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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

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Robert O. Phillips

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Study Motivation, Methodology, Findings and Conclusions

Operations Assessment Division, DTS - 59
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PREPARED BY:
U. S. Department of Transportation
Research and Special Programs
Administration
Volpe National Transportation
Systems Center
Cambridge, MA 02142

PREPARED FOR:
U. S. Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, DC 20591

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EXECUTIVE SUMMARY

Background

This two-volume study documents an investigation of controlled flight into terrain (CFIT) aircraft accidents involving turbine-powered aircraft with six or more passenger seats flying under Federal Aviation Regulations (FAR) Part 91 flight rules, and evaluating the potential for their prevention by ground proximity warning systems (GPWS). This study was performed by the Operations Assessment Division (DTS-59) and the Aviation Safety Division (DTS-67) of the Volpe National Transportation Systems Center, for the Aircraft Certification Service, Aircraft Engineering Division (AIR-100) of the Federal Aviation Administration (FAA).

A CFIT accident occurs when an airworthy aircraft, experiencing no contributory systems or equipment problems, under the control of a certificated, fully qualified flight crew not suffering from any impairment, is flown into terrain with no demonstrated prior awareness of the impending collision on the part of the crew. Because they involve high-speed impacts, CFIT accidents usually have disastrous results. CFIT accident reduction and prevention has been the focus of considerable effort on the part of government, industry and various public interest groups focusing on flight safety.

GPWS is an on-board flight instrument dedicated to CFIT accident prevention. GPWS will sound warnings (i.e., "Whoop Whoop! Pull Up!) to the pilot in situations where an aircraft comes dangerously close to terrain. These GPWS warnings require pilot response. GPWS is intended as a supplement to other flight instruments from which aircraft situational awareness may be determined.

This study was undertaken as part of the FAA response to the National Transportation Safety Board's (NTSB) recommendation A-95-35, dated April 3, 1995, made in response to investigation of a CFIT accident at Chantilly, VA on June 18, 1994, which resulted in 12 fatalities. This recommendation states the FAA should:

> "... require within two years that all turbojet-powered airplanes equipped with six or more passenger seats have an operating ground proximity warning installed."

This is the latest in a series of NTSB recommendations, dating back to 1971, to the FAA regarding CFIT accident prevention through mandatory GPWS installation. As of this date, the FAA does require GPWS on all large turbine-powered commercial air transport and air taxi aircraft (governed by FAR Part 121 and FAR

Part 135). However, CFIT accident frequency and severity among smaller corporate or business aircraft flying under FAR Part 91, as evidenced by the Chantilly crash, has led the NTSB to recommend the FAA extend GPWS requirements to this smaller aircraft fleet. At FAA request, the scope of this study was broadened beyond the NTSB recommendation regarding "turbojet" aircraft to include all "turbine-powered" aircraft, including turboprops.

Study Methodology

Investigation of NTSB and other data sources revealed a total of 44 aircraft accidents, occurring during the 10-year study period (1985-1994), which met all CFIT accident criteria: FAR Part 91 operation, turbine-powered aircraft with six or more passenger seats, no preimpact part or equipment problems, no pilot impairment, no loss of control, etc. The NTSB accident investigation file for each was reviewed in detail, with the objective of characterizing the last several minutes of flight before terrain impact. An attempt was then made to determine *if* current GPWS technology would have sounded a warning, and *when* the earliest GPWS warning would have sounded, had the aircraft been GPWS-equipped, based on the alarm threshold parameters of the five GPWS warning modes provided for current technology GPWS.

A simple geometric model was developed to explore critical relationships between four key variables (the aircraft's airspeed along its flight path V, the aircraft's flight path angle ϕ, the ground slope angle ψ, and the aircraft's altitude h_o) at this earliest GPWS warning point. This model enabled calculation of distance and time to impact from this warning point. Time to impact was then compared with an assumed minimum effective GPWS response time of 12-15 seconds, determined from several references. If the warning time before impact was greater than or equal to this minimum response time, it was assumed that the accident could probably have been prevented by current GPWS technology.

If the likely warning time interval prior to impact was less than this minimum response time, a further investigation was made to determine whether additional capabilities to be provided by Global Positioning System (GPS)-enhanced GPWS (EGPWS) equipment, which is currently entering production and will be commercially available in the near future, would have sounded more timely warnings than those provided by current GPWS technology.

Study Findings

Of the 44 CFIT accidents selected for study, 11 involved turbojet aircraft and 33 involved turboprops. These accidents could be categorized as low approach/ premature descent (23, or 52%), collision with rising terrain (11, or 25%), descent after takeoff or missed approach (5, or 11%), and gear-up landings (5, or 11%). The 44 accidents studied resulted in total destruction of 37 aircraft and 131 fatalities. An additional 19 persons survived with serious injuries, and 26 others survived with minor or no injuries.

Probable cause of these accidents, as determined by NTSB, was pilot error in all cases, principally through failure of the pilot-in-command (PIC) to maintain proper altitude, PICs using improper instrument flight rules (IFR) or visual flight rules (VFR) procedures, or poor PIC planning/decision-making. Contributing factors included the prevailing weather conditions and the dark night in many cases. In only two accidents did the NTSB assign partial responsibility for the accident to FAA air traffic control problems.

Prevailing meteorological conditions at the time of the accident played a major contributory role in many accidents. A total of 31 of the 44 accidents (70%) occurred during instrument meteorological conditions (IMC), in which visibility was obscured to such an extent that pilots had to rely on instruments, rather than visual reference, for situational awareness. Sixteen of these 31 accidents also involved "dark night," or conditions in which moon and stars were not present to illuminate the terrain. Only three accidents involved the combination of daylight and visual meteorological conditions, and these three accidents were gear-up landings. All 23 of the accidents categorized as low approach/premature descent occurred during IMC; in 15 of these cases, the measured cloud ceiling was 500' above ground level or less, and in 11 of these cases, horizontal visibility was one mile or less.

Review of accident data showed that current technology GPWS would have sounded a warning in 38 of 44 (86%) accidents studied. In the remaining six cases, GPWS warning modes either were not pertinent to the circumstances of the accident, or had been desensitized by pilot extension of landing gear and flaps into landing configuration, to avoid nuisance warnings on final approach and landing.

Applying the geometric model showed that in 33 of 38 cases where current technology GPWS would have sounded a warning, the warning time would have exceeded the assumed minimum effective GPWS response, and therefore the accident could probably have been prevented. Thus it is reasonable to expect current GPWS technology could have prevented 75% (33 of 44) of the accidents studied. Eight of the remaining 11 accidents, in which a warning would have sounded but not in time to prevent the accident, were categorized as low approach/premature descent, and three as collision with rising terrain.

The 33 accidents which could probably have been prevented with current GPWS technology destroyed 27 aircraft and caused 70 fatalities. An additional 17 persons survived these accidents with serious injuries, and 17 others with minor or no injuries.

EGPWS adds "forward-looking" and terrain clearance "floor" capabilities to address two major deficiencies with current technology GPWS: first, current GPWS only "looks down" and therefore provides little warning if terrain beneath an aircraft suddenly rises sharply, and second, an aircraft in stabilized approach descent, with flaps and gear extended in landing configuration, receives no warning even if it is descending towards a location other than a runway.

Examination of the 11 accidents which were not likely to have been prevented by current technology GPWS assuming EGPWS technology showed that 9 of these 11 could have been prevented by EGPWS. Thus EGPWS, had it been installed on the aircraft studied, would probably have prevented CFIT accidents in 42 of 44 cases (95%).

The 42 accidents which could probably have been prevented with current GPWS technology destroyed 35 aircraft and caused 127 fatalities. An additional 19 persons survived these accidents with serious injuries, and 25 others with minor or no injuries.

The two accidents which were not likely to have been prevented by either current technology GPWS or EGPWS were both categorized as low approach/premature descent. In both cases, the aircraft impacted about one nautical mile from the landing runway in a relatively steep descent.

Study Conclusions

Study results strongly support a conclusion that equipping aircraft with GPWS, or EGPWS when it becomes available, could be a particularly effective means of preventing CFIT accidents in the subject FAR Part 91 aircraft fleet. In light of the potential savings of human life and economic benefits in terms of aircraft losses/damage prevented, the FAA is urged to implement NTSB recommendation A-95-35. Based on the dramatic improvements in CFIT accident reduction effectiveness shown to be realized with the additional capabilities provided by EGPWS, the FAA is further urged to amend this recommendation to require installation of EGPWS, rather than current technology GPWS, in the subject aircraft fleet. Finally, based on the fact that 75% of the accidents studied involved turboprops, it is urged that the NTSB recommendation be broadened by the FAA to encompass all "turbine-powered" (i.e., not just turbojet) aircraft.

1.0 INTRODUCTION

1.1 Background

This is the first volume of a two-volume study investigating controlled flight into terrain (CFIT) aircraft accidents involving aircraft with six or more passenger seats flying under Federal Aviation Regulations (FAR) Part 91 flight rules, and evaluating the potential for their prevention by ground proximity warning systems (GPWS). This study was performed by the Operations Assessment Division (DTS-59) and the Aviation Safety Division (DTS-67) of the Volpe National Transportation Systems Center (VNTSC), Cambridge, MA. The study was performed for the Aircraft Certification Service, Aircraft Engineering Division (AIR-100) of the Federal Aviation Administration (FAA), in response to National Transportation Safety Board (NTSB) recommendation A-95-35, that the FAA require all turbojet-powered airplanes equipped with six or more passenger seats have an operating GPWS installed.

1.2 Controlled Flight Into Terrain

A CFIT accident occurs when an airworthy aircraft, experiencing no contributory systems or equipment problems, under the control of a certificated, fully qualified flight crew not suffering from any impairment, is flown into terrain (or water or obstacle) with no demonstrated prior awareness of the impending collision on the part of the crew. (1) A popular pilot's magazine article defines CFIT in much more graphic terms:

> "Controlled Flight Into Terrain: four words which describe what is probably a pilot's worst nightmare. Most (aviation) problems develop slowly and give lots of warning signs that something is wrong. Pilots often continue on in bullheaded stubbornness as the weather deteriorates or the fuel gauges drop to empty. But controlled flight into terrain is over with terrifying suddenness. One moment a plane is flying along in the clouds as usual, the crew going about their duties. The next moment it is nothing more than a smoking smudge on the side of a mountain." (2)

Because they involve high-speed impacts, CFIT accidents usually have disastrous results. CFIT accidents have been called the leading cause of fatalities in civil aviation. (3) Dr. Earl Weener, Chief Engineer for Airplane Safety at Boeing, has stated: "the CFIT accident represents the single greatest risk to commercial aircraft, crews, and passengers." (4)

CFIT accident reduction has been the focus of considerable effort over the past thirty years on the part of government, the aviation industry, and various public interest groups focusing on flight safety. Preventing CFIT is unfortunately not merely an issue to be addressed solely by pilot training; CFIT accidents have occurred in many cases even when highly experienced flight crews, with thousands of hours in their logs, were in charge.

The introduction of the radio altimeter in the late 1960's made possible development of an on-board flight instrument dedicated to CFIT prevention. Installation of this instrument, known as the ground proximity warning system (GPWS), in the civil aircraft fleet has been a significant breakthrough in CFIT accident prevention. (5)

1.3 Ground Proximity Warning Systems -- Current Technology

While early GPWS equipment was criticized by pilots as generating too many false alarms, subsequent enhancements have improved both the accuracy and informational content of alerts and warnings provided. Existing GPWS technology uses radio altimeter and/or barometric data as inputs for an on-board computer dedicated to hazardous ground proximity detection. This computer generates audible (i.e., "Whoop Whoop! Pull Up!") and visual warnings to a flight crew when threshold parameters of certain key variables, indicating inadvertent approach to terrain, are exceeded. (6)

Current GPWS equipment sounds warning during several different phases of flight to alert crews to the following five potentially hazardous flight conditions:

- o excessive rate of descent;
- o excessive rate of closure with terrain;
- o negative climb rate or altitude loss after takeoff or missed approach;
- o insufficient terrain clearance when landing gear or flaps are not set in landing configuration; and
- o excessive downward deviation from an instrument landing system glide slope signal on a precision approach. (7)

It should be recognized that GPWS alerts and warnings are intended as a supplement to other flight instrument data from which aircraft situational awareness may be determined by the pilot. They provide a "last-ditch" measure of safety against inadvertent contact with terrain. They are *not* intended as a substitute for careful flight planning and pre-flight preparation, effective flight crew coordination, strict adherence to proper flight rules and procedures, knowledge of aircraft capabilities and limitations, and assertive, clear communications between pilots and air traffic control personnel. (8)

1.4 Future GPWS Enhancements

Enhancements to GPWS currently entering production include added features, including the use of accurate aircraft positioning coupled with terrain data in the logic that determines when a GPWS warning is sounded. Integration of Global Positioning System (GPS) data, topographic maps, and information concerning airport and man-made flight obstruction locations into a GPS-enhanced GPWS (or EGPWS) will provide the pilot with "forward looking" capabilities, as well as a terrain clearance "floor" beneath the aircraft. It will provide earlier alerts and warnings concerning the locations of terrain or man-made obstructions in an aircraft's flight path, or concerning deviations from a published approach path, leading to a greater margin of safety in certain flight situations than that available with current GPWS technology. GPS-enhanced GPWS is expected to enter commercial service in 1996. (9)

1.5 GPWS Rulemaking Chronology

Installation of flight data recorders and cockpit voice recorders on aircraft beginning in the 1960's provided post-crash accident investigators far clearer insights than previously available into the circumstances leading up to accidents. (10) Beginning in the early 1970's, a number of studies conducted by the National Transportation Safety Board (NTSB), the British Civil Aviation Authority, and independent researchers investigating CFIT accidents found that certain of these accidents may have been prevented had the pilots of the aircraft involved been provided with GPWS warning of imminent terrain contact.

In 1971, the NTSB first recommended to the FAA that regulations be issued requiring large commercial air carriers to equip their fleets with GPWS. This recommendation was repeated in 1972; both recommendations were rejected by the FAA on the grounds that current flight instrumentation and procedures were safe, and that establishment of additional airway facilities and navigational aids to assist pilots on non-precision approaches was addressing the CFIT problem. The costs of installing GPWS in the commercial aircraft fleet, the FAA maintained, would exceed the benefits to be provided in terms of CFIT accident prevention, and these same benefits were already being achieved through the facility establishment program.

The NTSB again recommended FAA requirement for mandatory installation of GPWS on large commercial aircraft in 1973. The FAA this time responded by equipping one of its aircraft with GPWS and conducting flight tests and evaluation.

A 1974 CFIT accident in Virginia, involving a commercial jet airliner, resulted in 92 fatalities. Investigating this accident, the NTSB concluded that it could very likely have been prevented by on-board GPWS equipment, and once again recommended to the FAA that installation of GPWS equipment be mandatory in large commercial transports. (11) Acting on this recommendation, the FAA amended Section 121.360 and Section 135.153 of the Federal Aviation Regulations (FAR Parts 121 and 135) with language that required all FAR Part 121 and certain FAR Part 135 certificate holders (i.e., large turbojet-powered commercial passenger jet aircraft) to install GPWS equipment within one year.

In 1976, a Technical Standard Order, TSO-C92b, entitled Airborne Ground Proximity Warning Equipment, was issued by the FAA. This order prescribes operation of GPWS equipment, referencing a document designated DO-161A, developed by the Radio Technical Commission for Aeronautics (RTCA). The RTCA is an association representing aeronautical organizations in both government and industry which seeks sound technical solutions to problems involving aeronautical operations. It publishes reports making non-binding recommendations concerning these technical solutions. RTCA document DO-161A governs GPWS design and construction, describing in detail the minimum performance standards for GPWS, test procedures for ensuring equipment integrity, and specifying threshold values for the five separate GPWS warning modes.

In 1978, the GPWS installation requirement was extended by the FAA to smaller turbojet aircraft with 10 or more passenger seats. (12) Because turboprop (propeller-driven turbine) aircraft engines are more immediately responsive than turbojets to a pilot's terrain avoidance control actions, these aircraft were not included in the 1978 rulemaking.

A 1981 study reviewed the National Aeronautics and Space Administration's Aviation Safety Reporting System (ASRS) data from 1976-1980 concerning CFIT incidents (ground proximity flight events which were resolved short of impact through pilot-initiated recovery maneuvers). The ASRS is a repository of reports filed by flight crew members on an anonymous basis concerning flight incidents in which they were a participant. This study concluded that GPWS equipment was "the initial recovery factor in some ... serious incidents and apparently the sole warning in (other critical) ... instances which otherwise would most probably have ended in disaster." (13)

In 1986, the NTSB issued a study of three separate commuter air carrier accidents, all of which involved turboprop aircraft operating under FAR Part 135 flight rules. In this report, the NTSB noted that between 1975 and 1978, following the initial GPWS rulemaking addressing large air transport aircraft, CFIT accidents in this aircraft population had decreased by 75 percent. The NTSB report concluded that it was "convinced that each of these (three Part 135) accidents could have been prevented if the flight crew had been alerted to their proximity to the ground in sufficient time to have initiated missed approach procedures." (14) The NTSB therefore issued recommendation A-86-109 that the GPWS installation requirement be extended to all FAR Part 135 multi-engine, turbine-powered, fixed wing airplanes, (i.e., the commuter aircraft fleet) certificated to carry 10 or more passengers.

In assessing the merits of this recommendation, the FAA requested a detailed investigation of CFIT accidents involving turbine-powered aircraft operating under FAR Part 135. This investigation, carried out by the U. S. Department of Transportation's (DOT) Volpe National Transportation Systems Center (VNTSC), concluded in March 1989 that 18 of 27, or 66 percent, of these accidents occurring during the time period 1977-1988 might have been avoided had the aircraft involved been equipped with GPWS. (15)

Given the powerful support for GPWS in this aircraft fleet provided by the VNTSC report conclusions, the FAA in April 1990 issued a Notice of Proposed Rulemaking extending the FAR Part 135 (Section 135.153) GPWS requirement to "all turbine-powered aircraft with 10 or more seats." (16) This regulation was made final in April, 1992. The NTSB observed that in the two years between the initial notice and the final rulemaking, there were six more CFIT accidents involving these commuter aircraft worldwide, resulting in 63 fatalities.

Following the CFIT crash of a corporate jet in Rome, GA, in December, 1991, killing all 9 persons aboard, the NTSB again raised concerns to the FAA concerning installation of GPWS equipment, this time addressing smaller "business jet" aircraft which were not addressed by previous GPWS rulemakings. The NTSB noted three recent CFIT accidents involving turbojet aircraft operating under FAR Part 91 flight rules: the Rome, GA, crash mentioned above, as well as fatal crashes in San Diego, CA, and Kota Kinabalu, Malaysia. Its recommendation (dated July 8, 1992, and numbered A-92-055) stated: "Require all turbojet-powered airplanes that have six or more passenger seats to be equipped with a GPWS." (17)

FAR Part 91 flight rules dictate basic safety regulations applicable to all aircraft. FAR Parts 121 and 135 add more safety regulations for commercial aircraft which charge passengers individually for transport. Part 91 flights typically involve business, corporate, government or privately-owned aircraft in which passengers are not charged individually. Commercial aircraft also operate under Part 91 rules when they are on ferry, positioning, or training flights not carrying passengers.

The FAA's response to this recommendation, issued in August, 1992, was non-concurrence. The FAA concluded the underlying causes of the two domestic accidents cited were "air traffic control (ATC)/operations problems" involving failure of ATC to issue timely instrument flight rules clearances for aircraft flying under visual flight rules. In the third (Malaysian) case, the FAA noted the pilot in command had actually recognized dangerous ground proximity and initiated a climb prior to the crash. In making the determination not to require GPWS in all turbojet aircraft with six or more seats, the FAA cited the "operating environment most prevalent for (small) turbojet-powered airplanes (i.e., corporate/business flights between larger airports), the extent of radar service in the air traffic control system, and the employment of the minimum safe altitude warning (MSAW) system." (18) (MSAW warnings are automatically displayed to air traffic controllers on their radar screens at certain high-traffic airports when aircraft descend below specified threshold altitudes. They are then relayed verbally by controllers to pilots.) Again, the FAA maintained that the costs of GPWS installation in this aircraft fleet outweighed the benefits to be provided in terms of CFIT accident reduction, and that these benefits could be achieved through other means.

The NTSB reacted to this action stating: "The Safety Board is disappointed that the FAA does not agree with this recommendation ... the Board continues to believe that the recent accidents underscore the need to equip turbojet-powered airplanes ... with GPWS. Therefore the Board classifies recommendation A-92-055 as "Closed -- Unacceptable Action." (19)

In a related development, the International Civil Aviation Organization (ICAO) amended Annex 6 (Operation of Aircraft) of Part I (International Commercial Air Transport) of its Standards and Recommended Practices in 1995 to require that aircraft of over 5,700 kg (12,500 lb) or those seating more than nine passengers, be equipped with a GPWS by Jan 1, 1999. (20), (21)

Another CFIT accident in June, 1994, at Chantilly, VA, involving a small turbojet flying under FAR Part 129 rules, and resulting in 12 fatalities, led the NTSB again to recommend that the FAA "require within two years that all turbojet-powered airplanes equipped with six or more passenger seats have an operating ground proximity warning system installed." FAR Part 129 governs operation of a foreign air carrier within the U.S. Had this aircraft been U.S.-registered, FAR Part 91 rules would have applied. This recommendation, numbered A-95-35, was issued on April 3, 1995. (22)

1.6 Purpose of this Study

The FAA, in considering the merits of this latest NTSB recommendation concerning GPWS, again requested a detailed evaluation by the Volpe National Transportation Systems Center of CFIT accidents involving aircraft flying under FAR Part 91 flight rules. The two volumes of this study document this evaluation. While the NTSB recommendation addresses only turbojet-powered aircraft, the aircraft population included in this VNTSC evaluation has been broadened at FAA direction to include all turbine-powered aircraft, including turboprops. This broadening of study scope reflects the FAA's previous rulemaking experience regarding GPWS installation in FAR Part 135 aircraft.

The purpose of this study was twofold:

- to select for study CFIT accidents in the aircraft population of interest over a 10-year period (1985-1994);
- to determine whether, had current GPWS technology (as described in TSO-C92b) been installed on the aircraft in the accidents being evaluated, the GPWS would have sounded appropriate alerts/warnings in sufficient time for flight crew and aircraft to respond and avoid impact with terrain, effectively preventing the accident.

In cases where it was determined that current GPWS technology would not have prevented the accidents being evaluated, a further determination was made as to whether additional capabilities available with GPS-enhanced GPWS (EGPWS) technology could have prevented these accidents.

Fundamental questions addressed in this analysis include the following:

- would GPWS (or EGPWS) have activated an alarm or alert prior to the accident?
- which GPWS (or EGPWS) warning envelope (mode) would have been penetrated earliest prior to the accident?
- what would have been the likely warning time before impact from this earliest GPWS (or EGPWS) warning?
- would there have been sufficient time to effect a successful recovery maneuver following GPWS (or EGPWS) alert/warning activation, within acceptable flight crew and aircraft performance limits? (23)

1.7 Contents of this Volume

Following this introduction, this volume contains six additional sections, addressing the following subjects:

- o characterization of GPWS technology and its limitations, including the five warning modes incorporated in current GPWS and additional capabilities provided by EGPWS;
- o the criteria for and process used in selecting CFIT accidents relevant to this study;
- o the minimum effective GPWS response time, including pilot and aircraft time components of a terrain avoidance maneuver;
- o the simple geometric model used to calculate distance (and time) to impact from initial GPWS warning;
- o study methodology applied in analysis of each CFIT accident selected; and
- o study findings and conclusions.

In addition, this volume contains three appendices. Appendix A presents a derivation of equations used in the geometric model. Appendix B presents the graphs describing GPWS warning envelopes (threshold values) as contained in RTCA DO-161A, Minimum Performance Standards -- Airborne Ground Proximity Warning Equipment. Appendix C contains a glossary of acronyms and terms used in this document.

1.8 Contents of Volume Two

Volume Two of this study contains brief descriptions of each of the 44 CFIT accidents selected for study. Included in these descriptions are information on the following subjects:

- o accident background, including aircraft type, fatalities/injuries, flight plan, etc.;
- o meteorological conditions prevailing at the time and location of the accident;

- pilot/ATC actions during the last several minutes of the flight before impact, taken from transcripts of ATC recordings, witness or survivor testimony;
- impact characteristics, including location, airspeed and magnetic heading of aircraft, as well as landing gear/flap settings;
- probable cause of accident and any contributing factors as determined by NTSB investigation; and
- GPWS considerations, including relevant warning envelopes/altitudes, flight path parameters, time to impact, and determinations as to whether or not GPWS or GPS-enhanced GPWS (EGPWS) would have prevented the accident.

2.0 GROUND PROXIMITY WARNING SYSTEM (GPWS) TECHNOLOGY

2.1 Current GPWS Technology

Ground proximity warning systems in aircraft serve as an aid to flight crews in avoiding inadvertent contact with terrain. They are intended to supplement other flight instrument data from which aircraft situational awareness may be determined, annunciating the onset of hazardous proximity to terrain through alert messages, which escalate to warning messages as the aircraft's terrain clearance decreases. (24) Current technology GPWS equipment, as described in FAA Technical Standard Order C-92b (which references RTCA document DO-161A, Minimum Performance Standards -- Airborne Ground Proximity Warning Equipment) provides the flight crew a different set of alert and warning messages for each of five types of potentially hazardous flight condition recognized by the system, called GPWS modes. Table 1 presents operating altitude limits (expressed in feet above ground level, or feet AGL) and active sensor inputs for each GPWS mode. GPWS alert and warning messages for each mode are shown on Table 2. The envelopes (threshold values) for these GPWS warning modes, as contained in RTCA DO-161A, are presented in Appendix B of this document. The five GPWS modes are described below:

- GPWS Mode 1: Excessive rate of descent with respect to terrain. Alerts and warnings are provided by the equipment when, regardless of landing gear or flap position, the combination of barometric altitude sink rate and height above terrain falls within the threshold value stipulated in RTCA DO-161A.

- GPWS Mode 2: Excessive terrain closure rate. Alerts and warnings are provided by the equipment when the combination of the rate of change in height above terrain and height above terrain falls within the threshold value stipulated in RTCA DO-161A. There are two sub-modes: Mode 2A addresses aircraft not in landing configuration (i.e., without landing gear or flaps extended to their landing positions), and Mode 2B addresses aircraft in landing configuration.

- GPWS Mode 3: Negative climb rate (Mode 3A) or altitude loss (Mode 3B) after takeoff or missed approach. Alerts and warnings are provided by the equipment when the combination of barometric altitude sink rate and height above terrain falls within the threshold for Mode 3A, or when the combination of barometric altitude loss and height above terrain falls within the threshold for Mode 3B, as stipulated in RTCA DO-161A. Mode 3 alerts and warnings are independent of landing gear or flap position.

TABLE 1. GPWS MODES , OPERATING LIMITS, AND SENSOR INPUTS

GPWS MODE		OPERATING LIMITS (FEET AGL) MIN	MAX	SENSOR INPUTS
1 --	Excessive rate of descent with respect to terrain	50	2450	Radio Altitude Baro Rate
2A --	Excessive terrain closure rate, not in landing configuration	50	1800	Radio Altitude Baro Rate Gear/Flap Position
2B --	Excessive terrain closure rate, in landing configuration	220	790	Radio Altitude Baro Rate Gear/Flap position
3A --	Negative climb rate after takeoff or missed approach	50	700	Radio Altitude Baro Rate Gear/Flap Position
3B --	Altitude loss after takeoff or missed approach	50	700	Radio Altitude Baro Altitude Loss Gear/Flap Position
4A --	Insufficient terrain clearance not in landing configuration (gear not extended)	50	750	Radio Altitude Baro Rate Gear Position
4B --	Insufficient terrain clearance not in landing configuration (gear extended, but not flaps)	50	200	Radio Altitude Baro Rate Gear/Flap Position
5 --	Excessive deviation below instrument landing system (ILS) glide slope signal	50	1000	Radio Altitude Glide Slope Deviation Gear/Flap Position

Source: (25)

TABLE 2. SUMMARY OF GPWS ALERT AND WARNING MESSAGES

GPWS MODE		ALERT MESSAGE	WARNING MESSAGE
1 --	Excessive rate of descent with respect to terrain	"Sink Rate"	"Whoop Whoop Pull Up!"
2A --	Excessive terrain closure rate, not in landing configuration	"Terrain Terrain"	"Whoop Whoop Pull Up!"
2B --	Excessive terrain closure rate, in landing configuration	"Terrain Terrain"	"Whoop Whoop Pull Up!"
3A --	Negative climb rate after takeoff or missed approach	"Don't Sink"	"Whoop Whoop Pull Up!"
3B --	Altitude loss after takeoff or missed approach	"Don't Sink"	"Whoop Whoop Pull Up!"
4A --	Insufficient terrain clearance not in landing configuration (gear not extended)	"Too Low -- Gear"	"Whoop Whoop Pull Up!"
4B --	Insufficient terrain clearance not in landing configuration (gear extended, but not flaps)	"Too Low -- Flaps"	"Too Low -- Terrain"
5 --	Excessive deviation below instrument landing system (ILS) glide slope signal	"Glide Slope"	"Whoop Whoop Pull Up!"

Source: (26)

- GPWS Mode 4: Insufficient terrain clearance not in landing configuration. Alerts and warnings are provided by the equipment when the aircraft descends through 500' AGL (Mode 4A) with landing gear not extended (750' AGL if the aircraft's indicated airspeed exceeds 200 kts), or descends through 200' AGL (Mode 4B) with flaps not extended in landing position.

- GPWS Mode 5: Excessive deviation below instrument landing system (ILS) glide slope signal. Alerts and warnings are provided by the equipment when an aircraft is tuned to an ILS frequency and deviates in excess of 1.3 "dots," as indicated on the aircraft's ILS receiver, below the glide slope signal, when the aircraft is between 1000' AGL and 150' AGL. Below 150' AGL, the threshold deviation varies linearly from 1.3 dots low to 2.7 dots low to compensate for signal beam convergence. This warning can be inhibited by the pilot to allow for intentional flight below the glide slope in certain flight conditions, such as side-step maneuvers for landings on a parallel runway. (27)

In all cases except Mode 2B, warnings are inhibited at 50' AGL to avoid nuisance alarms associated with static pressure fluctuations while aircraft are in ground effect. (28)

2.2 Expected Flight Crew Response to GPWS Alerts/Warnings

Should the GPWS sound an alert, the flight crew must regard this as a caution. The expected response is for the pilot to apply control commands to correct the flight path or change the aircraft landing configuration such that the alert ceases. At the same time, the flight crew should perform a scan of flight instruments and controls to ascertain the reason for the alert. Until the cause has been determined, the flight crew should not attempt to re-establish the original flight path. (29)

Should the GPWS sound a warning, the flight crew must regard this as a call for "immediate and deliberate action, without exceeding the aircraft's limits or capabilities." (30) The FAA in 1981 issued an Air Carrier Operations Bulletin regarding GPWS equipment which stated: "In regard to a ... 'pull up' alarm, ... proper flight crew reaction entails an instantaneous response executed with the same single-mindedness associated with the execution of a missed approach procedure." (31) The expected response is to level the wings and simultaneously rotate the nose up. Landing gear, flaps, or spoilers should be retracted and power added to attain a maximum gradient climb, within the design performance limits of the aircraft. Once this climb is established, the crew should perform a scan of instruments, evaluate the situation, and report their action to air traffic control. Using the altimeter trend the crew should maintain a straight-ahead climb until clear of terrain, or until well above the minimum sector altitude (MSA). (32), (33)

In certain exceptional circumstances, leveling the wings may not be appropriate; for example, when the aircraft is on a curved approach, or is performing a missed approach procedure involving turns to avoid terrain. (34)

2.3 Limitations of Current GPWS Technology

Because current GPWS technology is based primarily on radio altimeter and barometric climb/descent rate inputs, it has no ability to "look ahead," but instead only "looks down," comparing aircraft altitude and climb/descent rate up to the present moment against alert and warning thresholds. The aircraft will receive very little or no warning should the ground beneath the aircraft suddenly rise at a steep gradient. In the extreme case, an aircraft flying over level terrain ending abruptly at a sheer vertical cliff will not receive any GPWS warning before impact.

The thresholds for GPWS Modes 1 and 2 have been set to provide approximately 20 seconds warning duration before impact over level terrain. Should there be rising terrain beneath the descending aircraft receiving a Mode 1 or 2 alert or warning, or if the aircraft is in an excessive rate of descent, this duration will be reduced. Aircraft in stabilized descent towards terrain will receive no GPWS Mode 1 or 2 warnings.

GPWS Mode 4 alerts and warnings are inhibited as landing gear and flaps are extended to prevent nuisance alarms as the aircraft nears terrain on approach and landing. Therefore, once its gear and flaps are extended in landing configuration, an aircraft in executing a stabilized, non-precision approach (i.e., one in which no glide slope guidance is provided) to a location *other* than a runway will receive no GPWS alert or warning. (35)

2.4 GPS-Enhanced GPWS (EGPWS) Technology

Several improvements have recently been introduced to GPWS equipment to address the limitations discussed above. These improvements are in addition to the basic five GPWS modes of current system performance. They are made possible by the commercial availability of low-cost on-board Global Positioning System (GPS) receivers for determining aircraft location, and by reductions in the cost of computer memory storage. (36) Building these capabilities into existing GPWS provides two very useful new equipment features: a "forward-looking" capability and a terrain clearance "floor."

The "forward-looking" capability of EGPWS is based on a realtime comparison of the aircraft's position, as determined by a built-in GPS receiver, with an on-board stored database of topographical and other flight obstruction data. Using this capability, projected prominent terrain features or other obstructions conflicting with an aircraft's flight path can be presented on a cockpit map display similar to that currently provided pilots by a navigation or weather radar display. Alerts and warnings are sounded based on algorithms which consider aircraft position (i.e., latitude/longitude), altitude AGL, climb/descent rate, and projected flight path in relation to stored terrain/obstruction data. The "Caution, Terrain" alert is typically sounded at 45-60 seconds before projected impact; this alert escalates to a "Terrain Ahead, Pull Up!" warning at 25-30 seconds before impact. This capability offers a significant improvement in GPWS alert and warning times in areas of precipitous terrain. (37)

The terrain clearance "floor" capability of EGPWS is also based on realtime comparison of an aircraft's position, as determined by GPS, with a stored database of airport runway location data. Unlike existing GPWS mode 4, this capability is independent of landing gear or flap settings. The terrain clearance "floor" is based on calculated distance to the runway threshold. To eliminate nuisance warnings, this "floor" ramps upward at 100' AGL per NM radial distance from the runway until it reaches the level of 500' AGL at 5 NM from the runway. This slope is well below the 2-1/2 to 3 degree glide slope design criteria for approach terrain clearances. Between 5 and 12 NM from the runway, the "floor" remains at 500' AGL. Beyond 12 NM, it ramps up again at 100' per NM until it reaches 800' AGL at 15 NM from the runway. Beyond 15 NM, it remains at 800' AGL. Like the existing GPWS mode 4 warning the "floor" sounds a "Too Low -- Terrain" warning as the aircraft descended through the floor altitude. The terrain clearance "floor" provides an extra measure of safety for non-precision approaches not available with current GPWS equipment. (38)

3.0 SELECTION OF CFIT ACCIDENTS FOR STUDY

3.1 Accident Selection Criteria

In choosing appropriate CFIT accidents for detailed investigation, the following selection criteria were used:

- The accidents occurred between Jan. 1, 1985, and Dec. 31, 1994.

- The aircraft involved in the accident was part of the fleet being studied. No accidents were included unless they involved turbine-powered aircraft flying under FAR Part 91 flight rules, having six or more passenger seats. In certain cases, accidents involved FAR Part 121 and FAR Part 135 aircraft on ferry or positioning flights and thus flying under Part 91 flight rules; these accidents were excluded, as they involved aircraft already equipped with GPWS equipment required by previous FAA rulemakings.

- The aircraft was in controlled flight at the time of the accident. The NTSB examines control system continuity very closely in post crash investigation to determine whether control malfunction was a cause. It also examines weather data to determine whether turbulence, low-level windshear, or ice accumulation affected aircraft controllability. No accidents considered by the NTSB to be caused by loss of control were included. However, instances in which aircraft remained in control up to initial CFIT impact, but *then* lost control and crashed, were included. "Hard landings," in which an aircraft executed a successful approach and landed on a runway, but touched down with sufficient force to cause damage, were excluded.

- All systems on the aircraft were operating normally at the time of the accident. The NTSB reviews engine/propeller teardown analyses in accidents where loss of power might be considered a contributing factor. Rotational damage on propellers and other engine parts, together with survivor or witness reports of preimpact engine noise or performance, are considered. No accidents judged by the NTSB to be caused by in-flight structural breakup, mechanical failure, loss of control continuity, loss of power, preimpact fire or explosion, or other in-flight part or equipment malfunction were included, nor were any accidents involving pilot distress calls. Gear-up landings were included only if they involved no malfunction that would have prevented normal landing gear extension.

- The pilot(s) were not impaired in any way at the time of the accident. No accidents considered by the NTSB to be caused by pilot fatigue or other drug- or alcohol-induced incapacitation (typically determined by autopsy and post-mortem pathological analysis) were included.

- The aircraft was engaged in routine, cross-country flight at the time of the accident. No accidents involving aerobatics or agricultural spraying applications (where close ground proximity is often deliberate) were included.

3.2 Accident Selection Process -- Domestic Accidents

The process of selecting appropriate CFIT accidents for this study began with a query to the National Aviation Safety Data Analysis Center (NASDAC) located in U. S. Department of Transportation (DOT) Headquarters, Washington, DC. The NASDAC database is maintained by the FAA Associate Administrator for Aviation Safety. It contains aircraft accident data as entered by NTSB personnel on the nine-page NTSB Form 6120.19A, Preliminary Report -- Aviation Accident. Accidents not investigated by NTSB are not included in this database. It was possible to structure sophisticated queries to search this NASDAC database using the above accident selection criteria. (39)

Initial NASDAC retrieval produced a list of 60 domestic accidents. For each of these 60 accidents, NASDAC was also able to provide NTSB Accident Briefs containing narrative descriptions of accident circumstances. Review of these briefs led to subsequent exclusion of 16 accidents because they involved Part 121 and Part 135 aircraft on ferry or positioning flights, or they clearly involved circumstances (i.e., possible pilot impairment or loss of control) violating certain CFIT accident selection criteria. The remaining 44 accidents were deemed worthy of further analysis, since they met all study selection criteria.

Comparison of the CFIT accident list obtained through initial NASDAC database retrieval with a second list of domestic CFIT accidents provided by Allied Signal, a GPWS equipment manufacturer, revealed discrepancies between these two lists for the 1985-1994 study time period. (40) To reconcile these discrepancies, a third source of accident data was consulted: a comprehensive listing of all small business jet and turboprop accidents. This listing, covering 14 manufacturers of turbojets and 7 manufacturers of turboprops meeting study criteria, included information on 344 small turbojet and 376 small turboprop accidents occurring worldwide during the 1985-1994 time period. Information on this comprehensive listing for domestic accidents was comparable in detail to the NTSB Accident Briefs provided by NASDAC; for foreign accidents, however, information was considerably less detailed. (41)

With this comprehensive list of accidents, it was possible to reconcile most discrepancies between the initial NASDAC retrieval and the Allied Signal CFIT accident list. Based on a review of the comprehensive list, 63 possible CFIT accidents deserving of further investigation were compiled. One crucial item of information, however, was missing from the comprehensive list: whether the accident aircraft was operating under FAR Part 91 flight rules. To verify whether an accident in the 63 considered deserving of further investigation involved FAR Part 91 operation, the list of candidate accidents selected was provided to NASDAC for a second round of information retrieval.

The second NASDAC retrieval produced NTSB Accident Briefs for each accident of interest, including flight rules governing the aircraft's operation during the accident flight. Review of these 63 Accident Briefs showed only 33 involved aircraft which had been operating under FAR Part 91 flight rules. Of these 33, 17 were judged to meet all CFIT selection criteria following a review of the accident narrative information.

Adding these 17 accidents to the 44 accidents obtained through the initial NASDAC retrieval, a list of 61 accidents was obtained. Briefs for each of these 61 possible CFIT accidents were next reviewed with the FAA Aircraft Certification Service, Aircraft Engineering Division (AIR-100), the organization requesting this study. During the course of this review, it was determined that 16 of these candidate accidents involved circumstances which made CFIT designation questionable. Excluding these accidents left a total of 45 for subsequent study.

A request was next made to the NTSB for access to the full files for these 45 likely CFIT accidents. The NTSB advised first running a retrieval, similar to that initially run on NASDAC data, on the official NTSB accident database to ensure no accidents had somehow been overlooked in the selection process to date. This NTSB retrieval produced 160 total accidents for review. However, because the NTSB query was not so sophisticated as the initial NASDAC query, 122 of these 160 were excluded, for a number of reasons. Over half of the 122 involved accidents during agricultural spraying operations; others clearly involved loss of control, mechanical problems, pilot impairment, etc. The remaining 38 corresponded very closely with the list obtained via previous NASDAC retrievals; only five of these 38 were not on this NASDAC list (these five involved gear-up landings or loss of control after initial CFIT impact). Adding these five to the previous NASDAC list produced a total of 50 accidents for further review.

Next, a detailed review of the full NTSB accident files for these 50 accidents was performed. Information discovered during the course of this review showed six of the 50 accidents reviewed involved questionable CFIT circumstances. These six accidents were therefore excluded from the study. As a result, a total of 44 domestic CFIT accidents were included this study. Information concerning these accidents is shown on Table 3.

3.3 Accident Selection Process -- Foreign CFIT Accidents

As part of this study, an attempt was also made to gather data on CFIT accidents occurring outside U. S. territory during the 1985-1994 time period. A list of 44 such accidents involving small turbine-powered aircraft meeting selection criteria was compiled from various sources. Unfortunately, detailed information on these accidents, similar to that found in the full NTSB accident files, was not available. For this reason, detailed analysis regarding whether or not these accidents could have been prevented by GPWS was not performed. A total of 24 of these accidents involved operations that would be considered similar to FAR Part 91 flight rules (i.e., they involved government, corporate, business, or private operations in which passengers were not charged individually for transport). These 24 accidents resulted in 82 fatalities. (42), (43)

Table 4 presents relevant data concerning these 24 foreign CFIT "Part 91" accidents. From this table, it is clearly evident that the CFIT problem extends well beyond the boundaries of the United States.

TABLE 3. DOMESTIC CFIT ACCIDENTS INCLUDED IN THIS STUDY

YR	MO	DA	CITY	ST	AIRCRAFT TYPE	REGISTRATION #
1985	1	4	WEST POINT	VA	MITSUBISHI MU-2B-25	N275MA
1985	2	13	ST. MARY'S	PA	BEECH G90	N2019U
1985	2	22	UTICA	MI	PIPER PA-31T	N100RN
1985	5	21	HARRISON	AR	CESSNA 501	N10GE
1985	6	9	HAMPTONBURGH	NY	BEECH 200	N148CP
1985	6	30	APPALACHICOLA	FL	BEECH 65-A90	N28SE
1985	8	23	FLAT ROCK	NC	PIPER PA-31T	N600CM
1985	10	9	CADILLAC	MI	GULFSTREAM 690A	N254PW
1985	11	11	DERRY	PA	CESSNA 441	N59MD
1985	11	27	EAST GREENWICH	RI	BEECH C90	N220F
1986	1	9	JACKSONVILLE	FL	PIPER PA-31T	N700CM
1986	7	16	NORTON SHORES	MI	CESSNA 441	N6857E
1986	7	25	CHARLEVOIX	MI	PIPER PA-31T1	N2317V
1986	10	19	LITTLE ROCK	AR	CESSNA 501	N2BT
1986	12	10	WINDSOR	MA	BEECH 100	N65TD
1987	3	27	EAGLE	CO	LEARJET 24A	N31SK
1987	7	7	NOVATO	CA	PIPER PA-31T2	N38WA
1987	9	8	BATESVILLE	IN	BEECH 100	N73KA
1988	1	18	HAZELWOOD	MO	PIPER PA-31T-620	N200RS
1988	1	18	HOUSTON	TX	HS 125-600B	XA-KUT
1988	9	23	EUGENE	OR	PIPER PA-31T-620	N234K
1988	11	18	LOCUST GROVE	AR	BEECH E90	N308PS
1989	1	2	MANSFIELD	OH	MITSUBISHI MU-2B-26	N500V
1989	5	10	AZUSA	CA	BEECH 200	N39YV
1989	6	29	CARTERSVILLE	GA	DSLT DA-20	N125CA
1989	9	15	MAYFIELD	KY	BEECH 100	N887PE
1989	10	1	HURDLE MILLS	NC	CESSNA 550-II	N53CC
1990	3	27	UVALDE	TX	BEECH 100	N696JB
1990	4	17	SHEBOYGAN	WI	ROCKWELL AC-690	N57175
1990	9	11	ALBUQUERQUE	NM	MRN SLNR MS760	N23ST
1990	9	24	SAN LUIS OBISPO	CA	CESSNA 500	N79DD
1990	11	30	RYDERWOOD	WA	AC-690A	N400N
1991	3	16	SAN DIEGO	CA	HS-125-1A	N831LC
1991	11	22	ROMEO	MI	BEECH 100	N24169
1991	12	11	ROME	GA	BEECH 400	N25BR
1992	2	16	BIG BEAR	CA	PIPER PA-31T-II	N60AW
1992	3	29	TAOS	NM	ROCKWELL AC-690A	N111FL
1992	4	9	ST. AUGUSTINE	FL	BEECH C90	N105FL
1992	6	24	ALAMOGORDO	NM	MITSUBISHI MU-2B-30	N108SC
1993	1	29	MARFA	TX	BEECH 65-A90	N363N
1993	5	1	MT. IDA	AR	BEECH 65-A90	N530N
1993	5	25	SANTA FE	NM	FAIRCHILD SA-226T	N241DT
1993	10	26	FRONT ROYAL	VA	BEECH 300F	N82
1994	6	18	CHANTILLY	VA	LEARJET 25D	XA-BBA

TABLE 4. FOREIGN "PART 91" CFIT ACCIDENTS, 1985-1994

Y	M	D	CITY	COUNTRY	MANUF/MODEL	REG #	FATAL	ACCIDENT TYPE
85	4	11	SALTA	URUGUAY	HS 125-700	LV-ALW	7	HIT RISING TERRAIN
85	8	27	CAPETOWN	SOUTH AFRICA	LEARJET 35A	ZS-INS	0	LOW APPROACH
85	12	31	KADINA	NIGERIA	HS 125-700	5N-AXP	7	LOW APPROACH
86	10	2	HAENERTSBURG	SOUTH AFRICA	DASSAULT DA-10	3D-ART	2	HIT RISING TERRAIN
86	12	15	CASABLANCA	MOROCCO	HS 125-600B	SN-AWS	10	LOW APPROACH
87	5	31	LUBECK	GERMANY	CESSNA CE-501	D-IAEC	2	LOW APPROACH
87	7	31	GUATEMALA CITY	MEXICO	LEARJET 23	28ST	2	LOW APPROACH / IMC
87	10	19	LEEDS-BRADFORD	ENGLAND	BEECH BE-200	G-MDJI	1	LOW APPROACH / IMC
89	1	12	CARACAS	VENEZUELA	BEECH BE-200B	597CP	2	HIT RISING TERRAIN
89	5	29	GIMLI	CANADA	BEECH BE-200	50HH	0	GEAR UP LANDING
89	9	23	POSADAS	ARGENTINA	LEARJET 25D	LV-MMV	2	LOW APPROACH
89	11	15	LANGFJELLTIND	NORWAY	CESSNA CE-550	LN-AAE	4	HIT RISING TERRAIN
91	2	8	STANSTED	ENGLAND	BEECH BE-200	F-GHBE	2	LOW APPROACH / IMC
91	2	16	HATFIELD	ENGLAND	CESSNA CE-500	11HJ	0	GEAR UP LANDING
91	5	21	BAUCHI	NIGERIA	CESSNA CE-550	5N-AMR	3	LOW APPROACH
91	6	17	CARACAS	VENEZUELA	GULFSTREAM G-1159	204RC	4	LOW APPROACH / IMC
91	9	4	KOTA KINABALU	MALAYSIA	GULFSTREAM G-II	204C	12	HIT RISING TERRAIN
91	12	27	PALMA	MAJORCA	BEECHJET 400A	I-ALSU	0	LOW APPROACH / IMC
92	10	19	PESQUERIA	MEXICO	ROCKWELL AC-680T	CAA38	8	DESCENT AFTER TAKEOFF
93	7	15	PANVEL	INDIA	BEECH BE-300	VT-EQM	4	LOW APPROACH
93	12	30	DIJON	FRANCE	BEECH BE-90	F-GERN	1	LOW APPROACH
94	1	18	KINSHASA	ZAIRE	LEARJET 24D	9Q-CBC	2	LOW APPROACH
94	5	27	PAPEETE	TAHITI	MITSUBISHI MU-2B-60	F-GHDV	5	LOW APPROACH
94	5	31	THOMPSON	CANADA	FAIRCHILD SA-226T	C-FFYC	2	LOW APPROACH

4.0 MINIMUM EFFECTIVE GPWS RESPONSE TIME

4.1 Recovery Scenario

A key factor in the design of ground proximity warning systems is the speed with which a terrain avoidance maneuver can be performed in response to a GPWS alert or warning message. The margin of safety provided by current GPWS equipment before projected impact is typically measured in seconds; an aircraft flying at 200 knots true airspeed can cover one nautical mile along its ground track every 18 seconds. An effective GPWS warning response involves sequential time components associated with both pilot and aircraft response.

4.2 Pilot Response Time

A pilot must continuously monitor his/her aircraft's flight environment, making control responses as appropriate to sensory inputs provided either from visual reference or from flight instruments. Pilot response time can be defined as the elapsed time between the onset of a given input signal (e.g., a GPWS alert or warning message) and the production of a physical reaction to that signal. In the simplest human response measurement case, a test subject rests a finger on a button, looking at a signal light and pushing the button when it illuminates. In this case, the reaction time (termed the "psychomotor response") between the lit signal and the pushed button can be expected to average about 1/5 of a second (200 milliseconds). As the complexity of monitoring tasks or the number of input stimuli increase, and the subject is required to make choices between alternative actions, as is the case in the modern cockpit, there is a longer delay between stimulus and response. It has been shown empirically that stress or high workload also increases reaction time. (44) Further, unexpected stimuli (such as GPWS warnings) can cause disruption of human performance, especially in the first one to five seconds following the stimulus. (45) Startling events (e.g., sudden loud noises) can cause even longer disruptions. A study of control responses following startle showed that the test subject's ability to process information inputs can be impaired for up to 60 seconds after the startling event. (46) For this reason, it is important to GPWS design that alert and warning messages inform and secure the attention of, but not startle, flight crews.

FAA requirements for "instantaneous" responses notwithstanding, the pilot response to GPWS may also be "conditioned" by the memory of past false warnings. False warnings can unfortunately be expected in any warning system, particularly if, like GPWS, it is specifically designed to have an extremely low false negative warning rate (i.e., situations in which ground proximity *was* hazardous, but GPWS warning *was not* sounded). To protect the lives of pilots and passengers, the GPWS must detect *all* hazardous terrain proximity situations, and it should err on the side of safety, sounding warnings even when data inputs are ambiguous. No perfect warning system exists which can detect all true events and filter out all false events. (47) The NTSB issued a report in 1989 concerning two FAR Part 121 air carrier accidents that clearly (as documented by cockpit voice recordings) involved delayed pilot response to GPWS warnings. Responding to these two accidents, the NTSB issued recommendation A-89-047 to the FAA, urging that the FAA review air carrier flight training programs and manuals to verify that "flight crews are trained and required to *immediately* execute a terrain avoidance maneuver when a GPWS alert is sounded and safe distance from terrain cannot be verified by visual or other means." The NTSB felt these two accidents may have been prevented had the pilots not wasted valuable time attempting to analyze or rationalize the GPWS warning, or question its reliability. (48)

A study was conducted to measure pilot responses to simulated Traffic Alert/Collision Avoidance System (TCAS) warnings. TCAS is a cockpit system whose purpose is similar to that of GPWS, in that it provides pilots aural and visual warnings of impending midair collisions with other aircraft. This study provides good insights into likely pilot response time to GPWS warnings, as test conditions were made as realistic as possible, with flight crews undertaking full cockpit workload for a twin-engine aircraft similar to those in the study fleet. This study showed in over 250 separate tests, the mean pilot response to a TCAS warning (the elapsed time between the onset of the warning and physical pilot control action) was 5.4 seconds. Almost 60% of test responses fell between four and six seconds, while 14% took 3 seconds or less, and 17% took more than six seconds. (49)

Based on the results of this study, it is reasonable to conclude that the pilot response time component of a GPWS terrain avoidance maneuver (assuming the pilot takes "instantaneous" action, as called for in the FAA Air Carrier Operations Bulletin) would be between four and six seconds. Assuming that control actions initiated by the pilot (to rotate to maximum climb attitude and apply maximum power) as a result of this warning would take at most another second to accomplish, the likely total pilot response time component is therefore on the order of five to seven seconds. (50)

4.3 Aircraft Response Time

The aircraft response time component in a GPWS terrain avoidance maneuver can be viewed as the interval between the pilot's initiating physical control action and a resulting rotation in the aircraft's attitude to maximum climb angle from its initial position at GPWS warning. This interval depends on a number of factors, including airspeed at warning, type of engine, and responsiveness of the aircraft to control commands.

On a turboprop aircraft, engine thrust is roughly proportional to throttle position. On turbojet aircraft, however, this is not the case. Turbojets are designed to operate at maximum efficiency at high revolutions per minute (RPM), the setting at which the aircraft is in cruise flight and at which the engine spends most of its operating time. A throttle increase on a turbojet operating at high RPM will result in a much higher increase in engine thrust than the same amount of throttle increase on a turbojet operating at low RPM. (51)

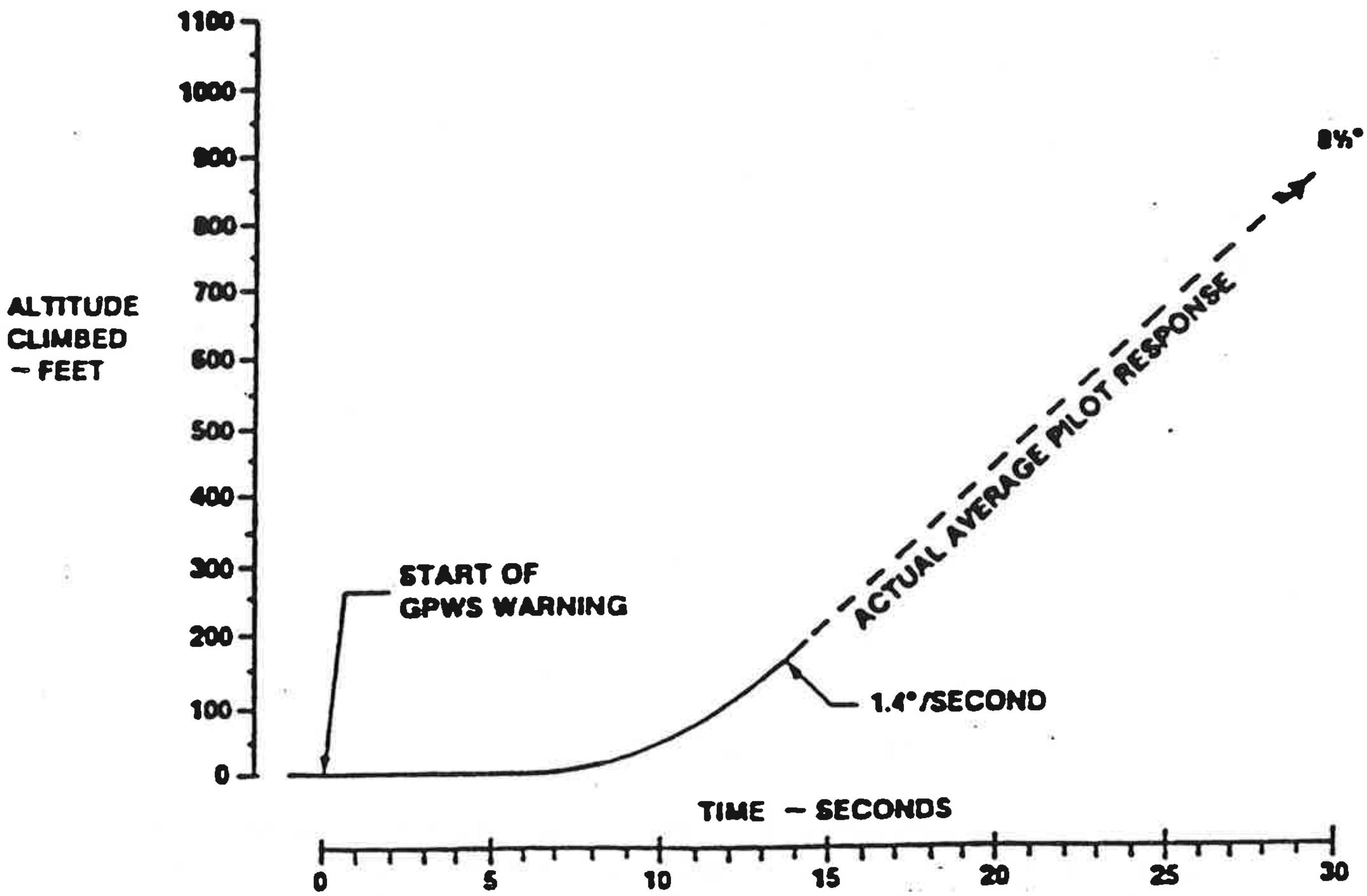
If a sudden demand is made by the pilot for full throttle, as is the case in the GPWS warning response, a turboprop engine will respond with full thrust in three to four seconds. A turbojet engine will respond with full thrust in this same interval if it is operating at high RPM (over 80% of maximum engine RPM) when full throttle is applied. However, if it is operating at low RPM, the turbojet engine must first "spool up" to high RPM before it will deliver maximum thrust. This process can take as long as four seconds. Thus achievement of full thrust from an idling turbojet engine can take as long as eight seconds. (52)

Analysis of data collected by a GPWS equipment manufacturer on a number of successful GPWS terrain avoidance maneuvers has shown that the average pilot response raised the aircraft into an 8-1/2 degree nose up attitude. Time to accomplish this rotation is on the order of one second, once maximum thrust is achieved. (53) It is therefore reasonable to conclude that the aircraft response time component of a GPWS terrain avoidance maneuver, including both achievement of maximum thrust and time to achieve at least an 8-1/2 degree climb attitude, will range from five seconds for turboprops and turbojets in takeoff or cruise flight where the engine is operating at high RPM, to 10 seconds for turbojets on approach operating at low engine RPM.

4.4 Minimum Effective GPWS Response Time

Adding together the minimum and maximum pilot and aircraft response time components of a GPWS terrain avoidance maneuver discussed above produces a range of between 10 and 17 seconds. One would expect the most probable minimum effective GPWS response interval to fall somewhere between these two extremes. Thus combinations producing the "outliers" in this range (fastest-responding pilots in fastest-responding aircraft, and slowest-responding pilots in slowest-responding aircraft) are less likely to occur than combinations producing overall responses somewhere in between. For this reason, responses in the 12 to 15 second range have been used in this study as the minimum effective GPWS response time. This 12-15 second response was then compared with GPWS warning times calculated for the various accidents analyzed. Figure 1 presents a graphical depiction of a typical GPWS terrain avoidance maneuver, in terms of altitude vs. elapsed seconds from initial warning. (54)

FIGURE 1. TYPICAL GPWS TERRAIN AVOIDANCE MANEUVER



Source: (54)

5.0 GEOMETRIC MODEL

5.1 Model Description

A simple analytical model was developed in a previous VNTSC study (55) to explore the critical relationship between a number of variables at the moment a GPWS alert or warning is initially sounded. These variables include the aircraft's flight path angle ϕ, the ground slope angle ψ, the aircraft's airspeed along its flight path V, and a warning altitude h_o.

It is assumed that when an aircraft is in descent, its flight path angle ϕ is less than 0, when an aircraft is in level flight its flight path angle ϕ is equal to 0, and when an aircraft is climbing its flight path angle ϕ is greater than 0. Similarly, it is assumed that when ground slopes downward relative to the horizontal its angle ψ is less than 0, when ground is level its angle ψ is equal to 0, and when ground slopes upward relative to the horizontal its angle ψ is greater than 0.

Given these parameters, it can be shown that there are five separate combinations of values of ϕ and ψ that will result in terrain impact, as follows:

- $\phi > 0, \psi > 0$: Aircraft climbing, but ground slope rising faster;
- $\phi = 0, \psi > 0$: Aircraft in level flight, and ground slope rising;
- $\phi < 0, \psi > 0$: Aircraft descending, and ground slope rising;
- $\phi < 0, \psi = 0$: Aircraft descending, and ground slope level; and
- $\phi < 0, \psi < 0$: Aircraft descending, but ground slope descending less.

These five combinations are shown graphically in Appendix A, Figures A-1 through A-5 . The flight path distance from the initial warning point to impact, f_d, can be expressed in terms of h_o, ϕ, and ψ:

$$f_d = h_o / (\tan \psi \cos \phi - \sin \phi) \qquad \text{equation (1)}$$

The derivation of Equation 1 for the five relevant combinations of ϕ and ψ is shown in Appendix A. Once f_d is known, then time from initial warning to impact T_w can be expressed in terms of f_d and V:

$$T_w = f_d / V \qquad \text{equation (2)}$$

6.0 STUDY METHODOLOGY

6.1 NTSB Accident File Review

Once the CFIT accidents meeting all selection criteria were identified, the complete NTSB accident record for each was reviewed. While the contents of each file varied, typical contents included NTSB form 6120.4, Factual Report -- Aviation Accident, with various sections and supplements presenting information on accident circumstances. This report contained information on flight history, accident location, meteorological conditions, pilot(s), aircraft, airport (if pertinent), impact, wreckage, fire (if any), and findings of medical/pathological studies. Accident files also generally contained photographs, maps, approach plates, airport diagrams or aeronautical charts of the accident vicinity. Also included were flight plan and other ATC documents as well as survivor interviews, descriptions obtained from ground witnesses, and statements by air traffic control personnel who had responsibility for handling the flight. In certain cases, transcripts of recorded controller interactions with aircraft on FAA radio frequencies were provided. Some accident files also contained analyses of available FAA radar data depicting the final minutes of flight. If engine teardowns or other analyses of wreckage were performed, reports documenting these investigations were also included.

Aircraft flying under FAR Part 91 flight rules are not required to be equipped with a cockpit voice recorder (CVR) or a flight data recorder (FDR), on-board aircraft instruments that provide information in post crash investigation. Only one of the accidents studied involved an aircraft with a CVR; transcripts of pilot conversations recorded by this device were included in that accident file. None of the accident aircraft in this study were equipped with a FDR.

Review of the NTSB accident file was intended to characterize, in as detailed a manner as possible, the final minutes of the flight up to and including impact, with the ultimate objective of reconstructing the aircraft's flight path. To this end, special attention was paid to any references contained in the file to the flight path, including maps of the ground track, radar data plots, data on aircraft configuration, airspeed and heading at impact. Also valuable in this regard were references in witness reports or recorded controller conversations to clearances, altitudes, headings, and approaches/navigational aids being used by the accident flight.

6.2 Determination of Likely GPWS or EGPWS Warning Time

For those accidents involving terminal approaches, the pertinent published approach procedure was obtained. For each accident reviewed, a U. S. Geodetic

Survey (USGS) 1 : 24,000 scale quadrangle map of the accident vicinity was also obtained. In some cases, several adjacent quadrangle maps were used.

On the USGS map, the accident location and heading at impact were plotted. Based on available data, the probable ground track of the flight for its final five to ten nautical miles (NM) was also plotted backwards from the impact point. Using elevation in feet above mean sea level (MSL) as the Y-axis, and distance in NM as the X-axis, it was possible to constructing a chart plotting relevant variables of interest. For accidents involving low approach or premature descent, X-axis (distance) values were measured from the approach runway threshold back to the impact point and from that point backwards along the ground track; for other accidents, they were measured backwards along the ground track from the impact point. Y-axis (elevation) variables included the following, if relevant:

- terrain contours and significant topographical features;
- the probable flight path of the aircraft, given available descriptive information, and taking into account terrain or obstructions cleared before impact;
- likely elevation of cloud ceiling;
- GPWS or GPS-enhanced GPWS warning envelopes; and
- published approach procedure profile.

Once the above data were plotted, a determination was made, using the warning envelope graphs of TSO-C92b as reference, concerning the GPWS mode that would have produced the earliest warning.

Once the earliest GPWS warning point was established, inputs for the geometric model discussed above were either calculated or obtained through reference to NTSB accident information. These inputs include flight path angle ϕ, the ground slope angle ψ, the aircraft's airspeed along its flight path V, and altitude h_o at the GPWS warning point. If a is the horizontal component of ground slope over a certain ground track distance, and b is the vertical component of ground slope over the same distance, ground slope angle ψ can be calculated using the formula:

$$\psi = \arctan (b / a) \qquad \text{equation (3)}$$

Similarly, if c is the horizontal component of the flight path over a certain flight path distance, and d is the vertical component of the flight path over the same distance, then flight path angle ϕ can be calculated using the formula:

$$\phi = \arctan (d / c) \qquad \text{equation (4)}$$

Airspeed V at the warning point was assumed to be the same as airspeed at impact indicated in the NTSB file. In some cases, where post crash investigation did not establish an exact airspeed, an estimated range was provided. Model input airspeed was taken as the mean of the lowest and highest values in this range.

Aircraft altitude at the warning point was dependent on GPWS mode, and the pertinent warning threshold envelope variables for each mode. For example, a GPWS Mode 4 warning would occur at 500' AGL if landing gear and flaps were not extended in landing configuration, and at 200' AGL if landing gear were extended, but flaps were not in landing configuration. GPWS warning threshold envelopes, as described in TSO-C92b, are shown in Appendix B.

Once the geometric model inputs were calculated or obtained, they were entered into a spreadsheet which took values of ground slope angle ψ, airspeed V, and altitude h_o at the GPWS warning point and applied equations (1) and (2) for a range of likely values of flight path angle ϕ. The result was distances and times to impact from the GPWS warning point for this range of flight path angles. Based on accident file information, the most likely flight path angle at the warning point was selected, and the warning time values associated with the next higher and lower angles in this range were used to provide an upper and lower bound on the likely warning time value.

This likely warning time interval was next compared with the minimum effective GPWS response time of 12-15 seconds as described above in section 4.4. If the likely warning time interval was *greater than or equal to* this minimum effective GPWS response time, it was assumed that the accident could probably have been prevented by current GPWS technology.

If the likely warning time interval was *less than* the minimum effective GPWS response time (i.e., current GPWS technology could probably *not* have prevented the accident), an effort was undertaken to determine whether GPS-enhanced GPWS (EGPWS) "forward looking" or terrain clearance "floor" features would have provided more timely warnings than current GPWS technology. Warning time for "forward looking" EGPWS was assumed to be 25 to 30 seconds, based on manufacturer information. Warning time for the terrain clearance "floor" features was based on determination of the earliest intersection of the accident aircraft flight path with the "floor," and application of the geometric model with the input variables associated with this initial EGPWS warning point. This "floor" threshold value was assumed to ramp upward at 100' AGL per NM radial distance from the runway threshold, until it reached 500' AGL at 5 NM from the threshold. Beyond this point, it was assumed to continue at 500' AGL to 12 NM from the runway.

6.3 Limitations of the Analysis

For certain accidents studied, NTSB accident files were incomplete in some respects, and judgments and assumptions had to be made concerning values of various input variables for the geometric model. For example, certain accidents left aircraft so thoroughly destroyed that investigators were unable to determine landing gear or flap positions at impact. For these accidents, it was necessary to assume likely flap positions given flight circumstances slightly before impact. In other cases, reconstruction of the exact flight path was not possible as there was no radar or other altitude data available. For these accidents, it was necessary to hypothesize the most likely flight path given pilot/controller conversations including references to navigational aids and altitudes, survivor or witness reports, terrain features/obstructions cleared before impact, etc.

The determination of a minimum effective recovery time of 12-15 seconds addressed a "generic" recovery maneuver in a GPWS warning situation. No attempt was made to "tailor" this recovery maneuver to address specific accident circumstances or aircraft performance capabilities. Application of the simple geometric model, while it did address critical relationships between flight parameters and terrain features at the warning point, did not allow for any variation in the aircraft's airspeed, climb/descent rate, or flight path *after* warning in its calculation of straight-line distance to impact. The likelihood of recovery from GPWS (or EGPWS) warning was based strictly upon calculated time to impact exceeding this minimum effective recovery time.

A key assumption in this analysis is that flight crews involved in the accidents studied would have responded immediately and appropriately to GPWS alerts and warnings when they sounded, had their aircraft been equipped with GPWS. GPWS is not an automatic control system; it is a system requiring pilot response. In no case, therefore, can it be claimed with absolute certainty that GPWS would have prevented an accident. In several of the accidents studied, there was little, if any, room for delay in this response if the accident was to be prevented.

An assumption of immediate and appropriate response may appear tenuous in some cases, as the flight crews in these accidents were involved in questionable breaches of established flight procedures (e.g., descent well below published approach minimums) before they crashed. GPWS warnings would likely have sounded during the course of these questionable maneuvers.

Assuming anything less than immediate and appropriate GPWS response, however, can only lead to speculation concerning what a "more probable" response might have been under the circumstances. Would the pilot(s) have delayed five seconds? ten seconds? Would they have ignored the GPWS completely? Because there is no way of predicting what the *actual* response would have been, one must assume it was the expected response to GPWS alerts and warnings: immediate, deliberate, and appropriate.

7.0 STUDY FINDINGS AND CONCLUSIONS

7.1. Categorization of Accidents Studied

A total of 44 domestic CFIT accidents in the time period 1985-1994 were investigated in detail (see Table 3).

Following a review of accident data, these 44 accidents could be grouped into four major categories:

- o low approaches or premature descents (23 total) in which aircraft on approach or performing missed approach maneuvers descended below published minimum altitude for the approach or missed approach and impacted terrain;

- o collision with rising terrain (11 total) in which aircraft during various phases of flight impacted terrain obstructions in their flight path;

- o descent after takeoff (4 total) or missed approach (one total) in which aircraft lost altitude shortly after takeoff or missed approach maneuver and impacted terrain; and

- o gear-up landings (5 total) in which aircraft landed on the landing runway, but with landing gear not extended due to inadvertent omission of this action by the pilot prior to touchdown.

Tables 5 and 6 show the category assigned to each accident investigated. The first page of these two tables shows all the accidents in the low approach/ premature descent category; accidents the three remaining categories are grouped vertically across the second page of these two tables.

7.2 Accident statistics

The 23 accidents categorized as low approach/premature descent resulted in 70 fatalities. Thirteen persons in these accidents survived with serious injuries, and an additional 13 survived with minor or no injuries. Of the 23 aircraft involved, 5 were turbojets and the remaining 18 were turboprops. All 5 turbojets and 16 of the 18 turboprops were destroyed; the 2 remaining turboprops (in the Eugene, OR, and Marfa, TX, accidents) sustained substantial damage.

The 11 accidents categorized as collision with rising terrain resulted in 55 fatalities. Only 1 person survived, with serious injuries. Of the 11 aircraft involved, 3 were turbojets and 8 were turboprops; all were destroyed.

The 5 accidents categorized as descent after takeoff or missed approach resulted in 6 fatalities. Five persons survived these accidents with serious injuries, and an additional 2 persons survived with minor or no injuries. Of the 5 aircraft involved, 2 were turbojets and 3 were turboprops. All 5 aircraft were destroyed.

The 5 accidents categorized as gear-up landings caused no fatalities or serious injuries. Eleven persons survived these accidents with minor or no injuries. Of the 5 aircraft involved, one was a turbojet and 4 were turboprops. All 5 aircraft sustained substantial damage.

7.3 NTSB Determinations of Probable Cause/Contributing Factors

Following its investigation of each CFIT accident studied, the NTSB issued a determination of probable cause. In some cases, other factors considered as contributing to the accident were also listed. Tables 5 and 6 present NTSB determinations of probable cause and contributing factors.

In all cases, the NTSB concluded pilot error was the primary cause. In only one case (Alamogordo, NM) was FAA air traffic control failure to issue a safety alert held to be a probable cause. In two other cases (San Diego, CA, and Jacksonville, FL), inadequate pre-flight information provided by ATC and failure of ATC to issue missed approach instructions were held to be contributing factors. In one accident (Eagle, CO), the NTSB concluded that flight crew use of an aeronautical chart which did not accurately depict terrain obstructions was a contributing factor. These were the only four accidents where operational items other than pilot error were cited by the NTSB as probable causes or contributing factors.

For those 23 accidents categorized as low approach or premature descent, the NTSB in all but one case (Harrison, AR) listed a probable cause as failure of the pilot-in-command (PIC) to maintain proper altitude on the approach. In all these accidents the pilots descended well below the minimum descent altitude (for non-precision approaches) or the decision height (for precision approaches). Improper instrument flight rules (IFR) or visual flight rules (VFR) procedures were also cited as a probable cause in 13 of these 23 accidents. Other items listed as probable causes included:

- improper PIC planning or decision-making (6 accidents);
- PIC disorientation (3 accidents);
- failure of the PIC to execute a missed approach procedure (3 accidents);

TABLE 5. PROBABLE CAUSE OF ACCIDENT AS DETERMINED BY NTSB

LOW APPROACH / PREMATURE DESCENT ACCIDENTS

PROBABLE CAUSE / ACCIDENT LOCATION	ST. MARYS, PA	UTICA, MI	HARRISON, AR	HAMPTONBURGH, NY	CADILLAC, MI	DERRY, PA	E.GREENWICH, RI	JACKSONVILLE, FL	NORTON SHORES, MI	WINDSOR, MA	HAZELWOOD, MO	HOUSTON, TX	EUGENE, OR	LOCUST GROVE, AR	MANSFIELD, OH	MAYFIELD, KY	HURDLE MILLS, NC	UVALDE, TX	SAN LUIS OBISPO, CA	ROMEO, MI	ST. AUGUSTINE, FL	MARFA, TX	CHANTILLY, VA
IMPROPER PIC PLANNING / DECISION MAKING	X				X			X	X											X			X
IMPROPER IFR / VFR PROCEDURE	X		X			X	X		X	X		X				X	X	X	X		X		X
FAILURE TO MAINTAIN PROPER ALTITUDE	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FAILURE TO MAINTAIN PROPER ILS GLIDE PATH											X		X										
PIC DISORIENTATION			X			X									X								
IMPROPER CONTINUATION OF VFR FLIGHT INTO IMC				X																			
FAILURE TO EXECUTE MISSED APPROACH PROCEDURE					X			X			X												
PIC INEXPERIENCE WITH AIRCRAFT																							X

TABLE 5, CONT'D. PROBABLE CAUSE OF ACCIDENT AS DETERMINED BY NTSB

COLLISION WITH RISING TERRAIN, DESCENT AFTER TAKEOFF OR MISSED APPROACH, AND GEAR-UP LANDING ACCIDENTS

PROBABLE CAUSE / ACCIDENT CATEGORY / LOCATION	**COLL. W/TERRAIN**	FLAT ROCK, NC	EAGLE, CO	AZUSA, CA	RYDERWOOD, WA	SAN DIEGO, CA	ROME, GA	BIG BEAR, CA	ALAMOGORDO, NM	MT. IDA, AR	SANTA FE, NM	FRONT ROYAL, VA	**DESCENT AFTER T.O.**	WEST POINT, VA	APPALACHICOLA, FL	CARTERSVILLE, GA	ALBUQUERQUE, NM	TAOS, NM	**GEAR-UP LANDING**	CHARLEVOIX, MI	LITTLE ROCK, AR	NOVATO, CA	BATESVILLE, IN	SHEBOYGAN, WI
FAILURE TO MAINTAIN PROPER ALTITUDE			X		X	X	X		X		X													
IMPROPER IFR / VFR PROCEDURE		X	X						X											X				
IMPROPER PIC PLANNING / DECISION MAKING				X	X	X	X	X			X	X												
CONTINUATION OF VFR FLIGHT INTO IMC				X			X	X				X												
POOR CREW COORDINATION						X									X									
FAILURE OF ATC TO ISSUE SAFETY ALERT									X															
FAILURE TO ESTABLISH PROPER CLIMB RATE										X					X	X	X	X						
PIC DISORIENTATION														X	X		X							
FAILURE TO FOLLOW CHECKLIST																					X		X	X
FAILURE TO EXTEND GEAR																				X	X	X	X	X
PIC DIVERTED ATTENTION																				X				

TABLE 6. FACTORS CONTRIBUTING TO ACCIDENT AS DETERMINED BY NTSB

LOW APPROACH / PREMATURE DESCENT ACCIDENTS

CONTRIBUTING FACTOR / ACCIDENT LOCATION	ST. MARYS, PA	UTICA, MI	HARRISON, AR	HAMPTONBURGH, NY	CADILLAC, MI	DERRY, PA	E.GREENWICH, RI	JACKSONVILLE, FL	NORTON SHORES, MI	WINDSOR, MA	HAZELWOOD, MO	HOUSTON, TX	EUGENE, OR	LOCUST GROVE, AR	MANSFIELD, OH	MAYFIELD, KY	HURDLE MILLS, NC	UVALDE, TX	SAN LUIS OBISPO, CA	ROMEO, MI	ST. AUGUSTINE, FL	MARFA, TX	CHANTILLY, VA
PREVAILING WEATHER CONDITIONS			X		X	X		X	X	X	X	X	X	X	X	X		X	X		X	X	
DARK NIGHT						X							X	X		X		X				X	
IMPROPER PIC PLANNING / DECISION MAKING		X				X	X			X													
TOPOGRAPHY			X			X				X				X									
PIC OVERCONFIDENCE / COMPLACENCY					X				X														
PIC SELF-INDUCED PRESSURE									X														
IMPROPER PROCEDURES USED BY ATC								X															
POOR CREW COORDINATION									X													X	

TABLE 6, CONT'D. FACTORS CONTRIBUTING TO ACCIDENT AS DETERMINED BY NTSB

COLLISION WITH RISING TERRAIN, DESCENT AFTER TAKEOFF OR MISSED APPROACH, AND GEAR-UP LANDING ACCIDENTS

CONTRIBUTING FACTOR / ACCIDENT CATEGORY / LOCATION	COLL. W/TERRAIN	FLAT ROCK, NC	EAGLE, CO	AZUSA, CA	RYDERWOOD, WA	SAN DIEGO, CA	ROME, GA	BIG BEAR, CA	ALAMOGORDO, NM	MT. IDA, AR	SANTA FE, NM	FRONT ROYAL, VA	DESCENT AFTER T.O.	WEST POINT, VA	APPALACHICOLA, FL	CARTERSVILLE, GA	ALBUQUERQUE, NM	TAOS, NM	GEAR-UP LANDING	CHARLEVOIX, MI	LITTLE ROCK, AR	NOVATO, CA	BATESVILLE, IN	SHEBOYGAN, WI
PREVAILING WEATHER CONDITIONS		X		X				X		X				X	X			X						
DARK NIGHT			X			X			X		X					X	X	X						
IMPROPER PIC PLANNING / DECISION MAKING			X					X																
TOPOGRAPHY				X		X		X	X															
PIC OVERCONFIDENCE / COMPLACENCY															X									
PIC SELF-INDUCED PRESSURE														X										
INADEQUATE INFORMATION PROVIDED BY ATC						X																		
POOR CREW COORDINATION																X						X		
PIC DISTRACTION																						X		X
FAILURE TO USE CHECKLIST																						X		
PIC LACK OF FAMILIARITY WITH GEOGRAPHIC AREA			X			X			X															
INACCURATE CHARTS			X																					
LACK OF VISUAL REFERENCE											X					X								

- o failure to maintain proper instrument landing system glide path (2 accidents);
- o improper continuation of visual flight rules (VFR) flight into instrument meteorological conditions (IMC) (one accident); and
- o PIC lack of familiarity with the aircraft (one accident).

In 16 of the 23 accidents categorized as low approach or premature descent, the NTSB held a contributing factor to be the prevailing weather conditions at the time of the accident. The dark night was also cited as a factor in 6 of these accidents. Other factors contributing to the low approach/premature descent accidents included:

- o improper PIC planning or decision-making (4 accidents);
- o the topography at the accident location (4 accidents);
- o PIC complacency or overconfidence in their piloting abilities (2 accidents);
- o poor flight crew coordination (2 accidents); and
- o PIC self-induced pressure (one accident).

For those accidents categorized as collision with rising terrain, the NTSB considered improper PIC planning or decision-making a probable cause in 7 of the 11 cases. Failure to maintain proper altitude was also cited as a probable cause in 6 cases. Other probable causes cited by the NTSB for these accidents included:

- o improper continuation of VFR flight into IMC (4 accidents);
- o improper IFR/VFR procedures (3 accidents);
- o poor flight crew coordination (one accident); and
- o failure to establish proper climb rate (one accident).

Factors found by the NTSB to have contributed to the 11 collision with rising terrain accidents included the prevailing weather conditions in 4 cases, the dark night in 4 cases, and the local topography at the accident site in 4 cases. Other factors cited as contributing to these 11 accidents include:

- o PIC lack of familiarity with the geographic area (3 accidents);

- improper PIC planning or decision-making (2 accidents);
- inaccurate charts used by the flight crew (one accident); and
- lack of visual reference (one accident).

In 4 of the 5 accidents categorized as descent after takeoff or missed approach, the NTSB found failure of the PIC to establish a proper climb rate as a probable cause. PIC disorientation (3 accidents) and poor flight crew coordination (one accident) were also cited as probable causes.

For the 5 descent after takeoff or missed approach accidents, the NTSB found prevailing weather conditions to be a contributing factor in 3 cases; the dark night was also cited as contributing in 3 cases. Other contributing factors in these 5 accidents included PIC overconfidence or complacency, PIC self-induced pressure, poor flight crew coordination, and lack of visual reference (one accident each).

In all of the 5 accidents categorized as gear-up landings, PIC failure to extend the landing gear was found to be a probable cause by the NTSB. PIC failure to follow the landing checklist was also cited in 3 cases, and PIC diverted attention was cited in one gear-up landing accident.

Factors cited by the NTSB as contributing to the 5 gear-up landing accidents included PIC distraction (2 accidents), poor flight crew coordination (one accident) and PIC failure to use the landing checklist (one accident).

7.4 Minimum Safe Altitude Warnings

One justification given by the FAA in non-concurrence with previous NTSB recommendations concerning mandatory GPWS installation is that the Minimum Safe Altitude Warning (MSAW) system already in place is likely to provide much of the functionality of an on-board GPWS. The MSAW system is currently operational at larger airports. It automatically scans radar data to detect whether aircraft on approach to these airports descend below a certain preset threshold altitude. If an aircraft descends below this altitude, an alert is issued automatically to the air traffic controller responsible for the aircraft. This alert is then relayed verbally by the controller to the pilot. It was considered useful to review the 44 accident files studied for evidence of MSAW warnings.

Based on information in the 44 accident files reviewed, the FAA's claim that MSAW can address the CFIT problem is somewhat suspect. Of the 44 accidents studied, most occurred near small airports where MSAW was not available. In only two cases (Houston, TX, and San Luis Obispo, CA) did the controller issue the pilot a low altitude warning, and it is not clear from the accident file whether this information was obtained by the controller via MSAW alert or simply by monitoring aircraft altitude data present on the controller radar display. In both cases, the warning did not prevent the accident. In 3 other cases (Jacksonville, FL, Rome, GA, and Alamogordo, NM) controllers asked pilots shortly before the accident to state current altitude, but issued no MSAW warnings. Two of the 44 accidents studied (Hazelwood, MO, and Chantilly, VA) occurred near large airports, where one would expect MSAW warnings to have been issued, but no MSAW alert was mentioned in the accident file in these cases.

7.5 Prevailing Meteorological Conditions

Table 7 presents a summary of meteorological conditions prevailing at the time of the 44 CFIT accidents studied. This table clearly shows that CFIT accidents, as one might intuitively expect, are far more likely to occur during weather or light conditions which reduce or obstruct pilot's vision. Only 9 of the 44 accidents studied involved visual meteorological conditions (VMC) in which there was no precipitation; of these 9, only 3 occurred during daylight (or dusk), and all 3 were gear-up landings. A total of 31 of the 44 accidents (70%) occurred during instrument meteorological conditions (IMC), in which visibility was obscured to such an extent that pilots had to rely on instruments, rather than visual reference, for situational awareness. Further compounding this situation is the fact that 23 of the 44 (52%) occurred during light conditions classified as "dark night," or overcast conditions in which moon and stars are not present to illuminate terrain for visual reference. A total of 16 accidents (36%) involved the combination of both IMC and dark night. As mentioned above, the NTSB cited meteorological conditions or dark night as a contributing factor in 28 of the 44 accidents (64%).

For those 23 accidents categorized as low approach or premature descent, prevailing meteorological conditions were clearly an important causal factor. All 23 of these accidents occurred in IMC; 14 of the 23 (61%) involved the combination of IMC and dark night. In 15 cases (65%), the measured cloud ceiling at the time of the accident was 500' AGL or less, and in 11 cases (48%), horizontal visibility was measured at one mile or less. Fog was listed as present at the accident site in 20 cases (87%) while rain or snow was present in the remaining 3; combinations of rain, snow or fog were mentioned in 8 (35%) cases.

TABLE 7. PREVAILING METEOROLOGICAL CONDITIONS AT TIME OF ACCIDENT

LOW APPROACH OR PREMATURE DESCENT ACCIDENTS

ACCIDENT LOCATION	WEATHER CONDITIONS	LIGHT CONDITIONS	LOWEST CEILING (FEET AGL)	VISIBILITY (MILES)	PRECIPITATION
ST. MARYS, PA	IMC	DARK NIGHT	1100	2	SNOW
UTICA, MI	IMC	DARK NIGHT	100	0.25	FOG
HARRISON, AR	IMC	DUSK	500	2	FOG/RAIN
HAMPTONBURGH, NY	IMC	DARK NIGHT	500	4	FOG/HAZE
CADILLAC, MI	IMC	DARK NIGHT	600	1	RAIN
DERRY, PA	IMC	DARK NIGHT	500	0.75	FOG
E. GREENWICH, RI	IMC	DARK NIGHT	300	2	FOG/DRIZZLE
JACKSONVILLE, FL	IMC	DARK NIGHT	300	1	FOG/RAIN
NORTON SHORES, MI	IMC	DAYLIGHT	1100	6	FOG
WINDSOR, MA	IMC	DAYLIGHT	800	7	FOG
HAZELWOOD, MO	IMC	DARK NIGHT	UNRPTD	0.375	FOG
HOUSTON, TX	IMC	DAYLIGHT	100	0.265	FOG
EUGENE, OR	IMC	DARK NIGHT	1800	0.25	FOG
LOCUST GROVE, AR	IMC	DARK NIGHT	500	2	RAIN
MANSFIELD, OH	IMC	DAYLIGHT	800	2.5	FOG/SNOW
MAYFIELD, KY	IMC	DARK NIGHT	200	3	FOG/RAIN
HURDLE MILLS, NC	IMC	DARK NIGHT	500	3	FOR/RAIN
UVALDE, TX	IMC	DARK NIGHT	300	1	FOG/RAIN
SAN LUIS OBISPO, CA	IMC	DAYLIGHT	100	0.125	FOG
ROMEO, MI	IMC	DAYLIGHT	200	0.75	FOG
ST. AUGUSTINE, FL	IMC	DAWN	300	UNRPTD	FOG
MARFA, TX	IMC	DARK NIGHT	1000	1.25	FOG
CHANTILLY, VA	IMC	DAWN	500	0.5	FOG

TABLE 7, CONT'D. PREVAILING METEOROLOGICAL CONDITIONS AT TIME OF ACCIDENT

COLLISION WITH RISING TERRAIN, DESCENT AFTER TAKEOFF OR MISSED APPROACH, AND GEAR-UP LANDING ACCIDENTS

ACCIDENT CATEGORY / LOCATION	WEATHER CONDITIONS	LIGHT CONDITIONS	LOWEST CEILING (FEET AGL)	VISIBILITY (MILES)	PRECIPITATION
COLL. W/TERRAIN					
FLAT ROCK, NC	VMC	BRIGHT NIGHT	1500	3	FOG/DRIZZLE
EAGLE, CO	VMC	DARK NIGHT	3000	15	NONE
AZUSA, CA	IMC	DAYLIGHT	5500	5	FOG
RYDERWOOD, WA	VMC	DARK NIGHT	3900	10	NONE
SAN DIEGO, CA	VMC	DARK NIGHT	UNL	NO	NONE
ROME, GA	IMC	DAYLIGHT	1000	10	FOG
BIG BEAR, CA	IMC	DAYLIGHT	4000	3	FOG
ALAMOGORDO, NM	VMC	DARK NIGHT	UNL	20	NONE
MT. IDA, AR	IMC	DAYLIGHT	200	0.75	FOG
SANTA FE, NM	VMC	DARK NIGHT	8000	40	NONE
FRONT ROYAL, VA	IMC	DAYLIGHT	1900	10	FOG
DESCENT AFTER T.O.					
WEST POINT, VA	IMC	DARK NIGHT	200	1	FOG/DRIZZLE
APPALACHICOLA, FL	VMC	DAYLIGHT	25000	3	HAZE
CARTERSVILLE, GA	VMC	DARK NIGHT	8000	2	FOG/HAZE
ALBUQUERQUE, NM	VMC	DARK NIGHT	UNL	15	NONE
TAOS, NM	IMC	DARK NIGHT	500	3	RAIN/SNOW
GEAR-UP LANDING					
CHARLEVOIX, MI	IMC	DAYLIGHT	500	7	FOG
LITTLE ROCK, AR	VMC	DAYLIGHT	UNL	15	NONE
NOVATO, CA	VMC	DAYLIGHT	UNL	30	NONE
BATESVILLE, IN	VMC	DAYLIGHT	2000	6	HAZE
SHEBOYGAN, WI	VMC	DUSK	UNL	10	NONE

Poor visibility also played a role in those accidents categorized as either collision with terrain or descent after takeoff or missed approach. In 11 of the 16 such accidents (69%), fog or other precipitation was present. The remaining 5 accidents occurred during dark night conditions over uninhabited, unlit terrain providing no visual reference to the flight crews involved.

As mentioned above, 3 of the 5 gear-up landing accidents occurred during daylight, VMC; pilot distraction or diverted attention appears to have played a larger role in causing these accidents than prevailing meteorological conditions.

7.6 Geometric Model Application Results -- Current Technology GPWS

Table 8 presents the results obtained from application of the geometric model described above in Section 5. The first column in this table states whether necessary conditions were met, based on a review of accident circumstances, for a GPWS warning to have sounded, had the aircraft involved been equipped with the current generation of GPWS. The second column in Table 8 lists the applicable GPWS mode which would have sounded the earliest warning in each accident. The third and fourth columns of this table present minimum and maximum warning times (in seconds) as calculated given the model inputs of flight path angle ϕ, the ground slope angle ψ, the aircraft's airspeed along its flight path V, and altitude h_o at the earliest GPWS warning point for each accident. Detailed descriptions of accident circumstances and the application of this model to each accident studied are provided in Volume Two of this study.

From Table 8, it can be seen that current GPWS technology would probably have sounded warnings in 38 of the 44 accidents studied (86%). This includes all of those accidents categorized as collision with terrain, descent after takeoff or missed approach, and gear-up landing. It also includes 17 of the 23 accidents categorized as low approach or premature descent. In the other 6 low approach/premature descent cases, the aircraft was in stabilized descent on a non-precision approach, with gear and flaps extended in landing configuration. In these cases, it is unlikely that mode 1 or 2 (Excessive Sink Rate or Excessive Terrain Closure Rate) would apply, since the aircraft was descending at a typical landing attitude of 2-4 degrees nose down. Mode 3 (Descent After Takeoff or Missed Approach) would not apply, since the aircraft involved were not in a takeoff or missed approach situation. Since the aircraft were in landing configuration, the mode 4 (Insufficient Terrain Clearance not in Landing Configuration) would be desensitized to prevent nuisance warnings on final approach. Mode 5 (Descent Below Glide Slope) would also not apply, since the approaches being flown in these situations did not include glide slope guidance.

TABLE 8. GEOMETRIC MODEL APPLICATION RESULTS
CURRENT TECHNOLOGY GPWS

LOW APPROACH OR PREMATURE DESCENT ACCIDENTS

ACCIDENT LOCATION	GPWS WARNING?	EARLIEST GPWS MODE	MIN. WARNING TIME (SEC)	MAX. WARNING TIME (SEC)
ST. MARYS, PA	YES	4	7	10
UTICA, MI	YES	4	18	25
HARRISON, AR	YES	2	14	16
HAMPTONBURGH, NY	NO	N/A	N/A	N/A
CADILLAC, MI	YES	1	12	15
DERRY, PA	YES	2	17	19
E. GREENWICH, RI	YES	5	38	42
JACKSONVILLE, FL	YES	1	12	13
NORTON SHORES, MI	YES	4	12	15
WINDSOR, MA	YES	2	17	19
HAZELWOOD, MO	YES	5	21	27
HOUSTON, TX	YES	5	13	18
EUGENE, OR	YES	5	53	86
LOCUST GROVE, AR	YES	4	13	16
MANSFIELD, OH	YES	5	18	23
MAYFIELD, KY	NO	N/A	N/A	N/A
HURDLE MILLS, NC	NO	N/A	N/A	N/A
UVALDE, TX	NO	N/A	N/A	N/A
SAN LUIS OBISPO, CA	YES	4	33	45
ROMEO, MI	NO	N/A	N/A	N/A
ST. AUGUSTINE, FL	YES	4	120	150
MARFA, TX	NO	N/A	N/A	N/A
CHANTILLY, VA	YES	5	56	73

TABLE 8, CONT'D. GEOMETRIC MODEL APPLICATION RESULTS
CURRENT TECHNOLOGY GPWS

COLLISION WITH RISING TERRAIN, DESCENT AFTER TAKEOFF OR MISSED APPROACH, AND GEAR-UP LANDING ACCIDENTS

ACCIDENT CATEGORY / LOCATION	GPWS WARNING?	EARLIEST GPWS MODE	MIN. WARNING TIME (SEC)	MAX WARNING TIME (SEC)
COLL. W/TERRAIN				
FLAT ROCK, NC	YES	2	9	12
EAGLE, CO	YES	4	7	9
AZUSA, CA	YES	2	7	60
RYDERWOOD, WA	YES	2	13	25
SAN DIEGO, CA	YES	2	18	20
ROME, GA	YES	2	10	11
BIG BEAR, CA	YES	2	26	70
ALAMOGORDO, NM	YES	2	18	20
MT. IDA, AR	YES	4	33	47
SANTA FE, NM	YES	4	42	63
FRONT ROYAL, VA	YES	4	25	28
DESCENT AFTER T.O.				
WEST POINT, VA	YES	3	51	120
APPALACHICOLA, FL	YES	3	16	30
CARTERSVILLE, GA	YES	3	16	28
ALBUQUERQUE, NM	YES	3	31	50
TAOS, NM	YES	3	13	30
GEAR-UP LANDING				
CHARLEVOIX, MI	YES	4	45	90
LITTLE ROCK, AR	YES	4	45	90
NOVATO, CA	YES	4	45	90
BATESVILLE, IN	YES	4	45	90
SHEBOYGAN, WI	YES	4	45	90

Reviewing accident circumstances for those 38 accidents in which it was considered likely that current technology GPWS would have sounded a warning, it was determined that mode 3 (Descent After Takeoff or Missed Approach), as expected, would have sounded the earliest warning in all 5 cases categorized as descent after takeoff or missed approach. The mode 2 warning (Excessive Terrain Closure Rate) would have sounded the earliest warning in 10 of the 44 accidents studied, including 3 categorized as low approach/premature descent and 7 categorized as collision with terrain. The mode 4 (Insufficient Terrain Clearance not in Landing Configuration) warning would have been the earliest indication of hazardous ground proximity in 15 other cases, including 4 of those accidents categorized as collision with terrain and all 5 categorized as gear-up landing, as well as 6 of those accidents categorized as low approach or premature descent. The mode 5 (Descent Below Glide Slope) warning would have sounded the earliest warning in 6 additional accidents in which the aircraft was on a full instrument landing system (ILS) approach in which glide slope guidance was provided. Finally, in the 2 remaining cases where warnings would have sounded, the mode 1 warning (Excessive Sink Rate) would have sounded first, as the aircraft was in a relatively steep descent before impact.

A review of the likely minimum and maximum GPWS warning times before impact in Table 8, as calculated by the geometric model, reveals that in 33 of the 38 cases in which current technology GPWS warnings would probably have sounded, the warning time from earliest GPWS warning to impact exceeded the assumed minimum effective GPWS response time of 12-15 seconds. However, it should be noted that in several of these 25 cases, the available warning time left almost no room for additional delay beyond this minimum effective response.

Of the 5 accidents in which current technology would have probably sounded a warning, but available response time did not exceed the minimum effective GPWS response, 3 were categorized as collision with terrain, and 2 were categorized as low approach/premature descent. In the collisions with terrain, it was generally the combination of steep ground slope and high airspeed that resulted in low warning times. In the low approach/premature descent situations, the combination of low altitude at warning (i.e., a 200' AGL mode 4 warning due to gear, but not flaps being set in landing configuration) and relatively steep aircraft descent angle generally led to low warning times.

7.7 Potential GPS-Enhanced GPWS (EGPWS) Impact on Model Results

An attempt was made, given available information on the next generation of GPS-enhanced GPWS (EGPWS) technology, to investigate further the 11 accidents in which current GPWS technology would either not have sounded a warning, or would have sounded a warning, but available response time with current GPWS technology did not exceed assumed minimum effective response time. This investigation was intended to determine whether EGPWS technology, which will be commercially available in the near future, would have provided an additional margin of safety beyond that available with current technology equipment. Results of this investigation are shown on Table 9.

For each of these 11 accidents, a determination was made concerning the appropriate warning mode which would be likely to sound the earliest alarm. Model application had shown that the five warning modes of current GPWS technology would not provide sufficient warning. EGPWS provides two additional capabilities beyond these five GPWS modes; it was these two capabilities ("forward-looking" display of terrain and obstructions in the aircraft's flight path, and terrain clearance "floor" independent of gear and flap settings) that were of interest. The first column of Table 9 presents the EGPWS mode which was assumed to provide the earliest warning in each case.

Of the 11 accidents investigated, it is assumed that the EGPWS "forward-looking" capability would have produced the earliest warning in 3 cases, each categorized as collision with terrain. Warning times with current technology GPWS mode 4 for these 3 cases were typically 7-10 seconds. Information provided by the manufacturer indicates the "forward-looking" capability will provide a minimum of 25-30 seconds of warning before terrain impact. This is a significant increase in warning time, which well exceeds the assumed minimum effective GPWS response time of 12-15 seconds.

It is assumed the EGPWS terrain clearance "floor" capability would have produced the earliest warning in the other 8 accidents investigated, each of which were categorized as low approach/premature descent. Since the EGPWS terrain clearance "floor" ramps up from the runway threshold, EGPWS "floor" warning time increases with distance from the runway. Typical increase in warning time afforded by the EGPWS "floor" over current technology GPWS was on the order of 10 seconds. In all but 2 of these 8 accidents, the EGPWS "floor" would have increased available warning time beyond the assumed minimum effective response time of 12-15 seconds. In these 2 exceptions, the aircraft impacted very near the landing runway threshold, in a relatively steep descent. The EGPWS terrain clearance "floor" altitude at EGPWS warning in these 2 cases was under 200' AGL.

TABLE 9. POTENTIAL FOR GPS-ENHANCED GPWS (EGPWS) TO PREVENT ACCIDENTS NOT CONSIDERED PREVENTABLE BY CURRENT GPWS TECHNOLOGY

ACCIDENT CATEGORY/ LOCATION	EGPWS MODE	MIN. EGPWS WARNING TIME (SEC)	MAX. EGPWS WARNING TIME (SEC)
LOW APP./PREM. DSCT.			
ST. MARYS, PA	FLOOR	17	20
HAMPTONBURGH, NY	FLOOR	8	10
JACKSONVILLE, FL	FLOOR	3	3
MAYFIELD, KY	FLOOR	11	22
HURDLE MILLS, NC	FLOOR	15	22
UVALDE, TX	FLOOR	17	20
ROMEO, MI	FLOOR	18	24
MARFA, TX	FLOOR	13	27
COLL. WITH TERRAIN			
FLAT ROCK, NC	FORWARD	25	30
EAGLE, CO	FORWARD	25	30
ROME, GA	FORWARD	25	30

7.8 Study Conclusions

The analysis results described above provide very compelling evidence that GPWS (and, better still, EGPWS when it becomes available) offers a significant potential for CFIT accident prevention in the aircraft fleet studied. Table 10 presents study conclusions, as well as aircraft losses and human casualties which could have been prevented by GPWS (or EGPWS). The first column of this table presents a determination, based on comparison of calculated warning time to minimum effective GPWS response time, whether each accident could have been prevented by current technology GPWS. The second column presents a similar determination concerning EGPWS for those cases where current GPWS technology would not have prevented the accident.

Of the 44 accidents studied in detail, it was determined that current GPWS technology would have provided sufficient warning to effectively prevent 33 (75%). Of the remaining 11, current technology would not have sounded any warning in 6 cases (14%), all involving low approach/premature descent. In 5 cases (11%), current technology would have sounded a warning, but probably not in sufficient time to prevent the accident.

Inclusion of the "forward-looking" and terrain clearance "floor" capabilities of GPS-enhanced GPWS (EGPWS) in the analysis changes these results significantly. It was determined that EGPWS would have sounded a warning in every one of the 44 accidents studied, and this warning would have occurred in sufficient time to increase the number of accidents effectively prevented to 42 (95%). The addition of EGPWS "forward-looking" capabilities was useful in preventing accidents classified as collision with terrain, where current technology GPWS would not have provided sufficient warning in 3 of the 11 cases studied, but EGPWS would likely have prevented all 11. The only 2 accidents (Hamptonburgh, NY, and Jacksonville, FL) not considered preventable by EGPWS were classified as low approach/ premature descent, in which the aircraft impacted very near the landing runway threshold (roughly one NM away in both cases) in a relatively steep descent.

The five right-hand columns in Table 10 show accident results in terms of aircraft losses and human casualties for the 44 accidents studied. In the column labeled "Aircraft Type," a "J" indicates a turbojet was involved in the accident. Similarly, a "P" in this column indicates a turboprop was involved. In the column labeled "Aircraft Disposition," a "D" indicates the aircraft involved was destroyed, and an "S" indicates the aircraft was substantially damaged. The remaining three columns of this table show the number of persons suffering fatal, serious, and minor/no injuries in each accident studied.

TABLE 10. AIRCRAFT LOSSES / ACCIDENT CASUALTIES
POTENTIALLY PREVENTABLE BY GPWS OR EGPWS

LOW APPROACH OR PREMATURE DESCENT ACCIDENTS

ACCIDENT LOCATION	PREVENTABLE WITH GPWS?	PREVENTABLE WITH EGPWS?	AIRCRAFT TYPE	AIRCRAFT DISPOSITION	FATALITIES	SERIOUS INJURIES	MINOR OR NO INJURIES
ST. MARYS, PA	NO	YES	P	D	2	0	0
UTICA, MI	YES	N/A	P	D	2	2	0
HARRISON, AR	YES	N/A	J	D	2	0	0
HAMPTONBURGH, NY	NO	NO	P	D	2	0	0
CADILLAC, MI	YES	N/A	P	D	2	0	0
DERRY, PA	YES	N/A	P	D	5	0	0
E. GREENWICH, RI	YES	N/A	P	D	2	0	0
JACKSONVILLE, FL	NO	NO	P	D	3	0	0
NORTON SHORES, MI	YES	N/A	P	D	3	3	0
WINDSOR, MA	YES	N/A	P	D	6	0	0
HAZELWOOD, MO	YES	N/A	P	D	1	3	0
HOUSTON, TX	YES	N/A	J	D	1	3	4
EUGENE, OR	YES	N/A	P	S	0	0	1
LOCUST GROVE, AR	YES	N/A	P	D	6	0	0
MANSFIELD, OH	YES	N/A	P	D	4	0	0
MAYFIELD, KY	NO	YES	P	D	6	0	0
HURDLE MILLS, NC	NO	YES	J	D	2	0	0
UVALDE, TX	NO	YES	P	D	0	2	0
SAN LUIS OBISPO, CA	YES	N/A	J	D	4	0	0
ROMEO, MI	NO	YES	P	D	3	0	0
ST. AUGUSTINE, FL	YES	N/A	P	D	2	0	0
MARFA, TX	NO	YES	P	S	0	0	8
CHANTILLY, VA	YES	N/A	J	D	12	0	0

TABLE 10, CONT'D. AIRCRAFT LOSSES / ACCIDENT CASUALTIES POTENTIALLY PREVENTABLE BY GPWS OR EGPWS

COLLISION WITH RISING TERRAIN, DESCENT AFTER TAKEOFF OR MISSED APPROACH, AND GEAR-UP LANDING ACCIDENTS

ACCIDENT CATEGORY / LOCATION	PREVENTABLE WITH GPWS?	PREVENTABLE WITH EGPWS?	AIRCRAFT TYPE	AIRCRAFT DISPOSITION	FATALITIES	SERIOUS INJURIES	MINOR OR NO INJURIES
COLL. W/TERRAIN							
FLAT ROCK, NC	NO	YES	P	D	5	0	0
EAGLE, CO	NO	YES	J	D	3	0	0
AZUSA, CA	YES	N/A	P	D	1	0	0
RYDERWOOD, WA	YES	N/A	P	D	5	1	0
SAN DIEGO, CA	YES	N/A	J	D	10	0	0
ROME, GA	NO	YES	J	D	9	0	0
BIG BEAR, CA	YES	N/A	P	D	7	0	0
ALAMOGORDO, NM	YES	N/A	P	D	6	0	0
MT. IDA, AR	YES	N/A	P	D	2	0	0
SANTA FE, NM	YES	N/A	P	D	4	0	0
FRONT ROYAL, VA	YES	N/A	P	D	3	0	0
DESCENT AFTER T.O.							
WEST POINT, VA	YES	N/A	P	D	1	0	0
APPALACHICOLA, FL	YES	N/A	P	D	0	0	2
CARTERSVILLE, GA	YES	N/A	J	D	2	0	0
ALBUQUERQUE, NM	YES	N/A	J	D	2	0	0
TAOS, NM	YES	N/A	P	D	1	5	0
GEAR-UP LANDING							
CHARLEVOIX, MI	YES	N/A	P	S	0	0	2
LITTLE ROCK, AR	YES	N/A	J	S	0	0	4
NOVATO, CA	YES	N/A	P	S	0	0	1
BATESVILLE, IN	YES	N/A	P	S	0	0	1
SHEBOYGAN, WI	YES	N/A	P	S	0	0	3

Table 10 shows the 33 accidents that current GPWS technology could probably have prevented resulted in total destruction of 27 aircraft and substantial damage to 6 others. These 33 accidents caused 97 fatalities. An additional 17 persons survived these accidents with serious injuries, and 17 others survived with minor or no injuries.

The 9 additional accidents considered as likely preventable when the capabilities of EGPWS technology are added to current GPWS technology resulted in total destruction of 8 aircraft and substantial damage to one other. These 9 accidents resulted in 30 fatalities. An additional 2 persons survived these accidents with serious injuries, and 8 others survived with minor or no injuries.

In total, therefore, EGPWS could probably have prevented 42 (95%) of the 44 accidents studied. These 42 accidents caused 127 fatalities. An additional 19 persons survived these accidents with serious injuries, and 25 others survived with minor or no injuries.

Eleven of those persons with minor or no injuries were in the 5 accidents categorized as gear-up landings; excluding these 5 accidents from the totals presents an even grimmer picture of CFIT accident survivability. If gear-up landings are excluded, the remaining 39 CFIT accidents were fatal to 131, or 79%, of the 165 persons involved.

Study results therefore strongly support a conclusion that equipping aircraft with GPWS (or EGPWS, when it is available) could be a particularly effective means of preventing CFIT accidents in the subject FAR Part 91 aircraft fleet. In light of the potential savings of human life and the economic costs of destroyed and damaged aircraft, the FAA is urged to implement NTSB Recommendation A-95-35 regarding installation of GPWS in turbojet aircraft with six or more passenger seats. Based on the improvements in CFIT accident reduction effectiveness shown by this study to be provided by GPS-enhanced GPWS (EGPWS) over current technology GPWS, the FAA is further urged to amend NTSB Recommendation A-95-35 to require installation of EGPWS, rather than current technology GPWS, in the subject aircraft fleet. Finally, based on the fact that 75% of the accidents studied involved turboprop aircraft, it is urged that the NTSB recommendation, as was the earlier recommendation for FAR Part 135 aircraft, be broadened by the FAA to encompass all "turbine-powered" (i.e., not just turbojet) aircraft.

APPENDIX A

DERIVATION OF GEOMETRIC MODEL EQUATIONS

DEFINITION OF VARIABLES

ϕ = flight path angle (nose up or nose down with respect to the horizontal)

ψ = ground slope angle (with respect to the horizontal)

h_o = altitude at GPWS warning (feet AGL)

f_d = distance along flight path to impact (feet)

x = horizontal component of f_d (feet)

y = vertical component of f_d (feet)

The following chart indicates the different combinations of aircraft flight path and terrain slope geometry in which result in impact, and for which equation (1) can be derived:

		Flight Path Angle, ϕ		
		>0	=0	<0
Ground Slope Angle, ψ	>0	eqn. (1)	eqn. (1)	eqn. (1)
	=0	no impact	no impact	eqn. (1)
	<0	no impact	no impact	eqn. (1)

Figures A-1 through A-5 on page A - 5 depict graphically the five cases of flight path and terrain slope geometry which result in impact.

Case 1: In this case, $\phi > 0$ and $\psi > 0$. From Figure A-1, we have

$$x = f_d \cos\phi$$
$$y = f_d \sin\phi$$

So

$$\tan\psi = (h_o + y) / x$$

Substituting for x and y,

$$\tan\psi = (h_o + (f_d \sin\phi)) / (f_d \cos\phi)$$
$$f_d \tan\psi \cos\phi = h_o + f_d \sin\phi$$
$$f_d (\tan\psi \cos\phi - \sin\phi) = h_o$$

and

$$f_d = h_o / (\tan\psi \cos\phi - \sin\phi)$$

which is equation (1).

Case 2: In this case, $\phi = 0$ and $\psi > 0$. From Figure A-2, we have

$$\tan\psi = h_o / f_d$$

or

$$f_d = h_o / \tan\psi$$

However, when $\phi = 0$,

$$\cos\phi = 1$$
$$\sin\phi = 0$$

Therefore,

$$f_d = h_o / (\tan\psi \cos\phi - \sin\phi)$$

reduces to

$$f_d = h_o / (\tan\psi).$$

Case 3: In this case, $\phi < 0$ and $\psi > 0$. From Figure A-3, we have

$$y = f_d \sin(-\phi)$$
$$= - f_d \sin\phi$$
$$x = f_d \cos(-\phi)$$
$$= f_d \cos\phi$$

and

$$\tan\psi = (h_o - y) / x$$

Substituting for x and y,

$$\tan\psi = (h_o - (- f_d \sin\phi)) / f_d \cos\phi$$

Therefore,

$$f_d \tan\psi \cos\phi = h_o + f_d \sin\phi$$
$$f_d = h_o / (\tan\psi \cos\phi - \sin\phi)$$

which is equation (1).

Case 4: In this case, $\phi < 0$ and $\psi = 0$. From Figure A-4, we have

$$h_o = f_d \sin(-\phi)$$
$$= - f_d \sin\phi$$

or

$$f_d = h_o / - \sin\phi$$

However, when $\psi = 0$,

$$\tan \psi = 0$$

Therefore,

$$f_d = h_o / (\tan\psi \cos\phi - \sin\phi)$$

reduces to

$$f_d = h_o / -\sin\phi$$

Case 5: In this case, $\phi < 0$ and $\psi < 0$. From Figure A-5, we have

$$\begin{aligned} x &= f_d \cos(-\phi) \\ &= f_d \cos\phi \\ y &= f_d \sin(-\phi) \\ &= -f_d \sin\phi \end{aligned}$$

And

$$\tan(-\psi) = (y - h_o) / x$$
$$-\tan\psi = (y - h_o) / x$$

Substituting for x and y,

$$-\tan\psi = (-f_d \sin\phi - h_o) / f_d \cos\phi$$
$$-f_d \tan\psi \cos\phi = -f_d \sin\phi - h_o$$

Multiplying both sides by (-1),

$$f_d \tan\psi \cos\phi = f_d \sin\phi + h_o$$

or

$$f_d = h_o / (\tan\psi \cos\phi - \sin\phi)$$

which is equation (1).

Figures A-1 Through A-5.

COMBINATIONS OF FLIGHT PATH AND TERRAIN GEOMETRY WHICH RESULT IN IMPACT

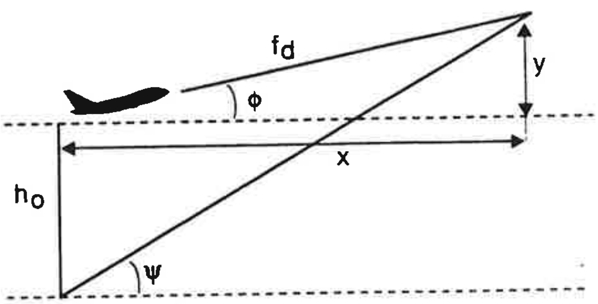


Figure A-1.
CASE 1: $\phi > 0$ and $\psi > 0$.

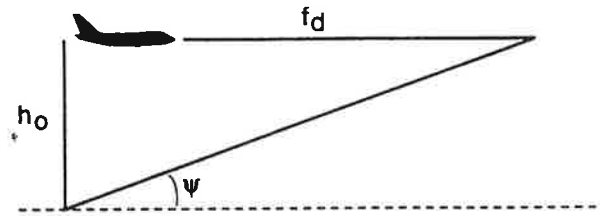


Figure A-2.
CASE 2: $\phi = 0$ and $\psi > 0$.

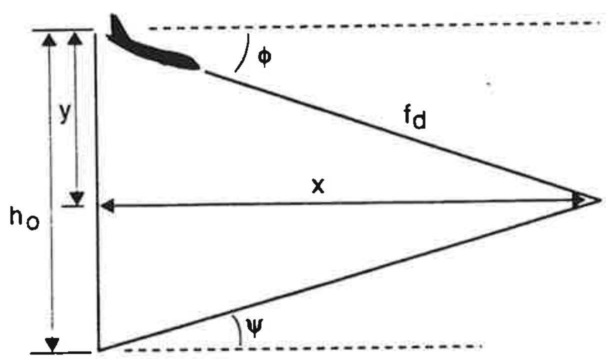


Figure A-3.
CASE 3: $\phi < 0$ and $\psi > 0$.

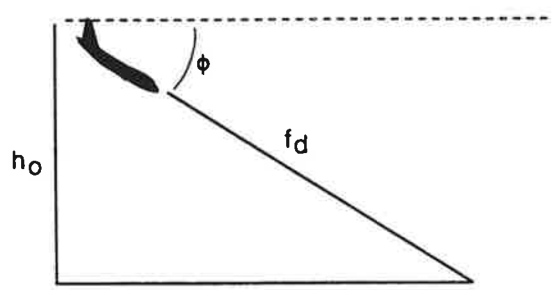


Figure A-4.
CASE 4: $\phi < 0$ and $\psi = 0$.

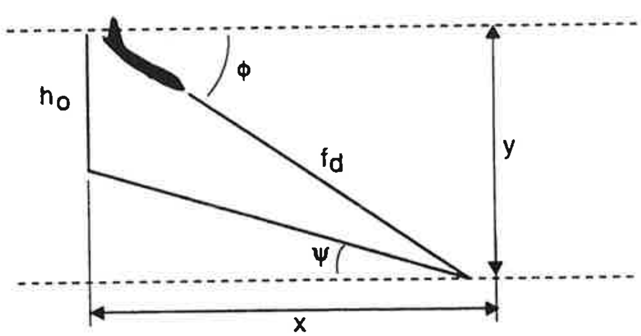


Figure A-5.
CASE 5: $\phi < 0$ and $\psi < 0$.

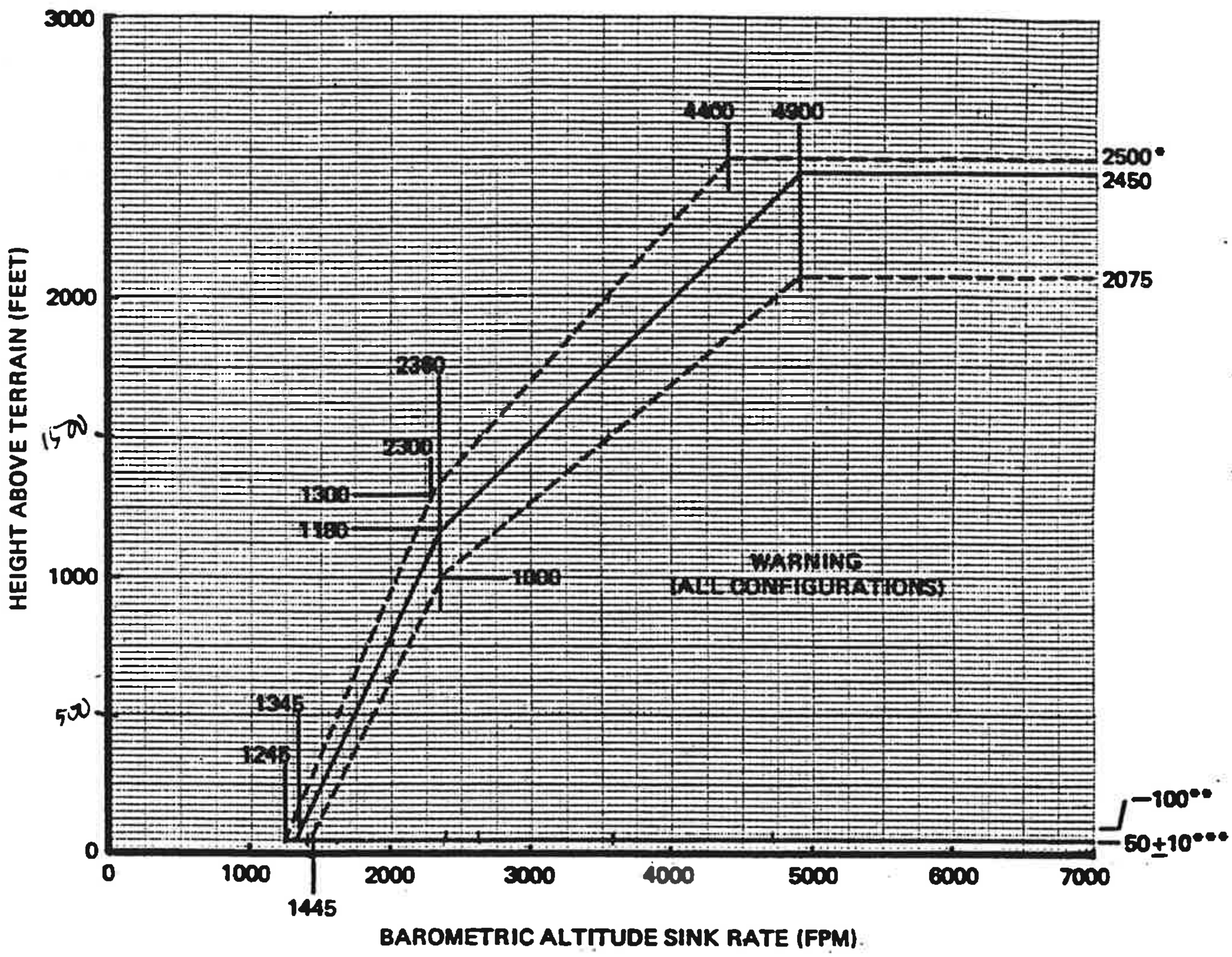
APPENDIX B

GPWS WARNING THRESHOLD ENVELOPES

This appendix contains the GPWS warning threshold envelopes, found in RTCA Document DO-161A, entitled Minimum Performance Standards -- Airborne Ground Proximity Warning Equipment, last revised May 27, 1976, and referenced in FAA Technical Standard Order TSO-C92c. These envelopes specify the values of various input parameters which will trigger GPWS warning activation for each of the five GPWS modes.

MODE 1, ENVELOPE 1.

EXCESSIVE RATE OF DESCENT WITH RESPECT TO TERRAIN



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

* Positive cutoff necessary at 2500 feet. (Recognize that radio altimeter reads 2500 feet (or more) at all heights greater than 2500 feet.)

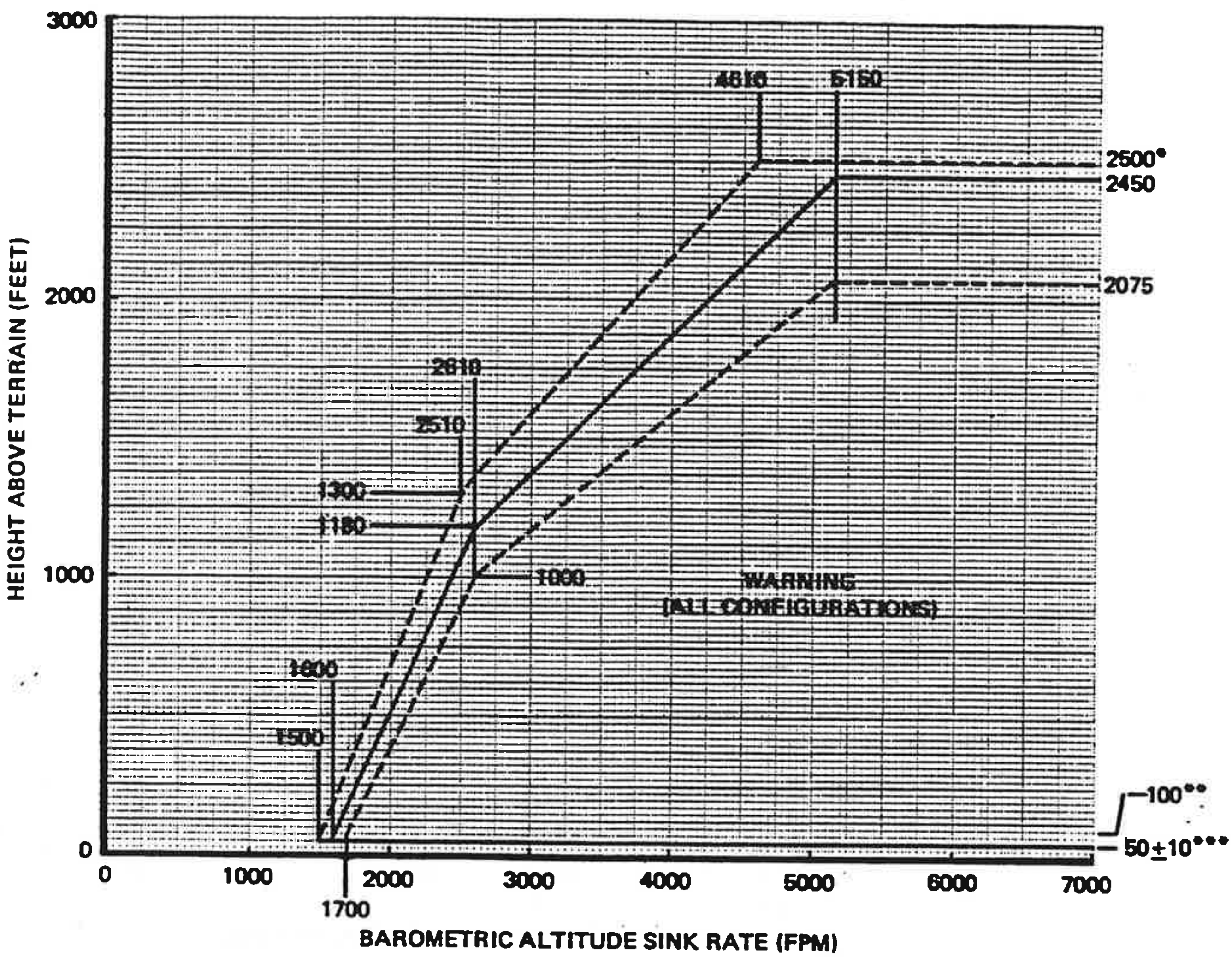
** Maximum ascending arming height.

*** Descent inhibit height.

MODE 1 IS FUNCTIONAL AT ALL TIMES.

MODE 1, ENVELOPE 2.

EXCESSIVE RATE OF DESCENT WITH RESPECT TO TERRAIN



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

* Positive cutoff necessary at 2500 feet. (Recognize that radio altimeter reads 2500 feet (or more) at all heights greater than 2500 feet.)

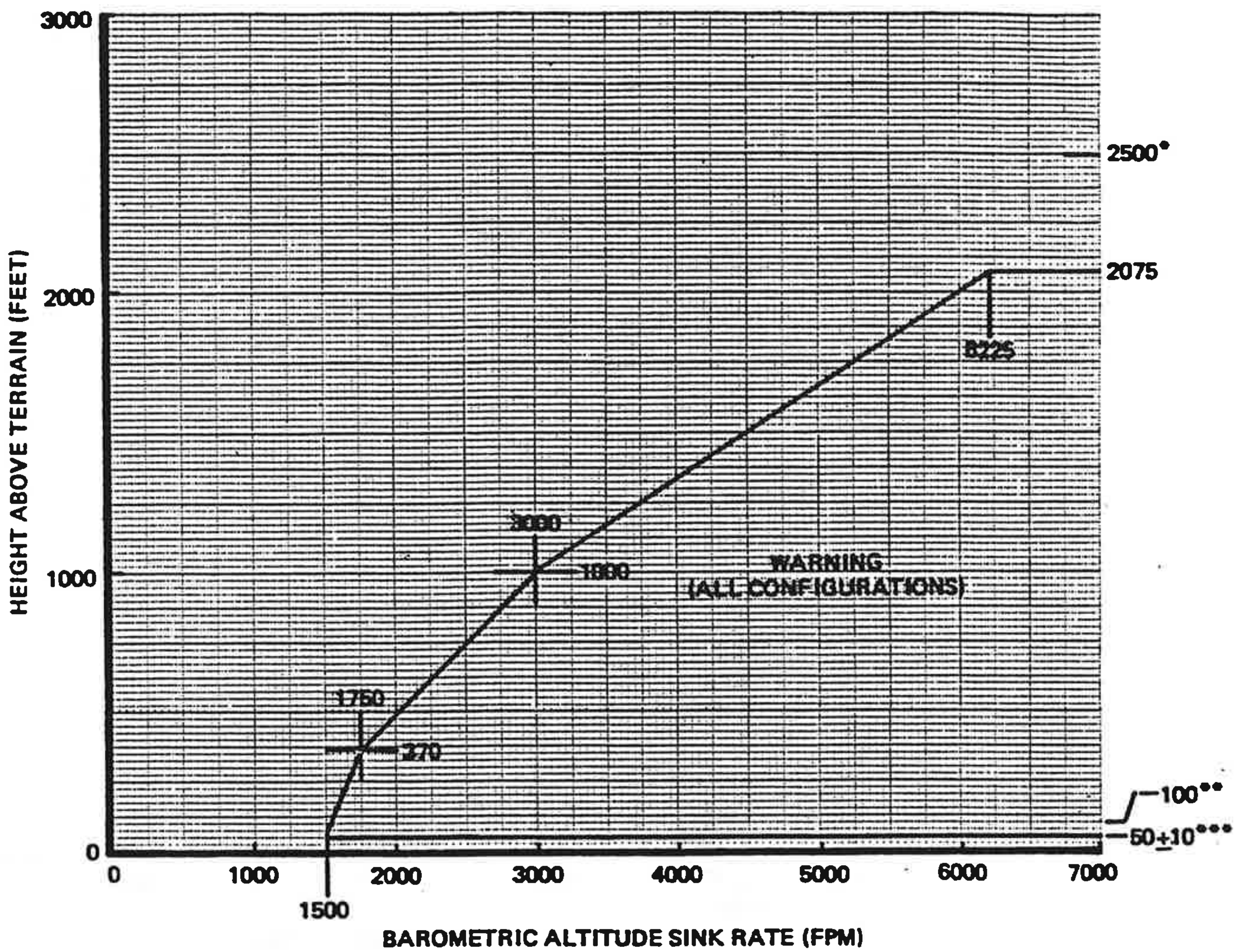
** Maximum ascending arming height.

*** Descent inhibit height.

MODE 1 IS FUNCTIONAL AT ALL TIMES.

MODE 1, ENVELOPE 3.

EXCESSIVE RATE OF DESCENT WITH RESPECT TO TERRAIN



Solid line is lower tolerance limit. Manufacturer shall declare selected position for nominal above this line and compute upper tolerance limit similar to that for Mode 1, Envelopes 1 and 2 (recognizing the need to minimize nuisance warnings) before applying test procedure T-1 of appendix B.

* Radio altimeter cutoff height.

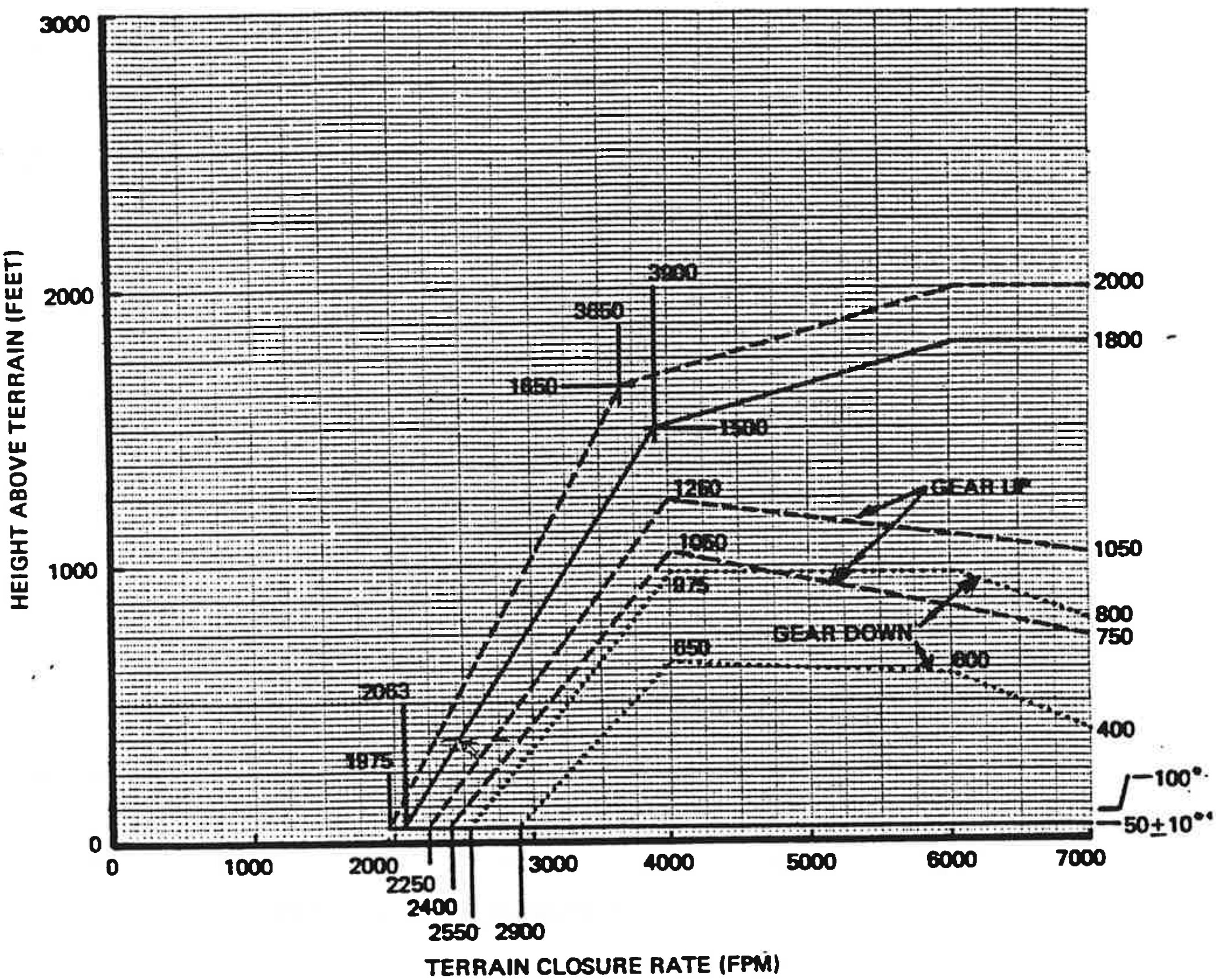
** Maximum ascending arming height.

*** Descent inhibit height.

MODE 1 IS FUNCTIONAL AT ALL TIMES.

MODE 2A.

EXCESSIVE CLOSURE RATE TO TERRAIN
(Flaps Not in Landing Configuration)



Solid lines are nominal values.

Dashed lines indicate tolerance limits when initiating test from 2450 feet.

Dotted lines indicate tolerance limits when initiating test from the nominal envelope.

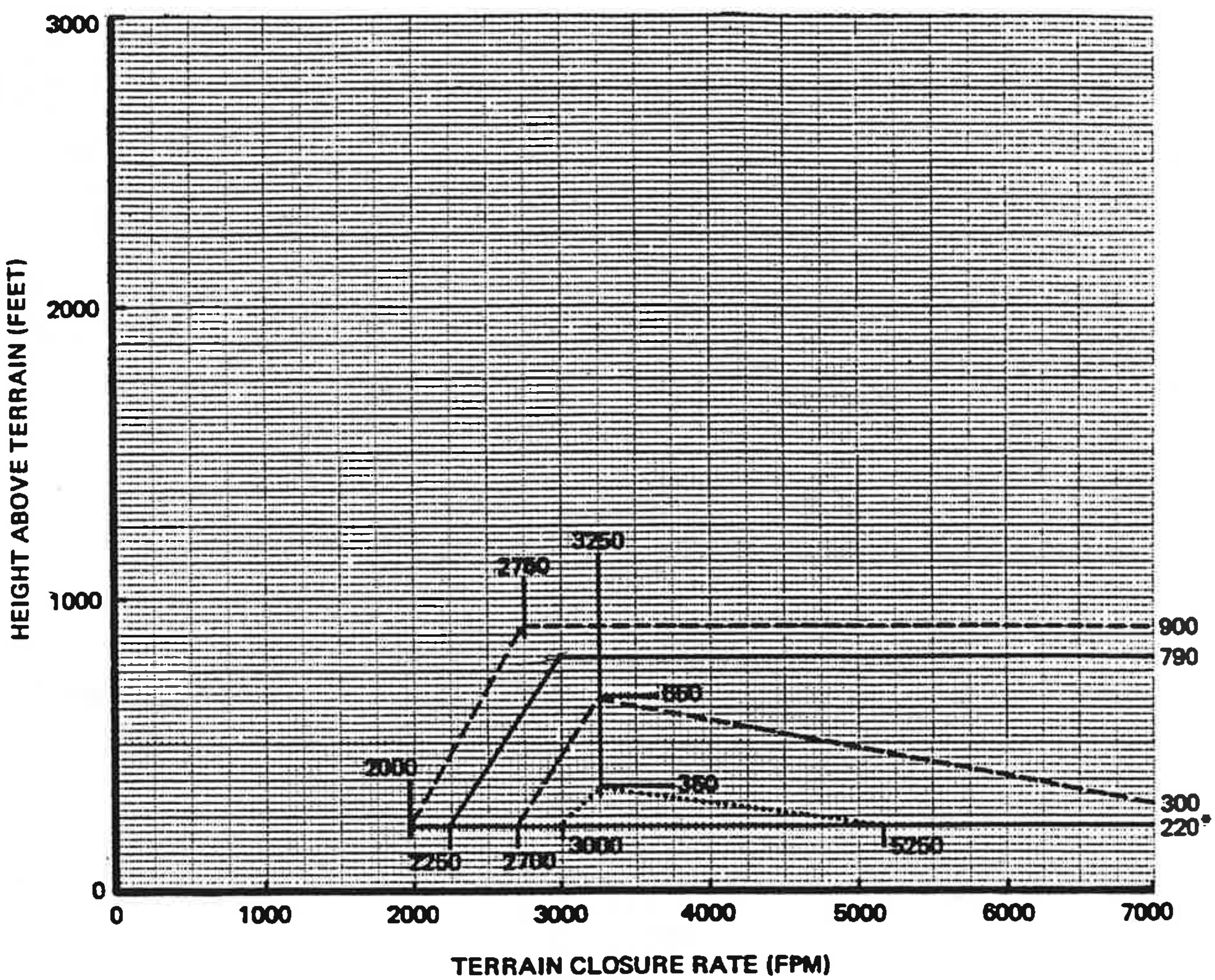
* Maximum ascending arming height.

** Descent inhibit height.

MODE 2A IS FUNCTIONAL AT ALL TIMES FLAPS ARE NOT IN LANDING CONFIGURATION

MODE 2B.

EXCESSIVE CLOSURE RATE TO TERRAIN
(Flaps in Landing Configuration)



Solid lines are nominal values.

Dashed lines indicate tolerance limits when initiating test from 2450 feet.

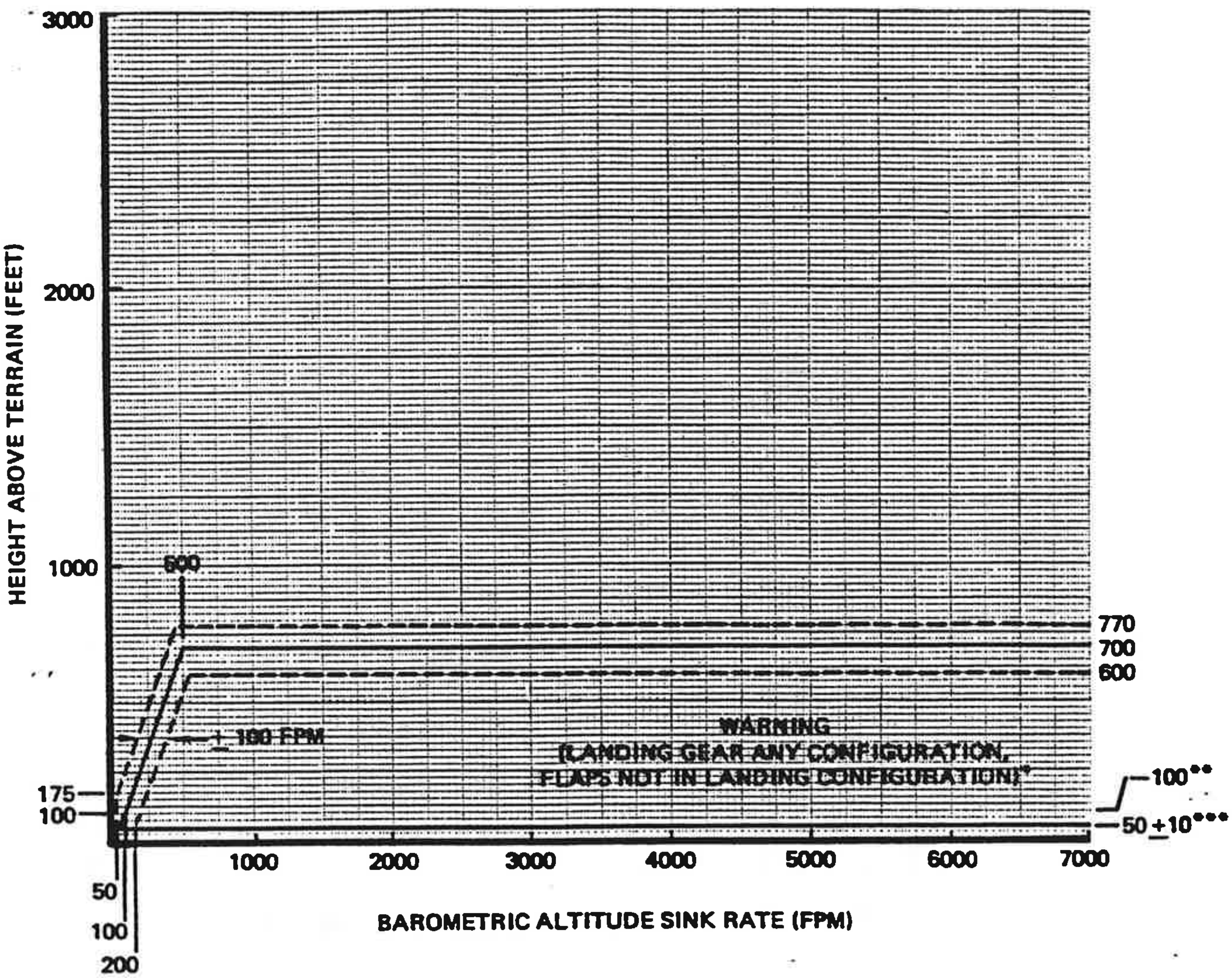
Dotted lines indicate tolerance limits when initiating test from 1500 feet.

* Maximum inhibit height.

MODE 2B IS FUNCTIONAL AT ALL TIMES FLAPS ARE IN LANDING CONFIGURATION AND IRRESPECTIVE OF LANDING GEAR POSITION.

MODE 3A.

NEGATIVE CLIMB (SINK) RATE BEFORE ACQUIRING 700 FEET TERRAIN CLEARANCE AFTER TAKEOFF OR MISSED APPROACH



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

*Optionally, all configurations except gear and flaps in landing configuration.

** Maximum ascending arming height.

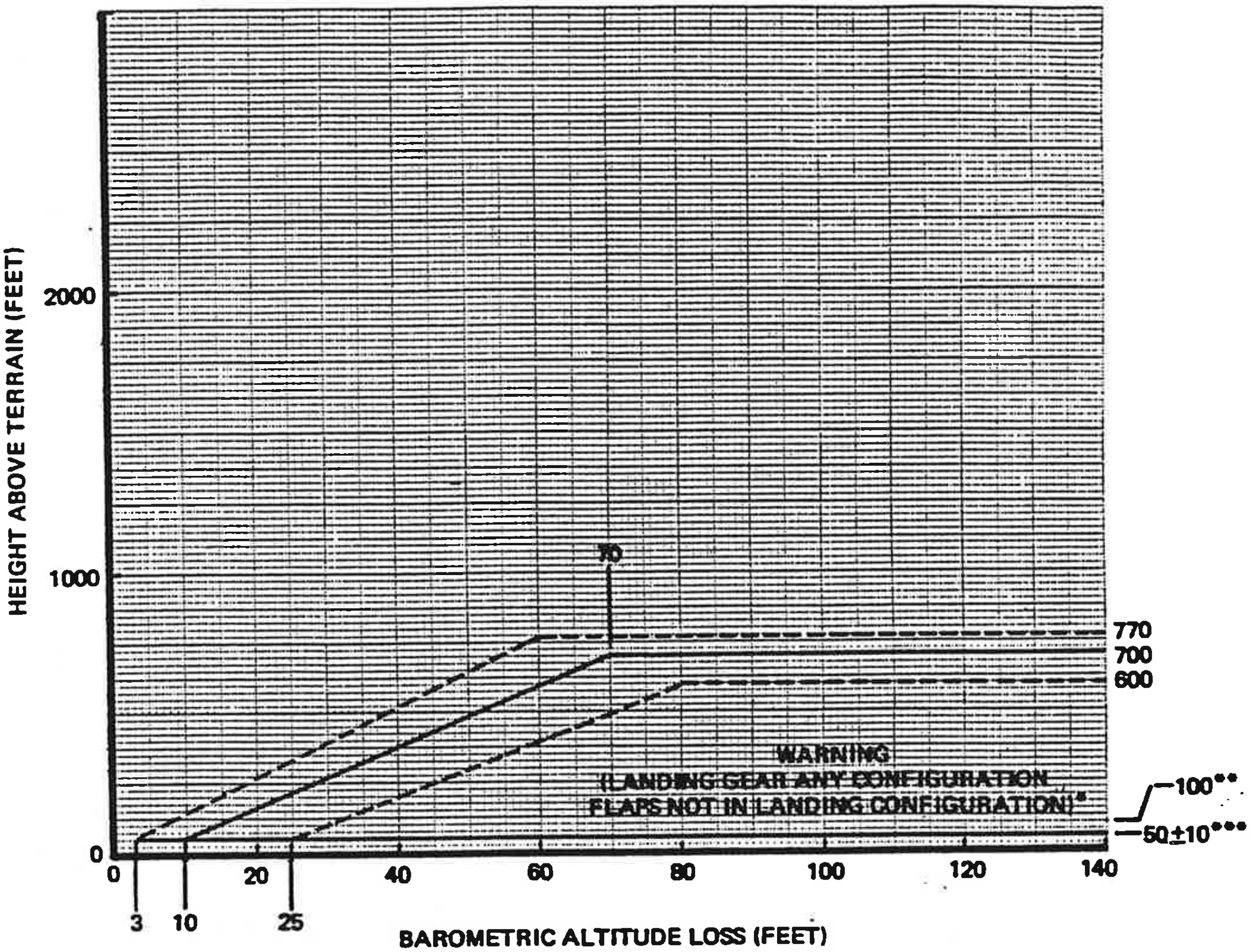
*** Descent inhibit height.

MODE 3A IS FUNCTIONAL DURING TAKEOFF OR MISSED APPROACH WHEN MODE 4 IS DISABLED.

TRANSITION TO MODE 4 BETWEEN 600 AND 770 FEET.

MODE 3B.

ACCUMULATED ALTITUDE LOSS BEFORE ACQUIRING 700 FEET TERRAIN CLEARANCE AFTER TAKEOFF OR MISSED APPROACH



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

*Optionally, all confiugrations except gear and flaps in landing configuration.

**Maximum ascending arming height.

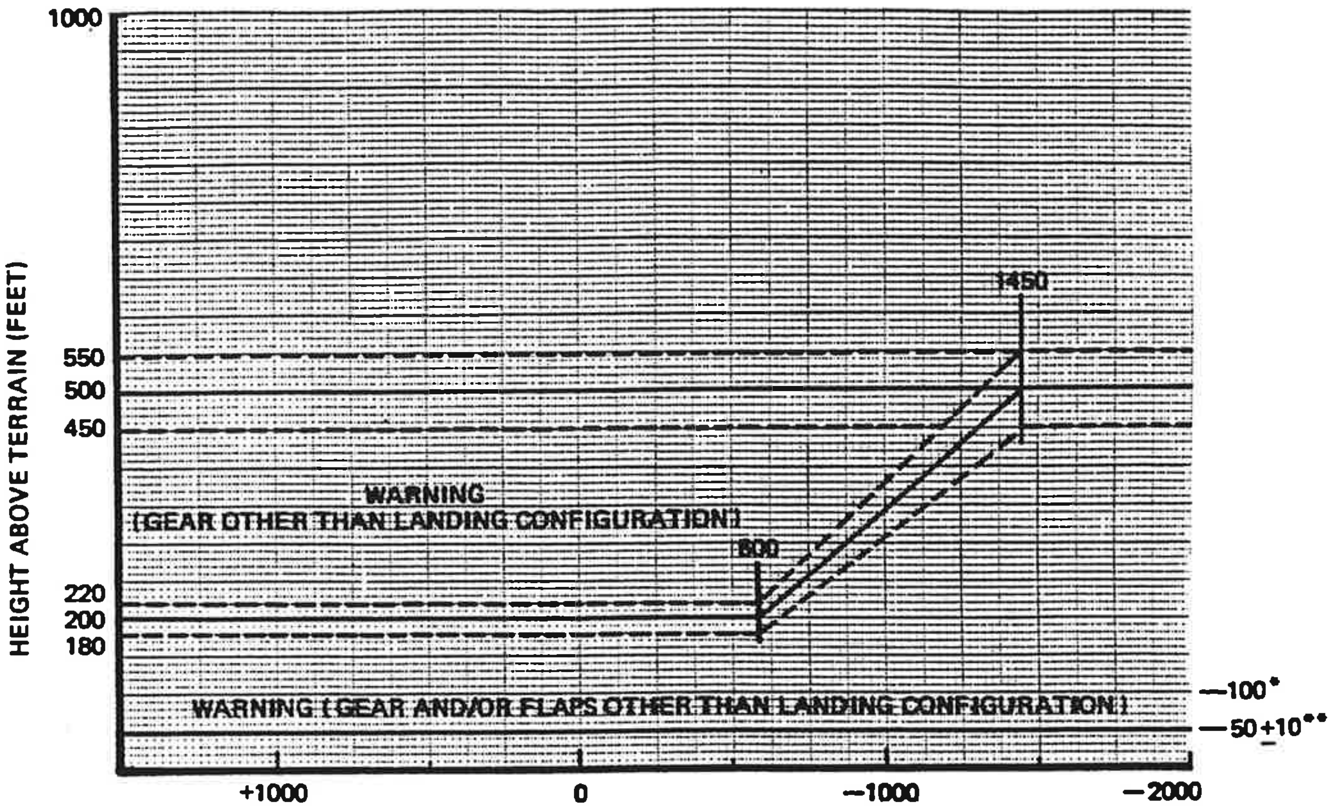
***Descent inhibit height.

MODE 3B IS FUNCTIONAL DURING TAKEOFF OR MISSED APPROACH WHEN MODE 4 IS DISABLED.

TRANSITION TO MODE 4 BETWEEN 600 AND 770 FEET.

MODE 4, ENVELOPE 1.

FLIGHT INTO TERRAIN WITH LESS THAN 500 FEET TERRAIN CLEARANCE AND NOT IN LANDING CONFIGURATION



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

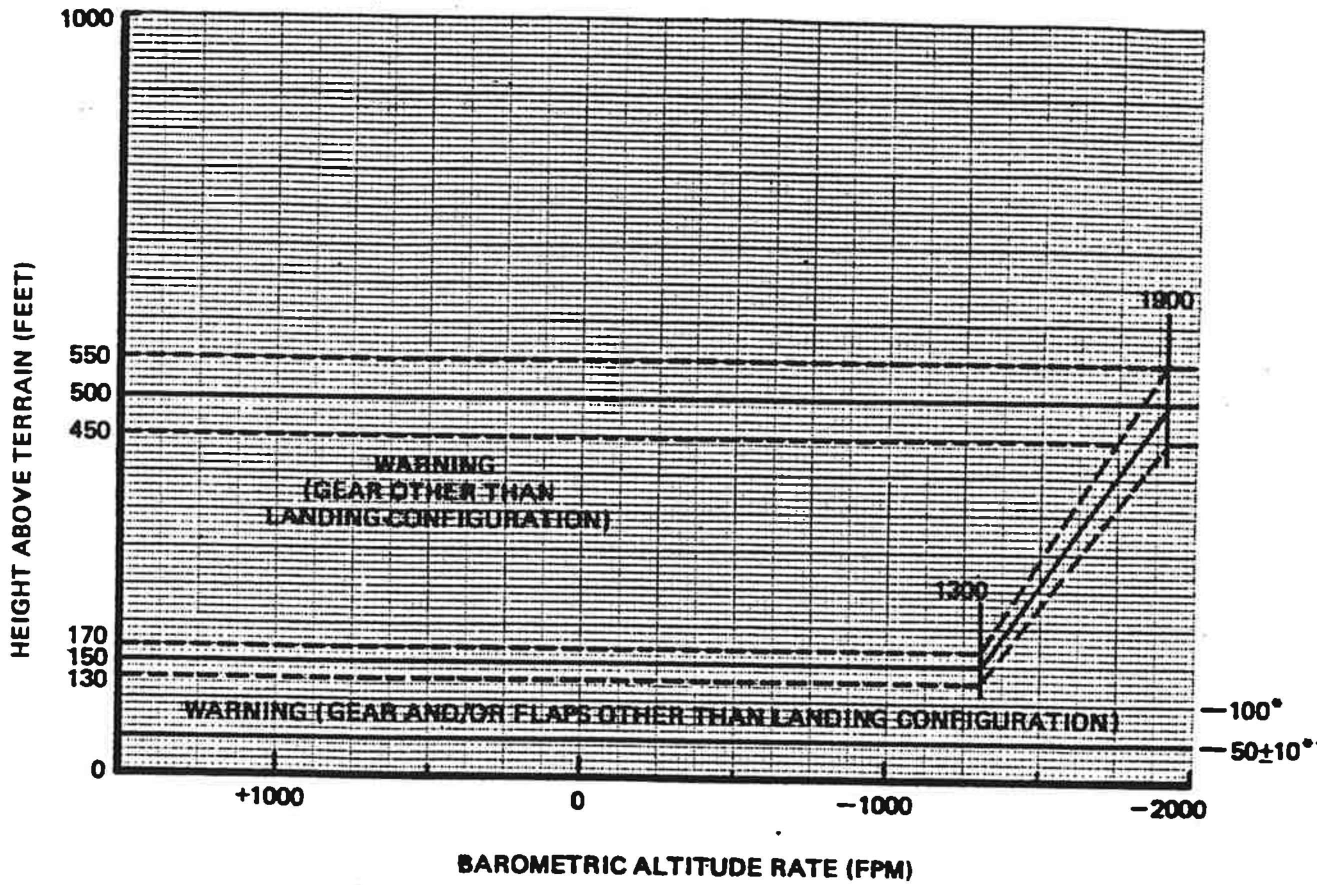
AUTOMATIC TRANSFER FROM MODE 4 TO MODE 3 MUST OCCUR WITHIN 2 TO 3 SECONDS UPON CHANGING AIRCRAFT CONFIGURATION WITHIN AREA BOUNDED BY GEAR AND/OR FLAPS OTHER THAN LANDING CONFIGURATION ENVELOPE WHEN EXECUTING MISSED APPROACH. ABOVE THIS BOUNDARY AIRCRAFT CONFIGURATION CHANGE SHALL NOT CAUSE TRANSFER OUT OF MODE 4. OPTIONALLY, AUTOMATIC TRANSFER FROM MODE 4 TO MODE 3 MAY OCCUR WITHIN 2 TO 3 SECONDS UPON CHANGING AIRCRAFT CONFIGURATION WITHIN AREA BOUNDED BY GEAR AND/OR FLAPS OTHER THAN LANDING CONFIGURATION ENVELOPE AND GEAR OTHER THAN LANDING CONFIGURATION ENVELOPE WHEN EXECUTING MISSED APPROACH. ABOVE 500 ± 50 FEET AIRCRAFT CONFIGURATION CHANGE SHALL NOT CAUSE TRANSFER OUT OF MODE 4.

* Maximum ascending arming height.

** Descent inhibit height.

MODE 4, ENVELOPE 2.

FLIGHT INTO TERRAIN WITH LESS THAN 500 FEET TERRAIN CLEARANCE AND NOT IN LANDING CONFIGURATION



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

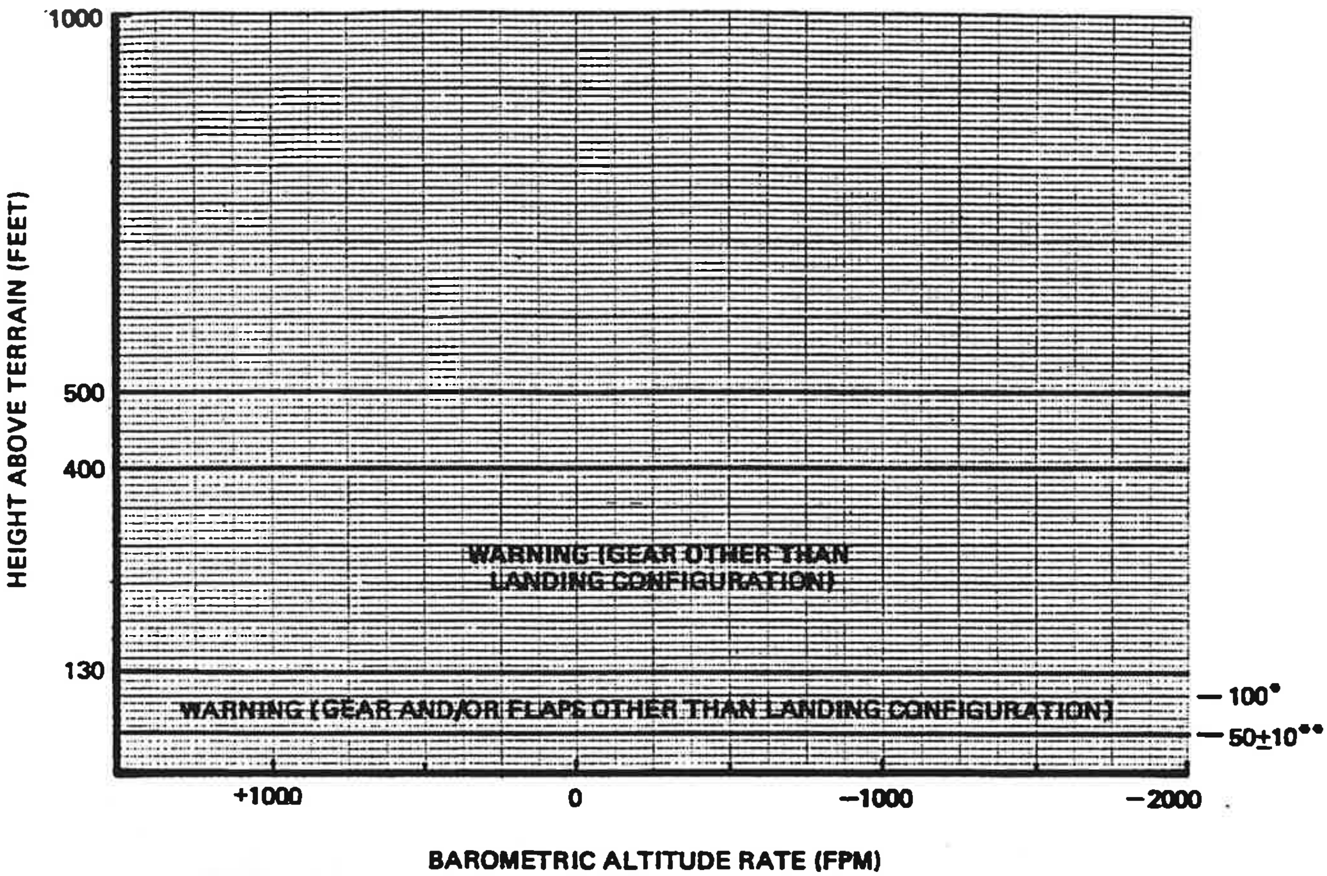
AUTOMATIC TRANSFER FROM MODE 4 TO MODE 3 MUST OCCUR WITHIN 2 TO 3 SECONDS UPON CHANGING AIRCRAFT CONFIGURATION WITHIN AREA BOUNDED BY GEAR AND/OR FLAPS OTHER THAN LANDING CONFIGURATION ENVELOPE WHEN EXECUTING MISSED APPROACH. ABOVE THIS BOUNDARY AIRCRAFT CONFIGURATION CHANGE SHALL NOT CAUSE TRANSFER OUT OF MODE 4. OPTIONALLY, AUTOMATIC TRANSFER FROM MODE 4 TO MODE 3 MAY OCCUR WITHIN 2 TO 3 SECONDS UPON CHANGING AIRCRAFT CONFIGURATION WITHIN AREA BOUNDED BY GEAR AND/OR FLAPS OTHER THAN LANDING CONFIGURATION ENVELOPE AND GEAR OTHER THAN LANDING CONFIGURATION ENVELOPE WHEN EXECUTING MISSED APPROACH. ABOVE 500 ±50 FEET, AIRCRAFT CONFIGURATION CHANGE SHALL NOT CAUSE TRANSFER OUT OF MODE 4.

*Maximum ascending arming height.

**Descent inhibit height.

MODE 4, ENVELOPE 3.

FLIGHT INTO TERRAIN WITH LESS THAN 500 FEET TERRAIN CLEARANCE AND NOT IN LANDING CONFIGURATION



Horizontal lines at 130 and 400 feet height above terrain are lower tolerance limits. Manufacturer shall declare selected positions for nominals above these lines and compute upper tolerance limits similar to those for Mode 4 Envelopes 1 and 2 (recognizing the need to minimize nuisance warnings) before applying test procedure T-4 of Appendix B.

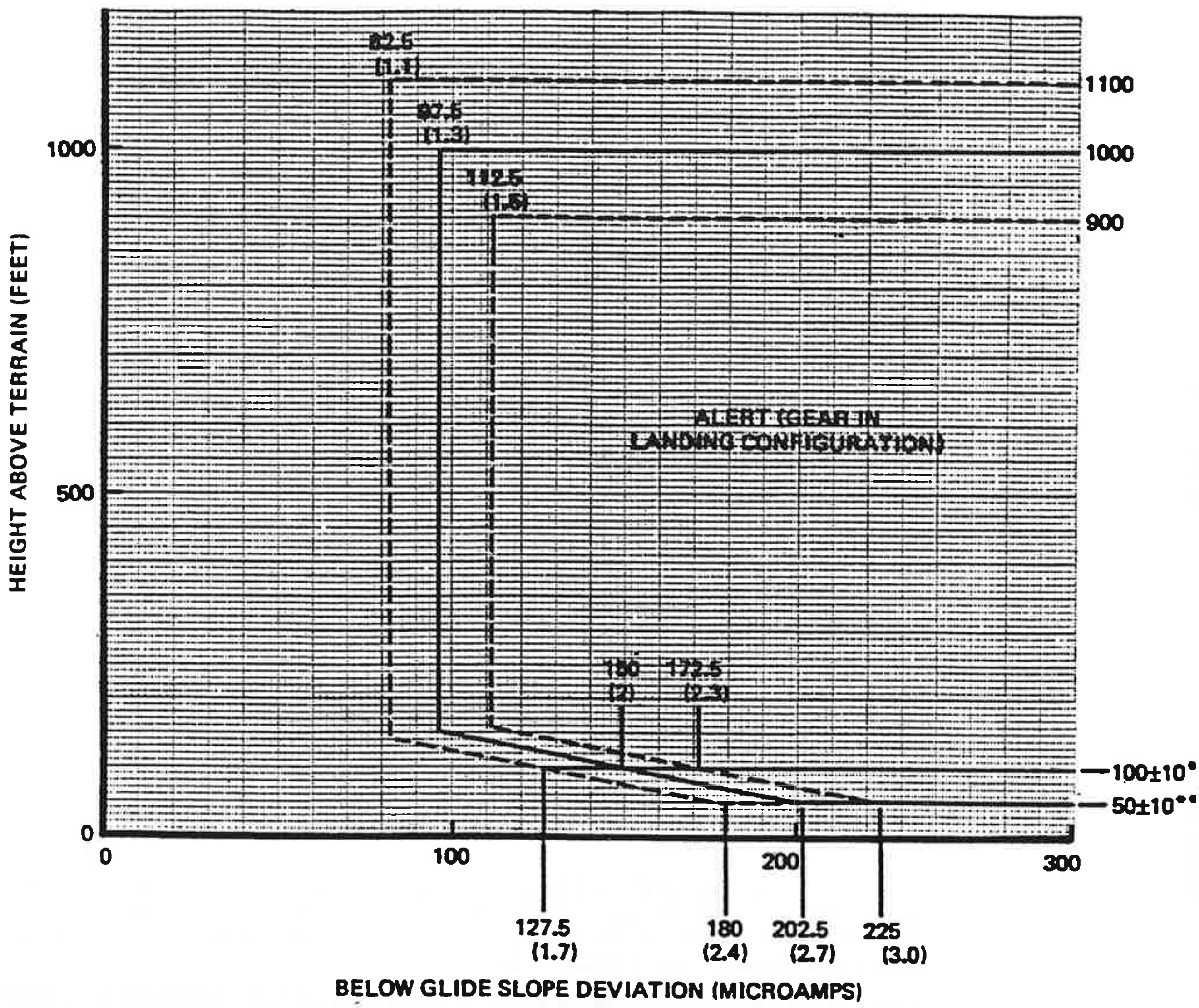
AUTOMATIC TRANSFER FROM MODE 4 TO MODE 3 MUST OCCUR WITHIN 2 TO 3 SECONDS UPON CHANGING AIRCRAFT CONFIGURATION WITHIN AREA BOUNDED BY GEAR AND/OR FLAPS OTHER THAN LANDING CONFIGURATION ENVELOPE WHEN EXECUTING MISSED APPROACH. ABOVE THIS BOUNDARY AIRCRAFT CONFIGURATION CHANGE SHALL NOT CAUSE TRANSFER OUT OF MODE 4. OPTIONALLY, AUTOMATIC TRANSFER FROM MODE 4 TO MODE 3 MAY OCCUR WITHIN 2 OR 3 SECONDS UPON CHANGING AIRCRAFT CONFIGURATION WITHIN AREA BOUNDED BY GEAR AND/OR FLAPS OTHER THAN LANDING CONFIGURATION ENVELOPE AND GEAR OTHER THAN LANDING CONFIGURATION ENVELOPE WHEN EXECUTING MISSED APPROACH. ABOVE 500±50 FEET, AIRCRAFT CONFIGURATION CHANGE SHALL NOT CAUSE TRANSFER OUT OF MODE 4.

*Maximum ascending arming height.

**Descent inhibit height.

MODE 5.

GLIDE SLOPE DEVIATION ALERTING



Solid lines are nominal values.

Dashed lines indicate tolerance limits.

Deviation in "Dots" shown in parenthesis.

*Automatic inhibit height upper limit.

**Automatic inhibit height lower limit.

APPENDIX C

GLOSSARY OF TERMS AND ACRONYMS USED IN VOLUME ONE

AGL -- above ground level; one measure of an aircraft's altitude, usually expressed in feet.

Airspeed -- the speed at which an airplane flies through the air, usually expressed in nautical miles per hour (knots).

Altimeter -- an aircraft instrument whose function is to indicate an aircraft's current altitude to the pilot. An altimeter uses an aneroid barometer to measure atmospheric pressure at current altitude and compares this ambient pressure with a reference ground-level barometric pressure value entered on the altimeter by the pilot. This reference pressure varies over time and place, and is a standard part of the weather briefing provided pilots by FAA advisory facilities. The lower the current pressure compared with the reference, the higher the aircraft's altitude.

Altitude -- a measure of the height of an aircraft above a certain level, usually expressed in feet above ground level or feet above mean sea level.

Approach -- that portion of an aircraft's flight which includes alignment with and descent towards the runway. An approach may be accomplished under visual flight rules, or under instrument flight rules, with reference to FAA air navigational facilities. VFR approaches are generally accomplished using a basic rectangular traffic pattern. For IFR approaches, the FAA publishes standard terminal approach procedures which state exactly all altitudes, headings, distances, minimum horizontal and vertical visibility parameters, and navigational facility names and frequencies for the pilot to use in order to accomplish a safe landing on a given airport runway. Charts indicating these procedures are known as "approach plates."

Approach Minimums -- a specified combination of horizontal visibility (expressed in miles) and vertical visibility (expressed as an altitude in feet above mean sea level) representing the minimum acceptable weather conditions for accomplishment of a safe landing on a given airport runway. If an aircraft on approach descends to the specified altitude and still cannot gain visual reference with the runway environment because the prevailing cloud ceiling is lower than the approach minimum, the pilot should declare and execute a missed approach.

ASRS -- Aviation Safety Reporting System. A computer database system, maintained by the National Aeronautics and Space Administration, which is a repository for flight crew reports of unsafe or hazardous practices or incidents, whether caused by pilots, ATC, or other factors. ASRS reporting is done on an anonymous basis, and provides a reasonably good indication of the frequency of certain flight problems which do not end in accidents.

ATC -- air traffic control. The process of issuing instructions and advisories to aircraft in order to positively enforce minimum standards for separation between them, thus preventing collisions, using airport resources efficiently, and facilitating the safe and expeditious movement of air traffic. In the United States, responsibility for air traffic control rests with the Federal Aviation Administration (FAA).

Attitude -- a description of an aircraft's alignment with respect to reference vertical and horizontal axes in three dimensions. Angles of variation from these axes, measured in degrees, are called roll, pitch, and yaw. The roll angle is also known as the "bank angle". Pitch is typically stated as a "nose down" or "nose up" angle.

Ceiling -- an indication of the limits of vertical visibility under prevailing weather conditions, expressed in feet above ground level. It may also be viewed as the height of the lowest layer of clouds or other obscuring weather conditions above ground level.

CFIT -- controlled flight into terrain. A type of aircraft accident which occurs when an airworthy aircraft, experiencing no contributory systems or equipment problems, under the control of a certificated, fully qualified flight crew not suffering from any impairment, is flown into terrain (or water or obstacle) with no demonstrated prior awareness of the impending collision on the part of the flight crew.

Clearance -- official permission for a pilot to execute a specific flight maneuver, such as approach and landing, issued by air traffic control personnel. Clearances are issued for the purpose of preventing collisions between aircraft and provide for safe and expeditious movement of air traffic. "Cleared for approach" or "cleared for landing" means that the approach or the runway will be clear of any other traffic.

Cockpit -- the portion of an aircraft including the flight crew seats, aircraft flight controls, radio communications equipment and flight instruments.

CVR -- Cockpit Voice Recorder. A device installed on an aircraft, whose purpose is to record all pilot conversations. Cockpit voice recorders aid in aircraft accident investigation. Their installation is required by regulation on some types of aircraft.

DH -- Decision Height. The altitude at which pilots flying instrument landing system approaches should either commit to landing, if the runway is in sight, or declare and execute a missed approach, if it is not. For most ILS approaches, DH is 200' AGL.

DOT -- Department of Transportation. The executive agency responsible for regulating transportation, including flight, within the borders of the United States. The DOT includes the Federal Aviation Administration.

EGPWS -- GPS-Enhanced Ground Proximity Warning System. A device, installed on an aircraft, which will compare current position (latitude and longitude) of the aircraft, as determined by a GPS receiver, with a stored database of topographic and airport/obstruction location information. Using the EGPWS, prominent terrain features or other obstructions ahead of an aircraft's flight path can be displayed on cockpit instruments. Audible and visual warnings will be sounded by the EGPWS based on inputs from other flight instruments indicating the aircraft's heading, climb/descent rate, and airspeed, if threshold parameters of certain key parameters are exceeded. Using EGPWS, a terrain clearance "floor" can be established, based on aircraft position relative to a destination airport, and independent of landing gear and/or flap settings. EGPWS therefore provides an extra measure of safety against inadvertent collision with terrain not available with current GPWS equipment.

FAA -- Federal Aviation Administration. The U. S. government agency, part of the Department of Transportation, responsible for operation and maintenance of the National Airspace System for air traffic control, and for regulating use of this system, as well as for certifying pilots and aircraft.

FAR -- Federal Aviation Regulations. The body of regulation, part of the Code of Federal Regulations, promulgated by the FAA, which prescribes legal requirements for pilots, aircraft, flight and air traffic control procedures.

FBO-- Fixed Base Operator. A business whose function is to provide services to aircraft and pilots at an airport, including providing fuel, food and ground transportation, etc. While an FBO may communicate with aircraft via radio, it has no responsibility for air traffic control.

FDR -- Flight Data Recorder. An on-board aircraft instrument, commonly called the "black box," which records certain key parameters of an aircraft's flight, including control actions, control surface positions, throttle positions, etc. FDR data can be used by post-crash investigators to completely reconstruct the aircraft's flight path prior to an accident.

Flaps -- Movable control surfaces on the trailing edge of an aircraft's wings which can be extended downward into the flow of air beneath the wings. Extending flaps has the effect of increasing lift and drag on the aircraft. This permits a slower airspeed and a steeper angle of descent during approach and landing. In some cases flap extension is also used to shorten takeoff distance.

Flight Path -- a line traced by a point on an aircraft as it flies through the air.

Flight Plan -- specified information, relating to the intended flight of an aircraft, that is provided orally or in writing to FAA air traffic control personnel. Information on a flight plan includes origin, destination, pilot, passengers aboard, alternate landing site, estimated takeoff time, estimated flight time, amount of fuel aboard, etc.

Frequency -- a discrete band of the electromagnetic spectrum to which radio transmitters and receivers can be tuned. FAA air traffic control facilities are assigned specfic frequencies (e.g., "One Twenty One Point Five") for communications with pilots.

Glide Slope -- An FAA air navigational facility which forms an integral part of the instrument landing system (ILS). The glide slope provides vertical guidance to pilots during approach and landing by radiating a signal along the proper glide path (usually about three degrees upward from the horizontal) linking the initial approach altitude with the runway touchdown zone. A receiver in the aircraft's flight instruments processes this signal and displays upward or downward vertical deviation from this path. An aircraft on an ILS approach which maintains alignment with the glide slope signal should descend successfully to the runway landing zone.

GPS -- Global Positioning System. A navigational system which relies on signals emitted by a network of satellites orbiting the earth. GPS receiver equipment, installed in aircraft, can use these signals to determine the aircraft's position (latitude and longitude) very precisely. Pilots can use this information to determine whether or not they are on course, and how far they are from their intended flight destination.

GPWS -- Ground Proximity Warning System. A device, installed on an aircraft, which uses radar altimeter and/or barometric data to compute when an aircraft inadvertently approaches too close to terrain. Its purpose is to provide flight crews an extra measure of safety against inadvertent collision with terrain. GPWS equipment sounds audible and visual alerts and warnings when certain threshold parameters of certain key variables are exceeded to alert flight crews to the following potentially hazardous situations:

- o excessive rate of descent;
- o excessive vertical rate of closure with terrain;
- o negative climb rate or loss of altitude after takeoff or missed approach;
- o insufficient terrain clearance with landing gear or flaps not set in landing configuration; and
- o excessive downward deviation from an instrument landing system glide slope signal during an ILS approach.

Ground Effect -- atmospheric conditions just above the earth's surface which cause an aircraft's wings to lose their lift and make an aircraft less responsive to control commands.

Ground Slope -- the relative deviation of the terrain from the horizontal, expressed as an angle in degrees, positive if upward and negative if downward.

Ground Track -- the line traced by a point directly under an aircraft as it flies over terrain.

ICAO -- International Civil Aviation Organization. An agency responsible for promoting agreement between nations concerning regulation of international flight.

IFR -- Instrument Flight Rules. FAA regulations governing flight under instrument meteorological conditions. IFR flight presumes pilots will not be depending on visual reference, but will instead be relying on their cockpit flight instruments for all necessary information. All pilots intending to fly under instrument flight rules must be certified to do so, must file an IFR flight plan and obtain IFR clearance from FAA air traffic control personnel.

ILS -- Instrument Landing System. A group of related FAA air navigation facilities whose purpose is to provide precision guidance to an aircraft for approach and landing, from the final approach fix to touchdown on the runway. An ILS will provide, via flight instruments, indication to pilots that they are flying a proper approach course and descent, even if weather conditions prevent their gaining visual reference with the runway environment. An ILS consists of a glide slope, a localizer, and marker beacons (usually an outer and middle marker, but on some approaches to larger airports an inner marker is also included). An aircraft flying an ILS approach will initially establish itself on the localizer signal, which indicates it is in proper horizontal alignment with the runway centerline. As it flies over the outer marker, it will normally capture the glide slope signal, and begin its descent. The aircraft will continue its descent, using glide slope and localizer signals to align itself with the correct approach course, and the marker beacon(s) to judge distance from the runway. Once the aircraft has descended to decision height, usually 200' AGL, the pilot makes a decision whether to commit to landing, if the runway is in sight, or to execute a missed approach, if not.

IMC -- Instrument Meteorological Conditions -- Weather conditions which include obstructions to visibility (low ceiling, fog, precipitation, etc.) to such an extent that flight under visual flight rules is not possible. Under IMC, pilots must rely on cockpit instruments for indications of aircraft altitude, heading, attitude, airspeed, climb/descent rate, etc., as they are lacking visual reference to provide this information. To fly in IMC, a pilot must be instrument-rated and have filed an IFR flight plan with the FAA.

Instrument Approach Procedure -- an approach which involves use of signals from navigational aid facilities to provide information for correct alignment of the aircraft, and which therefore requires the pilot to use cockpit flight instruments to accomplish this alignment.

Knot (kt) -- a unit of speed equal to one nautical mile per hour.

Landing Configuration -- the configuration of an aircraft as it prepares for landing, with landing gear and flaps extended.

Landing Gear -- that portion of an aircraft's undercarriage, containing struts and wheels, which allows it to roll along a runway for takeoff and landing. Except in very small aircraft, landing gear are retracted following takeoff into the wings and fuselage to reduce drag on the aircraft in flight. In preparation for landing, they are extended.

Magnetic Heading -- a measurement of direction, using magnetic north (zero degrees) as a reference, which, in combination with distance, can be used to exactly determine an object's (i.e., an aircraft's) position from a reference point.

MDA -- Minimum Descent Altitude -- the lowest altitude, expressed in feet above mean sea level, to which descent is authorized on a non-precision approach, in which no glide slope information is provided the pilot. For most non-precision approaches, MDA is approximately 500' AGL.

Missed Approach -- a flight maneuver performed by pilots when, upon reaching minimum descent altitude for a non-precision approach or decision height for a precision approach, the pilot does not gain visual reference with the runway environment, or other circumstances prevent landing on the selected runway. The missed approach maneuver includes application of takeoff power, retraction of flaps and landing gear, and establishment of a climbing (nose up) attitude along a specified heading and magnetic heading until a certain specified altitude and location is reached. Pilots executing a missed approach must inform ATC personnel of this action.

MSA -- Minimum Sector Altitude -- the lowest altitude for safe flight in a given sector of airspace, which provides safe vertical clearance above any man-made or terrain obstructions.

MSAW -- Minimum Safe Altitude Warning. A warning generated by air traffic control automation systems, displayed to air traffic controllers on their radar screens, indicating an aircraft has descended below a specified threshold altitude. MSAW warnings are relayed verbally by controllers to aircraft pilots.

MSL -- Mean Sea Level. The zero point of reference in altitude or terrain elevation measurements.

NASDAC -- National Aviation Safety Data Analysis Center. A repository of aviation safety data, maintained by the FAA.

NM -- Nautical Mile. A measure of distance, equivalent to 1/60 of one degree at the earth's equator, or 6,076.1 feet.

Non-Precision Approach -- a standard instrument approach procedure in which no glide slope information is provided. A pilot flying a non-precision approach may therefore have flight instrument information regarding airport location (distance and bearing from a VOR or NDB), horizontal alignment relative to the runway (from a LOC or LDA) and distance to the airport (from a DME), but no information regarding vertical alignment on the approach.

NTSB -- National Transportation Safety Board. The U. S. Government agency responsible for investigation of aircraft and other serious transportation accidents, and for determination of the probable cause of these accidents. In certain cases, the NTSB makes safety recommendations to the appropriate regulatory agency as a result of these investigations and determinations. In the case of aircraft accidents, these recommendations are made to the FAA.

PIC -- Pilot-in-Command. The pilot responsible for the operation and safety of an aircraft during flight.

Precision Approach -- a standard instrument approach procedure in which glide slope information is provided. A pilot flying a precision approach therefore has instrument information regarding horizontal alignment from a LOC, vertical alignment from a GS, and distance to the airport from markers (OM and MM).

RADAR -- Radio detecting and ranging. A facility which transmits high-frequency radio signals and receives them after they have been reflected off distant objects (i.e., aircraft). Echoes received, called radar returns, provide information on azimuth (angle above the horizontal), bearing (angle with reference to magnetic north) and distance to these objects. If the transmitter/receiver is allowed to rotate, then a 360-degree field of view is obtained, and successive returns from each rotation (sweep) of the radar allow calculation of airspeed, climb/descent rate, etc. The FAA uses both long-range (150 NM) and short-range (50 NM) radars to track and control aircraft.

RPM -- Revolutions per minute. A measure of engine speed (and therefore power being produced per unit time, all other factors being equal).

RTCA -- Radio Technical Commission for Aeronautics. An advisory body composed of representatives of government and industry, which seeks sound technical solutions to problems involving aeronautical operations.

Runway -- the paved surface(s) at an airport used by aircraft for takeoffs and landings. Runways are marked with numbers indicating their approximate bearing relative to magnetic north (for example, if a runway's bearing is 118 degrees magnetic, it will be labeled runway 12).

Sink Rate -- the speed at which an aircraft descends to lower altitude, usually measured in feet per minute (FPM).

Stabilized Descent -- descent of an aircraft to a lower altitude which is characterized by a gradual, controlled sink rate.

TCAS -- Traffic Alert/Collision Avoidance System. A cockpit advisory system, using radar data as inputs, which warns pilots, through aural and visual means, of impending mid-air collisions with other nearby aircraft.

USGS -- U. S. Geodetic Survey. The Government agency, part of the U. S. Department of the Interior, which has responsibility for producing topographical maps of the United States.

VFR -- Visual Flight Rules -- FAA regulations pertaining to flight under visual meteorological conditions. Pilots planning VFR flights are not required to file flight plans with or to receive clearance from the FAA. VFR flight rules presume the pilot has sufficient visual reference at all times for judging aircraft altitude, heading, attitude, airspeed, climb/descent rate, etc., and need not rely on flight instruments for any of this information.

Visibility -- the relative distance at which an object can be seen under prevailing weather conditions, usually expressed in miles or fractions of miles.

VMC -- Visual Meteorological Conditions -- weather conditions characterized by sufficient visibility for aircraft to operate under visual flight rules.

APPENDIX D

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