Altimeters

Definitions:

"Mercury Barometer", a device that measures atmospheric pressure by the height of a column of mercury in a glass tube, reported as inches of mercury ("Hg).

"Aneroid Barometer", a device that measures atmospheric pressure by the expansion/compression of a sealed container. In aircraft altimeters the container is flexible wafers.

"Indicated Altitude", what is showing on the face of the altimeter.

"True Altitude" – your actual height above the average level of the sea. Referred to as MSL (mean sea level).

What is Atmospheric Pressure?

Atmospheric pressure is the weight of all the air particles in the air directly **ABOVE** the measuring device. The "air particles" is comprised of about 78% nitrogen, 21% oxygen, a little carbon dioxide and some other stuff including variable amounts of water vapor.

Originally, a mercury barometer was used to measure atmospheric pressure and in the US atmospheric pressure is still reported in inches of mercury ("Hg). In the airplane, the measuring device is an Aneroid Barometer inside the altimeter. Atmospheric pressure varies depending on weather conditions.

What is the International Standard Atmosphere?

The International Standard Atmosphere (ISA), defines a hypothical day when at sea level, the atmospheric pressure is 29.92 "Hg and the temperature is 15 degrees centigrade.

What is the ISA standard lapse rate?

The ISA standard says that on average for each 1,000 feet increase in altitude the atmospheric pressure will <u>decrease</u> one (1) "Hg and the temperature will decreases two (2) degrees centigrade. Conversely, atmospheric pressure and temperature will <u>increase</u> the same amount for each 1,000 feet decrease in altitude. This pressure lapse rate is fairly accurate up to about 5,000 MSL then the rate starts changing.

How does an altimeter work?

To understand how an altimeter works we have to first understand the physics of a bag of potato chips.

Let's say we're at a potato chip manufacturing plant located at sea level somewhere in Mississippi. A worker fills a bag with potato chips and tightly seals the bag closed. We buy the bag of chips, jump in our car and head for Colorado. Along the way, as we go up in elevation, we notice the bag of chips is beginning to swell up and as we clear the top of Raton pass in New Mexico the bag explodes with a bang. The unexpected loud noise makes us jump and we almost veer off the road at the top of an 11,000 foot mountain. What happened?

Here's what. When the bag of chips was sealed back at the factory the air pressure trapped inside the bag was whatever it was that particular day at sea level. As we gained altitude on our way to Colorado going up in elevation the air pressure outside the bag continuality decreased causing the pressure inside the bag to be higher than the pressure on the outside, so the bag swelled up. At the top of Raton pass, with the outside pressure at its low point, the seal on the bag no longer could hold back the "high pressure" inside the bag. The seal ruptured and the high pressure inside the bag exploded outward.

So what's this got to do with altimeters?

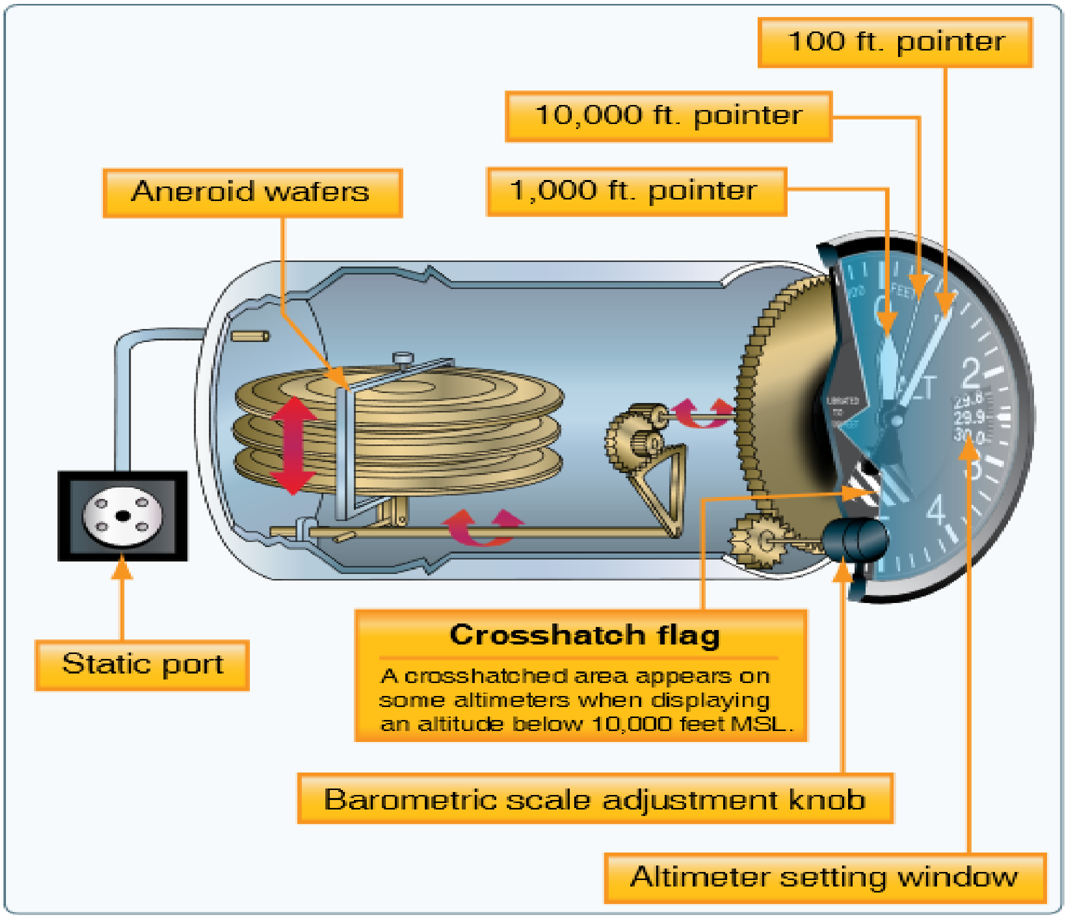
Altimeters have a tiny bag of potato chips built inside the housing. As the altimeter goes up in altitude the bag expands, as we go down the bag contracts. Pointers are attached to the bag so that we can see how much the bag is expanding and contracting.

Actually, it's not really a bag of potato chips, but the "sealed wafers" of an Aneroid Barometer inside the altimeter are doing the same thing the potato chip bag did.

The altimeter has a built in Aneroid Barometer who's "wafers" have a sealed in pressure of 29.92 "Hg. The wafers are connected to the hands on the numbered dial face through mechanical linkage. When the outside atmospheric pressure decreases the wafers expand, which moves the dial hands to a higher number. When the atmospheric pressure increases the wafers compress and the hands move to a lower number.

The altimeter is a mechanical device and cannot do arithmetic, but in effect it calculates how much to move the hands on the dial using the ISA lapse rate formula of one (1) "Hg change in atmospheric pressure equals 1,000 feet change in altitude.

The altimeter "feels" the atmospheric pressure through the static port on the side of the airplane.



VERY IMPORTANT INFORMATION:

The altimeter knows nothing about altitudes!!!

The altimeter moves the hands on the dial based on the amount of expansion/compression of the aneroid barometer wafers inside the housing.

The "Indicated Altitude" on the dial face only has meaning when the pilot has correctly adjusted the altimeter.

(NOTE: From here on we'll assume the pilot has set the altimeter correctly, either directly to field elevation, or from the latest altimeter setting. We'll also assume we're flying below 18,000 feet MSL).

An altimeter is an aneroid barometer that reacts to changes in atmospheric pressure.

As a *general rule* as the altimeter goes up in elevation the pressure drops, the wafers expand and the hands move to show a higher altitude. As we go down the pressure increases, the wafers contract and the hands move to a lower altitude.

But, how do the hands know how much to move as the bag of chips (I mean wafers) expand and contract?

Someone at the altimeter factory figured out that when the outside air pressure changes by 1 "Hg the wafers expand/contract a certain amount. So, for that exact amount of movement in wafer size they made the hands move 1,000 feet. In other words the altimeter was taught to follow the definition of the standard atmosphere pressure lapse rate. The hands don't do this all at once, as the wafers slowly expand/contract the hands slowly move accordingly.

Our on-board barometer doesn't know anything about altitudes, or temperatures, it only knows about pressure. Altitude has a significant effect on pressure and therefore the altimeter. Temperature however only affects air density, which can be a major contributor to the sometimes difference between Indicated Altitude and True Altitude.

When the altimeter was manufactured care was taken so that the pressure sealed inside the wafers was 29.92 "Hg. Pointer hands were carefully installed so that if the pressure outside the wafers was also 29.92 "Hg the hands would point at zero (0) feet.

As the wafers expand, or contract when the pressure changes by (1) "Hg the indicated altitude shows a change of 1,000 feet, even if that isn't true. For example, let's say that on this particular day the actual atmospheric pressure at sea level is 29.92 "HG and the indicated altitude is zero feet. All seems to be correct, so far. We take off and land at an airport that is exactly 1,000 feet above sea level. The actual AP at this moment at that airport is 28.30 "HG. Our altimeter has been taught that for every 1 "hg change in atmospheric pressure, change the indicated altitude by 1,000 feet. There has been a decrease of 1.62 "Hg in actual pressure, so the altimeter shows an increase in elevation of 1,620 feet. But that ain't true, we're setting on the ground at an airport that we know is 1,000 above sea level.

One more time…

The altimeter was built assuming that the atmospheric pressure at sea level is always 29.92 "Hg and that for each 1,000 feet of altitude change the pressure will change one (1) "Hg. Atmospheric pressure and temperature are lower going up, and higher coming down.

Consider an altimeter that is NOT adjustable and the hands were set at the factory to show zero (0) feet at 29.92 “Hg. Based on the ISA standard lapse rate, this altimeter would react as follows:

If the current atmospheric pressure is 29.92 “Hg, the altimeter would show an Indicated Altitude of zero (0) feet. [(29.92 – 29.92) x 1000 = 0]

If the atmospheric pressure is 28.92 “Hg the altimeter would show an Indicated Altitude of 1,000 feet. [(29.92 – 28.92) x 1000 = 1,000 feet]

The Kollsman Window:

We now know that altimeters are designed to follow the ISA standard of 1,000 foot change in altitude for each 1”Hg change in atmospheric pressure. But, the real atmosphere almost never exactly conforms to the ISA standard. Most of the time a change of 1 “Hg in atmospheric pressure **DOES NOT** occur in exactly 1,000 feet of altitude change.

Problem is, the ALTIMETER DOESN’T KNOW THIS. If the altimeter sees a change of 1 “Hg it moves the hands 1,000 feet, **even if it’s wrong**.

In order to get a more accurate reading of actual True Altitude (MSL), which works both on the ground and in the air, we need a way to compensate for the difference between the ISA standard the altimeter is based on and the actual atmospheric pressure Mother Nature has provided.

In 1928 Mr. Paul Kollsman came to the rescue when he invented something called the “Kollsman Window”, here’s how it works.

The small knob on the altimeter moves a scale of atmospheric pressure values in “Hg, at the same time it also moves the hands on the dial. When you turn the scale toward higher pressure numbers the hands of the dial move toward a higher altitude and vice-versa.

The numbers on the scale are called the “Altimeter Setting”. By setting the current altimeter setting in the Kollsman window the pilot is simply making an adjustment to the Indicated Altitude for non-standard atmospheric pressure.

It’s important to know that the altimeter DOESN’T KNOW you’re moving the hands and has no effect on the aneroid wafers in the altimeter. The altimeter, as well as, the pilot can move the hands, it’s hoped that together the resulting Indicated Altitude is a useful number.

What effect does non-standard ISA pressures and temperatures have on Indicated Altitude?

This is where things get a little “fuzzy”.

First a review:
Atmospheric Pressure is the weight of all the air particles ABOVE the airplane.

The altimeter knows nothing about altitudes, the only thing the altimeter knows how to do is:

- “Determine” the difference between 29.92 “Hg and the current atmospheric pressure.

- Then move the hands on the dial a corresponding amount consistent with the amount of pressure change. The amount the hands move is based on the ISA standard pressure lapse rate of 1 “Hg change in pressure = 1000 feet change in altitude. For example, a pressure change of .750 “Hg moves the hands 750 feet.

The ISA standard is based on the **assumed predictability** of atmospheric pressure and temperature at various altitudes. Air density is determined by atmospheric pressure and temperature and is a huge factor in determining Indicated vs True Altitude. If either pressure, or temperature is “non-standard” the air density will also be “non-standard” and the altimeter will need an adjustment value to show an Indicated Altitude that is close to the True Altitude MSL.

The altimeter follows pressure levels, not altitudes.
An altimeter knows NOTHING about altitudes, or temperatures, it only knows about atmospheric pressure. The reason temperature is part of the altimeter discussion is because temperature has an effect on air density and density is an important factor with Indicated and True Altitude.

For example if you intend to fly at 4,000 feet MSL, True Altitude **and you don’t** keep the Kollsman window set to the most current altimeter setting, and you fly into changing pressure, or temperature conditions, you’re actual True Altitude will be different than the Indicated Altitude showing on the altimeter.

Here’s why:

Let’s say, based on the atmospheric pressure and the last altimeter setting in the Kollsman window, your altimeter shows an Indicated Altitude of 4,000 feet.

It will remain this way, as long as, the atmospheric pressure above the airplane stays the same. However, if the pressure, or temperature is dropping, the pressure above the plane is also dropping, which causes the altimeter to falsely show that you’re climbing. (Pressure is getting less, so the altimeter thinks you’re climbing).

You drop the nose to descend back to 4,000 feet "Indicated Altitude", but actually you're going down in "True Altitude". You didn't go up in the first place, the atmospheric pressure above you went down, so the altimeter said you were climbing, when you weren't.

You descend back to 4,000 **Indicated Altitude**, but you're **True Altitude** is now less than 4,000 feet. You're descending, following the 4,000 foot pressure level down. The opposite happens if the pressure, or temperature is rising.

As atmospheric pressure gets lower there are fewer air particles above the airplane.

Hypnotically, let's say there are a total of 10 air particles above your airplane and with your current altimeter setting the weight (pressure) of these 10 particles causes your altimeter to show an Indicated Altitude of 4,000 feet.

If you fly into an area where the atmospheric pressure is dropping that means there are fewer air particles, therefore fewer air particles above the airplane. (Less pressure means fewer air particles). Because there are fewer air particles everywhere you no longer have the necessary 10 particles above the plane, the altimeter sees the "drop in pressure" and moves the hands to a higher Indicated Altitude suggesting that you're climbing, when you're not.

To keep your altimeter showing an Indicated Altitude of 4,000 feet (weight of 10 air particles above the airplane), you descend to get more air particles above you, which makes you go down in True Altitude.

This can be disastrous in mountainous areas where reporting stations may be few and far between. When flying in a mountainous area always give yourself at least 1,000 foot clearance above the tallest peak along your path.

The fix for this problem is to frequently set your altimeter to the most current altimeter setting available, preferably one in front of you. Doing so gives the altimeter a new adjustment for non-standard atmospheric pressure. That, combined with the amount of hands movement caused by the current atmospheric pressure will place the hands at the proper Indicated Altitude, which also should be fairly close to your actual True Altitude, at least for a while.

As air gets colder air particles drop and compress closer to the ground.

This is a tougher problem. Again, let's say there are a total of 10 air particles above your airplane and the weight (pressure) of these 10 particles along with your current altimeter setting causes your altimeter to show an Indicated Altitude of 4,000 feet.

If you fly into colder than standard air those 10 particles will drop down closer to the ground. (Cold air sinks, warm air rises). Some of these 10 particles are now below the airplane. The altimeter sees the drop in pressure and moves the hands to a higher Indicated Altitude indicating you're climbing.

To keep your altimeter showing an Indicated Altitude of 4,000 feet (weight of 10 air particles above the airplane), you will have to descend and get more air particles above the plane. So once again you're actually descending in True Altitude, but the Indicated Altitude still shows 4,000 feet.

The difficulty in this case comes because altimeter settings do not take into consideration non-standard temperature. The atmosphere has the same number of air particles, so the atmospheric pressure is the same and the altimeter setting is the same, but where these air particles are located is NOT the same. Due to the non-standard temperature lapse rate, the cold air particles are closer to the ground than expected.

You can have the latest altimeter setting in the Kollsman window, but because of non-standard cold air the Indicated Altitude may be higher than the actual True Altitude. This can be disastrous in mountainous areas. When flying in the mountains always give yourself at least 1,000 foot clearance above the tallest peak along your route and in particularly cold conditions double check your True Altitude using an E6B flight computer.

When you suspect this condition may occur, here's what you can do.

1. Using an E6B flight computer (manual, or electronic) calculate your True Altitude. You'll need to know:

   a) Pressure Altitude. (Set the Kollsman window to 29.92 "Hg and read the Indicated Altitude as Pressure Altitude).

   b) Outside Air Temperature in degrees centigrade.

   c) Indicated Altitude with the Kollsman window set to the closest current altimeter setting available.

2. Set the computed True Altitude as the Indicated Altitude on the dial face. This gives the altimeter an adjustment value that causes the Indicated Altitude to be close to the True Altitude.

3. Maintain that Indicated/True Altitude until you compute a new True Altitude.

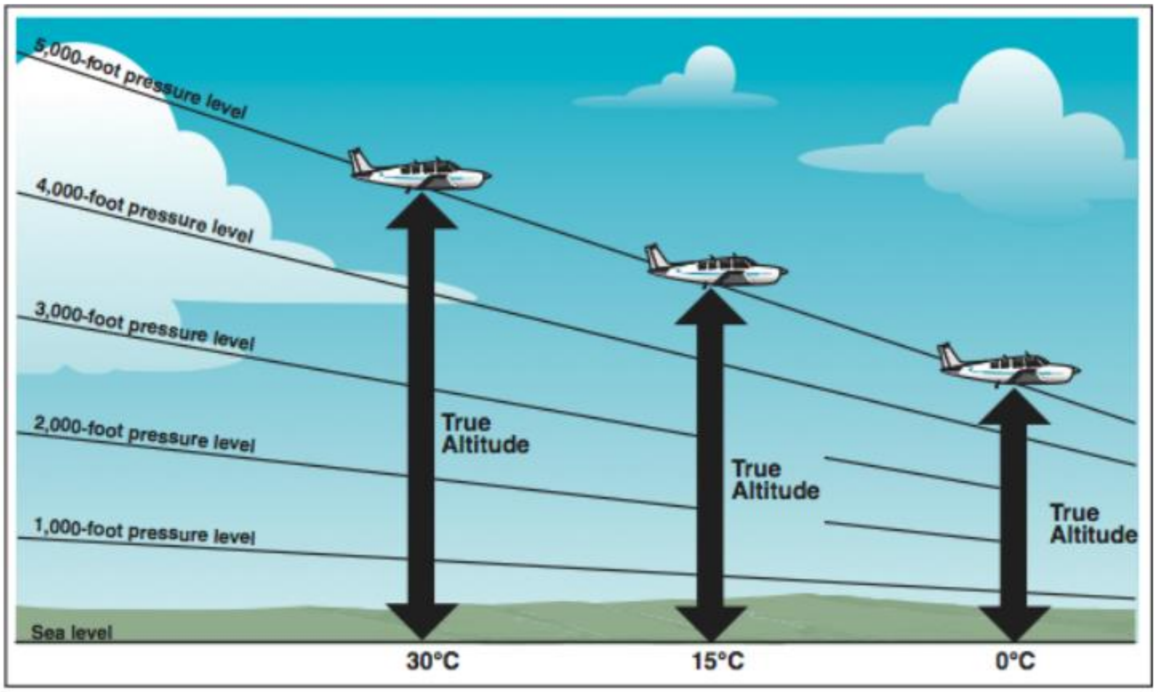


Figure 6-3. Effects of nonstandard temperature on an altimeter.

This is what a declining pressure level caused by cold air looks like. In this case the airplane is showing an Indicated Altitude of 5,000 feet, but the actual True Altitude is descending. Due to the non-standard cold temperature, the 5,000 foot pressure level is descending.

How the altimeter setting is calculated:

Assume we flew from an airport at sea level where the atmospheric pressure was the ISA standard 29.92 “Hg, to an airport that is 700 feet MSL. According to the standard lapse rate (1 ”Hg = 1,000 feet) , the atmospheric pressure at the destination airport should be **29.22** “Hg. (29.92 - .70 = 29.22).

However, let’s say the actual atmospheric pressure where we landed is **29.16** “Hg. That’s a difference of .06 “Hg, (29.22 - 29.16 = .06), which is a difference of 60 feet in elevation. (1 ”Hg is 1,000 feet, so .060 ”Hg = 60 feet).

If we didn’t changed the altimeter setting during the flight, and it’s still set to 29.92 “Hg, what would our Indicated altitude be upon landing?

True Altitude MSL (TA) = 700 feet
Altimeter Setting (AS) = 29.92 “Hg
Atmospheric Pressure (AP) = 29.16 “Hg

Indicated Altitude (IA) = [(AS) – (AP)] x 1000.

IA = [29.92 – 29.16] x 1000 = 760 feet.

Because of the lower than standard pressure, when we're on the ground the altimeter thinks we're still 60 feet above the airport.

What we need is an altimeter setting that adjusts the hands down by 60 feet so when on the ground the altimeter will read 700 feet, field elevation.
That calculation is AS = [(IA/1000) + AP], or (.7 + 29.16 = 29.86).

If you set the Kollsman window to 29.86 "Hg before landing the Indicated/True Altitude will be 700 feet MSL on the ground.

(Note: For instrument error and location on the airport, the FAA allows a maximum difference of 75 feet between Indicated Altitude and field elevation).

When you set the "current altimeter setting" in the Kollsman window you're establishing the correct starting position for the hands and as the altimeter moves the hands due to changes in atmospheric pressure the Indicated Altitude should stay close to your True Altitude. However, because actual atmospheric conditions almost never are exactly the same as the ISA standard lapse rates (the altimeter uses), in the air, the "Indicated" True Altitude won't be as precise as when you're on the ground.

The net effect of all this is with the current altimeter setting in the Kollsman window the Indicated Altitude on the ground should show field elevation and in the air it should be close to your True Altitude MSL, unless you run into really cold air.

Non-standard temperatures affect Indicated vs True Altitudes and is <u>NOT</u> corrected for by the current altimeter setting. The current altimeter setting only corrects for non-standard pressure. To correct for non-standard temperature you can use an E6B flight computer to calculate your actual True Altitude.

The current altimeter setting for each reporting station is available to pilots in various ways.

Things to Remember:

Non-standard atmospheric conditions exist most of the time, therefore it's very important to always have the altimeter set to the most current Altimeter Setting available to minimize potential errors.

When setting on the ground at a reporting station with the altimeter set to the current altimeter setting the Indicated Altitude should be within 75 feet of field elevation. If it's not, take your altimeter to the doctor.

If the airport you're at doesn't report altimeter settings, set the altimeter to the field elevation. (Note: When you do this by default the Kollsman window should be real close to the current altimeter setting)

A correctly set altimeter gets more accurate the closer to the ground you get.

Current altimeter setting does NOT correct for non-standard temperature.

Flying from **“High to Low, or Hot to Cold, look out below”,** your True Altitude may be lower than the Indicated Altitude.

Example problems:

True Altitude MSL (TA)
Altimeter Setting (AS)
Atmospheric Pressure (AP)

Indicated Altitude (IA) = [(AS) – (AP)] x 1000.

1. AS = 29.92, AP = 29.92, IA = ?

2. IA = 855, AP = 29.07, AS = ?

3. IA = 855, AS = 29.93, AP = ?

4. AS = 29.93, AP = 29.07, IA = ?

5. What is the ISA standard atmospheric pressure for an airport at 2000 feet MSL True Altitude?

6. On an ISA standard day what is the altimeter setting for the airport in question 5?

7. What is the Indicated Altitude, setting on the ground, at an airport located at sea level, with the altimeter set to ISA standard, if the atmospheric pressure is 29.82 “Hg?

8. Same as question 7, except the atmospheric pressure is 29.99 “Hg?

9. What is the altimeter setting if the Indicated Altitude is 0 feet and the atmospheric pressure is 29.82 “Hg?

10. If the temperature is colder than ISA standard which direction is the 4,000 foot pressure level going, Up, Down, or Level?

Answers:

1. IA = 0
2. AS = 29.93
3. AP = 29.07
4. IA = 860
5. 27.92 “Hg
6 29.92 “Hg
7. 100 feet
8. -70 feet (below sea level)
9. 29.82 “Hg
10. Down