A capacity for error only seems to be built into an altimeter.

It's up to the pilot to understand and compensate for its peculiarities

Your Altimeter—Saint Or Sinner?

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EDITOR'S NOTE: Bob Campbell writes from more than two decades of flying and instructing experience. He has flown over most of the world as barnstormer, instructor, airline copilot and captain, military pilot, test pilot and ferry pilot for the French Air Force. He spent the war years successively as a multi-engine instructor, B-24 commander, and Air Inspector of a combat group, picking up instructor ratings on some 20 types along the way (his ATR dates back to 1946). His hundreds of ground school students have ranged from beginners through airline captains. He abandoned flying for writing several years ago, and now engages is consultation and the production of training materials as president of Campbell Publications and Campbell Aeronautical Service, Inc.

You'll find some type of altimeter peering from the panel of every airplane you ever strap to your posterior, and you get so accustomed to its friendly face that—beyond giving its setting knob an occasional twirl—you never think twice about it. The unhappy fact is that your altimeter is probably the *least* reliable of all your flight instruments, that it's as moody and temperamental as a suspicious wife, and that it knows as many nasty tricks as a box full of hungry rattlesnakes. Precision or controlled flight would be impossible without it, but if at night, or on instruments, or even when just breezing through a day VFR cross-country, you simply accept its indications with blind confidence, it's quite capable of slipping you some unpleasant surprises just to vary the monotony.

Numerous accidents—and even more incidents—have been traced either directly or indirectly to the altimeter. They've all resulted from errors in setting or reading the altimeter, or failure to understand and allow for one or more of the built-in errors that are standard equipment in every altimeter. Since the pilot factor enters largely into all of these, it's obvious that the more you know about your altimeter the less chance you have of becoming an unwilling statistic.

Of course you remember from ground school daze that your altimeter doesn't really measure altitude. It's nothing more than an aneroid barometer that interprets an *approximate* measurement of atmospheric pressure in terms of elevation above a preset reference point. Its heart, as simplified in Figure 1, is a stack of aneroid wafers nested inside a bi-metal yoke and connected to the actuating arm that moves the machinery.

Each aneroid wafer is a partially evacuated, airtight metal cell, with a spring inside to prevent its complete collapse. The spring exerts a constant force against the cell walls, pushing them farther apart as outside pressure decreases, while any increase in that pressure compresses the cell. Increasing the number of cells merely increases the sensitivity of the altimeter. Cell wall movement is multiplied through the linkage until a change of 3/16 inch in cell thickness produces an indicated altitude change of 35,000 feet, but the mechanism is still delicate enough to show the altitude difference between a desk top and the floor.

The yoke provides compensation for the temperature lapse rate (15°C at sea level, decreasing by about 2°C for each 1,000 feet of altitude) of a standard atmosphere. If the temperature at a given altitude isn't standard, though, an altimeter at that altitude will be in error by an amount that depends on the difference between actual and standard temperatures. At best, then, your altimeter is reasonably correct only under the rare condition of standard temperature; at all other times its measurement of ambient pressure—and consequently its altitude indication—will be inaccurate. Figure 2 will help you visualize the reason for this error. Imagine your airplane at S, perched atop a 10,000 foot column of air at standard temperature, with its altimeter properly set to indicate 10,000 feet. This is the ideal condition that you'd like to—but don't—have all the time. If you now change the temperature of that air column without changing its horizontal dimensions, the effect of that change on its height is determined by Charles' law, which says that under constant conditions of weight and pressure the volume of any gas (including air) varies in direct proportion to its absolute temperature. If you cool your air column, then, it must shrink vertically. Your airplane sinks closer to the ground, as at C, but your altimeter *still indicates 10,000 feet.* Heating your supporting air column, on the other hand, just reverses the effect. The resulting vertical expansion, working like a jack under your automobile, forces your airplane upward to somewhere above its starting altitude, as at H, but your altimeter *still indicates 10,000 feet.*

This temperature error is just a

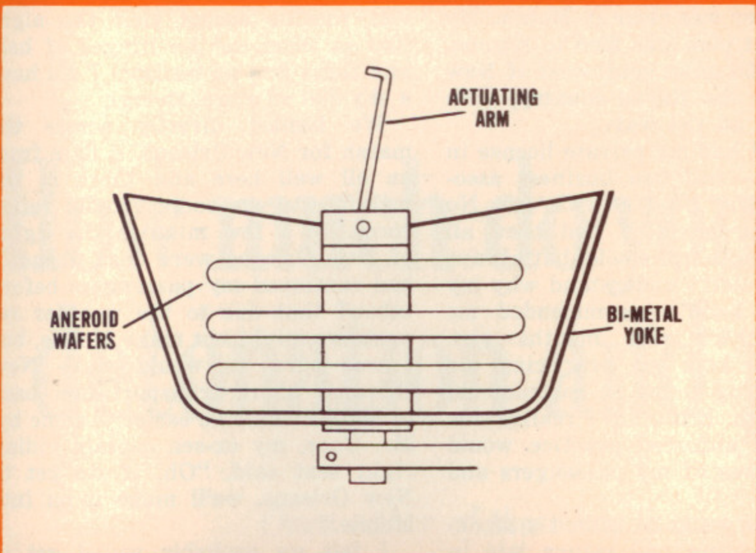

Figure 1 Elements of an altimeter

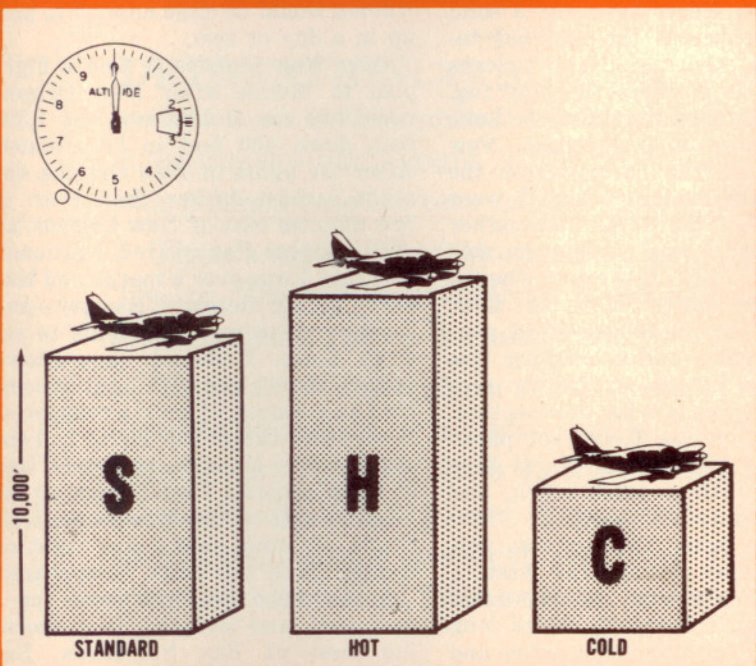

Figure 2 Altimeter error produced by temperature change at 10,000 foot reading

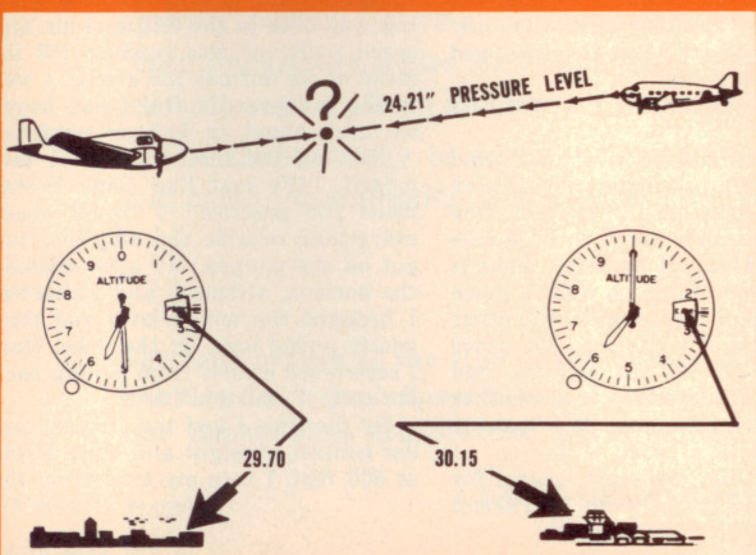

Figure 3 Error produced by en route pressure change

bit over 37/100 of 1% of the indicated altitude, or about 3.73 feet per 1,000 feet, for each 1°C of departure from standard temperature. This doesn't sound like much, but try it on for size at 10,000 feet with a temperature variation of only 15°C from standard, and you come up with a whopping altimeter error of about 560 feet. Before you start fretting about this discrepancy as it might affect an approach or landing under nonstandard temperature conditions, though, remember that the *total* error depends on your height *above terrain*. This means that the error diminishes as you lose altitude, vanishing entirely when you either reach the exact pressure level for which your altimeter has been set *or* touch the ground where the altimeter setting is the same as that cranked into your own instrument.

Under ordinary circumstances, use of any temperature correction in determining your flight altitude is prohibited by Section 60.25 of the Civil Air Regulations. Simply set your altimeter properly, and then fly a *calibrated* altitude. You probably won't be right at your assigned or intended altitude, but since all aircraft in any local area will be subject to exactly the same temperature error, you'll all be maintaining the proper vertical separation. About the only times you'll need to apply a temperature correction in flight will be to determine density altitude for purposes of power control, or to be sure of your terrain clearance under critical conditions. When used, the temperature correction is applied to your *pressure* altitude, which you get by reading your *calibrated* altitude with a pressure window setting of 29.92 inches. This calculation gives you your *true* altitude, which, of course, is directly related to the terrain and obstacle elevations shown on your charts.

Of course you're never guilty, but many pilots are too often careless about altimeter settings. CAR Section 60.25 tells you that at or below 23,500 feet MSL you should use the altimeter setting of a station within 100 nautical miles along your line of flight, or, if there is no such station, that of any other appropriate (within 100 nautical miles in any direction) station, or (without radio) that of your point of takeoff or appropriate settings available prior to departure. That's not as complicated as it sounds. If you've got a squawk-box, just use the horn to ask everybody along your route for the current altimeter setting—and then keep your own altimeter set accordingly. On cross-country without radio, it's a

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fine idea before takeoff to jot down the latest TWX sequence altimeter settings of stations along your route, and reset your altimeter to the proper pressure as you approach each of these stations in turn. This probably won't give you the exact current settings, but you'll at least be a lot closer than if you haven't touched your altimeter since takeoff.

This shouldn't be neglected even on VFR flights. A lot of traffic goes IFR at "thousands" altitudes even in perfect weather, mixing in the blue with VFR pilots using "thousands plus 500" altitudes. Figure 3 shows you what can happen. Leaving Sunken Heights, with an altimeter setting of 29.70, you've flightplanned VFR at 5,500 feet to Dusty Mudflat. At about the same time, Joe Pro wheels a transport type out of Dusty Mudflat, where the altimeter setting is 30.15, IFR for Sunken Heights at 6,000 feet. At the start, even though pressure is the same 24.21 inches of mercury at *both* flight altitudes, you have a comfortable 500 feet of vertical separation, and no sweat. The joker jumps out of the deck, though, when you both let VFR weather lull you into forgetting to reset your altimeters en route. Flying the same pressure level, you're actually approaching each other head-on—but with your respective altimeters still showing that same 500-foot safety margin. At modern cruising speeds, you'll probably pass close enough —if you're lucky—to give you an interesting couple of seconds and another hairy memory.

And how many reports have you read of airplanes flying into a hillside or mountain anywhere from 20 to a few hundred feet below the crest? Plenty! Mountain peaks, hills, and other obstacles hit airplanes only in self defense, but an improper altimeter setting on night VFR makes it only too easy to prove that the airplane will never replace the bulldozer, and statistics show that the experience isn't habit-forming. The moral is to use all available means of keeping your altimeter setting at or close to the local pressure.

You wouldn't misread your altimeter, of course, but even professional pilots somehow manage this almost every day. Poor cockpit lighting, distraction by other duties or by conversation, even mild oxygen starvation, just plain darned carelessness, or many other gremlins can make it easy to misread your altitude by a thousand feet, or even easier—and possibly even more dangerous—to misread the little figures in the pressure setting window. Have your copilot check your reading on every change of altitude or pressure setting, or if you're the only pilot aboard, check and recheck every reading of your own. The couple of seconds that this takes is cheap alongside the expense of pranging your kite in the dirt, and both your family and your insurance company will appreciate your thoughtfulness.

You'll find another altimeter pressure error when flying through a windy canyon or on the lee side of a hill or mountain with moderately stiff winds. The

Altimeter Accuracy Surveyed

Wing Tips, official publication of the Texas Aeronautics Commission, ran the results of an interesting survey on altimeter accuracy taken at Tradewind Airport, Amarillo, Tex., recently. Thirty lightplanes were checked—each plane's altimeter being set on the current altimeter setting and indicated altitude error above or below field elevation recorded.

Using the allowable Air Force altimeter error of plus or minus 75 feet as a guide, it was found that four of the 30 planes exceeded this allowable error (all four had plus errors of over 100 feet). Twenty-six showed readings too high, three were too low. Only one plane in 30 noted no error.

venturi-like effect of the canyon or hilltop artificially reduces the pressure, making your altimeter indicate *more* altitude than you really have. This error gets worse the closer you get to the ground, and reaches maximum during standing wave conditions, where altimeter errors of as much as 3,000 feet have been reported. Your only safeguard is to be sure you have plenty of altitude when in a pass or leeward of a mountain or hill.

Although instrument errors as such are practically nonexistent in modern altimeters, the static source location is still troublesome. The slight compression effect at most normal static sources makes the altimeter read just a bit too *low*, while most alternate static sources produce a reading that's a little on the *high* side. Then, too, attitude changes caused by extending either flaps or landing gear may alter pressure at the static source, with a corresponding change in the altimeter reading. In most lightplanes, the errors of the normal static source are small enough to be disregarded, and for all practical purposes indicated and calibrated altitudes are the same. Heavier types, though, may have normal source errors of as much as several hundred feet. Switching to alternate source in any airplane is likely to produce at least a 100-foot error, and maybe more. You should always use the appropriate altimeter correction card or curve to correct these errors, and fly at your *calibrated* (not indicated) altitude.

Even the smallest leak in your altimeter case or static line makes the altimeter read too high, by as much as several thousand feet in pressurized airplanes. In nonpressurized aircraft this error can't be detected on the ground except by testing the system, so be sure that this is done on each periodic or annual inspection or whenever you suspect your altimeter of inaccuracy.

Static source icing effectively seals the system against ambient pressure changes, so that, regardless of subsequent changes of actual altitude, your altimeter tends to hold the indication it had when your static source iced over. You can prevent this by timely use of pitot heat, or correct it by switching to alternate source, but if your airplane isn't equipped for either your only choice is to stay out of icing conditions.

Friction in the works may cause error in any altimeter. The vibration that might otherwise help to overcome this is largely damped out by modern panel mountings, so make it a habit to tap the face of the altimeter once or twice after each resetting, or when reading it on the ground with your engine dead.

Zero setting error is the difference between actual airport elevation and your altimeter reading on the ground with field pressure set into the reference window. This error is normally constant over the entire scale, and if comparatively slight should be applied as a constant correction to any altimeter reading in flight. If the error is large, though, your altimeter needs—and should get—prompt maintenance.

Prolonged flight at altitude produces a sort of "set" in the metal of the aneroid wafers, not unlike the rump-sprung stretching of a fat lady's girdle when she sits down. This effect, called hysteresis, always makes your altimeter read a little higher during descent than at the same actual altitude during climb. It corrects itself after a short period of level flight.

Contrary to popular belief, your altimeter doesn't "lag" during maneuvers, notwithstanding its failure to show a change the instant you raise or dump the nose. Momentum always tries to keep your airplane moving in a straight line, and an appreciable amount of time—increasing with either airspeed or weight—is needed for a changed angle of attack to overcome that tendency. As soon as your vertical rate starts to change your altimeter will respond, but just remember that the instrument indicates altitude—not attitude—and that it just isn't smart enough to anticipate vertical movement.

As you've seen, your altimeter has a split personality. It can be a guardian saint, or it can be a sinner that lies, cheats, and may steal your airplane or even your life. If you forget about its various pixies, you're just asking for the results of any or all of its dirty tricks. If you understand and allow intelligently for all its peculiarities, though, your flying will be somewhat less exciting—due to reduced frequency of hair-raising moments—but it will be a whole lot happier and safer! END