APPENDIX

A-1 CFIT Losses & GPWS

- Chart: World Civil CFIT Accidents Turbine Powered Aircraft (Graph)
- Commercial Jet Aircraft (39 Losses)
  8 Years 1988 thru 1995
- Same with GPWS - Pie Chart
- Corporate, Regional, Air Taxi (148 Losses)
  6 Years 1989 thru 1995

A-2 North American CFIT Losses & GPWS
20 Years 1975 thru 1995 Airline Jet Aircraft

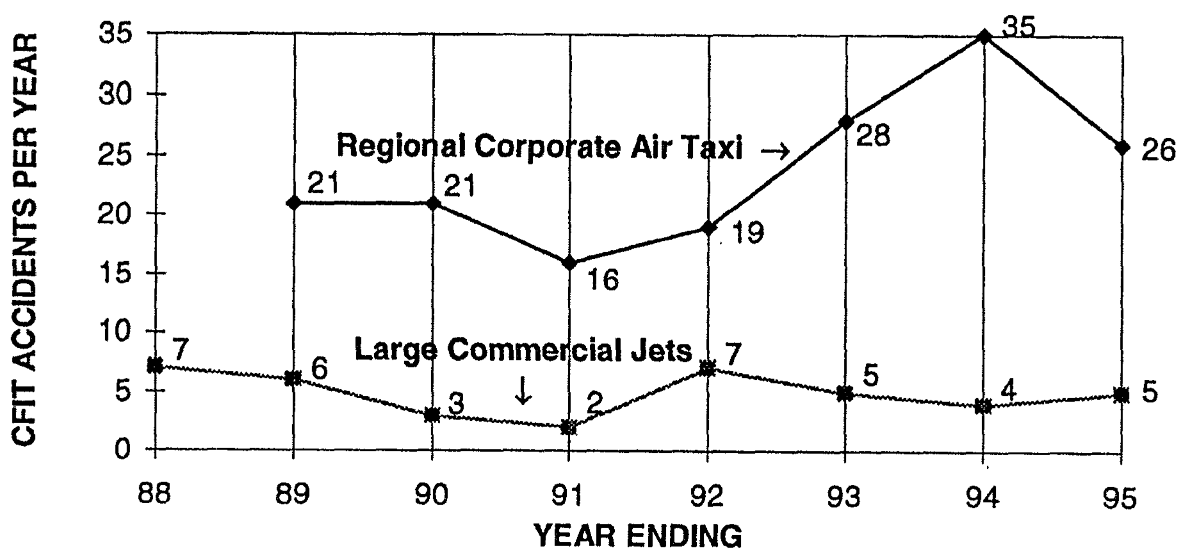
A-3 CFIT Accidents and Risk for U.S. Airlines - Large Commercial Jets
Pre 1975...................... 0.85 Accidents per million flights
Post 1975.................... 0.09 Accidents per millions flights

A-4 U.S.A. Part 135 Turbine Powered CFIT Losses 1982 thru 1995 (Graph)
~~Partial List (Table) of Part 135 CFIT Losses~~

A-5 Characteristics for Various Models of GPWS Equipment
and Bank Angle Description and Table of Accidents/Incidents

A-6 The Development of Ground Proximity Warning Systems

WORLD CIVIL CFIT ACCIDENTS
TURBINE POWERED AIRCRAFT



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CFIT ACCIDENTS (39) COMMERCIAL JET AIRCRAFT
EIGHT YEARS (1988 THROUGH 1995)

Year	Location	Aircraft
1995	Cali, Colombia	B757
	Windsor Locks, CT	MD-80
	San Salvador	B737-200
	Monrovia, Liberia	DC-9-31
	Cartagena, Colombia	DC-9-16
1994	Van, Turkey	B737-400
	Coventry, U.K.	B737-200
	Tamanrasset, Algeria	BAC1-11
	Vigo, Spain	DC-9/32
1993	Urumqi, China	MD-82
	Mokpo, Korea	B737-500
	Sorong, Indonesia	F-28
	Medellin, Colombia	B727-100
	Abijian, Ivory Coast	B707-320
1992	Kano, Nigeria	B707-320
	Kathmandu, Nepal	A300-B4
	Kathmandu, Nepal	A310
	Cruzeiro do Sol, Brazil	B737-200
	Athens, Greece	B707-320
	Kano, Nigeria	DC-8
	Strasbourg, France	A320
1991	Imphal, India	B737-200
	Santa Barbara, Venezuela	DC-9/30
1990	Nairobi, Kenya	B707-320
	Zurich, Switzerland	DC-9/30
	Unakleet, Alaska	B737-200
1989	Hulien, Taiwan	B737-200
	Tegucigalpa, Honduras	B727-200
	Tripoli, Libya	DC-10/30
	Paramaribo, Surinam	DC-8/62
	Kuala Lumpur, Malasia	B747
	Santa Maria, Azores	B707-320
1988	Ahmedabad, India	B737-200
	Rome, Italy	B707-300
	Lagos, Nigeria	B707-320
	Posadas, Argentina	MD-81
	Cucuta, Colombia	B727-100
	Ercan, Cypress	B727-200
	Izmir, Turkey	B737-200

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1995 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Scheduled	20 December	Cali, Colombia	B757	Hit Mtn 22 NM short of VOR DME Rwy 19. MKV GPWS installed and pilot pullup . Clipped top of mtn.	160 of 164; 5 rescues
Scheduled	12 November	Windsor Locks, CT	MD-80	Hit trees 2-3/4 NM from VOR Rwy 15. MK II GPWS.	of 72
Scheduled	9 August	San Salvador, G.S.	B737-200	Hit precipitous volcano on initial approach, VOR DME 25,; 12 second MK II GPWS Warning; Late pilot pull up.	65
Scheduled	26 July	Monrovia, Liberia	DC-9-31	Hit short of runway, tore off landing gear and burned.	12 S of 82
Scheduled	11 January	Cartagna, Colombia	DC-9-15	Premature descent 27 NM short of VOR-DME 36. MK I GPWS installed, but inoperative.	52

1994 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Scheduled	29 December	Van, Turkey	B737-400	Improvised 2nd approach to runway 03 using autoflight. MKV GPWS installed (GPWS not applicable). IMC. 4 NM short	58 of 76
Freight	21 December	Coventry, England	B737-200	Surveillance Approach - 1 NM short, hit H.V. tower at 65' AGL. IMC. Crew very tired.	5
Charter	18 September	Tamanrasset, Algeria	BAC1-11/500	After holding for 2 hours and low on fuel, VOR DME 03 approach made. Hit short by 1-1/2 NM. IMC. MKI installed but no warning.	4
Scheduled	21 March	Vigo, Spain	DC-9/30	Hit into approach lights, MKII GPWS installed.	--

1993 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Scheduled	13 November	Urumgi, China	MD-82	During ILS 25 approach, autopilot decoupled from glideslope. Aircraft hit into power line some 1-1/4 NM short of the runway. MKII GPWS operating.	12 of 92
Scheduled	26 July	Mokop, Korea	B737-500	During 3rd approach VOR-DME 06, the aircraft hit 4-1/2 NM short into 500' MSL ridge, MKV GPWS installed, no warning (No GPWS altitude callouts).	68 of 110
Scheduled	1 July	Sorong, Indonesia	F-28	During an NDB 26 approach, the aircraft impacted into the sea 0.6 short of the runway. No GPWS installed.	41 of 43
Scheduled	19 May	Medellin, Colombia	B727-100	During initial approach, the aircraft mistook NDB passage and turned away before reaching the NDB, and hit a mountain 30 NM from airport. No GPWS installed. IMC	132
Freight	15 January	Abidjan, Ivory Coast	B707-321	During an ILS approach to runway 21, the aircraft hit short by 10 feet. MKI GPWS installed. Glideslope function operative.	--

1992 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Freight	25 November	Kano, Nigeria	B707-320C	During VOR DME 06 approach, aircraft impacted 8-1/2 NM short. No GPWS installed. Night.	--
Scheduled	28 September	Kathmandu, Nepal	A300-B4	During a VOR DME 02 approach, the aircraft prematurely descended, impacted a mountain 9-1/2 NM short of runway 02. MKII installed.	167
Scheduled	31 July	Kathmandu, Nepal	A310-300	During a missed approach, the pilot became unaware of high terrain, impacting some 24 NM past the airport. MKIII GPWS installed, 17-second warning.	113
Freight	22 June	Cruzeiro Do Sol, Brazil	B737-200C	During a VOR approach to runway 10, aircraft hit short by 7-1/3 NM. Crew distracted by cargo smoke alert. Night. No GPWS.	3
Freight	24 March	Athens, Greece	B707-320	During an ASR radar approach to runway 33R, aircraft hit a mountain 4 NM from the runway. MKI.	7
Freight	15 February	Kano, Nigeria	DC-8	During a VOR DME approach to runway 06, the aircraft impacted some 9 NM short at night. No GPWS.	--
Scheduled	20 January	Strasbourg, France	A320	During a VOR TAC approach to runway 05, the aircraft prematurely descended, impacting some 10-1/2 NM short at night. No GPWS.	87 of 96

1991 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Scheduled	16 August	Imphal, India	B737-200	During initial approach and procedure turn to ILS/VOR runway 04, the aircraft hit a mountain 19 NM from the runway. IMC. MKI GPWS installed. 6-1/3 second warning (would have been 16 seconds with MKII).	69
Scheduled	5 March	Santa Barbara, Venezuela	DC-9/30	Enroute, the aircraft hit a 10,000 foot mountain. IMC. MKI GPWS working, but aircraft some 1700 feet below top. Pilot attempted recovery (almost made it). MKII would have given 4 seconds more warning time.	43

1990 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Freight-Charter	4 December	Nairobi, Kenya	B-707-320	During a second ILS approach, the aircraft impacted short of runway 06. No GPWS.	10
Scheduled	14 November	Zurich, Switzerland	DC-9/30	During an ILS approach to runway 14, the aircraft impacted 5-1/4 NM short into a hill at night. A glideslope failure, zero deviation, no flag, is a possible cause. MKII GPWS installed, no warning.	46
Positioning	2 June	Unalkaleet, Alaska	B737-200	During an LOC/DME approach to runway 10, the aircraft prematurely descended and impacted a hill 6-2/3 NM short.	--

1989 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Scheduled	26 October	Hualien, Taiwan	B737-200	During a night departure, the aircraft was turned the wrong direction toward terrain. During a turn back to the correct course, the aircraft hit a mountain. MKII GPWS installed and a warning given. Pilot tried to increase turn rate instead of pulling straight ahead.	54
Scheduled	21 October	Tegucigalpa, Honduras	B727-200	During a VOR DME approach to runway 01, the aircraft prematurely descended and impacted a mountain some 5-3/4 NM short. No GPWS.	131 of 146
Scheduled	27 July	Tripoli, Libya	DC-10/30	During a locator approach to runway 27, the aircraft hit short by 0.6 NM. IMC. Primitive GPWS (tone - MK1/2) installed, 7-1/2 seconds (MKII would have given 18 seconds).	75 of 199
Scheduled	7 July	Paramaribo, Suriname	DC-8/62	During a VOR DME (ILS up) to runway 10, the aircraft was being flown by Flight Director but locked in vertical speed with no glideslope capture. MKI GPWS installed. Six "Glideslope!" alerts given but F/O canceled alert. IMC.	175 of 183
Freight	19 February	Kuala Lumpur, Malaysia	B747-200	During an NDB DME approach to runway 33, the aircraft prematurely descended, impacting a hill 8-1/2 NM from the runway. MKI GPWS installed and warnings given some 16 seconds from impact.	4
Charter	8 February	Santa Maria, Azores	B-707-300	During an initial approach ILS 19, the aircraft hit a mountain some 5 NM from the airport. An MKI GPWS installed and gave a 6-1/2 second warning. MKII would have given 27-1/2 seconds of warning.	144

1988 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

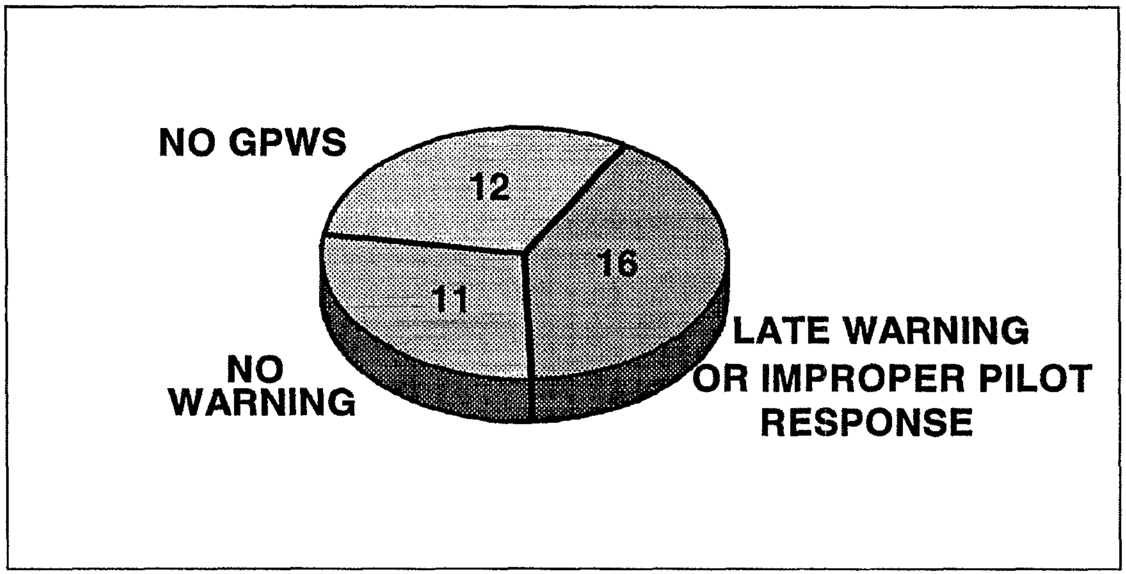
OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Scheduled	10 October	Ahmedabad, India	B737-200	During an LOC DME approach to runway 23, the aircraft hit short by 1.4 NM. IMC. MKI GPWS installed. No warning.	139 of 141
Scheduled	17 October	Rome, Italy	B707-300	During a VOR/DME approach to runway 34L, the aircraft hit short by 2-1/2 NM. IMC. No GPWS.	32 of 52
Scheduled	21 July	Lagos, Nigeria	B707-320	During an ILS DME approach to runway 19R, the aircraft impacted short by 8-1/2 NM from the runway. Night. IMC. No GPWS.	6
Freight	12 June	Posadas, Argentina	MD-81	During a VOR DME Locator approach to runway 01, the aircraft hit short of the runway by 1.7 NM. IMC. MKII GPWS installed.	23
Scheduled	17 March	Cucuta, Colombia	B727-100	During departure from runway 32, the aircraft diverted from the normal departure course because of traffic and impacted a mountain some 12-1/2 NM from liftoff. No GPWS.	143
Positioning	27 February	Ercan, Cyprus	B727-200	During a VOR approach to runway 16, the aircraft left the approach course and hit a mountain some 8 NM from the runway. MKII installed, timely alert, and pilot almost recovered.	15
Positioning	2 January	Izmir, Turkey	B737-200	During an ILS approach to runway 35, the aircraft impacted into a mountain some 19 NW west of the airport. MKI GPWS installed, but no warning.	16

1987 COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Freight	13 April	Kansas City, Missouri	B707	During a night ILS approach to runway 01, the aircraft impacted some 3-1/2 NM short of the runway. MKI GPWS installed but no alert or warning given. Failure of glideslope receiver to zero deviation and no flag suspected.	4

COMMERCIAL JET AIRCRAFT CFIT ACCIDENTS

EIGHT YEARS - 1988 THROUGH 1995



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1995 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS (26)

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Medevac	11 January	Masset, BC	LJ-25	Hit 4 NM short on NDB-A approach	5
Corporate	20 January	Kingston, Ontario	Be-90	Hit ground 10 NM outbound on front course of runway 01	--
Corporate	25 January	Allendorf, Germany	Ce Citation II	Hit short into trees	2 (4)
Cargo	29 January	Manaus, Brazil	DC 8-62	Hit INM short on ILS 10, managed a missed approach	--
Repositioning	30 January	Taipei, Taiwan	ATR-72	Hit short 9 NM following a false glideslope lobe ILS 10 night. MK II GPWS inoperative.	4
Air taxi	21 February	Big Trout Lake, Ontario	Be-A100	Hit 3 NM short on approach	8 of 11
Private,	3 March	Gainsville, Georgia	Ce-208B	Hit 1/4 NM short on NDB04 - Night - Poor visibility	(2)
Cargo	22 March	Reno Nevada	Ce-208B	Hit mountain 9-1/4 NM short of rwy 16R	1
Cargo	27 April	Alice Springs, Australia	IAI-1124	Hit ridge 5-1/4 NM short ILS/LOC DME 7	3
Corporate	4 May	Quito, Equador	G-II	Hit mountain 23 NM short at night - Possible misinterpretation of procedure	7
Scheduled Regional	25 May	Leeds, Bradford	EMB110	During initial climb to 3600 feet, the captain's ADI failed with no flag. The aircraft entered a left turn overbanked, spiral.	12
Scheduled	3 June	Panama City	B747-200	Undershot ILS 03 by 230 feet (major damage) ragged weather	--
Private	7 June	Gainsville, Florida	PA-32	Circling at night	6
Scheduled Regional	8 June	Palmerston North, NZ	DHC-8	Hit hill 7 NM short VOR DME 25. Landing gear distraction. Short MK II GPWS warning. Radio Altimeter problem?	3 of 21
Air Taxi	17 June	Catumbela, Angolia	CASA 212	Hit 9-1/2 NM short of RWY 27	48
Corporate Air Taxi	22 June	Tepico, Mexico	LJ-35	Hit short 4-1/2 NM on approach at night	2 (6)
Charter	9 August	West New Guinea, Indonesia	HS-748	Hit at 9200 foot level of 9600 foot mountain enroute.	10
Scheduled	14 August	Near Clai, Colombia	EMB-110	Hit mountain enroute	7
Ferry	1 September	Farewell, Alaska	SC-7	Hit mountain at 4800 feet during departure	1
Corporate	18 September	Chino, California	SA-226T	Hit short by 0.15NM for ILS runway 26	--
Corporate	21 September	Smyrna, Tennessee	MU-2B	Descent in turn on departure from 600 feet	2 S
Scheduled	9 September	La Macareva, Colombia	Casa-300	Hit short by 5 NM from the runway in fog.	20 of 21
Scheduled	21 September	Moeron, Mongolia	An-24	Hit mountain 12 NM from airport	43
Medevac	21 September	Amenas D.Z.	LJ-36	Visual night circuit from Rwy 23 to Rwy 05. Hit 1.8 NM short	1 S of 3
Regional	31 October	Piedras Negras Mexico	Ce-208B	Hit 7 nm short of runway	9/2 "S" of 11
Civil-Military	9 November	Cordoba, Argentina	F-27	Hit mountain 48 NM from airport on initial approach	53
Corporate	30 December	Eagle River, WI	Ce-560	Hit 4 NM short on VOR/DME Rwy 4, IMC	2
Corporate	31 December	Naples, FL	Ce-550	Hit cables at 2NM on VOR/DME Rwy, 4 IMC	2

5) Large Turbo Prop
(6) ≤ 30 Seat Turbo Prop
(9) ≤ 10 Seat Turbo Prop
(7) ≥ 10 Seat Jet

No GPWS installed on above aircraft unless noted.

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1994 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS (35)

Don Bateman

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Regional	9 Jan	Athens, Greece	DO-228	Hit ridge-powerlines 7 NM from runway, VOR-DME 18L.	--
Freight	14 Jan	Sydney, Australia	AC 690	Flew into sea 10 NM short at night, rwy 34.	1
Positioning Air Taxi	18 Jan	Kinshasa, Zaire	LJ-24D	Hit short 10 NM at night, visual 24.	2
Charter	24 Jan	Attenrhein, Switzerland	Ce-425	Flew into lake - 2 NM, final 10.	5
Positioning	27 Jan	Meadow Lake, Sask.	IAI-1124	Hit 2 NM SE - stall?, circling 26.	2
Scheduled	23 Feb	Tingo Maria, Peru	Yak-40	Flew into mountain FL131, NDB departure.	31
Sales Demo	24 Feb	Cleveland, Ohio	Be-400	Hit off runway ILS 23	0 of 5
Positioning Air Taxi/Cargo	7 March	Hayden, CO	AC-690	Hit trees on approach	1
Freight	9 March	Australia	SA-226	Hit short on approach	1
Air Taxi	23 March	Bogota, Colombia	Ce-VI-650	Hit hillside, initial approach 25 NM NW.	4
Scheduled	6 April	Latacunga, Ecuador	DHC-6	Hit 13,400 mtn 300' below crest, premature descent.	17
Regional	25 April	Nangapinoh, Indonesia	BN-2A	Hit mtn at 5400' level, initial descent.	10
Regional	27 April	Stratford, CT	PA-31T	Hit 3 NM short, final 06.	8
Corporate	7 May	Zaire, Kinshase	Be-200	Hit short of runway	9
Medevac Air Taxi	27 May	Papeete, Tahiti	Mu 2B	Hit short by 4 NM on ILS Rwy 04 approach	5
Medevac	31 May	Thompson, Manitoba	Merlin II	Hit FAF NB 3.4 short, B/C LOC. rwy 33.	2
Regional	13 June	Uruapan, Mexico	Metro II	Hit terrain while maneuvering for 3rd approach.	9
Scheduled	18 June	Palu, Indonesia	F-27	Hit mtn 3-1/2 NM short, initial approach.	12
Charter	19 June	Washington DC-Dulles	LJ-25D	Hit 1-1/2 NM short, ILS 1R.	12
Charter	26 June	Abidjan, Ivory Coast	F-27	Hit 2-1/4 NM short, VOR/DME 21	17
Government	9 July	Kulu, India	Be-200	Hit mtn 7 NM SW of airport, NDB.	13
Charter	17 July	Fort de France	BN-2B	Hit at 2780' mtn, 15' below crest, 6 NM, VOR/DME.	6
Private	24 July	Portsmouth, OH	PA-32T	Hit trees on rising terrain, departure rwy 18.	5 of 6
Gov't (Drug Enforce)	27 Aug	Pucalpa, Peru	CASA-212	Hit hill, NDB/VOR.	5
Charter	13 Sept	Abuja, Nigeria	DHC-6	Hit 5 NM short, VOR-DME 22.	2 of 5
Corporate	17 Sept	Texas	HS-125	Hit Trees on approach	--
Private	10 Oct	Missouri	AC 690	Hit into ground in initial climb	1
Freight	29 Oct	Ust-Ilimsk, Russia	AN-12	Hit short on approach by 1-2 NM at night.	21
Charter, Freight	4 Nov	Kebu, Nabire, New Guinea	DHC-6	Hit hill, approach.	4
Air Taxi	19 Nov	Saumer, France	Be-C90	Hit ground while circling after successful locator; (NDB) approach.	7
Air Taxi	22 Nov	Bolvovig, New Guinea	BN2A-2D	Hit hillside on initial approach.	7
Scheduled	10 Dec	Koyuk, Alaska	Ce-402	Hit short on approach.	5
Business	16 Dec	Michigan	Ce-501	Hit short into approach lights	--
Scheduled	17 Dec	Tabubil, Papua N. Guinea	DHC-6	Hit ridge enroute to Selbang (25 miles east) on initial climb.	28
Freight	30 Dec	Melbourne, Australia	MU-2	Hit short on ILS - Poor visibility	1

(3) Large Turbo-prop
(6) 10 to 30 Seat Turbo-Prop
(8) $\leq$ 10 Seat Turbo Prop
(5) $\geq$ 6 Seat Jet

No GPWS equipment on any of the above aircraft

DB95038

1993 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS

Don Bateman

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Regional-Schd	6 Jan	Paris, France	DHC-8	Hit short while repositioning ILS 27 to ILS 28	4
Air Taxi	8 Jan	Hermosillo, Mexico	L-35A	Hit Mountain on approach to VOR 23	9
Private	29 Jan	Marfa, TX	Be-90	Circling to runway 12, IMC after VOR 30	0 of 8
Regional-Schd	30 Jan	Ackh, Inur, Malaysia	SC-7	Hit terrain en route	16
Air Taxi	7 Feb	Iquacu, Brazil	Be-90	Hit 0.6 NM short - IMC; heavy rain	6
Air Taxi	8 Feb	Lima, Peru	PA-42-720	Hit mountain initial descent	6
AT-Non Sched	27 Feb	Rio de Janeiro	L-31	Hit short by 300 feet	--
Air Taxi	18 Mar	Trijillo, Peru	Be-90E	Hit mountain initial descent 50 NM short	4
Air Taxi	19 Mar	Dagali, Norway	Be-200	Hit 3 NM short LOC/DME 26, night	3 of 7
Reg'l-NonSchd	23 Mar	Cuiaba, Brazil	EMB 110	Hit terrain on climb out	6
Air Taxi-Med.	6 April	Casper, WY	MU-2B-35	Hit terrain on DME Arc ILS 8, night	4
Private	1 May	Mount Ida, AR	Be-90	Hit Mt. Ida (3 NM short). Climb IMC	2
Air Taxi-Trng	25 May	Sante Fe, NM	SA-226T	Hit hill while circling to Rwy 15 short 5 NM at night.	4
Reg' Cargo NS	5 June	El Yo Pal, Colombia	DHC-6	Hit short while circling	2
Regional-Schd	11 June	Young, Australia	PA-31	Hit rising ground while circling after ND approach	7
Reg-Carg-Sch	25 June	Atinues, Namibia	Be-200	Hit terrain on missed approach	3
Government	15 July	Bombay, India	Be-90	Hit hill on approach IMC	4
Regional-Schd	31 July	Bharatpur, Nepal	DO-228	Hit mountain on initial approach	19
Air Taxi-Med.	7 Aug	Augusta, GA	Be-90	Hit 1-1/2 NM short on approach IMC to ILS 17	4
AT-Positioning	17 Aug	Hartford, CT	SA-226T	Hit 1/3 NM short IMC to Rwy 02	2
AT-Positioning	27 Sept	Lansing, MI	Be-300	Hit 2 NM after 7.0 IMC turning	2
Regional-Schd	19 Oct	Orchid Is., Taiwan	DO-228	Undershoot	--
Regional-NS	25 Oct	Franz Josef Glacier, NZ	Nomad	Hit Glacier VMC into IMC	9
Gov't-FAA	26 Oct	Winchester, VA	Be-300	Hit terrain while awaiting IFR clearance	3
Regional-Schd	27 Oct	Namos, Norway	DHC-6	Hit 3 NM short on NDB approach	12
Regional-Schd	1 Dec	Hibbing, MN	BAe JS-31	Hit 3 NM short on LOC (B/C) Rwy 13	18
Regional-Schd	10 Dec	Sandy Lake, Ontario	HS 748	Climbing turn, back into terrain	7
AT-Positioning	30 Dec	Dijon, France	Be-90	Hit short on approach IMC	1

(2) Large Turbo-prop **(16) ≤ 10 Seat Prop** **Except for DHC-8, there was no GPWS on any of the above aircraft.**

(9) 10 to 30 Seat Turbo-prop **(2) ≥ 6 Seat Jet**

DB95038

1992 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS

Don Bateman

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Regional-Schd	3 Jan	Sarnac Lake, NY	Be-1900	Hit short at FAF on ILS 23 IMC.	2F/2S
Private	11 Feb	Lakeland, FL	Ce-425	Hit short of runway 05 IMC.	1
Charter	16 Feb	Big Bear, CA	PA-31T	Hit terrain at 6740' 7 NM east of airport.	7
Private	5 Mar	New Castle, CO	MU-2B	Hit mtn - LOC/DME "A" Gear Down; Approach flaps 10-1/2 NM short.	6
Private	29 Mar	Taos, NM	AC-390	Hit rising terrain on climb out; IMC night 3940' (visual); radio altimeter installed.	1, 5S
State Aircraft	9 April	St. Augustine, FL	Be-90	Hit short on VOR approach 007: 10 EDT IMC.	2
Regional-Tour	22 April	Maui, Hawaii	Be-18	Hit mtn enroute.	9
Regional-Schd	8 June	Anniston, AL	Be-99	Hit terrain during LOC 5 approach.	3F/2S
Personal	24 June	Alamagordo, NM	MU-2B	Hit mtn VMC during climbout 23:21 MDT - Night.	6
Regional-Schd	24 July	Ambeu, Indonesia	Vickers Viscount	Hit mtn during initial approach ILS/04.	71
Personal	13 Aug	Osway, MO	PA-31	Hit short rwy 32-IMC.	--
Personal	4 Sept	Longton, KS	PA-42	Hit wires on approach.	--
Government	19 Oct	Pesqueria, Mex (Monterey)	AC-680T	Hit terrain during climbout IMC.	6
Comm/Air Taxi	31 Oct	Grand Junction, CO	PA-42	Hit mtn 10 NM north RNAV-Cleared to ILS rwy 11. "Macks" int. eastbound 9400'-7800' cliff; IMC day 0315.	3
National Guard	11 Nov	Juneau, AK	Be-200	Hit mtn LOC/DME 20+ NM from runway.	8
Government	10 Dec	Quito, Ecuador	Sabreliner	Hit 3 NM short during VOR/ILS 35 approach.	12
Regional-Schd	13 Dec	Goma, Zaire	F-27	Hit short into terrain during initial approach VOR/DME 36.	37
Government	22 Dec	Quito, Ecuador	PA-31	Hit 3 NM short during VOR/ILS 35 approach.	5

(2) Large Turbo Prop
(2) 10 to 30 Seat Turbo Prop
(13) ≤ 10 Seat Prop
(1) ≥ 6 Seat Jet

No GPWS installed on any of the above aircraft.

DB95038

1991 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS

Don Bateman

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Corporate	11 Jan	Belo Horizontes, Brazil	LJ-25	Hit 2 NM short.	5
Air Taxi-Ferry	8 Feb	Stansted, UK	Be-200	Hit 2-1/2 NM short of the runway; possible altimeter error.	2
Corporate	12 Feb	Uganda, Kenya	HS-125	Hit mtn on initial approach.	3
Air Taxi	15 Mar	Brown Fld, CA	HS-125	Hit mtn on departure 8L.	10
Corporate	18 Mar	Brasilia, Brazil	LJ-25	Hit short.	4
Corporate	21 May	Bauchi, Nigeria	Ce-550	Hit short.	3
Corporate	17 June	Caracas, Venezuela	G-II	Hit 5 NM short to rwy 10.	4
Corporate	4 Sept	Kota Kinabalu, Malaysia	G-II	Hit mtn during missed approach.	12
Charter	17 Sept	Djibouti	L-100	Hit mtn VMC during initial approach.	4
Corporate	25 Sept	Holtenou Klel, Germany	DS-20	Missed approach.	1
Regional-Schd	27 Sept	Guadalcanal, Sol.	DHC-6	Hit mtn enroute.	15
Corporate	8 Oct	Hanover, Germany	Ce-425	Hit short on ILS 27R.	7
Air Taxi	22 Nov	Romeo, MI	Be-100	Hit 3 NM short on VOR/DME approach, IMC-fog.	4
Corporate	27 Nov	Paloma, Majorca	Be-400	Hit 1/4 NM short.	--
Corporate	30 Nov	Kelso, WA	AC 690	Hit mtn 13 NM short.	5/1S
Corporate	11 Dec	Rome, GA	Be-400	Hit mtn on departure.	9

(1) Large Turbo Prop
(2) 10 to 30 Seat Turbo Prop
(5) ≤ 10 Seat Prop
(8) ≥ 6 Seat Jet

No GPWS Installed on any of the above aircraft.

DB95038

1990 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS

Don Bateman

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Regional-Schd	15 Jan	Elko, Nevada	Metro III	Hit mtn at FAF VOR-A.	4-5/16
Regional-Schd	16 Jan	San Jose, Costa Rica	CASA	Hit mtn on departure.	23
Air Taxi-Cargo	17 Jan	Denver to Montrose, CO	Ce-208A	Hit 50' below Mt. Massive (14,221') near Leadville, CO.	1
Corporate	17 Jan	West Point, MS	Be-400	Undershoot.	--
Corporate	19 Jan	Little Rock, AR	G-II	Hit short on ILS.	7
Air Taxi-Cargo	29 Jan	Williston, VT	Ce-208B	Hit trees, power lines on climb out at major IMC.	2
Air Taxi-Cargo	29 Jan	Schuyler Falls, NY	Ce-208B	Hit 1-1/2 NM beyond rwy 19 during climb out IMC, night.	1
Schd-Freight	21 Mar	Tegucigalpa, Honduras	L-188	Hit mtn 6 NM short VOR/DME rwy 1.	3
Business	27 Mar	Uvalde, TX	Be-100	Hit terrain 4 NM south of field on approach in IMC-night.	--
Regional-Schd	20 April	Moosonee, Ontario	Be-99	Hit 7 NM short on VOR rwy 24.	1 of 4
Air Taxi	28 April	Tamanrasset, Algeria	Be-90A	Hit 4 NM short on approach.	6
Regional-Schd	4 May	Wilmington, NC	GN-24	Hit short on B/C Loc 16.	2
Air Taxi	11 May	Cairns, Australia	Ce-500	Hit mtn on initial approach.	11
Air Taxi	13 Aug	Cozuneil, Mexico	AC 1121	Undershoot.	1
Air Taxi	11 Sept	New Mexico	MS-760?	Hit mtn on departure.	2
Business	22 Sept	White Plains, NY	AC 690B	Hit short by 3 NM in IMC.	0 of 6
Air Taxi	24 Sept	San Luis Obispo, CA	Ce-500	Hit short on approach LOC 11.	4
Corporate	21 Nov	Keller Jock, Australia	Be-200	Initial approach.	3
Air Taxi	29 Nov	Sebring, FL	Ce-550	Undershot on approach rwy 11.	--
Business	30 Nov	Kelso, WA	AC-690A	Hit short by 8 NM night on initial approach into mountain.	5 of 6
Air Taxi-Cargo	21 Dec	Cold Bay, AK	Ce-208	Hit mountain enroute.	1

(1) Large Turbo Prop **(12) $\leq$ 10 Seat Prop**
(3) 10 to 30 Seat Turbo-Prop **(5) $\geq$ 6 Seat Jet**

No GPWS Installed on any of the above aircraft.

DB95038

1989 CORPORATE, REGIONAL, AIR TAXI CFIT ACCIDENTS

Don Bateman

OPERATION	DATE	PLACE	AIRCRAFT TYPE	COMMENTS	FATALITIES
Private	2 Jan	Mansfield, OH	MU-2B	Hit 8 NM short during an ILS 24 approach circle for 23. Night, IMC.	4
Private	7 Jan	Paducah, KY	Be-90	Hit mtn on departure.	3 of 15
Schd Freight	12 Jan	Dayton, OH	HS-748	Initial climb.	2
Air Taxi	12 Jan	Caracas, Venezuela	Be-200	Hit terrain while diverting in low cloud.	2
Charter	19 Feb	Orange County, CA	Ce-404	Hit mtn 20 NM short.	10
Air Taxi	23 Feb	Altenshein, Lake Contance, Switzerland	AC-690	Hit short to rwy 10. VMC into IMC.	11
Air Taxi	24 Feb	Helsinki, Finland	SA-226T	Hit short on ILS approach IMC.	6 of 7
Regional-Schd	10 April	Valence, France	FH-27T	Hit mtn, initial approach.	22
Air Taxi-Ferry	10 May	Azusa, CA	Be-200	Hit San Gabriel Mountain at 7300' level (departed Santa Monica).	1
Corporate	29 June	Cartersville, GA	DA-20	Initial climb, shallow into terrain.	2
Regional	31 July	Auckland, New Zealand	CV-580	Hit during initial climb.	34
Regional-Schd	3 Aug	Samos, Greece	SD-330	Hit mtn enroute.	16
Charter	7 Aug	Gambella, Ethiopia	DHC-6	Hit power lines - fog.	3 of 7
Air Taxi-Med	21 Aug	Mayfield, NY	Be-100	Hit 1/4 NM short at night IMC.	6
Business	15 Sept	Terrace, BC	Metro III	Missed approach LDA/DME.	7
Regional-Schd	26 Sept	Hurdle Mills, NC	Ce-550	Hit 2-1/2 NM short on approach.	2
Regional-Schd	28 Oct	Molokai, Hawaii	DHC-6	Hit mtn enroute.	20
Corporate	7 Nov	Ribeiro Das, Nevez	LJ	Hit hill on approach.	5
Private	2 Dec	Ruidoso, NM	Be-90	Hit short in procedure turn NDB approach IMC.	2
Air Taxi-Positioning	22 Dec	Beluga River, Alaska	PA-31T	Hit 8 NM short.	--
Regional-Schd	26 Dec	Pasco, WA	BAe JS-31	Hit short on ILS 21R.	4

(3) Large Turbo Prop
(6) 10 to 30 Seat Turbo-Prop
(10) ≤ 10 Seat Prop
(2) ≥ 6 Seat Jet

No GPWS Installed on any of the above aircraft.

DB95038

NORTH AMERICAN CFIT ACCIDENTS - CANADA, MEXICO, USA
20 YEARS - 1976 THROUGH 1995
LARGE COMMERCIAL JET AIRCRAFT
1995: 6000 Aircraft ~ 9.0 x 10 Flights/Year
1976: 3200 Aircraft ~ 5.0 x 10 Flights/Year

YEAR	CFIT ACCIDENTS	AIRCRAFT TYPE	U.S. LOCATION	OUTSIDE U.S.	TYPE OF APPROACH	TYPE OF OPERATION	ARTS III MSAW COVERAGE	GPWS TYPE	GPWS WARNING TIME	FATAL-ITIES
1995	2	B757		Cali, Colombia	VOR DME 19	Scheduled	No	MK V	11 sec	160 of 164
		MD-80	Windsor Locks		VOR 15	Scheduled	Yes	MK II	3 sec	5 rescued of 72
1994	0	--	--	--	--	--	--	--	--	--
1993	0	--	--	--	--	--	--	--	--	--
1992	0	--	--	--	--	--	--	--	--	--
1991	0	--	--	--	--	--	--	--	--	--
1990	1	B737-200	Unakaleet	--	LOC/DME	Repositioning	No	MK I	None	0
1989	2	B747-100	--	Kuala Lumpur	NDB	Freight	No	MK I	11 Sec	4
		B747-300	--	Santa Maria	VOR	Charter	No	MK I	6-1/3 Sec	144
1988	0	--	--	--	--	--	--	--	--	--
1987	1	B707-300	Kansas City	--	ILS	Freight	Yes	MK I	Inoperative*	4
1986	0	--	--	--	--	--	--	--	--	--
1985	1	B727-200		Lapaz	Initial VLF	Scheduled	No	MK I	<2 Sec	29
1984	0	--	--	--	--	--	--	--	--	--
1983	0	--	--	--	--	--	--	--	--	--
1982	0	--	--	--	--	--	--	--	--	--
1981	0	--	--	--	--	--	--	--	--	--
1980	0	--	--	--	--	--	--	--	--	--
1979	0	--	--	--	--	--	--	--	--	--
1978	1	B727-200	Pensacola	--	B/C LOC	Scheduled	No	MK I	9 Sec	3
1977	2	DC-8	Salt Lake City	--	Radar Vector	Freight	Masked	MK I	9 Sec	3
		DC-8	--	Niamey, Africa	VOR	Freight	No	MK I	0	2
1976	2	B-720	--	Barranquil	VOR	Freight	No	MK I	--	0
		DC-10	--	Instanbul	VOR	Freight	No	None	(Hi Desent)	0

*Glideslope Failure (Zero deviation no flag)

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CFIT ACCIDENTS AND RISK FOR U.S. AIRLINES
Large Commercial Jets

TYPE OF CFIT LOSS		CFIT ACCIDENTS AND RISK PER MILLION FLIGHTS				REDUCTION (-) OR INCREASE (+) (Times)
		PRE-GPWS 1960 thru 1975		POST GPWS 1976 thru 1994		
INITIAL CLIMB	Accelerating Descent	1	0.03	0	<0.001	>-100
INTO MOUNTAINOUS TERRAIN	-Climb Out -Initial Approach -Missed Approach	6	0.17	4	0.03	-5.7
LANDING SHORT	-Not Configured to Land	5	0.14	0	<0.01	-140
	-Configured to Land/No Glideslope	5	0.14	6	0.06	-2.3
	-Below Glideslope	8	0.22	0	0.001	-220
	-Excessive Descent Rate	5	0.14	0	0.001	-140
TOTAL CFIT ACCIDENTS & RISK		30	0.85 x 10^{-6}	10**	0.09 x 10^{-6}*	-9.6
	Flight Segments	35 x 10^6		108 x 10^6		+3.1
	Aircraft Numbers	2800 in 1976		4800 in 1994		+1.7

CFIT Risk 1990 thru 1994 (5 years)..............................0.028 x 10^{-6} flights
CFIT Risk 1985 thru 1994 (10 years)............................0.074 x 10^{-6} flights
In USA (2)--0.033 x 10^{-6} flights
Outside USA (3)--------------------------------------0.44 x 10^{-6} flights

10 CFIT Accidents
(1) Loss with NO GPWS installed
(1) Loss with glideslope receiver failure
(9) All lost equipped with MK I GPWS
- If aircraft had been fitted with MK II or better, losses would have been reduced probably to 6 (0.055 x 10^{-6}).
- If aircraft has been fitted with MK V/VI/VII system with "smart" altitude callouts, the losses would have probably been reduced to 3 (0.03 x 10^{-6}).

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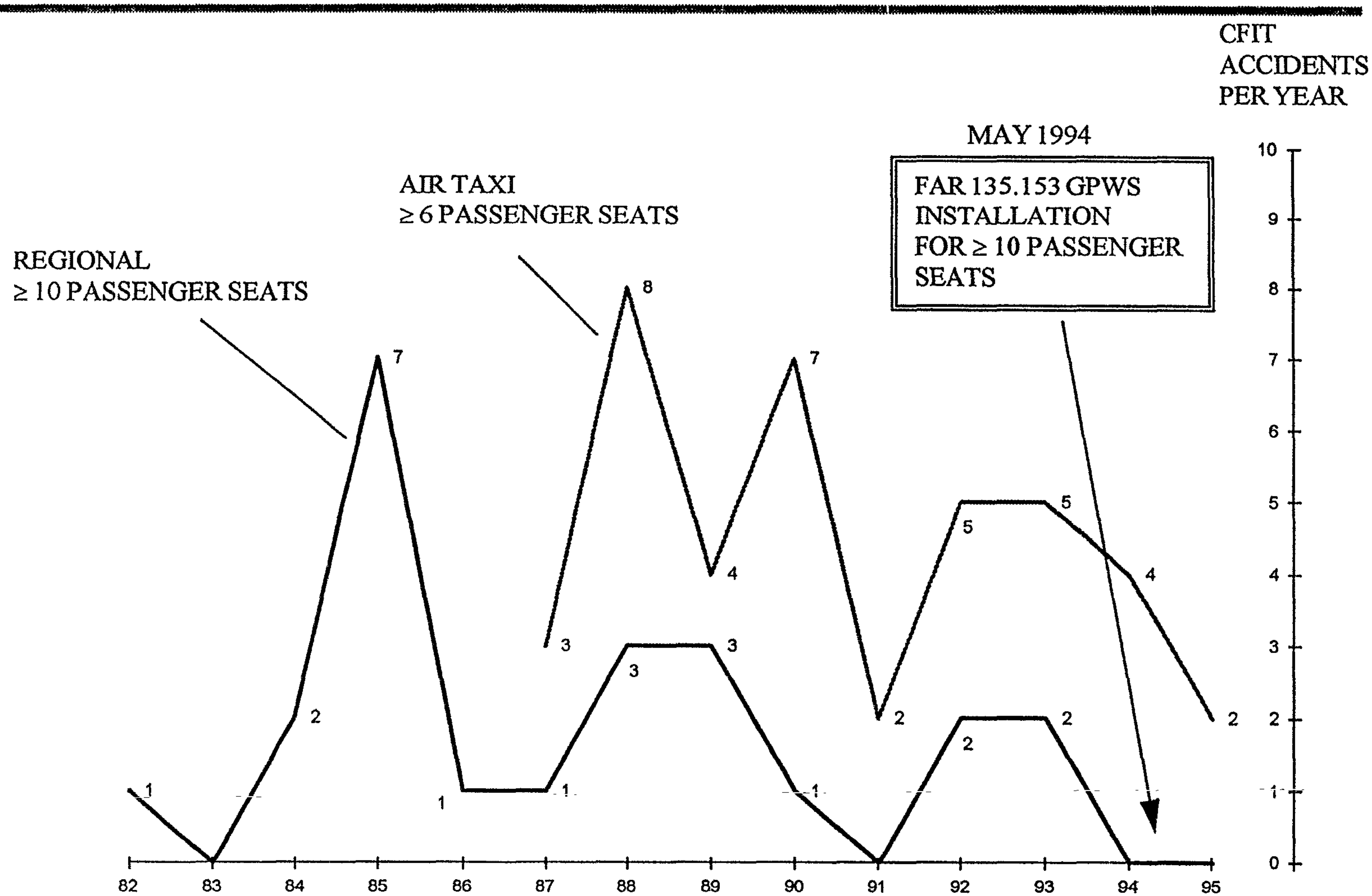
U.S.A. PART 135 CFIT ACCIDENTS
TURBINE POWERED AIRCRAFT



4/2/96

A 4

A-4 - PARTIAL LIST OF U.S. PART 135 TURBINE POWERED AIRCRAFT CFIT ACCIDENT LOSSES 1992 TO 1993 (NO GPWS ON ANY OF THESE AIRCRAFT)

1 Dec 1993	Hibbing, MN	BAe 31	LOC B/C 13	18 Fatalities
25 May 1993	Sante Fe, NM	SA-227	Circle 15	4 Fatalities
8 June 1992	Anniston, AL	Be-C99	LOC 5	3 Fatalities out of 53
January 1992	Samac Lake, NY	Be-1900C	ILS 23	2 Fatalities out of 4
15 March 1991	Brown Field, CA	HS-125	Departure 8L	10 Fatalities
4 May 1990	Wilmington, NC	GN-24	B/C Loc 16	2 Fatalities
15 January 1990	Elko, NV	Metro III	VOR-A	4 Serious Injury out of 16
26 December 1989	Pasco, WA	BAe 31	ILS 21R	4 Fatalities
21 August 1989	Gold Beach, OR	Be-C90	34	3 Fatalities
26 April 1989	Jacksonville, FL	SA-226	I. Wheels Up	--
28 October 1989	Molokai, HI	DHC-6	Enroute	20 Fatalities
4 October 1988	East Sound, WA	Be-99	Departure	-- Out of 4
17 May 1988	Little Rock, AK	AC 690	Visual 22	1 Fatality
19 February 1988	Raleigh-Durham, NC	Metro III	Departure 23	12 Fatalities
19 January 1988	Durango, CO	Metro III	VOR-DME 20	8 Fatalities out of 17
8 January 1988	Monroe, LA	GLS-36	ILS 04	2 Fatalities
5 February 1987	Florence, SC	SA-226	I. Wheels Up 36	--
28 August 1986	Lander, WY	Ce-441	Departure 21	7 Fatalities
13 March 1986	Alpena, MI	EMB-110	ILS 1	3 Fatalities out of 9
22 October 1985	Juneau, AS	LJ-24	LDA 8	4 Fatalities
16 October 1985	El Paso, TX	MU-2	Enroute	1 Fatality
11 October 1985	Homer City, PA	DHC-6	Enroute	1 Fatality
23 September 1985	Shenandoah Valley VA	Be-99	ILS 4	14 Fatalities
25 August 1985	Lewiston, MA	Be-99	ILS 4	8 Fatalities
20 August 1985	Gulkana, AK	LJ-24	VOR/TVOR 14	3 Fatalities
7 August 1985	Dallas, TX	SA-226	J. Wheels Up	--
7 April 1985	Williston, ND	SA-227	I. Wheels Up	--
22 March 1985	Los Angeles, CA	SA-226	I. Wheels Up 25 SR	1 Serious Injury
12 March 1985	Barter Island, AK	DHC-6	Go-Around	2 Serious Injury
14 March 1984	Myrtle Beach, SC	Be-99	I. Wheels Up	--
30 January 1984	Terre Haute, IN	SA-226	Departure	3 Fatalities
6 April 1983	Indianapolis, IN	L-35A	ILS	--
12 July 1982	Pueblo, CO	Metro III	Departure	2 Fatalities

DB95038

CHARACTERISTICS OF VARIOUS MODELS OF GPWS EQUIPMENT

1. **Basic Alert/Warnings (modes) applicable to all models:**

MODE 1	Excessive sink rate close to terrain
MODE 2	Excessive closure rate towards terrain
MODE 3	Negative climb rate after take-off
MODE 4	Insufficient Terrain Clearance based on configuration
MODE 5	Significant fly up glide slope deviation on approach

2. **Performance features of some GPWS models are:**

Mark 1/2

- Early, primitive GPWS system. Could not warn for many flight path into terrain situations, including flight path below the glide slope.
- Warning was a warbling continuous tone (woop-woop).

This system was installed on some 150 to 200 DC-8 / DC-9 / DC-10 aircraft outside of the United States. These units do not meet ICAO, U.S.A. or UK specified Minimum Performance Standards. Most have been replaced.

Mark I

An early, now obsolete, GPWS system that met the specified Minimum Performance Standards of TSO-C92b and U.K. CAA Specification 14.. This system could not provide a warning for some flight path towards terrain situations. The average warning time for flight into mountainous terrain was seven (7) seconds.

Warning is a 'Pull Up!" (or "Terrain") and a "Glide slope" alert

- "Pull Up!" was heard often in some operational environments. Pilots often waited to determine the reason for the warning, which sometimes took too long to cross check and determine the cause.

Over 4,000 of these systems were installed world wide, mostly in the U.S.A. Many of these systems, in the U.S.A., have been replaced with the MK II or MK VII. About ~~1100 remain in service in 1994.~~

Mark II **An obsolete system now, but the MK II gave significant improvement in performance as compared to the MK I, exceeding both the U.S.A. and the UK specified Minimum Performance Standards.**

- **Airspeed/Mach utilized to expand and contract some of the warning envelopes to enhance the performance. The average warning time for flight into mountainous terrain increased to twelve (12) seconds from (7) seconds.**
- **Most warning envelopes were reshaped to reduce unwanted warnings. Later modifications, based on airline provided data, significantly reduced the possibility of warnings during Air Traffic Controlled radar vectoring off instrument approach routes and procedures.**
- **Alert messages ("Sink Rate", "Too Low", Terrain", etc.) replaced "Pull Up"giving the reason for the warning. The "Pull Up" message was retained only for very time critical recovary from flight into terrain. Airspeed enhanced warning envelopes (dependent on phase of flight) were also utilized to change the alert message format.**

Over 5,000 of these systems are installed and are flying in revenue service around the world.

Mark III

- **Digital bus interface version of the Mark II. Now also obsolete.**
- **Some further performance improvements, but because of radio altimeter sensor limitations, the MK III proved to have some additional unwanted warnings compared to the Mark II.**
- **A limited Envelope Modulation feature, in a terrain data table form was added to improve warning time and to also reduce terrain induced nuisance warnings at some twenty world wide airports. Unfortunately, this table being incorporated in the software made the addition off new airports very difficult.**
- **Pin selectable limited voice menu, call outs and features.**

Mark III,s were installed on early B757's and B767's, the A300-600's, the A310's and A320's aircraft.
Most early B757 and B767 Mark III installations have been upgraded to the MK V system.

~~**Mark IV**~~ ~~**This system was used on some special mission military aircraft.**~~

Mark V

- This system has upgraded performance over the Mark III system.
- The Envelope Modulation feature was expanded and made easy to update via EE PROM programming at Of the 5,000 current world wide airports, a data base of only one hundred airports is in use. The airport data is available to the system via a look-up table that does not alter the operational software. This table can be expanded considerably if and when nuisance warnings, at a particular location, are brought to our attention and an analysis shows that the instrument and radar vectoring procedures give adequate terrain clearance.
- Pin selectable voice alitude call outs were expanded, and others such as " Bank Angle" added.
- To reduce the flight into terrain risk during non-precision approaches, an optional smart " 500 feet "call out and procedure are used.
- Wind shear detection algorithm and "Wind Shear " message, were added with priority.
- Available aircraft performance (total energy) is used to modulate some of the warning envelopes.

This system replaced the Mark III unit. The Mark V is installed on most new aircraft. It is basic equipment for all Airbus, Boeing new Fokker 100, BAE ATP and MD-11.

Mark VI

- This system's performance is similar to that of the Mark VII computer but designed especially for the special requirements of light business, regional turbo jet and turbo prop aircraft. Over 1200 aircraft in 1994 have MK VI GPWS installations. The number is rapidly growing.

Mark VII

- Upgraded performance is similar to the Mark V computer, but for analog avionic interfaces.
- Latest wind shear detection algorithm was implemented and built-in dual recovery guidance was provided.
- Pin selectable menu of call outs is provided, such as "Bank Angle ".
- To reduce the flight into terrain risk during non-precision approaches, an optional smart " 500 feet " call out and procedure is used by many of world wide airlines.

The latest versions of the MK VII offer an Envelope Modulation feature similar to the MK V. The Mark VII was designed to upgrade all Mark 1/2, Mark I and Mark II system installations giving superior performance and significantly reduced probability of unwanted warnings.

Enhanced GPWS V and Enhanced GPWS VII (EGPWS)

These new systems provide significantly improved performance over any past or present GPWS system. The EGPWS and installations. The basic GPWS independant functions are retained. The EGPWS has been designed to use the existing MK V and VII aircraft interfaces.

- "Look Ahead" algorithms utilize present, and predicted position are related to a worldwide terrain data base with aircraft climb performance to give a nominal one minute time alert to possible impact with threatening terrain.
- The system also provides a terrain output signal for use with cockpit Map Displays. The threatening Terrain Situation can be displayed on most existing color Weather Radar or EHSI displays.
- A terrain clearance floor is provided that surrounds the world's known civilian and military airfields to alert the pilots to possible premature descent into terrain or water independent of the aircraft configuration.
- The system also provides alerts to possible flight into significant obstacle/structures. This feature is only limited by the availability of the obstacle data.
- The EPWS comes in two computer versions, one to directly replace the MK V and the other to directly replace the MK VII, utilizing the existing interface wiring and installations of the world's airline fleet to advantage.

"Bank Angle" and other Forms of Alerting or Protection for Undetected Excessive Roll Angles

Aircraft have been lost when excessive roll angles have developed without detection by the flight crew. High undetected roll angles have resulted in high descent rates, during cruise buffet, loss of control, or scraped engine pods during landing. Some past incident/accident examples are shown in Table I. The risk of future incidents remain high.

These incidents have been caused by various factors:

- Undetected and uncommanded roll with autoflight or autopilot engaged (especially in cruise)
- Looking outside the cockpit at inadequate visual references during take-off climb or approach, Especially a problem at night with base turns circling and a lack of inside reference by the pilot to the panel attitude reference instruments. Other factors are looking for traffic, maneuvering for runway alignment, etc.
- Vertigo
- Expedited turns during take-off climb because of traffic, leading to uncoordinated flight control.
- Failed attitude reference display.

Many of these incidents arise because of lack of tactile sensory feedback. The tactile accelerations associated with coordinated steady high bank angle turns are often masked by the nose of the aircraft falling through with altitude loss.

To reduce the risk of such occurrences, various measures can be taken:

- Built in maximum bank limiters in "fly-by wire" automatic control systems.
- Enhance or emphasize high bank angles on the attitude display. On some displays, secondary data is dropped by the display to help the pilot focus on or correct the attitude problem.
- Visual and/or Aural Alerting when high or unusual roll angles are reached. Many forms are available; as an example, most GPWS equipment has options to annunciate "Bank Angle" when roll angles exceed $\pm$ 40 degrees or smaller angles when close to the ground. This capability provides independent means of protection against autopilot and instrument failures.

PARTIAL LIST OF EXCESSIVE BANK ANGLE CFIT ACCIDENTS/CFTT INCIDENTS

DATE	PLACE	AIRCRAFT TYPE	PHASE OF FLIGHT	CIRCUMSTANCES	FATALITIES
Various 1993-1992	Worldwide	Glass Cockpit	Enroute	Slow undetected rolls	--
6 June 1992	Panama	B737-200	Enroute	Slow undetected roll to 90 degrees believed to be ADI or Autopilot	47
15 Feb 1992	Toledo, Ohio	DC-8-63	Missed Approach	Slow undetected roll; autopilot; night	4
12 Dec 1991	N.W.T. Canada	B747-100	Enroute	Slow undetected roll; autopilot FL 310 to FL 190 for recovery	--
1990	Montreal-Paris	B747-200	Enroute	Slow undetected roll (71 degrees)	--
30 April 1989	Miami-London	B747-200	Enroute	Slow undetected roll (52 degrees)	--
Various	30 incidents +	B747-100/200	Various	Slow undetected rolls - at night or IMC	--
12 Jan 1989	Dayton, Ohio	HS-748	Take-off climb	Slow roll to 50 degrees for turn during climbout; night.	2
28 Oct 1988	Paris	B747-100	Final	Visual transition, alignment to runway at night, overbanked to 17 degrees at 100 ft.	--*
19 Feb 1988	Raleigh-Durham	Metro III	Take-off Climb	Expedited departure, overbanked to 45 degrees at 300 ft.	12
Dec 1987	Edmonton, Canada	DC-8-63F	Final	Visual transition at night to align with runway overbanked to 15 degrees at 150 ft.	--*
Nov 1986	London	B747-200	Final	Visual transition at night to align with runway.	--*
12 Nov 1980	Cairo	C-141	Turning base for final	Overbanked at night visual - no lights on ground	13
1 Jan 1978	Bombay	B747	Departure climb	Rolled to 80 degrees at 1400 ft --ADI failure no flag - night.	213
Oct 1977	Vancouver BC	B747	Turning base for Final	Slow roll to 50 degrees before detection in time	--
Sept 1977	Geneva (BA)	B747	Departure Climb	Roll slow but detected in time by F/O; ADI failure; no flag.	--

*Significant Damage

DEVELOPMENT OF GROUND PROXIMITY WARNING SYSTEMS (GPWS)

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DEVELOPMENT OF GROUND PROXIMITY WARNING SYSTEMS (GPWS)

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Abstract

Development of the GPWS in the early seventies and its installation into turbine powered commercial transport aircraft has significantly helped reduce Controlled Flight Into Terrain (CFIT) accidents. Today over 15,000 turbine transport aircraft in public commerce are fitted with this flight safety device. GPWS costs less than the exterior paint on the aircraft and easily repays its initial investment in less than two years. However, early GPWS had its limitations of unwanted warnings, late warnings, and no warnings when needed. Current Enhanced GPWS models will give the pilot much better awareness of flight into terrain situations, before a last moment mandatory escape maneuver is required, and will provide warnings in situations where the present system gives none. Greater immunity from unwanted warnings is also provided.

Controlled Flight Into Terrain (CFIT) Accidents and GPWS

In March 1931 a tri-motor Fokker, the *Southern Cloud*, took off on a flight from Sydney to Melbourne. It disappeared with its crew and passengers. All searching was in vain. The budding airline, ANA, could not bear the resulting negative publicity with its financial consequences and went into bankruptcy. In 1958, a surveyor discovered the wreckage near a summit in the Snowy mountains, 200 miles northwest of Melbourne.

Since the loss of the *Southern Cloud*, over 30,000 passengers and crew have lost their lives in terrain-related accidents. Flying a good airplane into the ground or water instead of the runway has resulted in about 60% of the total fatalities in public air transportation over the last ten years. With the advent of cockpit voice and data recorders in the 60's, it became evident that most of these CFIT accidents involved errors, not only in the cockpit, but often on the ground and in the procedures themselves. Flight procedures have evolved slowly to help reduce the risk, but the attitude of many in the industry has been that the pilots involved in such an accident were incompetent and should not have been flying in the first place. That attitude still persists today. "I would not have ever done anything so stupid!" was, and is, a common attitude.

Unfortunately, little thought or effort was given to building a broad pilot awareness of the CFIT hazard facing pilots and controllers. Very little training was given to pilots and controllers to help recognize CFIT "traps".

Today, many airlines are stressing pilot awareness programs that illustrate how a CFIT accident could happen to any pilot under the wrong fateful circumstances. This training is one of the most important cost effective safety measures that can be taken to reduce CFIT risk! Equipment such as GPWS takes a second place.

In the late 1960's, the introduction of the radio altimeter into large commercial jet aircraft as a pilot aid for reaching Category II Minimums also helped to reduce the CFIT accident risk. It made possible the simple concept of a GPWS, which originated in Europe at Scandinavian Airlines (SAS) in 1969. The concept was to give the pilots an alert based on abnormal aircraft flight path and abnormal terrain clearances with respect to the ground or water. The radio altimeter became the prime sensor. The system also utilized signals from other existing aircraft sensors, such as descent rate and glideslope deviation. My company, United Control at the time, became a pioneer in the development of the system.

The application and study of CFIT accident data, especially those derived from the aircraft flight path profile relative to the terrain, began to drive improvements in the system performance. With advent of the first EPROM digital memory, a synthesized voice "Pull Up!" replaced the original aural tone. In 1971, GPWS began to be installed voluntarily by SAS, CPAir, Maersk Air, Braniff, Pan American and other airlines. By 1973 Boeing was offering GPWS as a recommended safety device on all aircraft models, and in early 1974 Boeing made it basic to all models.

In late 1974, during the initial stages of a VOR-DME approach to Runway 2, at Washington Dulles airport, a B727 struck 50 feet below the last major ridge between the aircraft and the runway, some 20 NM from the runway. Ninety-two lives were lost. Many of the passengers worked and lived in the Washington DC area. The resulting public and media outcry forced the FAA to do something. Within two weeks, the FAA enacted operational rule FAR 121.360, requiring all large turbo-prop and jet aircraft to be fitted with GPWS within one year. Pilot training, mandatory reporting of warnings, or CFIT awareness programs were not required by the FAA.

The instant market created by the ruling was immediately filled by seven GPWS manufacturers, six of which had never built or flown such equipment. Performance meant little; the minimum to meet the rule. Price was all.

My company secured less than 25 percent of the US market, as many in the industry blamed my company, Boeing and Pan American for "forcing" GPWS on them: a useless annoyance they did not need.

Despite this very bad start for GPWS, with many nuisance warnings and many technical problems, CFIT losses in the USA Part 121 large turbo-prop and jet fleet began a significant and continuous drop (Ref. 1). As shown in Figure 1, the accident rate fell from an average of eight aircraft per year down to one aircraft every five years. The CFIT risk dropped from 2.2 aircraft per 10^6 flights to 0.07 aircraft per 10^6 flights! (During this time, the large US jet fleet increased from 2800 aircraft with 2.5×10^6 flights per year, to over 4800 aircraft with 7×10^6 flights per year.)

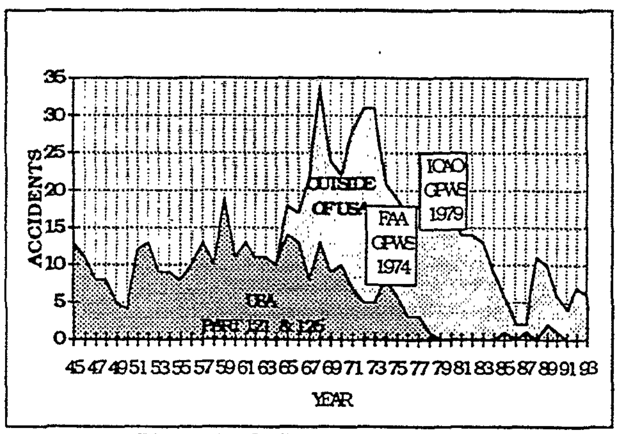

Figure 1 - CFIT Accident History

It would be an overstatement to claim GPWS is the sole contributor to this significant reduction. The continual investment by the FAA in expanding and upgrading the ATC radar and tools, such as ARTS III, Minimum Safe Altitude Warning System (MSAWS - a software add on to the radar), approach lighting, VASI, ILS, DME and other navigation aids, along with improved procedures, have all helped reduce the CFIT risk.

In sharp contrast, virtually none of the fleet of regional commuter (Part 135) turbine-powered aircraft with from 10 to 30 seats were equipped with a radio altimeter, let alone a GPWS. This fleet shared all of the improved ground aids and the ATC environment, but continued to lose an average of three aircraft per year in CFIT accidents. It took the FAA 20 years to extend GPWS requirements to Part 135 operations (10 seats to 30 seats). During that time, 33 aircraft were lost in CFIT accidents. All such aircraft are now fitted with a modern GPWS (but still with no requirements for training).

The largest CFIT losses now are found with Air Taxi aircraft, operating under Part 135 with less than ten seats. In the average year, eight twin turbo-prop Air Taxi aircraft are lost to CFIT.

An Assessment of the GPWS Record

Today there are approximately 15,000 civil transport aircraft worldwide fitted with some form of GPWS equipment. Half of this GPWS equipment is of 20 year-old vintage. The accumulated flight experience with GPWS since 1975 now exceeds 170 million flights and approximately 480 million flight hours. This is considerable experience for an avionics flight safety system. An assessment of the GPWS record reads as follows:

Positive Experience - North American Fleet. Where installed, GPWS has been effective in reducing CFIT risk:

- The demonstrated reduction in CFIT risk is about 20 times when using early generation GPWS equipment. For the latest GPWS equipment the reduction is about 50 times. GPWS has virtually eliminated many of types of terrain accidents which were so prevalent before 1975: undetected high descent rate, flight into mountainous terrain, descent back into the ground after takeoff, insufficient terrain clearance, and descent below the glideslope.
- If the pre-1975 average annual CFIT losses of eight large commercial jet aircraft per year had continued to 1993, we would have lost 150 aircraft and 7500 lives in CFIT accidents. Instead, the CFIT losses for the last 20 years have been seven aircraft and 187 lives. While aircraft accidents receive wide publicity, pilots and controllers rarely ever report CFIT incidents. Only a fraction of CFIT incidents ever become known. Incidents are most often reported when passengers or people on the ground become frightened. There were probably at least ten such incidents in North America last year, and five this year. A timely GPWS warning (even from primitive equipment) has been helpful in avoiding what might have become a CFIT accident.
- Many of the best airlines are educating their pilots to recognize and avoid potential CFIT traps. GPWS is

no panacea for eliminating CFIT accidents. In addition to GPWS, even better results can be obtained by making all pilots, controllers and managers aware of the CFIT hazard, and how any pilot or controller can be led into a trap. Flight standards and training need to be refocused and be shaped and emphasized to avoid these traps.

- The GPWS Minimum Operational Performance Standards (MOPS) written in 1975 and 1976 by the RTCA (DO-161a) and by the CAA (Specification 14) have served the industry well. The value of the MOPS has been proven over the last 19 years, and they should serve us well into the next century. Existing MOPS have not prevented evolutionary improvements in system performance, nor do they limit future improvements. Contrary to myth, there are no patents that prevent any manufacturer from meeting these well proven minimum standards.
- Analysis of reported GPWS alerts has led to the identification of a dozen airports where there were marginal terrain clearances for the published instrument approach procedures, as well as marginal radar vectoring altitudes. Many of these procedures have been improved by the FAA, making the procedure safer as well as compatible with GPWS.
- The incidence of unstabilized approaches has been reduced by a factor of five. GPWS alerts caused by these approaches have influenced pilot techniques in positive manner (at the cost of some pilot resentment). (Refs 2 and 3)
- GPWS costs much less than the paint on a typical large transport aircraft. The average investment in GPWS equipment and its installation has been paid back within 1 to 3 years, based on replacement aircraft costs and average settlement costs on the lives lost. Few avionics safety systems have been as cost effective.

__Negative Experience - North American Fleet.__ Since 1975, seven aircraft fitted with GPWS equipment have been lost to CFIT accidents (see Table 1).

1977	Salt Lake City	DC-8
1978	Pensacola	B727
1985	La Paz	B727
1987	Kansas City	B707
1989	Santa Maria	B707
~~1989~~	~~Kuala Lumpur~~	~~B747~~
1990	Unakaleet	B737

Table 1 - U.S. CFIT Losses 1975 to 1993

It is instructive to examine the circumstances of these accidents in more detail:

- All seven CFIT loss were aircraft fitted with first generation, 1975 vintage, GPWS equipment (MK I). Much of this equipment has since been replaced with improved performance equipment. However, about 30% of the North American fleet is still fitted with MK I GPWS. This equipment does not inform the pilot of the reason for the "Pull Up!" ("Terrain!" on some aircraft), nor does it use aircraft speed logic for enhancing warning time (Ref. 4). It also has a relatively high unwanted "Pull Up!" warning rate.
- Identifying the cause of the warning allows the pilots to verify the specific cause and help reduce reaction time. This would have helped the flight crew at Pensacola recognize that inadvertent descent rate and insufficient terrain clearance over the water was the reason for the warning. At Santa Maria identifying the cause would have helped the pilots recognize that mountainous terrain was the reason for the warning. At Kuala Lumpur an aural message would have helped the pilots recognize the reason for the warning was that they were very close to the ground before reaching the Final Approach Fix (FAF).
- Later versions of GPWS would have significantly improved the warning times at Santa Maria, La Paz, and Salt Lake City, as shown in Table 2, had later generation equipment been installed:

Salt Lake City	13 seconds vs 9 seconds
La Paz	16 seconds vs 2 seconds
Santa Maria	27 seconds vs 6.3 seconds

Table 2- Warning Time Improvement Using Airspeed Logic

Unfortunately, the original implementation of the airspeed logic also caused an increase in the number of unwanted warnings during initial approach in parts of Europe and Australia. This was particularly bothersome for those states which do not have a speed limit at the lower altitudes. British Airways provided flight data for these incidents, and this helped our designers to reduce unwanted warnings significantly without losing the extra warning time provided by airspeed logic.

- For the Kansas City ILS approach accident, the GPWS glideslope function apparently was inoperative; the suspected cause being an inoperative glideslope receiver (similar to the DC-9 Zurich accident in 1991). A typical GPWS installation uses the Captain's glideslope receiver deviation and flag. GPWS is a "single thread" system, receiving only one radio altimeter, one set of air data signals, etc., all from the Captain's side. This is a system weakness in GPWS. At least two other incidents have occurred where the aircraft descended well below the glideslope. (A DC10 incident at Portland, Oregon is one example.) In each case the instrument procedure uses a VOR radial or DME value for determining the step down fixes along the approach path. Also in each case, the pilot flying was the co-pilot, and the Captain was monitoring with the #1 Navigation receiver in VOR-DME mode with no glideslope signal. In the modern glass cockpit architecture, the ILS (localizer and glideslope) receiver is independent of the VOR navigation receiver, and so there is less risk that the GPWS has no functioning glideslope deviation input.

The Unakaleet accident occurred from premature stable descent from an incorrect step down fix on a localizer-DME non-precision approach while in landing configuration. The GPWS gave no warning. This is a major weakness of GPWS systems for jet aircraft which normally change to landing configuration at the FAF, thus eliminating the 'insufficient terrain clearance' warning floors. Turbo-prop aircraft usually do not commit to landing flaps until the field is in sight. For this reason, GPWS has been more effective on turbo prop aircraft than turbojet aircraft. For a normal descent rate, with the aircraft in landing configuration and no glideslope, the GPWS cannot determine that there is no airport at the bottom of the descent path. On a worldwide basis, this 'no warning' situation for GPWS has occurred in about 40% of the cases of CFIT loss (see Figure 2).

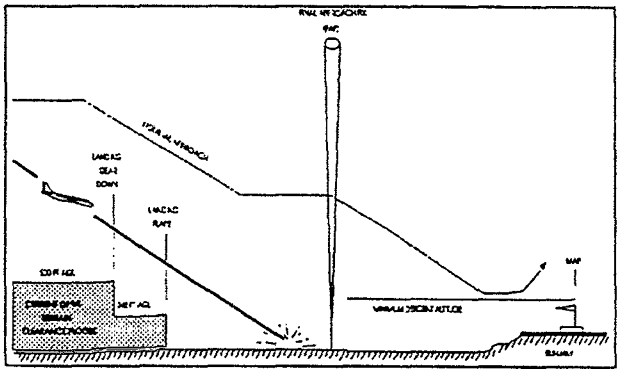

Figure 2 - The GPWS 'No Warning' Situation

- For each of the seven accidents shown in Table 1, none of the pilots had ever received training on CFIT hazard awareness or GPWS functions and limitations, nor had they practiced recoveries from terrain conflicts. Until recently, only a handful of airlines had invested in such valuable cost effective training measures. Training might have altered the outcome at Salt Lake City, where it is speculated that the co-pilot performed a late pull-up maneuver after a GPWS "Pull Up!" warning. His action resulted in an estimated pitch attitude of 28 degrees nose-up, and could have saved the aircraft had it not been for the subsequent actions of the Captain. Believing that stall was imminent, the Captain is presumed to have pushed the aircraft nose back down to 10 degrees. Two more seconds at the higher attitude was all that was required to clear the mountain. It is illogical that pilots are required to train for windshear recovery, while no training is required for terrain recovery. Training, and sharing details of CFIT incidents and accidents between pilots and controllers, are invaluable in achieving awareness of the hazard and in maximizing the value of GPWS (see Ref 5 for one example of how this can be accomplished).

While many pilots grumble about "false warnings," very few are formally reported in North America. The problem is real, but if the pilot has any reason to believe the warning could have possibly been caused by his or her flying, they don't get reported. A false engine fire warning is readily reported, but GPWS warnings are probably under-reported by a factor of some 50 times. Lack of pilot reports and flight data has been a significant impediment to improving the system. Much of the progress towards the elimination of false or unwanted warnings is owed to flight data from a few European air carriers who have encouraged their pilots to report such events. A major source of nuisance warnings has been caused by radio altimeters losing track of the ground and not dropping the flag signal. It is usually difficult to correct problems of this kind, since the radio altimeter is often essential to the auto-land integrity, and modifications require extensive software validation time and expense. It has been demonstrated that by voting and averaging three radio altimeters, a significant reduction in unwanted warnings can be achieved. Other techniques, such as modulation of the GPWS alert envelopes at specific locations, have also been used effectively. A major reduction in unwanted warnings is achievable without the loss of GPWS warning when truly needed.

__The Worldwide Experience With GPWS (See Ref 6).__ By reviewing the world-wide CFIT losses over the last five years (1989 to 1993) for large commercial airline jet aircraft, the positives and negatives of GPWS experience correlate well with the previous discussion (see Table 3).

1993	Urumgi, China	MD-80
	Sorong, Indonesia	F-28
	Medellin, Columbia	B727-100
	Abijian, Ivory Coast	B707-320
1992	Kano, Nigeria	707-320
	Kathmandu, Nepal	A300-B4
	Kathmandu, Nepal	A310
	Cruzeiro do Sol, Brazil	B737-200
	Athens, Greece	B707-320
	Kano, Nigeria	DC-8
	Strasburg, France	A320
1991	Imphal, India	B737-200
	Santa Barbara, Venezuela	DC-9-30
1990	Nairobi, Kenya	B707-320
	Zurich, Switzerland	DC-9-30
	Unalakleet, Alaska	B737-200
	Bangalore India	A320
1989	Hulien, Taiwan	B737-200
	Tegucigalpa, Honduras	B727-200
	Tripoli, Libya	DC-10
	Paramaribo, Surinam	DC-8-62
	Kuala Lumpur, Malaysia	B747
	Santa Maria, Azores	B707-320

Table 3 -Commercial Large Jet Aircraft CFIT Accidents (23)

For the past five years we have lost about five aircraft per year to CFIT accidents (excluding Soviet built aircraft). Approximately one half of these CFIT losses were aircraft not equipped with GPWS. Of the world's fleet of 11,000 or so aircraft, 300 aircraft (3%) are not equipped with GPWS, and 50% of the CFIT losses are associated with this 3% of the fleet. Another thirty percent of CFIT accidents occur with the 470 or so 'first generation' jet aircraft (B707, DC-8, etc.) which today make up less than five percent of the world's civil jet fleet. Those aircraft that have GPWS are fitted with early, primitive performance, equipment.

Of the fourteen losses where GPWS was installed, nine aircraft were fitted with early MK I GPWS for which warning times can be very short, or too late for recovery. Later generation GPWS would have more than doubled the warning time, and told the pilots the specific problem or reason for the "Pull Up!"

Four aircraft were in 'no warning' situations, i.e. landing configuration, no glideslope, stable descent into a place where there was no runway. This is a weakness that is partially addressed in current GPWS equipment by the use of a 'Smart' altitude callout such as "five hundred", and with a specific cockpit procedure to go-around if the runway environment is not in view. A 'Smart' callout is not heard on normal ILS approaches, only on non-glideslope approaches (i.e. non-precision approaches). This procedure is being utilized by some major airlines. In new systems, introduced this year, a Minimum Terrain Clearance Floor around the airport will be used (see below).

Enhanced GPWS (refs 7, 8, and 9)

Several practical and cost effective system performance improvements have been introduced into new GPWS equipment this year. These improvements are backward-compatible with the GPWS installations presently installed on most glass cockpit digital aircraft. The enhanced system uses existing sensors and signals as presently provided to the GPWS. The form factor, power, and weight of the new computer are essentially the same as for the original GPWS computer. The enhancements are in addition to the original GPWS functions, and do not compromise basic system performance.

Some of the improved performance features are:

Terrain Clearance Floor. This additional terrain clearance floor, based on aircraft position, is independent of landing gear and landing flap settings, and provides a "Too Low, Terrain!" alert to the pilot if there is insufficient terrain clearance on approach. This feature could help save one aircraft per year in worldwide commercial large jet operations.

About 1½ aircraft per year world wide impact short of the runway with no GPWS warnings during non-precision approaches. The median impact point has been 5¼ NM short of the runway. The terrain clearance floor provides a warning if during an ILS approach the glideslope equipment (airborne or ground) has failed or, for some reason, is not being used by the crew and the aircraft prematurely descends short of the runway.

The 'floor' lies below the nominal 300 feet per NM final approach slope (-2.8 degrees), and blankets the terrain or water around the airport at 75 feet AGL per NM. (see figure 3 and 4). The floor is based on distance to the runway and radio altitude, distance to the runway being computed from current aircraft position (lat/long) and stored position of the airport.

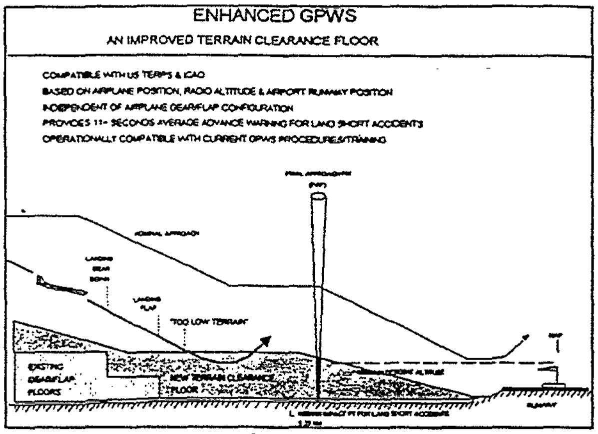

Figure 3 - Terrain Clearance Floor, Profile View

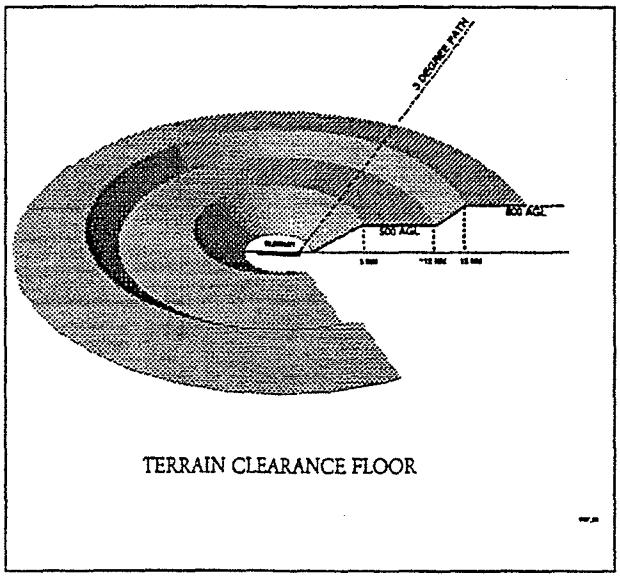

Figure 4 - Terrain Clearance Floor Viewed from Above

The 75 feet AGL per NM slope is well below the design criteria for terrain clearances and obstacles found in U.S. and ICAO standards, and provides an average of about 10 seconds of warning before impact.

The accuracy of the data defining aircraft present position and the runway threshold determines the timeliness of the warnings, and also the margin against unwanted warnings. Aircraft position from FMS/GPS is weighted against quality factor and the distance of floor cutoff from the runway is automatically modulated to prevent unwanted warnings. The runway data required is readily available in digital format, and needs only a moderate amount of memory (approximately 32k Bytes) to cover the 5000 civil and military airports worldwide which have runways of 4000 feet or longer.

Airports and runway data do change with time, but relatively slowly when compared to navigation data. It is anticipated that updates of such data will be infrequent, perhaps once every two or three years.

<u>"Terrain Ahead" Alerting And Warning</u>. If pilots could be alerted earlier for Controlled Flight Towards Terrain (CFTT) situation, before the aircraft is into precipitous terrain, then the CFIT risk and need for maximum effort recovery in response to a GPWS warning is significantly reduced.

In 1982, AlliedSignal (then Sundstrand Data Control) began developing 'look ahead' algorithms that used the present position and projected flight path of the aircraft, together with stored terrain data, to predict a potential terrain threat ahead of the aircraft. Because commercial transport aircraft do not typically fly in very close proximity to terrain (except when landing), relatively low resolution elevation data is sufficient to provide effective terrain awareness (typically 100 feet vertical resolution, and from ½ NM to 8 NM or more horizontal resolution, depending on distance from the airport). However, even this level of terrain data storage taxed the technology available in the 80's and made practical systems cost-prohibitive.

In the 90's, flash memory technology has progressed to the point where it is now not only possible, but practical, to store the terrain data for the entire world within current generation digital GPWS computers. Special terrain data compression routines have been developed to further minimize memory requirements and reduce costs.

Error-tolerant algorithms have been developed that consider aircraft position, track, absolute altitude and flight path in relation to stored terrain data to determine if the projected flight path conflicts with terrain ahead of the aircraft. This feature has been coined 'look ahead' alerting, and offers a significant improvement in advance alerting times for flight into very precipitous terrain. The voice messages "Caution! Terrain!" and "Terrain Ahead! Pull Up!" are given if the projected time to impact is less than predetermined values. It was recognized from the outset that such a function must be carefully designed to avoid unwanted alerts in order to be effective especially for airports in mountainous areas. Distance from the airport, navigation data quality, and terrain database quality factor are used to automatically determine how far ahead of the aircraft the trajectory can be reliably projected and used. The design approach for the 'look ahead' alerting has been to lean towards the prevention of unwanted alerts. The existing tried and proven GPWS warning modes continue to independently monitor the aircraft's flight path with respect to the terrain. In this manner, overall system effectiveness always meets or exceeds what is available and certified on aircraft operating today.

Two 'look ahead' algorithms are used to provide "Caution! Terrain!" and "Terrain Ahead! Pull Up!" alerting when needed (see Figure 5).

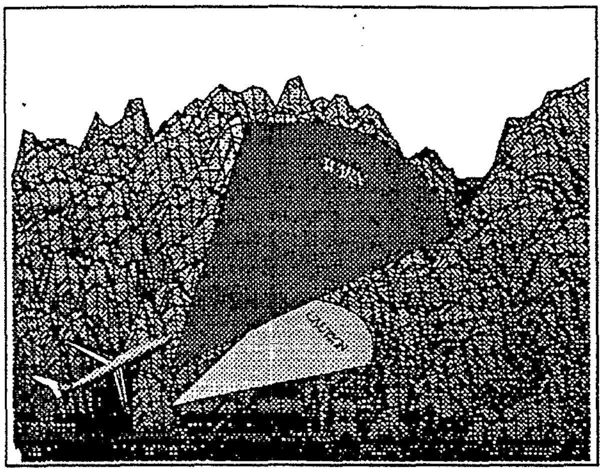

Figure 5 - Look Ahead Volumes

The "Caution! Terrain!" algorithm gives about 60 seconds of advance alerting for a potential flight path into terrain, while the "Terrain Ahead! Pull Up!" algorithm gives about 30 seconds of warning. Both algorithms are modulated by the terrain clearance floor around the airport. Both algorithms also look up a nominal 6 degrees of flight path climb angle to ensure that the alerts are timely. The "Terrain Ahead! Pull Up!" warning recovery procedure is identical to the existing GPWS recovery procedure. To validate the system, our test aircraft has been flown against worst case mountainous airports in North America. Many of North America's worst CFIT accident flight paths and locations have also been flown to demonstrate warning times that greatly exceed the current GPWS warnings. It is interesting to note, however, that current GPWS terrain warnings can occur earlier than the new 'look ahead' alerts if the aircraft flies over preamble terrain.

With the end of the cold war, terrain data bases to support this function are readily available in digital form for a significant fraction of the airports around the world, especially in the Northern hemisphere. Some airports are in areas for which digital terrain data is not available, at least not for civil use. In the majority of these cases, terrain data is available in map form. AlliedSignal has acquired or currently is in the process of acquiring all digital data that is available, and we are digitizing map data (with help from airlines) for places where digital data is not available. Again, the relatively low resolution requirements for this terrain data make it practical to generate the databases. Areas around international airports and alternate airports worldwide are being incorporated into the "Enhanced GPWS" terrain database. In the event that terrain data for some areas is simply not available in any reliable form at this time, then that area can be added to the database later. Of course, aircraft operating in areas that are not covered by the terrain database will still benefit from the independent GPWS warning modes.

Database updating is supported in the Enhanced GPWS computer through a front panel PCMCIA port. Our customers will be provided with flash memory cards which can be plugged into the PCMCIA port to update the terrain database. The upload is both quick and simple.

Terrain Awareness Display. For enhancing the pilot's awareness to potential threatening terrain in controlled flight towards terrain (CFTT) situations, a map display of the terrain situation is very helpful. The Enhanced GPWS is designed to provide an output which can be used to depict threatening terrain optionally on an EFIS Navigation Display or a dedicated Weather Radar indicator.

Adding terrain to a Navigation Display, while appearing to be a simple task, must meet several requirements:

- It must be accomplished in a clear, unambiguous manner, and be intuitively obvious to the pilot.
- It must require little, if any, pilot training.
- It must add a minimum of clutter to the existing display.
- It must not impair the display of basic navigation data
- It must integrate well and not be confused with presentations of weather (precipitation and turbulence), predictive windshear alerts and TCAS displays.
- It must not become an instrument to navigate by.
- It must be practical and cost effective.

Adding new information such as terrain to existing cockpit displays can be very expensive if it requires major changes the EFIS Symbol Generators. Adding a new display is in most cases out of the question. (The relative cost of installing identical equipment, such as TCAS II, into a "classic" (analog) aircraft and a glass cockpit is about $150,000 versus $450,000. The cost driver is the effort required in validating software changes in the symbol generators.)

One method of minimizing the changes to the cockpit and the EFIS symbol generators is to utilize the existing ARINC 453 Weather Radar data bus that is fed to the EFIS Navigation Display or the dedicated weather radar indicator. By proper use of colour and style of data presentation, the terrain display can be clearly differentiated from weather data. Very little change, if any, is required to the symbol generators.

Priority of information displayed, display range, when and how the pilot brings up such data are flight deck design considerations. One such Terrain Display is shown in Map Mode in Figure 6.

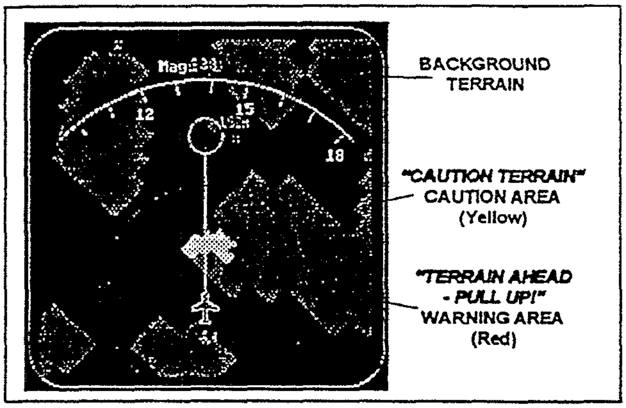

Figure 6 - Terrain Display

In our flight test and demonstration aircraft, threatening terrain can be displayed on the weather radar indicator. In the event of a 'look ahead' terrain alert, the terrain picture is presented and the display range is automatically set to 10 NM. Manual selection of terrain is also available to the pilots. The terrain is displayed referenced to the aircraft's altitude: terrain more than 2000 feet below the aircraft is not displayed, terrain closer than 2000 feet begins to be shown as low density pattern of yellow dots. As the terrain becomes closer to the aircraft, the density of the dots increases to a maximum value where the terrain is at or above the aircraft altitude. The display requires no mental calculations by the pilots in order for them to assess their relationship to threatening terrain. No charts or reference to instruments are required. Terrain depiction is free of elevation numbers and contours that add clutter. When the terrain threat is within the "Caution! Terrain!" range the conflicting terrain image turns solid yellow. (The terrain image is composed of a grid of overlapping rectangles, and is visually unique.) When the terrain threat progresses to the level of a "Terrain Ahead! Pull Up!" warning, the conflicting terrain image turns a solid red colour. As a successful recovery is made, the terrain image will change from red to solid yellow, and then to a dot pattern of progressively decreasing density until the altitude of the aircraft is more than 2000 feet above any terrain in the immediate 10 NM area, when the display will disappear entirely.

Some Conclusions

- Early GPWS equipment, in spite of its limitations, has been effective in reducing the CFIT risk, saving aircraft and lives. CFIT risk was reduced by about 20 times when the original GPWS equipment was installed, and by about 50 times when the latest GPWS is used.
- Significant improvements have been made to GPWS performance over the last 20 years.
- The greatest CFIT hazard remains the non-precision approach. About 40 percent of all CFIT losses are occurring during VOR-DME/LOC-DME approaches. For no-glideslope approaches where full landing flap is used, early generation GPWS provides little if any warning for stable descent into water or ground where there is no runway. This has not been a problem on turbo-prop aircraft, where landing flap is not usually selected until the field is in sight. GPWS is being upgraded to address this weakness.
- The recent availability of terrain data bases for civil use, and advances in solid state memory have made additional GPWS enhancements practical and cost effective. Earlier alerts can be given for flight paths into precipitous terrain, and flight paths short, or off, the airport. The threatening terrain can be displayed on most existing colour weather radar displays and or Electronic Flight Instrument System displays in a practical low cost manner.
- The Enhanced GPWS will again lower the CFIT accident risk significantly, probably to less than 0.01 aircraft per million flights. Perhaps this time, twenty years after the first installation of GPWS, there will be a bit more credibility in the estimate.

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