How to Calibrate Instruments

With some effort, every pilot can own a panelful of accurate instruments.

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Flight instruments that give wrong readings can be worse than no instruments at all, especially if the errors are unknown. And if the unknown error is great enough, it can be deadly. An airspeed indicator, new or yellow-tagged and accurate on the bench, may not be even close to correct after installed.

Those of us who build our own aircraft pick up instruments from many sources. Some have been bench-tested, others have not. But no matter where or how we come by our instruments, no matter how expensive they were, the accuracy of many instruments is dependent on the installation. An airspeed indicator's accuracy is more a function of the pitot and static installation than the instrument. So it is with a magnetic compass. Even the cheapest compass is more accurate than the most expensive one that is subjected to local magnetic fields.

Electric engine instruments are notoriously inaccurate, regardless of what make. In a nutshell, you cannot count on the accuracy of even the best instruments installed in a new aircraft until they have been calibrated in that installation. Inaccurate engine-temperature instruments can ruin or severely shorten the life of your engine. An inaccurate instrument can be worse than no instrument at all, and it might endanger your life.

If you are building an experimental aircraft and have a lackadaisical attitude about safety, then skip this article and may God be your copilot! By the same token, if you are one of those perfectionists who insist on absolute accuracy, this article is not for you either. But for the rest of us who want the safety of reasonable accuracy without spending more to calibrate your instruments than you did to buy them, read on!

Swinging a compass and correcting or noting errors can be a time-consuming effort. But especially for the cross-country pilot, the results can be worth the work.

The instruments most likely to be inaccurate and most likely to cause us problems due to this inaccuracy are altimeter, airspeed indicator (ASI), cylinder-head temperature (CHT), oil temperature, outside air temperature (OAT) and magnetic compass.

The average homebuilt airplane is likely to need all of these instruments. To the novice, selection becomes the first problem. Select an altimeter that you believe is accurate, a new one or a yellow-tagged instrument. The airspeed indicator is an inherently simple and accurate instrument if in good condition. Select a new or yellow-tagged instrument.

Most of us will purchase electric temperature instruments both for their size, simplicity of installation and cost. Even the best ones are probably not going to please you with their accuracy but, when calibrated, even the economy models will do the job well enough.

If you have any extra money to spend on instruments, I suggest you consider a vertical-card compass. The non-TSO one (same accuracy as the most expensive one) is less than $200, and that's only about $100 more than a wet compass with all of its problems. Although the east/west turning error is the same as with the wet compass, the overshoot is less and it reads the same way the gyro compass does. Did you ever read your mag compass, finding it 10° left of south, set the gyro 10° left of south for a 20° error? Many good pilots have.

Altimeter

The altimeter that reads correctly on the ground and has no internal problems will read right in the air only if the static line does not introduce an error. That is very easy to verify. After checking that the static line is not clogged, has no leaks and is connected to the altimeter, go to a flat airport. With the engine off, read the altimeter. Rev up the engine and note any change in reading (assumes static line is in propwash). If there *is* any change, move the static-tube inlet position. Note the reading at takeoff. There should be no change. These two simple checks are sufficient. Buzzing the top of a radio tower also works but can be very dangerous and is probably illegal as well. A bad location of the static port will cause inaccurate airspeed, rate of climb and altimeter readings.

Outside Air Temperature

Knowing the outside air temperature is essential to the ASI calibration. Calibration of the OAT is indeed simple, but there are some pitfalls to avoid. Make sure the OAT probe and dial are not in direct sunlight and insure that nothing is touching the probe such as bugs and dirt. If you have a weather-observation station on the field, you can use the station reading. Otherwise, maybe you can borrow a lab-grade thermometer from the lab of a local high school or college. If your OAT thermometer is off more than 3° F scrap it. The author recently purchased a digital, electronic, inside/outside thermometer (Radio Shack, $14.95) that is accurate within 2°. The outside probe was mounted inside a NACA cabin inlet air duct. Neat, attractive, no drag and effective.

Engine Temperature Instruments

Electric temperature instruments are subject to two errors that may be additive or may cancel out. One method of calibrating these is simple and accurate enough for most purposes. Place a coffee can of motor oil on a hot plate and put a candy thermometer in the oil, keeping the bottom of the thermometer off the bottom of the can. Remove the CHT sensor and the oil temperature sensor from the engine. A good ground is very important. Turn on the master switch and start heating the oil. Record the readings from 150° to 300° on the oil temp and from 150° to 600° on the CHT. If the error is excessive, you may want to complain, buy new senders and/or instruments, do your own instrument repairs or whatever is right for you.

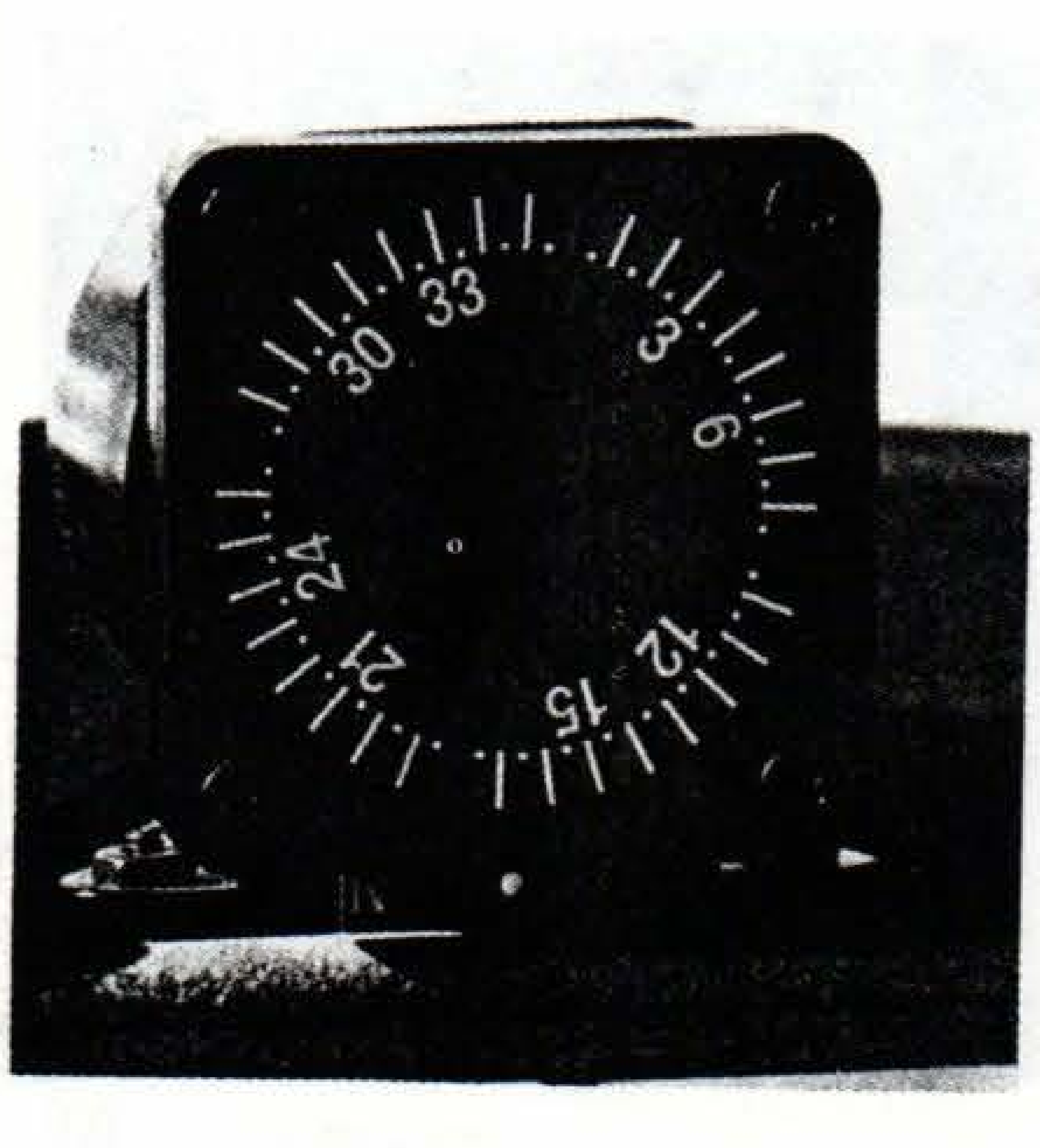
Airspeed Indicator

Airspeed indicators should be calibrated for many reasons, not the least of which is to make sure you are telling the truth when you tell your buddies how fast your new plane flies. Until you know that your static pickup is located correctly, you cannot calibrate your ASI because it is dependent on both the static pressure and the dynamic pressure (pitot pressure). Do the static tests described above before proceeding with the pitot calibration.

Quick-and-Dirty Method

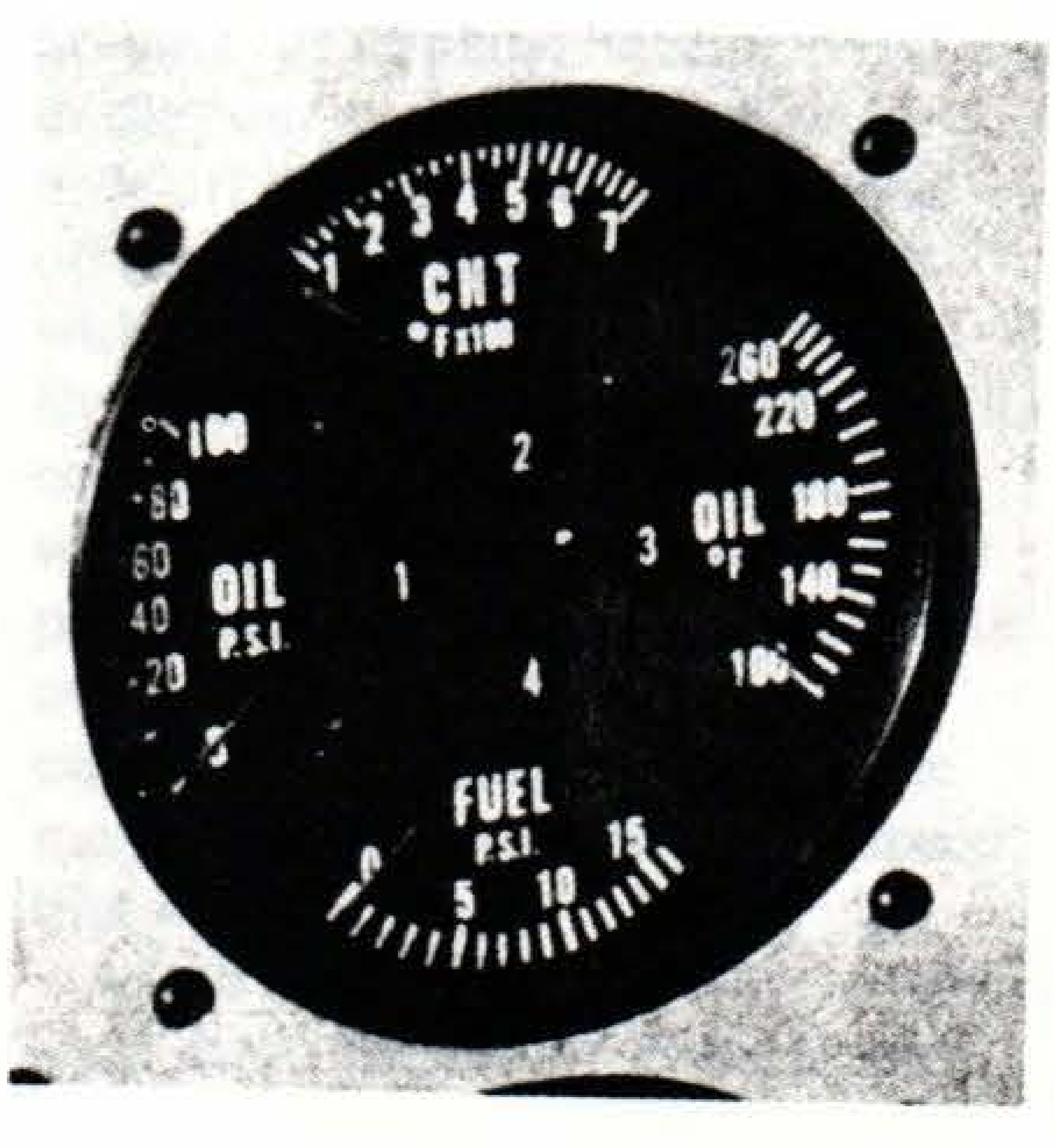
Here are two methods to calibrate

Author Tom Williams recommends use of a vertical-card compass. Some errors are less than with a standard wet compass, and they are easier to read correctly.

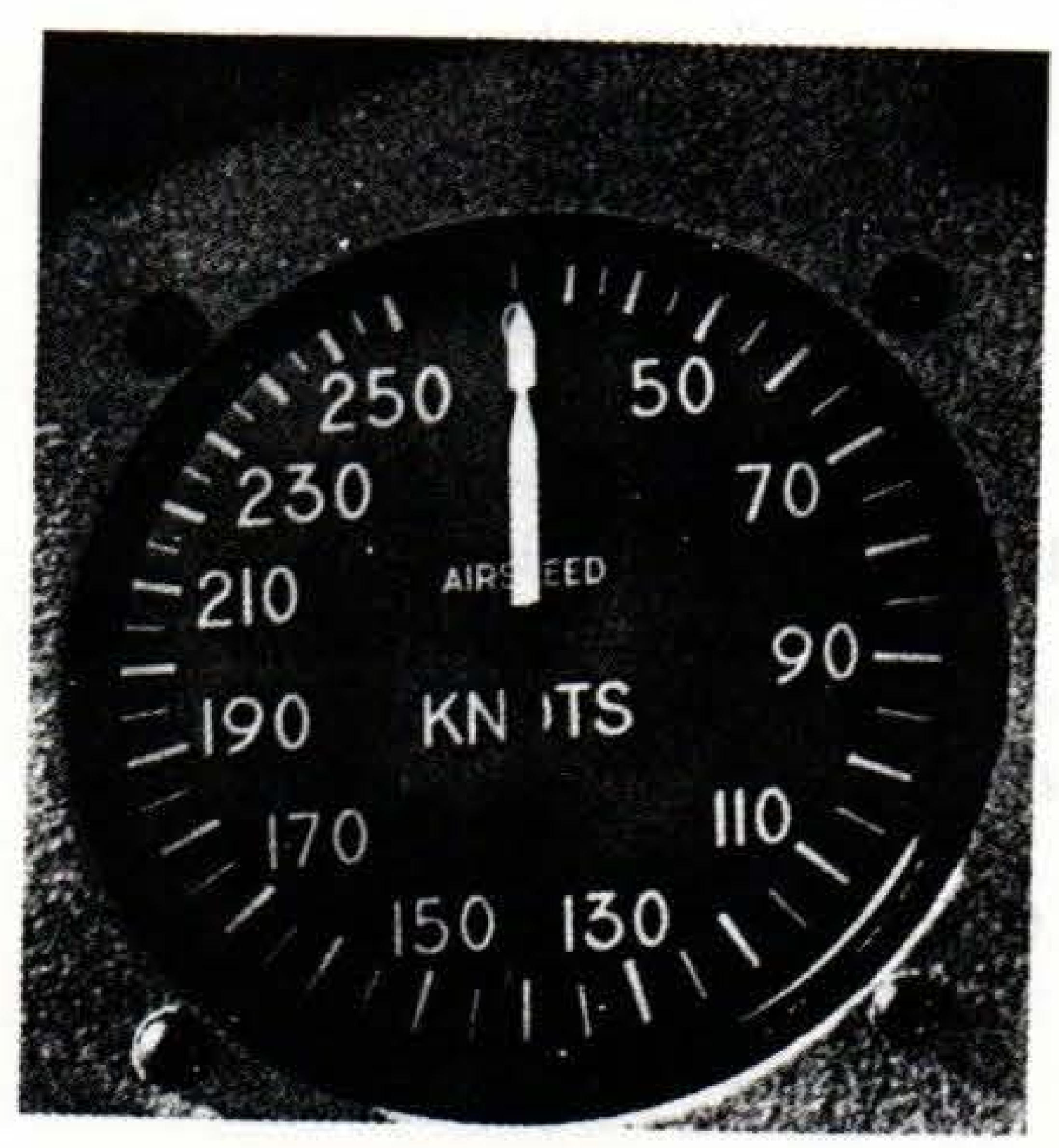


Photos: Tom Williams

Both cylinder head- and oil-temperature gauges can be calibrated using fairly simple techniques.



Various procedures can greatly reduce or even eliminate airspeed indicator errors.



Your airspeed indicator. The first is quick and dirty. It will get you in the ball park (within 5 knots), but is really not accurate enough for navigational purposes. You must have a loran C installed and working and be in a very good signal area. It should be noted, however, that loran receivers tend to lose their signals during turns and time to stabilize must be allowed after each turn.

The first premise in ASI calibration is that true airspeed (TAS) is equal to groundspeed when the wind component is eliminated. This can be done by flying four legs on the four cardinal headings (north, south, east and west) and averaging the ground speeds. It's that simple. Set the altimeter to 29.92 inches. Climb to an altitude where the air is very stable. A good choice is 7500 feet because 75% power is available at full throttle on a normally aspirated engine. Open the throttle wide open and fly *level* on a north heading. When all has stabilized, read your IAS, OAT, pressure altitude (altimeter set at 29.92) and loran groundspeed. Repeat this on the other cardinal headings.

Using a navigation computer, calculate the TAS. It should be the same on all four headings. Average the four groundspeed readings. The average groundspeed is the corrected TAS. Working backwards on the computer, calculate the CAS (calibrated airspeed). CAS - IAS = Correction.

Williams recommends using a $14.95 Micronta indoor/outdoor thermometer from Radio Shack. It is switchable for Celsius or Fahrenheit.

Accurate Method

To do the job right involves the most work of all the calibrations in this article, but it is also the most fun and rewarding. It is a flying exercise and is best accomplished with a passenger, although I have done it solo more than once.

The first step is to pick a flight course. The course should be about six miles long for a 200 mph craft or three miles for a 100 mph plane—about a two-minute run. The course must be perpendicular to the wind. Ideally the wind would be calm. I did this in California's Mojave Desert along a north/south freeway with a westerly wind and in South Carolina along and east/west railroad with a slight northerly wind. The course must be straight, easy to see, and perpendicular to the wind. The length need not be exactly three or six miles, so long as you know its length exactly, but it should be terminated on each end with a road or something crossing it perpendicular to the course. Once the course is picked, measure it on a sectional chart in statute or nautical miles commensurate with mph or knots on your ASI. (Instrument pilots use knots and nautical miles, and once you get used to these units, you'll never use statute miles in the air again.) If you have a copilot, give him the stopwatch so you can concentrate on the heading and altitude.

The accuracy of the calibration procedure depends on the ability of the pilot to hold altitude within 20 feet and heading within 5°. Select an altitude of 100 to 500 feet. Set the altimeter to 29.92. *Do not use the local altimeter setting*. The timing should be sighted off a wing, and the time should be recorded to within one second. The runs are to be made in 5-knot or 5-mph increments from pattern speed to top speed. *Do not crab into the wind*. Make each run holding the airplane heading parallel to the course, allowing the plane to drift off course. If you have a wind off your left wing, you would start with the course off your right wing. By holding the heading the plane will end up with the course off your left wing having drifted to the right. The plane will have gone a longer distance over the ground but will have gone exactly course-distance through the mass of moving air, and it is airspeed that we are after.

Make the run up the course, then back down the course, twice at each airspeed. Example: at 90 knots IAS, run south, then north, then south, then north. Set up at 95 knots and make two more runs each way, and so on. When you change airspeeds, retrim as necessary and allow the plane to settle down before you make the runs. Make standard-rate turns smoothly and hold the altitude at all times. The altimeter should be set at 29.92 regardless of the barometric pressure. Having a timer on board really helps the pilot concentrate on his heading, altitude and speed. On each run record the time, IAS, altitude and OAT.

After all the runs have been completed, average the four runs at each airspeed. This is done by adding the numbers and dividing by 4. Then using your E6B or electronic navigation computer, calculate the true airspeed for these average runs. Since your distance traveled through the air on each run is equal to the length of the course, the groundspeed is equal to the airspeed and any difference is the instrument/pitot error. Average the times for the four runs at each IAS by adding the times and dividing the total by 4. Convert the seconds to fractions and minutes by dividing the seconds by 60. Example: 2:15 (2 minutes 15 seconds) $= 2 + 15/60 = 2.25$ minutes. Use the following formula to find the groundspeed: $60 \times D/T = GS$. Example: course length = 6.40 miles, average time = 2:15 D = 6.4 T = 2.25 GS $= 60 \times 6.4/2.25 = 170.67$ mph (or knots if distance is in nautical miles).

Make a table and record for each set of runs the average IAS, GS and error. Make a graph with IAS along the bottom and error up the side. Plot all the points and draw a line between the points. Draw a second line, missing some or all of the points as necessary to make the line smooth. Don't be surprised if the line is flat or nearly so. Do be surprised if the line goes from negative to positive or even if it forms a hill or valley. If the line is not nearly straight and nearly flat, you probably have bad data or a defective calculator. Some airplanes change angle of attack considerably with speed changes. This can cause a curved line. Airplanes like a Cessna 152, which can slow to 60 and go all-out to 100, are likely to have a flat curve with that narrow speed range. But a Lancair, which can fly from a speed of 70 mph to a top speed of over 225 and require as much as 8° of negative