THE PERFORMANCE OF WARNING SYSTEMS IN AVOIDING CONTROLLED-FLIGHT-INTO-TERRAIN (CFIT) ACCIDENTS

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ABSTRACT

This paper examines the performance of two systems to prevent Controlled-Flight-Into-Terrain accidents, including their development and preimplementation issues and attitudes. The airborne version, the Ground Proximity Warning System, was required for certain large turbine-powered airplanes. The ground-based system, the Minimum Safe Altitude Warning, is a feature of the ARTS-3 system. Accident data from National Transportation Safety Board (NTSB) and reports from the Aviation Safety Reporting System (ASRS) were used in assessing performance. It is concluded that these systems have dramatically reduced accidents. Although false and nuisance alarms continue, no evidence suggests that they have caused any accident. The tenacity of the alarms--especially the GPWS--as well as appropriate triggering criteria seem to be basic to their success.

INTRODUCTION

Battelle's Columbus Laboratories operates the Aviation Safety Reporting System (ASRS) for the NASA Ames Research Center. The authors recently studied Controlled-Flight-Toward-Terrain (CFTT) occurrences recorded within the ASRS data base. This data base currently contains 24,000 reports of discrepancies and deficiencies in the aviation system, authored by pilots, air traffic controllers, and others.

The CFTT study disclosed interesting facts concerning the impact of two warning systems on the day-to-day operational aviation system. The systems implemented to preclude Controlled-Flight-Into-Terrain (CFIT) accidents are the airborne system known as the Ground Proximity Warning System (GPWS) and the ground-based system, known as Minimum Safe Altitude Warning (MSAW)--a functional element of the automated radar terminal system (ARTS-3) installed at some 63 major US airports.

The reports studied include valid alarms (some appear to have prevented a disastrous accident) and false or nuisance alarms (some of which created new hazards). It was recognized that if this information were supplemented with CFIT accident data for the periods before and after GPWS/MSAW implementation, plus information on the

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attitudes and issues preceding implementation, an interesting and potentially useful paper might result.

WARNING SYSTEM IMPLEMENTATION

In December 1974, the Federal Aviation Administration (FAA) adopted a rule requiring a GPWS in certain large turbine-powered (turboprop and turbojet) aircraft by December 1, 1975 (FAA, 1974a). Specifically, the rule applied to turbine-powered airplanes with maximum gross weights over 12,500 pounds operated under Parts 121, 123, and 135 of the Federal Aviation Regulations. These parts covered all airlines certificated by the Civil Aeronautics Board, scheduled commuter carriers, and Air Travel Clubs as well as many large corporate aircraft certificated under these rules.

Paragraph 121.360 of FAR 121 sets forth the requirements for an acceptable GPWS. In general, the system was to provide for four warning modes:

- Mode 1 - Excessive Sink Rate Close To Terrain
- Mode 2 - Excessive Closure Rate Close To Terrain
- Mode 3 - Negative Climb After Takeoff
- Mode 4 - Descending Into Terrain With Gear Or Flaps Up

The acceptable GPWS performance was further outlined in an Advisory Circular issued on December 31, 1974 (FAA, 1974b).

Numerous additional amendments affected the requirements for GPWS design and use by: (1) defining specific technical performance and environmental standards for GPWS systems (FAA, 1975a); (2) incorporating Mode 5, Operation Below the Glide Slope, by June 1, 1976; (3) extending some GPWS installation dates until June 1, 1976, in recognition of delays in equipment deliveries; (4) waiving a provision prohibiting deactivation of the GPWS system, until September 1, 1976, in recognition of equipment reliability problems and attendant false alarms; (5) redefining the aircraft covered by the ruling, exempting the required GPWS system for aircraft with up to 30 passenger seats, a maximum payload up to 7,500 pounds, and a maximum zero-fuel weight up to 35,000 pounds; and (6) further revising equipment standards, involving alteration of the warning envelopes, to reduce false and nuisance warnings (FAA, 1976).

In 1976/1977 a separate, ground-based warning system (also intended to prevent CFIT accidents) was implemented. This system, the MSAW element of ARTS-3, had been under development for the FAA since the early 1970s. MSAW became operational at Los Angeles and Washington, D.C., in November 1976; initial operation at Denver, Detroit, Houston, and St. Louis was in January 1977, and at the remaining 57 ARTS-3 terminals by mid 1977.

With MSAW the air traffic controller receives a visual signal and an aural alarm when an eligible aircraft penetrates or is predicted to penetrate (by extrapolating descent rates) a predetermined minimum safe altitude in the terminal area. MSAW operates in two modes. The one provides for surveillance in all parts of the terminal area except the final approach corridor. The second is tailored to monitor aircraft altitude versus position during the final approach.

ISSUES AND ATTITUDES

The initial GPWS ruling was issued just days after the crash of Trans World Flight 514--a Boeing 727--into a mountain near Dulles International Airport. This was but one in a succession of CFIT accidents in the late 1960s and early 1970s. The FAA had been evaluating airborne warning systems relating to CFIT accidents and was planning to adopt a GPWS ruling in April 1975. However, the pressures following the Flight 514 accident prompted the FAA to act in December 1974.

Prior to 1975, accidents in which airliners flew into the ground while in controlled flight had been a leading cause of accidents. According to McDermott (1975), over 50 percent of all airline crashes in the prior 20 years had fallen into that category. Bateman found 115 CFIT-type airline accidents for use as case studies (Bateman, 1972). In part, radar altimeters and altitude alert systems (barometric altimeter) were developed because of a concern for such accidents. However, efforts to develop a comprehensive GPSW didn't start until 1966.

Advocacy for a mandatory domestic GPWS system probably began with the NTSB about 1970. Subsequently, the Airline Pilots Association (ALPA) advocated such systems. By 1974, the Boeing Airplane Company was planning to install GPWS in new aircraft. In May of 1974, following its fourth fatal CFIT accident in three years, Pan American World Airways initiated a program to equip its entire fleet with GPWS systems. In September 1974, prior to the TWA 514 accident, FAA had announced intent to adopt a GPWS ruling in early 1975.

There were legitimate doubts about the need for, or the prospective effectiveness of, such systems. Some were skeptical of GPWS effectiveness in cockpits already containing 200 alert and warning lights and 20 or more warning bells, buzzers, and sirens (McDermott, 1975). They speculated that if it was effective, it would be because unlike the other warning systems it (1) couldn't be ignored and (2) couldn't be turned off. The FAA's skepticism was clear in its original amendment requiring GPWS (FAA, 1974a):

> "The FAA believes that present instrumentation and inflight procedures provide for safe and adequate terrain clearance as long as proper flight crew member discipline is maintained and appropriate flight operations procedures are followed. However, notwithstanding those instruments and procedures . . . a number of air carrier accidents involving large turbine-powered airplanes have been caused by inadvertent contact with the ground, and might have been avoided if a ground proximity warning system had been

installed to give warning of the impending disaster to the flight crew."

Nor were these sectors alone in their skepticism. In a technical paper presented in early 1977, one human-factors expert wrote:

"An appealing, though perhaps somewhat simplistic, answer to vigilance and attention problems is to install warning devices which are assumed to be attention demanding . . . There is never a guarantee that any stimulus, regardless of its psychophysical dimensions, will be correctly attended to 'correctly' because one of the usual ways of dealing with warning devices, particularly in the auditory mode, is to shut them off. The proposed ground proximity warning systems in the cockpit may be well intentioned, and may indeed prevent some CFIT accidents, but human factors specialists would do well to regard them with a measure of skepticism. (Wiener, 1977)"

GPWS/MSAW IMPACT ON CFIT ACCIDENTS

To our knowledge, the impact of GPWS and MSAW implementation has not been examined heretofore. That does not deny a general awareness in the aviation community of fewer CFIT accidents. Bateman (1978) noted the reduced airline CFIT accident fatalities during the early years following GPWS introduction and the continuing fatal accidents experienced by unequipped corporate fleets and U.S. military transports.

To quantify the impact of GPWS and MSAW systems on CFIT accidents, we examined NTSB accident data for 1971 through 1980, including unpublished data for 1979 and 1980 from internal NTSB records.

To qualify as an "appropriate" CFIT accident, an accident had to involve the aircraft and operations types affected by the GPWS regulations.* That is, it must involve a large turbine-powered aircraft operated under FARs 121, 123, or 135. Accident fatalities were not a criterion; the interest is in accidents of the CFIT type, not their survivability. In fact, major airframe damage was not even a criterion. Thus, as long as the aircraft made contact with ground, water, or obstacles thereon, the accident was of interest--even if the crew was able to get the aircraft airborne again following impact.

The more subtle criterion was that prior to impact the events in the cockpit qualify the accident as Controlled-Flight-Into-Terrain defined as:

"Controlled-flight-into-terrain accidents are those in which an aircraft, under the control of the crew, is flown into terrain (or

*This approach might fail to capture aircraft not required to have GPWS but equipped with altitude-reporting transponders and whose accident frequency might be affected by MSAW alone.

water or obstacles) with no prior awareness on the part of the crew of the impending disaster."

Many accidents in the NTSB files involving hard landings, and runway undershoots were excluded because the evidence of poor piloting technique or control problems brought about by other causes disqualified them from being considered "controlled flight".

In the 10-year period of interest, 19 accidents were identified which met the criteria discussed above (See Table 1). It was observed that the number of accidents in the years following GPWS and MSAW implementation were markedly reduced as shown in Figure 1. If the study period is divided--1971 through 1975, and 1976 through 1980--the second period can be reasonably labeled as post-GPWS. By December 1, 1975, it is estimated that approximately 80 percent of the required installations were completed. While the ensuing period was marked by some deactivations due to false alarms, most systems were installed and functioning by September 1, 1976. Because MSAW implementation was from November 1976 through June 1977, it is somewhat less precise to call the second period a post-MSAW period.

Seventeen qualifiable CFIT accidents occurred during the first period. By contrast, only two accidents occurred in the second period. This is a statistically significant reduction. By one test*, the probability of this being a coincidental reduction is less than seven in one million. This dramatic reduction cannot be attributed to decreases in aviation activity. In fact, except for a 7 percent drop from 1973 to 1974, activity increased in every year from 1971 through 1979 (FAA, 1979). Thus, the authors see no reasonable alternative to concluding that these two warning systems have had a profound effect in reducing CFIT-type accidents.

The two CFIT accidents during the second period occurred in 1977 and 1978. Both aircraft were equipped with GPWS systems. The 1977 accident involved a United Airlines DC-8F cargo flight near Kaysville, Utah. The 1978 accident was the more publicized crash of a National Airlines B-727 in Escambia Bay near Pensacola, Florida. In the United accident, the GPWS is believed to have given an alert prior to impact--an inoperative Cockpit Voice Recorder precluded determining this with certainty. In the latter case, the GPWS did provide an alert. The alert was ignored. The problem was compounded by the Flight Engineer's action of shutting the GPWS off following the alarm without the pilot's knowledge.

*Assuming that the number of accidents in any 5-year period is Poisson distributed, then in the period 1971-1975, the number of accidents is Poisson distributed with a mean rate of 17 accidents per 5-year period. Given that rate, the probability of observing two or less accidents in the second 5-year period is calculated as being 6.7×10^{-6}.

TABLE 1
Identified CFIT Accidents During the Period 1971 Through 1980 From NTSB Data

Date and Location	Description	NTSB Report No.
02-17-71 Gulfport, MS	Southern Airways DC-9-15 struck electrical transmission line 8,900' from runway during VOR Approach to Runway 13	AAR-71-14
06-07-71 New Haven, CT	Allegheny Airlines Convair 580 struck beach cottages 4,890' from runway during a non-precision approach to Runway 2	AAR-72-20
06-22-71 Martha's Vineyard, MA	Northwest Airlines DC-9-31 struck water 3 miles short of runway during VOR Approach to Runway 24	AAR-72-4
07-25-71 Manila, P.I.	Pan American Airways Boeing 707 hit mountain far from airport following premature descent in preparation for ILS Approach	Unpub.
09-04-71 Juneau, AK	Alaska Airlines Boeing 727 struck mountain 18.5 miles from airport during Localizer Approach to Runway 8	AAR-72-28
12-29-72 Miami, FL	Eastern Airlines L-1011 struck ground during unintentional descent while holding at 2,000' 18 miles from airport	AAR-73-14
04-10-73 Toledo, OH	Eastern Airlines Boeing 727 struck trees 6,400' short of runway during a Localizer Backcourse Approach to Runway 25	AAR-73-17
07-22-73 Papeete, Tahiti	Pan American Airways Boeing 707 struck water 3 miles from airport while in a departure turn from Runway 4	Unpub.
07-31-73 Boston, MA	Delta Airlines DC-9 struck seawall 3,000' from runway during ILS Approach to Runway 4R	AAR-74-3
09-08-73 King Cove, AK	World Airways DC-8 struck mountain 15.5 miles from airport following a descent preparatory to making an instrument approach	AAR-74-6
09-27-73 Mena, AR	Texas Int'l Convair 600 struck mountain during cruising flight	AAR-74-4
01-30-74 Pago Pago, Samoa	Pan American Airways Boeing 707 struck trees 3,865' short of runway during ILS Approach to Runway 5	AAR-74-15 & AAR-77-7
04-22-74 Bali, Indonesia	Pan American Airways Boeing 707 crashed into high ground 37 miles from airport during NDB Approach procedural turn	Unpub.
09-11-74 Charlotte, NC	Eastern Airlines DC-9-31 crashed 3.3 miles from runway during VOR/DME Approach to Runway 36	AAR-75-9
12-01-74 Berryville, VA	Trans World Airlines Boeing 727 struck ridge 25 miles from airport following clearance to VOR/DME Approach to Runway 12	AAR-75-16
08-30-75 Gambell, AK	Wien Air Alaska F-27B struck mountain while circling to land following a missed approach	AAR-76-1
11-12-75 Raleigh, NC	Eastern Airlines Boeing 727 struck ground 282' short of runway during an ILS Approach to Runway 23	AAR-76-15
12-18-77 Kaysville, UT	United Airlines DC-8F crashed into mountain while holding in preparation to landing	AAR-78-8
05-08-78 Pensacola, FL	National Airlines Boeing 727 crashed into water 3 miles from runway during Radar Approach to Runway 25	AAR-78-13

GPWS/MSAW EFFECT ON THE OPERATIONAL DOMAIN

Traditionally, the ability to acquire significant quantities of useful information from the operational aviation world--especially that pertaining to human error--has been quite limited. Bateman (1978), in his paper assessing early performance of GPWS systems, says:

> "What about reported saves? It would be the rare individual pilot, indeed, who would ever inform his chief pilot or company president that he almost flew the company's airplane into a mountain top, save for a timely, GPWS warning (let alone a copilot or flight engineer's shout of 'Pull Up'). This is human nature. On the other hand, we will surely hear of any nuisance alarm or false warning.
>
> As a result of this human element, the reported incidents of GPWS warning will normally be those where the aircraft position or unsafe flight path is caused by factors other than crew judgement. An example is improper ATC instruction."

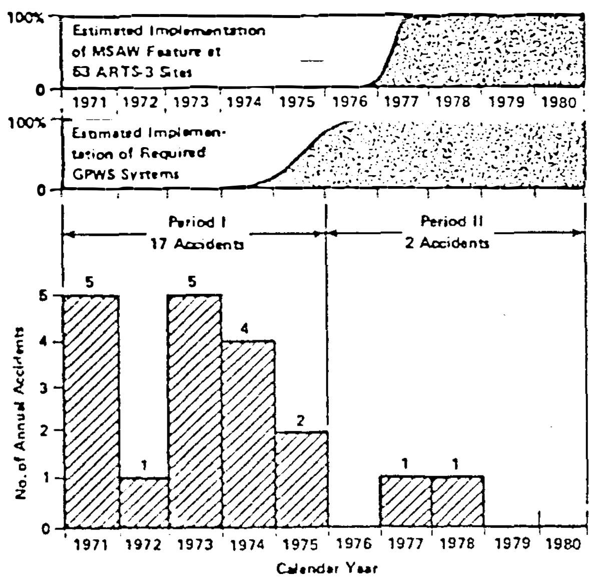

FIGURE 1. Frequency of Controlled-Flight-Into-Terrain Accidents Before and After GPWS/MSAW Implementation

This situation was dramatically altered with the advent of the ASRS in 1976. This voluntary reporting system offers both confidentiality and limited immunity to the reporter in exchange for information on discrepancies and deficiencies in the national aviation system. A large fraction of the 24,000-plus reports received to date are self-incriminating to the reporter.

A recent ASRS study "An Investigation of Reports of Controlled Flight Toward Terrain (CFTT)" focused on reports from July 1976 through October 1980. For the period, the ASRS data base contains about 23,000 reports. Of these, 266 reports outline occurrences or situations providing insight into the CFTT problem area and 51 specifically mention either GPWS or MSAW. While the 266 reports involve general aviation and scheduled air carriers, the 51 GPWS/MSAW reports deal almost exclusively with air carrier operations.* Some imply that the GPWS/MSAW alarm was appropriate; others allege the resulting alarm to have been false or a nuisance (see Table 2).

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*The 22 MSAW alarms contained one general aviation and one military case.

The 22 valid GPWS or MSAW alarms include six where the GPWS or MSAW gave the first warning of trouble and where, due to other factors, the authors believe a CFIT accident would have otherwise resulted. GPWS and MSAW each accounted for three of these probable saves. Two other incidents, reported after the CFIT study was completed, fit in this category. Both involved MSAW alerts. One is an ASRS report received in November 1980; the other is the well-publicized incident involving the Argentine Airlines Boeing 707 on a collision course with the 110-story World Trade Center in New York City on February 20, 1981. The two incidents described below indicate the dramatic nature of some of these probable saves. The first example, a "GPWS save" in February 1977, at Hill AFB, Utah, involved an air carrier transport. The incident occurred during daylight hours and under Instrument Meteorological Conditions (IMC).

"The GPWS actuated with a red light and 'whoop-whoop pull-up'. At this time, we were on a radar vector by HIF Approach at an assigned altitude of 11,000 feet. Vector heading assigned at that time was 250 degrees. Radio altimeter was observed to pass 2,500 feet rapidly, and power was initiated, climb attitude established. The radio altimeter passed through 800 feet and gradually started up during the climb. After passing the crest of the mountain, everything returned to normal."

TABLE 2
Distribution of Reported
GPWS/MSAW Alarms

System	Total Reports	Validity of Alarm: Valid	Validity of Alarm: False/Nuisance
GPWS	28	12	16
MSAW	22	10	12
BOTH	1	0	1
	51	22	29

The assigned 11,000 foot altitude was the normal Minimum Vectoring Altitude (MVA) in use. Ordinarily, it would have provided adequate clearance of a 9,674 foot MSL mountain peak in route. However, following landing, an investigation revealed a deep low pressure trough aloft. Because of it, and its effect on the barometric altimeter, the aircraft was probably 1,400 feet lower than its altimeters indicated. The MVA for that area was subsequently raised to 12,000 feet.

The second example, an "MSAW save" in November 1980, near Tampa, Florida, involved a large air carrier transport. The incident occurred at night under IMC conditions.

"The aircraft was executing a Localizer Back Course Approach to Runway 18R at Tampa International Airport. Keno, which is the final approach fix on the approach, is located 5.5 miles from the airport and has a mandatory crossing altitude of 2,000 feet. The aircraft made his initial call up to Tampa Tower stating that he was coming up on Keno. At this time, he was cleared to land, which he then acknowledged and asked if the visibility was still holding at a couple of miles. He was told the visibility was 5 miles and

> he acknowledged. I received a low altitude alarm for him as he was about 4 miles from the airport and his altitude indicated 300 feet. I immediately issued a low altitude alert advising him of his position and his altitude which now indicated 200 feet. He acknowledged and said he was checking it."

In a November 19, 1975 letter, the Air Transport Association of America (ATA) petitioned the FAA to amend FAR paragraphs 121.303 and 121.360 to provide relief until September 1, 1976, from the requirement that the ground proximity warning system required by paragraph 121.360 be in operable condition before takeoff. This petition was motivated by false alarm problems experienced by ATA's member airlines. In its amendment acting on this petition FAA quoted parts of the ATA letter (FAA, 1975b).

> "At least two major carriers are experiencing an unacceptably high number of false and nuisance alarms. More specifically, a false warning occurs when the system alarms, although system parameters do not call for one. For example, warnings have occurred on takeoff when the alarm sounds while the aircraft is in a positive rate of climb well outside the TSO envelopes which would require the warning. Warnings have occurred in cruise at high altitude for unexplained reasons, as well as during approach when the aircraft is on the localizer and glide slope over flat terrain."

The ATA was concerned with the effect of numerous false and nuisance warnings.

> "Pilots will quickly lose confidence in this system if this continues for even a short period of time. Once they lose confidence, it will be practically impossible to regain. Then, the efforts of both FAA and industry to realize the safety benefits which this system promises will have gone for nothing. We will have spent thousands of man-hours and millions of dollars on a black box that nobody trusts."

As reported earlier, the ASRS system received reports detailing both GPWS and MSAW false or nuisance alarms. While their number is not a valid statistical indicator of the actual number of false alarms experienced, the reports provide some useful insight into the phenomenon (see Table 3).

While false alarms for GPWS and MSAW occurred in all phases of flight, most occurred in the final approach phase (see Table 4).

Of the 29 incidents, 12 occurred in visual meteorological conditions (VMC), 8 in IMC. The remainder were not identified. The amount of VMC operation--in contrast with that in IMC--may influence the number of reports received in that category. The high number of VMC incidents may also result from the wider range of flight paths flown in VMC, as opposed to precision instrument approach flight paths. The probability of violating the alarm envelopes of these systems would be greater under such circumstances.

TABLE 3

Distribution of Reported False or Nuisance GPWS/ MSAW Alarms by System and Year

Calendar Year	Total Reports	Warning System GPWS	MSAW	Both
1976*	5	5	0	0
1977	6	2	4	0
1978	11	6	4	1
1979	4	2	2	0
1980**	3	1	2	0
	29	16	12	1

*Includes only the last 6 months
**Includes only the first 10 months

TABLE 4

Distribution of Reported False or Nuisance GPWS/ MSAW Alarms by System and Phase of Flight

Phase of Flight	Total Reports	Warning System GPWS	MSAW	Both
Climb	1	1	0	0
Cruise	1	1	0	0
Descent	3	2	0	1
Initial Approach	1	1	0	0
Final Approach	22	10	12	0
Unknown	1	1	0	0
	29	16	12	1

The reporters of these incidents--83 percent pilots--expressed various concerns about false or nuisance alarms. These concerns indicated four hazards: (1) encountering a midair collision while performing a mandatory pull-up, (2) losing control of the aircraft while distracted, (3) ignoring a valid alarm because of system credibility problems, and (4) ignoring a valid alarm through a misunderstanding of exactly what triggered it.

In four reported cases the flight responded to a GPWS alarm with the required pull-up maneuver. Each alarm was subsequently discovered to have been false. Since each such uncoordinated pull-up has some risk of a midair collision, the pilots wonder if the cure isn't worse than the disease.

In many cases the distraction of the alarms--both MSAW and GPWS--was cited as the greatest concern. That such distraction could lead to a loss of control was realized in two reported cases. In a daylight visual approach to San Francisco International Runway 28L, full flap extension could not be achieved in the late stages of the final approach. Because of other traffic and a fog bank in the missed-approach corridor, a decision was made to continue the approach to landing.

> "Increasing the sink rate to approximately 1,500 feet per minute and spooling the engines simultaneously provides a good stable platform two miles from the end of the runway. This was the maneuver that was in progress at the time the ground proximity warning system was triggered to a pull-up alert because of the increased sink rate. Since there is no means of silencing the GPWS system and since the audio level is extremely high, all cockpit and tower communications were blocked at this point in time. Speed callouts, sink rate callouts, height above the runway call-outs were not possible. This, in effect, denied a coordinated crew function. The landing was effected without incident."

One terse pilot report tells the story of a daylight VMC approach to Honolulu.

"GPWS malfunction in gusty wind conditions on short final, on glide slope, gear down, full flaps (50 degress), speed ^{V}Ref + 10 knots, GPWS says 'too low, flaps'. A quick scan showed everything OK. Alert second officer pulled circuit breaker. Distraction caused airspeed to go below ^{V}Ref at a time when recovery was difficult. False signals from GPWS, which occur often, create such a distraction that flight safety is impaired."

Numerous reporters expressed concern that false alarms hurt the system's credibility and lead to ignoring it when valid. Two dramatic cases of ignored valid alarms demonstrate this type of problem. The first is a night approach to Tampa International Airport under VMC conditions.

"Approach to 18R using VASI was stabilized and in visual glide path. At approximately 300 to 400 feet MSL, ground proximity warning system activated giving a 'pull-up'. Immediate reaction was 'what the hell is causing it to go off this time', meaning in my mind 'what's wrong with the GPWS', not 'what is it trying to tell me'. I have experienced literally dozens of these warnings where there was no significance to the warning. I am conditioned. I did glance over to see that the landing gear was indicating down and locked and the First Officer pushed the glide path cancel light. But we continued to touch down. During roll out I discovered that the flaps were at 25 degrees, which is not a landing flap . . ."

The second example involves a nighttime approach to Kansas City Airport under VMC conditions. After planning for an approach to Runway 01, the flight was granted permission for a more expedient approach to Runway 19. The clearance came late, and the aircraft had to be maneuvered significantly to make the change.

"I was prepared for a steep initial descent in a short turn-in, had frequency and localizer course at hand and already selected. I kept the Flight Director bars centered through the approach. The GPWS alarm went off but was ignored as giving erroneous warnings . . . normal landing followed. Not until later did I realize I had the wrong ILS frequency selected."

Alarms have been construed as false because the flight crew did not understand which factor triggered the alert. This has happened in MSAW alerts where the tower has advised of a "low altitude" alert. The flight crew checks the altitude only to find that it is normal when excessive rate of sink was the cause of the alarm.

CONCLUSIONS

GPWS and MSAW warning systems have brought about a dramatic reduction in CFIT accidents and undoubtedly have saved hundreds of lives. GPWS or MSAW was likely the sole factor in the prevention of several accidents; in other cases, while accompanied or followed by other warnings, their role was likely decisive in preventing the accident.

Although false alarms are a nuisance and cause for concern, there is no evidence of any accident having been caused by such false alarm.

Many pilots and controllers are not aware of the net benefit of the GPWS/MSAW systems. One ASRS report reflects a view held by many: "In my opinion and also the opinion of my fellow pilots, the GPWS is more likely to cause an accident than to prevent one."

The efficacy of the GPWS system, versus the perceived value of warning devices held by some, probably traces to its two unique characteristics - it can't be ignored and it can't be disarmed with anonymity. How much room this leaves for adding other tenacious alarms remains to be seen.

In the face of serious hazards to flight (e.g., the rash of CFIT accidents prior to 1975), it may not be optimal or desirable to carry prevention device or procedures development to perfection before implementation.

The valid (alarm criteria are met) but nuisance alarms frequently benefit flight safety by inducing the crew to examine, in retrospect, the conditions leading to the alarm. This has led to the detection of system problems or deficiencies.

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