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CALIBRATION OF A PITOT-STATIC RAKE

Hampton P. Stump

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CALIBRATION OF A PITOT-STATIC RAKE

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PREFACE

This report concerns an analysis of a calibration performed at the National Bureau of Standards (NBS), Gaithersburg, Maryland, where the primary measurements were obtained and reported in U.S. customary units. Therefore, in the interest of clarity and reader ease of understanding, these same customary units will be used primarily in this report followed by the International System (SI) units in parentheses where applicable. Also, comparable SI equations will follow the U.S. customary equations and SI scales will be added to all data plots presented with customary units. In addition, the tables supplied by the NBS (1 through 4) will be converted (ref. 1) to SI units and included in this report. This method of units presentation has been cleared for this paper by the Chief, Scientific and Technical Information Division and is essentially in accordance with Langley Announcement 59-76 (Oct. 21, 1976), Use of the International Systems of Units (SI) in NASA Scientific and Technical Publications.

SUMMARY

A five-element pitot-static rake was tested at the National Bureau of Standards (NBS), Gaithersburg, Maryland, to confirm its accuracy and determine its suitability for use at Langley during low-speed tunnel calibration primarily at the full-scale tunnel. The rake was tested at one airspeed of 74 miles per hour (33 meters per second) and at pitch and yaw angles of 0 to ± 20 degrees in 4-degree increments. An analysis of the data shows that the pitot-static rake can be used to make tunnel measurements with an uncertainty of 1 percent or better.

INTRODUCTION

The pitot-static rake is used as a standard in Langley's full-scale tunnel for determining windspeed and angle of attack (AOA) during tunnel model testing. Since this rake is the heart of the measurement system used for determining tunnel conditions, it was decided to have its accuracy confirmed in the low-speed wind tunnel at the National Bureau of Standards, Gaithersburg, Maryland. Of particular interest are the differential pressures generated across the rake as it was pitched and yawed through the various known angles in a precise flow velocity environment.

SYMBOLS

A	polynomial coefficient
P	pressure, pounds per square foot or newtons per square meter
V	velocity, miles per hour or meters per second; variable in curve regression polynomial
Y	differential pressure, pounds per square inch; variable in curve regression polynomial
X	angle, degrees (pitch or yaw)
ΔP	tunnel dynamic pressure, pounds per square foot (psf) or newtons per square meter
ρ	density, slugs per cubic foot or kilograms per cubic meter

PHYSICAL CONSTANTS USED

g	acceleration due to gravity, equals 32.1741 feet per second squared or 9.80665 meters per second squared
P_S	standard atmospheric pressure, 2116.22 pounds per square foot or 1.013250×10^5 newtons per square meter

TEST APPARATUS

Pitot-Static Rake

The pitot-static rake (figs. 1, 2, and 3) was hand carried to and from NBS to avoid possible shipping damage. The rake consists of five tubes approximately 30 inches long (76 cm) and 0.875 inch (22 mm) in diameter. Each tube has a hemispherical nose with the total pressure port (P_{total}) located in the center of the nose. A series of static pressure holes (P_{static}) are located approximately 4 inches (10 cm) downstream from the probe tip and equally spaced around the probe's circumference. Four smaller holes (P_{top}, P_{bottom}, P_{left}, and P_{right}) for determining AOA are located 45 degrees downstream of the total pressure tap along the surface of the hemispherical nose. The difference in pressure across P_{top} and P_{bottom} (vertical plane) yields a measure of pitch, and the pressure difference across P_{left} and P_{right} (horizontal plane) denotes yaw.

NBS Standard

The calibration standard used by the NBS was the 5- by 7- by 25-foot-long (1.5- by 2.1- by 7.6-meter) test section of a closed-circuit wind tunnel. This tunnel has an entrance contraction ratio of 25:1. Installed in the entrance are 25 fine mesh screens 1 foot (30 cm) apart. Each screen is designed to reduce test section turbulence by 1 percent. This tunnel can produce a flat profile throughout the test section's cross sectional area to within 0.1 percent with a turbulence level of less than 0.05 percent. Tunnel pressure is measured with a precision NBS designed micromanometer whose accuracy has been determined to be 0.01 percent of reading over the range 5 to 150 mph (2.2 to 67 m/s). The manometer fluid used for these tests was benzene (C_6H_6) which has the desirable features of low wetting action (will not adhere to tube wall), low vapor pressure, good stability, and a much sharper (flatter) meniscus than water, oil, or mercury. Tunnel test section walls are smooth, hard finished, and polished wood. Flow velocities are produced by two variable speed fans. Test section velocities are stated by NBS to have a total uncertainty of $\pm$ 0.2 percent.

TEST PROCEDURE

The pitot-static rake assembly was positioned on the centerline of the NBS tunnel and held in place by a support which included a large dividing head to facilitate the accurate production of compound angular positions of pitch and yaw with respect to the flow.

To utilize the angular increments of pitch and yaw provided by the dividing head, it was first necessary to fix the geometry of the pitot-static rake relative to tunnel zero AOA. This was accomplished by using a precision level on the rake tubes for horizontal alinement and a dividing head for centering and alining the assembly in the vertical plane to within 0.001 inch (0.0254 mm). A telescope mounted outside the tunnel was used to view the assembly to confirm that alinement was maintained relative to the tunnel during the various aspects of the test. The six pressure taps on each tube were identified as shown in the following listing and are the same as shown on the NBS calibration data (tables 1 through 4).

DESIGNATION	TAP NUMBER	PRESSURE SYMBOL
P_{left}	1	P_1
P_{top}	2	P_2
P_{right}	3	P_3
P_{bottom}	4	P_4
P_{total}	5	P_5
P_{static}	6	P_6

Note: Taps number 2 and 4 were in the vertical (pitch) plane and taps number 1 and 3 were in the horizontal (yaw) plane.

The symmetry of the assembly was confirmed by observing near zero differential pressures across taps number 2 and 4, and 1 and 3 for each tube (with flow) with the rake in zero AOA position, prior to starting tests.

In addition to the pressures given in the listing above, three other pressures were measured for the purpose of determining the NBS tunnel velocity:

P_∞ = free stream static pressure as measured using the NBS standard pitot-static tube

P_b = prevailing atmospheric pressure

ΔP_s = dynamic pressure as measured using the NBS standard pitot-static tube

All pressures given in tables 1 through 4 are in units of psi x 10^3 and all speeds are in miles per hour (mph). Tables 5 through 8 are the same data in SI units. The complete isentropic flow relationship was used in determining the velocity and hence the effects of compressibility are included in reported values of airspeed.

Data Acquisition

With the rake alined in zero AOA, a nominal flow velocity of 74 mph (33 m/s) was established and pressure measurements recorded. This included six pressures for each of the five tubes plus the tunnel standard pressure.

The rake was then yawed through $\pm$ 20 degrees in 4-degree increments while maintaining zero pitch angle. At each position, conditions were allowed to stabilize and all pressures recorded. Next, zero angle of yaw was maintained and the rake was pitched $\pm$ 20 degrees in 4-degree increments using the same data acquisition procedure.

Rake pressures were recorded as read and the NBS standard pressures were used to calculate the actual velocity for each position using the equation

$$V = \frac{\left(\frac{2\ \Delta P}{\rho}\right)^{\frac{1}{2}} 3600}{5280} \tag{1}$$

where

V = velocity, miles per hour (mph)

ΔP = tunnel dynamic pressure, pounds per square foot (psf)

ρ = density, slugs/ft^3

3600 = seconds per hour

5280 = feet per mile

The same equation using SI units becomes

$$V = \left(\frac{2\ \Delta P}{\rho}\right)^{\frac{1}{2}} \tag{2}$$

where:

V = velocity (m/s)

ΔP = differential press (N/m^2)

ρ = density (Kg/m^3)

RESULTS AND DISCUSSION

In analyzing the data, tables 1 through 4, using the dynamic pressure measured across taps number 5 and 6 (P_{total} minus P_{static}), and equation (1) to calculate the velocity as determined by the Langley pitot-static rake, it is clear that all the data at zero angle of attack are accurate to within 1 percent. For example, the point of best agreement (table 1, tube number 1, where the dynamic pressure was measured to be 0.0933 psi (643.3 N/m^2) at a density of 0.002296 slugs/ft^3 (1.18 Kg/m^3)) yields a velocity of 73.77 mph (32.98 m/s) which differs from the NBS free stream velocity of 73.7 mph (32.95 m/s) by only 0.09 percent. Likewise, table 2, tube number 1, where the pressure is given as 0.09405 psi (648.5 N/m^2) at a density of 0.002258 slugs/ft^3 (1.16 Kg/m^3) the velocity is calculated to be 74.69 mph (33.39 m/s) or only 0.9 percent higher than the NBS true airspeed of 74 mph (33.08 m/s). All other data points concerning velocity at zero AOA are within those limits.

Since there is no way to confirm the angulr data by theoretical calculation, it is being used as given by the NBS calibration. For example, with the rake installed in the full-scale tunnel at zero degrees pitch and an observed differential of 0.08835 psi (609.15 N/m^2) across taps 1 and 3, tube number 2 (table 1), the yaw angle would be taken as 12 degrees. Under these conditions, the differential pressure across taps 1 and 3 on the other four tubes (1, 3, 4, and 5) has been observed to be within tolerance of those listed on the NBS calibration report. This data has been plotted (figures 4 through 13) showing differential pressure as a function of yaw and pitch angle. These curves were calculated using the least square third order polynomial regression as follows:

$$Y = A_4 X^3 + A_3 X^2 + A_2 X + A_1 \tag{3}$$

where:

Y = differential pressure (psi)

X = angle (pitch or yaw), degrees

A_n = polynominal coefficient to be determined

The third order fit was selected because it is the first ascending order to provide an acceptable fit for all the data. Precision of this curve fit is better than 0.5 percent. As can be seen from figures 4 through 13, the pitot-static rake has good symmetry; i.e., the slope of the curve is the same for both positive and negative angles. Also the individual curves show no significant difference when superimposed on one another. This curve similarity confirms the feeling that the aerodynamic design of the rake is sound and that no interference exists between the tubes, or the tubes and the strut.

CONCLUDING REMARKS

A five-element pitot-static rake was tested at a wind speed of 74 mph (33 m/s) at the NBS to confirm its accuracy and suitability for use as a standard during tunnel testing in the Langley full-scale tunnel. Analysis of the NBS data shows that the rake can be used to establish tunnel windspeed and angle of attack with an uncertainty no greater than 1 percent.

Measured differential pressures at the hemispherical tip of each element, when plotted against fixed yaw and pitch angles (0 to ± 20°), yielded curves which demonstrate close similarity in element performances, excellent element symmetry and a strong potential for obtaining precise angle of attack measurements.

REFERENCES

1. Mechtly, E. A.: The International System of Units Physical Constants and Conversion Factors (Revised) 1969.

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REPORT OF CALIBRATION

on

NASA Pitot-Static Tube Rake

submitted by

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Reference: Purchase Order No. L-31249A dated August 5, 1975.

The calibration was performed in the five-foot by seven-foot rectangular test section of the NBS closed-circuit dual test section wind tunnel. The Pitot-static tube rake assembly was positioned near the center line of the tunnel, using the support system supplied by NASA.

The rake was tested at angles of pitch and yaw specified by NASA, at one value of air speed. At each angle of pitch and yaw the pressure difference for pairs of pressure taps, designated by NASA, was determined.

The test results are given in the attached tables as part of this report. The average air speed, $\overline{V}$, for each angular position is given in the bottom row of each table. The average of $\overline{V}$ over all tests was 73.8 mph. The numerical designation of the tubes and the pressure taps, and the sign convention used is as suggested by NASA and included in this report as Table 5.

For the Director,

P. S. Klebanoff, Chief
Aerodynamics Section
Mechanics Division, IBS

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Table I

NASA Pitot-Static Rake

Angle of Pitch Equals 0 Degree

Tube No.	Taps No.	Angle of Yaw, degrees: 0	4	8	12	16	20	0
		Pressure Difference, psi x 10^3						
1	5 - 6	93.33	95.36	96.95	97.88	98.10	97.01	94.34
	4 - 2	- 1.03	- 1.35	- 1.29	- 1.53	- 1.95	- 1.52	- 1.38
	1 - 3	- 1.85	26.73	57.05	84.15	106.94	127.97	- 2.33
2	5 - 6	94.25	94.95	96.87	98.28	98.24	97.41	94.11
	4 - 2	- 3.50	- 3.63	- 3.56	- 3.48	- 4.29	- 5.12	- 3.43
	1 - 3	0.50	29.41	60.20	88.35	110.72	131.95	0.16
3	5 - 6	94.40	95.13	96.98	98.36	97.99	97.21	94.16
	4 - 2	- 1.90	- 2.12	- 2.13	- 2.25	- 2.94	- 2.02	- 1.83
	1 - 3	- 2.89	26.84	57.84	85.56	107.84	129.58	- 3.25
4	5 - 6	94.37	95.13	97.07	98.47	97.94	97.41	94.15
	4 - 2	- 0.22	- 0.16	0.17	0.54	0.16	0.58	- 0.18
	1 - 3	- 6.70	22.83	53.90	82.88	105.59	127.31	- 7.07
5	5 - 6	94.18	95.03	96.69	98.10	96.70	95.77	93.92
	4 - 2	- 1.16	- 1.10	- 0.88	- 0.53	- 0.68	- 0.07	- 1.08
	1 - 3	2.22	31.49	62.39	90.63	110.99	132.83	1.95
	Velocity (mph)	73.7	73.7	73.7	73.7	73.5	73.5	73.7
	Density (slugs/ft^3)	.002296	.002292	.002293	.002291	.002287	.002285	.002288

Table 2

NASA Pitot-Static Rake

Angle of Pitch Equals 0 Degree

Tube No.	Taps No.	Angle of Yaw, degrees: 0	-4	-8	-12	-16	-20	0
		Pressure Difference, psi x 10^3						
1	5 - 6	94.05	94.72	96.14	97.49	97.42	96.12	93.58
	4 - 2	- 1.27	- 1.26	- 1.01	- 0.84	- 0.66	- 0.57	- 1.37
	1 - 3	- 2.27	- 31.05	- 60.68	- 88.63	- 110.55	- 130.86	- 2.82
2	5 - 6	93.69	94.42	96.16	97.09	97.10	95.59	93.25
	4 - 2	- 3.37	- 2.94	- 2.62	- 2.53	- 2.69	- 2.46	- 3.33
	1 - 3	0.13	- 29.49	- 60.14	- 87.14	- 110.31	-131.51	- 0.36
3	5 - 6	93.73	94.38	96.26	97.38	97.41	96.01	93.24
	4 - 2	- 1.80	- 1.13	- 1.14	- 0.95	- 0.97	- 1.47	- 1.83
	1 - 3	- 3.19	- 32.22	- 62.38	- 90.17	-112.84	-133.03	- 3.83
4	5 - 6	93.72	94.48	96.19	97.35	97.37	95.65	93.28
	4 - 2	- 0.15	- 0.15	- 0.42	- 0.77	- 0.94	- 2.53	- 0.18
	1 - 3	- 7.01	- 36.67	- 67.12	- 94.47	-116.40	-135.81	- 7.57
5	5 - 6	93.57	94.29	96.10	97.53	97.60	95.80	93.08
	4 - 2	- 1.06	- 0.74	- 1.11	- 1.30	- 1.62	- 1.57	- 1.10
	1 - 3	1.91	- 27.62	- 58.08	- 86.57	-110.65	-129.97	1.40
	Velocity (mph)	74.0	74.0	73.9	73.9	73.7	73.6	74.0
	Density (slugs/ft^3)	.002258	.002255	.002253	.002252	.002245	.002243	.002246

Table 3

NASA Pitot-Static Rake

Angle of Yaw Equals 0 Degree

Angle of Pitch, degrees

Tube No.	Taps No.	0	4	8	12	16	20	0
		Pressure Difference, psf x 10^3						
1	5 - 6	95.48	95.28	96.27	96.97	95.95	94.58	95.13
	4 - 2	- 1.27	26.56	52.56	78.25	101.21	122.22	- 1.14
	1 - 3	- 1.03	- 1.89	- 1.89	- 1.87	- 1.95	- 1.82	- 1.36
2	5 - 6	95.07	95.18	96.22	96.75	95.60	94.41	94.71
	4 - 2	- 3.32	25.02	51.87	78.56	101.24	123.00	- 3.21
	1 - 3	1.38	1.70	1.86	2.49	3.11	3.68	1.23
3	5 - 6	95.12	95.24	96.22	96.97	96.02	94.72	94.71
	4 - 2	- 1.84	25.93	52.33	77.78	100.54	122.25	- 1.61
	1 - 3	- 1.97	- 2.12	- 2.46	- 2.12	- 2.00	- 1.34	- 2.24
4	5 - 6	95.03	95.28	96.24	96.82	96.02	94.97	94.73
	4 - 2	- 0.48	27.03	53.09	79.36	102.22	122.86	- 0.22
	1 - 3	- 5.82	- 6.23	- 6.76	- 6.37	- 5.99	- 5.13	- 6.17
5	5 - 6	94.71	95.01	95.86	96.74	96.09	94.89	94.39
	4 - 2	- 1.51	26.05	51.79	77.69	100.38	121.39	- 1.19
	1 - 3	2.42	2.96	3.44	4.50	5.23	5.99	2.26
	Velocity (mph)	73.8	73.7	73.7	73.6	73.6	73.6	73.7
	Density (slugs/ft^3)	.002309	.002305	.002304	.002304	.002302	.002300	.002299

Table 4

NASA Pitot-Static Rake

Angle of Yaw Equals 0 Degree

Angle of Pitch, degrees

Tube No.	Taps No.	0	- 4	- 8	- 12	- 16	- 20	0
		Pressure Difference, psi x 10^3						
1	5 - 6	94.46	95.48	97.05	98.05	98.58	97.73	94.99
	4 - 2	- 1.14	- 28.34	- 57.07	- 79.78	-104.20	-125.18	0.85
	1 - 3	- 3.22	- 2.78	- 2.20	- 0.83	- 0.49	0.11	0.96
2	5 - 6	94.17	94.53	96.46	97.63	97.91	96.74	94.64
	4 - 2	- 2.96	-30.15	-58.79	-82.03	-107.51	-127.34	- 1.22
	1 - 3	- 2.36	- 2.29	- 2.67	- 1.87	- 2.51	- 3.15	1.90
3	5 - 6	94.11	94.68	96.30	97.45	97.53	96.52	94.69
	4 - 2	- 1.22	- 28.00	- 56.70	- 80.56	-104.74	-125.27	0.02
	1 - 3	- 4.19	- 3.60	- 3.22	- 1.89	- 1.93	- 1.57	0.10
4	5 - 6	94.14	94.63	95.94	96.97	97.09	96.04	94.60
	4 - 2	- 0.02	- 26.48	- 54.89	- 77.56	-101.78	-121.92	1.62
	1 - 3	- 8.20	- 7.68	- 7.63	- 6.29	- 6.13	- 5.73	- 3.88
5	5 - 6	93.88	94.18	95.56	96.75	97.02	95.66	94.28
	4 - 2	1.16	-24.42	-51.90	-76.31	-100.83	-1[illegible].94	1.44
	1 - 3	1.02	0.92	0.65	1.64	0.79	0.31	5.69
	Velocity (mph)	73.9	73.8	73.8	74.1	74.3	74.3	74.3
	Density ($slugs/ft^3$)	.002280	.002279	.002277	.002263	.002261	.002260	.002257

Table 5

NASA Pitot-Static Rake

Angle of Pitch Equals 0 Degrees

Angle of Yaw, Degrees

Tube No.	Taps No.	0	4	8	12	16	20	0
		Pressure Difference, N/m^2						
1	5 - 6	643.49	657.49	668.45	674.86	676.38	668.86	650.46
	4 - 2	- 7.10	- 9.31	- 8.89	- 10.55	- 13.44	- 10.48	- 9.51
	1 - 3	- 12.76	184.30	393.35	580.20	737.33	882.33	- 16.06
2	5 - 6	649.83	654.66	667.90	677.62	677.35	671.62	648.87
	4 - 2	- 24.13	- 25.03	- 24.55	- 23.99	- 29.58	- 35.30	- 23.65
	1 - 3	3.45	202.78	415.07	609.16	763.39	909.77	1.10
3	5 - 6	650.87	655.90	668.66	678.17	675.62	670.24	649.21
	4 - 2	- 13.10	- 14.62	- 14.69	- 15.51	- 20.27	- 13.93	- 12.62
	1 - 3	- 19.93	185.06	398.80	589.92	743.54	893.43	- 22.41
4	5 - 6	650.66	655.90	669.28	678.93	675.28	671.62	649.15
	4 - 2	- 1.52	- 1.10	1.17	3.72	1.10	4.00	- 1.24
	1 - 3	- 46.20	157.41	371.63	571.44	728.02	877.78	- 48.75
5	5 - 6	649.35	655.21	666.66	676.38	666.73	660.31	647.56
	4 - 2	- 8.00	- 7.58	- 6.07	- 3.65	- 4.69	- .48	- 7.45
	1 - 3	15.31	217.12	430.17	624.88	765.25	915.84	13.44
	Velocity m/sec	32.95	32.95	32.95	32.95	32.86	32.86	32.95
	Density Kg/m^3	1.183	1.181	1.182	1.181	1.179	1.178	1.179

Table 6

NASA Pitot-Static Rake

Angle of Pitch Equals 0 Degrees

Angle of Yaw, Degrees

Tube No.	Taps No.	0	4	8	12	16	20	0
		Pressure Difference, N/m^2						
1	5 - 6	648.46	653.08	662.87	672.17	671.69	662.73	645.22
	4 - 2	- 8.76	- 8.69	- 6.96	- 5.79	- 4.55	- 4.62	- 9.45
	1 - 3	- 15.65	-214.08	-418.38	-611.09	-762.22	-902.25	- 19.44
2	5 - 6	645.97	651.01	663.00	669.42	669.49	659.07	642.94
	4 - 2	- 23.24	- 20.27	- 18.06	- 17.44	- 18.55	- 16.96	- 22.96
	1 - 3	0.90	-203.33	-414.65	-600.81	-760.57	-906.74	- 2.48
3	5 - 6	646.25	650.73	663.69	671.42	671.62	661.97	542.87
	4 - 2	- 12.41	- 7.79	- 7.86	- 6.55	- 6.69	- 10.14	- 12.62
	1 - 3	- 21.99	-222.15	-430.10	-621.70	-778.01	-917.22	- 26.41
4	5 - 6	646.18	651.42	663.21	671.21	671.35	659.49	643.15
	4 - 2	- 1.03	- 1.03	- 2.90	- 5.31	- 6.48	- 17.44	- 1.24
	1 - 3	- 48.33	-252.83	-462.78	-651.35	-802.55	-936.38	- 52.19
5	5 - 6	645.15	650.11	662.59	672.45	672.93	660.52	641.77
	4 - 2	- 7.31	- 5.10	- 7.65	- 8.96	- 11.17	- 10.82	- 7.58
	1 - 3	13.17	-190.43	-400.45	-596.88	-762.91	-896.12	9.65
	Velocity m/sec	33.08	33.08	33.04	33.04	32.95	32.90	33.08
	Density Kg/m^3	1.164	1.162	1.161	1.161	1.157	1.156	1.158

Table 7

NASA Pitot-Static Rake

Angle of Yaw Equals 0 Degree

Angle of Pitch, Degrees

Tube No.	Taps No.	0	4	8	12	16	20	0
		Pressure Difference, N/m^2						
1	5 - 6	658.32	656.94	663.76	668.59	661.56	652.11	655.90
	4 - 2	- 8.76	183.13	362.39	539.52	697.82	842.68	- 7.86
	1 - 3	- 7.10	- 13.03	- 13.03	- 12.89	- 13.44	- 12.55	- 9.38
2	5 - 6	655.49	656.25	663.42	667.07	659.14	650.94	653.01
	4 - 2	- 22.89	172.51	357.63	541.66	698.03	848.06	- 22.13
	1 - 3	9.51	11.72	12.82	17.17	21.44	25.37	8.48
3	5 - 6	655.83	656.66	663.42	668.59	662.04	653.08	653.01
	4 - 2	- 12.69	178.78	360.80	536.28	693.20	842.89	- 11.10
	1 - 3	- 13.58	- 14.62	- 16.96	- 14.62	- 13.79	- 9.24	- 15.44
4	5 - 6	655.21	656.94	663.56	667.55	662.04	654.80	653.14
	4 - 2	- 3.31	186.37	366.04	547.17	704.79	847.10	- 1.52
	1 - 3	- 40.13	- 42.95	- 46.61	- 43.92	- 41.30	- 35.37	- 42.54
5	5 - 6	653.01	655.07	660.94	667.00	662.52	654.25	650.80
	4 - 2	- 10.41	179.61	357.08	535.66	692.10	836.96	- 8.20
	1 - 3	16.69	20.41	23.72	31.03	36.06	41.30	15.58
	Velocity (m/sec)	32.99	32.95	32.95	32.90	32.90	32.90	32.95
	Density (Kg/m^3)	1.190	1.188	1.187	1.187	1.186	1.185	1.185

Table 8

NASA Pitot-Static Rake

Angle of Yaw Equals 0 Degree

Tube No.	Taps No.	Angle of Pitch, Degrees: 0	4	8	12	16	20	0
		Pressure Difference, N/m^2						
1	5 - 6	651.28	658.32	669.14	676.04	679.69	673.83	654.94
	4 - 2	- 7.86	-195.40	-393.49	-550.07	-718.44	-863.09	5.86
	1 - 3	- 22.20	- 19.17	- 15.17	- 5.72	- 3.38	0.76	6.62
2	5 - 6	649.28	651.77	665.07	673.14	675.07	667.00	652.52
	4 - 2	- 20.41	-207.88	-405.35	-565.58	-741.26	-877.98	- 8.41
	1 - 3	- 16.27	- 15.79	- 18.41	- 12.89	- 17.31	- 21.72	13.1[illegible]
3	5 - 6	648.87	652.80	663.97	671.90	672.45	665.49	652.87
	4 - 2	- 8.41	-193.05	-390.94	-555.45	-722.16	-863.71	0.14
	1 - 3	- 28.89	- 24.82	- 22.20	- 13.03	- 13.31	- 10.82	0.69
4	5 - 6	649.08	652.45	661.49	668.59	669.42	662.18	652.25
	4 - 2	- 0.14	-182.57	-378.46	-534.76	-701.75	-840.61	11.17
	1 - 3	- 56.54	- 52.95	- 52.61	- 43.37	- 42.27	- 39.51	- 26.75
5	5 - 6	647.28	649.35	658.87	667.07	668.93	659.56	650.04
	4 - 2	8.00	-168.37	-357.84	-526.14	-695.20	-826.96	9.93
	1 - 3	7.03	6.34	4.48	11.31	5.45	2.14	39.23
Velocity (m/sec)		33.04	32.99	32.99	33.13	33.22	33.22	33.22
Density (Kg/m^3)		1.175	1.175	1.174	1.166	1.165	1.165	1.163

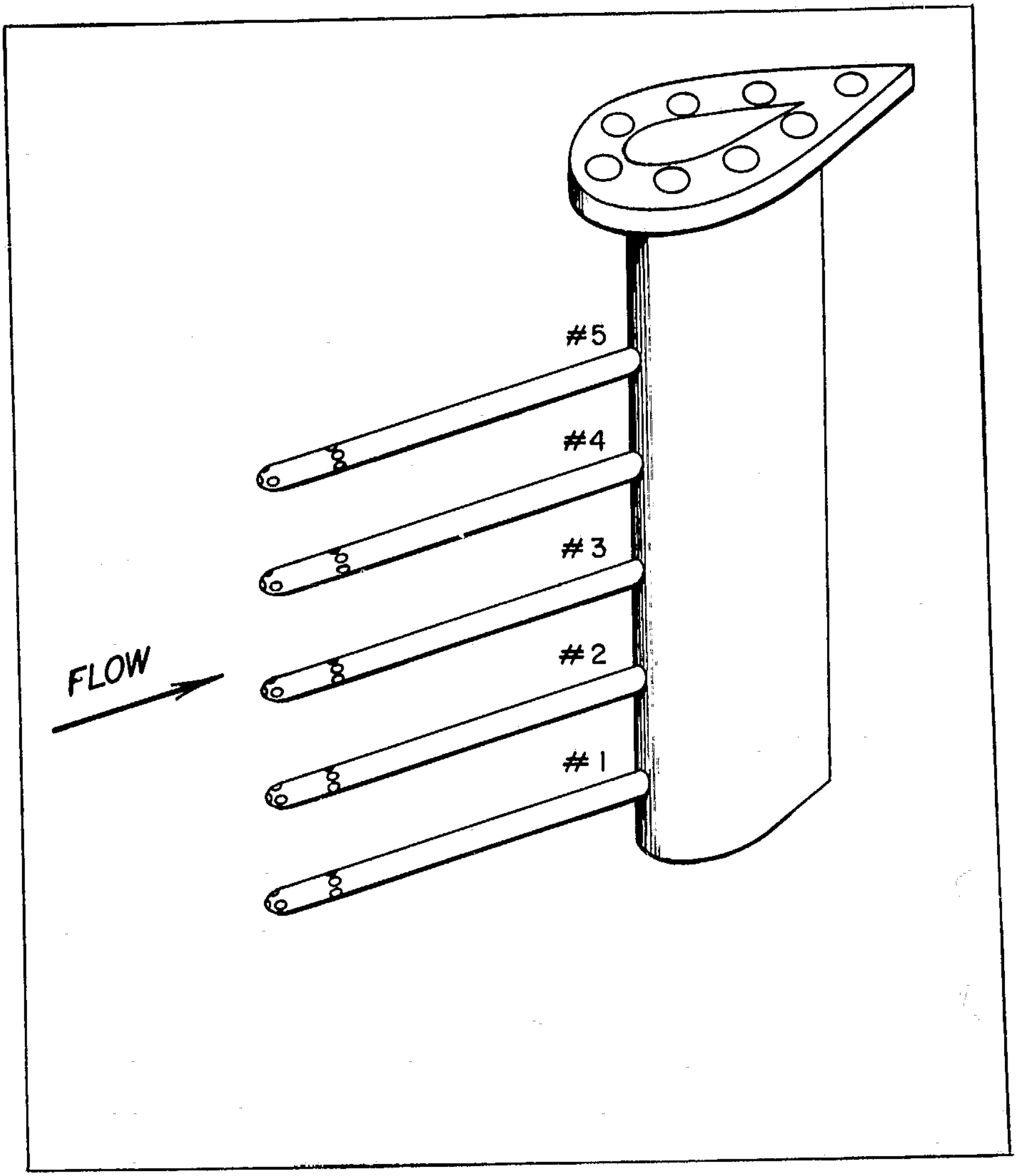

FIGURE 1 - FULL SCALE TUNNEL PITOT-STATIC RAKE.

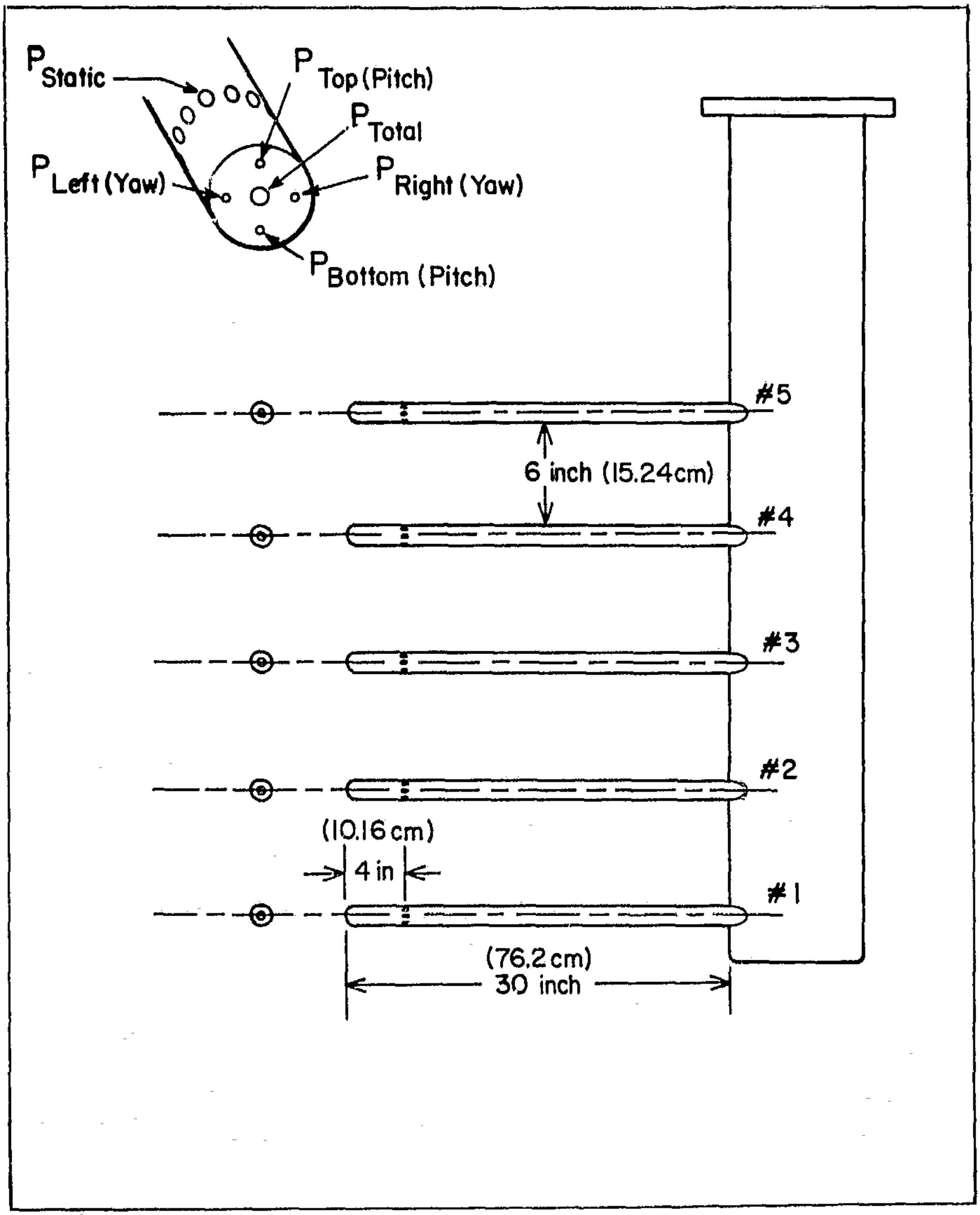

FIGURE 2 - FULL SCALE TUNNEL PITOT-STATIC RAKE.

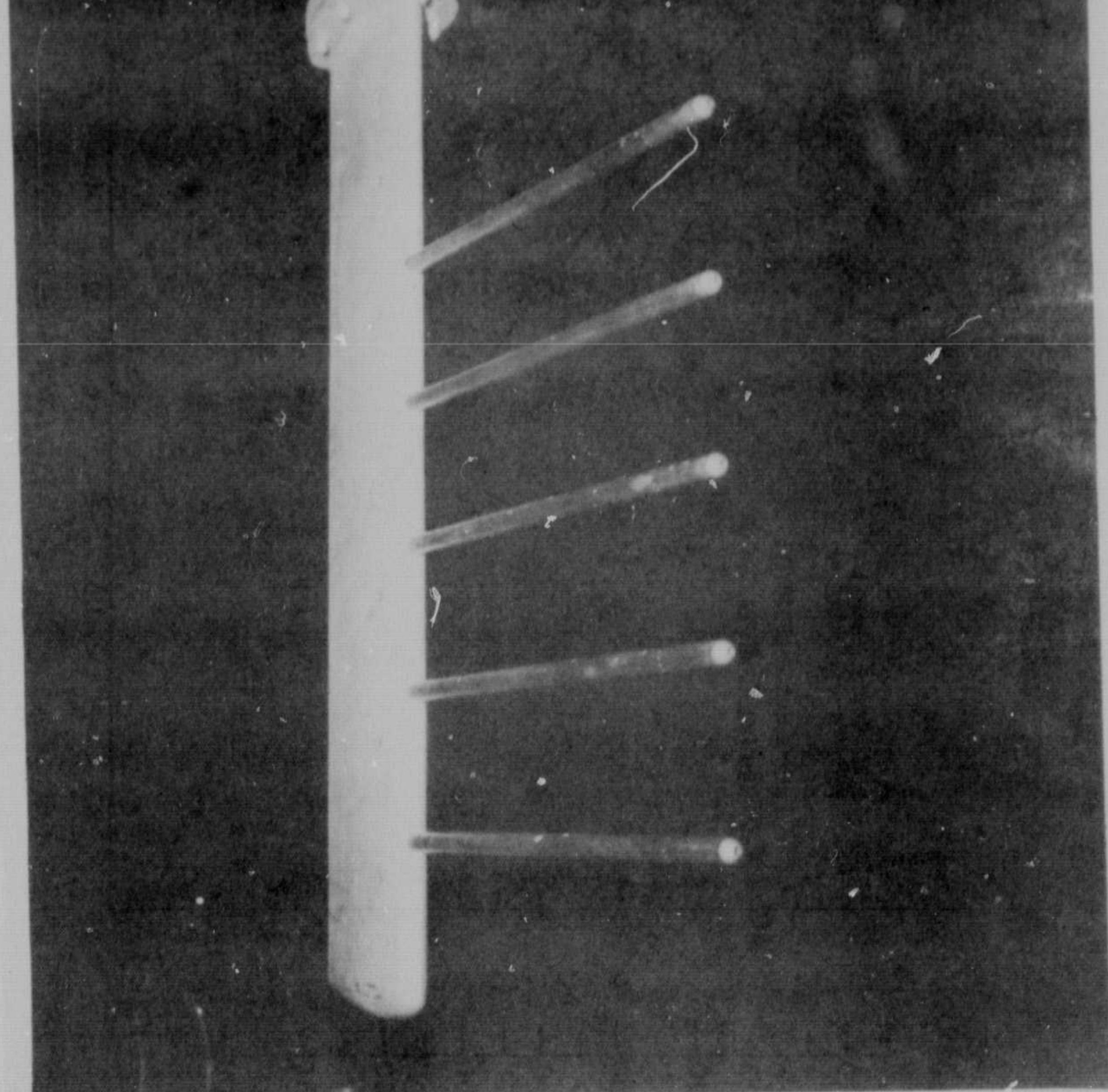

FIGURE 3 - 5 TUBE PITOT-STATIC RAKE DEPLOYED IN FULL SCALE TUNNEL.

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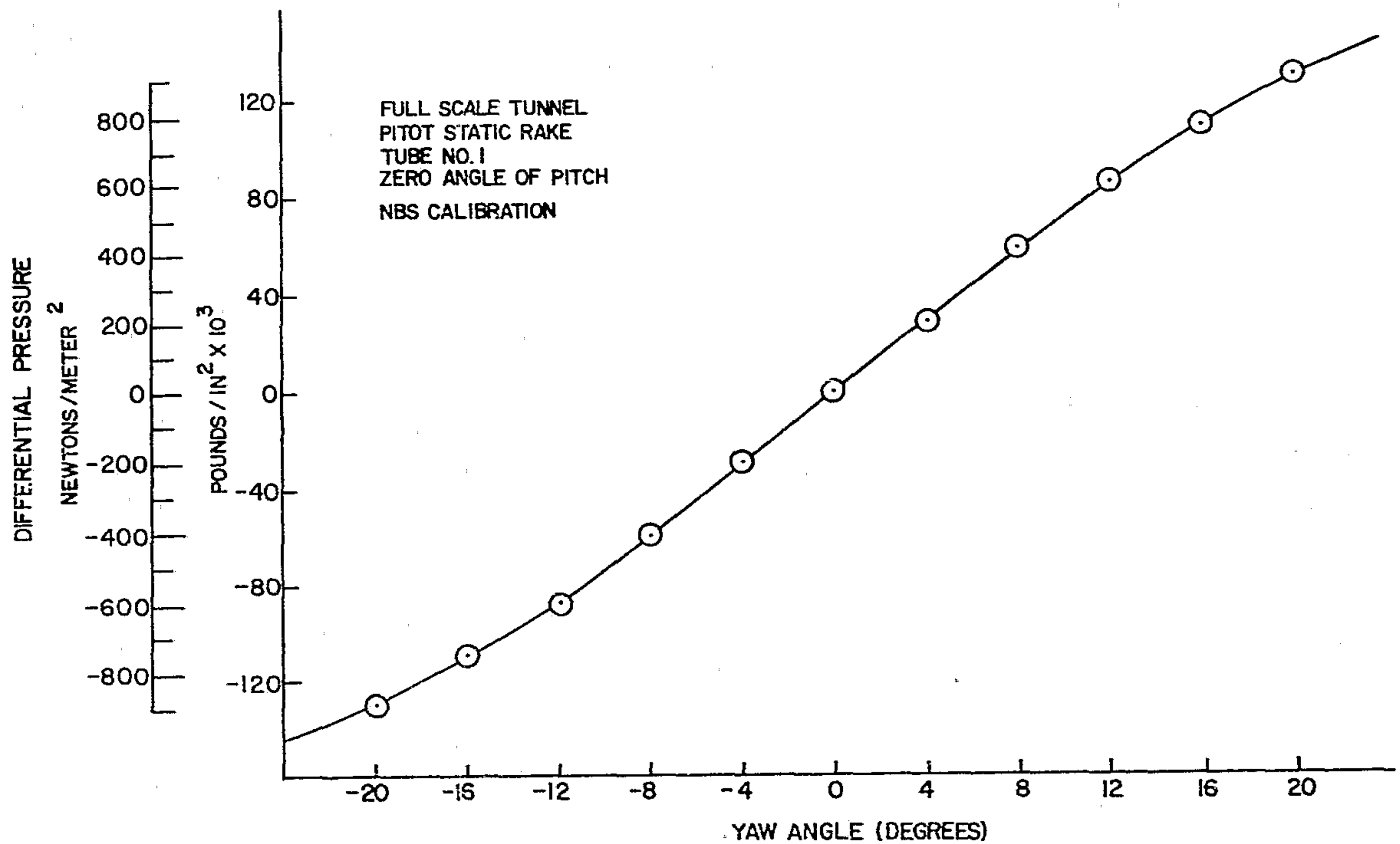

Figure 4 Differential pressure as a function of yaw angle.

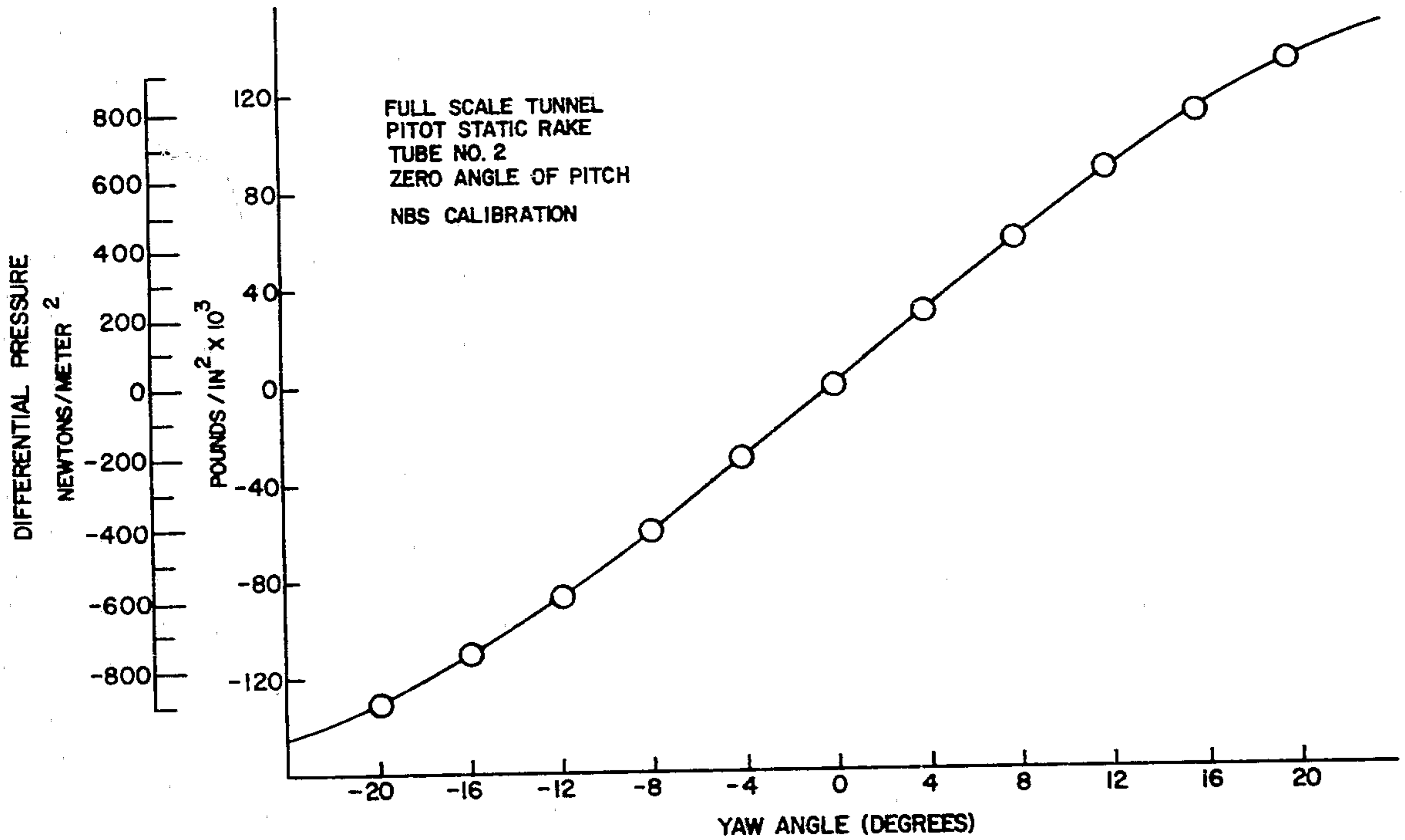

Figure 5 Differential pressure as a function of yaw angle.

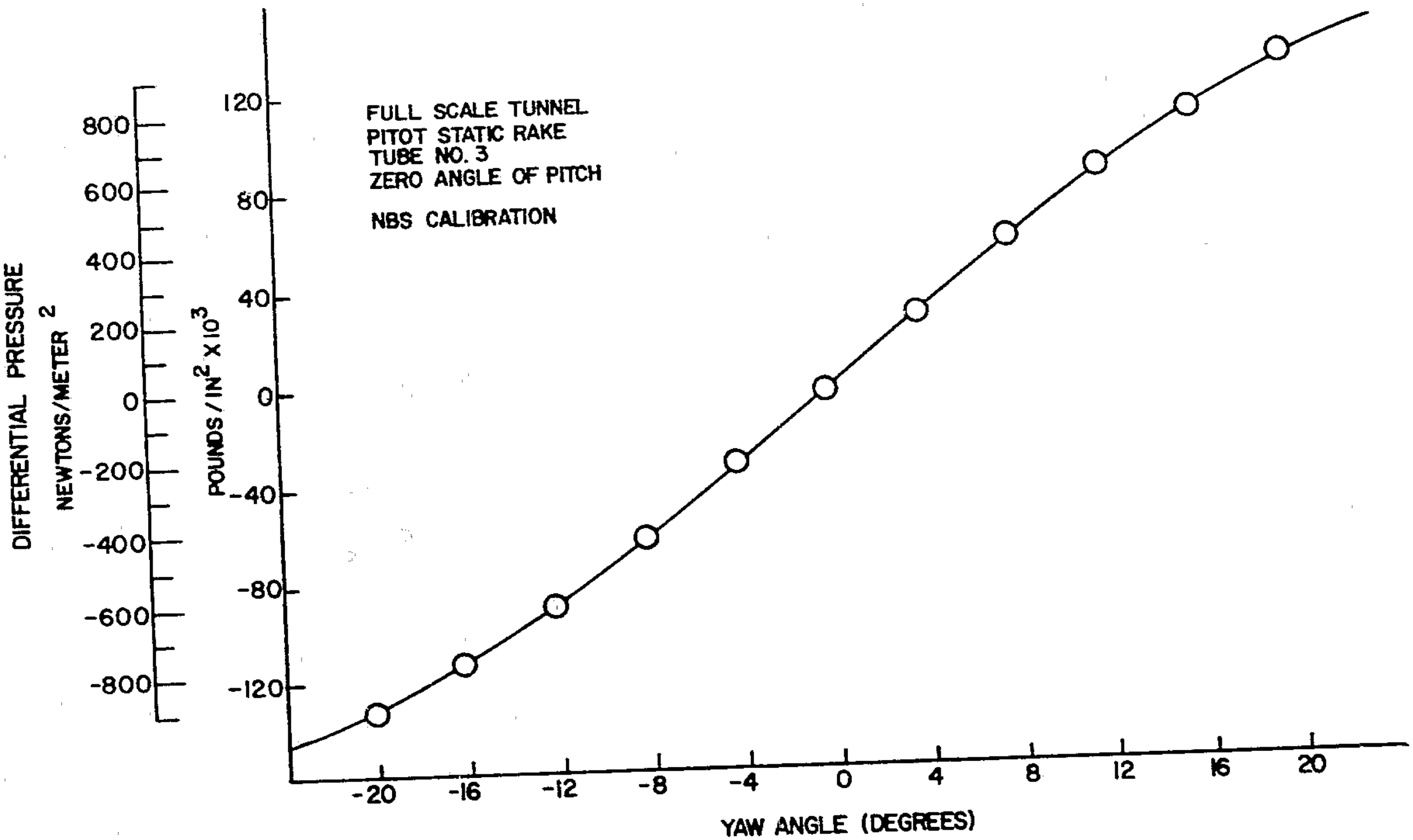

Figure 6 Differential pressure as a function of yaw angle.

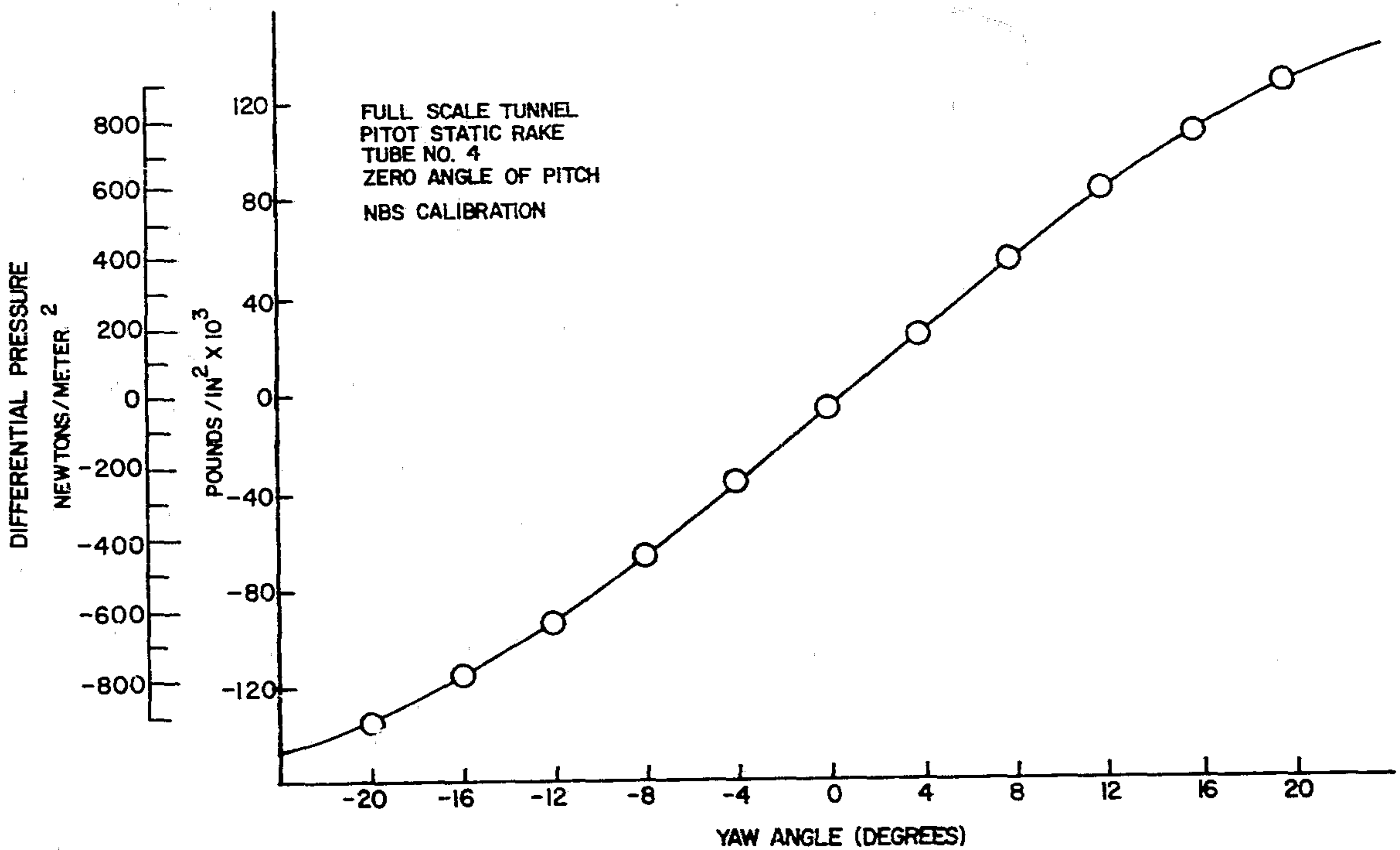

Figure 7 Differential pressure as a function of yaw angle.

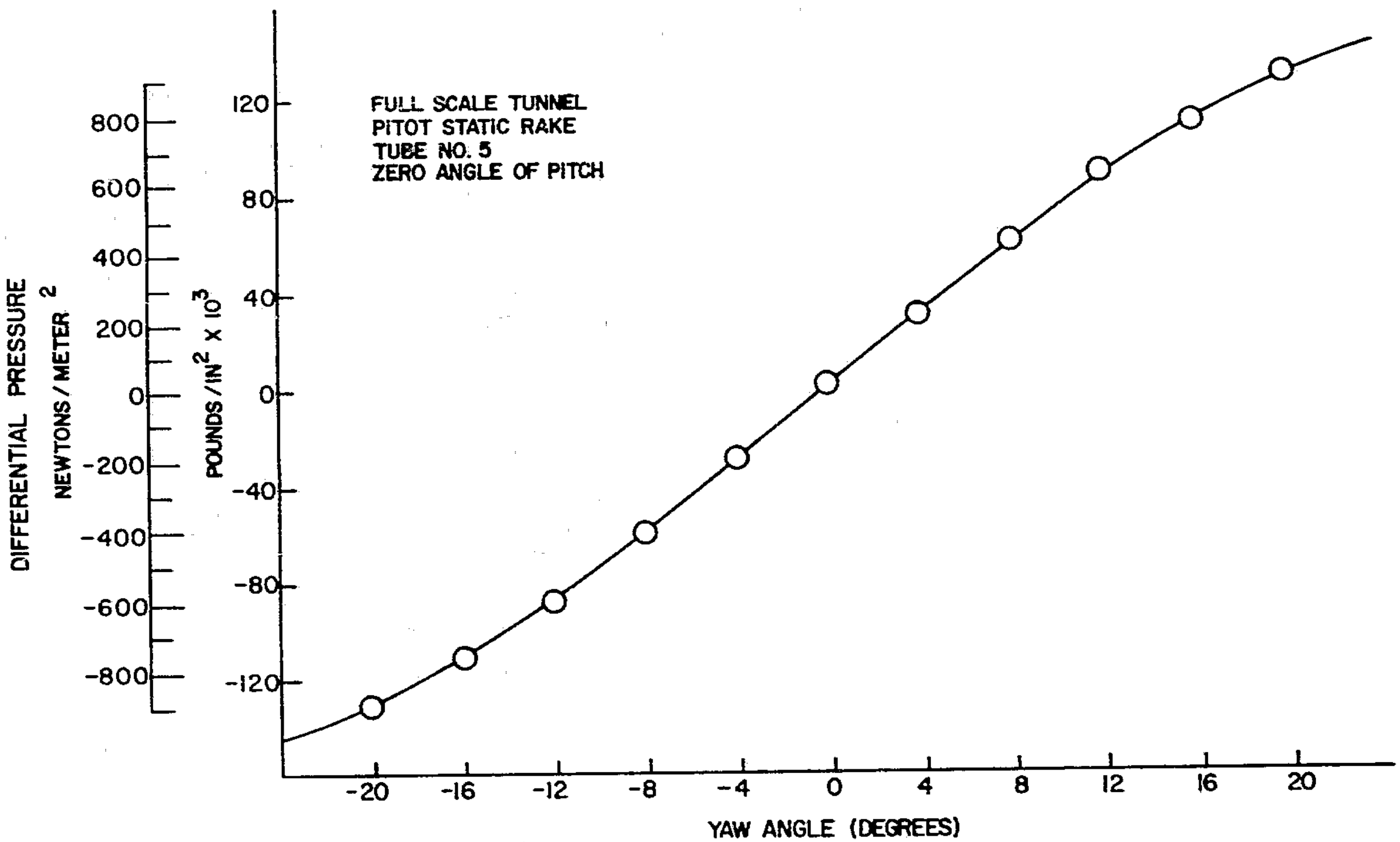

Figure 8 Differential pressure as a function of yaw angle.

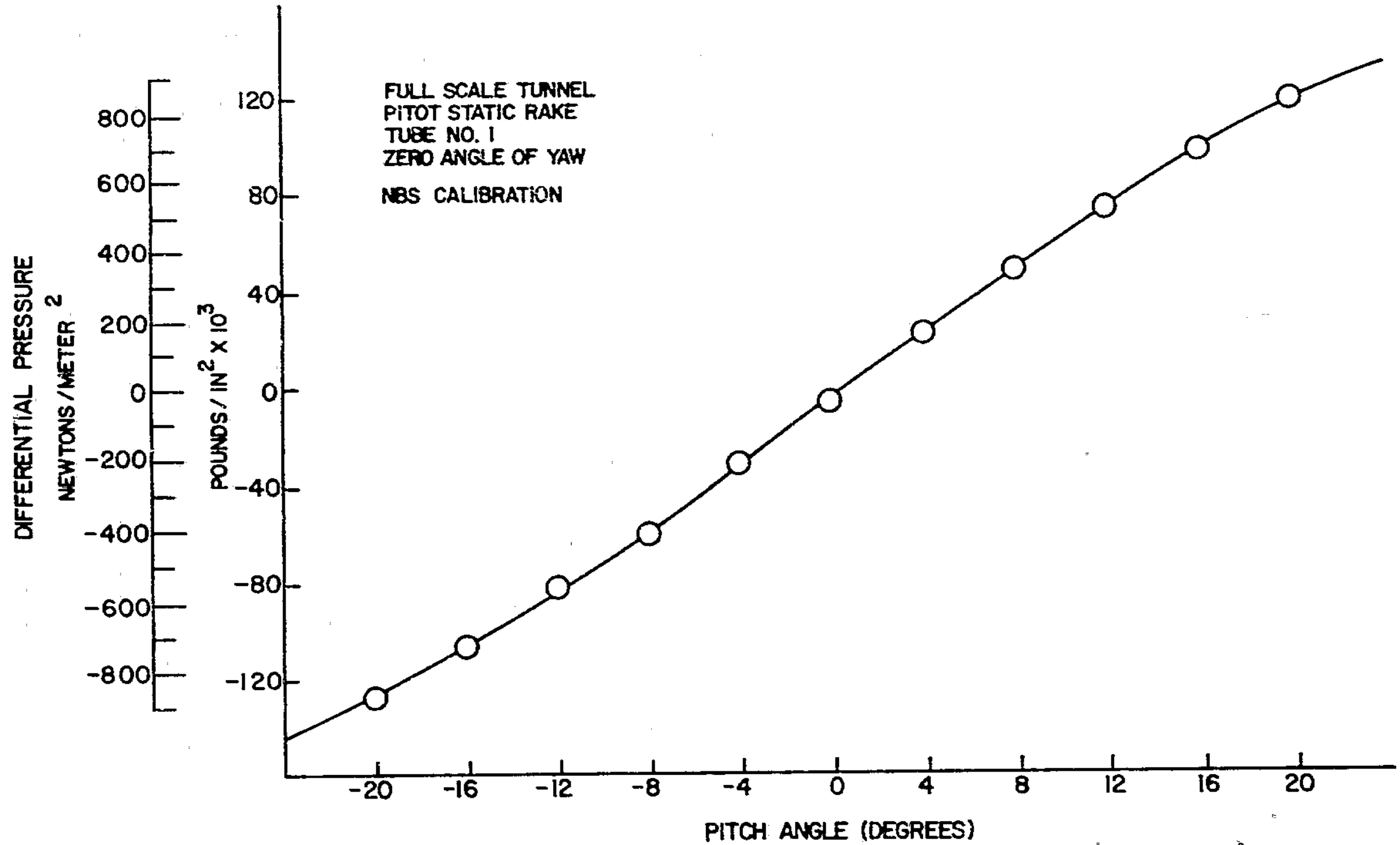

Figure 9 Differential pressure as a function of pitch angle.

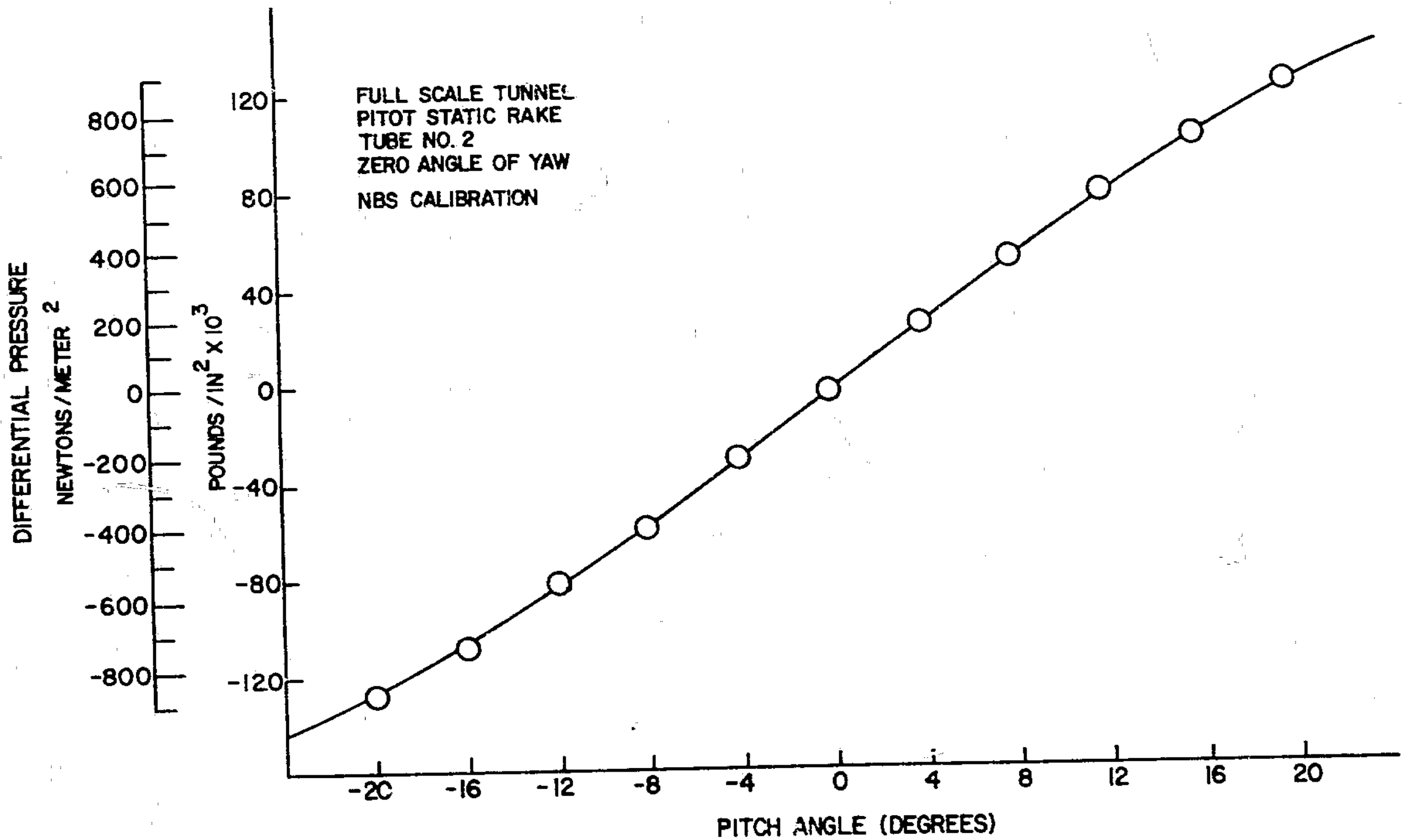

Figure 10 Differential pressure as a function of pitch angle.

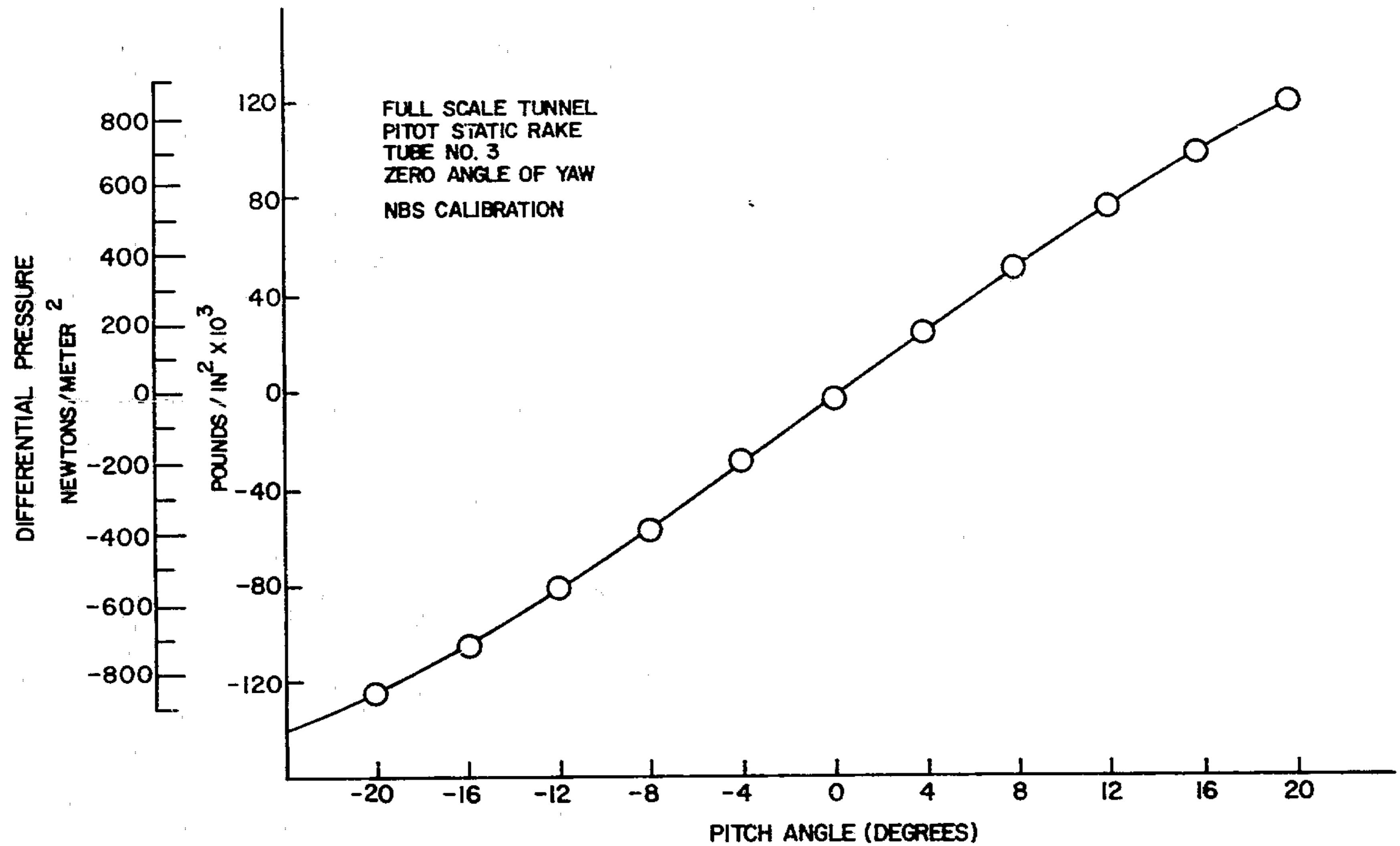

Figure 11 Differential pressure as a function of pitch angle.

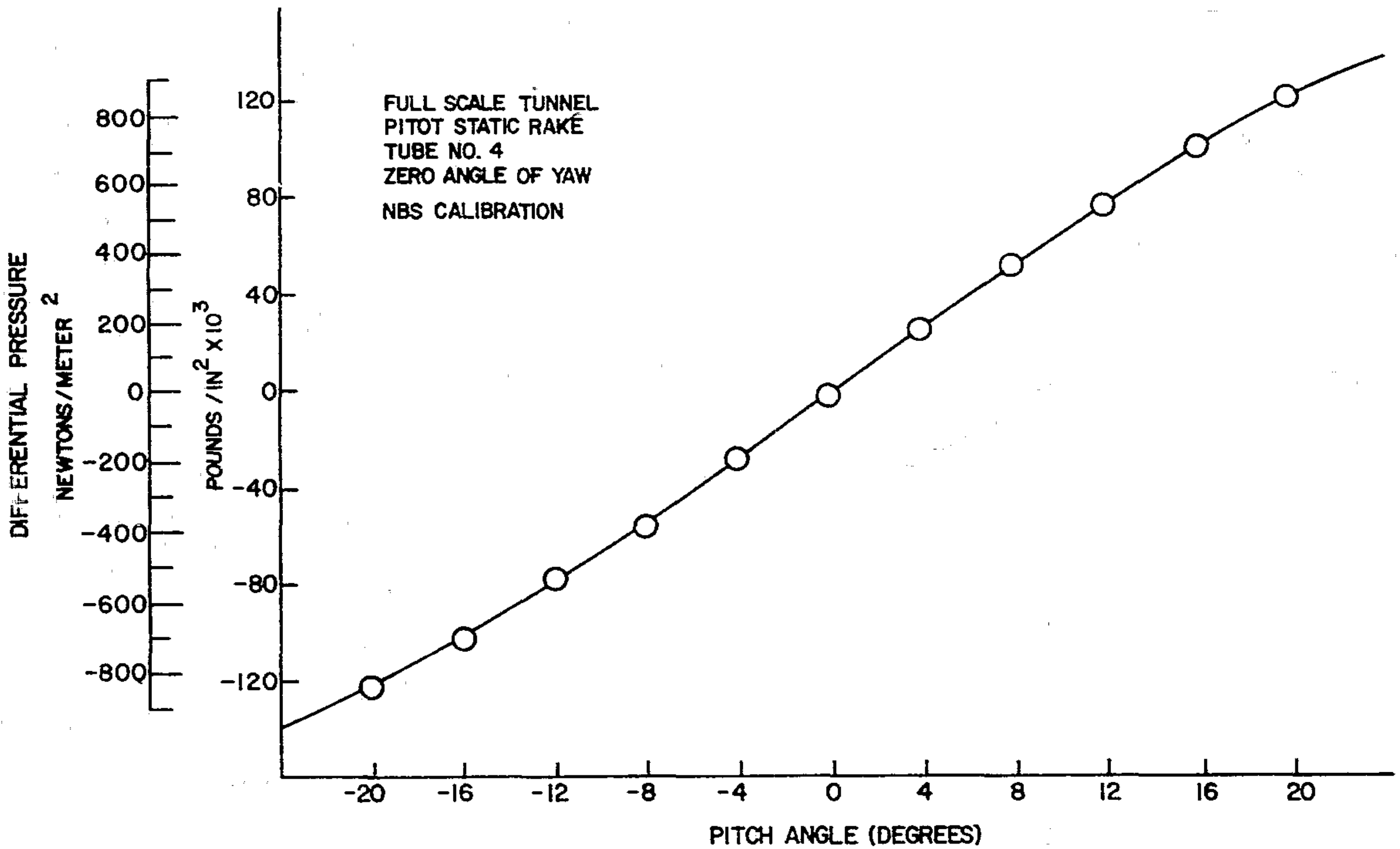

Figure 12 Differential pressure as a function of pitch angle.

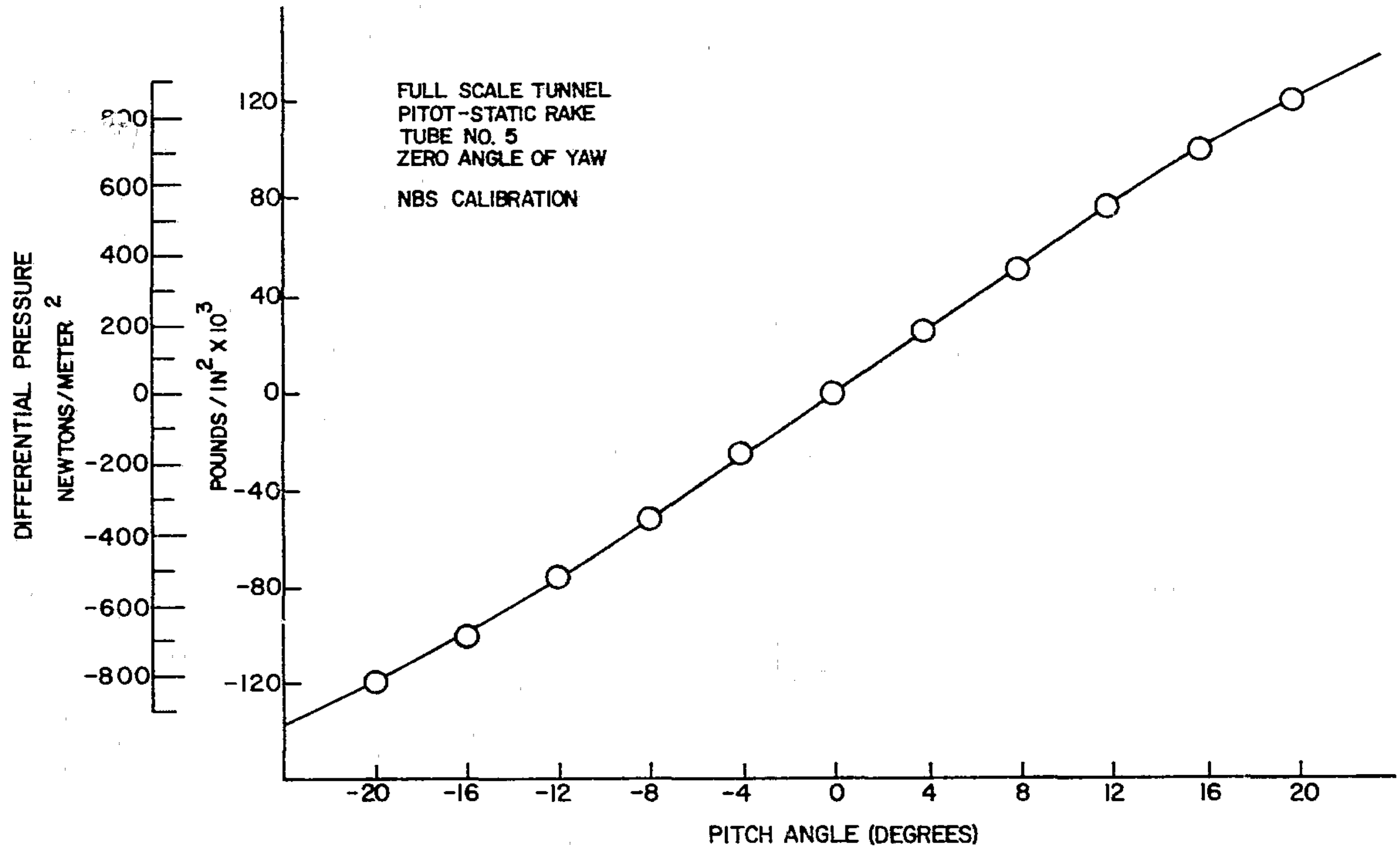

Figure 13 Differential pressure as a function of pitch angle.