Inertia-moment factor in airplane’s form design

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Abstract

The paper describes new approaches of moments of inertia shape formation of future technology aircrafts. Defined preferable zones of placing fuel and payload accordingly its mass. Rated regularities between the geometric characteristics of alternative variants of placing fuel in the wing and payload in the fuselage and the moment of inertia parameters of the aircrafts

Developed: the inertia-moment models and algorithm, software package to determine the moment of inertia characteristics of the aircraft with sufficient accuracy, intuitive 3D interface for viewing and easy processing of computations.

1. Introduction

Linear dimensions increase, which is specific for modern long-haul passenger/cargo aircrafts, leads to moments of inertia growth and sizeable changes during the flight up to fourth-fifth degree proportional linear dimension, and at the same time it leads to required control moment reserve growth, which is inconsistent with the control system opportunities and requirements and requires appropriate action of the designers. A good example of this can be serve the aircrafts of such design companies as Airbus, Boeing, Sukhoi, Ilyushin etc. All these factors are in contradiction with the possibilities of control systems, and require appropriate actions by the designers.

There are several possible areas of research to obtain the required level of controllability. The firsts associated with available control moment increase, and the seconds associated with the required control moment reduction and stabilization during the flight. But all this areas leads, on the one hand, to wing’s moments of inertia increase, and, as a result, it leads to whole aircraft’s moments of inertia value increase, and on the other hand, it leads to power consumption increase.

Analysis of the problem[1,2,3,4,5,6,7,8] reveals the special actuality of the moments of inertia future technology aircraft shape formation (fig. 1)., especially the problem of required controllability level providing due to airplane’s moments of inertia decrease , and supplying moments of inertia values stability during the flight

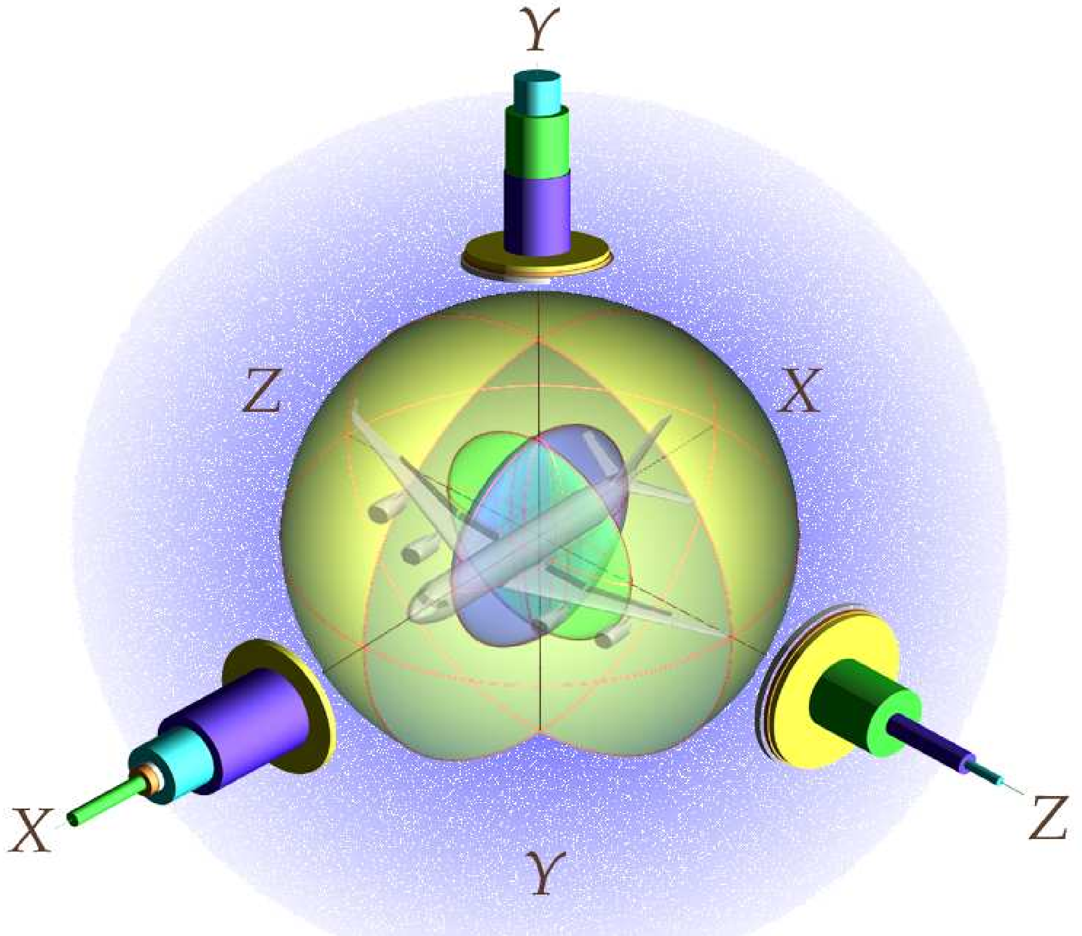

fig. 1 Airplane moment of inertia model

2. Features of airplane's layout, taking into account moments of inertia

2.1 Features of airplane's layout, taking into account moments of inertia over axis OX

In many respects inertia-moments characteristics are determined by circuitry in aircraft's form design.
It realized airplane's layout and inertia-moments schemes forming on the basis of the adopted circuit decisions, depending of fuel and payload masses. The forming is concluding on coordination of airplane's aggregates and inertia-moments determination. The next stage is characterized by actions aimed to groups of items identifying, for which mass and layout zones are known, as well as control over the ratio of inertia-moments of individual aggregates and airplane's systems. It allows to create an equation of the aircraft existence in the moments of inertia parameters over axis OX (1).

$$1 = \bar{I}_{p}^{ox} + \bar{I}_{e.c}^{ox} + \bar{I}_{f.n.e}^{ox} + \bar{I}_{p.u.}^{ox} + \bar{I}_{c.s.s}^{ox} + \bar{I}_{f}^{ox} + \ldots + \bar{I}_{af}^{ox} \qquad (1)$$

где: $\bar{I}_{p}^{ox}$ - The relative moment of inertia of airplane's units (payload) over corresponding axes (OX);

p - payload (passengers, cargo, etc);

$e.c.$ - equipment which provides certain conditions of comfort and placing of payload;

$f.n.e$ - flight and navigation equipment;

$p.u.$ - power unit;

$c.s.s.$ - airplane's control system of aerodynamic surfaces;

$f.$ - fuel;

$af.$ - airframe (fuselage, wing, empennage, landing gear).

Practically all inertia-moments of units entering into the equation of existence (1) depend on the full moment of inertia of the airplane. For example, we will consider as first approximation dependence between wing's moment of inertia the moment of inertia of all plane. In the case of airplane's inertia-moment over longitudinal axis increase, for performance of requirements on stability and controllability $\dot{\omega}_x$ and $T_{кр}$, it is necessary to increase control system effectiveness in the roll channel. The efficiency increase within the limits of an existing technological level leads to control system weight increase and its moment of inertia. As consequence, it leads to inertial loadings increase, which, in turn, conducts to airframe weight increase. Thus, there is a chain reaction connected with growth of airplane's moments of inertia. It is possible to show that each of components of the full aircraft's moment of inertia definitely reflects performance of the set requirements.

By results of the spent analysis (fig. 2, fig. 3, fig. 4) of mass characteristics and zones of passenger airplane's main units configuration it has been defined that in most cases the gradient of airplane's inertia-moments change depends on mass and layout parameters of the engine and fuel.

Thus, at the set in large quantities-geometrical parameters of the plane the basic components influencing inertial characteristics concerning an axis OX are: the weight of fuel in a wing, zones of fuel placing and engines. Hence, the given components of the equation of inertia-moment balance can be considered as the parameters defining inertia-moments layout of the airplane and, finally, shape of a control system.

Stabilization of inertia-moment indicators during flight is one of the primary goals of long-haul passenger airplane's layout[2]. It is connected by that, that considerable change of degree of controllability leads to change of laws of airplane's controllability, and on emergency flight configuration it leads to expected loss of aircraft's controllability.

In turn restrictions on the inertia moments on emergency flight configuration directly influence on a choice of alternative approaches to reservation maintenance in a control system, directed on deduction of controllability level in the set limits in case of occurrence of refusals in the control system.

2.2 Features of airplane's layout, taking into account moments of inertia over axis OZ

Most considerably inertia-moments characteristics over axis OZ for airplanes of the classical scheme are influenced by weight of a payload and its placing. Dependence on an arrangement of engines and fuel tanks is shown at level of a choice of the layout scheme of these units and further poorly depends on geometrical parameters of aircraft's layout, therefore their increment at the analysis of small increments can be accepted equal to zero

The carried out analysis has shown that the size of the moment of inertia of the payload can make from 20 % to 60 % from total value of the moment of inertia on axis OZ of all plane. As considerable influence on inertia-moments layout over axis OZ renders a fuselage (25-50 % from Jz of whole aircraft), in some smaller degree – horizontal and vertical empennage.

For reduction of moment of inertia values over OZ it is necessary:

- To reduce weight of fuselage and empennage (the new constructional decisions, new materials etc.);

- To increase diameter of a fuselage, i.e. to lead shape of the plane to a "flying wing». Thanks to this decision – the radius of inertia of a fuselage and a pay load decreases (at weight preservation) over axis OZ, loadings on a control system in the longitudinal channel decrease, that in turn influences to mass characteristics of empennage, thereby even more reducing the inertia moment over OZ. But at the same time, value of the moment of inertia over OX increases, and a control system loadings thus increase in the roll channel that gives a gain of wing's weight (because of increase required capacities of a control system), and, accordingly, Jz values increases.

2.3 Features of airplane's layout, taking into account moments of inertia over axis OY

Inertia-moments characteristics over OY of the classical scheme airplane are complexly depends on parameters of inertial-moments layout concerning two other axes – OX and OZ. The average airplane's moment of inertia over OY makes 96 % from the sum of the moments of inertia over axes OX and OZ.

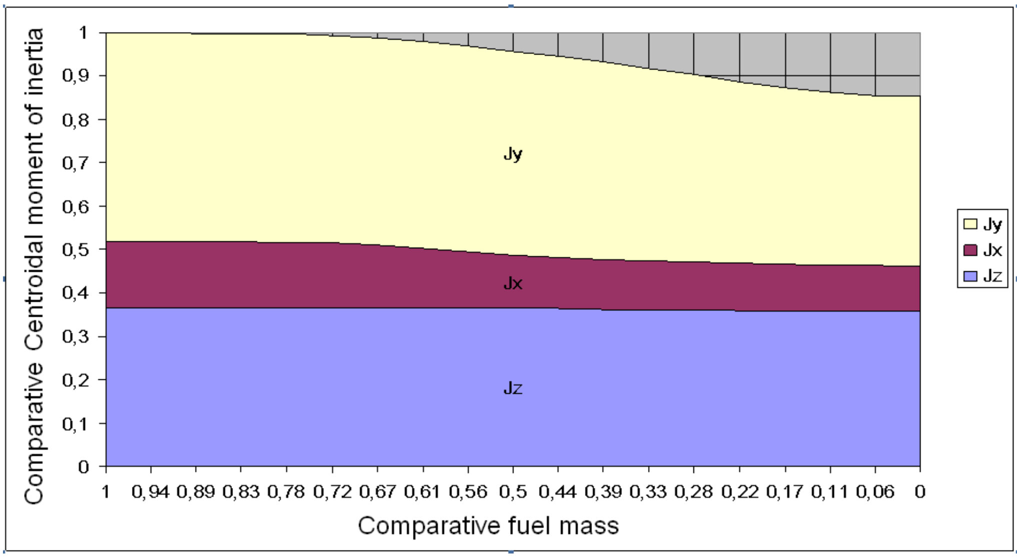

fig. 2. The analysis of airplane's relative inertia-moments change in the course of a fuel expenditure

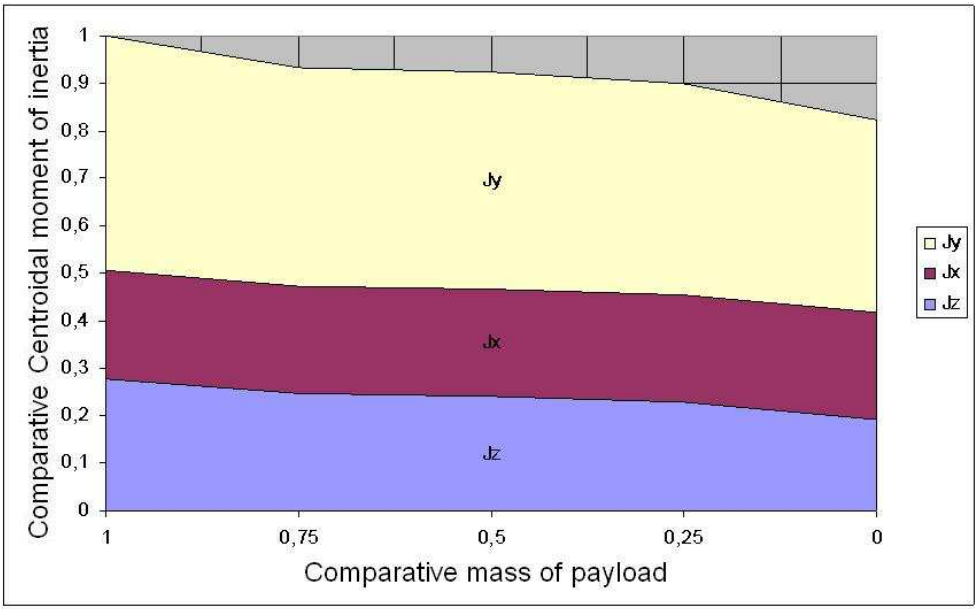

Fig. 3. The analysis of airplane's relative inertia-moments change in the course of payload mass

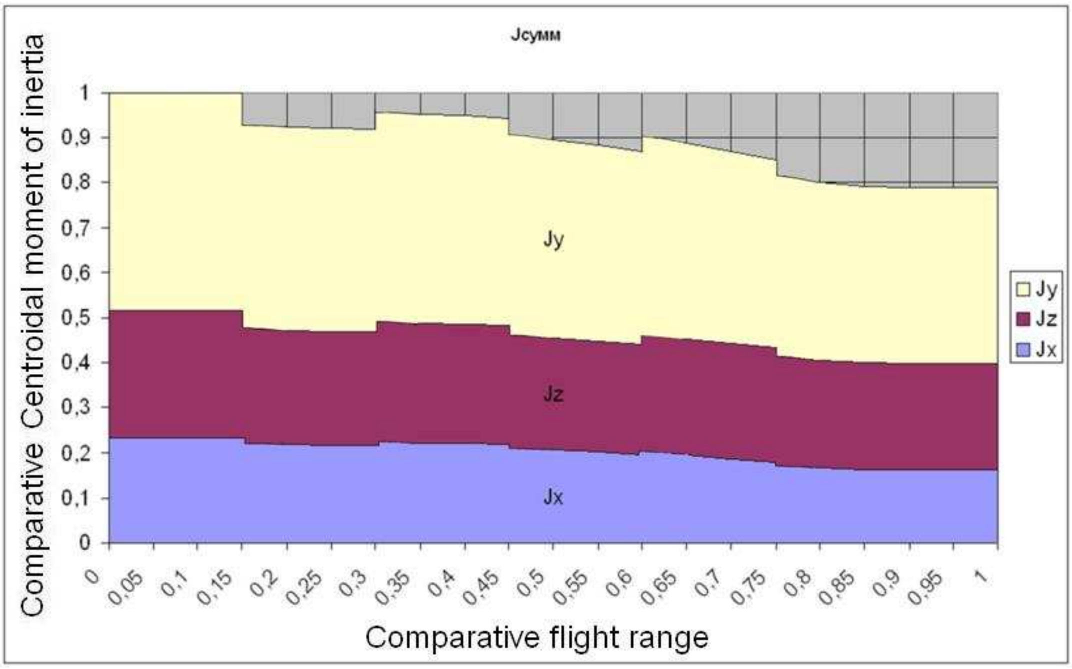

Fig. 4. The analysis of fire hydroplane's relative inertia-moments change in the course of payload mass (water intake, water evacuation) and fuel expenditure during flight range

8.3 The program complex defining inertia-moment characteristics of airplanes at early design stages «M. И.Ф.» («M.I.F»)

he program complex "M.I.F." was created on the programming language Borland Delphi 6.0, uniting tools of logic, mathematical and intellectual modeling, modern multimedia graphic 3D accelerators on the basis of API OpenGL which give rich possibilities of imitation of dynamic systems.

At the main window of the program (Fig. 5) there are special panels, on which results of all calculations are placed, and the multimedia screen on which in a mode of real time the changes occurring to airplane's inertia-moment layout are displayed during calculations. On the given screen are displayed: the general moments of inertia of the plane in a kind of inertia ellipsoid, own and portable moments of inertia of aircraft's units in the form of the cylinders which radius designates radius of the moment of inertia of the given unit, and height – weight of the unit. The menu which had from above at the main window, – serves for creation, opening and preservation of projects, export of results of design works to other programs, a conclusion of results to print, and, also a choice of alternative variants of calculation and reception of the program help.

The first variant of inertia-moment parameters definition, which is offered to a user (a Fig. 6), is a application, which calculates the values of the airplane's axial moments of inertia by empirical formulas, considering mass and dimensional characteristics of given type of airplane (take-off weight, airframe weight, fuel weight, and wingspan and length of a fuselage). This kind of calculation allows to define inertia-moments characteristics of the chosen type of the plane to within 20 %. Further – the user is offered to specify the received results in windows of calculation of the axial moments of inertia of aircrafts main units, and their positioning in layout space (a Fig. 7). After definition of aircraft unit's inertial-moments characteristics, accuracy of results raises to 10 %. The problem of inertia-moment accuracy increase to 5 % dares in the application defining the plane moments of inertia of each unit and using formal-heuristic models of all systems.

The program is created on the program complex Delphi that provides its modularity and possibility both to attach to itself various applications, and to be a part of larger complexes.

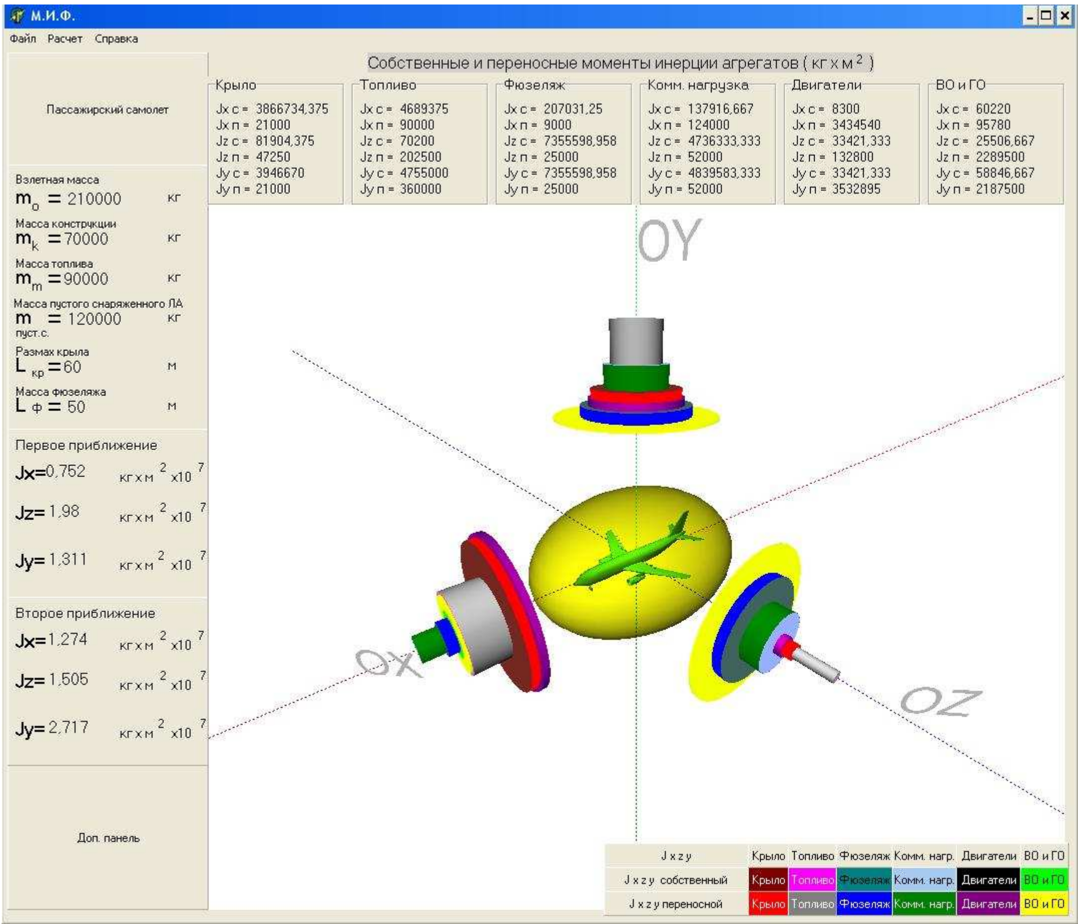

Fig. 5 The main window of the programm

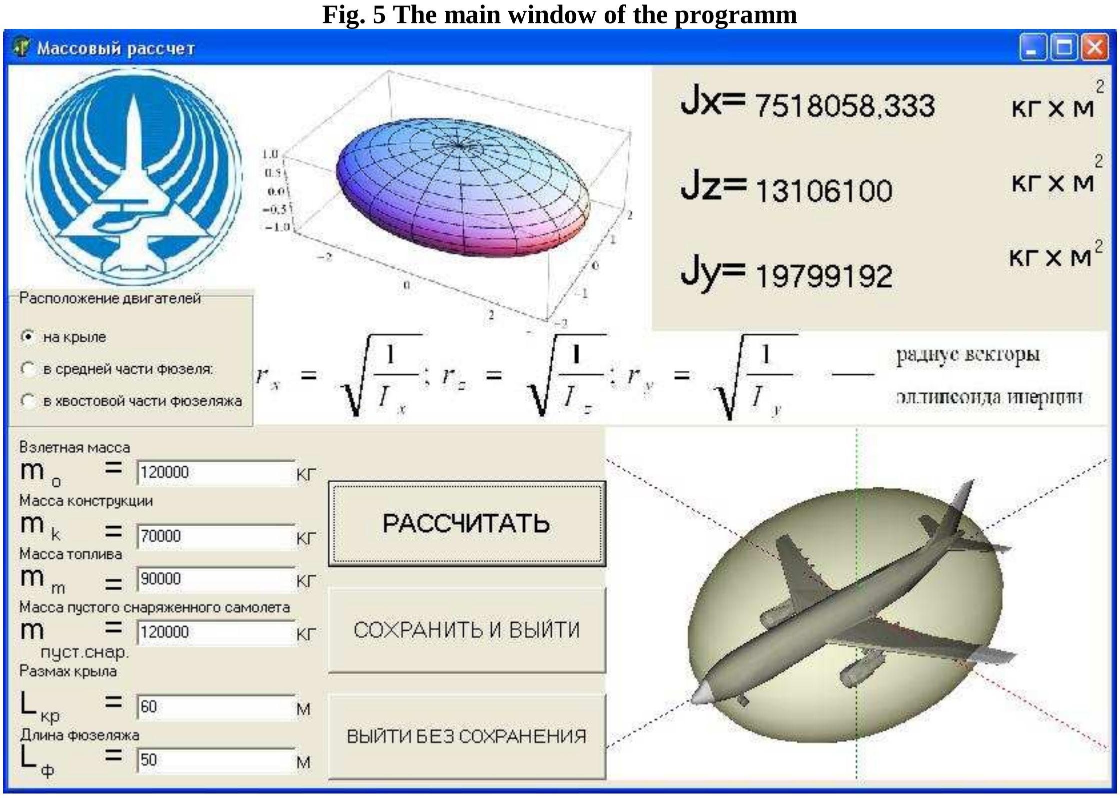

Fig. 6 Definition of moment-inertia characteristics to within accuracy of 20 %

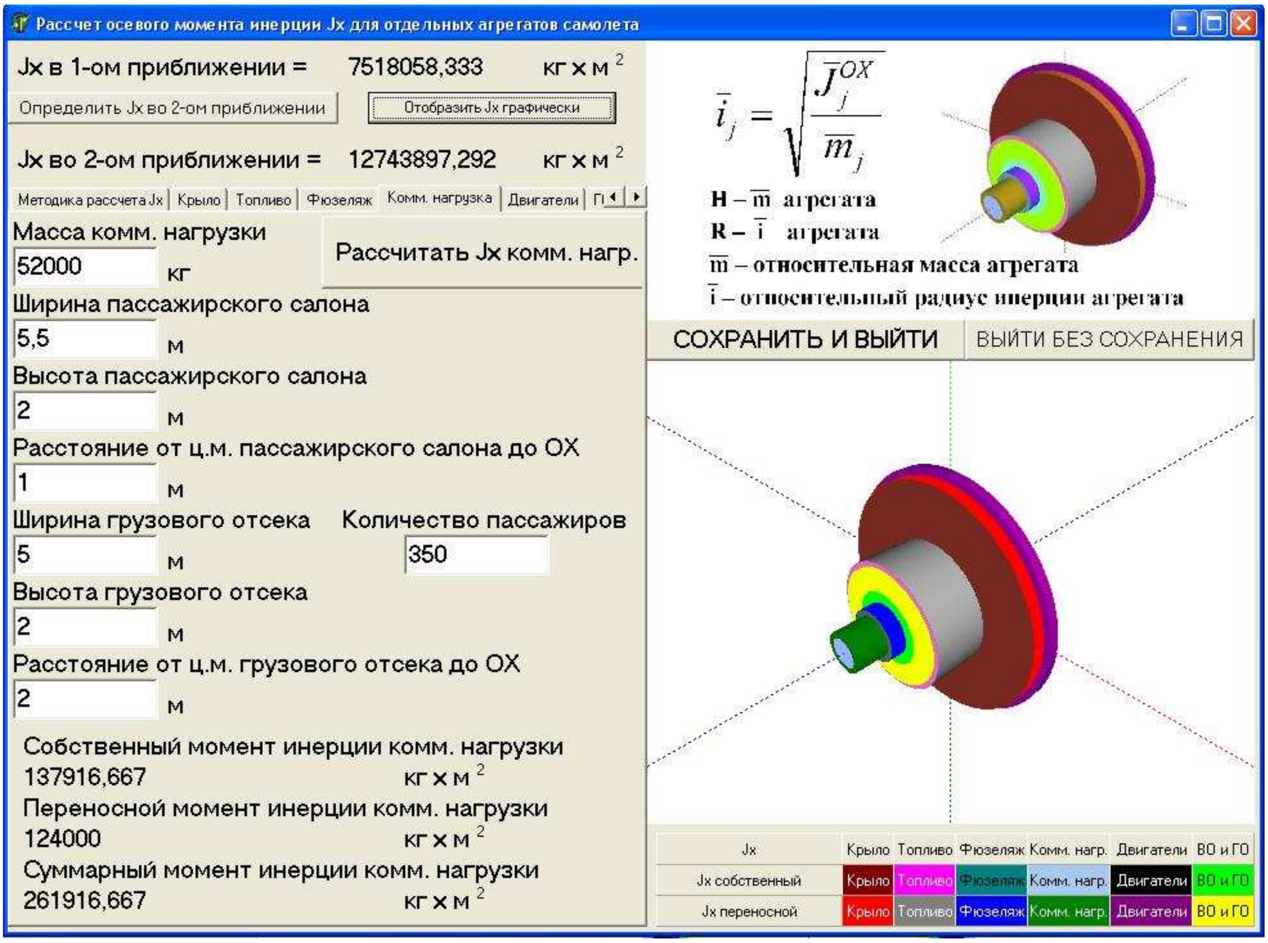

Fig. 7 Definition of moment-inertia characteristics to within accuracy of 10 %

3 Conclusion

In the course of work on given paper:

- Types of airplanes for which the analysis of inertia-moments characteristics is actual are revealed: planes of vertical takeoff and landing[5], seaplanes, long-haul passengers aircrafts;
- The analysis of geometrical configuration of zones of an engines arrangement , fuel and payload placing is made;
- An iterative number of techniques of definition of the moments of inertia of whole plane and separate units with ranges of accuracy of 20 %, 10 %, 5 % are developed;
- The set of algorithms for definition of inertia-moments characteristics of long-haul passengers aircraft, on the basis of the developed iterative number of corresponding techniques, is generated;

The data of the analysis, application of models and algorithms of program «M.I.F.» will allow to raise qualitatively accuracy of definition of momentno-inertial characteristics of perspective planes already at a stage of preliminary designing that further will qualitatively improve characteristics of developed planes, will provide reduction of cost of aircraft design.

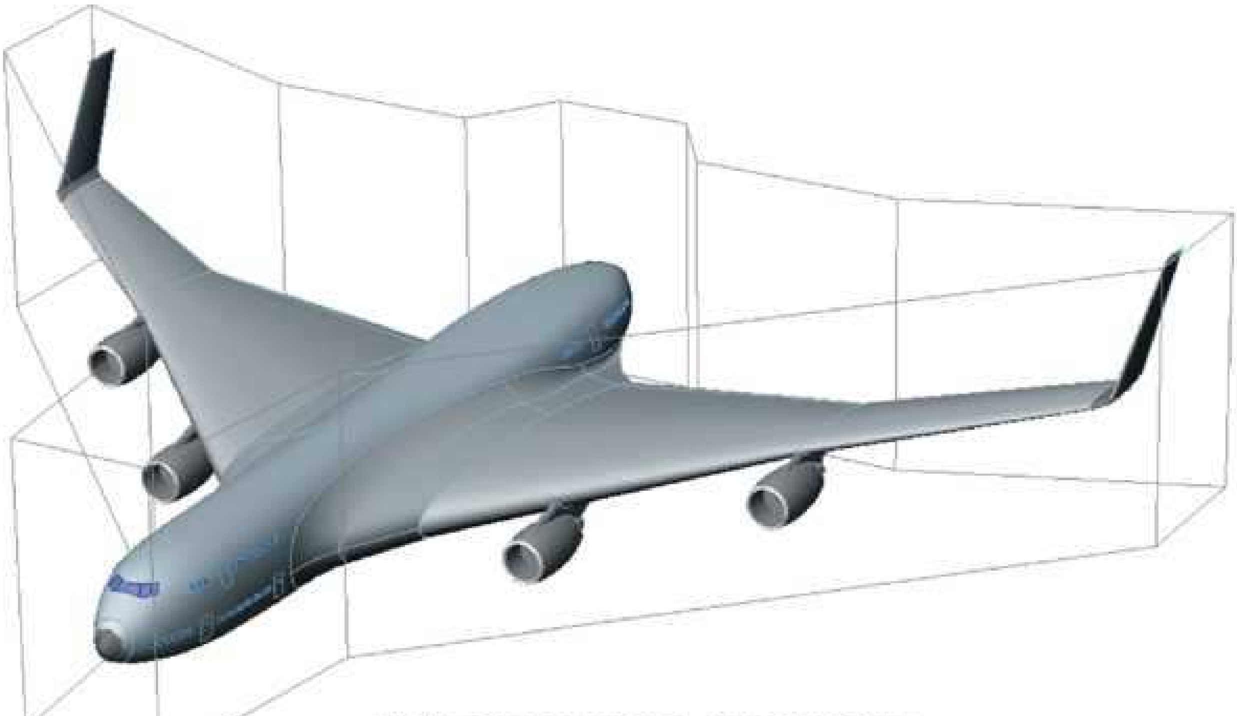

Fig. 8. Example of the airplane's layout scheme with the raised operating ratio of accessible space

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