# Method of Pilot's Flight Style Model Building Based on Statistical Data

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#### Abstract

The presented research is devoted to the problem of the influence of the human factor on the safety of aircraft in civil aviation. It analyzes the pilot's flight style, which characterizes his individual characteristics of aircraft piloting. The analysis of flight style is carried out using a specially developed mathematical model. It is based on the Kruskal-Wallis criterion. This is a method of mathematical statistics that allows performing a comparative analysis of the parameters of several or more samples. The values of the pitch angle of the aircraft on the glide path were used as initial statistical data, that is when the aircraft was landing. The paper analyzes the data obtained during the performance of real flights of the Boeing-737-500 when it was piloted by a pilot of one of the Ukrainian airlines. Using the developed model, a comparative analysis of the average pitch value in four samples was carried out. The results of the statistical data processing showed that when a pilot performs repeated flights under normal flight conditions, its flight style does not change. The obtained result does not contradict the normal distribution law. The next stage of the research involves the study of changes in the pilot's flight style in abnormal flight conditions, increased psychophysical tension of the pilot. and poor health. Thus, the pilot's flight style can be one of the diagnostic parameters of the influence of the human factor on the safety of an aircraft flight.

#### **Keywords**

Flight trajectory, glide path, human factor, parameters amplitude, Kruskal-Wallis criterion, pitch angle.

# 1. Introduction

In the technical operation of aircraft, one of the key tasks is to ensure the safety of their flights. It depends on many factors, and in particular:

- on the technical condition of the aircraft; •
- weather and other external conditions;
- pilot errors during piloting; •
- errors of the aviation engineering service during the maintenance and repair of the aircraft and • other.

Each of these factors is a random event that can appear itself at any time during the flight. Therefore, in order to minimize the negative appearance of the above mentioned factors, it is necessary to carry out a set of special procedures.

Currently, special attention is paid to issues related to the influence of the human factor [1-13] on the safety of aircraft flights. According to statistics, this is due to the fact that most of the events that are prerequisites for air crashes or air crashes occur through human error. Therefore, the solution of

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problems on this issue is not only of scientific, but also of practical interest. Scientific papers [14] highlight the tasks of the influence of the human factor on flight safety at various stages of an aircraft flight. In these works, the concept of pilot error can be divided into two categories:

- the first category is a mistake made by the pilot as a result of an inadequate assessment of an abnormal flight situation or as a result of the pilot's high psychophysiological tension in difficult aircraft flight conditions;

- the second category of errors is a direct error, which is made by the pilot due to his individual characteristics, as well as because of his temporarily worsened psycho-emotional or physical condition.

That is, an error of the second category is an error without the influence of an external factor as a causal link. In order to significantly reduce the risk of pilot error of the first category, it is necessary to periodically carry out anti-stress training on a simulator of a specific type of aircraft both for an individual pilot and training him as part of the crew [15, 16].

To reduce the risk of a pilot error of the second category when piloting an aircraft, this paper proposes to monitor the pilot's flight style. It is assumed that the pilot's flight style, with sufficiently good professional training, maintained for the entire flight. A change in the flight style to varying degrees will indicate a pilot's tendency to make mistakes or about his poor health.

The flight style of a pilot is a technique for piloting an aircraft, which is characterized by its individual characteristics. Usually, a pilot's flight style is formed when pilot gains a certain piloting experience. It is unique and characteristic only for a particular pilot.

In the presented research, the monitoring of flight style is carried out using the developed mathematical model. It is based on the Kruskal-Wallis statistical test. It allows a comparative analysis of the medians of several samples. The Kruskal-Wallis criterion is multidimensional and rank, widely used in psychology and other fields of science.

Thus, the main goal of this paper is to study the pilot's flight style under normal aircraft flight conditions using a specially developed mathematical model based on the Kruskal-Wallis statistical criterion.

## 2. Methods and materials

The transcription data of the aircraft Boeing-737-500 flight information was obtained from the airline for the analysis of flight styles. To do this, the sections of real flights were taken after approaching the glide path until landing.

The landing approach took place at different airports, so the length of the glide path and, accordingly, the amount of data differ. To analyze the flight information data, the pitch amplitudes in the above flight segments were taken. For calculations, a computer algebra system from the class of computer-aided design systems Mathcad was used. Due to the fact that a shortened glide path negatively affects the psycho-physiological tension of pilots [14], it is advisable to determine whether the pilot's flight style is preserved in different flight conditions.

To solve this problem, a method based on the Kruskal-Wallis test was applied, which is a nonparametric analogue of one-way variance analysis and detects differences in the distribution position.

# 2.1. General information

The great attention is paid to flight safety in civil aviation, although the occurrence of air crashes is unlikely. There are single events that lead to aviation accidents. Some of them are associated with inadequate reflexes of the human operator in the event of increased psychophysiological tension.

To eliminate this phenomenon, it is necessary to evaluate the characteristics of the ergatic aircraft control system for preparing crews for special flight situations and systematize anti-stress training. In addition, it is necessary to create suitable conditions and crew prompts to prevent the above mentioned situations. To solve this problem, theoretical and experimental studies are required to develop methods for assessing the characteristics of an ergatic aircraft control system. Therefore, it is necessary to improve the functioning of ergatic and intelligent systems, to study the influence of operational factors on the aircraft performance indicators. In the process of many years of research, a connection was established between changes in the pilot's psychophysiological tension and flight parameters. The main

studies were carried out on integrated aircraft simulators for the roll angle. For the study, a section of the glide path was taken, on which, to create psychophysiological tension for pilots, failures were introduced [15] on the aircraft integrated simulator. Since the analysis of landing cannot be correctly simulated on aircraft integrated simulator, studies of the influence of psychophysiological tension were carried out directly on landing, depending on the length of the glide path [16]. The flights were considered in the director approach mode [17, 18].

# 2.2. Analysis of statistical data for homogeneity

Let's consider the method of building a model of a pilot's flight style on a concrete example of statistical data. Statistical data for analysis are given in Table 1. This data consists of four datasets. Each dataset contains the results of pitch angle measurement during landing. The pilot for each dataset is the same. Landing is carried out on a Boeing 737-500.

	Dataset 1		Dataset 2			Dataset 3		Dataset 4		
_	1.1	2.6	4.8	0.5	0.5	1.5	1.6	0.9	1.2	2.7
	1.2	2.7	4.5	0.8	1	0	1.8	0.2	2.5	2.7
	1.4	2.9	4.8	1.1	0.5	-1	1.4	1.4	2.8	3.5
	1.3	3	3.9	1.3	1.5	0	1.5	0.6	2.1	1.8
	1.3	2.7	3.7	1.5	1.9	1.5	1.7	1.9	2.1	2.5
	1.4	2.5	3.5	1.9	2.3	2.5	1.9	2.2	2.9	2.2
	1.5	2.7	2.7	2.1	1.9	0	2.4	2.5	2.8	0.5
	1.4	2.3	2.5	2.2	2.4	0.5	2.6	3.2	1.5	1.5
	1.5	2.4	2.3	2.6	1.7	0	2.9	3.6	2.3	2.7
	1.6	2.5	1.9	2.2	2.6	1	3.2	3.8	2.1	1.8
	1.7	2.7	2.3	1.9	2.8	1.5	3.6	4	1.7	1.5
	1.7	2.6	2.1	2.6	1.7	2	3.2	3.9	2.2	2.2
	1	2.8	2.9	2.3	1.4	-0.3	2.7	3.7	2.4	2.4
	1.8	2.9	2.7	1.8	1.9	1.4	2.4	3.5	2	2.1
	1.9	3	2.4	1.7	2.1	1.8	1.9	3.7	2.6	1.5
	1.5	3.1	2.9	1.5	2.5	2	1.4	3.9	2.2	1.8
	1.6	3.3	3.1	2.3	2.7	0.5	0	4.1	3	2.5
	2		3.5	3.1	2.5	1	1.2		2.2	2.1
	1.8		4.1	3.3	2.5	1.3	0		2.1	2.3
	2		3.8	3.6	2.8	1.8	1.3		1.1	1.8
	1.7		3.3	2.9	3.1	2.5	1.9		0.8	2.5
	1.9		3.4	2.7	3.1	1.7	2.5		1.2	1.7
	1.9		3.8	3.21	2.8	0	2.4		2.5	2
	2.2		3.6	3.5	2.5	1.8	2.8		0.8	2
	2.3		3.5	4	2.3	0	2.6		0.9	1.8
	2.5		3.2	3.6	2.6	1.6	3.2		1.3	2.5
	2.6		2.8	3.2	1.9	1.3	3.4		1.7	2.8
	2.4		2.6	2.7	1.5	1.7	2.4		2.1	3.2
	2.3		2.2	2.5	1.3	-0.5	1.6		2.2	3.9
	2.5		1.9	1.8	1	0.5	2		2.1	4.5
	2.4		1.5	1.7	0.8	0.3	1.6		2.7	4.6
	2.5		1.2	1.4	0.6	3.2	2.4		2.5	4
	2.6		0.9	1.1	0.2	2.7	0.8		2.1	4.2
	2.4		0.7	0.7	0	0	0.7		2.8	4.8

Datasets for four flights and same pilot

Table 1

Dataset 1 contains the results of  $k_1 = 51$  measurement and is placed in the first and second columns of Table 1. Dataset 2 contains the results of  $k_2 = 136$  measurement and is placed in the third – sixth columns of Table 1. Dataset 3 contains the results of  $k_3 = 51$  measurements and is placed in the seventh and eighth columns of Table 1. Dataset 4 contains the result of  $k_4 = 68$  measurement and is placed in the in the ninth and tenth columns of Table 1.

The total amount of observation is equal to

Table 2

$$N = \sum_{i=1}^{4} k_i = 306.$$

Preliminary statistical analysis for each dataset was performed based on finding point estimates of statistical characteristics, namely the mathematical expectation, standard deviation, skewness and kurtosis.

The results of statistical characteristics calculations are shown in Table 2.

Statistical characteristics of datasets									
	Dataset Minimum		Maximum	Mean	Standard	Skewness	Kurtosis		
	number	value	value	value	Deviation				
	Dataset 1	1	3.3	2.149	0.587	-0.15	-1.058		
	Dataset 2	-1	4.8	2.007	1.159	-0.1	-0.28		
	Dataset 3	0	4.1	2.276	1.089	-0.195	-0.716		
	Dataset 4	0.5	4.8	2.296	0.864	0.809	1.287		

Analysis of the numerical values of the statistical characteristics shows that the datasets are characterized by approximately the same mathematical expectations, but the variance for the first and fourth datasets is noticeably smaller, which can be explained by the smaller amount of observation. In addition, the fourth dataset is characterized by positive skewness and kurtosis values.

The datasets volume of 51 and 64 observations is too small to reliably determine the density of the probability distribution for the measured data. It is natural to try to combine these data into one set. However, for this, it is necessary to conduct a detailed statistical analysis on the homogeneity of the initial samples. That is, it is necessary to check the hypothesis whether the specified datasets belong to the same population.

Non-parametric methods can be used to solve this problem. The main property of these methods is the independence of decision-making reliability on the distribution law of the analyzed data. The literature considers a large number of methods that are robust to the type of distribution law, including sign methods, the Pearson test, the Wilcoxon test, the Mann-Whitney test, the Kruskel-Wallis method, and other variance analysis techniques.

Since the analyzed datasets contain a different number of observations and their number is more than two, it is quite obvious that in this case an approach based on Kruskel-Wallis statistics can be applied. Let's consider this approach in more detail.

The first step in the calculation is to combine the available datasets into a single sample. The visual view of the implementation for the combined sample of the studied data is shown in the Figure 1. For this sample, numerical data are converted into their number in the corresponding order statistics. That is, for each value of the dataset, it is necessary to find its rank, which will be denoted by a function Rank(i), where  $i \in [1; N]$  – counting number in sample,  $Rank(i) \in [1; N]$ . It should be noted that the samples may contain the same values of the random variable. In this case, the ranks may not be integers. In the case of multiple repetitions of the sample value, it is necessary to replace the corresponding ranks with the corrected average values of these ranks.

The rank statistics for the studied data are given in the Table 3.



Figure 1: Data trend for a combined sample

# Table 3

Ranks for initial statisti	cs
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Dataset 1		Dataset 2				Dataset 3		Dataset 4	
43.5	213.5	305	20	20	75.5	86.5	35	48	227
48	227	301.5	31	39	8.5	109	14.5	196.5	227
63	248	305	43.5	20	1	63	63	239.5	276.5
54.5	253	292.5	54.5	75.5	8.5	75.5	24.5	144.5	109
54.5	227	286	75.5	123	75.5	96	123	144.5	196.5
63	196.5	276.5	123	167	196.5	123	156	248	156
75.5	227	227	144.5	123	8.5	179	196.5	239.5	20
63	167	196.5	156	179	20	213.5	263.5	75.5	75.5
75.5	179	167	213.5	96	8.5	248	282	167	227
86.5	196.5	123	156	213.5	39	263.5	289	144.5	109
96	227	167	123	239.5	75.5	282	296	96	75.5
96	213.5	144.5	213.5	96	134.5	263.5	292.5	156	156
39	239.5	248	167	63	3	227	286	179	179
109	248	227	109	123	63	179	276.5	134.5	144.5
123	253	179	96	144.5	109	123	286	213.5	75.5
75.5	257	248	75.5	196.5	134.5	63	292.5	156	109
86.5	270	257	167	227	20	8.5	298.5	253	196.5
134.5		276.5	257	196.5	39	48		156	144.5
109		298.5	270	196.5	54.5	8.5		144.5	167
134.5		289	282	239.5	109	54.5		43.5	109
96		270	248	257	196.5	123		31	196.5
123		272.5	227	257	96	196.5		48	96
123		289	268	239.5	8.5	179		196.5	134.5
156		282	276.5	196.5	109	239.5		31	134.5
167		276.5	296	167	8.5	213.5		35	109
196.5		263.5	282	213.5	86.5	263.5		54.5	196.5
213.5		239.5	263.5	123	54.5	272.5		96	239.5
179		213.5	227	75.5	96	179		144.5	263.5
167		156	196.5	54.5	2	86.5		156	292.5
196.5		123	109	39	20	134.5		144.5	301.5
179		75.5	96	31	16	86.5		227	303
196.5		48	63	24.5	263.5	179		196.5	296
213.5		35	43.5	14.5	227	31		144.5	300
179		27	27	8.5	8.5	27		239.5	305

The second step of the calculation is to determine the total ranks for each dataset separately, that is, to calculate the corresponding values according to the formulas

$$Rank_{sum}(j) = \sum_{w=1}^{k_j} d_{w,j},$$
(1)

where *j* corresponds to the dataset number, i.e.  $j \in [1; 4]$ .

The third step of the calculation is to obtain the so-called Kruskel-Wallis statistic h according to the formula

$$h = \frac{12}{N(N+1)} \sum_{j=1}^{4} \frac{\left(Rank_{sum}(j)\right)^2}{k_j} - 3(N+1).$$
(2)

For the case when the values in the sample are not repeated, formula (2) is final.

If we have a sample with repetitions, it is necessary to calculate the correction factor according to this formula

$$C_{cor} = 1 - \frac{1}{(N-1)N(N+1)} \sum_{u=1}^{p} ((t_u - 1)t_u(t_u + 1)),$$
(3)

where p is the number of repeated values in the dataset,  $t_u$  is the number of identical ranks in the *u*-th repetition group.

Corrected value h of statistic

$$h_{cor} = \frac{h}{C_{cor}}.$$
(4)

The sample under the study contains repeated values. The merged dataset contains 48 duplicate values with a repetition range from 2 to 22. For a visualization of values repetitions, a series of distributions can be built; its graphical form for the initial data is shown in Figure 1.



Figure 2: The probability mass function for the combined dataset

For the studied dataset, the value of the h statistic according to formula (2) is 3.008, the correction coefficient according to formula (3) is 0.999. Then, according to expression (4), we get the corrected value h of the statistic, which is equal to 3.012.

At the last step of the calculation, we need to find the decision threshold. If the adjusted value h of the statistics is less than the threshold value, then a decision is made about the homogeneity of the data

and the combination of the specified datasets into one is reasonable. Otherwise, a decision is made about the heterogeneity of the data.

The decision threshold is determined according to the chi-square distribution tables. The number of degrees of freedom is equal to a value that is one less than the number of combined datasets. Let's take a significance level of 0.05. Then for three degrees of freedom the decision threshold is 7.81.

In our case  $h_{cor} = 3.012 < h_{th} = 7.81$ . Therefore, the hypothesis about the homogeneity of the data given in Table 1 is accepted.

Hence, we conclude that combining four datasets into one is statistically justified.

#### 2.3. Checking the data model for a normal distribution

A preliminary analysis of the combined dataset provides the following point estimates of the statistical characteristics

$$min(d) = -1;$$
  
 $max(d) = 4.8;$   
 $mean(d) = 2.14;$   
 $standard deviation(d) = 1.017;$   
 $skewness(d) = -0.074;$   
 $kurtosis(d) = 0.219.$ 

To describe the combined dataset, let's try to use the normal distribution law with the density of the form

$$f(x) = \frac{1}{1.017\sqrt{2\pi}} e^{-\frac{(x-2.14)^2}{2.068}}$$

The distribution histogram for the combined dataset (for the case of nine clustering intervals) and the theoretical probability density function are shown in Figure 1.



**Figure 3**: The distribution histogram for the combined dataset and the theoretical probability density function

Even a visual analysis of the histogram and the theoretical probability density distribution shows their convergence. To make a final decision, Pearson's chi-square goodness-of-fit test was applied.

The calculation gives the value of the parameter  $\chi^2 = 8.885$ . For a significance level 0.05 and six degrees of freedom, the critical value is 12.59. So, the calculated value is less than the threshold, so we make a decision about the possibility of applying the normal distribution law for the pilot's flight style model in the case of normal operation of the equipment without failures.

#### 3. Results and discussions

As a result of the research, it was found that with different landing approaches, i.e. with a different amount of data, combining four datasets into one is statistically justified. This suggests that with different psychophysiological loads, using a non-parametric method, it was found that the pilot's flight style and quality of piloting technique do not change [19–29].

However, when evaluating the quality of piloting technique, it must be taken into account that the formation of flight style is carried out without the analysis that is presented in this paper. Various interpretations are possible when determining the laws of distribution. For the already formed flight style, the most effective will be a comparison of flights without failures and with failures introduced before approaching the glide path on the integrated aircraft simulator.

It follows from the above that it is necessary to create a data bank of flight styles using flight parameters based both on simulators and on real flights (Figure 1). For each type of aircraft, systems and recommendations should be developed for processing data and some recommendations should be issued by the instructors.



Figure 4: Scheme of the data bank of flight style using flight parameters

## 4. Conclusions

The paper is devoted to the solution of important scientific problem of ensuring flight safety, related to the human factor in terms of improving piloting style in cases of aircraft equipment failure, worsening weather conditions and features of the location of the airfield. To track the stressful situation affecting the pilot, statistical data processing is usually performed regarding the trends of the measured indicators.

However, such trends have the small sample size, which reduces the effectiveness of building mathematical models and synthesizing algorithms for detecting changes in the pilot's flight style.

The paper discusses the issue of substantiating the possibility of combining measured data arrays for various stressful situations. The solution of this task is based on the Kruskal-Wallis statistical test which confirmed the proposed hypothesis about combining data arrays. Using the proposed method, a comparative analysis of the pilot's flight style was carried out during four real flights of the Boeing-737-500 aircraft. The results of statistical data processing showed that when performing these flights under normal flight conditions, the pilot's flying style does not change. The generalized statistical model of the pilot's flight style data does not contradict the normal distribution law.

The obtained result of the statistical analysis of the data of the pilot's flight style makes it possible to develop a method for continuous monitoring of the pilot's flight style during the flight in order to reduce the risk of pilot error of the second category.

Based on the conducted research, the following recommendations can be made:

1. It is necessary to collect data for each pilot in various stressful situations during the approach of the aircraft to land and form appropriate data banks.

2. The ability to merge data arrays must be checked based on Kruskal-Wallis test.

Future research directions will be related to the synthesis and analysis of procedures for processing the collected data to identify the stressful situation based on the pilot's flight style.

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