Transponder Basics

There's a whole lot more to your transponder than a blinking light and an IDENT button. In this article, AVweb's avionics guru teaches you everything you need to to know about transponders and altitude encoders. Even the most grizzled veteran pilot is likely to learn a thing or two.

by Tom Rogers, Ph.D. (trogers@avweb.com)

It's getting to be almost impossible to fly anywhere without a Mode C transponder. This equipment is now required in all Class A, B, and C airspace, within 30 miles of primary Class B airspace airports, and anytime you're above 10,000 feet. And if the FAA has its way, that altitude will soon drop to 6,000 feet.

ATC is watching you

ATC radar facilities presently have both both primary and secondary radar. Primary radar (sometimes called "skin paint") works on the principle of bouncing high-powered microwave pulses off objects and detecting the reflected echo. It's the same sort of radar that was used in World War II to detect enemy aircraft.

Primary radar has lots of limitations. It works best with large all-metal aircraft, not so well on small, composite aircraft, and not at all with some of the new "stealth" technology. (There's some debate as to how well it works tracking flying saucers.) Its range is limited by terrain and precipitation. It's rather indiscriminite about what it detects: airplanes, trucks, hills, trees. And it only reports a target's azimuth and range, not its altitude.

Secondary radar was invented to overcome these limitations. It depends on a "transponder" in the aircraft to respond to interrogations from the ground station. Depending on the type of interrogation, the transponder sends back an identification code (Mode A) or altitude information (Mode C).

Transponders are also sometimes referred to as "beacons", and another name for secondary radar is "ATC Radar Beacon System" or ATCRBS (pronounced "at-crabs").

Today, virtually all ATC radar installations are equipped with both primary and secondary radar capability. However, the FAA is threatening to decomission primary radar from its enroute facilities. If they did this, centers would no longer be able to "see" any aircraft that were not transponder-equipped or whose transponder failed. Center controllers and pilot groups like AOPA are opposed to this, and it remains to be seen if anything comes of it.

Radar ground stations

If you take a close look at an ATC radar ground station, you'll see that they actually consist of three separate antennas. The biggest and most obvious one is the primary radar antenna, which looks like a parabolic dish that goes round and round (10 times a minute for approach control radar, 6 times a minute for long-range center radar). This antenna transmits powerful pulses and then listens for echoes. It is used to detect aircraft "skin paint" and also can detect weather to some degree.

The second ground station antenna, called the directional antenna, is used to send interrogations to airborne transponders and to receive replies from those transponders, providing secondary radar capability. It is a bar-shaped affair that is usually perched atop the primary radar antenna and rotates along with it. It's called "directional" because, like the primary radar antenna, it is designed to beam the interrogations and to receive the replies only from the direction it is pointed.

However, the directional antenna is less than perfectly directional. To design a perfectly directional antenna, you'd have to make it infinitely large...not too practical if you need to rotate it 10 times a minute. Real-world directional antennas have weaker "side lobes" in addition to the "main lobe". The side lobes are too weak to be a problem for distant aircraft, but for aircraft close to the antenna site they are a big problem. Unless something was done about them, the side lobes would cause a close-in aircraft to show up as three or four different targets on the controller's screen, causing no end of confusion.

Side lobe supression

That's where the third antenna comes in. It's called the omnidirectional antenna because it radiates equally in all directions. Every time the directional antenna sends out an interrogation (which consists of a pair of pulses known as P1 and P3), the omnidirectional antenna sends out its own pulse (called P2). The signal from the omnidirectional antenna is designed to be much weaker than the main lobe of the directional antenna, but stronger than its side lobes.

When the transponder receives an interrogation, it compares the strength of the three pulses it receives. If the P2 pulse is weaker than the P1 and P3 pulses, then the transponder knows it's hearing the main lobe from the directional antenna, and it replies to the interrogation. On the other hand, if P2 is stronger than P1 and P3, then the transponder knows it's hearing a side lobe and so it doesn't respond. Pretty clever, huh?

Interrogations and replies

The ground station transmits its interrogation pulses on an "uplink" frequency of 1030 Megahertz, and the transponder replies on a "downlink" frequency of 1090 Megahertz. Effective range of secondary radar is usally about 110 miles, although this can vary considerably from one site to another.

The ground station may send a Mode A interrogation to request the transponder code or a Mode C interrogation to request the aircraft altitude. The only difference between Mode A and Mode C interrogations is the time interval between the P1 and P3 pulses. Ground stations normally alternate the two types of interrogations, and send them quickly enough that the transponder receives several of each on each sweep of the radar antenna. (Modes B and D are used by the military and in other countries, but are of no concern to most of us.)

By the way, the transponder's output power (typically about 200 watts), frequency (1090 MHz), and "side lobe supression" logic are among the things that your radio shop tests when you bring in your aircraft for its biennial transponder certification check. These biennial tests are mandated by FAR 91.172, and are required for all aircraft, not just those that fly IFR.

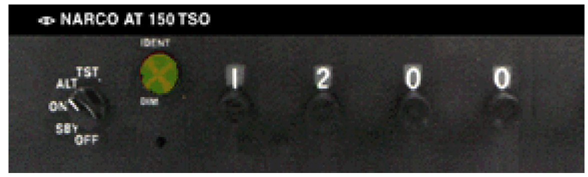
Squawk 5678?

Transponder codes are four digit numbers with the digits limited to the range 0-7. For you computer geeks, it's a 12-bit number expressed in octal notation...non-geeks may safely ignore this. If a controller assigns you a code with an 8 or 9 in it, check to see if it's April 1st...if not, you might want to call the facility supervisor when you get on the ground and suggest a urinalysis.

All aircraft transponders now must comply with TSO 74b or 74c. If yours doesn't comply to this TSO then legally you can't even turn it on VFR. Almost all transponders do comply with this but watch out for old Narco AT-50 King KT-75 units...they might be illegal if not properly modified.

The mode switch

Nowadays, most of our transponders have a mode switch with four positions labelled OFF, STBY, ON and ALT. Some have a fifth position marked TEST. They also have an IDENT button, a reply light, and four code selector switches.



After you start your engine, you should turn your transponder from OFF to STBY. This allows it to warm up but won't permit it to respond to interrogations. If your aircraft has an avionics master switch, you may safely leave the transponder in STBY and never even bother to turn it OFF.

When you take the runway for takeoff, turn your transponder to the ALT position, which enables it to respond to both Mode A and Mode C interrogations. Even if you don't have an altitude encoder installed, you should operate your transponder in the ALT mode. The reason for this is that the ground station is still looking for Mode C "framing pulses" from your transponder, even if there's no altitude information accompanying them.

If you forget to switch to ALT before takeoff, the controller will probably remind you by instructing you to "recycle your transponder." That's polite controllerspeak for "wake up, dipstick!" If your transponder was in STBY, you can just switch it to ALT and there's no foul. But if your transponder was switched OFF and you launch into the clag, that's bad news...some transponders take up to three minutes to warm-up before they will respond to interrogations. Believe me, those could be the longest three minutes of your life!

If your altitude encoder malfunctions and starts putting out bogus altitude information, the controller may instruct you to "stop altitude squawk." If he tells you this, you should change your transponder's mode switch from ALT to ON. This enables it to respond to Mode A interrogations but prevents it from responding to Mode C ones. The only time you should ever operate your transponder in the ON (rather than ALT) mode is when ATC specifically instructs you to do so. Furthermore, since the problem might have been with the ground equipment instead of yours, you should probably ask the next controller you talk to if you can "squawk altitude" again and have him check whether or not it seems to be working.

Squawk ident

From time to time, a controller may ask you you to "squawk ident" or simply to "ident". In this case, you should push the button on the transponder marked IDENT. This should cause the reply lamp to stay full bright for about twenty seconds, after which it resumes its usual spastic flashing...this is normal. When you push the IDENT button, it adds an extra pulse to your replies that causes your target on the controller's radar scope to change appearance. (It either "blooms" on an approach control radar screen, or has a flashing "ID" on a center radar screen.) Controllers sometimes use this to help find your target, or to make sure the target they think is you really is.

Most transponders have the capability of having a remotely-mounted IDENT button. If your transponder is hard to reach, you might want to have your radio shop install a remote IDENT button on your yoke or in another easy-to reach location.

Modern transponders are fairly reliable. They do have a couple of expensive parts, however. In fact, if the main output tube of an older transponder fails, it's often more cost-effective to install a new solid-state transponder than to fix the old one.

Altitude reporting

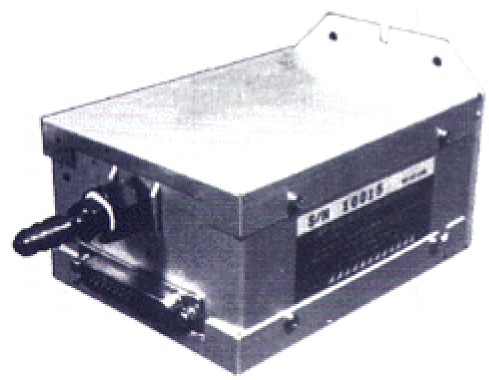
The altitude-reporting capability of your transponder transmits your aircraft's PRESSURE ALTITUDE (rounded off to the nearest 100 feet) whenever it receives a Mode C interrogation and is switched to ALT mode. You might recall from your private pilot groundschool that pressure altitude is what the altimeter reads if you set it to 29.92 In. Hg. Because the transponder reports pressure altitude, the altimeter setting that you dial into your altimeter's Kollsman window has absolutely no effect on your Mode C altitude reports. It is this fact that makes "blind encoders" (which are mounted behind the panel and have no setting knob at all) practical.

Now you might ask, "if my altimeter is set at 30.23 and the Mode C is putting out altitude referenced to 29.92, won't the controller see my altitude incorrectly?" No, because ATC's ground equipment automatically adjusts your Mode C readout for the local altimeter setting (which its computer knows about). That's why it's important always to make sure your altimeter is set to the altimeter setting that ATC gives you from time to time. That way, the controller will be seeing the same altitude that you're seeing.

Altitude encoders

The transponder depends on an external altitude encoder to provide the digitized pressure altitude that the transponder needs for its Mode C replies. The encoder is connected the same static air line as the altimeter and is wired electrically to the transponder.

The encoder may be either a separate unit ("blind encoder") or integrated into the aircraft altimeter ("encoding altimeter"). Encoding altimeters save space and help ensure that the encoder and altimeter agree, but they are fairly expensive.



The regulations say that your encoder and altimeter must be within 125 feet of each other. If you get too much error, ATC may ask you to "stop altitude squawk". If this happens more than once, it's time to visit your friendly avionics shop to get the altimeter and encoder married. I would explain how they are married, but marriage is not by expertise.

The cheaper blind encoders have a solid-state pressure transducer that is used to sense altitude; more expensive ones and all encoding altimeters use an aneroid type as used in a standard type altimeter. The solid-state transducers tend to lose their calibration with age, which means that frequent adjustments may be needed to keep it within the 125 foot correspondence limits required by the regs. The aneroid type encoder seldom needs adjustment. What this means is that what you save in the purchase price of a cheap solid-state encoder will ultimately be offset by higher maintenance costs. I recommend the aneroid type...you can usually install them then forget about them.

What about Mode S?

There's a new type of transponder called a Mode "S" transponder that is required for TCAS and may support datalink. A few years ago, the FAA tried to mandate that the fleet retire their Mode A/C transponders and upgrade to Mode S, but this move was strongly resisted by AOPA and other general aviation groups. At present, the rules to force the transition to Mode S have been put on indefinite hold, and aircraft that aren't required to be TCAS-equipped (which includes most of our owner-flown airplanes) continue to use the older and far less expensive Mode C units.

The FAA is now talking about a future ATC system based not on radar surveillance, as is used today, but on "automatic dependent surveillance" in which aircraft continually transmit their GPS position to ground stations which keep track of them and tell controllers where they are. In view of this, it's possible that Mode S may become obsolete before we need to worry about it.

About the Author...

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Tom's company, Avionics West, Inc., is one of the worlds largest discounters of handheld and panel-mount avionics for general aviation. They offer all leading brands of aviation electronics at deep-discount prices. Every item sold by AWI is covered by a 30-day no-questions-asked return privilege. Avionics West features handheld GPS receivers from Garmin and Lowrance; headsets from David Clark, LightSPEED and Telex; and panel-mount GPS navigators from II Morrow. AWI stocks these units and generally sells them at prices substantially below the manufacturers' "Minimum Advertised Price" (MAP). Consequently, AWI is not permitted to advertise these prices on its web site, but you can obtain them by sending an email to the AWI auto-responder at avionics-specials@avweb.com, or by telephoning AWI at 1-805-928-3601 (M-F, 8-5 Pacific).

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