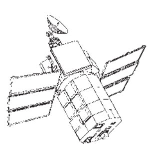
GPS Technology

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 to particular GPS receivers. Some 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. The Air Safety Foundation will update this Safety Advisor on a regular basis.

The promise of access to every airport in the land in almost any weather was once a distant dream. But thanks to Global Positioning System (GPS) technology, the dream has become reality.



How Is GPS Different from VOR?

GPS is a navigational system that calculates your position from 24 satellites orbiting the earth. In airplanes, GPS course indicators show your 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 your position on an electronic chart and, with additional software and/or equipment, it can show your 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 computer-based navigation system that offers many features unavailable in VOR navigation. How these additional features are accessed and controlled by pilots depends on which make and model of GPS receiver you're using.
   - 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.

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 indictors to "resolve" their relationship to a particular course. Resolverless GPS indicators act like an

ILS localizer. They indicate your 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. A GPS 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.

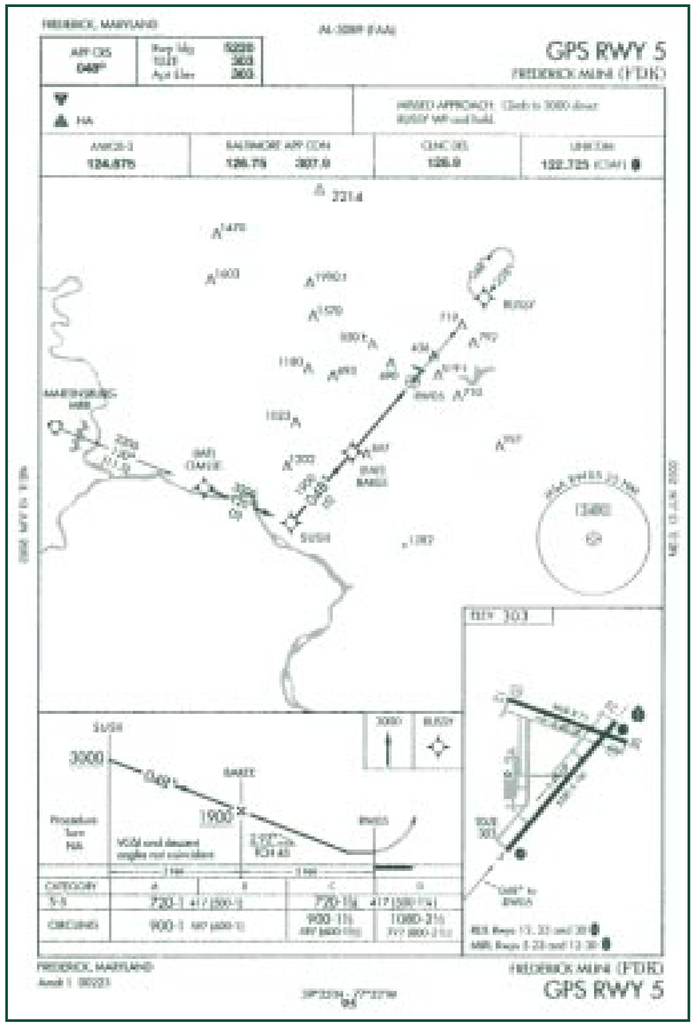
- If you don't want to proceed to the next waypoint in a sequence, i.e., if you want to hold referencing a waypoint, you may or may not have to manually suspend the automatic sequencing function depending on which GPS receiver you're using.

4. Instrument approaches designed for GPS are easy to fly but interrupting an approach, e.g., abandoning the approach and receiving vectors to final, can result in a high pilot work load close to the ground. GPS approaches that overlay traditional approach procedures can have a very high work load.

- Pilots must 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 you are 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 0.3 nm either side of course.



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 promised, the FAA is rapidly developing GPS capability that will provide approaches with vertical guidance to thousands of airports. Moreover, 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.

But even in this GPS age, VOR/DME/ILS are still major players in the National Airspace System and will remain so for years to come. Because of persistent technical problems and concerns about reliability, GPS may never be the sole means navigation system once promised. Instead, some form of backup may be necessary–probably a skeletal VOR system or even loran. Nonetheless, the FAA is proceeding with its ambitious Wide Area Augmentation System (WAAS) — technology that provides a correction factor to GPS receivers that makes them more accurate and more reliable. WAAS, expected before the end of 2003, will also make vertical guidance possible on most GPS approaches and initial WAAS precision approach minima will be slightly higher than CAT I ILS minima. The FAA is also investing significant resources in Local Area Augmentation Systems (LAAS) that will eventually replace ground-based Cat II/III instrument landing systems. For the short term, these developments mean that aircraft owners should expect to retain VOR and ILS equipment in some form, but GPS will increasingly shoulder the burden for en route navigation and for approaches into outlying airports.

The pilot of a Cessna 172 experienced icing in IMC. 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 GPS has been in use since the beginning. Civil users were at first unable to receive as precise a signal as the armed forces. They were provided a somewhat degraded signal referred to as selective availability (SA). As civil use of GPS increased, Congress exerted pressure on the Department of Defense to provide more GPS accuracy for civil applications. Consequently, SA was turned off in 1999.

The Road to IFR

GPS didn't spring fully formed into the world of navigation. In its early years, it was only sporadically available, due to a limited number of satellites. By the mid-1990s, the system had its full 24-satellite constellation in orbit. As satellites age they are replaced with new models.

Tentatively beginning in 2003, at least one and probably two new GPS frequencies will be made available. Dual frequency navigation will improve the accuracy and reliability of the basic GPS signal and significantly decrease errors due to atmospheric effects. However, basic GPS is still not accurate enough for precision approaches, even with SA off. Precision approaches will require wide area or local area augmentation.

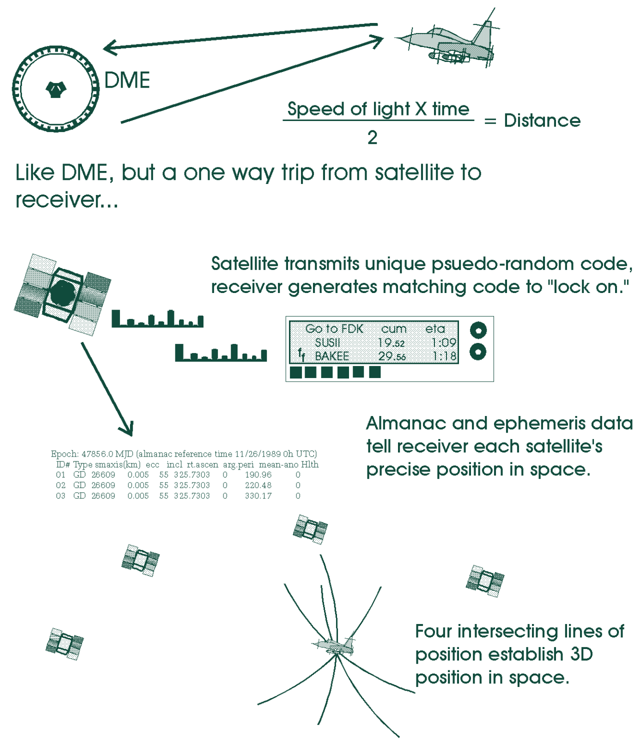
A commercial pilot in a Cessna 182 experienced an alternator failure in night IMC. Using a handheld GPS receiver he navigated to a nontowered airport but was unable to activate the pilot controlled lighting system. He landed next to the runway with minor damage to the airplane and no injuries to the crew and passengers. *Although regulations prohibit use of handheld GPS receivers for instrument operations, this pilot exercised his PIC authority and successfully coped with the emergency.*

How GPS Works

To grasp how GPS works, think of DME. An airborne DME is actually a transceiver. It sends a pulse to the ground station and times how long the station takes to send a reply. By multiplying that time by the speed of light and dividing by two — remember, it's a two-way trip — the DME converts time to distance. Subsequent calculations provide speed and time to station. If you could tune several DME stations and draw lines of position, you'd be located at the point where the lines intersect.

This is exactly how the DME-DME systems used in some airliners and high-end general aviation aircraft work. GPS operates similarly, except that the ranging process is a one-way trip from the satellite to the receiver. Satellites broadcast a navigation/time reference that GPS receivers use to calculate range.

GPS in a Nutshell



Satellites Talk, Receivers Listen

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 pin-points 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.

So How Accurate Is GPS?

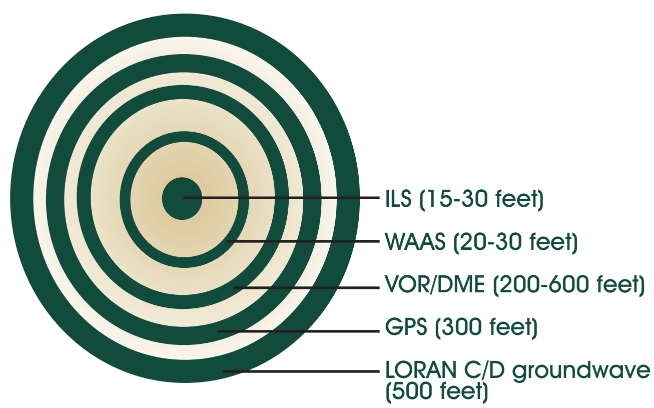
GPS accuracy is dependent on a number of factors resulting in varied accuracy claims. Perhaps the best way to look at accuracy is a worst-case scenario, i.e., with selective availability on, unaugmented GPS will be accurate to within 300 meters (993 feet) 99.99 percent of the time. Under the same conditions, GPS will be accurate to within 100 meters (331 feet) 95 percent of the time. Since these figures consider a combination of accuracy degrading circumstances and conditions, pilots can expect to see significantly greater accuracy in everyday navigation. With selective availability off and/or with differential correction GPS accuracy increases.

Condition	SA On	SA Off	WAAS	LAAS
Accuracy	330 – 990 feet	100 - 330 feet	Better than 23 feet	Under develop-ment but better than WAAS
	100–300 meters	30 – 100 meters	7 meters	

Why Handhelds Won't Do the Job for IFR

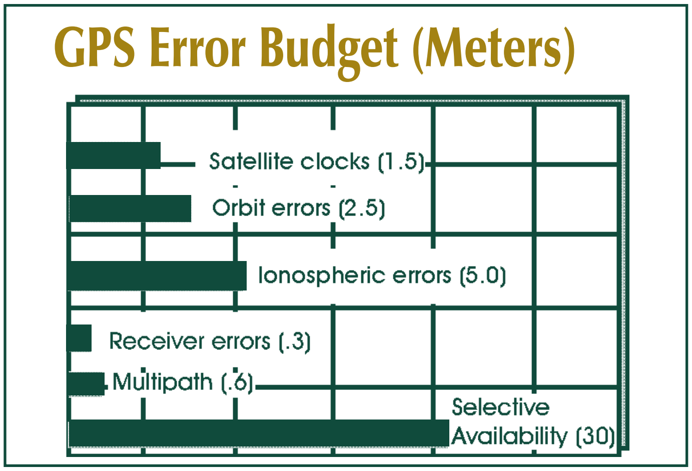
Because the GPS constellation provides good coverage, panel mount receivers with unrestricted antennas nearly always navigate in three dimensions. Handheld receivers don't always do as well. With their antennas shadowed by wings or other aircraft structures, they occasionally revert to two dimensions or lose coverage entirely. Because their antennas cannot be optimally located and because their power supplies cannot be guaranteed, handheld GPS units are not likely to be certified for IFR navigation.

GPS Accuracy Compared



GPS: Still Not Perfect

At the runway threshold, an ILS is capable of 15- to 30-foot accuracy so unaugmented GPS — even with SA off — 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.



RAIM – The “Off” Flag – Sort Of

For the short term, the method of addressing this shortcoming in GPS is called receiver autonomous integrity monitoring (RAIM). TSO C129 — the GPS technical standard order for first generation IFR-approved GPS — requires all IFR-approved receivers 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 limit for en route operations, the alarm must be issued within 10 seconds.

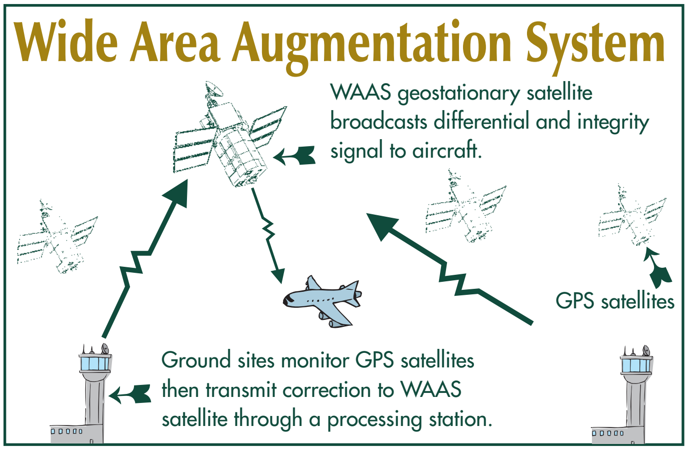
If a RAIM alarm is active, the receiver will continue to navigate in en route mode, but it will not operate in approach mode until the RAIM limitation is resolved. RAIM will be the primary means of assuring integrity until WAAS is fully operational. But RAIM is limited in its ability to quickly detect navigation faults; thus some other means is necessary for precision approaches.

Another concern is jamming. 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 and LAAS, can meet the requirements for navigation in the National Airspace System, but that jamming continues to be a risk.

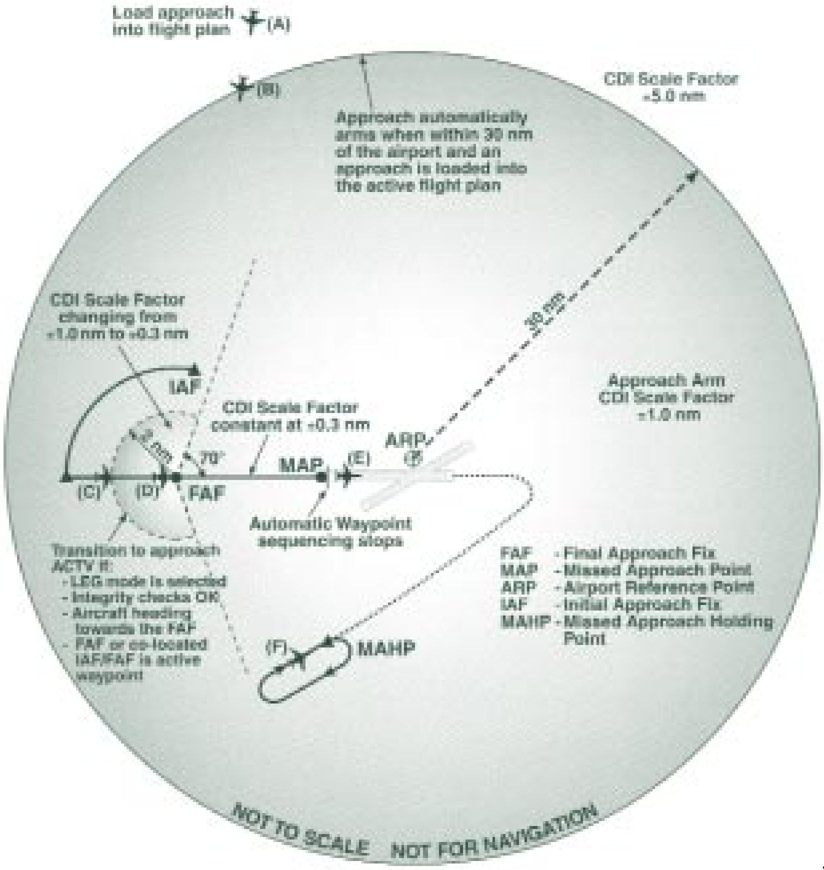
Another review was conducted in 2001 by the WAAS Independent Review Board. The IRB affirmed the FAA's direction for WAAS-GPS and recommended that a third WAAS satellite be added to the constellation. The third satellite was funded in late 2001.

Differential to the Rescue

As shown in the graphic at left, GPS errors are clearly understood and can be compensated for, primarily by what's called differential navigation. This is accomplished through a monitoring station that samples GPS data from passing satellites, detects inconsistencies, and broadcasts a differential 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 can be broadcast over a wide area—thus WAAS—or a local area, as with LAAS.



Both forms of differential can also include an integrity message, thus flagging a potentially ambiguous or erroneous navigation signal. However, local area differential 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.

Wide area differential, on the other hand, can be broadcast over large areas and, in September 2001, the FAA made a test WAAS signal available. The first aviation WAAS receiver to market was the Garmin 295 handheld. IFR-approved panel-mount receivers should be available sometime in 2003, when the FAA says WAAS initial operational capability will be announced.

Although a date has not been established, WAAS will eventually solve both the accuracy and integrity problems of GPS and will make Cat I ILSs possible almost everywhere. Twenty-four WAAS ground monitoring stations now sample signals from GPS satellites passing overhead. They uplink corrective signals to two geostationary satellites covering the U.S. In spring 2002, the FAA received funding for a third WAAS satellite, which will address minor short-comings in signal coverage.

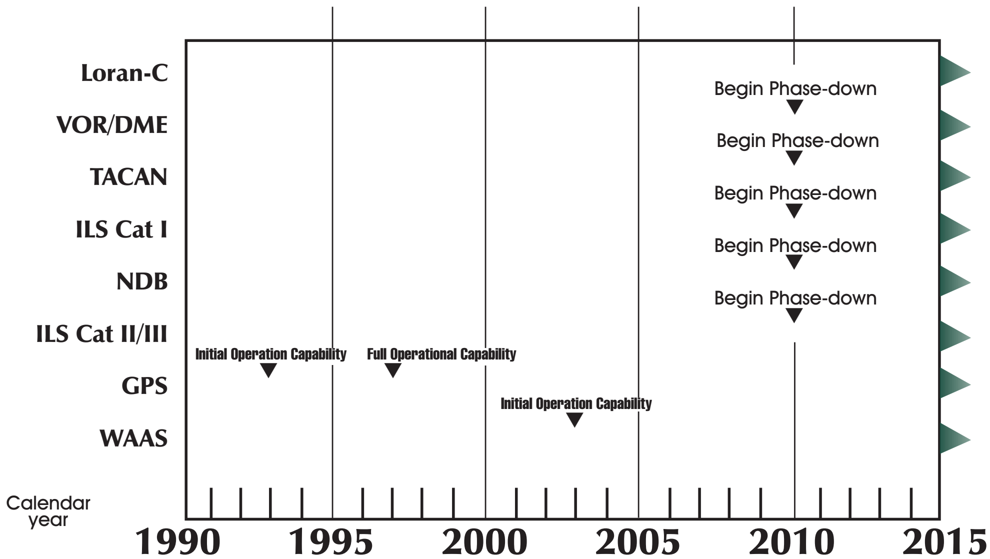
WAAS satellites broadcast corrected GPS signal data to airborne WAAS-capable receivers. WAAS signals carry a ground-based integrity broadcast capable of a six-second alarm limit. The WAAS signal also contains an embedded navigation message, allowing receivers to use it as part of the navigation solution, just as though it were another GPS satellite.

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 cetified 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 ceiling and 3/4 mile visibility.

For Cat II and Cat III ILSs, the FAA has decisively shifted to local area differential systems and has spon-sored contract work to develop LAAS Cat II and Cat III ILSs. How-ever, for the foreseeable future, con-ventional ground systems will remain in place for Cat II and Cat III ILS systems and pilots shouldn't expect to see many — if any — Cat I systems decommissioned.

It now appears that LAAS-based ILS will apply mostly to airline opera-tions needing Cat II/III capability and that it will require dedicated cockpit hardware currently not available. For light general aviation aircraft, WAAS-based precision approaches of some kind will be the major player for at least the next decade. As for future equipment, WAAS navigators will be built to the specifications of TSO C146, the details of which were being finalized in the spring of 2002. Most manufacturers expect to have some WAAS-capable equipment available when, or shortly after, the FAA announces WAAS initial capability in 2003.



Note: This information is subject to change.
Source: 2001 Federal Radionavigation Plan

First-generation IFR navigators built under TSO C129 are not expected to be WAAS upgradeable. Some second-generation C129 units are expected to be upgradeable in some fashion, either through a hardware or software upgrade.

For those pilots who wish to retain first-generation 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 much in the near term.

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.

Currently, IFR-certified GPS receivers cost between $4,500 and $15,000 to buy and install, plus an additional $300 to $700 a year for required database revisions.

First-generation GPS receivers are no longer widely marketed although many are available on the used market. Although neither as automated nor as simple to operate as state-of-the-art navigators, first-generation TSO C129 receivers still perform well and may represent a good buy for some owners. New receivers, however, have features and the "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 Bendix/King KLN94—and larger color multifunction displays such as Avidyne's FlightMax series and the UPS Aviation Technologies MX20. As of spring 2002, IFR-approved receivers are still governed by TSO C129 while the follow-on TSO for WAAS-capable receivers will be TSO C146. These are complex documents that have yielded complex avionics.

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

Although receivers vary from manufacturer to manufacturer, they share some common attributes. Receivers approved for en route and terminal operations only are called "A2" receivers while those approved for nonprecision approaches are known as "A1" receivers.

Although the TSO 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.

Moreover, C129 didn't require standard terminology. For example, what Garmin and Trimble call "hold," Bendix/King calls "OBS." Hold means the navigator is manually set to suspend autosequencing. This allows the pilot to make a procedure turn or hold at a designated waypoint. The lights, switches, and annunciators used to control these functions are not consistent from receiver to receiver. Future receivers built under TSO C146 are expected to be somewhat simpler and more standardized, but they will not be as easy to operate as a VOR receiver.

En Route Only Receivers

En route (A2) receivers can be the primary source of IFR navigation. Just like loran they 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 service volumes, again assuming radar monitoring is available. **Note: An en route GPS 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 en route receiver has is the integrity provided by RAIM.

En route (A2) and approach (A1) 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 to use an expired database, as long as the pilot has available current information to manually check and correct any data that's changed.

Many pilots ask about 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.

Approach-Approved Receivers

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 operational differences relate to the autosequencing, annunciation and RAIM flagging requirements for approach-capable receivers. For en route operations, both receiver types are essentially identical.

Approach-approved receivers require a significantly more complex installation than either a VFR loran or GPS or even 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 gear. In early C129 navigators, 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 you're in GPS mode but are trying to intercept a VOR radial or a localizer, you're likely to be off course and confused in short order.

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.

What's a Resolver?

All Garmin and Bendix/King installations (KLN 90B, KLN 89B, and KLN 94) use a resolver-type coupling between the receiver and the CDI/HSI. Trimble and Northstar designs do not. Both of these units are no longer in production but are nonetheless found in many used aircraft. UPS Aviation Technology's IFR navigators—initially sold under the IIMorrow name—also use a resolverless indicator.

In the resolver-type design, the CDI/HSI needle reacts much as it does with conventional VOR. In other words, if the pilot selects a course on the receiver, the OBS must be set to the correct course in order to achieve proper sensing.

In the resolverless design, when the pilot selects a course on the receiver, the OBS has no effect on needle behavior. The needle will respond in the same way as if a conventional nav/com were tuned to a localizer. The pilot selects a specific course on the receiver using knobs or keys. The CDI needle will then display the aircraft's position relative to the course selected on the receiver.

Note: To avoid confusion, ASF recommends that pilots always set the correct course on their course indicator(s).

IFR Databases

To be legal for IFR approaches, a receiver has to have a current database, revised to the 28-day cycle. **The receiver will not lock out approaches if the database is expired. 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 $600. One-shot revisions are available for all receivers and are legal for approaches, providing they meet the current 28-day cycle. Having a current receiver database, however, still doesn't obviate the recommendation that current charts also be aboard the aircraft. Although there's no legal requirement for current charts and plates for light aircraft Part 91 general aviation operations, 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 FAR91.103.

Flying Approaches: Old vs. New

GPS navigators are, by TSO requirement, 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, but thereafter, cannot alter the order of events. 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 into 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.

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—the UPSAT 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 some don’t—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 .3 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.”

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 Trimble 2000 Approach, Northstar M3, and IIMorrow’s approach-capable GPS receivers incorporate an autohold feature. Based on groundtrack, 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.

Although these three receiver brands work similarly in principle, they vary in detail. The Northstar M3, for example, is fully automated, while the Trimble and IIMorrow products are better described as “semi-automated.” The newer Garmin receivers follow this design principle as well and thus require no external mode switch for selecting autosequencing; all of the controls are on the box itself.

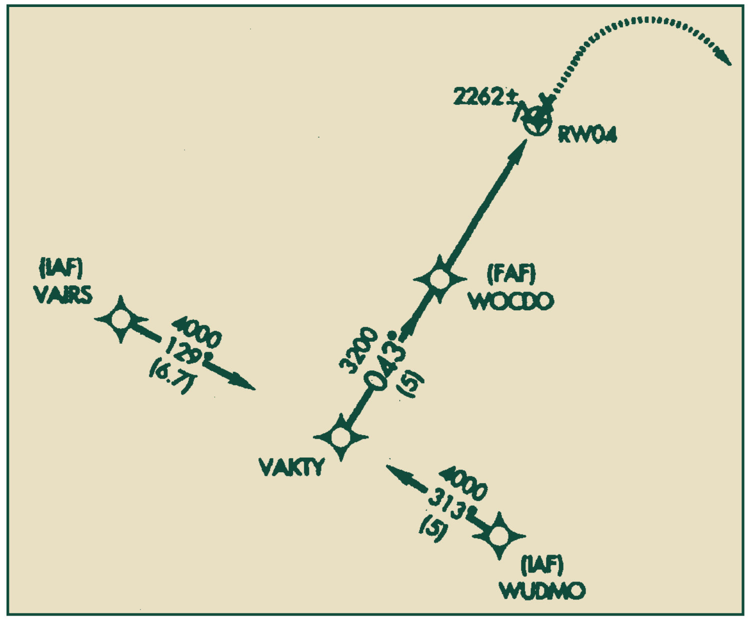
ASF recommends that pilots who are not well experienced with the make and model GPS being flown avoid overlay approaches or any approaches that require a course reversal. GPS receivers perform best, and there is much less chance of confusion, when the receiver can autosequence through the entire approach. 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. Refer to your approach plate and 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.

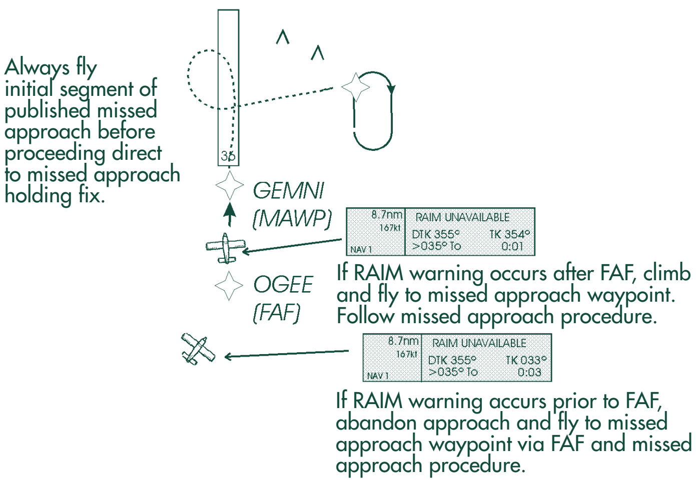


First-generation GPS approaches, which were simply overlaid over existing nonprecision approaches, required a great degree of pilot input to fly. Second-generation approaches, however, use the terminal arrival area concept, in which the initial segments are constructed in a T-shape, so the procedure 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.

RAIM Warnings



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."

While en route to the destination, predictive RAIM comes into play. The receiver continually calculates a new ETA and calculates RAIM. It's critical to understand that just because the receiver predicts RAIM will be available at the destination, that doesn't guarantee you'll have sufficient satellite coverage when you arrive, only that the receiver expects to have sufficient coverage to calculate RAIM. It's possible, for example, that a satellite could become unhealthy while you're en route or signals from satellites low on the horizon could be masked by terrain. The receiver's RAIM function has no way of knowing about terrain masking.

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.

Both FSS and DUAT provide GPS notams. To access them on DUAT, use "GPS" as the location identifier. GPS notams are primarily useful for planned outages. GPS receivers detect unusable satellites and automatically reject them from RAIM calculations. However, the receiver can't know about a predicted future outage unless you tell it. Some receivers have a way of manually deselecting a satellite. Some do not.

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 2002 some 3,400 GPS stand-alone 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.

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 (meaning you navigate to one fix, cross it, and proceed to the next fix), overlays

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

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 .3 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” (FFs) on both the plan and profile view of their approach plates. FAA/NACO is in the process of incorporating FF fixes into the plan view of their GPS overlay approach plates.

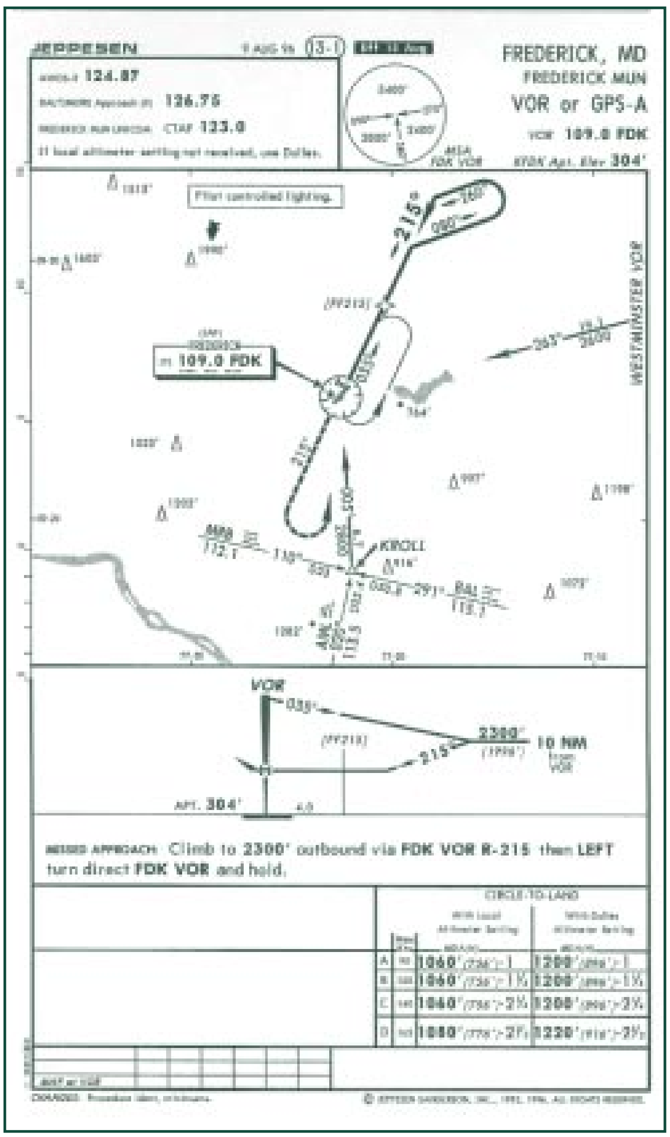
In the most recent charting change, FF fixes, e.g.., FF215 at Frederick, MD, are now charted as a five-letter identifier, e.g.., DABBI at Machias, ME. However, this change may not yet be available on all charts.

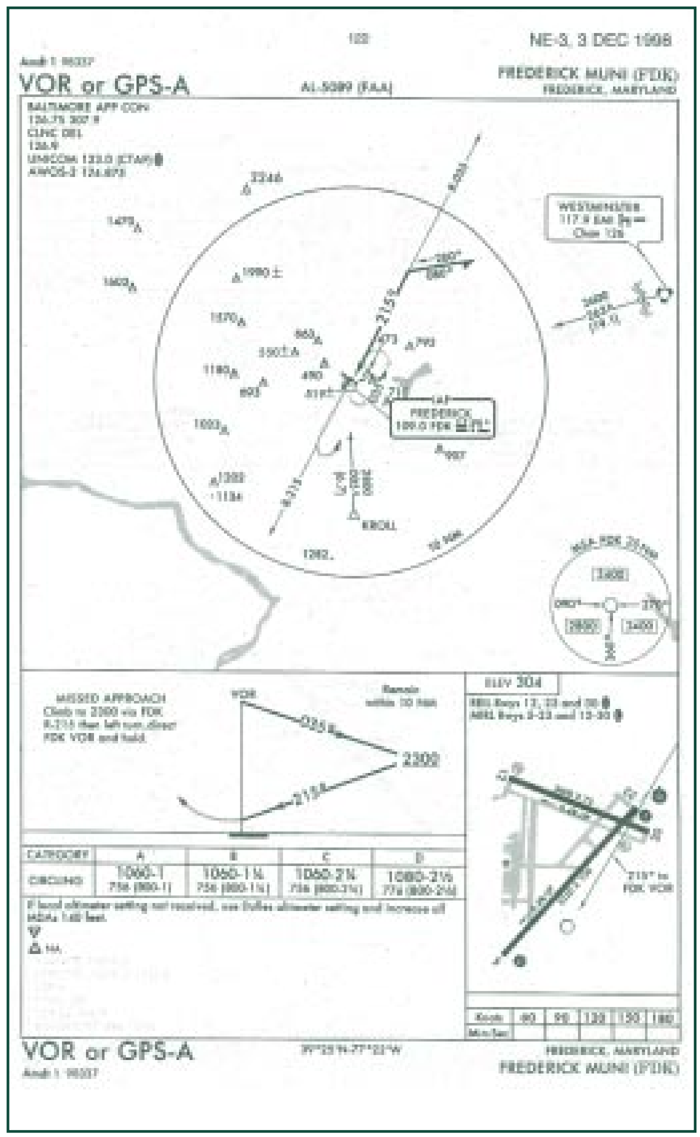
Caution: If your database is not current, it may contain the old-numbered fix instead of the five-letter identifier, and it will not match what is on your approach plate, so be sure your database is up-to-date.

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





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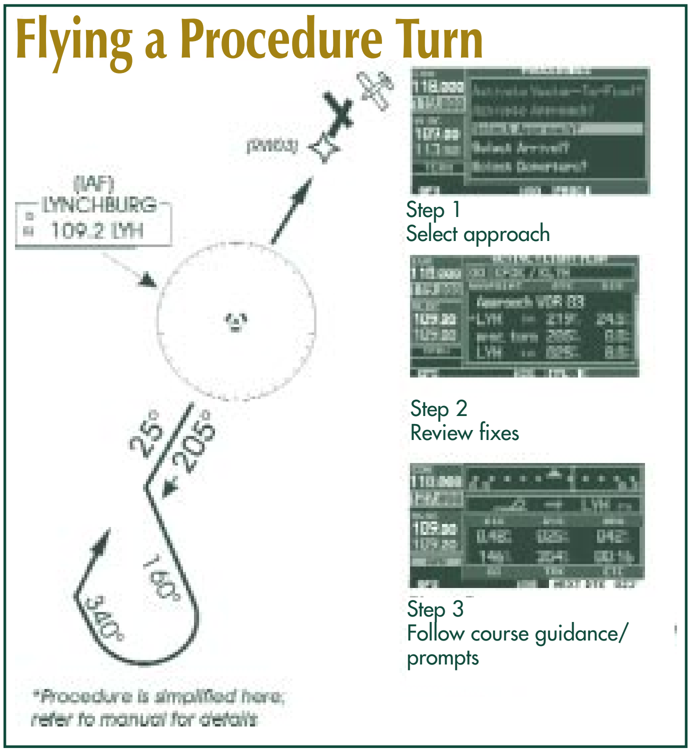
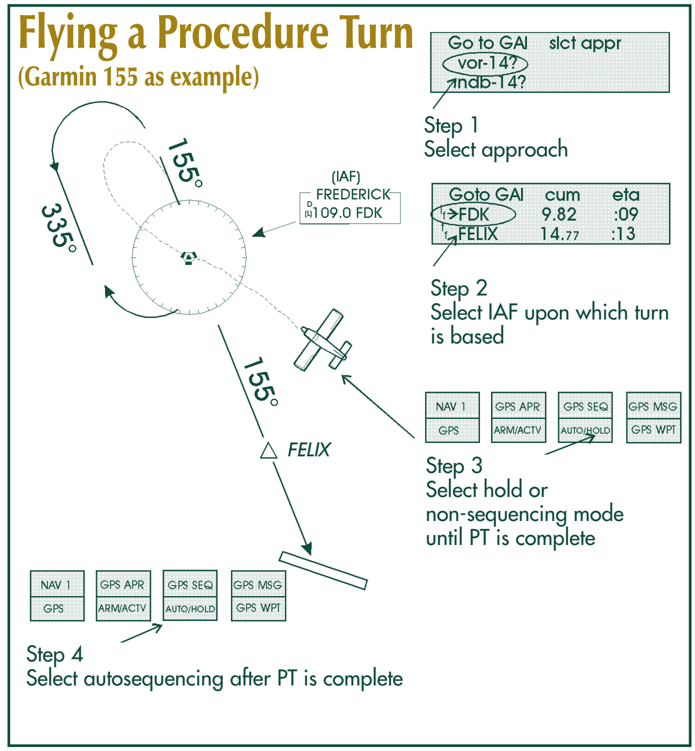




GPS-based approaches have significant advantages over conventional ground-based procedures. GPS fixes aren't subject to the same displacement errors that plague VOR and NDB. GPS fixes can be placed anywhere so, barring any major obstacles, approaches can almost always be aligned with the runway and lower 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.

The graphic above depicts the steps necessary to fly an approach using a first-generation navigator, such as a Bendix/King KLN 90B or a Garmin 155. Although there are some common features between these and newer receivers, the latest units are more automated.

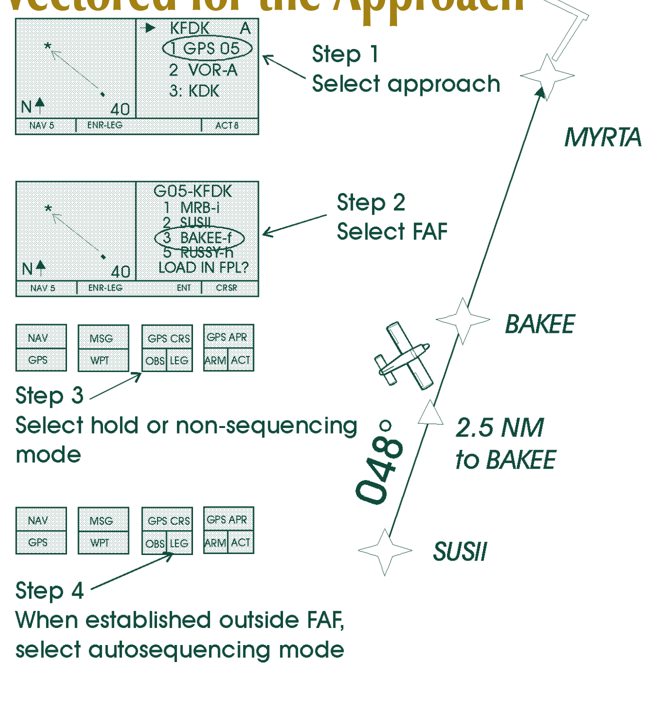
The first step is to scroll through the receiver's menu and select the approach, followed by the fix at which the approach will commence. At busy airports, you'll likely be vectored into the approach, so autosequencing will commence at the final approach fix. In this case, you'd select the FAF as the 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.

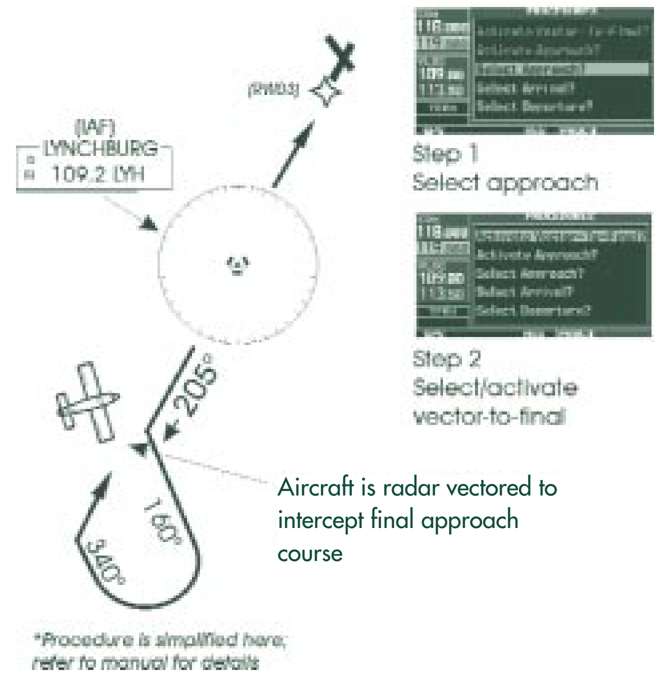
Hold vs. Autosequencing

If you're vectored to a point outside the FAF, you don't want the receiver to begin autosequencing until you're established on the final approach course. The receiver must be set in "hold" mode until you intercept final, then set to autosequence when you're established. The VTF—vector to final—feature does this automatically. Similarly, if you need to make a procedure turn, you'll need to temporarily suspend autosequencing, fly to the fix upon which the turn is based, then resume autosequencing when you're established inbound, outside the FAF.

Vectored for the Approach



Using Vector-to-Final



Some receivers may display a prompt or "pop-up" on various segments of the approach, but it's up to pilots to understand when autosequencing must be engaged. If you forget to engage it, the receiver will not transition to the approach mode. Again, the early IIMorrow, Northstar, and Trimble products — and the newest generation of Garmin receivers — set the hold function automatically, requiring little or no input by the pilot. The early Bendix/King and Garmin receivers require manual autosequence setting.

Traps 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.*

- On manual units, 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.

- By TSO requirement, when the receiver transitions to approach-active mode, the CDI scale will smoothly change from one mile to .3 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. By TSO requirement, a GPS receiver 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 alongtrack stepdown fixes. In recent years, databases include 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.

Some New Procedures

It appears that WAAS procedures will be available in three levels of precision:

RNAV MINIMA

CATEGORY	A	B	C	D
GLS PA DA	N/A			
LNAV/DA VNAV	1500/24 318 (400-1/2)			1500/40 318 (400-3/4)
LNAV MDA	1700/24 518 (600-1/2)		1700/50 518 (600-1)	1700/60 518 (600-1 1/4)
CIRCLING	1760-1 578 (600-1)		1760-11/2 578 (600-1 1/2)	1760-2 578 (600-2)

- An ILS-like approach to be named.
  –Minima will be slightly higher than a Cat I ILS.
- LNAV/VNAV, which features vertical guidance.
  –Minima will be about 100 feet higher than the approach above.
- LNAV, which is essentially identical to current stand-alone GPS procedures.
  –Minima will be the same as conventional nonprecision approaches.

Obviously, these approaches require WAAS-capable receivers. These will likely differentiate between the various types of WAAS procedures via menu selection.

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, 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.

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. The minimum condition for GPS substitution is a TSO C129 GPS receiver approved for en route or A2 operations.

Common Questions About GPS

I've noticed that first-generation C129 GPS receivers are being sold at bargain prices. Are these receivers obsolete?

No. First-generation C129 GPS will function normally for the foreseeable future, including nonprecision approaches. However, most will not be upgradeable to WAAS standards and will thus not have the capability to serve as sole means of IFR navigation.

Should I be thinking about removing VOR or DME from my airplane?

DME perhaps. VOR no. As of spring 2002, the FAA was far from certain that GPS will ever be approved as a sole means or primary system of navigation. Some backup will almost certainly be necessary. Currently, VOR is still required for IFR operations but IFR-approved GPS can freely substitute for DME and ADF. If your current VOR and DME are relatively state-of-the-art and you have room in your panel, there's no particular advantage in removing them.

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, in one unit. Without adequate redundancy, however, the loss of that unit could compromise safety.

I have an IFR loran. Now that loran has been extended indefinitely, should I keep it in the panel or replace it with GPS?

Loran's future is unknown. The FAA has funded research to examine loran as a backup to GPS but it's unlikely to ever be approved for approaches. Keep the loran if you have room in the panel and have use for it in your flying.

Will WAAS really allow sole means navigation with GPS?

The best guess now is no. The FAA and other agencies still have concerns about GPS's reliability and integrity. The current sentiment is that backup of some kind will be required. Operational experience may change that view over the next decade.

Some approaches require ADF; can GPS substitute?

Yes. IFR-approved GPS can substitute for ADF on ADF-required approaches. 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.

GPS displays altitude. Why can't it be used for vertical guidance?

GPS altitude is expressed as a height above the surface of the GPS spheroid; it's not the same as MSL altitude or even AGL altitude, since the spheroid is an average mathematical value, not an absolute value above the surface. Further, GPS vertical accuracy is only about a sixth of its horizontal accuracy. When WAAS comes online, vertical accuracy will be greatly improved.

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.

Can I use GPS to file direct to my destination?

Yes, but as with all random routings, you must be in radar contact while operating off airways. Be careful to check on special use airspace and minimum off route altitudes (MORA).

What if there's no working VOR aboard, but I'm in radar contact; am I legal to operate IFR?

Technically, no. GPS is still supplemental navigation. VOR is still required.

What regulation says that?

GPS hasn't been committed to regulation yet. The guidance is currently found in Advisory Circular (AC) 90-94 and in the Aeronautical Information Manual.

Will I get busted for having an out-of-date database?

As of this writing there's no enforcement history on GPS. In any event, you should have a current database before flying IFR. For en route operations, it's legal to use current paper charts to check fixes in an expired GPS database. For approaches, you'll need a current database revised to the 28-day cycle.

Appendix

GPS History

GPS satellites were always considered consumables that would require periodic replacement. The original Block I satellites—built by Rockwell—had a design life of five years, although many lasted longer. The current replacement NAVSTAR satellites—so-called Block IIRs—are made by Lockheed Martin and launched as needed to maintain a minimum constellation of 24. The replacement satellites are improved versions of the original designs that include better clocks and power systems. They also have "180-day autonomy"—the capability to provide navigation data without uploads from ground stations for as long as six months.

NAVSTAR sounds like a trade name, but it's actually an acronym meaning NAVigation System by Timing And Ranging. Each satellite contains four very accurate clocks, navigation and communications transceivers, solar panels and batteries, and a system of spinning reaction wheels that keep the satellite pointed at the earth. The clocks, essential to the accuracy of GPS, are accurate to a nanosecond (a billionth of a second, or the amount of time it takes light to travel one foot). GPS satellite clocks gain or lose only one second in 160,000 years.

GPS satellites orbit at an altitude of 10,898 miles for a 12-hour orbital period. It takes about one-eleventh of a second for the GPS signal to reach your receiver. Constellation GPS satellites are not geostationary; however, satellites used in the WAAS program are, and orbit at about 24,000 miles. The mid-altitude orbit of GPS NAVSTARs gives the best combination of good coverage, constantly varying geometry, and ease of deployment.

How GPS Works

GPS receivers listen for satellite broadcasts that provide almanac and ephemeris data so the receiver will know where the satellite is located in space, and a coded navigation/timing message. This information is processed to establish a line of position from the receiver to the satellite. Four intersecting lines of position allow the receiver to determine its position. Each satellite broadcasts on the same frequency, but each transmits a unique code called pseudo-random code. The receiver generates matching code that it slews to lock on to the satellite's navigation/timing message. Once locked on, the receiver can calculate a rough distance called a pseudo-range.

In order to eliminate pseudo-range errors, the receiver must synchronize its clock to the satellite clocks. It does this by determining the range to at least four satellites and then adjusting the receiver clock until all four ranges or lines of position cross through the same point in space. If the four lines of position don't pass through the same point in space, the receiver assumes its clock is slightly inaccurate and adjusts the clock until all of the ranges agree. This process is known as "correcting the clock bias" and is the reason a GPS receiver has to see at least four satellites to compute a three-dimensional position. It can compute position with only three satellites, but the pilot has to provide the receiver with one of the lines of position in the form of altitude.

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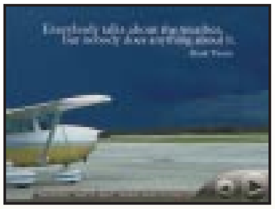

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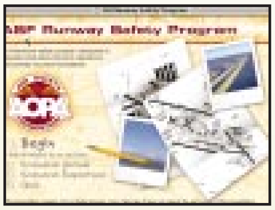

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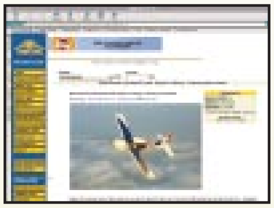

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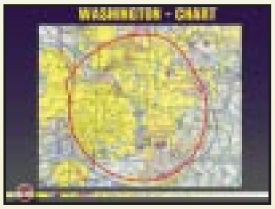

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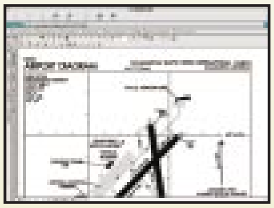

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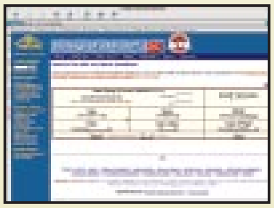

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