How High Is 'Up'?

Figure 1. A modern three-pointer-type sensitive altimeter, showing a barometric-pressure setting of 29.95 in. Hg. and an indicated altitude of 300 feet msl. The barber-pole-striped sector of the dial will be masked when the airplane is at approximately 16,000 feet.

The altimeter—its history, its uses, and its limitations

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Author's photos except as noted

Figure 2. A sensitive altimeter with triangular airport-altitude reference marks. In this illustration, an airport altitude of 310 feet has been set into the instrument. When the airplane is on the ground, the pointers will indicate zero.

Figure 3. A digital-type altimeter, with range from -1,200 feet to +50,000 feet. This instrument also provides a code to the transponder for reporting altitude in 100-foot increments.

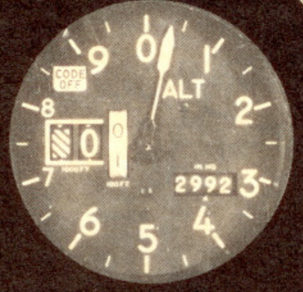

Photo courtesy of Kollsman Instrument Corporation

■■ Have you ever considered just how much we depend upon the altimeter? VFR flying is easier, night flying is safer, and IFR flying is possible because of this instrument that tells us, though indirectly, our height above the terrain.

The altimeter found in most of our light airplanes has an airtight aluminum or plastic case with a heavy glass front. The mechanism within consists of two or three evacuated bellows—thin disks of beryllium, copper, or stainless steel—mounted in a temperature-compensating frame. An opening in the frame permits pressure from the pitot-static system to surround the bellows, which expand or contract in response to changes in outside air pressure as the aircraft climbs or descends. This linear movement is transmitted by a gear arrangement, causing the pointers on the face of the instrument to revolve. A spring-loaded counterweight cancels out or minimizes any effect of gravity on the mechanism.

Three pointers are used on most modern altimeters (see Figure 1). The long pointer makes one revolution for each 1,000 feet; the middle pointer, one revolution for each 10,000 feet; and the short pointer, or sometimes a triangular marker, one revolution for each 100,000 feet. A cutout in the altimeter dial forms a window for the barometric-pressure scale. A knob, located either at bottom center or, more usually, at the 7 o'clock position, rotates the pointers and the barometric scale when the pilot applies the altimeter-setting correction.

With slow and unpressurized airplanes, it wasn't difficult for a pilot who momentarily misread his altimeter to determine whether he was flying at 7,000 or 17,000 feet. The time required to get up or down left no doubt, and unpressurized cockpits clinched the matter. A pressurized airplane, however, can change altitude at a tremendous rate, with cockpit altitude changing at a completely different rate. In such instances, the pilot, when under stress, can mistake his altitude. For this reason, a sector of the altimeter dial marked like a barber pole is visible at low altitudes and is completely masked above about 16,000 feet.

A simple, straightforward presentation of altitude has not been easy to attain. Early in the 1600s, the Dutch physicist Isaac Beekman discovered that atmospheric pressure decreased as height above the ground increased. Balloon flights as early as 1783 used mercury barometers to measure altitude. The mid-1800s brought such an improvement in the aneroid (no liquid) barometer that it took over as the standard device for altitude measurement.

The earliest airplane pilots were not much concerned with instrumentation. Keeping their flimsy machines in the air was such a feat in itself that knowing exact height above the ground was of little concern. When flights over terrain of differing elevations started to be commonplace, the need for an altimeter became apparent.

The primitive altimeter resembled a common aneroid barometer with the scale in feet rather than inches of mercury. The pointer made one revolution for the complete range of the instrument, which was, up to the middle 1920s, about 20,000 feet. The expansion of the evacuated diaphragm was made linear by an auxiliary spring. A knob allowed the pilot to set the altimeter to zero before taking off, which was an improvement; however, this primitive instrument failed to provide the accurate altitude information needed by pilots for precision flying. Changes in barometric pressure, when an airplane flew from one area to another, often caused so much error that the instrument would be all but valueless for showing height above the ground.

Two developments made precision flying possible: radio communications between the airplane and the ground, and the sensitive altimeter. In 1927, Paul Kollsman conceived the idea of the convoluted diaphragm, which acted as its own spring and made the instrument linear with respect to altitude. It provided an accuracy not previously thought possible. With a new altimeter designed around this bellows, and with radio communication possible between the airplane and the ground, the pilot could adjust his altimeter to the barometric pressure reported at the field where he was landing. This he could do simply by adjusting the barometric-pressure setting, or "Kollsman number," on the face of the instrument.

Two methods of barometric-pressure correction have been used: the airport-altitude method and the presently used altimeter-setting method. In the past, using the first method, the ground-station operator adjusted his master altimeter to 29.92 in. Hg. (standard sea-level barometric pressure). His altimeter then indicated the altitude, above or below the airport, at which standard sea-level pressure existed. This airport altitude was radioed to the pilot, who adjusted his barometric correction knob, moving two small, triangular reference marks to the reported airport altitude (see Figure 2). The altimeter's pointers then indicated altitude above the reporting station. At touchdown the altimeter read zero.

The need for knowing height above objects other than reporting stations brought about the altimeter-setting system. Station barometric pressure is read and a correction is applied. This correction is equal to the pressure drop caused by the elevation of the reporting station above sea level. The corrected reading, the altimeter setting, is radioed to the pilot. With this value set in the

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barometric window, the altimeter indicates the elevation of the airplane above mean sea level. Surveyed elevations of all terrain, towers, and airports are marked on aeronautical charts. A simple mathematical calculation provides the airplane's height above these objects.

As flying has become more precise, different methods of altitude measurement have emerged. With altimeter setting in the barometric window, the pilot flies an indicated altitude. His height is referenced from existing mean-sea-level pressure. The barometric scale must be adjusted to altimeter settings along the route of flight. Indicated altitude is useful where the distance traveled in a given time period is relatively short.

Aircraft flying at or above 18,000 feet msl use pressure altitude. For this type of indication, the barometric dial is adjusted to 29.92 in. Hg. Height is referenced from standard rather than existing sea-level pressure. An airplane flying cross-country, holding a consistent flight level, will vary in its height above sea level; however, all airplanes operating in this portion of the airspace have their altimeters set the same, so vertical separation is maintained.

Indicated altitude is important for terrain clearance, and pressure altitude for vertical separation, but density altitude is needed for computing airplane and engine performance.

A window in most modern flight computers indicates the altitude in standard air that corresponds to the existing conditions of temperature and pressure. This is density altitude. In hot air, density altitude is high, and the airplane and engine perform as if the airplane were at a higher altitude in standard air.

When the pilot makes his initial call to the tower, he is given the altimeter setting. When this is adjusted in the barometric window, the pointers should indicate the surveyed elevation of the airport. If there is a discrepancy between the reading of the pointers and the airport elevation, a correction must be applied each time an altimeter setting is made. If an error of more than 75 feet exists, it is a good idea to have the instrument checked.

When the altimeter setting is adjusted on the instrument, compensation is made for variation in both atmospheric pressure and temperature. If a pilot should fly from an area of high barometric pressure into an area of lower pressure without resetting his altimeter, the instrument will not know that this decrease in pressure was caused by a drop in atmospheric pressure instead of a climb, and will indicate an altitude higher than that at which the airplane is actually flying. In the same way, if the airplane should fly into an area of higher pressure without the pilot's resetting his altimeter, the altimeter will interpret the increase in pressure as a descent and will indicate an altitude lower than that at which the airplane is flying.

Another atmospheric change not corrected by the altimeter is density error caused by temperature variation. As you fly into an area of lower temperature with the same atmospheric pressure, the pressure levels, or gradients, become closer together. A given pressure level (indicated altitude) will be closer to the ground in cold air than in warm. The converse is also true: pressure levels are more widely separated in warm air, and an airplane will be higher than the altimeter indicates.

For as long as the government has been involved in air safety, there have been requirements for maintaining close scrutiny of the engine and airframe condition. At one time, little consideration was given to instrument condition and accuracy; however, after a spot check of altimeters showed a wide disparity in the accuracy of these instruments used for instrument flying, FAA became concerned and issued an amendment to FAR Part 91, "General Operating and Flight Rules." This amendment requires a check of the accuracy of the altimeter and the integrity of the static system each 24 calendar months for every airplane operating under IFR.

Because the familiar altimeter, with its three pointers, can be misread in times of stress, digital altimeters have

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been developed (see Figure 3). In this type of instrument, the aneroid capsule drives two or three drum-type counters to indicate thousands and hundreds of feet. A single pointer still sweeps the dial for each 1,000 feet to provide a closer reading.

A new generation of pneumatic altimeters is now in use. All the information needed by the altimeter is fed into an air data computer, where the necessary static-source corrections are made. The output of the computer drives a servo-type indicator that gives the pilot a readout up to five digits.

Radar beacon transponders have made the task of the traffic controller easier and more effective. A limitation of the ATC system has been its inability to show controllers the altitude of the target aircraft; however, this information can now be furnished by altitude-coded transponders. An encoder is driven by the same aneroid mechanism that drives the altimeter drums and pointer, providing a code for the transponder to reply to the ground radar with information on the airplane's altitude. The information is then transmitted in Mode C of the transponder, in 100-foot increments, to the traffic control center.

Since February 1972, altitude alerters have been required on all turbojet aircraft. The altitude alerter may be operated by its own aneroid system—by information from the panel altimeter—or may be operated from the radar altimeter. The pilot simply sets into the instrument the altitude at which he wants to be alerted. When he approaches this altitude, the alerter signals him by an audible tone and a light.

The last few seconds of an approach are the ones where absolute accuracy is most needed. Yet this is where the pneumatic altimeter is inherently weakest—terrain clearance. Precision height measurement by barometer requires accurate pressure settings and precise knowledge of terrain elevation. To overcome this limitation, the absolute, or radar, altimeter has been developed. A time-measuring instrument measures the elapsed time between the transmission of a high-frequency pulse of electrical energy and its reception after it has bounced off the terrain below the airplane. Decision-height indicator lights are incorporated in some aircraft. Activated by a signal from the radar altimeter, they tell the pilot when he has reached his decision height on an approach.

An amplification of the decision-height indicator is a "heads up" display from Bonzer, Inc. This is a four-light display on the glare shield. It is driven by the radar altimeter and shows the pilot his absolute altitude in 100-foot increments. At 1,000 feet, a green light flashes. As the pilot descends, the lights or combinations of lights change each hundred feet until, below 100 feet, a red light flashes.

The altimeter, from the 1780s to the present, has been the most widely used instrument of manned flight. Man is essentially a two-dimensional creature. When we enter the three-dimensional world of flight, we must use mechanical means to provide vertical orientation. From the mercury barometer to altitude-coded radar beacons, the developments in height measurement have paralleled those of the airplane and have amplified its utility. □

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