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ДОПУСТИТИ ДО ЗАХИСТУ
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_____________ Грищенко Ю.В.
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(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ (ОСВІТНЬОГО СТУПЕНЯ) “МАГІСТР”

Тема: «Інформаційна система попередження наближення землі сучасного літака»

Виконавець: ________________________________ Ганна ПЛИТУС

Керівник: ___________________________________Олексій ЧУЖА

Консультанти з окремих розділів пояснювальної записки:

Охорона праці: ____________________________________Катерина КАЖАН

Охорона навколишнього середовища: __________________Леся ПАВЛЮХ

Нормоконтролер: _____________________________Василь ЛЕВКІВСЬКИЙ

Київ 2022

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY

Department of Avionics

ADMIT TO DEFENCE
Department head

_____________ Hryshchenko Y.V.
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GRADUATE WIRK

(EXPLANATORY NOTE)

GRADUATE OF EDUCATIONAL AND QUALIFICATION LEVEL

(EDUCATION DEGREE)

"MASTER"

Theme: «The Ground Proximity Warning System of Modern Aircraft**»**

Done by: ____ Hanna PLYTUS

Supervisor: ____ Oleksii CHUZHA

Consultants from individual sections of the explanatory note:

Labour protection: __________________________________ Kateryna KAZHAN

Environment protection:_____________________________ Lesya PAVLYUKH

Standard controller: _________________________________ Vasyl LEVKIVSKY

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NATIONAL AVIATION UNIVERSITY
Faculty of Aeronautics, Electronics and Telecommunications.
Department of avionics

Specialty 173.03 "Avionics"

APPROVED
Head of Department
_______Y. HRYSHCHENKO
«____» ________________ 2022.

TASK
for execution graduate work
Hanna Plytus

1. Topic of the thesis: «The Ground Proximity Warning System of Modern Aircraft», approved by the rector's order from «13» September 2021 №1413/ст.

2. The term of the work: from 05.09. 2022 to 30.11.2022.

3. Initial data for work: structure and technical characteristics of the Weather Radar of AN-148 aircraft, structure and specification of Terrain Avoidance and Warning System of AN-148 aircraft – «GPWS-2000» .

4. Contents of the explanatory note (list of issues to be developed):
General Characteristics and Principle of Operation of Ground Proximity Warning System. The Terrain Avoidance and Warning Systems of Modern Aircraft. Measurement of Projected Altitude on the Aircraft Flight Path. Labor protection. Environmental protection.

5. A list of mandatory graphic material (with a precise definition of mandatory drawings, diagrams, tables, etc**.).** Tables of equipment characteristics, equipment location, structure and its examples, schemes illustrated equipment operation.

6 . Calendar plan-schedule

№ п/п	Task	Deadline
1	Validate the rationale of graduate work theme	05.09-06.09
2.	Carry out a literature review	07.09-09.09
3	Develop the first chapter of diploma	10.09-24.09
4.	Develop the second chapter of diploma	25.09-09.10
5.	Develop the third chapter of diploma	10.10-08.11
6.	Develop the fourth chapter of diploma	09.11-12.11
7.	Develop the fifth chapter of diploma	12.11-14.11
8.	Obtaining a review of the diploma	14.11-15.11
10.	Issuance of an explanatory note	15.11-20.11
11.	Preparation for review	20.11-24.11

7. Consultants from individual departments

Section	Consultant (post, Name)	Date, signature	
		Issued the task	I accepted the task
Labour protection	Kateryna Ivanovna		
Environmental protection	Pavlyukh Lesya		

8. Issue date of the assignment: «____» ____________ 2022.

Supervisor of the thesis ___________ Oleksii CHUZHA

The task took to perform ___________ Hanna PLYTUS

ABSTRACT

Explanatory notes to master's work "Ground Proximity Warning System of Modern Aircraft": _ pages, 47 figures, _ references.

AVIATION, FLIGHT SAFETY, INFORMATION TECHNOLOGIES, EMERGENCY SITUATIONS, WARNING SYSTEMS, AURIAL MESSAGES, GROUND PROXIMITY WARNING SYSTEM, TERRAIN AVIODANCE AND WARNING SYSTEM.

Object of the investigation – the operation of Ground Proximity Warning System.

Purpose of the master's work – the research of the implementation of the "TERRAIN" sub-mode of the Weather Radar with the aim to obtain data from profile flight radar for the Ground Proximity Warning System.

Method of investigation – conducted research is based on theoretical analysis of the ability of Weather Radar to operate in "TERRAIN" sub-mode in order to work as a profiled flight radar; mathematical calculations of Weather Radar ideal model of sensor for Ground proximity Warning System.

Scientific novelty – It is proposed to expand the use of pulse-type radar capabilities in order to improve the accuracy of GPWS. Based on the calculations of the radar characteristics, the advisability of its use as a source of data on the situational monitoring of the ground relief has been theoretically proved. Moreover, as a result of the analysis, it is proposed to develop a new radar mode "TERRAIN", which will allow the radar to be used as an adjacent system to the GPWS.

LIST OF CONTENTS

LIST OF ABBREVIATIONS

AOA	Angle Of Attack
AP	Antenna Pattern
BITE	Built-In Test Equipment
CFIT	Control Flight Into Terrain
CU	Control Unit
DEU	Display Electronics Unit
EGPWS	Enhanced Ground Proximity Warning System
ESA	Effective Scattering Area
FMC	Flight Management Computer
GND PROX	Ground Proximity
GPS	Global Positioning System
GPWC	Ground Proximity Warning Computer
GPWM	Ground Proximity Warning Module
GPWS	Ground Proximity Warning System
TAGS	Time Automatic Gain Control
TAWS	Terrain Avoidance and Warning System
TCF	Terrain Clearance Floor
Tx	Transmitter
TERR	Terrain
PFR	Profile Flight Radar
Rx	Receiver
WXR	Weather Radar

INTRODUCTION

In the late 1960s, a series of Controlled Flight Into Terrain (CFIT) accidents, in which the pilots did not lose control of the aircraft, killed hundreds of passengers.

Controlled flight into terrain (CFIT) is an accident in which an aircraft strikes the ground, water, or an obstacle without the pilot flying losing control. Although a mechanical problem can be the cause of a CFIT, pilot error is the most common factor. It may be due to navigational error, weather misjudgement, lack of awareness of terrain height, or spatial disorientation.

Accidents resulting from a voluntary action by the person flying, such as an act of terrorism or pilot suicide, are not considered CFIT, nor are situations where the aircraft is out of control at the time of impact.The term was invented by Boeing engineers in the late 1970s. According to Boeing, for the period 2003 to 2012, CFIT type of accident was the second most deadly after LOC (Lost Of Control), causing almost a thousand deaths in aircraft and among outsiders during this period.

So, during the 1970s, numerous studies were conducted to discover the causes of these accidents. These accidents could have been avoided if the aircraft had been equipped with ground proximity warning systems (GPWS).

In 1974, the Federal Aviation Administration declared GPWS mandatory on large aircraft to prevent accidents.

In 2000, the FAA amended its operating rules to require that all US-registered turboprop aircraft with six or more passenger seats (excluding pilot and co-pilot seats) be equipped with an FAA-approved ground proximity warning system.

The distance between the aircraft and the ground is measured by the radiosonde (or radio altimeter). Depending on the height and the flight configuration, the computer can inform the pilot of a danger by audio or visual messages.

Nowadays, manufacturers and airlines are still constantly working to reduce accidents connected with CFIT. The most common solutions are improved pilot training, mainly by asking pilots to pay attention to their on-board instrumentation, but also the develop and improve of efficient safety systems, such as the ground proximity warning system (GPWS) that today became mandatory for all commercial aircrafts and not only.

The main input data of modern GPWS systems are values from the radar altimeter and barometric altimeter sensors. When entering the GPWS system, these data are analyzed according to certain algorithms (which also take into account the current position of the mechanization of the wheels, the position of the chassis, etc.) by the on-board computer of the system, which then issues the appropriate visual and sound signals to the pilot.

When flying at low altitudes, a certain biased distance is measured to the possible point of collision with an obstacle or the earth's surface, in order to avoid a close-range collision. Modern TAWS systems use mathematical models and calculations to determine the distance to an obstacle. However, these models cannot provide the aircraft system with the necessary information about the previous relay and obstacles in real time; such modeling cannot take into account and predict artificial changes in the terrain and surrounding environment. They are also characterized by certain inaccuracies of absolute height maps, the accumulation of error when determining the coordinates of the aircraft, etc.

That is why this work is dedicated to expanding the capabilities of the early warning system about the approach of the ground, since the main idea is to use the weather radar available on the aircraft as a sensor of the current change in the topography of the ground or to predict the object on the plane's path.

The choice of the topic and the relevance of the thesis is that solving the problem of direct measurement of the change in the topography of the terrain at a certain shifted distance is an important issue for ensuring and achieving the safety of aircraft flights at low altitudes.

It is supposed to measure some offset distances to a probable obstacle using weather radar equipment on board modern aircraft.

Thus, the object of the study is the operation of the ground proximity warning system of the approach of the aircraft, which works on the database of the weather radar.

The purpose of this work is to obtain a synthesis of two systems without changes in their design specifications, with minimal changes to on-board systems and with the most effective work result, which increases the safety of the aircraft flight. It is assumed that the proposed combination of the two systems will allow real-time monitoring of changes in the terrain during low-altitude flights, and early warning of potential danger and the level of its threat.

CHAPTER 1

GENERAL CHARACTERISTICS AND PRINCIPLE OF OPERATION OF GROUND PROXIMITY WARNING SYSTEM

1.1. The problematic of aircrafts collision with terrain surface and obstacles

The instrument that helps pilots in their task is the Ground Proximity Warning System: it is an electronic system that sends a warning if there is a danger of collision with the ground. This system allows crews to fly even when the aircraft is very close to the ground and therefore to perform precision landings and take-offs.

This system is fundamental to an aircraft and greatly enhances safety and situational awareness, so there are rules that pilots must follow whenever the ground proximity warning is activated. When there is a GPWS alert, pilots therefore react quickly and act according to well-defined procedures.

The GPWS, according to the FAA, the US Federal Aviation Administration, is a type of Terrain Awareness Warning System (TAWS). It was developed by C. Donald Bateman, a Canadian engineer in the 1960s, but the FAA made it mandatory in 1978 for all aircraft with more than 10 passengers: it was a real revolution for the air transport industry, as it considerably reduced the number of air accidents per year caused by CFITs, an acronym that stands for Controlled Flight Into Terrain, i.e. accidents in which the pilot, unaware of his proximity to the ground and with the aircraft fully under control, hits the ground, a mountain or another obstacle.

Through many studies and innovations in the field of flight safety, a significant reduction in the number of these types of controlled flight in terrain (CFIT) accidents has been achieved. Statistics show that the introduction of the ground proximity warning system had the greatest effect. The Fig.1.1 shows that the number of CFIT incidents has decreased significantly since the mandatory fitting of 10-30 passenger turbine aircraft with Ground Proximity Warning Systems (GPWS). Moreover, since CFIT type accidents are statistically one of the most fatal accidents, this trend of decreasing accidents of this type has a significant impact on flight safety, improving it.

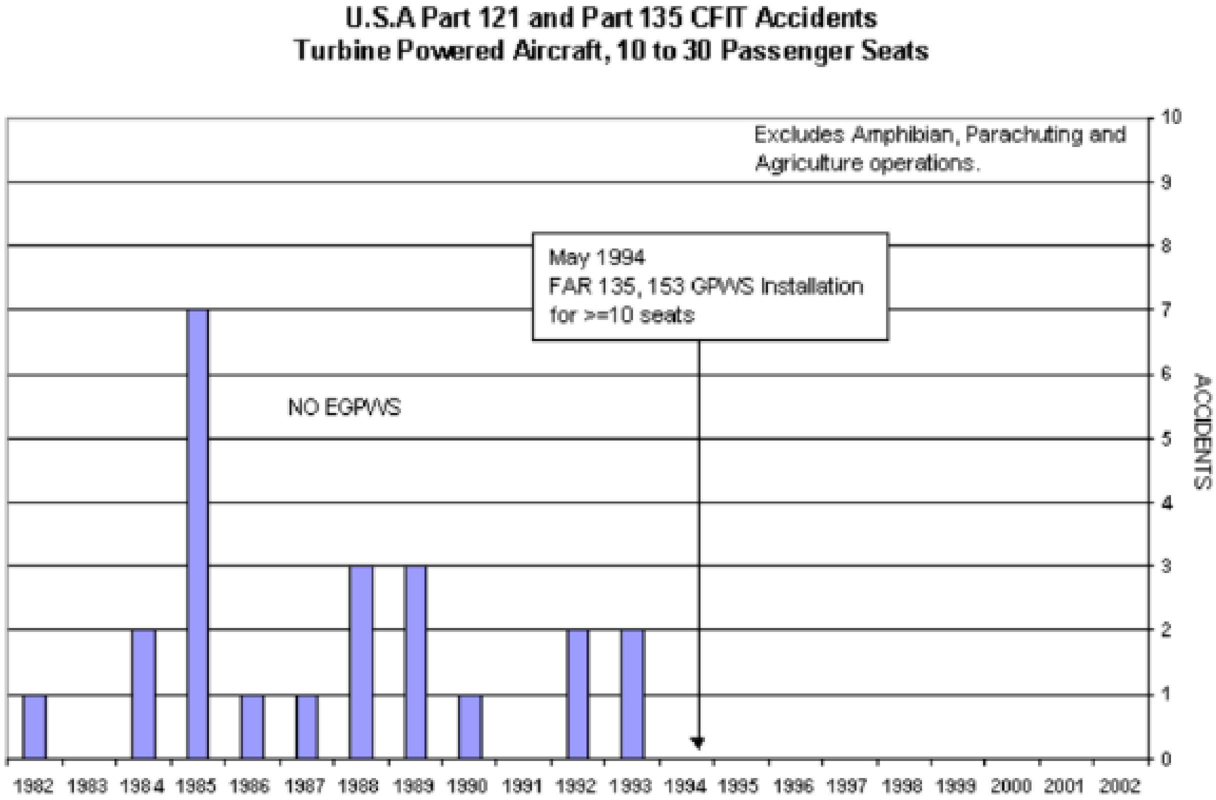

Fig.1.1. Effect of GPWS on CFIT accidents

The Ground Proximity Warning System (GPWS) is a piece of aircraft equipment designed to prevent controlled flight into terrain by providing warnings or alarms to the pilot when the aircraft comes too close to the ground.

A more advanced device called E-GPWS (Enhanced GPWS) includes a geographic database that allows the elevation of the terrain around the aircraft to be displayed by knowing its location. The aircraft's position is transmitted to the E-GPWS by the on-board navigation systems (depending on the case, GPS, FMS, inertial units, etc.). The EGPWS is more efficient than the GPWS thanks to the knowledge of the terrain in front of the aircraft and the display of the terrain on the onboard instruments.

GPWS, E-GPWS, and all systems designed to prevent controlled flight into terrain in general, are called Terrain Awareness and Warning Systems (TAWS).

The GPWS uses a radio altimeter (radiosonde) to measure the distance of the aircraft from the ground, and then compares this data with the satellite position of the aircraft and a database of terrain morphology, in order to anticipate the risk of collision and warn pilots. The Fig. 1.2 shows the principle of the radio altimeter.

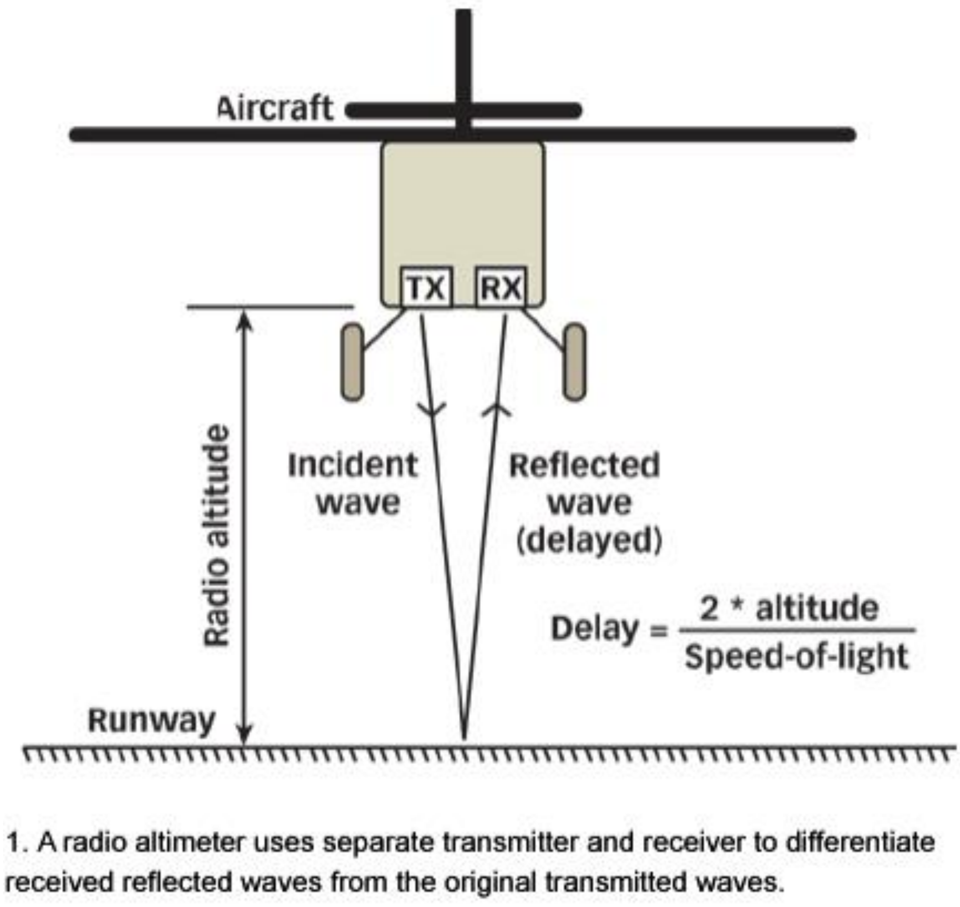

Fig. 1.2. Principle of operation of radio altimeter.

It is an extremely useful system for guiding aircraft, but sometimes it has to take account of special circumstances, such as the presence of obstacles near the runway: in this case the rate of descent can be very high, as in the case of airports located near mountains and skyscrapers, so it will be necessary to modify the GPWS parameters.

1.2. Principle of operation of the Terrain Avoidance and Warning System. Main modes of the Terrain Avoidance and Warning System operation

1.2.1. Principle of operation

American federation imposed the installation of GPWS on all the apparatuses in several countries. The first GPWS system, which has been installed on aircraft since 1974, includes numerous alerts for various flight situations. They have five modes of operation:

1) Mode 1: Excessive glide slope.
2) Mode 2: Excessive approach rate.
3) Mode 3: loss of altitude after take-off.
4) Mode 4: proximity to the ground with landing gear inbound flaps.
5) Mode 5: Descent below glide slope.

These modes are automatically activated in the GPWS computer. With the technical development of aeronautical safety especially concerning electronic systems. A more advanced device called ENHANCED-GPWS or EGPWS has become available today. It is equipped with a geographical database which allows the detection of the terrain conditions in front of the aircraft.

It is thus enhanced by information from the: GPS, Radio altimeter, Heading and vertical airspeed indication, the aerodynamic unit, and the radio navigation system.

This system gives an audible and visual alarm if the aircraft gets too close to the ground. The GPWS is considered as one of the most important on-board safety systems on the aircraft given the considerable contribution it makes. It reduces the number of crashes since its installation.

The E-GPWS is an on-board electronic warning system designed to prevent an aircraft from approaching the ground (Fig.1.3). It uses radio altimeter information to detect if the aircraft is getting too close to the ground and triggers a "whoop, whoop terrain, terrain-pull up, pull up" warning to the pilot. The GPWS is activated during the critical take-off and landing phases and alerts the pilot and/or triggers control commands when these calculations show that the aircraft is falling below a minimum distance from the ground.

By constantly comparing the information provided by its own terrain database as well as by the radar altimeter and satellite navigation (GPS), it constantly monitors the position of the aircraft in relation to the ground and thus virtually excludes the risk of ground contact.

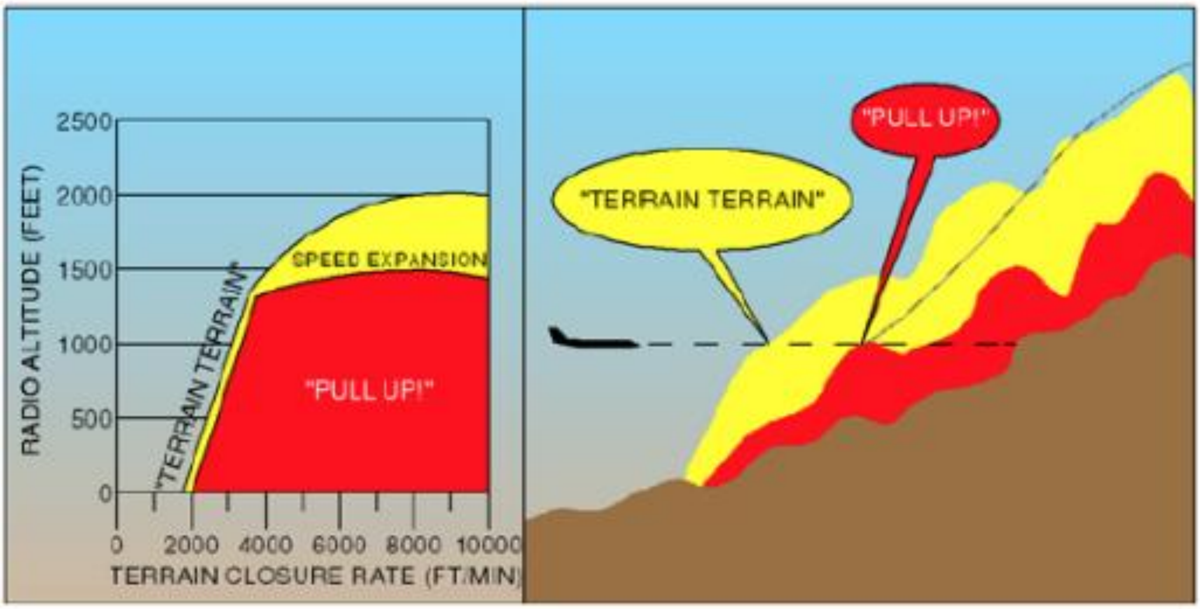

Fig.1.3. Enhanced Ground Proximity Warning System (EGPWS)

1.2.2. Modes of operation of EGPWS

Mode 1 - Excessive descent rate: provides alerts and warnings for high rates of descent when the aircraft is close to the ground. This mode is dependent on altitude and barometric rate and is independent of aircraft configuration (flap position and landing gear), it becomes functional when the aircraft's altitude exceeds 10 feet. If the aircraft enters the first warning zone indicating an excessive loss of altitude, the "Sink Rate ″ message will be heard and the Pull Up indicator will light up. If the sink rate is not corrected, the aircraft will enter the second warning area, and the Sink Rate message will change to the Whoop-whoop -pull Up warning. "Whoop-whoop -pull up", with the indicator still on, in order to prevent the aircraft from falling too far and the pilot must correct the trajectory (Fig.1.4).

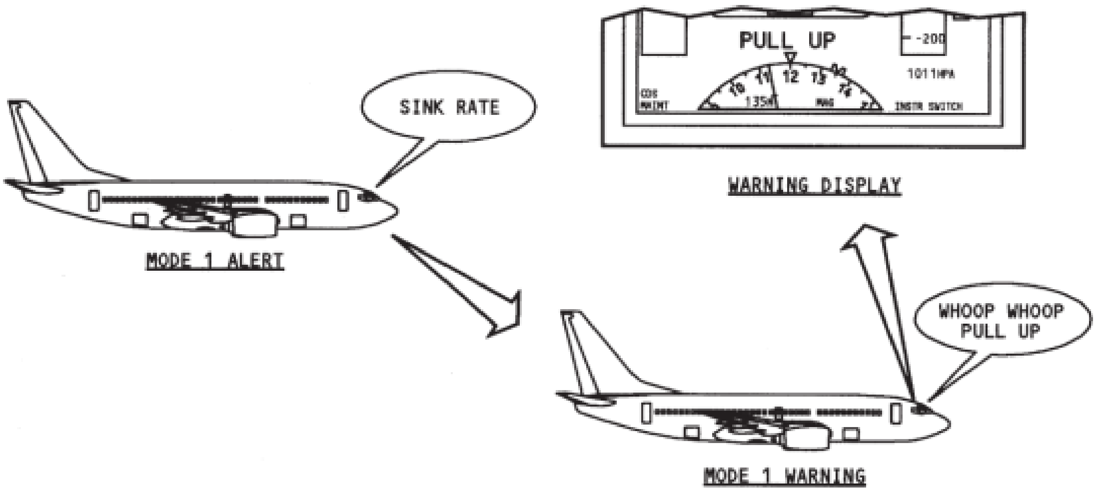

Fig.1.4. Mode 1-Excessive descent rate.

Mode 2 - Excessive Terrain Closure Rate: provides alerts and warnings when the approach rate to the ground is very high. Mode 2 has two sub-modes, mode 2A and mode 2B. This mode depends on the Mach number, altitude, barometric rate and the aircraft configuration (flap and landing gear position).

The 2A mode (Fig.1.5): occurs for a high approach rate if the flaps are less than 25 units (not in the landing configuration). This mode can have an alert state or a warning state. For an alert state, the GPWC gives the audible message, "LAND LAND" and the DEU display shows "PULL UP".

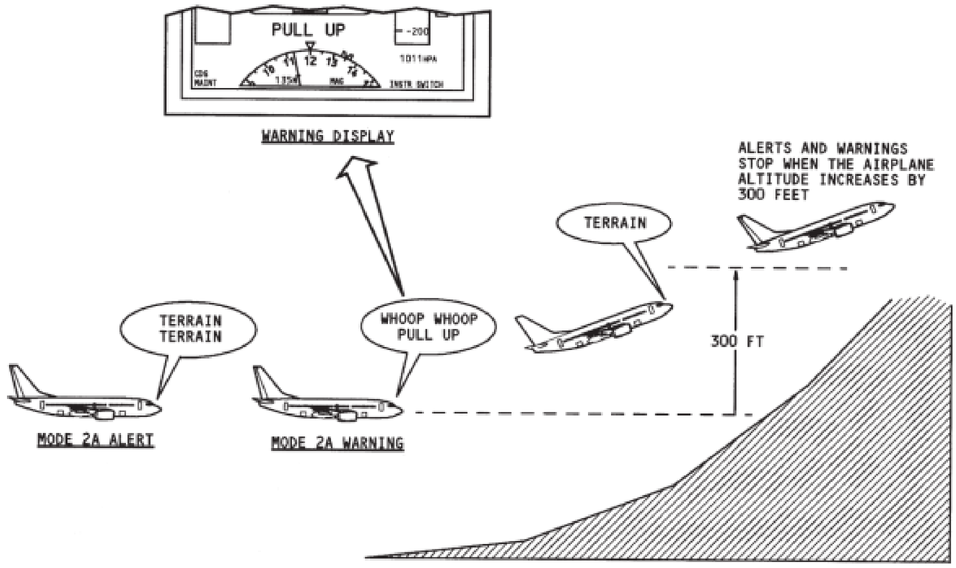

Fig.1.5. Mode 2A- Excessive Terrain Closure Rate.

The 2B mode (Fig.1.6): gives alerts for a high approach rate if the flaps are in the landing configuration (more than 30 units).

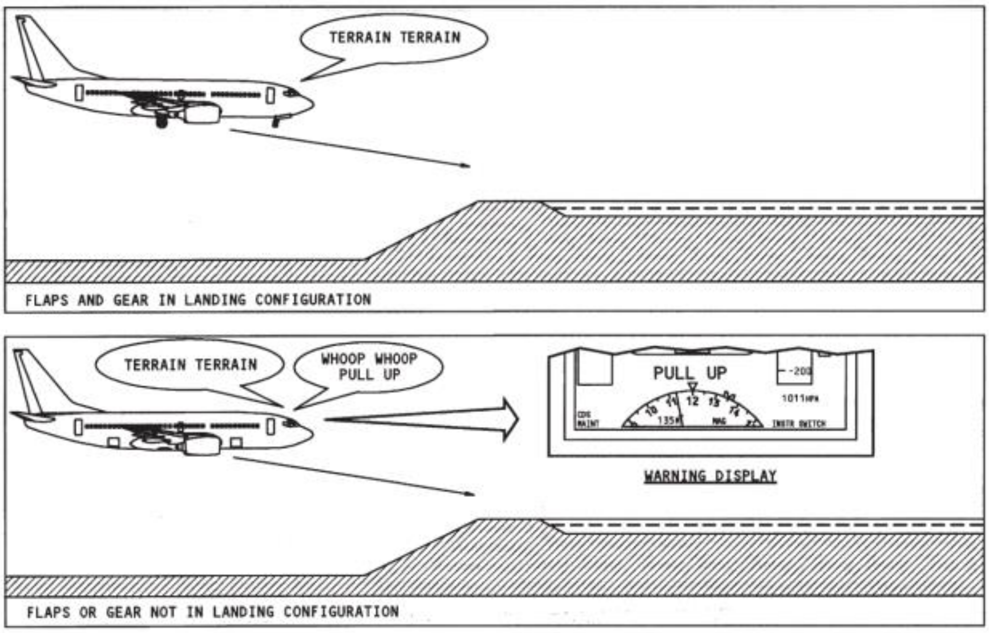

Fig.1.6. Mode 2B- Excessive Terrain Closure Rate.

Mode 3 - Loss of altitude after take-off of go-around: alerts are activated when there is a large loss of altitude during take-off, or during a missed approach with the Flaps up, or with the landing gear on. When the aircraft reaches 1500 feet radio altitude, mode 3 becomes non-alert. Mode 3 has two sub-modes (3A and 3B) (Fig.1.7).

Sub-mode 3A: Gives alerts when the aircraft loses altitude after take-off. The loss depends on the evaluation rate and the altitude of the aircraft. Sub-mode 3A gives the audible message "DON'T SINK".

Sub-mode 3B: Gives alerts for minimum land clearance. The terrain clearance and increases when the aircraft's altitude is high during take-off. In this mode 3B 3, the PFD (primary flight display) shows the message "PULL UP".

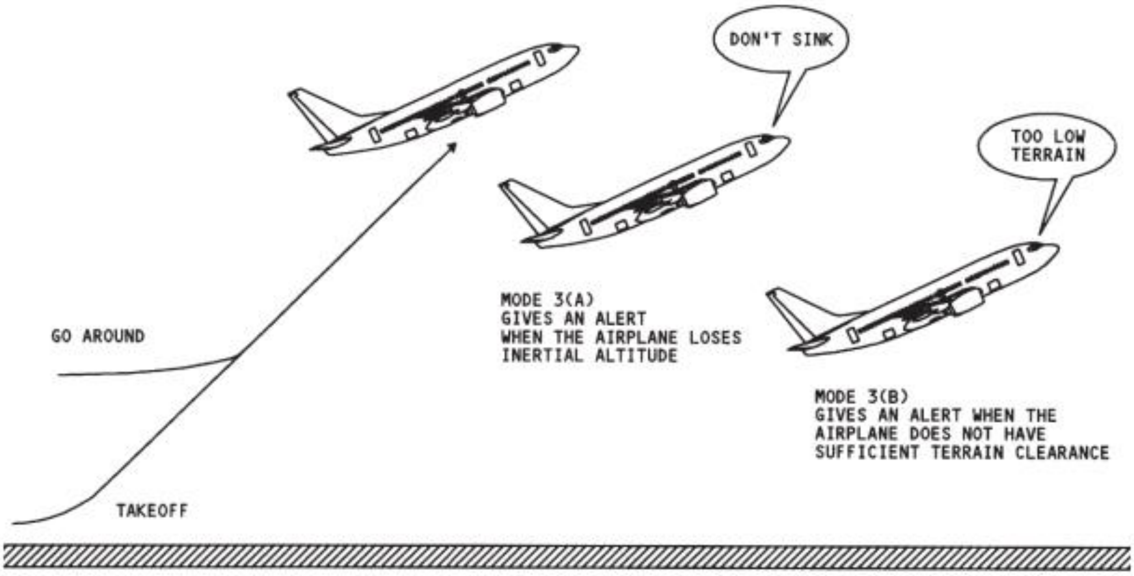

Fig.1.7. Mode 3- Loss of altitude after take-off or go-around.

Mode 4 - unsafe terrain clearance and not in landing configuration: provides alerts when the aircraft is too close to the ground, and the landing gear or flaps are not in the landing configuration state. Mode 4 has two sub-modes (4A and 4B). (Fig.1.8).

The GPWC gives an alert for mode 4A when the landing gear is not extended. Mode 4A gives an audible message "TOO LOW GEAR" at base airspeeds is high. Mode 4B gives an auditory message "TOO LOW FLAPS" if the aircraft is at low airspeed (airspeed decreases), or "TOO LOW TERRAIN" when the airspeed is high. When the GPWC gives a Mode 4 alert, the mode detector also sends a discrete signal on an ARINC 429 data bus to the DEU to raise the message "PULL UP".

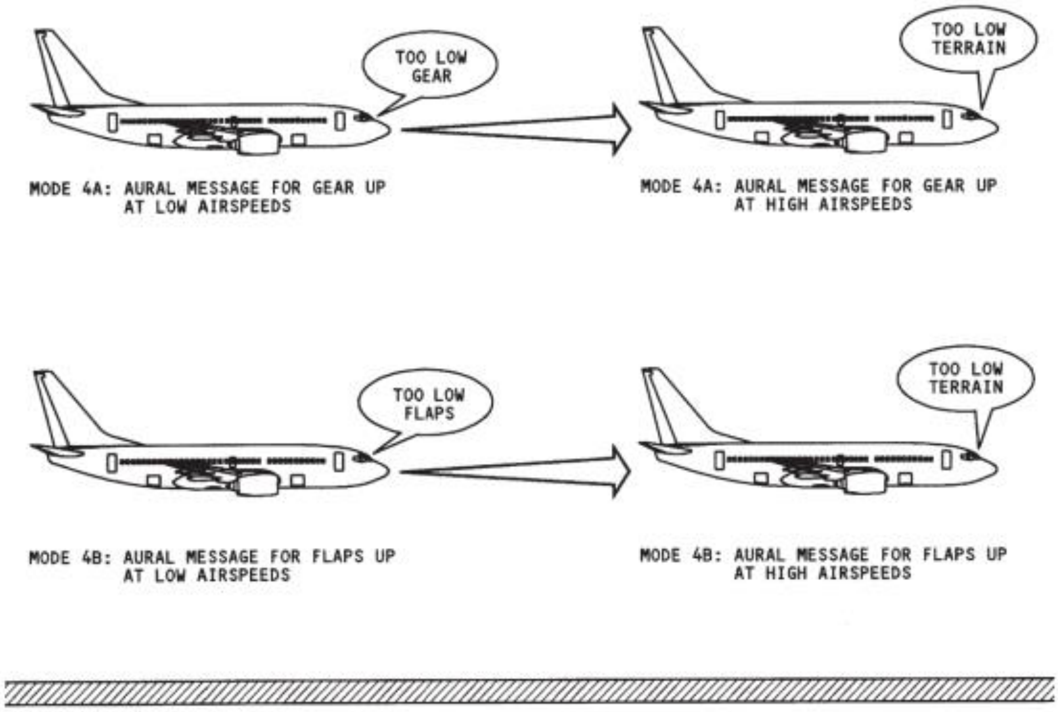

Fig.1.8. Mode 4- unsafe terrain clearance and not in landing configuration.

Mode 5 - Descent below glide slope (Fig.1.9): the GPWC provides an alert when the aircraft is landing below the glide slope axis during the approach if the landing gear is down.

For Mode 5 alerts, the GPWC gives an audible "GLIDE SLOPE" message. The volume level of the auditory message increases and repeats more rapidly as the field gets more closely. Pressing the Glide Slope Switch will disable the Mode 5 alerts.

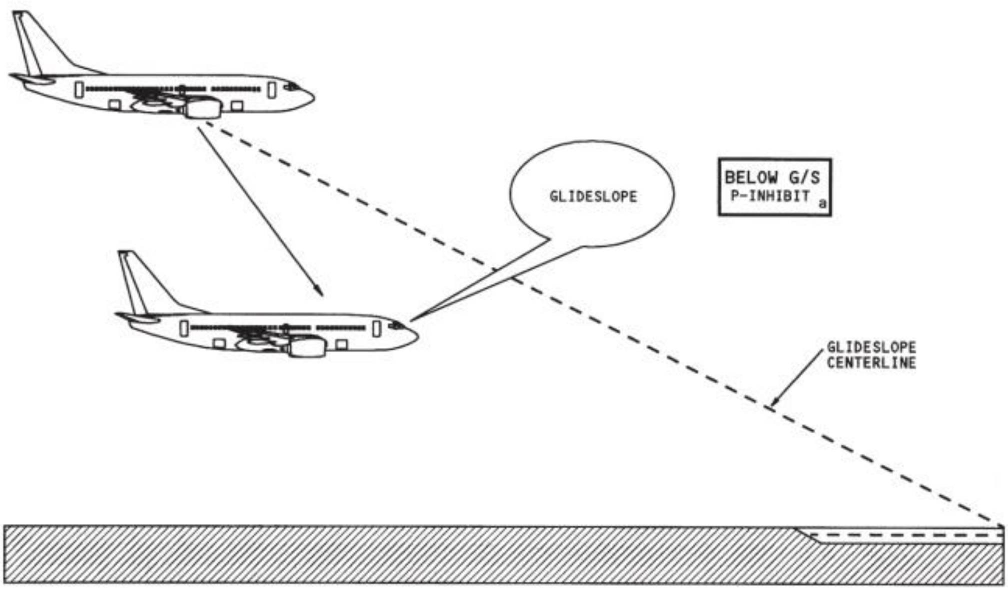

Fig. 1.9. Mode 4- Descent below the glide slope.

Mode 6 - Descent below minimum or advisories (Fig.1.10): provides low audible messages, when the aircraft is descending through lower altitudes with the landing gear down. The options available for mode 6 are:

- Low altitude.
- Low minimum.
- Low approach minimum.
- Low bank angle (roll alert).

At the start of low altitudes at 2500 feet, there is an option to give the audible message "TWENTY-FIVE HUNDRED" or radio altitude. The low minimum option gives a low audible message. When the aircraft descends through the decision altitude gauge and set on the EFIS command box.

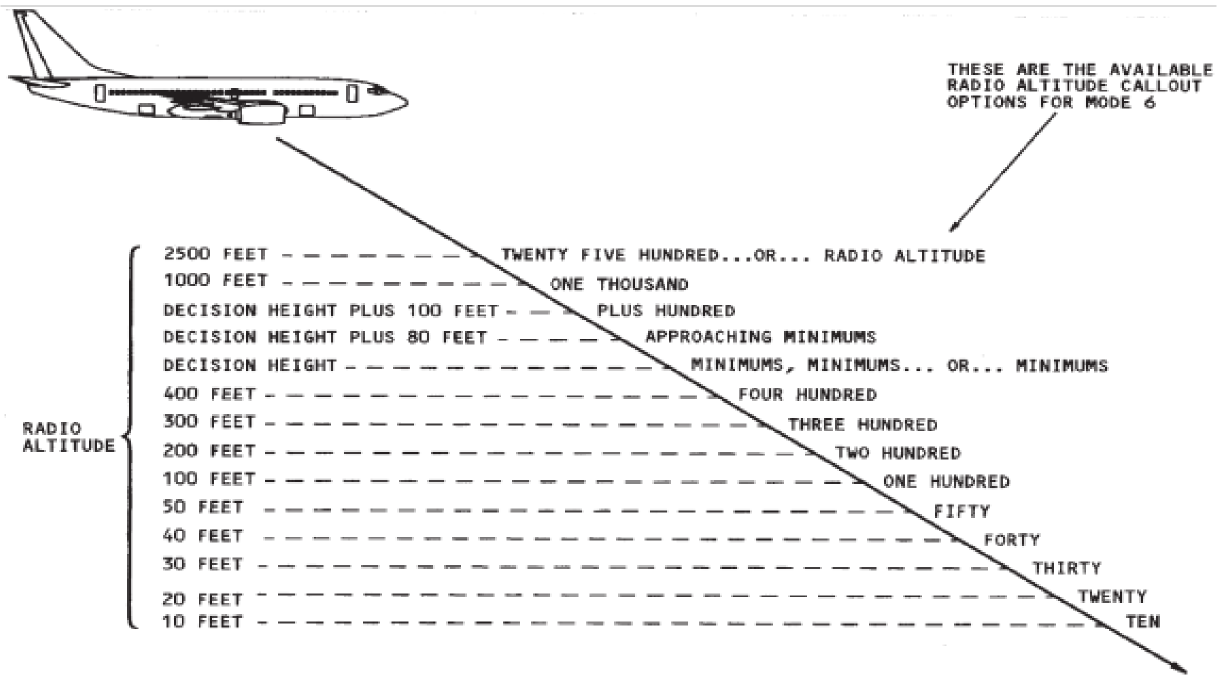

Fig. 1.10. Mode 6-Descent below minimum or advisories.

Mode 7 - Warning for Windshear conditions (Fig.1.11): the GPWC gives mode 7 warnings when there are horizontal and vertical windshear conditions during approach or takeoff. This mode provides warnings during take-off or approach when the altitude is below 1500 feet.

For Mode 7 warnings, the GPWC gives the audible message "Windshear Windshear Windshear" with a sound. The GPWS sends a discrete signal to the DEU to make the red "Windshear" message displayed on the primary flight display PFD (Primary Flight Display). Mode 7 warnings have the highest priority.

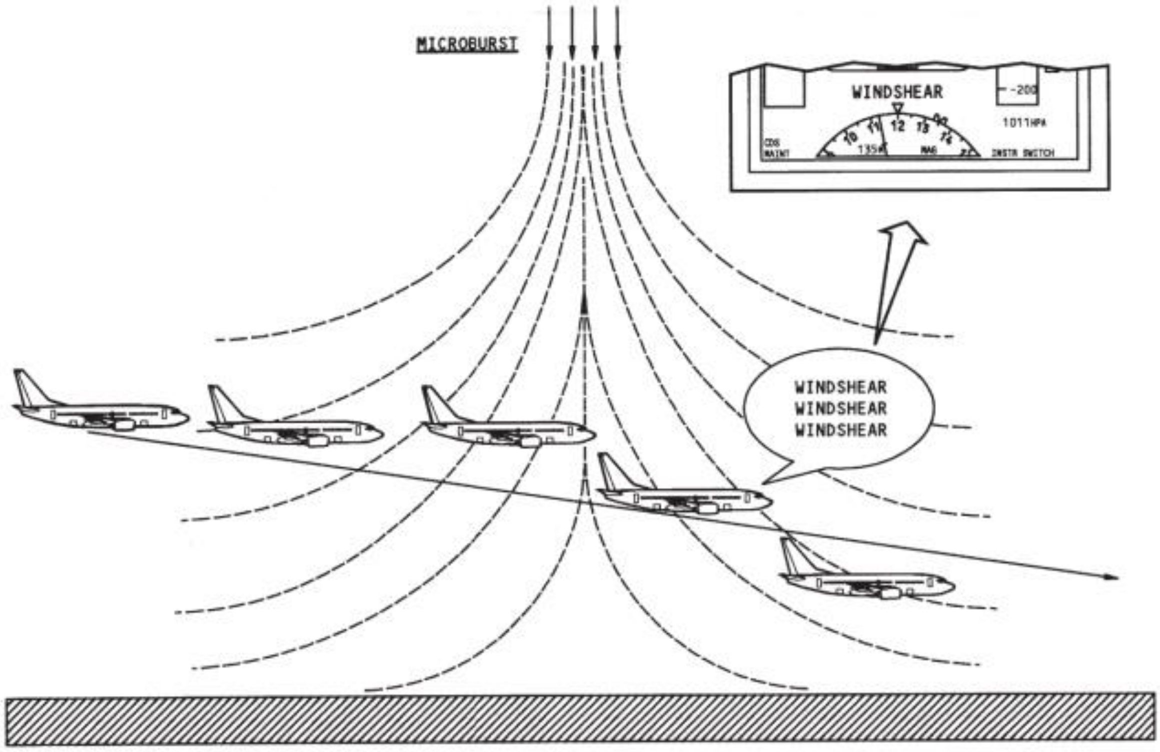

Fig. 1.11. Mode 7-Windshear.

1.3. Interaction of the Terrain Avoidance and Warning System with other systems of an aircraft

EGPWS terrestrial warning systems (TAWS) shall have the following characteristics:

- operate at any time of the day and year in simple and difficult weather conditions at different geographical latitudes, as well as over mountain peaks and water surfaces;
- time of readiness of the product to work after switching on or off the power supply should be no more than 30 seconds;
- The unit must be powered from the on-board direct current network with a nominal voltage of 27 V;

- the device must retain its characteristics after exposure to high humidity (relative humidity up to 90% and temperature up to 40°C).

The EGPWS (TAWS) system is connected to many aircraft instruments and systems. At different stages of the flight, the system computer uses data from the following main instruments:

1) from the GNSS satellite navigation system receiver:

- geographical latitude of the current location of the aircraft;

- geographic longitude of the current aircraft location;

Note. The maximum permissible geographic coordinate error is 0.93 km (0.5 NM) at the landing stage, 1.852 km (1 NM) near the airfield and 3.7 km (2 NM) outside the airfield area;

- geometric height of the aircraft above the reference ellipsoid - the Earth model of the World Geodetic System WGS-84. Maximum permissible error is 100 m; - satellite navigation system (GNSS) accuracy parameter, estimated by the built-in RAIM function. The maximum permissible error is of 100 m for HDOP = 1.5 (Horizontal Dilution of Precision);

2) from the automated flight control system (AFCS) to provide data on airspeed, true heading angle, trajectory inclination angle; 3) from gyroscopic sensors of the spatial position of the sun relative to the horizon plane (from the vertical) to provide information on roll angle; 4) from the air signals system:

- corrected airspeed, calculated taking into account instrumental and aerodynamic corrections. The permissible error is 9 km/h at speeds up to 100 km/h, 3.7 km/h at speeds up to 370 km/h and 7.4 km/h at speeds up to 834 km/h - altitude by barometric altimeter;

- vertical speed;

5) from the ILS or MLS radio landing system - analog signals in the form of voltages proportional to the deviations of the aircraft from the equal signal zones and glideslope trajectories of the ILS radio landing system, and subsequently MLS, course readiness signals and glideslope trajectories, as well as signals proportional to the selected landing course with a tolerance of 2°;

6) from the radio altimeter - an analog signal in the form of a constant voltage that is proportional to the true altitude of the Sun above the terrain of the Earth's surface in the operating range of the radio altimeter, and a discrete signal (+27 V) about its serviceability. Acceptable error is 1 m (or 4%) in the range 0 ... 150 m and 5% - over 150 m;

7) from landing gear and flaps position indicators, in particular from

- the flaps release limit switch to the landing position for sending a discrete signal to the EGPWS processor (+27 V);

- limit switch for the compressed position of the front landing gear strut (aircraft on the ground) to supply a discrete signal to the EGPWS processor (+27 V);

- the limit switch of the chassis exhaust (usually the left strut) in the "landing" position to supply a discrete signal to the EGPWS processor (+27 V);

8) from the automatic angle of attack sensor and overload alarm (AUASP) for short-term interruption of the EGPWS system functioning in case of a threat of aircraft stall;

9) from an external temperature sensor to take into account changes in engine efficiency caused by temperature changes. The maximum permissible error is 4.5°C;

10) from the centering and fuel consumption sensors to obtain information on the current value of the aircraft weight taking into account its rate of climb. The maximum permissible error is 100 kg.

If EGPWS system is installed on domestic aircraft equipped with analog systems, a universal interface unit, which performs analog-to-digital conversion of information, is necessary for operation of the digital computer (this device is not shown in the diagram in Fig. 2.29). The EGPWS computer is connected to TCAS II. When a threat of collision with the ground is detected and sound and light recommendations are issued, the TCAS II system is signaled to switch to the "TA ONLY" mode, in which this system does not issue any recommendations and sound messages. This provides the priority of the EGPWS system. The EGPWS computer sends a failure signal and signals corresponding to the issued emergency recommendations for recording in the MSRP flight data recording equipment. EGPWS system reproduces voice messages and recommendations through the onboard intercom (OIC) and loudspeaker (LSU) devices.

Conclusions of Chapter 1

In this section, the problems of aircraft collision with the ground and objects during controlled flight were considered, as well as an overview of the history of the development of TAWS systems on aircraft.

Section 1 also includes a general overview of the main modes of GPWS operation and their features. It is worth noting that with the development of technology and the introduction of the EGPWS system, there are more available modes of operation of this system, and their algorithms have become more complex. However, this allows to provide a high level of "predictability" of the collision with the ground.

An important part of Chapter 1 is the analysis of GPWS operation in conjunction with other aircraft systems that provide data for processing in the system.

CHAPTER 2

THE TERRAIN AVOIDANCE AND WARNING SYSTEMS OF MODERN AIRCRAFT

2.1. Overview of the terrain avoidance and warning system «GPWS-2000» of the AN-148 aircraft

When interacting with the aircraft's avionics, the GPWS-2000 system is intended to warn the crew of a possible situation, the development of which may lead to an unintentional collision of the aircraft with the ground or water surface, as well as for early warning in the presence of danger in the direction of flight and in case of untimely descent. Prevention is carried out by giving voice and light signals, as well as by forming visual information about the nature of the underlying surface on the MFI on the basis of electronic databases of the terrain, artificial obstacles and airfields in the direction of flight.

The warning alarm is issued in the following modes:

- Mode1: if the vertical barometric rate of descent exceeds the set thresholds;
- Mode 2: exceeding the set threshold values of the rate of approach to the ground or water surface;
- Mode 3: loss of barometric altitude during takeoff or departure for the second circle;
- Mode 4: flight near the ground surface with flaps not in landing configuration or with landing gear not released;
- Mode 5: excessive downward deviation from the radio glide path in excess of the established threshold value during landing;

- Mode 6: passing a set threshold value of the difference between the relative barometric and geometric altitude;
- Mode 7: passing a number of predetermined altitude values during the landing approach; issuing voice messages;
- Mode 8: if roll thresholds are exceeded on the route and during landing approach;
- in case of danger in the direction of flight (early warning);
- in case of premature descent.

2.1.1. Description of system

The block of GPWS-2000 is a structurally and functionally complete device, which performs all the functions of the GPWS system, collects information from the connected systems, processes, converts it and issues warning signals to the crew.

The following devices are installed on the front panel of the unit: a fuse holder; a connector designed to connect, if necessary, to a PC for diagnostics of the GPWS; two LEDs "Counter. 1", "Counter. 2", "Counter. 3" are covered with lenses. An electrical connector designed to connect the unit with the aircraft feeder is installed on the rear panel of the unit. It is installed and mounted on the frame. Grounding bars are provided on the unit and frame to ensure metallization.

The GPWS-2000 structural diagram is shown in Fig. 2.1. The sources of input information of the system are:

- Radio altimeter A-053 - provides the system with radio altitude signal and its serviceability signal;
- ICHSP system (Information complex of high-speed parameters) - outputs to the system signals of relative (N_{rel}) and absolute (N_{abs}) barometric altitude, instrument speed (V_{instr}), vertical speed (V_v) and signals of its serviceability;
- Course 93M - provides deviation signal from radio glide path and serviceability signal;
- Course vertical No. 2 - outputs signals of gyromagnetic heading roll;

- OSL - outputs signals of a given track angle, track speed, geographical coordinates;
- CSGAE (Control system for general aircraft equipment) - outputs single commands "Landing gear engaged" (LGE), "Landing gear released" (LGR), "Flaps - in landing position" to determine the stages of flight and enable different modes of the system operation on the input of the GPWS.

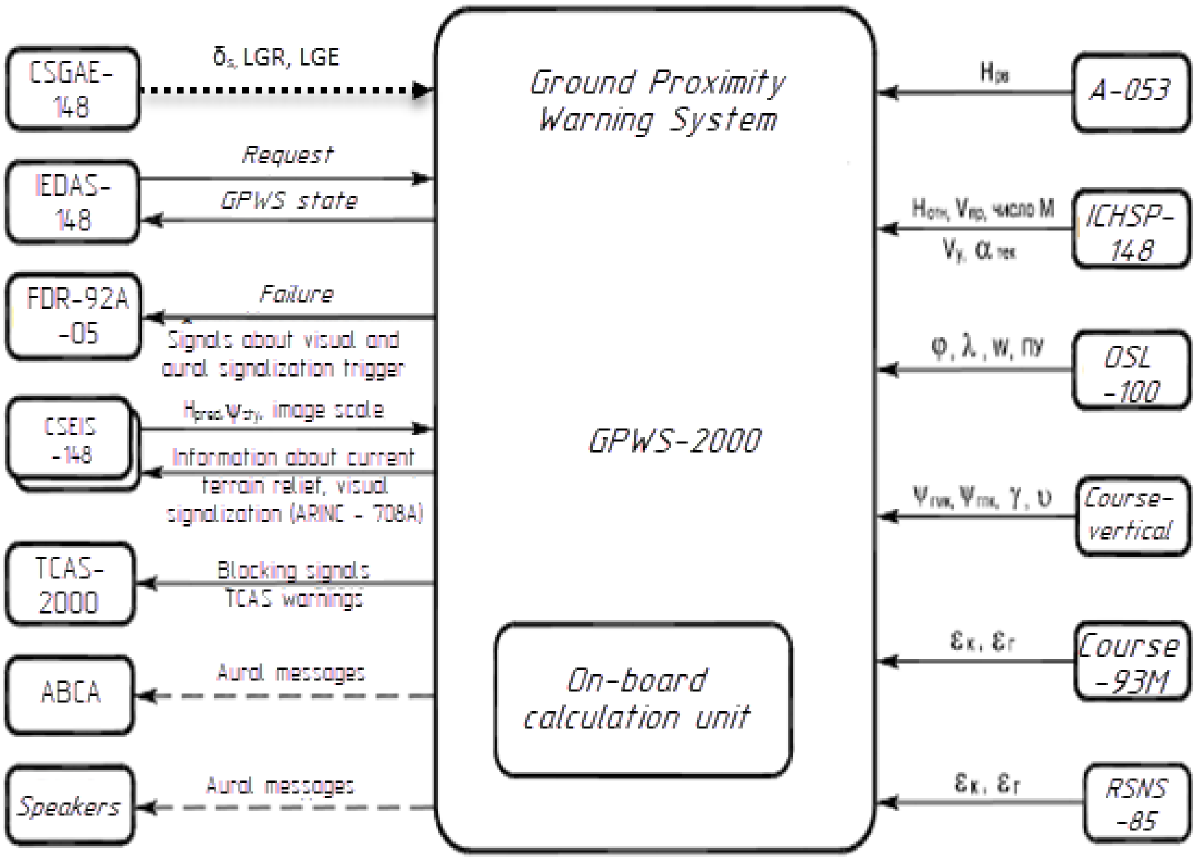

Fig.2.1. Structural scheme of the GPWS-2000

The signals of the input information sensors are analyzed in the GPWS. When the incoming signals correspond to dangerous situations, the onboard computer (OC) generates signals about the danger coming to the CSEIS, the internal communication system in the flight recorder. Announcements (in a female voice) are listened to in the phones and are accompanied by light signaling on the indicators of the CSEIS. Indicators of the CSEIS are shown in the table of messages.

Before the message "PULL UP" two "WHOOP" beeps of variable pitch and volume are always emitted. In case of simultaneous receipt of two or more commands, the command with higher priority is issued. Automatic transfer switchboard is powered by direct current of 27 V from the busbar Bus1 of the left switchgear 27 V through automatic transfer switchboard protection device.

Control and monitoring bodies of the AN-148 aircraft GPWS-2000 are shown in Fig. 2.2.

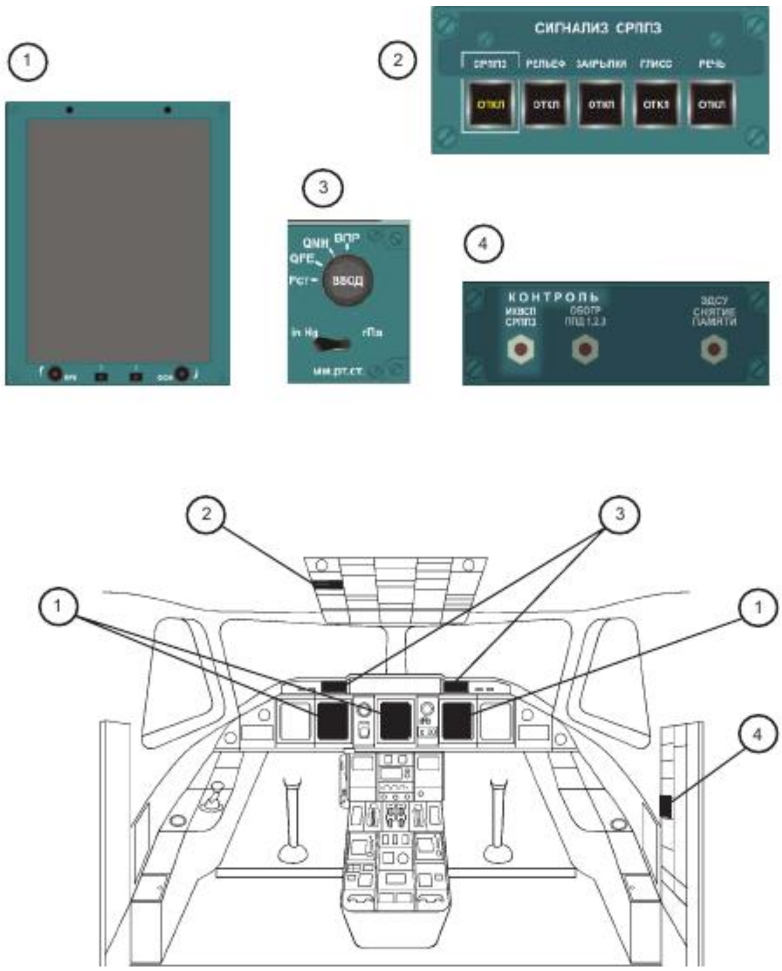

Fig.2.2 Control and regulation units of GPWS-2000 of AN-148 aircraft

2.1.2. The GPWS-2000 system principle of operation

Primary information sensors signals are analyzed in the computer. When the value of the input signals corresponds to dangerous situations, the computer generates danger signals that are sent to the SPU, to the display and to the flight recorder.

The built-in system controls provide:

- formation of the signal Serviceability of the SGPWS;

- blocking of the warning signal in the absence of serviceability of the GPWS;

- preflight check without the use of control and verification equipment.

The system is checked by pressing the button "CONTROL of ICHSP, GPWS" on the right panel of the preflight preparation.

The flight information display on the instrument panel is shown in Fig. 2.3.

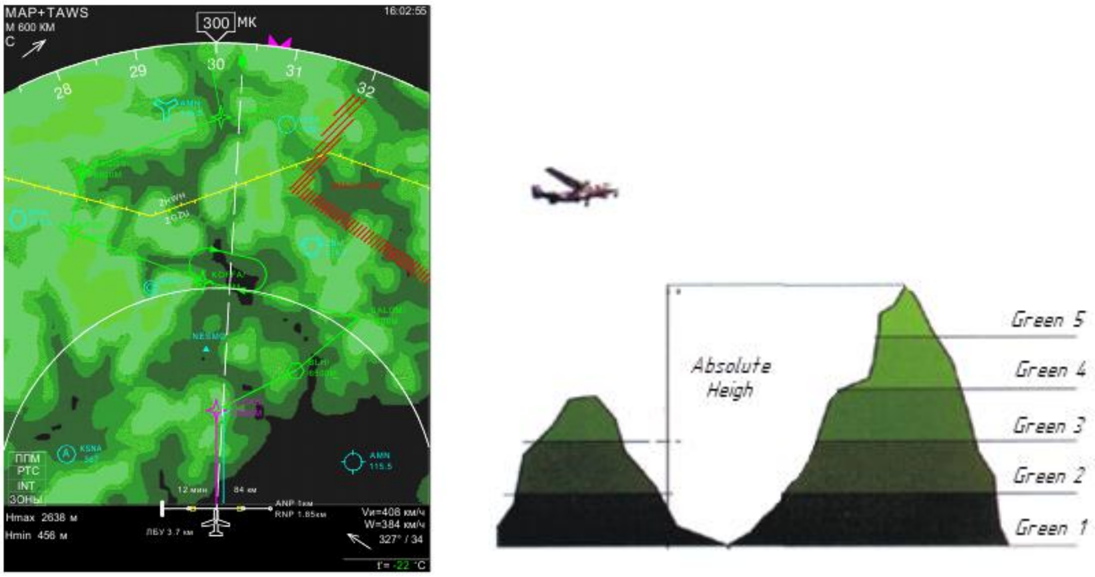

Fig.2.3.a) Screen with “MAP + TAWS” (absolute heights)

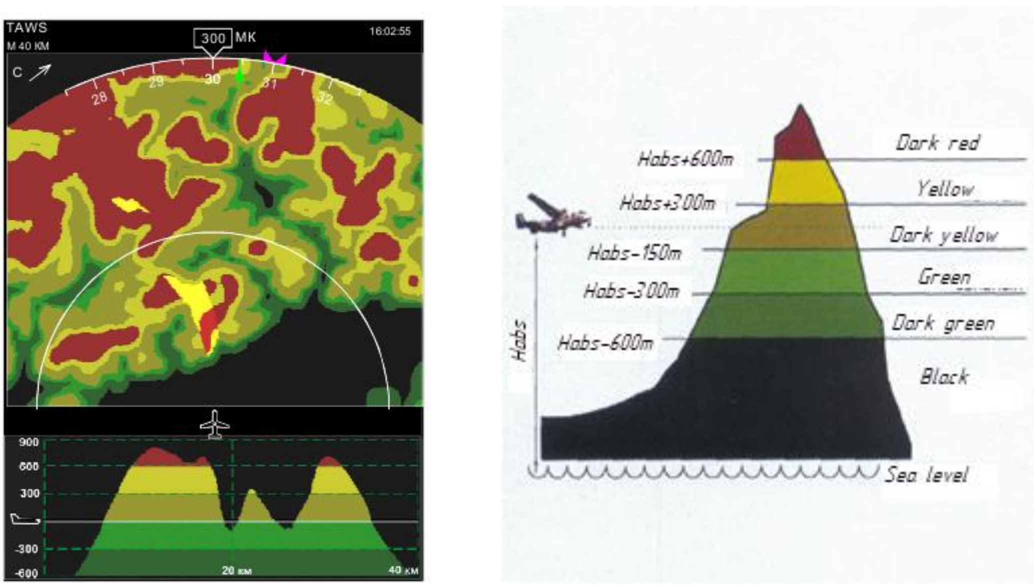

Fig. 2.3.b) Screen “TAWS” (relative heights)

Messages displayed on the CSEIS indicators and their audible warnings are shown in Table 2.1:

Table 2.1

Message and audio support (text + (т) tone + (v) voice)	Indicator			Reason of message
	«CPI»	«CISS»	«MFI»	
	Message category			
1	2	3	4	5
DANGEROUS TERRAIN + (v) DANGEROUS DESCEND , PULL UP (t) wup-up	Emer	-	-	The rate of descending is greater than limits which set for Mode 1.
DANGEROUS TERRAIN+ (v) a) TERRAIN, TERRAIN, PULL UP + (t)wup-up (v) б) TERRAIN	Emer	-	-	The speed of approaching the terrain exceeds the limits for mode 2
DANGEROUS TERRAIN + (v) DO NOT DESCEND	Emer	-	-	Loss of the altitude during take-off and returnto the second circle, which exceeds the established limits for Mode 3
DANGEROUS TERRAIN + (v) a) LOW LANDING GEAR, LOW TERRAIN (v) б) LOW FLAPS, LOW TERRAIN.	Emer	-	-	The altitude lower than permitted in non-landing configuration (mode 4 «GPWS »)
DANGEROUS TERRAIN + (v) TERRAIN AHEAD+	Emer	-	-	

(t) «vup» twice + (v) PULL UP Change the color of the underlying surface in the alarm zone to the red.	-	-	+	The presence of dangerous elements of the terrain surface («GPWS » mode)
TERRAIN + (v) TERRAIN AHEAD (v) LOW TERRAIN + Change the color of the underlying surface in the alarm zone to yellow	Warn -	- -	- +	
LOWER THAN GLIDEPATH + (v) GLIDEPATH	Warn	-	-	Deviation down from glidepath (mode 5 «GPWS »)
TERRAIN + (v) HAZARD AHEAD+ (t) «vup» twice + (v) PULL UP	Warn	-	-	Premature descending during the final landing approach («ПСВ» mode)
(v) CHECK OUT THE ALTITUDE	-	-	-	Difference between the relative barometric altitude and the true altitude at landing approach using the pressure QFE (Mode 6 « GPWS »)
(v) THREE HUNDRED, ONE HUNDRED FIFTY, ONE HUNDRED, SISXTY,	-	-	-	Passage of the altitudes predetermined above the surface of the ground in a

THIRTY, TWENTY, FIFTEEN, TEN, FIVE, THREE, TWO, ONE				mode of descending (mode 8)
BREAKDOWN RELIEF	-	Warn	Warn	Breakdown the early warning function
«СРППЗ» BREAKDOWN + (t) bell	-	Warn	Warn	Total failure of «GPWS»
«СРППЗ» TURN ON INDICATION + (т) bell	-	Warn	Warn	Appearance in the range of the work of the « GPWS » relief on height ≤ 610 meters.
+ FLASHING YELLOW POINTER OF THE BOUNDARY ROLL (V) HIGH ROLL	Warn	-	-	Achievement of the boundary roll
NO CONNECTION WITH « GPWS » + (t) bell	-	-	Warn	Lack of communication with the system of « GPWS » when the information indicator from the « GPWS » is displayed info.

2.2. Overview of the enhanced ground proximity warning system of the Boeing-737 NG aircraft

2.2.1. General description and operation

The EGPWS system of the medium-haul aircraft "Boeing 737 NG" is designed to warn the crew about dangerous flight conditions when approaching the ground, as well as to warn about flying in gusty wind conditions. Warnings are provided by visual and audible alarms.

EGPWS consists of the following components (see Fig.2.4):

- The two loudspeakers;
- The two amber "BELLOW G/S" warning buttons;
- The ground proximity warning module EGPWM (Enhanced Ground Proximity Warning Module);
- The ground proximity warning computer EGPWC (Enhanced Ground Proximity Warning Computer);
- The PIN Program switch module;
- The TERR/WXR relay 745;
- The TERR/WXR relay 746.

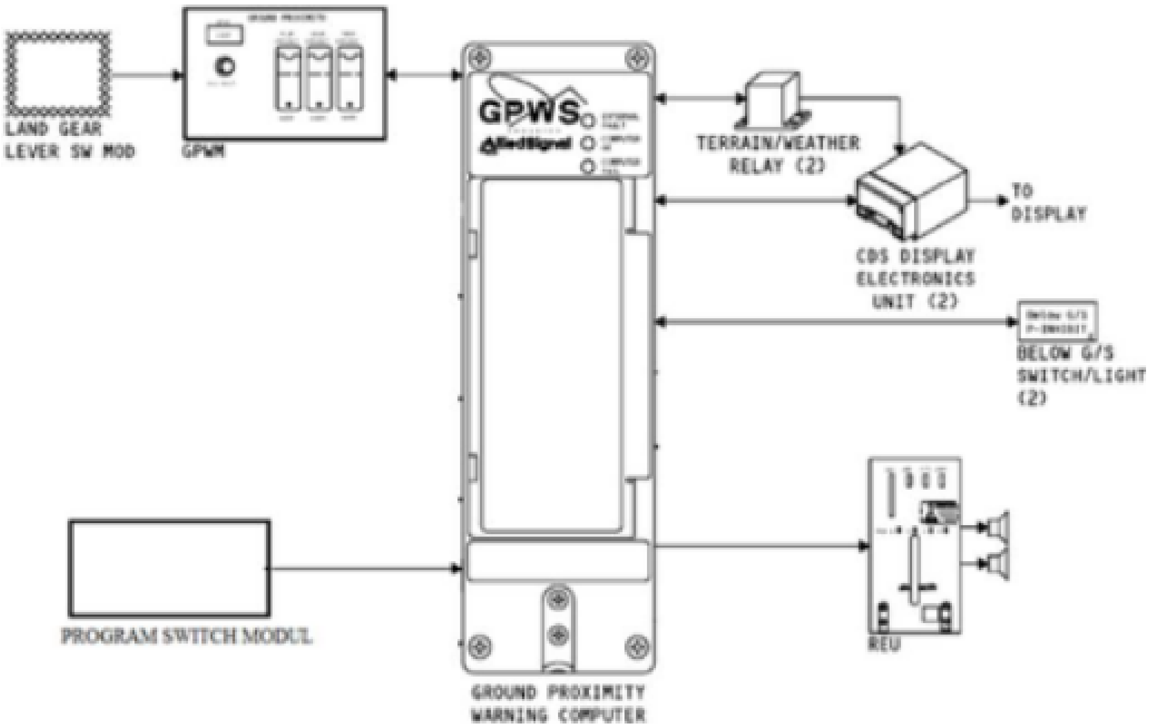

Fig. 2.4 Block diagram showing the components of the EGPWS

The components that make up the EGPWS are located in different places in the aircraft: in the cockpit, in the electronic payload bay, etc. The EGPWS components that exist in the cockpit are located as shown in Fig.2.5:

1. Two speakers: The speakers are connected to the EGPWS through the REU (Remote electronic unit) and provide electronically generated warnings from the EGPWS.

2. Two amber "BELLOWS G/S" control buttons: The "BELLOW G/S" indicator buttons have two functions - they light up flashing to warn the crew that the aircraft is below the Glideslope track during mode 5; to deactivate Mode 5, simply press one of these indicator buttons.
3. The ground proximity warning module EGPWM: it is the interface for interaction between the crew and the EGPWS.

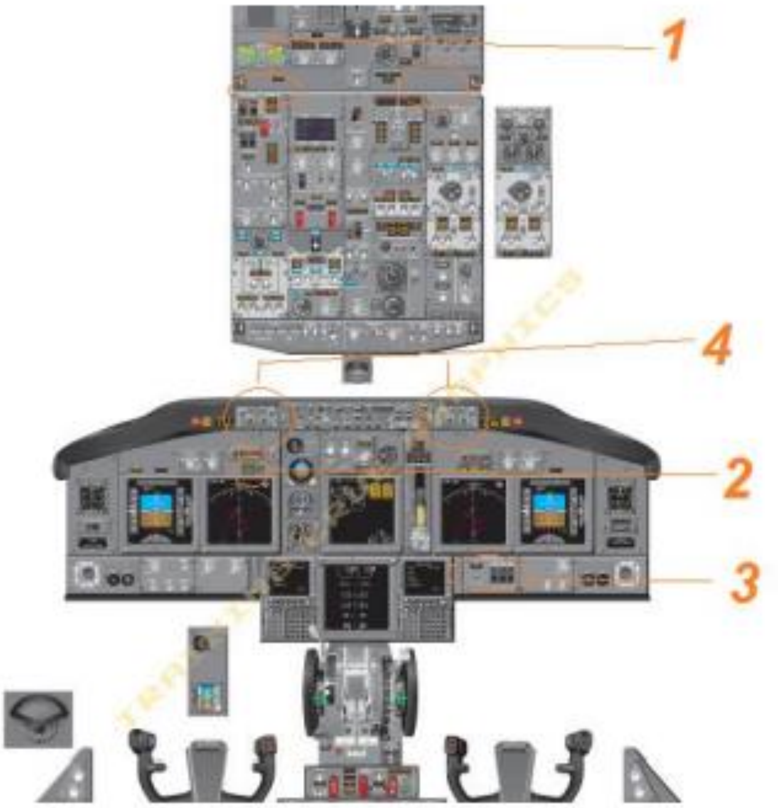

Fig. 2.5 Location of EGPWS components in the cockpit

The Ground proximity-warning computer (EGPWC) is located in compartment E1 of the electronic bay on shelf E 1-1 (Fig.2.6). The GPWC is the main component of the EGPWS system, comparing the profile of the aircraft flight. The position of the flaps and airspeeds, and terrain clearance to determine if there is a warning or condition. warning condition. That is, the GPWC compares the aircraft's position and the runway location and determines whether there is a warning condition.

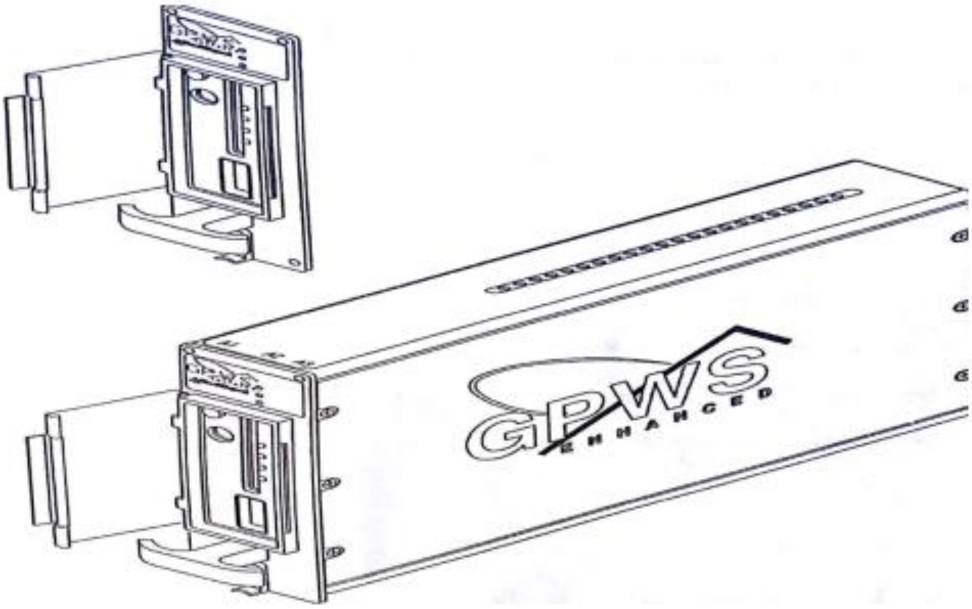

Fig. 2.6 Location of EGPWS components in the cockpit

The main element of GPWS is the ground proximity warning system computer. The computer sets limits for triggering warnings and compares the position of the aircraft relative to the ground with these limits. GPWC generates appropriate signals for audible and visual alarms and transmits them to the appropriate alarms.

Information about the flap and landing gear position is necessary in order to prepare or delay a certain mode. These signals can be ignored by setting the "flap or gear inhibit switch" on the GPWS control panel to the "inhibit" position.

The output signals for alarm visualization are used to illuminate the PULL UP, BELOW G/S alarms and the WINDSHEAR message. These signals are also fed into the TCAS system.

Various flight parameters come from the associated systems and are used to calculate the aircraft status for the ground approach warning system. These input parameters consist of analog and digital signals (Figure 2.7). The output audio signals are fed to the digital audio system and the parametric flight data storage of the ATC. The computer of the ground approach warning system issues a signal to trigger the INOP signal board, if a GPWS failure and/or unreliability of the input signals is detected.

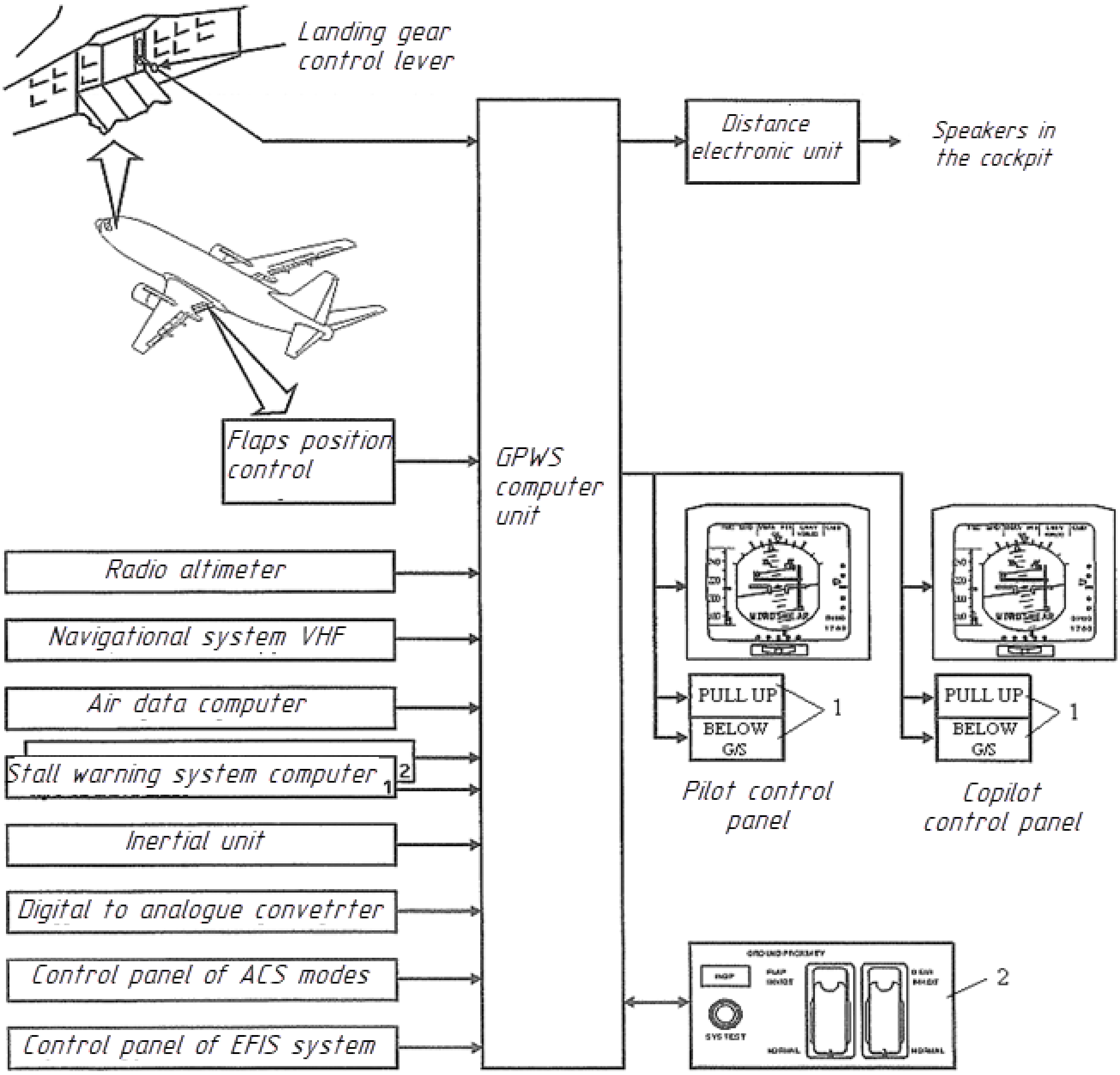

Fig. 2.7. Functional diagram of the EGPWS of the aircraft "Boeing 737": 1 - light signals; 2 - control panel of the ground proximity warning system.

2.2.2. Modes of operation

The EGPWS has seven operating modes, which are automatically activated in the GPWS computer. The pull up light is activated during the first four modes. The mode 5 warning is followed by a "Blue G/S" light, mode 6 produces only a verbal warning, and mode 7 produces only a visual warning. Mode 6 produces only a verbal warning, and Mode 7 produces a warning followed by illumination of the "Windsher" lamp.

- Mode 1: Excessive glide slope.

- Mode 2: Excessive approach rate.
- Mode 4:
  - 4A: Ground proximity to incoming landing gear.
  - 4B: Ground proximity to incoming flaps.
- Mode 5: Descent below glide slope.
- Mode 6: Descent below minimum.
- Mode 7: Warning for windshear conditions.

Each mode of the EGPWS system corresponds to specific visual and auditory indications. indications.

Mode 1: alerting and warning conditions can occur for a radio altitude from 10 to 2450 feet the type of annunciation depends on the rate of descent, and the radio altitude. The first annunciation is an alert. If the rate of descent does not decrease, the annunciation changes to a warning. The LRU (line replaceable unit) provides the inputs and the ADIRU (air data inertial reference unit). The GPWC mode sensor calculates the rate of descent of the inertial vertical speed.If not available, the mode sensor uses an internally calculated altitude rate. If both data are invalid, the barometric altitude rate from the ADIRU is used. When the GPWC uses the barometric altitude rate, the lower altitude cut-off changes from 10 to 30 feet. When there is a warning (danger) to the flight, the mode sensor sends in discrete to GPWC to make advanced audio messages. The audio messages go to REU (remote electronics unit) which sends them to the cockpit speakers. Fig. 2.8 shows the principle of operation of mode 1:

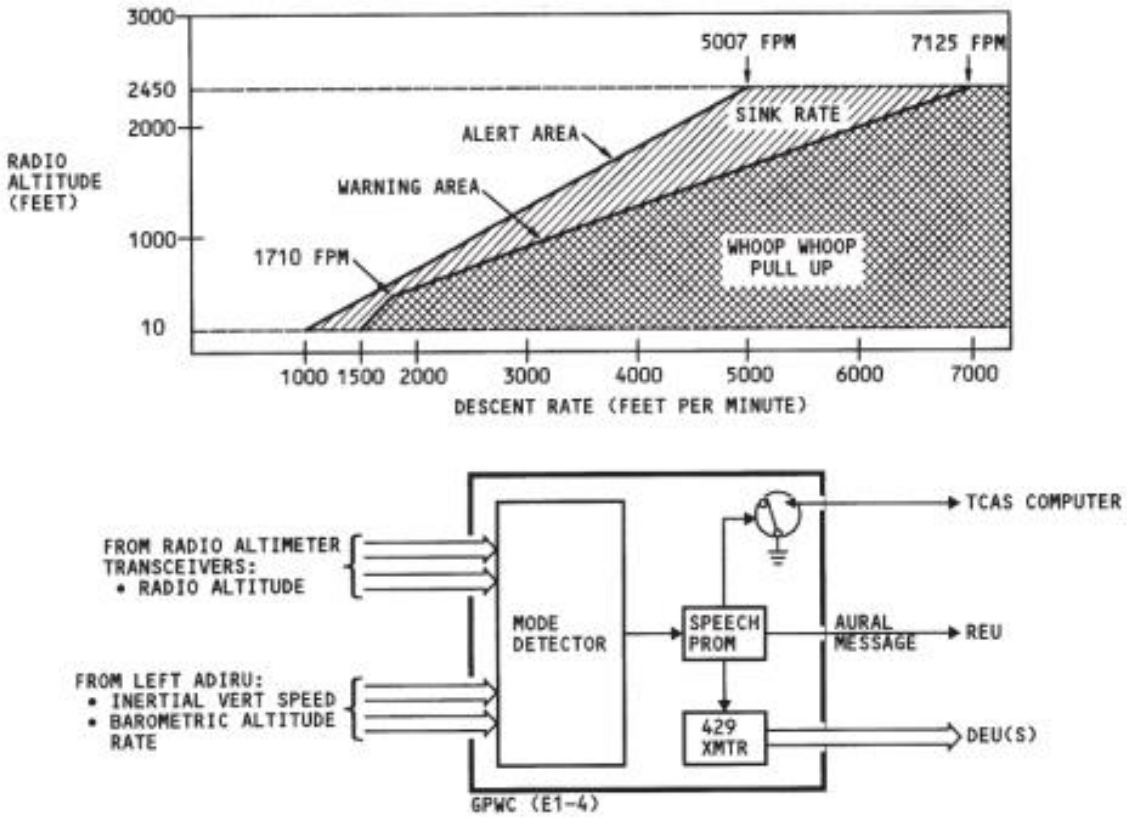

Fig. 2.8. Mode 1 principle of operation

Mode 2 (Fig. 2.9) : alerts occur between 30 and 1650 feet of radio altitude, for airspeeds less than 220 knots. The upper limit rises to 2450 feet of radio altitude for airspeeds between 220 knots and 310 knots. The GPWS uses the rate of descent of altitude and the position of the flaps to calculate the lower limit. When there is a flight hazard warning, the mode sensor sends a discrete signal to GPWC to make the audible messages go ahead.

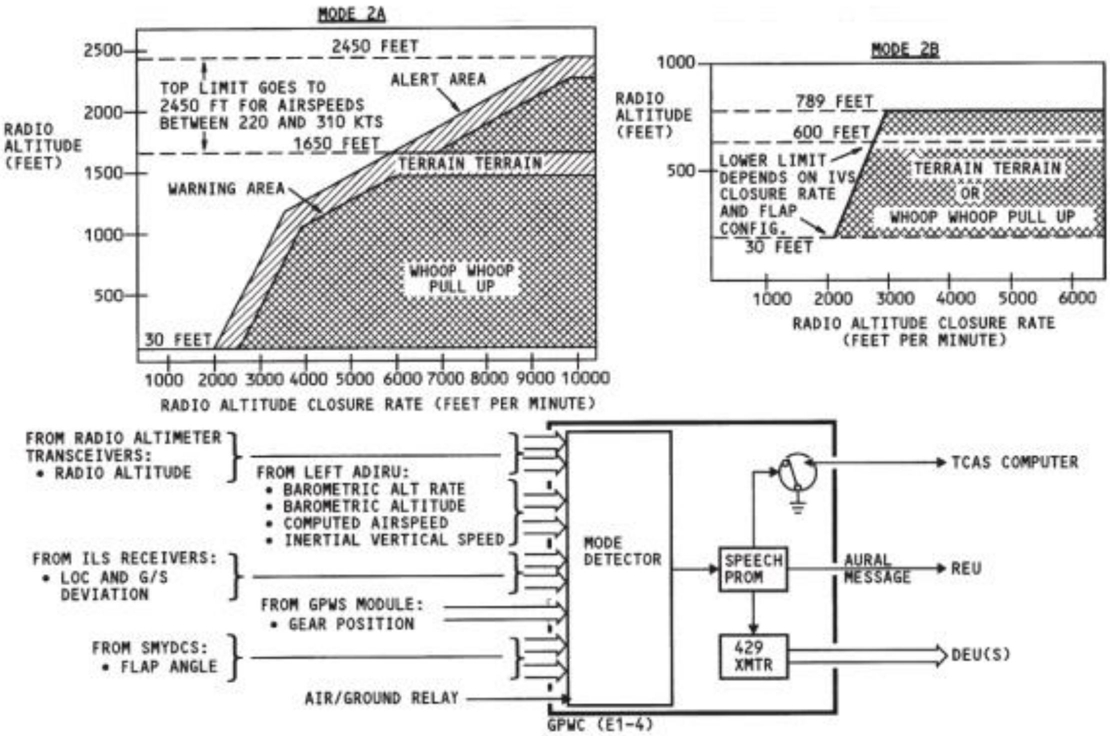

Fig. 2.9. Mode 2 principle of operation

Mode 3 (Fig.2.10) : operates when one of these conditions is true:

- The aircraft rises after being below 245 feet in the landing configuration (gear, flaps 30 units larger).
- Aircraft takes off.
- Mode alerts are produced between 30 and 1500 feet.

The 3A mode alert changes with the change in aircraft altitude rate, and the 3B mode alerts occur when the aircraft altitude is lower than the altitude value given by the GPWC. The filter begins operation while climbing at 150 feet and retains 75% of the actual aircraft altitude.

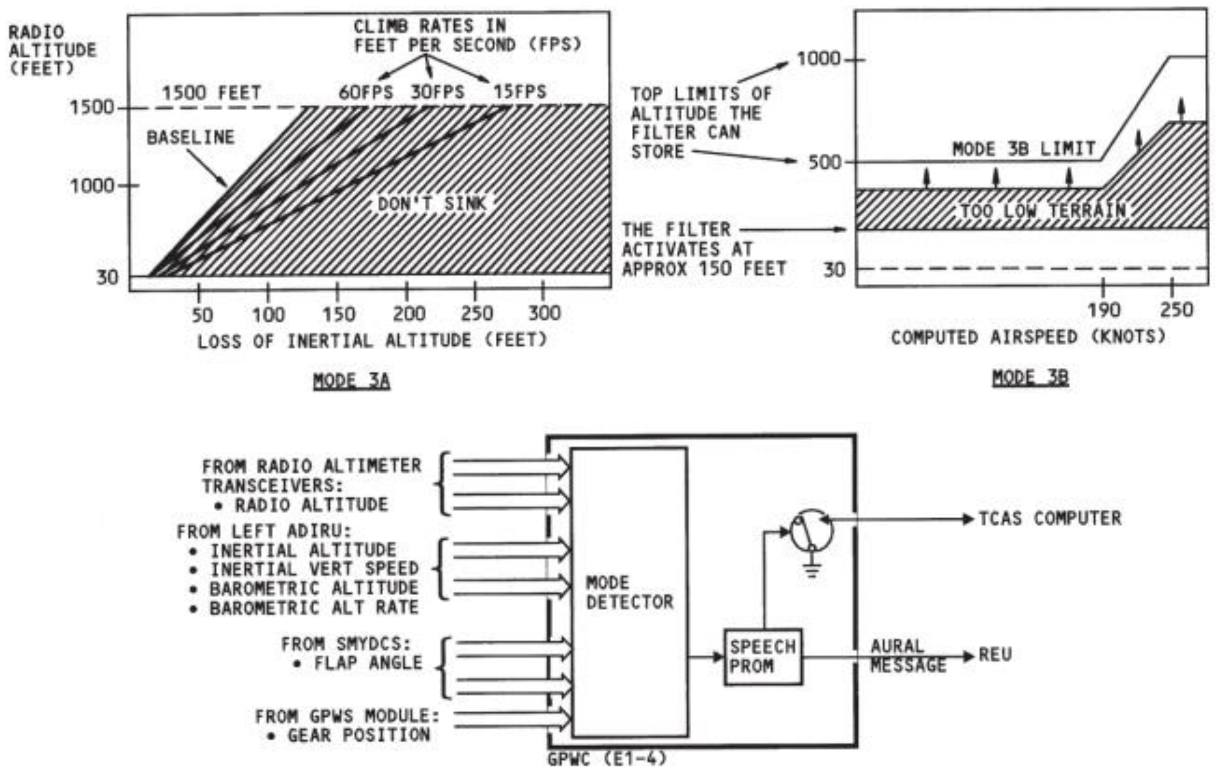

Fig. 2.10. Mode 3 principle of operation

Mode 4 (Fig. 2.11): warnings occur between 30 and 1000 feet. The altitude limits for Mode 4A and Mode 4B are lower at low airspeeds.

The Mode 4A alert occurs if the landing gear is not down below the altitude limit. The mode 4A altitude limit is 500 feet when the airspeed is below 190 knots, and 1000 feet at high airspeed. The Mode 4A "TOO LOW GREAR" auditory message changes to "TOO LOW TERRAIN" when the airspeed is below 190 knots.

The Mode 4B alert occurs if the landing gear are down and the flaps are not configured for landing below 190 knots. configured to land below the altitude limit. The 4B mode altitude limit is 245 feet when the airspeed is below 159 knots and it is 1000 feet at high airspeed. at high airspeed.

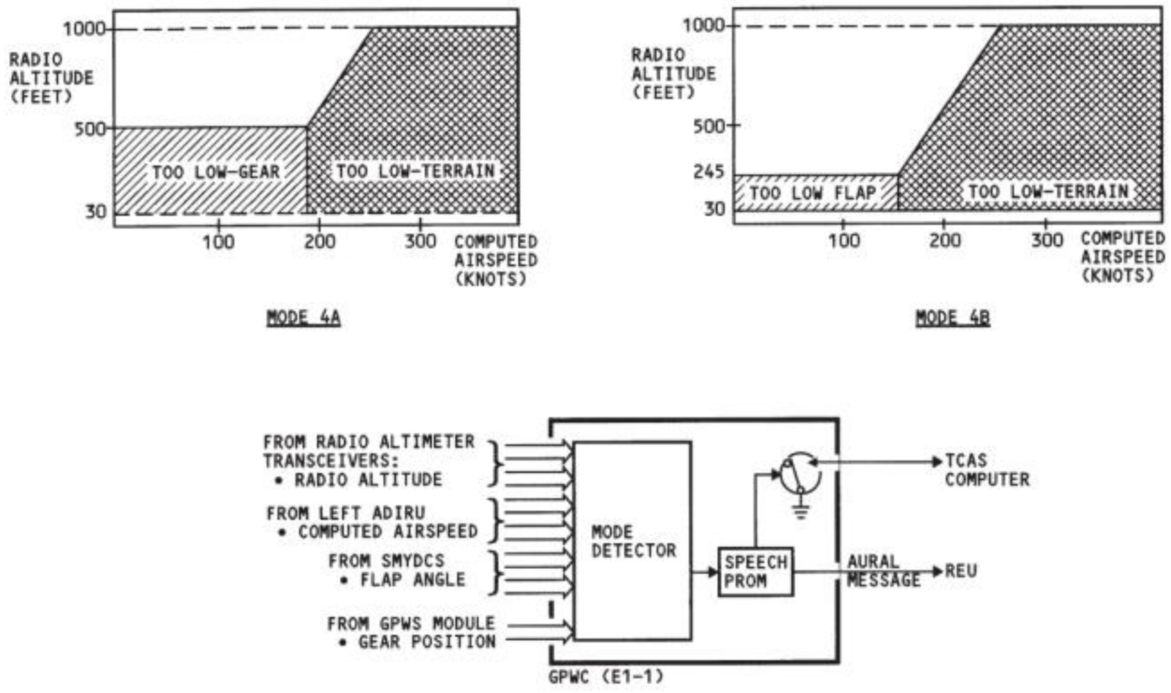

Fig. 2.11. Mode 3 principle of operation

Mode 5 (Fig.2.12): alerts can occur between 30 and 1000 feet radio altitude. The interval of the audible messages depends on the altitude and the glide slope deviation.

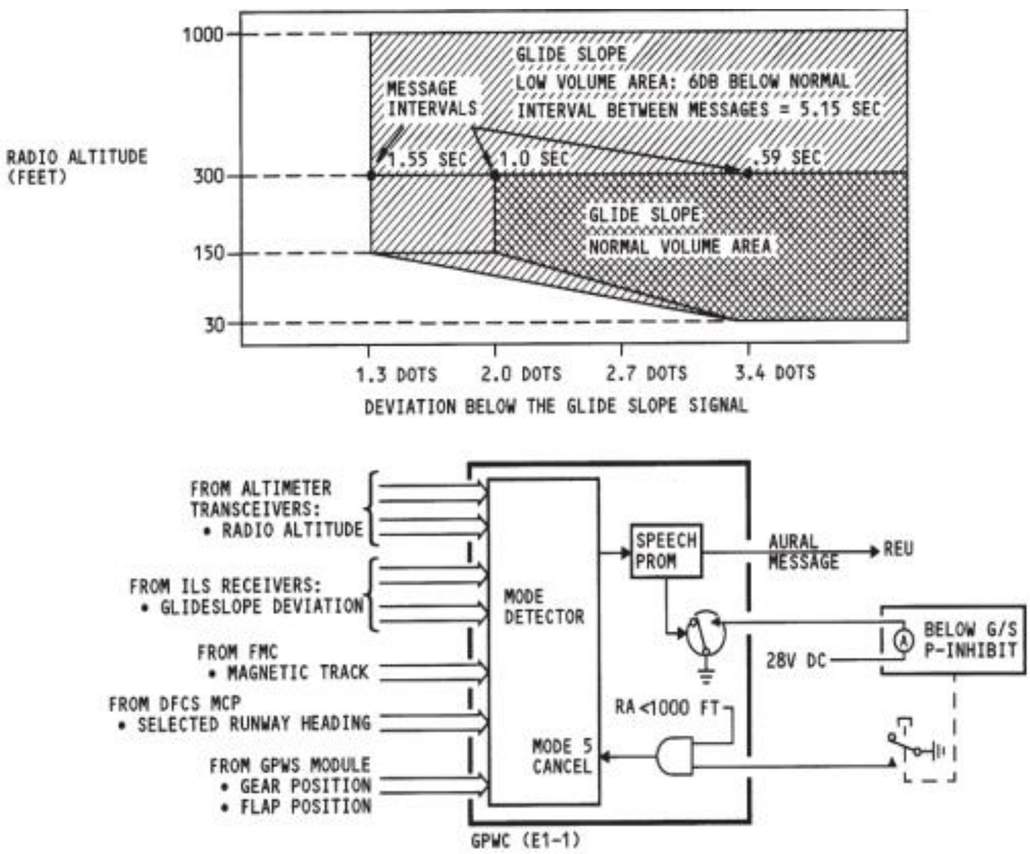

Fig. 2.12. Mode 3 principle of operation

Mode 6: low angles of attack occur when the aircraft's angle of attack is plus 10 degrees and the altitude between 30 and 130 feet. Above 130 feet the angle of attack occurs between 30° and 45°, the audible message given is "BANK ANGLE, BANK ANGLE".

The GPWC receives inputs from the following units:

- Radio altimeter.
- GPWS module.
- Left ADIRU.
- DEU 1 and 2.

The GPWC uses this data to calculate Mode 6 alerts:

- Radio altitude.
- Landing gear position.
- Rolling altitude.
- Decision gauge.

Mode 7: The GPWS gives "WINDSHEAR" warnings for these conditions:

- A large volume of wind pushed the aircraft vertically to the ground.
- A sudden change in airspeed.
- The LRU supply data for mode 7 operation is:
- Radio altimeter transceivers.
- ADIRU (air data inertial reference unit).
- SMYD (stall management yaw damper).
- The GPWS uses this data to detect a windshear condition:
- Radio altitude (AT).
- Inertial vertical speed.
- Indicated angle of attack (ADA).
- Yaw and roll angle.
- Minimum operating speed.
- Flap position.
- True and calculated airspeed.

For Mode 7 warnings, the GPWC gives the audible message "Windshear Windshear Windshear" with a sound. The GPWS sends a discrete signal to the DEU to make the red "Windshear" message displayed on the primary flight display PFD (Primary Flight Display). Mode 7 warnings have the highest priority.

Conclusions of Chapter 2

When comparing the AN-148 Ground Proximity Warning System and the Boeing-737 NG Enhanced Ground Proximity Warning System, it is possible to note that both systems use information obtained from sensors of different aircraft systems. In both cases, the radio altimeter is the main sensor which can directly measure the altitude of the aircraft above the ground, but it has certain limitations in measuring altitude, as its operating range is from 0 to 1500 m of true altitude measurement.

To predict the situation of collision of the aircraft with the ground, the terrain is estimated in the direction of flight. During prediction, it is impossible to directly measure the intensity of changes in the terrain relief at a projected point, so mathematical modeling methods are used in prediction.

To improve the accuracy of predicting warnings of dangerous approach to the ground, it is necessary to measure the change in the terrain at a certain safe distance in the direction of the aircraft movement. Therefore, for such measurements it is offered to use onboard radar and radio remote sensing systems.

CHAPTER 3

MEASUREMENT OF PROJECTED ALTITUDE ON THE AIRCRAFT FLIGHT PATH

Implementation of Terrain Avoidance and Warning System (hereinafter TAWS) allows to increase the time given to the crew to make decisions and correct piloting errors. The main sensor of the early warning system that directly measures the distance to the ground is a low altitude radio altimeter, but it can only measure the true altitude (H_0) under the aircraft. When flying at low altitude, it is necessary to predict the trajectory of the aircraft and consider the possibility of its approach to the earth's surface at critical altitudes. Prediction is performed at a certain projected distance, sufficient to perform an emergency avoidance maneuver.

Such forecasting is currently performed by the TAWS. The prediction is made relative to the known coordinates of the aircraft, which are determined by the flight computer system (FCS) on the basis of the known course, which is determined by the heading system. The result of the prediction is a point of airspace on the flight path of the aircraft at a certain projected distance sufficient to perform the maneuver to avoid collision with an obstacle. Prediction of the possible approach of the aircraft flight trajectory to the earth's surface at critical altitudes is performed by calculating the true height of the trajectory at the projected point in accordance with the digital terrain model of the earth's surface stored in the memory of the flight control computer system.

In such way, the work of TAWS to avoid collision with the ground surface is reduced to determining the true altitude of the aircraft flight path in some projected point. The existing prediction system has a number of disadvantages, the main of which are errors in measuring the course and coordinates of the aircraft location, inaccuracies in the map of absolute heights of the earth's surface relief due to artificial and natural changes in relief. To reduce the impact of inaccuracies on the forecasting results, it is necessary to use sensors for direct measurement of the intensity of changes in the terrain.

To avoid collision with the earth's surface, the aircraft must maneuver in the vertical plane in compliance with the safe true height H_0 above the earth's surface. Such a flight is called a profile flight.

3.1. Flight with terrain envelope

The flight at low altitudes with enveloping of terrain is called profile flight. To perform a safe profile flight, profile flight radars are used as a sensor for direct measurement of changes in the terrain relief at some projected point.

To perform a profile flight, it is necessary to know the projected altitude of the aircraft at the safe range D_0, which is chosen so that there is time to perform the maneuver with permissible overload. By comparing the measured projected altitude Hy with the specified (safe) H_0, the automatic system controls the aircraft so that the projected altitude is always greater than the specified one:

$$H_y \geq H_0$$

Two types of trajectory profile flight are distinguished: :

- with maneuvering in the vertical plane;
- with maneuvering in the horizontal plane,

which in turn have subspecies.

Flight with maneuvering in the vertical plane along the envelope of the obstacle tops must be performed in such a way that the height of the flight path is not less than the specified one (Fig. 3.1). And in the areas between the tops of obstacles, the flight is performed along the shortest trajectory.

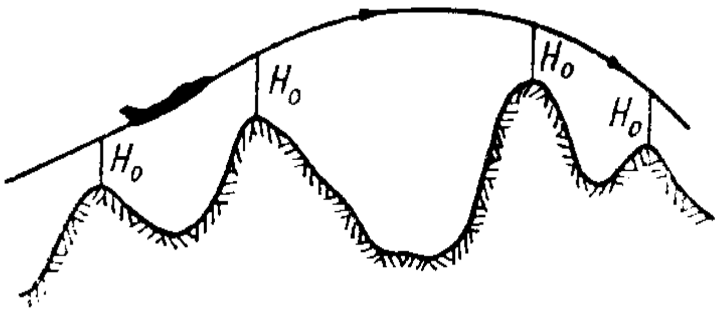

Fig. 3.1. Flight with envelope of obstacle tops

The flight with maneuvering in the vertical plane, which provides the closest approximation of the trajectory to the vertical profile of the terrain, is called a flight with terrain envelopment (Fig. 3.2).

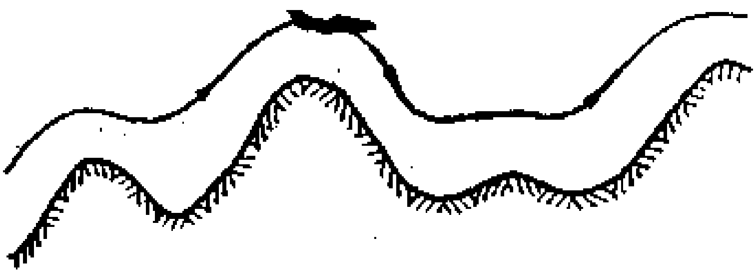

Fig. 3.2. Flight with terrain bending

Flight with maneuvering in the horizontal plane, in which the aircraft bypasses the highest obstacles without changing the flight altitude is called obstacle avoidance flight (Fig.3.3).

Fig. 3.3. Flight with obstacle avoidance

Flying at low altitudes during manual piloting sharply increases the risk of collision with suddenly arising obstacles [5]. The pilot does not have time to react to the appearance of obstacles, so to improve flight safety, aircraft control at low altitudes must be automated or provide an alarm about changes in the terrain.

When flying around obstacles, the aircraft shall perform the maneuver in the vertical plane in compliance with a constant safe altitude H_0 above the ground surface (Fig.3.4).

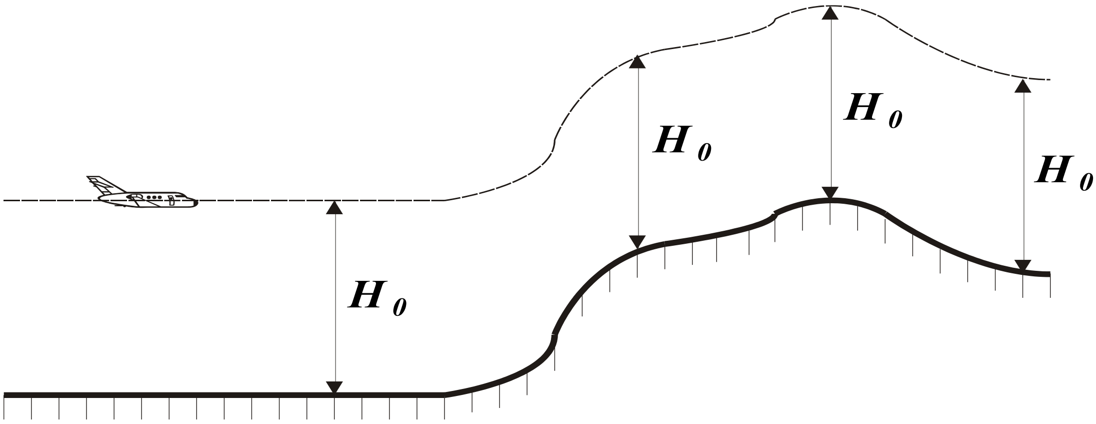

Fig. 3.4. Flight pattern with obstacle avoidance at low altitude

Such profile flights are impossible without ground reference sensors, i.e. profile flight radar (PFR), which warn the crew in advance about the presence of obstacles on the flight path, as they can receive information about the range and projected altitude in any weather conditions, in any lighting. There are rangefinder and anglefinder radars.

The projected height N_y above the point of the earth's surface ahead of the aircraft at range D is determined from the AOB triangle (Fig. 3.5):

$$H_y = D\sin\beta,$$

where *D* – range measured to the projected point;

β - angle of inclination of the beam of the antenna pattern (AP) of the PFR relative to the velocity vector.

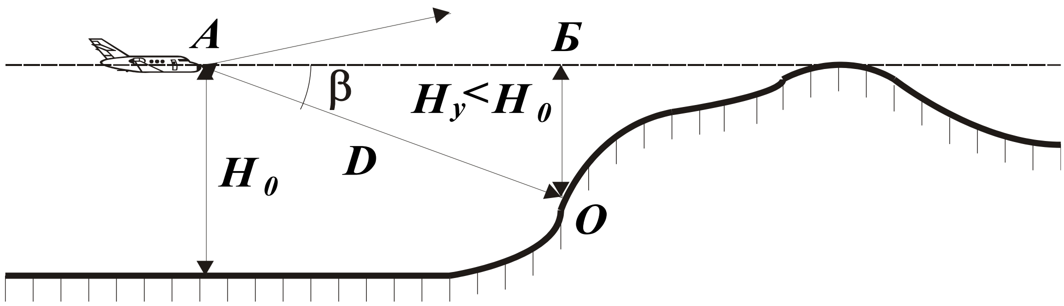

Fig. 3.5. Scheme of projected height calculation

There are long-range and angular radars. In the **long-range radars**, the antenna is fixed, and the beam of the AP is fixed at an angle β to the aircraft axis. To overcome the obstacle, the range to the projected point is measured. During the flight, a maneuver is performed in the vertical plane so that the measured range D is equal to the safe reference range D_0. In this case, the projected height N_y will be equal to the reference height H_0 (Fig. 3.6).

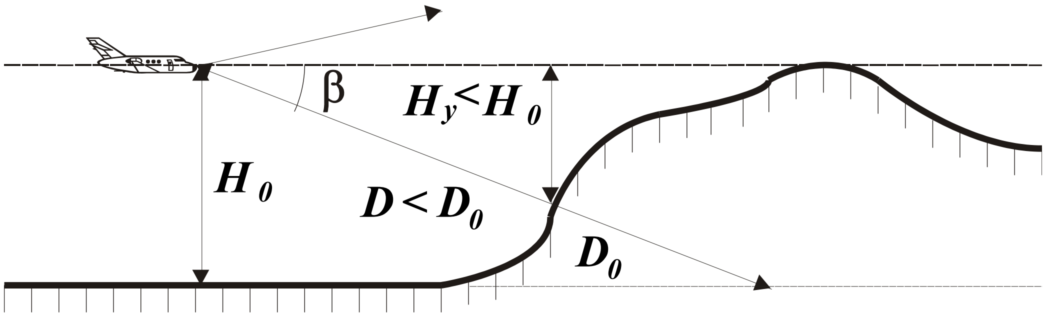

Fig. 3.6. Operational scheme of a long-range PFR

In the **angular PFR** the value of the measured range ($D = D_0$) is fixed by moving the antenna in the vertical plane. To overcome obstacles, the angle of inclination of the AP beam β is measured, and the pilot performs a maneuver in the vertical plane so that $\beta = \beta_0$, while $H_y = H_0$ (Fig. 3.7).

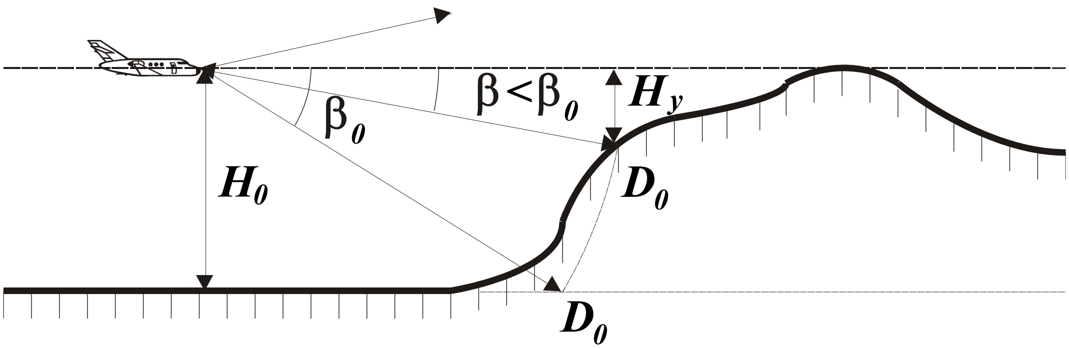

Fig. 3.7. Operational scheme of an angular PFR

Consequently, the radar of the profile flight should ensure the passage of obstacles at distances sufficient to perform the maneuver in the vertical plane.

3.2. Pulse profile flight radar

The radar of the profile flight should provide measurement of the height of obstacles at distances sufficient to perform a maneuver to overcome them. Thus, the range of the PFR depends on the maneuvering properties of the aircraft, its flight speed and terrain. For modern aircraft at $V \le 1000$ km/h it should be at least 5...20 km, and for helicopters - 0.5...5 km.

The error σ_{H_y} in calculating the flight altitude H_y above the projected point should not exceed the rms value of the change in flight altitude σ_m due to atmospheric turbulence. This makes it possible to determine the required range measurement accuracy:

$$\sigma_D \le \frac{\sigma_m}{\sin\beta},$$

and the angle of view of the projected point:

$$\sigma_\beta \le \frac{\sigma_n}{D_0 \cos\beta_0} \text{ (rad).}$$

Since during the flight at low altitudes the angle β is units of degrees, the accuracy of determination H_y will be mainly influenced by the measurement errors of the angle of view β of the projected point. Thus, at $\sigma_m = 5$ m and $D_0 = 5$ km, the measurement error of the angle β should not exceed 0.36′, which can be ensured by counting by the maximum method and the beam width of the RS beam in the vertical plane of the order of 6...10′. To obtain such a width of the beam of the AP, for example at $\lambda = 1$ cm, the antenna should have a linear size in this plane of the order of 5...6 m. It is impossible to install such an antenna in the nose of the aircraft. Therefore, in the PFR, β is measured by the comparison method, in which the required measurement accuracy β is provided at a beam width of about 1...3°, which can be realized with a linear antenna size of about 40...60 cm.

Usually, a monopulse system of measuring the angle β with equal signal direction (ESD) in the vertical plane is used in the PFR. It allows simultaneously (without applying the beam tilt) to determine the flight altitude along the course in the area $D_{min}...D_{max}$ by measuring the angle between the ESD and the direction to the observed point of the earth's surface in this area.

As an example, let us consider the structural diagram of the range-finding type of PFR (Fig. 3.8), the antenna of which is mounted stationary at an angle β_0 to the aircraft axis. The PFR provides range measurement to a projected point of the earth's surface and outputs an error signal $\Delta D = D_{вим} - D_0$ to the control system to perform a maneuver in the vertical plane.

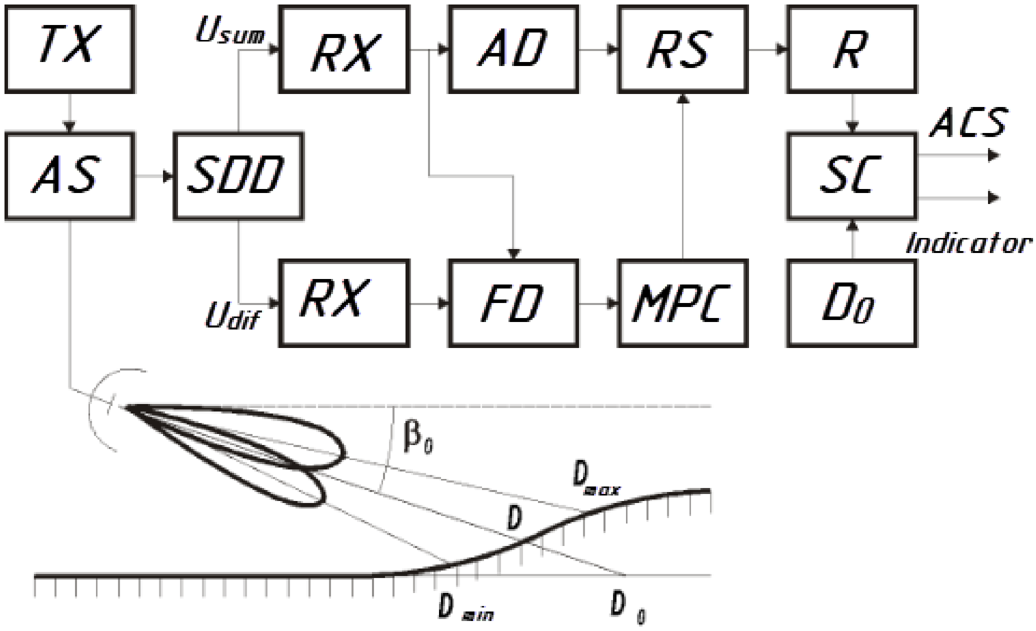

Fig. 3.8. Structural scheme of PFR of long-range type

The transmitter generates radio pulses with a given carrier frequency and repetition period. These pulses pass through the antenna switch (AS) and are radiated into space. The pulses reflected from the ground enter the sum-difference device (SDD), where the sum and difference signals are formed. Both receivers are opened in the range of $D_{міn}$ ... $D_{макс}$ to reduce the range of received signals by range.

The amplified total signal is fed to the phase detector (PD). The measuring pulse circuit (MPC) and range selector (RS) are designed to ensure that the range is measured only to the point of the earth's surface located on the ESD. At the moment of arrival of the signal reflected from the point of the earth's surface located on the ESD, the voltage at the output of the PD is zero. The MPC produces a short pulse that opens the RS.

At this moment, a pulse is sent from the output of the amplitude detector (AD) through the open RS to the rangefinder (R). The rangefinder measures the distance to the point of the earth's surface on the ESD and outputs a voltage proportional to this distance. In the subtraction circuit (SC), this voltage is compared with the voltage proportional to the reference range, and an error signal is produced, which can be fed to the ACS for automatic low-altitude flight control or to the indicator (I).

When flying at low altitudes and using rangefinder-type PFR, the following feature is observed: at the moment of time when the aircraft is near the top of the obstacle, the radar contact of the AP with the ground surface is broken, therefore, in real flight conditions, the PFR cooperates with the low altitude radio altimeter. When flying over the top of the obstacle (before the radar contact with the ground is reached), the control signal is formed by comparing the flight altitude measured by the RA with the reference value H_0.

In order to perform safe flights at low altitudes, it is necessary to include a PFR as a sensor of physical communication with the ground surface in the structure of the TAWS. In addition, it is necessary to introduce a low-altitude flight mode into the automatic control system of the aircraft, i.e. to automate the flight at low altitudes by transferring control to the autopilot using the RPF signals.

Detection of changes in the relief of the earth's surface by the long-range radar of the profile flight is performed by constant measurement of the inclined distance to the projected point on the earth's surface by a fixed antenna. When this distance decreases, the absolute height of the relief increases, the intensity of the distance decreases at a constant flight altitude and speed shows the steepness of the slope, i.e. the intensity of the relief changes.

Thus, knowing the actual flight altitude of the aircraft and its course, the analysis of the intensity of changes in the terrain at the projected point will allow to calculate the actual flight altitude of the aircraft at the projected point, and compare it with the safe altitude, that is, to implement the algorithm of safe flight at low altitudes.

There are several types of implementation of measurements of inclined distance to the projected point, these are:

- application of profile flight radar (Fig. 3.9);
- application the range function of the meteorological radar station (MNRLS) in the "Terrain" mode;

- application of radio or optoelectronic rangefinders.

The use of an additional flight profile radar or a separate range finder only for measuring the inclined range on board a civil aircraft is impractical due to the increase in aircraft weight and the number of power consumers. In addition, it is necessary to find a place to install a radar antenna that has the same dimensions as the TAWS antenna.

Fig. 3.9 . Radar of profile flight "Relief"

Moreover, some modern radar systems of military aircraft have the function of RPP, for example, radar "Zhuk-MSF" of Su-30 aircraft (Fig. 3.10). But in the weather navigation radar stations of civilian aircrafts the function of PFR is not implemented.

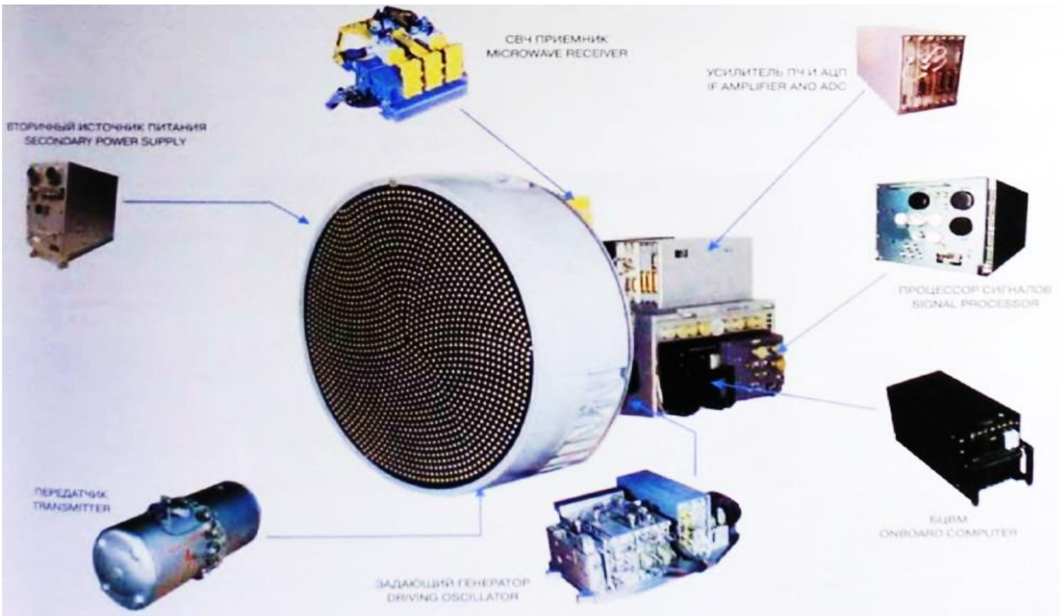

Fig. 3.10. The «Zhuk-MSF» eather radar with PFR function

The analysis of technical information sources showed that there are proposals for the use of other on-board devices as PFR.

In particular, the teachers of the Avionics Department of NAU received a patent for a utility model "Complex automatic extrapolator with the functions of measuring the vertical speed gradient of the aircraft and the steepness of the mountain slope on a scanning radio altimeter". The patent stipulates that the disadvantage of the TAWS system is the small available time for pilots to make decisions on gentle mountain slopes. Vertical extrapolation systems work effectively on smooth mountain slopes, and horizontal extrapolation systems - on sharp mountain slopes, so there is no maximum decision-making time before impact on the mountain surface. Therefore, it is proposed to apply a complex analysis using horizontal and vertical extrapolation, which provides:

- with the help of the vertical extrapolation (VE) channel the effective operation of the system on sharp mountain slopes;
- with the help of the horizontal extrapolation (HE) channel the effective operation of the system on smooth mountain slopes.

This allows to prevent accidents on both steep and gentle mountain slopes.

The introduction of a functional channel of horizontal extrapolation and a scanning radio altimeter into the system distinguishes the proposed complex automatic extrapolator with the functions of measuring the gradient of the vertical speed of the aircraft and the steepness of the slope of the mountains from similar samples, as it allows to increase the efficiency of the crew on steep slopes while maintaining the function of vertical extrapolation on gentle slopes, which ensures the prevention of accidents.

Also, at the scientific conferences of the Avionics Department, the use of a pulse radio altimeter as a PFR was considered, which allows to constantly measure the distance D to the projected point and determine the projected height Hy, that is, to constantly monitor the change in the terrain of the earth's surface and provide information to the TAWS. However, the use of radio altimeters has a significant drawback - radio altimeters have a large beam bridge angle of about 50°, and therefore entails extensive scanning of the earth's surface with the capture of unnecessary information and the formation of false warnings. In addition, the short range of the frequency radio altimeter about 2-3 km is also a disadvantage of their use.

Thus, in the thesis it is proposed to use a meteorological radar station with the function of measuring the distance by a narrow beam in the "EARTH" mode and a fixed antenna position as a range-finding PFR on regional and mainline aircraft.

3.3. Weather radars

Weather radars (WXR) are, first of all, an autonomous source of meteorological information, and in the mode of earth surface survey WXR is an autonomous means of navigation. The main purpose of WXR is to detect dangerous for flight hydrometeorological formations, navigational survey of the earth's surface, determination of the angular position and distance of the observed objects.

3.3.1. Composition and principles of WXR operation

Usually WXR is a pulse radar, the principle of operation of which is based on the use of secondary (reflected) radiation of radio waves by various objects (inhomogeneities) encountered on the path of propagation of the probing signal.

Fig. 3.11 shows a simplified scheme of the airborne radar. This is one of the variants of the classical scheme of the pulse radar, which takes into account the peculiarities associated with the installation of the radar on board the aircraft. This scheme does not correspond to the real block structure of the WXR, but only explains the principle of operation of the airborne radar.

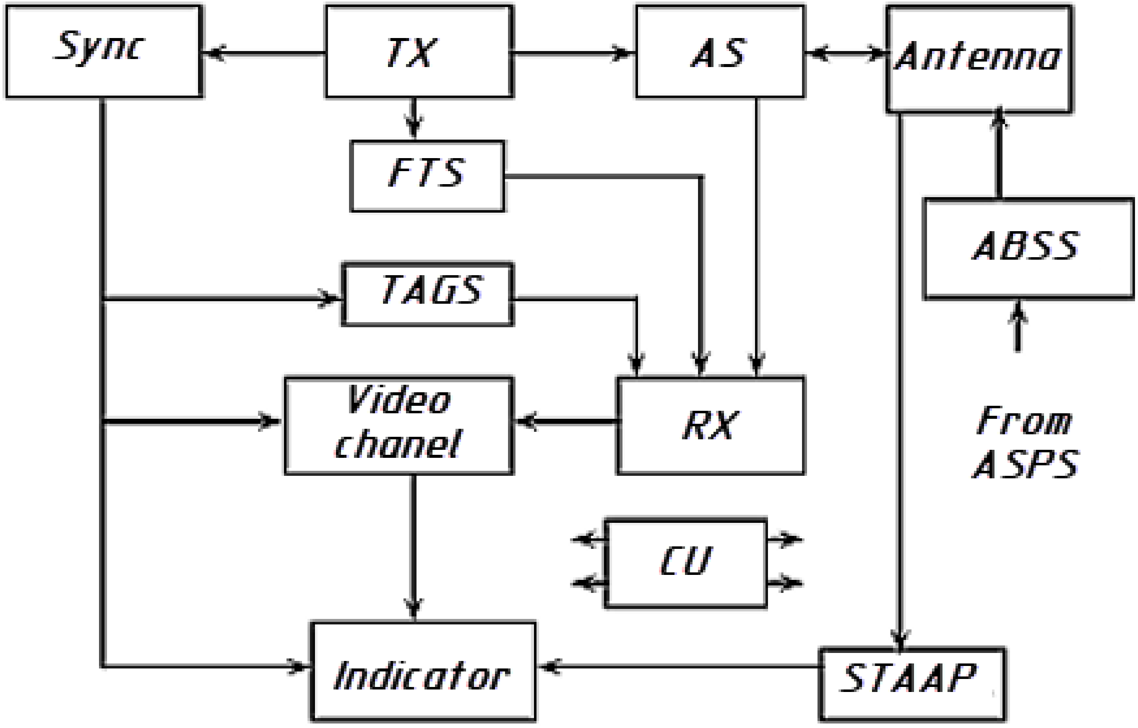

Fig. 3.11. Simplified scheme of the weather radar

The transmitter (Tx) generates powerful microwave energy pulses of the required duration and shape. Synchronizer (Sync.) is used to coordinate in time the operation of all radar units and the formation of calibration range marks, and it is possible to start the synchronizer with a start pulse from the transmitter (as shown in the diagram) or vice versa - start the transmitter with a pulse generated in the synchronizer.

The antenna is designed to form a LS of the required shape, radiate the energy of the probing pulses and receive the energy reflected (or re-radiated) by objects.

The receiver (Rx) is designed to detect signals reflected from objects against the background of noise and obtain useful information from them.

The antenna switch (AS) is designed for automatic alternate connection of the antenna to the transmitter output (for the time of emission of the probing pulse) or to the receiver input (at other times). The switching frequency is equal to the repetition rate of the probing pulses. In the video channel (Videochan.), along with the amplification of the received signals, they are mixed with scale marks, and signals are processed in order to highlight special radar information (for example, about dangerous meteorological formations). The indicator is designed to display radar information, usually in polar coordinates azimuth-distance, as well as auxiliary information. The scanning scheme, which is included in the indicator unit, provides the deflection of the electron beam in the indicator tube and, together with the system of synchronous transmission of the antenna angular position (STAAP), forms a radial-sector (or radial-circular) scan. The automatic frequency tuning system (FTS) provides automatic tuning of the receiver to the frequency of the transmitter signal. The device of time automatic gain control (TAGC) automatically changes the gain of the receiver in such a way as to ensure uniform amplification of signals reflected from objects located at different distances from the radar. To do this, at first, when receiving signals reflected from closely located objects, the receiver gain is made minimum, and then gradually increases, and when receiving signals reflected from the most distant targets, the gain reaches the maximum value.

The peculiarity of the WXR, related to its installation on board the aircraft, is the presence of an antenna beam stabilization system (ABSS), which serves to compensate for the influence of aircraft evolutions (roll, pitch) on the radar image. The signals of the aircraft spatial position sensor (ASPS) are used as the initial information for this purpose. The control unit (CU) is used for remote operational control and management of the WXR during its flight and technical operation.

In recent years, the world's leading companies have begun to produce coherent-pulse airborne radars, the scheme of which differs from that shown in Fig. 3.11 by additional links that provide the receiver with a reference signal carrying information about the phase of the emitted oscillations.

The scheme presented in Fig. 3.11, for better understanding, describes the principle of operation of analogue radar. In modern digital radars, after the detector, the signal is converted into digital form, and the node designated as "Video Channel" in the diagram implements digital signal processing, and all communications between the blocks are carried out in digital form, except for the ultra-high-frequency communication between the antenna and the transmitter-receiver (Fig. 3.12).

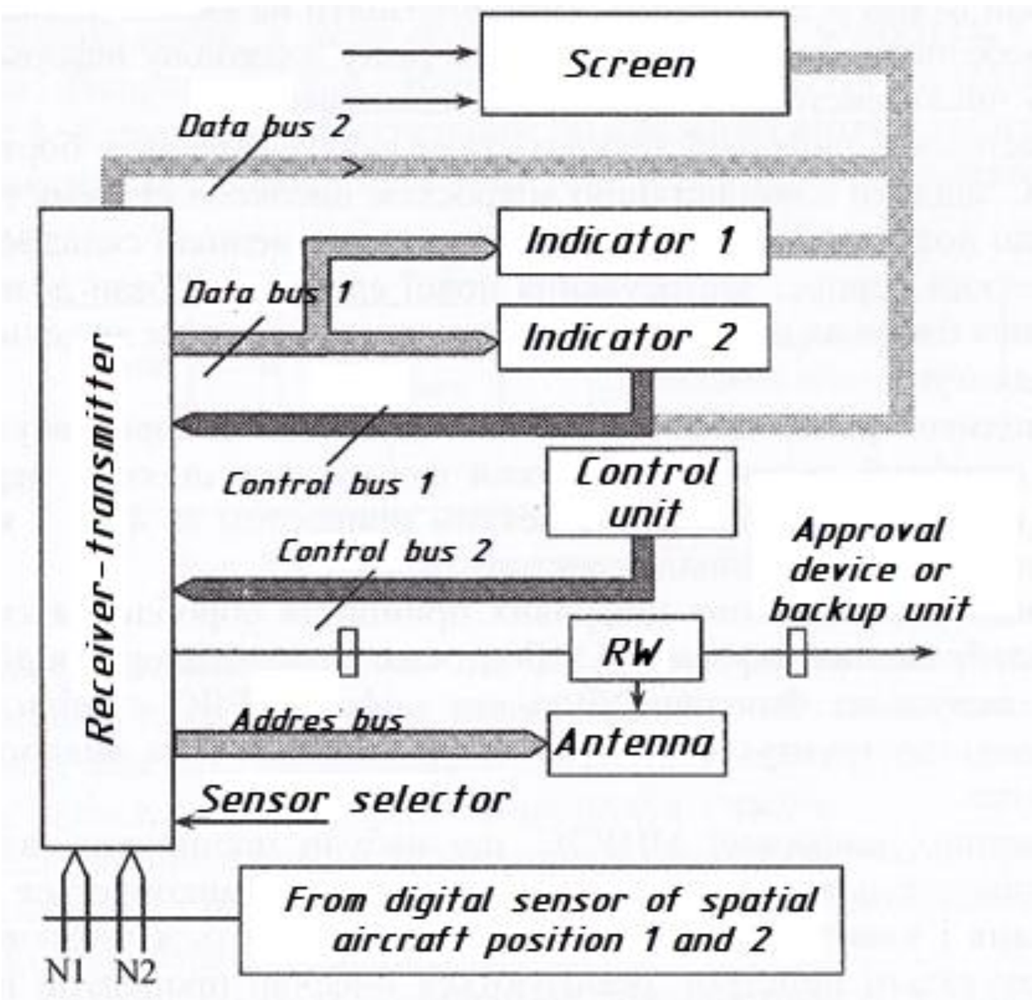

Fig. 3.12. Structure of the digital WXR

Modern digital WXR (Fig. 3.12) contains all the elements of the generalized scheme (Fig. 3.11). In particular, the nodes that perform the functions of transmitter, receiver, antenna switch, AFA, TAGC, are located in a single block - receiving-transmitting. It is worth noting the features of the functioning of a number of nodes related to the digital control of the system. For example, the gain of the receiver, which implements the necessary law of the VFD, changes according to the code coming from the control panel or the main indicator (display) in the bits of the control word provided for this purpose. The video channel includes nodes located in the transmitter-receiver and indicators, all of which are designed to process signals only in digital form.

The transmitter, located in the transceiver unit, generates microwave pulses, which are transmitted through the waveguide through the switch to the antenna and radiated into space. The transmitter is synchronized by the control unit signals.

Signals reflected from the target from the antenna output through the waveguide are transmitted to the receiver input. The coupling between the receiver and the transmitter is provided by an antenna switch located in the transceiver unit. At the output of the receiver, the ADC and the distributor are enabled. That is, from the output of the receiver signals are received in digital form, according to Arinc 708 the main system is 512 range cells.

The indicator unit together with signals on the data bus receives information about:

- angular position of the antenna;
- time of radiation of the probing pulse;
- selected range scale;
- tilt of the antenna beam;
- selected operating mode, etc.

In addition, the receiver-transmitter receives digital data on the position of the aircraft in space (from the gyro sensor) via a special bus. In the transceiver unit, this information is processed and signals are sent to the antenna unit, taking into account the roll and pitch of the aircraft. They are also control signals for adjusting the position of the antenna.

The transceiver unit has two inputs of digital data on the spatial position of the antenna (sources N1 and N2). This is because there can be two gyro sensors on the aircraft to increase reliability by redundancy.

Similarly to any on-board avionics, WXR must be certified for a certain type of aircraft, that is, it is necessary to obtain a special certificate - a certificate confirming the compliance of the equipment with airworthiness standards and other mandatory requirements.

3.3.2. Characteristics of modern WXR

Leading manufacturers of airborne avionics AlliedSignal, CollinS, Honeywell, Rockwell and others supply the world market with a wide range of on-board WXR.

Table 3.1 presents information on the technical characteristics of some WXR, Ukrainian and foreign production: "Primus 870", "Buran A-140" and A-813 "Kontur".

Table 3.1

Specification of modern WXR

Characteristics of weather radars	Primus 870	Buran A-140	Kontur A-813
Operation requency, MHz	-	9345	9345
Pulse duration, µs:	-	1-8	1,6
Pulse power, kW;	1,3	5,0	3,5
Transmitter type	Magn	Magn.	Magn.
Antenna type	WSSA	WSSA	WSSA
Antenna size, cm;	30,5 45,7	61	37,7 34,0
Beam width, deg;	7,5 4,9	4,0	6,0 10,0
Scanning sector, grad.	60 120	150 90	90
Weight of WXR, kg	-	17,0	16,0

Notes: Magn. - magnetron; WSSA - waveguide-slot antenna array.

On-board radars have a block design. The main units of modern WXR are usually an antenna, a transceiver and an indicator (display) with a control panel. The appearance of the main units of WXR is shown in Figs. 3.13, 3.14.

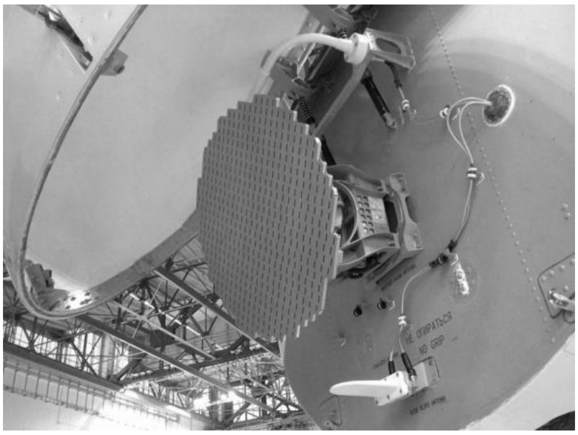

Fig. 3.13. Antenna unit of the SSJ-100 aircraft

Fig. 3.14. Receiver-transmitter and control panel of SSJ-100 WXR

Multifunctional integrated display systems are often used on board modern airliners. In such cases, the main units of MFIRS are an antenna unit, transceiver and control unit (panel). As a rule, the antenna unit is located in the nose of the aircraft under the radio-transparent fairing (Fig. 3.13).

The receiver-transmitter (see Fig. 3.14) is placed in the lower nose compartment behind the ceiling on which the antenna is mounted. In classical designs, transceivers are connected to the antenna by means of waveguides (feeders). But there are also known monoblock designs in which the antenna and transceiver are structurally a single unit. This eliminates the wave path with a rotating joint, which is a source of energy losses and interference. The monoblock design is used in the Buran-A WXR.

Take a closer look at the "Buran-A" WXR of the AN-148 aircraft.

Weather radar station "Buran - A" is designed for:

– radar inspection of airspace (in the horizontal and vertical planes) in order to identify areas dangerous for flights;

- radar inspection of the ground and water surface for aircraft navigation by characteristic land and water landmarks;

- determination of inclined range and heading angles of observed radar landmarks and meteorological formations.

The detection range of radio-contrast objects depends on the flight altitude and characteristics of the irradiated object, for example:

– dull cumulonimbus thunderstorm formations.................................... 150-400 km.

– big cities.. up to 350 km.

– background of the countryside and the shores of water bodies……....100-150 km.

– industrial facilities .... 40-80 km.

– turbulent zones in the middle of weather formations…………………...10-60 km.

The operation of the WXR is controlled by the control panel, and the radar image indication is displayed on the multifunctional indicators in the crew cab.

The main modes of operation of the "Buran-A" MNRLS are: "Control", "Terrain", "Meteo" and sub-modes - "Profile", "Turbulence", "Stabilization", "Tilt-automatic".

The "Control" mode is used to check the operability of the WXR and its communication channels with the built-in control means.

The "Terrain" mode is intended for radar survey of the earth and water surface and formation of a radar map of the area.

The "Meteo" mode is intended for radar inspection of the airspace ahead of the aircraft in order to detect hydrometeorological formations and assess their danger.

The sub-mode "Profile" is intended for viewing meteorological formations in the vertical plane (at distances of ≈ 40 km).

The "Turbulence" sub-mode is designed to detect areas of dangerous turbulence in weather formations and is automatically enabled in the "Meteo" mode if the observation range is set to 40 km or less. At long distances, the "Turbulence" sub-mode is automatically disabled.

The "Stabilization" sub-mode is designed to stabilize the antenna beam direction during aircraft evolutions (roll ± 20° and pitch ± 10°). The sum of roll, pitch and slope angles of the antenna is limited within ± 30°, in the horizontal plane the antenna movement is limited within ± (85 ± 3)°.

The "Tilt-Auto" sub-mode is designed for automatic control of the antenna tilt during the aircraft altitude evolution. The sub-mode is switched on or off in the "Ground" or "Meteo" mode at the "Dialog" level, for which the symbol "N/A OFF" on the radar control panel must be switched to "N/A ON" or vice versa.

Antenna tilt angles in "Terrain" mode are presented in Table 3.2:

Table 3.2

Antenna tilt angles in "Earth" mode

Set range, km	Flight altitude, km				
	1.0	2.0	4.0	6.0	10 0
	Antenna tilt angles, degrees				
600	-	-	-	-	-2,75
320	-	-1,5	-2,25	-2,5	-4,5
160	-1,25	-2,5	-4,25	-5,5	-7,0
80	-3,5	-4,75	-6,5	-7,5	-12,5
40	-5,0	-10,5	-10,5	-15	
20	-9,0				

Thus, the "Buran-A" WXR in the "Earth" mode can inspect the earth's surface at flight altitudes of 1000 - 2000 m at a projected range of 20-40 km, while the WXR antenna is deflected towards the ground at angles β = 5°-10°. And due to scanning, it surveys a vast area of the earth's surface in search of radio-contrast landmarks or tracks a detected landmark with a narrowly directed beam.

Therefore, to determine the distance to a radio-contrast landmark in the "TERRAIN" mode or to a dangerous weather formation in the "METEO" mode, any WXR must have a rangefinder function with active location and have a range measurement subsystem.

3.3.3. WXR range measurement subsystem

Range measurement by radar methods is based on the assumption of rectilinear propagation of radio waves at a constant speed. Therefore, to measure the range to the target, it is enough to measure the delay time of the signal reflected from the target relative to the emitted radar signal.

Range measurement methods are divided into amplitude, frequency and phase depending on which of the parameters of the received radio signals is used to measure the delay time.

Among the radars with the amplitude method of range measurement the most widespread are pulse stations. The principle of their operation is illustrated by the scheme in Fig. 3.15.

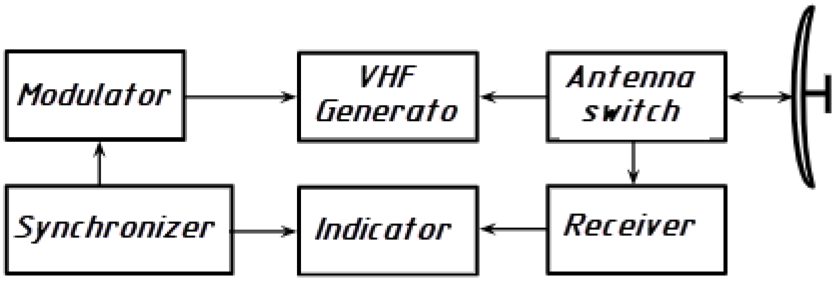

Fig. 3.15. Functional diagram of the pulse radar rangefinder

The high frequency generator, controlled by a pulse modulator, generates short high-frequency pulses (probing signals) with a specified repetition period.

The probing signal can be written by the following expression:

$$u_{ген}(t) = U_0 \cos(\omega_0 t + \psi_0) \quad \text{при } t_0 \le t \le t_0 + \tau_и,$$

where t_0 - start of counting on the time axis, coinciding with the start of the pulse; τ_i - pulse duration; U_0 - oscillations amplitude; ψ_0 - initial phase of oscillations.

For the time of emission of each probing pulse, the antenna is connected to the generator by means of an antenna switch; the rest of the time the antenna is connected to the receiver. The signals reflected from the target after conversion in the receiver are sent to the output device, where the delay time t_D is measured by comparing the moments of emission of the probing pulse and reception of the reflected one (Fig. 3.16).

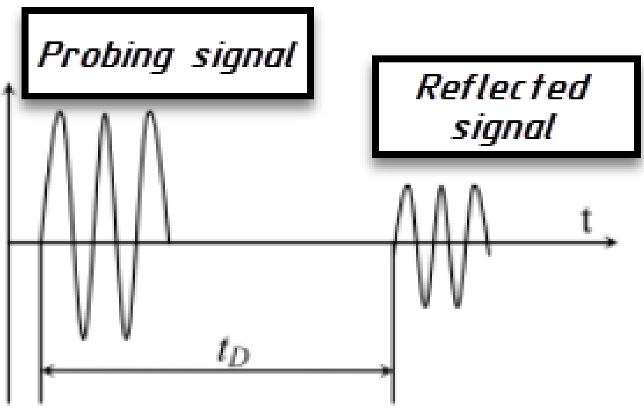

Fig. 3.16. Voltage curves of the pulse method of range measurement

Synchronization of processes in the radar transmitter and measuring device is provided by a synchronizer. As an output device in pulse radar can be used cathode ray tubes, liquid crystal displays or automatic counting devices:

$$\Delta D_{\text{одн}} \leq cT_{и}/2 .$$

All elements of the pulse rangefinder are part of a modern WXR that allows pulse radars to measure the range to irradiated objects.

3.4. Calculation of energy characteristics of WXR with range control function

As input data for the calculation of WXR are taken operational performance (technical characteristics) that determine the possibility of using the radar to perform the task. We will study the characteristics of WXR for the possibility of using it as a radar of profile flight.

One of the most important parameters of any radar is the wavelength at which it operates. In reality, there are no restrictions on the frequency bands used in radar, but for the WXR, the X-band (8-12 GHz) was selected, from which, to perform the tasks of the WXR, the range f = 9345 - 9375 MHz was selected.

When choosing a wavelength, it is usually necessary to take into account the nature of the reflection from the surfaces to be irradiated, as well as the fact that the wavelength and the width of the radiation pattern determine the geometric dimensions of the antenna, and since the antenna will be installed on the aircraft, its dimensions are limited.

Taking into account the ranges of modern domestic WXR, it is possible to calculate the wavelength:

$$\lambda_{\mathrm{r}} = \frac{\mathrm{c}}{\mathrm{f}} \ (m).$$

where c – speed of radio wave propagation in the atmosphere.

$$\lambda_r = \frac{300}{f_0} = \frac{300}{(9345-9375)} = 0{,}032\ m.$$

So, the WXR wavelength is $\lambda_{\mathrm{r}} = 0{,}032$ m or 3,2 cm (centimeter range of radio waves).The wavelength and width of the antenna radiation pattern (ARP) determine the geometric dimensions of the antenna. The formula for the relationship between these quantities is:

$$\theta_{0,5} = \frac{\pi \cdot \lambda}{3d_a} \ \text{(rad)}$$

where $\theta_{0,5}$ – width of the directional pattern at half power level,

da – antenna size.

Taking into account that the WXR "Buran" of the AN-148 aircraft has a waveguide-slot antenna array with a diameter of da = 61 cm (see Table 3.1), we obtain:

$$\theta_{0,5} = \frac{3{,}14 \cdot 0{,}032}{3 \cdot 0{,}61} = 0{,}0549 \ \text{(rad)} = 3{,}173°$$

The results of calculating the normalized transmitter power required to ensure the maximum range of the radar at different wavelengths are shown in Fig. 3.17.

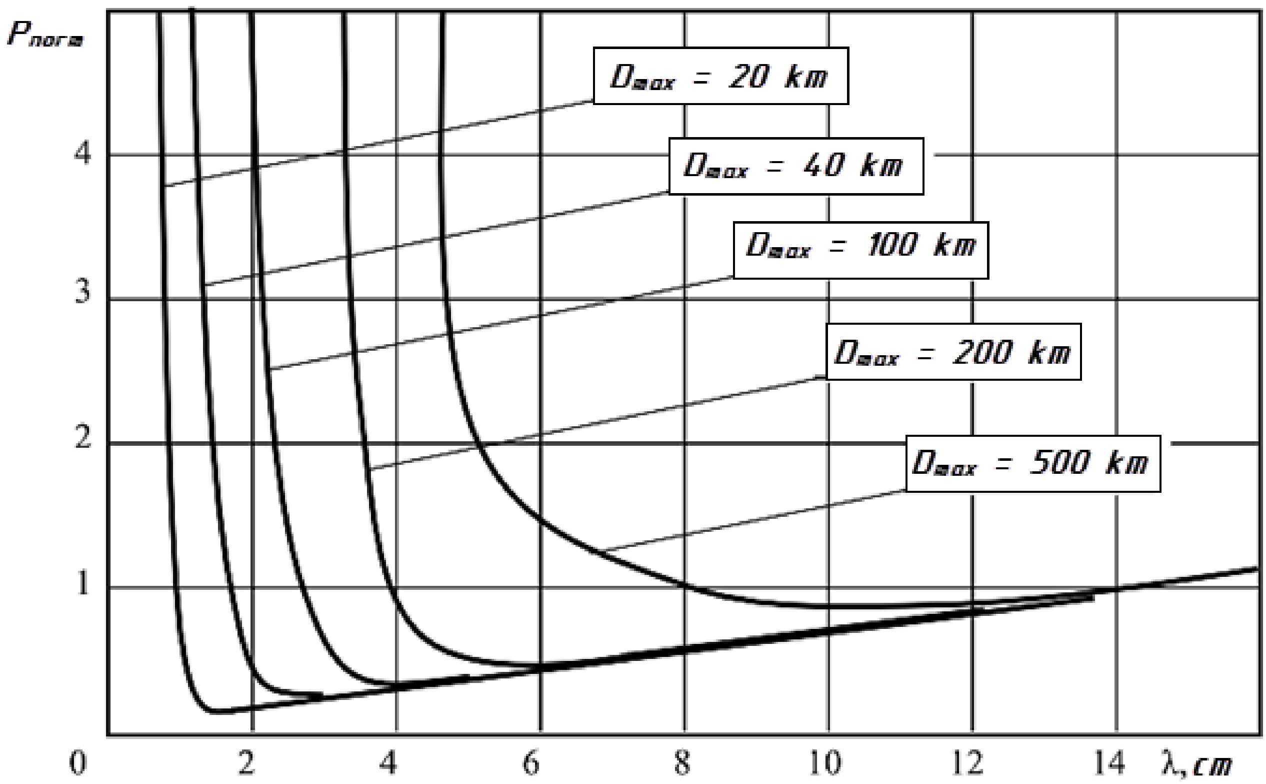

Fig. 3.17. Dependence of the normalized signal power of the R_{NORM} transmitter, necessary to ensure the range of D_{MAX}, on the wavelength λ

The most complete and simple description of the influence of various factors on the operation of radar is the basic radar range equation. One of the forms of writing this equation determines the power of the received signal, which is written by the expression:

$$P_{rx} = \frac{P_{tx} G_a}{4\pi D^2} \cdot \frac{\sigma_s}{4\pi D^2} \cdot A_r$$

Where P_{tx} – radiation power; G_a – antenna gain; D – distance to the irradiated object; σ_s – effective scattering area (ESA) of the object (S); P_{rx} – power of the received signal; A_r – effective aperture area of the receiving antenna.

The first factor of the expression is the radiation power flux density at a certain distance D from the radar of the irradiated object. The second factor takes into account the distribution of electromagnetic energy in space depending on the distance between the irradiated object and the receiving antenna and characterizes the distribution of the signal reflected from the object. The third factor characterizes the receiver antenna.

Since the maximum distance of radar signal detection depends on the minimum power of the detected signal, the basic radar equation can be written in the form:

$$D_{max}^4 = \frac{P_{tx} G_a A_r \sigma_s}{(4\pi)^2 P_{th\ rx}}.$$

where $P_{th\ rx}$ – minimum threshold power of the receiver.

And in the case when the receiving and transmitting antennas are the same, or one receiving and transmitting antenna, the effective aperture area of the receiving antenna is related to the antenna gain by the expression:

$$G_a = \frac{4\pi A_r}{\lambda^2}$$

Then we can obtain the expression for determining the maximum range of the WXR:

$$D_{max} = \sqrt[4]{\frac{P_{tx} \cdot G_a^2 \cdot \lambda_r^2 \cdot \sigma_s}{(4\pi)^3 \cdot P_{th\ rx}}},$$

In order to use WXR as a PFR, it is necessary to determine the minimum transmitter power to detect a dangerous terrain change at a distance of τ = 132 seconds of flight. For an average aircraft speed of V = 700 km/h, the maximum distance of the predicted climb trajectory will be:

$$D_{rx} = V \cdot \tau = 0.194 \cdot 132 = 25.6\ km.$$

Then the expression of the minimum transmitter power will be

$$P_{tx} = \frac{D_{rx}^4 (4\pi)^3 \cdot P_{th\ rx}}{G_a^2 \cdot \lambda_r^2 \cdot \sigma_s},$$

To solve this expression we find the unknown components G_a, σ_s, $P_{\text{th rx}}$.

Minimum threshold power of the receiver $P_{\text{th rx}}$ characterizes the minimum signal power that can be processed by the system and for modern WXR is about $P_{th\,rx} =\cdot\ 10^{-12} W$.

If the transmitting and receiving antennas are of the same type, they have the same antenna gain, which is expressed by

$$G_{\text{a}} = \eta_{\text{a}} \frac{4\pi^2}{\theta_{\text{a}}^2} \quad \text{або} \quad G_{\text{a}} = \eta_{\text{a}} \cdot D_A$$

where η_a – antenna efficiency;

θ_{a}^2 – half width of the AP (in radians);

D_A – directional coefficient of the antenna.

First, let's find D_A – directional coefficient of the antenna:

$$D_A = \frac{4\pi}{\theta_{\text{a(rad)}}^2}, \quad \text{тоді} \quad D_A = \frac{4 \cdot 3{,}14}{0{,}055} = 4097{,}7$$

For waveguide-slot antennas the efficiency is $\eta_{\text{a}} = 0{,}75 - 0{,}85$, then

$$G_{\text{a}} = 0{,}8 \cdot 4097{,}7 = 3278{,}1$$

Effective scattering area (ESA) is a parameter that determines the efficiency of electromagnetic radiation scattering by an object. It is a quantitative measure of the ratio of the power density (density) of the signal scattered in the direction of the receiver to the power density of the radio wave entering the object.

For the radar in the "Earth" mode, the object is a section of the earth's surface. Obviously, the calculation must be carried out for the surface with the minimum ESA. When choosing the wavelength, we determined that such a surface is a mountain (stones) with a forest cover. The Earth's surface belongs to the class of surface-distributed objects, since its size exceeds the size of the bottom. ESA of such objects is determined by the formula:

$$\sigma_{\text{s}} = \sigma_0 \cdot S_{\text{I}},$$

where σ_0 – pecific ESA of the ground surface area; S_{I} –the irradiated area.

Specific ESA of the ground surface 0 is taken from Table 3.3 for $\lambda_{WXR} = 3$ см, incidence angle 10° of horizontal (HH) and vertical polarization (VV) and converted the value of specific ESA to the power ratio according to the table 3.4:

Table 3.3

Approximate values of specific ESA

Objects	***Incidence angle***	σ₀, дБ		
		λ = 3,0 см		λ = 70 см
		ГГ	ВВ	ГГ, ВВ
Excitement sea, 2 points	10	−40	−32	−50
	20	−38	−28	−45
	50	−35	−30	−42
Excitement sea, 6 points	10	−35	−30	−35
	20	−30	−25	−32
	50	−27	−22	−30
Runway	10	−40	−30	−60
	20	−32	−24	−58
	50	−20	−18	−55
Prairie, winter, snow	10	−23	−23	−60
	20	−17	−17	−55
	50	−14	−14	−50
Prairie, summer, grass	3	−35	−35	−60
	10	−16	−15	−55
	20	−15	−15	−53
	50	−12	−12	−50
Desert, stones, sand	10	−18	−20	−45
	20	−15	−17	−40
	50	−12	−14	−35
Forest	10	−14	−14	−35
	20	−14	−15	−30
	50	−12	−12	−25

Table 3.4

Conversion of power ratio in dB:

L	40 dB	20 dB	10 dB	6 dB	3 dB	1 dB	0 dB	−1 dB	−3 dB	−6 dB	−10 dB	−20 dB	−40 dB
P1/P0	10000	100	10	≈ 4	≈ 2	≈ 1.26	1	≈ 0.79	≈ 0.5	≈ 0.25	0.1	0.01	0.0001

Then we obtain the specific EPR of the surface area:

$$\sigma_0 = -20\text{ dB} = \frac{1}{100}\text{(times)}.$$

Irradiated surface area S_I is found by the following expression:

$$S_I = \pi \cdot D^2 tg^2 \frac{\theta_a^2}{2},$$

Then foe $D \geq 25000$ m we will obtain:

$$S_I = 3{,}14 \cdot 25000^2 \mathrm{tg}^2 \frac{0{,}055}{2} = 1485642{,}4 \text{ m}^2,$$

As a result, the ESA of the irradiated area will be::

$$\sigma_s = \sigma_0 \cdot S_I, = \frac{1485642{,}4}{100} = 14856{,}4 \text{ m}^2.$$

Now let's determine the minimum power of the WXR transmitter when receiving information from the earth's surface at a distance of 25000 m:

$$P_{tx} = \frac{25000^4 \cdot (4 \cdot 3{,}14)^3 \cdot 10^{-12}}{3278{,}1^2 \cdot 0{,}032^2 \ \cdot 14856{,}4} = 4.7\ W,$$

Thus, the minimum average transmitter power for the operation of WXR in the mode of long-range profile flight radar is 4.7 watts.

Let us calculate the duration of the WXR pulses taking into account the range resolution of about ΔD = 500 m (where $\gamma_D \geq 1$ - resolution reduction factor). The expression for determining the duration of the probing pulses is:

$$\tau_{\mathrm{imp}} = \frac{2\Delta D}{\gamma_D c} = \frac{2 \cdot 500}{1 \cdot 3 \cdot 10^8} = 3.33\ \mu s\ .$$

Thus, the duration of the sensing pulses should be $\tau_{\text{імп}} = 3{,}33\ \mu s$.

In pulse ranging radars, the period of probing pulses Ti is selected from the condition of unambiguous range measurement D and should be greater than the maximum possible delay of the reflected signal (taking into account the maximum range of the radar - 300 km):

$$\mathrm{T_i} = \frac{2{,}5\ D_{max}}{c} = \frac{2.5 \cdot 3 \cdot 10^5}{3 \cdot 10^8} = 2500\ \mu s$$

Transmitter power affects the range of the radar. There are pulse and average transmitter power which are related by the following relation:

$$P_{\mathrm{i}} \cdot \tau_{\mathrm{i}} = P_{av} \cdot \mathrm{T_i},$$

Hence, knowing from the characteristics of the pulse power of the transmitter (see Table 3.1), we find the average power of the transmitter:

:

$$P_{\text{tx av}} = P_{\mathrm{i}} \cdot \frac{\tau_{\mathrm{i}}}{\mathrm{T_i}} = \frac{5000 \cdot 3{,}33}{2500} = 6{,}7\ W,$$

and apply it to determine the range of WXR as a radar of profile flight:

$$D_{max} = \sqrt[4]{\frac{P_{tx\,av} \cdot G_a^2 \cdot \lambda_r^2 \cdot \sigma_s}{(4\pi)^3 \cdot P_{th\,rx}}} = \sqrt[4]{\frac{6{,}7 \cdot 3278{,}1^2 \cdot 0{,}032^2 \cdot 14856{,}4}{(4 \cdot 3{,}14)^3 \cdot 10^{-12}}} = 27366{,}7\ km,$$

Calculations of the main characteristics of the WXR in ideal conditions (without taking into account the influence of signal re-reflection from the earth's surface and signal absorption by the atmosphere) showed that it can be used as a pulse rangefinder in the implementation of the profile flight.

3.5. Implementation of WXR as a radar of profile flight in the GPWS

As a sensor for measuring changes in the relief of the earth's surface in the projected zone in front of the aircraft, it is most appropriate to use a meteorological radar in the mode of measuring the distance to the ground with a narrowly directed beam.

The main advantages of using WXR as a PFR are:

- the presence of the range measurement function (D);
- narrow beam pattern (λ_r);
- high resolution in range (ΔD), azimuth ($\Delta\alpha$) and elevation angle ($\Delta\varphi$;
- the ability to change the angle of inclination of the beam of the directional diagram (β);
- possibility of beam stabilization during aircraft evolutions (roll, pitch);
- digital processing of parameters with the ability to automatically transmit signals to collision warning devices;
- possibility of changing the power of the emitted signal.

To date, the onboard WXR is already used as a means of preventing collisions with obstacles. But only with the participation of the crew.

Ground obstacles (mountain peaks, hills and high-rise buildings) are detected during the inspection of the space using a symmetrical narrow LD antenna. This reduces the probability of observing interfering reflections from the earth's surface at all flight altitudes exceeding a certain specified height (1000 m). When avoiding obstacles (including thunderstorm zones), it is important that the viewing sector does not change its position in space during rolls and pitching of the aircraft. Therefore, the antenna's directional axis must be stabilized in space.

The situation that arises when approaching a mountain peak. Illustrates Fig.3.18. When the aircraft flies at a constant altitude H and is far enough from the obstacle, the horizontally directed divergent beam of the radar irradiates a significant part of the mountain. As you approach the mountain, the irradiation zone of the obstacle decreases. Therefore, the illumination on the screen becomes smaller (Fig.3.19).

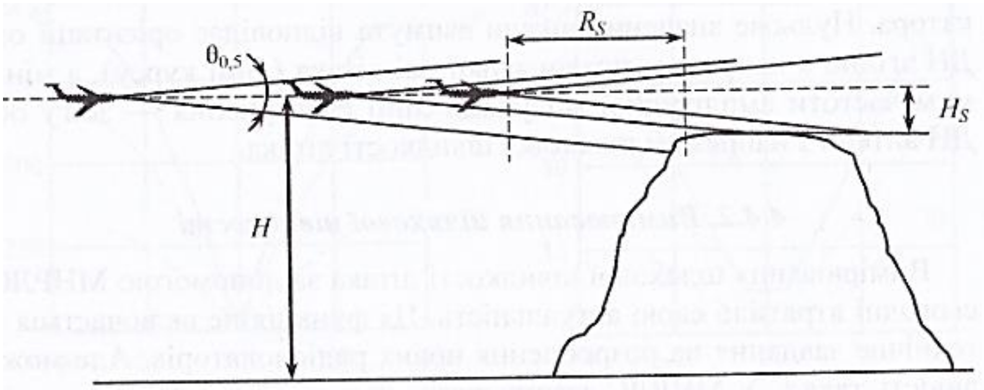

Fig. 3.18. Safety circle method

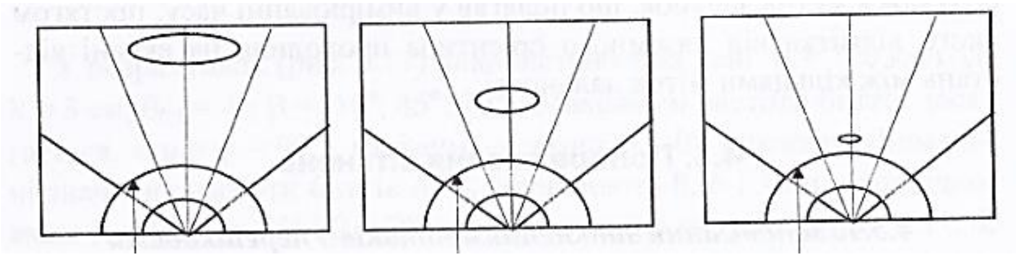

Fig. 3.19. Reduction of illumination from the mountain during it approaching

If the aircraft flies over the peak with a safe excess of H_s, then at some distance R_s from it the mountain will be out of the radiation zone of the GPWS. If the width of the AP is equal to $\theta_{0.5}$ то

$$R_s = \frac{H_s}{\sin\left(\frac{\theta_{0.5}}{2}\right)} \approx \frac{2H}{\theta_{0.5}}$$

In case of safe overflight of mountain peaks (for example, 600 m), the radius of the sector on the screen, within which there is no reflection from the earth's surface, is 10...15

km (with AP width of 30...40). The circle (sector) with radius Rs is called the conditional safety circle. When flying at a safe altitude and approaching a mountain peak at a distance of the radius of the safety circle, the signal from the mountain peak on the indicator screen disappears before reaching the conditional mark of the safety circle. If the illumination from the obstacle crosses the safety circle, it is necessary to gain altitude to ensure the required excess. The safety circle may be marked on the light filter of the WXR indicator, the safety circle mark may be formed electronically, finally, it may not be shown on the screen at all, but the pilot always knows the distance corresponding to the conditional safety circle, and he must not allow the illumination from the approaching obstacle to enter this circle.

Analysis of the principle of operation of the WXR and its modes of operation showed that in addition to the existing modes and sub-modes of operation, it is possible to introduce an additional sub-mode of WXR operation in the "Earth" mode, for example, "Relief". In this sub-mode, depending on the altitude of the aircraft, the WXR antenna switches from the scanning mode to the beam fixation mode at a given angle towards the ground in accordance with Table 3.3. This will make it possible to inspect the terrain at a distance ahead of the aircraft of about 25 km, which is sufficient to perform a maneuver in case of an obstacle along the flight route.

WXR can implement the range or angular function of the profile flight radar, as it can accurately measure the ranges and angles of the antenna.

When implementing the range-finding method of profile flight, the WXR will constantly measure the distance to the earth's surface and compare the change in relief in front of the aircraft with the digital model stored in the memory of the flight computer or TAWS. That is, in addition to performing the function of safe flight, there is a real opportunity to implement a survey-comparative method of navigation without the participation of the crew.

When performing turns or aircraft evolutions, the WXR antenna will maintain a stable position in space and perform terrain analysis tasks on the commands of the heading system.

One of the main modes of GPWS - "Terrain Assessment by Flight Direction" - is used to check the absence of terrain elements and artificial obstacles within the established working space by predicting and modeling dangerous situations. With the use of WXR in the "Terrain" mode, the forecasting will be much more accurate because there are a priori further for calculating the characteristics of the terrain.

In addition, during turns, the WXR antenna can also deviate additionally towards the turn to analyze the terrain over which the aircraft will fly.

For modern aircraft it is recommended to use digital coherent-pulse WXR "Buran-A" of the regional aircraft An-148 as a radar of profile flight (Fig. 3.20, 3.21).

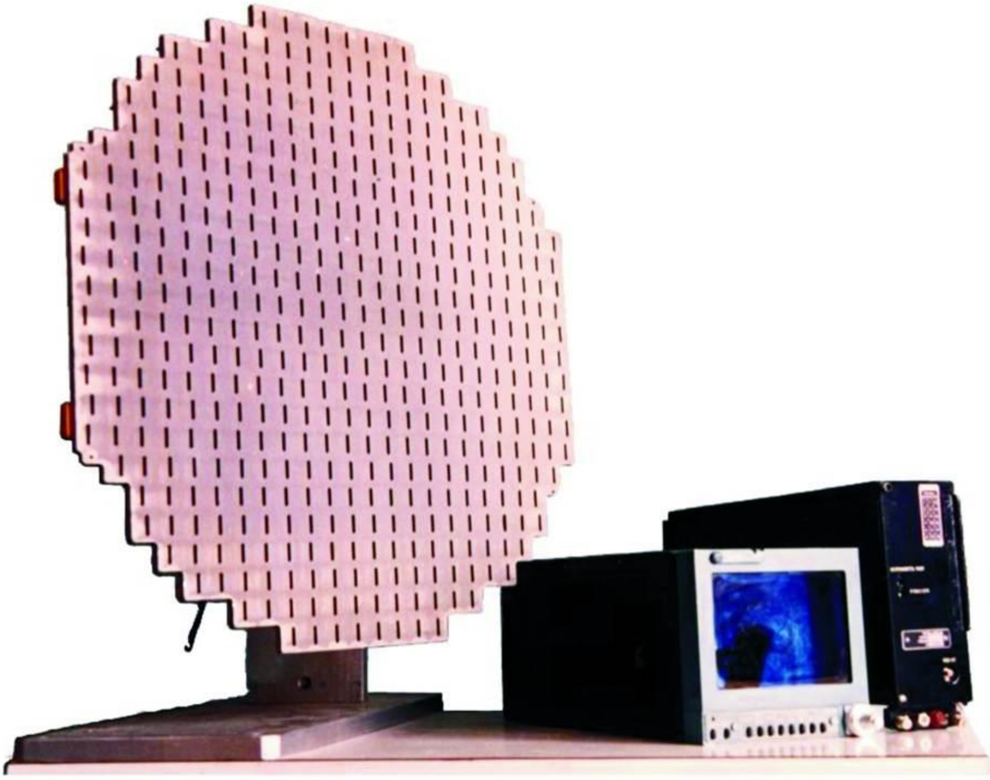

Fig. 3.20. Scheme of placement of RV BB on the AN-148 aircraft

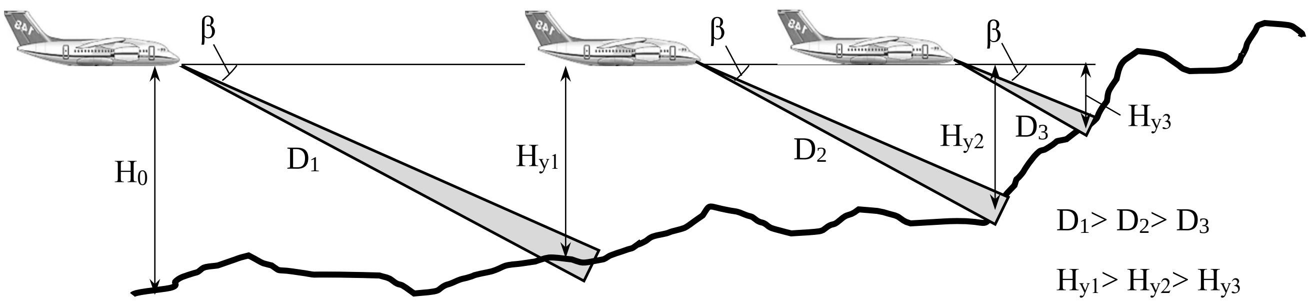

Fig. 3.21. Implementation of AN-148 MNRLS for terrain assessment

Automated use of WXR in conjunction with the GPWS-2000 system as a profile flight radar provides for the creation of a new sub-mode of WXR "Relief" and the implementation of some algorithms for information exchange. The structural diagram of the GPWS-2000 system with WXR as a terrain analysis sensor is shown in Fig. 3.22.

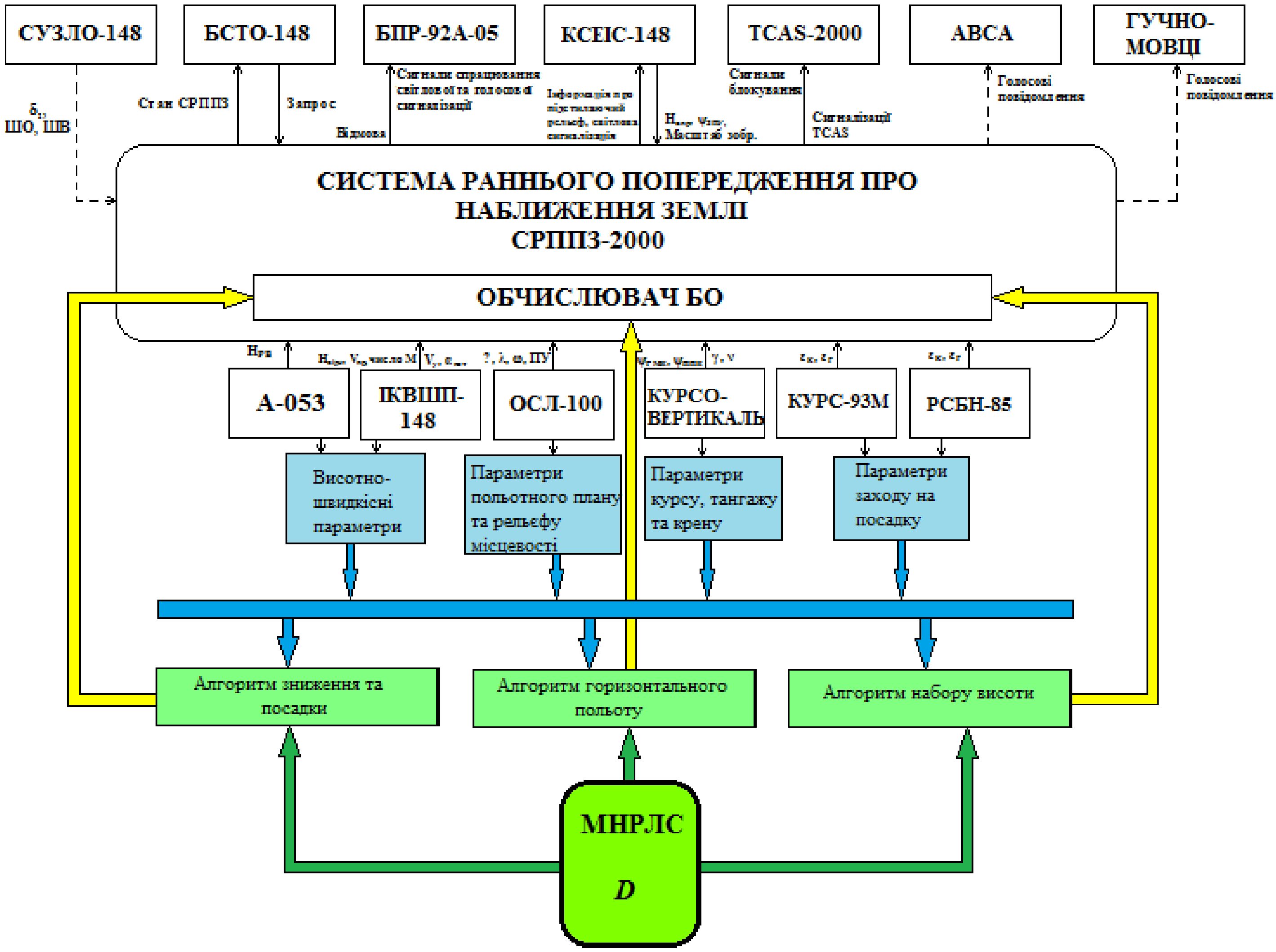

Fig.3.22. Block diagram of GPWS-2000 system with WXR as a sensor of relief analysis

The connection of the radar with the forward direction is necessary for determining the parameters D and H_y taking into account the evolution of the aircraft (pitch and roll angles). Providing the same information to the OSL will allow comparing the terrain at a biased point with the flight plan information. And the presence of D and Hy signals in the navigation systems of the Course and the RSBN will allow for the control of the terrain change at low altitudes when approaching.

The algorithm of horizontal flight analyzes the true altitude of the aircraft, if it is much higher than the relief of the earth's surface, for example 4000-11000 TAWS is inappropriate to use as a sensor of TAWS. And if the difference in altitude is less than 700 feet (213 m), the crew should switch on the "Terrain" mode, in which the WXR performs the function of a profile flight radar and provides information to the TAWS to form the necessary warnings to the crew when the terrain changes, or to issue commands directly to the automatic control system for climb.

Conclusions of Chapter 3

The GPWS operation in predicting collision avoidance with the ground surface is reduced to determining the actual height of the aircraft's flight path at a projected point. The existing prediction system has a number of drawbacks, the main ones being errors in the measurement of the aircraft's flight path and location coordinates, inaccuracies in the numerical terrain models due to artificial and natural changes. To reduce the impact of inaccuracies on forecast results, it is necessary to use sensors to directly measure changes in the terrain.

To perform a safe low-level flight as a sensor to directly measure changes in the terrain of the earth's surface in a certain projected point it is used profile flight radar.

Thus, in the Chapter 3 it is proposed to use a weather radar station with the function of measuring the distance by a narrow beam in " TERRAIN " mode and a fixed antenna position as a telemetry PFR on commercial aircrafts.

Calculations of the main characteristics of the WXR under ideal conditions have shown that it can be used as a pulse range finder in profile flight implementation.

The automated use of the WXR in combination with the GPWS-2000 system as a profile flying radar involves the creation of a new WXR sub-mode "Relief" and the implementation of some algorithms for information exchange.

Further development of this proposed sub-mode can be related to its integration into the EGPWS system of a modern wind-powered ship. Also, the subject of further research is the development of an algorithm for the application of the sub-mode "TERRAIN" of WXR by pilots, the development of the panel design and the definition of message signals.

CHAPTER 4

LABOR PROTECTION

In this chapter we will analyze possible hazardous factors of the work environment during the work with the ground proximity warning system. The task is to consider occupational safety and health measures for protection of the subject. The subject of protection is an airline pilot working in an aircraft fitted with ground proximity warning system during flight. In this case, the pilot's workplace is the aircraft cockpit, where he or she performs tasks of piloting, navigation and system management.

4.1. Harmful and hazardous working factors

The working conditions of aircraft pilots can be characterized by highly specific working environment of crew cabin, irregular schedules, work during night and possible high level of mental stress. The specific factors of the work environment can depend on the type of the aircraft, flight time, weather conditions, terrain, etc. We may consider several general environmental factors of an aircraft pilot during the flight [10]:

- Ergonomics of the crew cabin. This includes placement of gauges, displays, control panels, communication equipment, outside visibility, tightness of the cabin, etc. The most important indicators and controls must be easily readable and reachable. The comfort of the pilot also must be considered. Most aircraft cabins have problem of limited space.

- Lighting protection. Bright sunlight entering the cabin can blind pilots and if directly hitting the digital displays, it can make them unreadable. This can result in pilots straining their vision, as well as additional efforts in reading gauges. Thus, the availability of protective curtains, sunshades and use of polarized glasses should be considered.
- Microclimate. Temperature, humidity and air pressure are regulated by the aircraft's air conditioning system. However, for the most part of flights, air pressure is lower than the sea level and humidity can drop significantly, which may lead to discomfort and health risks.
- Noise. Aircraft engines produce dangerous levels of noise. Aircraft must be designed with consideration of noise protection, so the noise pollution in the cabin crew doesn't exceed allowed levels. Means of noise protection, such as headphones also may be used. Additional sources of noise are auditory warnings system, radio noise and noise from other equipment. Loud sounds and noise may damage hearing over time and distract the pilots, reduce productivity and serve as additional stress factor.
- Vibrations. During the flight, aircraft engines and other equipment produce vibrations. Excess levels of vibrations may lead to discomfort or long-term health effects.
- Communication. During the flight it is important to follow special procedures of communication between air traffic control, flight crew and cabin crew in order to avoid any misunderstanding and exclude unnecessary chatter on the radio. This can lead to additional mental and social stress.
- Electromagnetic radiation. Various systems of an aircraft, mainly radio navigational and communication equipment, whether radars, can emit intense electromagnetic fields. This may affect health of the pilots.
- Flight conditions. In case of flying in harsh weather conditions, during night, in busy air traffic, or over difficult terrain, aircraft pilots endure additional stresses. This can lead to mistakes and reduced productivity. Constant high levels of stress may lead to long-term health effects.

- Flight and fire safety. Malfunctioning of equipment, human error or other factors can lead to dangerous incidents. To ensure safety, respective emergency procedures must be followed by the crew. The required safety and emergency equipment must be available and easily accessible by the crew. This may include emergency checklists, oxygen masks, fire extinguishers, smoke hoods, fire axes, live vests etc. Aircraft is also equipped with fire extinguishing system designed to extinguish engine fire or fires in cargo compartments. Fire safety also should be considered in the design of the aircraft, mainly by implementation of fire resistance materials, fire detection and extinguishing systems, engine firewalls, fuel tanks protection, etc.
- Work schedule. Aircraft pilots often work by irregular schedule and during night. To protect the health of the pilots and exclude safety risks due to lack of sleep or fatigue, total flight hours should be limited. Additional problems arise in the case of long-haul flights, when large shifts of time zones occur. This can lead to additional stress and fatigue, also affecting health in a long-term.

We also can consider possible occupational hazards of the aircraft pilot, during work in the crew cabin. Some of such hazards are highly specific for such working environment:

- High level of mental stress due to various factors, described above;
- Jet lag as result of changing time zones;
- Strain of vision;
- Dehydration due to low humidity;
- Hearing damage due to noise;
- Danger of falling or injury due to working in narrow spaces;
- Harmful effects of sitting for long periods of time;
- Danger of aircraft incidents, such as depressurization, fire, equipment malfunctioning, possible electrocution, etc.

To ensure occupational safety, several regulations are applied. The general regulations regarding working conditions are considered in The Law of Ukraine on labor protection, dated 14.10.1992 [1]. In addition, several state standards are used, such as:

- State sanitary norms of industrial noise, ultrasound and infrasound DSN 2.3.6.037-99;
- State sanitary norms of industrial general and local vibration DSN 3.3.6.039-99;
- State sanitary norms of the microclimate of industrial facilities DSN 3.3.6.042-99;
- General requirements regarding the provision of occupational health and safety by employers, approved by the order of the Ministry of Emergency Situations No. 67.

However, such generalized standards may not be sufficient for aviation industry. The regulations and rules in aviation are set internationally by ICAO and in Ukraine by the Air code of Ukraine. Some of normative regulations regarding occupational safety in aviation are:

- Law of Ukraine "On the state program of aviation security of civil aviation".
- Order of the Ministry of transportation "On the approval of the Instructions on actions of the crew in case of emergency situations on board the aircraft during passenger air transportation" 17.06.2008 No. 48/DSK.
- Order of the Ministry of transportation "On approval of the Program for quality control of safety of aviation entities" 04.20.2007 No. 329.

4.2. Analysis of the noise influence into the cabin crew

Sound is the propagation of a sound wave in an elastic medium. It is characterized by the frequency of sound vibrations, amplitude, and time changes of vibrations. The sound spectrum is divided into infrasound, the frequency of sound wave oscillations of which is in the range from 0 to 20 Hz (a person does not perceive these sounds by the hearing organs). Sounds with a frequency of 20 to 20,000 Hz (the sound range that a person hears). Frequency from 20,000 Hz to 109 Hz - ultrasound, from 109 and above - hypersonic (human ear does not perceive them).

Noise is the oscillation of a sound wave in the sound range, characterized by variable frequency and amplitude, instability in time, which do not carry useful information for humans. Noise is considered to be sounds that adversely affect the human body, interfere with its work and rest. Noise is often called an adverse sound. Noise is characterized by sound speed, frequency, sound pressure, intensity.

Noise standards for workplaces are regulated by sanitary norms and the state standard. Noise is standardized: ГОСТ 12.1.003-2014 "Noise. General safety requirements", "Sanitary norms of permissible noise levels at workplaces" № 3223 12.03.1985 and ДСН 3.3.6-037-99 "State sanitary norms of industrial noise of ultrasound and infrasound" [3,4].

Permissible sound pressure levels in octave bands frequencies equivalent to the sound level at cabin crew workplace (cockpit) are given in the Table 4.1 [2].

Table 4.1 Permissible sound pressure level for work place of passenger and transport aircraft and helicopters crew

Type of working activity, workingplace	Sound pressure levels in dB in octave bands with geometric mean frequencies, Hz								
	31.5	63	125	250	500	1000	2000	4000	8000
Working places of cabin crew (pilot, co-pilot) and stewards	107	95	87	82	78	75	73	71	69

Noise is a general biological irritant and under certain conditions can affect all systems of human life. It can be especially dangerous for aircraft pilots, whose work requires maximum concentration and quick decision-making [5,8].

Pilot error during flight operations has important consequences for flight efficiency and safety. Environmental factors in the cockpit can influence the likelihood of pilot error. Among such factors are humidity, temperature, pressure, vibration and noise. However, such factors have been neglected in surveys covering factors affecting pilot performance. The large European pilot survey on Health Effects in the Aircraft Cockpit (HEACE) and the evaluation of 12 cabin noise models indicate a significant impact of noise on pilot performance. A survey of pilots of the Croatian national airline showed that the impact of aviation noise on pilots at least once compromised the safety of 27.8% of turbofan pilots, 38.5% of turboprop pilots and 38.5% of turboprop pilots [6,8].

Therefore, let us consider the consequences of adverse effects of noise on humans:

- daily exposure to intense noise at high frequencies - 4000 Hz and more (leads to an occupational disease - hearing loss, a symptom of which is slow hearing loss in both ears)
- very high sound pressure can lead to rupture of the eardrum (the most unfavorable for the hearing organs are high-frequency noises - 1 000-10 000 Hz);
- direct impact of noise on various parts of the brain, which disrupts the normal processes of higher nervous activity and is expressed in rapid fatigue, general weakness, irritation, apathy, memory loss, sweating, etc. At the same time, this negative impact can affect before there are problems with the perception of sounds by the hearing organs;
- negative impact of noise on the organs of vision (decreased visual acuity and sensitivity to color distinction);
- vestibular apparatus suffers from noise, gastrointestinal tract functions are disturbed, intracranial pressure increases, metabolic processes in the body are disturbed, etc.

However, the study of a small group of pilots with an average level of experience suggests that cumulative noise exposure may not have a significant impact on the performance of a number of standard piloting operations related to aviation and navigation [7]. In contrast to previous studies, the present work considered cumulative rather than instantaneous noise, given that numerous studies have shown the ability of chronic noise exposure to cause long-term changes in pilot performance, e.g. from a temporary to a permanent shift in sensitivity threshold. The maximum cumulative exposure investigated here was up to 40% of the recommended daily dose, so further studies are needed to investigate whether exposure to noise above these levels may affect performance. Although we have investigated a number of flight elements of varying complexity, studies involving a full flight that include, for example, vibration or other flight-related forces may allow a more comprehensive assessment of how environmental factors affect pilot performance.

4.3. Recommendations to reduce the noise influence into the cabin crew

Protection against the influence of aircraft noise on the human body is carried out in two ways. The first is appropriate structural changes of aircraft power plants, application of special modes of take-off and landing of aircraft, use of airfield noise silencers, transportation of aircraft on the airfield by towing means, construction of aircraft engine testing stations, etc.

This method can be called active, since noise is eliminated at its source.

The second method is passive. It consists in the use of anti-noise, that is, personal protective equipment against noise, which significantly reduces the effect of noise not only on the auditory analyzer, but also on the cerebral cortex as a whole.

Pilots working in noise conditions must strictly observe the work and rest regime. Normal sleep lasting at least 8 hours is especially important for them.

Ways to reduce noise of aerodynamic and hydrodynamic origin are as follows [10]:

- Reducing the speed of air and liquids, which provides a laminar mode of their flow (if possible);
- Design and provision of engine and nacelle structures at the development stage, which contain sound-absorbing materials and absorb the sound and vibrational energy that falls on them;
- Providing of structural elements of the aircraft that crush the flows, thus reducing their energy;
- Providing for a clear priority of warning messages from systems in the cockpit, as their redundancy and overlapping can lead to loss of attention of the pilot/copilot and further piloting errors;

- use of serviceable headsets that meet aviation requirements and take into account the anatomical features of human hearing perception.

One of the simplest and most cost-effective ways to reduce noise is to use sound insulation and sound absorption techniques.

4.4. Fire safety

To reduce the risk of fire and its spread, the aircraft shall be equipped with: structural means that warn of the occurrence and spread of fire; systems and devices for detecting fire in fire hazardous areas and signaling it to the crew; fire extinguishing systems in fire hazardous areas; drains to remove the accumulation of flammable liquids and their vapors from places of possible accumulation on the aircraft.

On the aircraft, fire hazardous areas are engine compartments, as well as compartments where power and heating installations operating on fuel are located. In addition, all areas of the aircraft in which there is a potential for fire due to the destruction or damage of any structural elements, units and assemblies, as well as the appearance of the flow of flammable liquids in the presence of ignition sources (for example, internal engine cavities) may be fire hazardous.

It is necessary to exclude self-ignition of flammable liquids in places of their contact with structural elements of the aircraft. For this purpose, in all cases, the maximum temperature of these elements should not exceed 200°C [5].

To reduce the likelihood of fire during an emergency landing, emergency systems are provided for switching on the supply of extinguishing agent to fire-hazardous compartments. Elements of the aircraft structure, which may be exposed to exhaust gases, are made of fire-resistant materials. Fire alarm and extinguishing systems must be fast, reliable and located in all fire hazardous areas.

According "Technical requirements and administrative procedures for flight operation in civil aviation", section CAT.IDE.A.245 Protective oxygen apparatus and respirators for crew members [7]:

- All sealed airplanes, as well as non-sealed airplanes, with a GVW greater than 5,700 kg or an MOPSC greater than 19, must be equipped with self-contained breathing apparatus (SCBA) for eye, nose and mouth protection; the following devices must be able to provide protection for at least 15 minutes:
- oxygen for each flight crew member on flight deck duty;
- breathing gas for each assigned cabin crew member at his or her workstation;
- breathing gas for portable PBE per flight crew member at their workplace for airplanes operated with more than one flight crew member and no cabin crew member.
- The flight crew PBE must be installed in the flight crew compartment and be readily accessible for immediate use by each flight crew member at their workstation.
- A cabin crew PBE must be installed adjacent to each designated cabin crew member's workstation.
- Airplanes must be equipped with additional portable PBEs that are installed adjacent to the portable fire extinguisher specified in CAT.IDE.A.250 or adjacent to the cargo compartment entrance if a portable fire extinguisher is installed in the cargo compartment.
- The PBE when in use shall not interfere with the use of the means of communication specified in CAT.IDE.A.170, CAT.IDE.A.175, CAT.IDE.A.250, CAT.IDE.A.270 and CAT.IDE.A330.

As it is stated at CAT.IDE.A.250 Portable fire extinguishers []:

- The airplane must be equipped with at least one portable fire extinguisher in the flight crew cabin.
- At least one portable fire extinguisher shall be located (or readily accessible for use) in each galley on board that is not located in the main passenger cabin.
- At least one portable fire extinguisher must be available for use in each Class A and B baggage compartment and in each Class E cargo compartment to which crew members have access in flight.
- The type and quantity of extinguishing agent for the fire extinguishers required on board shall be appropriate to the type of fire likely to occur in the compartment;

also, the type of extinguishing agent must be selected in such a way as to minimize the effect of toxic gas concentration in passenger cabins and crew cabins.

Table 4.2 contains the minimum number of portable fire extinguishers with which airplanes must be equipped; such fire extinguishers shall be conveniently located in each passenger compartment for possible use in the event of a fire hazard.

Table 4.2 Number of portable fire extinguishers

MOPSC	Number fire extinguishers
7-30	1
31-60	2
61-200	3
201-300	4
301-400	5
401-500	6
501-600	7
601 or more	8

CHAPTER 5

ENVIRONMENTAL PROTECTION

In this chapter we provide the analyze possible of hazardous influence on environment during the work with the ground proximity warning system of modern aircraft. The task is to consider negative impact on the environment and human health of the system researched in the diploma. The subject of protection is cabin crew, passengers and surrounding nature and air.

5.1. The effect on the environment of the GPWS system operation combining with weather radar

Radio navigation is a system equipped with receivers that allow determining the location of an aircraft relative to beacons on the ground. One such device is a radio altimeter, the data of which is used by the GPWS system to determine the position of the aircraft.

Since the GPWS system described in this paper receives data from a WXR system, it is important to note that the main units of modern WXRs are usually an antenna, a transceiver, and an indicator (display) with a control panel. All these devices are a source of electromagnetic radiation, which to varying degrees affect the environment.

The Fig.1 as an example shows that there are many antennas and receivers of different types on the aircraft, which together can affect human health during prolonged stay in an environment with high density of electromagnetic radiation [1]. That is why the crew is the first to be exposed to electromagnetic waves, as they spend a lot of time in the cockpit full of electronic devices.

The biological effect of electro-magnetic waves during long-term exposure is cumulative, which leads to the development of long-term consequences, such as blood cancer, brain tumors, hormonal diseases, degenerative processes of the central nervous system [2].

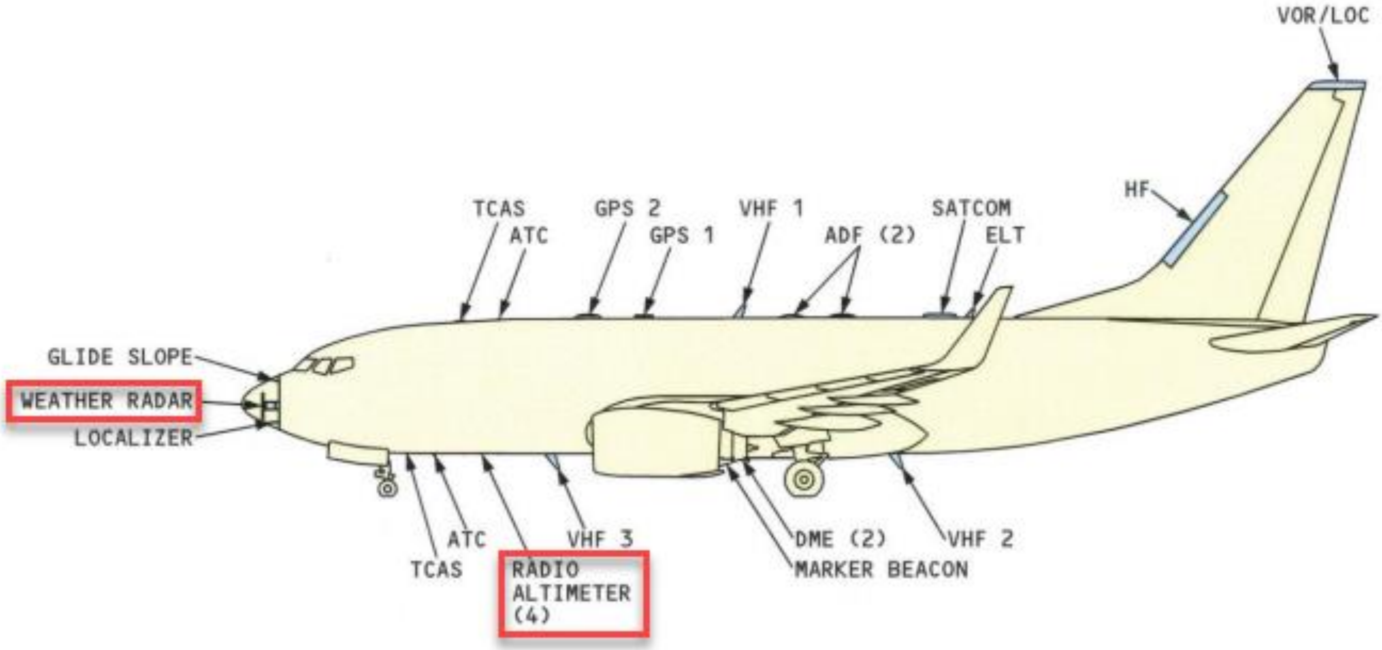

Fig.5.1 Location of Boeing 737 NG aircraft antennas

5.2. Analysis of harmful and hazardous influence on the environment by the GPWS operation on-board of aircraft

From the environmental point of view, a modern aircraft can be considered as a complex of electromagnetic energy radiation that has a harmful effect on the environment and humans. The sources of radiation include radars, communication equipment, etc.

Among the aircraft systems, the sources of high-frequency electromagnetic radiation are radio technical means:

- radio equipment of external and internal communication (communication, command and emergency radio stations);

- radio navigation equipment (onboard survey radars, Doppler radars measuring speed and wear angle, radio altimeters, radio compasses, radio distance meters);

- radio equipment of aircraft landing systems (overview, control and landing radars, radio direction finders, radio beacons).

Since radar equipment emits electromagnetic energy in the NPS, it is possible to generate electromagnetic fields (EMF) of high intensity - a real threat to living beings [3].

The most biologically active are decimeter, centimeter (WXR) and especially millimeter waves. Medical and biological studies of the impact of microwave radiation on living organisms have shown that it can disrupt (suppress) the activity of the central nervous system, destroy protein molecules contained in the blood, change the functions of human endocrine organs. Negative impact of electromagnetic radiation is increased by the noise factor.

Interacting with a living organism, electromagnetic waves are partially reflected and partially propagated in them and absorbed. The degree of impact depends on the amount of energy absorption by body tissues, wavelength (with decreasing wavelength biological activity increases) and the size of the biological object.

Such absorption of electromagnetic energy will cause thermal effect, which is manifested by significant heating of tissues. The presence in the human body organs with weak thermoregulation mechanism (brain, eyes, kidneys, gall bladder, etc.) leads to their increased sensitivity to electromagnetic radiation. For example, irradiation of human eyes with centimeter microwaves can increase the temperature in the back of the lens by 20 ° C and cause cataracts.

The fact of EMF influence on higher human nervous activity and bioelectrical activity of the brain is proved. It is established that the most sensitive to EMF are endocrine, immune and reproductive systems human endocrine, immune and reproductive systems. Periodic exposure to EMF can lead to persistent changes in hormonal balance, adversely affect genetic structures.

In order to protect the population and prevent occupational diseases, the maximum permissible levels (MPL) of EMF are established, i.e. such values of its parameters that, when exposed daily in the mode inherent in this source, do not cause diseases or health deviations in the population (without limitation of sex and age), which are determined by modern research methods during the exposure period or long after its termination.

Today, the impact of electric and magnetic fields with a frequency of 10...30 kHz is estimated by the conduction current density. It is believed that the conduction current density j < 0.1 μA/cm2 induced by an external field does not affect the brain functioning, since the pulse biocurrents flowing in it are of higher values.

In the frequency range from 30 to 100 kHz, the mechanism of action of the fields through the excitation of nerve and muscle cells gives way to thermal action, and the determining factor is the specific absorption power (W/kg). It is believed that the safe limit is 0.4 W/kg.

To prevent diseases associated with the action of radio frequencies, the maximum permissible levels of intensity and energy flux density (EFD) at the workplace of personnel and for the public are established. In the frequency range of 60 kHz...300 MHz at the workplaces of personnel during the working day, the intensity should not exceed the permissible limit established by ГОСТ.

It is also worth mentioning, that the danger of electromagnetic fields is increased by the fact that they are invisible and can not be detected by the senses. For example, the thermal effect of radio waves will be greater the longer the wave, which in turn is caused by the depth of its penetration into the human body. Such surface heating will not trigger the human protective mechanism - thermoregulation. This is one of the reasons that generates a dismissive attitude of workers to the danger of exposure [4].

Since the proposed structure of the GPWS system involves the use of WXR, one of the components of which is a waveguide-slot antenna (Fig.2), it should be noted that the concepts of "near" and "far" zones are associated with the antenna field. The near zone (Fresnel) lies at a distance of 1-3 diameters of the antenna. The far zone (Fraunhofer) is the formation zone. For omnidirectional radiation, the near zone coincides with the induction zone. For LF, MF, HF, VHF, UHF installations, the working zone falls into the induction zone, and for microwave installations - into the irradiation zone [5].

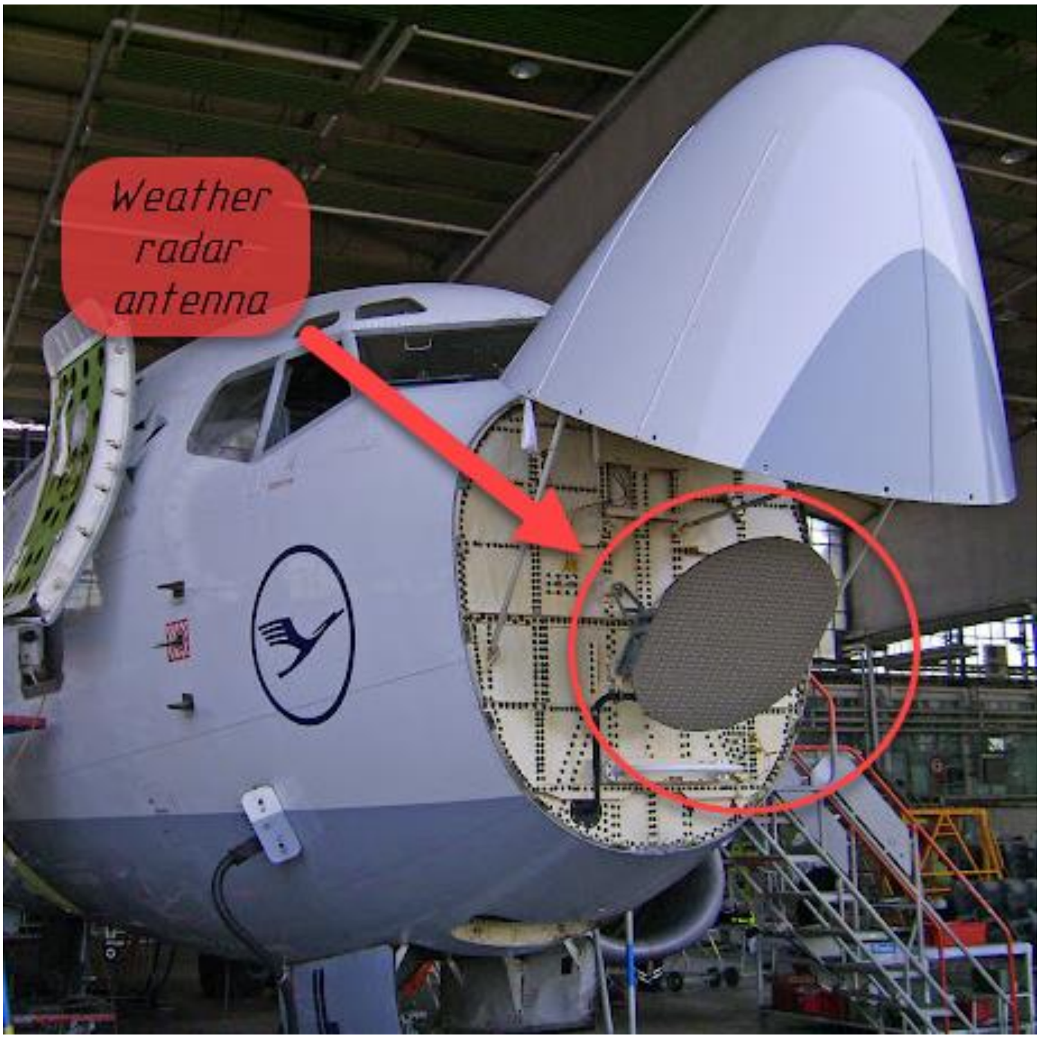

Fig. 5.2 Weather radar antenna right in front of the cockpit

5.3. Recommendations to reduce environmental the impact

The increasingly widespread use of radio electronics in modern life has forced Japanese scientists to turn to the search for effective methods of protection of specialists working with devices that emit electromagnetic waves. According to the representative of the Japanese company "Nissinbo", they have developed special clothing that protects against electromagnetic waves. Vests of these clothes are made of polyester with a multilayer lining. The lining is made of copper and nickel threads that reflect 99.9% of electromagnetic waves coming from electronic equipment [6].

There are the following measures to protect the crew and passengers of the aircraft from EMF include the following [8,9]:

- if possible, placement of devices, antennas, radio stations that emit EMF in such a way as to minimize the possible exposure of people;

- ensure that personnel stay in the EMF zone for the minimum time necessary for the work;

- install devices on the aircraft, the power of radiation sources of which should be the minimum necessary;

- allocation of EMF radiation zones with appropriate safety signs;

- dosimetric monitoring.

- shielding of radiation sources with metal solid and mesh screens. The intensity of exposure can also be reduced by absorbing coatings (often the screen material is foil).

- shielding of places where people are located on the aircraft;

- use of warning alarms;

- use of personal protective equipment;

- provide periodical medical check-ups for aircraft crew;

- set limit on working hours for aircraft crew to reduce time spend under electromagnetic radiation effect.

Conclusions to the Chapter 5

This section considers the possible human exposure to radio equipment that is part of the GPWS and WXR systems. In particular, radio altimeters, antennas, receivers, etc. are sources of electromagnetic waves. Taking into account the fact that the aircraft is a combination of such sources of electromagnetic radiation, it creates an electromagnetic field, which, with prolonged exposure to humans, can lead to negative consequences. First of all, it causes a threat to the health of pilots and other crew members, as they spend a significant part of their working time there.

Finally, in this section, safety measures are proposed to reduce the impact of the electromagnetic field on the health of the crew and passengers of the aircraft. They can be conditionally divided into technical (through the introduction of aircraft design features and proper shielding of electromagnetic radiation sources) and organizational (aimed at reducing the time spent under the influence of the electromagnetic field and timely detection of its negative effects). The most effective and most commonly used method is shielding of the source or workplace, the shapes and sizes of the screens are varied and should correspond to the conditions of use.

CONCLUSIONS

The system of early warning of a collision with the ground issues reactive warnings and predictive warnings to the crew about the possibility of the aircraft colliding with the ground, which allows to increase the time given to the crew to make a decision and correct piloting errors.

However, after analysis of Ground Proximity Warning System of AN-148 aircraft and Enhanced Ground Proximity Warning System of Boeing-737 NG aircraft, it was found that the Terrain Avoidance and Warning Systems have a number of disadvantages. Since the system uses digital models that have a certain update period and do not provide up-to-date information in real time when predicting the flight path of the aircraft, there is a risk of the aircraft encountering artificial or new obstacles that were not in the database of the Ground Proximity Warning System.

Moreover, when flying at low altitudes, an error in determining the coordinates of the aircraft's location is a threat, which in turn can lead to an inaccurate calculation of the distance to an obstacle or to the earth's surface.

In order to eliminate these shortcomings, it is proposed to use the profile flight radar to determine the proximity of the aircraft to the current terrain or obstacle. In this work, weather radar is considered as such a profile flight radar. For simplification of use of the system, it is possible to add the "TERRAIN" sub-mode of weather radar in which the weather radar antenna will be in a fixed position.

The weather radar of the AN-148 aircraft was taken to calculate the profile flight radar parameters, and the synthesis of its data transmission and the GPWS-2000 system was described. The synthesis of these systems will enable monitoring the current topography of the earth's surface, predicting a possible collision with the ground or obstacles, and issuing appropriate warnings and alarms to aircraft pilots. The described solution can significantly increase the safety of flights at low altitudes.

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