WAAS New?

WAAS technologies continue to evolve and improve – are you ready?

by Matthew McDaniel

In 2007, I delivered one of the first aircraft to be factory-built with WAAS-enabled avionics installed. It was a turbo-normalized Cirrus SR22TN. Not only did I have to fly this aircraft and use its avionics, I had to teach its owner to do the same. This included full utilization of its dual WAAS-approved Garmin GNS-430W navigators. In theory, that sounds simple enough, as I was already well versed in the Garmin 400/500-series avionics (in a variety of aircraft, including King Airs), but information on the new WAAS components was scattered about their huge manuals, and only addressed my operational questions. Information about WAAS-specific terminal procedures, approach plates, and related topics was scarce, so I began to dig.

Unearthing the information I desired was arduous and consisted mostly of piecing tidbits from numerous sources into a cohesive whole. Eventually, I felt educated enough on the topic to begin teaching my clients, which then expanded into a series of seminars I presented around the country. The pilot populace began to realize what I already had; information on WAAS was hard to come by.

By 2010, my seminars had run their course and WAAS was a well established IFR tool, existing in both factory-new aircraft and retrofitted older aircraft, but WAAS continued to evolve and expand, and sadly, detailed information about those evolutionary changes remained difficult to find. I experienced a seemingly endless stream of pilots who flew WAAS-equipped aircraft, thinking they had a good handle on it, only to learn after a day of WAAS-heavy IFR training, that they didn't. In recent months, this problem began anew, as emerging technologies slipped into the WAAS lexicon, with little or no heads up given to those of us utilizing WAAS regularly. I will try to increase your understanding of these latest upgrades, while reviewing some of the things that helped get us to this point.

Technical Overview

The International Civil Aviation Organization (ICAO) defines the standards and practices for the Satellite Based Augmentation System (SBAS). The Wide Area Augmentation System (WAAS) falls under the umbrella of SBASs. WAAS consists of a number of components, each integral and indispensable to the safe and efficient operation of the system. These components are:

- A network of pre-existing GPS satellites: As of December 2012, the entire constellation of (U.S.) GPS satellites numbered 32, of which only 24 are required for "reliable" coverage. Typically, at least nine of these satellites are visible from any point on the ground at any given time with four required for three-dimensional GPS position, and five considered to be the minimum to achieve WAAS capability.
- Ground Reference Station (GRS): These facilities initially became operational with 25 stations scattered mainly across U.S. territories. The GRSs are positioned to "see" all the GPS satellites over the United States at any given time and to monitor their GPS signals and data, looking for errors. As of January 2013, the number of GRSs stood at 38 (20 in the Continental United States, seven in Alaska, one each in Hawaii and Puerto Rico, four in Canada, and five in Mexico). With the exception of Indianapolis Center, each U.S. Air Traffic Control Center (ARTCC) hosts at least one GRS within its geographic boundaries. The data collected by the GRSs is sent to Master Ground Stations.
- Master Ground Station (MGS): The original MGSs (one on each U.S. coast) have since been supplemented with a third mid-continent station. The MGSs collect all data compiled by the GRSs and create GPS correction (augmentation) messages to address errors found in the GPS data. Those correction messages are sent to Ground Uplink Stations.
- Ground Uplink Station (GUS): The original three GUSs have now doubled in number to six. The GUSs uplink the correction messages from the MGSs to Geostationary Satellites.
- Geostationary Satellite (GEO): Unlike the primary GPS satellites, the GEOs orbit with the earth's rotation (rather than around the earth), allowing them to maintain the same geographic position above earth. The FAA leases transponder space on three GEOs (two being sufficient for full U.S. coverage). The GEOs send signal corrections to WAAS-capable receivers. They also send range information to those same receivers, thereby further increasing accuracy by acting as additional GPS satellites "in view."

To summarize, we now have a robust GPS satellite constellation and WAAS infrastructure, each with sufficient redundancy to reasonably assure normal operations, even during periods of specific component failures or scheduled maintenance. Nonetheless, GPS satellites are still subject to a number of errors which need assessment and augmentation. Potential errors include atmospheric and ionospheric disturbances, satellite orbit errors, timing errors (clock drift), and satellite malfunctions.

The Ground Reference Stations receive GPS signals similar to any GPS receiver, but are specifically looking for signal errors and collecting that data. The GRSs, in turn, send that data to the Master Ground Stations. The MGSs augment the GPS signals by creating error correction messages. The corrections are then sent to the geostationary satellites, via Ground Uplink Stations. The GEOs continuously send the corrective messages to the WAAS receivers in our aircraft, and apply the corrections to the standard GPS signals they are also receiving. The resultant output is highly-accurate GPS positional information, suitable for both vertical and horizontal guidance in terminal operations. WAAS receivers also incorporate automatic Receiver Autonomous Integrity Monitoring (RAIM) that refreshes five times per second. This enables the receivers to annunciate any integrity issues. When GPS signal degradations exist, an automatic downgrade in approach capability will occur. For example, when the GPS/WAAS signal will not support LPV, but is determined to be adequate for LNAV/VNAV, "L/VNAV" will annunciate, rather than "LPV," even if the approach has published LPV minima. In such cases, LNAV/VNAV minimums take precedence. While rare, this does happen in the real world and I have experienced it several times during WAAS approaches.

Several other nations have made significant progress in their own SBAS/WAAS systems. Several of those country's systems are planned to be compatible with the U.S. system, while others won't be. Canada and Mexico are already well underway in implementing WAAS approaches into their airspace systems. Japanese (Asian), European, Russian, Chinese and Indian systems are all in various stages of development/implementation.

WAAS Approaches and Operational Overview

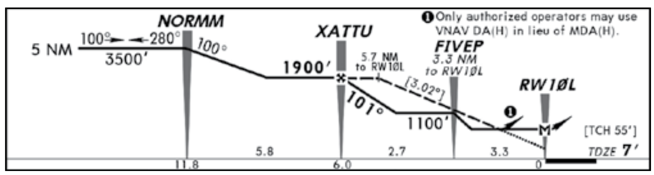
Initially, there were three primary types of WAAS approach procedures available to pilots with WAAS-certified navigation units (LPV, LNAV/VNAV, and LNAV). Those have since evolved in scope and, in some instances, in procedural aspects. Additionally, other WAAS type approaches have been subsequently introduced, as the system has expanded.

LNAV+V

The LNAV+V Approach (Lateral Navigation with for-reference-only glidepath) is a bit of an amalgamation. The LNAV portion represents the most basic level of WAAS-enabled approaches. The "+V" portion, however, is not part of the TERPS criteria or certification process for these terminal procedures. Rather, it is a glidepath that is generated by the WAAS navigator to give the pilot for-reference-only vertical guidance. "LNAV+V" is the way most WAAS navigators annunciate such an approach, but the corresponding line of minima on the approach plate will be either the "LNAV" line (on WAAS-enabled GPS approaches) or the Straight-In line on the rapidly disappearing stand-alone GPS approaches (more on those later). The "+V" does not influence the approach minimums and, thus, does not require a separate line of minima. It in no way allows the pilot to continue below published LNAV minimums without at least the minimum in-flight visibility and the runway environment in sight.

Initially, the computer-generated glidepath was basically just a slope between the Final Approach Fix (FAF) and the Missed Approach Waypoint (MAWP). On approaches with step-down fixes between the FAF and MAWP, this sometimes resulted in the glidepath crossing below minimum step-down fix altitude(s). The FAA and avionics manufacturers became aware of this and began reprogramming the computed vertical guidance to keep it at/above all minimum crossing altitudes inside of the FAF. This was done by changing the angle, usually resulting in a steeper glidepath, that is not intercepted until some distance inside of the FAF (assuming interception occurs at the minimum FAF crossing altitude). Jeppesen charts depict this glidepath and the intercept point in the profile view, while government charts make it less obvious (Figure 1). This improvement is an ongoing process and LNAV+V approaches that suffer from deceptive vertical guidance almost certainly still exist. Even with this for-reference-only-glidepath improvement project well underway, all "+V" vertical guidance is and will remain uncertified. Vigilance is required of the pilot to ensure that utilizing such information will not result in busting minimum crossing altitudes at published step-down fixes.

JEPPESEN CHART



GOVERNMENT CHART

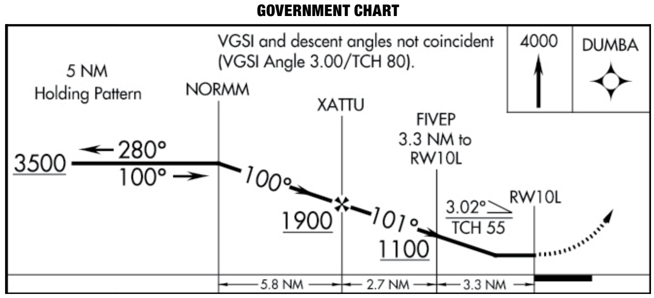
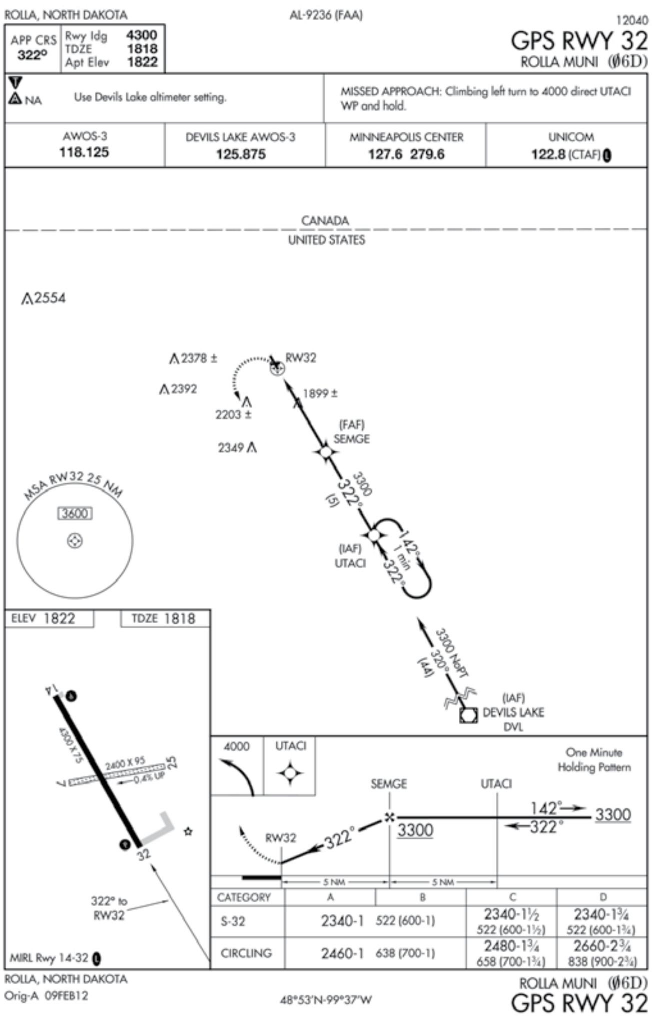


Figure 1: *The profile view of the San Francisco Int'l (KSFO) RNAV (GPS) 10L approach. In the Jeppesen version (top) the for-reference-only ("+V") glidepath is depicted with a dashed line between XATTU (FAF) and RW10L (MAWP). A delayed glidepath intercept point is specifically shown as being 5.7 NM to waypoint RW10L. This delayed intercept results in a steeper than standard glidepath (3.02°), but ensures the glidepath will cross the step-down fix (FIVEP) at/above the published minimum of 1100 feet. The government version (bottom) does not depict the +V glidepath at all, nor the precise point of intercept. The non-standard glidepath slope is noted, as is the fact that this slope is not coincident with the Visual Glideslope Indicator (VGSI) which, in this case, is a 3.00° PAPI, left of the runway. On the Jeppesen version, this VGSI note appears in the Notes section of the briefing strip, near the top of the full plate.*

Stand-Alone GPS

The stand-alone GPS approach is becoming rare, but still exists. These are GPS approaches that have not been surveyed and/or modified to meet WAAS criteria. They can be quickly identified in two ways: First, they are titled simply "GPS [Runway Number]" versus "RNAV (GPS) [Runway Number]." The RNAV title was originally introduced for early Area Navigation approaches, based on older technology avionics. As GPS has supplanted those technologies and become the default area-navigation source, it was decided that "RNAV" would become the universal term, covering most categories of GPS, WAAS, and RNP approaches. The second clue is the minimums section, which, if alignment and slope allow, will include a line for straight-in minimums (labeled "S-[runway number]") and circling minimums (Figure 2). No reference to LNAV exists on these approaches. Nonetheless, most WAAS navigators will interpret these

Figure 2: *The GPS 32 approach into Rolla, N.D. (06D). This non-WAAS approach is identified by the lack of "RNAV" in the procedure's title. Straight-in minimums are depicted as "S-32" rather than "LNAV," as well. The minima section of the Jeppesen version, is nearly indistinguishable from an RNAV/WAAS approach, with the only difference being whether "LNAV" appears above the MDA(H) altitude or not.*



procedures as LNAV GPS procedures and annunciate them as such. Additionally, if straight-in minimums exist, the WAAS navigator will often generate a for-reference-only glidepath and annunciate LNAV+V once the FAF becomes the active waypoint. As mentioned in the LNAV+V section, this glidepath is uncertified and should not be relied upon to ensure adherence to step-down fix minimum altitudes. In addition, because these stand-alone GPS approaches have not entered into the WAAS network at all, they would not be subject to any of the glidepath corrections discussed in the LNAV+V section. As a result, extra vigilance should be exercised when utilizing any glidepath generated for these procedures.

LP

The LP Approach (Localizer Performance with no vertical guidance) was not introduced during the initial phase-in of WAAS procedures, nor was it incorporated into the operational software of the initial cadre of WAAS-certified navigators. As such, most WAAS-equipped King Air aircraft do not currently include LP-capabilities.

The only way to know for sure that your GPS/WAAS receiver is LP certified and capable is via such a statement in the Flight Manual Supplement and/or Approved Supplemental Flight Manual(s). Beware that a navigator that is LPV-capable is not necessarily LP-capable. Of course, we know that King Air aircraft exist with a seemingly endless variety of avionics and navigation equipment packages. This includes fully integrated glass flightdecks (factory installed or via aftermarket STC) and a variety of WAAS-enabled GPS navigators from such popular manufacturers as Garmin. Some of those avionics manufacturers have developed newer software for their WAAS equipment in order to incorporate LP capabilities. For instance:

- The Garmin GNS Series (excluding the GNS-480) with system software Version 3.30 and subsequent are fully LP capable.
- Garmin G1000 Series (available in King Airs via STC) with system software Version 13.0 and subsequent are fully LP capable. As of this writing, Version 13.0 is only available in the Piper Seneca installation. It will become available in other G1000 applications dependent upon requests for LP capabilities from those specific aircraft manufactures (for OEM installations) or specific STC holders (for aftermarket installations).
- Garmin GTN Series with system software Version 2.0 and subsequent are fully LP capable.
- For other WAAS navigators and the various factory installed integrated avionics packages, contact Beechcraft and the specific avionics manufacturers to determine LP capability and software versions which may support such capabilities.

NOTE: Owner/operators should order or download the latest avionics manuals and manual supplements (to determine LP capability and to match currently installed software versions). Check with your aircraft and avionics manufacturers for ordering information or downloading links to such documents.

LP approaches are popping up in areas where LPV approaches are unable to meet the necessary criteria for certified vertical guidance due to terrain, obstructions, or conflicting airspace. LPs are more precise than LNAV approaches because they take advantage of angular lateral guidance (similar to a localizer without glideslope), rather than the linear lateral guidance of LNAV. This provides a narrower surface footprint to the lateral guidance, potentially excluding intrusive terrain and/or obstructions, allowing lower minimums than would be possible with the wider footprint of an LNAV course.

Most LP approaches should exist in WAAS navigator's databases (whether they contain LP capability or not) because most LP approaches also incorporate LNAV minima. (Note: There are a few exceptions, such as LP approaches that have no published LNAV minima and LP approaches which are introduced out of sync with database revision cycles.) How will non-LP-capable WAAS receivers operate if an RNAV approach with LP minimums is loaded and activated? Most non-LP WAAS navigators will recognize the approach as a basic LNAV-only procedure and treat it as such. They will often annunciate "LNAV+V" to indicate reception of a GPS/WAAS signal sufficient for LNAV terminal procedures and that the navigator itself will provide a for-reference-only glidepath. In all such cases, the pilot is authorized to utilize only the LNAV minima and to disregard the LP minima (Figure 3). Use of the for-reference-glidepath down to the LNAV Minimum Descent Altitude (MDA) is at the discretion of the pilot. In cases where a "+V" glidepath is not generated by the navigator, "LNAV" will be the annunciation and the same LNAV minimums apply.

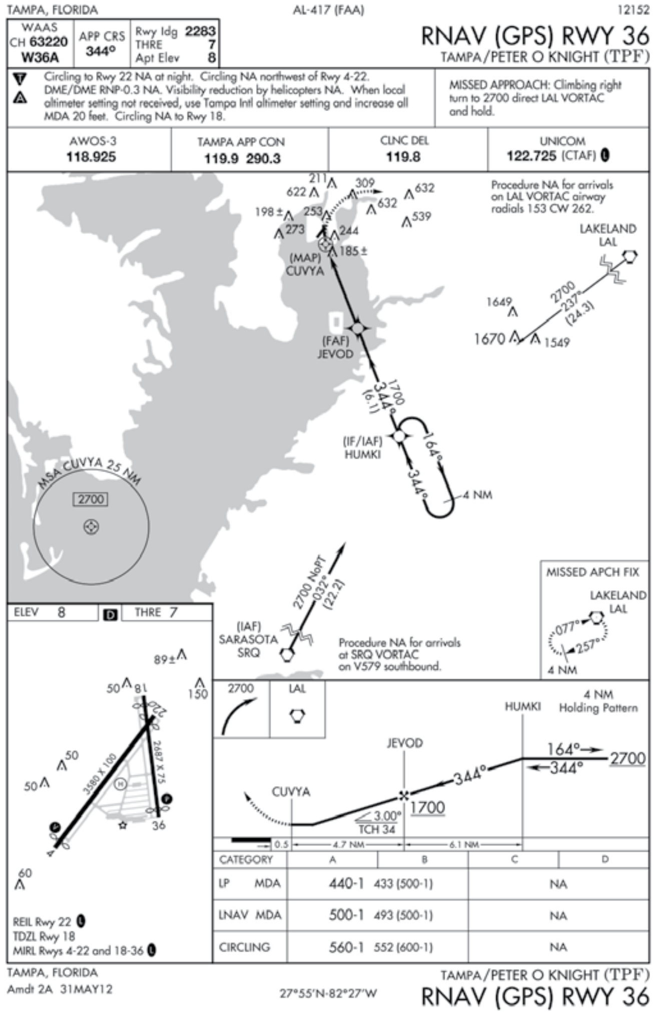


Figure 3: *Tampa/Peter O. Knight Airport's RNAV (GPS) 36 approach contains LP minimums. While the LP minimums offer a 60-foot advantage, many current-generation WAAS receivers do not have the capability (or the latest software updates) to support LP navigation. Those receivers will default to LNAV and will usually provide a for-reference-only glidepath, as well. With or without such a "+V" glidepath, the LNAV minimums are controlling for users of non-LP-capable GPS receivers.*

If your WAAS receiver is LP capable, and the satellite/WAAS signal strength is sufficient, it will annunciate "LP" when the FAF becomes the active waypoint. In addition, no glidepath (certified or otherwise) will be generated or displayed. Since WAAS navigators default to the highest level of service, LP will always supersede LNAV (or LNAV+V) when signal strength allows. Manually forcing the navigator to downgrade from LP to LNAV+V (in order to generate a for-reference-only glidepath) is not possible. There is no such animal as an LP+V, so bear in mind that LP approaches must be flown without vertical guidance and that the pilot will either have to apply old-school "dive and drive" techniques or manually calculate the necessary descent rates to utilize a "stabilized" approach technique. In the end, LP capability can be a catch-22 when compared to LNAV+V; more precise lateral guidance (always) and lower minimums (usually), but at the cost of vertical guidance.

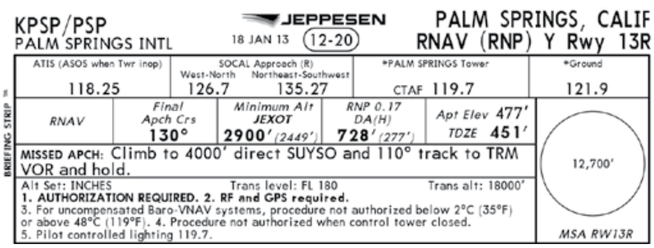
If you are considering an avionics upgrade in the near future, a good question to ask is whether the model you are considering has LP capability and/or GLS/LAAS capability (see below) and/or will be upgradable to such capabilities.

GLS and LAAS/GBAS

In true aviation fashion, GLS is an acronym within an acronym, initially referred to as the Global Navigation Satellite System (GNSS) Landing System. The Aeronautical Information Manual (AIM) now refers to GLS as the Ground Based Augmentation System (GBAS) Landing System. In the early evolution of GLS, Local Area Augmentation System (LAAS) was the popular term which encompassed GLS. ICAO now refers to LAAS as GBAS, thus the AIMs updating of its terminology (nonetheless, the LAAS term does appear on GLS approach plates).

Whatever acronym tongue twister you prefer, GLS is to GPS/WAAS approaches as Cat. II and III are to ILS approaches. In the very simplest terms, LAAS/GBAS can be thought of as an additional layer of GPS signal correction/augmentation, far more localized in nature than the wide area nature of WAAS. Basically, the already corrected WAAS signals would be further analyzed and augmented via localized ground stations, dedicated to a specific airport or multiple airports in relatively small geographic areas (20-30 mile radius). The result is ultra-high signal precision, allowing for precision approach procedures. The long-term intentions are for GLS to support capabilities for below 200 feet DAs, with very low visibility or Runway Visual Range (RVR) minimums; possibly even zero-zero auto-land capabilities. When such high precision GLS approaches become available, they will likely entail Special Aircraft And Aircrew Requirements (SAAAR). SAAAR notations have given way to the less verbose "Authorization Required" (AR) statement on many existing RNP approach plates, and I anticipate this will be the case with future GLS approaches containing less than 200 feet/half-mile minimums. Jeppesen charts place the AR statement within the *Notes* section, while government charts contain a bold AR statement below the minimums table (Figure 4).

JEPPESEN CHART



GOVERNMENT CHART

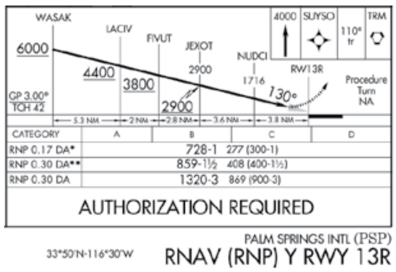


Figure 4: *The Palm Springs (KPSP) RNAV (RNP) Y 13R is an example of an Authorization Required (AR) approach. The Jeppesen plate (top) places the AR statement in the Notes section of the Briefing Strip (see Note 1). The government plate (bottom) prints a bold AR statement immediately below the minima section. As GLS approaches are developed with less than 200 feet and half-mile minimums, it is a good bet that AR limitations will apply to such procedures, as well.*

GLS was always in the grand plan for WAAS/LAAS capabilities. As such, initially, it was included as the top category in the minima section of approach plates, but with an "N/A" notation, indicating no such minimums yet existed. This was referred to as a "Placeholder" line (Figure 5). But GLS languished, while the approval of LPV approaches accelerated. Most approaches with GLS placeholder lines were LNAV/VNAV approaches, which were soon improved to LPV capabilities. The GLS placeholder line instead became the LPV minima line and the decision was made to publish GLS approaches as separate procedures, necessitating dedicated approach plates (Figure 6).

Thus far, most GLS approaches have typical Cat. I ILS minimums (200 feet and one-half mile or 2400 RVR). As the LAAS/GBAS systems, infrastructure, and procedures evolve and are validated, we can expect the network of GLS approaches to expand and for their minimums to decrease in inverse proportion to their increasing precision. As with LP approaches, your current WAAS-capable navigator cannot be assumed to also be GLS/LAAS/GBAS capable, as WAAS avionics development began several years ahead of LAAS. Only your approved aircraft and avionics manuals can tell you definitively if they are LAAS/GBAS capable and certified. Currently Boeing and Honeywell are the leading players in GLS-capable aircraft and avionics, but neither is likely to have a monopoly for long.

By the Numbers

Under the original proposal for WAAS approach procedure implementation, 8,900 WAAS-capable approaches were planned. That number represented the quantity of public-use runways at least 3,200 feet long in the United States. As of February 2013, the actual number of WAAS approach procedures had reached almost 12,800! The breakdown of those by specific type is as follows, from most precise to least precise (all numbers current as of February 7, 2013).

- GLS (GBAS Landing System, also known as LAAS): The new kid on the WAAS block is just getting out of the gate, with Newark Liberty (KEWR) and Houston Intercontinental (KIAH) airports as the first recipients. But it is poised to make a very big impact on U.S. aviation. Currently, 11 such approaches have been commissioned at those two airports. Eight of them have 200-foot DAs, while all but two have DAs of less than 250 feet.
- LPV Approach (Localizer Performance with Vertical guidance): From the beginning, the LPV was thought of as the GPS/WAAS equivalent of a standard ILS approach. The lateral guidance is at least as precise as a traditional localizer. The vertical guidance is to a Decision Altitude (DA) as low as a Cat. I ILS under ideal conditions and with appropriate airport infrastructure. By November 2008, LPV approaches outnumbered ILSs in the United States. LPV approaches have now reached a whopping 3,055 procedures (at 1,533 individual airports) and 768 of those have 200-foot DAs. Perhaps the best part is that 1,739 of those LPVs are at non-airline airports (1,268 of which do not have any ILS approaches). That is a massive increase in low-IFR capabilities for GA pilots.
- LNAV/VNAV Approach (Lateral and Vertical Navigation): In areas or situations where the stringent requirements for LPV cannot be met, but certified vertical guidance is still possible, the LNAV/VNAV approach is a worthy substitute. LNAV/VNAV procedures now number 2,939 (at 1,438 airports), with 1,626 of those procedures located at 972 non-airline airports.

CATEGORY	A	B	C	D
GLS PA DA	NA			
LNAV/VNAV DA	1380-1¼ 493 (500-1¼)			
LNAV MDA	1380-½ 493 (500-½)		1380-¾ 493 (500-¾)	1380-1 493 (500-1)
CIRCLING	1420-1¾ 533 (600-1¾)	1460-1¾ 573 (600-1¾)		1460-2 573 (600-2)

Figure 5: *The minimums section of a now-outdated RNAV (GPS) approach plate (government version). This LNAV/VNAV WAAS approach was one of the many that contained a "placeholder" line in the minima section for future GLS capability. Instead, most such approaches were upgraded to LPV capability and GLS approaches are now being published with dedicated approach plates instead.*

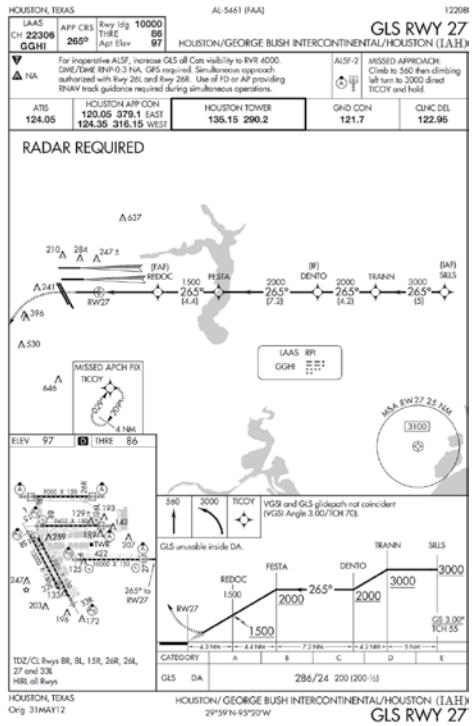


Figure 6: *Houston's Intercontinental Airport (KIAH) hosts several of the initial cadre of certified/published GLS approaches. No special authorization is required to fly a standard GLS, but GLS/LAAS-compatible navigation equipment is. This makes such approaches available to only a tiny segment of aircraft (for now). Also notice Notes 3 and 4: While certain simultaneous parallel approaches are authorized in conjunction with this GLS, participating in such operations requires both a flight director and an autopilot to be providing the RNAV track guidance. Keep a close eye on the development of GLS-capable avionics, as I expect they will become available for GA aircraft in the not-too-distant future.*

- LP (Localizer Precision with no vertical guidance): LPs opened the second generation of WAAS when the first LP was published at Peter O. Knight Airport (KTPF) in Tampa, Fla. in March 2011. In barely two years, they already number 413 procedures at 299 airports, including 357 procedures at 256 non-airline airports.
- LNAV (Lateral Navigation only) [may exist with or without a "+V" for-reference-only glidepath]: Most LNAV/VNAV, LP, and LPV approaches also include LNAV-only minima for situations of degraded GPS signal integrity. In those cases, the WAAS navigator will annunciate "LNAV" or "LNAV+V" (rather than "LPV," "LP," or "L/VNAV"), and LNAV minimums become controlling. Furthermore, many LNAV-only approaches exist in areas where the criteria for certified vertical guidance cannot be met. Currently, 5,619 such approaches exist (at 2,581 U.S. airports), with 3,840 of those procedures at 2,040 non-airline airports.
- Finally, we are left with the endangered stand-alone GPS approach. These procedures have been decreasing steadily as they are surveyed by the FAA and converted to RNAV approaches with LNAV minimums (and often further upgraded to LNAV/VNAV, LP, or LPV). They will continue to decrease in number as this replacement process drives them towards extinction. Currently, only 183 remain active at 139 airports, with the vast majority being at non-airline airports.

At the risk of sounding clichéd, WAAS has become a game-changer. Especially for general aviation pilots who regularly fly IFR to small airports (which previously had no vertical guidance approaches or, in many cases, no approaches at all). The recent expansions of the WAAS system will only serve to bolster that game-changing truth, particularly as LP and GLS-capable avionics (or upgrades) hit the market. The airlines still subsist mainly on traditional ILSs, with a handful now embracing the technology of RNP approaches (a topic for another time). Yet, within GA, we are experiencing versatility and capability that even the pilots flying big-iron are envious of. KA

About the Author: Matthew McDaniel is a Master & Gold Seal CFII, ATP, MEI, AGI, & IGI. In 22 years of flying, he has logged nearly 13,000 hours total, over 5,000 hours of instruction-given and over 2,500 in King Airs and the BE-1900D. As owner of Progressive Aviation Services, LLC *(www.progaviation.com)*, he has specialized in Technically Advanced Aircraft and Glass Cockpit instruction since 2001. Currently, he also flies the Airbus A-320 series for an international airline and holds six turbine aircraft type ratings. Matt is one of only 26 instructors in the world to have earned the Master CFI designation five consecutive times. He can be reached at *matt@progaviation.com* or (414) 339-4990.