

Data Processing in the Pilot Training Process on the Integrated Aircraft Simulator

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Abstract – Flight safety is an integral part of air transportation. Flight accidents are highly unlikely to appear but most of them are caused by the human factor. The aircrew training system for abnormal operations relies on integrated aircraft simulator-based exercises. Crew needs to be trained not to degrade piloting technique quality when facing increased psychophysiological tension. Therefore, methods evaluating the characteristics of ergatic aircraft control systems, warning systems for deterioration due to failures in avionics systems, piloting technique quality, and abnormal operation algorithms are necessary. An analysis of the bank angle has revealed that there are hidden increased tension manifestations in the human operator expressed in the transition of the flight parameter variation from a stationary random process to deterministic fluctuations in the form of a sinusoid. The goal of the research is to increase the efficiency of pilots' training using integrated aircraft simulators based on the design and implementation of statistical data processing algorithms. To achieve the goal of the research, two algorithms for detecting deterministic fluctuations based on the Neyman-Pearson criterion and the optimal Bayesian criterion are developed. The presented algorithms can be used in the integrated simulator software to automate the decision-making process on piloting quality.

Keywords – Aircraft; Algorithm design and analysis; Data analysis; Detection algorithms; Human factors; Random processes; Training.

I. INTRODUCTION

Modern aircraft have highly reliable avionics and other systems [1]. Flight accidents are unlikely to take place. Aircraft control automation exempts the crew from routine actions and frees up time for decision-making. At the same time, the crew experiences increased psychophysiological tension when taking control in case of failures (malfunctions) in avionics systems and other equipment [2].

The process of flight personnel's training in civil aviation includes abnormal operation exercises on integrated aircraft simulators (IASs). It is very important to inculcate a consistent pattern of an action sequence in such situations [3]. However, the combination of several simultaneous failures cannot be worked through. On the Tu-154 B2 IAS, it

was previously identified that 70 % of pilots without special training have an increase in the amplitude of aircraft operation parameters (AAOPs) due to their increased psychophysiological tension in case of aircraft equipment simultaneous failures (two and more) [4]–[6].

Modern aircraft crew preparation should give training in adequate actions taken when negative factors occur simultaneously [7]. This is modelled by complex avionics failures (malfunctions) on an IAS.

To assess the characteristics of the ergatic aircraft control system, it is advisable to apply mathematical statistics, statistical decision theory, probability theory methods [8].

II. LITERATURE REVIEW AND PROBLEM STATEMENT

Crew needs to be trained not to degrade their piloting technique quality when facing increased psychophysiological tension. Therefore, it is necessary to develop methods evaluating the characteristics of ergatic aircraft control systems due to failures in avionics systems to objectively determine piloting technique quality during abnormal operations.

Distribution laws to describe all kinds of events are used in various fields of science – in ergonomics [9], the reliability theory of engineering systems [10]–[14].

The probability of an increase in AAOP occurrence is connected with aircraft equipment and avionics failures and malfunctions [15]. According to the laws of aircraft operation parameter distribution, the characteristics of the ergatic aircraft control system can be estimated. In [16]–[21], methods for distinguishing deterministic fluctuations in the form of a sinusoid from a stationary random process are described.

In this paper, based on the statistics of one of the important operation parameters on the An-148 IAS (bank angle), the problems of choosing the bank angle distribution law and algorithms for detecting the harmonic component in bank angle trends are solved.

The practical application of the above-mentioned algorithms and the corresponding methods based on them serves the purpose of piloting technique quality assessment in the ergatic control

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system of modern aircraft. The algorithms developed in the article are related to solving statistical data processing problems. For illustrative purposes, Fig.1 shows the implementation of a number of operation parameters on the An-148 IAS. These implementations correspond to the case when there are several failures in the aircraft avionics system. Figure 1 shows that the realisations are stochastic in nature.

There are often hidden increased tension manifestations in the human operator, which are expressed in the transition from a stationary random process to deterministic fluctuations in the form of a sinusoid. Sometimes this is not

accompanied by an increase in the amplitude of parameters. This is due to the fact that with further exposure to other negative factors, the values of the amplitude of parameters significantly increase.

Taking into account the goal of the research, the following objectives need to be considered:

- 1) analysis of bank angle trends with no equipment failures;
- 2) analysis of bank angle trends in case of equipment failures;
- 3) synthesis and analysis of data processing algorithms for detecting a deterministic fluctuation in the bank angle trend.

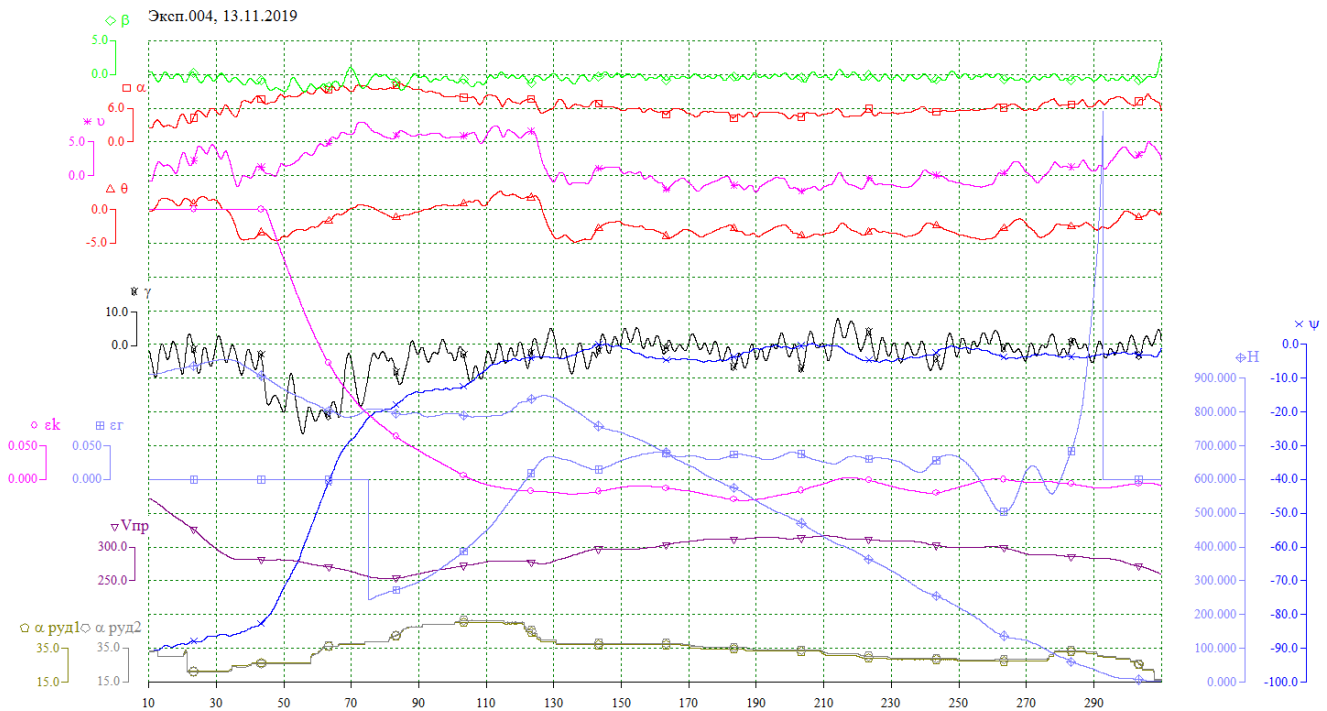


Fig. 1. IAS “Flight” with failures of the first and third fly-by-wire channels, and the control failure of the left aileron and interceptors on the port wing, where V_{is} is instrument speed (km/h); ψ is a magnetic course (degrees); Θ is a flightpath angle (degrees); γ is a bank angle (degrees); ν is a pitch angle (degrees); α is the angle of attack (degrees); β is a sideslip angle (degrees); H is geometric altitude (m); ek is a deviation from the course equisignal zone (DDM); eg is a deviation from the glide path (DDM); α is the engine control lever position (degrees).

III. PROBLEM SOLUTION

Different data sets on bank angle trends are analysed during the statement of the research goal. This article presents illustrative examples of the obtained experimental statistics of flight results on the An-148 IAS. Let us consider flights with a total number of failures n , when $0 \leq n \leq 2$. In this case, it is a flight without failures and with the jamming of the left slat. The initial data for the analysis is given in Table I.

The following designations are made in Table I: i is a measurement number, γ_i is the result of the i -th measurement.

Let us perform the preliminary analysis of these data. The total amount of data is 54, the average value is 0.787, the variance is 10.58, the standard deviation is 3.253, and the coefficient of variation is 4.133.

We have plotted the bank angle distribution histogram during the approach performed by a pilot between the 3rd and 4th turns and after the 4th turn before landing for seven data grouping intervals (Fig. 2).

TABLE I
INITIAL DATA

i	1	2	3	4	5	6	7	8	9
γ_i	-9	5	-2	0.5	5	2	0.5	2	-4
i	10	11	12	13	14	15	16	17	18
γ_i	-2	-5	1	-2	1	0	-2	-1	-3
i	19	20	21	22	23	24	25	26	27
γ_i	2.5	-0.5	0	-2	0	-1	4	0	-8
i	28	29	30	31	32	33	34	35	36
γ_i	-6	0	-2	4	1	-1	-4	-1	-6
i	37	38	39	40	41	42	43	44	45
γ_i	-3	2	5	-1	3	-4	-1	-6	-5
i	46	47	48	49	50	51	52	53	54
γ_i	6	3	-3	-2	0.5	-3	-0.5	-0.5	0

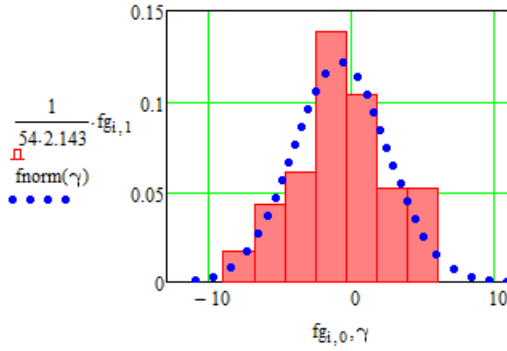


Fig. 2. Construction of a histogram of γ values and its approximation based on the Gaussian law.

We also checked the agreement degree between theoretical and statistical distributions based on the Gaussian hypothesis using Pearson’s chi-squared test χ^2 . Theoretical probabilities are calculated as follows:

$$p_k = \int_{\text{int}_k}^{\text{int}_k + \text{step}} f(x) dx,$$

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-m)^2}{2\sigma^2}},$$

where int_k is the boundaries of group intervals, step is group interval width, m is the mathematical expectation, σ is the standard deviation.

The value of the chi-squared test is calculated according to the formula:

$$\chi^2 = \sum_{k=1}^M \frac{(n_k - Np_k)^2}{Np_k},$$

where n^k is the frequency of the source data falling into the group interval k , M is the number of group intervals, N is the sample size.

For the data in Table I, the chi-squared test value is $\chi^2 = 2.478$.

The calculations showed that the bank angle statistical distribution γ does not contradict the theoretical Gaussian distribution with a probability of approximately 0.7 for the number of freedom degrees χ^2 of distribution – 4.

Earlier studies indicate that, with such a probability distribution, piloting technique quality does not deteriorate during flights without failures [15].

Let us now consider flights with complex failures $n \geq 3$. In this case, we deal with the second (right) engine failure and a failure of the second and fourth fly-by-wire channels, the lack of the right aileron control. To simplify the selection of the theoretical distribution, we change the amplitude values of the bank angles. The data for analysis is given in Table II.

The preliminary analysis of these data was performed. The total amount of data is 136, the average value is 3.57, the variance is 86.324, the standard deviation is 9.291, and the coefficient of variation is 2.603.

For eight data grouping intervals, we construct a histogram (Fig. 3). Let us check the degree to which the theoretical Gaussian distribution agrees with the statistical one according to the chi-squared test χ^2 (Fig. 4).

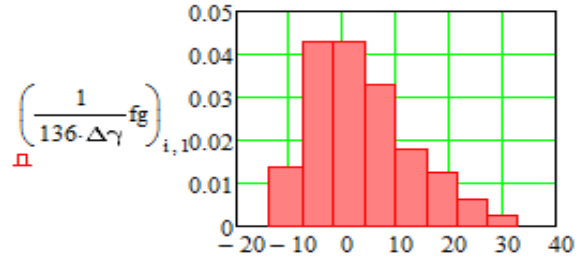


Fig. 3. Constructing a histogram of γ values.

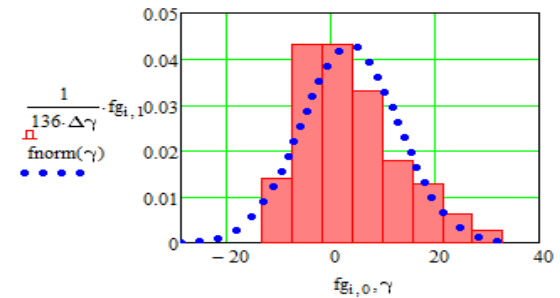


Fig. 4. Agreement verification of the theoretical Gaussian distribution with the statistical one according to the chi-squared test χ^2 .

TABLE II
INITIAL DATA

i	1	2	3	4	5	6	7	8	9
γ_i	32	15	25	15	18	13	14	8	17
i	10	11	12	13	14	15	16	17	18
γ_i	7	24	-12	-3	-12	3	-4	10	4
i	19	20	21	22	23	24	25	26	27
γ_i	25	4	25	-10	23	0	33	17	20
i	28	29	30	31	32	33	34	35	36
γ_i	9	14	-1	18	-1	4	-2	10	2
i	37	38	39	40	41	42	43	44	45
γ_i	3	-7	-12	-4	1	-7	10	-9	2
i	46	47	48	49	50	51	52	53	54
γ_i	-10	10	-1	17	3	19	6	17	5
i	55	56	57	58	59	60	61	62	63
γ_i	20	10	18	3	5	-5	4	-4	5
i	64	65	66	67	68	69	70	71	72
γ_i	-3	9	-2	3	5	3	-4	3	-3
i	73	74	75	76	77	78	79	80	81
γ_i	7	13	2	4	-6	-1	-6	-3	-9
i	82	83	84	85	86	87	88	89	90
γ_i	3	-1	7	0	11	6	5	9	3
i	91	92	93	94	95	96	97	98	99
γ_i	4	-6	-4	-9	-6	-12	2	-3	-13.5
i	100	101	102	103	104	105	106	107	108
γ_i	4	9	2	5	-2	0	-8	0	-5
i	109	110	111	112	113	114	115	116	117
γ_i	-2	-5	3	0	5	4	7	0	13
i	118	119	120	121	122	123	124	125	126
γ_i	6	13	-4	-3	-4	-2	-1	-3	0
i	127	128	129	130	131	132	133	134	135
γ_i	-3	-3	-2	3	2	3	-1	-3	0
									-3

Having performed similar calculations for the data in Table II, the value of the chi-squared test is $\chi^2 = 13.86$. Using the corresponding tables, we can conclude that the value with χ^2 distribution and five degrees of freedom will exceed the value of 13.86 with a probability of less than 0.02. Since this probability is too low, the Gaussian hypothesis can be rejected as implausible.

Let us verify the agreement of the theoretical lognormal distribution and the statistical one according to Pearson's chi-square test χ^2 (Fig. 5).

The analytic expression for the lognormal distribution is the following:

$$f(x) = \frac{1}{(x-q)\sigma_1\sqrt{2\pi}} e^{-\frac{(\ln(x-q)-m_1)^2}{2\sigma_1^2}},$$

where q is the minimum sample value, m_1 and σ_1 are the distribution parameters.

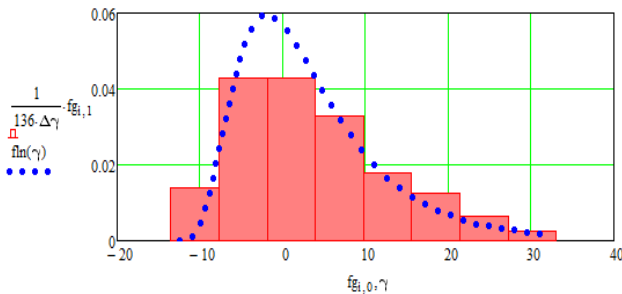


Fig. 5. Listing of the agreement verification between the theoretical lognormal distribution and the statistical one according to Pearson's chi-square test χ^2 .

For the given source data, the following values of the distribution parameters σ_1 and m_1 were calculated provided that q is -13.5 , the statistical estimate of the mathematical expectation m is 3.57 , and the statistical estimate of the standard deviation σ is 9.291 :

$$\sigma_1 = \sqrt{\ln\left(\frac{\sigma^2 + (m-q)^2}{(m-q)^2}\right)} = 0.509,$$

$$m_1 = \ln(m-q) - 0.5\sigma^2 = 2.708.$$

Having performed similar calculations for the data in Table II for a lognormal distribution, the following value was obtained $\chi^2 = 15.835$. Using the corresponding tables, we can conclude that the value with χ^2 distribution and four degrees of freedom will exceed 15.835 with a probability of less than 0.01.

Since this probability is too low, the lognormal distribution hypothesis can be rejected as implausible.

Let us verify the agreement of the theoretical generalized Weibull distribution and the statistical one according to Pearson's chi-square test χ^2 (Fig. 6).

We will also check the agreement between the theoretical generalized Weibull distribution and the statistical one according to Pearson's chi-square test.

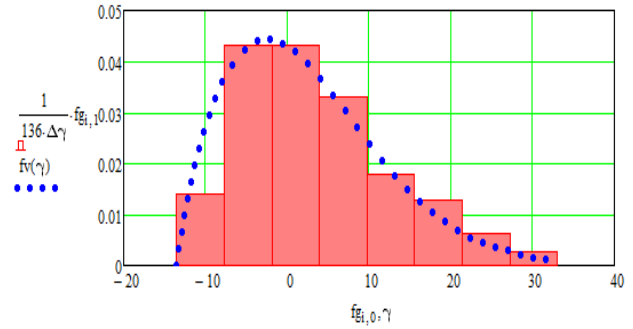


Fig. 6. Agreement verification of Weibull distribution and the statistical one according to Pearson's chi-square test χ^2 .

We will estimate the parameters of the generalized Weibull distribution based on the method described in [22]:

1. For the source data, we calculate the estimated skewness ratio according to the formula

$$\text{Skewness} = \frac{\frac{N}{(N-1)(N-2)} \sum_{i=1}^N (x_i - \bar{x})^3}{\left(\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2\right)^{3/2}},$$

where $\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i$ is the average sample value, N is the sample size.

For the studied data, it is the following:

$$\text{Skewness} = 0.808.$$

2. Based on the estimated skewness ratio, according to the table [10], we calculate the values of:

– form parameter:

$$b = f(\text{Skewness}) = 1.75,$$

– coefficients:

$$g_b = f(\text{Skewness}) = 0.52,$$

$$K_b = f(\text{Skewness}) = 0.89.$$

3. We estimate the scale parameter by the formula

$$a = \frac{\sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2}}{g_b}.$$

For the studied data a equals 17.867.

4. We determine the estimated scale parameter by the formulas

$$q' = \bar{x} - aK_b,$$

$$q = \begin{cases} q', & \text{if } q' \leq \min(X), \\ \min(X), & \text{if } q' > \min(X). \end{cases}$$

In this case, $q' = -12.322$, $\min(X) = -13.5$; therefore, $q = -13.5$.

Based on the calculations for the data in Table II, in case of the generalized Weibull distribution, the value of the chi-squared test is $\chi^2 = 4.265$. Using the corresponding tables, we can conclude that the value with χ^2 distribution and four degrees of freedom will exceed the given value of 4.265 with a probability of less than 0.4. Since this probability is quite high, the generalized Weibull distribution hypothesis can be considered as the one not contradicting the experimental data.

It should be noted that these failures complicate aircraft control. It is connected with the control system and the influence of aerodynamic forces. However, when “flying” with the same individual failures and in combination with other failures, the distribution law is normal.

This indicates an increase in the pilot’s psychophysiological tension and the need for IAS exercises to learn how to deal with an increase in AAOP. As can be seen in Fig. 1, on the glide path, the bank angle does not exceed 12° when $n \geq 3$, which with a large margin corresponds to the norms of the flight operations manual. However, with further flight task complication, bank increases to 33° .

We will carry out a synthesis of algorithms for detecting the presence in bank angle trends of components indicating complex failures and possible further severe aircraft operation complications. Let us suppose that there is hypothesis H_0 (there are no problems during the flight) and alternative hypothesis H_1

(there are complications). In general, in case of H_0 , the probability density function of the bank angle is Gaussian, and in case of H_1 this distribution density has the form of a generalized Weibull distribution.

To solve the detection problem in this case, the analytics will be difficult, so we make the following assumption. Based on the analysis of the bank angle parameter in Fig. 1, we suggest that for complex failures we have a model for changing the bank angle in the form of an additive combination of two components: Gaussian noise and harmonic oscillations.

Then an indicator of complex failures is the presence of a sinusoidal signal in the mixture.

To check the detection quality, we will simulate the original signals.

We will model a normal situation without failures. This situation corresponds to the normal Gaussian noise. The signal implementation in case of a normal situation is shown in Fig. 7. Let us model a flight in difficult conditions, in which the psychophysiological tension in the human operator takes place. In this case, we use a discrete sinusoid as an information signal with the amplitude $U = 5$ and the period $T = 4$. A mixture of the information signal and the normal Gaussian noise (the situation with severe aircraft operation complications) is shown in Fig. 8.

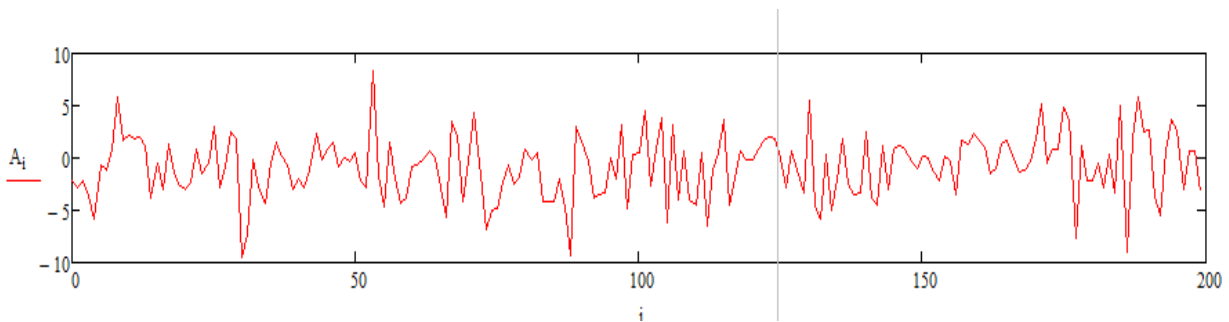


Fig. 7. Graph modelling a random function of a parameter in flight without failures.

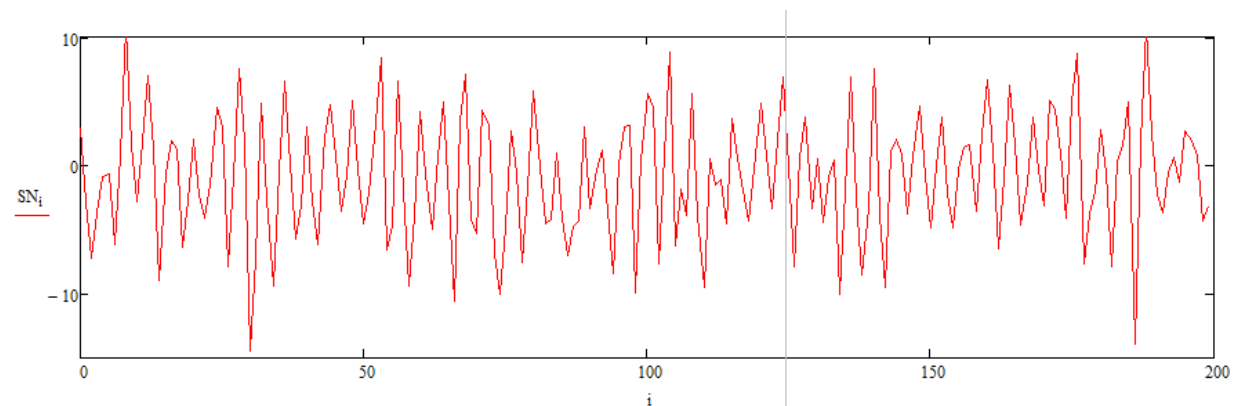


Fig. 8. Graph modelling a random function of a parameter in abnormal aircraft operation conditions.

Let us mathematically synthesize the signal detection algorithm. For the assumptions made, the detection problem comes down to the verification of simple hypothesis H_0 that the

sample implementation is described by a multidimensional Gaussian distribution, against the simple alternative H_1 that the sample implementation contains a useful sinusoidal signal. In

this case, the samples are considered independent random variables. Then

$$f(x_1, x_2, \dots, x_N / H_0) = \frac{1}{(\sigma\sqrt{2\pi})^N} e^{-\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{2\sigma^2}},$$

$$f(x_1, x_2, \dots, x_N / H_1) = \frac{1}{(\sigma\sqrt{2\pi})^N} e^{-\frac{\sum_{i=1}^N (x_i - \bar{x} - S_i)^2}{2\sigma^2}},$$

where σ is the standard deviation, and S_i is known samples of the sinusoidal signal.

We consider the parameters \bar{x} and σ as known as they can be identified based on the monitoring process results with no failures.

The likelihood ratio, which determines the decision statistics, is calculated by the formula

$$l(x_1, x_2, \dots, x_N) = \frac{f(x_1, x_2, \dots, x_N / H_1)}{f(x_1, x_2, \dots, x_N / H_0)}.$$

Consequently,

$$\begin{aligned} l(x_1, x_2, \dots, x_N) &= \frac{\frac{1}{(\sigma\sqrt{2\pi})^N} e^{-\frac{\sum_{i=1}^N (x_i - \bar{x} - S_i)^2}{2\sigma^2}}}{\frac{1}{(\sigma\sqrt{2\pi})^N} e^{-\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{2\sigma^2}}} = \\ &= e^{\frac{-\sum_{i=1}^N (x_i - \bar{x} - S_i)^2 + \sum_{i=1}^N (x_i - \bar{x})^2}{2\sigma^2}}. \end{aligned}$$

To simplify mathematical calculations, we will use the log-likelihood ratio, then

$$\begin{aligned} \ln l(x_1, x_2, \dots, x_N) &= \ln e^{\frac{-\sum_{i=1}^N (x_i - \bar{x} - S_i)^2 + \sum_{i=1}^N (x_i - \bar{x})^2}{2\sigma^2}} = \\ &= \frac{\sum_{i=1}^N (2S_i(x_i - \bar{x}) - S_i^2)}{2\sigma^2}. \end{aligned}$$

Consequently,

$$\ln l(x_1, x_2, \dots, x_N) = \frac{1}{\sigma^2} \sum_{i=1}^N S_i(x_i - \bar{x}) - \frac{1}{2\sigma^2} \sum_{i=1}^N S_i^2.$$

According to the Neyman-Pearson criterion, the decision threshold V is selected based on the solution of the following equation in case there is no sinusoidal oscillation in the analysed mixture:

$$\Pr\left(\frac{1}{\sigma^2} \sum_{i=1}^N S_i(x_i - \bar{x}) - \frac{1}{2\sigma^2} \sum_{i=1}^N S_i^2 \geq V / H_0\right) = \alpha.$$

In this case, the decision threshold was determined by statistical modelling based on the Monte Carlo method. For a given sample size and the parameter $\alpha = 0.025$, as well as the parameters of the detected sinusoidal oscillation, $V \approx 0$.

In case of an optimal Bayesian detector, the threshold can be determined according to the following procedure. Let us rewrite the decisive statistics in the form

$$\frac{1}{\sigma^2} \sum_{i=1}^N S_i(x_i - \bar{x}) = \ln l(x_1, x_2, \dots, x_N) + \frac{1}{2\sigma^2} \sum_{i=1}^N S_i^2.$$

Then

$$\frac{1}{\sigma^2} \sum_{i=1}^N S_i(x_i - \bar{x}) = \ln \mu c + \frac{1}{2\sigma^2} \sum_{i=1}^N S_i^2.$$

$$\sum_{i=1}^N S_i(x_i - \bar{x}) = \sigma^2 \ln \mu c + 0.5 \sum_{i=1}^N S_i^2,$$

where $\mu = \frac{q}{p}$, $c = \frac{C_{01} - C_{00}}{C_{10} - C_{11}}$, q and p are the prior probabilities

of the hypothesis and the alternative, C_{00} together with C_{11} are costs associated with correct decisions, C_{01} and C_{11} are costs associated with erroneous decisions (in this case, $C_{01} > C_{00} \geq 0$ and $C_{10} > C_{11} \geq 0$).

Thus, the decision threshold for an optimal Bayesian detector is the following:

$$V = \sigma^2 \ln \mu c + 0.5 \sum_{i=1}^N S_i^2,$$

and the decision rule is:

- 1) to accept H_0 , if $\sum_{i=1}^N S_i(x_i - \bar{x}) < V$;
- 2) to accept H_1 , if $\sum_{i=1}^N S_i(x_i - \bar{x}) \geq V$.

Let us consider a method that meets the Neyman-Pearson criterion. If the decision statistics DS exceeds a threshold, then in mixed functions there is a sinusoidal signal.

We will carry out calculations for the simulation results illustrated in Figs. 7, 8.

If there is no sinusoidal signal, we obtain the value of decision statistics $DS = -130.782$. Let us consider statistics with a sinusoidal signal, i.e., in the mixed function decision statistics $DS = 146.997$ exceeds the allowable threshold $V \approx 0$.

The analysis of the proposed algorithm is carried out based on the Monte Carlo statistical simulation. During the simulation, the following characteristics are calculated:

- 1) operating characteristics;
- 2) probabilities of type I and type II errors.

At the first simulation stage, statistical data for hypothesis H_0 are generated for the given number of procedure repetitions. For a simulation procedure, the events of the exceeded or non-exceeded threshold are determined. After that, the total quantity of threshold-exceeding events is calculated. The ratio of this quantity to the number of procedure repetitions is the probability α^* of type I error.

At the second simulation stage, statistical data for the alternative H_1 are generated. The ratio of the total quantity of non-exceeded-threshold events to the number of procedure repetitions is the probability β^* of type I error.

The operating characteristic is calculated in the following way. For different values of information signal amplitude, the correct detection probability D^* is calculated. After that, the corresponding dependence of probability D^* on signal amplitude is plotted.

Multiple simulations have confirmed the effective detection of a sinusoidal signal for a given interference situation. Monte Carlo statistical simulation results for 10 000 repetition procedures show that this detection algorithm is characterised by the following probabilities of erroneous decisions $\alpha^* = 0.0263$ and $\beta^* = 0.0011$.

Let us consider the Bayesian optimal detector with the following a priori data:

- the probability of an emergency situation $p = 0.001$, and the probability of abnormal operations $q = 0.999$;
- cost matrix:

$$C_{00} = 0, \quad C_{01} = 10,$$

$$C_{10} = 100, \quad C_{11} = 0.$$

Let us calculate the signal threshold

$$V_p = \sigma^2 \cdot \ln \left(\frac{q}{p} \cdot \frac{C_{01} - C_{00}}{C_{10} - C_{11}} \right) + 0.5 \cdot \sum_{i=0}^{N-1} (S_i) = 129.1.$$

We will carry out calculations for the simulation results shown in Figs. 7, 8.

In the absence of a sinusoidal signal, the value is the following:

$$DS = \sum_{i=0}^N [S_i(A_i - m)] = 72.975.$$

Decision statistics is less than the threshold, so we can conclude that there is no sinusoidal signal, and only noise is present. We then consider statistics with a sinusoidal signal. Wherein:

$$DS = \sum_{i=0}^N [S_i(A_i - m)] = 257.3.$$

Monte Carlo statistical modelling results for 10 000 repetition procedures show that this detection algorithm is characterised by the following probabilities of erroneous decisions $\alpha = 0.0012$ and $\beta = 0.0349$.

Let us consider the actual bank angle of the IAS “flight” ($n \geq 3$) with a full fly-by-wire failure (a failure of all four channels, i.e., undamped backup control) and the second (starboard) engine failure (Table III). Figure 9 shows a bank angle graph with fixing the amplitudes.

Decision statistics for the first method according to the Neyman-Pearson criterion (decision threshold $V \approx 0$)

$$DS = \sum_{i=0}^{N-1} \frac{2S_i \cdot (\xi_i - m) - (S_i)^2}{2 \cdot \sigma^2} = 13.333.$$

For the second method according to the Bayesian approach

$$V_p = \sigma^2 \ln \left(\frac{q}{p} \cdot \frac{C_{01} - C_{00}}{C_{10} - C_{11}} \right) + 0.5 \sum_{i=0}^{N-1} (S_i) = 356.438.$$

$$DS = \sum_{i=0}^{N-1} [S_i(\zeta_i - m)] = 435.$$

Thus, the two considered algorithms based on the Neyman-Pearson criterion and the optimal Bayesian criterion revealed the presence of a determinate sinusoidal component in this IAS “flight”.

TABLE III
BANK ANGLE DATA

i	1	2	3	4	5	6	7	8	9
γ_i	-5	-8	-11	-8	-4.5	-7	-10.5	-13	-15
i	10	11	12	13	14	15	16	17	18
γ_i	-10.5	0.5	8	5	2	5	7	3	-1.5
i	19	20	21	22	23	24	25	26	27
γ_i	0	2	-2	-6	-5	2.5	-9	-15.5	-10
i	28	29	30	31	32	33	34	35	36
γ_i	-3	-9.5	-16	-5	6.5	-5.5	-1.5	-7	0
i	37	38	39	40	41	42	43	44	45
γ_i	-6	-12.5	-21	-16	-10	-12.5	-9.5	-5	-7
i	46	47	48	49	50	51	52	53	54
γ_i	-9	-4.5	0	-5	-11	-5	0.5	-1	-2.5
i	55	56	57	58	59	60	61	62	63
γ_i	-1	1	-2.5	-6	-3	-1	-2	-3	-1
i	64	65	66	67	68	69	70	71	72
γ_i	3.5	5	3.5	1.5	5	8	5	2	3
i	73	74	75	76	77	78	79	80	81
γ_i	1.5	-1	1.5	4	0	-3	-6.5	-0.5	6
i	82	83	84	85	86	87	88	89	90
γ_i	3	-1.5	3	6	0	-6	-3	0	-6
i	91	92	93	94	95	96	97	98	99
γ_i	-10	-7	-2.5	-7.5	-11	-8	-4	-7	-10.5
i	100	101	102	103	104	105	106	107	108
γ_i	-7	-3.5	-7.5	-12	-10	-7	-8	-10	-7.5
i	109	110	111	112	113	114	115	116	117
γ_i	-1.5	-4	-1	3	0	-2.5	-0.5	2	-0.5
i	118	119	120	121	122	123	124	125	126
γ_i	-3	-1	1.5	-2	-5	-3	1.5	0	-3
i	127	128	129	130	131	132	133	134	135
γ_i	-0.5	3	0.5	1	0	-1.5	0.5	2	0
i	136	137	138	139	140				
γ_i	-2	-0.5	1.5	-0.5	-2.5				

To analyse the efficiency of the proposed algorithms, the operating characteristic was calculated. The characteristic was constructed based on Monte Carlo statistical modelling results for 10 000 repetition procedures. During statistical modelling the probability of correct detection was calculated for different values of informational signal amplitude.

The operating characteristics for two algorithms of detection are shown in Fig. 10. The figure also shows that operating characteristics have the same increasing trend.

To assess the quality of pilots' training for abnormal flight operations, it is advisable to have a statistical data bank of the

results of the developed algorithms. The comparison of pilots' training quality should be based on the results obtained during the IAS "flight" with the same set of failures.

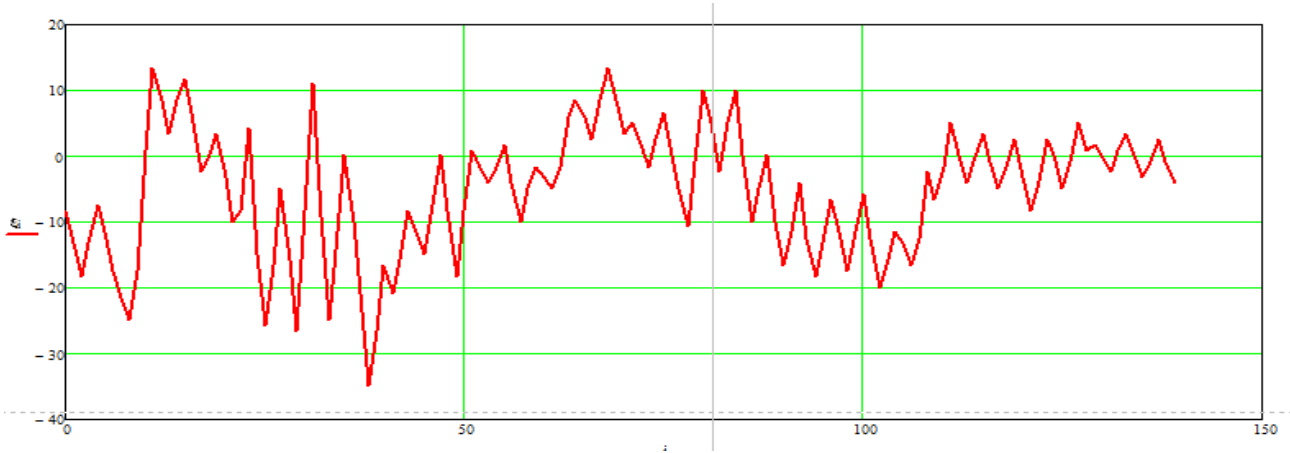


Fig. 9. Bank angle graph versus the time of the IAS "flight" with a full fly-by-wire failure (undamped backup control) and the second (starboard) engine failure, where the amplitude of the parameter is $U = 3$, the period is $T = 4$.

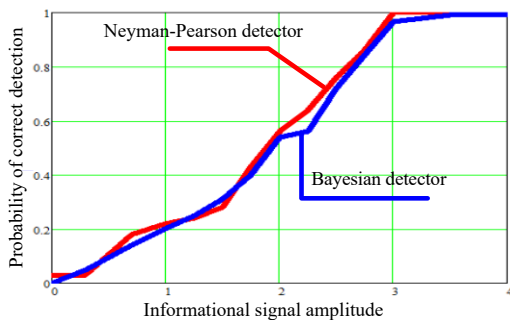


Fig. 10. The operating characteristics for two algorithms of detection.

IV. CONCLUSION

The issues of "flight" data processing on integrated aircraft simulators are an urgent scientific task in terms of improving methods and tools of flight crew training. Modern simulators allow pilots' exercises in both ordinary "flight" conditions and complex ones with more than two failures. An analysis of the trends of a number of "flight" parameters shows that data processing should be statistical since the implementation of the "flight" parameters is generally a random process.

Based on the undertaken studies on the An-148 IAS, it was found that without failures or in case of a single-event upset, the statistical distribution of such an important parameter as the bank angle did not contradict the Gaussian law. With the simultaneous occurrence of more than two serious failures, the statistical distribution of the bank angle did not contradict the generalized Weibull distribution. During such "flights", the quality of piloting technique deteriorates. The level of the pilot's psychophysiological tension increases. Cases, when flight parameters exceed the permissible values, are more

frequent. These standards are set out in the flight manual for this type of aircraft.

To automate the detection process of piloting technique quality deterioration in "complex" failures, two detection algorithms were developed based on the Neyman-Pearson criterion and the optimal Bayesian criterion. In the synthesis of detection algorithms, the assumption was used that a harmonic component was found in the bank angle trend with "complex" failures. This allowed simplifying the analytical form of data processing.

It is necessary to create a database of flight processing results based on the developed algorithms. For a comparative assessment of crew training level, it is necessary to have a unified list of the failure complex in the IAS flight control system. Failures that do not affect the aircraft dynamics and in case there are duplicate devices when there is an avionics system failure are more adequate.

The main objective of such training is to teach the crew to take adequate actions when facing increased psychophysiological tension during abnormal aircraft operations.

Thus, the scientific novelty of this research is associated with the synthesis of a new data processing method to detect pilots' individual properties negatively affecting the quality of piloting technique. In addition, based on the obtained results, new methods can be developed and implemented in the pilots' training process.

In general, the results obtained in the framework of the research can be used to improve An-148 IAS software in order to automate the decision-making process on the level of aircraft pilot' training.

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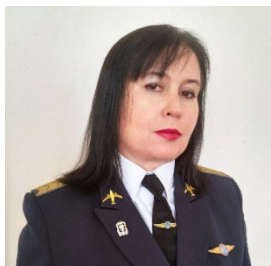
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