УДК [629.7.052:621.37]:629.735.45

Compact Radar System Safe Helicopter Landing

Vladimir A. Malyshev and Viktor G. Mashkov*
Military Education and Research Centre
of Military-Air Forces «Military-Air Academy
Named After Professor N.E. Zhukovsky and Yu.A. Gagarin»
54a Starykh Bol'shevikov Str., Voronezh, 394064, Russia

Received 03.02.2018, received in revised form 20.09.2019, accepted 07.10.2019

Practical realization the radar device is capable safe landing an aircraft of the helicopter type on unprepared sites in any time the day, in VFR and IFR weather conditions, in the presence natural and artificial interference. The calculation range based on measuring the transit time of the signal to the earth's surface and back. The results in each time on the LCD display, applied to it the scale range elevations of objects with a height exceeding the permissible limits, which are in dangerous proximity to the aircraft under.

Keywords: radar system, helicopter landing, unprepared pad, a blind landing.

Citation: Malyshev V.A., Mashkov V.G. Compact radar system safe helicopter landing, J. Sib. Fed. Univ. Eng. technol., 2019, 12(7), 792-801. DOI: 10.17516/1999-494X-0179.

Малогабаритная радиолокационная система безопасной посадки вертолета

В.А. Малышев, В.Г. Машков
Военный учебно-научный центр Военно-воздушных сил
«Военно-воздушная академия
имени профессора Н.Е. Жуковского и Ю.А. Гагарина»
Россия, 394064, Воронеж, ул. Старых Большевиков, 54а

Рассмотрена практическая реализация устройства радиолокационного типа, способного обеспечить безопасную посадку воздушного судна вертолетного типа на неподготовленные площадки в любое время суток, в простых и сложных метеоусловиях, при наличии естественных и искусственных помех. Вычисление дальности основано на измерении времени прохождения

* Corresponding author E-mail address: mvgblaze@mail.ru

сигнала к земной поверхности и обратно. Выдача в каждый момент времени на ЖК индикатор, с нанесенной на нем шкалой дальности, отметок от объектов с высотой, превышающей допустимые нормы, которые находятся в опасной близости под воздушным судном.

Ключевые слова: радиолокационная система, посадка вертолета, неподготовленная площадка, слепая посадка.

Landing on an unprepared ground is one of the most difficult aspects piloting of the helicopter, it is associated with an increased risk accidents and casualties. The need for landing on unprepared sites occurs primarily in the military aviation: landing, evacuation, shipping ammunition and supplies in combat – in these tasks it is often necessary to put the helicopter in unprepared or undeveloped area landing (or hover directly above it). Blind landing on unprepared ground becomes the cause a significant percentage of accidents.

One the key problems when landing on unprepared ground are the conditions insufficient visibility (eng. degraded visual environment, CIV). Under CIV means weak or zero optical visibility of the outside environment due to any the following factors or a combination: weak light, adverse weather conditions (fog, snowstorm, etc.), raising the propeller of the helicopter vortex solid particles [1].

When landing on dry or snow-covered soil air jet from the main rotor of the helicopter picks up suspended solids that critically reduces visibility and may lead to an incorrect assessment by the pilot of the helicopter position relative to the earth, moreover, may go undetected obstacles in the landing zone (large stones, static and moving objects). The term «dusty whirlwind» (brownout) describes this phenomenon during landing or takeoff on a dry surface. Similar conditions during landing or takeoff on a snowy surface described by the term «snowdrift» (whiteout). As the entrance of the helicopter in the dusty (snow) cloud visibility intended for planting landmarks worsens, and then eliminated completely [1, 2]. In addition, adverse weather conditions or insufficient light in the landing zone can be shrubs, trees, power lines, masts, buildings, structures, etc.

For a radical solution the question of safety in such situations, it is necessary to develop a special compact radar system intended for installation on aircraft helicopter type and providing a solution to the problem safe landing of the aircraft day and night in all weather conditions.

Code name sample – sensors (PRCTR), comprising a receiving-transmitting unit; a special processor I processing; antenna-feeder device (AFD); AFD PRCTR drive, with a system of stabilization and control; indicator; voltage regulators (if necessary).

Requirements PRCTR to ensure work assignment under the following conditions of flight carrier:

- flight altitude 50...10 m;
- minimum allowed pitch and roll;
- providing a sensing of the earth's surface in the regime of incoherent pulse radar with the following parameters:

a) millimeter wavelength range λ = 8 mm (f_0 = 37,5 GHz);
b) a linear resolution 1 m in range and azimuth;
c) the removal the zone survey is not dependent on the altitude of the aircraft is 15 m;
d) the range detection ground (sea) objects must be 100 m;

- indicating object level indicator on the LCD with an interval 0,5 s.

Analysis of radar PRCTR

Structurally PRCTR performed by the functional block method in the form of separate units and devices. Digital indicator hazardous area is installed in the helicopter cockpit on the instrument panel. Two transmit-receive module mounted under the fuselage.

PRCTR is a dual-channel non-coherent pulse radar station (radar), which is characterized by the following:

- every time the ground surface is irradiated by a nanosecond-duration radio pulses, and the radiation of the probing signal occurs through two narrow spaced antenna. One the antennas rigidly mounted, the antenna pattern (AP) is directed downwards under the aircraft. The second antenna is rotating in the horizontal plane the platform and includes a tilt mechanism of the antenna in elevation. AP this antenna sequentially scans the region of the earth’s surface under the aircraft at some distance from the vertical, describing a circle in the horizontal plane. Depending on the current height of the aircraft changes the angle the antenna in order for the scanned region did not change;
- processing the received signals incoherent, dual channel, comes down to measuring the time signal the earth’s surface and back through two channels. The time interval between the emitted and the reflected pulse – current distance to the object. The difference in delay signals the first and the second channel at each moment time, taking into account the correction factor for the slant range the second channel indicates the relative elevation the place landing of the aircraft.

The main objective PRCTR the results in each moment time (period of repetition $T = 0{,}5$ s) on the LCD indicator printed on it a scale distances the markers from objects with a height exceeding the permissible limits, which are in dangerous proximity under the aircraft. The calculation range PRCTR is based on measuring the transit time the signal to the earth’s surface and back. The time interval between the emitted and the reflected pulse is measured by counting the number measurement pulses generated by a highly stable oscillator.

Method pulse distance measurement, which is the basis algorithm of functioning PRCTR is as follows.

The launch the device measuring the current distance is performed at the time the radiated pulses from the synchronizer of the radar (Fig. 1). As a result, the generator the counting pulses (GCP) begins to form a sequence pulses with repetition period $T_{сч}$, and $T_{сч} \ll T_{и}$, where the repetition $T_{и}$ period of the probing pulses. At the same time begins to form the gate pulse in the shaper pulse selector (SPS). At the time formation the leading edge of the pulse selector feature selector impulses (SI). As a result, the digital pulse counter (DPC) start to do the counting pulses (CP) and DPC counts the number of pulses received at its input.

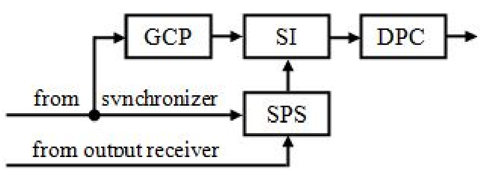

Fig. 1. Principle of operation radar PRCTR

Counting the counting pulses continues until, until the locking mechanism SI. Locking of SI occurs at the time formation the trailing edge the selector pulse, which occurs upon entrance of SPS the signal reflected from the target from the output of the receiver radar. Thus, the output the DPC resulting digital code corresponding to the delay time $t_д$ the signal reflected from the target. Therefore $t_д = N_д T_и$, where the $N_д$ – number of clock pulses received on the input of the DPC $t_д$. Hence the distance D to the target

$$D = \frac{ct_д}{2} = \frac{cN_д T_{сч}}{2}. \quad (1)$$

Due to the fact that the measured value range in each channel change only when the number $N_д$ changes per unit, there is a discrete reference $t_д$, and hence the range to target discrete and equal $\Delta D = 0{,}5cT_{сч}$.

Clear countdown the distance to the target is possible when $t_д \le T_и$. Therefore, choosing the repetition period $T_и$ the probing pulses at a predetermined maximum range $D_{макс}$, should be found from the condition

$$T_и \ge t_{д\ макс} = \frac{2D_{макс}}{c}. \quad (2)$$

Given the fact that $D_{макс}$ = 50 m, and hence $t_{д\ макс}$ = 0,33 μs, and repetition period is taken with some margin equal to the $T_и$ = 1 μs.

Based on the fact that the error in determining the relative elevation the place of landing aircraft shall not exceed 1 m, the error in determining the distance to the object is chosen equal to ΔD = 0,5 m and $T_{сч}$ must not exceed 3 ns.

For a given maximum range the radar $D_{макс}$ and the desired error definition ΔD you can define the maximum number bits of the binary counter is needed to implement DPC, from the condition

$$2^n \ge D_{макс} / \Delta D = 2^7.$$

Power ratio

In accordance with the range equation of the radar

$$D^4 = \frac{2\frac{Pu}{Q} G S_a \sigma_{уд} \delta x \delta r}{(4\pi)^2 N_0 R_0 \alpha_n}, \quad (3)$$

regardless the type probing signal receiving resolution 1 m in range and azimuth impulse requires a transmitter power 1 mW at specific effective reflection surface underlying surface $\sigma_{уд}$ = – 14 dB, the desired signal (background area)/internal noise R_0 = 20 dB; the losses of the processing α_n = 20 dB, the power spectral density noise $N_0 = 4 \times 10^{-21}$ W/Hz, duty cycle

$$Q = \frac{T_и}{\tau_и} = 170$$

for the duration the probe pulse $\tau_и$ = 6 ns, G = 200, the antenna gain and effective area of antenna $S_a = 0/15^2$ m^2.

To provide predetermined energy capacity either antenna of large area and low average power of the transmitter, either a small antenna, but at a higher transmitter power.

PRCTR scheme involves the use nanosecond pulses (6 ns) to reduce the «dead zone» (lack impulse radar) up to 10 m and the calculation error the distance to object – 0,5 m. In this case, the antenna switch high speed, to lock the receiver at the time of radiation. Must also provide isolation between the receiving and transmitting channels for the attenuation the penetrating signal transfer channel in receiver.

As the probing signal, without overloading the system PRCTR additional processing, it is better to use a simple and widespread sequence unmodulated rectangular pulses duration with τ_u carrier frequency of f_0 = 37,5 GHz.

To obtain resolution in the range of 1 m requires pulse durations

$$\tau_u = \frac{2\delta r}{c} = 6 \text{ ns}.$$

When T_u = 1 μs, duty cycle Q = 170 that can be implemented in the existing components.

Depending on the tactical tasks solved PRCTR to reduce the weight and size dimensions the antenna system PRCTR selected millimeter wavelength range λ = 8 mm. In the range wavelengths λ = 3 mm difficult to realize in practice the individual elements the block diagram PRCTR, for example, reference oscillator, antenna switch, etc.

Block diagram

The main elements PRCTR include a transmitter that generates radio-frequency pulses; antenna-feeder device that emits radio pulses and receiving them after reflection; a receiver for amplifying and converting the reflected pulses; a display; a synchronizer for coordinating operation the transmitter, receiver and indicator. The possible auxiliary devices can include radar system adjustment the carrier frequency for suppression of active noise.

Transmitter

The synchronizer trigger pulses the reference oscillator the transmitter that generates the radio millimeter wavelength range λ = 8 mm with a duration 6 ns rectangular shape. As a reference generator small capacity it is possible to use vacuum small generators on the basis lamp backward wave or Gunn diodes and avalanche transit-time diodes.

Antenna-feeder device

This device includes two antennas, antenna switch and control system diagram for the mobile antenna.

One the antennas rigidly fixed, AP directed vertically down under the aircraft. The second antenna is rotating in the horizontal plane the platform and includes a tilt mechanism of the antenna in elevation. Control system depending on the current height the aircraft governs AP this antenna. It includes a mechanism rotation and tilt the antenna, the angle sensor antenna and the control unit.

Based on the system requirements PRCTR to determine the working area in the implementation the planting should come from the following positions (Fig. 2):

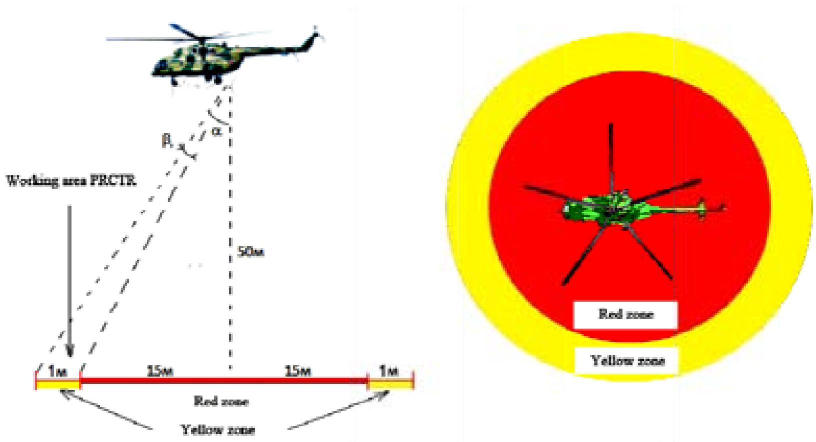

Fig. 2. The pattern PRCTR

– the width the zone around the helicopter 1 m;
– removal zone R = 15 m (determined based on the size the helicopter with working propellers, for example, the size the MI-8 is 26 m);
– working height PRCTR from 50 m to 10 m.

Based on the requirements (resolution and altitude range), the angle inclination the movable antenna should be changed in accordance with the law of

$$\alpha = arctg\frac{R\delta r/2}{H_{тек}}, \tag{4}$$

where δr the resolution in range, $H_{тек}$ the current altitude of the aircraft. Which corresponds to the angle 17.2° and a maximum height 50 m and 57,2° at a minimum height 10 m.

The variation the angle the antenna in time need to implement discretely, depending on the elevation changes the aircraft. If the step is equal δr, the error determining the removal work zone PRCTR defined as $\Delta R = tg\alpha$, will be changed from 30 cm to 1,55 m, which will have a significant impact on the accuracy of the system PRCTR in General. Therefore, it is additionally necessary to carry out the aggregation management system the mobile antenna with onboard inertial systems, measurement error changes the height which does not exceed a few centimeters.

To determine the type and size the antennas, first the required AP we use the Fig. 2. Since the fixed AP with a decrease in height VS the resolution of the radar is improved, then AP at the maximum operating altitude PRCTR should be $2\Theta_{0,5}$ = 1,05°. At a minimum height PRCTR in such AP the resolution will be about 0,6 m.

As an antenna with such a narrow AP and small size size is advisable to use mirrored parabolic antenna (MPA), which consists the irradiator and the mirror (Fig. 3, where: h – depth of the mirror; f – is the focal length; $2\varphi_o$ – angle of aperture; $L_з$ – maximum linear opening). The mirror converts the curvilinear wave front of the radiator to a flat front, wherein the aperture is provided MPA synphasicity field.

From the theory antennas according to the amplitude-phase distribution, the width of the AP can be estimated using the ratio:

$$2\theta_{0,5} = 58{,}9^{o}\frac{\lambda}{L_з}. \quad (5)$$

Solving the inverse problem, $L_з = 2R_з = 45$ cm. The sidelobe level get equal minus 17 dB, and the directivity factor

$$D_0 = \frac{4\pi}{\lambda^2}\cdot \pi R_з^2 = 40 \text{ dB}. \quad (6)$$

To convert spherical front MPA in the flat front, you need to use a mirror with a parabolic profile. For calculation of reflector antennas are used in the ratio:

$$L_з^2 = 16fh \text{ and } L_з = 4f\cdot tg(\frac{\varphi_o}{2}). \quad (7)$$

How $2\varphi_o = 120°$ get a $f = 19{,}5$ cm and $h = 6{,}5$ cm.

The bandwidth operating frequencies is determined MPA acceptable reduction of the gain and the allowable change width AP. MPA polarization determined by the polarization the radiator.

As irradiators use a weakly directional antenna there are point reflectors and linear. Point reflectors form a spherical wave front and these include open end the waveguide, helical antenna and horn antenna.

The main requirements for irradiators, are: the formation the desired wave front; AP feed needs to provide a certain «interception» energy mirror; minimum shading the aperture the mirror. Most often used as reflectors MPA the open end the waveguide. For the standard waveguide width the AP in the E-plane is, and in the H-plane. To increase the BOTTOM in the H-plane 120° it is possible to use the irradiator (Fig. 4, $\varphi = 60°$), with $a = 4{,}4$ mm and $b = 3{,}4$ mm, are calculated from the formulas

$2\theta_{0,5}^{H} = 66\frac{\lambda}{a}$ and $2\theta_{0,5}^{E} = 51\frac{\lambda}{b}$ respectively.

To ensure circular scan mobile antenna region around the aircraft and display object level indicator on the LCD with an interval 0,5 s, it is necessary that the angular velocity rotation the platform (disk's) was 120 rpm (2 revolutions/s). To reduce the requirements on the frequency rotation is possible due to the increase in the period of review space, the dependence is directly proportional.

The tilt mechanism the antenna in elevation should work to change the altitude of the aircraft in increments 0,1 m, then the error capture in the study area will not exceed 15%.

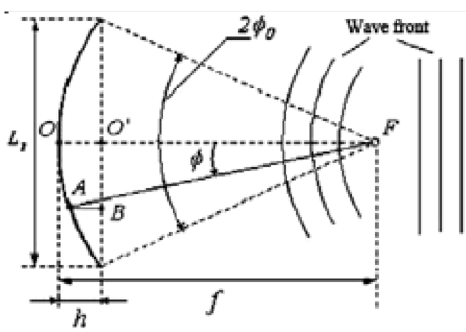

Fig. 3. Mirror parabolic antenna

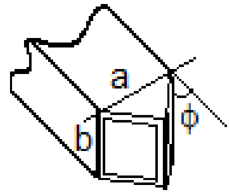

Fig. 4. Opening feed

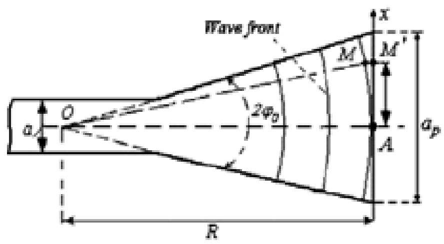

Fig. 5. Horn antenna

Width AP fixed antenna should not exceed 30° in E and H-planes. In this case, in order to reduce the final cost the system PRCTR advisable to use a horn antenna (Fig. 5). Horn antennas are a simple and broadband antennas.

To calculate the optimal H-plane sectorial horn are used in the following ratio:

$$R^{н}_{onm} = \frac{a_p^2}{3\lambda} \text{ and } 2\theta^{н}_{0,5} = 80\frac{\lambda}{a_p}; \tag{8}$$

to calculate the E-plane sectorial horn

$$R^{E}_{onm} = \frac{b_p^2}{2\lambda} \text{ and } 2\theta^{E}_{0,5} = 56\frac{\lambda}{b_p}. \tag{9}$$

Therefore, with λ = 8 mm, a = 21 cm, b = 1,5 cm and R_{onm} = 2 cm.

Receiver

The receiver should be performed in the homodyne scheme with a low noise radio frequency amplifier (LNA) to as little as possible to limit the reception weak signals. The bandwidth the receiver should be consistent with the spectrum width the received signals.

Consider the principle operation PRCTR simplified block diagram (Fig. 6). High-stability reference oscillator high-frequency vibrations by using frequency modulator generates a predetermined form the probe pulse signal at the carrier frequency, which is triggered by the signals the synchronizer is to ensure consistency the entire transceiver system. In the power amplifier at the output the transmission path is not necessary, since a power 1 mW obtained directly from the reference oscillator.

After antenna switch, a periodic sequence of pulses is radiated by each antenna (movable and stationary) within its specified radiation pattern. The polarization the radiated and received waves is determined by the design the antennas (polarizers). At full polarization sensing and reception, each

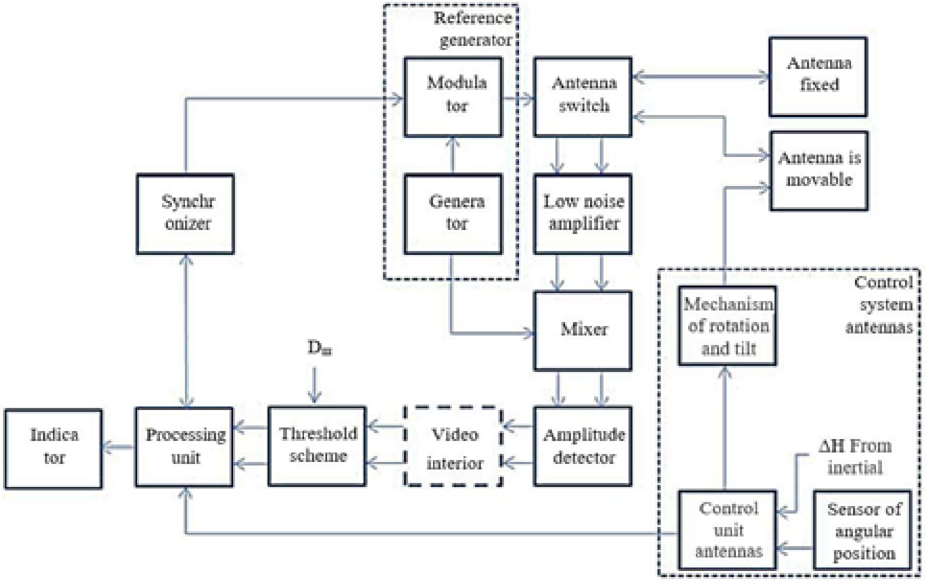

Fig. 6. Asimplified block diagram PRCTR

antenna generates four independent channels for the reception the waves with polarization GG, VV, GV and VG. Further, in the structure PRCTR is considered one the channels.

The system stabilization and control moves AP the mobile antenna in accordance with the required level the earth's surface. When «telescoping» the review antenna provides continuous illumination a given area (ring) the earth's surface by tracking them when you change the height and trajectory of aircraft. This is monitored by the signals from inertial systems and sensors of angular position.

Automatic switching the transmitting channel at the receiving antenna is in the switch. The choice switch is primarily for insertion loss, isolation between channels and switch time. Modern switches have the capability implementing a complete transition from reception mode to transmission in units nanoseconds, which significantly reduces the dead zone visibility millimeter radar.

The antenna switch can be made in the form of functionally finished microwave module on GIS technology using open-frame switching p-i-n diodes or using MEMS technology.

Electromagnetic waves reflected from objects in the viewing area receives both fixed and movable antennas to form two signals corresponding to the channel height measurement (fixed antenna) and the channel range (movable antenna). After amplification in low noise amplifier radio frequency electromagnetic pulses high frequency oscillations received on the second input the mixer. Next is the quadrature processing and detection.

From the output the amplitude detector signals are fed to the threshold device, where the detection threshold is set in accordance with the criteria detection, and the measured variance the noise $D_{ш}$.

For the case using packs of radio pulses $N_n = 5$ ($\tau_u = 6$ *нс*, $Q = 2$) is videointerior, where non-coherent accumulation signal, allowing to increase the ratio signal/noise at the input the threshold circuit. However, the use packs nanosecond pulses with a low duty cycle, requires further study the feasibility this on the existing components.

In the structural diagram depicts a two-channel signal processing unit, which performs counting the counting pulses prior to the receipt signals from the threshold circuits and generates a digital code corresponding to the delay time the signal in the channel range and digital code corresponding to the delay time the signal in channel height. The code values the height and angle the movable antenna unit angular position sensors is calculated, the estimated range the study area («ring» overview of the mobile antenna). This value is compared with the measured range and if the difference exceeds the threshold level, the results level the indicator the dangerous object in the area landing the aircraft. The threshold level should change depending on the current height the aircraft, which should be considered in the processing unit. To determine the angular position the threat object relative to the aircraft in a processing unit receives data from inertial sensors and angular position sensors.

The functioning the system processing is provided by a set algorithms for solving problems (algorithmic, software) and hardware (analog and digital processors, and computers).

When implementing the proposed scheme should be paid special attention when selecting the reference oscillator of highly stable millimeter band ultrashort pulses, high-speed antenna switch for transmitting and receiving channel and rotating the gyro-stabilized platform.

Conclusion

Thus, the implementation industry-developed sensors for the safe landing an aircraft the helicopter type in the conditions insufficient visibility on an unprepared ground will reduce the risk accidents and casualties.

References

[1] Сажаем вертолет вслепую: обзор технологий синтетического зрения [Электронный ресурс] – Режим доступа: http://www.geektimes.ru/post/280278/ – Заглавие с экрана. [Plant the helicopter in the blind: technology overview synthetic vision [Electronic resourse] – Access: http://www.geektimes.ru/post/280278/ (in Russian)]

[2] Особенности взлетов и посадок на пыльных, песчаных или заснеженных площадках [Электронный ресурс] – Режим доступа: http://www.svvaul.ru/component/k2/600-osobennosti-vzletov-i-osadok-na-pylnykh-peschanykh-ili-zasnezhennykh-ploshchadkakh/ – Заглавие с экрана. [Features takeoffs and landings in dusty, sandy or snow-covered sites [Electronic resourse] – Access: http://www.svvaul.ru/component/k2/600-osobennosti-vzletov-i-osadok-na-pylnykh-peschanykh-ili-zasnezhennykh-ploshchadkakh/ (in Russian)]