COOLING TOWER INSTITUTE

Recommended Practice For Airflow Testing of Cooling Towers

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FOREWORD

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The following procedures are intended to document the conventional methods of measuring airflow. We realize that there are much more highly technical methods available. We also realize that our members have varied needs, some simple, some extremely demanding. This treatise is intended to assist the greatest number of people to be knowledgeable of several current techniques to measure the airflow from their fans. We hope it will be helpful.

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Airflow Testing of Cooling Towers

There are two basic instruments for airflow testing of cooling towers: Anemometer or pitot tube. The purpose of each is to measure the velocity at a point. After a number of points are measured to obtain a representative or average velocity. the total airflow is calculated using the net discharge area of the fan. Each of these instruments is discussed below.

1. Anemometer

The anemometer is basically a calibrated propeller. As the air turns the propeller, its speed of rotation is counted mechanically or electrically.

1.1 The oldest design is a vane anemometer, which measures the linear feet, or meters of air moving through it and provides a mechanical readout. When combined with a unit of time (usually 30 sec. or one minute), the velocity in feet per minute can be computed. In use, the anemometer is held in the air stream on a pole at the prescribed spot. A timer calls "start", and the operator pulls a string to start the anemometer. At 30 seconds, for example, the timer calls "stop". The operator stops the reading, retrieves the anemometer, reads the thousands, hundreds and unit counts. He records the reading, resets the counter and moves to the next spot. The readings are later adjusted using a calibration curve and doubled to give a feet per minute reading. As you can see, this instrument is clumsy and takes two skilled people to make repeatable measurements. Note that if a "yaw" measurement were needed, the operator would have to read or estimate and record the yaw angle as well as the counter reading for each spot.

1.2 Today there are many electronic direct reading anemometers available although accuracy and moisture resistance varies with cost. A typical instrument displays velocity in Ft./Min. or M/S and temperature °F or °C. It can average many readings over typically 2 or 16 second intervals and can store readings in it's memory which can later be downloaded through a standard RS232L interface into a computer.

1.3 An upscale version would be a propeller anemometer which has a digital readout based on an analog D.C. voltage proportional to the wind velocity. This is an unshrouded propeller with a tiny generator which can be attached to a pole with a standard 3/4" NPT (pipe) thread.

1.4 Propeller anemometers are available as small as 1" diameter to 8 or 9" diameter, shrouded or unshrouded. Generally the larger the diameter the more accurate the measurement and less the sensitivity to the swirl or yaw effect.

2. Pitot Tube

The pitot tube measures velocity pressure as the difference between total and static pressure at a point. This pressure is measured with an inclined monometer or an electronic pressure transducer. Temperature must also be measured so the density at each point can be computed. Once density and velocity pressure are measured at a point, the velocity can be computed by the formula:

$$V = 1096.2 * C * (VP/D)^{1/2}$$

Where 1096.2 = Unit conversion factor
C = Pitot tube calibration coefficient
VP = Local velocity pressure (inches - H_2O)
V = Local velocity (ft/min)
D = Local Air Density (lbm/ft^3)

For wet towers a special pitot tube with larger than normal holes in the nose is required. The purpose of the large holes is to prevent water droplets from clogging the tube, causing erroneous readings.

There are several types of pitot tubes available, some are very sophisticated for high velocity measurements. For our general purposes, velocity pressures will typically be less than 0.5 inches-H_2O.

For fan testing in moist air, the Prandtl type design is recommended. However, other types could also be adapted for cooling tower use.

A pitot tube developed for cooling tower use should first be calibrated against a well designed pitot tube in a dry air situation. ASME PTC 19.2 - 1987, Part 2 describes a method of calibration of a pitot tube. This will allow any correction factors necessary to account for the true performance of the modified tube to be determined.

2.1 Pressure Measurement

The velocity pressures which must be measured in a cooling tower application are typically less than 0.5 in-H_2O. Impact and static pressures are somewhat higher and can occasionally exceed 1.0 in-H_2O. Their pressures fluctuate rapidly due to the turbulence of the flow and the proximity of the measurement to the fan blades. This makes some method of dampening advisable. This can be accomplished by using a porus-plug damper in the capillary tube of the manometer or using an electronic read-out with a provision for calculating an average signal or pressure over a set time interval.

Any pressure measurement device suitable to these conditions can be used. A simple inclined manometer is often used. Pressure gauges and electronic pressure transducers have also been used successfully. The pressure measurement device should be checked against a reliable standard before the test and at least once during the test.

When pressure measurement is desired in addition to flow measurement, a system of valves is often used to connect the various pressure signals to the measurement device. These valves can be operated either manually or electrically.

2.2 Temperature Measurement:

Air temperature should be measured with an electronic temperature sensor attached to the pitot tube. Hand held thermistor types work well for this purpose.

Air temperature is measured to determine the density of the air. In cases where saturation cannot be assumed, it may be necessary to measure both wet and dry bulb temperature. In these cases, a wetted wick must be provided for the wet bulb sensor.

2.3 Barometric Pressure Measurement:

Barometric pressure can be measured by any suitable means. Mercury manometers are often used. Electronic absolute pressure transducers have also been used.

2.4 Other Apparatus:

The pitot tube should be attached to a light aluminum tube with sufficient strength and length to traverse the radius of the fan cylinder. This tube is usually supported by the fan cylinder itself and by a tripod mounted on the fan deck. The pitot tube should be connected to the pressure measurement device by flexible hoses. The temperature sensor must be connected to the output device by a suitable length of wire. The wire and hose should be firmly attached to the aluminum tube to prevent their being entangled in the fan or other cooling tower structure.

3. Where to Measure

Generally there is a precise distance from the edge of the fan ring in each of four quadrants of the inlet or discharge area where measurements are taken. A minimum number of points for a fan would be 20, four points in each of five equal area bands. These points are calculated on the basis of the fan ring diameter and seal disc or hub diameter if no seal disc is used. Some fan manufacturers specify an "aerodynamic hub" diameter when defining net free area. In this case, consult the manufacturer for the recommended inside diameter used to calculate equal area band locations. These measurements are all in one "plane". Where that plane of measurement is chosen is discussed in section 3.2.

Imagine a fan discharging air. On the inlet side, the air flow is fairly uniform - except around beams or other obstacles. On the discharge side the direction is significantly changed and at the center, airflow becomes negative but is blocked by the fans seal disc or hub. The air at the blade tips is still axial but the air vectors near the center of the fan are progressively "bent over" by the effect of the torque applied by the fan blades. At the center of the fan, the air actually wants to reverse direction 180°. This is called the "swirl effect". The net effect would be turbulence close to the center of the fan on the discharge side.

Also, consider if the fan has a short fan ring or a tall velocity recovery stack. The closer the measurement to the fan the less swirl effect is seen. For a tall stack, there is a cone of swirling air which travels many fan diameters before all discharge air becomes uniform (axial) again.

Using a pitot tube close to the exit or inlet side of the fan may require drilling four holes approximately 1 1/2" diameter at 90° through the stack for access. Plug the holes with a rubber plug or other means after the test is completed.

3.1 Yaw

The fan imparts a horizontal and a vertical velocity component to the air. The angle produced by these two components is the "YAW" angle. The vector resolution of these components yields the actual air velocity. However, to correctly determine the air flow leaving the tower, only the vertical or axial components of the velocity need be measured. This can be accomplished by two methods:

(a) Position the anemometer perpendicular to the fan axis so that only the axial component of velocity is measured.

(b) Tie a string or streamer onto the anemometer rod. The streamer will show the "local" velocity direction so if you hold the anemometer perpendicular to the streamer it will measure the air velocity in it's "yaw" direction. You then must read the yaw angle from a protractor on the anemometer handle and record it, along with the velocity read. The axial or vertical component will be:

VA = V yaw * Cos. θ

Where: VA = Axial (vertical) Velocity

V yaw = Velocity measured in the direction of the yaw angle.

Cos θ = Cosine of yaw angle

This adds considerably to the time consumed per test but does increase the accuracy of the results.

This would apply to either an anemometer or pitot tube if measurements are taken on the discharge side of the fan.

If you can use a pitot tube on the inlet side of fan (with or without a VR stack) several errors are avoided.

Inlet air, close to the plane of the fan is rather axial - therefore almost no yaw is present.

The confusion of the effect of swirl or yaw at the discharge, at the top of the stack is avoided. The Net Free Area, free of swirl, is well defined. A "caveat" would be that you must not measure within 12 inches of a beam under the fan because of turbulence which would affect the reading. Better to move over into clear air a distance of at least 1.5 times the width of the obstruction or beam.

3.2 Recommended Measurement Locations

First choice (with or without V.R. Stack): in the fan inlet as close as possible to the fan.

Second choice (Short Fan Ring): Over the fan with an anemometer or pitot making yaw corrections.

Third choice (V.R. Stack): At the top of the stack, making yaw corrections. Net Free Area is considered from the edge of the stack to the edge of the cylinder formed by the seal disc or hub diameter or aerodynamic hub diameter as specified by the manufacturer.

Obviously the location you choose will be tempered by the tower configuration being measured, the equipment you have and the time allotted for the test. If you are just comparing two fans, the important thing is consistency. Measure them both exactly the same way. You may or may not choose to measure yaw angles. You may not have pitot equipment. You may not be able to drill four holes in the stack to get under the fan. Your air flow measurement may not have to be absolute, but you're looking for relative differences in performance between fan A and fan B. All these things can effect your measurement location and method of measurement.

3.3 Recommended Test Conditions

Airflow tests will be inconclusive if (A) ambient winds exceed 10 mph or (b) if wind is gusting over 15 mph.

4. Comparisons of Accuracy: Pitot vs Anemometer

The following was reported in the CTI paper TP-84-15 by Wheeler, Wilber and Starnes, as a result of testing using anemometer vs pitot tube. Compare average difference in ACFM (two runs each)

Average ACFM (% difference)...0.96%

Pitot Tube Repeatability was ±....0.19%

Anemometer Repeatability was ±..0.75%

There is no authoritative number you can place on accuracy of a particular instrument. Effect of variations on wind changes during the test, accuracy of calibration, proficiency of the tester, and choice of measurement location affect the overall "absolute" accuracy of the flow measurement. For example, the following results using the same operators, measuring the same cell, using the same instrument with the same fan setting. Again, from data reported in TP-84-15:

Pitot Tube ACFM		Anemometer ACFM	
1,488,900		1,466,500	
1,494,500		1,488,600	
1,544,800		1,540,500	
1,496,300		1,480,100	
1,547,400			
1,514,380	Avg.	1,493,925	Avg

Percent difference between readings:

3.8 % (pitot) 4.8 % (anem.)

Percent difference between average readings of pitot vs anemometer was 1.4 %

Keep in mind these are with well calibrated instruments in the hands of trained technicians.

5. Preparing For Air Flow Test

- Decide where you're going to test
- Measure the inside diameter of the ring or stack at the measurement plane and the outside diameter of the seal disc or fan hub if no disc is used. Obtain "aerodynamic hub" diameter from manufacturer if no seal disc is used.

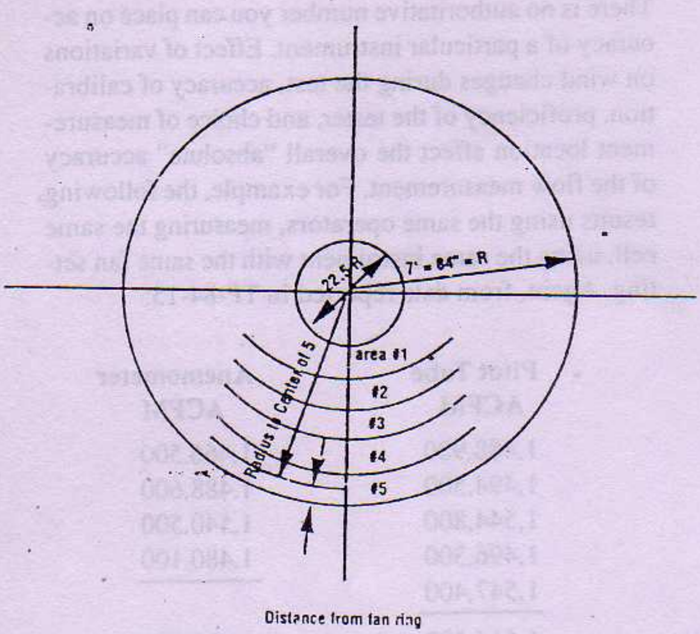
- Calculate the distance to the center of the equal area bands using the net free area calculated from step two.
- Prepare your equipment

(a) Mark off the distances to the measurement points with tape around the pole of your instrument. Lay out from the center of the anemometer to the edge of the fan ring for each equal area band. Calculation method is shown below.

(b) If you're measuring temperature, attach a thermocouple to the pole with its sensing bulb near the end so that airflow and temperature are both measured.

6. Calculate Anemometer/Pitot Locations

A typical airflow test requires measuring velocity at the center of 5 equal area bands in four quadrants. This



is 20 readings total and is considered the minimum acceptable number. For fans over 20 ft. diameter, 10 equal area bands should be considered.

6.1 Let DF equal the inside diameter of the fan ring. Let DSD equal the Seal Disc, Hub diameter or "Aerodynamic Hub Diameter".

6.2 Calculate the following:

- Gross Area (AG) = .7854 $(DF)^2$
- Net Free Area (NFA) = .7854$(DF^2 - DSD^2)$
- Area/Band (A/B) = NFA/(2 •Number of Bands)

6.3 Area within center of Band 5 = (AG - A/B) $FT^2 = A_5$

$$R_5 = \sqrt{\frac{A_5}{\pi}} \text{ ft. Radius to center of band 5}$$

6.4 Area within center of Band 4 = $(A_5 - 2 \bullet A/B) = A_4$

$$R_4 = \sqrt{\frac{A_4}{\pi}} \text{ ft. Radius to center of band 4}$$

6.5 Area within center of Band 3 = $(A_4 - 2 \bullet A/B) = A_3$

$$R_3 = \sqrt{\frac{A_3}{\pi}} \text{ ft. Radius to center of band 3}$$

6.6 Area within center of Band 2 = $(A_3 - 2 \bullet A/B) = A_2$

$$R_2 = \sqrt{\frac{A_2}{\pi}} \text{ ft. Radius to center of band 2}$$

6.7 Area within center of Band 1 = $(A_2 - 2 \bullet A/B) = A_1$

$$R_1 = \sqrt{\frac{A_1}{\pi}} \text{ ft. Radius to center of band 1}$$

6.8 Calculate distances from fan ring to anemometer measurement points.

d5 = D/2 - R5
d4 = D/2 - R4
d3 = D/2 - R3
d2 = D/2 - R2
d1 = D/2 - R1

6.9 Sample Problem:

Calculate anemometer positions to measure flow from a 14 ft. fan in a 14'2" fan ring with a 45" seal disc.

DF = 14'2" = 14.166 ft.
DSD = 45" = 3.75 ft.

AG = 157.63 ft^2
NFA = 146.59 ft^2
Area per Band (A/B) = 14.66 $ft.^2$
Area to center of Band 5 = A_G - A/B = A_5 = 142.97 ft^2

$$\text{Radius to center of Band 5} = \sqrt{\frac{142.97}{\pi}} = 6.75 \text{ ft.}$$

Area to center of Band 4 = A_5 - (2 * A/B) = 113.65 ft^2

$$R_4 = \sqrt{\frac{113.65}{\pi}} = 6.01 \text{ ft.}$$

Area to center of Band 3 = A_4-29.32 = 84.3

$$R_3 = \sqrt{\frac{A_3}{\pi}} = 5.18 \text{ ft.}$$

Likewise: $A_3 = 84.33$ ft_2
$R_3 = 5.18$ ft.
$A_2 = 55.01$ ft_2

$R_2 = 4.18$ ft.

$A_1 = 25.69$ ft^2

$R_1 = 2.86$ ft.

Check: A_1 - A/B should equal ASD

$25.69 - 14.66 = 11.03$ ft^2

ASD = 11.04 ft^2 (Check)

6.10 Calculate anemometer positions measured from fan ring: (See 6.8)

Band	Center Point Radius (ft.)	Distance From Fan Ring (ft.)
5	6.75	0.33
4	6.01	1.07
3	5.18	1.90
2	4.18	2.90
1	2.86	4.22

7. Example of Airflow Test with Anemometer

Typical equipment would consist of:

(a) A digital, battery powered anemometer with the ability to sample air velocity in 2 second or 16 second averages. A lightweight rod is marked with measurement distances from the fan ring to position the anemometer. A Davis DA4000 anemometer was used for the example test.

(b) A digital protractor was clamped to the anemometer pole to allow reading the yaw angle.

(c) A cloth streamer was attached to the anemometer rod adjacent to the propeller housing.

7.1 Preparation Before Test

(a) Measure fan ring diameter and hub or seal disc diameter

(b) Calculate net free area

(c) Calculate distance from edge of fan ring or stack to center of 5 equal area bands. Note there will typically be five but could be more on large fans. This would be the "number of bands" chosen in 6.2.

(d) Measure from center of anemometer for each of the distances and mark a ring on the anemometer handle with tape or black marker.

(e) Clamp protractor on anemometer handle so that when anemometer is resting on a horizontal surface, protractor reads "zero" degrees.

(f) Tie a streamer on the rod, adjacent to anemometer.

(g) Prepare data sheet with four quadrants (NE, SE, NW, SW) allowing space for at least 15 readings and an average for each quadrant.

7.2 Test Procedure

(a) Set up a work location in the first quadrant.

(b) Move anemometer to first mark (closest to ring).

(c) Align anemometer so that it is perpendicular to cloth streamer, record angle.

(d) Start anemometer taking 16 second averages of velocity, record three runs (each position).

(e) Repeat for each position each quadrant. Note that near fan ring yaw angles can be quite large and near hub velocity decreases significantly. Wind direction and velocity makes readings in each quadrant slightly different.

7.3 Example of test: Wind was 6 mph during test. Temperature was considered uniform over fan area and throughout test.

Fan ring diameter = 14' 2" = 14.166 ft

Seal disc diameter = 59", 4.92 ft

NFA = 138.62 ft^2

Area band = 13.862 ft^2

Radius to center of band (in)		Distance from fan ring (in)
Band 5	80.1	3.9
Band 4	71.7	12.3
Band 3	62.3	21.7
Band 2	51.1	32.9
Band 1	36.6	47.4

Data:

QUAD	POS.	YAW(θ)	V(FPM)	V	V COS θ
SE	5	29	1469,1695,1735	1633	1428
	4	21	1379, 1508, 1444	1444	1348
	3	22	1578, 1570, 1547	1565	1451
	2	42	1646, 1632, 1565	1614	1199
	1	52	1077, 1102, 995	1041	641

Avg. Vv = 1213

QUAD	POS.	YAW(θ)	V(FPM)	V	V COS θ
SW	5	85	1599, 1573, 1572	1581	138
	4	52	1704, 1708, 1701	1704	1049
	3	27	1708, 1703, 1703	1705	1519
	2	29	1491, 1239, 1531	1420	1421
	1	48	795, 821, 800	805	539

Avg. Vv = 933

QUAD	POS.	YAW(θ)	V(FPM)	V	V COS θ
NE	5	41	1500, 1615, 1619	1578	1191
	4	21	1791, 1799, 1792	1794	1675
	3	22	1719, 1726, 1724	1723	1598
	2	32	1719, 1724, 1706	1716	1455
	1	46	690, 849, 777	772	536

Avg. Vv = 1291

QUAD	POS.	YAW(θ)	V(FPM)	V	V COS θ
NW	5	86	1549, 1625, 1687	1620	113
	4	31	1829, 1837, 1831	1832	1570
	3	26	1723, 1724, 1714	1720	1546
	2	35	1669, 1693, 1701	1688	1383
	1	50	837, 905, 745	829	533

Avg. Vv = 1029

$$\text{Overall Vv} = \frac{1213+933+1291+1029}{4}$$

$$= 1117 \text{ FPM}$$

$$\text{ACFM} = 1117 \text{ ft/min} \times 138.62 \text{ ft}^2 = \underline{154{,}839}$$

APPENDIX
TYPICAL EQUIPMENT

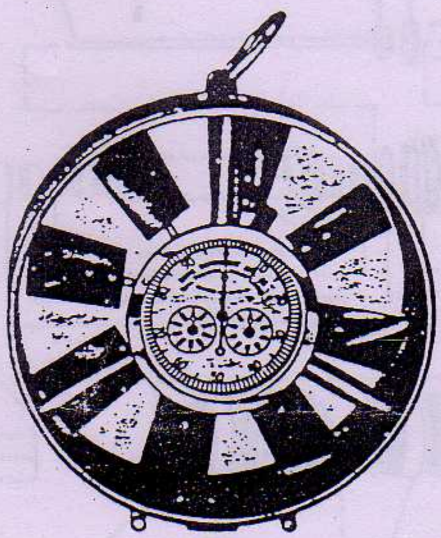


FIG. 1
VANE ANEMOMETER

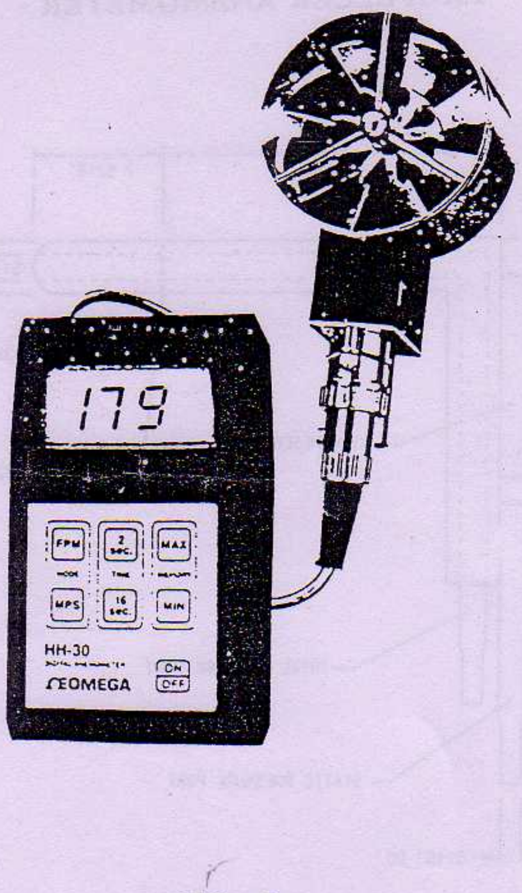


FIG. 2
ELECTRONIC ANEMOMETER

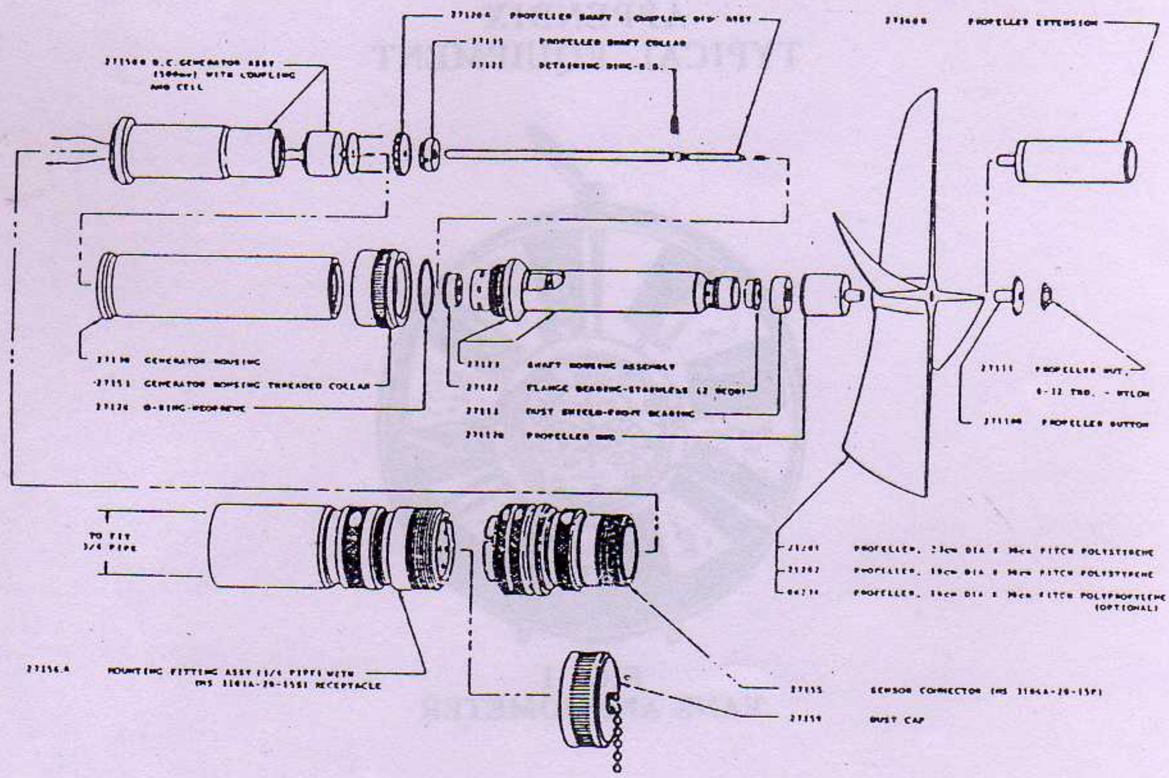


FIG. 3
PROPELLER ANEMOMETER

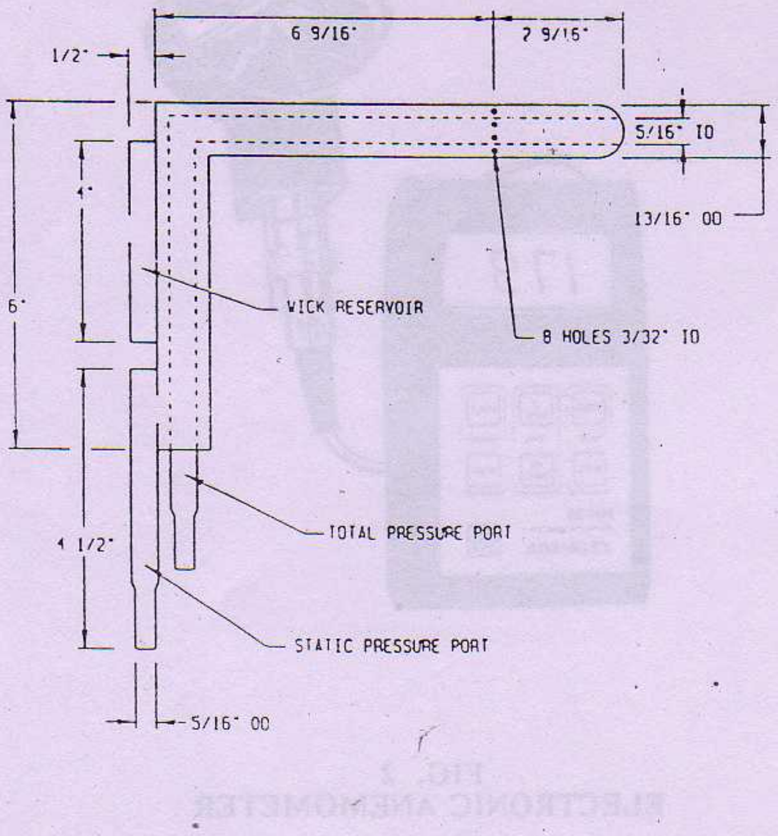


FIG. 4
SPECIAL PRANDTL PITOT TUBE

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