Acousto-Optic Marker for Determining the Weight and Center of Gravity of the Aircraft

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Abstract
The article shows the application of a new method for determining the center of gravity and weight of the aircraft and the process of its implementation. For this purpose, using the acousto-optic marker is measured displacement of the front and rear sides of the fuselage and is determined the center of gravity and weight on the basis of the obtained values. The method is synthesized on the basis of an acousto-optic modulator operating in Bregg diffraction mode. The distance determined by the laser rangefinder is used as the support parameter. Based on the support parameter is formed a high-precision measurement marker perpendicular to it.

Keywords: aircraft, acousto-optic modulator, acousto-optic marker, center of gravity, weight.

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Hava gəmisinin kütlə və ağırlıq mərkəzinin təyini üçün akustooptik marker

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Xülasə

Məqalədə hava gəmisinin çəki və ağırlıq mərkəzinin təyini üçün yeni üsulun tətbiqi və onun reallaşması prosesi göstərilmişdir. Bunun üçün akustooptik markerdən istifadə edərək füzelyajın ön və arxa tərəflərinin yerdəyişməsi ölçülür, alınmış qiymətlər əsasında çəki və ağırlıq mərkəzi təyin edilir**.** Üsul Breq difraksiyası rejimində işləyən akustooptik modulyator əsasında sintez olunur. Dayaq parametri kimi lazer uzaqlıqölçəni vasitəsi ilə təyin edilmiş məsafə istifadə edilir. Dayaq parametri əsasında ona perpendikulyar olan və yüksək dəqiqliyə malik ölçü markeri formalaşdırılır.

Açar sözlər: hava gəmisi, akustooptik modulyator, akustooptik marker, ağırlıq mərkəzi, çəki.

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Акустооптический маркер для определения веса и центра тяжести воздушного судна

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Аннотация

В статье показано применение нового метода определения центра тяжести и веса воздушного судна и процесс его реализации. Для этого с помощью акустооптического маркера измеряется смещение передней и задней сторон фюзеляжа и по полученным значениям определяется центр тяжести и масса. Метод синтезирован на основе акустооптического модулятора, работающего в режиме дифракции Брегга. Расстояние, определяемое лазерным дальномером, используется как опорный параметр. По опорному параметру формируется перпендикулярный ему высокоточный измерительный маркер.

Ключевые слова: воздушное судно, акустооптический модулятор, акустооптический маркер, центр тяжести, вес.

Introduction

Incorrect calculation of the weight and center of gravity of aircraft has a direct impact on flight safety and aircraft control. The report of the Interstate Aviation Committee states that overloading of aircraft and incorrect calculation of the center of gravity causes to significant losses and fatalities. There were 50 crashes on gas turbine aircraft due to loading and centralization errors between 1958 and 2019. It should be noted that accidents occur more often in charter flights. The following is a list of aircraft accidents that occurred due to overloading and improper centralization of the aircraft [1]:

- On November 4, 2015, an accident occurred in Crimea due to incorrect calculation of the take off weight and center of gravity of the Cessna-336 aircraft. The flight crew and passengers were killed in the crash;
- On 05.06.2016, after aircraft landing, the wings of the aircraft BAe-125 on the flight Krasnodar-Tyumen-Neryungri were damaged due to improper centering.

Currently, three main methods are used to determine the loading rate and center of gravity of an aircraft [2]. These include the graphical method, the visual control method and the scales method. A brief description of these methods is as follows.

1. Graphic method. Depending on the information in the registration office, the loading schedule is completed according to the design of the aircraft, and the distribution of cargo on the aircraft and the location of the center of gravity are determined.

The main disadvantages of the method: requesting a new document for incorrect calculations; a lot of time spent on filling out documents; the results of the calculation depend on the level of knowledge of the employee.

2. Visual control method. Unlike the first method, calculations in this method are performed by computer.

The main disadvantages of the method: taking into account the approximate average value for the weight of passengers in the calculations; the results of the calculation depend on the information received from the registration department.

3. Scales method. When measuring with the scales system, the weight (W) and center of gravity of the aircraft are determined based on the indicators (W1, W2, W3) of the scales placed under the main and nose landing gears. Despite a number of advantages, the scales method has the following disadvantages: high material costs for the purchase of scales; the need to allocate the aerodrome area required for the installation of scales on site; the need for additional technical means to lift the aircraft on the scales and a lot of time lost; practical impossibility of applying the scale method for passenger aircraft.

In the graphical method widely used in modern times to determine the loading rate of an aircraft, it is very difficult or impossible to accurately determine the characteristics of accidents that occur due to the complexity of providing accurate reports. It is not advisable to use the traditional methods and tools listed above to solve the problem of non-contact distant determination of the dimensions or any size of the object. Because none of them provides high accuracy and can not be used to determine small dimensions (centimeters and smaller order). Modern aircraft use only one on-board method of measuring the center of gravity and mass of the aircraft, the reliability of the information is not so high.

Method

As a result of studying the shortcomings of the methods used to determine the center of gravity and mass of the aircraft, we proposed a new method [3].

Weight and center of gravity are determined by measuring the vertical displacements of the front and rear sides of the aircraft from the support points to the ground surface relative to the center of gravity of the aircraft missile stationed on the ground.

To do this, the image of the aircraft is animated on a monitor through a camera. On the same monitor, the measuring grid is animated using software developed to solve the problem.

The scaling factor for the measuring grid is determined based on the known dimensions of each aircraft and the real-time values of its dimensions that remain constant during the loading process (for example, the length of the fuselage, the distance between the wing points). Then the Y1, Y2 absolute values of vertical displacements of the front and rear parts of the fuselage are calculated. The obtained results are compared with the normative values Y1n, Y2n corresponding to the empty weight of aircraft (figure 1).

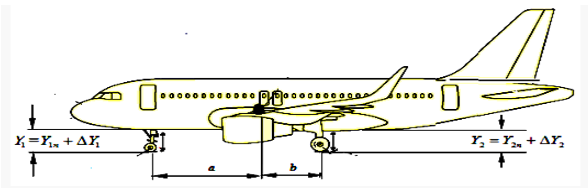

Figure 1 – Vertical displacement of fuselage of the aircraft

Based on the above algorithm, the structural scheme of the method for distant determination of weight and centralization of aircraft is compiled as figure 2.

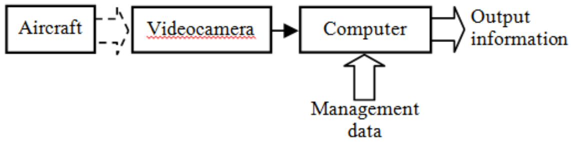

Figure 2 – Distant determination of the weight and center of gravity of the aircraft

According to the structural scheme, the images of the aircraft formed by the video camera are entered into the computer. At the same time, a measuring grid is formed on the computer with the help of "Camera Grid" software. By means of appropriate operations, the description of the aircraft is combined with the measuring grid.

As can be seen from the image, it is possible to quickly determine the displacements based on the "measuring grid" formed on the basis of the "Camera Grid" program. Obviously, it is possible to increase the measurement accuracy to pixels. Usually such high accuracy is not required and the accuracy as parts of a millimeter is as satisfactory.

In any case, the process of distant measurements is carried out on the basis of the selected marker, and the parameters of the measuring grid are adjusted to that marker. Obviously, the accuracy of the measurement is determined by the accuracy of the selected marker. In the distance measurement process described above, one of the pre-known characteristic dimensions of the research object is used as a marker. It is clear that distant measurement is impossible if the characteristic dimensions of the research object are not known. In this case, it is necessary to have another marker. Choosing the right marker is the main difficulty of the proposed method for determining small dimensions.

From the above, it is clear that the establishment of a method of forming a high-precision marker and the device that implements this marker is highly relevant.

The marker required for distant measurements should meet the requirements of simplicity and accuracy. It should also be simple to use. It is clear that the preparation for and implementation of the measurement process should not interfere with the flight preparation process. This indicates that it is undesirable to install any marker on the frame of the aircraft. Thus, a problem of distant formation of a high-precision marker arises.

Theoretical and experimental investigation of the frequency, time and energy characteristics of the acousto-optic processor have shown that the photo-elastic effect has a high potential in the context of the formation of a distant marker [4].

A device called an acousto-optic modulator (AOM) is used to realization the photo-elastic effect [5, 6]. AOM consists of a photo-elastic medium FEM mounted at one end electro acoustic transducer (EAT) and at the other an acoustic absorber (AU). Glass or crystalline materials are used as FEM. The EAC converts the input signal into an elastic wave. This wave forms the running diffraction cage to side AA in the FEM. That diffraction cage reveals itself such as periodic changes in the density of the medium. Directed at a certain angle to the surface of the FEM laser beams scatter from the running diffraction cage - diffraction process takes place [7].

The Raman-Nath and Bragg diffraction regimes can be realize in the AOM [8, 9].

It is more convenient to give an analytical description of the use mechanism and formation of acousto-optic marker on the basis of high-precision measuring system (figure 3). This system includes an acousto-optic processor (AOP), a video camera, collecting lens, a laser distance measurement and a monitor. AOP creates points corresponding to Bragg diffraction on the measured object. The distance between points x_0 is calculated based on the distance to the object D measured via laser distance measurement. The resulting value is used to select the scaling for the report grid.

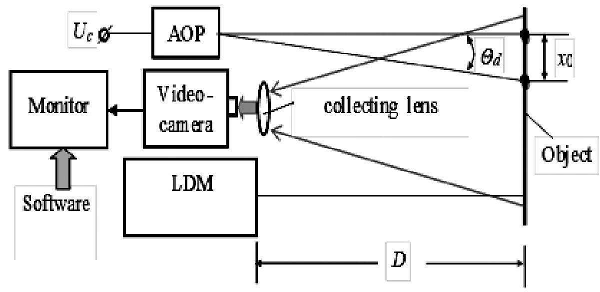

Figure 3 – Distance control and measurement system based on acousto-optic marker

The image of the object along with those points is transmitted to the monitor by a video camera. At the same time, the monitor is synthesizing a report grid via compatible software.

Experimental studies

Experimental approbation of the idea of realization presented above of the acousto-optic marker was implemented the center frequency was performed on an AOM with f_0=80*MHz.*

The report and experimental graph of the marker static adjustment characteristics based on the values given in Table 1.

We can calculate the accuracy of measurements based on experimental and theoretical estimates. Given the data in the table, we determine the standard deviation (σ), the mean error (ν), the probability error (ε).

First we find the numerical average of the theoretical values (table 1).

Table 1 – Static adjustment characteristics of the marker

№	Frequency, MHz	Slide of spot caused by light flood, *mm*	
		Theoretical result	Experimental result
1	70	55,88 (x_1)	56
2	72	57,48 (x_2)	57,5
3	74	59,08 (x_3)	59
4	76	60,67 (x_4)	61
5	78	62,27 (x_5)	62
6	80	63,87 (x_6)	64
7	82	65,46 (x_7)	65
8	84	67,06 (x_8)	67
9	86	68,66 (x_9)	69
10	88	70,25 (x_{10})	70
11	90	71,85 (x_{11})	72

We must first calculate the numerical mean:

$$\overline{x} = \frac{1}{11}\sum_{i=1}^{11} x_i = \frac{702{,}53}{11} \approx 63{,}86\, mm$$

The standard deviation is calculated using the following formula:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2} = 5{,}26 \text{ mm}$$

Given that the average error is defined as $\nu = 4/5 * \sigma$ and the probability error is $\varepsilon = 2/3 * \sigma$, we get ν=4,208 mm; ε=3,156 mm.

Accordingly, we can make calculations based on experimental results (table 1).

We must first calculate the numerical mean:

$$\overline{x} = \frac{1}{11}\sum_{i=1}^{11} x_i = \frac{702{,}5}{11} \approx 63{,}86\, mm$$

The standard deviation is calculated using the following formula:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2} = 5{,}03 \text{ mm}$$

Given that the average error is defined as $\nu = 4/5 * \sigma$ and the probability error is $\varepsilon = 2/3 * \sigma$, we get ν=4,024mm; ε=3,018 mm.

As can be seen, the experimental and theoretical estimates are close to each other. This confirms the high accuracy of the marker.

Conclusion

The proposed technological scheme allows optimization of the weight and center of gravity control process.

The software for generating variable coordinate grids provides the high accuracy of the vertical distance between fuselage of the aircraft and ground.

The method of forming based on acousto-optic effect of the distance marker and the device realizing it provides the high accuracy of contactless measurements.

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