Telecommunication Warning of the Crew about the Failure of On-Board Radio Altimeters

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Abstract

The article is devoted to the study of the quality of aircraft steering at the landing stage in the conditions of aircraft instrumentation failure. The paper shows that the quality of gliding piloting depends not only on the level of pilots' professional training but also on the level of their psychophysiological stress and coordination of actions under stress. This approach to assessing the quality of piloting is new, allowing for a deeper analysis of the crew's stress resistance, unlike the relativistic theory, which only takes into account mental time. The failure of a low-altitude radio altimeter on board an aircraft is considered a source of psychophysiological stress for the crew. It was found that the maximum amplitudes of the spectra of autocorrelation functions of the roll angle on the glide path differ significantly depending on the pilot's psychophysiological stress during glide piloting. The operating time to failure for analog and digital radio altimeters was obtained by calculation and analysis. For radio altimeters of modern aircraft, the DN distribution law was used as a failure model. The paper also substantiates the expediency of conducting anti-stress training for crews with the introduction of aircraft instrumentation failure elements into its methodology at the stage of an aircraft landing.

Keywords 1

Reliability, psychophysiological state, failure, operating time, telecommunication system

1. Introduction

During the maintenance of civil aviation aircraft, one of the key tasks is to ensure flight safety. It largely depends on the reliability of onboard and ground navigation systems, as well as the level of professional training and crew coordination. The most difficult stages of an aircraft flight are take-off and landing. This is due to the high psychophysiological load on the crew. It is the result of significant tension due to the increased concentration of the pilots' attention. At these stages, and especially during the landing approach, it is necessary to control the angular and trajectory parameters of the flight with high accuracy, simultaneously conduct a visual assessment of the situation overboard, and exchange information with ground services [1]. Pilots' tension is also caused by potentially dangerous flight factors: proximity to the ground, low flight speed, increased angle of attack, fast-moving processes, and time constraints [2, 3].

This article was aimed at studying the reliability of the radio altimeter, which is indispensable when landing, especially in low visibility conditions.

An altimeter is a device in aviation technology that is used to measure the height of an aircraft above the Earth's surface using radio waves or other technical means. The role of the radio altimeter in aviation safety includes the following functions [4–6].

Navigation function: The radio altimeter provides accurate information about the height of the aircraft above the ground, which is a key parameter for ensuring flight safety and navigation. Knowing the exact altitude allows pilots to effectively control the flight, avoid obstacles, and comply with the established

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minimum altitudes. Supporting landing safety: Radio altimeters are used to support safe landings by providing pilots with information about their height above the ground.

Ground proximity warning: The radio altimeter is the main sensor in ground proximity warning systems for low-altitude flights, allowing pilots to react in time to changes in altitude.

Minimizing the risk of altitude loss: An important role of the radio altimeter is to avoid losing altitude below safe levels, especially at low flight altitudes when interfacing with TCAS.

Integration with autopilots and safety systems. Many modern radio altimeters can integrate with other avionics systems, such as autopilots and collision avoidance systems, to provide coordinated and automated flight control.

In general, the radio altimeter plays a critical role in maintaining flight control accuracy and flight safety by providing the crew and onboard systems with the necessary altitude parameters to operate the aircraft efficiently and safely in various flight conditions.

Therefore, the study of the probability of failure of radio altimeter components and their impact on the psychophysical state of the crew during landing is relevant to increasing the stress resistance of pilots in difficult flight conditions.

2. The Statement of the Problem

Studies on a complex aircraft simulator have shown that the introduction of failures negatively affects the psychophysiological state of the crew. As a result, the quality of the piloting technique deteriorates. Studies were conducted on the changes in flight parameters during failures of individual avionics systems in roll [7] and pitch [8].

The analysis found the laws of distribution of a random variable in fault-free flights and flights with complex failures and performed a spectral analysis for the trend in roll and pitch angle [9]. The information obtained is the basis for assessing the quality of pilot training.

This is especially important during the approach phase. In addition, the paper synthesizes an algorithm for detecting the presence of complex failures in the trends of roll and pitch. Unacceptable values above these parameters may result in a landing accident.

Therefore, it is important to prepare pilots for special situations and to take measures to predict failures of aircraft equipment. It is also important to warn the crew about the occurrence and preconditions for such an event. Many publications have been devoted to the technical solution of this issue [10–15].

3. Materials and Methods

The stress and anxiety caused by instrument unreliability in the context of aviation operations is an integral part of pilots' psychological state. Instrument unreliability can create a great deal of tension and uncertainty for pilots, challenging them to deal effectively with unexpected situations.

Observing unreliable equipment can be anxiety-inducing, creating uncertainty and ambiguity. Pilots who are aware of the possibility of malfunctions may experience a constant state of alertness and anxiety, making them more attentive to any signs of anomalies.

Stress caused by unreliable instruments can be reflected in increased levels of nervous system activity, which can cause pilots to feel physically and emotionally stressed.

This condition can affect their ability to focus, make quick decisions, and interact with the equipment.

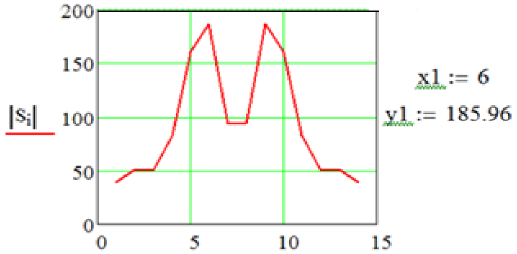
One of the key causes of stress is the anxious anticipation of possible problems or the reaction to problems that have already occurred. Pilots may feel the pressure of being responsible for the safety of their crew and passengers, which adds to the emotional strain and increases anxiety levels.

The psychophysiological stress of pilots affects the quality of their piloting.

The analysis of the flights of the Boeing 737 aircraft revealed that the maximum amplitudes of the spectra of autocorrelation functions of the roll angle on the glide path differ significantly depending on the pilot's state when flying on the glide path (Fig. 1).

The amplitude of the spectrum in the first case is equal to $y1 = 185.96$, in the second case—$y1 = 23.356$.

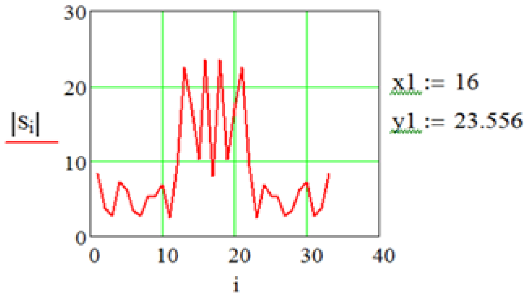
$$S_t = \sum_1^{14}\left(\Psi_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{15}}\right),$$



a)

$$S_t = \sum_{i=0}^{33}\left(\Psi_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{34}}\right)$$

(a)



(b)

Figure 1: Listing of the spectra of non-normalized autocorrelation functions of the roll angle on the glide path: (a) landing (pilot 2, aerodrome X) with increased psychophysiological stress of pilots (t = 60c); (b) landing (pilot 3, aerodrome N) without increased psychophysiological stress (t = 260c)

That is, the amplitudes of the spectrogram y1 for landing an aircraft with increased psychophysiological stress of pilots are 7.96 times higher than normal.

In summary, stress and anxiety due to unreliable instrumentation make it difficult for pilots to be fully disengaged and respond to contingencies with high performance. Effective training, psychological preparation, and improved safety systems can help reduce the impact of stress and anxiety on pilots and improve the overall safety of aviation operations.

In most cases, there is a simple failure stream that satisfies the conditions of ordinality (the probability of more than one failure at one time is negligible), stationarity (the probability of occurrence of exactly m failures in a time interval depends on the length of the interval and does not depend on its location on the time axis) and the absence of aftereffects (for two-time intervals, the number of failures in one does not depend on the number of failures in the other). In this case, the law of distribution of time between failures is exponential, and the parameter of the failure rate is a constant value. In this case:

$$T_0 = \frac{1}{\omega}, \quad R(t) = e^{-\omega t}.$$

The exponential law of reliability is determined by the inverse function of the probability of failure and can be expressed as follows:

$$R(t) = e^{-\lambda t}.$$

where: R(t) is the reliability function (probability of failure) at time t, λ is the failure rate parameter, which is the inverse of the average duration of failure, and e is the Euler number, approximately 2.71828.

This formula describes how the probability of system uptime changes over time. The longer the time t, the lower the probability of remaining in the uptime state.

The failure rate λ can be interpreted as the number of failures per unit time. Thus, the mean time between failures (mean time between failures) can be defined as $\frac{1}{\lambda 1}$.

This mathematical approach to reliability and failures allows us to model and analyze the operation of systems in terms of safety and efficiency.

Certain tolerances and assumptions are taken into account to calculate the estimated reliability level of the unit:

- failures of product elements are interdependent and failure of any element leads to failure of the product as a whole.
- only sudden failures occur in the product, gradual failures are excluded from consideration.
- redundancy of components and elements is not provided.
- maintenance of the product is carried out within the time limits specified in the documentation.
- the periods of running-in and aging are excluded from consideration, i.e. the period of normal operation is considered. Given these assumptions, the law of distribution of the time between failures is exponential.

Only the period of normal operation is considered; the period of running-in and aging is not considered in Fig. 2.

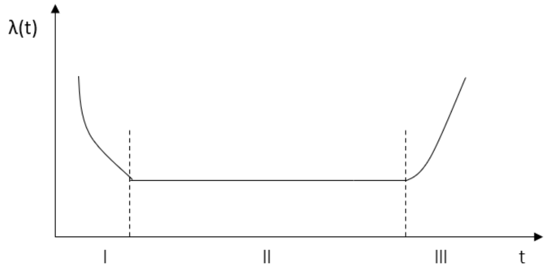


Figure 2: Area I—the period of running-in, Section II—period of normal operation, Area III—aging period

The calculation process determines the composition of the units, devices, and assemblies that make up the system. In some cases, a logic diagram of the system's fault tolerance is drawn up, which is a sequential chain.

To calculate the average duration of a system's uptime, we use the following formula $\frac{1}{\lambda 1}$.

The radio altimeter receiving and transmitting unit is built on the following element base: resistors, capacitors, connectors, chokes, relays, transistors, and microcircuits. The values of the failure rates of the components are taken from the relevant reference books. In general, these λ-characteristics depend on the operating conditions of the elements (temperature, humidity, atmospheric pressure, mechanical impact). At such assumptions the law of distribution of non-failure operation time is exponential, and the failure rate of an item and its costs does not depend on time.

During design, the structure of blocks, devices, and units completing the system is determined. Sometimes thus the logic circuit of the reliability system, which represents a series circuit is made. For each device block, the failure rate Λ_i is determined by the formula:

$$\Lambda_i = \sum_{j=1}^{n} m_j \lambda_j K_{hj},$$

where n is the number of standard ratings of elements in the block with the same load factor, m_j is the element quantity (amount) of j-s a standard rating, λ_j is the failure rate of an element with a load factor.

In other words, the working failure rates of all the elements included in the block are added. So, let's calculate the average time between failures for the unit:

$$\frac{1}{\lambda\text{р}+\lambda\text{к}+\lambda\text{г}+\lambda\text{д}+\lambda\text{р}+\lambda\text{тр}+\lambda\text{м}} = \frac{1}{0{,}01+0{,}014+0{,}005+1+0{,}06+0{,}06+0{,}024} = 8{,}5 \cdot 10^5 \text{ h}$$

After failure intensity of all blocks are determined, is defined (determined) failure intensity systems under the formula

$$\Omega = \sum_{i=1}^{N} M_i K_{tli} \Lambda_i ,$$

where N is the number of types of blocks and the devices that are included in the item, M_i is the number of identical blocks (devices) i-s type, K_{tli} is a factor of **time loading** i-s the block, showing long to an operating time of the block in the structure of the system.

Further, the time between failures of the system is determined (defined).

$$T_2 = \frac{1}{\Omega}.$$

The durability of any technical object, including petrol stations, is characterized by the patterns of its limit state.

According to DSTU 2860-94, the limit state of an object is a condition in which further operation of the object is unacceptable or impractical, or restoration of its working condition is impossible or impractical.

Upon reaching the limit state, the operation of the asset is terminated and it is subject to write-off or major (medium, scheduled) overhaul if provided for in the operational documentation.

An event that consists of an object reaching a limit state is similar to a failure by analogy with reliability.

The transition of an item to a limit state is determined by a significant number of factors, so such a transition for each item is a random event, and the time or operating time from the start of operation to the onset of the limit state is a random variable.

4. Results and Discussions

This result was obtained for an outdated altimeter used on An-26 aircraft. For modern aircraft, the DN distribution law is used as the failure model. In this case, the derivation of the analytical dependence for calculating the failure rate parameter is given in [16], and the final result is as follows:

$$\omega(t)=\sum_{i=1}^{N} n_i \sum_{m=1}^{\infty} \frac{m\sqrt{t_{0i}}}{\nu_{0i} t\sqrt{2\pi t}} \exp\left[-\frac{(t-mt_{0i})^2}{2\nu_{0i}^2 t_{0i} t}\right],$$

where m is the number of failures during the operation period t; t_{0i} is the known mathematical expectations; t_{0i} is the operating time to failures of all elements. Thus, after the intersection of the curves in Fig. 3, there is an overestimation of the data on the average time between failures when calculating λ by the method [16].

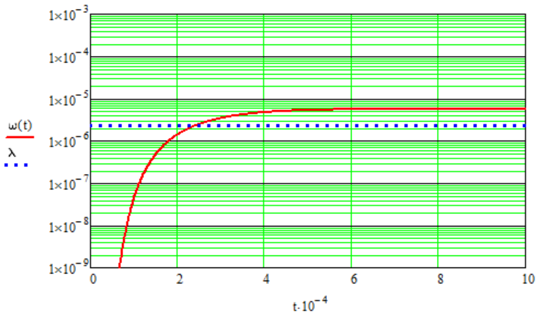


Figure 3: Graph of dependence of failure intensity ω(t) on DN-failure model and λ(t) on exponential failure model

For the exponential model, the tolerance for $\omega(t)$ may be the value of:

$$\omega_{\partial on}=\frac{1}{T_{в.з}},$$

where $T_{в.з}$ is given the mean time between failuresв in technical documentation.

The obtained results are relevant for the theory and practice of design and improvement of TRS operation systems. The emphasis on statistical data processing algorithms for timely detection and prevention of failures and, accordingly, reducing the risks of possible losses in the TRS OS is justified. The proposed data processing methods make it possible to increase the level of TRS reliability by performing preventive maintenance.

The future scope is associated with several directions. If we assume that the statistical characteristics of the distributions for defining parameters are priori unknown, then it is advisable to develop adaptive algorithms of prediction. Another direction is connected with taking into account a large number of OS elements. Such accounting can allow a more complete assessment of both possible risks and the consequences of their occurrence.

5. Conclusions

The pilot's psychophysiological state plays a key role in ensuring the safety and efficiency of aviation management operations. Avionics failures can have a significant impact on this state, creating stressful situations and causing physical and emotional strain. Flight conditions, where every second counts, require pilots to be not only highly skilled but also able to effectively manage their conditions.

Avionics failures can cause pilots anxiety and uncertainty, disrupting their normal control and navigation routines. Stress associated with changes in instrumentation can affect pilots' concentration and attention, which is critical to ensuring the safety of an aircraft.

The pilot's psychological state in the event of onboard equipment failures can range from uncertainty to high levels of anxiety. Therefore, the pilot's effectiveness in solving problems and making quick and correct decisions can be significantly impaired by stressful conditions.

Also, high levels of stress can affect physical performance, increasing the risk of fatigue and reducing the ability to react quickly to changing situations.

A pilot must be able to effectively adapt to new circumstances and quickly overcome stressful situations. Training and failure simulations help pilots develop stress management strategies and maintain mental clarity during critical situations.

The overall conclusion is that the interaction between the pilot's psychophysiological state and avionics failures is essential to ensure the safety and success of aviation missions. Understanding these aspects allows for the development of improved training, maintenance, and psychological preparation strategies for pilots.

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