GPS Technology

Note: The information contained in this publication was accurate at printing, but because GPS technology is evolving rapidly, it should be considered perishable. This Safety Advisor refers mainly to IFR-approved panel-mount GPS receivers, since no handheld or yoke-mount GPS units are currently approved for IFR navigation. Pilots should always refer to the manufacturer's operating guide for information specific to their receivers.

GPS: How It Began

GPS owes its development to the strategic and tactical needs of the U.S. military. During the 1970s, the Department of Defense developed GPS primarily as an all-purpose navigation system to improve position finding for ships at sea, aircraft, and ground combat units.

GPS is a great tool for pilots, but there's more to it than just the "Direct-To" button.

The first GPS satellite was launched in 1978 and GPS was declared fully operational in 1995. The GPS constellation is comprised of at least 24 satellites, but the total number is sometimes greater. Although the system was designed by and for the military, civilian use of the system has been available since the beginning. Civil users were at first provided a somewhat degraded signal referred to as selective availability (SA), but Congress exerted pressure on the Department of Defense to provide increased GPS accuracy for civil applications. Consequently, SA was turned off in 1999.

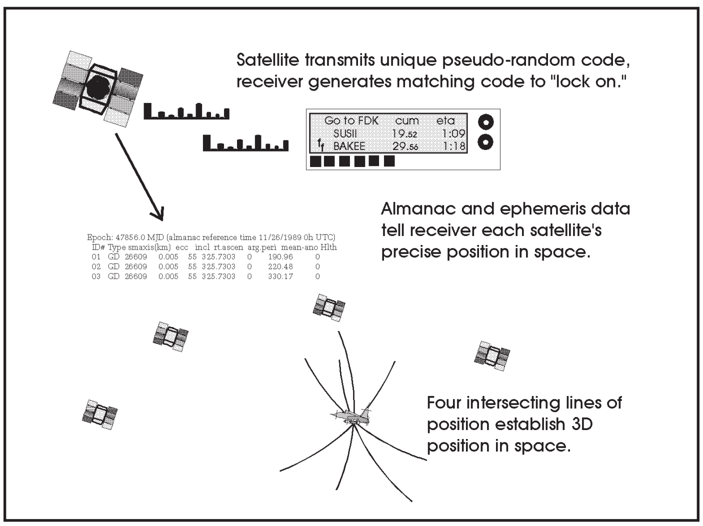
How GPS Works

GPS works by ranging and triangulating aircraft position from a group of satellites. Of the 24 GPS satellites currently in orbit, a minimum of four are needed to determine an aircraft's three-dimension position. GPS measures distance by calculating the amount of time it takes a navigation and time reference radio signal from the satellite to make a one-way trip to the GPS receiver in the airplane.

To calculate range, the receiver has to know two things: exactly where a satellite is in space, and exactly when the signal left the satellite. Satellites broadcast almanac data to tell the receiver generally where all the satellites are and ephemeris (precision celestial data) that pinpoints each satellite's position in space. When a new GPS receiver is turned on, it must download the almanac and ephemeris data before it can determine position. This usually takes several minutes.

The receiver establishes lines of position from at least four satellites, corrects for any timing errors, and displays your position within a few hundred feet. At least four satellites are preferred but three will do in a pinch if the pilot provides a fourth line of position—altitude.

Close call: The pilot of a Cessna 172 encountered icing in instrument meteorological conditions (IMC). Unable to maintain altitude, he descended below radar coverage in mountainous terrain. Using a handheld GPS and sectional charts, the pilot was able to land at a nontowered field that had no instrument approach. This pilot was extremely lucky and probably wished he'd made a better assessment of weather before the flight. Happily, GPS helped him out of what could easily have been a fatal situation.



How Is GPS Different from VOR?

GPS course indicators use a CDI needle to show position relative to a selected course, much like VOR. But GPS can also show position on an electronic chart, and (with additional software and/or equipment) it can show altitude above terrain. The list of GPS features is long and growing but the principal differences between GPS and VOR navigation are:

1. GPS is a satellite- and computer-based navigation system that offers many features unavailable in VOR navigation. How these additional features are accessed and controlled by pilots depends on the make and model of GPS receiver.

- With additional features comes complexity. *GPS receivers are more complex than VOR units, and pilots must commit the time and resources necessary to thoroughly understand their operation, especially for operations in IMC.*

2. GPS receivers can store a sequence of locations (waypoints) and will provide navigation information to each waypoint in that sequence. As each waypoint is reached, the next waypoint in the sequence automatically becomes the active waypoint. This function is referred to as autosequencing, and files of waypoints are called "flight plans" or FPL. A GPS instrument approach is a sequence of waypoints leading from the initial approach fix (IAF) to the missed approach point (MAP) and from there to the missed approach holding point.

- If a pilot doesn't want to proceed to the next waypoint in a sequence (e.g., he wants to perform a hold or procedure turn before continuing), he has to manually suspend autosequencing.

3. VOR uses resolver course indicators. Some GPS installations do not.

- A VOR indicator always displays your relationship to a particular radial. By turning the omni bearing selector knob (OBS) until the course deviation indicator (CDI) centers, you can determine the radial you're currently on—and, thus, your angular position with respect to the VOR station. Resolverless GPS indicators act like an ILS localizer: They show relationship to a course regardless of the position of the OBS. Pilots with resolverless GPS installations must select the desired course on the GPS receiver itself.

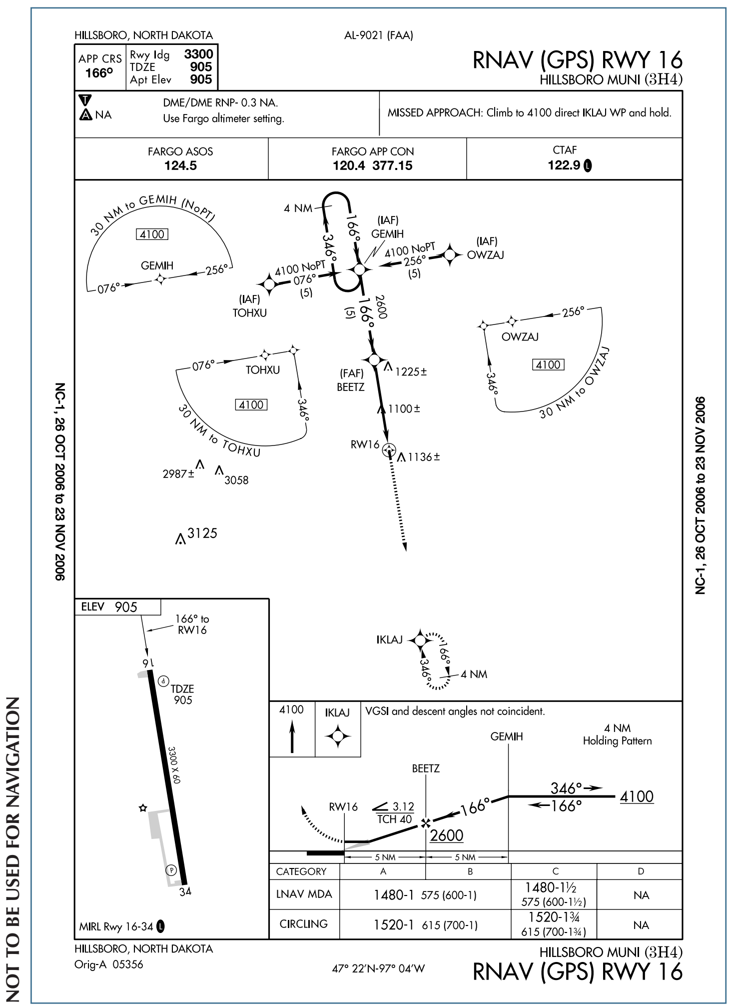
4. Instrument approaches designed for GPS are easy to fly, but any interruption of the waypoint-to-waypoint sequence can result in high pilot workload close to the ground. Examples include missing an approach early, or bypassing one or more waypoints when receiving radar vectors to final approach.

- Pilots should be thoroughly familiar with their GPS receivers before flying instrument approaches in IMC.

5. GPS receivers calculate magnetic course from true course information and display the information as a great circle track. There are several ways of doing this calculation and pilots should know that even though GPS may not always agree with VOR, the difference will be slight.

6. VOR/LOC receivers show angular displacement from a selected course. Thus, the closer to a VOR station, the more sensitive the course indication. In other words, a small deviation from course that might go unnoticed 50 miles from the station will "peg" the CDI needle when within a mile or so of the VOR. GPS shows course deviation in nautical miles (nm) off course. In en route navigation, the CDI will show ± 5 nm either side of course centerline. When within 30 miles of a destination airport, the GPS will enter "terminal" mode and increase sensitivity to ± 1 nm either side of the course. When within 2 nm of the final approach waypoint, the GPS sensitivity will smoothly increase from 1nm to ± 0.3 nm either side of course for nonprecision and LNAV/VNAV approaches. This makes GPS easier to fly when close to the waypoint, as is typically the case on an approach.

GPS is now found in most light aircraft cockpits, and many GPS installations are certified for en route IFR and nonprecision approaches. As GPS evolves, avionics manufacturers are



GPS provides poor-weather access to airports that may not have had instrument approaches in the past. Hillsboro, ND, for example, has only GPS approaches.

integrating it into equipment that's more versatile, easier to operate, and capable of giving pilots unprecedented confidence in situational awareness—for example, the glass panel systems that are becoming relatively common in GA aircraft.

The FAA has developed a phase-out schedule for most non-GPS forms of electronic navigation. NDB/VOR/ILS are all included in the FAA's phase-out schedule, but will nonetheless remain major players in the National Airspace System for years to come. GPS cannot be used as a sole means of navigation until all the current GPS satellites are replaced, a project known as GPS III. The benefits of this project are not expected until 2011 or later, although the FAA has granted operators who navigate in oceanic airspace and certain remote areas (including Alaska) the approval to use GPS as a sole means for navigation. Another exception is the Wide Area Augmentation System (WAAS), which uses corrected GPS satellite information for navigation. Aircraft currently equipped with a WAAS receiver may use WAAS as a primary means of navigation.

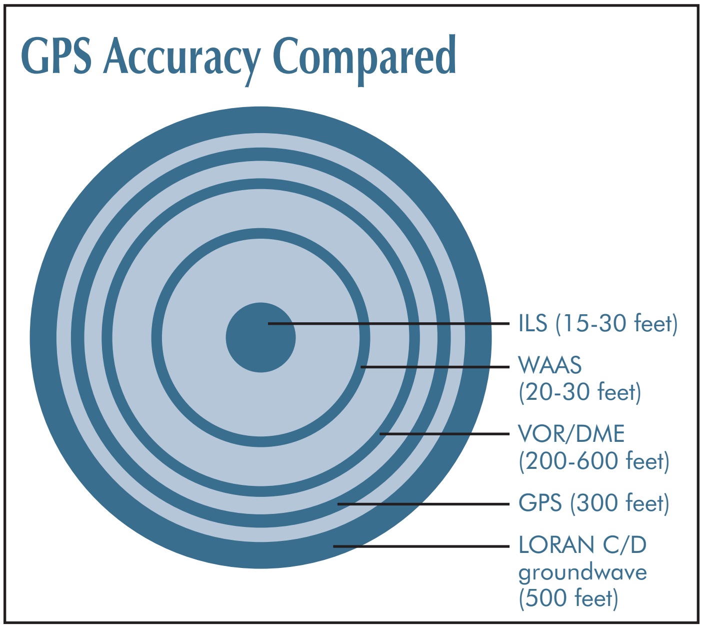
How Accurate Is GPS?

GPS Standard Positioning Service (SPS) provides horizontal positioning accuracy of 100 meters or less 95 percent of the time, and 300 meters or less 99.99 percent of the time. A second level of GPS service, Precise Positioning Service (PPS), is more accurate than SPS but is only available to specially authorized military, government, and civilian users.

Condition	SPS	WAAS	LAAS
Accuracy	330 – 990 feet	Better than 23 feet	Under development but better than WAAS

Why Handhelds Won't Do the Job for IFR

Because the GPS constellation provides good coverage, panel-mount receivers with unrestricted antennas nearly always navigate in three dimensions. Handheld GPS receivers, while popular and used as a backup by many pilots, don't always do as well. With their windshield or glareshield antennas shadowed by wings or other aircraft structures, they occasionally revert to two dimensions or lose coverage entirely. They also lack the ability to warn pilots when GPS satellites are providing questionable data (see "RAIM—The 'Off' Flag"), and do not have a fixed, uninterruptible power source. Currently, there are no handheld GPS receivers that meet FAA Technical Standard Order (TSO) requirements for IFR certification.



GPS Accuracy Compared

At the runway threshold, an ILS is capable of 15- to 30-foot accuracy, so standard GPS is not accurate enough for precision approaches (especially in the vertical dimension, where GPS is far less accurate than it is laterally). Another concern is integrity—the ability to detect ambiguity in a navigation solution. Because GPS is a multiple-ranging system, its accuracy depends on the accuracy of each individual satellite. VOR and ILS signals are monitored continuously and stations are shut down if a problem is detected. That instantly trips a flag in the cockpit, warning the pilot not to navigate from that station. A GPS satellite problem may go undetected until the satellite passes over a ground monitoring station. That could take an hour or more.

RAIM—The "Off" Flag

Receiver Autonomous Integrity Monitoring (RAIM) addresses the shortcomings in GPS technology. All IFR-approved GPS receivers are required to have RAIM. RAIM works by overdetermining position using at least five satellites, or four satellites and a barometric altitude input from an encoding altimeter or altitude encoder. The receiver will issue a RAIM alarm (an annunciator light or display warning) if it detects questionable data from one or more satellites.

For **en route** operations, RAIM must issue an alarm within 30 seconds of detecting an integrity fault. For **nonprecision approaches**, the alarm must be issued within 10 seconds.

If a RAIM alarm is active, the receiver will continue to navigate in en route mode, but it will not operate in approach mode until the RAIM limitation is resolved. RAIM is limited in its ability to quickly detect navigation faults, so some other means is necessary for precision approaches. One method for achieving precision approach capability is the Wide Area Augmentation System (WAAS), which uses the GPS satellite network. More about WAAS later.

Another concern is interference—both accidental and intentional. GPS is easily jammed using strategically placed low-power transmitters. In 1998, the FAA commissioned the Johns Hopkins Applied Physics Lab to study how vulnerable GPS is to external jamming. The study found that GPS, when augmented by WAAS or a Local Area Augmentation System (LAAS), can meet the requirements for navigation in the National Airspace System, but that jamming continues to be a risk.

Differential to the Rescue

Both WAAS and LAAS help GPS compensate for errors through a system known as differential navigation. This system uses a ground monitoring station that samples GPS data from passing satellites, detects inconsistencies, and broadcasts a correction signal to airborne receivers. Industries other than aviation—notably agriculture, marine, and surveying—have used differential for a number of years, achieving accuracy down to the centimeter level in some applications. For aviation use, differential information needs to be broadcast either over the entire United States, a very wide area—thus WAAS—or a local area, as with LAAS.

Both forms of differential also include integrity assurance, thus flagging a potentially ambiguous or erroneous navigation signal. However, LAAS is limited to a geographically small area, typically 25 miles or so, and like conventional ILS it requires ground equipment and a dedicated receiver in the airplane. Also because of its limited coverage area, it is useful only for GPS approaches at airports within that very limited area.

WAAS broadcasts GPS correction signals nationwide, and north into parts of Alaska. WAAS technology solves both the accuracy and integrity problems of GPS and could eventually provide an approach with minimums comparable to Cat I ILS at many airports. WAAS satellites broadcast corrected GPS signal data to WAAS-capable receivers. WAAS signals carry a ground-based integrity broadcast capable of a six-second alarm limit. The WAAS signal also contains an embedded navigation message, allowing receivers to use it as part of the navigation solution, just as though it were another GPS satellite. First-generation IFR-approved receivers are not likely to be WAAS upgradeable. Some second-generation units may be upgradeable, either through a hardware or software update, but this is not true in all cases.

"Enabled" vs. "Certified": The term "WAAS-enabled" simply means that a receiver is capable of receiving the WAAS augmentation signal. It says nothing about whether that receiver can legally be used as a primary means of navigation under IFR (or to fly a WAAS approach, for that matter). For example: A number of handheld receivers are WAAS-enabled, despite the fact that they can't be used as a primary means of navigation under IFR.

For those pilots who wish to retain first-generation IFR-approved receivers, the good news is that they will continue to function and will be capable of flying existing non-precision GPS approaches, procedures that aren't likely to change.

About GPS Receivers

Since their introduction over a decade ago, IFR-approved GPS receivers have evolved considerably, from rudimentary numerical displays to full-color devices with moving maps and multifunction display (MFD) technology. Currently, IFR-certified GPS receivers cost between $4,500 and $15,000 to buy and install, plus an estimated $700 or more a year for required database revisions.

Caution: Pilots shouldn't underestimate the need for receiver-specific training. Know how the receiver works before using it for IFR. ASF recommends computer-based training (a GPS simulator), a thorough checkout from a knowledgeable instructor, and enough practice in VMC to feel comfortable in the soup. Even then it's a good idea to raise your minimums until you've had some actual IMC experience with GPS.

GPS is an integral part of glass cockpit installations.

Many first-generation GPS receivers are available on the used market. Although neither as automated nor as simple to operate as state-of-the-art navigators, first-generation receivers still perform well and may represent a good buy for some owners. New receivers, however, have many now-standard features and "hooks" available for additional features such as airborne datalink for weather and collision avoidance information. They also tend to be more user-friendly.

Newer receivers incorporate color displays—as in the Garmin GNS 400/500 series and the Bendix/King KLN-94—and can accommodate larger multifunction displays. GPS is also an integral component of the glass panel systems (the Avidyne FlightMax Entegra and Garmin G1000, for example) that are rapidly becoming the industry standard in factory-new GA aircraft.

Receiver	VOR/LOC	GPS En route	GPS Approach	GPS WAAS
Capability	En route, LOC/ILS	En route	En route, Terminal, Approach	En route,Terminal, CAT I, Approach
Accuracy	LOC 15-30 feet (5-10 meters) at runway threshold	300 feet (100 meters)	300 feet (100 meters)	21 feet (7 meters)
Flagging-Integrity	Flags loss of signal	Alarm within 30 seconds of fault detection	Alarm within 30 seconds of fault detection	Alarm within 6 seconds of fault detection
Range	Line of Sight	Unlimited	Unlimited	Unlimited
Required Equipment	VOR/LOC/ Glide Slope Receivers for Cat I ILS. Additional equipment & training for Cat II & III ILS	En route certified GPS receiver and certified installation	En route & approach certified GPS receiver and certified installation	En route & approach certified WAAS GPS receiver and certified installation

It's important for pilots to remember that although GPS receiver certification requirements are considered inviolate, each manufacturer satisfies them in a different way—particularly with regard to required switches, annunciators, and the autosequence function. In the latest generation of IFR-approved receivers, for example, autosequencing of waypoints is more highly automated than it is in first-generation equipment, which required manual input and setup from the pilot. *Current GPS receivers are not required to use standard terminology. For this reason, pilots should spend plenty of time becoming familiar with each GPS unit they use.*

IFR En Route Only Receivers

IFR en route approved receivers can be used for random, off-airways routes, *as long as the aircraft is in radar contact*. Similarly, one can navigate to fixes beyond standard VOR range, again assuming radar monitoring is available.

Note: A GPS certified only for IFR en route cannot be used as the sole means of navigation. VOR, NDB, or navigational equipment appropriate to the ground facilities to be used must be aboard, as described in FAR 91.205. Generally, en route approved receivers provide essentially the same navigation information as a VFR-only loran or GPS, the principal difference being that an IFR-approved en route receiver has RAIM.

Spend plenty of time learning a new receiver. PC-based simulators, receiver docking stations, and aircraft "ground power" switches can make this easier and cheaper.

To be certified for approach use, the GPS receiver must be linked to an external CDI in the pilot's direct field of vision.

It's quite possible that a receiver capable of being IFR-approved was not certified for IFR when it was installed. In this case, it should be placarded "GPS Not Approved for IFR." For en route flying, it's legal (if not wise) to use an expired database, as long as the pilot has available current information, such as current low altitude en route charts, to manually check and correct any data that's changed.

IFR Approach-Approved Receivers

IFR approach-approved receivers include all of the design features of an en route receiver plus some requirements peculiar to the way GPS approaches are designed and flown. These requirements have to do with autosequencing, annunciation, and RAIM flagging. For en route purposes, both receiver types are essentially identical.

IFR approach-approved receivers require a significantly more complex installation than either a VFR loran or an en route-only GPS. The receiver's navigation output must be connected to a conventional CDI or HSI. If the GPS shares an indicator, there must be some means of switching from GPS to the conventional nav mode. In early GPS receivers, switching was done with an external switch/annunciator package. However, newer equipment, such as the Garmin 400/500 series, uses a button on the navigator itself for this function.

> **Tip:** Pilots must be sure to understand which mode they're operating in. If in GPS mode but trying to intercept a VOR radial or a localizer, you're likely to be off course and confused in short order. The same applies for departure. If the receiver was in the VOR mode for landing out of the ILS, for example, and the subsequent departure is based on flying GPS off the sequenced flight plan, the mode selector must be set to GPS.

All IFR GPS installations must provide the following annunciations:

- When the GPS is connected to the HSI or CDI – a waypoint alert annunciator to indicate turn anticipation and impending waypoint passage.
- When the receiver approach mode is armed and when it is active.
- When the GPS is autosequencing for the approach or when autosequencing is temporarily suspended to allow a procedure turn or a vector.

Annunciator design and labeling vary from receiver to receiver and, occasionally, between the same brands and models of receivers. Pilots are cautioned to read the receiver manual carefully to clear up any ambiguities. IFR-certified installations usually require altitude data (used by the RAIM function) from either an encoding altimeter or a blind encoder.

IFR Databases

While not technically required, the most convenient way to keep GPS data current is to subscribe to a GPS database update service, which is revised on a 28-day cycle. Although the receiver will not lock out approaches if the database is expired, using old database information for IFR operations is unsafe and strongly discouraged. It's up to the pilot to keep the database current. Database media vary with receivers. Some use a front-loading card similar to the memory cards used for digital cameras, while older units may have a rear-mounted cartridge. In the past few years, database availability has changed dramatically. It's now possible to download current data from Web-based sources and then transfer it to a data card.

Database revision services vary widely in cost and format, with the average yearly subscription for 28-day service costing about $700.

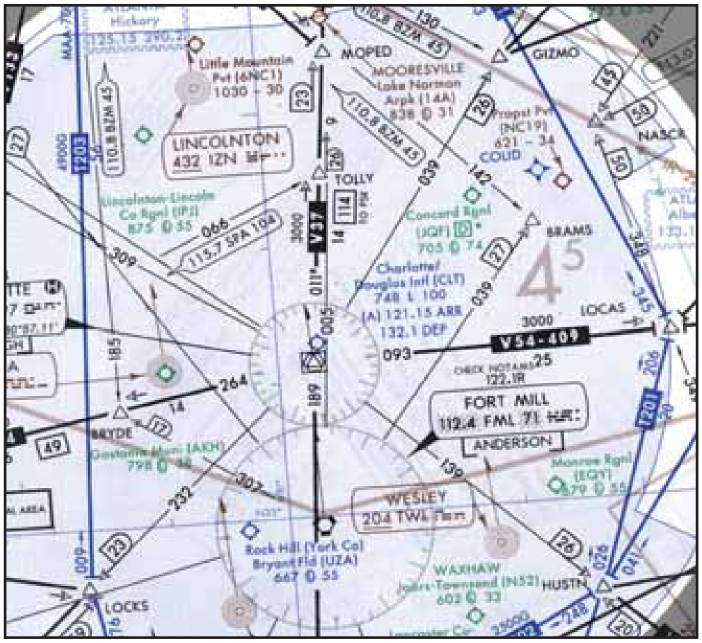
> **Tip:** Having a current receiver database doesn't mean you shouldn't also have current charts aboard the aircraft. Although there's no legal requirement for general aviation light aircraft to carry current charts and approach plates, in the event of an accident or incident the FAA would likely cite the pilot for failure to have all available information concerning the flight (FAR 91.103).

Flight Planning with GPS

For many pilots, one of the most attractive features of GPS is the fact that it offers direct, airport-to-airport navigation. That's great in theory, but in practice there's more to it than punching the "Direct-To" button and following the active course line. For one thing, in the congested airspace that exists in many parts of the country, you're not likely to be cleared "direct" on a flight of any duration. For another, special use airspace often interferes with direct flights. On the bright side, the inherent flexibility of GPS means there's no reason you can't file a flight plan that follows airways until clear of obstacles and then request a more direct route.

Also, pay close attention when entering the flight plan in 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" in the GPS (rather than "KMRB"), you'd be directed to the Martinsburg VOR—six miles east of the airport.

> **T-Routes:** IFR GPS users operating around certain terminal areas have a new routing option. RNAV IFR Terminal Transition Routes (T-Routes, or RITTRs) can help pilots avoid detours in busy airspace. Marked in blue on low-altitude IFR en route charts and designated with a "T" followed by a three-digit number (e.g., T306), they show up in GPS databases and are filed just like Victor airways. Because they're not subject to the line-of-sight limitations of traditional navaids, RNAV routes sometimes have lower MEAs than Victor airways in the same area.



T-Routes provide new routing options for IFR GPS users flying around busy terminal airspace.

Flying Approaches: Old vs. New

GPS navigators are designed to fly approaches as miniature routes. In other words, the waypoints must be flown in exactly the order they're stored in the database. When a full approach is to be flown—that is, via a nonradar feeder route or a procedure turn—the pilot can choose which initial approach fix (IAF) to use. Each segment of the approach is flown as a TO-TO leg, meaning when the receiver reaches one waypoint in the approach, it automatically sequences TO the next, until reaching the missed approach point (MAP), at which point autosequencing stops. If the pilot doesn't initiate the missed approach segment, it's assumed that the flight will either land straight in or circle to land.

Autosequencing is also required if the pilot is vectored onto the approach. To keep the receiver from sequencing before intercepting the final approach course, pilots must ensure the appropriate waypoint—usually the final approach fix—is the active waypoint, manually suspend autosequencing, then reengage it once established on the final approach course. Some receivers offer a vectors to final (VTF) feature that sets a path direct to the final approach course.

ASF recommends a thorough make and model-specific GPS checkout and some IFR practice in VMC before using GPS for instrument approaches. Once qualified, pilots should practice GPS navigation frequently to maintain proficiency. Be sure to use an instructor or a qualified safety pilot, coordinate with ATC for traffic advisories, and try not to practice in high-density airspace.

Costly Distraction: A Cessna 310 landed gear-up because its pilot, busy working with a new GPS, forgot to lower the gear. Like any new technology, GPS can demand a lot of attention until operators become thoroughly familiar with its use. Strict attention to the landing checklist or, better yet, an instructor or safety pilot on board could have averted an expensive and embarrassing incident.

Early GPS receivers—many of which are still in service—required the pilot to select or suspend autosequencing via a manual switch. Newer models have largely automatic sequencing control. If the pilot has selected the approach function, the receiver will automatically arm approach capability when the aircraft is within 30 miles of the airport. At this point, the approach-armed annunciator will illuminate, if the receiver design requires this, and the CDI scale will transition from five miles to one mile (the terminal scale).

Multifunction displays can do a lot more than just display GPS data. This one, for example, is showing traffic information derived from ADS-B.

Once established on the intermediate segment two miles outside the final approach fix (FAF), the receiver will automatically switch to the approach-active mode and the CDI scale will transition from one mile to three-tenths of a mile. The approach-active annunciator will illuminate.

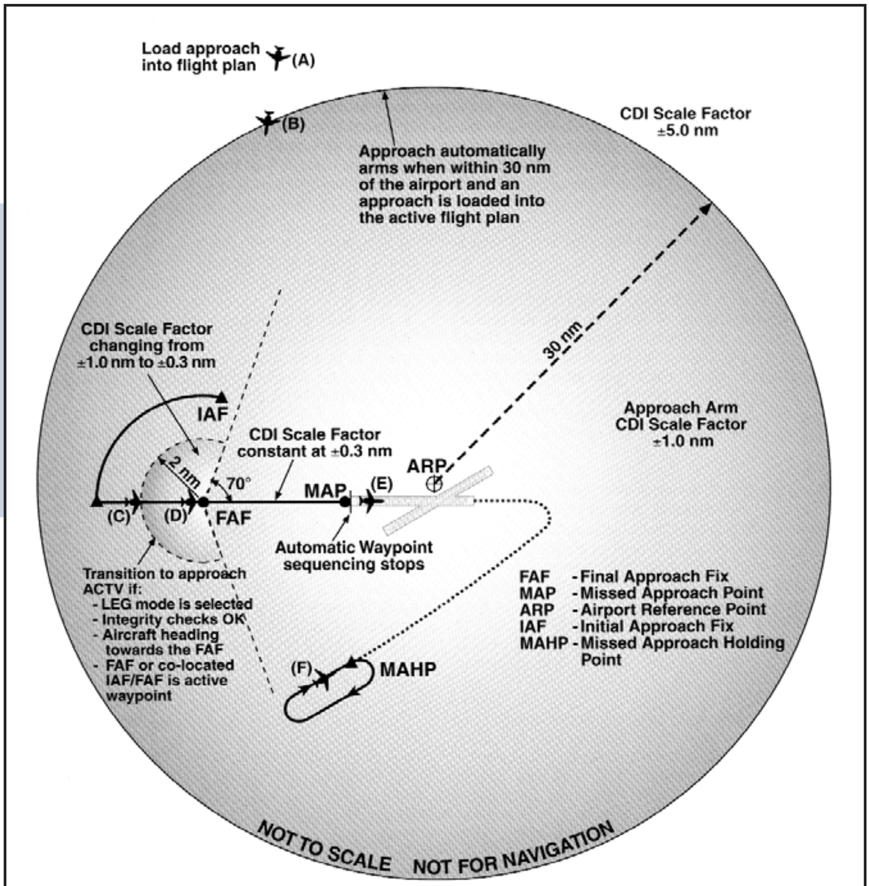


Figure 6-1 KLN 90B Approach Diagram

Autosequencing vs. Hold

One of the more confusing aspects of GPS operation is the hold function. The hold function tells the receiver, "Wait a minute, don't start sequencing yet. We need to complete the procedure turn first." Or, "We're being vectored, don't sequence until we're on the final approach course, outside the FAF."

If being vectored to a point outside the FAF, a pilot doesn't want the receiver to begin autosequencing until established on the final approach course. The receiver must be set to "hold" mode until intercepting final, then set to autosequence when established. Similarly, to make a procedure turn, temporarily suspend autosequencing, fly to the fix upon which the turn is based, then resume autosequencing when established inbound, outside the FAF. Forgetting to re-engage autosequencing means the receiver will not transition to the approach mode.

Although GPS receiver brands work similarly in principle they vary in detail. Early Garmin and Bendix/King receivers used dedicated annunciators/switches to perform this task. Garmin calls the autosequencing mode "auto" and the hold mode "hold." One of the annunciators is thus labeled GPS SEQ: AUTO/HOLD. Bendix/King calls the autosequencing mode "LEG" and the hold mode "OBS" and has an annunciator labeled just that way. (The KLN 89B has a dedicated OBS button on the receiver itself.)

Flying the early Garmins or either of the Bendix/King receivers, the pilot selects the hold or OBS mode in situations when a procedure turn is necessary or when being vectored to a point outside the FAF. Once established on the inbound course, the pilot reverts to auto or leg mode and the receiver resumes autosequencing. Some receivers incorporate an autohold feature. Based on ground track, these receivers assume that a procedure turn is planned if the course is greater than 70 degrees from the final approach course and automatically set hold mode. Once the aircraft is established on the inbound course, the pilot manually re-engages autosequencing.

ASF recommends that pilots who are not experienced with the make and model GPS being flown avoid overlay approaches or approaches that require a course reversal. GPS receivers perform best, and there is much less chance of confusion, when the receiver can autosequence through the entire approach. On overlay approaches, use conventional navaids as primary guidance and GPS as backup.

IAFs and Fix Selection

Whether vectored for the approach or cleared for the full procedure, it's up to the pilot to set up the receiver to navigate to the correct fix. When vectored, you'd normally set the receiver to navigate to the FAF. This is done by scrolling through the list of available approaches and selecting the desired approach. Once the approach has been selected, the receiver menu will prompt you to enter the desired approach fix. If a procedure turn is planned, you'll have to select the IAF upon which the turn is based. The available IAFs will be presented in a menu list, allowing the pilot to pick the appropriate fix. Once again, autosequencing must be interrupted until the procedure turn is completed and the aircraft is established on the final approach course.

If the approach calls for a NoPT segment, select the appropriate IAF, fly to it, and set the receiver to autosequence through the entire procedure. There are no course reversals in this instance so there's no need to interrupt autosequencing. First-generation GPS approaches, which were simply overlaid on existing nonprecision approaches, required a great degree of pilot input to fly. Second-generation approaches, however, use the terminal arrival area concept, in which the initial segments are constructed in a T-shape, so the procedure can be entered without the need for a course reversal.

RAIM Warnings

All IFR-approved GPS receivers are equipped with RAIM. Three levels of RAIM are used: en route, terminal, and approach. En route and terminal-level RAIM provide integrity warnings within 30 seconds of detecting a suspected navigation error. For approach operations, the RAIM alarm will appear within 10 seconds. RAIM is a two-step process. First, the receiver has to determine whether enough satellites are above the horizon and in the proper geometry to make RAIM available. Second, it must determine if the RAIM algorithm indicates a potential navigation error, based upon the range solutions from those satellites.

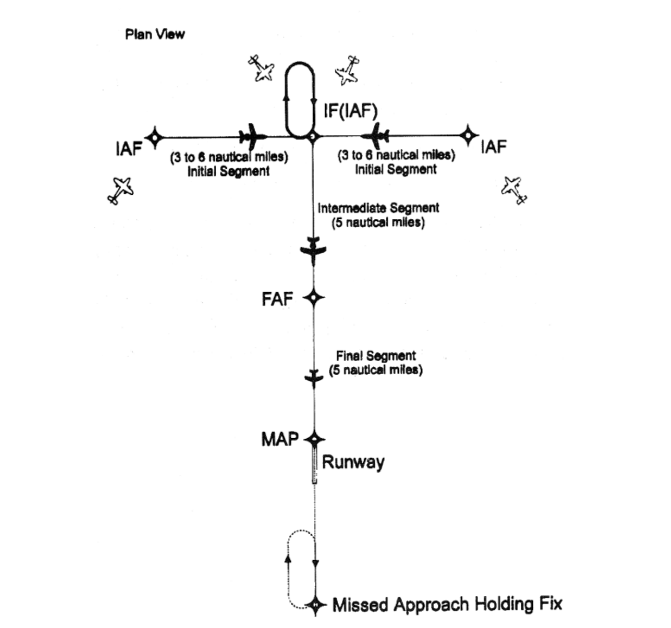
There are two kinds of RAIM warnings. (1) When the receiver produces a RAIM-not-available alarm, it's saying, "There could be something wrong with the navigation solution, but I don't have enough satellite information to know for sure." (2) If it indicates a RAIM error alarm, it's saying, "I have enough satellites available but there's something wrong with one of them or the nav solution in general."

If a RAIM warning occurs while en route, the receiver will continue to function and provide navigation information, although it may or may not have degraded accuracy. If either an "unavailable" or "accuracy" RAIM warning occurs prior to the FAF on an approach, the approach function will be disabled. However, the receiver will continue to navigate in terminal or en route mode. If the RAIM flag occurs after the FAF, the receiver will continue to operate in approach mode for five minutes, after which it will automatically revert to en route or terminal-only mode, which will affect the CDI's sensitivity.

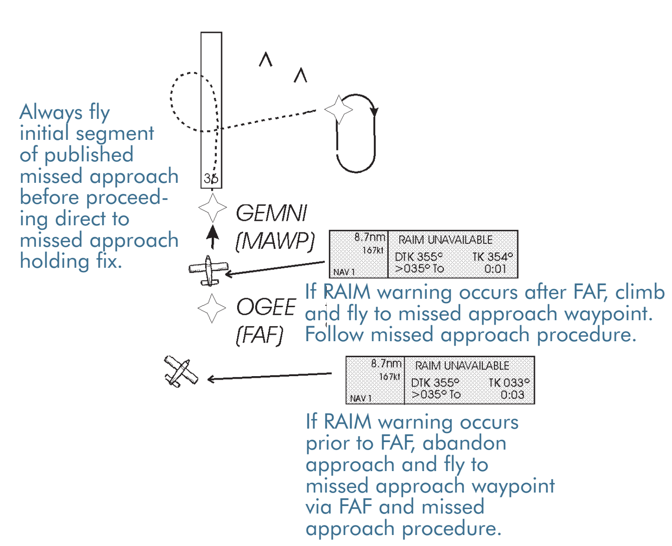
Some GPS receivers allow the user to deselect satellites. This feature can be used when satellite outages are planned. A satellite that has been deselected will not be used in RAIM calculations. NOTAMs are published for planned satellite outages. These NOTAMs can be obtained through the FSS or through DUATS by using "GPS" as the location identifier.

GPS Approaches: Current and Future

The first GPS nonprecision approaches were published in late 1993 as GPS overlays. The FAA has made steady progress and by 2006 several thousand GPS stand-alone procedures were on the books—some to airports that previously had no approaches at all.



RAIM Warnings



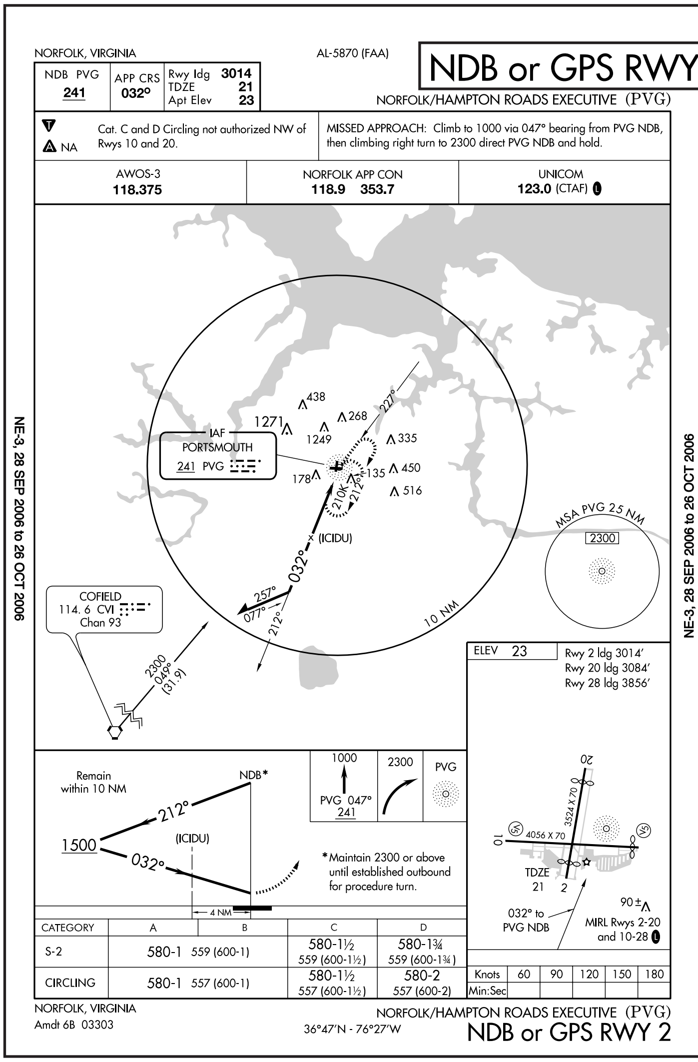
Although the initial overlay-type approaches are slowly being phased out, they will continue to exist at some airports for quite a while. Because GPS approaches are designed as a TO-TO system (requiring navigation to one fix, cross it, and proceed to the next fix), overlays are not a perfect fit with the underlying procedure. Some conventional approaches, for example, have no FAFs, so a GPS would be unable to navigate to a fix, nor would it know when to switch CDI sensitivity from the one-mile terminal value to the three-tenths mile used on the final approach segments.

This problem is solved by inserting synthetic, GPS-specific fixes on approach overlays. Jeppesen charts these "sensor final approach fixes" on both the plan and profile view of their approach plates. FAA/NACO is in the process of incorporating FAF fixes into the plan view of their GPS overlay approach plates.

Stand-Alone Approaches

Early stand-alone GPS approaches were labeled as such but newer procedures are now called RNAV approaches, recognizing the fact that some more sophisticated aircraft are equipped with flight management systems (FMS) in which GPS may be only one of several navigation sensors. As of 2006, stand-alone GPS approaches were labeled as RNAV (GPS). Moving forward, the FAA will slowly adopt a single terminology, renaming all GPS approaches as RNAV. This change of terminology is expected to take several years.

GPS-based approaches have significant advantages over conventional ground-based procedures. GPS fixes aren't subject to the same displacement errors that plague VOR and NDB.



If you see the word "or," it's an overlay approach, and can be flown using either GPS or conventional navaids.

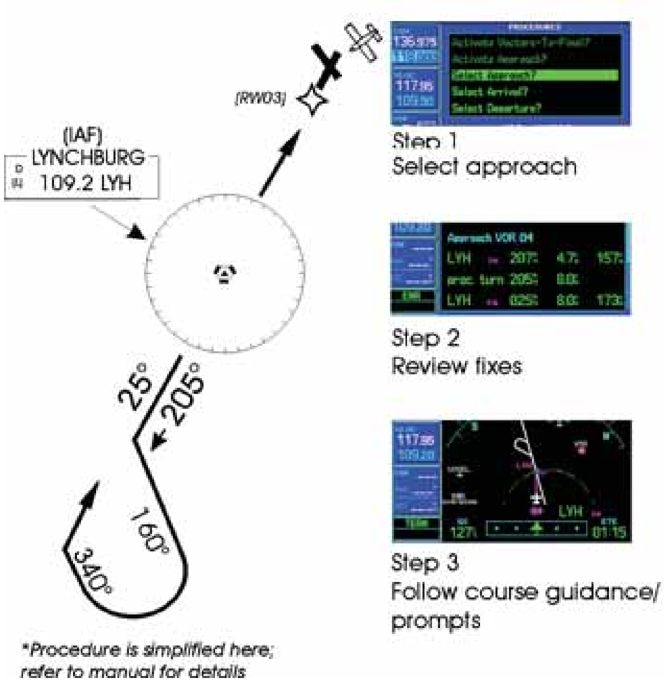
GPS fixes can be placed anywhere, so barring any major obstacles, approaches can almost always be aligned with the runway and lower minimums may be possible because the obstacle protection trapezoids narrow as they get closer to the runway. With freedom to place fixes anywhere, approach designers no longer have to rely so heavily on procedure turns to obtain alignment on the final approach course. Some stand-alone GPS approaches do have procedure turns, usually at the request of ATC. These are always holding patterns in lieu of procedure turns.

Approaches can be programmed into a receiver while flying direct to an airport, or appended to a route or even a STAR. Once set up, the receiver will automatically sequence from fix to fix until it reaches the missed approach point.

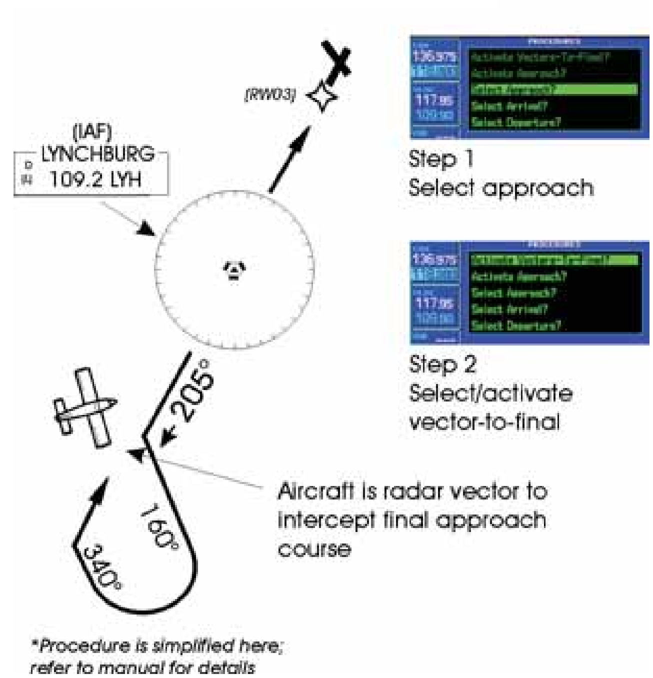
The first step is to scroll through the receiver's menu and select the approach, followed by the fix at which the approach will commence. At busy airports, you'll likely be vectored onto the approach, so autosequencing will commence at the final approach fix. In this case, you'd select the FAF as the first fix. Newer receivers with the "vector to final" (VTF) feature will automatically load the FAF as the first fix.

With an approach selected, the receiver automatically arms the approach function when within 30 miles of the airport. It may prompt you to acknowledge this and it may request the

Flying a Procedure Turn



Using Vector-to-Final



local altimeter setting, which is required in order to compute RAIM. Again, in newer receivers, this function is automatic. If you anticipate flying a full approach, either via a nonradar transition or a procedure turn, select the appropriate IAF from the menu on the receiver screen.

Tips and Tricks

- When setting up an approach, it's easy to select the wrong IAF, or select an IAF in place of a FAF. Be sure of your selections before acknowledging. Also, bear in mind that the "arm" function is not the same as the "approach active" function. Don't mistake the arm annunciator light for the approach-active light and descend before the approach is active.

- Pilots have also made the mistake of beginning a descent to the MDA when the approach active annunciator illuminates outside the FAF. Remember: Descent is predicated upon waypoint passage—not approach active status.

- Common errors when vectored include engaging autosequencing too soon, or forgetting to engage it outside the FAF. If a procedure turn is planned, you must engage the hold mode; otherwise the receiver will assume you want to turn inbound at the IAF. Avoid procedure turn situations unless you're very familiar with your GPS receiver.

- When GPS receivers transition to approach-active mode, the CDI scale will smoothly change from one mile to three-tenths of a mile. Normally, this is transparent to the pilot but, in some cases, the CDI scale will change rapidly enough to be confused as an off-course indication. Keep an eye on the approach-active annunciator light and use caution when making large course changes just outside the FAF during the approach-active transition.

- Use caution when executing missed approaches. GPS receivers must be capable of deactivating the approach mode and nominating the missed approach holding waypoint (MAHWP) as the next active waypoint. If you push the direct-to key during the approach phase, the receiver will cancel approach mode and indicate a course direct to the missed approach holding fix, automatically centering the CDI needle. That may or may not correspond with the first segment of the missed approach. It certainly won't if the direct-to key is pushed before reaching the missed approach point. Check the chart before proceeding and fly the initial segment of the missed approach procedure before engaging the GPS direct-to function. Plan to contact ATC for further clearance as soon as possible.

When using GPS for distance information, be certain you're measuring from the correct waypoint, fix, or navaid.

DME and Countup/Countdown

Since GPS can substitute for DME on approaches that require DME, use care in identifying stepdown fixes. In recent years, databases have started including localizer antennas as named waypoints; thus, on an ILS-DME, the GPS should exactly match the DME distance. However, if you haven't selected the localizer as the active waypoint, your GPS distance will be from another datum, perhaps the airport reference point.

In some cases, this will cause a "countup/countdown" indication that will be confusing for the pilot. In other words, GPS will always count down the distance to the next fix. It would be easy for an unwary pilot to confuse GPS distance to a stepdown fix, e.g., three miles, with a stepdown fix that is three DME from the airport or MAWP. To avoid this, brief the profile section of the plate carefully before flying an overlay.

IFR-Certified GPS in Lieu of...

In mid-1998, the FAA approved broad use of IFR-certified GPS as a substitute for VOR, DME, and ADF. Essentially, an IFR-certified GPS can be used in place of DME in any situation, with a few exceptions. You can use GPS in lieu of DME if the named fix appears in the GPS database or if the datum upon which the fix is based is in the GPS database. In other words, if you were flying a VOR-DME approach without DME aboard, the GPS can substitute if the required fixes are named and included in the GPS database or if the VOR upon which the approach is based can be found in the GPS database.

You can use GPS in lieu of ADF on an ILS for a stepdown fix or when ADF is required in a special equipment note. The only exception is this: If you don't have ADF aboard, you can't use GPS to fly an NDB approach that isn't overlaid. In other words, no ADF—no NDB approach, unless it's also an overlay. There are three instances in which DME or ADF are still required.

1. NDB approaches that do not have an associated GPS overlay approach must still be flown using an ADF.

2. A non-GPS approach procedure must exist at the alternate airport when one is required to be filed by regulation. If the non-GPS approaches on which the pilot must rely require

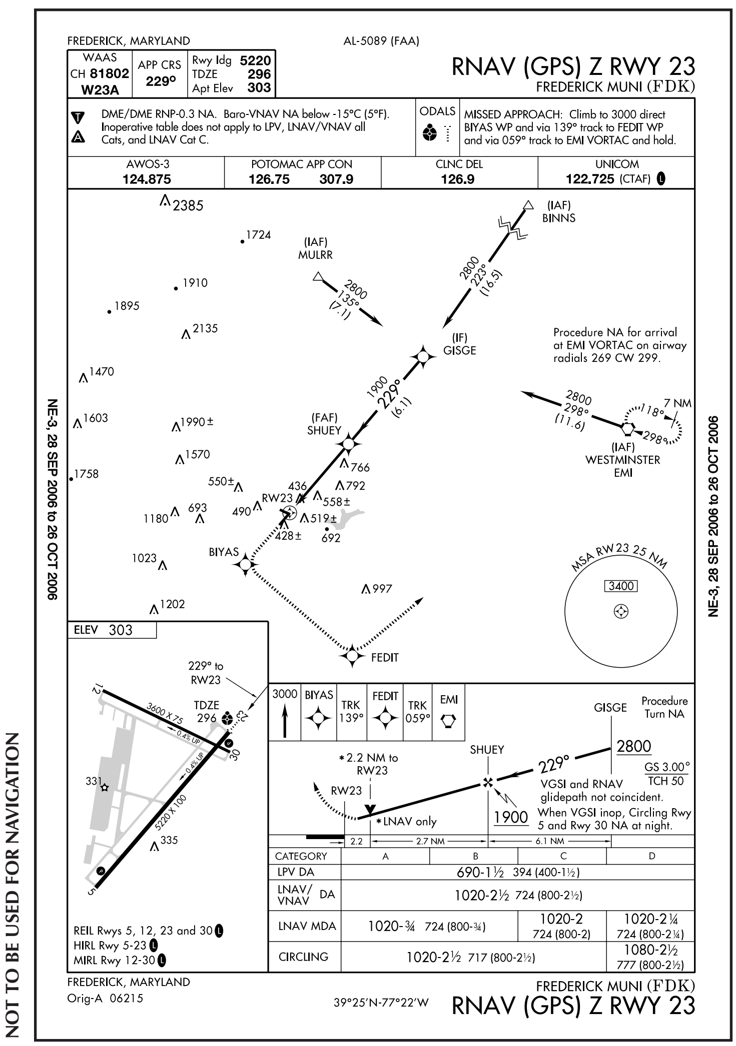
DME or ADF, the aircraft must be equipped with DME or ADF avionics as appropriate. GPS substitution for DME/ADF is not permitted in this case.

3. DME transmitters associated with a localizer may not be retrievable from your GPS until the manufacturer incorporates them in the database. Pilots are not authorized to manually enter coordinates.

As long as conventional nav equipment is aboard, pilots can use an IFR-approved GPS receiver for direct IFR routings and can substitute GPS when the ground-based part of the system is off the air.

WAAS and the Future

The Wide Area Augmentation System (WAAS) was commissioned by the FAA on July 10, 2003. WAAS is a satellite navigation system that augments the GPS Standard Positioning Service (SPS) (see RAIM – The "Off" Flag). WAAS provides better integrity and accuracy than GPS SPS. The vertical guidance



A stand-alone approach showing LPV, LNAV/VNAV, and LNAV minimums. Non-WAAS receivers can only use the LNAV or circling minimums.

provided by WAAS can be used to guide aircraft during all portions of flight, and can provide precise approach guidance. WAAS uses both satellites and ground-based stations to provide corrections to stand-alone satellite information. Signals from the GPS satellites are monitored by wide area ground reference stations to determine if corrections need to be made. Each wide-area ground reference station relays this data to another ground based station, a wide area master station, where any required corrections are computed. If corrections are required a correction message is prepared and uplinked to a geostationary satellite. The message is then broadcast to WAAS receivers within the satellite coverage area of the GEO satellite through a ground uplink station. WAAS's accuracy is required to be 7.6 meters vertical and horizontal. With the corrected satellite information, WAAS accuracy is within 2 - 3 meters horizontally, and 1 -2 meters vertically.

With the use of WAAS technology additional instrument approaches will be available at airports. These new approaches provide ILS like minimums, and include:

- LPV—(Localizer Performance with Vertical guidance) Provides lateral and vertical navigation. LPV offers decision altitudes as low as 200 feet with visibility minimums as low as one-half mile, when the terrain and airport infrastructure support the lowest minimums.

- LNAV/VNAV—(Lateral Navigation / Vertical Navigation) A vertically guided approach with a typical decision altitude (DA) of 350 feet.

- LNAV—(Lateral Navigation) Offers lateral guidance only. At many airports, LNAV approaches will have lower minimums than existing nonprecision approaches. Non-WAAS receivers can only use the LNAV or circling minimums.

While LNAV/VNAV and LPV approaches provide a glideslope, they do not meet the more stringent standards required for precision approaches. Therefore, a new class of instrument procedures has been developed to accommodate approaches that offer vertical navigation but do not meet the strict ICAO requirements for precision approaches. In addition to falling into a new category of approaches, LNAV/VNAV approaches often have a higher DA than the MDA on an LNAV approach due to the location of the missed approach point (MAP) on LNAV approaches. This often causes pilots to take a second look at their approach plates.

WAAS technology has enabled more than just additional approach procedures. Capstone, currently being used in Alaska to provide traffic, terrain, and weather information to pilots, and Automatic Dependent Surveillance-Broadcast (ADS-B) utilize WAAS technology. Satellite-based aircraft positioning and ADS-B datalink technologies work together to provide radarlike surveillance of aircraft in nonradar airspace. ADS-B determines aircraft location, altitude, and other information, which is broadcast directly to other ADS-B equipped airplanes. The FAA has installed a number of ADS-B ground stations along the East Coast and in other areas. They transmit free graphic weather and radar-derived traffic, as well as supporting ADS-B.

Common Questions About GPS

When will GPS officially become the sole navigational source?

There are no plans to mandate redundant navigation. If an aircraft is equipped with WAAS, it meets regulatory requirements. However, optional equipage with backup navigation systems will also exist. In 2001, a government study concluded there was excessive risk to expect the public to rely on sole-means GPS for safety of life operations (e.g., flying) without providing a backup option. Since that time, the FAA has been assembling a strategy that takes advantage of a minimal block of VORs to operate the National Airspace System should a GPS jamming or failure event occur. Loran is another option, and the FAA is considering this as an alternative navaid as well. The government is committed to providing a basic backup capability—not a robust backup capability.

If I equip my airplane with GPS, will I need two of them?

Not necessarily. Although it's customary to have two nav/coms in most airplanes, there's no regulatory requirement for this. Many owners are now installing a GPS nav/com but keeping one conventional nav/com in the panel. GPS receivers combine many functions, i.e., nav, com, moving map, and transponder in one unit. Without adequate redundancy, however, the loss of that unit could compromise safety.

Some approaches require ADF; can GPS substitute?

Yes. With certain exceptions, IFR-approved GPS can substitute for ADF on ADF-required approaches (provided the approach is in the GPS database). If the approach is not in the GPS database, a pilot cannot fly the approach without an ADF in the aircraft. It can also substitute for DME on DME-required approaches. As we mentioned before: Be careful about what you're counting up or down to.

Can I use IFR-approved GPS to navigate along airways?

Yes, if you can maintain the airway centerline, as described in FAR 91.181. However, you cannot legally use GPS to operate at minimum obstacle clearance altitudes (MOCA) beyond 22 miles of a VOR unless you're in radar contact. If you have WAAS, the MOCA restriction is removed.

Can I use GPS to file direct to my destination under IFR?

Yes, but as with all random routings, you must be in radar contact while operating off airways. Be careful to check special use airspace and off-route obstruction clearance altitudes, and know that in busy airspace you'll likely be cleared for something other than a direct route.

Am I required to carry the GPS Flight Manual Supplement onboard my aircraft?

An IFR-certified GPS unit must be accompanied by its Flight Manual Supplement. This is just as important as the weight and balance or any other required aircraft document.

What specific avionics have to be installed in an aircraft to file a /G flight plan?

The aircraft must have an IFR-certified GPS and the GPS Flight Manual Supplement must be on the aircraft.

What is the cost of the annual database revisions?

It depends somewhat on the manufacturer and database size, but generally about $700 per year.

Will the FAA violate me for having an out-of-date database?

According the AIM, current data is required for IFR operations and when GPS is used in lieu of ADF and/or DME. Current paper charts can be used to verify fixes when using an expired database for en route and terminal (but not approach) operations.

What's the difference between "en route" and "terminal" operations?

In terminal mode, the receiver's CDI sensitivity changes from the five miles used in en route mode to the one mile standard for terminal mode.

Is there an interactive GPS simulator that can help me understand how to use my particular GPS receiver?

For listing of manufacturer's simulators and GPS manuals please visit http://www.aopa.org/asf/gps.html

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