NUMERICAL MODELING PROBLEMS OF OPERATING PROCESS OF COMBUSTION CHAMBERS OF GTE AND SOLUTION APPROACHES

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ABSTRACT

Designing of new gas turbine engines (GTE) is considered to be one of the world key scientific and technical tasks. It is attaining growing topicality due to increasing usage of these engines not only in power plants of airborne vehicles, but also in power systems. Rising of efficiency and meeting ecological norms are key requirements, imposed to designed engines. Meeting these requirements is not possible without development of new combustion chamber (CC) of GTE. For achieving this goal, computer modeling technique is widely used. Upon that a range of problems occur, without solving which it is not possible to create and produce new products with required technical specifications. Wide range of these problems can generally be divided into two categories:

- Problems, related to provision of calculation on computers;
- Problems of mathematical modeling of CC operating process.

In this article the authors have presented their knowledge and background as for solution of these issues, gained in the course of CC engineering process. Author experience gives evidence that the usage of engineering analysis must be accompanied with verification of computer-based calculations according to results of full-scale experiments and development of new calculation technologies that would provide required accuracy.

Keywords: gas turbine engine, combustion chamber, engineering analysis package, geometric model, computational region, grid model.

INTRODUCTION

Engineering of the new GTE combustion chamber is considered to be extremely challenging task [1,2,3], since it is imposed with a variety of requirements, like: minimal size; high combustion efficiency; minimal losses of total pressure; combustion stability; provision of ignition under conditions of high altitude; absence of oscillating combustion; required output temperature field etc.

The task of engineering is to create CC that would meet the requirements of technical specifications as much as possible. Analysis of the mentioned requirements shows that meeting them is complicated by some contradictions [4]. For example, reduction of CC cross dimensions by means of increasing flow rate leads to increasing hydraulic losses, and the will to reduce them my means of reduction of intensity of mixing combustion products with the air leads to increase of output temperature field non-uniformity [5]. That is why engineering of CC is considered an optimization problem, which should be solved basing on compromise. Search for such compromise solution is promoted by the usage of numerical simulation [6].

METHODS

The method used in numerical simulation of operational process of CC gas turbine engines included:

- Creation of geometric model by using Siemens PLM Software NX 8.5;
- Generation of grid model in ANSYS Meshing (ANSYS 13 WorkBench);
- Creation of mathematical model;
- Performance of calculations in ANSYS Fluent (ANSYS 13 WorkBench);
- Visualization and analysis of the results.

Calculations were performed at multiprocessor personal computer, as well as at supercomputer “Sergey Korolyov”. Personal computer has the following characteristics: processor - Intel(R) Core™ i7 CPUX980 @ 3.33 GHz, random-access memory - 24 GB. Supercomputer “Sergey Korolev” consists of 896 processors 2xIntelXeon X5560, 2.80GHz; total random-access memory equals 1, 3125 TB.

Samara State Aerospace University has more than 30 years of expertise in design and operational adjustment of combustion chambers of gas turbine engines with leading enterprises of Russia. Within the framework of cooperative efforts with JSC “Kuznetsov” according to Regulation of Government of Russian Federation No.218, new engineering and operational adjustment technologies has been worked out with a common use of computer calculations.

Combustion chamber is important part in providing of technical characteristics of gas turbine engines. However, comparing to other engines, numerical modeling is significantly impeded due to features of operation process of CC. This adds complexity to the process of automated engineering of GTE. Thus, the issues of computer technologies application to creation of GTE CC require urgent solutions.

These problems can be divided into two categories:

- Problems of computing calculations provision;
- Problems of mathematical modeling of CC operational process.

The border between these categories is rather conventional. Let us examine the problems of both categories in more details.

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In realization of numeric calculations on computer the following stages may be distinguished:

- Creation of geometric model;
- Generation of grid model;
- Creation mathematical model;
- Calculation performance;
- Visualization and analysis of results.

Creation of 3D model by using CAD software is performed both based on available technical documentation or by using preliminary sketches. The main issue here is that CAD system provides creation of detailed solid model (Figure-1), while CAE system requires grid model for using of technique of finite elements or volumes.

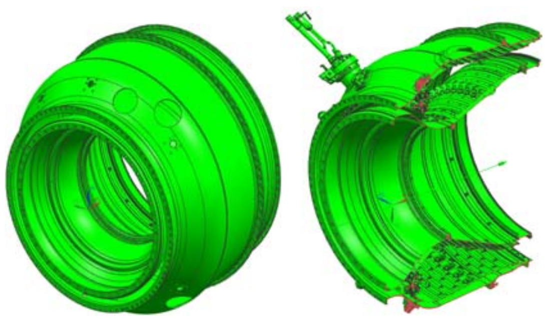
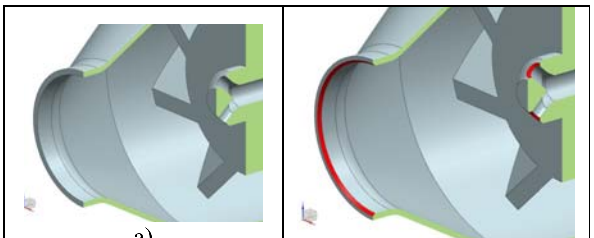


Figure-1. Geometric model of combustion chamber.

Limitedness of contemporary ECM resources and capabilities of program packages that are being used result in impossibility of grid generation on detailed geometrical model that would reflect all peculiarities of CC construction, as well as further calculations in CAE system on the base of such grid model. That is why two approaches are being realized simultaneously:

- Simplifications of geometric model;
- Limitations for fragments of computational region of huge combustion chambers.

Simplification of initial model allows reducing number of elements in grid model to avoid problematic areas and to improve its quality. This would reduce calculation time, and sometimes provides the possibility of it. Simplified analogue of three-dimensional model should provide reliability of estimates and not to twist physics of events running in studied object. Clear definition of approaches to its creation is absent, while removal of bevels, roundings and other elements from the model may lead to substantial spread of calculations; results from the actual parameters. Figure-2 shows simplified model and realistic geometry of spray nozzle of GTE CC. At the analysis of gas flowing from spray nozzle, simplifications of basic geometry like exclusion of bevels may result in miscalculations.



a) b)

Figure-2. Model of fluidal gas burner of CC of gas turbine engine.
a) Simplified model; b) real-geometry model (with bevels)

Stiffening of structural analyst knowledge about CC working process could be a way out.

Grid generation on some part of the model, usually on some sector (Figure-3) leads to the situation that is similar to the one when in full-scale experiment not the whole combustion chamber is being tested, but some section of it. For accuracy of calculation results both sector model and section must reproduce periodic part of full CC. However, engineers avoid multiplication of main elements in order to avoid undesirable effects (e.g. vibroacoustic phenomena). Such elements as ignition units, air income cradles etc. also do not let form authentic sector. Thus, just from the beginning, when the model is being formed, divergence of calculation results in comparison with full-scale experiment data laid out.

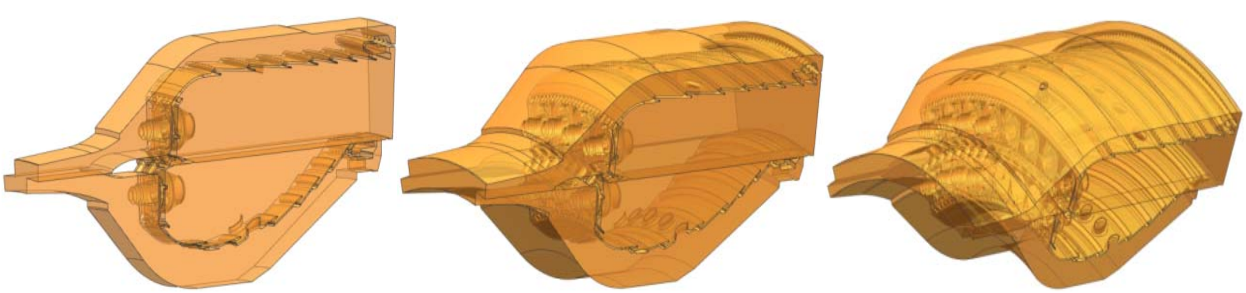


Figure-3. General view of selected calculation sectors.

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In the process of choosing configuration of sector model it is necessary to be aware of combustion chambers operation process and how some elements of the construction influence it. This problem can be solved fully only if the model of the whole combustion chamber is calculated.

Another major problem of CC modeling is a need in creation of more than one grid models. In the performance of strength-related task modeling of metal parts is of prevailing importance, while at computational fluid dynamics, configuration of inner volume, which gas flow is performed in, is very important (Figure-4). At calculation of combustion process, requirements to calculation model are similar to the ones, imposed to gas flow model. The most difficult way of modeling is calculation of heat-stressed condition. In this case conjugated model is used, which is basically a combination of two abovementioned models. Thus, of the long-run objectives is creation of a single unified model.

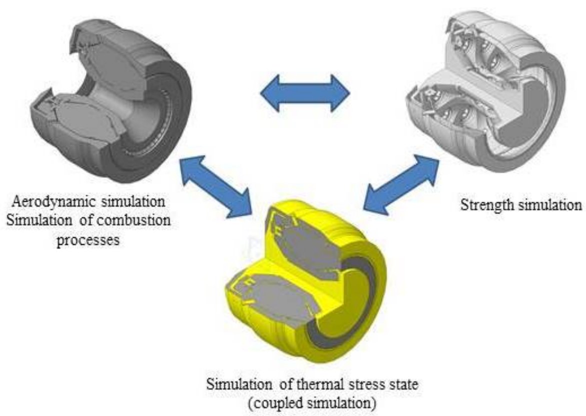
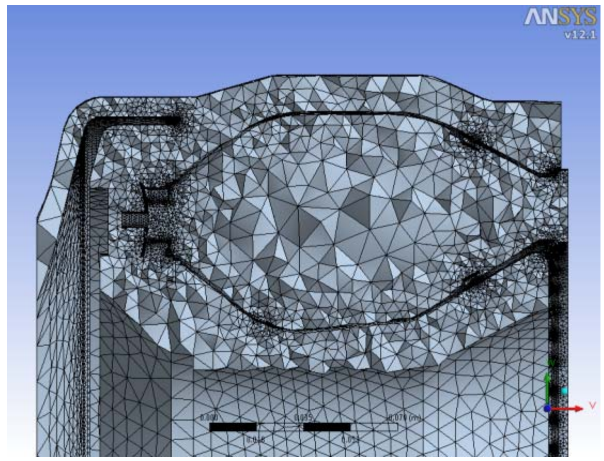


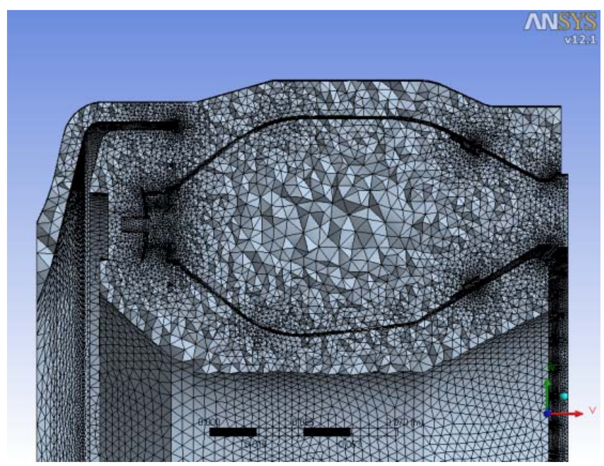
Figure-4. Models for calculation of various characteristics of GTE CC.

An important aspect of 3D modeling is time spent on it. Reproduction of such complex object as combustion chamber in a view of three-dimensional model is a very difficult task. Each element of combustion chamber is created in a fixed sequence and in fact this process is equal to manufacturing process of this element. For solution of this problem, with participation of this article authors, basic modeling technologies of main elements geometry have been created on the base of parameter-oriented models, which allow promptly changing sizes and make standard modifications. This allowed significantly reduce time needed for creation of three-dimensional model.

The next range of problems is connected with generation of grid models. For instance, it is desirable that the number of end elements in grid model does not exceed optimal limited number, below which required accuracy is not delivered. Grid generation is a rather difficult stage, since required segmentation can not always be performed without making changes to geometry of the area, which is subject to segmentation. Intrinsically, grid model generation is performed through successive approximation method, where complexity of grid structure and its practicability are assessed at each stage. Key factor of solving issues with grid generation is calculator expertise.
Summing up, we can point out that validity of results of numeric modeling is laid yet at the stage of geometric and grid models creation. Form deviation at building of 3D model, incorrect type and number of end elements, as well as many other reasons may lead to false results. Thus, for example, experience has shown that at location in any canal section of the object, having a plane of less than 5-7 elements along vertical extent, character of calculable flow will fall a long way short of the real one - Figure-5.



a)



b)

Figure-5. Grid models for gas turbine engine CC a) coarse grid; b) qualitatively adapted grid.

The stage of mathematical model building includes selection of coordinate system, record of required differential equations and establishment of initial and boundary conditions. For description of both stationary and non-stationary flows of viscous compressible gas Navier-Stokes equations are used. Depending on selected dimension of solvable problem, three-dimensional definition of initial equations may be used, or their

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simplified variant that allows reducing machine time consumption. For combustion chambers, considering that they involve complex three-dimensional gas flows, switch to numeric modeling can be observes, which is based on complete Navier-Stokes equations.

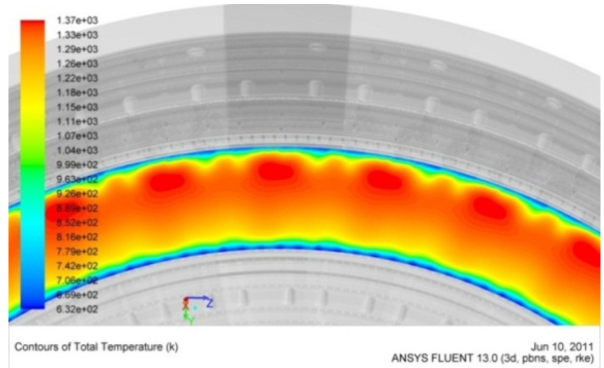
Initial conditions define distribution of speed, temperature and pressure at the time point t=0. The way they are established will define machine time consumption.

Establishments of boundary conditions while solving complete Navier-Stokes equations is performed for all boundaries of computational domain. Boundary conditions on the input of computational area is usually presented as speed distribution or working fluid consumption, direction of medium movement, distribution of complete pressure and temperature, as well as turbulence characteristics. For the purposes of simplification and reduction of calculation time, calculation of equilibrium flow with averaging of value parameters at the input is commonly used for description of aerodynamic processes in CC.

There is a wide range of CC-related problems, associated with the usage of mathematical models of specific calculations, for example fuel spreading, its combustion and generation of hazardous substances. Here success may be achieved by means of switching from embedded package programs to self-engineered products.

Among the problems of calculations realization there are problems, connected with the usage of parallel calculations. While worked at supercomputer some problems of organizational provision may occur: it is necessary to define calculation priorities for particular tasks, to have enough random-access memory, specific licensees for the usage of program packages.

Visualization and analysis of estimated data have its problems as well. Unlike traditional, one-dimensional calculations, three-dimensional one allows changing parameters in three-dimensional coordinates. That is why engineers of combustion chambers face difficulties while obtaining huge volumes of information, which may impede to assess the processes, taking place in studied object. For presentation of calculation data it is possible to use both standard graphs, typical for one-dimensional calculation and plain / volumetric pictures, shown on Figure-6.



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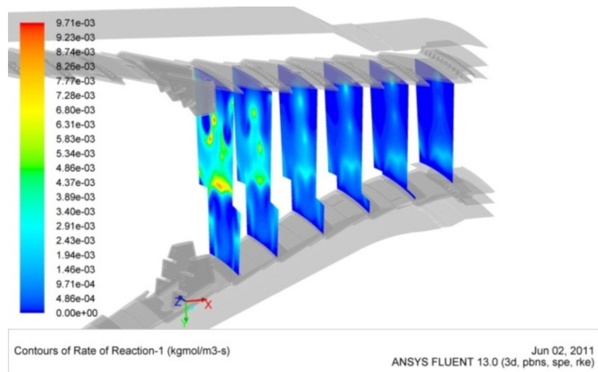

b)

Figure-6. a) Temperature field in CC output, b) chemical reaction speed change.

Meanwhile, the problem of analysis and visualization of obtained calculation data on a grand scale remains open.

Problems of the second category, namely, problems of mathematical modeling of CC operational process are directly related to general state-of-the-art of contemporary science. It is obvious that some components of working process currently are not studied enough to be used for accurate mathematic description. For instance, there is a lack of programs that would allow precise calculation of fluid fuel atomization, drops locus, their vaporization, drop burning, generation of hazardous substances etc. Issues, connected with mathematic modeling of CC working process is possible only in conditions of consolidation of new developmental methods and calculation programs with their further testing and feasibility demonstration in full-scale modeling experiment. A range of problems here can be solved by studies that involved laser technologies, allowing study aerodynamic flow structure in details, to give scientific credence to usage of particular turbulence models etc.

An important aspect of CC engineering is provision of its collaborative work with other elements of gas turbine engines, and ultimately with compressor and turbine. Traditionally each nod is engineered separately from the others per peculiar methods, and their influence on each other is estimated based on final tests results, which is has negative impact on its characteristics. Thus, it is necessary to investigate interconnections of various engine nods yet at design stage. At the moment modern computer technologies (even supercomputers) do not have enough facilities for accessing exceptional quality of combustion chambers designing, being a part of gas turbine engines. Nevertheless, authors experience in development of small-sized GTE has shown that this approach helps improve characteristics of designed GTE significantly.

DISCUSSIONS

This article presents authors expertise in the field of combustion chambers designing by using CAD/CAE software [7, 8]. It has been demonstrated that calculations accuracy may be increased through great experimental efforts on operational process investigation, adjustments of calculation methods and its verification per bench tests [9]. This work is beneficial for its analysis of main problems of CC computer engineering. New problems will be constantly occurring in the course of CC operation, and the ways to resolve these problems will be developed as well. Thus, the problems, related to non-stationary modeling processes in combustion chambers and its calculation as a part of GTE become more and more topical today.

SUMMARY

Engineering and adjustment of long-range combustion chambers show that without usage of engineering analysis packages it is not possible to meet specified requirements for such products in required within established time frames. Problems of CC computer engineering mainly reflect traditional issues of their creation along with problems of computer modeling of complex technical objects. Only complex usage of new and traditional computing technologies in conjunction with experimental researches allows create combustion chamber that would be as much close to the optimal CC as possible.

CONCLUSIONS

a) Qualitative result in CC engineering may be obtained only at combination of numeric and full-scale experiments.
b) Independent calculations of CC at present stage of technologies development does not allow obtaining required result for the engine that is why it is reasonable to perform optimization calculation of CC as a part of GTE.
c) GTE improvement features may be accessed by improving operational process of combustion chamber that is why further development of optimization methods is required.

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