION, TEMPERATURE AND FLUID HEAD IN THE CONNECTING LINES BETWEEN THE TWO INSTRUMENTS.

NO.	FORCE TEST (N)	FLUID BUO. TEST	SURF. T. (N)	TEMPERATURE TEST	HEAD C.(PA)
201.	.58976915+01	.00000000	.00000000	.10000032+01	-.4810727+00
202.	.58976915+01	.00000000	.00000000	.10000039+01	-.4810822+00
203.	.17461493+02	.00000000	.00000000	.10000039+01	-.1424324+01
204.	.29025611+02	.00000000	.00000000	.10000042+01	-.2367597+01
205.	.34807494+02	.00000000	.00000000	.10000027+01	-.2839220+01
206.	.34807494+02	.00000000	.00000000	.10000028+01	-.2839220+01
207.	.23243443+02	.00000000	.00000000	.10000030+01	-.1895958+01
208.	.11679504+02	.00000000	.00000000	.10000031+01	-.9526914+00

AFTER COMPUTATION OF THE PRESSURE GENERATED BY THE STANDARD AT THE REFERENCE LEVEL OF THE INSTRUMENT UNDER TEST THE FOLLOWING FUNCTIONS ARE FITTED TO THE DATA.

FIT 1 F=PA
FIT 2 F=PA-T
FIT 3 F=PA(1+B(1)P)
FIT 4 F=PA(1+B(1)P)-T
FIT 5 F=PA(1+B(1)P+B(2)P**2)
FIT 6 F=PA(1+B(1)P+B(2)P**2)-T
FIT 7 F=PA(1+B(2)P**2)
FIT 8 F=PA(1+B(2)P**2)-T

WITH F FORCE ON TEST INSTRUMENT
P PRESSURE AT REF LEVEL
A EFFECTIVE AREA OF TEST INSTRUMENT
B(1) AND B(2) PRESSURE COEFFICIENTS
T TARE WEIGHT (FORCE).

THIS TABLE LISTS THE OBSERVATION NUMBERS, PRESSURE AND THE RESIDUALS OF THE FITS CONVERTED TO THE EQUIVALENT PRESSURES.

OBS. NO.	PRESSURE KPA	RESIDUALS FIT1,PA	RESIDUALS FIT2,PA	RESIDUALS FIT3,PA	RESIDUALS FIT4,PA
0.	.0000000	.0000000	.1312606+02	.0000000	.7395883+01
1.	.7026680+03	-.2944043+01	.7262097+01	.2451431+01	.5602786+01
2.	.7026820+03	-.1737308+02	-.7166995+01	-.1197752+02	-.8826239+01
8.	.1391527+04	-.3273608+01	.4069992+01	.4827752+01	.5062633+01
3.	.2080407+04	-.4456101+01	.2487628-01	.3793193+01	.2343860+01
7.	.2769289+04	-.8989565+01	-.7371220+01	-.3150420+01	-.5051602+01
4.	.3458178+04	-.6690383+00	-.1913356+01	.2018073+00	-.9188383+00
5.	.4147043+04	.6900561+01	.2793680+01	.2452703+00	.1137468+01
6.	.4147043+04	.6502879+01	.2395998+01	-.1524116+00	.7397863+00

OBS. NO.	PRESSURE KPA	RESIDUALS FIT5,PA	RESIDUALS FIT6,PA	RESIDUALS FIT7,PA	RESIDUALS FIT8,PA
0.	.0000000	.0000000	.2598365+02	.0000000	.8332308+01
1.	.7026680+03	.3237069+01	.6958885+01	.1004954+01	.5503114+01
2.	.7026820+03	-.1119188+02	-.7470347+01	-.1342401+02	-.8925921+01
8.	.1391527+04	.5355329+01	.1244998+01	.3667362+01	.4847791+01
3.	.2080407+04	.3602217+01	.2969260+00	.3741204+01	.2474354+01
7.	.2769289+04	-.3966511+01	-.3011262+01	-.2130964+01	-.4543565+01
4.	.3458178+04	-.5920133+00	.2897124+01	.1396449+01	-.4293719+00
5.	.4147043+04	.6750021+00	-.2106509+00	-.1403981+00	.7839627+00
6.	.4147043+04	.2773202+00	-.6083328+00	-.5380800+00	.3862808+00

IN ORDER TO DETECT ANY EFFECT DUE TO THE ROTATION DIRECTION OF THE PISTONS THE RESIDUALS FROM FIT 6 ARE SEPARATED WITH RESPECT TO THE DIRECTION OF ROTATION OF THE PISTONS AND TABULATED.

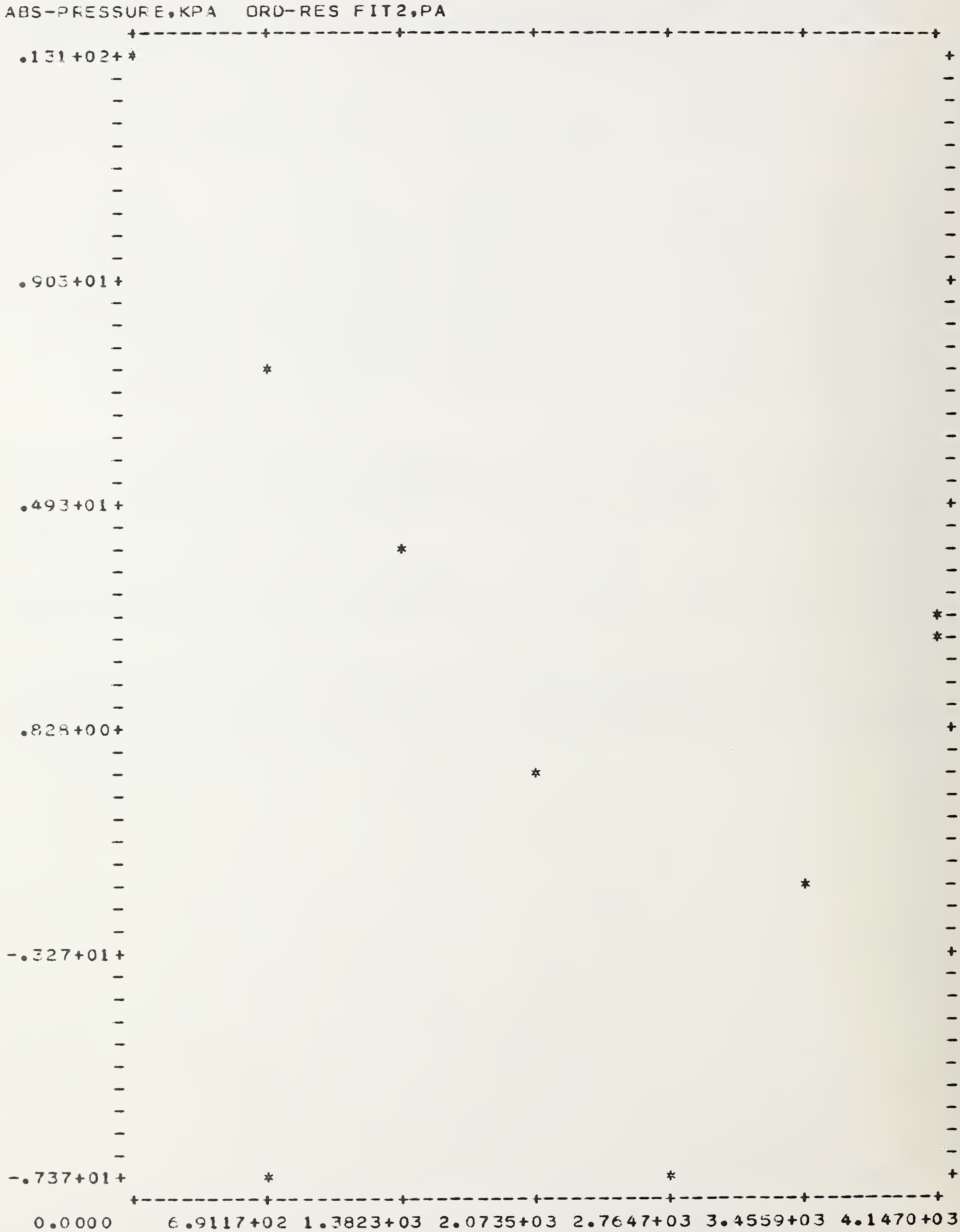
OBS. NO.	PRESSURE KPA	1=CW -1=CCW	TEST CW,PA	TEST CCW,PA	1=CW -1=CCW	STD. CW,PA	STD. CCW,PA
0.	.0000	0.	.0000	.0000	0.	.0000	.0000
1.	.7027+03	1.	.6959+01	.0000	1.	.6959+01	.0000
2.	.7027+03	-1.	.0000	-.7470+01	1.	-.7470+01	.0000
8.	.1392+04	1.	.1245+01	.0000	1.	.1245+01	.0000
3.	.2080+04	1.	.2969+00	.0000	1.	.2969+00	.0000
7.	.2769+04	1.	-.3011+01	.0000	1.	-.3011+01	.0000
4.	.3458+04	1.	.2897+01	.0000	1.	.2897+01	.0000
5.	.4147+04	1.	-.2107+00	.0000	1.	-.2107+00	.0000
6.	.4147+04	-1.	.0000	-.6083+00	1.	-.6083+00	.0000

FIT 4 DETERMINES THE EFFECTIVE AREA A, THE FIRST PRESSURE COEFFICIENT B(1), AND THE TARE T. THE RESIDUALS OF THIS FIT, CONVERTED TO PRESSURE, ARE PLOTTED AS FUNCTION OF PRESSURE. TRENDS, ERRORS IN INDIVIDUAL POINTS, TARE ERRORS, HYSTERESIS ETC CAN EASILY BE DETECTED.

NOTE THAT AN S-SHAPE OF A CURVE THROUGH THE DATA INDICATES A QUADRATIC TERM IN THE PRESSURE COEFFICIENT, WHICH IS INCLUDED IN FIT 6

FIT 6 DETERMINES THE EFFECTIVE AREA A, THE TWO PRESSURE COEFFICIENTS B(1) AND B(2),AND THE TARE T. THE RESIDUALS OF THIS FIT, CONVERTED TO PRESSURE, ARE PLOTTED AS FUNCTION OF PRESSURE. TRENDS, ERRORS IN INDIVIDUAL POINTS, TARE ERRORS, HYSTERESIS ETC CAN EASILY BE DETECTED.


ABS-PRESSURE,KPA ORD-RES FIT1,PA
.690+01
.205+01
-.281+01
-.766+01
-.125+02
-.174+02
0.0000 6.9117+02 1.3823+03 2.0735+03 2.7647+03 3.4559+03 4.1470+03


ABS-PRESSURE,KPA ORD-RES FIT2,PA
.131+02
.903+01
.493+01
.828+00
-.327+01
-.737+01
0.0000
6.9117+02
1.3823+03
2.0735+03
2.7647+03
3.4559+03
4.1470+03

THE RESULTS OF THE TEST ARE COMPILED IN THIS TABLE. IT LISTS THE COEFFICIENTS AND THEIR TRIPLED STANDARD DEVIATIONS DUE TO RANDOM SOURCES OF ERRORS AND, FOR THE HIGHEST PRESSURE, THE UNCERTAINTY IN PRESSURE DUE TO THE UNCERTAINTY IN THESE COEFFICIENTS.

SELECTION RULES:

ANY FIT FOR WHICH THE TRIPLED STANDARD DEVIATION OF A COEFFICIENT IS LARGER THAN THE COEFFICIENT IS DISCARDED.

THE FIT WITH THE SMALLEST STANDARD DEVIATION OF THE RESIDUALS REPRESENTS THE DATA MOST CLOSELY.

AMONG NEARLY EQUIVALENT FITS THE ONE WITH THE SMALLER NUMBER OF COEFFIECIENT SHOULD BE USED.

COEFF,FIT 1	COEFF,FIT 2	COEFF,FIT 3	COEFF, FIT 4	
8.393291-06	8.393326-06	8.393211-06	8.393269-06	AREA, M**2
0.000000	0.000000	2.695255-09	1.396792-09	PRES COEF B1 KPA-1
0.000000	0.000000	0.000000	0.000000	PRES COEF B2 KPA-2
0.000000	0.000000	0.000000	0.000000	
0.000000	1.101709-04	0.000000	6.207580-05	TARE, N
3.278385-06	4.500194-06	9.528252-06	2.466510-05	3 STD DEV A/A
0.000000	0.000000	2.610492-09	4.995972-09	3 STD DEV B1 KPA-1
0.000000	0.000000	0.000000	0.000000	3 STD DEV B2 KPA-2
0.000000	0.000000	0.000000	0.000000	
0.000000	1.045358-04	0.000000	2.026503-04	3 STD DEV T, N
2.566283-02	1.697980-02	1.719967-02	1.742184-02	3 RES STD DEV KPA
3.278385-06	7.303462-06	2.035407-05	5.120567-05	3 STD DEV P-MAX/P MAX

COEFF,FIT 5	COEFF,FIT 6	COEFF,FIT 7	COEFF,FIT 8	
8.393193-06	8.393567-06	8.393242-06	8.393289-06	AREA, M**2
4.359405-09	-1.576991-08	0.000000	0.000000	PRES COEF B1 KPA-1
-2.824117-13	2.359468-12	4.380851-13	2.183635-13	PRES COEF B2 KPA-2
0.000000	0.000000	0.000000	0.000000	
0.000000	2.180884-04	0.000000	6.993549-05	TARE, N
2.466523-05	9.137254-05	6.506812-06	1.426122-05	3 STD DEV A/A
1.757493-08	4.305591-08	0.000000	0.000000	3 STD DEV B1 KPA-1
2.943438-12	5.882021-12	4.569781-13	6.672689-13	3 STD DEV B2 KPA-2
0.000000	0.000000	0.000000	0.000000	
0.000000	4.344023-04	0.000000	1.616099-04	3 STD DEV T, N
1.868752-02	1.668562-02	1.797761-02	1.703261-02	3 RES STD DEV KPA
1.481704-04	3.335662-04	1.436591-05	3.037987-05	3 STD DEV P-MAX/P MAX

THE TOTAL TRIPLED STANDARD DEVIATION OF A COEFFICIENT IS THE SUM OF THE TRIPLED STANDARD DEVIATION DUE TO RANDOM SOURCES OF ERROR LISTED ON THE PRECEDING PAGE PLUS THE SYSTEMATIC UNCERTAINTY LISTED BELOW:

COEFFICIENT	STST. UNCERTAINTY	
A	5.40-05	A/A
B1	0.00	KPA-1
B2	0.00	KPA-2

WE SUGGEST TO USE FIT NUMBER: 1

FOR THE DIRECTOR

NATIONAL MEASUREMENT LABORATORY

James F. Schooley

JAMES F. SCHOOLEY
CHIEF, TEMPERATURE MEASUREMENTS
AND STANDARDS DIVISION
CENTER FOR ABSOLUTE PHYSICAL QUANTITIE

RGD
P-7772
52200/5220607

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
NATIONAL MEASUREMENT LABORATORY
WASHINGTION, D.C. 20234

R E P O R T O F C A L I B R A T I O N

ONE DOUBLE -RANGE DEAD WEIGHT PISTON GAGE
SUBMITTED BY

NBS-BOULDER

INSTRUMENT RECEIVED:MAY 18,1981 TEST COMPLETED:JUNE 5,1981
REFERENCE: COST CENTER
NO.7732571

DESCRIPTION

NBS IDENTIFICATION NO.: P-7772A
MANUFACTURER: RUSKA
MANUFACTURER'S SERIAL NO.: NONE
MANUFACTURER'S TYPE NO.: NONE
WEIGHTS WERE NOT RECEIVED WITH THE INSTRUMENT.

PISTON NO.: TL-497 PRESSURE RANGE: 1.4 TO 103 KPA
CYLINDER NO.: TL-497 CYLINDER TYPE: SIMPLE
NOMINAL SIZE: 3.4E-4 SQ. METER

REFERENCE TEMPERATURE, T(S) = 23.0 DEGREES C.

THE INSTRUMENT WAS LEVELED SO THAT THE AXIS OF ROTATION OF THE PISTON WAS VERTICAL.

OBSERVATIONS WERE MADE WITH MANUAL ROTATION OF THE WEIGHTS ON THE TEST GAGE.

THE TEMPERATURE WAS MAINTAINED NEAR 23 DEGREES C AND CORRECTIONS WERE BASED ON READINGS OF AN ATTACHED THERMOMETER.

NBS WEIGHTS WERE USED IN THE CALIBRATION.

REFERENCE LEVEL AND PISTON POSITION, THE REFERENCE LEVEL IS 0.010 METER ABOVE THE LOWER EDGE OF THE WEIGHT HANGER. THE GAGE WAS OPERATED WITH THE LOWER EDGE OF THE WEIGHT HANGER AT THE LEVEL OF THE INDEX LINE MARKED ON THE PISTON/CYLINDER HEAD ASSEMBLY.

THE INSTRUMENT WAS CALIBRATED WITH NITROGEN USED AS THE PRESSURE TRANSMITTING FLUID.

IF A TARE ERROR IS INDICATED,IT SHOULD BE ADDED ALGEBRAICALLY, IN PA, TO THE PRESSURE DEVELOPED BY THE GAGE.

VALUES OF CHARACTERISTIC PARAMETERS OF THE INSTRUMENT WITH THE ESTIMATED UNCERTAINTY OF THE DETERMINATION ARE GIVEN IN THE FOLLOWING TABLE(S). EXPLANATORY INFORMATION IS GIVEN IN THE ENCLOSED ''SUPPLEMENT FOR REPORTS ON DEAD WEIGHT PISTON GAGES''.

TO FACILITATE THE DETECTION OF ERRORS THE WEIGHT NUMBERS, GAGE TEMPERATURES, DIRECTION OF ROTATION (1.=CW, -1.=CCW) AND JACKET PRESSURE P-J ARE LISTED FOR ALL OBSERVATIONS. OBSERVATION NUMBERS 101 TO 199 REFER TO THE STANDARD, AND 201 TO 299 REFER TO THE TEST INSTRUMENT. MASS AND DENSITY OF THE WEIGHTS ARE LISTED IN THE WEIGHT TABLE.

OBS. NO.	TEMP(C)	ROT	P-J(PA)	WEIGHT NUMBERS				
101.	23.58	1.	0.	601.	428.	528.	529.	530.
				531.	488.	489.	492.	495.
				296.	298.			
102.	23.58	1.	0.	601.	428.	528.	529.	530.
				531.	488.	489.	492.	495.
				296.	298.			
103.	23.61	1.	0.	601.	428.	521.	526.	529.
				530.	531.	488.	489.	492.
				494.	294.			
104.	23.62	1.	0.	601.	428.	521.	522.	523.
				524.	525.	526.	527.	529.
				530.	531.	488.	489.	491.
				297.				
105.	23.62	1.	0.	601.	428.	521.	522.	523.
				524.	525.	526.	527.	529.
				530.	531.	488.	489.	491.
				297.				
106.	23.65	1.	0.	601.	428.	521.	522.	523.
				524.	526.	528.	529.	530.
				531.	488.	489.	492.	493.
				495.	295.	299.		
107.	23.68	1.	0.	601.	428.	521.	522.	523.
				529.	530.	531.	488.	489.
				492.	493.	294.	297.	298.
				299.				
108.	23.68	1.	0.	601.	428.	521.	522.	523.
				529.	530.	531.	488.	489.
				492.	493.	294.	297.	298.
				299.				
201.	23.54	1.	0.	600.	557.			
202.	23.54	-1.	0.	600.	557.			
203.	23.52	1.	0.	600.	552.	557.	559.	
204.	23.51	1.	0.	600.	552.	553.	554.	555.
				556.	557.	558.	559.	
205.	23.50	-1.	0.	600.	552.	553.	554.	555.
				556.	557.	558.	559.	
206.	23.50	1.	0.	600.	552.	553.	554.	555.
				557.	558.			
207.	23.50	1.	0.	600.	552.	553.	554.	559.
208.	23.50	-1.	0.	600.	552.	553.	554.	559.

WEIGHTS NOT LISTED IN THE WEIGHT TABLE ARE ASSIGNED NUMBERS 600 TO 699. THOSE USED IN THIS RUN ARE LISTED ON THIS PAGE. THEY INCLUDE PISTON, WEIGHT HANGERS ETC OF THE INSTURMENT UNDER TEST. ALSO LISTED ARE THE CHARACTERISTICS OF THE STANDARD USED IN THIS TEST AND AVAILABLE DATA FOR THE INSTRUMENT UNDER TEST.

NUMBER	MASS	DENSITY
600.	.047207629	7.670
601.	.046982191	7.670

CHARACTERISTICS OF THE STANDARD

1.2200000+02	STANDARD
3.3571380-04	AREA IN M**2
0.0000000	PRESSURE COEFFICIENT B IN PA(-1)
0.0000000	
0.0000000	
0.0000000	CIRCUMFERENCE OF PISTON IN M
0.0000000	OIL BUOYANCY (VOLUMN) CORRECTION ABOVE CYLINDER
1.0000000-05	THERMAL EXPANSIVITY OF PISTON /DEG C
4.5500000-06	THERMAL EXPANSIVITY OF CYLINDER /DEG C
0.0000000	
2.3000000+01	REFERENCE TEMPERATURE OF STANDARD DEG C
0.0000000	PZ (PA)
0.0000000	SZ ZERO CLEARANCE JACKET PRESSURE COEFFS. PA/N
0.0000000	QZ (PA/N**2)
0.0000000	D (1/PA)
0.0000000	E JACKET PRESSURE COEFFICIENTS
0.0000000	F
5.7000000-05	3 SIGMA A/A
0.0000000	3 SIGMA B1
0.0000000	3 SIGMA B2

2.0000000+02	INSTRUMENT UNDER TEST
3.4000000-06	AREA IN M**2
0.0000000	PRESSURE COEFFICIENT B FROM PREVIOUS CALIBRATION IN PA-1
0.0000000	
0.0000000	
0.0000000	CIRCUMFERENCE OF PISTON IN M
0.0000000	
1.0000000-05	THERMAL EXPANSIVITY OF PISTON /DEG C
4.5500000-06	THERMAL EXPANSIVITY OF CYLINDER /DEG C
-6.0000000-03	DIFFERENCE IN REFERENCE LEVELS IN M
2.3000000+01	REFERENCE TEMPERATURE OF THE INSTRUMENT UNDER TEST
1.1310000-03	DENSITY OF PRESSURE FLUID IN G/CM**3
9.8579999-06	PRESSURE COEFFICIENT OF DENSITY IN PA-1
0.0000000	SURFACE TENSION OF PRESSURE FLUID IN N/M

THIS TABLE LISTS THE FORCE GENERATED BY THE LOAD ON THE STANDARD INSTRUMENT. AN AIR BUOYANCY CORRECTION HAS BEEN APPLIED. ALSO LISTED ARE THE CORRECTIONS FOR SURFACE TENSION, TEMPERATURE, JACKET PRESSURE AND PRESSURE COEFFICIENT OF THE STANDARD.

NO.	FORCE STD (N)	FLUID BUO. STD	SURF. T. (N)	TEMP. STD	JACKET PRESSURE	PRESS. COEFF.
101.	2.77549+00	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
102.	2.77549+00	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
103.	9.71434+00	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
104.	3.51569+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
105.	3.51569+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
106.	2.82178+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
107.	1.89662+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00
108.	1.89662+01	0.00000	0.00000	1.00001+00	1.00000+00	1.00000+00

THIS TABLE LISTS THE FORCE GENERATED BY THE LOAD ON THE INSTRUMENT UNDER TEST. AN AIR BUOANCY CORRECTION HAS BEEN APPLIED. ALSO LISTED ARE THE CORRECTIONS FOR SURFACE TENSION, TEMPERATURE AND FLUID HEAD IN THE CONNECTING LINES BETWEEN THE TWO INSTRUMENTS.

NO.	FORCE TEST (N)	FLUID BUO. TEST	SURF. T. (N)	TEMPERATURE TEST	HEAD C.(PA)
201.	.27752383+01	.00000000	.00000000	.10000079+01	-.5660143-02
202.	.27752383+01	.00000000	.00000000	.10000079+01	-.5660143-02
203.	.97137386+01	.00000000	.00000000	.10000076+01	-.1981075-01
204.	.35154501+02	.00000000	.00000000	.10000074+01	-.7169649-01
205.	.35154501+02	.00000000	.00000000	.10000073+01	-.7169649-01
206.	.28215921+02	.00000000	.00000000	.10000073+01	-.5754530-01
207.	.18964913+02	.00000000	.00000000	.10000073+01	-.3867842-01
208.	.18964913+02	.00000000	.00000000	.10000073+01	-.3867842-01

AFTER COMPUTATION OF THE PRESSURE GENERATED BY THE STANDARD AT THE REFERENCE LEVEL OF THE INSTRUMENT UNDER TEST THE FOLLOWING FUNCTIONS ARE FITTED TO THE DATA.

FIT 1 F=PA
FIT 2 F=PA-T
FIT 3 F=PA(1+B(1)P)
FIT 4 F=PA(1+B(1)P)-T
FIT 5 F=PA(1+B(1)P+B(2)P**2)
FIT 6 F=PA(1+B(1)P+B(2)P**2)-T
FIT 7 F=PA(1+B(2)P**2)
FIT 8 F=PA(1+B(2)P**2)-T

WITH F FORCE ON TEST INSTRUMENT
P PRESSURE AT REF LEVEL
A EFFECTIVE AREA OF TEST INSTRUMENT
B(1) AND B(2) PRESSURE COEFFICIENTS
T TARE WEIGHT (FORCE).

THIS TABLE LISTS THE OBSERVATION NUMBERS, PRESSURE AND THE RESIDUALS OF THE FITS CONVERTED TO THE EQUIVALENT PRESSURES.

OBS. NO.	PRESSURE KPA	RESIDUALS FIT1,PA	RESIDUALS FIT2,PA	RESIDUALS FIT3,PA	RESIDUALS FIT4,PA
0.	.0000000	.0000000	.1429185+00	.0000000	.2168070+00
1.	.8267363+01	-.2020515+00	-.7382170-01	-.1895215+00	-.3465071-01
2.	.8267363+01	-.2020515+00	-.7382170-01	-.1895215+00	-.3465071-01
3.	.2893613+02	.1439494+00	.2354569+00	.1767322+00	.2118017+00
7.	.5649477+02	-.1305441+00	-.8800017-01	-.9536394-01	-.1421587+00
8.	.5649477+02	-.1305441+00	-.8800017-01	-.9536394-01	-.1421587+00
6.	.8405226+02	.2403270+00	.2339094+00	.2497840+00	.2101202+00
4.	.1047219+03	-.3707709-01	-.8021859-01	-.6536945-01	-.4127884-01
5.	.1047219+03	-.2429294-01	-.6743443-01	-.5258529-01	-.2849469-01

OBS. NO.	PRESSURE KPA	RESIDUALS FIT5,PA	RESIDUALS FIT6,PA	RESIDUALS FIT7,PA	RESIDUALS FIT8,PA
0.	.0000000	.0000000	.2180873+00	.0000000	.2015142+00
1.	.8267363+01	-.1210731+00	-.3430501-01	-.1966552+00	-.3769040-01
2.	.8267363+01	-.1210731+00	-.3430501-01	-.1966552+00	-.3769040-01
3.	.2893613+02	.2736695+00	.2112032+00	.1611284+00	.2206319+00
7.	.5649477+02	-.1226487+00	-.1422083+00	-.1072171+00	-.1416321+00
8.	.5649477+02	-.1226487+00	-.1422083+00	-.1072171+00	-.1416321+00
6.	.8405226+02	.1501688+00	.2107139+00	.2500355+00	.2016978+00
4.	.1047219+03	-.2946957-01	-.4143494-01	-.5635694-01	-.3916290-01
5.	.1047219+03	-.1668541-01	-.2865078-01	-.4357278-01	-.2637875-01

IN ORDER TO DETECT ANY EFFECT DUE TO THE ROTATION DIRECTION OF THE PISTONS THE RESIDUALS FROM FIT 6 ARE SEPARATED WITH RESPECT TO THE DIRECTION OF ROTATION OF THE PISTONS AND TABULATED.

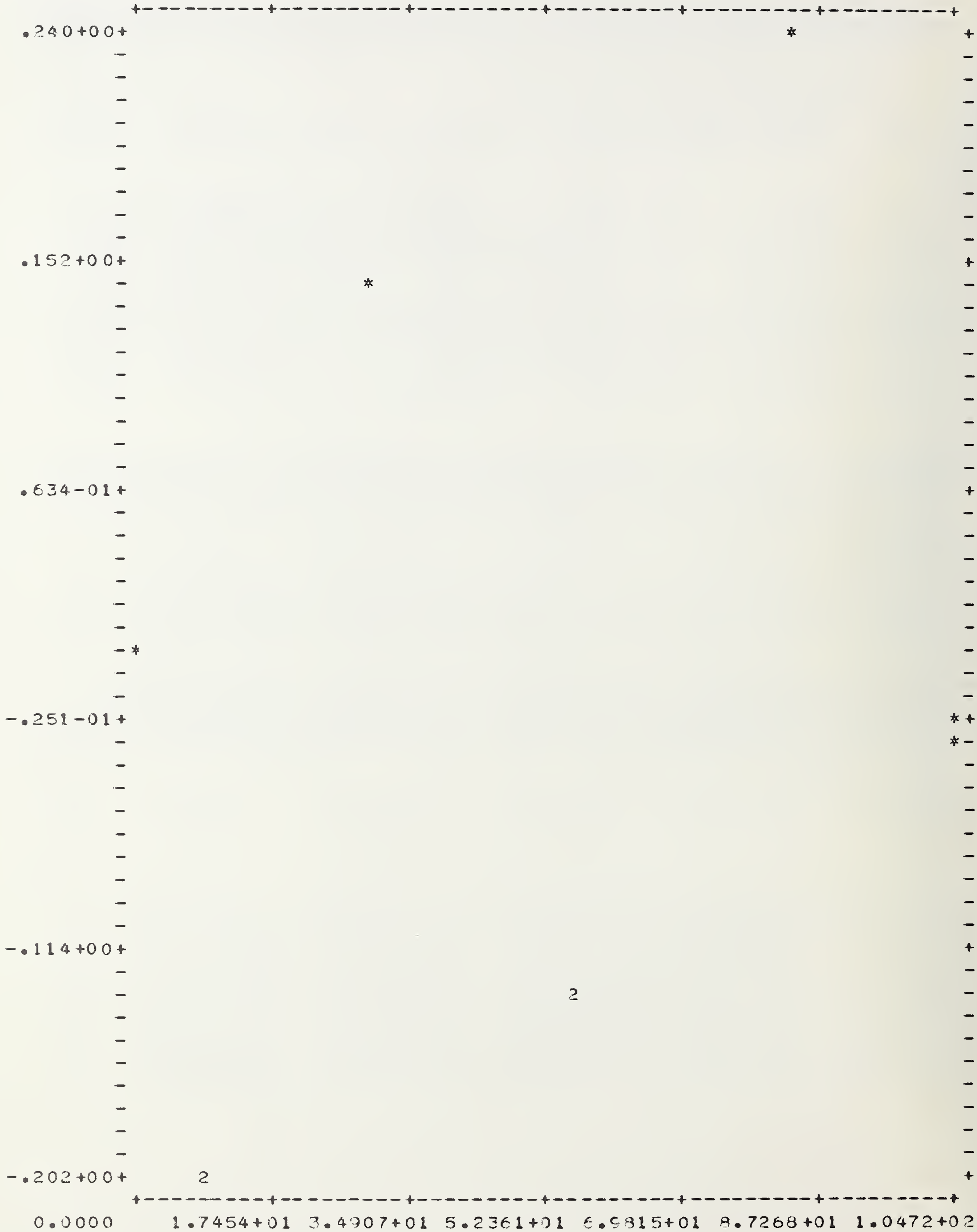
OBS. NO.	PRESSURE KPA	1=CW -1=CCW	TEST CW,PA	TEST CCW,PA	1=CW -1=CCW	STD. CW,PA	STD. CCW,PA
0.	.0000	0.	.0000	.0000	0.	.0000	.0000
1.	.8267+01	1.	-.3431-01	.0000	1.	-.3431-01	.0000
2.	.8267+01	-1.	.0000	-.3431-01	1.	-.3431-01	.0000
3.	.2894+02	1.	.2112+00	.0000	1.	.2112+00	.0000
7.	.5649+02	1.	-.1422+00	.0000	1.	-.1422+00	.0000
8.	.5649+02	-1.	.0000	-.1422+00	1.	-.1422+00	.0000
6.	.8405+02	1.	.2107+00	.0000	1.	.2107+00	.0000
4.	.1047+03	1.	-.4143-01	.0000	1.	-.4143-01	.0000
5.	.1047+03	-1.	.0000	-.2865-01	1.	-.2865-01	.0000

FIT 4 DETERMINES THE EFFECTIVE AREA A, THE FIRST PRESSURE COEFFICIENT B(1), AND THE TARE T. THE RESIDUALS OF THIS FIT, CONVERTED TO PRESSURE, ARE PLOTTED AS FUNCTION OF PRESSURE. TRENDS, ERRORS IN INDIVIDUAL POINTS, TARE ERRORS, HYSTERESIS ETC CAN EASILY BE DETECTED.

NOTE THAT AN S-SHAPE OF A CURVE THROUGH THE DATA INDICATES A QUADRATIC TERM IN THE PRESSURE COEFFICIENT, WHICH IS INCLUDED IN FIT 6

FIT 6 DETERMINES THE EFFECTIVE AREA A, THE TWO PRESSURE COEFFICIENTS B(1) AND B(2),AND THE TARE T. THE RESIDUALS OF THIS FIT, CONVERTED TO PRESSURE, ARE PLOTTED AS FUNCTION OF PRESSURE. TRENDS, ERRORS IN INDIVIDUAL POINTS, TARE ERRORS, HYSTERESIS ETC CAN EASILY BE DETECTED.

ABS-PRESSURE,KPA   ORD-RES FIT1,PA



ABS-PRESSURE,KPA ORD-RES FIT2,PA

THE RESULTS OF THE TEST ARE COMPILED IN THIS TABLE. IT LISTS THE COEFFICIENTS AND THEIR TRIPLED STANDARD DEVIATIONS DUE TO RANDOM SOURCES OF ERRORS AND, FOR THE HIGHEST PRESSURE, THE UNCERTAINTY IN PRESSURE DUE TO THE UNCERTAINTY IN THESE COEFFICIENTS.

SELECTION RULES:

ANY FIT FOR WHICH THE TRIPLED STANDARD DEVIATION OF A COEFFICIENT IS LARGER THAN THE COEFFICIENT IS DISCARDED.

THE FIT WITH THE SMALLEST STANDARD DEVIATION OF THE RESIDUALS REPRESENTS THE DATA MOST CLOSELY.

AMONG NEARLY EQUIVALENT FITS THE ONE WITH THE SMALLER NUMBER OF COEFFIECIENT SHOULD BE USED.

```
COEFF,FIT 1 COEFF,FIT 2 COEFF,FIT 3 COEFF, FIT 4

 3.356916-04 3.356922-04 3.356910-04 3.356937-04 AREA, M**2
 0.000000    0.000000    1.851413-08-4.007678-08 PRES COEF B1 KPA-1
 0.000000    0.000000    0.000000    0.000000    PRES COEF B2 KPA-2
 0.000000    0.000000    0.000000    0.000000
 0.000000    4.797654-05 0.000000    7.278028-05 TARE, N


 2.633971-06 4.521828-06 1.229878-05 2.002653-05 3 STD DEV A/A
 0.000000    0.000000    1.328606-07 1.722349-07 3 STD DEV B1 KPA-1
 0.000000    0.000000    0.000000    0.000000    3 STD DEV B2 KPA-2
 0.000000    0.000000    0.000000    0.000000
 0.000000    1.023281-04 0.000000    1.508193-04 3 STD DEV T, N


 5.022220-04 4.704085-04 5.348234-04 4.917515-04 3 RES STD DEV KPA
 2.633971-06 7.432660-06 2.621220-05 4.235351-05 3 STD DEV
                                                      P-MAX/P MAX


COEFF,FIT 5 COEFF,FIT 6 COEFF,FIT 7 COEFF,FIT 8

 3.356874-04 3.356937-04 3.356914-04 3.356931-04 AREA, M**2
 3.336919-07-4.304209-08 0.000000    0.000000    PRES COEF B1 KPA-1
-2.061204-09 1.712985-11 7.678588-11-2.339563-10 PRES COEF B2 KPA-2
 0.000000    0.000000    0.000000    0.000000
 0.000000    7.321007-05 0.000000    6.764661-05 TARE, N


 3.395029-05 7.592434-05 7.952472-06 1.271211-05 3 STD DEV A/A
 9.380736-07 1.657469-06 0.000000    0.000000    3 STD DEV B1 KPA-1
 6.073343-09 9.713267-09 8.673673-10 1.010118-09 3 STD DEV B2 KPA-2
 0.000000    0.000000    0.000000    0.000000
 0.000000    2.615848-04 0.000000    1.366206-04 3 STD DEV T, N


 5.332904-04 5.497928-04 5.392947-04 4.921266-04 3 RES STD DEV KPA
 1.987915-04 3.634609-04 1.746460-05 2.767606-05 3 STD DEV
                                                      P-MAX/P MAX
```

THE TOTAL TRIPLED STANDARD DEVIATION OF A COEFFICIENT IS THE SUM OF THE TRIPLED STANDARD DEVIATION DUE TO RANDOM SOURCES OF ERROR LIST- ED ON THE PRECEDING PAGE PLUS THE SYSTEMATIC UNCERTAINTY LISTED BELOW:

COEFFICIENT	STST. UNCERTAINTY
A	5.70-05 A/A
B1	0.00 KPA-1
B2	0.00 KPA-2

WE SUGGEST TO USE FIT NUMBER: 1

FOR THE DIRECTOR

NATIONAL MEASUREMENT LABORATORY

JAMES F. SCHOOLEY
CHIEF, TEMPERATURE MEASUREMENTS
AND STANDARDS DIVISION
CENTER FOR ABSOLUTE PHYSICAL QUANTITIES

STATE OF COLORADO

DEPARTMENT OF AGRICULTURE
1525 Sherman Street
Denver, Colorado 80203
(303) 839-2811

September 14, 1981

REPORT OF TEST

OWNER: National Bureau of Standards
Boulder, Colorado

Cert. No: 7428
S/N: 28337

DESCRIPTION: Ruska dead weight tester weights.

The standards described below have been tested and compared sith the standards of the State of Colorado, and have been found to have the apparent mass vs brass corrections as indicated below. The effect of air bouyancy has been considered negligible.

ITEM NUMBER	APP. MASS VS BRASS	UNCERTAINTY
1	1.30084 lb	0.87 ulb
2	1.30078	"
3	1.30073	"
4	1.30080	"
5	1.30079	"
7	0.520319	0.69 ulb
8	0.520313	"
9	0.260165	"
10	0.130072	0.24 ulb
11	0.0520390	0.19 ulb
12	0.0520339	"
13	0.0260203	0.18 ulb
14	0.0130124	0.17 ulb
15	0.0065115	"

The uncertainty figure is an expression of the overall uncertainty using three standard deviations as a limit of the effect of random errors of measurement, the magnitude of systematic errors from known sources being negligible.

THESE CERTIFICATIONS ARE TRACEABLE TO THE NATIONAL BUREAU OF STANDARDS.

ALL CERTIFICATES ISSUED BY THE COLORADO DEPARTMENT OF AGRICULTURE-METROLOGY LABORATORY EXPIRE ONE YEAR FROM THE DATE OF ISSUANCE.

F H Brzoticky, Chief Metrologist
Colorado Metrology Laboratory
3125 Wyandot St.
Denver, Colorado 80211

Form M-WM-45
Rev. 12-75

COLORADO DEPARTMENT OF AGRICULTURE

WEIGHTS AND MEASURES-METROLOGY LABORATORY

3125 Wyandot   Denver, Colorado 80211

(303)839-2845

Date: Sept. 14, 1981

CERTIFICATE of weights and measures tested, sealed, calibrated.

OWNER National Bureau of Standards   Identification or S/N: 28337

ADDRESS Boulder, Colorado   Make/description: Ruska dead weight tester weights

SUBMITTED BY: Chas. Sindt

Avdp. Weight		Grain-Gram-Etc. Weights	Volume Measures	Linear or other measures	Remarks
____ 1000 lb.	____ 8 oz.	____	____ 1000 gal.	____	
____ 500 lb.	____ 4 oz.	____	____ 100 gal.	____	
____ 50 lb.	____ 2 oz.	____	____ 50 gal.	____	
____ 25 lb.	____ 1 oz.	____	____ 25 gal.	____	
____ 20 lb.	____ 1/2 oz.	____	____ 20 gal.	____	
____ 10 lb.	____ 1/4 oz.	____	____ 10 gal.	____	
____ 5 lb.	____ 1/8 oz.	____	____ 5 gal.	____	
____ 3 lb.	____ 1/16 oz.	____	____ 3 gal.	____	
____ 2 lb.	____ 1/32 oz.	____	____ 2 gal.	____	
____ 1 lb.	____	____	____ 1 gal.	____	
____ lb.	____	____	____ 1/2 gal.	____	
____ lb.	____	____	____ 1 qt.	____	
____ lb.	____	____	____ 1 pt.	____	
____ lb.	____	____	____	____	
____ lb.	SEE REPORT OF	TEST ATTACHED	____	____	

(X) MASS: The test weights described above have been compared with the standards of the State of Colorado and found (adjusted) to be within the tolerances for their class as prescribed by the National Bureau of Standards.

(X) See "Report of Test/Calibration" attached.

(   ) LENGTH: The linear measures described above have been compared with the standards of the State of Colorado and found to be within the tolerances prescribed by the National Bureau of Standards for this type of equipment.

(   ) VOLUME: The volumetric standards described above have been compared with the standards of the State of Colorado and found (adjusted) to deliver ________________ at ______ °F.

(   ) ________________

This value applies when a ______ second drain period is used following the cessation of the main flow.

(   ) FREQUENCY: The tuning fork described above has been compared with the standard frequency output of the National Bureau of Standards. This is to certify the above described tuning fork has been tested and found to oscillate at ______ Hz. When used with a doppler radar traffic gun operating at ______ MHz, it will result in a reading of ______ mph.

(N/A)-(Not Applicable)

THIS CERTIFICATION IS TRACEABLE TO THE NATIONAL BUREAU OF STANDARDS. THIS CERTIFICATE ISSUED BY THE COLORADO DEPARTMENT OF AGRICULTURE WEIGHTS AND MEASURES-METROLOGY LABORATORY FOR STANDARDS HERE LISTED EXPIRE 1 YEAR/S AFTER THE DATE OF CERTIFICATION.

____
Colorado State Metrologist

No. 7428

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBS TN-1052	2. Performing Organ. Report No.	3. Publication Date February 1982

4. TITLE AND SUBTITLE

An Accuracy Statement for a Facility Used to Calibrate Static Pressure Transducers and Differential Pressure Transducers at High Base Pressure

5. AUTHOR(S)

C. F. Sindt and J. F. LaBrecque

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

American Gas Association
1515 Wilson Blvd.
Arlington, VA 22209

The Gas Research Institute
10 West 35th Street
Chicago, IL 60616

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A facility has been developed to calibrate pressure transducers that are used in the NBS Gas Mass Flow Facility. Both static and differential pressure transducers can be calibrated. An air dead weight tester is the standard for static transducers in the range from 3.8 to 4.5 MPa. An air dead weight tester is also the standard for the differential pressure transducers in the range of 2.5 kPa to 50 MPa; a cistern manometer provides the transfer for the standard to a base operating pressure of 4.1 MPa. The calibration of the air dead weight gage adds ±69 ppm to the calibration of the cistern manometer. This, plus the uncertainties in the high pressure corrections to the cistern manometer and our measurement of the mercury temperature, contributes ±690 ppm to the uncertainty of the differential pressure transducer calibrations.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

calibration; differential manometer; piston gage; pressure difference; pressure transducer; standards.

13. AVAILABILITY

☒ Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

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NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress on March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau's technical work is performed by the National Measurement Laboratory, the National Engineering Laboratory, and the Institute for Computer Sciences and Technology.

THE NATIONAL MEASUREMENT LABORATORY provides the national system of physical and chemical and materials measurement; coordinates the system with measurement systems of other nations and furnishes essential services leading to accurate and uniform physical and chemical measurement throughout the Nation's scientific community, industry, and commerce; conducts materials research leading to improved methods of measurement, standards, and data on the properties of materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; develops, produces, and distributes Standard Reference Materials; and provides calibration services. The Laboratory consists of the following centers:

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THE NATIONAL ENGINEERING LABORATORY provides technology and technical services to the public and private sectors to address national needs and to solve national problems; conducts research in engineering and applied science in support of these efforts; builds and maintains competence in the necessary disciplines required to carry out this research and technical service; develops engineering data and measurement capabilities; provides engineering measurement traceability services; develops test methods and proposes engineering standards and code changes; develops and proposes new engineering practices; and develops and improves mechanisms to transfer results of its research to the ultimate user. The Laboratory consists of the following centers:

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Programming Science and Technology — Computer Systems Engineering.

[1]Headquarters and Laboratories at Gaithersburg, MD, unless otherwise noted;
mailing address Washington, DC 20234.
[2]Some divisions within the center are located at Boulder, CO 80303.