Understanding the altimeter

What you see isn't always what you have

by Jack Willams

Flying is an adventure for most pilots--sometimes more adventure than they really want.

A pilot's report to Canada's Aviation Safety Reporting Program about an attempt to land through low clouds on a remote, icy runway is an example. The airplane's altimeter indicated that the airplane was still 300 feet above the ground when "the nosewheel struck the ice," the report says. The pilot immediately applied full power, climbed away from the ground, and returned safely to the departure airport.

What happened? The air pressure was lower at the destination airport than at the departure airport, but the pilot had not reset the altimeter because the airport didn't have radio weather data, which includes information on altimeter settings.

A student pilot could get by without learning much about the aircraft's altimeter because landings during training are made when the lowest clouds are well above the runway. An altimeter reading that's 300 feet too high could go unnoticed with no consequences. This doesn't mean the correct altimeter setting isn't important until a pilot begins flying in poor visibility. For one reason, air traffic controllers expect all aircraft to fly at assigned altitudes. A would-be pilot should begin to learn how altimeters work and how to properly use them soon after training begins.

In aviation, *altitude* refers to how high an aircraft is above mean sea level; that is, how high the aircraft is above the average level of the Earth's oceans. The *altimeter* is the instrument that supplies this information.

Obviously, the important figure is how high the aircraft is above the ground, including mountaintops and things attached to the ground such as tall buildings and television towers. Two problems: An aircraft that zoomed and dived to hold the same height above mountains would be the ultimate thrill ride. Also, radar is the only reliable way to measure an aircraft's height above the Earth's surface. Compared with ordinary altimeters, radar is expensive, heavy, and complicated.

An ordinary aircraft altimeter is nothing more than a sensitive barometer, an instrument that measures air pressure. It works to measure height above sea level because the air's pressure decreases at a more or less regular rate as you ascend. Standard atmosphere tables show how this works. The table [below] is an abbreviated version that gives altitude in feet above mean sea level, pressure in inches of mercury, and temperature in degrees Fahrenheit.

The standard atmosphere		
Altitude (Feet)	Pressure (Inches of mercury)	Temperature (degrees Fahrenheit)
Surface	29.92	59.0
1,000	28.85	55.4
2,000	27.82	51.9
3,000	26.81	48.3
4,000	25.84	44.7
5,000	24.89	41.2
6,000	23.98	37.6
7,000	23.09	34.0
8,000	22.22	30.5
9,000	21.38	26.9
10,000	20.58	23.3

Atmospheric pressure decreases at a regular rate as altitude increases.

Using the table, you can see that you could mark a barometer so that when the pressure is 28.86 inches of mercury, the instrument would read 1,000 feet; 27.82 inches of mercury 2,000 feet, and so on. You can also see why for the lower atmosphere we can use the rule of thumb that the pressure decreases by about (but not exactly) one inch of mercury for each 1,000 feet of altitude gained.

You can think of the standard atmosphere as being more or less the Earth's average atmosphere. As with any average, the figures for pressure and temperature can be higher or lower at any particular time than those shown for any altitude.

Weather changes that affect temperatures and air pressures cause the complications in understanding and using an altimeter. This is why an aircraft's actual height above mean sea level is its *true altitude* while what the altimeter says is the *indicated altitude.*

Part of the pilot's job is to ensure that the indicated and true altitude are the same, or so close to the same it doesn't make the flight dangerous. To see how this works, imagine that you parked your airplane at a sea-level airport on an "average" day when the temperature was 59 degrees F and the barometric pressure 29.92 inches of mercury. The altimeter in your airplane would look much like the one in Figure 1 [on top right], except that all three indicators would be pointing straight up, showing that you are at zero altitude. Let's also assume that you used the adjusting knob to set the reading in the Kollsman window to 29.92. (The window is named for Paul Kollsman, who invented the first accurate altimeter in 1928.)

When you return to the airport the next day the weather map is showing an area of low air pressure over the region, and the airport's barometer is reading 29.42 inches of mercury. When you begin your preflight inspection, you see that the long needle is pointing at 500, the middle (short, fat) hand is between 0 and 1, and the shortest hand has barely moved--the altimeter is showing an altitude of 500 feet.

That's just what you would expect since the altimeter is really only a barometer, calibrated to show altitude, and a pressure of 29.42 inches of mercury (using our rule of thumb) is found at 500 feet in the standard atmosphere. Before going flying, you have to set the altimeter.

Since your airport has an automated weather report broadcast, you tune it in and hear that the altimeter setting is 29.42. You turn the adjusting knob until 29.42

shows in the Kollsman window. When you do this, all three needles return to "0," which is correct since as you sit on the ramp at the sea level airport your altitude is zero.

In this case, the airport is said to have an *elevation* of zero since elevation is the height of the ground at a particular location above mean sea level.

Our first lesson in using an altimeter is that if you know the elevation of an airport that you're parked at, you can set the altimeter to read the airport's elevation and you'll have the correct altimeter setting. This is handy when you are at an airport without weather reports.

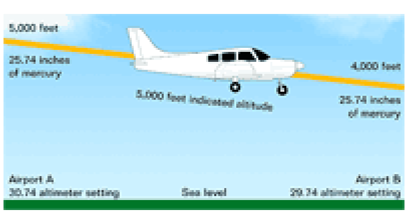
What happens when you are flying to an airport that's not at sea level? You need the correct setting before you land.

In this case, the altimeter setting amounts to what a barometer at that location would read at sea level at that time. One way to obtain such a reading would be to dig a well down to sea level and lower a barometer to the bottom. Fortunately, weather observers have much easier ways.

One way would be to have a well-calibrated altimeter with an easy-to-read Kollsman window. As the air pressure changes the observer would adjust the altimeter to station elevation and read the setting from the Kollsman window. The way it's normally done, however, is to read the *station pressure*--the actual air pressure at the station--and use a mathematical formula to calculate the altimeter setting.

Today, of course, computers do the calculating. In fact, you can go to the weather calculator on Web site of the National Weather Service office in El Paso, Texas, and do the calculation, maybe using a reading from a home barometer. Scroll down to "Altimeter Setting" in the "Pressure Conversions" section of the page. If you wonder what the formula looks like, click on "Formulas" to the right of "Altimeter Setting."

Now we're ready to see what happens if you fly from an airport with one altimeter setting to another with a different setting, which is going to be the case if you fly very far.



gure 2 shows what happens when an airplane flies from an area of high pressure to an area of low pressure.

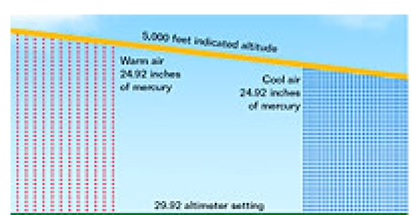


Figure 3: How differences in temperature affect indicate altitude.

Let's see what happens when you take off from an airport where the setting is 30.74, climb to 5,000 feet altitude, and fly to a place where the setting is 29.74. To keep it simple, we'll make both airports at sea level. Figure 2 shows what happens. At Airport A, on the left, you set your altimeter to 30.74 and since you're at sea level, it reads 0 for altitude. As you climb the altimeter senses lower and lower pressure until the pressure is 25.74 inches of mercury. The altimeter reads 5,000, and you level off and head for Airport B on the right.

Since the surface pressure is lower at B than at A, all of the levels aloft at a particular pressure slope down from A to B, as shown by the "Indicated 5,000 feet" line across the top. You're so busy holding an indicated altitude of exactly 5,000 feet and enjoying the view that you neglect to obtain the altimeter setting for Airport B and do not reset your altimeter.

As you arrive over B, your altimeter still reads 5,000 feet. But, how high are you actually above the sea level airport? When you reset your altimeter to Airport B's 29.74 reading, you see that you are really 4,000 feet above the ground.

You can see where the saying, "high to low, look out below" comes from. If you fly toward an area of lower pressure you need to look out below because things such as mountaintops and television towers could be closer than you think. If you set your altimeter at 29.74 before leaving B and flew back to A without resetting the altimeter, you would be 1,000 feet higher than the indicated altitude when you arrived back at Airport A.

When you're taking a knowledge test, you can sketch a diagram like Figure 2 after you sit down (don't bring it to the test) to help you figure out the answers to altimeter questions.

The "high to low look out below" rule applies to temperature as well as to air pressure. As air warms, the molecules of its various gases begin moving faster and spread out, as indicated in Figure 3. In other words, air expands as it warms and contracts as it cools, as most materials do.

The air pressure at the surface is really a measure of how many air molecules are above the barometer. Warm air can have the same surface pressure as cold air, as shown in Figure 3, but the column of warm air will be higher. This is why the *tropopause*--the boundary between the atmosphere's lower level and the stratosphere--is about 10 miles above sea level in the tropics but only around six miles up in polar regions. As Figure 3 shows, as you fly from warm air into cold air your true altitude could be descending even though indicated altitude stays the same, and the altimeter settings along the route do not change.

Altimeters found in most general aviation aircraft have no way of adjusting for temperature, but you can use a flight computer to estimate how much lower than indicated altitude you are in cold air. Any such figures are only estimates, however, because you use only the temperature at your flight level for the calculations and this assumes that the air is cooling at a uniform rate between you and the ground.

Cold air that lowers pressure levels is only one reason why you need to worry more about altimeter readings during the winter than in the summer, especially in the cold parts of the world. Winter also brings stronger and faster-moving cold fronts. As a front moves into an area the air pressure drops and then rises again after the front passes. This means that altimeter settings can change more often and by greater amounts in winter than summer. You need to be alert to these changes on cross-country trips.

While true and indicated altitudes are the only kinds that general aviation pilots have to worry about most of the time, you should also be familiar with *pressure altitude*. This is the indicated altitude you get when you set your altimeter at 29.92 inches of mercury. In the United States all aircraft flying higher than 18,000 feet use pressure altitudes.

Performance charts or calculations to obtain figures such as takeoff distances sometimes require pressure altitude. If you need this figure for preflight calculations, and can't sit in an airplane on the ramp to see what you get when you set the altimeter to 29.92, you can use the El Paso weather calculator to figure pressure altitude using airport elevation and station pressure. Since weather offices don't report station pressure, you can use the calculator to find station pressure, using the altimeter setting.

Knowing all about how altimeters work, and the necessity for using the correct settings won't do you much good if you make a simple mistake when writing down information from a controller or the Automatic Terminal Information System (ATIS). An airline crew reported just such a mistake to NASA's Aviation Safety Reporting System: "The 30.06 altimeter setting we used was actually the wind speed and direction and was written [on the ATIS information card as] 3006. In my mind, this was a reasonable altimeter setting. The ATIS setting was actually 29.54," a pilot told NASA.

Even after you feel confident that you know all a pilot needs to know about altimeters and use this knowledge on every flight, a simple mistake can trip you up. Don't hesitate to ask a controller for the altimeter setting, or anything else, if you have even the slightest doubt.

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