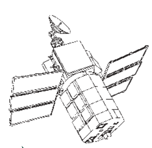
GPS Technology

The promise of access to many more airports in almost any weather was once a distant dream. But thanks to Global Positioning System (GPS) technology, the dream is getting close to reality.



Note: The information contained in this publication was accurate at printing but because GPS technology is evolving rapidly, this information must 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. Some units discussed are no longer in production and features of others may change from what is discussed here. Pilots are advised to refer to the manufacturer's operating guide for information specific to their receivers.

How Is GPS Different from VOR?

GPS is a navigational system that calculates position from 24 satellites orbiting the earth. In airplanes, GPS course indicators show position relative to a selected course in much the same way as VOR, so GPS provides the same information pilots have been using for years. But wait - there's more. 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 instrument meteorological conditions.

2. VOR uses resolver course indicators. Some GPS installations do not.
   - Pilots navigating with VOR know they can rotate

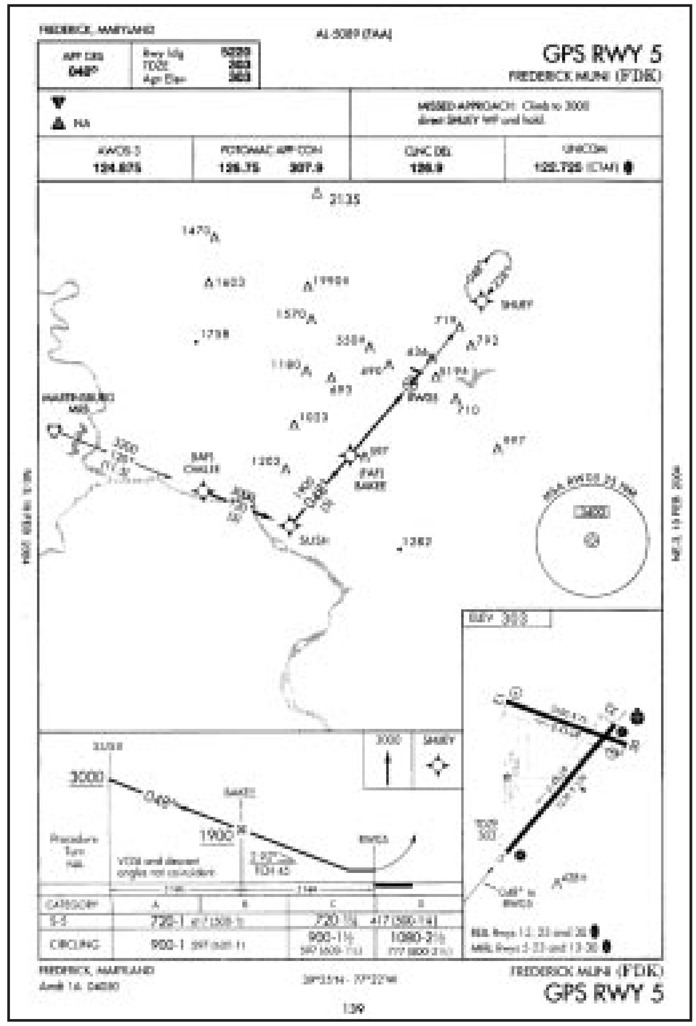
the omni bearing selector (OBS) on their course indicators to "resolve" their relationship to a particular course. Resolverless GPS indicators act like an ILS localizer. They indicate relationship to a course regardless of the position of the OBS. Pilots of resolverless GPS installations must select the desired course on the GPS receiver itself.

3. 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 way point in a sequence, i.e., hold at one of the way points along the way, he will have to manually suspend the automatic sequencing function.

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 might include missing an approach early, or bypassing one or more waypoints by receiving radar vectors to final approach.
   - Pilots should be thoroughly familiar with their GPS receiver 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, although 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 will be 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 references course deviation to 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 ± three-tenths 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.



NOT TO BE USED FOR NAVIGATION

GPS is now found in most light aircraft cockpits, and many GPS installations are certified for en route IFR and for nonprecision approaches. As GPS evolves, avionics manufacturers are improving and integrating this remarkable navigation system into equipment that's more versatile, easier to operate, and capable of giving pilots unprecedented confidence in situational awareness.

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. However, VOR/DME/ILS will 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 equiped with a WAAS receiver may use WAAS as a primary means of navigation.

The pilot of a Cessna 172 experienced icing in Instrument Meteorological Conditions. Unable to maintain altitude, he descended below radar coverage in mountainous terrain. Using a handheld GPS receiver 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 a better assessment of weather had been made before flight. Happily, GPS contributed to a way out of what could have been a fatal situation.

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.

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 more GPS accuracy for civil applications. Consequently, SA was turned off in 1999.

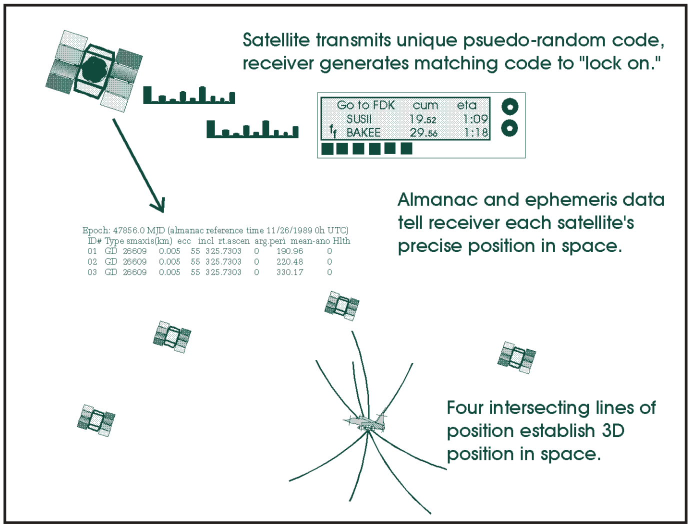
How GPS Works

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 about 12 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.

GPS in a Nutshell



So How Accurate Is GPS?

GPS Standard Positioning Service (SPS) provides, to all users, horizontal positioning accuracy of 100 meters or less, with a probability of 95 percent and 300 meters with a probability of 99.99 percent. A second level of

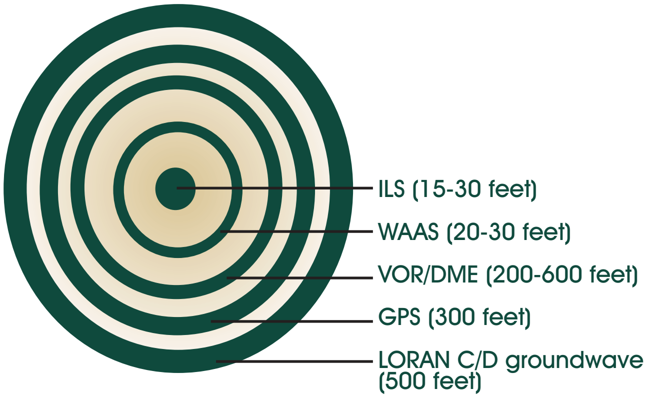
GPS service, Precise Positioning Service (PPS), is more accurate than SPS but is only available to specially authorized military, government, and civilian users.

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

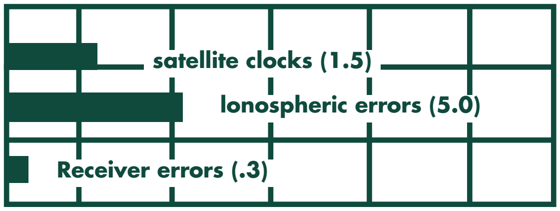
Because the GPS constellation provides good coverage, panel mount receivers with unrestricted antennas nearly always navigate in three dimensions. Handheld GPS receivers, while popular and used by many pilots as a navigation back up, don't always do as well. With their windshield or glareshield antennas shadowed by wings or other aircraft structures, they occasionally revert to two dimensions or lose coverage entirely. Currently, there are no handheld GPS receivers that meet the Technical Standards Order (TSO) requirements of the FAA for IFR certification.

GPS Accuracy Compared



At the runway threshold, an ILS is capable of 15- to 30-foot accuracy, so GPS is not accurate enough for precision approaches, especially in the vertical dimension, where GPS is far less accurate than it is in the lateral dimension. 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.

GPS Error Budget (Meters)



RAIM - The "Off" Flag

Receiver autonomous integrity monitoring or RAIM addresses the shortcomings in GPS technology. All IFR-approved GPS receivers are required to have RAIM. A RAIM algorithm works by over-determining 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 approach operations 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; thus some other means is necessary for precision approaches. One method for ensuring precision approach capability is the Wide-Area Augmentation System (WAAS) which uses the GPS satellite network. More about WAAS later.

Another concern is accidental and intentional GPS interference. 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 nearly a decade, 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.

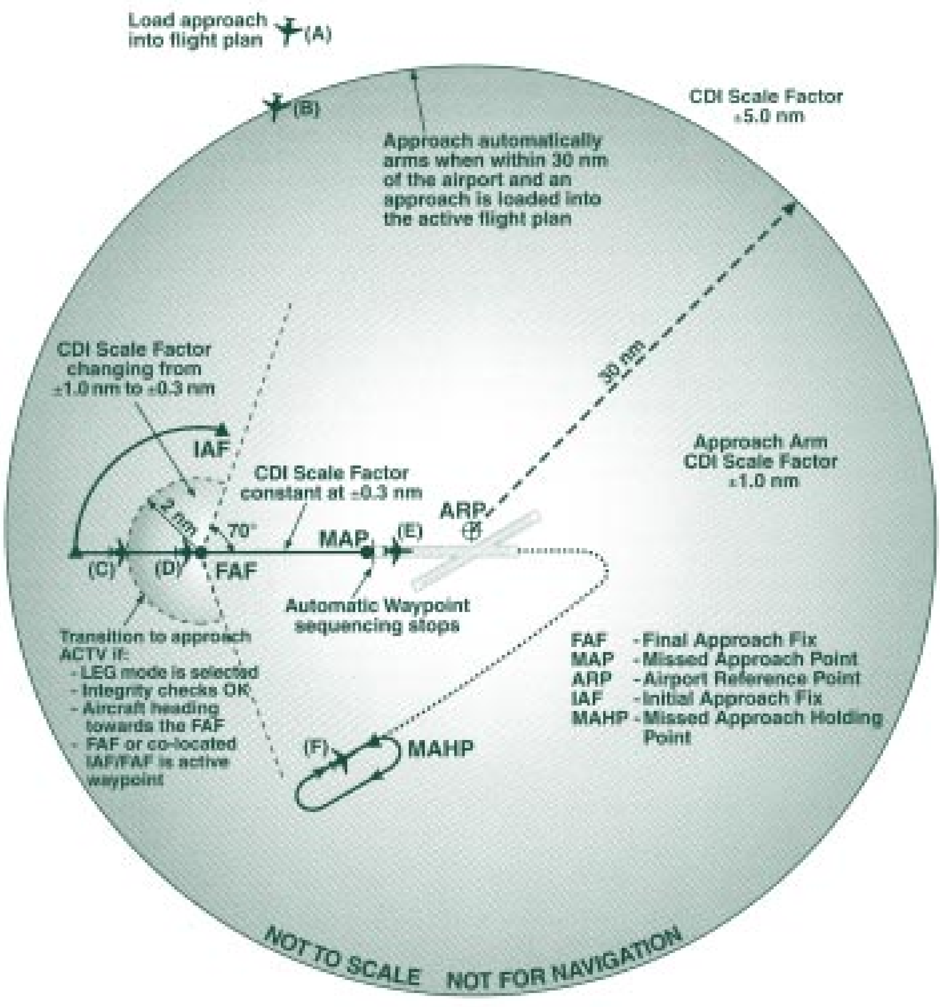


Figure 6-1 KLN 90B Approach Diagram

Both forms of differential also include an 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 upgrade, but this is not true in all cases.

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

About GPS Receivers

Since their introduction nearly a decade ago, IFR-approved GPS receivers have evolved considerably, from rudimentary numerical-only displays to full-color devices with moving maps and multifunction display (MFD) technology. Many of these GPS receivers also contain "smart" VHF radios that automatically access the GPS database for appropriate frequencies.

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

* Initial minima will likely be 300-foot DA and 3/4 mile visibility.

Although GPS receiver certification requirements are considered inviolate, each manufacturer satisfies them in a different way, especially 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 time becoming familiar with each GPS unit they use.

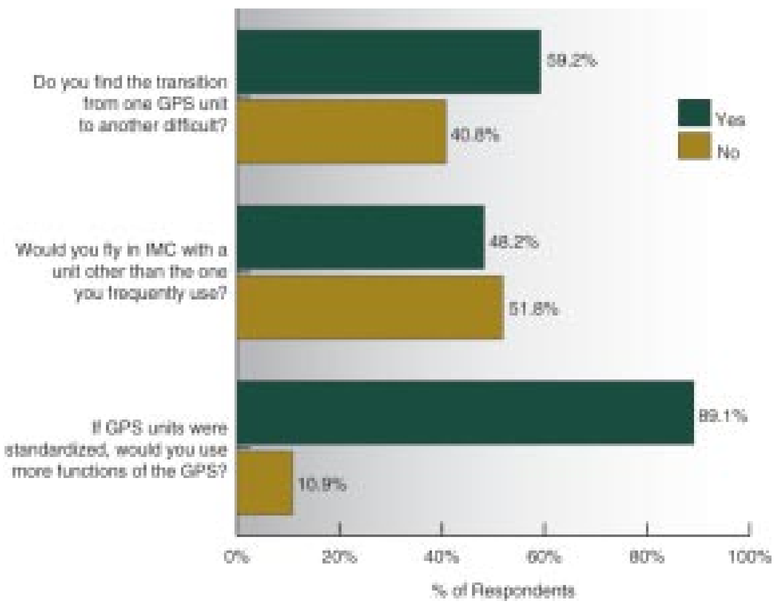
Currently, IFR certified GPS receivers cost between $4,500 and $15,000 to buy and install, plus an estimated $700 or more a year for required database revisions.

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 data link for weather and collision avoidance information. They also tend to be more user-friendly.

Newer receivers incorporate color displays-as in the Garmin 400/500 series and the CNX80 series, as well as the Bendix/King KLN94-and larger color multifunction displays such as Avidyne's FlightMax series and the Garmin MX20.

Caution: Pilots shouldn't underestimate the need for training. Know how the receiver works before using it for IFR. ASF recommends using 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.

AOPA Member Opinions on GPS Standardization



(Taken from a 2003 survey of callers to AOPA's technical help line. This is not a statistically random sample.)

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. En route approved receivers provide essentially the same navigation information as a VFR-only loran or GPS, although the features vary from brand to brand. The principal addition an IFR-approved en route receiver has is the integrity provided by RAIM.

En route and approach receivers must be IFR certified for the aircraft in which they are installed. Aircraft flight manuals should have a brief supplemental section describing the GPS system, and the logbooks should have the appropriate endorsements. It's quite possible that a receiver that's 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 – but 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 differences relate to the autosequencing, annunciation and RAIM flagging requirements for approach-capable receivers. For en route operations, 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 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.

Note: 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 indicate 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 means of keeping the 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 know the database is current. Database media vary with receivers. Some have a front-loading card similar to a computer PCMCIA flash memory device 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 burn this into the receiver's data card.

Database revision services vary widely in cost and format, with the average yearly subscription for 28-day service costing about $700. Having a current receiver database, however, still doesn't alleviate the recommendation that current charts also be aboard the aircraft. Although there's no legal requirement for general aviation light aircraft to carry current charts and approach plates on board the aircraft, 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, per FAR 91.103.

Flying Instrument 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 re-engage it once established on the final approach course. Some GPS receivers offer a Vectors to Final (VTF) feature that sets a path direct to the final approach course. **Note:** 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.

A Cessna 310 was involved in a gear-up landing incident. The pilot indicated that he was busy working his new GPS and inadvertently forgot to lower the landing 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 a costly and embarrassing incident.

Early GPS receivers-many of which are still in service-required the pilot to select autosequencing or to suspend autosequencing via a manual switch. Newer models-like the Garmin AT GX series and the Garmin 400/500 series- have largely automatic sequencing control. Further, newer units also have a "vector-to-final" option, which allows the pilot to set the navigator to automatically begin sequencing upon joining a final approach course via vector. 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).

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.

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 in "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. It's up to pilots to understand when autosequencing must be engaged. Forgetting to engage it 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 annunciator/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. The TNL 2000 Approach, Northstar M3, and Garmin AT approach-capable GPS 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 autoseqencing.

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.

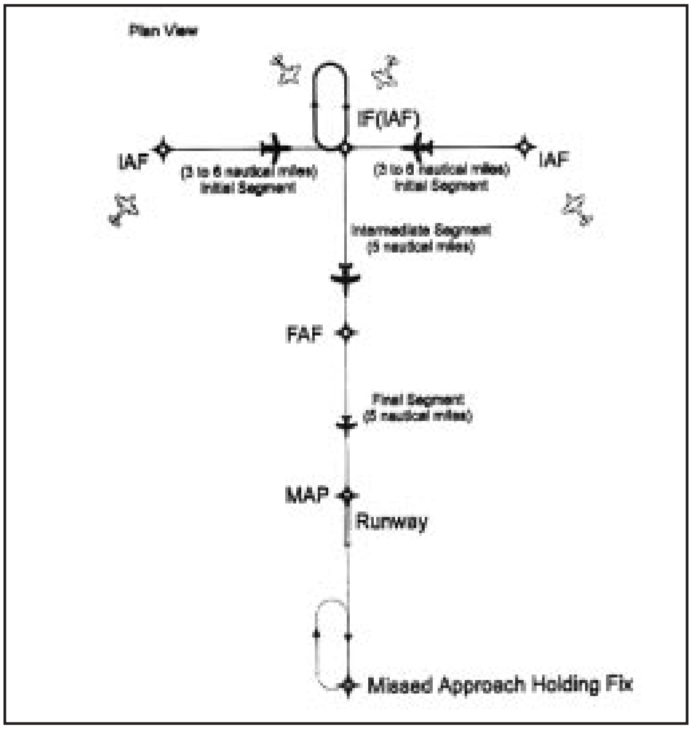
IAFs and Fix Selection

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.

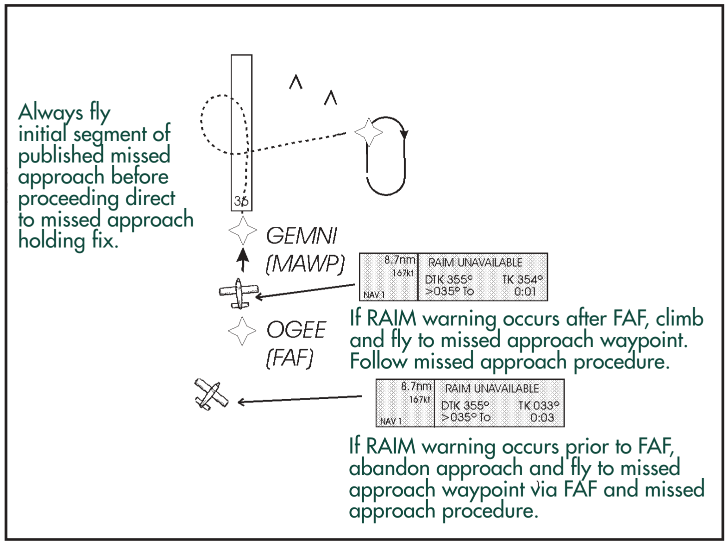


RAIM Warnings

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 if 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."

RAIM Warnings



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 (see Tips and Tricks section).

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 2004 some 4,348 GPS standalone procedures were on the books-some to airports that previously had no approaches at all.

Helicopter-only GPS approaches have also been developed. These are annotated "special crew qualification required." Both the missed approach and departure segments - if approved - use a 20 to 1 obstacle clearance plane rather than the standard 40 to 1 plane. For this reason, it's critical that helicopters not exceed 70 knots during the missed approach and instrument departure phases. Before flying a helicopter-only GPS procedure, a pilot should obtain instruction from a CFII familiar with the requirements for these procedures.

GPS Overlay Fix Examples	
D006J	A DME arc fix, with "D" meaning DME, 006 the radial and "J" the distance, 10 miles (J is 10th letter of alphabet)
ORW19	Alongtrack fix at DME 19
FF142	Final approach fix on 142° course
MA142	Missed approach fix on 142° course
RW14	Missed approach point, runway 14
CF151	Capture or course fix on 151° radial

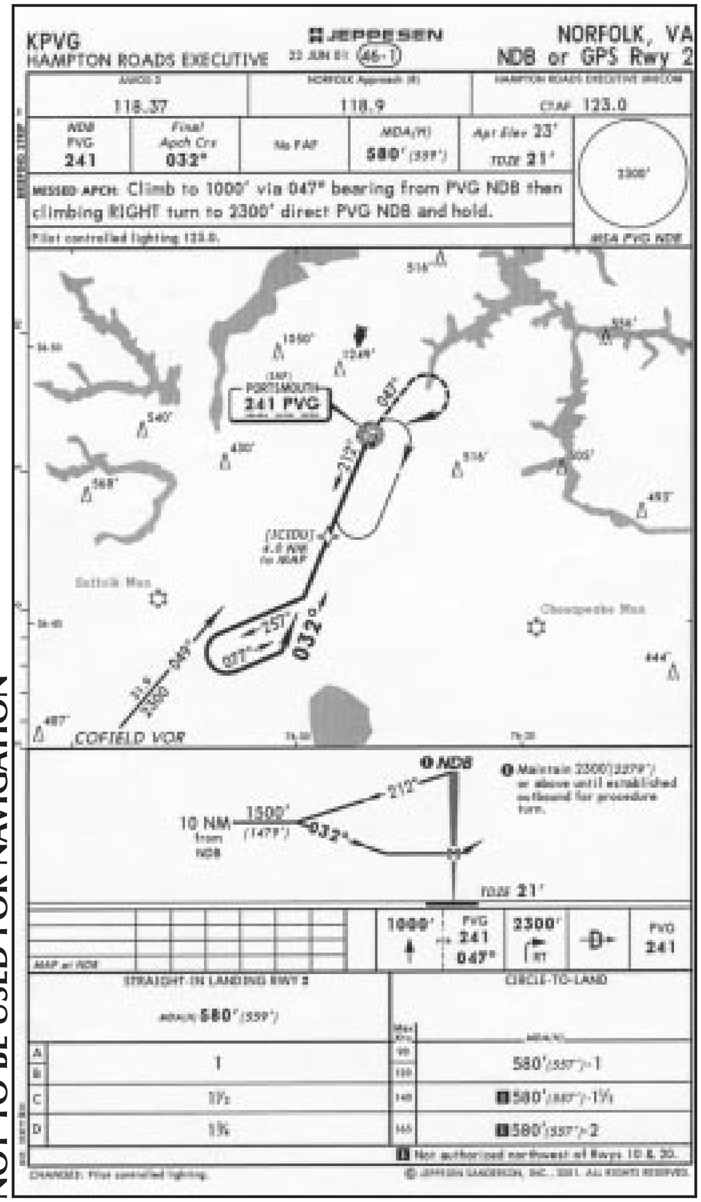
Although the initial overlay-type approaches are slowly being phased out, they will continue to exist at some airports for quite a while. Because GPS approaches are designed as a TO-TO system (requiring navigation to one fix, cross it, and proceed to the next fix), overlays are not a perfect fit with 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" (FAFs) 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

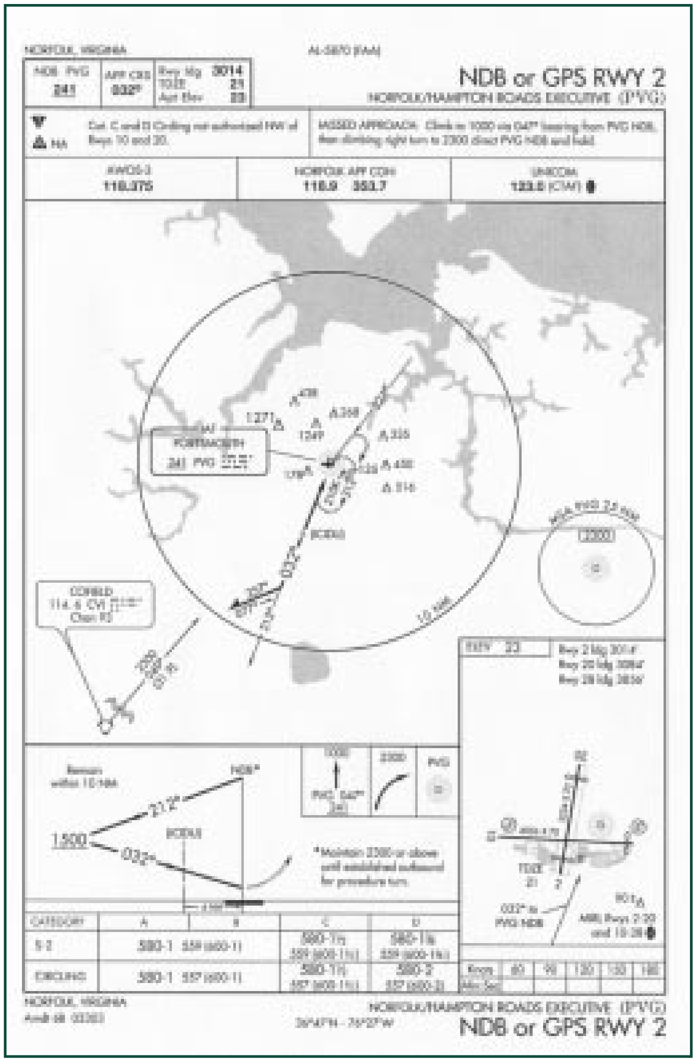
Early stand-alone GPS approaches were labeled as such but newer procedures are now called RNAV approaches, recognizing the fact that some more sophisticated aircraft are equipped with flight management systems (FMS) in which GPS may be only one of several navigation sensors. As of 2002, stand-alone GPS approaches were labeled as both GPS and as RNAV. 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.

NOT TO BE USED FOR NAVIGATION



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. 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 they can be appended to a route or even a STAR. Once set up, the receiver will automatically sequence from fix to fix until reaching the missed approach point.

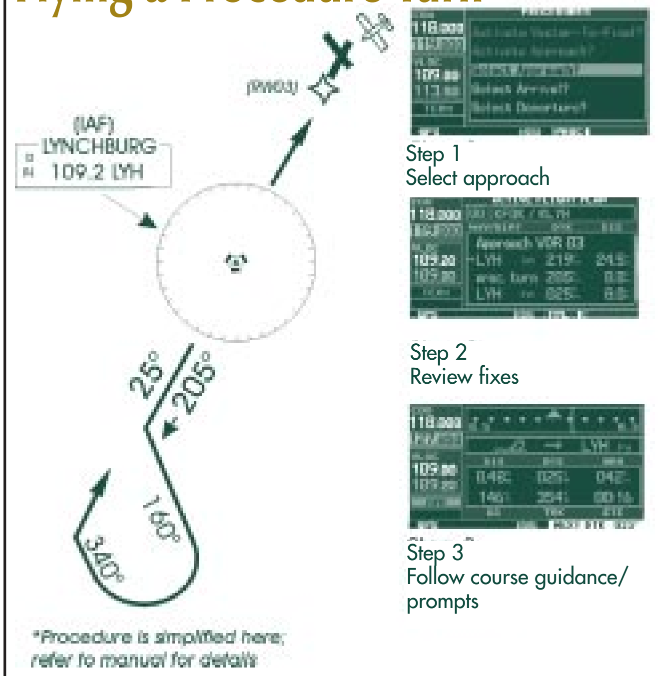


NOT TO BE USED FOR NAVIGATION

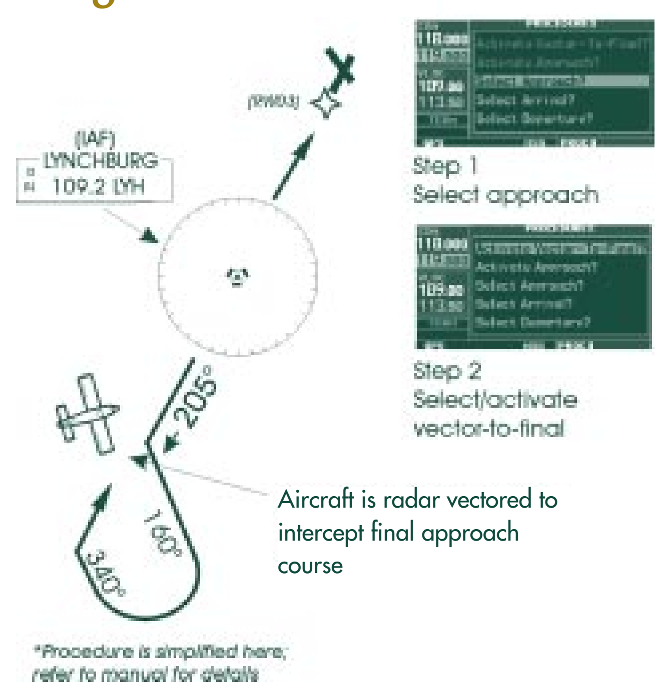
The first step is to scroll through the receiver's menu and select the approach, followed by the fix at which the approach will commence. At busy airports, you'll likely be vectored into the approach, so autosequencing will commence at the final approach fix. In this case, you'd select the FAF as the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

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

Flying a Procedure Turn



Using Vector-to-Final



Tips and Tricks

- When setting up an approach, it's easy to select the wrong IAF or to 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 begun descent to the MDA when the approach active annunciator illuminates outside the FAF. Descent is predicated on 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 flying with receivers that require manual sequence setting - early Garmin and Bendix/King, for example - be careful about engaging the autosequencing mode too close to the FAF. Doing so will occasionally cause the receiver to mis-sequence and show a position inside the FAF. To avoid this, make sure to engage autosequencing at least three miles outside the FAF.

- 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 the missed approach. 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 will not 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.

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-Approved 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 just 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 provided by WAAS can be used to guide aircraft during all portions of flight including providing precision approach guidance.

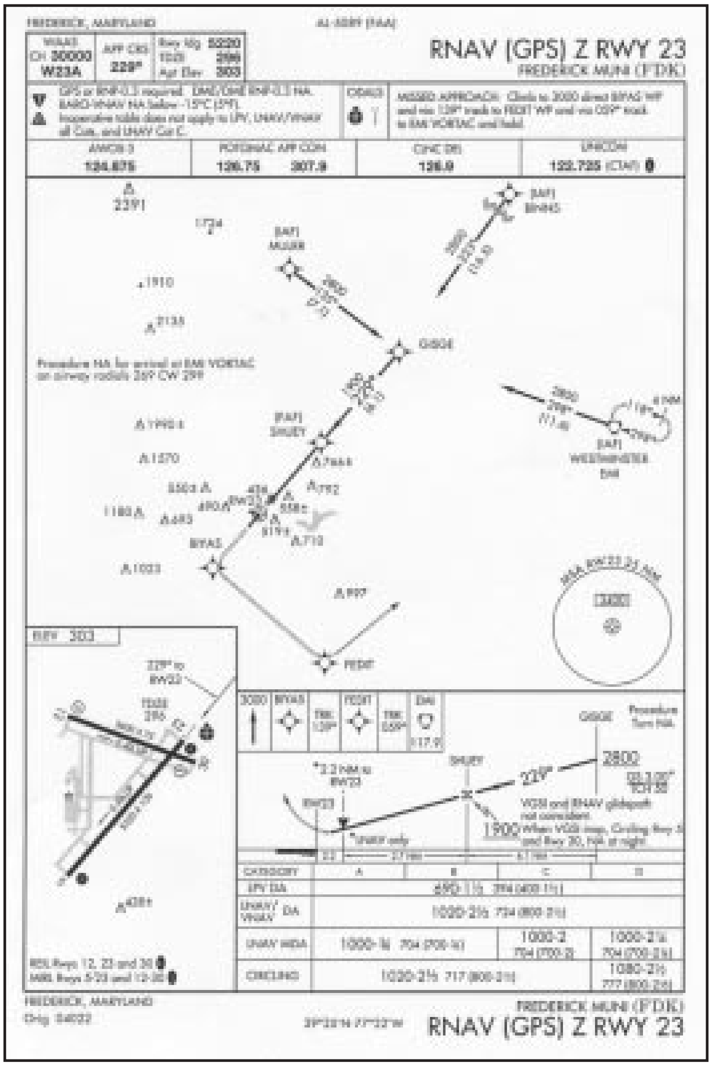
WAAS uses both satellites and ground-based stations to provide corrections to stand alone satellite information. Signals from the GPS satellites are monitored by wide-area ground reference stations to determine if corrections to the satellite information need to be made. Each wide-area ground reference 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. Labeled "RNAV RWY XX" these approaches include:

- o **LNAV-** (Lateral navigation) Offers lateral guidance only. These approaches have a minimum descent altitude (MDA) of 250 feet. At many airports, LNAV approaches will have lower minimums than existing non-precision approaches.
- o **LNAV/VNAV-** (Lateral navigation / vertical navigation) A vertically guided approach with a decision altitude (DA) of 350 feet.
- o **LPV –** (Localizer Performance with Vertical guidance) Provides lateral and vertical navigation. LPV offers decision altitudes as low as 250 feet with visibility minimums as low as one-half mile, when the terrain and airport infrastructure support the lowest minima.

While LNAV/VNAV and LPV approaches provide a glide slope, these approaches 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 classification of approaches, an LNAV/VNAV approach has 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 data link technologies work together to provide radar-like surveillance of aircraft in non-radar airspace. ADS-B determines aircraft location, altitude, and other information, which is broadcast automatically, once-per-second, directly to other ADS-B equipped airplanes. The FAA is now planning to install a handful of ADS-B ground stations along the east coast, transmitting 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 back-up 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 back-up 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 too. 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. 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 can not 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 clearnace altitudes.

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 in the aircraft. 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

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. Currently a handheld GPS is not certified for any IFR operations.

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

In terminal mode, the receiver's CDI sensitivity scales 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 unit?

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

What GPS boxes offer weather uplink?

At this time the only GPS navigation system that is capable of displaying weather is the GARMIN 430/530. Other units, such as Apollo CNX80, will soon have this ability as well. The only other way to get weather in the cockpit is through a separate multi-function display that uses the weather data link receiver and panel-mount GPS.

Does WAAS really allow sole means navigation with GPS?

Yes. The FAA has published a NOTAM authorizing the use of WAAS for IFR in the United States. As part of that NOTAM, the FAA says, ". . . WAAS avionics are evaluated without reliance on other navigation systems. As such, installation of WAAS avionics does not require the aircraft to have other equipment appropriate to the route to be flown".

WAAS is active, WAAS receivers work, and there are WAAS approaches, why can't we use them yet?

At the time of publication there was one WAAS receiver certified for VNAV approaches. However, be patient more certified receivers are on the way.

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SA01-05/04