Civil Aviation Authority

CAA Paper 85015

Human factors in accidents due to controlled flight into the ground

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SUMMARY

The paper reviews a number of accidents caused by large passenger carrying public transport aircraft inadvertently flying into the ground or water. The lessons to be learned in the areas of human factors and the benefits of airborne equipment (particularly GPWS) are discussed. The paper does not make specific recommendations but reminds flight crews of circumstances which can lead to such accidents.

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HUMAN FACTORS IN ACCIDENTS DUE TO CONTROLLED FLIGHT INTO THE GROUND

INTRODUCTION

At the beginning of 1982, the Civil Aviation Research and Development Board (CARDPB), which is comprised of representatives from all branches of the aviation industry and related government bodies, requested the Civil Aviation Authority (CAA) to carry out an analysis of fatal accidents involving fixed wing public transport aircraft. They considered that if such an analysis was able to highlight a number of specific causes for such accidents, research directed at the problems concerned would be a very cost-effective way of promoting safety.

In order to obtain as large a data base as possible, information from the CAA Safety Data Unit Occurrence Reporting System was augmented by the CAA World Airlines Accident Summary and accident data from ICAO. The data assembled covered the period from January 1976 to February 1982 and was restricted to aircraft with a maximum authorised all-up weight greater than 5,700 kgs. Only accidents where a definite cause had been established were included.

Of the 350 fatal accidents that occurred during the period under review, 171 involved were passenger aircraft. Twelve of these occurred in the USSR or China and have not been included because adequate information was not available. A further 33 accidents also had to be excluded as it was not possible to classify them on the information available.

Table 1 gives a breakdown of these accidents by 29 distinct causal factors. These factors have been listed under a number of main headings, within which they are ordered by number of fatalities. Within the table there are multiple references to a number of accidents. For example, a navigational error may result in collision with high ground leading to the accident appearing under both headings. The different causal factors are therefore not always `causes', sometimes being merely part of the chain of events in the accident. It is evident from Table 1 that controlled flight into the ground is the single largest cause of accidents accounting for more than 2000 fatalities.

It had been hoped that the introduction of Ground Proximity Warning Systems (GPWS) would reduce the incidence of such accidents. The fitment of such equipment is a standard given in ICAO Annex 6 for public transport aircraft with a maximum authorised weight over 15 tonnes or capable of carrying more than 30 passengers if the individual certificate of airworthiness was issued after 1st July 1979. For similar aircraft with a certificate of airworthiness registered before that date ICAO recommends the fitment of GPWS. There have been indications that the incidence of such accidents has been reduced in the United States which complies with the ICAO standards and recommendations. The fact that some states do not so comply may explain why this reduction has not been reflected world wide.

It was decided that a more detailed study should be undertaken and that this would be most profitable if it could be related to reasonably well equipped, more modern aircraft.

ANALYSIS

Of the 48 accidents originally identified, 26 were selected as suitable for detailed examination, 17 of these involving flight into high ground and 9 controlled flight into the surface (undershoot). The basis of the selection was that they were either turbo-prop or pure jet aircraft which under the standards or recommendations laid out in ICAO Annex 6 should have been fitted with GPWS and that as far as could be ascertained from the information available, they were free from technical problems which might give rise to doubt as to whether they were truly under control prior to impact. The accidents concerned are listed in Tables 2a and 2b, and the reference numbers used in this paper refer to those shown in the tables.

Because of the difference in circumstances which apertain to flight into high ground as opposed to the surface, it was decided to look at the two groups separately, albeit analysing them in the same manner. On the assumption that none of the accidents arose out of a deliberate action, then the pilot must have been unaware of the proximity of the high ground or surface, or following a warning failed to achieve an adequate response. Two questions must therefore be addressed:

(a) Was vital information about the proximity of the terrain available on the flight deck but disregarded?

(b) Was the pilot misled by false information or was the information simply not there?

CONTROLLED FLIGHT INTO TERRAIN (CFIT)

An essential part of the analysis is to try and establish the reason for the aircraft being in the proximity of high ground. Pilots do not knowingly get into a situation where GPWS is their only means of protection. Table 2a lists the accidents considered. Table 3 summarises the main causes as far as can be assessed from the accident reports.

As can be seen, the most common reason for the aircraft becoming close to high ground is departure from IFR procedures. Some of these occurred in parts of the world where known terrain problems might have been expected to discourage non-standard procedures.

Whilst it is difficult to be certain in all cases, some of the deviations appear to have arisen out of a deliberate act and others to be inadvertent. In other cases, possibly number 10, the deviation may appear to have been justified on the information available to the commander.

From other sources, such as confidential reports, we know that on occasion deliberate deviations have occurred for operational or personal reasons. It is difficult to know what might be helpful in the latter cases, except placing a greater emphasis during initial and continuation training on terrain awareness for we are not yet in a position to select aircrew on the basis of personaility profiles.

In cases where it would appear that information was available, the obvious question is, why wasn't it used? One possibility is that it was not presented in a manner that was easy to interpret, the high ground not being sufficiently emphasised, or the pilot having difficulty orientating the track of the aircraft to his map. ICAO have sponsored some study of the presentation of terrain and safety altitude data on aeronautical charts, and a number of improvements have already been made. The introduction of the "glass cockpit" gives a new opportunity to look at this problem. It is within the scope of modern technology to produce "Map" modes as a common feature of modern electronic flight displays. Such a display showing the aircraft track and its relation to high ground would seem a desirable feature.

We know that on occasions information has been available and has not been utilised by the crew. In some instances this has arisen because inter-crew relationships and crew co-ordination have led to an inadequate exchange of information. In others, a somewhat negative approach to briefing on terrain clearance and a lack of emphasis during training may have played their part. The possible improvement that might come about if more emphasis was given to training in "flight deck resource management" and more use made of line orientated flight training, is worthy of examination.

At the present time a review of the safety altitudes is normally part of a verbal briefing. Greater emphasis would occur if a positive action was required.

Since aircraft come into close proximity to the ground despite those measures designed to keep them on a safe path, we need a warning device such as GPWS and to examine the benefits of such a device. In order to try and establish the benefit of fitting GPWS the accident data was examined from three aspects.

(a) The installation and operational state of GPWS equipment

(b) Where GPWS was not installed and operational, the likely benefits which would have been gained had the aircraft been so fitted.

(c) Where an operational GPWS was fitted, the response of crew to any warning given.

INSTALLATION OF GPWS

Of the 17 accidents examined, 9 aircraft had no GPWS equipment installed. Two aircraft were fitted with GPWS which had been rendered inoperative as a result of company policy in order to maintain commonality with other aircraft in the same fleet which were not equipped. In the remaining six cases, four aircraft were known to be fitted but in two cases insufficient information was available (Nos 12 and 16).

POSSIBLE BENEFITS OF GPWS WHERE IT WAS NOT AVAILABLE

Using all available information from the eleven accidents to aircraft not having the protection of GPWS, it is likely that in 9 cases such equipment would have given a warning which, given a correct and timely response by the crew, could have resulted in the accident being avoided. In one case (No 1) it is thought that GPWS could have been beneficial but lack of precise data on terrain detail precluded a definite conclusion. In the other case (No 3) the aircraft was in the landing configuration rendering the appropriate mode (Mode 4) inoperative.

ACCIDENTS TO AIRCRAFT WITH OPERATIONAL GPWS

Four such accidents were examined. In the first (No 10) a GPWS warning was received and acted upon promptly and correctly. However, the warning was received only six seconds prior to impact and there was insufficient time to avoid the accident. However, it should be pointed out that GPWS equipment available at the time would have given a greater warning time and could have enabled the accident to be avoided.

In the second (No 14) a GPWS warning was received 27 seconds before impact. The crew reacted by applying power but also initiated a level turn. The system ceased to give a warning as the aircraft flew over a valley but impact followed soon afterwards. Had a climb been initiated on receipt of the initial warning it is possible that the accident would have been avoided.

In the third accident (No 15) there is insufficient information on GPWS warnings from which to draw any conclusions.

One accident (No 17) resulted from an incomplete response to a GPWS warning. The initial warning was received 13 seconds prior to impact when the aircraft was descending. The crew arrested the descent but continued to fly level until impact, when one wing clipped the top of a mountain. Once again had a climb been initiated on initial receipt of the warning, then the accident would have been avoided.

EFFECTIVENESS OF GPWS

The analysis appears to indicate that in general GPWS is an effective protection against CFIT accidents provided that prompt and correct actions are taken when a warning is received. However, three accidents were identified where GPWS warnings were not or would not have been sufficient to prevent the accident. In Accident No 10, the aircraft was being flown in conditions that made it difficult for the crew to maintain visual reference both to the horizon and to terrain features. Aircraft in this situation will always be vulnerable in such situations and procedures prior to descent must be well planned and adhered to at all times.

The second (No 3) was caused by the positive decision of the crew to descend to low altitude in order to become visual. Selection of land flap would have rendered GPWS inoperative in this phase of flight. It is probable that if a crew decides to take this sort of action, no warning system will be of help.

In the third accident (No 16) the aircraft was climbing and could therefore probably not have increased its rate of climb sufficiently to avoid terrain. Aircraft are vulnerable in the climb out but since on taking off they should know their exact position and should not fly into areas where a CFIT accident becomes likely. Provided that they adhere to standard procedures they will remain clear of high ground.

CONTROLLED FLIGHT INTO SURFACE (CFIS)

Although it is sometimes difficult to differentiate these types of accident from the CFIT type it was considered that these should be considered separately from since the aircraft impacted with an essentially flat surface. Nine accidents were identified which provided suitable information for analysis and these are listed in Table 2b.

One accident (No 26) occurred in good visual conditions and was associated with the psychological state of the captain. It is to be hoped that routine medical screenings would normally prevent this type of occurrence. All the remaining accidents occurred in conditions of reduced visibility due to fog, rain or the hours of darkness. Four of these were over the sea where judgement of height by usual reference is known to be difficult. Despite this, ILS was available in only two of these four cases, Nos 23 and 25) and in one of these (No 23) although tuned, the facility was not used. Whilst ADF, SRA and VOR/DME approaches are well established means of letting down they provide limited glideslope guidance compared with a full ILS approach. In two accidents (Nos 19 and 20) the primary cause of the accident was human error leading in one case to the inadvertent deployment of the ground spoilers and in the other, more setting of the altimeter. On a well co-ordinated flight deck errors of this nature should have been picked up by other crew members.

GPWS can protect against this type of accident in three ways. Mode 4 warns against proximity to the ground but is inactivated when the aircraft is in the landing configuration. Mode 1 will detect an excessive sink rate but will not be activated by the normal rate of descent used on approach. Mode 5 detects excessive deviation below the ILS glideslope but of course this assumes that ILS is provided on the runway in use and that it has been tuned by the aircraft.

In only three of the nine accidents was the aircraft fitted with GPWS (Nos 21, 25, 26). In all but one case (No 18) there were survivors, which indicates that descent rates at impact were not very high, suggesting that the Mode 5 warning would be the most suitable protection.

ILS was available in three of the accidents mentioned in Table 2(b). The conclusions surrounding one of these (No 26) have already been mentioned and it is not possible to say more than that a warning was received. In a further case (No 23) the ILS was tuned but not being used. Had GPWS been fitted in this case a warning would have been given. In accident No 25, a warning was received 5 seconds prior to impact. The only other aircraft (No 21) fitted with GPWS was performing as SRA approach. A Mode 1 warning was received but due to a crew misunderstanding the warning was inhibited. No overshoot action was taken by the commander due to his misreading of the altimeter leading him to think that there was time to recover the situation and still carry out a landing.

DISCUSSION

In the light of the analysis carried out it is obvious that there is a need to study the human factors involved and the technical aids available in order to prevent a potentially dangerous situation ending in disaster.

As has already been stated a pilot, or sometimes a whole crew, may make a deliberate decision to descend below the prescribed safety height or deviate from standard operating procedures. Provided that all the relevant information was available to them it is difficult to see what could be done to resolve this particular problem other than emphasise the potential consequences during training and whenever else an opportune moment presents itself. It is more common for deviations from standard operating procedures to be inadvertent. These deviations may arise because the relevant information is either not easily available or difficult to interpret in relation to the aircraft's flight path. The presentation of terrain and safety altitudes has been under study for some time under the auspices of ICAO. Although a final format has not yet been agreed upon, a number of improvements have already been made on current charts. The introduction of the `glass cockpit' provides a further opportunity for improvements in this area and displays which show the flight path of the aircraft and its relationship to high ground are being studied.

In some cases an aircraft has been hazarded by a simple error by a crew member. In multi-crew aircraft it is to be hoped that such mistakes would be picked up and remedied by other members of the crew. A number of airlines have introduced training in `flight deck resource management' and are using line orientated flight training. Both of these practices might be expected to improve inter-crew relationships and help maximise the role of the various crew members. At the present time, briefing on minimum sector altitudes and safety heights is given by the aircraft commander and is a passive exercise. If other crew members are distracted by anything during the brief the information may not be assimilated. A more active approach such as a requirement to set a videcounter, preferably displayed near height information would enhance the exchange of information and provide a ready reminder.

Examination of accidents due to flight into the surface shows that a number of these occurred in situations which are known to be hazardous such as visual approaches over water in poor visual conditions. Because the information available is limited it is difficult to do more than draw attention to this and to point out that only one accident occurred on a full ILS approach. Whilst ILS was available in two othes in one it was not used and in the other the psychological state of the captain was an overriding factor.

Accepting that potentially dangerous situations will continue to arise the benefits of GPWS need stressing. Information from data collected by NASA (Ref 1) has identified situations where a GPWS warning has avoided accidents involving US registered aircraft. It can be presumed that similar situations have occurred with aircraft of other states. The accident data suggests that the fitting of modern GPWS equipment should considerably reduce the incidence of accidents involving flight into the ground provided that the correct action is taken on receipt of a warning. The accident analysis shows that in some cases reactions to warnings given do not receive correct and timely action, i.e. an immediate application of power and the initiation of a climb. It is accepted that pilots will always react to warnings properly if their exposure to false warnings (those caused by technical malfunctions) or nuisance warnings (those caused by genuine penetrations of the GPWS envelope in known safe situations) is kept to an acceptably low level. At some airfields it has proved difficult to avoid nuisance warnings. The danger of nuisance warnings at such airfields is that an accident could result from the dismissal of a genuine warning as a nuisance one.

As has been mentioned previously, extreme care must be taken on approaches in poor visual conditions especially over water if glideslope guidance by ILS or PAR is not available. The protection of Mode 5 of GPWS is only available if ILS is both provided and used. In an ideal world it would be expected that ILS would be provided on all runways used by modern transport aircraft but such a world does not exist. Crews are left to make use of such aids as are available to ensure a safe approach.

The purpose of producing this paper is to emphasise the factors which lead to perfectly serviceable aeroplanes inadvertently flying into the ground or the sea whilst the crew have full control. Whilst new technical advances will help to improve this aspect of air safety there is obviously scope for a review of current practices.

To most of the aviation world, much of what has been written here may appear to be straightforward common sense (or good airmanship). Nevertheless accidents of this particular type continue to happen and it is felt that a short paper highlighting the factors which could lead to a disaster would be helpful.

REFERENCES

1. NASA CR 166230 - An Investigation of Reports of Controlled Flight Towards Terrain - Porter and Loomis - April 1981

TABLE 1

CAUSAL FACTORS FOR FATAL PASSENGER AIRCRAFT ACCIDENTS

Readers should note that in this table any one accident may appear in the data for more than one causal factor. The values of total accidents and fatalities are therefore less than the sums of the individual entries.

	CAUSAL FACTORS	NUMBER OF FATALITIES	NUMBER OF ACCIDENTS
AIRCRAFT FAILURE	Structure failure	687	9
	Fire/explosion in cabin	535	5
	Instrument/control failure	363	5
	Engine fire	121	3
	Engine failure	100	7
	Rotor/propellor blade failure	33	4
	Landing gear failure	28	6
WEATHER	Turbulence/windshear/lightning	473	7
	Ice accumulation on wings in flight	22	1
NAVIGATIONAL	Navigational error	807	8
	ATC directions unclear	146	1
	False ILS/VOR indications	92	2
CONTROLLED FLIGHT INTO THE GROUND	High ground	1676	32
	Undershoot	449	16
HUMAN FACTORS (PRE-FLIGHT PLANNING)	Pre-flight planning inadequate	349	16
	Ice/snow not removed from wings	79	2
	Run out of fuel	75	3
	Aircraft overloaded/improperly		
HUMAN FACTORS (DURING FLIGHT)	Pilot's decision inadequate	1537	15
	Improper balked landing procedure	269	6
	Deficient ATC instructions	218	3
	Late landing on wet runway/overrun	141	4
	Continuing VFR flight in poor visibility	77	4
	Vehicle on runway on landing	43	2
AIRCRAFT COLLISION	One on ground	575	2
	Both airborne	355	6
HOSTILE ACTION	Sabotage	225	4
	Other hostile action	127	4
	Hijack	120	3
TOTAL	(each accident counted only once)	6163	126
UNKNOWN		1458	45

TABLE 2(a): FATAL CFIT ACCIDENTS TO LARGE TURBO-JET AND TURBO-PROP AIRCRAFT (PASSENGER CARRYING) 1976-1981

ACCIDENT NO.	A/C TYPE	LOCATION	DAY NIGHT	WEATHER	PHASE OF FLIGHT	GPWS FITTED	IF "NO" COULD GPWS HAVE HELPED	REASONS FOR PROXIMITY TO TERRAIN
1	B727	Turkey	Night	Clear	App/Ldg	No	Probably	Attempt to make visual judgement of position at night
2	Viscount	Equador	Day	Overcast	App/Ldg	No	Yes	VFR Operation in IMC - overfamiliarity with route
3	DC8	Maylasia	Dusk	Heavy	App/Ldg	No	No	Early descent below MDA on VOR approach
4	BAC 111	Argentina	Night	Overcast	App/Ldg	No	Yes	Failure to notice indications showing unserviceable VOR ground station.
5	Viscount	Equador	Day	Rain	App/Ldg	No	Yes	Reversion to VFR operation in unsuitable conditions
6	F28	Indonesia	Night	N/K	App/Ldg	No	Yes	Descent below MSA, ATC or navigation error
7	F28	Indonesia	Night	N/K	App/Ldg	No	Yes	Knowingly descending below MSA
8	HS748	India	Day	Rain	App/Ldg	No	Yes	False ILS indications received - no cross-check
9	DC9	Italy	Night	Some IMC	App/Ldg	No	Yes	Discontinued IFR procedure to avoid bad weather
10	DC10	Antartica	Day	Clear	ER	Yes	-	Deviation from planned track due in difficult visual conditions (snow covered, featureless landscape)
11	F28	Turkey	Day	Fog	App/Ldg	Yes*	Yes	Large deviation from localiser
12	B727	Iran	Night	Overcast	App/Ldg	Nk	Yes	Deviation from ATC routing, disregard of MSA, poor crew coordination
13	B727	Brazil	Night	NK	App/Ldg	Yes*	Yes	Deviated from instrument approach procedure
14	B727	Tenerife	Day	Cloud at site	App/Ldg	Yes	-	Navigational disorientation compounded by misunderstanding with ATC
15	F27	Bolivia	Day	Overcast	App/Ldg	Yes	N/K	Little information available - aircraft not conforming with ATC
16	Viscount	Colombia	Day	Drizzle	Climb	NK	Probably not	Attempt to fly VFR in IMC
17	DC9	Corsica	Day	Fog	App/Ldg	Yes	-	Descent below MSA for reasons not determined - nav error (?)

*In these cases GPWS was fitted but had been rendered inoperative to give fleet commonality

TABLE 2(b) FATAL ACCIDENTS AS A RESULT OF CONTROLLED FLIGHT INTO THE SURFACE 1976-81

LARGE TURBO-JET AND TURBO-PROP AIRCRAFT

ACCIDENT NO.	A/C TYPE	LOCATION	DAY/NIGHT	APPROACH OVER LAND/ WATER	GPWS FIT	WEATHER	TYPE OF APPROACH	COMMENTS
18	B707	Thailand	Night	Land	None	Shallow fog	ADF	Disorientation
19	TU134	Rumania	Twilight	Land	None	Not known	ADF	Inadvertent deployment of ground spoilers
20	S210	Madiera	Night	Sea	None	CAVOK	Visual	Altimeter setting error
21	B727	USA	Night	Sea	Yes	Fog	SRA	Mode 1 warning given - overshoot action not taken. Warning inhibited by Flight Engineer after 9 seconds
22	DC9	Italy	Night	Sea	No	Rain	VOR/DME	Visual reference only
23	F27	New Zealand	Day	Sea	No	Rain	Visual	ILS tuned but not used
24	N262	Algeria	Night	Land	No	Not known	Not known	Limited information
25	B747	Korea	Twilight	Land	Yes	Fog patches	ILS	Mode 5 Alert 5 seconds prior to impact
26	DC8	Tokyo	Day	Sea	Yes	Good	ILS	Psychological condition of captain

Table 3 - Reasons for Close Proximity to Terrain - CFIT Accidents

REASON	Deviation from IFR procedures	Equipment failure	Descent below MSA	Geographical disorientation	Navigation Error	Poor airmanship in approach
Number of Accidents	7	2	1	2	3	2