Proceedings of 24th International Conference "MECHANIKA 2019"

Combustion Chamber of Adaptive Type of the Perspective Multi-Mode Aviation Gas-turbine Engine

Viktors GUTAKOVSKIS*, Vladimirs GUDAKOVSKIS**
** Riga Technical University, Kalku str.-1, Riga, Latvia, Viktors.gutakovskis@rtu.lv*
*** Scientific Researcher , Vladimirs.gudakovskis@gmail.com*

1. Introduction

The article discusses the direction of development of promising multimode aviation gas turbine engines (GTE). It is shown that the development of GTE is on the way to increase the parameters engine workflow: gas temperatures in front of the turbine T^*_g and the degree of pressure increase in the compressor P^*_K. It is predicted that the next generation engines will operate with high parameters of the working process, T^*_g = 2000 – 2200 K, π^*_K = 60 - 80. At this temperature of gases in front of the turbine, the working mixture in the combustion chamber (CC) is stoichiometric, which sharply narrows the range of stable operation of the CC and its efficiency drops sharply in off-design gas turbine engine operation modes. To expand the range of effective and stable work, it is proposed to use an advanced aviation GTE: Adaptive Type Combustion Chamber (ATCC). A scheme of the ATCC and the principles of its regulation in the system of a multi-mode gas turbine engine are presented. In the regulation of ATCC, algorithms for adaptive choice of options and self-adjusting adaptive algorithms can be used. The use of ATCC in future aviation multimode GTEs will greatly expand their range of stable and efficient operation.

2. State of the art

The development of aviation gas turbine engines (GTE) follows the path of constantly increasing the parameters of the working process, increasing the temperature of gases in front of the turbine –T^*_g and increasing the degree of pressure increase in engines - $\pi^*_к = P^*_к / P^*_в$ ($P^*_к$ - pressure for the compressor of the engine, P^*_B - pressure on an entrance to the engine). This allows to significantly improve the performance of promising GTEs of the next generation. The growth of T^*_g with a simultaneous increase in π^*_K to lead to an increase in the specific thrust of the engine $R_c = R / G_A$ (R - engine thrust, G_A - air flow through the engine and frontal thrust $R_F = R_{TO} / F_m$). R_{TO} is the engine take-off power, F_m is the area of the mid-section of the engine.
The higher the R_F, the smaller the frontal dimensions of the engine and the specific gravity of the engine $Y_{ENG} = G_{ENG} / R$ (G_{ENG} - engine mass). R_F and Y_{ENG} - characterize the level of engine excellence.

The increase in the values of T^*g and π^*_K to lead to an increase in the work cycle and efficiency. Table 1 presents the growth trend of T^*_g and π^*_K among various generations of aviation GTEs.

As a rule, multimode GTEs are calculated on the maximum power mode, which is characterized by the optimal parameters of its thermodynamic cycle. It is the mode that corresponds to the size of the flow part of the engine, and the main parameters of the working process T^*_g and $\pi^*_к$.

For other, off-designed (not calculated) engine operating conditions, compromise decisions are made and the parameters of the working process in this mode are tightened to the optimum. This is achieved by various methods of regulating the flow part of the GTE. This is made possible due to the many modes of operation of the aircraft.

Multimode aircraft at various stages of flight solve various problems; therefore, for each engine operating mode corresponding to the stage of flight of the aircraft, certain requirements are imposed. These requirements are aimed at ensuring the maximum performance of the engine and power plant, while the reserves of the gas-dynamic stability of the engine in these modes must be provided. Thus, promising future aviation gas turbine engines will have a large number of controlling influences on the working process in the engine, which will lead to an increase in the adjusted parameters of the gas turbine engine. This will allow one to actively influence the working process of the GTE and carry out the optimal tuning of the engine for each stage of the flight of the aircraft.

Another feature of the multi-mode aircraft is the flight at supersonic cruising modes, which should be carried out on unforced engine operating modes.A promising direction to meet this requirement is the creation of so-called stoichiometric engines. In these engines, all the oxygen in the air entering it is used to burn the fuel in the main combustion chamber (CC) to produce high T^*_g.

Table 1

The growth trend of T^*_g and π^*_K among various generations of aviation GTEs.

Generation of GTE	I	II	III	IV	V	VI
T^*_g, K	1000-1150	1150-1250	1300-1450-	1500-1650	1850-1900	2100-2200
π^*_K	3-5	7-13	14-20	20-35	20-50	60-80

Getting T^*_g = 2000-2200 K in a CC of a perspective gas turbine engine requires that the combustion air excess coefficient $\alpha_{CC} = G_A / G_F * L_O$ (G_A is the flow rate of air entering the CC, G_F is the fuel consumption entering the CC, L_o is the theoretically necessary amount of air for complete combustion of 1 kg of fuel, for aviation kerosene L_O = 14.8 [1]) was α_{CC} = 1.1-1.2.The calculated dependence of the temperature of the combustion products on the coefficient of air excess (α) is shown in Fig. 1 [2]. The value $\alpha = 1$ is called stoichiometric [2], and CC, in which α_{CC} is close to stoichiometric value, are called stoichiometric (high-temperature CC). As can be seen from Fig. 1, the operating range of stoichiometric CCs is very narrow in the range of α_{CC}. In multimode GTE maneuverable airplane α_{CC} varies in a wide range. Fig. 2 presents the range of variation of the CS in the GTE maneuverable, multimode airplane [3].

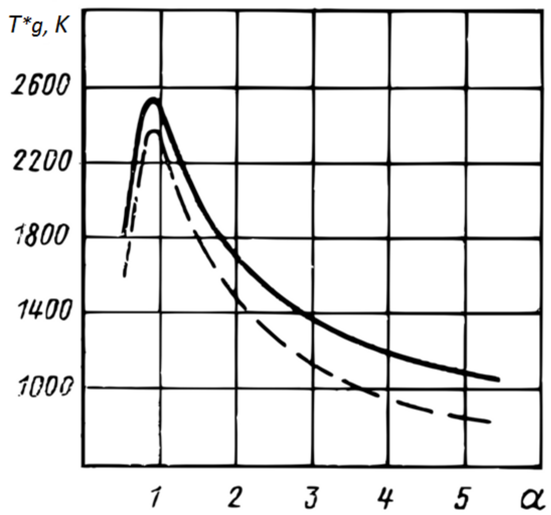

Fig. 1 Estimated dependence of the temperature of the combustion products of fuel oil on the coefficient of excess air:–– at T^*_K = 600 K; - - - with T^*_K = 300 K

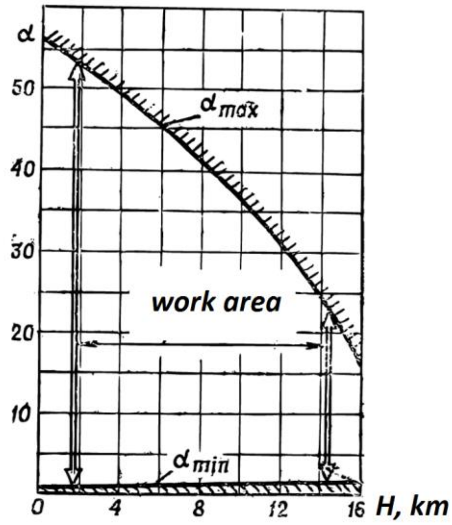

Fig. 2 The range of variation of α_{max} and α_{min} of the CC in the multimode GTE of (maneuverable) airplane

As can be seen in the graph above, to ensure the possibility of stable and efficient operation of high-temperature stoichiometric CC and T^*_g = 2000-2200 K in a multi-mode gas-turbine engine, it is necessary to use elements of the control of the combustion chamber [4]. In [5, 6] various methods of regulating the main combustion chamber (CC) of a multimode GTE are described. Although these methods of regulating the main CC were mainly aimed at obtaining better characteristics for the emission of pollutants, they can also be used to improve the characteristics of the high-temperature main CC. Adjustment in the main CC is aimed at maintaining the specified composition of the fuel-air mixture in the combustion zone. Maintaining the required composition of the mixture in the CC can be facilitated by the supply of fuel distributing it to the combustion zones. Several combustion zones are created that operate on the corresponding GTE operation modes [1]. Figure 3 shows the manufactured CC by company SNEKMA with two zones of combustion chamber areas.

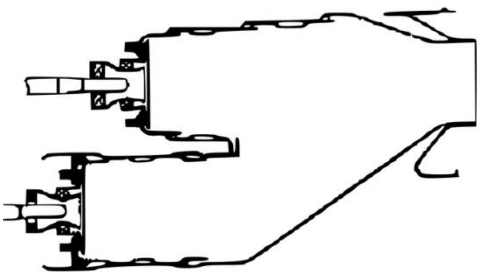

Fig. 3 Two-work area CC of the company SNEKMA [3]

The main drawback of such burning is the inefficient use of the volume of the CC. In some modes of operation, the gas turbine engine of the zone type uses only half of its working volume. Another way to maintain a given composition of the mixture in the CS is the redistribution of air entering the CC, depending on the mode of operation of the GTE. Air is distributed by using, for example, an adjustable front device [4]. In Fig.4. is presented combustion chamber (CC) with adjustable front-mounted device.

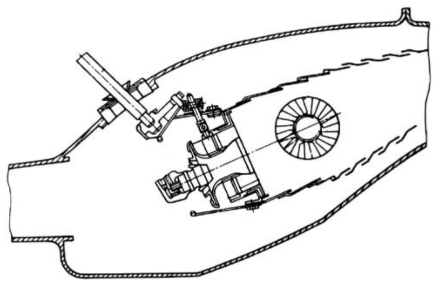

Fig. 4 The CC scheme with an adjustable front-mounted device [4]

3. Hypothetical adaptive type combustion chamber.

Also, by changing the flow area of the holes in the flame tube, it is possible to vary the air supply to the combustion zone in various combinations to maintain a given α_{CC} [5,6]. Another method for regulating the composition of the mixture in the primary combustion zone of a CC is to change its geometric dimensions in accordance with changes in the operating conditions of a multi-mode gas turbine engine, and the air supply is redistributed throughout the entire flame tube. Currently, the adjustability of the elements of the CC is sufficiently broadly developed. Various adjustable nozzles, swirlers with adjustable blade installation angle and changing the walking cross-sectional area, front-facing devices with preliminary organization of the air mixture fuel and control of its supply, adjustment of the CC volume with redistribution of air throughout the flame tube, etc.

Based on the above, it is possible to schematically present a hypothetical high-temperature CC for a multi-mode perspective GTE. In fig. 5 shows a hypothetical high-temperature CC with workflow control element or adaptive type CC (ATCC).

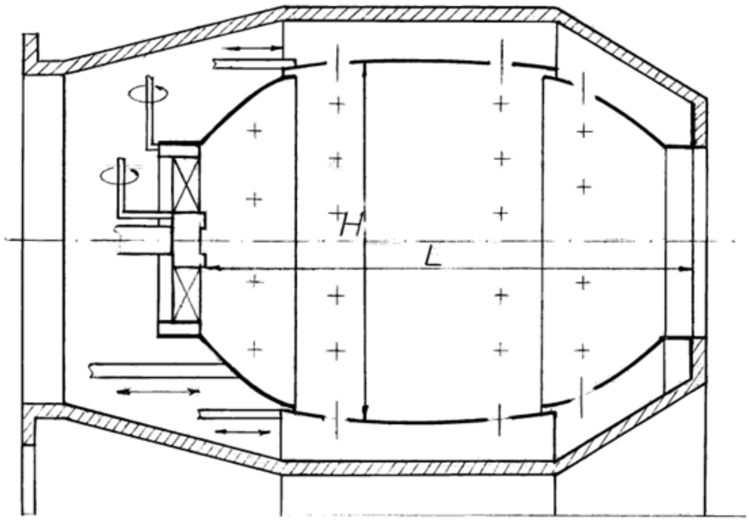

Fig. 5 Diagram of the hypothetical adaptive type combustion chamber (ATCC)

A combustion chamber in which elements of adjustable geometric dimensions are used in accordance with the operation mode of the GTE, as a rule, the volume of CC and, accordingly, redistribution of air supply to the combustion and mixing zone, is called an adaptive type CC of an adaptive type. Fig. 5 schematically shows the known elements of the regulation of the CC. In the future, other elements of regulation of high-temperature CC can be developed. An obstacle for use of effective control of multi-mode CC of the GTE is the design complexity of the controlled CC, high-temperature GTE operation modes and limitations in the level of development of modern materials science and technology. The application of adjustability in a high-temperature ATCC is aimed at maintaining a given $\alpha_{CC,}$ at which the CC works sufficiently effectively, with a high combustion efficiency η_g [2], this also leads to the expansion of its range of stable operation.

Table 2 presents the adjustable parameters, the control actions and the achieved adjustability objectives for the hypothetical ATCC of multimode GTE. The implementation of the management of ATCC is adjustment system. The adaptive adjustment system of a high-temperature CC of a multimode GTE can be implemented in two ways.

First - is the adaptive choice of options, as the simplest.

Second - is a self-adaptive adaptive system, as more complex.

Adjustment via method of adaptive choice of options is the choice of control actions (variant of the CC) under conditions of a priori uncertainty [7, 9, 10].

Table 2

The adjustable parameters, the control actions and the achieved adjustment objectives for the hypothetical ATCC of multimode GTE

N, P	Adjustable parameter	Designation	Control action	The purpose of regulation on GTE modes
1.	Air supply to the fuel injector	F_{VF}	The area of the orifices of the air flow through the nozzle	Coordination of the spray angle of the geometry of the CC
2.	Spinning the air in the front of the device	φ_z	Swirl Blade Installation Angle	Coordination of the sizes of the zone of processing currents of the geometry of the CC
3.	Air flow through the front device	F_z	The area of the openings of the flow sections of the air supply through the swirler	Maintaining a given α_{CC} in the primary combustion zone
4.	Changing the geometric dimensions of the CC	V_K	The volume of the flame tube KS (change in length- L and height - H)	Coordination of the volume of the flame tube CC and its dimensions to the mode of operation of the GTE
5.	Supply of secondary air flow-along the length of the CC	F_{OK}	The area of the openings of the flow areas of the secondary air supply to the flame tube	The distribution of the secondary air supply throughout the volume of the CS to maintain a given α_{CC}
6.	Fuel supply to the CC	G_{FJ}	Adjustable fuel supply through the nozzle	Specified fuel supply, depending on the mode of operation of the GTE

In this direction, the ATCC has several fixed positions of all control actions distributed over the GTE operation modes. Where for each range of GTE operation mode there corresponds to "its own" version of the CS, which in these conditions realizes the best performance. Each variant of the COP corresponds to a fixed position of the control action. In this way:

$$\alpha_{CC} = f\left(\sum_{i=1}^{n} {}_{CC_i}\right), \tag{1}$$

and

$$_{CCi} = f\left(G_{FJ}; F_{VFi}; \varphi_{zi}; F_{zi}; V_{ki}; F_{OKi}\right) \tag{21}$$

Graphically characterization of the relative coefficient of completeness of combustion $\overline{\eta_g} = \eta_g / \eta_{g\max}$ η_g – current combustion ratio, $\eta_{g\max}$ – maximum coefficient of completeness of combustion) depending on the α_{CC} for ATCC with an adaptive choice of options can be represented in the following form, Fig.7. $\overline{\eta_g} = f\left(\alpha_{CC}\right)$.

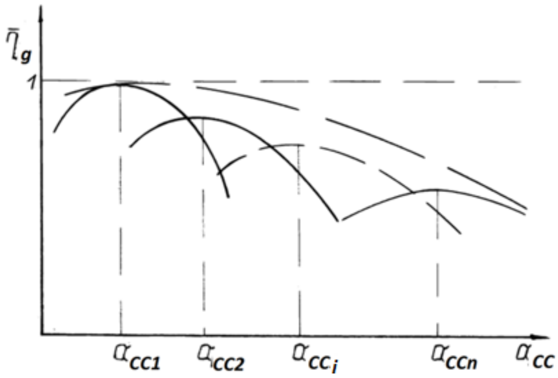

Fig. 6 Characteristic adaptive type combustion chamber (ATCC) with an adaptive choice of options

The generalized characteristic of the ATCC is the curve of the peaks of the variants. Thus, given the formula (1) we get:

$$\overline{\eta_g} = f\left(\sum_{i=1}^{n} {}_{CC_i}\right). \tag{3}$$

When using the self-regulated adaptive system ATCC, the rule for determining the control actions changes in the course of GTE operation. In this case, the adaptive control algorithm will be a combination of adjustment and adaptation algorithms [8]. The adaptive control system will be a dynamic system consisting of a ATCC and a device implementing an adaptive control algorithm, with the control algorithm to be determined over the entire range of operation of a multimode GTE. In this case, the ATCC characteristic will appear as follows, see Fig.7

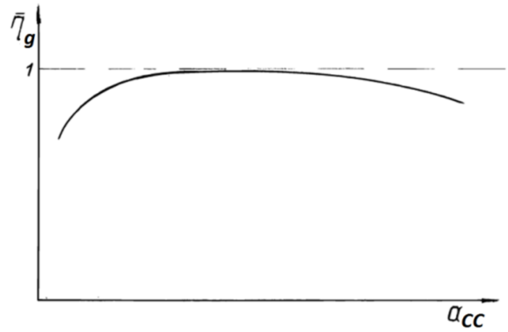

Fig. 7 The characteristic of ATCC with the self-adjusted adaptive system of regulation

In this way:

$$\overline{\eta_g} = f\left(\alpha_{CC}\left(\bar{u}\right)\right), \tag{4}$$

where: $\bar{u}$ – control vector.

4. Conclusions

1. It is necessary to clarify the definition of an adaptive type CC (ATCC).
2. Based on the above, ATCC multimode GTE is a CC with a large number of control actions on the organization of the workflow (advanced management) and the system of adaptive management.
3. As can be seen in Figs. 6 and 7, the application of ATCC in a high-temperature multi-mode gas turbine engine will significantly reduce its specific fuel consumption (C_R) in all operating modes.
4. Since the increase in the coefficient of completeness of combustion of fuel (η_g) leads to a decrease in C_R [2]:

$$C_R = \frac{3600 * Q}{\eta_g * H_u * R_C}, \tag{5}$$

where: Q - Heat release during the combustion of fuel in the CC; H_u - thermal conductivity of fuel.

5. At the same time, the task of expanding the range of stable engine operation is being solved.

References

1. Inozemzev A.A., Sandratsky V.L. Gas-turbine engines, OJSC "Aviation Engine", Perm, 2006, 1204 p.
2. Nechaev, Yu.N., Fedorov, R.M. The theory of aviation gas turbine engines. Part 2 M., Mechanical Engineering, 1978, 336 p.
3. Lysenko N.M. Practical aerodynamics of maneuverable aircraft. Textbook for flight personnel. Under general ed. Lysenko N.M. , M., Military Publishing, 1977, 439 p.
4. Nechaev, Y.N. and others. Aircraft turbojet engines with variable workflow for multimode aircraft. M .: Mechanical Engineering, 1988, 176 p.

5. Lefevr A. Processes in the combustion chamber of the CCD. translated. from English M. Mir, 1986, 566 p.
6. Gupta A. et al. Swirling threads; Translated from English M., Mir, 1987, 588 p.
7. Nazin A.V., Poznyak A.S., Adaptive choice of options. Recurrent Algorithms - M. Nauka, 1986, 288 p.
8. Fradkov A.L. Adaptive control in complex systems: searchless methods. M. Science, 1990, 296 p.
9. Lozano R., Adaptive Control, Springer, 2012. 562.p.
10. Feng G., Lozano R. Adaptive Control Systems. Elsevier. 1999, 352 p.

Ph.D., V.GUTAKOVSKIS, Dr.sc.ing. VLADIMIRS GUDAKOVSKIS

Summary.
This paper presents the investigation of existed combustion chamber type's construction. It's adjustment and all necessary parameters analysis. After wide analysis of working characteristics the adaptive control system is developed consisting of a ATCC and a device implementing an adaptive control algorithm, with the control algorithm to be determined over the entire range of operation of a multi-mode GTE.

Keywords: aviation, gas turbine engine, combustion chamber.