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Imaging Method Application Peculiarities in Contactless Determination of Aircraft Loading Limitations

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ABSTRACT— ***In this paper, we determine graphs and mathematical expressions which describe the relation between the measurements and the distance changes as a result of analysis of the taken pictures of objects and their new utilization methods to determine of loading limitation.***

Keywords --- loading, centre of gravity, cockpit, landing gear, nose and main gear

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It is a known fact that safe operation of aircraft substantially depends on the proper loading and precise determination of the center of gravity. According to French air accident agency BEA report, dated 25 December 2003, improper loading and lack of the information accuracy about the loading of freight compartment caused control failures and fatal aircraft accident [1]

According to the report of the Interstate Aviation Committee (IAC) [2], the overloading of aircraft, inaccuracy computation of the center of gravity range are the leading cause of great losses and death. In 1958-2001 years about 30 accidents associated with the errors of loading and the center of gravity took place in the gas turbine engine aircraft. 12 of the crashes are resulted in the death of 345 persons. It is a known fact that such accidents or incidents often occur in the non-scheduled flights.

Nowadays three equally important methods (Graph method, Visual surveillance, Weighing method) are widely used for determining the actual loading and the location of the center of gravity [3]

As mentioned above, the comparative analysis of method and techniques used for proper loading and precise calculation of the center of gravity range of the aircraft, states that the solution of the problem haven't been found and objective realities of the researches conducted in the field are notable.

Setting up of a system, which will provide operational distance measurements to indicate proper loading limitations and precise calculation of the center of gravity for any types of aircraft, can overcome the problem. For this purpose, the measurements of vertical shift of the forward and the aft portions of the fuselage, which depend on loading as well, maybe used to determine relative to this values center of gravity of the aircraft.

Relations between the loading and the vertical shift of the forward and the aft portions of the fuselage can be given similar to the formulas used for automobile and trucks [4] shown as below:

$$M \cdot \left(Y_1^{//} \frac{b}{L} + Y_2^{//} \frac{a}{L} \right) = P_1 + P_2 ; \quad I \cdot \left(\frac{Y_1 - Y_2}{L} \right) = P_1 a - P_2 b , \tag{1}$$

M - Empty-Weight of the aircraft;

a – is the distance between the nose landing gear and the center of gravity; distance between main landing gear and the center of gravity; $\boldsymbol{Y_1}$, $\boldsymbol{Y_2}$- vertical shifting of the forward and the aft portions of fuselage; $\boldsymbol{P_1}$, $\boldsymbol{P_2}$-loading the forward and the aft portions of fuselage; L- distance between the nose landing gear and between main landing gear ***L=a+b***; I- inertial moment relative to axis, perpendicular to the image surface.

When the aircraft does not move **1** is equal to **0**. In this case, (3) the system of equations can be given as below[5]:

$$M\left(Y_1^{//}\frac{b}{L}+Y_2^{//}\frac{a}{L}\right)=P_1+P_2;\;\; P_1=\frac{b}{a}P_2. \tag{2}$$

After certain conversions and integration, we can get:

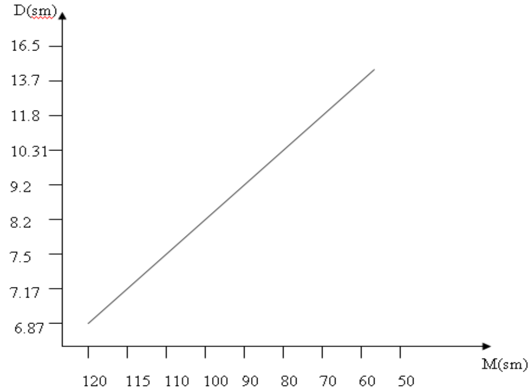
$$m_1=M_0\times b\times\left(\frac{Y_1\times b+Y_2\times a}{L^2\times(Y_{1st}-Y_{1\max})}\right)+\frac{M_0\times b}{L} \tag{3}$$

$$m_2=M_0\times a\times\left(\frac{Y_1\times b+Y_2\times a}{L^2\times(Y_{2st}-Y_{2\max})}\right)+\frac{M_0\times a}{L} \tag{4}$$

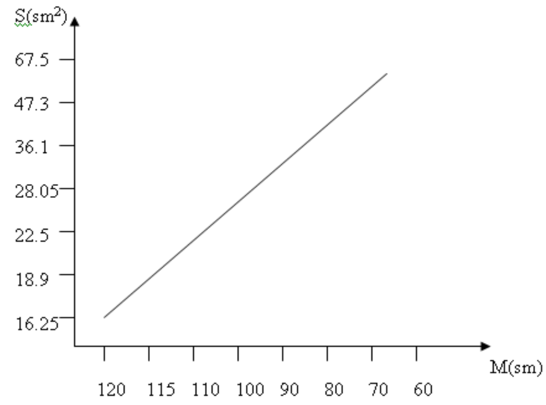
If we will compare the definitions of Y_1, Y_2 and with the Y_{1sr}, Y_{2st} parameters of sums, the overloading of the forward and the aft portions of fuselage can easily be determined, Y_{1max}, Y_{2max} –maximum distance between fuselage and ground after maximum weighting. However, the definition of the proper loading limitation and precise calculation of the center of gravity range of aircraft can be found as a result of the operational vertical shift distance measured on the forward and the aft portions of fuselage.

The imaging method offered in this article is to solve the latter problem. Advanced numerical methods for handling of description will enable the radio electronic devices to define minor changes in descriptions created in real time [6, 7]

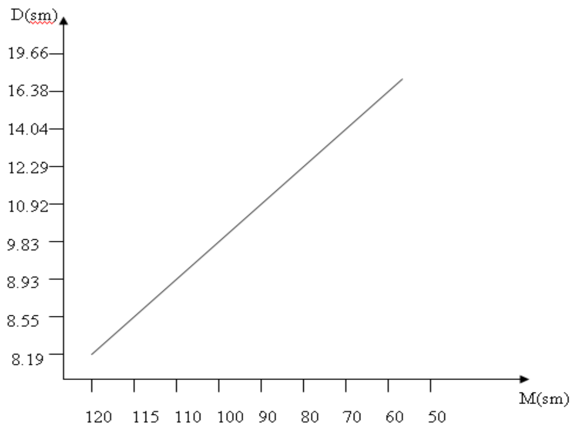
Provision of measuring accuracy is based on the mathematical expression of relation between the measurements of object and distance. Having taken both of the objects (box, radio) beforehand, their pictures were taken from some distance. The dimensions of the box used in the taken pictures are **7.5×20.5cm**, the diagonal is **22cm**, the dimensions of the radio are **12.5×21.5cm**, the diagonal is **25cm**, and focusing distance of the camera is **F=1.83cm**. The box figures are placed at distances of **120, 115, 110, 100 cm** accordingly. 20 pictures for each of them were taken decreasing the distance between the camera and objects. As a result of measurements, on the basis of relation between diagonals and areas of the objects and distance to the figure, the following graphs were compiled. (**Figure** 1)



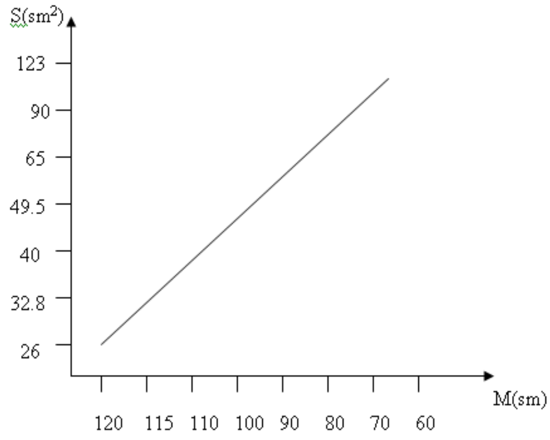
A



B



C



D

Figure 1.

$$I/F=G/M \quad (5)$$

Figure 1 shows that the diagonal and area ***(A, B)*** of the object and the diagonal and area ***(C, D)*** of the radio change depending on distance.

There is a relation formula between the measurements of substance and the distance to the substance. Here F- focusing distance, G- real measurement of substance (real diagonal), ***I*** – measurement picture (diagonal of picture), M- distance to the substance. It is applicable to use ΔI for precise definition of the distance.

In order to determine I_{real1}, the object is placed at a special distance and its picture is taken. And I_{cal}- is determined on the basis of expression (5).

$$\Delta I = I_{real}/I_{cal} \qquad (6)$$

To calculate I_{real1} we will place the object on a defined distance and will take it's photo. I_{cal} can be found based on a formula (5)

$$I_{cal} = F \times G / M_{known} \qquad (7)$$

If we take the expressions $M_{known} = 110cm$ in Figure1,b, and the distances $I_{real} = 7.5cm$, $F = 1.83cm$, $G = 22cm$, into consideration, it can be easily found that $I_{cal} = 1.83 \times 22/110 = 0.366cm$

Then, ratio $\Delta I = 7.5/0.366 = 20.5$ for each box on photo. By this way, constant is determined for any substances. The changes of distance between the object and camera is expressed by the following formula

$$Y = G \times F \times I / I_{real}.. \qquad (8)$$

If we take the expressions (8) into (3),(4) consideration, it can be

$$m_1 = M_0 \times b \times \left(\frac{G \times F \times \Delta I / I_{real1} \times b + G \times F \times \Delta I / I_{real2} \times a}{L^2 \times (Y_{1st} - Y_{1\max})}\right) + \frac{M_0 \times b}{L} \qquad (9)$$

$$m_1 = M_0 \times a \times \left(\frac{G \times F \times \Delta I / I_{real1} \times b + G \times F \times \Delta I / I_{real2} \times a}{L^2 \times (Y_{2st} - Y_{2\max})}\right) + \frac{M_0 \times a}{L} \qquad (10)$$

Here, I_{real1} and I_{real2} are the measured diagonals of pictures taken by camera which was placed later in the forward portions of the center of gravity of aircraft.

Change of the distance

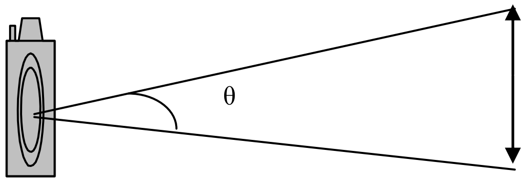


Figure 2. Definition of distance of the basis of angle change

If the expression is defined on the basis of

$$Y = G/\theta \qquad (11)$$

$$m_1 = M_0 \times b \times \left(\frac{G \times b/\theta_1 + G \times a/\theta_2}{L^2 \times (Y_{1st} - Y_{1\max})}\right) + \frac{M_0 \times b}{L} \qquad (12)$$

$$m_1 = M_0 \times a \times \left(\frac{G \times b/\theta_1 + G \times a/\theta_2}{L^2 \times (Y_{2st} - Y_{2\max})}\right) + \frac{M_0 \times a}{L} \qquad (13)$$

Here, θ_1 and θ_2 are determined using dependence on the distance change in the camera which was placed later in the forward portions of the center of gravity of aircraft.

The operation algorithm of the imaging method is as following. During aircraft loading the scale coefficient defined in real conditions is determined on the basis of the known dimensions values and the constant dimensions (for example, the length of fuselage, the distance between three points of wings) of aircraft. Then, the absolute values (Y_1, Y_2) of vertical shift of the forward and aft portions of fuselage are calculated. The achieved results are compared with normalized values of ***Y1st, Y2st***.

According to conducted researches and analysis, we conclude that by determining aircraft vertical displacement using imaging method, aircraft loading coefficients and dependent center of gravity percentage can be calculated contactless with high accuracy and in a much faster, compared to methods mentioned above. Possibility of the full automation and subsequent data transfer to aircraft services network is the other advantage of this method.

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