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IMPLEMENTATION OF THE FUNCTIONAL SIMULATOR OF AIRCRAFT ELEMENTS DESIGN PROCEDURES AT THE STAGE OF THE LIFE LIMIT

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ABSTRACT

The present article describes the structure of the functional simulator of the conceptual design process of the long-range aircraft elements as well as the underlying methodology of the computer-assisted design (CAD) of long-range aircraft elements. The methodology is based on previously developed authorial mathematical model and includes the implementation of information, application software, and algorithmic support. To implement this methodology, namely the calculating stage of long-range aircraft characteristics, as well as to build its three-dimensional model using the integrated development environment platform Microsoft Visual Studio 2010, we have developed FuseCAD software tool, characterized by the possibility of adjusting the result basew fd on the selected criterion in the interactive mode, as well as constructing a three-dimensional model of the aircraft and the arrangement of its passenger cabin, and exporting them to CAD systems with the use of API functions of CAD systems.

Keywords: aircraft element, functional simulation, long-range aircraft, object oriented programming, conceptual design, computer-aided design.

1. INTRODUCTION

The design of modern aircraft (AC) is associated with the fulfillment of strict requirements for reliability, efficiency and ease of operation and maintenance. The change in the characteristics of the passenger cabin, passenger capacity, and aircraft cargo compartment leads to change in other characteristics (e.g., geometrical, aerodynamic, and mass properties). This circumstance reflects the complexity of the design process, which is typical for long-range aircraft and its elements, exposed to significant changes in the course of designing modifications, and does not allow for efficient design without the use of mathematical simulation [1].

When formalizing conceptual design procedures of aircraft elements, the process is described by a mathematical model, which allows moving from solution of individual tasks to design of a unified complex system. Under the mathematical model we understand the formally described system, which displaying or reproducing the object of study can replace it, so that model study gives us the necessary information about the original object [2].

The problem of designing elements reasonable for a specific aircraft type with minimum take-off weight while maintaining (increasing) the number of passengers is represented by the following objective function

$$f = m_0 \cdot \mathrm{k}_{\mathrm{w.i.}} \to \min \tag{1}$$

where m_0 – is the aircraft take-off weight, kg; $\mathrm{k}_{\mathrm{w.i.}}$ – is the integral weight factor.

The integral weight factor is used to account for the parameters of all characteristic groups used as input values (the fuselage surface area $\mathrm{F}_{\mathrm{f.s.}}$, the number of passengers $\mathrm{n}_{\mathrm{pass.}}$, per unit length shear stress in the sidewalls and the arches of the fuselage $\mathrm{T}_{\mathrm{s.w.}}$ and $\mathrm{T}_{\mathrm{a.f.}}$). The integral weight factor $\mathrm{k}_{\mathrm{w.i.}}$ is a function of the weight perfection characteristics, given in relative units

$$\mathrm{k}_{\mathrm{w.i.}} = (\overline{\mathrm{m}_{\mathrm{com}}/\mathrm{m}_{\mathrm{o}}}) \cdot \mathrm{k}_{\mathrm{w,i}} + (\overline{\mathrm{m}_{\mathrm{BOW}}/\mathrm{n}_{\mathrm{pass}}}) \cdot \mathrm{k}_{\mathrm{w,i}} + \overline{\mathrm{F}_{\mathrm{f.s}}} \cdot \mathrm{k}_{\mathrm{w,i}} + \overline{\mathrm{T}_{\mathrm{s.w}}} \cdot \mathrm{k}_{\mathrm{w,i}} + \overline{\mathrm{T}_{\mathrm{a.f.}}} \cdot \mathrm{k}_{\mathrm{w,i}} \tag{2}$$

where $(\overline{\mathrm{m}_{\mathrm{com}}/\mathrm{m}_{\mathrm{o}}})$ - is the ratio of useful load to the design take-off weight (loading factor) at which the strength of the aircraft meets the requirements of "Airworthiness standards" (AP-25); $(\overline{\mathrm{m}_{\mathrm{BOW}}/\mathrm{n}_{\mathrm{pass}}})$ - is the ratio of the aircraft basic operational weight (BOW)to the number of passenger seats;(weighing per passenger seat); $\overline{\mathrm{F}_{\mathrm{f.s.}}}$ - is the wetted surface area of the airframe, which takes into account the relationship between geometric characteristics and takeoff weight of the aircraft; $\overline{\mathrm{T}_{\mathrm{s.w}}}$ – is per unit length shear stress in sidewalls of the fuselage; $\overline{\mathrm{T}_{\mathrm{a.f}}}$.– is per unit length shear stress in arches of the fuselage; $\mathrm{k}_{\mathrm{w,i}}$ – is the weighting factor (rank), assigned to each parameter.

Constraint systems and variables for the mathematical model are presented in [3].

2. METHODS

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Methodological support of the research is based on the methods of system analysis, mathematical simulation, and statistical analysis, grounded in modern information technology, structural-parametric synthesis, and mathematical programming.

The mathematical model serves the basis for the development of conceptual design automation procedures of long-range aircraft elements which is grounded on the interaction of human and computer, where actions of the designer are complemented by the processing capabilities of the computer, implemented through specific algorithms [6, 7].

3. MAIN PART

The proposed automation methodology of conceptual design procedures of long-range aircraft elements, based on the above mathematical model, includes the implementation of information, application software, and algorithmic support. The following conceptual design stages are implemented by the software:

- calculation of the aircraft structural and geometrical characteristics;
- calculation of the aircraft mass properties;
- calculation of the aircraft performance characteristics;
- calculation of the aircraft aerodynamic characteristics;
- calculation of the aircraft strength weight characteristics;
- calculation of the aircraft ergonomics;
- report generation on the aircraft elements automated design program operation suitable for printing and previewing (in the form of obtained characteristics and characteristic curves);
- construction of three-dimensional model of designed aircraft and the arrangement of its passenger cabin;
- investigation and calculation of the aircraft aerodynamic characteristics.

We represent the automation methodology of conceptual designing procedure of aircraft elements by IDEF0 chart, designed according to the functional design methodology SADT. Figure-1 shows a set of interrelated activities: input information, which undergoes processing, control and output information, as well as the stage implementation mechanism are identified for each of the stages [9].

At the first stage (Figure-1) we generate input data. The advanced requirements specification for design of the certain aircraft element, which comes from the customer, serves control action. Based on the statistical data about the type of designed aircraft or parameters of the modernized aircraft, as well as requirements of aircraft airworthiness standards of the corresponding category, we form a set of input data, consisting of geometry and structural form parameters, weight, aerodynamic, performance parameters and ergonomics, designed for use in computer code to calculate the desired characteristics.

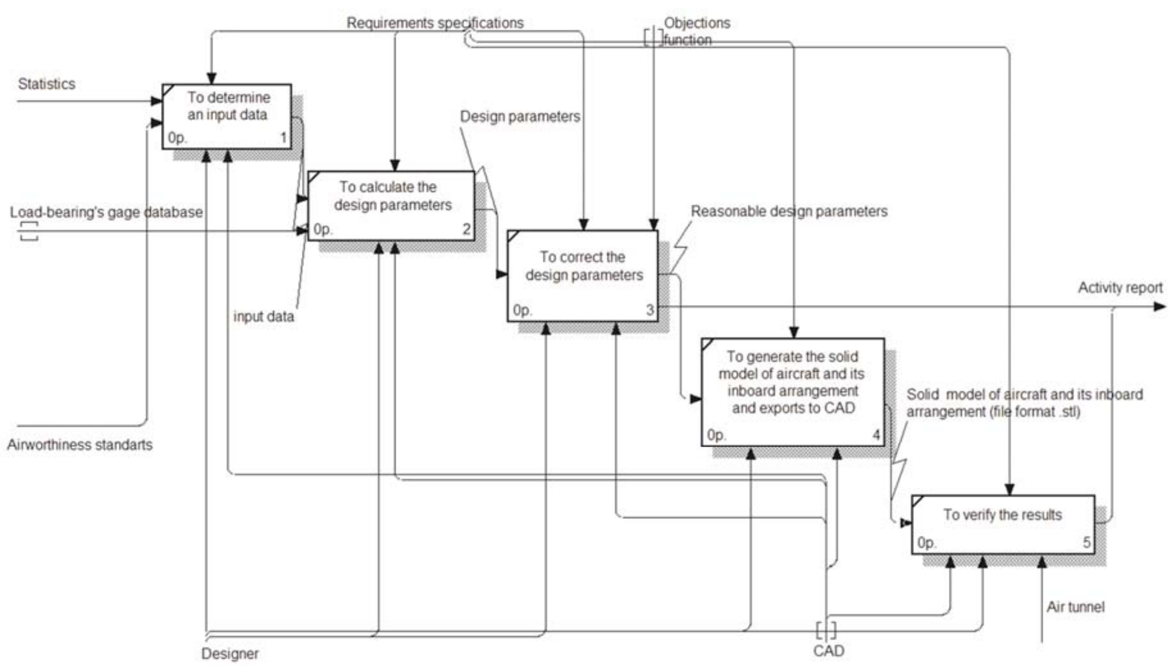

Figure-1. Rout of the long-range aircraft elements design presented in the form of IDEF0 chart.

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The set of input data generated at the first stage serves the input information at the second stage (Figure-1). The input information is complemented also by the rolling shapes database used for the calculation of structural properties. Performers at the second stage are designer and computer-assisted design (CAD), in particular, the FuseCAD software tool. Output information consists of the set of design parameters obtained in consequence of using the FuseCAD software tool.

The third stage (Figure-1) consists in construction of characteristic curves of the objective function depending on the parameters given the applicability limits of the mathematical model. The designer assigns a certain value to the selected parameter in the dialog mode, while the software tool automatically recalculates other output parameters according to selected input value. Output information consisting of a set of adjusted parameters is generated in the form of a report about the software tool operation. Adjusted parameters serve the basis for the generated 3D model of the aircraft and the arrangement of the passenger cabin, which are exported to the selected CAD system that is the essence of the fourth stage of the aircraft elements design.

At the fifth stage (Figure-1) impact mechanisms are supplemented by wind tunnel and CAD ANSYS for verification of the results obtained. Aircraft flow-past parameters are set based on the preliminary design requirements specifications and accordingly to the results obtained at previous stages. Computer and physical models have geometrical parameters obtained using the software tool. The sequential execution of all the stages indicated in the diagram (Figure-1) results in generation of the output data, which include a set of rational parameters of the aircraft element with regard to the integral weight criterion, as well as 3D model of the aircraft and the arrangement of its passenger cabin.

Based on the above conceptual design methodology algorithm, we have developed the "Computer code for computer-assisted design of long-range aircraft fuselage" [4], using the Microsoft Visual Studio 2010 integrated development environment (IDE) on high-level object-oriented programming language C#, which includes the implementation of the information (database), software, and algorithmic (private algorithms for certain groups of characteristics) support [8].

4. RESEARCH RESULTS

In accordance with the calculated set of characteristics (structural and geometric parameters, weight, performance, aerodynamic, and strength parameters) [3] the program generates 3D model of the designed aircraft using programming language-independent cross-platform software interface Open GL (Open Graphics Library) (Figure-2), which is able to export 3D model to CAD "Compass" (horizontal menu). The interaction of the software tool with CAD "Compass" is implemented through Application Programming Interface (API) technology, which provides a set of procedures and functions to control given CAD system [10].

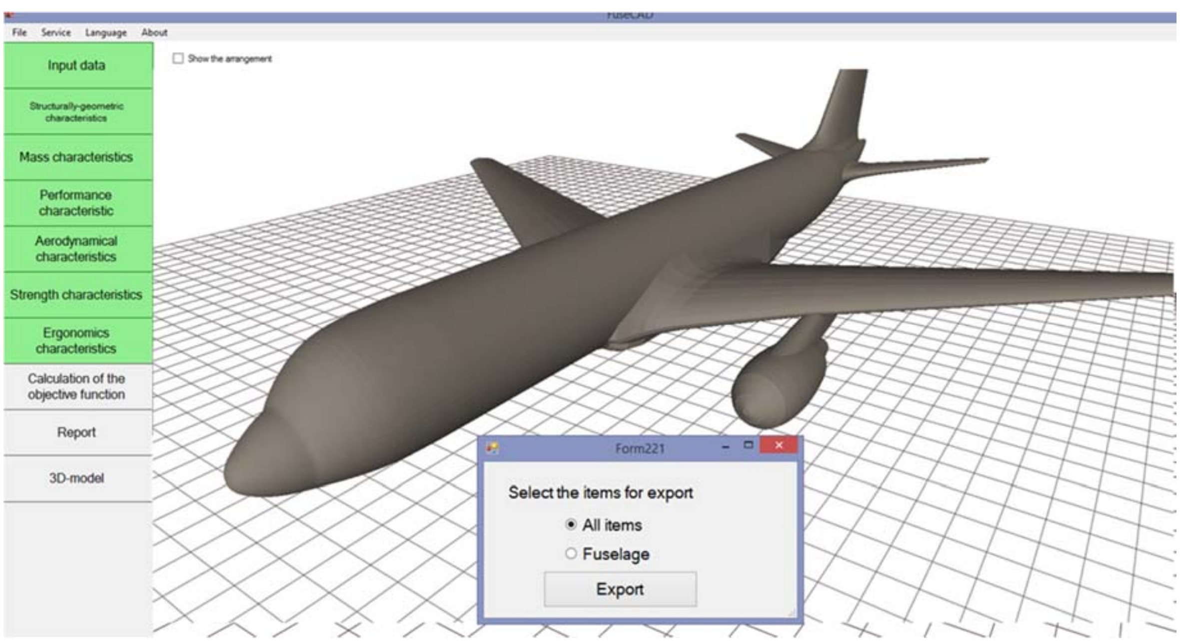

Figure-2. Three-dimensional model of the designed aircraft.

Three-dimensional model of the passenger cabin arrangement received based on the calculation results of the ergonomics is also generated with the use of Open GL. The arrangement is visualized by marking check box labeled "Show arrangement" of the program graphical interface. Figure-3 presents two options for the inboard arrangement corresponding to different source data.

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Through API plug-in modules it is possible to interact with "Unigraphics NX" (NX Open API), Solid Works (API), and other CAD software to export the model [5].

A software module for calculating the objective function provides opportunity to calculate output parameters using patterns of change in the objective function when changing the values of the output characteristics within the established intervals in accordance with constraints [3].

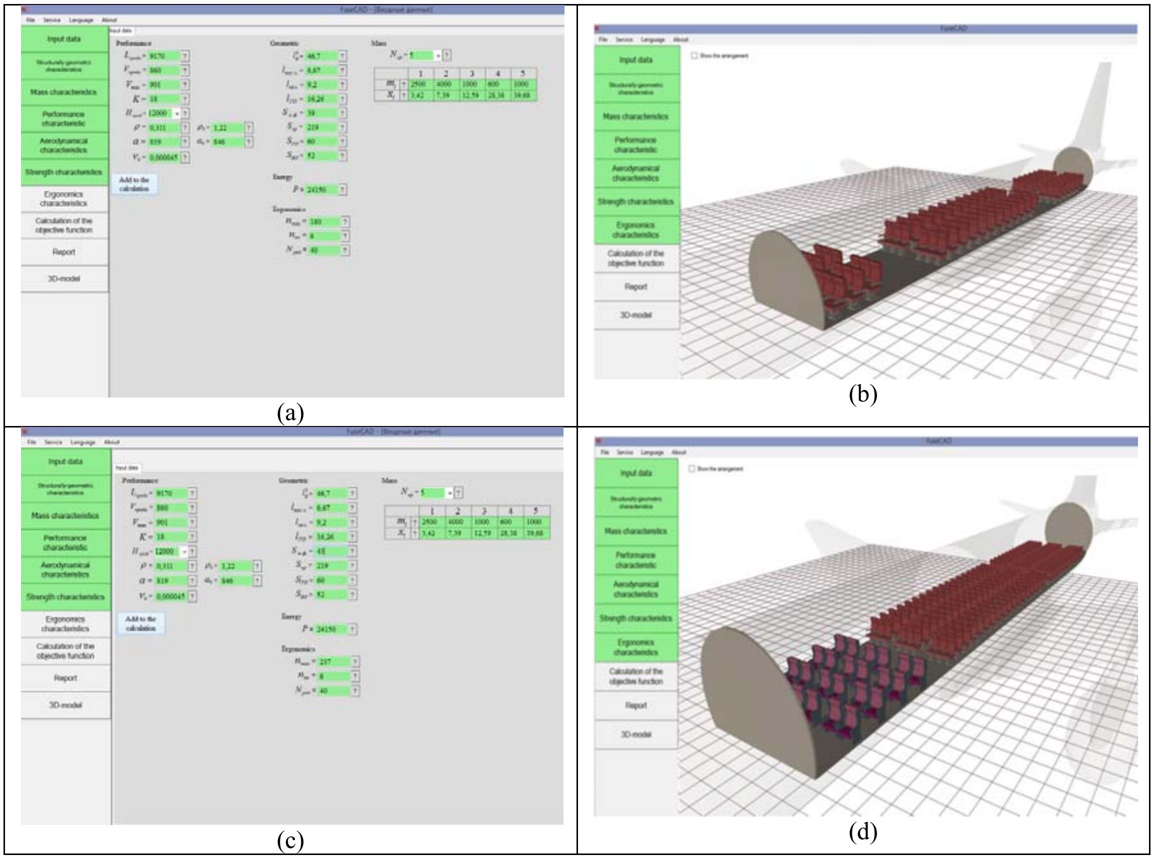

Figure-3. Arrangement of the passenger cabin:
a) input data for narrow-body aircraft; b) single-class arrangement of narrow-body aircraft;
c) input data for wide-body aircraft; d) combined arrangement of wide-body aircraft.

For inclusion the correlation between the objective function and output characteristics into the computer code, the objective function is expressed via an output parameter. As an example, consider the value of the objective function depending on the length of the aircraft fuselage L_f.

Calculation formula for plotting this diagram in the computer code looks like the following (fragment):

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```
dlina[0] = 30;
for (int x = 1; x <= 99; x += 1)
{
dlina[x] = dlina[x - 1] + 0.5;
          }
for (int x = 0; x <= 99; x += 1
          {
double l0otDliny = dlina[x] / (Math.Pow((1.3 * 0.2 * Math.PI) /
Convert.ToDouble(Perem.koefformi), 0.333));
doublem_tsnew = Perem.k_TS * Perem.m_otnt;
doublem_sunew = Perem.k_su * Perem.udvesdvig * Perem.tagovooruj;
doublem_obuprnew = (250 + 30 * Convert.ToDouble(Perem.nPas)) / Perem.m_0ish + 0.06 +
Perem.m_snaraj;
doublem_kotnnew = ((Perem.alfanew * Perem.koefrazgrkr * Perem.peregA *
Math.Pow((Perem.m_0ish * Perem.udlinkr / (1000 * Perem.udnagrnakr) + 5.5 /
Perem.udnagrnakr), 0.5))
* (1 + Perem.betta_1 * l0otDliny / Convert.ToDouble(Perem.dfe) * Perem.mbezraz +
Perem.betta_2) + 0.065) * Perem.k_ntp;
doublemNullotDliny = (Perem.m_komnew + Perem.m_eknew) / (1 - m_kotnnew - m_sunew -
m_obuprnew - m_tsnew);
```

This procedure results in generation of diagram reflecting the dependence of objective function on the length of the fuselage that is displayed in the insert "Calculation of the objective function" (Figure-4).

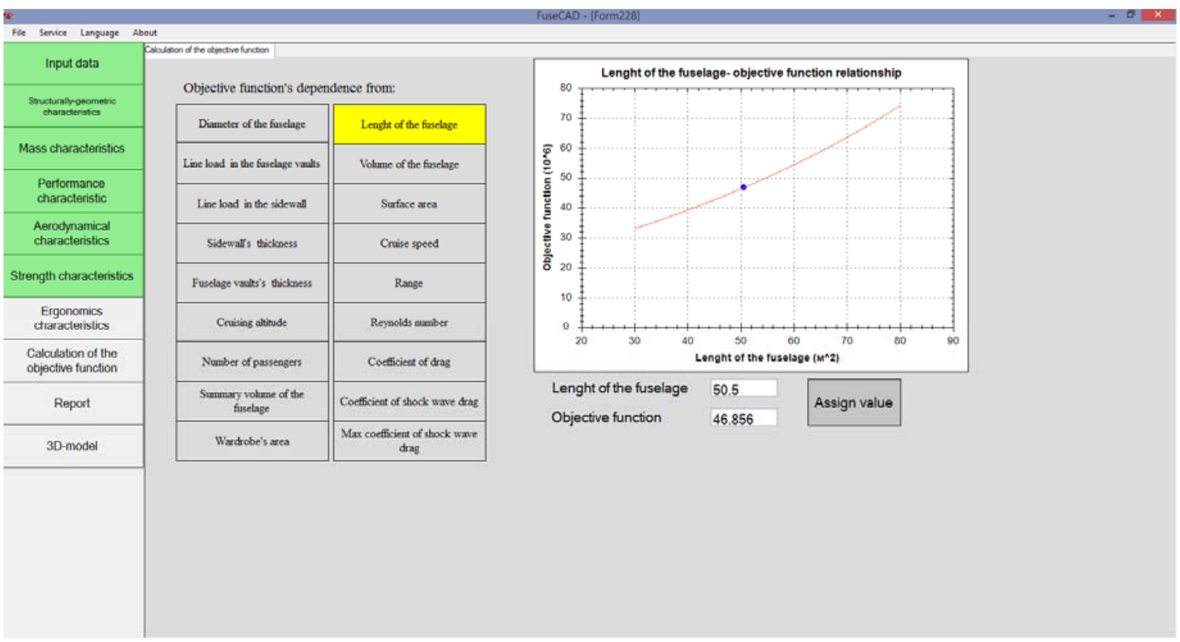

Figure-4. Objective function versus the length of the fuselage.

As an example, Figures 5, 6 and 7 represent dependencies of the objective function on the other output parameters, computed using the FuseCAD software.

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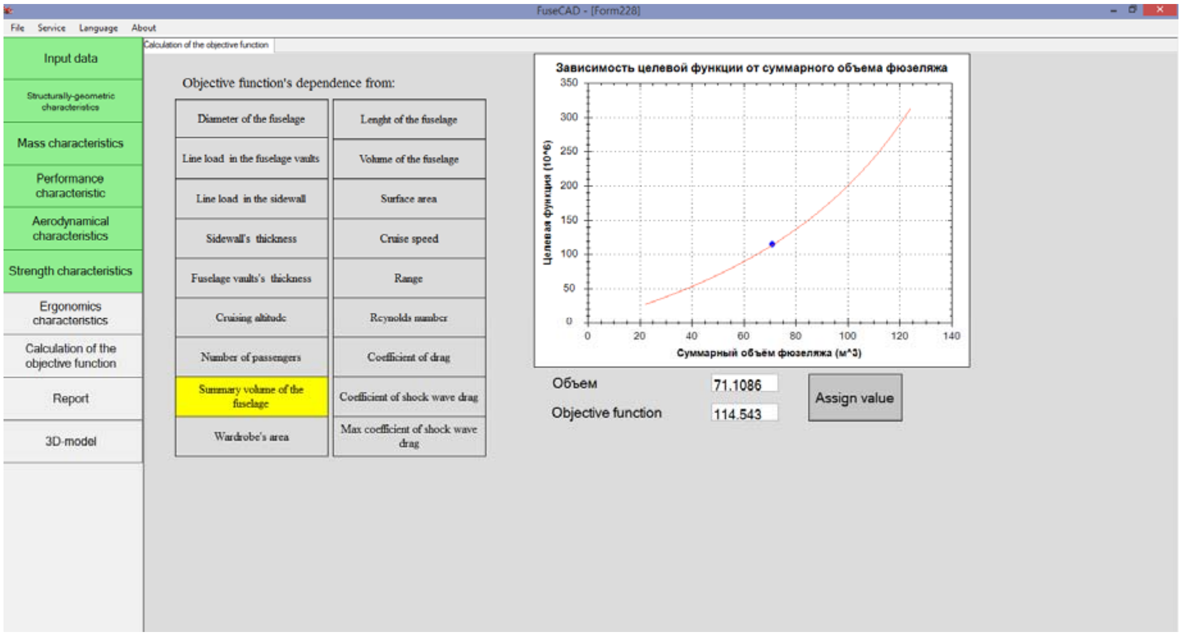

Figure-5. Objective function versus the total volume of cargo in the aircraft.

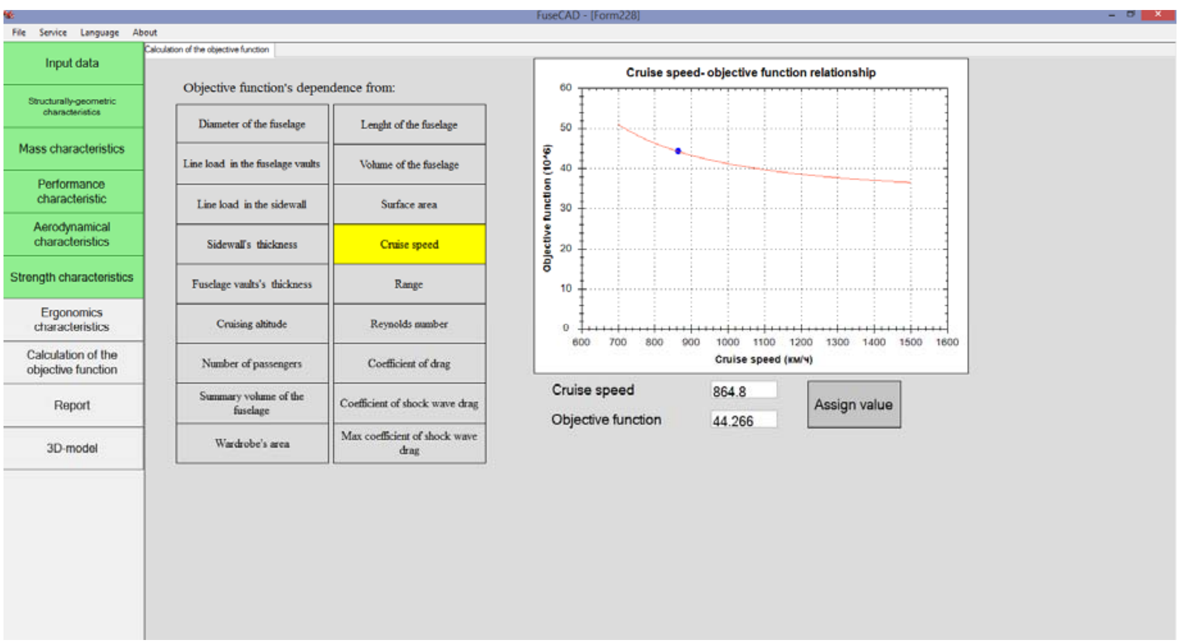

Figure-6. Objective function versus the course speed.

The FuseCAD software tool allows the user to assign a new value to the diameter of the fuselage according to the diagram and in accordance with the assigned value to recalculate other output parameters, thus adjusting interactively design outputs of the long-range aircraft element, obtaining the most rational parameters for minimum takeoff weight.

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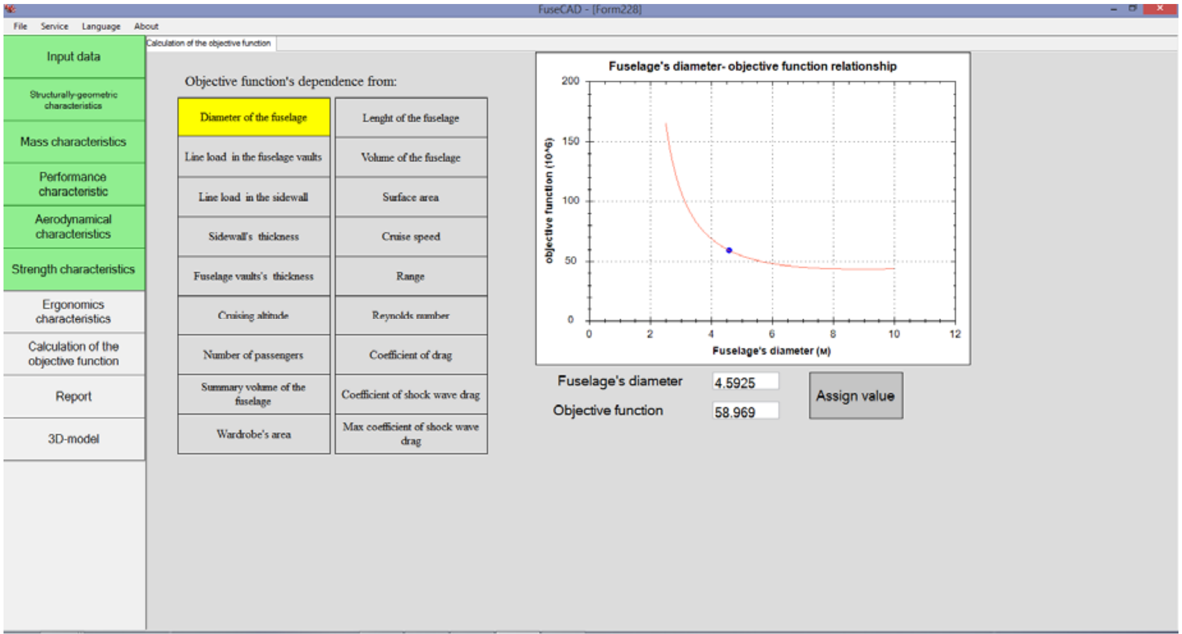

Figure-7. Objective function versus the diameter of the fuselage.

5. DISCUSSION OF THE RESULTS

We propose the automation technique for conceptual design procedures of aircraft elements. The use of integral weight factor allows adjusting the conceptual design outcomes according to selected values of the design parameter by taking into account aircraft group characteristics.

6. CONCLUSIONS

The functionality of developed CAD software for aircraft elements allows:

- calculating aircraft elements characteristics;
- displaying identified dependencies in graphical and digital form;
- adjusting the design output and building 3D models of the aircraft as well as the passenger cabin arrangement with the use of API functions of CAD systems.

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