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GROUND PROXIMITY WARNING SYSTEM - GPWS

ABSTRACT

In this article the technical description of the Ground Proximity Warning System (GPWS) is presented in order to consider some of the flying safety factors in commercial aviation, as well as the aspects of interaction between the pilot and the system itself during the flight. Since it has been confirmed in practice that the installation and utilisation of GPWS in aircraft significantly reduces the hazards caused by the Controlled Flight Into Terrain (CFIT) further development of GPWS equipment presents one of the most important steps in preventing the ultimate consequences of such aircraft disasters.

KEY WORDS

GPWS, CFIT, EGPWS

1. INTRODUCTION

One of the most frequent types of aircraft accidents is the controlled flight into terrain (CFIT). These accidents were designated as a separate group of accidents in the sixties, whereas earlier they had been grouped into other categories. Great losses in human lives and material wealth have made the aircraft manufacturers and air carriers undertake certain measures in order to increase the safety of air traffic in this respect.

In the early seventies, the air company *Scandinavian Airlines System (SAS)* developed a concept of a device that was called GPWS - *Ground Proximity Warning System*. The device had to warn the pilot of the danger of barriers or of the ground proximity, using information obtained by the radio-altimeter and processed by a computer.

At the end of 1974, a Boeing 727 crashed in approaching the Dulles airport, Washington D.C. and more than 90 persons were killed. This accident caused the US Department of Transportation, i.e. the Federal Aviation Administration (FAA) to bring a regulation on the obligatory installation of the ground proximity warning system into all big jet and turboprop aircraft of the capacity of more than 30 passengers or 7500 lbs (≈3400 kg), by the end of 1975. The International Civil Aviation Organization (ICAO) followed the decision brought by FAA and from 1979 introduced standards for obligatory installation of GPWS into all big commercial jet aircraft.

All these efforts have resulted in significant reduction of the number of aircraft accidents caused by the controlled flight into terrain, and a substantial increase in the air traffic safety. However, although the number of accidents has been reduced, they still happen and the existing devices need to be constantly improved, and the crew needs to be trained for the possible emergency situations.

2. CONTROLLED FLIGHT INTO TERRAIN

Controlled flight into terrain is a situation in which a technically completely properly operating aircraft with highly skilled crew comes into unwanted contact with a barrier, ground or water surface, which can have catastrophic consequences. The causes which lead to such accidents are the following:

- problems of determining the exact flight altitude;
- not knowing the safety flight altitude;
- misunderstanding in communication with flight control;
- unawareness of the aircraft crew regarding the situation;
- not abiding by the standard procedures;
- especially risky phases of flight;
- errors in the operation of the auto-pilot;
- insufficient quality of pilot training;

Problems related to determining the actual flight altitude may be divided into two groups: inconsistency of the measuring units and irregular pressure setting on the altimeter (Baro Setting). Although measuring units are regulated and standardised in aviation, there are still many institutions, air carriers and other air traffic participants who, for various reasons, do not abide by them. Thus, the altitude is measured both in metres (SI - international system of measuring units) and feet (Anglo-Saxon system), and the pressure is measured by Pascal (Pa), Bar or the height of mercury column in inches (InHg). The usage of measuring units is related to the flying area, and the crew has to be ready to apply the obtained data whether they are expressed in standard units or not. Another problem is setting of the pressure in an altimeter, since flight altitude is obtained from the difference between the reference pressure (data provided by the flight control) and the ambient pressure, measured by the aircraft instruments. In the majority of countries the reference pressure is QNH pressure (pressure at the zero altitude above sea level), and in some areas QFE pressure is used (pressure at the airport altitude above sea level), and this may lead to the failure in setting the altimeter and to significant deviations from the actual altitude.

At every moment, the pilot has to know the position of the aircraft in relation to the ground, which includes the knowledge of the exact flight altitude, position of the possible barriers and procedures of avoiding them.

Instrumental Flying Regime (IFR) Charts provide the pilot with a number of data about the safety altitudes (minimum safety altitude, minimum altitude on the route, safety altitude in case of danger, minimum altitude of avoiding barriers), which are extremely useful in adverse conditions of reduced visibility.

In the communication between the pilot and the flight control, the controller may make a mistake, and the pilot may not hear or may misinterpret the controller's instruction. In order to avoid such mistakes, the discipline in radio-communication needs to be maintained and all the controller's instructions that may be ambiguous, dubious or that are not in accordance with the pilot's idea of aircraft location, have to be cleared.

Excessive self-confidence of the pilot reduces the awareness of the situation. Modern navigation equipment and auto-pilot installed in the aircraft, the flight routine in the same aircraft on the same route, frequently lead to dangerous distraction. The possible false alarms of GPWS may cause the pilot not to react to a correct and justified warning.

Many studies have shown that the usage of well defined and standardised procedures increases the flight safety. Not abiding or not understanding the procedures increases the danger of controlled flight into terrain. The development and implementation of standard procedures is the task of all the air traffic participants.

Table 1 shows that some phases in flight are more critical than others due to the dangers of controlled flight into terrain. This particularly refers to the take-off phase and the initial climbing (25.2% of the total number of accidents, and only 2% of the total flight time) and to the final approach and landing phases (41.4% of accidents in 4% flying time). On the contrary, 4.5% accidents occur during the cruising phase which takes 60% of the flying time. The majority of accidents caused by controlled flight into terrain occur within the radius of 10 nautical miles from the runway. This indicates the need for maximum concentration of the pilot during the critical phases of flight.

Table 1: Critical flight phases

Flight phase	Percentage of accidents due to CFIT [%]	Percentage of total flying time [%]
taxiing	2	0
takeoff	14.5	1
initial climbing	10.7	1
reaching the altitude	7.4	13
cruising	4.5	60
descent	7.2	10
initial approach	12.3	11
final approach	24.8	3
landing	16.6	1

The application of the auto-pilot is a great help for the pilots, but the constant improvements made to the aircraft systems and their complexity increase the possibility of error in entering the data required for the operation of the system. The pilot must constantly monitor the operation of the auto-pilot and check the navigation data and intervene when necessary. A great number of accidents occurs when the pilot relaxes while the auto-pilot is switched on.

Many accidents related to controlled flight into terrain are caused by low quality pilot training. The most sophisticated equipment in aircraft and at the airports, high quality operative procedures and precise navigation maps will not prevent accidents if the aircraft crew is not adequately trained and skilled in using it.

3. GROUND PROXIMITY WARNING SYSTEM

The Ground Proximity Warning System (GPWS) provides pilots with audio and visual signalling in case when the aircraft approaches dangerously near to the ground, when the descent speed is too high, the angle of descent is too big or in case of dangerous manoeuvres near the ground. Based on the data obtained from inertial systems built in the aircraft, GPWS also discovers the dangerous windshear. Audio signals and voice messages are transmitted over the integrated audio system to the pilot ear-

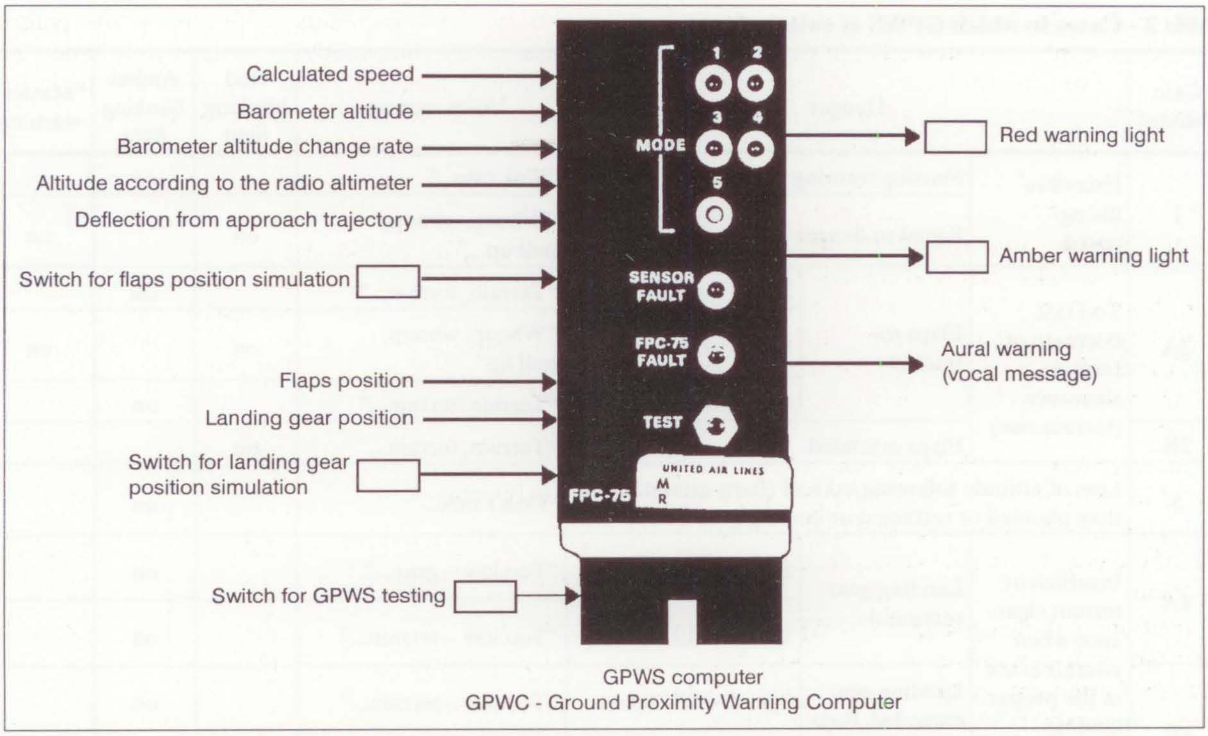

Figure 1 - Ground proximity warning computer *(GPWC)*

phones and loudspeakers in the cockpit. The basic data used by GPWS is the altitude received from the radio altimeter, so that no data need to be entered by the pilot.

GPWS has several disadvantages. The most important disadvantage is the consequence of the fact that the radio altimeter gives the real time altitude from beneath the aircraft, so that a barrier in the form of a steep tall cliff, tower or building cannot be detected. In such cases, the warning comes too late or fails completely. Also, in case of windshear, the pilot has very little time from the moment of the warning to the moment of entering the dangerous area. For stable flight in landing configuration onto a place without a runway, there will be no warning by GPWS.

The ground proximity warning system consists of:

- ground proximity warning computer (GPWC);
- warning indicators (visual and aural);
- switch for position simulation of the flaps or the landing gear.

The ground proximity warning computer (GPWC), presented in Figure 1, is an analogue-digital device which processes the data obtained from several different sources and its output provides light and audio warning signals. Besides, it has the possibility of self-testing and checking of the current condition, as well as of memorising and recording a certain number of errors in operation. During testing or solving the problems, an indicator is switched on inside the computer - a LED diode.

The visual warning indicators are a red blinking light (*Pull Up Light*) which is switched on in case of extreme danger and an amber blinking light (*Ground Proximity - Glide Slope Inhibit Light Switch*) representing the first warning signal. Together with the red warning light, the main ("*Master*") switch is turned on, which is activated in case of any danger. Audio warning indicators are various, pre-recorded or synthesised voice messages which are switched on in particular cases.

The switches for simulating the position of flaps or landing gear make it possible to switch off the warning signals when pilots, for special reasons, consciously continue into a situation which corresponds to the one that would switch on the GPWS. An example of such a situation is the aircraft approach in landing when the pilot decides on a lower angle of flaps than the one usual and foreseen for landing.

4. GPWS OPERATION MODES

Cases in which warning signals are switched on are listed in Table 2.

Further, certain Warning Modes are described in more detail. The numerical values of parameters which affect the switching on of the signals and the range within which the signal is switched on, can be differentiated according to the size and the performance characteristics of the aircraft. Also, some other Warning Modes can be added (too high roll, windshear, etc.).

Table 2 - Cases in which GPWS is switched on

Case (Mode)	Danger			Voice message	Red blinking light	Amber blinking light	"Master" warning
1	Excessive diving speed	Starting warning signal		"Sink rate..."		on	
		Signal of danger		"Whoop, whoop, pull up..."	on		on
2A	Too fast decrease of terrain clearance (terrain rise)	Flaps re-tracted	Initial warning signal	"Terrain, terrain..."		on	
			Signal of danger	"Whoop, whoop, pull up"	on		on
			Regaining altitude	"Terrain, terrain..."		on	
2B		Flaps extended		"Terrain, terrain..."	on		
3	Loss of altitude following takeoff (flaps extended less than planned or retracted or landing gear lifted)			"Don't sink..."		on	
4A	Insufficient terrain clear-ance when aircraft is not in the proper landing configuration	Landing gear retracted	Speed < 190 knots	"Too low – gear..."		on	
			Speed > 190 knots	"Too low – terrain..."		on	
4B		Landing gear extended, flaps extended less than planned	Speed < 154 knots	"Too low – terrain..."		on	
			Speed > 154 knots	"Too low – flap..."		on	
5	Deflection from the proper course in approach to landing (landing gear extended)			"Glide slope..."		on	

4.1. Mode 1 -Excessive landing speed

Warning of this type is switched on in case of excessive landing speed regarding terrain clearance (Figure 2). Mode 1 does not depend on the aircraft configuration - the position of flaps and landing gear. The warning starts when the aircraft terrain clearance falls below 2450 ft (≈750 m). The range of warning is divided into two sections (Figure 3):

- initial range with the warning amber light on and the voice message "*Sink rate...*"
- range of danger when the red light is on, "*master*" warning switch and the voice message "*Whoop, whoop, pull up...*"

4.2. Mode 2A - Too fast decrease of terrain clearance, flaps retracted

The warning is switched on in case of too fast decrease of terrain clearance with regard to the ground rise, while the flaps are retracted (Figure 4). If the aircraft speed is less than 190 kn[1] (≈350 km/h) the initial warning (amber light, message "Terrain, Terrain...")

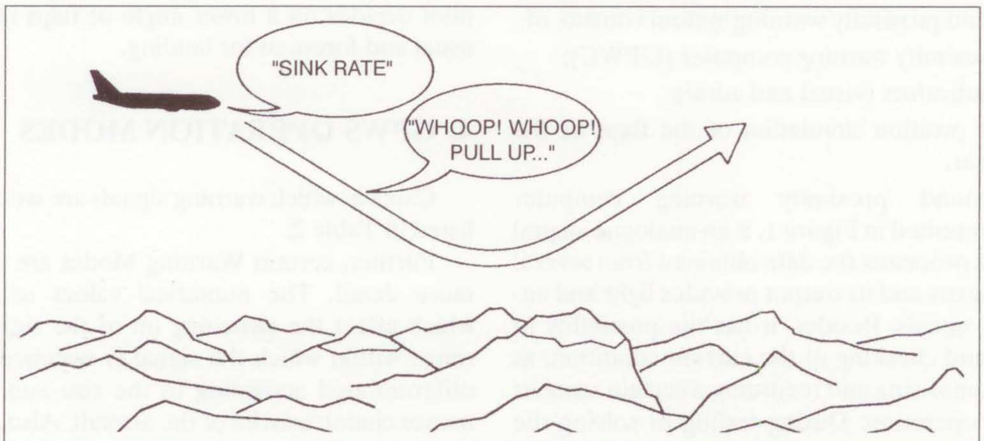

Figure 2 - Mode 1 – Excessive diving speed

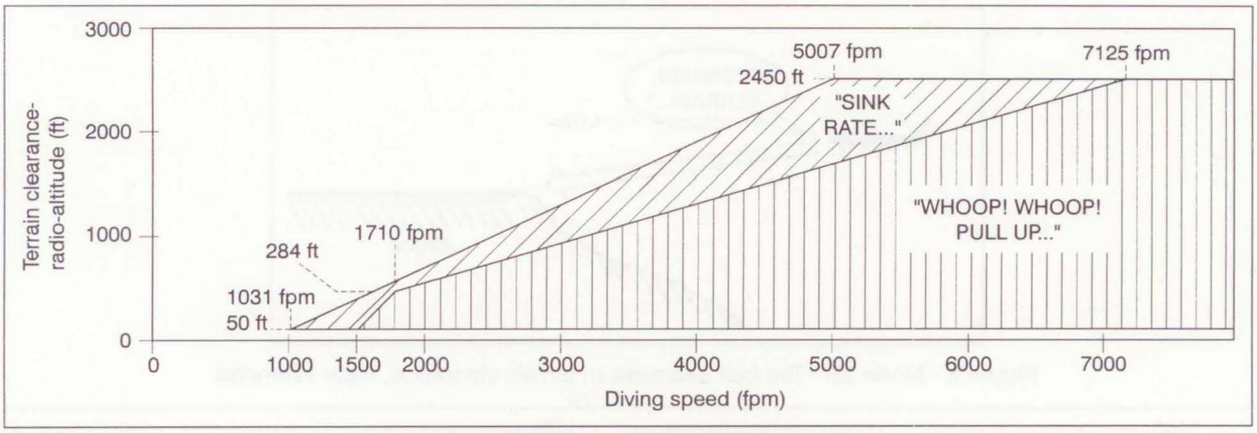

Figure 3 - Warning range in Mode 1

starts at the altitude of 1650 ft (≈500 m). For speeds greater than 250 kn (≈460 km/h) the warning appears at 2450 ft (≈750 m). Between 190 kn and 250 kn, the upper limit for the start of the warning changes linearly depending on the speed (Figure 5). If the terrain clearance continues to decrease, there is the light indicating danger (red light, "master" warning switch and voice message "*Whoop, whoop, pull up...*"). When the dangerous zone has been left, the initial warning is switched on again, and it stops when the aircraft flying altitude increases by 300 ft (≈90 m). The warning also stops if the landing gear is extended, which means when the aircraft approaches landing.

4.3. Mode 2B - Too fast decrease of terrain clearance, flaps extended

The warning is indicated when the terrain clearance is less than 789 ft (≈240 m) and has the character of advice (Figure 6). The warning stops at a certain

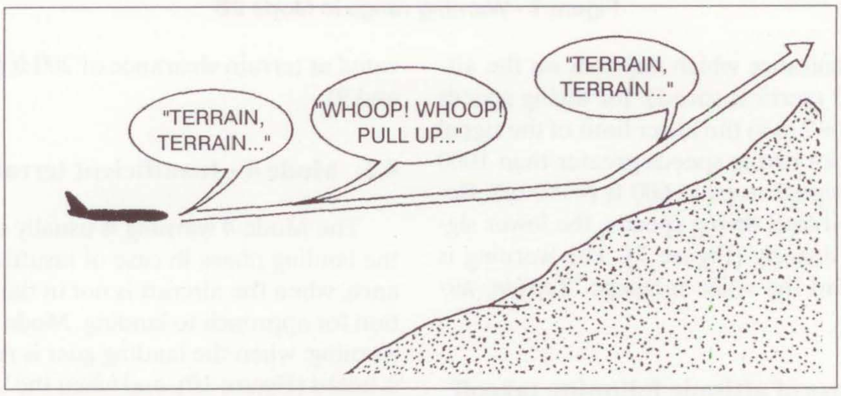

Figure 4 - Mode 2A - Too fast decrease of terrain clearance, flaps retracted

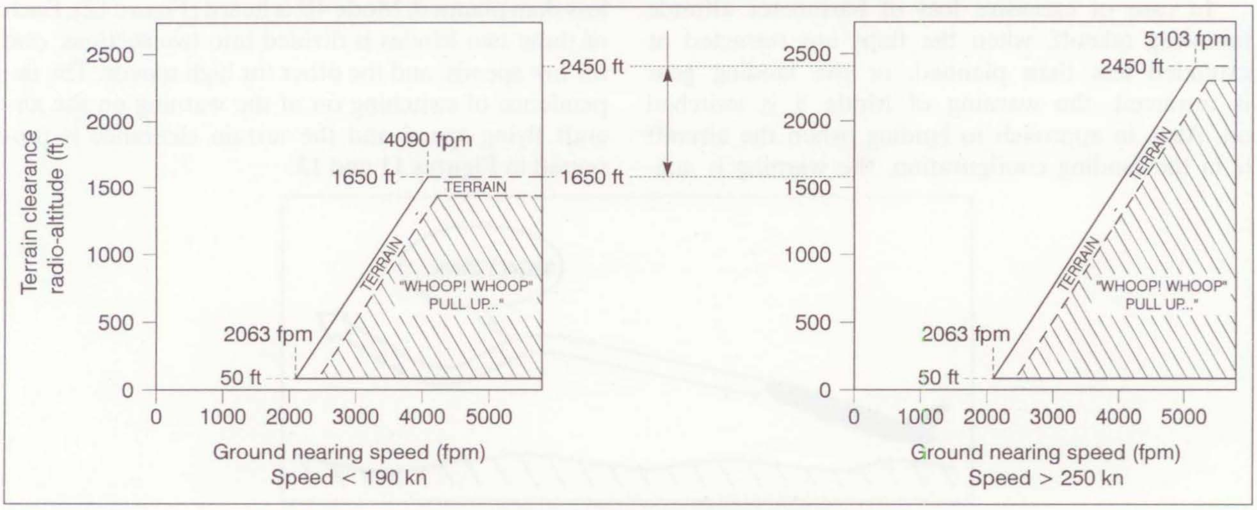

Figure 5 - Warning range in Mode 2A

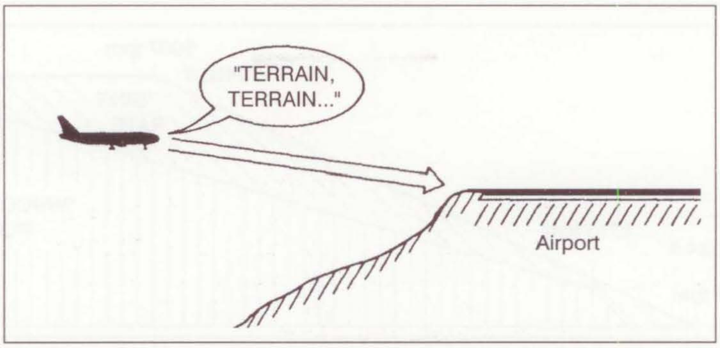

Figure 6 - Mode 2B - Too fast decrease of terrain clearance, flaps extended

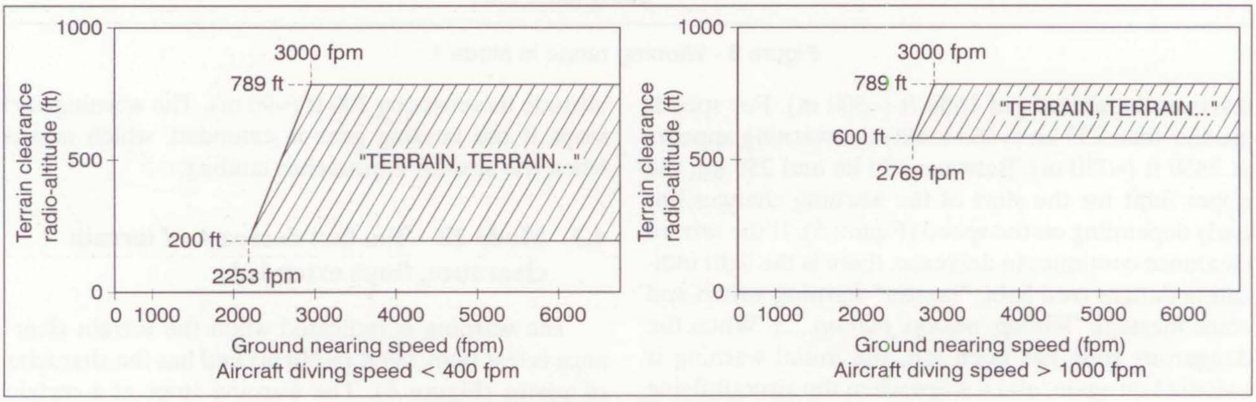

Figure 7 - Warning range in Mode 2B

value of terrain clearance which depends on the aircraft diving speed (vertical speed): for diving speeds less than 400 fpm ($\approx$ 2 m/s) the lower limit of the signal is 200 ft ($\approx$60 m); for diving speeds greater than 1000 fpm ($\approx$5 m/s) the signal stops at 600 ft ($\approx$180 m). Between these two aircraft diving speeds, the lower signal limit changes linearly (Figure 7). The warning is the amber light and the voice message "*Terrain, terrain...*".

4.4. Mode 3 - Loss of altitude following takeoff

In case of excessive loss of barometer altitude following takeoff, when the flaps are retracted or extended less than planned, or the landing gear is retracted, the warning of Mode 3 is switched on. Also, in approach to landing, when the aircraft is in the landing configuration, the warning is activated at terrain clearance of 200 ft ($\approx$60 m) (Figures 8 and 9).

4.5. Mode 4 - Insufficient terrain clearance

The Mode 4 warning is usually switched on during the landing phase in case of insufficient terrain clearance, when the aircraft is not in the proper configuration for approach to landing. Mode 4 has two forms of warning: when the landing gear is retracted, Mode 4A is heard (Figure 10), and when the landing gear is lowered, but the flaps are extended at an angle which is less than planned, Mode 4B is heard (Figure 12). Each of these two Modes is divided into two sections: one for low speeds, and the other for high speeds. The dependence of switching on of the warning on the aircraft flying speed and the terrain clearance is presented in Figures 11 and 13.

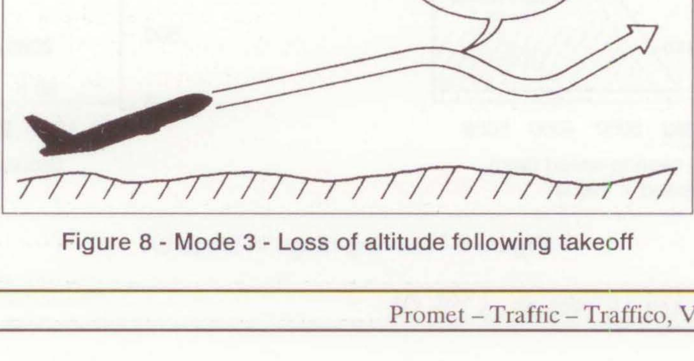

Figure 8 - Mode 3 - Loss of altitude following takeoff

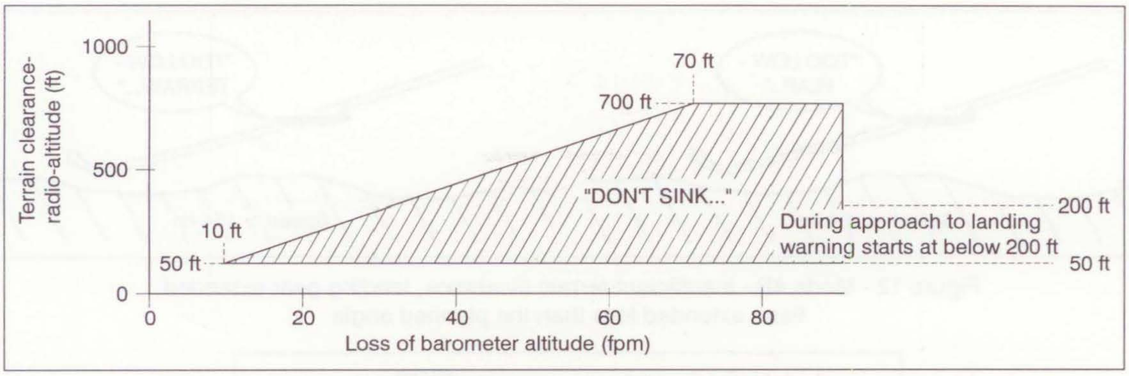

Figure 9 - Warning range in Mode 3

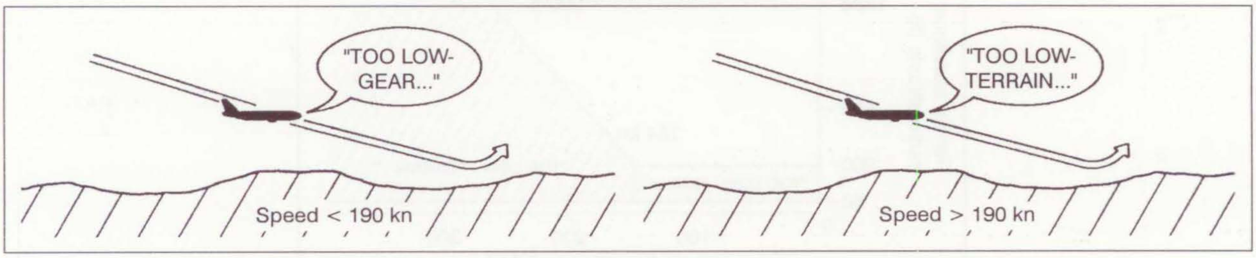

Figure 10 - Mode 4A - Insufficient terrain clearance, landing gear retracted

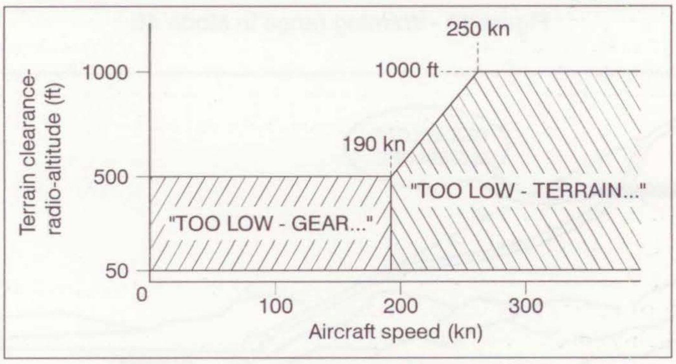

Figure 11 - Warning range in Mode 4A

4.6. Mode 5 - Deflection below the approach trajectory

The warning appears in cases of excessive deflection below the approach trajectory with the lowered landing gear (Figure 14). In the initial phase of landing below the planned trajectory, the warning starts with the amber light and vocal message *"Glideslope..."* which has 6 dB lower volume level than normal. If the descent tendency below the trajectory continues, the same message is repeated, but at normal volume level. The limits of warning being switched on regarding terrain clearance and deflection from the approach trajectory, are presented in Figure 15.

5. ENHANCED GROUND PROXIMITY WARNING SYSTEM

The advance of technology has improved the ground proximity warning system. Whereas the conventional GPWS was based on the current position of the aircraft, the enhanced GPWS can predict entering into the dangerous area. This has been achieved by entering digital maps covering more than 90% of the Earth's surface, and especially for the areas around airports, into the database used by the GPWS computer. The introduction of the global positioning system (GPS) has enabled more precise and reliable determining of the aircraft position. By comparing the data on the aircraft position, speed and vertical speed, radio and barometer altitude, data obtained from navigation and inertia systems, as well as the indicator for the position of the flaps and landing gear with the data from the database about the terrain configuration, provides safe and justified warning in case of danger. The crew is able to continuously monitor the situation on the screen where the height of barriers in front of the aircraft is indicated by colours: green indicating terrain clearance of minimum 2,000 ft (≈610 m), amber - terrain clearance of 1,000 ft (≈305 m), and red indicating that terrain clearance is 500 ft (≈150 m) or

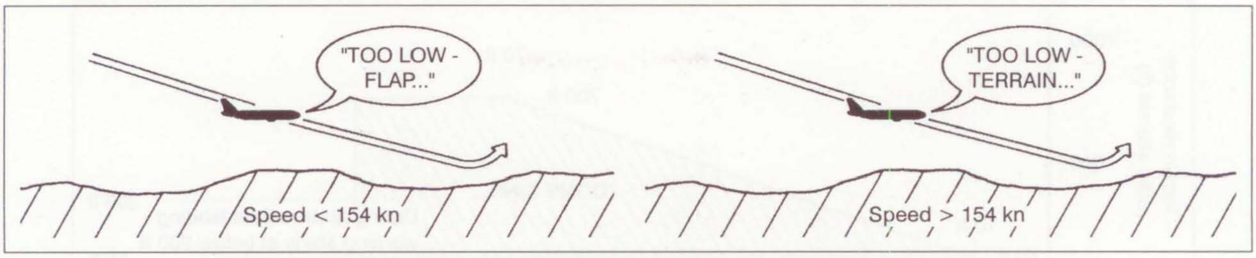

Figure 12 - Mode 4B - Insufficient terrain clearance, landing gear extended, flaps extended less than the planned angle

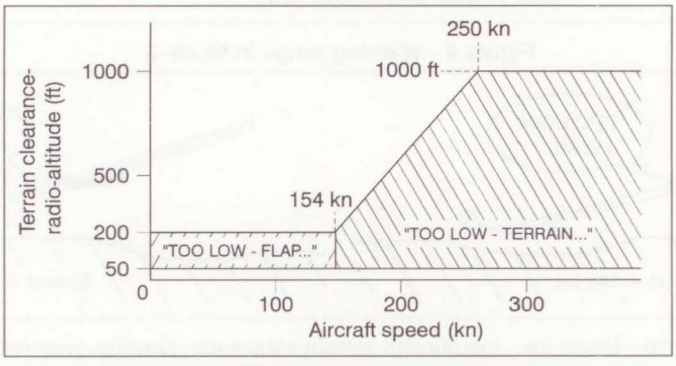

Figure 13 - Warning range in Mode 4B

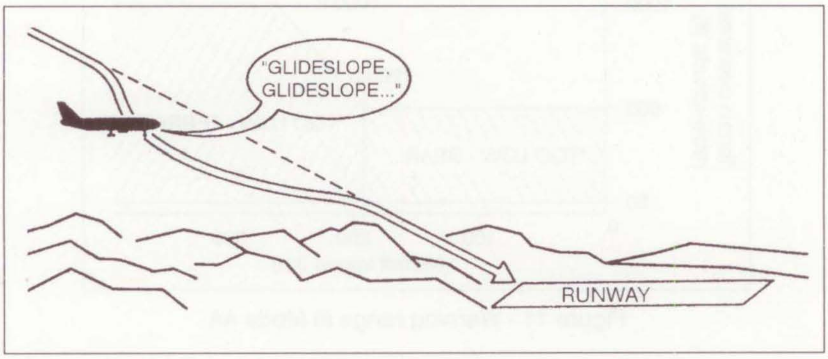

Figure 14 - Mode 5 - Deflection below the planned approach trajectory

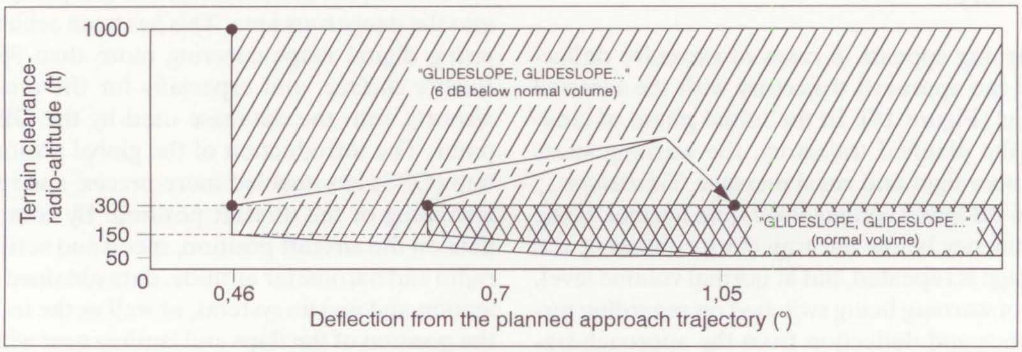

Figure 15 - Warning range in Mode 5

less, or that the height of the barrier is even greater than the current aircraft flight level (Figure 16).

The enhanced GPWS provides also the possibility to adjust the warning envelope to the situation, especially near airports where the surrounding is not adequate for takeoff or approach of aircraft. By using the information on the aircraft flight and terrain configuration, the computer computes the most suitable operating envelopes.

The computer of the enhanced GPWS continuously checks the operation of certain parts of the system, which includes checking the operation of the

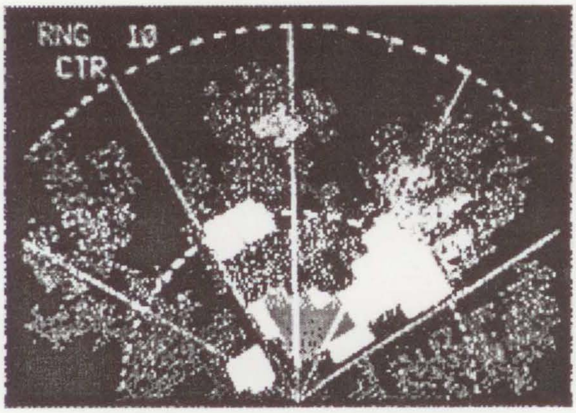

Figure 16 - Display of the enhanced ground proximity warning system

processor, memory and the generator of vocal messages.

6. CONCLUSION

Participants in any kind of transport, including air transport, are obliged to do everything they can in order to improve the traffic safety. Development and improvement of the ground proximity warning system proves that investing in programs regarding traffic safety enhancement is justified. The continuous trend in reducing the number of aircraft accidents included in the category of "controlled flight into terrain" owing to the GPWS indicates the need for further enhancement of its characteristics and expansion of its operating range, which has been also supported by the legislative regulations according to which the air carriers and aircraft manufacturers are obliged to install the ground proximity warning systems into the aircraft. Studying the causes and consequences of other types of aircraft accidents it is necessary to develop the equipment and the procedures which would eventually reduce the risk of accidents to a minimum.

SAŽETAK

SUSTAV UPOZORAVANJA NA BLIZINU TLA

U ovome se članku, kroz tehnički opis Sustava upozoravanja na blizinu tla (GPWS), razmatraju neki sigurnosni čimbenici letenja u komercijalnome zrakoplovstvu, kao i aspekti odnosa pilota prema uređaju tijekom eksploatacije u letu. Budući je njegovom ugradnjom i uporabom u zrakoplovima evidentiran nagli pad broja nesreća uzrokovanih Kontroliranim letom u prepreku (CFIT), na polju sigurnosti letenja tehničko-tehnološki razvoj GPWS-a predstavlja jedan od najznačajnijih koraka u borbi protiv redovito katastrofalnih posljedica navedenoga tipa nesreća.

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