Computer-aided Design of Axial Flow Turbine Structure of Aviation GTE

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***Abstract*— The article discusses the issues of modeling the design of axial turbines of aircraft engines. Modeling is carried out using the developed expert decision-making system "AM". The advantage of using this system in the early stages of engine design is shown. This advantage is achieved by selecting the most optimal material for the main assembly units of an aircraft engine based on various calculations that represent the mathematical model of the expert system. It is shown that the expert system in addition to the selection of material also carries out the selection of measures to improve the resistance of the material to the external environment, and the recommended modes of surface treatment. As an example, the results of computer-aided design of the elements of the flow channel of high and low pressure turbine assemblies of a two spool turbojet engine with afterburner and mixed flow for a 4th generation military highly mobile aircraft are given. The results of the design simulation are compared with the actual design of the prototype engine. Comparison of the results is carried out both in terms of geometrical parameters (diametrical dimensions of the flow part and the dimensions of the chords of the nozzle assembly and blades), and in terms of mass characteristics.**

Keywords—expert system, choice of material, gas turbine engine, strength calculations, computer-aided design, node mass estimation

I. Introduction

The development of modern aviation gas turbine engines is a challenge. Design begins with the implementation of thermogasdynamic calculation, optimization of the parameters of the cycle, followed by the design design and the implementation of various strength calculations. As a result, the constructive appearance of the engine, its main characteristics, overall dimensions are formed and the weight of the main components and the engine as a whole is determined [1, 2]. In practice, there are situations when, in terms of aerodynamic quality, engine components are perfect, but individual parts do not withstand the applied loads or thermal stresses during the assigned resource. Because of this, it is necessary to change the design of the part (weight it), change the material, apply different types of preparation and surface treatment, various coatings. After the design has been changed, refining calibration calculations (gas-dynamic, thermal and strength) are made anew. The engine design process represents cyclically iterative iterations, the number of which is determined by the convergence to reach the extremum of the goal function. Application in the early stages of the design of various software systems allows you to speed up the design process and significantly reduce the cost of it [3].

II. Expert System

The considered expert system (ES) is developed on the basis of the DVIGw simulation modelling system (SMS) [4]. This ES includes a decision support system and is intended for computer-aided design and development of the structures of the main components and parts of aircraft engines [5]. ES contains a rich set of mathematical models of engine nodes. This allows you to simulate, explore and predict the various modes of the GTE arbitrary schemes. Also, ES can simulate ground power plants based on aircraft engines [6].

In addition, the developed ES contains separate structural elements (SE) for the strength analysis of the main nodes of the gas-air duct of the engine. Also includes the SE for the selection of materials, coatings and other types of surface preparation of parts and the nodes of the engine tract [7, 8].

For the selection of materials for engine parts, a database has been developed for ES with basic physical and mechanical properties of various steels and alloys most commonly used in aircraft structures (about 200 items) [9–12]. ES AM can work both with a database of metallic materials and with a database of composite materials (CM). When modeling parts from CM, a sequential search of the matrix material and the fiber material from the database with a search of the reinforcement coefficient is carried out [13].

When modeling, the SE of the ES get the necessary information from the SE "engine" (engine air inlet, compressor, combustion chamber, turbine, afterburner, exhaust nozzle), analyze and process it. The gas-dynamic calculation of the node is made. Then, the design of its structure [14-16], which is calculated for strength [17-19], is performed. Thereafter SE ES refer to the database of materials (or the database of composite materials), read a line from the database with the properties and characteristics of the material [20]. Further, the ES assigns points to each material. Points are awarded for the working temperature of the material (which is compared with the calculated temperature of the analyzed parts), for tensile strength (the greater the tensile strength of the material at these temperatures, the more points the material has), for density (the greater the density of the material, the lower the points) , for the manufacturability of the material (technological properties - weldability, stampability, the possibility of casting, machining parameters, etc.). The program sort out materials from the database and forms a list of five materials that scored the maximum number of points (Fig. 1) [21, 22].

When simulating the turbine blades, the ES distributes the cooling air flow along the steps and between the nozzle

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apparatus (SA) and the blade wheel (BW). The cooling system of the blade is designed depending on the proportion of cooling air and the adopted cooling scheme. Design is carried out by approximation of experimental data [14, 17]. In addition, the blade airfoil temperature is determined in various sections in height.

A feature of the developed ES is that it works with the minimum necessary amount of input information. This allows you to sort out a large number of design options and materials in a short period of time. In addition, the system allows an expert assessment of the simulated structure and helps to make a decision on the design of the designed product.

The purpose of this study is to test the efficiency of the ES in simulating the high and low pressure turbine assembly (HPT and LPT) of the two spool turbojet engine with afterburner and mixed flow (TSTEAMF) for the 4th generation highly maneuverable fighter.

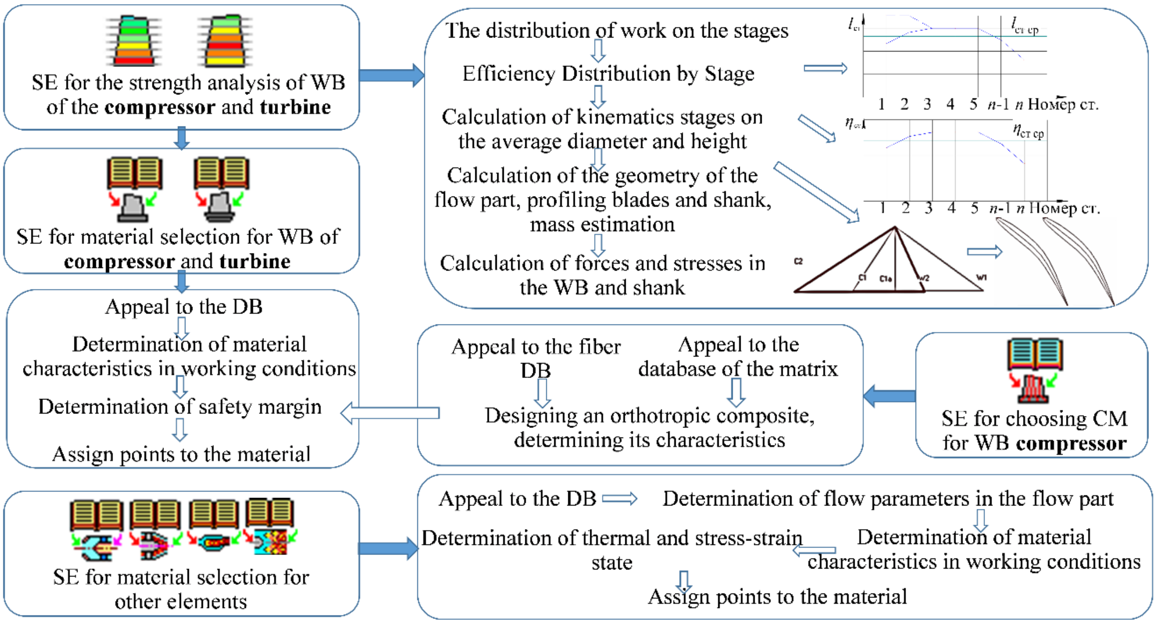


Fig. 1. Mathematical model of ES

III. MODELING AXIAL TURBINES

In the developed ES, a topological model of an aviation serially produced TSTEAMF for a 4th generation highly maneuverable military aircraft with structural elements was compiled. These elements perform the designing of turbines and produce a choice of material (Fig. 2). Next, the engine is identified on takeoff full afterburner and maximum modes [23, 24]. By the design of the prototype, the cross-sectional areas and the values of reduced velocities at the inlet and outlet of the nodes were determined [24, 25].

The expert system made a gas-dynamic calculation of the HPT and LPT, profiled the flow part of the turbines. The simulation results are presented in Fig. 3. To test the efficiency of the ES, the simulation results are compared with the construction of the nodes. In fig. 4 shows the 3D solid-state model of a HPT working blade, built in the NX 8.0 CAD system. With the help of this model, the main geometrical dimensions and mass of blade elements were determined. In fig. 5 superimposed the results of modeling the flow part (dashed line) on the longitudinal section of the engine turbine. As can be seen from the figure, the design of the elements of the flow part, proposed by the ES, is quite close to the engine design. The simulation error is associated with a complex three-dimensional profiling of the real structure. Although such an insignificant error is acceptable for the initial design stages, the ES allows the selection of the optimal node design.

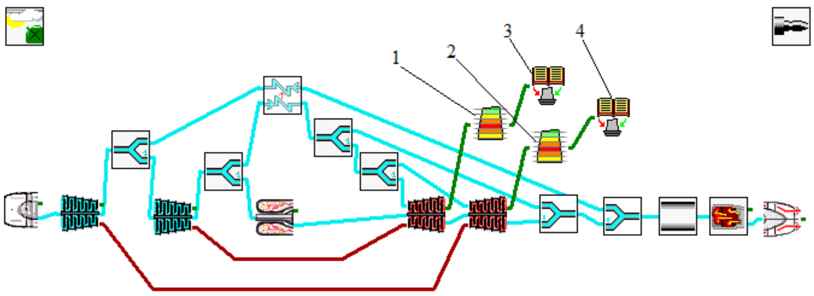
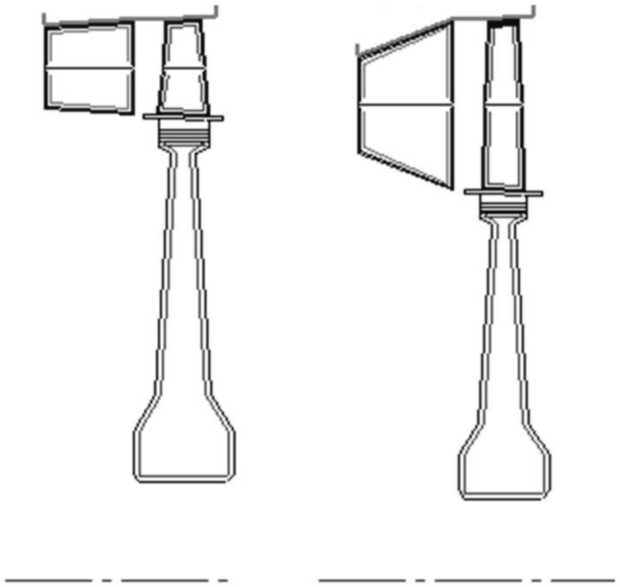
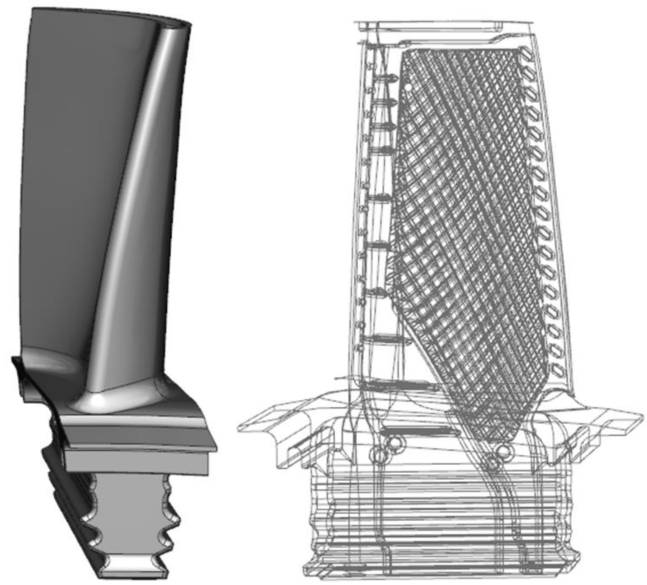


Fig. 2. Topological model TSTEAMF 4th generation, where 1 - SE Strength HPT blades, 2 - SE Strength LPT blades, 3 - SE Material HPT blades, 4 - SE Material blades LPT



a) b)

Fig. 3. The design of the elements of the flow part of the turbine assembly, proposed by the expert system, where a) HPT, b) LPT



a) b)

Fig. 4. 3D model of a HPT working blade in the NX CAD system, where a) a solid model of a blade, b) a frame model of a blade

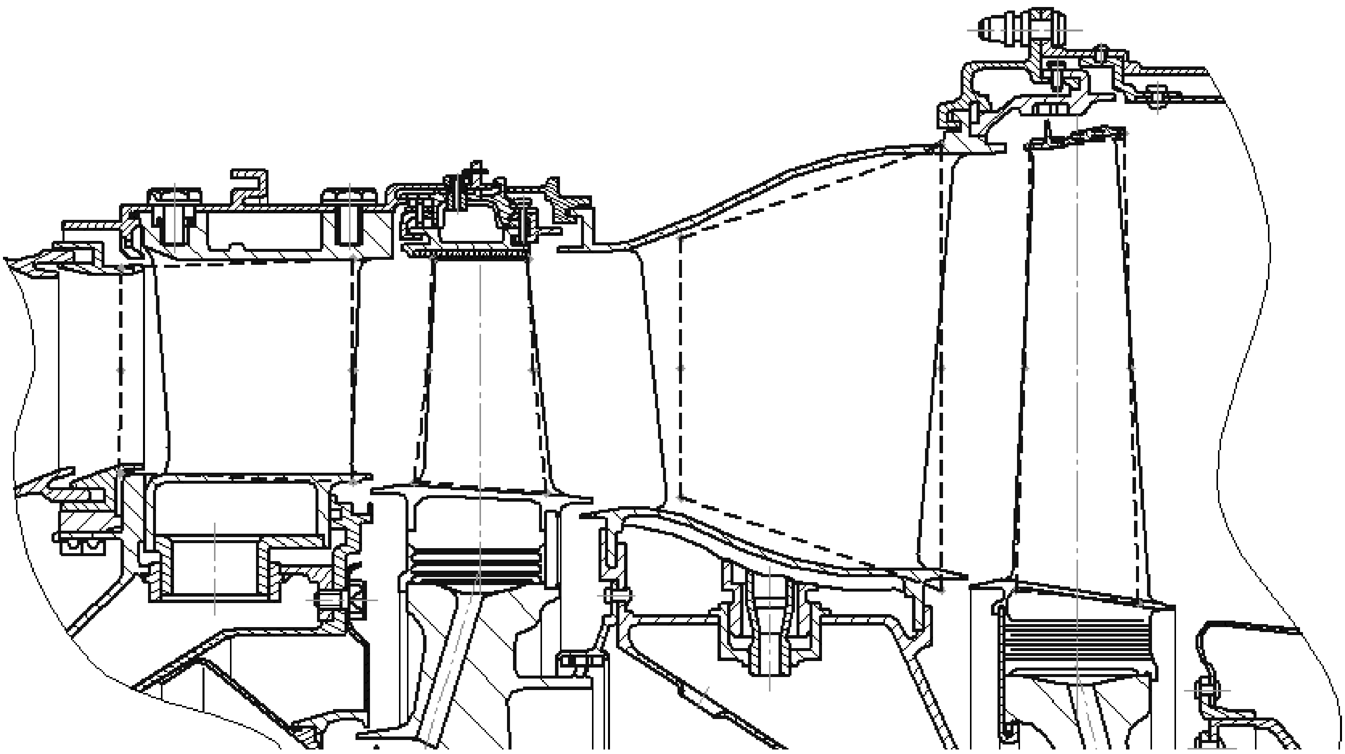


Fig. 5. Comparison of engine turbine design and design proposed by the expert system (dashed line)

These results can be used to estimate the accuracy of the geometrical dimensions obtained using the ES and the number of blades of both turbines. In this case, the modeling error does not exceed 8%. (Table 1). When modeling the nozzle assembly (NA) of the HPT, the expert system proposed a design with a chord 20% larger, and when simulating the NA LPT, it was 10% smaller than the chord NA of the engine. In this case, the axial gaps between the blade rims are modeled quite accurately (error not more than 5%).

TABLE I. RESULTS OF MODELING FLOW PARTS OF TURBINES TSTEAMF

Knot	**Construction of TSTEAMF**						**Modeling results**					
	HPT			***LPT***			***HPT***			***LPT***		
Diameter	***inter.***	***av.***	***out.***	***inter.***	***av.***	***out.***	***inter.***	***av.***	***out.***	***inter.***	***av.***	***out.***
inlet NA, mm	622,5	675,6	728,7	602,0	670,0	738,0	620,9	674,1	727,4	608,2	675,7	743,1
inlet WB, mm	617,5	675,4	733,3	568,4	678,4	788,4	616,2	674,1	732,1	560,1	675,7	791,3
outlet WB, mm	607,3	670,9	734,4	553,6	675,8	798,0	610,9	674,1	737,3	553,5	675,7	797,9
Chorde of WB, mm	35,5	32,6	30,6	36,5	31,1	28,7	36,9	29,9	27,6	34,2	30,6	30,4
Chorde of NA, mm	52,3	53,7	57,8	71,9	78,7	86,9	64,9			70,6		
Number of NA	42			33			43			32		
Number of WB	90			90			90			89		
Material of WB	ZhS-32			ZhS6-U			ZhS6-U; ZhS-32; Zhs-6F; VKLS20; ZhS-36			ZhS6-U; ZhS-6F; VKLS20; ZhS36; ZhS-32		

Also, the expert system (SE Material of the turbine blade) performed a search of various materials from a special database of aviation materials. According to the results of the analysis of the properties and characteristics of the material and the results of the performed strength calculations (SE Strength of the turbine blade), the ES assigned points to each material. As a result of the simulation, the system formed a list of five materials that scored the maximum number of points (Table 1). According to the simulation results, it was obtained that for working blades of both turbines, the maximum number of points was gained by the material ZhS6-U, from which the working blades of the LPT were made (Fig. 6). And the nickel alloy ZhS-32, from which the HPT blades are made, is in second place in the simulation.

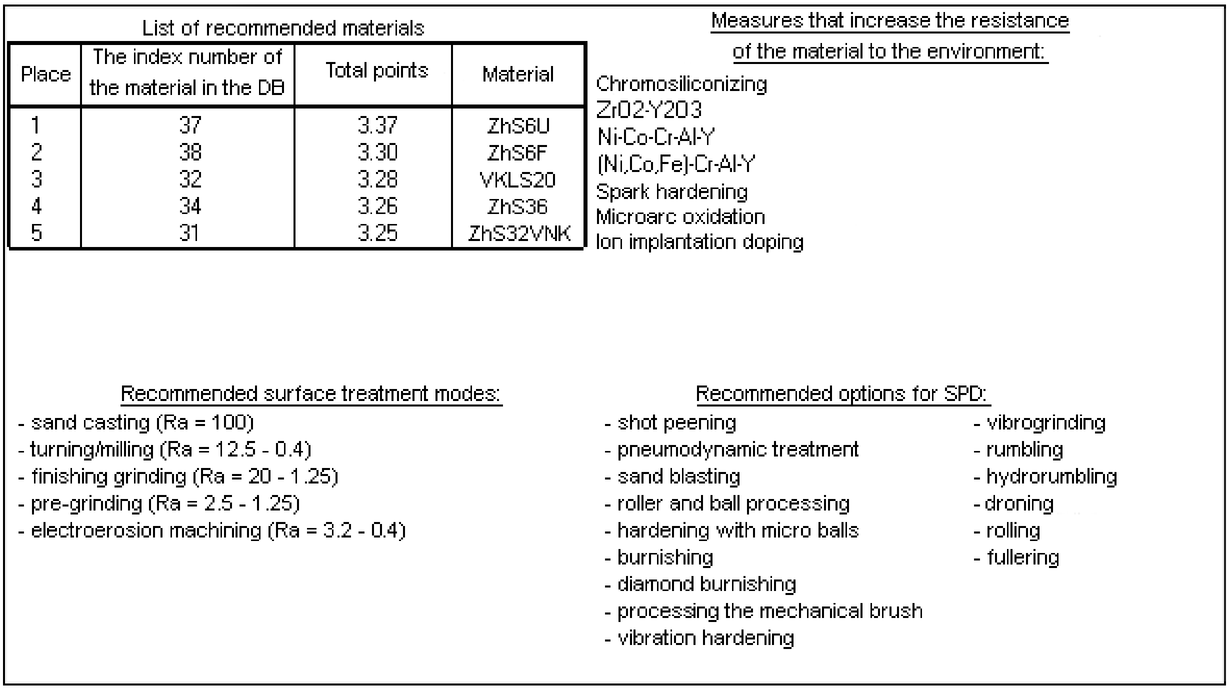
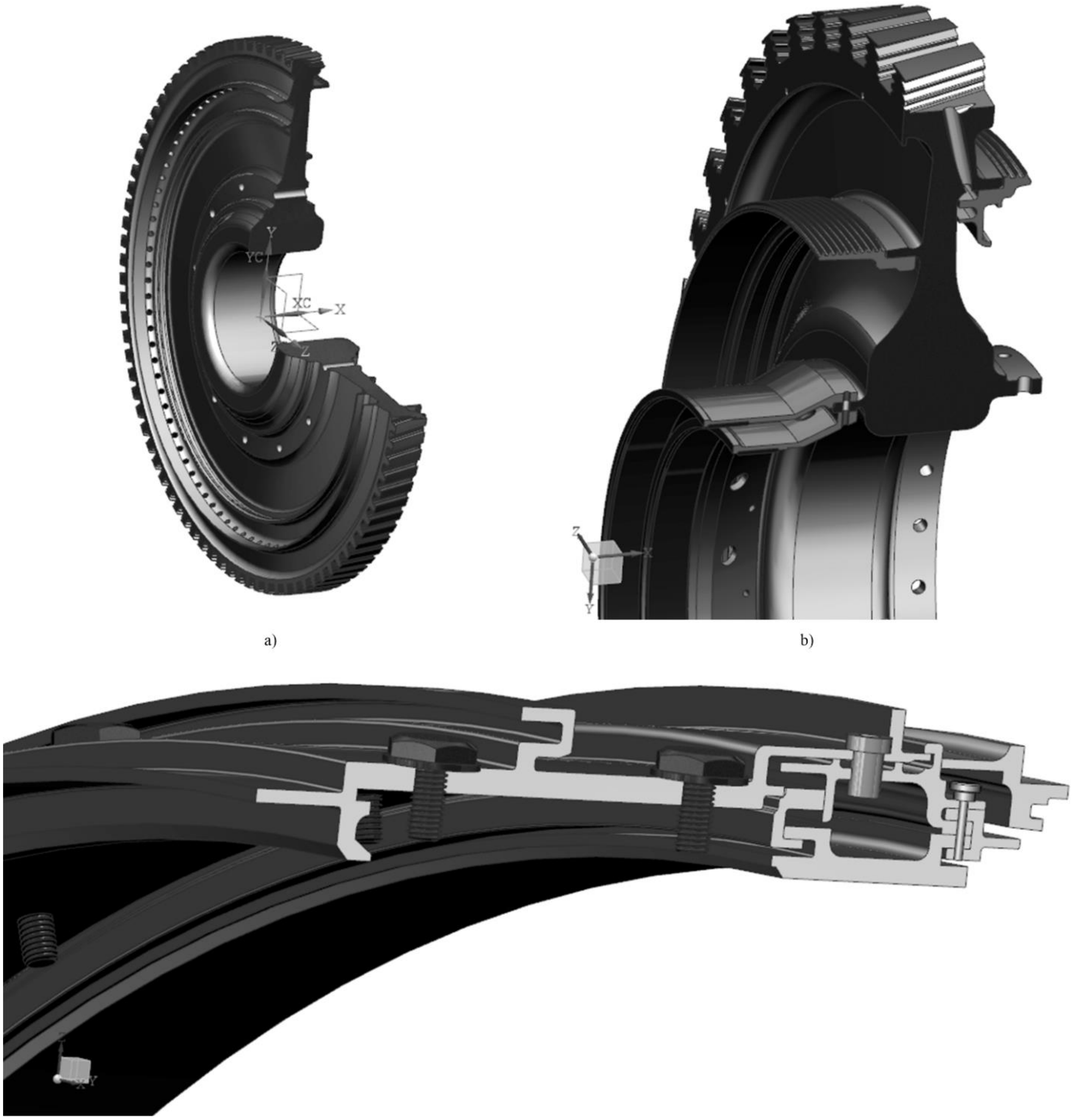


Fig. 6. The results of the choice of material for the working blade LPT

As a result of the work of the ES, the dimensional and mass characteristics of the modeled nodes and their individual elements are determined. The simulation results are shown in Table 2. The mass of individual structural elements was determined using 3D solid models (Fig. 7). The error in modeling the mass of the blade does not exceed 3%. The error in modeling disks is about 2%. The weight of case parts is simulated worst of all (the error is 14%). This is due to the fact that in the ES algorithms there is a method for determining the thickness of the hull based on the conditions of static strength. In the actual design of the case, on the contrary, there are parts that ensure the fastening of various elements, cooling and the minimum radial clearance of the blades. The length of the stage of the HPT, the resulting simulation corresponds to the design of the engine. When modeling LPT length of stage was 15% less than in the design of the engine.

TABLE II. WEIGHT-AND-DIMENSIONAL CHARACTERISTICS OF MODELED NODES

Parameter	The result of modeling TSE (design TSTEAMF)	The result of modeling TSE (design TSTEAMF)
Mass pen of WB, g	56,21 (56,24)	77,80
weight of shank blade, g	107,4 (104,3)	80,6
Mass of WB, g	163,6 (160,5)	158,4
Crown mass NA, kg	18,4	17,6
Crown mass WB, kg	14,7 (14,4)	14,1
Disk mass, kg	69,03 (70,14)	54,33 (53,18)
Case mass, kg	10,97 (12,81)	3,79
Stage mass, kg	113,1	89,6
Stage length, mm	115,7 (116,5)	125,4 (148,4)



c)

Fig. 7. Model of turbine elements: a) disk HPT, b) disk LPT, c) case HPT

IV. Conclusion

According to the results of the research, it can be concluded that the developed ES can simulate the design of various components of aircraft engines and select materials for them. When modeling turbines TSTEAMF design proposed by the ES, slightly differs from the actual design. The list of materials of turbine blades on the first or second position contains materials used in the actual design. The main geometric dimensions of the node in the simulation correspond to the design (average relative error of 3.6%), the masses of the main elements are modeled quite accurately (the relative error of modeling does not exceed 3%). Given the relatively high speed of execution of calculations, when modeling new engines, it is possible in a short period of time to analyze a large number of possible designs and select the most optimal one.

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