17

Enhanced Situation Awareness

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17.1 Enhanced Ground Proximity Warning System

The Enhanced Ground Proximity Warning System (EGPWS)* is one of the newest systems becoming standard on all military and civilian aircraft. Its purpose is to help provide situational awareness to terrain and to provide predictive alerts for flight into terrain. This system has a long history of development and its various modes of operation and warning/advisory functionality reflect that history:

- Controlled Flight Into Terrain (CFIT) is the act of flying a perfectly operating aircraft into the ground, water, or a man-made obstruction. Historically, CFIT is the most common type of fatal accident in worldwide flying operations.
- Analysis of the conditions surrounding CFIT accidents, as evidenced by early flight recorder data, Air Traffic Control (ATC) records, and experiences of pilots in Controlled Flight Towards Terrain (CFTT) incidents, have identified common conditions which tend to precede this type of accident.
- Utilizing various onboard sensor determinations of the aircraft current state, and projecting that state dynamically into the near future, the EGPWS makes comparisons to the hazardous conditions known to precede a CFIT accident. If the conditions exceed the boundaries of safe operation, an aural and/or visual warning/advisory is given to alert the flight crew to take corrective action.

*There are other synonymous terms used by various government/industry facets to describe basically the same equipment. The military (historically at least) and at least one non-U.S. manufacturer refer to GPWS and EGPWS as Ground Collision Avoidance Systems (GCAS), although the military is starting to use the term EGPWS more frequently. The FAA, in its latest regulations concerning EGPWS functionality, have adopted the term Terrain Awareness Warning System (TAWS).

17.2 Fundamentals of Terrain Avoidance Warning

The current state of the aircraft is indicated by its position relative to the ground and surrounding terrain, attitude, motion vector, accelerations vector, configuration, current navigation data, and phase of flight. Depending upon operating modes (see next section) required or desired, and EGPWS model and complexity, the input set can be as simple as GPS position and pressure altitude or fairly large including altimeters, air data, flight management data, instrument navigation data, accelerometers, inertial references, etc. (see Figure 17.1.)

The primary input to the "classic" GPWS (nonenhanced) is the Low Range Radio (or Radar) Altimeter (LRRA), which calculates the height of the aircraft above the ground level (AGL) by measuring the time it takes a radio or radar beam directed at the ground to be reflected back to the aircraft. Imminent danger of ground collision is inferred by the relationship of other aircraft performance data relative to a safe height above the ground. With this type of system, level flight toward terrain can only be implied by detecting rising terrain under the aircraft; for flight towards steeply rising terrain, this may not allow enough time for corrective action by the flight crew.

The EGPWS augments the classic GPWS modes by including in its computer memory a model of the earth's terrain and man-made objects, including airport locations and runway details. With this digital terrain elevation and airports database, the computer can continuously compare the aircraft state vector to a virtual three-dimensional map of the real world, thus predicting an evolving hazardous situation much in advance of the LRRA-based GPWS algorithms.

The EGPWS usually features a colored or monochrome display of terrain safely below the aircraft (shades of *green* for terrain and *blue* for water is standard). When a potentially hazardous situation exists,

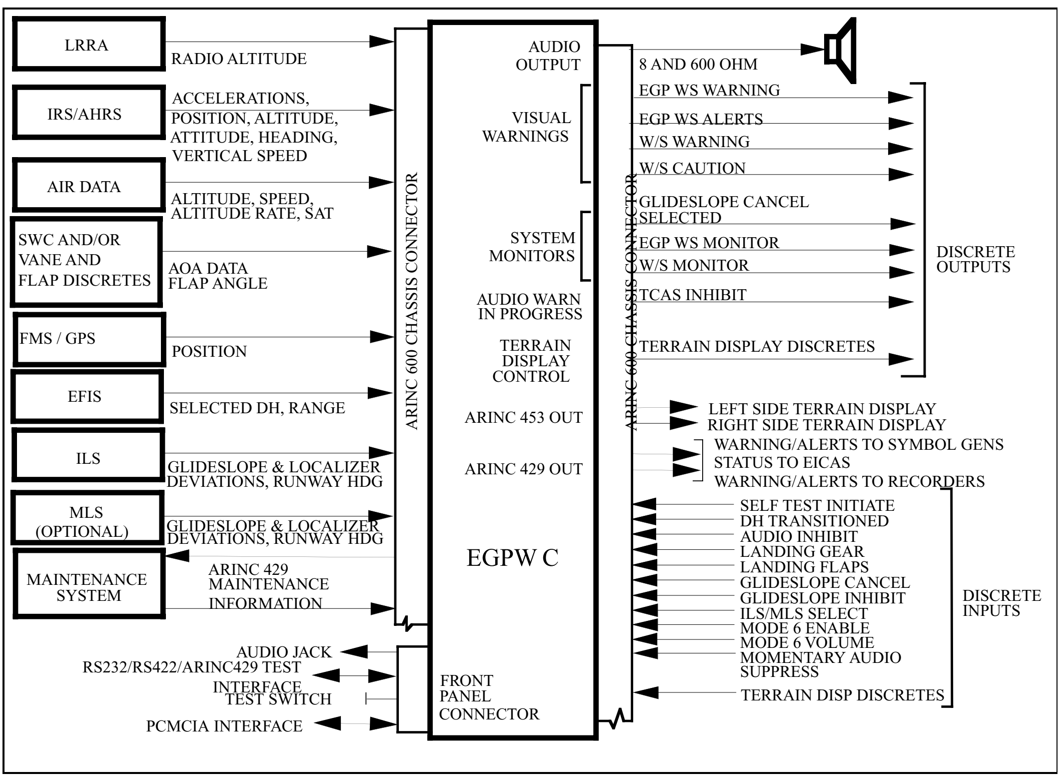

FIGURE 17.1 Typical air transport EGPWS installation.

the EGPWS alerts the flight crew with aural and/or visual warnings. Advisory (informative) situational awareness information may consist simply of an aural statement, for example, "One Thousand," as the aircraft height AGL passes from above to below 1000 ft. Cautionary alerts combine an informative aural warning, e.g., "Too Low Flaps" for flying too low and slow without yet deploying landing flaps, with a *yellow* visual alert. The cautionary visual alert can be an individual lamp with a legend such as "GPWS" or "TERRAIN;" it can be a yellow text message displayed on an Electronic Flight Instrument System (EFIS) display; or, in the case of the enhanced alert with a display of surrounding terrain, the aural "CAUTION TERRAIN" or "TERRAIN AHEAD," accompanied by both a *yellow* lamp and a rendering of the hazardous terrain on the display in *bright yellow*.

When collision with terrain is imminent and immediate drastic recovery action must be taken by the flight crew to avert disaster, the standard aural alert is a loud, commanding "PULL UP" accompanied by a *red* visual alert. Older aircraft with no terrain display utilize a single red "pull up" lamp; modern EFIS-equipped aircraft put up the words PULL UP in bright red on the Primary Flight Display (PFD). On the display of surrounding terrain, usually integrated on the EFIS Horizontal Situation Indicator, the location of hazardous terrain turns *bright red.**

17.3 Operating Modes

The various sets of hazardous conditions that the EGPWS monitors and provides alerts for are commonly referred to as **Modes**.** These are described in detail in the following paragraphs.

Modes 1 through 4 are the original classic GPWS modes, first developed to alert the pilots to unsafe trajectory with respect to the terrain. The original analogue computer model had a single red visual lamp and a continuous siren tone as an aural alert for all modes. Aircraft manufacturer requirements caused refinement to the original modes, and added the voice "Pull Up" for Modes 1 through 4 and a new Mode 5 "Glideslope". Mode 6 was added with the first digital computer models about the time of Boeing 757/767 aircraft introduction; and Mode 7 was added when windshear detection became a requirement in about 1985.***

The latest addition to the EGPWS are the Enhanced Modes: Terrain Proximity Display, Terrain Ahead Detection, and Terrain Clearance Floor. For many years, pilot advocates of GPWS requested that Mode 2 be augmented with a display of approaching terrain. Advances in memory density, lower costs, increased computing power, and the availability of high-resolution maps and Digital Terrain Elevation Databases (DTED) enabled this advancement. Once displayable terrain elevation database became a technical and economic reality, the obvious next step was to use the data to *look ahead* of the aircraft path and predict terrain conflict well before it happened, rather than waiting for the downward-looking sensors.

Combining the DTED with a database of airport runway locations, heights, and headings allows the final improvement — warnings for normal landing attempts where there is no runway.

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*Note that all of the EGPWS visual indication examples in this overview discussion are consistent with the requirements of FAR 25.1322.

**The EGPWS modes described here are the most common for commercial and military transport applications. Not discussed here are more specialised warning algorithms, more closely related to terrain-following technology, that have been developed for military high-speed low-altitude operations. These are more related to advanced terrain database guidance, which is outside the scope of enhanced situation awareness function.

***Though not considered CFIT, analysis of windshear-related accidents has resulted in the development of reactive windshear detection algorithms. At the request of Boeing, their specific reactive windshear detection algorithm was hosted in the standard commercial GPWS, about the same time the 737-3/4/500 series aircraft was developed. By convention this became Mode 7 in the GPWS. The most common commercially available EGPWS computer contains a Mode 7 consisting of both Boeing and non-Boeing reactive windshear detection algorithms, although not all aircraft installations will use Mode 7. There also exist "standalone" reactive windshear detection computers; and some aircraft use only predictve wind shear detection, which is a function of weather radar.

17.3.1 Mode 1 — Excessive Descent Rate

The first ground proximity mode warns of an excessive descending barometric altitude rate near the ground, regardless of terrain profile. The original warning was a straight line at 4000 ft/min barometric sinkrate, enabled at 2400 ft AGL, just below the altitude at which the standard commercial radio altimeters came into track (2500 ft AGL). This has been refined over the years to a current standard for Mode 1 consisting of two curves, an outer cautionary alert and a more stringent inner warning boundary. Exceeding the limits of the outer curve results in the voice alert "Sinkrate;" exceeding the inner curve results in the voice alert "Pull Up."

Figure 17.2 illustrates the various Mode 1 curves, including the current standard air transport warnings, the DO-161A minimum warning requirement, the original curve and the Class B TSO C151

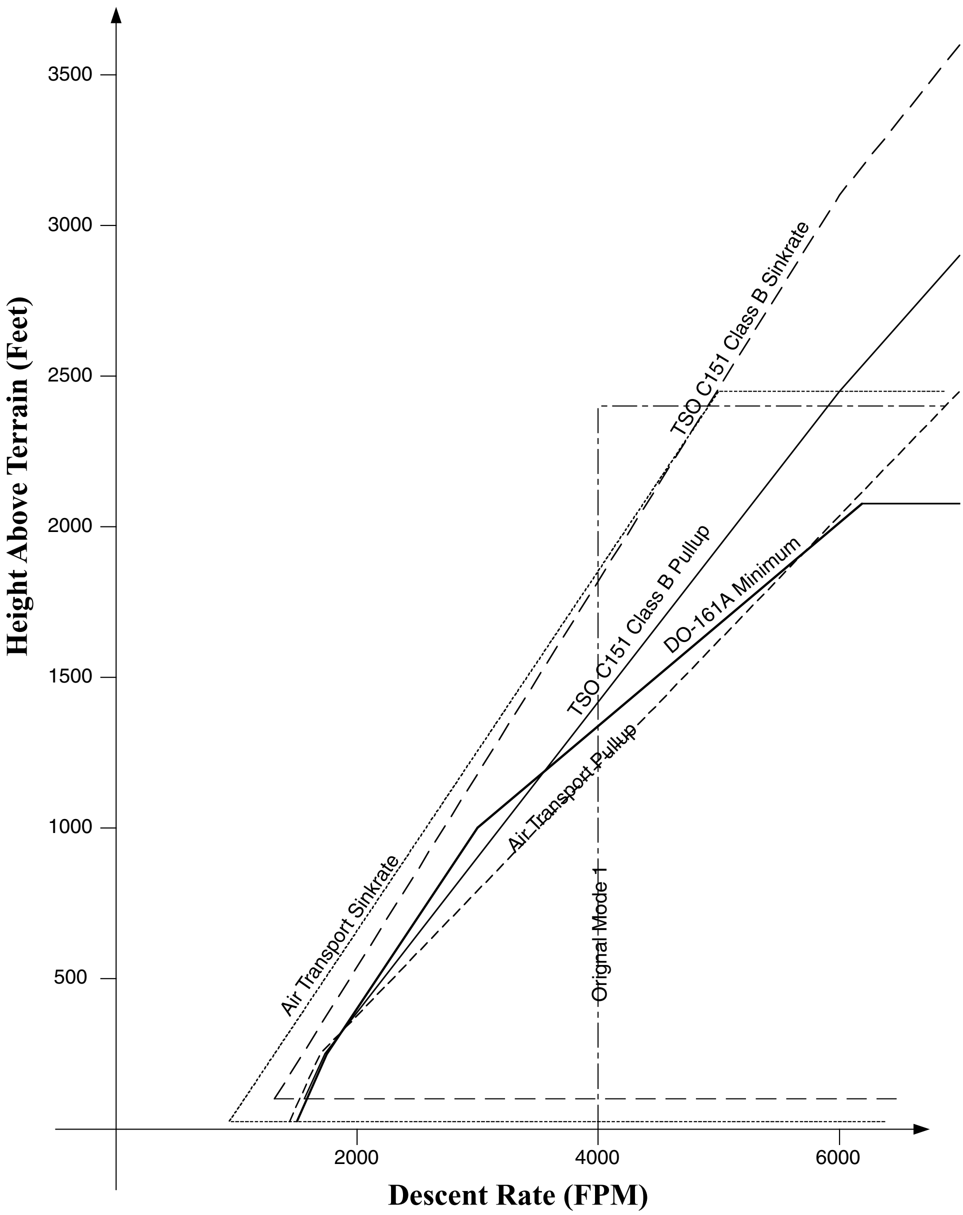

FIGURE 17.2 Mode 1 warning curves.

curves for 6 to 9 passenger aircraft and general aviation. Note that the Class B curves, which use GPS height above the terrain database instead of radio altitude are not limited to the standard commercial radio altimeter range of 2500 ft AGL.

17.3.2 Mode 2 — Excessive Closure Rate

Rate-of-change of radio altitude is termed the closure rate, with the positive sense meaning that the aircraft and the ground are coming closer together. When the closure rate initially exceeds the Mode 2 warning boundary, the alert "Terrain Terrain" is given. If the warning condition persists, the voice is changed to a "Pull Up" alert.

Closure rate detection curves are the most difficult of the classic GPWS algorithms to design. Tall buildings, towers, trees, and rock escarpments in the area of final approach can cause sharp spikes in the computed closure rate. Modern Mode 2 algorithms employ complex filtering of the computed rate, with varying dynamic response dependent upon phase of flight and aircraft configuration. The Mode 2 detection algorithm is also modified by specific problem areas by using latitude, longitude, heading, and selected runway course — a technique in the EGPWS termed "Envelope Modulation."

Landing configuration closure rate warnings are termed Mode 2B; cruise and approach configurations are termed Mode 2A. Figure 17.3 illustrates some of the various Mode 2A curves, including the original first Mode 2 curve, the current standard air transport Mode 2A "Terrain-Terrain-Pull-Up" warning curve, and the DO-161A nominal Mode 2A warning requirement. Note that the Class B TSO C151 EGPWS does not use a Radio Altimeter and therefore has no Mode 2.

17.3.3 Mode 3 — Accelerating Flight Path Back into the Terrain after Take-off

Mode 3 (Figure 17.4) is active from liftoff until a safe altitude is reached. This mode warns for failure to continue to gain altitude. The original Mode 3, still specified in DO-161A as Mode 3A, produced warnings for any negative sinkrate after take-off until 700 ft of ground clearance was reached. The mode has since been redesigned (designated 3B in DO-161A) to allow short-term sink after take-off but detect a trend to a lack of climb situation. The voice callout for Mode 3 is "Don't Sink." This take-off mode now remains active until a time-integrated ground clearance value is exceeded; thus allowing for a longer protection time with low-altitude noise abatement maneuvering before climb-out.

Altitude loss is computed by either sampling and differentiating altitude MSL or integrating altitude rate during loss of altitude. Because a loss is being measured, the altitude can be a corrected or uncorrected pressure altitude, or an inertial or GPS height. Typical Mode 3 curves are linear, with warnings for an 8-ft loss at 30 ft AGL, increasing to a 143-ft loss at 1500 ft AGL.

17.3.4 Mode 4 — Unsafe Terrain Clearance Based on Aircraft Configuration

The earliest version of Mode 4 was a simple alert for descent below 500 ft with the landing gear up. Second generations of Mode 4 added additional alerting at lower altitudes for flaps not in landing position. The warning altitude for flaps was raised to the 500-ft level for higher descent rates. There are three of these types of Mode 4 curves still specified as alternate minimum performance requirements in DO-161A (see Figure 17.5).

Modern Mode 4 curves are airspeed-enhanced, rather than descent rate alone, and for high airspeeds will give alerts at altitudes up to 1000 ft AGL.

Currently, EGPWS Mode 4 has three types of alerts based upon height AGL, mach/airspeed, and aircraft configuration, termed Modes 4A, 4B, and 4C (Figure 17.6). Two of the curves (4A, 4B) are active during cruise until full landing configuration is achieved with a descent "close to the ground" — typically 700 ft for a transport aircraft. Mode 4C is active on take-off in conjunction with the previously described

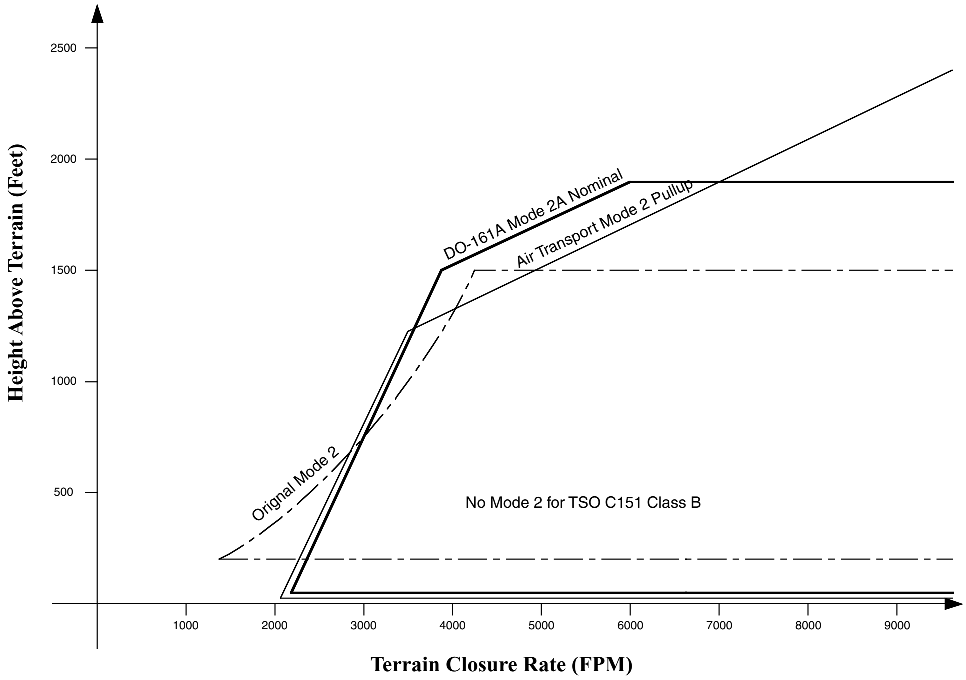

FIGURE 17.3 Mode 2 curves.

Mode 3. All three alerts are designed with the intent to warn of flight "too close to the ground" for the current speed/configuration combination. At higher speeds, the alert commences at higher AGL and the voice alert is always "Too Low Terrain." At lower speeds, Mode 4A warning is "Too Low Gear" and the Mode 4B warning is "Too Low Flaps."

Mode 4C compliments Mode 3, which warns on an absolute loss of altitude on climb-out, by requiring a continuous gain in height above the terrain. If the aircraft is rising, but the terrain under is also rising, Mode 4C will alert "Too Low Terrain" on take-off if sufficient terrain clearance is not achieved prior to Mode 3 switching out.

17.3.5 Mode 5 — Significant Descent Below the ILS Landing Glide Path Approach Aid

This Mode warns for failure to remain on an instrument glide path on approach. Typical warning curves alert for 1.5 to 2.0 dots below the beam, with a wider divergence allowed at lower altitudes. The alerts and warnings are only enabled when the crew is flying an ILS approach, as determined by radio frequency selections and switch selection. Most installations also include separate enable switch and a warning cancel for crew use when flying some combination of visual and or other landing aids and deviation from the ILS glide path is intentional. Although the mode is typically active from 1000 ft AGL down to about 30 ft, allowance in the design of the alerts must also be made for beam capture from below, and level maneuvering between 500 and 1000 ft without nuisance alerting.

Figure 17.7 illustrates the Mode 5 warnings for a typical jet air transport. When the outer curve is penetrated, the voice message "Glideslope" is repeated at a low volume. If the deviation below the beam increases or altitude decreases, the repetition rate of the voice is increased. If the altitude/deviation combination falls within the inner curve, the voice volume increases to the equivalent of a warning message and the repetition rate is at maximum.

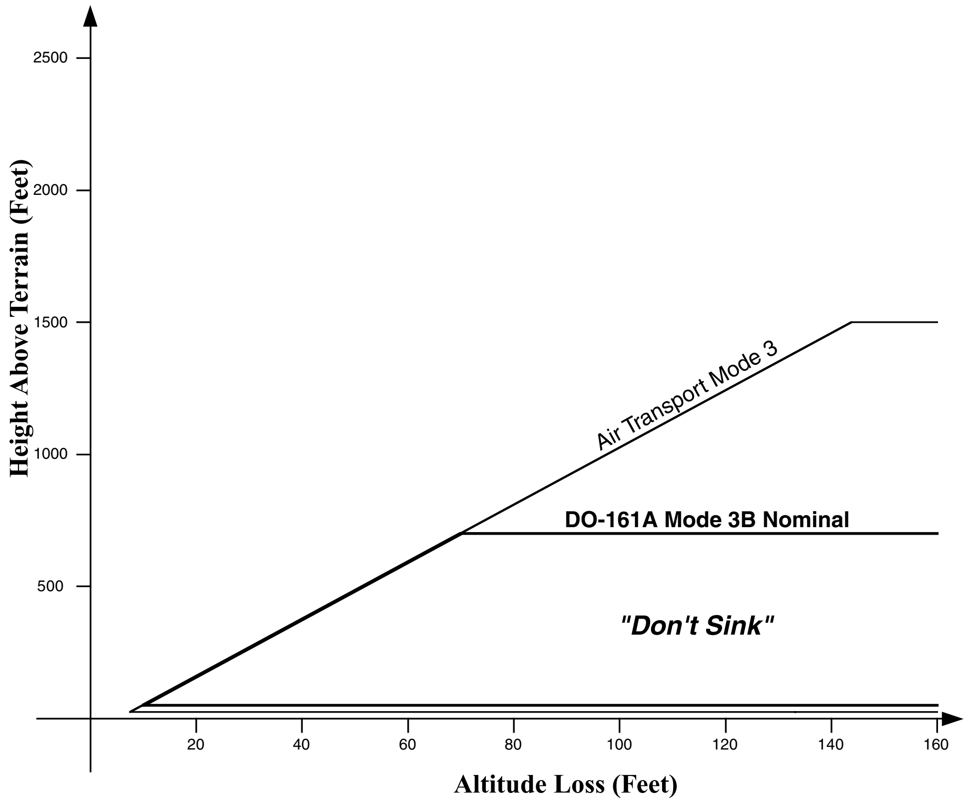

FIGURE 17.4 Mode 3 curves.

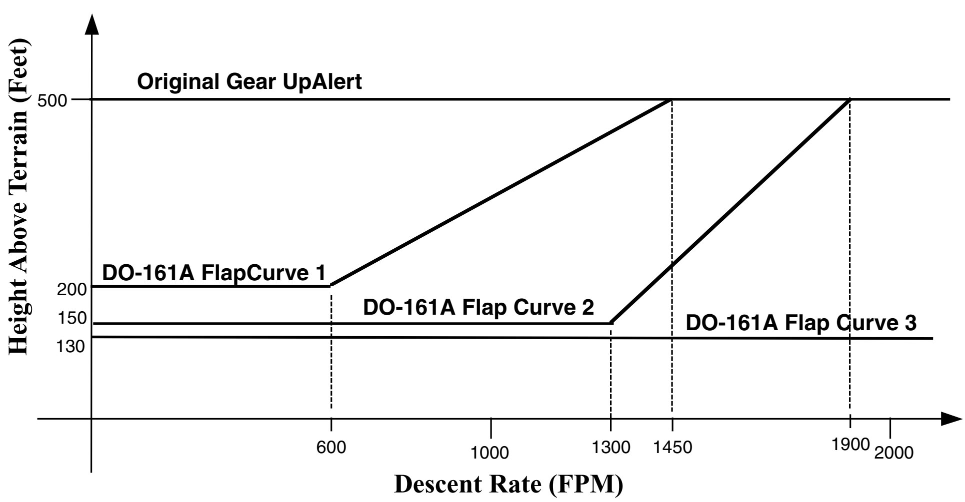

FIGURE 17. 5 Old GPWS Mode 4 curves.

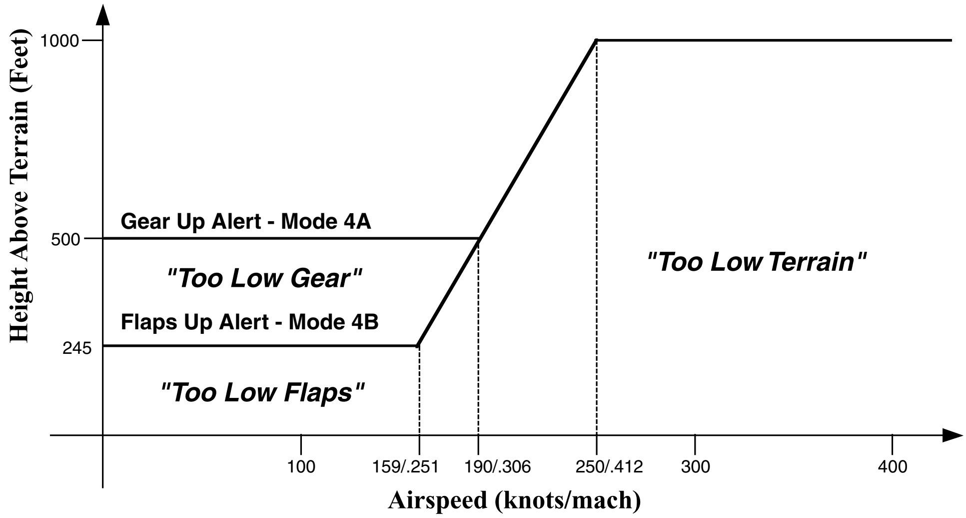

FIGURE 17.6 EGPWS Mode 4.

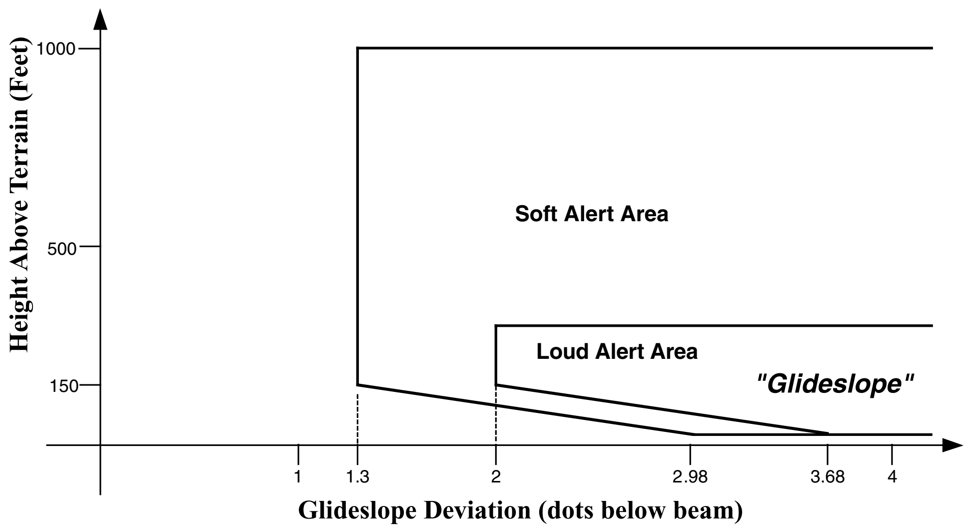

FIGURE 17.7 EGPWS Mode 5.

17.3.6 Mode 6 — Miscellaneous Callouts and Advisories

The first application of this Mode consisted of a voice alert added to the activation of the decision height discrete on older analog radio altimeters. This voice alert is "Minimums" or "Decision Height," which adds an extra level of awareness during the landing decision point in the final approach procedure. Traditionally, this callout would be made by the pilot not flying (PNF). Automating the callout frees the PNF from one small task enabling him to more easily monitor other parameters during the final approach.

This mode has since been expanded as a "catch all" of miscellaneous aural callouts requested by air transport manufacturers and operators, many of which also were normally an operational duty of the PNF (see Figure 17.8). In addition to the radio altitude decision height, callouts are now available at barometric minimums, at an altitude approaching the decision height or barometric minimums, or at various

Callout Voice	Description
Radio Altimeter	Activates at 2500 feet as radio altimeter comes into track
Twenty five hundred	(alternate to Radio Altimeter)
One Thousand	Activates at 1000 feet AGL
Five Hundred (smart)	Activates at 500 feet AGL for non-precision approaches only
One Hundred	Activates at 100 feet AGL
Fifty	50 feet AGL
Forty	40 feet AGL
Thirty	30 feet AGL
Twenty	20 feet AGL
Ten	10 feet AGL
Approaching Minimums	100 feet above the selected decision height
Minimums	At pilot selected decision height – may be AGL or barometric
Decision Height	(alternate to Minimums)

FIGURE 17.8 Examples of EGPWS Mode 6 callouts.

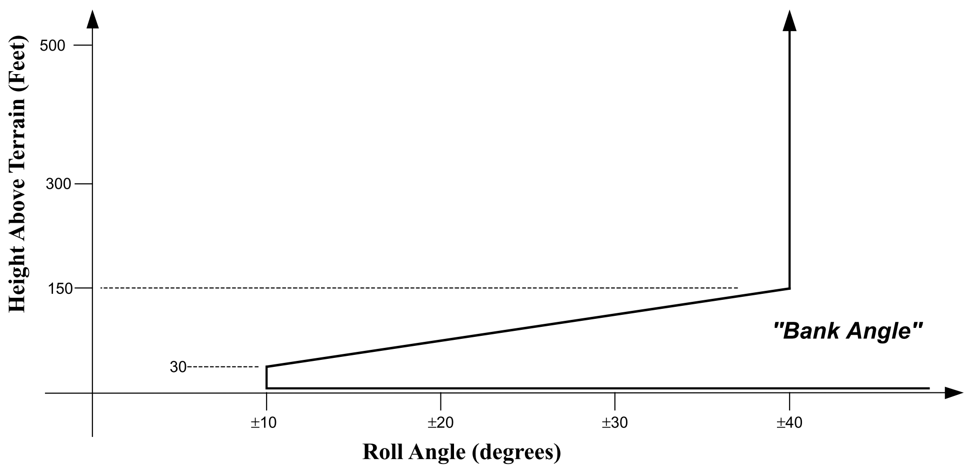

FIGURE 17.9 EGPWS Mode 6 overbank (excessive roll) alert.

combinations of specific altitudes. There are also "smart callouts" available, that only call the altitude for nonprecision approaches (ILS not tuned). The EGPWS model used on Boeing aircraft will also callout for V_1 on take-off and give aural "engine out" warnings. Finally, included in the set of Mode 6 callouts are warnings of overbanking (excessive roll angle).

17.3.7 Mode 7 — Flight into Windshear Conditions

Windshear is a sudden change in wind direction and/or windspeed over a relatively short distance in the atmosphere and can have a detrimental effect on the performance of an aircraft. The magnitude of a windshear is defined precisely in engineering terms by the sum of the rate of change of horizontal wind, and the vertical wind divided by the true airspeed of the aircraft:

$$F = -\left(\frac{w_{\text{wind}}}{V_A} + \frac{\dot{u}_{\text{wind}}}{g}\right)$$

where

F is expressed in units of g and is positive for increasing energy windshears

w_{wind} = vertical wind velocity (fps), positive for downdrafts

$\dot{u}_{\text{wind}} = \frac{du_{\text{wind}}}{dt}$ = rate of change of horizontal wind velocity

V_A = true airspeed (fps)

g = gravitational acceleration, 32.178 fps^2

There are various techniques for computing this windshear factor from onboard aircraft sensors (air data, inertial accelerations, etc.). The EGPWS performs this computation and alerts the crew with the aural "Windshear, Windshear, Windshear," when the factor exceeds predefined limits as required by TSO C117a.

17.3.8 Envelope Modulation

Early GPWS equipment was plagued by false and nuisance warnings, causing pilots to distrust the equipment when actual hazardous conditions existed. Many approach profiles and radar vectoring situations violated the best-selected warning curve designs. Even as GPWS algorithms were improved, there still existed some approaches that required close proximity to terrain prior to landing.

Modern GPWS equipment adapts to this problem by storing a table of known problem locations and providing specialized warning envelope changes when the aircraft is operating in these areas. This technique is known as GPWS envelope modulation.

An example exists in the southerly directed approaches to Glasgow Scotland, Runway 23. The standard approach procedures allow an aircraft flying level at 3000 ft barometric altitude to pass over mountain peaks with heights above 1700 ft when approaching this runway. At nominal airspeeds the difference in surrounding terrain height will generate closure rates well within the nominal curve of Figure 17.3. With the envelope modulation feature the GPWS, using latitude, longitude, and heading, notes that the aircraft is flying over this specific area and temporarily lowers the maximum warning altitude for Mode 2 from 2450 ft to the minimum 1250 ft AGL. This eliminates the nuisance warning while at the same time providing the minimum required DO-161A protection for inadvertent flight closer to the mountain peaks on the approach path.

17.3.9 "Enhanced Modes"

The enhanced modes provide terrain and obstacle awareness beyond the normal sensor-derived capabilities of the standard GPWS. Standard GPWS warning curves are deficient in two areas, even with the best designs. One area is immediately surrounding the airport; which is where a large majority of CFIT accidents occur. The other is flight directly into precipitous terrain, for which little or no Mode 2 warning time may occur.

The enhanced modes solve these problems by making use of a database of terrain and obstacle spot heights and airport runway locations arranged in a grid addressed by latitude and longitude. This combined terrain/airports/obstacle database — a virtual world within the computer — provides the ability to track the aircraft position in the real world given accurate x-y-z position combined with the aircraft velocity vector.

This database technique allows three improvements which overcome the standard GPWS modes shortcomings: terrain proximity display, terrain ahead alerting, and terrain clearance floor.

17.3.9.1 Terrain Proximity Display

The terrain proximity display is a particular case of a horizontal (plan view) moving map designed to enhance vertical and horizontal situational awareness. The basic display is based upon human factors studies recommending a minimum of contours and minimum of coloring. The display is purposely compatible with existing three-color weather radar displays, allowing economical upgrade of existing equipment.

Terrain well below the flight path of the aircraft is depicted in shades of green, brighter green being closer to the aircraft and sparse green-to-black for terrain far below the aircraft. Some displays additionally allow water areas to be shown in cyan (blue). Terrain in the proximity of the aircraft flight path, but posing no immediate danger (it can be easily flown over or around) is depicted in shades of yellow. Terrain well above the aircraft (nominally more than 2000 ft above flight level), toward which continued safe flight is not possible, is shown in shades of red.

17.3.9.2 Terrain Ahead Alerting

Terrain (and/or obstruction) alerting algorithms continually compare the state of the aircraft flight to the virtual world and provide visual and/or aural alerts if impact is possible or probable. Two levels of alerting are provided, a cautionary alert and a hard warning. The alerting algorithm design is such that, for a steady approach to hazardous terrain, the cautionary alert is given much in advance of the warning alert. Typical design criteria may try to issue caution up to 60 s in advance of a problem and a warning within 30 s.

Voice alerts for the cautionary alert are "Caution, Terrain" or "Terrain Ahead." For the warnings on turboprop and turbojet aircraft, the warning aural is "Terrain Terrain Pullup" or "Terrain Ahead Pullup," with the pullups being repeated continuously until the aircraft flight path is altered to avoid the terrain.

In conjunction with the aural alerts, yellow and red lamps may be illuminated, such as with the standard GPWS alerts. The more compelling visual alerts are given by means of the Terrain Awareness Display. Those areas that meet the criteria for the cautionary alert are illuminated in a bright yellow on the display. If the pullup alert occurs, those areas of terrain where an immediate impact hazard exists are illuminated in bright red. When the aircraft flight path is altered to avoid the terrain, the display returns to the normal terrain proximity depictions as the aural alerts cease.

17.3.9.3 Terrain Clearance Floor

The standard Modes 2 and 4 are desensitized when the aircraft is put in landing configuration (flaps down and/or gear lowered) and thus fail to alert for attempts at landing where there is no airport. Since the EGPWS database contains the exact position of all allowable airport runways, it is possible to define an additional alert, a terrain clearance floor, at all areas where there are no runways. When the aircraft descends below this floor value, the voice alert "Too Low Terrain" is given. This enhanced mode alert is also referred to as premature descent alert.

17.4 EGPWS Standards

ARINC 594 — Ground Proximity Warning System: This is the first ARINC characteristic for Ground Proximity Warning Systems and defines the original analog interfaced system. It applies to the original model (MkI and MkII) GPWS systems featuring Modes 1–5, manufactured by Sundstrand Data Control, Bendix, Collins, Litton and others. It also applies to the AlliedSignal (Honeywell) MkVII digital GPWS, which featured Modes 1–7 and a primarily analog interface for upgrading older models.

ARINC 743 — Ground Proximity Warning System: This characteristic applies to primarily digital (per ARINC 429 DITS) interfaced Ground Proximity Warning Systems, such as the AlliedSignal/Honeywell MkV series, which was standard on all newer Boeing aircraft from the 757/767 up through the introduction of the 777.

ARINC 762 — Terrain Avoidance and Warning System: This characteristic, still in draft form at the time of this writing, is an update of ARINC 743 applicable to the primarily digital interfaced (MkV) Enhanced GPWS.

ARINC 562 — Terrain Avoidance and Warning System: This proposed ARINC characteristic will be an update of ARINC 594, applicable to the primarily analog interfaced (MkVII) Enhanced GPWS.

RTCA DO-161A — Minimum Performance Standards, Airborne Ground Proximity Warning System: This 1976 document still provides the minimum standards for the classic GPWS Modes 1–5. It is required by both TSO C92c and the new TSO C151 for EGPWS (TAWS).

TSO C92c — Ground Proximity Warning, Glideslope Deviation Alerting Equipment: This TSO covers the classic Modes 1– 6 minimum performance standards. It basically references DO-161A and customizes and adds features of the classic GPWS which were added subsequent to DO-161A, including voice callouts signifying the reason for the alert/warnings, Mode 6 callouts, and bank angle alerting.

CAA Specification 14 (U.K.) — Ground Proximity Warning Systems: This is the United Kingdom CAA standard for Modes 1–5 and also specifies some installation requirements. As with the U.S. TSOs, Spec 14 references DO-161A and customizes and augments features of the classic GPWS which are still required for U.K. approvals. Most notably, the U.K. version of Mode 5 is less stringent and requires a visual indication of Mode 5 cancellation. Spec 14 also requires that a stall warning inhibit the GPWS voice callouts, a feature which is found only on U.K.-certified installations.

TSO C117a — Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes: This TSO defines the requirements for EGPWS Mode 7, reactive low level windshear detection.

TSO C151a — Terrain Awareness and Warning System (TAWS): This new TSO supersedes TSO C92c for certain classes of aircraft being required to feature the enhanced modes. It also extends coverage down to smaller aircraft, in anticipation of further rulemaking requiring GPWS type equipment. It describes two classes of TAWS equipment, the standard EGPWS becomes Class A. For smaller aircraft with limited equipment, a new Class B set of requirements are created that add a subset of the DO-161A modes that can be accomplished soley with a source of three-dimensional position and an airports and terrain database.

FAR 121.360 — This rule requires GPWS on most "for revenue" passenger aircraft, including air transport, charters, and regional airlines.

TAWS NPRM — This proposed rulemaking would replace FAR 121.360 and also modify Parts 135 and 91 to require GPWS per TSO C92c or EGPWS per TSO C151 Class A or B on all turbine-powered aircraft of 6 or 10 seats or more. The final form of the proposed rule is fluid at the time of this writing but is expected to released in March of 2000.

Further Information

1. *Controlled Flight Into Terrain, Education and Training Aid* — This joint publication of ICAO, Flight Safety Foundation, and DOT/FAA consists of two loose-leaf volumes and an accompanying video tape. It is targeted toward the air transport industry, containing management, operations, and crew training information, including GPWS. Copies may be obtained by contacting the Flight Safety Foundation, Alexandria, Virginia.
2. *DOT Volpe NTSC Reports on CFIT and GPWS* — These may be obtained from the USDOT and contain accident analyses, statistics, and studies of the effectivity of both the classic and enhanced GPWS warning modes. There are a number of these reports which were developed in response to NTSB requests. Of the two most recent reports, the second one pertains to the Enhanced GPWS in particular:
    - Spiller, David — Investigation of Controlled Flight Into Terrain (CFIT) Accidents Involving Multi-engine Fixed-wing Aircraft Operating Under Part 135 and the Potential Application of a Ground Proximity Warning System (Cambridge, MA: U.S. Department of Transportation, Volpe National Transportation Systems Center) March 1989.
    - Phillips, Robert O. — Investigation of Controlled Flight Into Terrain Aircraft Accidents Involving Turbine Powered Aircraft with Six or More Passenger Seats Flying Under FAR Part 91 Flight Rules and the Potential for Their Prevention by Ground Proximity Warning Systems (Cambridge, MA: U.S. Department of Transportation, Volpe National Transportation Systems Center) March 1996.