Measuring the Flow of Air

By Forrest M. Mims III

There are various applications for devices that detect the movement of air. This month's column will discuss some of them and describe two simple devices you can build to measure the movement of air. One device is a cup anemometer patterned after those meteorologists use to measure windspeed. The other is a hot-wire anemometer capable of detecting minute movements of air.

Applications for Air Movement Sensors

The most obvious application for devices that detect the movement of air is the measurement of windspeed. A closely related application is the measurement of the speed of a vehicle or aircraft. Airspeed indicators are also used to measure the velocity of air in a wind tunnel.

Air-movement detectors and sensors are sometimes used to monitor the blower in a heating or cooling system. The detector triggers a warning signal or shuts down the system when the air flow falls below a preset level. This same principle can be used to monitor the air flow in a clean-room environment.

Air-flow detectors can be used to count objects on an assembly line or detect the edge of a nearby object. This application is accomplished by directing a jet of air toward the sensor. Objects passing between the jet and the sensor block the flow of air and actuate the sensor.

Finally, air-flow detectors have many uses in science and medicine. They can be used to monitor respiration and the flow of oxygen. Air-pressure switches can be used by disabled people to trigger electrical circuits and to operate computers. The operator simply puffs into (or sips from) a plastic tube to close the switch.

Hot-Wire Anemometer

The electrical resistance of a conductor changes with temperature. For example, a platinum wire that has a resistance of 2 ohms at 0 degree C has a resistance of 2.5 ohms at 100 degrees C. In this case, the temperature coefficient of the wire is 0.002/degree C (0.5 ohm/2 ohm/100).

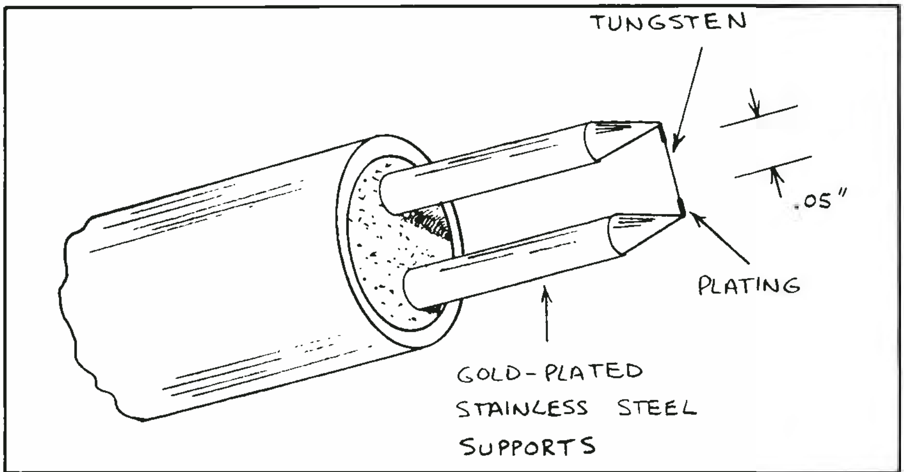


Fig. 1. A typical commercial hot-wire sensing element.

Air flowing past a heated wire tends to cool the wire, thereby lowering its resistance. By monitoring the resistance of the heated wire and taking the temperature of the surrounding air into account, it's possible to measure the speed of the air past the wire. A sensor designed for this specific purpose is commonly called a hot-wire anemometer.

Hot-wire anemometers can be used to measure very small changes in air movement. Since the active surface area of the device can be quite small, hot-wire anemometers are very useful for accurately portraying the flow of air and the turbulence around wind tunnel models. They can even be used to detect the movement of air created by the vibrating wings of a small insect.

Among the materials best suited for making hot wire-anemometers are tungsten, platinum and an alloy of platinum and iridium. Tungsten has a higher temperature coefficient of resistance than platinum (0.004/degree C). When heated, however, tungsten tends to oxidize much more rapidly than platinum.

Figure 1 shows one kind of commercial hot-wire anemometer. Notice that the active area of the probe is determined by the plating applied to either end of the tungsten wire. In recent years the sensing element of this basic probe has in many cases been replaced by a tiny quartz rod coated with a thin film of platinum. This sensor, which is called a hot-film anemometer, responds more quickly to variations in air flow, since a much smaller mass of metal is heated and cooled.

It's easy to experiment with hot-wire anemometry, since an ordinary flashlight bulb makes an effective hot wire sensor. All that's necessary is to remove the glass envelope from the bulb and monitor the current flowing through the filament. A change in the air flowing past the heated filament will change the resistance of the filament and, hence, the current flowing through it.

Of course the current flowing through the filament of the exposed light bulb must be much *lower* than that applied when the unbroken bulb functions as a light generator. Otherwise, the filament will quickly burn up. Figure 2 shows a simple circuit I've devised that both applies a safe current and permits the monitoring of the current through the filament for this purpose.

In operation, a 7805 voltage regulator supplies a constant voltage that is applied to an incandescent flashlight lamp in series with 50-ohm, 5-watt resistor *R1*. Variations in the air flowing past the filament cause fluctuations in the resistance of the filament and, hence, the current through both the filament and *R1*.

The filament of *L1* and *R1* form a voltage divider. As the resistance of *L1* changes in response to the air flow past its heated filament, the voltage applied to the inverting input of the 741 op amp varies accordingly. The 741 amplifies the voltage fluctuations and sends them to a voltmeter.

Potentiometer *R5* controls the gain of the op amp [gain = −(R5/R2)]. Potentiometer *R4* permits the output of the 741 to be zeroed when a measurement session is begun. Note: Unless the battery leads are short, it's important to bypass all power-supply connections with 0.1-microfarad capacitors. Connect the capacitors close to the two ICs.

A common PR13 flashlight bulb can be used for *L1*. Unless you want to use a lamp socket, solder a pair of insulated wire leads to *L1*. You must use care when removing the glass envelope from the lamp, because of the hazard presented by the sharp glass and the possibility of breaking the fragile filament. I wrap several layers of masking tape around the envelope, squeezing the tape at the top of the bulb so that no glass is visible. Then I place the taped envelope between the jaws of a C-clamp or a vise and very slowly tighten until the bulb's glass envelope pops. If the tape is pressed around the entire envelope, all the broken glass will usually lift away with the tape. With needle-nosepliers, I carefully remove any small shards of glass protruding from the metal base of the bulb.

Caution: A flashlight bulb may propel glass fragments a considerable distance if it is broken without appropriate protection. Therefore, it's imperative that you wear safety glasses or a face shield when breaking a flashlight bulb. Avoid using pliers or a hammer to break a bulb, since the filament may be damaged, and sharp shards of glass will fly all over the place.

The chief drawback of the circuit in Fig. 2 is the high current required by the 7805/*R1*/*L1* combination (about 250 milliamperes). While this is only about half the current required by a 6-volt lantern light, it's much too high for powering the circuit with the 9-volt transistor radio battery used to power the amplifier. Therefore, it's best to power this portion of the circuit with a pair of 6-volt lantern batteries connected in series.

The 7805/*R1*/*L1* combination dissipates about 3 watts of power. Therefore, if the circuit is to be operated for more than a few tens of seconds, the 7805 should be fitted with a suitable heat sink. Likewise, *R1* should be a 5- or 10-watt resistor. Too small a power rating will cause *R1* to be destroyed.

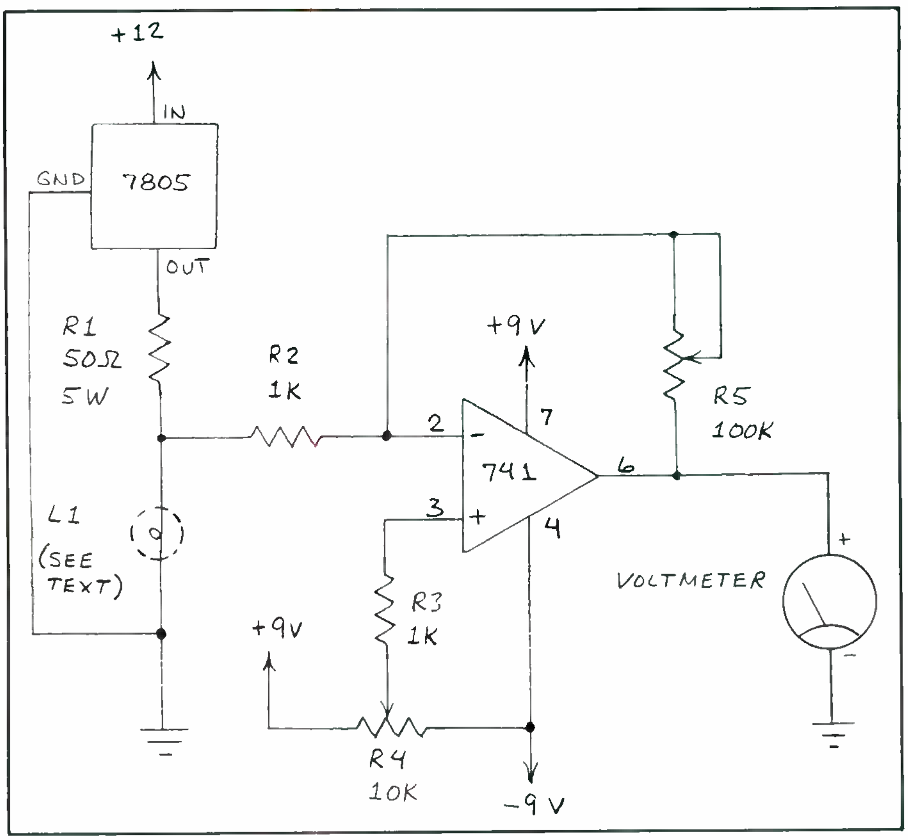
The basic circuit in Fig. 2 is amazingly sensitive. While testing it, I found that slowly passing a hand by *L1* caused an increase of about 1.5 volts in the output when *R5* was a 100,000-ohm resistor. Gently exhaling and inhaling near the exposed filament of *L1* caused the output voltage to swing even more.

It's important to note that when the gain of the circuit in Fig. 2 is made very high, setting the output to 0 by means of *R4* can be very difficult, since *L1* is so sensitive. You might want to try placing a small cover or container over *L1* while adjusting *R4*. Also, you can simplify calibration by operating the circuit at lower sensitivity levels.

Because *L1*'s filament is very fragile, you may want to devise a housing to protect it. A length of plastic tubing placed over the metal socket is one possibility. Holes can be cut in the plastic to permit the flow of air. The filament should be kept dry, since even a small drop of water will cause the filament to be quickly destroyed if the circuit is activated.

The hot wire anemometer in Fig. 2 is much too sensitive to monitor more than the gentlest breeze. But it can be used to detect drafts sneaking into a house

Fig. 2. A basic hot-wire anemometer circuit.



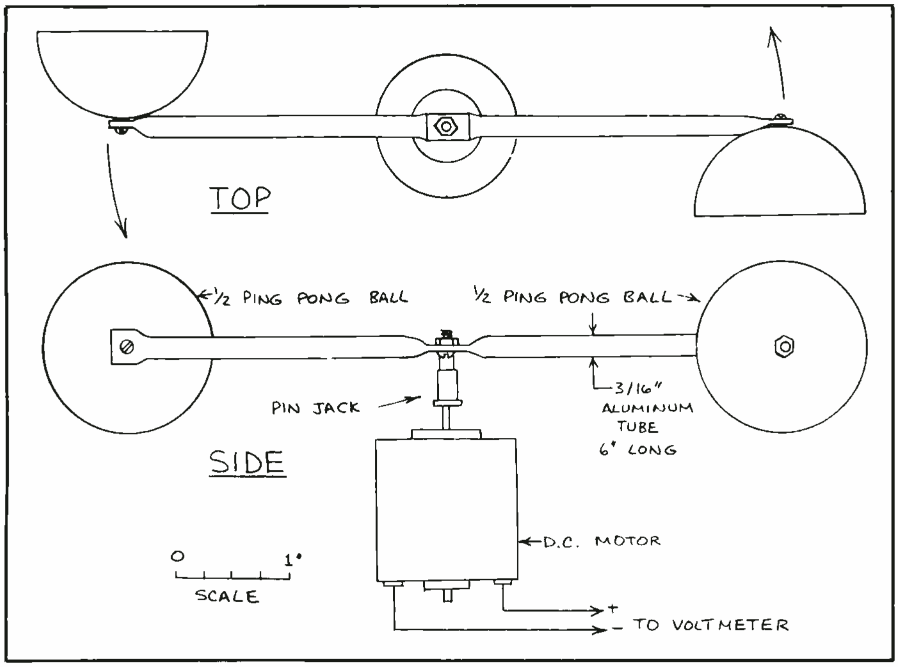
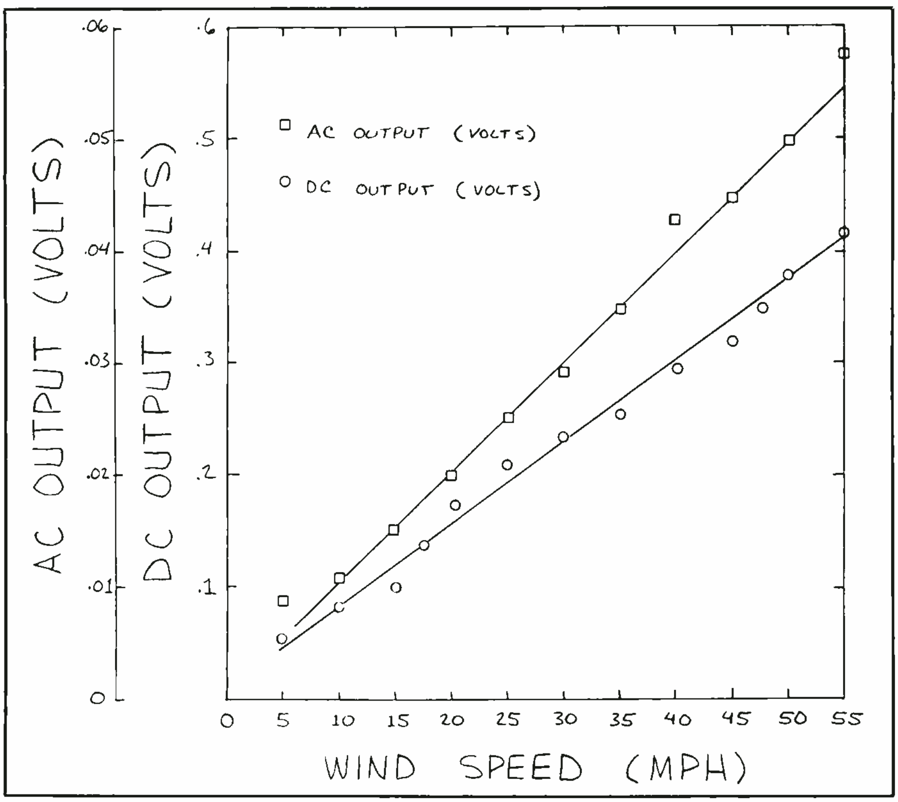


Fig. 3. A make-it-yourself cup anemometer.

Fig. 4. Calibration curve for cup anemometer.



through doors, windows and electrical outlets. It can also be used in experiments that detect respiration. A comparator can be connected to the output of the 741 so the circuit can indicate when the air flow exceeds a desired level.

Cup Anemometer

A dc motor functions as a generator when its shaft is rotated by an external force. Therefore, a dc motor can be used to make a very simple anemometer. I once applied this principle to make a miniature anemometer that measured the air speed of a wind tunnel. The wind tunnel, which was strapped onto the passenger side of a car, was used to test a miniature guided rocket. The anemometer was made by attaching a small balsa cone to the shaft of a dc motor. Four blades fashioned from the lid of a tin can were inserted into the balsa to form a propeller.

There are many ways to fashion a cup anemometer based on this principle. Figure 3 shows construction details of a simple cup anemometer that I recently assembled. The two cups are halves from split ping-pong balls. They are attached with 4-40 hardware to the ends of a 6" × 3/16" hollow aluminum tube (available from hobby shops).

The ends of the tube are flattened with pliers and then drilled to receive the mounting screws. The center of the tube is flattened at a 90 degree angle to the flattened ends and drilled. The solder lug from a pin jack is bent at a right angle and secured to the center of the tube with 4-40 hardware. The receptacle end of the pin jack is then pressed onto the shaft of a small dc motor.

Use care when slicing the ping-pong balls in half. I used a sharp hobby knife and wore heavy gloves. Ping-pong balls are tough, so you must be careful.

To test the anemometer, I used a length of flexible metal strap (available in hardware stores) to secure the motor to one end of a sturdy aluminum rod. I then mounted the rod to the side mirror on the passenger side of a pickup truck and connected the motor's leads to a voltmeter. My son Eric then drove the truck at various speeds on a still day, while I recorded voltage readings.

Figure 4 is a graph that shows the ac and dc readings Eric and I obtained during the test session. The cups begin to rotate when the wind speed reaches 3 to 4 mph. The speed at which your anemometer begins to rotate and the slope of the calibration curve is dependent upon the motor you use. The output from the motor is reasonably linear. This corresponds nicely with results I obtained with the wind tunnel anemometer described above.

During the tests, I noted some fluctuations of the voltage output at certain speeds. When this occurred, the voltage reading would jump back and forth over a range of a few tens of millivolts. Therefore, I recorded what appeared to be the average voltage.

The anemometer in Fig. 3 can be improved by adding another pair of cups. In its present configuration, the cups don't always turn when the wind is below 10 mph unless they are perpendicular to the oncoming wind. The motor must be protected from rain should this anemometer be installed outdoors. One possibility would be to install a split ping-pong ball over the top of the motor. It could be mounted to the 4-40 hardware that holds the pin jack in place. The split ball should rotate with the cups and keep rain from entering the top of the motor.

Going Further

You can find much more information about devices that detect and measure the flow of air at any good library. An excellent article on hot-wire anemometry is "Hot Wire and Hot Film Anemometry" by Eric Nelson (*Sensors*, September 1984, Pp. 17 through 22).

The Sharper Image (680 Davis St., San Francisco, CA and other stores in Houston, Denver and Los Angeles) sells the TurboMeter™, a compact anemometer with a shrouded fan and a digital readout. This unit, which measures winds up to 100 mph, sells for $79 (plus $3.50 postage). The TurboMeter and other anemometers are sold also by Edmund Scientific (101 E. Gloucester Pike, Barrington, NJ 08007).

For more information about Honeywell's ultra-sensitive air pressure switch, see "The Forrest Mims Circuit Scrapbook" (McGraw-Hill, 1983, Pp. 138-140). Included in this reference are experimental circuits that permit disabled people to control external devices by puffing into or sipping from a plastic tube. Also included is an experimental respiration detector circuit. The wind tunnel anemometer mentioned above is also described in this book (Pp. 133 to 134). ME