



GPS from the Ground Up

With each passing year, GPS becomes a more integral part of the general aviation (GA) cockpit. As displays get larger, and as more functionality is added, GPS is starting to bridge the gap between traditional avionics “boxes” like VOR and ADF and the integrated flight management systems found in airliners and corporate jets.

The result, paradoxically, is that GPS receivers themselves—rather than becoming more prominent—are fading into the background. Why? Because when all is said and done, a GPS is a “black box” that generates a latitude, longitude, altitude, direction, and speed. What pilots are usually talking about when they use the term “GPS” is not the receiver itself, but all the peripheral hardware and software that’s wrapped around it. And as the avionics industry has demonstrated, there are few limits on the shape and sophistication of that hardware and software.

An analogy: In 1975, computers were expensive and exotic. Today they’re cheap, and no one thinks much about them because they’re everywhere—hidden in everything from car engines to refrigerators.

GPS is following a similar path, which is one reason we won’t spend much time talking about how it actually works. What we *will* talk about are ways to get the most utility you can from it while ensuring that it remains a tool that works for you—not the other way around.

Fundamentals

The technology of GPS is complex, but the basic concept behind it is simple. A receiver pulls in signals from multiple satellites, determines how long the signals took to arrive, and uses that information to triangulate its own position. If it can “see” three satellites, it can figure out where it is over the ground. If it can see at least four, it can determine its altitude as well.

GPS has revolutionized the way we fly, but using it safely takes preparation and prudence.



From datalink weather and traffic information to 3-D synthetic vision systems, more and more functionality is being bundled around GPS.

Every GPS receiver does exactly that—no more, no less. Some are a little faster than others, and some can use correction signals from ground stations to produce a more accurate position fix, but they’re still spitting out a latitude, longitude, altitude, speed, and direction.

From there, things get a little more complicated. Manufacturers have never been required to standardize user interfaces (knobs, buttons, keypads) or functionality, so it generally takes some adjustment for pilots to move from one receiver to another. Still, the shared purpose of aviation GPS receivers means that certain core functions are common to virtually all of them, and that root-level compatibility makes things a little easier for transitioning pilots. Even so, it’s not the same as moving from one VOR receiver to another: It takes a significant amount of time and practice to use a new system proficiently in real-life situations.

Of course, the ultimate importance of proficiency varies with the circumstances. A pilot planning to use a new receiver for simple VFR flights can probably jump in the cockpit and (with caution) start using it on trips almost immediately.

But there’s a caveat here, one that points to the reason it’s becoming more difficult to talk about “GPS” in a monolithic sense. You might be able to use a Garmin GNS-530 (a GPS/NAV/COM unit) for that VFR flight without much preparation or training...but it wouldn’t be smart to try the same thing with its big brother, the G-1000. The G-1000 has a built-in GPS receiver, but it’s also a full glass panel system that replaces the traditional



Recent trends toward larger, FMS-style keyboards (and fewer multifunction keys) hold promise for easier data entry and quicker transitions to new equipment.

flight and engine instruments. It’s a very complex, capable system—not something you use without training, IFR or VFR.

RNAV. Area navigation, or RNAV, is a generic term that applies to several different systems that can determine an aircraft’s position, speed, and direction of flight. GPS is just one of those systems.

Of course, for IFR, it’s never a good idea to use a GPS receiver for primary navigation without being thoroughly familiar with it—or, at the least, well prepared to fall back on other navigation systems if necessary. The best way to gain familiarity and proficiency is to take a purposeful, systematic approach to learning about the system (see Figure 1).

The goal is to reach a point at which you can make the equipment do what you need without using any more brainpower than absolutely necessary. Getting to that point frees up time and mental resources to do other important things in the cockpit—anticipate ATC’s next curveball, keep an eye on weather, monitor your fuel situation, and so on. That means better situational awareness, and better airmanship overall.

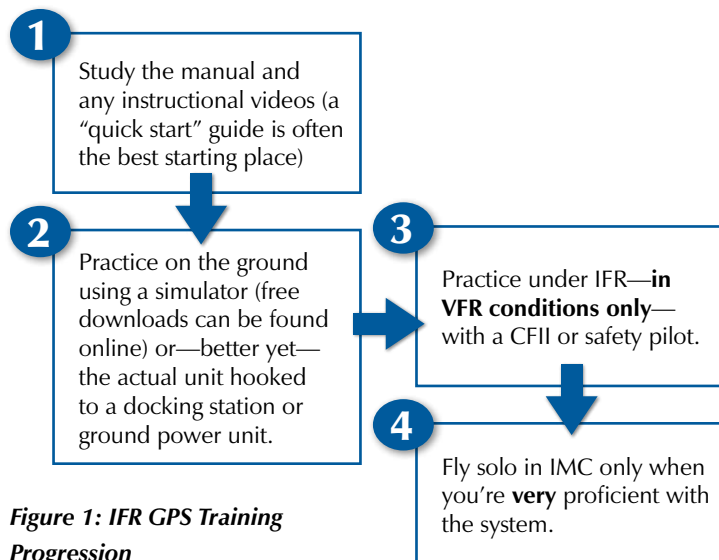


Figure 1: IFR GPS Training Progression

Prerequisites. Getting ready to go it alone with a new receiver in IMC? Here are some tasks you should be able to accomplish (without referring to the manual) before you do:

- Load and activate a flight plan
- Add, delete, and edit flight plan waypoints
- Find airport/navaid information
- Suspend autosequencing
- Set up and fly a holding pattern
- Load and activate an approach
- Change the initial approach fix selection
- Initiate the missed approach sequence

Route Planning

For many pilots, one of the most attractive features of GPS is direct, airport-to-airport navigation. That's great in theory, but in practice there's more to it than punching "Direct" and following the active course line. For one thing, in the congested airspace over many parts of the country, you're not likely to be cleared "direct" on a flight of any length. For another, special use airspace often interferes with direct flights.

On the bright side, there's no reason you can't file a flight plan that follows airways until clear of obstacles and goes direct thereafter. Even so, it's worth noting that in most cases the time/distance savings of going direct rather than via airways is smaller than you'd imagine.

For VFR, filing a flight plan with GPS is no different than normal, but for IFR there are a couple of things to re-



GPS offers a great deal of flexibility in route selection, but remember that "direct" isn't always the best choice.

member. If you're filing direct and planning to fly an approach at the destination, file to an initial approach fix, rather than the airport itself. Second, if you're filing an off-airways route, include at least one waypoint for each air route traffic control center (ARTCC) through which you'll be flying. When naming these waypoints in your flight plan, use something recognizable to ATC—a radial and distance from a VOR, for example.

Databases, Charts, and Equipment

There are a few other things to keep in mind as you prepare for a flight with GPS. First, the navigational database: For VFR flights (or if using the receiver for situational awareness under IFR), there's no requirement to have a current database, but be wary of possible changes to airports, airspace, and obstructions. In other words, bring appropriate charts, and use them!

IFR is a little different. Databases are updated on a 28-day cycle, and although the regulations don't specifically require a current database, FAR 91.103 requires pilots to be familiar with "all available information" pertinent to the flight. For that reason, it's conceivable that failing to update the database could lead to trouble with the FAA. However, pilots are allowed to use an expired database for IFR en route and terminal (not approach) operations, so long as they verify that the data is still correct.



Electronic chart displays can be very helpful in the cockpit, but it's still a good idea to have paper charts available.

Pilots who have multifunction displays (MFDs) or electronic flight bags (EFBs) capable of displaying electronic charts often ask whether it's still necessary to carry paper charts. The answer? Although there's no specific legal requirement to carry current charts and approach plates, the FAA could, again, potentially cite the pilot for failing to become familiar with all available information concerning the flight. For that reason—and because charts, unlike electronic displays, never “crash”—ASF recommends having current paper charts available in the aircraft.

What about handheld receivers? Modern handheld units are often extremely well featured, so it's no surprise that pilots are sometimes tempted to use them for primary navigation under IFR. Still, there are several good reasons not to. Handhelds don't have fixed power sources or permanent antennas, and since they don't have RAIM (which we'll discuss later) they can't warn pilots of potential issues with the data they're providing.

All that said, however, a handheld receiver can be an invaluable tool for situational awareness under IFR. Simply being able to see, on a moving map, where you stand relative to nav aids, airports, and airways is very helpful, as is having an alternate means of navigation in the event of a VOR or ADF failure. Some handhelds can even use GPS data to create representations of the primary flight instruments, giving you a secondary “panel” in the event of a vacuum pump failure.

RAIM

Much as VOR receivers give pilots a way to determine that the validity of navigation information (“off” flags and audio identifiers), IFR GPS receivers can warn pilots when the data they're providing is potentially inaccurate for

one reason or another. The system that does this is called RAIM—Receiver Autonomous Integrity Monitoring.

In addition to airborne alerts, most receivers have a RAIM prediction mode that can warn pilots in advance of likely unreliable signals along the route.

Because the reliability of GPS is entirely dependent upon satellite signal availability, it's important to check for GPS notams before flight. These are issued to advise pilots when signals are expected to be unreliable. Flight Service doesn't automatically provide them during briefings, so be sure to ask.

Programming and Taxi

Time is money, so the old saying goes, and nowhere is that more true than in aviation. None of us like to waste time on the ground, but don't get impatient: Get your clearance and program the route into the GPS *before* you taxi out (and preferably before starting the engine). In a moving aircraft, all the button pushing and knob twisting of flight plan entry is just too much of a distraction. More than one runway incursion has been caused by a “heads-down” pilot preoccupied with the GPS.



Ground power switches power up the avionics without using the master switch (which also spins up instrument gyros, etc). They're relatively inexpensive, they help conserve battery power, and—if the alternative is letting the engine run—they can save a lot of money over time.

Handheld receivers have become impressively capable in recent years. They can be great tools for situational awareness—but don't rely on them for navigation under IFR.



During taxi, keep your eyes where they belong—outside the cockpit.

As an aside, an MFD capable of displaying the aircraft's GPS-derived location on the airport diagram can be very helpful while taxiing at unfamiliar airports. However, it's still important to keep your eyes outside the cockpit as much as possible.

Pay close attention while programming the flight plan into the receiver: It's easy to select the wrong waypoint by mistake. For example, if you filed the Martinsburg, WV, airport as a waypoint, but accidentally entered "MRB" (rather than "KMRB") in the GPS flight plan, you'd be directed to the Martinsburg VOR—six miles east of the airport.

Departure

After takeoff, it's important to be ready for changes of plan—for example, if ATC modifies your clearance to remove an intermediate waypoint. Know exactly what it takes to edit the flight plan: This is where all the study

Dangerous Distraction. The following account is taken from an actual report to the Aviation Safety Reporting System: *"I had touched down, after making three calls on approach, only to have a Bonanza almost taxi onto the active runway to back-taxi for takeoff. He stopped with his propeller approximately three feet from the runway's west edge. He indicated he was 'messing with his GPS' and not watching. The truly sad situation is there is a parallel taxiway to take him to [Runway] 16 without having to back-taxi on the runway."*

and preparation you've done ahead of time pays for itself. Remember that bypassing the flight plan structure and just going "direct" to the new waypoint can cause problems later in the flight.

If you're having trouble getting the GPS reprogrammed, ask ATC for a heading to get you started in the right direction before spending a lot of time troubleshooting the receiver. Also, remember that it's a good idea to be ready to fall back on other navigation devices in the event of a GPS issue. Make it a point to keep the nav radio tuned to nearby VORs during your flight—it'll give you a leg up if you need to switch over.

Single-Pilot IFR. Flying solo in adverse weather is challenging—and when you throw GPS into the mix, it can easily demand more than a pilot can offer. ASF recommends that pilots consider a dependable autopilot "required equipment" for solo flights into IMC, particularly when using GPS.

En Route Issues

For the most part, working with GPS during the cruise portion of the flight is simple. Apart from any ATC-assigned re-routes or holds, it's just a matter of maintaining course and letting the receiver autosequence from one waypoint to the next.

For VFR, it's important to cross-check the displayed route against the sectional chart, and what you're seeing out the window. Don't get complacent just because GPS has made your navigational chores lighter.

With IFR receivers, you'll notice that the receiver will transition from terminal to en route mode as you leave the area of the departure airport. From a functional

standpoint, this just means that the sensitivity level of the course deviation indicator (CDI) has decreased. In terminal mode, full needle deflection is one nautical mile. In en route mode, full deflection becomes either two or five nautical miles, depending on the type of receiver. This is only a difference in display scale: The receiver still operates with the same precision.

What if ATC tells you to hold at a navaid or waypoint? Functionality and terminology vary somewhat from receiver to receiver, but in most cases you have to manually switch the receiver to “suspend” mode. This temporarily interrupts the flight plan, so the receiver doesn’t autosequence to the next waypoint. Then you can select OBS (omni-bearing selector) mode: This allows the GPS to behave like a VOR receiver. Once you’re in OBS mode, you use the OBS knob on the external CDI to select the inbound radial for the hold. After that, the CDI will provide course guidance with a To or From readout, just like a VOR. On the last trip around the holding pattern, pressing “Suspend” again tells the receiver to start autosequencing again.



Pilot workload reaches its peak during the arrival and approach phases of flight. This is when it’s most critical to be proficient with the GPS.

Learning the Hard Way. The following account is taken from an actual report to the Aviation Safety Reporting System: *“I had loaded the approach into the GPS and was attempting to load ‘direct to’ the fix when the aircraft entered an unusual attitude. As I attempted to correct the situation I believe I became more and more disoriented. After some harrowing moments with significant changes in altitude, I was able to regain straight and level flight. I continued to be disoriented. It appeared that my HSI had become unusable. Center indicated that I was flying in circles. With the help of the controller I was able to land successfully. I believe that distractions while attempting to program the GPS led to unusual attitudes and loss of control of the aircraft. Subsequent loss of the HSI and IMC conditions led to further disorientation. Single-pilot IFR can be difficult with multiple tasks to be performed. I feel that if I would have had a trustworthy autopilot and had it engaged I would not have gotten into the situation. In the future I do not plan to fly single pilot IFR without a fully functional autopilot on board.”*

Arrival and Approach

As you near the destination airport, the GPS automatically cycles back to terminal mode and full CDI deflection decreases from either two or five miles to one mile. Now the main consideration is getting ready for the approach (if one is necessary). Approaches are like “mini flight plans” stored in the databases of IFR-certified receivers. Both RNAV and non-RNAV approaches are included. If you’re flying a non-RNAV approach (an ILS, for example), the receiver can perform backup navigation and situational awareness duties, but remember that the traditional navigation system should still be the primary reference.

Once an approach is selected, the receiver will ask you to choose either a specific transition (one of the initial approach fixes), or “vectors to final.” Choosing vectors to final basically puts the receiver in “hold” mode (i.e., turns autosequencing off) until the aircraft intercepts the final approach course. Unless ATC has told you to expect vectors, select the most likely transition for your direction of arrival. This can be changed later if necessary—assuming you know how to reprogram the receiver.

With a transition selected, the receiver will guide you through the approach, waypoint-by-waypoint. Receivers

vary, but you may have to switch over to OBS mode (the same as you would if assigned a holding pattern) if a procedure turn is necessary. That said, most RNAV approaches are structured in such a way that procedure turns are rarely necessary.

WAAS. WAAS (the Wide Area Augmentation System) uses ground-based facilities to monitor and correct the GPS signal. This makes it significantly more accurate, and allows for RNAV approaches that provide with vertical guidance and near-ILS minimums. Unlike aircraft equipped with “normal” GPS, those with WAAS-certified receivers are not required to carry a backup navigational system (e.g., VOR). Another difference: In place of RAIM, WAAS receivers use a more advanced system called Fault Detection and Exclusion (FDE).

Some receivers automatically “arm” the approach once it’s been loaded; others require the pilot to do it manually. This lets the receiver transition to its most precise setting, approach active mode, two miles from the final approach waypoint (FAWP)—or, for WAAS units, when the FAWP becomes the active waypoint. At that point, full deflection of the CDI decreases from one mile to three-tenths of a mile. This change in scale normally goes unnoticed, but in some cases it can be confused for an off-course indication. For that reason, be cautious about making significant course corrections just outside the FAWP.

During the approach, it’s also important to remember the potential for a RAIM failure. If one occurs prior to the FAWP, the receiver won’t transition into approach mode—which means it won’t reach the proper sensitivity level. Verifying that the receiver is in approach mode should be part of your normal FAWP checklist: If for some reason it isn’t, execute the missed approach.

If a RAIM failure occurs after the FAWP, non-WAAS receivers will continue to operate in approach mode (without any flags or annunciations) for up to five minutes while the pilot completes the approach. If a flag or warning does appear after the FAWP, execute the missed approach.

Many RNAV approaches now include WAAS minimums. From a charting perspective, the situation is similar to an ILS procedure that includes localizer-only minimums: The chart is largely the same, but the procedures differ

somewhat depending on the type of equipment used to fly the approach. Figure 2 (below) explains the different minimums you’re likely to see on RNAV approach charts.

Missed Approach

Missed approach procedures vary among GPS units. For example, some WAAS receivers automatically transition to the missed approach procedure, while non-WAAS units require pilot input. “On those receivers, hitting the “Suspend” or “Direct” button normally selects the first fix on the missed approach as the next waypoint. The receiver drops out of approach mode and indicates a course direct to that waypoint.

But that may not be the course you want to fly. Consider, for example, a missed approach procedure whose first leg involves a turn off the final approach course. If you hit “Direct” before reaching the missed approach point (MAP), the receiver will call for an immediate turn (and possibly take you out of protected airspace), when in fact you should maintain the final approach course until the MAP.

The missed approach should never be an afterthought. Always think through the steps involved ahead of time, and contact ATC for instructions as soon as possible after going missed—but remember to fly the airplane first.

LNAV:	Normal (i.e., non-WAAS) nonprecision minimums.
LNAV/ VNAV:	The less precise of the two types of vertically guided WAAS minimums.
LPV:	A more precise type of WAAS approach that can provide ILS-like minimums. Think of LPV as standing for “Localizer Precision with Vertical guidance.”
LP:	The WAAS equivalent of a localizer-only approach. Used in locations where terrain and/or obstructions don’t allow for vertical guidance, but where the accuracy provided by WAAS is helpful anyway.

Figure 2. RNAV approach minimums.

Conclusion

GPS has been a revolutionary force in the general aviation cockpit. It can dramatically enhance situational awareness, open up more airports, and expand routing options—and it's becoming more capable, and more integrated into everyday flying all the time.

As with any technology, though, GPS has certain draw-

backs. It can significantly increase cockpit workload and distractions, and learning to use all the “bells and whistles” can be challenging. Safe pilots understand that it takes practice and patience to learn a new receiver. They know, too, that it's always good to have a helping hand—whether from a co-pilot or an autopilot. But most of all, they keep their priorities straight: Flying the airplane, and maintaining situational awareness, **always** comes first.

GPS Tips

VFR Create a “runway extension” to provide an additional visual reference to the final approach leg.	IFR Always pay attention to the CDI source! Is it being “fed” by the GPS or a VOR/localizer receiver?
VFR Create a user-defined waypoint to serve as a secondary aid to avoid terrain or airspace.	IFR Keep track of whether you're in NORMAL or OBS mode, and always know which mode you should be in.
VFR Set up airspace alerts to warn you of upcoming airspace, such as Class B, restricted, and prohibited areas.	IFR If you're falling behind during arrival, ask ATC for delaying vectors and be ready to fall back on traditional navigation if things get too hectic.
VFR Use the ETA on your GPS to easily determine the accuracy of your preflight planning.	IFR Don't start your descent to the MDA just because the GPS announces that it's switched to approach mode.
VFR Use the timer function to remind yourself to switch fuel tanks at regular intervals.	IFR On the missed approach, don't hit the OBS or “Direct” key too soon: The receiver may direct you to start a turn too early.



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Publisher: Bruce Landsberg • Writer: Brian D. Peterson
Project Manager: Paul Deres

Edition No. 1 2/09 380029