The Use of Raw GPS for Vertical Navigation

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Biography

Andrew Graham is a project engineer with NAV CANADA's Satellite Navigation Program Office in Ottawa, Canada, where he is involved in data collection and flight trials in support!of GPS applications for aircraft. Mr. Graham holds an engineering degree from the University of Ottawa, a commercial pilot's licence and an instrument rating.

Abstract

The safety benefits of approaches with vertical guidance are well recognised, but this level of service is typically available only at major airports (with ILS) or to aircraft with sophisticated and costly avionics (Baro VNAV).

In May 2000, when selective availability was set to zero, GPS accuracy increased significantly. Ionospheric effects are now the major source of error, yet even at the height of the sunspot cycle, vertical accuracy in the order of 8.5 m (95%) is being observed.

Studies indicate that raw GPS, with suitable monitoring techniques, is able to meet the certification requirements for VNAV equipment, and in fact outperforms currently certified barometric VNAV systems in terms of accuracy and integrity.

Newer TSO C129a panel mount receivers are being designed with analogue hardware to support!VNAV, and the aviation databases already accommodate the parameters required to define a vertical path.

This paper investigates the concept of using raw GPS altitude data to provide vertical guidance, with integrity, on LNAV-only and LNAV/VNAV approaches.

Introduction

This paper explores the possibility of using the raw (unaugmented) GPS signal to provide vertical approach path guidance to aircraft that:

- are not equipped with SBAS (WAAS), GBAS (LAAS) or Baro VNAV avionics, and/or
- operate outside SBAS (WAAS) service areas (e.g. Northern Canada).

There is considerable pressure to bring the safety benefits of vertical guidance to all aircraft operators. Flight Safety Foundation studies indicate a fivefold reduction in the approach and landing accident rate for approaches with vertical guidance. The US NTSB, following its investigation of the Korean Air Flight 801 accident at Guam, recommended "*that all air carrier airplanes that have been equipped with on-board navigational systems capable of providing vertical flightpath guidance make use of these systems for flying nonprecision approaches whenever terrain factors allow a constant angle of descent with a safe gradient.*" And finally, the provision of vertical guidance is consistent with FAA safety initiatives, as expressed in the US Secretary of Transportation's Safety Summit and the FAA Administrator's "Safer Skies" initiative.

Improved safety would also result from the fact that the pilots would always follow the same general approach procedure, regardless of the type of approach flown.

There are also efficiency benefits. If all approaches have vertical guidance, the costs to train pilots and check their proficiency can be reduced significantly.

Concept

Recent observations suggest that the nominal (fault-free) vertical accuracy performance of raw GPS is as good as, or better, than that of certified Baro VNAV systems. This suggests that regulators evaluate the potential of raw GPS to bring vertical approach guidance (to support!LNAV/VNAV approaches) to virtually all aircraft.

To implement, a vertical path would be computed in the avionics, based on the vertical path angle (VPA), threshold coordinates, and threshold crossing height (TCH) or glide path intercept point (GPIP). Using the 3-D GPS position, deviations from this path would be presented on a vertical deviation indicator (VDI) while the aircraft is established on the final approach course.

Planned augmentation systems will provide a measure of vertical accuracy and integrity consistent with the level of service. While it is widely recognized that integrity must be assured in some form, one currently certified system, Baro VNAV, provides no such function.

GPS can deliver the accuracy necessary to support!operations up to and including LNAV/VNAV, while maintaining integrity through the application of appropriate baro monitoring methods.

Applicability

The concepts presented in this paper are applicable to operations with TSO C129a Class A1 (stand alone, approach capable) or B1 (integrated, approach capable) receivers, modified if necessary, and to TSO C145/146 (WAAS) receivers.

Background

The concept of using GPS for VNAV evolved from a study to determine if a low-cost baro encoder-serializer could be incorporated into a light aircraft to permit Baro VNAV operations. A GPS receiver, flat-panel display, DGPS truth system and data logging equipment were installed in a Cessna 172 aircraft. Preliminary flight trials suggested that a 2-sigma navigation system error (NSE) of about 40 feet was possible from the Baro VNAV device. NSE data from twelve approaches are shown in Figure 1.

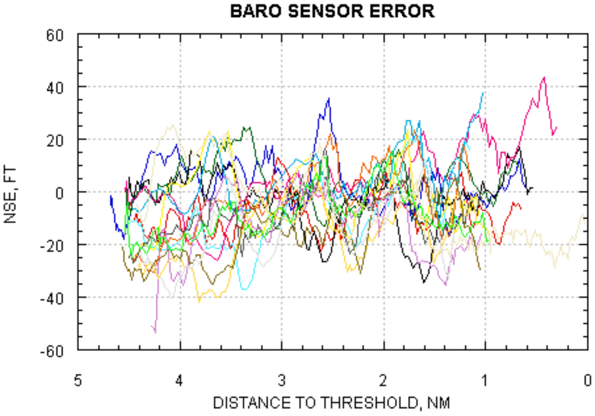

Figure 1: Baro Sensor Error

After selective availability (SA) was turned to zero, it was decided to investigate the possibility of using raw GPS as an integrity check of the barometric altitude. Subsequent flight trials showed that altitude data from raw GPS data were superior to those of the baro sensor in terms of accuracy, noise, and stability, as shown in Figure 2.

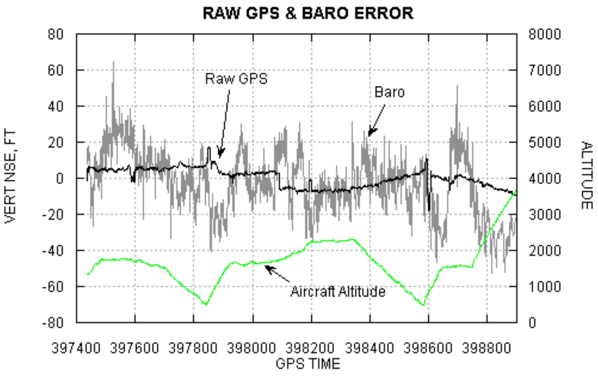

Figure 2: Raw GPS and Baro Error

These data show that the raw GPS vertical NSE remained within ±20 feet while the barometric altimeter error vertical NSE ranged from +65 feet to –50 feet. In addition to the larger values of the NSE, the barometric altimeter demonstrated significantly higher levels of noise than GPS.

As a result, the focus of the study was changed to assess the feasibility of providing GPS-based vertical guidance. This would require demonstrating that the accuracy and integrity of GPS are at least equivalent to certified barometric VNAV systems. The sections that follow compare GPS and baro vertical performance to the standard for VNAV systems.

Accuracy

The accuracy requirements for VNAV systems differ slightly, depending on the standards document. AC 20-129 calls for a navigation sensor error (NSE) of ±100', and suggests that flight technical error (FTE) has been demonstrated to be ±200'. These may be combined (RSS) to yield a total system error (TSE) of ±224'.

RTCA DO-236A specifies ±160' (based on RVSM-capable altimetry systems and avionics). For existing (non-RVSM) aircraft, the requirement is:

Altimetry ±140'
RNAV equipment ±100'
FTE: ±200'
Total (RSS): ±265'

All the accuracy requirements listed above are 99.7% values.

AC 90-97 notes that FTE of +100/-50 feet is acceptable.

A recent FAA report!shows the 95% and 99.99% raw GPS vertical accuracy (during a three month period, averaged over eight sites) to be 8.5 m (28') and 14.8 m (48') respectively. If we assume a Gaussian error distribution (this is supported by observation), a 99.7% (3σ) figure may be reasonably estimated to be in the order of 12 m (39'). When an analysis was performed selecting data collected during periods of significant solar activity, the 99.7% performance degraded to around 14 m (46').

A summary of the accuracy data from the study is reprinted below in Table 1 (all values are metres).

NSTB Site	95% Horiz	95% Vert	99.99% Horiz	99.99% Vert
Anderson	5.421	8.954	8.988	16.399
Atlantic City	6.228	8.708	9.892	15.753
Dayton	5.939	8.659	9.475	15.439
Elko	5.457	8.382	9.023	16.968
Great Falls	7.401	8.190	11.045	13.424
Oklahoma City	5.522	8.537	8.598	13.608
Kansas City	5.606	8.251	8.777	13.487
Salt Lake City	5.586	8.223	8.318	12.943

Table 1: Horizontal and Vertical Accuracy Statistics for the Quarter (source: FAA)

Data logging by NAV CANADA in Ottawa over a three month period showed performance consistent with the FAA observations.

Based on the observed performance, GPS meets the vertical accuracy requirements. On the other hand, ionospheric disturbances and satellite malfunctions may result in degraded GPS accuracy. Mitigation techniques must be used to ensure that pilots do not use hazardously misleading information (HMI). These have been developed and will be introduced later in this paper.

Barometric altimetry is susceptible to errors resulting from the fact that the properties of the atmosphere rarely correspond to the International Standard Atmosphere (ISA), the assumption under which altimeters are calibrated. The most significant of these is temperature, although much of the effect of non-standard temperatures may be removed using a simple compensation algorithm. It is unclear whether the accuracy requirements referenced earlier include temperature effects. However, without compensation, most of the error budgets would be spent on temperature-induced error alone. For example, when the ground temperature is -12°C (10°F), the true altitude of an aircraft flying at 1000' AGL would be 100 feet lower than indicated.

Errors may be introduced through other means. The following is an excerpt from a January, 1998 Aviation Notice published by NAV CANADA:

... NAV CANADA has become aware of a number of incorrect altimeter settings being reported from human surface weather observation sites. The problem is systemic, with apparent errors being detected on the average of once per day. Approximately 70% of these errors would have placed an aircraft lower than its indicated altitude, some by as much as 1000 feet.

There is also the possibility of blunder errors, where the pilot sets the altimeter incorrectly, or fails to reset the altimeter when necessary.

Pilots are required to check altimeter accuracy before takeoff. If the indicated altitude differs from aerodrome elevation by more than 75 ft (50 ft in Canada), the altimeter is considered out of tolerance. Biennial altimeter certification standards specify 20 ft, although this does not include additional effects such as friction and hysteresis. These figures suggest that a significant portion of the specified vertical accuracy has been allocated even before the start of the flight.

GPS is not susceptible to temperature effects or altimeter reporting or setting errors. Guidance along a vertical path using GPS is very reproducible from day to day. Normal GPS accuracy meets or exceeds the accuracy requirements for certified Baro VNAV. These facts make the use of GPS as an altitude source very compelling.

Integrity

The integrity function protects the pilot against using hazardously misleading information (HMI). In the context of this paper, hazard equates to flying too far below the nominal vertical path. SBAS (WAAS) and GBAS (LAAS) provide vertical integrity to support!approaches with vertical guidance, including precision approach. RAIM provides the integrity function for current non precision, or LNAV, approach operations using raw GPS, but RAIM applies only in the horizontal plane.

Two options for providing vertical integrity are presented for consideration. The first, pilot monitoring, is limited to applications that use LNAV approach design criteria. Basically, it classifies the vertical guidance as advisory only; the altimeter remains the primary vertical reference. Thus the pilot uses the vertical guidance as a tool to manage a constant descent, stabilized approach, while using the altimeter to ensure that stepdown altitudes are respected. The along-track position is used to determine the current applicable minimum altitude, for which RAIM provides the integrity. (This concept is currently being proposed for addition to DO-229C, with provision for an upgrade to existing TSO C129a receivers.)

Figure 3 illustrates the vertical profile that would be flown on an existing LNAV-only approach.

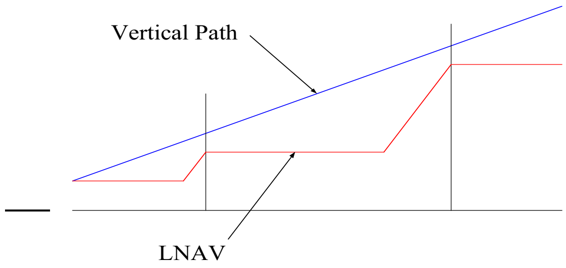

Figure 3: Vertical Profile

The pilot monitoring option works for LNAV because these approaches use an obstacle surface that is parallel to the ground; once past a stepdown waypoint, the pilot may descend immediately to the next published altitude. This technique would not be suitable for LNAV/VNAV approaches, which use an obstacle surface that slopes up and away from the runway threshold.

The second option uses a <u>GPS-baro comparitor</u> to provide continual integrity checks during flight. A barometric encoder (or encoding altimeter), interfaced to the GPS receiver, would provide baro data (the pilot would input the altimeter setting and probably the airport!temperature), which would be compared with the GPS-derived altitude. If these disagreed by more than a specified amount, the vertical would be flagged to alert the pilot. Aside from being automated, this technique has the advantage of using two altitude sources that are completely independent, and could be sufficiently robust to support!LNAV/VNAV procedures. Some measure of protection against altimeter setting errors might also be provided as a side benefit. This technique would be supplemented by the pilot cross-checking the published altitude at the final approach fix, as is done now on precision approaches.

The proposed WAAS LNAV/VNAV (APV 1) integrity standard calls for a 50 m Vertical Protection Limit (VPL). This means that the computed VPL must bound the actual error with a confidence of $1\text{-}10^{-7}$, and that the LNAV/VNAV level of service will be available when the VPL is less than 50 m. It is important to note that there is no requirement for the actual error to be less than 50 m. Rather, 10^{-7} refers to the probability of a missed integrity alert.

In the case of the GPS-baro comparitor concept, we may assess a measure of integrity by estimating the probability of HMI. For LNAV/VNAV, we wish to generate an alert, with a reliability of at least $1\text{-}10^{-7}$, when the GPS vertical error exceeds 50 m; HMI may be defined as the failure of such an alert occurring. Suppose we flag the vertical when the GPS and baro altitudes disagree by more than 25 m. (This number seems reasonable based on observed GPS and baro encoder errors.) We are now interested in the probability that the GPS error is at least 50 m (in the direction that places an aircraft too low) while the baro error is at least 25 m in the same direction. Integrity equivalent to a 50 m VPL is achieved when the probability of this occurring is less than 10^{-7}.

Assuming that the fault-free errors are Gaussian (for simplicity, we are in the position, rather than the pseudorange domain), and using conservative estimates of 9 m and 10 m for $\sigma_{GPS,z}$ and σ_{baro}, respectively,

$$P[Err_{GPS,z} > 50m] = \Phi(50/\sigma_{GPS,z}) = 1.38 \times 10^{-8}$$

$$P[Err_{baro} > 50m] = \Phi(25/\sigma_{baro}) = 0.0062$$

$$P[(Err_{GPS,z} > 50m) \text{ and } (Err_{baro} > 20m)] = 8.56 \times 10^{-11}$$

The GPS faulted condition needs to be considered as well.

The above analysis does not account for the fact that the ability to follow the desired vertical path depends on an accurate along-track position. Any along track error would be reflected in a vertical offset between the defined path and the desired path. This error, called the horizontal coupling error (HCE), is defined *as the vertical error resulting from horizontal along-track position estimation error coupling through the desired path* (DO-236).

For the purposes of this analysis, we are interested in bounding the vertical error, including the HCE component of vertical error. Based on the normal relationship between GPS horizontal and vertical error (from Table 1, the horizontal error averages 70% of the vertical error) we could expect that when the GPS-baro comparitor detects a 50 m error in the vertical, it is detecting a 35 m error in the horizontal. This would imply a negligible 1.8 m HCE (35 m x tan 3°). On the other hand, a malfunction in a low elevation satellite could conceivably result in a horizontal error that is significantly larger than the vertical error. If we rely on RAIM (in approach mode, with 0.3 NM HAL) to detect horizontal errors, then in the worst case (HPL = HAL = 0.3 NM), the HCE would be 29 m (0.3 NM x tan 3°). This would mean that in order to meet the 50 m requirement, an alert must be generated when the GPS vertical error cannot be guaranteed to be less than 21 m, unless the 29 m value can be reduced. Fortunately, with the baro comparitor, this should be achievable. To determine the expected reduction, it will be necessary to consider the likelihood of a satellite failure, not detected by the GPS Master Control Segment, that results a horizontal error that is significantly greater than the vertical error. (This implies a very low elevation satellite.) Specifically, we are interested in the joint probability of:

1. An along track component of the horizontal error > x, where x is the horizontal error corresponding to the maximum allowable HCE;
2. A small vertical error, undetectable by the baro comparitor;
3. No RAIM alert at the 0.3 NM level.

Intuitively, such a combination of conditions seems to be very unlikely, but this needs to be assessed formally.

Reduction of the 29 m HCE value could also be achieved by requiring a more stringent HAL for vertical guidance, or perhaps by making the GPS-Baro tolerance a function of the HPL.

Finally, a MITRE Corporation analysis showed that the probability of a horizontal error greater than 0.25 NM in the absence of a RAIM alert at the 2.0 NM (en route) level was in the order of 10^{-8}/hr. This study could be extended to consider the probability of a horizontal error greater than x (as defined above) with approach RAIM (0.3 NM).

As an example, if we consider that the HCE term can be reduced to 15 m (this implies a horizontal error of 0.16 NM), and we use $\sigma_{GPS,z} = 6$ and $\sigma_{baro} = 7$ estimated from observations, the probability of HMI becomes 2.1 x 10^{-10}. This represents the probability of a GPS vertical error exceeding 35 m and a baro error exceeding 10 m in the same direction. (The false alarm rate for this case is 7 x 10^{-4}.)

This overview is intended to suggest that the baro comparitor concept may be consistent with the requirements for LNAV/VNAV integrity. It is recognized, however, that considerably more investigation is required.

It should be pointed out, however, that the additional cost and effort!to develop and certify the GPS-baro comparitor may outweigh the incremental operational benefits of LNAV/VNAV versus LNAV-only.

Operational Concept

Similarly to existing approvals, the pilot would select and load the approach. For installations with a GPS-baro comparitor, a prompt to enter the local altimeter setting (as required) and, probably, the station temperature would occur as part of the GPS approach selection. Failure to input the required data would preclude the programming of an approach.

Once the aircraft was established on the intermediate or final segment, if a vertical path were defined in the database, ILS-type deviations would be presented to the pilot. The pilot would intercept the vertical path, ideally from below, and would fly a stabilized approach using the guidance provided.

Where a GPS-baro comparitor is not installed, it would be the pilot's responsibility to ensure that the aircraft did not follow a path that would violate any published altitudes. If it became apparent that such a violation would occur, the pilot would be required to maintain level flight at or above the applicable minimum altitude until passing the next stepdown waypoint.

Where a GPS-baro comparitor is installed, if a GPS-baro disagreement were detected, the vertical flag would be dropped, and the vertical guidance denied. The pilot would then be obliged to revert to the LNAV procedure and minima.

Workload

The programming of the GPS approach, including entering the local altimeter setting and temperature, would be accomplished, as it is now, a distance from the final approach area. This would be completed before the final approach begins.

Flying with vertical guidance, even with the pilot monitoring option, is analogous to current Baro VNAV operations, and is similar in task and workload to flying an ILS while monitoring the altimeter for the FAF crossing height.

Database Issues

Current C129a receivers do not require a vertical path to be defined, and there was some concern that the database cards would not contain the information necessary to determine the vertical path angle. However, some manufacturers have reserved database fields for the vertical path angle and threshold crossing height with an upgrade path to WAAS in mind. This means that it will not be necessary to maintain a separate set of database cards for VNAV-capable receivers.

The database information currently supplied to the manufacturers contains a vertical path angle, either defined by the State, or computed from minimum segment altitudes. The vertical path angle is set to zero for approaches where vertical guidance is inappropriate (eg. offset final approach segments). Threshold crossing heights are either supplied by the State, or defaulted to 50'.

Guidance Sensitivity/Scaling

In Baro VNAV operations, the vertical guidance is linear, with sensitivities varying among manufacturers and installations. The system used for the initial flight testing of the raw GPS concept used a combination of linear and angular guidance for both lateral and vertical, consistent with the specifications contained in DO-229 for WAAS receivers. This has proven quite satisfactory and has advantages over the purely linear implementation. First, the guidance has the "feel" of an ILS; there are definite human factors and training benefits to making the pilot interface as consistent as possible among all procedures. Second, making the guidance more sensitive with decreasing distance to threshold should reduce the FTE in the final approach segment, leaving more latitude in the error budget to accommodate potentially larger values of NSE.

Flight tests were conducted to assess various scaling options against the AC 90-97 FTE requirements. Four different methods of presenting the vertical guidance were investigated:

- linear throughout the approach, with a full-scale sensitivity of ±50 feet,;
- linear, but using ±100 feet FSD;
- scaling as defined in the WAAS MOPS (DO-229), i.e. angular, with FSD equal to 0.25 x VPA, or 0.75° in this case, becoming linear at the point where the angular full scale becomes ±50 feet;
- MOPS strategy, but switching to linear scaling at ±100 feet.

All flights were conducted in the C172, hand flown, in VFR conditions, during warm days with moderate thermal activity below 1000' AGL.

Once the aircraft was established on the vertical path, the +100/-50 foot FTE requirement was met using all four methods. The primary difference was flyability. The ±50' linear scaling was too sensitive; intercepting the vertical path was difficult, and oscillation often resulted from the fact that a relatively small vertical FTE caused a large VDI deflection.

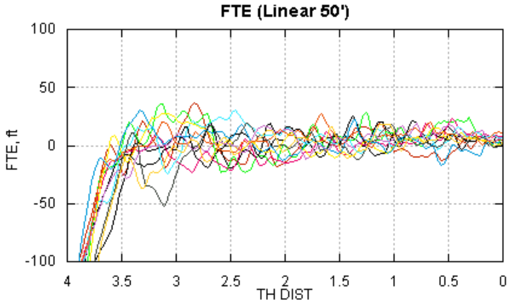

Figure 4: FTE (±50' Linear Scaling)

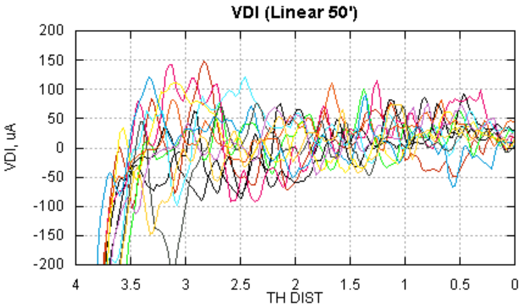

Figure 5: Vertical Deflection (±50' Linear Scaling)

The ±100' linear implementation was better, but the intercept was still a bit difficult.

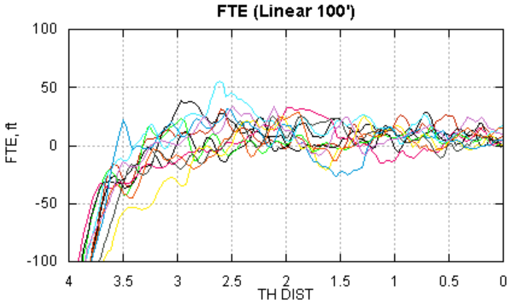

Figure 6: FTE (±100' Linear Scaling)

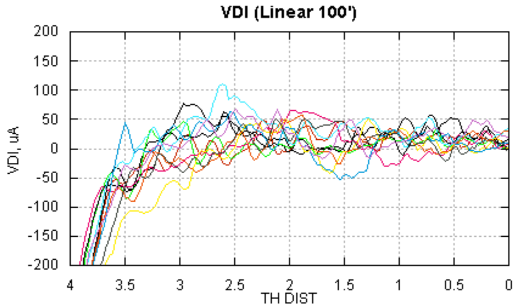

Figure 7: Vertical Deflection (±100' Linear Scaling)

The flyability using the MOPS scaling was more satisfactory. As expected from angular guidance, the FTE was somewhat higher at the start of the segment, but decreased closer to the runway. The angular guidance made intercepting the vertical path easier.

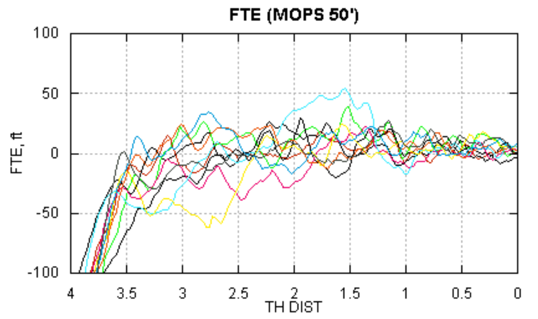

Figure 8: FTE (MOPS Scaling)

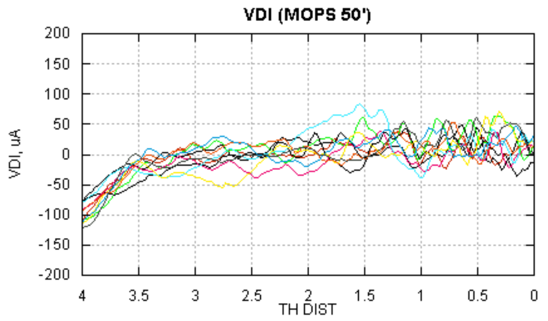

Figure 9: Vertical Deflection (MOPS Scaling)

One consequence of the higher sensitivities is that a higher display update rate is required. Flyability suffers with large, step changes to an analogue navigation display that is updated infrequently. C129a receivers are required only to maintain an update rate of 1 Hz, and it is not reasonable to expect current products to accommodate anything faster. Switching to linear guidance at FSD = ±50’ became a bit too sensitive to fly accurately with the 1 Hz update rate. However, the option that used ±100 feet as the maximum sensitivity worked well.

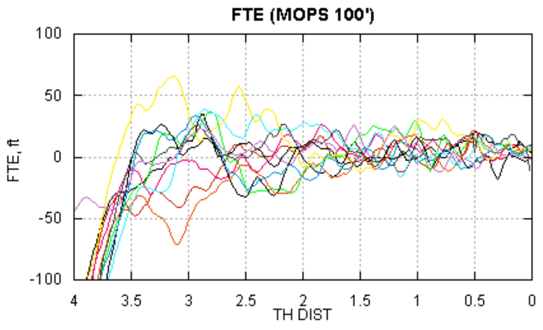

Figure 10: FTE (MOPS (±100’) Scaling)

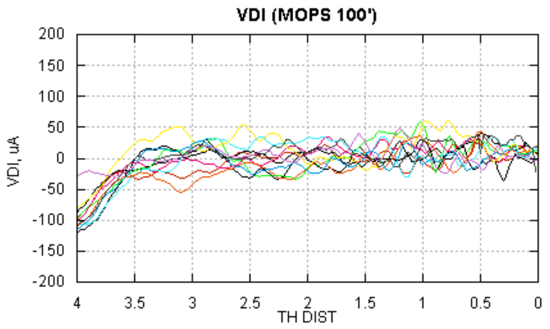

Figure 11: Vertical Deflection (MOPS (±100’) Scaling)

The FTE for the hybrid angular-linear scaling compares favourably with that of a typical ILS.

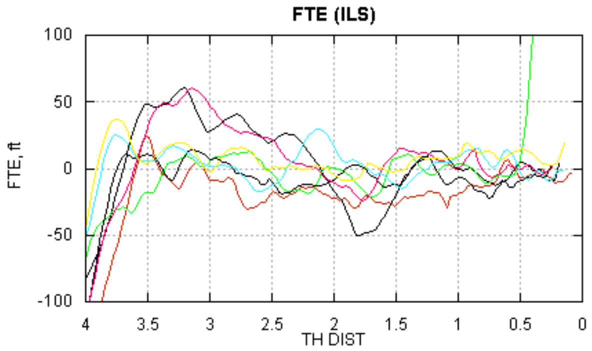

Figure 12: FTE Using ILS

It is recommended that some latitude be given to manufacturers to implement vertical guidance with due consideration to FTE and flyability. Future work may assess the linear ±150 feet sensitivity defined in AC 20-129. (Initial trials suggest that this would be satisfactory.) Also, perhaps AC 90-97 could be revisited to determine if the +100/-50 FTE requirement is necessary throughout the entire approach, or could be made a function of distance from the runway.

Blind Encoder Use

The idea of employing existing blind encoders (currently used with ATC transponders and for C129 baro aiding) is being investigated. These have the advantage of being inexpensive, already installed in most aircraft, and, in fact, already connected to many approach-capable receivers. The least significant bit of the encoder’s altitude output changes every 100 feet, at the 50-foot point. For example, at the instant that the encoder changes from 900 to 1000 feet, a pressure altitude of 950 feet can be inferred. Altimeter settings (and temperature compensation, as required) could then be applied, and the comparison with GPS altitude performed. Such a comparison would occur every 100 feet of descent. The

C172 system was modified to interface with the aircraft's encoder. Each time a change was detected in the encoder output, a data record containing the encoder altitude and differential GPS altitude was stored. This permitted the simulation of the GPS-baro integrity comparison proposed for LNAV/VNAV operations. The results of a flight test to assess the viability of this concept are shown in Figure 13. A series of climbs and descents was flown between 700 and 3000 feet ASL, as indicated by the upper line on the plot and the Y-axis on the right. The lower line, using the Y-axis on the left, shows the difference between the encoder altitude, corrected for altimeter setting and temperature, and the differential GPS truth altitude.

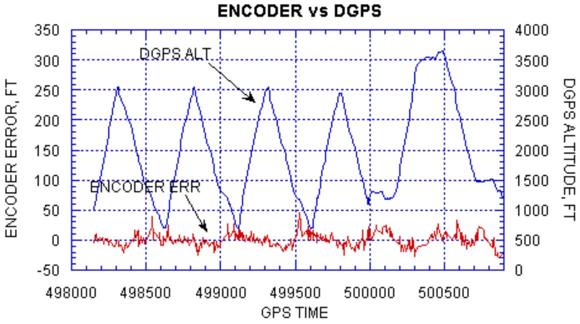

Figure 13: Encoder/DGPS Performance

FAR 43 specifies calibration procedures and specifications for altimeters and encoders. It should be noted that, to accommodate this application, encoders would require calibration to a tighter tolerance than is currently required. However, this is a simple procedure for any maintenance facility to accomplish.

Other Issues

There are a few technical and operational issues still to be considered.

- While the WAAS database specification requires that runway thresholds be defined using the height above the ellipsoid, current databases provide only the height above the geoid (i.e. ASL). Consequently, a model of the geoid must exist in the receivers, to convert between ellipsoidal and geoidal heights. These are typically based on a lookup table, and are subject to errors. While these are normally small enough to be ignored (less than a metre) some assessment is required to establish the maximum error that could be introduced. This will not apply to TSO C145/146 WAAS receivers.
- The effects of the update rate/guidance sensitivity issue on flight director and autopilot operation need to be considered. GPS velocity-based interpolation and smoothing of the vertical guidance may be possible, and perhaps necessary.

Conclusion

The benefits of providing vertical guidance on instrument approaches are well established. Accident rates could be reduced considerably through the provision of vertical guidance, resulting in a constant stabilized descent on all approaches. To date, this capability has existed only in the most sophisticated aircraft, but GPS technology makes this benefit available to all, with performance that meets or exceeds the requirements of current LNAV/VNAV (APV 1) systems.

The provision of higher levels of service, such as APV 2 (GLS) and Category 1 equivalent (GLS PA) will continue to require GBAS or SBAS. However, there is a role to play for Baro and GPS VNAV as a backup and in regions of the world where augmentation systems are not available.

In summary, the safety and operational benefits associated with the GPS-based vertical guidance make the concept worthy of further consideration and development.

Acknowledgement

The contribution of Mr. Ross Bowie, NAV CANADA Satellite Navigation Program Manager, for his ready guidance and feedback, is gratefully acknowledged.

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Appendix B – Acronyms and Abbreviations

AC	Advisory Circular
AIM	Aeronautical Information Manual
APV1	Approach with Vertical Guidance (Level 1 - VPL ~ 50)
APV 2	Approach with Vertical Guidance (Level 2 - VPL ~ 20)
AGL	Above Ground Level
ASL	Above Sea Level
ATC	Air Traffic Control
CDI	Course Deviation Indicator
CFIT	Controlled Flight Into Terrain
DA	Decision Altitude
FAA	(US) Federal Aviation Administration
FAF	Final Approach Fix
FAWP	Final Approach Waypoint
FMS	Flight Management System
FSD	Full Scale Deflection
FTE	Flight Technical Error
GBAS	Ground-Based Augmentation System (eg. LAAS)
GLS	GNSS Landing System (VPL ~ 20) (= ICAO APV 2)
GLS PA	GNSS Landing System (VPL ~ 12)
GNSS	Global Navigation Satellite System
GPIP	Glide Path Intercept Point
HAL	Horizontal Alert Limit
HCE	Horizontal Coupling Error
HMI	Hazardously Misleading Information
HPL	Horizontal Protection Level
IFR	Instrument Flight Rules
ILS	Instrument Landing System
ISA	International Standard Atmosphere
LAAS	Local Area Augmentation System
LNAV	Lateral Navigation
MAP	Missed Approach Point
MASPS	Minimum Aviation System Performance Standards
MDA	Minimum Descent Altitude
MOPS	Minimum Operational Performance Standards
NM	Nautical Mile(s)
NPA	Non Precision Approach
NSE	Navigation Sensor Error
NTSB	National Transportation Safety Board
RAIM	Receiver Autonomous Integrity Monitor
RNAV	Area Navigation
RNP	Required Navigation Performance
RVSM	Reduced Vertical Separation Minimum
RSS	Root Sum Square
SA	Selective Availability
SBAS	Space-Based Augmentation System (eg. WAAS)
TCH	Threshold Crossing Height
TSE	Total System Error
TSO	Technical Standard Order
VDI	Vertical Deviation Indicator
VFR	Visual Flight Rules
VNAV	Vertical Navigation
VPA	Vertical Path Angle
VPL	Vertical Protection Level
WAAS	Wide Area Augmentation System

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