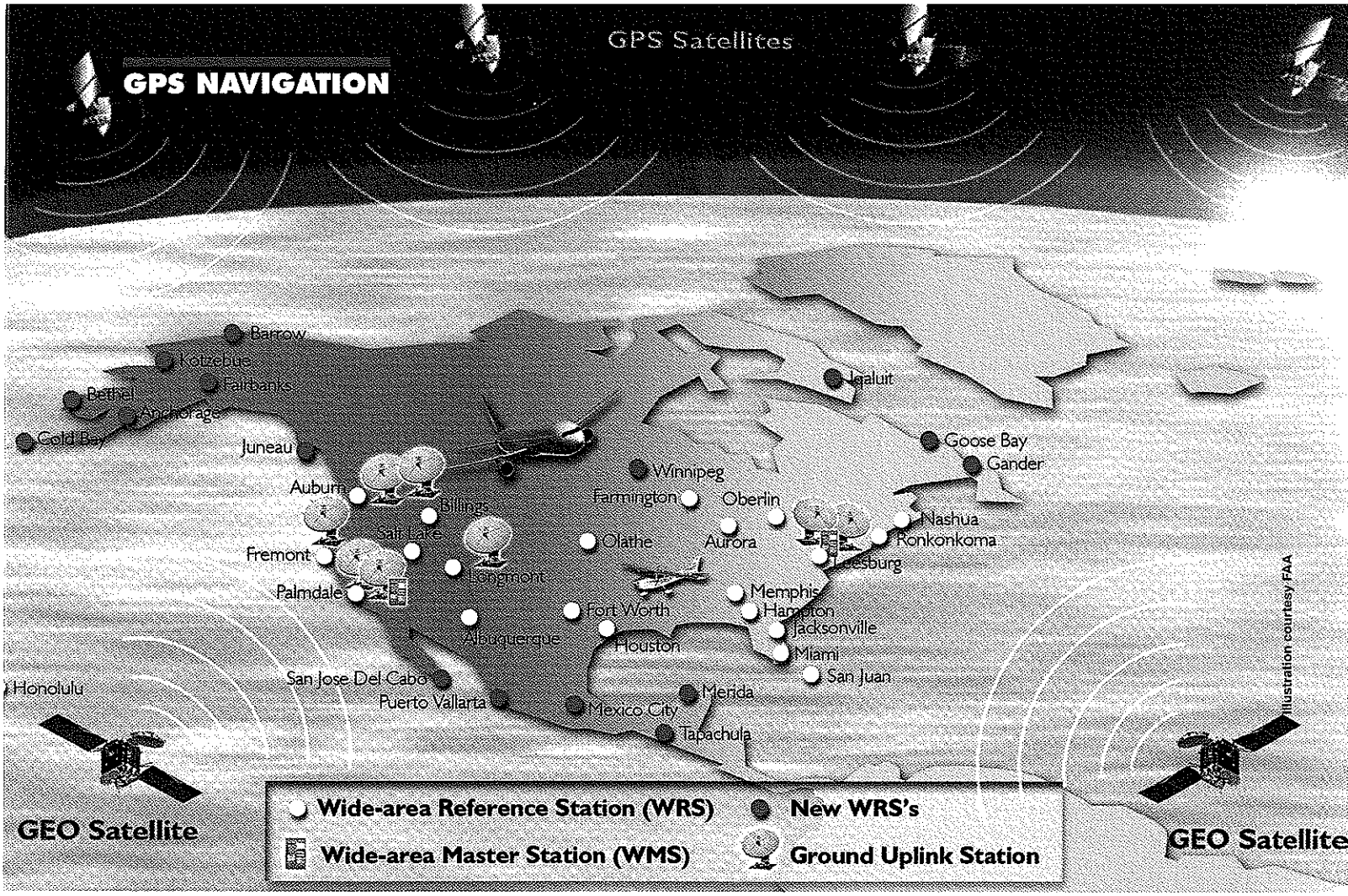


What WAAS means for pilots

Augmented GPS provides increases in capability.

By Larry Oliver
ATP. Learjet, Gulfstream II/III/IV, Falcon and Boeing aircraft

WAAS uses a network of ground reference stations in the lower 48, Alaska, Hawaii and Puerto Rico that monitor GPS satellite signals. Additional stations are planned in Alaska, Canada and Mexico. Ground stations collect and process GPS information and send it to WAAS master stations.

LPV approaches, LNAV/VNAV, RNP, RAIM, FDE—these are all relatively recent terms in the aviation vocabulary, and they all have links to the Wide Area Augmentation System (WAAS).

This article attempts to explain both what WAAS is and what advantages it offers from a pilot's perspective.

The global positioning system (GPS) has been serving aviation users for more than a decade with increasing significance. Although the basic GPS service fails to meet the integrity requirements critical to safety of flight, receiver autonomous integrity monitor (RAIM) indications and equipage for reversionary navigation mitigate this issue. (Integrity is the ability of the system to provide timely warnings to users or to shut down when it should not be used for navigation.) Aircraft using GPS equipment under IFR must be equipped with an approved and operational alternative means of navigation appropriate to the planned route.

GPS basics

The GPS constellation nominally comprises 24 satellites in low Earth orbit (LEO). Each one transits the globe in around 12 hours and transmits a message containing various bits of data, which are then received by an aircraft and converted into position, velocity and time. The data bits are a complex message containing pieces of information that include time, satellite position and system health.

GPS positioning capability has proven to be accurate to around 30 meters horizontally, under most conditions. If the signal exceeds prescribed limits, an alarm is triggered. Average accuracy is around 20 m. FAA tracks GPS system accuracy—with millions of data samples over many years, the agency has a high degree of confidence in the stated system performance parameters for horizontal accuracy. Vertical

accuracy hasn't always been as good, occasionally being off by hundreds of meters.

The navigation portion of an aircraft's GPS or flight management system (FMS) takes this positioning information and computes the essentials to provide guidance to its next point. With an FMS-equipped aircraft, the GPS signal becomes a positioning input into the FMS position calculation. For aircraft with a standalone GPS, its system contains both positioning and navigation elements in the same unit.

Sources of satellite error

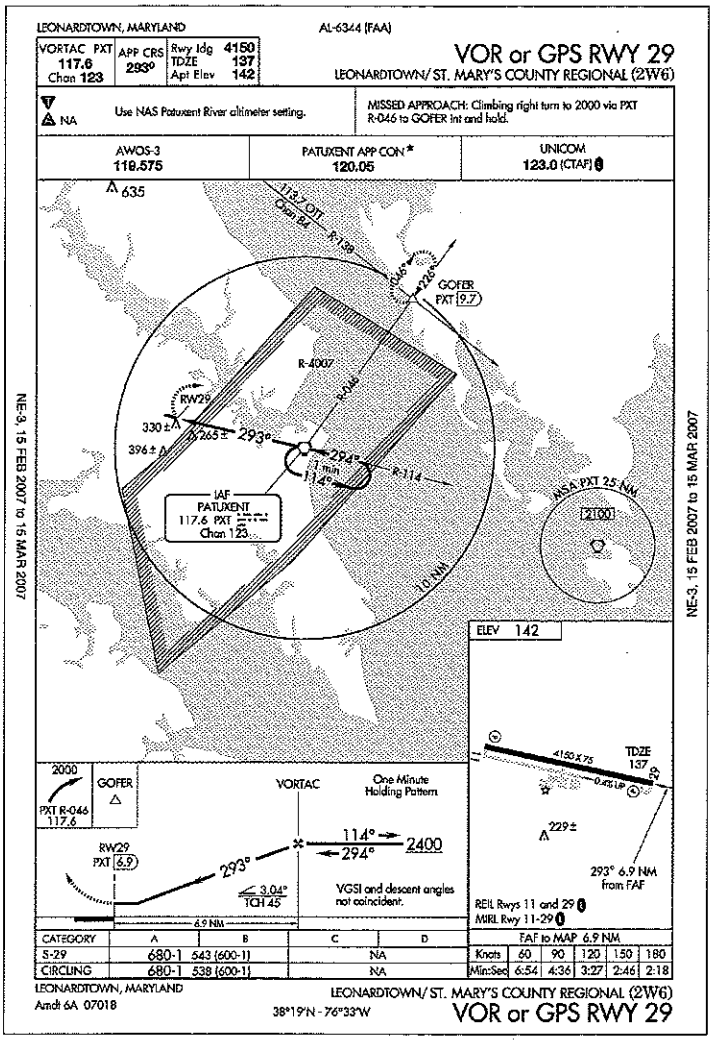
The satellite signal is used to determine a pseudo-range position. Position is determined by measuring the time taken for the signal to reach the aircraft, rather than a direct measurement of the exact satellite location (therefore the "pseudo"). Since the speed of light is about 186,000 miles/sec, accuracy of the satellite clock is critical. After all, a 1/10-second error could translate into an 18,600-mile position error. Satellite clocks are extremely accurate, but are still a source of position error, even if only a few meters.

A second source of error is ionospheric interference. Disturbances of this sort can bend the signal slightly, again contributing to a small position error. There are still other possible sources of error, such as solar flares and multipath errors, but clock and ionospheric errors are the most frequent. Fortunately, these errors are generally only of a few meters and do not inhibit the use of GPS. However, if GPS were even more accurate and more reliable, more could be done with it. This is the reason for WAAS.

GPS instrument approaches

GPS approaches have been around for 10 years. The earliest approaches were "overlays," where the user could substitute GPS for the underlying navigational aid. One example is an approach with the nomenclature VOR or GPS RWY 23. These approaches were the easiest way to get GPS into operation in IMC. By using the same basic criteria as a VOR approach, pilots could simply use the GPS signal in lieu of another navigation aid. FAA stopped adding overlay approaches several years ago, but a few remain in the procedures books. See approach plate for 2W6 (Leonardtown MD).

To fly this kind of approach, the aircraft must have the correct GPS equipment installed, but it does not need to have the underlying equipment (in this case, VOR). The 2W6 approach is notable for what it doesn't have—a channel number or LNAV/VNAV or LPV minima line. It does indicate that you can fly this approach using either VOR or GPS. You are not required to use (or have) both systems—either one will suffice. Today, for example, as FAA adds new approaches, the plates are now titled as RNAV (GPS) RWY XX.



Early GPS approaches simply replicated the original ground-based navaid (VOR).

RAIM

One of the functions of RAIM is predicting whether you will receive a GPS signal suitable for navigation. RAIM requires 5 operational satellites in view and with suitable geometry. All GPS equipment used for IFR must have RAIM or an equivalent system-monitoring function. Operational guidance exists which describes pilot actions if RAIM is lost. If your position lacks sufficient satellite signals, the GPS unit may exceed the position integrity performance limits and give you a RAIM alert.

FDE

GPS fault detection and exclusion (FDE) allows the system to segregate the input of a faulty satellite and maintain its ability to navigate accurately.

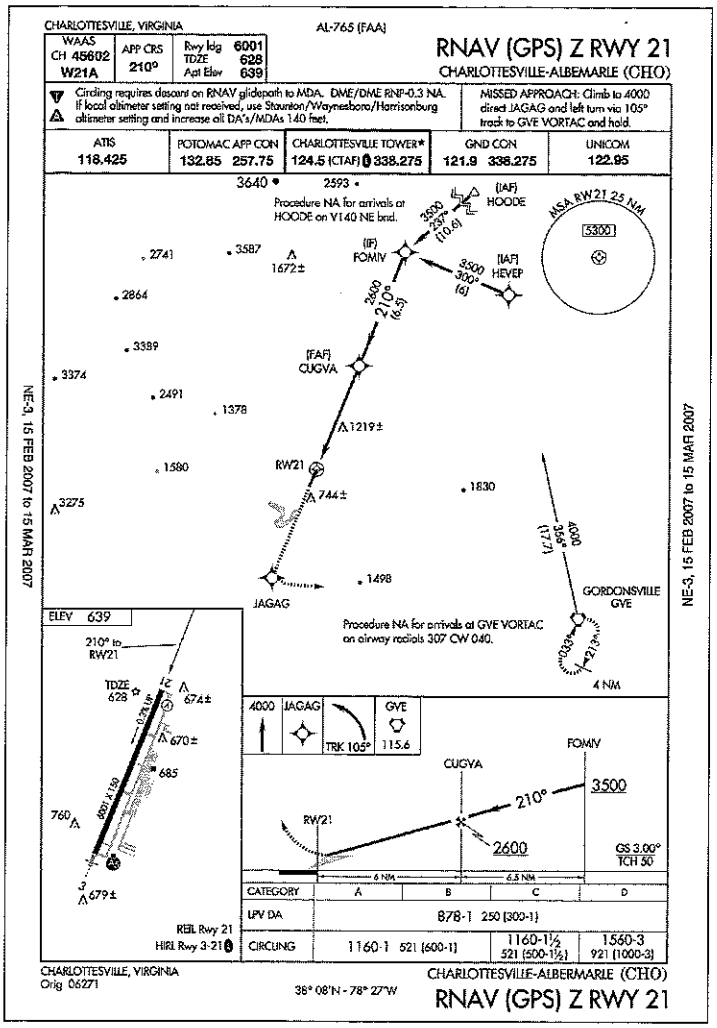
The message broadcast by the satellites contains orbit information and time code. GPS satellite Notams contain predicted satellite outages (eg, planned maintenance). Some GPS avionics allow the pilot to deselect a satellite vehicle—the GPS receiver then determines RAIM availability for a predicted time and location.

Most GPS receivers allow a predictive RAIM check by entering destination and ETA on the appropriate page—the equipment will indicate approach availability at that time and location. If flying a published GPS departure, availability of RAIM should be ensured prior to departure. Remember, this is predictive—there is always a possibility a failure may occur enroute, just as there is a possibility a failed satellite could be returned to service. Finally, for GPS approaches, you must have RAIM at the final approach fix. The receiver will perform this function automatically 2 nm prior to the final approach fix.

Enter WAAS

FAA has placed 37 WAAS reference station sites in North America. Each site "knows" its precise location. It then compares the satellite-determined location against its known location and transmits this information to a WAAS master station (WMS). The WMS receives input from all receiver sites and it prepares a correction factor to improve the system accuracy. This correction factor is broadcast to a geostationary satellite, which rebroadcasts the message to WAAS-enabled GPS receivers.

The first benefit of WAAS is that positioning information accuracy is improved to around 2–3 m, both horizontally and vertically. There are additional benefits—the geostationary satellites improve signal availability, since they act as yet another GPS satellite in addition to their WAAS function. They also improve system integrity.



The latest iteration of GPS approaches. The "Z" indicates that this approach has the lowest minimums for RNAV approaches to this runway.

With the improved accuracy and integrity, WAAS-enabled aircraft can fly LNAV/VNAV (as well as LPV) approaches. These approaches provide vertical guidance, and yield an approach which is safer than typical "dive-and-drive" nonprecision approaches. LNAV/VNAV approaches can have minimums as low as 300 ft. While some other systems can fly LNAV/VNAV, WAAS generally makes this approach available for aircraft without barometric vertical navigation (baro-VNAV) avionics. Using WAAS also avoids the LNAV/VNAV restrictions associated with temperature and altimeter.

The latest addition is the LPV approach. Adapted from ICAO's approach with vertical guidance (APV), localizer performance with vertical guidance (LPV) requires the WAAS signal and provides approaches with minimums as low as 200 ft. From a pilot standpoint, it looks and flies almost identically to ILS, but without the occasional bumps and dips found in some ILS approaches. The benefits of the LPV approach are measurable. Because of requirements for siting localizer and glideslope transmitters, it can cost more than $2 million to install an ILS, and sometimes it's difficult to find optimum real estate for these items.

With WAAS, the signal in space is already present, so there is no equipment-siting issue. In fact, the airport doesn't require any hardware or software as long as an instrument runway already exists. This is a tremendous opportunity for airports seeking expanded IMC capabilities to avoid costs. As of Dec 2006, there were 640 LPV approaches, and FAA plans to add another 300 this year.

But don't reach for your terminal procedures book and look for a heading that says LPV RWY 32. LPV is a line of minima, and it only appears on RNAV (GPS) approaches.

When looking at the approach book, there may be instances of RNAV (GPS) Y or Z approaches. The Y or Z simply designates that there is more than one RNAV approach to a particular runway. In such cases, the Z approach provides lower minimums than the Y approach. The pilot's task is to choose the correct approach based on aircraft equipage (and navigation database). See Y and Z approach plates, shown at left, for CHO (Charlottesville VA).

Some new features are apparent in these Y and Z approaches. The upper left box notes WAAS Channel 45602, yet the WAAS satellites all broadcast on the same frequency. This should be thought of not as a channel number, but as a page number, and a means of ensuring that the correct approach has been selected. Below the channel box is a note regarding DME/ DME RNP-0.3 NA. This means that the approach cannot be flown using an FMS-equipped aircraft that relies on DME for updating.

On the Z approach there is no LNAV/VNAV minima line. This is because the Z approach displays the lowest minima available, so the LNAV/VNAV line is found on the Y approach. Even the circling minima on the Z approach are lower than on the Y approach.

The WAAS geostationary satellite, as well as providing a correction message, acts as an additional GPS satellite and ensures sufficient GPS inputs for positioning. As such, it obviates the need for a RAIM check.

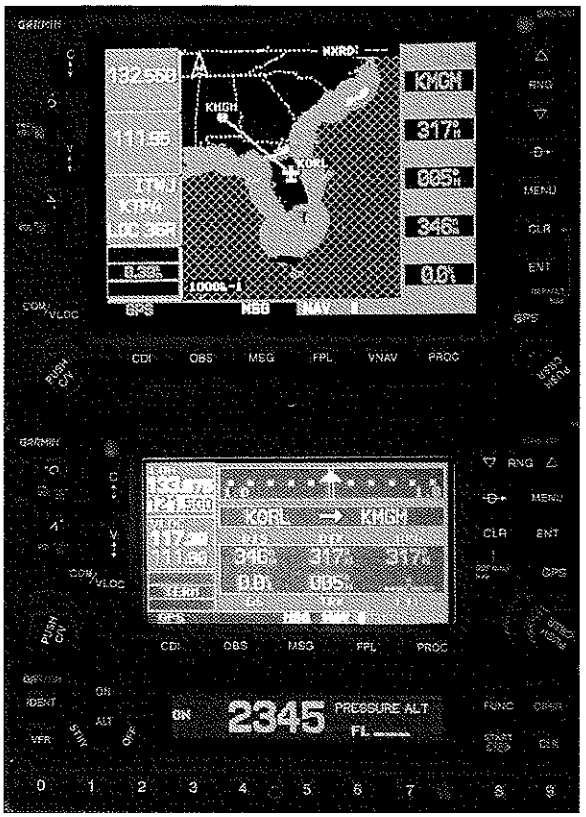
WAAS Notams

WAAS requires distribution of 2 types of Notam information—event-driven notification of system degradation (eg, satellite out of service) and algorithmically derived predictions of the potential site-specific impact of system outages.

To lessen the impact on the Notam system, FAA established that

no predictive Notam service or operational restrictions would be applied for any airport with more than an average of one predictive Notam per day, due to vertical availability issues.

Each of the LNAV/VNAV and LPV procedures at these locations is identified in the remarks section with the character W reversed out of a black box—a symbol defined in the legend of each of the US Terminal Procedures books. The restriction is as follows. "Note: The [W] symbol indicates outages of the WAAS vertical guidance may occur daily at this location due to initial system limitations. WAAS Notams for vertical outages are not provided for this approach. Use LNAV minima for flight planning at these locations, whether as a destination or alternate. For flight operations at these locations, when the WAAS avionics indicate that LNAV /VNAV or LPV service is available, then vertical guidance may be used to complete the approach using the displayed level of service. Should an outage occur during the procedure, reversion to LNAV minima may be required. As the WAAS coverage is expanded, the [W] will be removed."



Garmin's GNS430W and 530W are TSO'd to FAA C146a criteria for enroute, terminal and approach phases of flight. Both units use a 15-channel GPS receiver generating 5 position updates per second.

Photo by Jack Sykes

Regulatory guidance

Due to initial system limitations, there are certain restrictions on WAAS operations. Pilots may plan to use any instrument approach authorized with WAAS avionics at a required alternate. However, when using WAAS at an alternate airport, flight planning must be based on flying the RNAV (GPS) LNAV minima line, or minima on a GPS approach procedure, or a conventional approach procedure with "or GPS" in the title. CFR Part 91 nonprecision weather requirements must be used for planning.

On arrival at an alternate, when the WAAS navigation system indicates that LNAV/VNAV or LPV service is available, vertical guidance may be used to complete the approach using the displayed level of service. The term "unreliable" is used in conjunction with GPS and WAAS Notams. The term is an advisory to pilots indicating the expected level of WAAS service (LNAV/VNAV, LPV) may not be available. Note—it is important not to mistake "unreliable" for "unavailable."

"WAAS unreliable" Notams are predictive in nature and published for flight planning purposes. On commencing an approach at locations with such Notams, the vertically guided approach may be used as long as the avionics indicate that the service is available. Should an outage occur during the approach, reversion to LNAV minima may be required.

Summing up

WAAS provides a correction message directly from a geostationary satellite to the aircraft receiver. It improves system accuracy from around 30 m to 2–3 m horizontally. It also improves GPS availability and integrity.

These improvements have enabled FAA to create the LPV approach, which looks and flies like an ILS approach, and has minimums as low as 200 ft. The major benefit is the ability to provide LPV approaches inexpensively to a wide variety of runways, giving pilots more instrument approaches with vertical guidance.

Looking ahead

FAA expects significant growth in the number of airplanes flying in the National Airspace System (NAS). To accommodate this growth, FAA plans to make changes in the NAS to improve efficiency. These changes will focus on performance-based navigation, in which aircraft will be certified to perform within specific parameters.

The agency will not specify what sensors will be required, and will leave it up to manufacturers and operators. Some aircraft may use DME-based computations (through a flight management computer), while others will use GPS/WAAS, but the resulting navigational capability will be the same. Under an RNP system, there will eventually be restrictions on operations in certain kinds of airspace, just as there are restrictions today regarding aircraft without transponders or VHF communications.

FAA will continue to expand the use of GPS and WAAS. The agency expects to publish around 300 new LPV approaches this year. The current number of approaches that can be flown using WAAS equipment is 2891. This includes LNAV, LNAV/VNAV and LPV approaches. WAAS has proved reliable, safe and cost-effective, and its use will continue to expand.

Not all GPS or WAAS receivers can perform all functions. As usual, the AFM (supplemented) is the necessary source document for determining what approaches can be flown legally.

An ATP-rated pilot with around 4000 hours, Larry Oliver has flown Learjets, Gulfstreams, Falcons and Boeing aircraft. His career includes stints as COO of a Part 135 operation and VP of sales for a major aircraft manufacturer.

Q. What is WAAS, and what does it do for me?

A. WAAS stands for Wide Area Augmentation System. It improves the accuracy of the GPS signal from typically 20 to 30 meters to around 2 or 3 meters (horizontally and vertically). With the improved accuracy and integrity of the WAAS signal, you can fly lateral navigation/vertical navigation (LNAV/VNAV) and localizer performance with vertical (LPV) approaches. You can also use a Global Positioning System (GPS) approach for your instrument flight rules (IFR) alternate. ▲

Q. How does WAAS work?

A. WAAS uses a system of ground stations to compare GPS positioning versus a precisely surveyed, known position. A correction message is developed and transmitted to a geostationary satellite, which then re-broadcasts this message to the airborne WAAS receiver. The receiver applies the correction to its calculated position, providing the improved accuracy. ▲

Q. What's the purpose of the RAIM check?

A. RAIM stands for Receiver Autonomous Integrity Monitor, and the RAIM check is a means of determining whether you will have sufficient satellites in view for your departure, arrival and destination to provide an accurate navigation solution. A RAIM check is a requirement for using basic GPS for navigation and approach while IFR. En Route and terminal RAIM predictions are available at www.raimprediction.net ▲

Q. Is a RAIM check required when using a WAAS receiver?

A. No, there is no requirement for a RAIM check when using a WAAS receiver. WAAS can receive information from two WAAS geostationary satellites, in addition to the GPS satellites, which ensures that you will have sufficient coverage in the continental United States. ▲

Q. I see several new types of approaches published. What equipment do I need to fly an LNAV approach? How does LNAV differ from LNAV/VNAV? What is an LPV approach?

A. A GPS-equipped aircraft is considered an RNAV (area navigation) aircraft. With an approved GPS, you can fly RNAV approaches using the LNAV minima line. You can NOT fly the LNAV/VNAV line unless you have either a certified baro-VNAV system (rare), or have a certified WAAS receiver.

LPV stands for localizer performance with vertical guidance. It uses the improved accuracy of the WAAS signal to provide horizontal guidance that is equivalent to the accuracy of a localizer. It also incorporates vertical guidance. In essence, it looks and flies like an ILS, and it can get you down as low as 200' above ground level (AGL). You MUST have a certified GPS/WAAS receiver to fly an LPV approach. LNAV height minimums are typically around 400' AGL, while LNAV/VNAV may be 300' AGL, and LPV can be as low as 200' AGL. ▲

Q. I understand that some GPS receivers provide vertical guidance. If my receiver displays vertical guidance, can I fly the LPV minima line?

A. If your GPS receiver is certified to TSO C145/146, then yes, you may fly instrument approach procedures to LPV minima. Beware that some GPS receivers offer advisory vertical guidance—this is not the same thing as LPV. Consult with the approved flight manual supplement for specific limitations of your certified GPS receiver. ▲

Q. What is a T-Route?

A. A T-Route is similar to a victor airway, but it is defined by GPS points, and not by the location of a Very High Frequency Omni-directional Range (VOR). You can file and fly a T-Route using your certified GPS system. These T-Routes are being expanded throughout the National Airspace System. They will allow more direct routing, reduce pilot and controller workload, and help increase system capacity. ▲

Q. I rent airplanes when I fly. How do I know exactly what I can or cannot do?

A. If a GPS or WAAS unit was installed as original equipment, it will be referenced in the aircraft flight manual. If it was installed later, it should have been installed in accordance with a Supplemental Type Certificate (STC). The last step of most STC approvals is to incorporate the operating handbook for the equipment as a supplement to the flight manual. In other words, there should be a clear paper trail documenting the equipment, nomenclature, and then approved uses as described in the aircraft flight manual and supplements. If the aircraft flight manual doesn't specifically authorize a particular maneuver or procedure, then you cannot legally perform it in that aircraft. ▲

Q. I have a hand-held GPS, and it works great in the airplane. When will I be allowed to rely on it for navigation?

A. Your unit may work great, but it does not incorporate many of the features that ensure safety or operational utility. For example, most of these units do not include fault detection and exclusion, do not include updatable databases that can be validated, and do not comply with the appropriate technical standards orders that address performance, reliability and integrity. It is not likely that these will be certified for any use in aircraft in the foreseeable future. Contrast this with the systems certified under TSO-C146 and you will get a better idea of the capability and robustness of a system designed for primary navigation. ▲

Q. What about required navigational performance (RNP)?

A. The FAA is moving towards a system of RNP. WAAS is a key element of RNP as it provides the most accurate method of updating any navigational system. While RNP requires a total system approach, it does not detract or replace anything related to WAAS. Instead RNP builds upon the accuracy of WAAS to provide more efficient use of limited airspace. ▲

Q. WAAS equipment costs a lot of money. How do I know that WAAS won't go away—much like MLS?

A. The FAA has now developed more than 6,000 instrument procedures using satellite navigation, and you can fly an procedures with WAAS equipment. In addition, we have been adding 300 LPV approaches per year, and now have m 900* LPVs. We are making major changes to the National Airspace System that place even more reliance upon satel navigation. WAAS is the most accurate satellite navigation source available. It is a critical piece of all of our plans an remain so indefinitely. ▲

**Number of published LPVs as of September 2007*

References:

- Aeronautical Information Manual (Section 1)
- TSO-C129, "GPS as a Supplement to En Route Navigation"
- TSO-C145a, "Airborne Navigation Sensors Using the GPS Augmented by the Wide Area Augmentation System"
- TSO-C146a, "Stand-Alone Airborne Navigation Equipment Using the GPS System Augmented by the Wide Area Augmentation System"
- Advisory Circular AC 90-94, "GPS Equipment for IFR En Route and Terminal Operations"
- Roadmap for Required Navigational Performance