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GENERALIZED ALGORITHM FOR ASSESSING PILOT PREPAREDNESS FOR SPECIAL FLIGHT SITUATIONS

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Introduction

In our previous articles, a number of methods for training pilots to counteract the simultaneous influence of adverse factors, i.e., factorial overlaps, were considered [1]. A human operator in flight may be exposed to a wide range of negative factors, including weather conditions, the complexity of the approach for landing, and failures and malfunctions in avionics. Modern integrated circuits are more reliable than analog-to-digital components. However, currently, malfunctions frequently occur on most operational aircraft. This leads to increased psychophysiological stress of flight crews during flight.

The reliability of both avionics and human operators is subject to stochastic analysis. Therefore, methods for assessing crew readiness for emergency flight situations are based on the laws of probability theory and mathematical statistics. These issues, such as the probability density distribution of changes in flight parameters, have been extensively studied by many authors [2]–[5]. Some studies focus on statistical information processing [6]–[9]. The works discuss expectation maximization algorithms, parameter vectors associated with threats, and other algorithms [10]–[12]. These scientific investigations have formed a significant foundation for current research.

Problem Statement

In previous articles, a number of methods for training pilots to counteract the simultaneous influence of adverse factors, i.e., factorial overlaps, were considered. During complex onboard equipment failures, it is advisable to assess the quality of piloting using correlation fields of flight parameters. The method for determining piloting quality based on contours (contour figures) of correlation fields of flight parameters under avionics and onboard equipment failures demonstrates sufficient effectiveness for creating analyzers of early failure indicators [13].

The analysis of autocorrelation functions and their spectra was applied to evaluate the quality of the landing approach on the B-737-500 using a shortened glide path. High gain coefficients in the autocorrelation functions and their spectra were observed during the shortened glide path approach [14].

As a result of studies conducted on the KTS An-148 simulator, it was established that, in the absence of failures or with single failures, the statistical distribution of such important parameters as roll and pitch angles does not contradict the normal distribution law. Under the simultaneous effect of more than two severe failures, the statistical distribution of the roll angle conforms to a generalized Weibull distribution. During such “flights,” the quality of piloting deteriorates. The level of psychophysiological stress in the pilot increases. Cases in which flight parameters exceed permissible limits are observed more frequently. These limits are established in the flight operations manual of the respective aircraft type [15].

One of the variants of the procedure for applying trend algorithms to analyze pilots’ counteraction to overlapping factors is as follows. Given numerical data or plots of changes in heading, roll, and pitch (γ) from the end of the fourth turn to landing, it is necessary to determine the distances from extrema to zero. Then, the differences between subsequent extrema (without taking the absolute value) of each parameter are calculated. The resulting amplitude values (A) are taken in absolute value. The maximum and minimum values of A for each parameter are identified (under the condition A > 1′). The half-periods (T) corresponding to the maximum and minimum values of each parameter, are then calculated:

$$\Delta A=\frac{A_{\max}-A_{\min}}{A_{\min}};\ \Delta T=\frac{T_{\max}-T_{\min}}{T_{\min}}. \quad (1,2)$$

After this, a general picture of the multichannel variation of parameters is constructed:

$$\Delta\Delta A_{\gamma,\psi,\vartheta}=\sqrt{\Delta A_{\gamma}^{2}+\Delta A_{\psi}^{2}+\Delta A_{\vartheta}^{2}};$$
$$\Delta\Delta \mathrm{T}_{\gamma,\psi,\vartheta}=\sqrt{\Delta \mathrm{T}_{\gamma}^{2}+\Delta \mathrm{T}_{\psi}^{2}+\Delta \mathrm{T}_{\vartheta}^{2}} \quad (3,4)$$

Amplitudes can be measured and plotted on the coordinate axis when working with numerical values in degrees, and when working with graphs—in arbitrary units; the periods, respectively, are expressed in seconds and in arbitrary units.

When using trend algorithms, it is advisable to compare () the deflections of the ailerons, rudder, and elevator with ($\Delta\Delta A_{\gamma,\psi,\vartheta}$) the changes in the parameters:

$$\Delta\Delta\delta_{Э,H,B}=\sqrt{\Delta\delta_{Э}^{2}+\Delta\delta_{H}^{2}+\Delta\delta_{B}^{2}}; \quad (5)$$

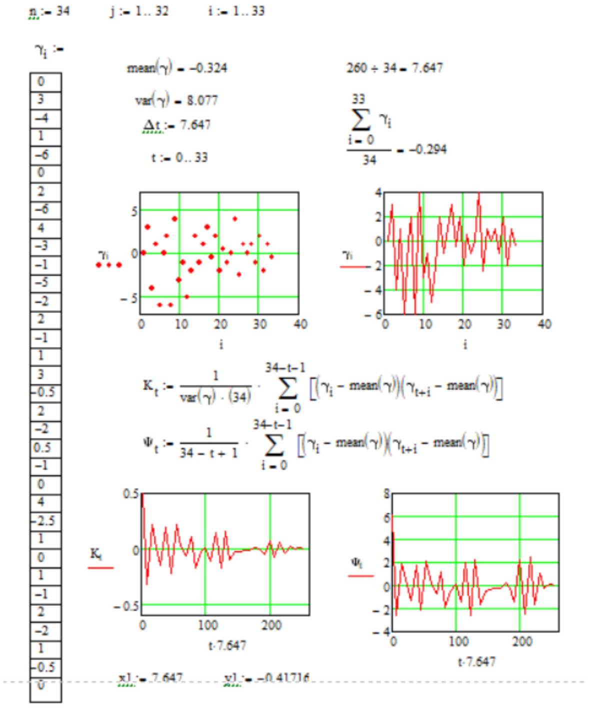
$$\Delta\Delta \mathrm{A}_{\gamma,\psi,\vartheta}=\sqrt{\Delta \mathrm{A}_{\gamma}^{2}+\Delta \mathrm{A}_{\psi}^{2}+\Delta \mathrm{A}_{\vartheta}^{2}}. \quad (6)$$

For example, during turbulence, the discrepancy can be used to assess the quality of piloting technique, since in severe turbulence an experienced pilot does not allow large deviations of parameters, although the use of the rudder and ailerons is significant. In the presence of objective monitoring systems (OMS) on a full-flight simulator (FFS), this factor may be disregarded, since turbulence can be excluded from the instructor’s control panel.

Problem Solution

From the above-mentioned methods, the issue arises of the prompt and convenient transfer of the results of assessing the quality of flight crew training to flight safety instructors. Previously, pilot counteraction charts for factor overlap based on the half-period values of the roll angle, indicating maximum amplitudes during the landing approach, were developed. A zone of factor resonance was identified, where the highest values of the roll angle were observed. However, these data are insufficient. At present, computing technology has significant capabilities.

During the landing approach, changes in the roll angle exhibit an ergodic and stationary nature. Therefore, for analysis, the autocorrelation function is sufficient (Fig. 1). For further analysis, it is advisable to compute the amplitude spectrum in Mathcad (Fig. 2) using the fast Fourier transform function fft(v).



n := 34 j := 1..32 i := 1..33

γ_i :=

0
3
–4
1
–6
0
2
–6
4
–3
–1
–5
–2
2
–1
1
3
–0.5
2
–2
0.5
–1
0
4
–2.5
1
0
1
–1
2
–2
1
–0.5
0

mean(γ) = –0.324

var(γ) = 8.077

Δt := 7.647

t := 0..33

260 ÷ 34 = 7.647

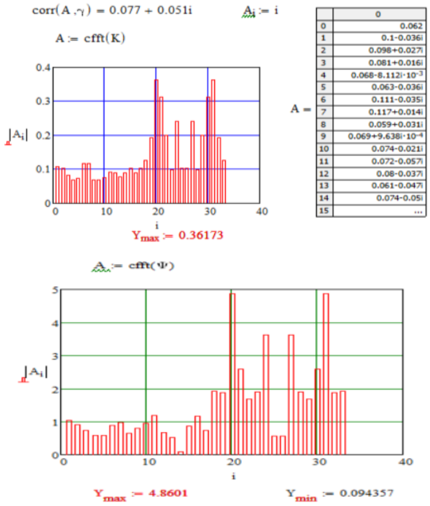
$$\frac{\sum_{i=0}^{33}\gamma_i}{34}=-0.294$$

$$K_t:=\frac{1}{\mathrm{var}(\gamma)\cdot(34)}\cdot\sum_{i=0}^{34-t-1}\left[(\gamma_i-\mathrm{mean}(\gamma))(\gamma_{t+i}-\mathrm{mean}(\gamma))\right]$$

$$\Psi_t:=\frac{1}{34-t+1}\cdot\sum_{i=0}^{34-t-1}\left[(\gamma_i-\mathrm{mean}(\gamma))(\gamma_{t+i}-\mathrm{mean}(\gamma))\right]$$

x1 := 7.647 y1 := –0.41716

Fig. 1. Listing of the calculation of the normalized (y_1=−0.41716) and non-normalized autocorrelation functions of the roll angle from the end of the fourth turn to landing



corr(A, γ) = 0.077 + 0.051i

A := cfft(K)

A_i := i

A =

	0
0	0.062
1	0.1-0.036i
2	0.098+0.027i
3	0.081+0.016i
4	0.068-8.112i·10⁻³
5	0.063-0.036i
6	0.111-0.035i
7	0.117+0.014i
8	0.059+0.031i
9	0.069+9.638i·10⁻⁴
10	0.074-0.021i
11	0.072-0.057i
12	0.08-0.037i
13	0.061-0.047i
14	0.074-0.05i
15	...

Y_{max} := 0.36173

A := cfft(Ψ)

Y_{max} := 4.8601 Y_{min} := 0.094357

Fig. 2. Listing of the calculation of the spectrum of the normalized and non-normalized autocorrelation functions of the roll angle from the end of the fourth turn to landing

Further, a comparison of the maximum and minimum values of the spectrum of the non-normalized autocorrelation function of the roll angle from the end of the fourth turn to landing is carried out according to formula (1).

However, the roll angle does not provide complete information about flight quality. Therefore, for analysis it is necessary to use formulas (1–4) of the trend algorithms. In the chart provided to the flight crew training instructor (Fig. 3), the final assessment of crew training quality should be indicated, i.e., the result of comparison using trend algorithms of “flights” and the spectra of autocorrelation functions with and without failures.

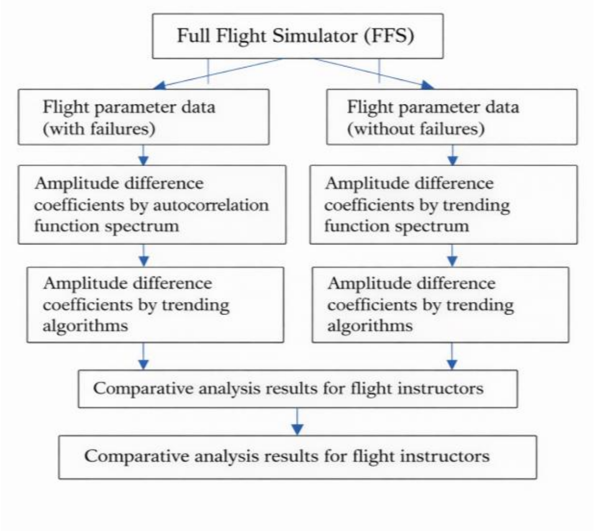


Fig. 3. Data processing scheme for presentation to instructors

Methodological Recommendations

1. Command staff and instructors should be aware that modern aviation events are of a low-probability nature and, despite pilots being trained to act in special situations, the causes of most aviation events related to the human factor are the crew’s inability to act adequately in the occurrence of low-probability overlapping factors.

2. Flight instructors must know and teach crews theoretical information about the phenomenon of increasing amplitudes of aircraft flight parameters (IAPFP), which may lead pilots to erroneous actions.

3. Command staff should introduce into pilot training programs on complex simulators (CTS) training for crews in counteracting complex failures (three simultaneously acting failures) that simulate low-probability overlapping factors.

4. CTS instructors should determine deviations in piloting technique quality associated with IAPFP using special charts (developed at the National Aviation University “KAI”), which will allow identification of such negative phenomena as factor resonance and the amplification of pilots’ dynamic stereotype.

5. CTS instructors should introduce failures before the fourth turn, and these should not affect the aerodynamics or controllability of the aircraft.

6. When a deterioration in piloting technique quality associated with IAPFP is identified, the instructor should draw the pilot’s attention to this and conduct a repeated “flight” with complex failures.

7. Command staff should organize the collection of information on the level of crew preparedness to counteract negative overlapping factors and transmit it for further analysis to specialists in the human factor.

The analysis of distribution laws requires a larger amount of experimental data and, accordingly, time. In the chart for quantitative analysis, it is necessary to record the difference in the values of χ^2 of the normal distribution law for “flights” with failures and without them.

For qualitative analysis of flights with failures and for further work, it is necessary to determine to which theoretical distribution of flight parameters the obtained statistical distribution can be attributed (Fig. 4).

When performing complex flight tasks, the pilot requires real-time information about the quality of automation operation in the aircraft control system.

However, the system may sometimes fail. As a result, it can misinform the pilot. One of the causes is distorted information received from individual sensors. Another cause is failures occurring in electronics, mainly associated with p–n junctions (n – negative, electronic; p – positive, hole-type; or an electron–hole junction—the region at the interface of two semiconductors of p- and n-type, in which the transition from one type of conductivity to another occurs) in electronic components.

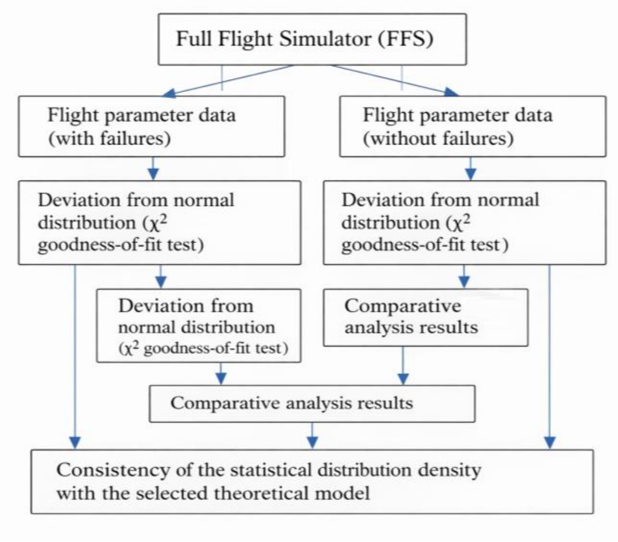


Fig. 4. Data processing scheme for research purposes

In the case of complex failures of onboard equipment, it is advisable to assess the quality of piloting technique using correlation fields of flight parameters.

Indicators of the strength of the relationship make it possible to characterize the dependence of the variation of the resultant variable on the variation of the factor variable.

In the analysis of correlation field contours, the most promising approach is the study of the relationship between the angle of attack and the roll angle. In this case, the relationship between the parameters α (angle of attack) and γ (roll angle) is investigated, and based on its type, the presence or absence of a failure is determined.

The angle of attack α is the angle between the projection of the aircraft velocity onto the X, Y, Z plane and the longitudinal axis of the aircraft-fixed coordinate system. The angle is considered positive if the projection of the aircraft velocity onto the normal axis is negative.

The roll angle γ is the angle between the lateral axis and the axis displaced to the position corresponding to zero yaw angle of the aircraft. The angle γ is positive when the displaced axis coincides with the lateral axis by a clockwise rotation when viewed in the direction of the longitudinal axis.

The application of the contour correlation field method for diagnosing complex flight situations. It has been scientifically and experimentally proven that when avionics failures occur in the flight control system, the configuration of the contour field, which determines the correlation relationship between piloting technique parameters, changes from stochastic to functional.

The forms of manifestation of relationships are very diverse; in the most general form, functional and correlation relationships are distinguished.

Thus, visual analysis of the correlation field makes it possible to identify not only the presence of a statistical dependence (linear or nonlinear) between the studied variables, but also its strength and form. This is of essential importance for the next stage of analysis—the selection and calculation of an appropriate correlation coefficient.

The correlation dependence between variables can be described in various ways. In particular, any form of relationship can be expressed by a general equation of the form Y = f(X), where the variable Y is a dependent variable, or a function of the independent variable X, called the argument. The correspondence between the argument and the function can be represented by a table, formula, graph, etc.

In the case of a failure, correlation fields effectively disappear, and a deterministic functional relationship between piloting technique parameters emerges.

The problem of recognizing complex avionics failures of aircraft using the contour correlation field method makes it possible to create a new type of failure analyzers that enable the pilot to recognize a complex flight situation and make the correct decision to ensure flight safety.

Thus, the proposed method for determining piloting quality based on the contours (contour figures) of correlation fields of flight parameters consists in identifying the presence or absence of areas of contour figures of correlation fields of flight parameters, thereby detecting the initial signs of the appearance or absence of avionics failures under complex flight conditions.

The method for determining piloting quality based on contours (contour figures) of correlation fields of flight parameters under avionics and onboard equipment failures demonstrates sufficient effectiveness for creating analyzers of early failure indicators.

During complex failures associated with transitions from flight segments of the trajectory to non-flight segments and back, effects of complete transformation are observed, with planar contour figures converting into linear configurations.

The transition to the analysis of correlation field contours when recognizing contour figures is limited to 4–6 reference points in order to detect signs of complex failures based on the presence or absence of contour areas. This is critically important for analyzing rapidly occurring failures, the cycles of which are comparable to the sensorimotor reaction time of aviation operators.

Consider, for example, an experiment on the AN-140 aircraft with engine shutdowns to simulate failures. The first and second engines of the AN-140 were sequentially shut down during cruise flight at an altitude of 3.5–4 km. This simulation was necessary to analyze failures that do not lead to non-flight segments of the trajectory, as well as to determine how the contour areas of correlation fields transform under such class of failures.

The results of the engine failure simulation on the AN-140 aircraft are presented in Tables 1–2 and in Fig. 5 [16]. Flight prior to failure, with the first engine operational, is shown in Table 1 and Fig. 5.

Table 1. Flight parameters prior to failure of the first engine

Parameters	Δt_1	Δt_2	Δt_3	Δt_4	Δt_5
α	11	10	2.5	5	5
γ	2.5	7.5	-2	18	0

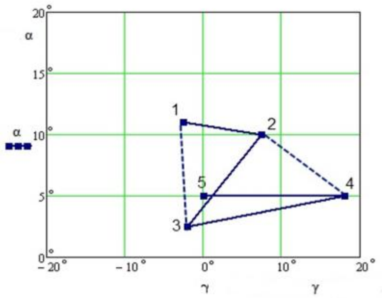


Fig. 5. Flight prior to failure of the first engine

Next, in a similar manner, the areas of the correlation fields were determined during and after the engine failure.

During the failure, the first engine was non-operational.

The areas of the correlation field contours were determined (Table 2):

A. For the first engine:

S1 = 75 см2

S2 =30 см2

S3 =50 см2

ΔS1 = 75/50 = 1,5

ΔS2 = 30/75 = 0,4

ΔS3 = during failure / after failure ==0,6

Table 2. Determination of correlation field areas

Indicator Type	Before Failure	During Failure	After Failure
S	$S_1 = 75$ cm^2	$S_2 = 75$ cm^2	$S_3 = 75$ cm^2
Comparison Indicators	$\Delta S_1 = 1.5$	$\Delta S_2 = 0.4$	$\Delta S_3 = 0.6$

Thus, it is necessary to conduct a sufficient number of experiments according to the “fit” / “unfit” principle (Fig. 6).

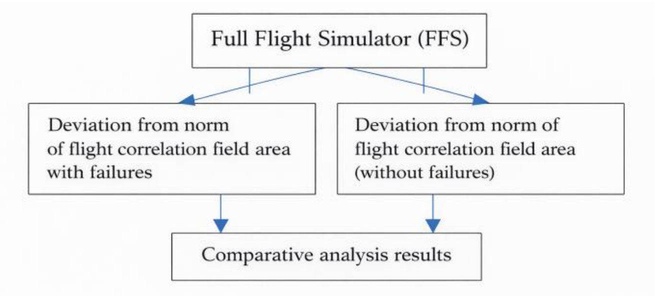


Fig. 6. Assessment of pilots’ piloting quality based on correlation field areas

This proposal for developing a card to assess pilots’ piloting quality based on correlation field areas requires the development of a program and a sufficient amount of statistical data on flight parameters.

It should be noted that a large number of specialists are engaged in pilot training for emergency flight situations [17–20].

Conclusions

The developed scheme for assessing pilots’ piloting quality, based on amplitude difference coefficients of flight parameters, the spectrum of autocorrelation functions, and amplitude difference coefficients of parameters according to trend algorithms, is intended to provide information to instructors. The presented calculation listings demonstrate the feasibility of developing real-time data transmission to the instructor team, as well as subsequent storage in a database.

Refined data on deviations from the normal distribution and the correspondence of statistical distribution density to the selected theoretical distribution, according to the χ^2 goodness-of-fit criterion, will allow rapid and accurate assessment of piloting quality in emergency flight situations. In the same manner, calculations of electronic equipment reliability are performed.

Assessment of pilots’ piloting quality based on correlation field areas provides additional information and may be useful as supplementary visual data.

Critical roll and pitch angles can lead to the risk of lift loss. This is especially dangerous at low altitudes, i.e., along the glide path. Analysis of the autocorrelation function spectra of roll and pitch angles in actual flights has shown a deterioration in piloting technique quality with a shortened glide path, whereas no such deterioration occurs with a normal glide path. This decline in piloting quality is associated with increased psychophysiological stress on crew members. Training in this area should be conducted on a comprehensive aircraft simulator. Prior to entering the glide path, comprehensive failures should be simulated to induce psychophysiological stress on the crew. The positive outcome of such training will be uniform amplitude indicators of roll and pitch angles, both with and without simulated failures.

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GENERALIZED ALGORITHM FOR ASSESSING PILOT PREPAREDNESS FOR SPECIAL FLIGHT SITUATIONS

Currently, significant attention is paid to the training of flight personnel for emergency flight situations. During training on full-flight simulators, various scenarios involving aircraft system failures are practiced. However, it is practically impossible to simulate the simultaneous occurrence of multiple avionics failures. Therefore, in addition to rehearsing specific scenarios, it is necessary to conduct anti-stress training. This training involves simulating the simultaneous impact of multiple adverse factors in a real flight (factorial overlaps) by introducing three concurrent failures on a full-flight simulator. This article is devoted to optimizing the application of methods developed at the Department of Avionics and Control Systems for preparing aircraft crews for flights under emergency conditions. Schemes have been developed for creating functional evaluation cards for assessing flight personnel performance by instructors.

***Keywodrs**—Human factor; parameter amplitude; autocorrelation functions; spectrum analysis; flight piloting technique.*

Грищенко Ю., Тачиніна О., Чужа О., Соломаха Т.

УНІФІКОВАНИЙ АЛГОРИТМ ОЦІНЮВАННЯ ГОТОВНОСТІ ПІЛОТА ДО СПЕЦІАЛЬНИХ ЛІТАКОВИХ СИТУАЦІЙ

На сьогодні значна увага приділяється підготовці льотного персоналу до надзвичайних ситуацій під час польоту. Під час навчання на повнорозмірних тренажерах відпрацьовуються різноманітні сценарії, пов’язані з відмовами систем літального апарату. Однак практично неможливо змоделювати одночасну появу кількох відмов авіоніки. Тому, крім відпрацювання конкретних сценаріїв, необхідно проводити антистресове навчання. Таке навчання передбачає моделювання одночасного впливу кількох несприятливих факторів у реальному польоті (факторіальні накладання) шляхом введення трьох одночасних відмов на повнорозмірному тренажері. У цій статті розглядається оптимізація застосування методів, розроблених на кафедрі авіоніки та систем керування, для підготовки льотних екіпажів до польотів за надзвичайних умов. Розроблено схеми створення функціональних оцінювальних карток для оцінювання роботи льотного персоналу інструкторами.

***Ключові слова** — людський фактор; амплітуда параметра; автокореляційні функції; спектральний аналіз; техніка пілотування.*

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