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Directions for improving of the geophysical support system for the effective operation of radio equipment of civil aviation

New quality indicators of the geophysical support system for the effective operation of radio equipment of civil aviation are proposed. New principles of prospective load planning of the geophysical support system for the effective operation of radio equipment are proposed in order to solve the problems of the negative impact of space weather on them.

General characteristics of the geophysical support system for the effective operation of radio equipment of civil aviation.

Heliogeophysical equipment complexes, which are part of the geophysical support system, are complex systems assembled from disparate devices that monitor the near-Earth space, the Earth's geophysical environment under various operating conditions, including extreme space weather. In general, the effectiveness of a multi-level of the geophysical support system for the effective operation of radio equipment depends on its parameters and external conditions.

It should be noted that geophysical forecasts currently have a number of shortcomings: 1) forecasts are mostly qualitative; 2) the quality of forecasts of the geophysical state decreases with increasing prematurity [1]; 3) the time of the beginning of the geomagnetic disturbance at the altitude of air flights is determined on average with an accuracy of about a day; 4) the reliability of the forecast of the real arrival of a geomagnetic disturbance does not exceed 50% [2]; 5) heliogeophysical events that were not predicted by the forecast are quite often observed.

If we denote by $X = \{ x_i \}, i = 1, p$ a set of system parameters characterizing both the elements of the system and the connection between them and by $Y = \{ y_s \}, s = 1, m$ a set of system parameters characterizing both the elements of the system and the connection between them, and by:

$$E = E\left(X, Y\right), \qquad (1)$$

Practical value is represented only by those systems of geophysical support, the efficiency of which exceeds a certain threshold level E^*, i.e.:

$$E \geq E^*, \qquad (2)$$

Usually, the threshold level is $E^* \geq 80\%$.

The geophysical support system must have several operating modes (quiet heliogeophysical conditions, disturbed heliogeophysical conditions, strongly disturbed heliogeophysical conditions (for example, a strong magnetic storm $K_p = 9$, solar-proton events with high-energy proton flows of $E = 100{,}000$ pfu, Wolff number over 100, etc (Table 1). Evaluation of the effectiveness of the geophysical system for ensuring the effective operation of radio equipment under any operating conditions depends on its parameters and external conditions.

Table 1.

Ranges of changes in indices and ionospheric parameters, characteristic for selected levels of disturbance of the heliogeophysical situation [1]

The level of disturbance	Index type				
	W	$F_{10,7}$	K_p	Dst	ΔfoF2
quiet heliogeophysical conditions	0–10	<85	0–2	<160	±10 ; ±15
weakly disturbed heliogeophysical conditions	11–50	< 120	3–4	<230	±11–15 <±20
disturbed heliogeophysical conditions	51–100	< 160	5–6	<320	±16–20 <±30
strongly disturbed heliogeophysical conditions	101–150 and >	> 160	7–9	>321	> ±20 > ±30

Notes: Dst-index is measured in nTesla; ΔfoF2 is measured as a % of the moving median (in the numerator are half-daily values of ΔfoF2, in the denominator as hourly values).

The study of the environment (extreme environmental conditions) allows, on the one hand, determining the weak (vulnerable) points of the operated radio equipment, and, on the other hand, to determine, on this basis, possible directions for the development of radio engineering systems based on new physical principles. In addition, knowledge of natural extreme parameters of the geophysical environment can be used to determine the space of features, on the basis of which it is possible to identify the nature (source) of the origin of this extreme state of the environment [3]. The correct operational identification of the natural or artificial nature of the origin of the extreme state of the functioning environment will allow timely adoption of adequate decisions to counter this state, either by compensating for the negative impact of the environment, or by eliminating the source that forms this state.

Development of indicators of the quality of the system of geophysical assurance of the effectiveness of radio technical means in the field of civil aviation.

New quality indicators of the geophysical support system for the effective operation of radio equipment of civil aviation

Simulation modeling of ground measuring complexes allows to evaluate the reliability indicators, spatio-temporal and energy characteristics of the work of ground measuring complexes in various situations. For a comprehensive assessment of the reliability of obtaining heliogeophysical information, taking into account the characteristics of the on-board and ground equipment of the geophysical support system, you can use a structural scheme of reliability, which includes the end-to-end path of the radio line "on-board measuring complex-ground measuring complex". Such a scheme is represented by series-parallel structures with redundancy of structure elements. The measuring complex (on-board and ground) is represented by a set of separate radio channels "on-board – ground" in the form of successive connected systems (devices): on-board equipment for measuring geophysical information – on-board antenna – ground antenna – ground station for measuring geophysical information. With such a construction of the ground measuring complex of the system of geophysical support for the effective operation of radio equipment, the task of obtaining geophysical information from the test object is considered completed if at least one ground station received the required amount of information.

The probability of obtaining geophysical information is accepted as a generalized indicator of the reliability of the measuring complex of the geophysical support system. The probability of obtaining geophysical information in the geophysical support system for the effective operation of radio equipment of civil aviation in general has the following form:

$$R_{i\,g} = R_{ba} \cdot R_{bAnt} \cdot \left[1 - \prod_{i=1}^{i=n} \left(1 - R_{NAi} \cdot R_{NSi} \right) \right], \quad (3)$$

where n is the number of stations used to receive and register the flow of geophysical information; R_{ba} is probability of trouble-free operation of on-board equipment; R_{bAnt} is probability of operation of the on-board antenna; R_{NAi} is probability of trouble-free operation of the i-th terrestrial antenna; R_{NSi} is the probability of failure-free operation of the i-th ground station.

The probability depends on the reliability of the station's equipment and the conditions for receiving geophysical information, which is determined by the energy reserve in the radio line.

If we do not take into account the influence of the probability of trouble-free operation of the on-board geophysical equipment and the on-board antenna on the generalized indicator of the reliability of the measuring complex, then the probability of obtaining geophysical information by the ground measuring complexes will, if assumed R_{ba} $R_{bAnt} = 1$, have the following form:

$$R_{Nig} = 1 - \prod_{i=1}^{i=n} \left(1 - R_{NAi} \cdot R_{Nsi} \right), \quad (4)$$

The initial data required for the assessment of reliability indicators of obtaining measurement information in the system of geophysical support by means of simulation modeling under any conditions of operation can be presented in the following groups: 1) composition of ground stations, their geodetic coordinates; 2) the flight path of the on-board measuring device (spacecraft of the space segment and/or aircraft of the aviation segment); 3) technical characteristics of on-board and ground equipment; 4) directional diagrams of on-board antennas as a function of radio communication angles θ, φ; 5) restrictions on the size of the seat angle (β ≥ 5°).

The tasks of operational and current planning are quite successfully solved by the existing planning system. However, modern requirements for information systems, to which the geophysical support system belongs, dictate the need to improve the quality of operational and current planning. This is an increase in the speed of information processing, the updating of existing software complexes, as well as the application of other measures that contribute to modernization within the framework of the system human-machine interaction.

Along with increasing the accuracy of forecasting the geophysical situation, the complexity of the forecasting methods also increases, as painstaking and continuous work of operators is required to record and analyze changes in existing and promising models of geophysical environments and profiles describing the heliogeophysical situation.

An important evaluation criterion of the effectiveness of the system of geophysical support of radio technical means in the field of civil aviation of Ukraine is the quality of prospective plans for the use of technical measuring means of the system of geophysical support under any conditions of their operation. As such an indicator for evaluating the effectiveness of the geophysical support system, we suggest using the level of intensity of technical measuring devices at all stages of existence [4]. For example, the number of corrections to the plan between the stages of its formation and implementation, the number of backup or duplicative sessions of manual control can become criteria for assessing the intensity of prospective planning of the use of technical measuring tools of the geophysical support system [5].

We propose to determine such an indicator as the intensity ratio of the plan by comparing the relevant indicators with an established measure or an existing benchmark (for example, scientifically based or optimal plan indicators). Then the tension coefficient G_N of the geophysical support system can be determined by the formula:

$$G_N = \frac{Y_{pl}}{Y_{et}}, \qquad (5)$$

where Y_{pl} is the planned or actual indicator of the plan; Y_{et} is reference or normative indicator.

Thus, it is possible to analyze the number of corrections of prospective plans for loading technical means of the geophysical support system at the stage of their implementation and introduce a corridor based on their permissible number, that is, a normative indicator. Then $G_N > 1$, if the number of corrections is more than permissible, it will indicate that the plan is poorly formed. At the same time, it must be taken into account that the number of corrections to the long-term plan depends on many, sometimes not always predictable, factors.

A high-quality forecast of the loading of technical means is necessary for decision-making on the optimization of the structure of the geophysical support system, increasing the efficiency of the use of technical means, in the management of the geophysical support system.

To solve the problems of long-term planning of the loading of technical means of the geophysical support system, it is proposed to use the following principles: 1) the use of various methods of forecasting the geophysical situation in the complex of the geophysical support system; 2) flexibility in the use of statistical data with a change in the data slice; 3) efficiency of obtaining forecasts of various conditions of the heliogeophysical situation; 4) evaluate the intensity level of the plan for the use of technical means of the geophysical support system.

The first principle requires the selection of a forecasting method that gives the most accurate result when covering a smaller amount of statistical data. The combination of extrapolation methods with simulation modeling methods must be used depending on the goals of forecasting the geophysical situation.

The second principle of improving the quality of long-term planning of the loading of technical means of the geophysical support system is necessary in order for forecasting to use statistical data that most fully reflect the ground and space geophysical conditions. This can be achieved by using, for example, different depths of the forecast of the heliogeophysical situation. Also, statistical data must be divided into different categories and groups.

The effectiveness of long-term planning is required when making decisions about the possibility of performing the tasks of managing the geophysical support system with ground and space technical means in the event of a sharp change in the heliogeophysical situation.

Conclusions. The criteria developed and presented in this paper for evaluating the effectiveness of the geophysical support system for the effective operation of radio equipment of civil aviation of Ukraine have important practical and applied significance in the conditions of strict requirements for the promptness of decision-making in air traffic management, the need to ensure high accuracy characteristics of determining the coordinates of the location of aircraft , the need to ensure the efficiency of radio technical means under any heliogeophysical conditions of operation, the proportionality of periods of disturbance of the medium of radio wave propagation, when there is a sharp deterioration in the quality of solving the tasks set before the information means of civil aviation, with an interval of decision-making.

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