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Aerospace system of preservation of parametric and speech information for the investigation of flight accidents

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Abstract
The growth of passenger air transport requires the continuous development of methods and means of improving aviation security. Practice has proven that investigating aviation accidents and proposing countermeasures is an effective method of ensuring flight safety [1-3] It is based on information about accidents and incidents. The issues of increasing the survivability of parametric and speech information for investigating accidents are considered.

1. Introduction

ICAO indicates the high value of information of airborn devices of objective control, as an additional source of information, for evaluating crew actions and aircraft (AC) equipment in flight, maintaining aircraft and preventing accidents. To date, all aircraft (with the exception of only the smallest) are equipped with FDR and CVR.
Flight recorders include sensors, units of signal conversion and processing, and data concentrator (recording devices with the data recording medium) that record parametric data (data from control units, instruments and systems, etc.) and audio data on the media. The registers are usually provided the ability to bind the recorded parameters to the real-time scale.
Information recorded by the flight recorder is of great importance in the accident investigation. Analysis of the results of the investigation of the accident with aircrafts on which the flight recorder was not installed showed that in 38% of the cases of the accident, the presence of the recorded information would significantly contribute to determining the causes of the accident. For the other 35% of the causes of the accident, the information recorded by the flight recorder could not be determined unambiguously from the registered information, and only for 27% of the accidents did not provide significant assistance in investigating the causes of the accident [4].
There is a special standard FAA TSO C123b / C124b, which correspond to modern recorders: the data must remain intact at overloads in 3400G for 6.5 ms (falling from any height), full fire coverage for 30 minutes (fire from the ignition of the fuel in an aircraft collision with the ground) and being at a depth of 6 km during the month (when the plane fell into the water at any point of the World Ocean, except for the depressions, the probability of falling into which is statistically small) [5].
The requirements for the information preservation of were also determined: resistance to shock loads up to 1000g (pulse up to 10 ms), to temperatures of 1000 °C (15 min), to aggressive liquids (2 h) and sea water (5 days). To meet the requirements, special flight information (FI) protective equipment is used - a durable, heat-resistant and heat-shielding container, means of buoyancy and slowing down the speed of fall [6].
Speech CVR and parametric FDR recorders can be combined into one, but in any case, the records are precisely time-bound. Meanwhile, parametric recorders do not record all the flight parameters (although now there are at least 88, and most recently, until 2002, there were only 29), but only those that can be useful in the investigation of disasters. The complete data (about 2000 parameters) of what is happening on board is recorded by operational recorders: their data are used to analyze the actions of pilots, repair and maintenance of aircraft, etc. - they do not have protection, and after a catastrophe, they are no longer available.
In those rare cases when accidents, catastrophes occur, the only and most reliable source of information on the technical parameters of the aircraft and the crew's actions are records of the flight recorders.
This situation makes it difficult to establish the true causes of air crashes and leads to a significant increase in the time of investigation. Backing up information on board the aircraft is not able to solve the problem of ensuring its availability and completeness in case of the plane crash.

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One of the ways to solve the formulated problem is the feasibility of creating an aerospace system for registering the parameters of the aircraft throughout the entire flight operation from the moment the engines start up during takeoff and till landing at the destination airport.
Such system will allow to move from the average reliability indicators of the aircraft systems to individual assessments of the aircraft conditions and its systems at the base airport. In our opinion, this will significantly change the procedure for investigating flight accidents, and for aircraft manufacturer companies will provide objective monitoring of the current state of the aircraft and, as a result, informed decisions about the possibility of its further operation.

2. The concept of aerospace system creation

When an accident occurs, it is investigated by the government with jurisdiction over the area where the plane flies. Figure 1 shows a fragment of the ICAO roadmap. The map is intended for flights on air traffic service (ATS) routes in the airspace of the Republic of Kazakhstan (Chapter 7 ICAO Annex).
For the investigation of flight accidents and the prerequisites for them there are some general methodological recommendations. These recommendations were developed on the basis of the generalization of many years of experience in the operation of aircraft on internal and international air lines. At the same time, the progress of the accident investigation process and the methods used in this process depend on the specific conditions and circumstances under which it occurred. The specific complexity of the tasks that have to be addressed in the process of investigating accidents puts it at the level of a complex research work.
In this case, it may be necessary to perform various calculations, to conduct special laboratory studies to study the causes of such failures and malfunctions. Analysis of recorder data allows to identify the objective causes of the accident and contributes to the improvement of flight safety. This is a difficult task based on decoding the flight recorder data [7, 8]. However, aviation specialists and representatives of special services are not always able to access this information. The problem is multiply complicated by the loss of the flight recorder as a result of the explosion of the aircraft, its fall into the deep sea of the world's ocean or on the territory controlled by extremist groups [9-12].
Even if a recorder is detected, it is possible that the degree of its damage will not allow extracting the necessary minimum of useful information when decrypting records [13, 14].

Figure 1: Flight recorders after the air crash

As a result, a variety of approaches, attitudes and opinions are generated in the investigation of flight accidents, which leads to inconsistencies and a decrease in the effectiveness of aviation security. This situation makes it difficult to establish the true causes of air crashes and leads to a significant increase in the time of investigation. Backing up information on board the aircraft does not solve the problem. In the case of a plane crash, the unprotected components of the avionics are almost completely destroyed. Thus, the problem of increasing the survivability of onboard parametric and speech information for investigating accidents comes to the fore.
The concept of aerospace system creation based on the following principles is proposed.

1. The system should contain the fundamental principles, strategic goals, objectives and priorities for ensuring the safety of aircraft operations in the context of GADSS.
2. The system should be developed on the basis of international treaties and other normative acts of ICAO, ITU and other international aerospace organizations.
3. The system should adequately reflect the features of air traffic control technology. The general technological scheme, which determines the functionality of the system, consists of the stages of data collection, their primary processing and archiving, the formation of a telemetric frame, the solution of applied monitoring tasks and the user interface.
4. The system should reflect the on-board information survivability indicators, ensure one-sided transmission of the on-board service information, dual redundancy (flight recorder, satellite complex), protection of communication channels for information transfer.
5. The system closes withdraw into the information resources of the base airport of the aircraft.

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Taking into account the principles outlined, the aerospace system should ensure the removal and transmission of the on-board telemetric information at all stages of the aircraft operation in real time: during pre-flight preparation of aircraft, in takeoff, flight and landing mode until the engines are completely stopped.
To ensure the implementation of these concepts and functions, a functional addition is proposed for the onboard control system of parametric and speech information, which includes a satellite communications system in the Ku / Ka band based on the use of a low-profile antenna [15]. This addition removes many restrictions on the amount and speed of the on-board information transmission, minimizes the costs of creating ground-based satellite communications systems and allows implementing the architecture of the aerospace system server based on typical solutions.

3. The information cover of the aerospace system for the preservation of parametric and speech information

Figure 2 shows a fragment of the ICAO enroute chart. The chart is intended for flights on ATS routes in the airspace of the Republic of Kazakhstan (ICAO, Chapter 7, Annex 4).

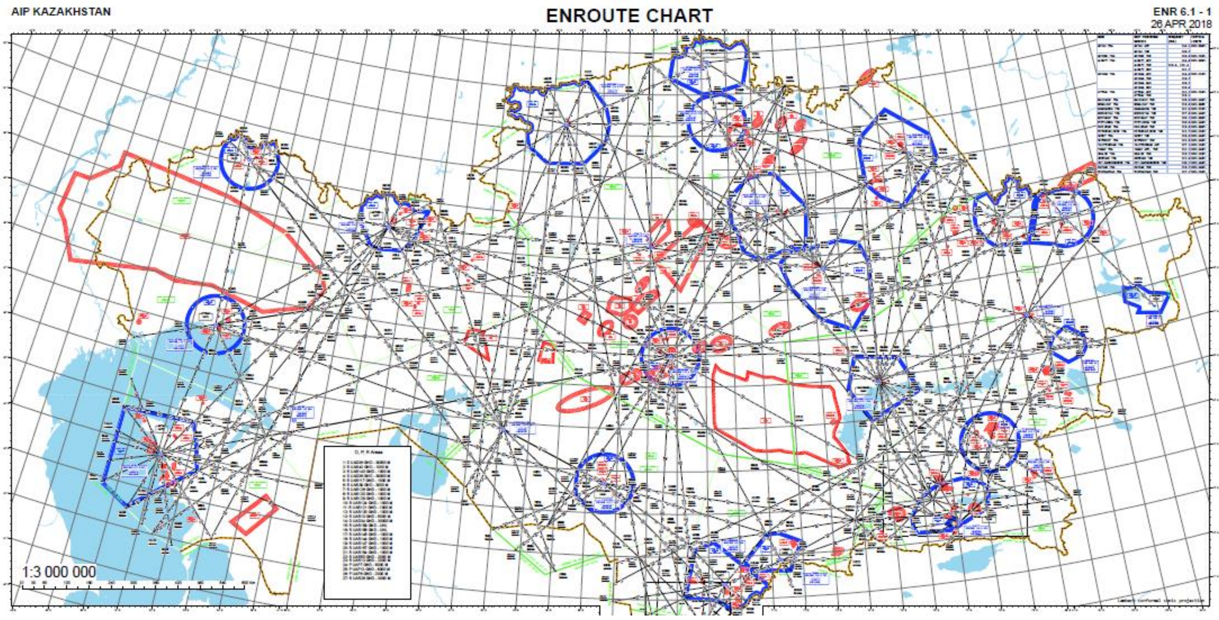

Figure 2: ICAO enroute chart on the territory of the Republic of Kazakhstan

The chart shows airfield hubs in 21 cities of Kazakhstan. Aerodromes in these cities are the base airfields of the aircraft of RK airlines. The total aircraft fleet of the main airlines such as Air Astana, SCAT, Bek Air, Qazaq Air which are involved in the regular passenger traffic is more than 60 aircraft with an average age of 3 to 20 years. As noted in the committee, in the modern practice of foreign aircraft industry adopted the approach of "operation by state" without limiting the total resource. At the moment, manufacturers define such a maintenance program that allows to monitor the state of the structure of the aircraft and its units throughout life. If deviations are detected, the necessary types of repair are applied – as explained in the Civil Aviation Committee of the Republic of Kazakhstan.
Under these conditions, the creation of the aerospace system for the preservation of parametric and speech information lies in line with the general trend of digitization of aircraft operation in order to ensure the safety of air transportation.
The information cover of the aerospace system (ASS) for the preservation of parametric and voice information includes three components: the on-board system for collecting and transmitting parametric and speech information via satellite communication channel, the orbital constellation of communication satellites KazSat-2 and KazSat-3 and the ground communication system.
Each aerodrome is equipped with a satellite communications system for receiving telemetric information, as well as a computer network with a local server for processing and archiving telemetric information on individual aircraft. The computer network architecture can be implemented in parallel with the dispatch control system of the aircraft.
Technological map of the aircraft flight can be divided into separate stages: preflight control of the state of the aircraft with the issuance of a notice of readiness, taxiing, takeoff and climb, movement on the route, glide-path capture, touchdown, landing run, towing to the parking area, engine stop.

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4. Airborne segment of the Aerospace System

The industry standard for data collection on Airbus aircraft is the Flight Data Interface Management Module (FDIMU). This compact integrated data acquisition and recording system is available for installation on the A318 / A319 / A320 / A321 and A330 / A340 aircraft families, which allows to operators with several types of aircraft to use the same Aircraft Condition Monitoring System (ACMS) technology and programming tool in their fleet. The CAN bus is used as the data receiving-transfer bus.

CAN bus is widely used in industrial automation, aviation, road and rail transport due to high data rates and reliability. Using CAN bus provides the following benefits:

– high reliability due to automatic disconnection from the network of failed nodes;

– lack of hierarchy among network nodes, in other words, the “master” - “slave” scheme is not applied to the functioning of the network;

– each network node is able to receive any information transmitted via the bus;

– high noise immunity due to common mode interference suppression by the differential transceiver;

– presence of arbitration of messages allowing to avoid damage to the transmitted information in the event of a conflict in the network.

The choice of physical media is carried out taking into account the expected operating conditions. So in different conditions a single-wire line (within a printed circuit board), a two-wire line, a twisted pair or a fiber-optic line can act as a carrier. One of the main advantages of the considered bus is ensured precisely by its physical implementation. Thus, when using differential voltages, the bus continues uninterrupted operation. At the same time, even the use of a simple twisted pair significantly increases the noise immunity of the system as a whole.

Therefore, the SATCOM-On-The-Move (SOTM) communication system is the most efficient alternative for creating reliable, continuous, and rapidly deployable broadband connectivity for our applications.

In general, the system can be represented as follows (Figure 3)

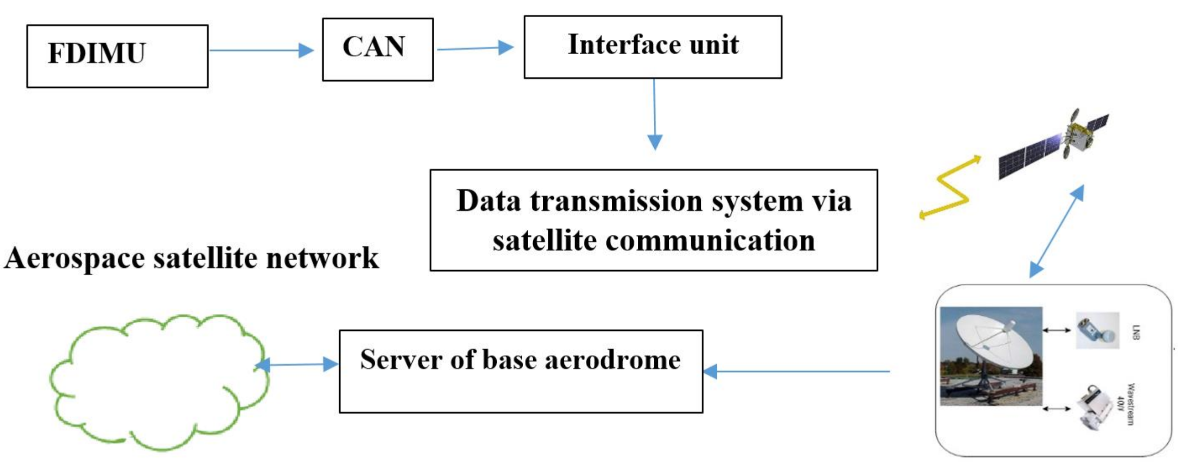

Figure 3: Generalized diagram of the aerospace system of preservation of parametric and speech information

To receive data from the CAN bus and then transmit it via a satellite communication channel, it is necessary to use an interface unit. Further, all data passing through the satellite modem are connected in series with the antenna system, a satellite transmitter, as well as a LNB receiver.

Currently, manufacturers offer dozens of antenna tracking systems for use on aircraft. Most have fundamental limitations, such as providing reception-only performance or working in a spectrum, such as the L-band, which is not suitable for broadband. Thus, it is possible to identify the main types of antennas that can be used in an aerospace system on board of the aircraft.

1. Electronic phased array. In electronically steered phased array antennas, where the beam forming and shaping functions is performed by microwave shifters, the shifters insert a given amount of path delay (phase shift) into each radiating element. The amount of the delay is a function of the beam pointing angle and the beam shape desired. A dedicated computational device, usually referred to as a beam steering controller computes the individual phase shift commands for each phase shifter and outputs this information to the phase shifter. An advantage to electronically steered phased array antennas is that they can be calibrated, or tuned by adjusting the phase shift command of each phase control module. [16] The aircraft will not be able to serve higher latitudes or if the longitude is significantly different from the satellite's longitude. To ensure continuous communication, more satellites will be required, or it is

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necessary to increase the number of elements in the expansion of the total area of the phased array.However, this is a costly effort and increases the complexity of the device.

2. Flat panel. The most significant driver of demand for flat panel antennas is form factor. Flat panel antennas are small, compact, transportable, require little power and most offer high throughput. Mechanical steering can be a benefit to parabolic and flat panel antennas as it enables a much broader range of elevation, and thus can enable operations in more far-reaching locations and for a broader range of applications. But it should be noted, that the reflector is affected by adjacent satellite interference when the aircraft is operating near the equator. [17]

3. Reflector antenna. The reflector antenna is the most popular in spacecraft antenna systems because of its structural simplicity and light weight. It is also a matured design. The main disadvantage is that the reflector needs to be offset to avoid blockage of the feed point. This offset eliminates the rotational symmetry of the optical aperture, and the scan range is limited to a few bandwidths.

4. Variable Inclination Continuous Transverse Stub (VICTS) array antenna. The basic aperture is circular and its area can be made as large as the aircraft permits. The two-dimensional scan mechanism for the VICTS array involves the simple rotation (common and differential) of two coplanar plates, one (upper) comprised of a one-dimensional lattice of continuous radiating stubs and the second (lower) comprised of one or more static line-sources. Mechanical rotation of the upper plate relative to the lower changes the scan angle in elevation. Common rotation of the two plates in unison changes the azimuth direction. Polarization control and diversity is supported by adding a third polarizer layer to alter the angle of linear polarization. With an enlarged capture area provided by the concentric circular plates, the effective gain of the antenna is still competitive with mechanically steered antennas (reflector, plate and horn arrays) for the majority of flights. In addition, the antenna has one of the lowest profiles [18].

5. The orbital segment of the aerospace system and coverage by Kazakhstani satellites

In preparation for WRC-15, an input document was submitted by ICAO to the WG 5B (https://www.itu.int/md/dologin_md.asp?lang=en&id=R15-WRC15-C-0017!!MSW-R) for consideration, containing a draft Concept for the operation of the Global Alert and Safety System for Aircraft Flight (doc. 5B / 783, version 4.4). This document notes that one of the many reasons forcing the aviation community to maintain a high level of security is the willingness to learn important lessons from events that occur quite rarely. The tragedies of Flight 370 of Malaysian Airlines and Flight 447 of Air France revealed vulnerabilities in the current air navigation system that impede the timely detection and localization of aircraft suffering distress.

This significantly reduces the effectiveness of search and rescue operations and rehabilitation work. In those rare cases where accidents occur, rescue survivors have the highest priority, followed by the restoration of the wreckage of the aircraft and flight recorders. Data analysis of these recorders is very important to support the investigation of an accident, which can, through identification of the causes of the accident, contribute to the enhancement of flight safety. The same document states that the effectiveness of search and rescue operations should be increased through the development and implementation of the Global Alert and Safety System for Aircraft Flight Safety (GADSS). This system will store information about the movement of the aircraft and, in the case of a forced landing or landing on water, the location of the survivors, the aircraft and the recovered recorders. This Concept defines the high level requirements and objectives pursued by GADSS. Its implementation will affect air traffic control conditions, search and rescue, and accident investigation. It is assumed that the key difference of GADSS from the existing aircraft tracking system will be the built-in disaster tracking module that can be activated automatically, manually or from an earth station.

This Concept defines the upper level of GADSS operation with a description of the users of flight information at all stages of the flight (normal and abnormal), including timely and accurate positioning of the aircraft suffering distress. The Concept does not establish specific technical solutions that monitor the position of aircraft.

In the documents submitted for WRC-15 consideration, it was proposed to include the issue of GADSS on the WRC-19 agenda and proposed a draft Resolution governing the conduct of research. During WRC-15, the text of the draft Resolution was revised, including provisions for ICAO requirements for both terrestrial and satellite segments, including quantitative analysis and definition of radio requirements for GADSS (data traffic requirements for different segments of the GADSS system, information on radiocommunication requirements for applications that ensure the safety of human life, performance criteria for terrestrial and satellite systems), analysis the existing distributions to the relevant air services and determining whether any additional spectrum is required for the implementation of GADSS. Taking into account these proposals, this agenda item was included in the WRC-19 agenda.

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At present, it is proposed to use a satellite communication system based on geostationary satellites KazSat 2, KazSat3 for the operation of the aerospace system. Coverage areas of these satellites are shown in figures 4, 5.

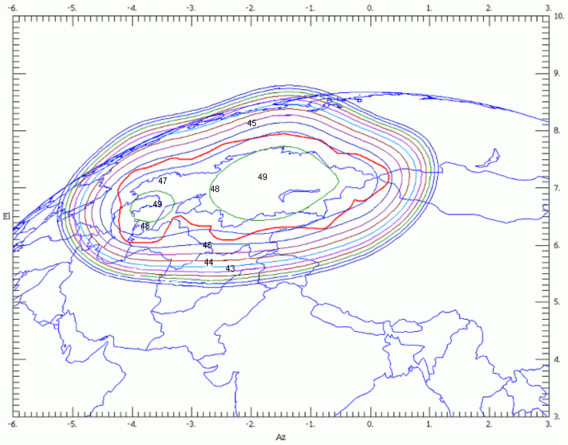

Figure 4: Coverage map for KazSat-2, 86.5^0 East

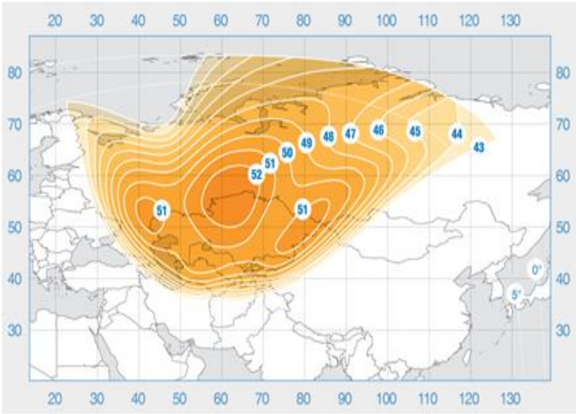

Figure 5: Coverage map for KazSat-3, 58.5^0, East

6. Conclusion

Studies conducted by the authors have shown the high relevance of the problem of preserving parametric and speech information during the flight of the aircraft. With all the variety of problem solving, the dominant solution is the improvement and protection of flight recorders, which are installed on all aircraft. To date, methodological materials and documents on accident investigation have been developed. Ultimately, the information from the flight recorders has a significant impact on the results of the analysis. The methods developed for this are based on the use of the methods of phonoscopic and spectral analysis of flight recorder records. Data analysis of the recorders allows to identify the objective causes of the accident. However, aviation specialists and representatives of special services are not always able to access this information. The problem is multiply complicated by the loss of the flight recorder as a result of the explosion of the aircraft, its fall in the deep-sea part of the world ocean or on the territory controlled by extremist groups. Even if a recorder is detected, it is possible that the extent of its damage will not allow extracting the necessary minimum of useful information when decrypting records. As a result, a variety of approaches, attitudes and opinions are generated in the investigation of flight accidents, which leads to inconsistencies and a decrease in the effectiveness of aviation security.

The development of digital technologies and satellite telecommunications allowed the integration of the achievements of aviation and space technology in the creation of an aerospace complex for the preservation of parametric and speech information. Until now, the main obstacle to the widespread use of the system has been the high cost of satellite frequency resource. The existing satellite communication system INMARSAT, which is installed on board an aircraft, despite the low cost of traffic, does not meet the increasing demand for the transmission of large amounts of information in the L-frequency range. The coordinated work of ITU and ICAO has led to an understanding of the gratuitous allocation of the broadband frequency spectrum to solve the problem of maintaining flight information. The emergence of low-profile antennas has brought the decision on the use of the aerospace system on all aircraft.

This paper proposes a concept for building such a system with a significant expansion of the recording format throughout the entire life cycle of an aircraft and assessing its condition. To this end, using the example of the Kazakhstani air traffic control sector, it is proposed to create an information and analytical system for operating aircraft based on high-performance servers at the airports where aircraft are based. At the same time, the telemetric monitoring of the parametric and voice information begins from the moment of the pre-flight information by reading the information from more than 2000 sensors via the telemetric communication channel. Regardless of the location of the aircraft, this information enters the server of the airport where it is based. During the flight - takeoff, flight mode, landing, the amount of information transmitted can be reduced to the level of information from the flight recorders. At these stages, the information also arrives at the server of the airport where the aircraft is based. Under the conditions of Kazakhstan, taking into account the coverage area of the KazSat 2 and KazSat 3 satellites, this is a quite achievable task.

Aircraft equipment with a satellite telemetry system includes, in addition to standard means of monitoring and storing parametric and voice information, functional additions of coordination with a low-profile antenna system. Such devices were tested by us on traction rolling stock and showed their performance.

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It should be noted that the equipment of the ground and airborne segment of the aerospace system does not require large financial costs. However, despite the obviousness of the effectiveness of the proposed method of preserving parametric and speech information at all stages of the life cycle of an aircraft, we may encounter organizational difficulties. In this regard, we propose to implement a pilot project within a fairly long territory of Kazakhstan. Such a choice will at the initial stage avoid numerous negotiations on the Handover technology and limit the satellite network of one territory.

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