

## Analysis of a passenger mass influence on the model of identifying the aircraft takeoff weight and its takeoff balance data

This article provides a new model of the take-off weight and balance of the aircraft determining process, as well as the weight distribution of passengers' law. These materials allow a simulation of one of the main operations in the preparation for departure process.

**Key words:** load sheet, take off, weight, balance, aircraft, model.

**Formulation of the problem.** Finding of a takeoff weight and a center of gravity position of the aircraft is one of the most important operations in a preparation for a departure. Quality of a decision-making about the departure determines the safety of the flight, and can be estimated by the probability of an error. Analysis of the causes of air accidents for forty-three years, given in [1] shows that the culprit of disasters in the 50% of cases is the aircraft crew. Overload of the aircraft occurs in the 0.8 % of such cases. Hence one of the ways to reduce the probability of a flight accident [2, 3] is to create an automatic decision support system (ADSS) about the accordance of the weight and balance of the aircraft to their requirements.

Reviewing the practice of the takeoff weight and center of gravity compliance verification to the specified norms [4, 5] and learning the theory of the monitoring quality estimation [6] make it possible to find multiple causes of the errors: errors of the weight and the center of gravity of the aircraft means of measuring; a simplified approach to the weight of an onboard equipment estimation; a hypothesis of the constancy of the weight of crew members, passengers, fuel and oil; a method of calculating the aircraft center of gravity position (Fig 1.).

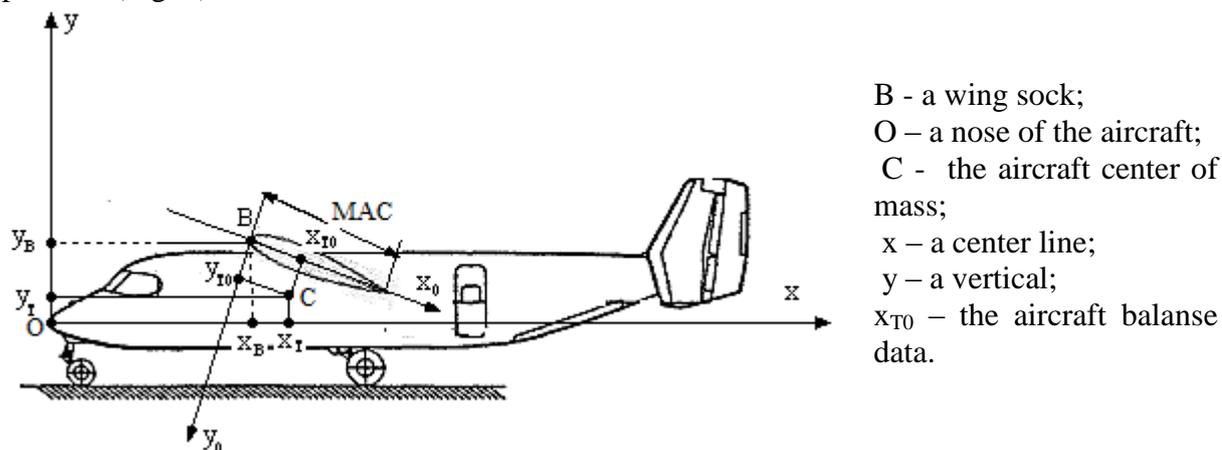


Figure1 - Associated with the aircraft coordinate systems

To reduce the impact of these causes of errors on the monitoring quality one has to consider real changes in a weight of the people on board from one person to another, as well as the method of calculating the aircraft center of gravity position. There are several methods for determining the origin of the airplane gravity relatively to the middle aerodynamic chord (MAC) (balance data) (Fig. 1.) One of the most frequently used method for the balance data determining is based on using a balance schedule [4, 5, 7] (Fig. 2).

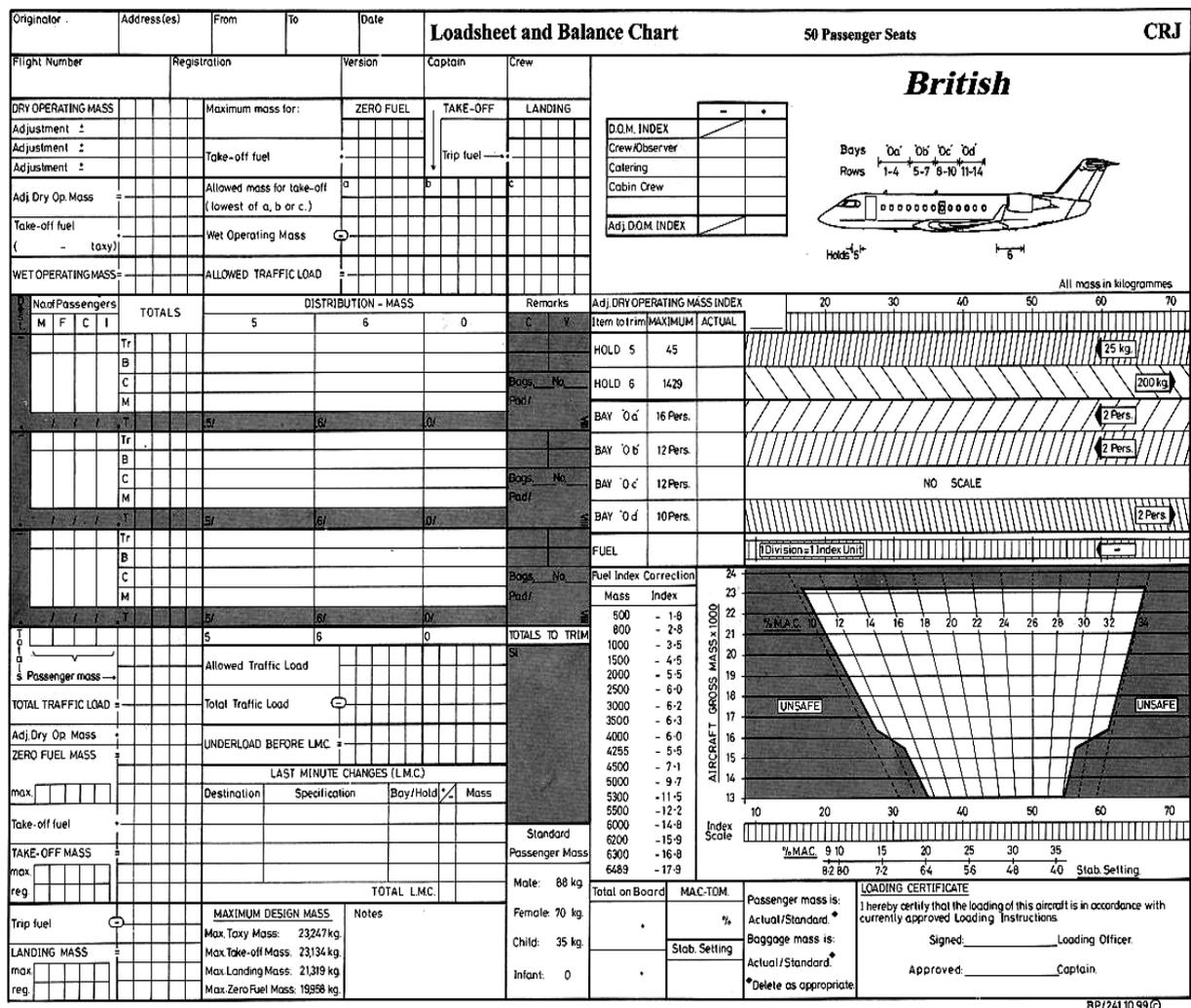


Figure2 – Loadsheets and Balance Chart

Examination of the figure 1 and the balance schedule (Fig. 2) in accordance with the results of the monograph [6] shows that for calculating the probability of an error of a valid decision on the weight and balance of the aircraft specified values it is necessary to determine the characteristics of the measurement errors of all parameters and the mechanism of their effect on the result.

**The main task** of this paper is to develop a block diagram of the process of checking the weight and the center of gravity position with the help of the load sheet and to evaluate a person's weight distribution law.

**The main material of the article.** Studying the technology of the aircraft takeoff weight and the balance detecting with the help of the loadsheets shows that it is possible to divide this technology on the number of the technological operations. These operations include determining the weight and the balance of the equipped aircraft, the use of the nomograms "Balance of equipped plane", "Trunk", "Passenger seat", "Pilots", "Fuel", "Take-

off and landing weight". Perform each of these steps allows oneself to fill all parts of the loadsheet and is accompanied by two types of errors. The first type is the measurement errors of an initial data. The second type is the errors of application points on the scale.

The first process step makes it possible to determine the equipped aircraft weight and balance with the help of the fomula

$$P_{CH}^C = P_0^{\Pi} + \varphi_{P0} + P_{CH} + \varphi_{C1}, \quad (1)$$

$$x_{T0}^C = x_{T0}^{\Pi} + \varphi_{X0} + \Delta x_{CH} + \varphi_{X1}, \quad (2)$$

where  $P_0^{\Pi}$  is a weight of the empty aircraft which is measured and indicated on the form;  $\varphi_{P0}$  is an error of the weight measurement;  $x_{T0}^{\Pi}$  is the empty aircraft balance;  $\varphi_{X0}$  is an error of the balance measurement;  $P_{CH}$  is the equipment and materials weight;  $\varphi_{C1}$  is an error of the equipment and materials weight measurement;  $\Delta x_{CH}$  is the balance variation due to the onboard equipment and materials;  $\varphi_{X1}$  is an error of the  $\Delta x_{CH}$  measurement.

The second process step is served for the transition from the numerical values of  $P_{CH}^C$  and  $x_{T0}^C$  to the nomograms. As a result, it appears a point with the coordinates  $x_{T0}^C$  and  $P_{CH}^C$  given in a non-orthogonal coordinate system. Putting points  $x_{T0}^C$  and  $P_{CH}^C$  on the scales of this coordinate system accompanys with a job error of the equipped aircraft weight  $n_{PC}$  and a set error of the equipped aircraft balance  $n_{XC}$ .

The third step is "Trunk". It is serv for finding the weight of a baggage  $P_b$  in the form of

$$P_b = P_{b0} + \varphi_b, \quad (3)$$

where  $P_{b0}$  is the true weight of a luggage;  $\varphi_b$  is an error of the laggage weight measurement. Also, this step is used to determine changes in the aircraft balance data by loading cargo in the trunk. Let us denote the error of applying a value of  $P_b$  to the axis of the chart as  $n_2$ .

The fourth step is called "Passengers". It allows estimate the change in aircraft balance data because of the passengers on board placement. Initial data for its execution are the numbers of seats and a passenger weight. The passenger weight  $P_{mi}$  is considered to be constant in order to simplify the calculations. If we denote the actual weight of the passenger  $P_{fi}$ , then

$$P_{fi} = P_{mi} + \varphi_{mi}, \quad (4)$$

where  $i$  is a seat number;  $\varphi_{mi}$  is a deviation of the actual passenger weight from the weight adopted for the calculation. Drawing  $P_{fi}$  on the nomogram accompanies the error  $n_{ni}$ . Depending on the type of an aircraft the load sheet may has  $N$  scales to accommodate the weight of passengers. ( $N$  is a number of seats).

By analogy with the fourth step in the fifth step, which is called "Pilots", are searched the balance data changes caused by the presence of the crew in the cockpit. The balance data changing is find by means of the nomogram as a result of the crew weight depositing on a scale of "Pilots". The crew weight should be found by the formula

$$P_E = \sum_{i=1}^n P_{\Pi i} + \sum_{i=1}^n \varphi_{\Pi i}, \quad (5)$$

where  $P_E$  is a crew weight;  $n$  is the number of cabin crew members;  $P_{\Pi i}$  is the weight of a pilot number  $i$ ;  $\varphi_{\Pi i}$  is a deviation of the actual pilot weight from the weight adopted for the calculation.

The sixth step serves to assess the impact of a mass consumption on the aircraft balance data. To do it, you must find the weight of fuel  $P_T$  and cause the obtained value on the proper scale of the loadsheet.  $P_T$  search is performed on the base of the following equation

$$P_T = P_{T0} + \varphi_{T0}, \quad (6)$$

where  $P_{T0}$  is the true weight of fuel on the board;  $\varphi_{T0}$  is an error of the fuel weight measurement. The process of applying the value of  $P_T$  on a scale accompanies an error  $n_{T0}$ .

The seventh step called "Take-off weight" makes it possible to evaluate take-off weight of the aircraft  $P_b^C$  and take-off balance data  $x_b^C$ . Estimation of the weight  $P_b^C$  occurs taking into account equations (1) (3) - (5) and (6) as the sum

$$P_b^C = P_{CH}^C + P_b + \sum_{i=1}^N P_{fi} + P_E + P_T. \quad (7)$$

Obtained from the equation (7) value P with the aggregate result of the sixth step allows us to estimate the center of mass position in a tolerance zone and to make the decision about a quality of the aircraft balance. Obviously, the presence of the measurement errors  $\varphi$  and the inaccuracies of the scale deposition on the nomogram points  $n_c$  lead to the errors in determining the weight  $P_b^C$  and the balance  $x_b^C$  of the aircraft. In this regard, when deciding on correct loading pilot can make mistakes with can be the first or the second kind [6]. The monograph [6] shows that the probability of these errors can be found as a posteriori probability of making the wrong decision.

Let's use a simulation method for determining the posterior probabilities. The necessary conditions for the use of this method are the existence of a model of the take-off weight and balance of the aircraft search process and the availability of an information about the laws of the errors distribution. Let's imagine the model of the take-off weight and balance evaluation process in the form of the block diagram to fulfill this condition. Denoting the processing operations described above in the form of rectangles and considering the equations (1) - (7) make it possible to represent the block diagram as shown in Fig. 3.

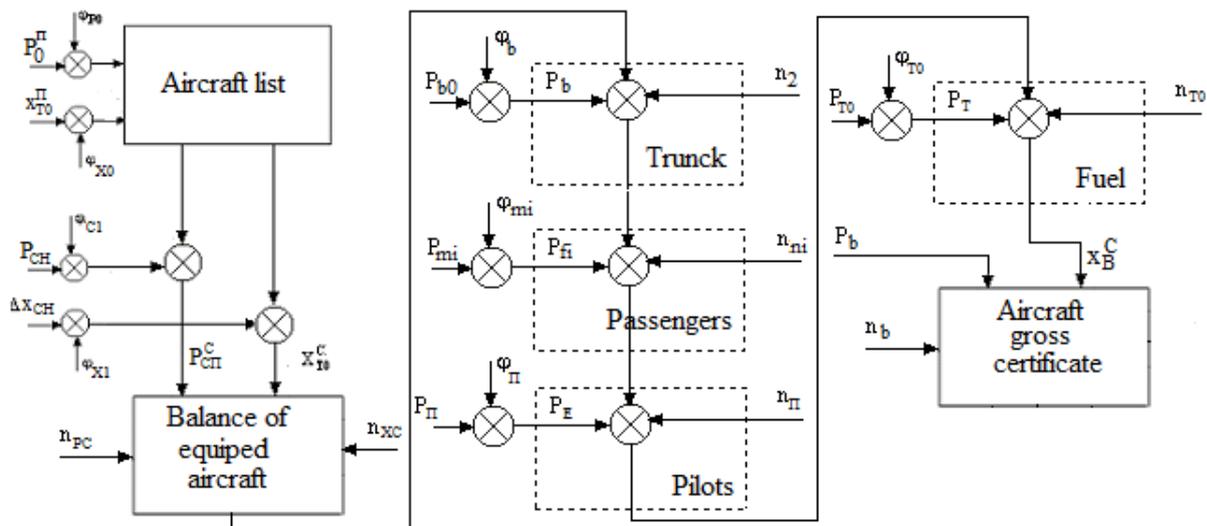


Figure3 – The block diagram of the load sheet

Determination of the distribution law of the weight and balance estimating errors can be achieved, if we know the laws of the each process step error distribution. Central place in the above mentioned technology takes the weight of a passenger or a crew member measurement error  $\varphi_{\Pi}$ .

Obviously, the weight of the passenger as an element of a people majority is a random value. Let's use the experimental data about the weight of 250 man which varied in the range from 43 kg to 125 kg and the set of procedures forth in the books [9 -11] to assess the weight distribution law.

In accordance with the procedure provided in the books [9, 10] expectation  $\langle P_r \rangle$ , mode  $M_0$ , median  $M_e$ , range  $R_p$ , standard deviation  $\sigma_p$ , coefficient of weight variation  $v$  were

calculated. Values of these numerical characteristics of the sample weights of people are presented in tabular 1. A weight distribution histogram is shown in the Fig. 4.

Table 1 – Values of the numerical characteristics

Name	$\langle P_r \rangle$ , kg	$M_0$ , kg	$M_e$ , kg	$R_p$ , kg	$\sigma_p$ , kg	$v$ , %
Value	63.3	60	63.8	30.9	5.95	9.4

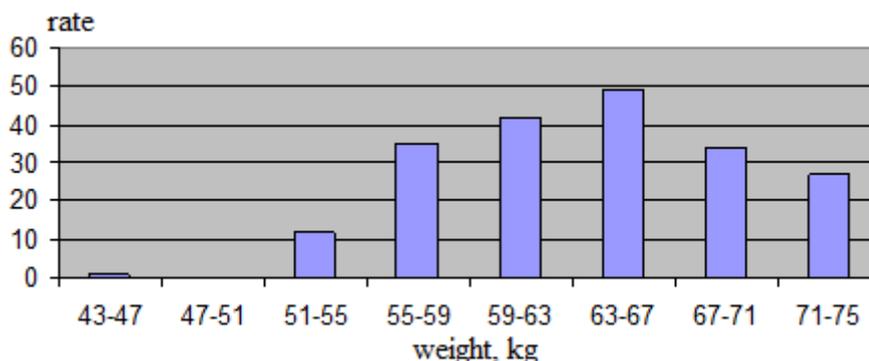


Figure 4 – The weight distribution diagram

Since the values of  $\langle P_r \rangle$ ,  $M_0$ ,  $M_e$  differ little, a scatter in the data is small relative to the average, and also considering a view of the histogram in Fig. 5, according to the results from [9, 10] can be accepted the hypothesis of the normal distribution.

For the final decision on the weight distribution law we use the Kolomogorov-Smirnov criterion  $D$  [11]. Since the calculated value of this criterion  $D$ , calculated on a sample with a volume of 200 units, is equal to

$$D_{n=200,0.10} = 0.072 \quad (8)$$

and it is less than the critical value 0.077 than it is possible to accept the hypothesis of the normal passengers weight distribution.

**Conclusions.** Results of the study permit us to formulate the following conclusions:

- the presence of the measurement errors and the graphic constructions inaccuracies leads to the appearance of the first and the second kind errors in deciding the aircraft balance data;
- calculation of the aposteriori probability of making the correct decision about the weight and balance accordance to the norms can be carried out by using a simulation model presented in the article;
- to simulate the process of determining the takeoff weight and balance of the aircraft based on the loadsheet method it is necessary to evaluate the distribution law of the graphic constructions inaccuracies and to consider the mass of fuel changing at lower temperatures.

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#### **Аналіз впливу маси пасажирів на модель ідентифікації злітної ваги та центрівки літака**

Зменшити вплив похибок оцінювання ваги та центрівки літака методів завантажувального графіка на результат прийняття рішення про виліт.

У статті здійснено визначення змісту технологічних операцій при використанні завантажувального графіка літака для визначення його злітної ваги та центрівки. На цій основі розроблена імітаційна модель технологічного процесу яка дозволить визначити апостеріорні ймовірності прийняття хибного рішення. Доведено, що закон розподілу мас людини наближається до нормального та визначені його параметри.

В статті показано, що поява помилок першого та другого роду при прийнятті рішення про можливість вильоту пов'язана перш за все з неточностями виміру первинних параметрів та похибками у графічних побудовах.