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АЕРОКОСМІЧНИЙ ФАКУЛЬТЕТ
КАФЕДРА ПІДТРИМАННЯ ЛЬОТНОЇ ПРИДАТНОСТІ ПОВІТРЯНИХ СУДЕН

ДОПУСТИТИ ДО ЗАХИСТУ
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«_____»_____________2020 р

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ
«МАГІСТР»

ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема: **“ Дослідження методів покращення основних характеристик камер згорання двохконтурних турбореактивних двигунів”**

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MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

AEROSPACE FACULTY

AIRCRAFT CONTINUING AIRWORTHINESS DEPARTMENT

PERMISSION TO DEFEND
Head of the department
Dr. tech. sciences, Prof
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«____»_______________2020

MASTER'S DEGREE THESIS

(EXPLANATORY NOTE)

GRADUATE OF EDUCATIONAL DEGREE

«MASTER»

FOR EDUCATIONAL-PROFESSIONAL PROGRAM
«MAINTENANCE AND REPAIR OF AIRCRAFT AND AVIATION ENGENS»

Topic: **"Investigation of methods improvement of turbofan turbojet engines combustion chambers main characteristics"**

Created by: _____________ **S.O. Svichkar**

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Kyiv 2020

NATIONAL AVIATION UNIVERSITY

Faculty: Aerospace faculty
Aircraft Continuing Airworthiness Department
Educational and Qualifications level: «Master Degree»
The specialty: 272 «Aviation transport»
Educational-professional program «Maintenance and Repair of Aircraft and Engines»

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Graduate Student's Degree Work Assignment

Svichkar Serhii

1. The topic of the work: **«Investigation of methods improvement of turbofan turbojet engines combustion chambers main characteristics»** approved by the Rector's order of October 02, 2020 № 1881/ст.
2. The work fulfillment terms: since October 5, 2020 until December 13, 2020 and since December 21, 2020 until December 31, 2020.
3. Initial data for the project (thesis): data about combustion chamber design and composition, data about effect of aviation engines on the environment.
4. The content of the explanatory note: analysis of aviation engines harmful substances emission and methods of their reduction, the study of different combustion chamber designs for turbofan engines.
5. The list of mandatory graphic materials: pictures of combustion chambers of different types; general view of CFM56-5B and its algorithm of activation of fuel nozzles; graphic of NOx emissions during flight stages; graphic of aviation emissions growth throughout time.

Graphic materials is represented in the view of presentation Microsoft Power Point

6. Calendar schedule

Task	Fulfillment term	Completion mark
Literature review of materials for degree work	05.10.2020-10.10.2020	
Analysis of technological process of work fulfillment	11.10.2020 – 15.10.2020	
Preparation of necessary equipment for research carrying out	16.10.2020 – 22.10.2020	
Work on a special part of degree work	23.10.2020 – 15.11.2020	
Processing of research results	16.11.2020 – 20.11.2020	
Fulfillment of individual sections of degree work	21.11.2020 – 04.12.2020	
Processing of master's degree work	05.12.2020 - 13.12.2020	

7. Advisers on individual sections

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labour precaution	O.V. Konovalova		
Environmental protection	M.M. Radomska		

8. Assignment issue date "_____"____________2020.

Degree work supervisor: ________________________________E.P. Yasynitskyi
(signature)

Assignment accepted for fulfillment _____________________S.O. Svichkar
(signature)

ABSTRACT

The explanatory note to master's degree work «Investigation of methods improvement of turbofan turbojet engines combustion chambers main characteristics»

95 pages, 27 figures, 3 tables, 40 literature sources.

Object of study – Combustion chambers types of turbofan engines.

The purpose of degree work – is to reduce the emissions of turbofan engines by using various kinds of combustion chambers.

Research method – case studing and observation of designed, produced and currently in use combustion chambers.

A complex analysis of methods of burning the air-fuel mixture by different combustion chambers in turbofan engines was concluded. We considered the advantages and disadvantages of different types of combustion chambers and their methods of igniting the fuel-air mixture. A comparison of the methods of ignition of the fuel-air mixture was carried out. All the issues are described as fully as possible, thesis is completed in accordance with all requirements of the degree works fulfillment, the specifics of specialty is taken into account.

This degree work contains described measures of improving the combustion chamber of turbofan engine, it contains recommendations concerning the improvement in the production of combustion chambers for modern aircrafts, to continue reducing the aviation effect on environment. This work was directed for researching these problems.

COMBUSTION CHAMBER, EMISSIONS, FUEL COMBUSTION COEFFICIENT

LIST OF DESIGNATIONS

$\boldsymbol{D_{ftd}}$ **-** Flame tube diameter

C_f - Fuel combustion efficiency

T_{ch}- Temperature in combustion chamber

p_{ch}- Pressure in combustion chamber

a_{ch}- Excess air factor

X_{ch}- velocity of the combustion chamber inlet

LPP – Lean Premixed Pre-vaporized

RQL – Reach-Quench-Lean

LDI – Lean direct injection

CC – Combustion Chamber

GTE – Gas turbine engine

CONTENT

INTRODUCTION

Aircraft engines produce emissions that are similar to other emissions resulting from fossil fuel combustion. However, aircraft emissions are unusual in that a significant proportion is emitted at altitude. These emissions give rise to important environmental concerns regarding their global impact and their effect on local air quality at ground level.

Aircraft emit gases and particles which alter the atmospheric concentration of greenhouse gases, trigger the formation of condensation trails and may increase cirrus cloudiness, all of which contribute to climate change.

Aircraft are estimated to contribute about 3.5 per cent of the total radiative forcing (a measure of change in climate) by all human activities and that this percentage, which excludes the effects of possible changes in cirrus clouds, was projected to grow.

The effects of some types of aircraft emissions are well understood, and the effects of others are not, and a number of key areas of scientific uncertainty that limit the ability to project aviation impacts on climate and ozone.

The ICAO Assembly in 2001 urged to promote scientific research aimed at addressing the uncertainties identified in this Report and requested the Council to continue to cooperate closely with the IPCC and other organizations involved in the definition of aviation's contribution to environmental problems in the atmosphere and the need to take initiatives for a scientific understanding of the problems

This work contains methods of reduction of turbofan engines emissions by means of using different types of combustion chambers. This paper also describes how each kind of combustion chamber increase the coefficient of fuel combustion which leads to lower emissions of harmful substances.

PART 1
COMBUSTION CHAMBER OF JET ENGINES

1.1 Purpose of combustion chambers

Combustion chambers are designed to convert the chemical energy of the fuel into thermal energy of the gas stream by combustion. [1]

Gas turbine engine combustion chambers perform several important functions for engine operation. They are used to convert the energy of the gas exiting the engine into the energy of the jet thrust of a given direction, maintain the appropriate operating mode of the turbocharger, transport gas in the fuselage or engine nacelle, reducing the noise level of the power plant, shielding direct infrared radiation from the engine, etc. In this case, the main requirement must be met: a stable combustion process and a high completeness of fuel combustion are ensured. The requirement of trouble-free starting (ignition) of combustion chambers in flight conditions is also important. This is necessary to ensure that the engine is restarted when it is turned off automatically in the air and to reliably turn on the afterburner. [2]

1.2 Combustion chamber operating principle

In all combustion chambers, stable combustion ensured, in essence, in the same way - by creating a stream of hot gases in the chamber moving towards the main flow of air and atomized fuel (zones of return currents). In this case, the fuel and air are mixed, the fuel evaporates and the air-fuel mixture ignites. Counter currents of air and hot gases are organized by combustion stabilizers (swirlers), with the help of which at the beginning of the chamber a zone with reduced pressure is created and a return flow of air and hot gases occurs (Fig 1.1).

In principle, any combustion chamber consists of a casing, a flame tube and a frontal device with nozzles and swirlers. The working volume of the combustion chamber is divided into two zones - combustion and mixing.

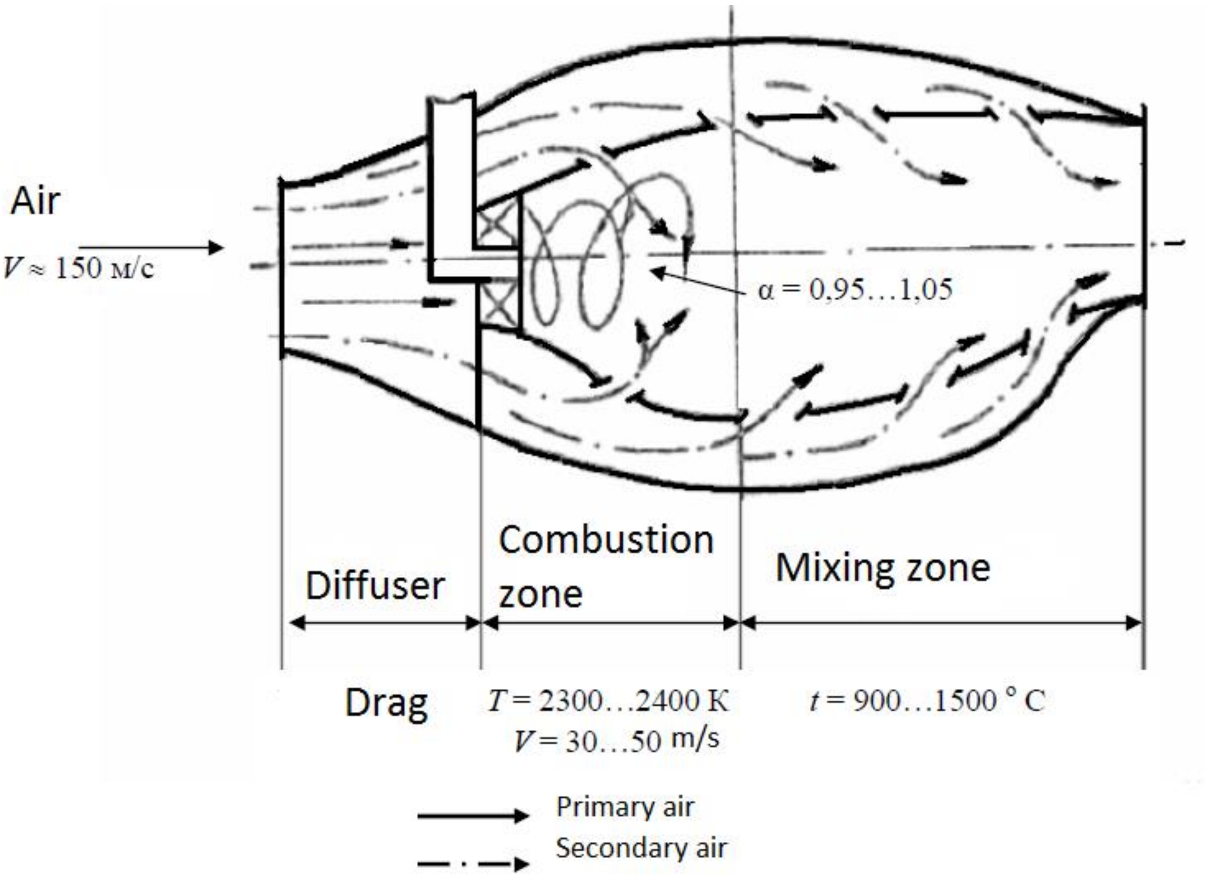


Fig 1.1 - GTE combustion chamber diagram

The air entering the combustion chamber from the compressor, front the device is divided into two parts. A smaller part (25 - 40% of the total amount), or "primary" air, enters through the swirler into the flame tube, where it mixes with fuel and forms a stream of favorable speed (30 - 50 m / s) and composition of the fuel-air mixture, in which is the combustion reaction. The temperature of the combustion products in this case reaches 2300 - 2400 K. Most, or "secondary" air, at high speeds (120 - 150 m / s) flows around the flame tube, cooling it, enters through special holes and nozzles into the mixing zone, where, mixing with the fuel combustion products, it lowers their temperature and forms a gas flow with a given temperature field at the turbine inlet. There is no clear boundary between the combustion and mixing zones.

High completeness of fuel combustion is ensured by supplying such an amount of air to the combustion zone so that the excess air ratio is close to unity ($\alpha = 0.95 ... 1.05$; for burning 1 kg of kerosene, it is necessary to supply 14.8 kg of air, such a mixture is called stoichiometric). An increase in temperature in this zone to 1800 - 2300 K contributes to better evaporation of the fuel, provides an increase in the rate of oxidation reactions and makes the combustion process intense, stable and complete.

The supply of "primary" air along the length of the combustion zone is carried out gradually. With a staged supply of side streams of primary air, afterburning of small fuel droplets and combustion of evaporating medium and large droplets of fuel is ensured. In addition, the overall flow additionally intensifies the mixing and combustion process. The optimal distribution of the "primary" air supply along the combustion length is usually specified during the experimental fine-tuning of the chamber on the stand.

The turbulence of the flow is ensured in the combustion zone, which is achieved by installing a bladed air swirler, perforated plates in the front device, as well as by organizing radial flows of air jets coming out through holes in the walls along the length of the flame tube.

Stabilization of the flame front is provided in the combustion zone. To stabilize the flame front, blade swirlers or bluff bodies are used, installed in the front device of the flame tube.

The main parts of the combustion chamber are cooled by incoming air and sometimes fuel.

1.3 Types of combustion chambers

There are two types of aircraft combustion chambers: main and afterburner.

The main combustion chambers operate at temperatures of 1800 - 2000 ° C. The permissible gas temperature at the outlet of the main combustion chambers is limited by the capabilities of the material and the method of cooling the turbine blades. The main combustion chambers operate during the entire flight of the aircraft, they are reliable, have an efficiency within 0.96.

Afterburner combustion chambers operate at high temperatures and gas velocities. They are designed to increase thrust during take-off and during flight maneuvers.

1.4 CONSTRUCTION DIAGRAMS OF COMBUSTION CHAMBERS

The main combustion chambers of a GTE can classified according to several criteria which are listed below.

1.4.1 Classification by the type of fuel-air mixture formation

By the type of fuel-air mixture formation: with evaporative mixture formation (fuel is supplied in the vapor phase - APU TA-6, turboshaft GTE T-700-GE-700 from General Electric, USA) and spraying (fuel is supplied in the liquid phase in the form of droplets along the gas flow or against the gas flow - АЛ-7, АИ-25, etc.).

1.4.1.1 Evaporation chambers

Evaporation chambers ensure high efficiency of fuel combustion and environmental cleanliness of the engine. However, they are used relatively rarely due to the complexity of the evaporation system, which is a set of tubes located in the combustion zone. Fuel evaporation and its partial thermal cracking occur in the tubes, which can lead to coking of heavy fuel fractions in the tubes, overheating and burnout of the tubes. When the tube burns out, an enriched air-fuel mixture with an excess air ratio of $\alpha \approx 0.25 ... 0.3$ can form in it, which can lead to an engine explosion.

1.4.1.2 Spray chambers

Spraying chambers are predominantly used in modern gas turbine engines. The fuel is supplied to the combustion zone through nozzles downstream in a sprayed state with a droplet diameter of 40 - 100 microns. In early gas turbine engine designs, when the mixing process was insufficiently studied, to improve the quality of atomization of fuel and its better mixing with air, it was supplied against the air flow, which caused the nozzles to heat up intensively and the fuel at the exit from them was coked.

In modern gas turbine engines (for example, in Д-36, Д-136, НК-8, НК-22, НК-144 and others), the fuel from the centrifugal nozzle is sprayed not immediately into the combustion zone, but under the cap, in which the fuel is intensively mixed with hot air coming from the compressor. Up to 75% of the fuel evaporates under the cap, and not only the air-fuel mixture, but also the air-steam mixture comes out of it into the combustion zone. The use of this method of fuel supply improves the combustion efficiency and reduces negative effect on environmental of the chamber.

1.4.2 Classification by the direction of flow of air and combustion products

In the direction of the flow of air and combustion products: direct-flow (Д-36, АМ-3, Р-11, etc.), counter-flow (ГТД-350) and mixed (loop - АИ-9, АИ-450 and half-loop - ГТД-3Ф);

1.4.2.1 Direct-flow axial combustion chambers

Direct-flow axial combustion chambers received the highest distribution on modern gas turbine engines as having minimal hydraulic losses. Their diametrical dimensions usually do not exceed the diameters of compressors and turbines (Fig. 1.2).

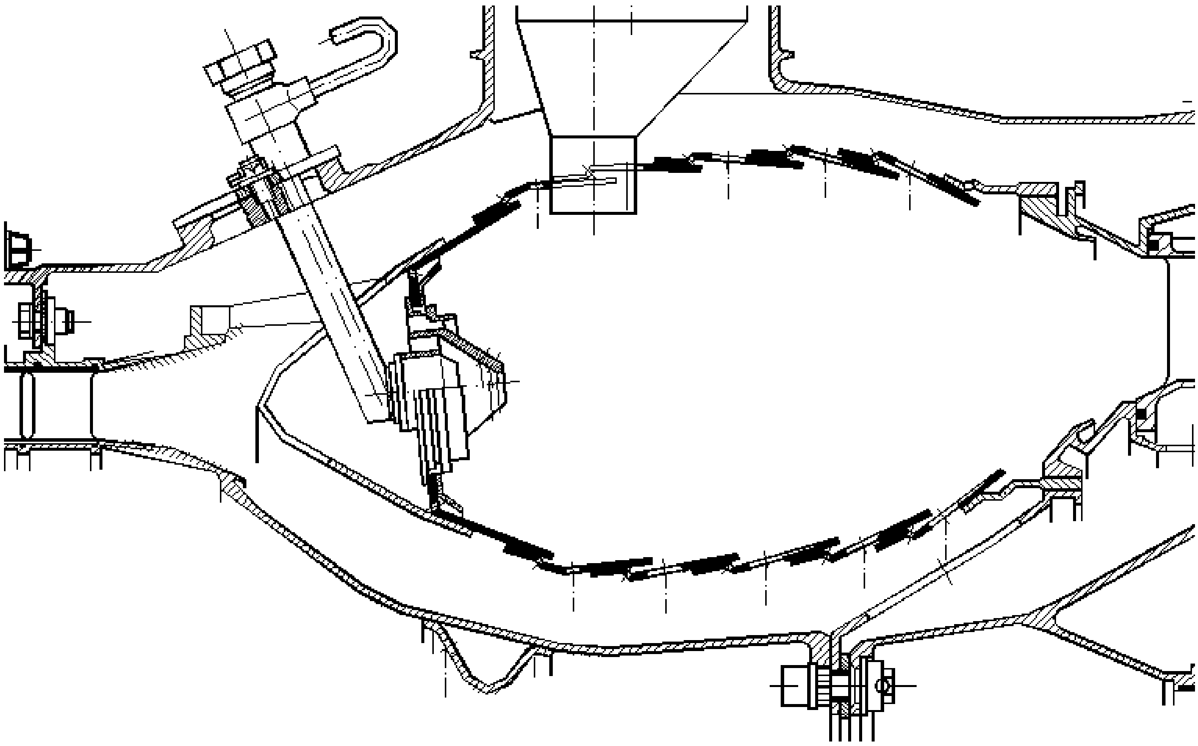


Fig 1.2 - Direct-flow axial combustion chamber of GTE DW-2

The disadvantage of such combustion chambers is the increased axial size, which leads to an increase in the total length of the engine, the distance between the rotor bearings and, accordingly, to the complication and weighting of the engine design.

Axial dimensions can be reduced by using hinge (Fig. 1.3) or half-loop chambers, however, hydraulic losses in them are higher than in the axial chambers.

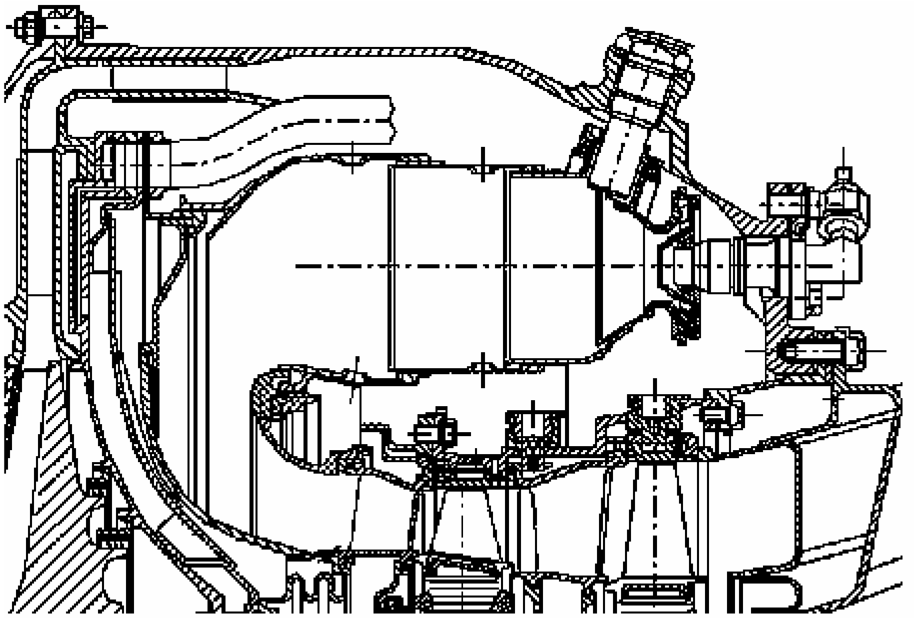


Fig 1.3 - Loop combustion chamber of helicopter GTE

1.4.2.2 Counter flow combustion chambers

Counterflow chambers significantly reduce the distance between rotor bearings. They are used on small-sized gas turbine engines or auxiliary power plants, i.e., they are advisable when the decisive requirement is to reduce the mass and dimensions of the engine, even if this leads to increased hydraulic losses in camera. Since counterflow and loop combustion chambers have high hydraulic resistance, but much smaller axial dimensions, they are used in small-sized GTEs (low-power helicopter engines, gas turbine starters, disposable engines, onboard power units, auxiliary engines).

1.4.3 Classification by design and layout on the engine

By design and layout on the engine: tubular or individual, tubular-annular and annular.

1.4.3.1 Tubular (individual) chamber

Tubular (individual) chamber (ВК-1, РД-45, РД-500, Walter M-701) consists of a flame tube located inside the casing (Fig. 1.4). The number of such cameras on the engine is from 6 to 22 pieces. Cameras are located evenly around the circumference of the engine along its axis or at a slight angle to the axis. Individual chambers are interconnected by flames transfer pipes for transferring flame to chambers from starting igniters or from adjacent working chambers. These combustion chambers fit well with a centrifugal compressor. Since the volume of one chamber is small, this makes it easier to fine-tune the chamber when creating an engine. Individual chambers provide the engine with high survivability and are easy to operate and repair.

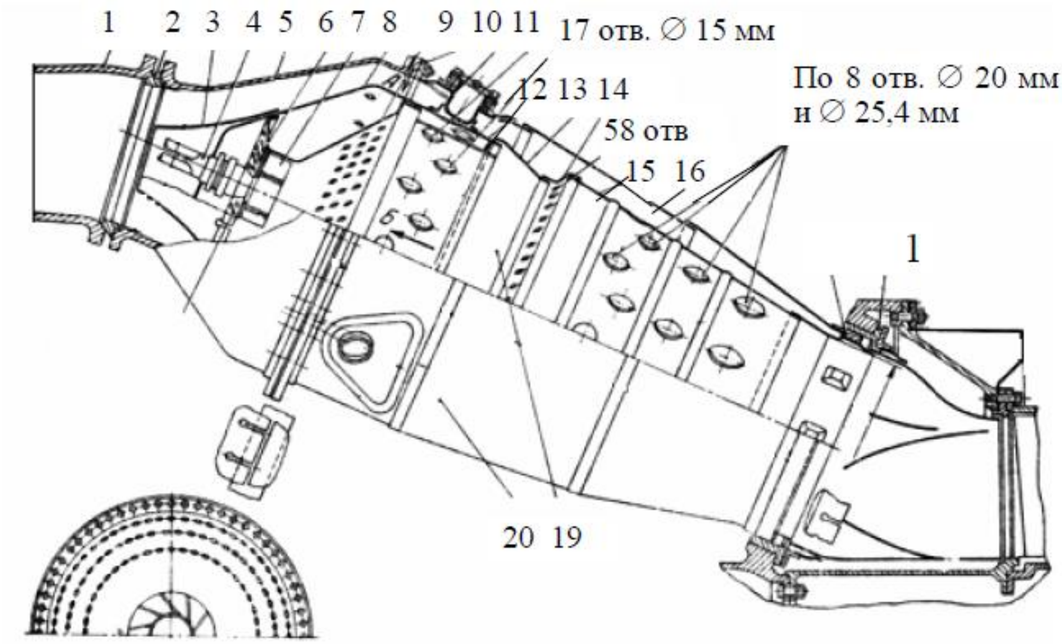


Figure: 1.4 - Tubular combustion chamber: 1 - compressor branch pipe; 2 - spherical steel ring; 3 - neck of the flame tube; 4 - nozzle; 5 - outer casing of the camera; 6 - small conical partition with holes; 7 - blade swirler; 8 - the front wall of the flame tube; 9 - large conical baffle with holes; 10 - spherical steel ring; 11 - centering glass; 12 - cylindrical part of the flame tube; 13 - conical part of the flame tube; 14 - connecting perforated ring; 15 - rear conical part of the flame tube; 16 - welded section casing; 17 - centering ring; 18 - bushing; 19 - fire tube; 20 - outer welded casing

The disadvantages of tubular chambers include the large mass of the set (up to 12-15% of the engine mass), the need for a gas collector, a large number of connections requiring tightness, and increased hydraulic resistance. In addition, the tubular chambers are not included in the power circuit of the motor stator, which requires the use of additional power elements in the stator design.

1.4.3.2 Annular combustion chambers

Annular combustion chambers structurally consist of a single flame tube having an annular cross-section and external and internal casings, which are usually the power elements of the engine stator (Fig. 1.5). These cameras are compact, fit well into the engine dimensions. They use the chamber volume most efficiently. By weight, they are only 6 - 8% of the engine weight.

The annular combustion chamber consists of an outer and an inner shell, forming an annular space in which an annular flame tube is concentrically located. It is formed by external and internal mixers, which are united by a front-line device that includes from 10 to 132 (in the used designs) burners with nozzles (РД-20, АЛ-7Ф, НК-12, АИ-25, НК-8-2, Д-36, Д-136, Д-436, РД-33, АЛ-31 etc.).

The field of temperatures, velocities and pressures of gases at the exit from the annular chamber has the greatest uniformity. The annular chamber has low hydraulic losses, it is easier than in an individual chamber, the problem of tight connections is solved.

Disadvantages of annular chambers:

- the difficulty of fine-tuning to ensure stable combustion, rigidity and strength, especially with large sizes of flame tubes and high air flow rates at its high pressure;

- the complexity of inspection and repair of the flame tube in operation.

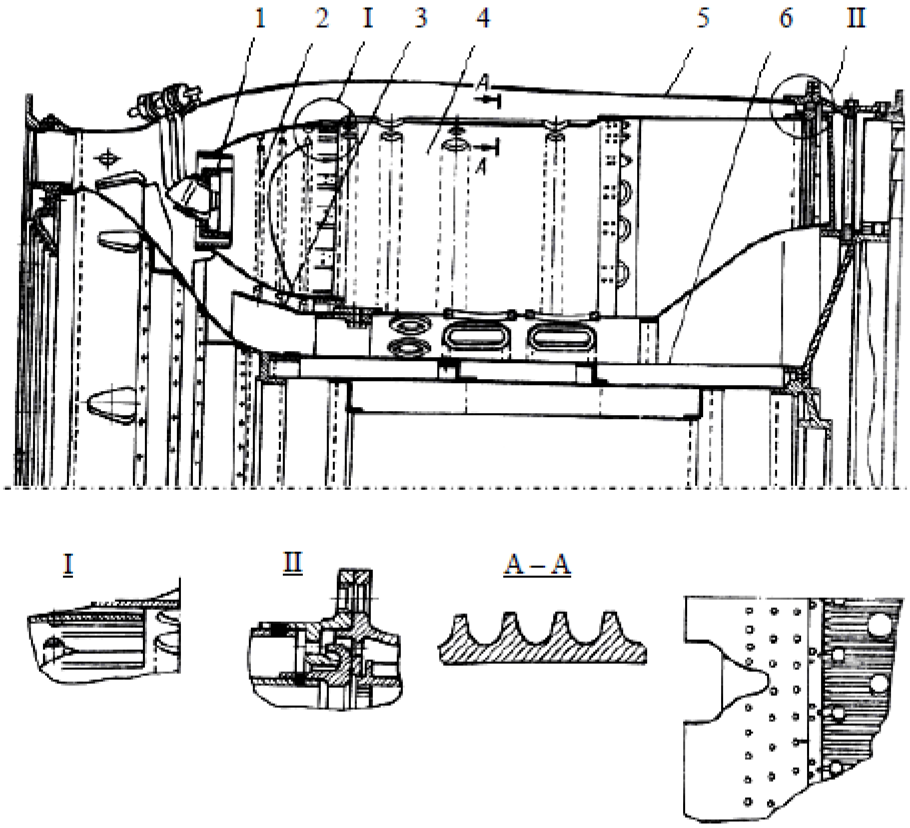


Figure: 1.5 - Annular combustion chamber: 1 - blade stabilizer; 2 - block of heads; 3 - deflector for leveling the air flow; 4 - fire tube; 5 - outer casing; 6 - inner casing

1.4.3.3 Tubular annular combustion chambers

Tubular annular combustion chambers combine some of the advantages of annular and tubular chambers (engines РД-9Б, АМ-3, Д-30П, Д-30-КП/КУ, Р-95Ш, etc.).

Structurally, they consist of separate flame tubes (from 9 to 14 pieces) located in an annular cavity formed by the outer and inner chamber housings, which are usually included in the power circuit of the engine stator, and are interconnected by a common gas collector and flame transfer pipes (Fig 1.6) The diametrical dimensions of the outer casing most often do not exceed the diameters of the compressor and turbines.

The gaps between the flame tubes are usually selected from the condition of ensuring ease of assembly and in the designs made are within

$$\Delta = (\mathbf{0,15} \dots \mathbf{0},21)D_{ftd} \qquad (1)$$

where D_{ftd}- flame tube diameter.

When the flame tubes are located, an attempt is made to ensure a uniform flow of air along the sections of the chamber from the outside and from the inside from the flame tube.

In terms of their mass characteristics, ease of operation and repair, and the complexity of fine-tuning, these chambers occupy an intermediate position between annular and tubular combustion chambers.

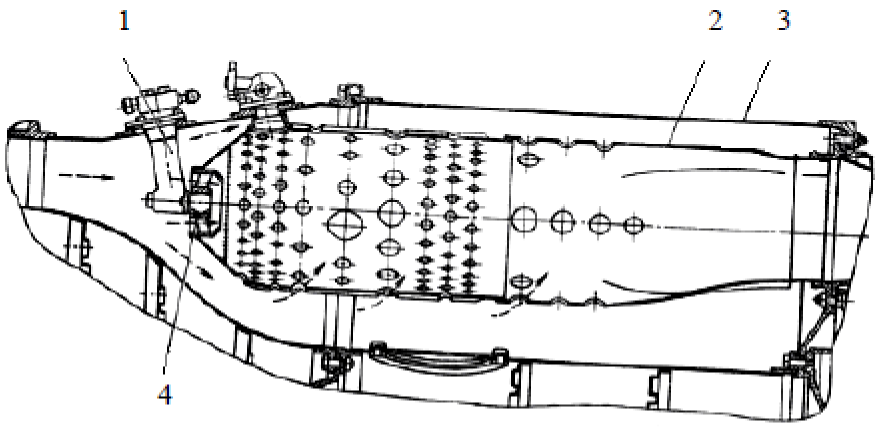


Fig 1.6 - Tubular-annular combustion chamber: 1 - nozzles; 2 - fire tube; 3 - camera casing combustion; 4 - stabilizer (swirler)

1.4.4 Classification by fuel combustion scheme

According to the fuel combustion scheme**: two-zone** and **two-tier**, provided heating a low level of emission of carbon monoxide CO and unburned HC hydrocarbons at low thrust modes and low level of emissions of nitrogen oxides at high thrust modes.

Comparative evaluation of tubular, annular and tubular-annular combustion chambers is given in Table. 1.1.

Table 1.1

Combustion chamber type	Advantages	Disadvantages
Tubular	Good mechanical strength. Good field matching fuel and air flows. Low air consumption during bench tests.	Large dimensions and weight. Significant loss of full pressure laziness. A large number of sealed connections. Difficulty with implementation transfer of flame.
Annular	Minimum length and weight. The minimum frontal area spare the engine. The minimum loss is complete the pressure. Rapid spread flame.	Large stresses in the external the shell of the flame tube. During bench tests of the COP air flow required equal to consumption in the engine. It is difficult to reconcile the flow fields fuel and air. It's hard to ensure stability outlet temperature fields.
Tubular annular	Good mechanical strength ness. Good field matching fuel and air flows. Low air consumption during bench tests. Small losses of full pressure laziness. Smaller than tubular chambers, length and mass.	Smaller than the ring, com- pact camera. Connecting required branch pipes. Difficulties in throwing the flame.

1.5 Construction elements of the combustion chambers of GTE

Regardless of the design of the main combustion chambers, all of them have in common the following design elements:

- diffuser;
- fire tube;
- combustion stabilizers (swirlers);
- mixers;
- starting ignitors;
- drain valves;
- fuel manifolds with fuel injectors.

For tubular and tubular-annular chambers, in addition, using There are flame transfer pipes and gas collectors.

In many aircraft engines, the air velocity at the outlet of the compressor can reach 150 m / s, and sometimes even higher. Combustion of fuel in an air stream with such a speed is unreasonable not only because of the great difficulties in the rotor process, but also because of the excessively large total pressure loss. Diffusers are used to reduce the speed of the air entering the combustion chamber and reduce the pressure loss to an acceptable level.

The purpose of the diffuser is not limited only to reducing the velocity, it must also ensure the conversion of the velocity head into pressure with minimal losses and create a stable uniform velocity field in front of the flame tube. In (Fig 1.7) presents two fundamentally different approaches to diffuser design. At present, a continuous (smooth) diffuser has found application, which provides the maximum degree of conversion of the velocity head into pressure, and a stall diffuser, in which there is a sharp expansion of the section with a flow stall. The breakaway diffuser is much shorter than the continuous one. Its significant disadvantage is increased losses pressure.

Both types of diffusers are widely used today. However, gradually, designers are beginning to give more preference to breakaway diffusers. This is mainly due to the technological difficulties associated with the manufacture of non-separable diffusers. The design of a continuous diffuser with a large opening angle (up to 35 - 40°) is also possible. To ensure uninterrupted flow, the flow in such a diffuser is divided into two or three channels with small opening angles (Fig 1.8).

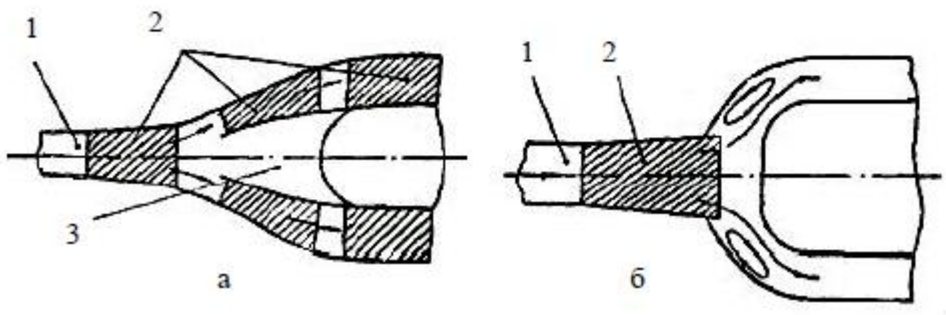


Fig 1.7 - Diffuser schemes: a) circular smooth diffuser: 1 - "soothing" section; 2 - areas of flow deceleration; 3 - air collector (frontal device); b) an annular diffuser with a sudden expansion: 1 - "soothing" area; 2 - section of the diffuser flow

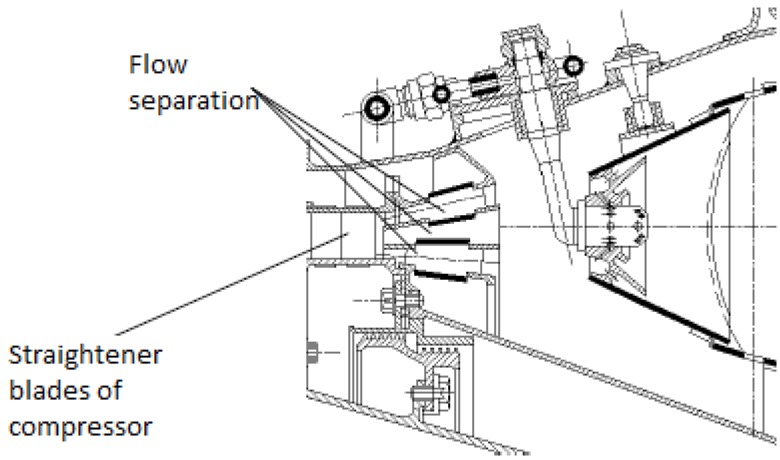


Fig 1.8 - Continuous split diffuser (annular combustion chamber of the АИ-25 engine)

The design of a diffuser, in which the flow is controlled by a vortex, is currently being investigated as promising (Fig 1.9). This is a sudden expansion diffuser that uses an efficient air extraction system to prevent flow separation. In diffusers with opening angles of 15 ° and 30 °, it is possible to halve the pressure loss during suction through the slot on the wall from 4 to 10% of the mass flow rate of the main stream.

By suctioning 4% of the air flow rate in the 35 ° diffuser, the pressure loss can be reduced to such a level as in a conventional 12 ° diffuser. The exhaust air can be used to cool the turbine blades.

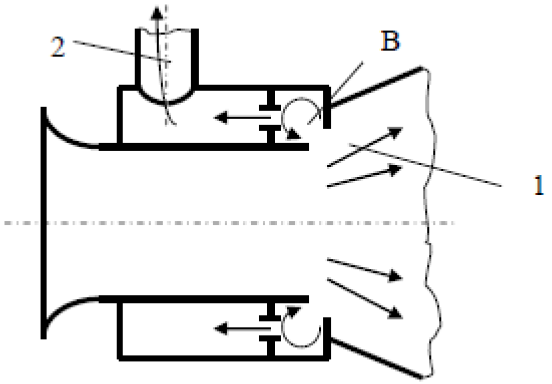


Fig 1.9 - Vortex controlled diffuser: 1 - turbulent region; 2 - air suction; 3 - vortex chamber

The design of the front-line device (FLD) determines the temperature of the gas at the outlet from the chamber, the thermal state of the flame tube wall, the completeness of fuel combustion, the level of smoke and the reliability of the chamber. Distinguish FLD with injectors that supply fuel directly to the zone of return currents, and FLD, in which the fuel is pre-mixed or sprayed in a certain amount of air before the mixture enters the cavity of the flame tube.

FLDs of the first type were widely used in the combustion chambers of the first gas turbine engines. Distinguish FLD "grating type" (combustion chambers of engines Д-30П, Д30П, Д25В, Д30КП/КУ), with a vane swirler (combustion chamber of the АЛ-7 engine), as well as with a stall swirler (combustion chamber of the АИ-20 engine). These FLDs have a number of significant disadvantages: tendency to warping; high smoke levels; high density of thermal radiation of the flame on the walls of the flame tube.

These disadvantages do not allow the use of these FLDs for promising engines with a large value of the air temperature behind the compressor. FLD of the second type with preliminary aeration of the fuel flame with primary air use the kinetic energy of the air flow to atomize the fuel (combustion chambers of engines Д-36, Д-136, НК-8-2, Р-29-300). FLD with pneumatic spray can reduce pressure in the fuel supply system.

In addition to the considered design options, there are combustion chambers, which are called evaporative by the type of FLD. They are characterized by low reliability of the evaporator tube located in the combustion zone.

In modern gas turbine engines, the average air flow rate at the inlet to the combustion chamber always exceeds the flame propagation speed, therefore, to ensure a stable combustion process, measures must be taken to ensure flame stabilization. Stabilization is carried out by creating local zones with low velocities of the air-fuel mixture and reverse currents in their head part (in the FLD) combustion products. Recirculating flows are usually organized by placing swirlers of the primary air flow or poorly streamlined bodies - stabilizers in the FLD, by creating jet near-wall flows (Fig 1.10).

The most common stabilizer designs are blade stabilizers, which are usually performed with 10-14 blades (ВК-1, РД-9Б, АЛ-7Ф engines). Conical stabilizers are also widely used, which work as bluff bodies, and the flow swirls behind the edges of the cones, as a result of which reverse currents arise (АИ-20, АИ-25 engines).

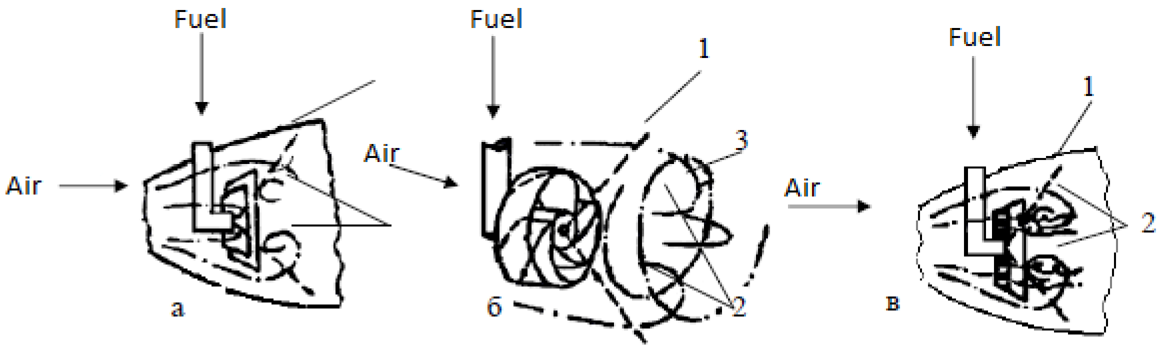


Fig 1.10 - Schemes of conical (a), scapular (b) and jet stabilizers: 1 - angle of the fuel spray cone; 2 - reverse flow zones; 3 - air vortex

FLD "grating type", having many small holes or notches in the end wall of the combustor, work as jet stabilizers. Small areas of openings for air supply in comparison with the cross-sectional area of the flame tube lead to the appearance in the center of a reduced pressure and a zone of return currents (engines Д-20П, Д-30П, Д-30КП / КУ, Д25В).

1.5.1 Flame tubes

The flame tubes operate in very difficult conditions, since the combustion process takes place at high temperatures (up to 1275 K) in an oxidizing environment. The presence of large temperature gradients, sharp thermal shocks when starting, stopping and changing the engine operation mode lead to the appearance of large temperature stresses in the parts of the flame tube, and the presence of free oxygen at high temperatures leads to gas corrosion and burnout of the walls. It is the resource of the flame tubes that determines the resource of the entire combustion chamber.

To ensure the required resource of the flame tube, the next series of constructive and technological measures. 1) The flame tubes are not included in the engine power circuit. 2) For the manufacture of flame tubes, high-quality high-temperature and heat-resistant nickel-chromium alloys (X20H80T, XH60B, XH70Ю, XH38BT, X24H25T). For combustion chambers operating at a temperature of 900 ° C, materials can be used X20H80T, XH38BT, XH75MBTЮ at a temperature of 950 - 1100 ° C – XH60B. These alloys have high strength, resistance to gas corrosion, tolerate vibrations well, provide sufficient ductility, ease of punching, drawing, bending and welding.

3) The connection between the individual elements of the flame tube is performed with low rigidity ("expansion joints") in order to reduce to the possible minimum the thermal stresses arising from unequal heating of these elements during engine operation.

4) In places of possible concentration of temperature stresses (except for holes, punching), flanging is performed, followed by blunting and polishing of the edges, seaming of caps or thickening of the walls due to welding of linings.

5) The walls of the flame tube are protected from heating from the side of the flame torch by creating a wall curtain of relatively cold "secondary" air (Fig 1.11).

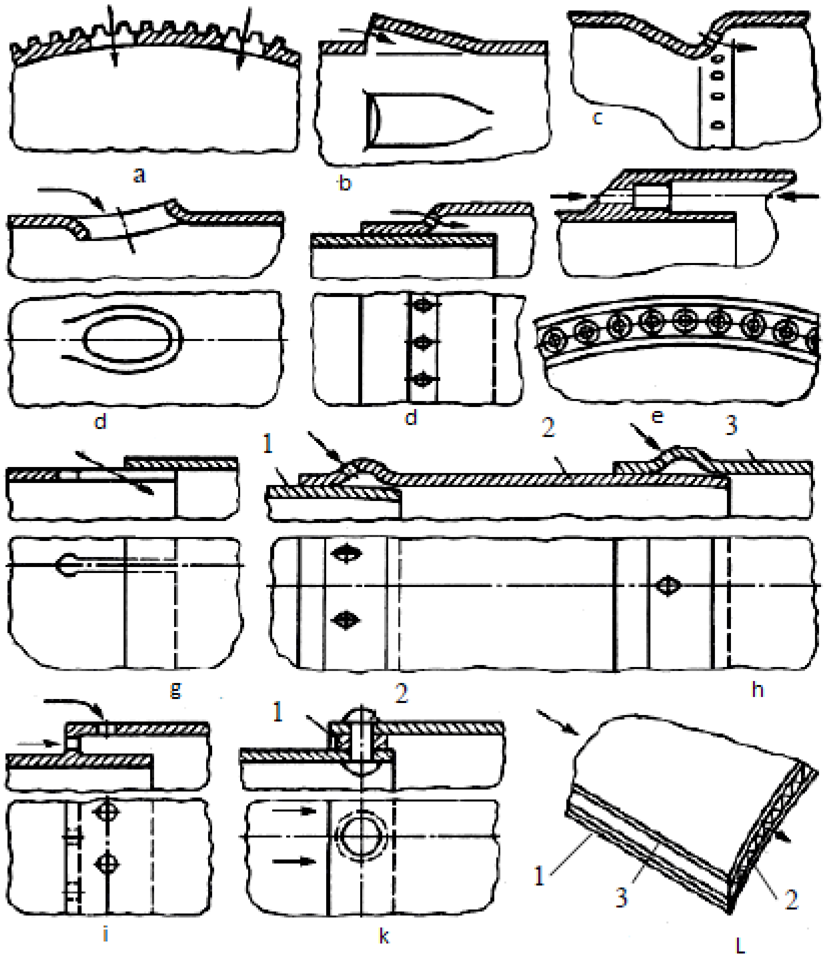


Fig 1.11 - Elements of flame tubes: a - ribbed surface; b - slots; c, d - holes; d, h - holes and guide visors: 1,2,3 - sections of the heat pipes; e - holes for double expansion; g - slots; i - the formation of protective layer; к - connection of sections with rivets: 1 - washer; 2 - rivet; L - honeycomb material: 1.3 - walls; 2 - corrugated filler

The main disadvantage of the film cooling system is that it uses only about 5% of the cooling resource of the cooling air coming from the compressor.

1.5.2 Mixers

The mixers supply secondary air to the inside of the flame tube to reduce the gas temperature in front of the turbine to a predetermined value. To prevent cold air from getting into the zone of return currents and not disturbing the fuel combustion process due to local cooling of gases, secondary air is introduced gradually through a system of holes or mixing pipes of various sections (Fig 1.12).

The secondary air jets must have a large penetration depth into the hot gas flow in order to reduce the gas temperature not only at the walls, but also in the core of the flow.

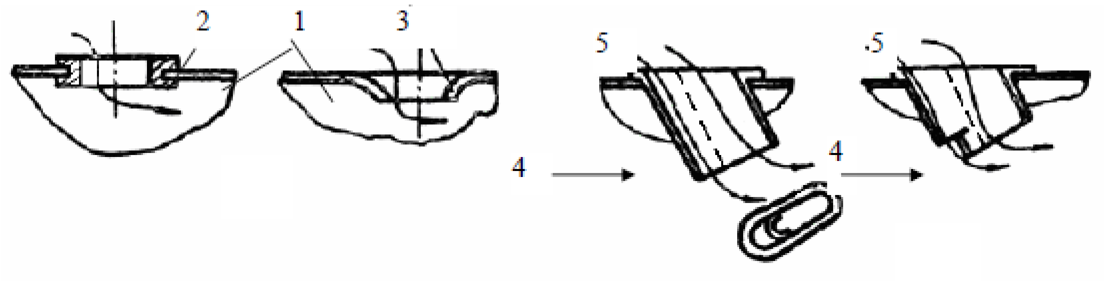


Fig 1.12 - Air supply elements: a - piston and edging; b - slotted branch pipes with protection of the leading edges from burnout: 1 - the wall of the flame tube; 2 - piston; 3 - edging; 4 - gas flow; 5 - secondary air flow

The depth of penetration of jets of secondary air into the flame tube of the chamber (Fig 1.13) is calculated from the dependence

$$H = d(0{,}3 + 0{,}415 \frac{W_o}{w_{CH}})(\frac{l}{d})^{0{,}63} \quad (2)$$

where H is the depth of penetration of the jet (Fig 1.13); d - hole diameter; W_o and w_{CH} are the velocity of the secondary air in the hole and the velocity of the carrying gas flow; l is the current length of the flame tube.

The disadvantage of the simplest approach through a round hole is a large temperature gradient between the edges of the hole and the area around it. This phenomenon contributes to the occurrence of significant thermal stresses, often leading to cracks and breakages of the flame tubes.

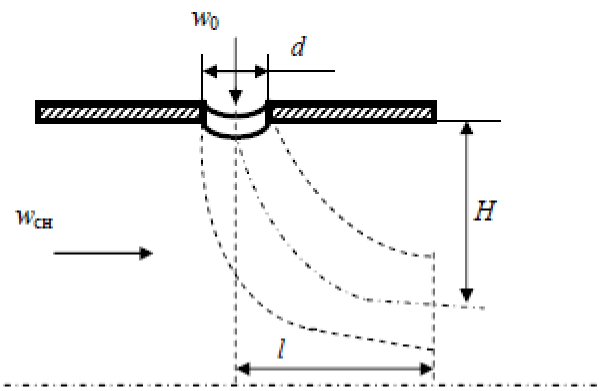


Fig 1.13 - Scheme for calculating the depth of penetration of secondary air

The depth of penetration can be increased by moving the cut of the hole inside the pipe by means of the slotted pipe. Disadvantage of such a structure is frequent flashing or burning of the pipes. To eliminate this defect, a branch pipe design is used, which provides cooling of its leading edge with specially supplied air.

The improvement of gas turbine engines occurs in our management of reducing the specific fuel consumption and the level of emissions of harmful substances. In turn, this makes it difficult to cool the flame tubes of the combustion chambers, which is caused by an increase in temperature and air pressure at the inlet to the chamber.

An increase in heat dissipation by means of longitudinal fins located on the outer surface of the pipe is used very rarely, which is explained by the low efficiency of convective cooling in comparison with film cooling, as well as an increase in the mass of the flame tube. In addition, the manufacture of the finned section is a laborious task.

Research is currently underway on new, more efficient cooling systems, such as sprayed film cooling, perforated sprayed cooling, and convective film cooling (Fig 1.14).

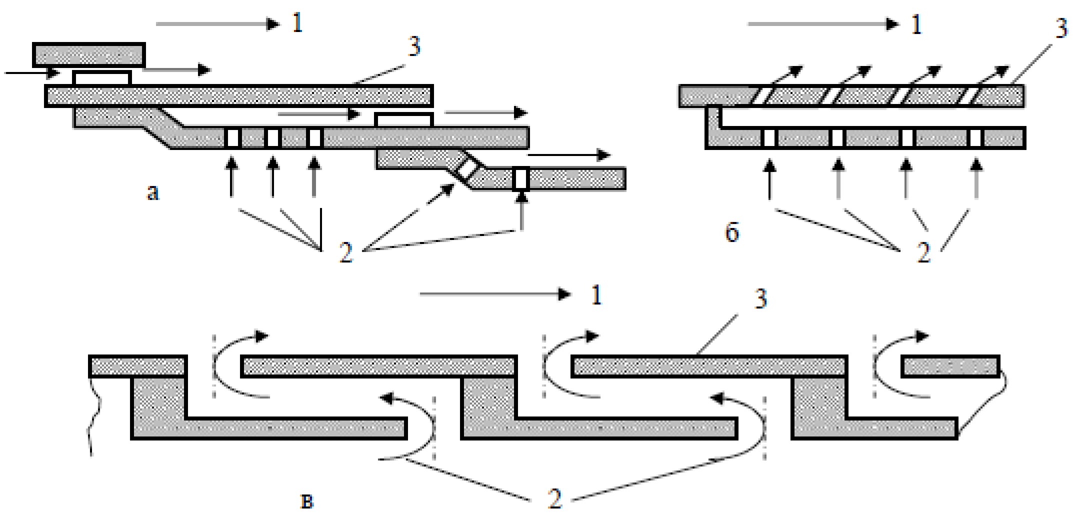


Fig 1.14 - Combustion chamber flame tube cooling systems: a) film cooling with irrigation; b) perforated cooling with irrigation; c) convective film cooling; 1 - gas flow; 2 - openings for supply and discharge of cooling air; 3 - inner wall of the flame tube

During operation of the combustion chamber, the enamel coating can be completely or partially worn out due to erosion entrainment by the gas flow.

The walls of the flame tube are covered along the inner surface a layer of heat-resistant enamel coatings. Such a coating with a low thermal conductivity provides a decrease in the wall temperature due to its thermal insulation properties and partial reflection of radiation from combustion products. For typical camera operating conditions combustion ceramic coating 1 mm thick with a thermal conductivity coefficient $\alpha = 0.66$ W / (m2 K) provides a decrease in the temperature of the chamber wall by 100 K. In addition, the enamel coating protects the flame tube metal from oxidation at high temperatures. For alloy ХН60В, enamel of the ЭВ-55 type is used, the main components of which are silicon dioxide and chromium oxide (thanks to the latter, the enamel is green). Heat-resistant enamels significantly reduce speed oxidation of metals at elevated temperatures. So, ЭВ-55 coating reduces the oxidation rate of alloy 1Х18Н9Т by 6 - 8 times. Significant disadvantages of enamel coatings are their low heat resistance and impact strength.

During the operation of the combustion chamber, the enamel coating can be completely or partially worn out due to erosion entrainment by the gas flow and restored by secondary application during engine repair.

The combustion chamber casing operates in lighter temperature conditions. It is often included in the power circuit of the engine, and, in addition, it is affected by a significant pressure drop between the environment and the internal cavity of the combustion chamber. Therefore, it is made from cheaper materials, such as КХ18Н9Т or ВЖ102 there are no such stringent requirements on the part of technology as for flame tubes.

To increase the efficiency and reduce the level of toxicity of the exhaust products of the combustion of gas turbine engines with high degrees of increase in air pressure in the compressor, studies are being carried out on two-zone and two-tier chambers with sequential and parallel arrangement of combustion zones.

In conventional combustion chambers with one combustion zone, high efficiency of the working process is ensured in the area of the design mode, and at low loads, the quality of combustion deteriorates sharply, the completeness of fuel combustion decreases to 88 - 93%.

When forcing the working volume on the load, the combustion process improves, but the yield of nitrogen oxides increases significantly due to an increase in temperature in the combustion zone.

In two-zone and two-tier combustion chambers, the noted disadvantages can be eliminated. In such chambers there is a standby combustion zone, which provides a low level of emission of carbon monoxide CO and unburned HC hydrocarbons at low thrust modes, and the main combustion zone, which allows to obtain a low level of emission of nitrogen oxides NOx on high thrust modes. The emission of the main toxic components according to the results of experimental studies was: NOx - 7.9 g / kg (35), CH - 0.3 g / kg (30), CO - 24 g / kg (73) in a radial-axial two-zone combustion chamber ; NO3 - 7.2 g / kg; CH - 2 g / kg; CO - 21 g / kg in a two-tier chamber. In parentheses, the values of the emission of toxic components of the serial chamber of the CF-50C engine (USA), which do not provide for measures to reduce the toxicity of combustion products, are given.

In the combustion chamber of the Pratt-Whitney E3 engine, the inner and outer shells of the flame tube are composite. The inner shell has 48 individual segments and the outer shell has 72.

The disadvantages of the considered design include: the complexity of the design; significant mass; great value. The use of a segmented flame tube design opens up possibilities for the use of ceramic materials. It should be noted that the technology for manufacturing segmented flame tubes is still under development. Work on improving the designs of two-zone combustion chambers should be aimed at simplifying them, reducing weight and cost without increasing the level of emission of harmful substances.

Conclusion to part 1

1) Combustion chambers are designed to convert the chemical energy of the fuel into thermal energy of the gas stream by combustion.

2) In all combustion chambers, stable combustion is ensured by creating a stream of hot gases in the chamber moving towards the main flow of air and atomized fuel (zones of return currents).

3) Combustion chambers can be classified by: the type of fuel-air mixture formation, the direction of flow of air and combustion products, design and layout on the engine, fuel combustion scheme.

4) Regardless of the design of combustion chambers they all have in common the following elements: diffuser, fire tube, combustion stabilizers (swirlers), mixers, starting ignitors, drain valves, fuel manifold with fuel injectors.

PART 2

CHARACTERISTICS OF THE GTE COMBUSTION CHAMBERS

2.1 Main combustion chamber parameters

As part of a turbojet engine, the main combustion chamber operates in a wide range of air and fuel consumption, temperature and pressure of the flow behind the engine compressor. The efficiency of a camera is determined by a large number of characteristics. The most important of them are the characteristics of the completeness of fuel combustion (full-scale characteristics) and stall characteristics, since fuel efficiency, emissions of pollutants (CO and CH) and engine performance depend on them. The overall characteristics of the combustion chamber are the dependences of the fuel combustion efficiency C_f on the air flow rate through the chamber O_{ch}, its temperature T_{ch}, pressure p_{ch} and the excess air factor a_{ch}. Discontinuous characteristics - the dependence of the reduced air velocity at the chamber inlet X_{ch} on the value of a_{ch} at the breakdown (termination) of combustion at different values of p_{ch} and T_{ch}.

The most important characteristics of the combustion chamber are complete and stall characteristics. Since these characteristics determine the efficiency and reliability of the engine. Full-fledged characteristics determine the dependence of the combustion efficiency ratio C_f on the parameters of the engine operating process (p_{ch}, T_{ch}, O_{ch}) and the excess air ratio in the chamber (a_{ch}). The emission of such pollutants as CO and C_XH_Y is closely related to the full-scale characteristics of the chamber, since the higher the value of C_f, the lower the emission of CO and C_XH_Y. The breakdown characteristic is the dependence of the excess air ratio, at which combustion is stalled in the combustion chamber, on the air velocity at the inlet to the combustion chamber at different values of p_{ch} and T_{ch}.

The value of the excess air ratio in the operating modes in the main combustion chamber is a_{ch} –2.5 ... 5. Homogeneous mixtures of this composition are non-combustible. Therefore, in the main combustion chambers, the air supply is distributed along the length, and the fuel is introduced at the head of the flame tube through the nozzles.

Due to this, in the first half of the flame tube, the mixture is much richer (a_{ch}) = 1.2 ... 1.8) than in the whole chamber, which ensures an intensive combustion process here.

At the head of the flame tube there is a circulation zone in which the combustion process is stabilized. The combustion chamber volume is divided into characteristic zones. The primary zone is located between the front device and the first row of large openings through which secondary air is supplied. Further, there is a secondary zone, which ends in the section, where the average value of the excess air factor in the main modes is a_{ch} = 1.5 ... 2. Here, in these modes, the combustion process ends. This is followed by a mixing zone, in which mixing air not used for combustion is supplied, and a gas collector. A significant amount of air (20 ... 30%) is supplied through the cooling system tangentially to the walls to protect them from contact with hot gas.

A large number of physical and chemical processes take place in the combustion chamber (fuel spraying, mixing it with air, burning fuel, mixing combustion products with air, etc.), the flow structure is very complex, therefore, a large number of scientific studies are devoted to the study of the working process of combustion chambers - research work, and the calculation of the characteristics of combustion chambers is a difficult task.

2.2 Combustion process termination

Under some conditions, the combustion process in the chamber may stop. The reason for this may be too much "lean" or "rich" of the mixture. The stationary combustion process is possible only with continuous ignition of the fresh mixture by some source (stabilization of the combustion process). In the combustion chambers, such a source is a high-temperature gas filling the circulation zone behind the frontal device of the main chamber or behind the bluff body (stabilizer) of the afterburner. In part of the circulation zone, volumetric combustion of a mixture of fuel and air occurs. Here a stationary process is possible provided that the residence time of the mixture in this zone is equal to or greater than the time of the chemical reaction of the mixture combustion. Failure to comply with this condition occurs combustion breakdown.

The mechanism of stabilization of the combustion process and the limits of stable combustion in terms of a_{ch}, speed and other parameters strongly depend on the specific conditions of fuel combustion and the design of burners.

2.3 Vibration state of combustion chamber structural elements

To assess the vibration state of the combustion chamber structural elements, a digital recorder-analyzer of dynamic processes "MIC-3M", manufactured by НПП "Мера", is used as a digital vibration recording system, to determine the source of increased vibration. It is designed to measure and analyze the signals of vibration sensors installed on the elements of the combustion chamber, as well as to measure other analog signals in the frequency band up to 28000 Hz with an amplitude of up to 8.5 V.

To determine the unevenness of the temperature field of the combustion chamber in the engine, the turbine nozzle apparatus is prepared (Fig 2.1).

To measure the temperature, 158 chromel-alumel thermocouples were installed on the blades of the prepared nozzle apparatus, forming five control belts. Temperature measurement is carried out in the range 0 ... 1100 ° C with an error of ± 1% at a confidence level of P = 0.95 [3].

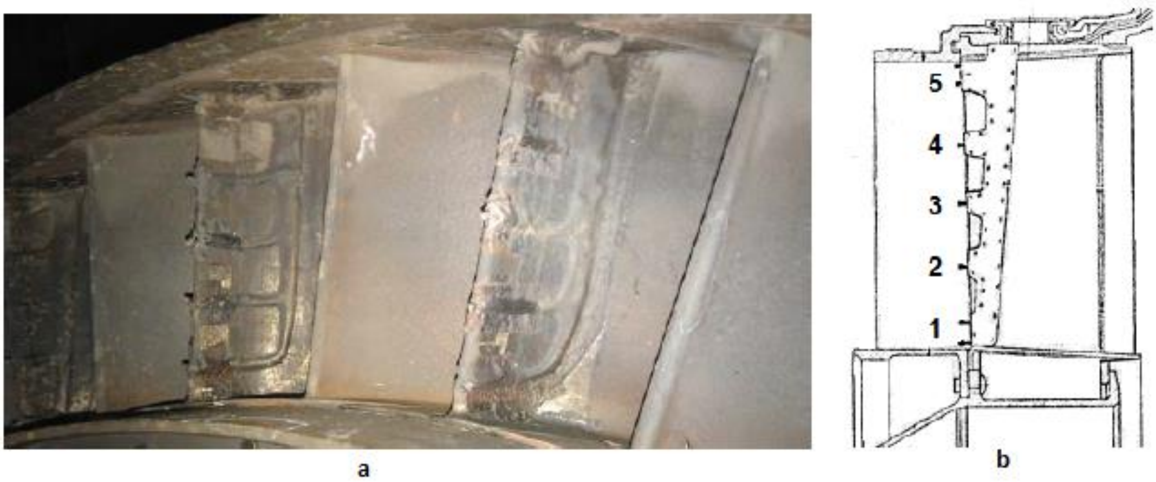


Fig 2.1 - Prepared nozzle apparatus turbofan engine (a); thermocouple layout (b)

2.4 Temperature measurement

In the process of engine operation, temperature measurements are made on the turbofan engine operating modes of interest from 8 to 20 MWt. Then the data is processed and circular and radial irregularities of the temperature field are formed.

On (Fig 2.2) we can see radial diagrams in absolute and relative values, from which it can be seen that with an increase in the regime, an increase in temperature is observed, as well as the similarity of curves at the exit from the chamber. Plots in relative values for each mode practically coincide.

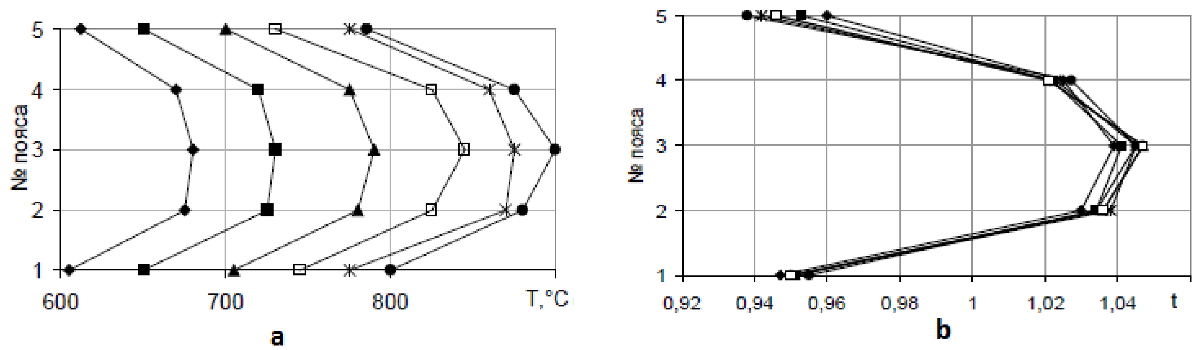


Fig 2.2 - Radial plot: a - in absolute values; b - in relative values.

Modes: ♦ *– 0,5N;* ■ *– 0,65N;* ▲ *– 0,8N;* □ *– N; * – 1,1N;* ● *– 1,2N*

In the process of engine operation, temperature measurements are made on the GTE operating modes of interest from 8 to 20 MW. Then the data is processed and circular and radial irregularities of the temperature field are formed.

Fig 2.2 shows radial diagrams in absolute and relative values, from which it can be seen that with an increase in the regime, an increase in temperature is observed, as well as the similarity of curves at the exit from the chamber. Plots in relative values for each mode practically coincide.

To determine the temperature state of the walls of the flame tube, they are prepared with the installation of chromel-alumel thermocouples, consisting of chromium-alumel and alumel thermal conductors wrapped in a silica thread. The thermocouple junction is attached to the parts of the flame tube by resistance welding, thermal conductors - with foil staples.

Thermocouples laid through the flame tube are assembled into a bundle and removed from the outer casing of the combustion chamber through an inspection hatch. Then the thermocouples are led to the preparation harness, which is connected to the recording equipment, equipped with a special thermal module. According to the test results, places of elevated temperature are identified, which should not be higher than the maximum permissible 1000 ° C for ЭП-648 alloy.

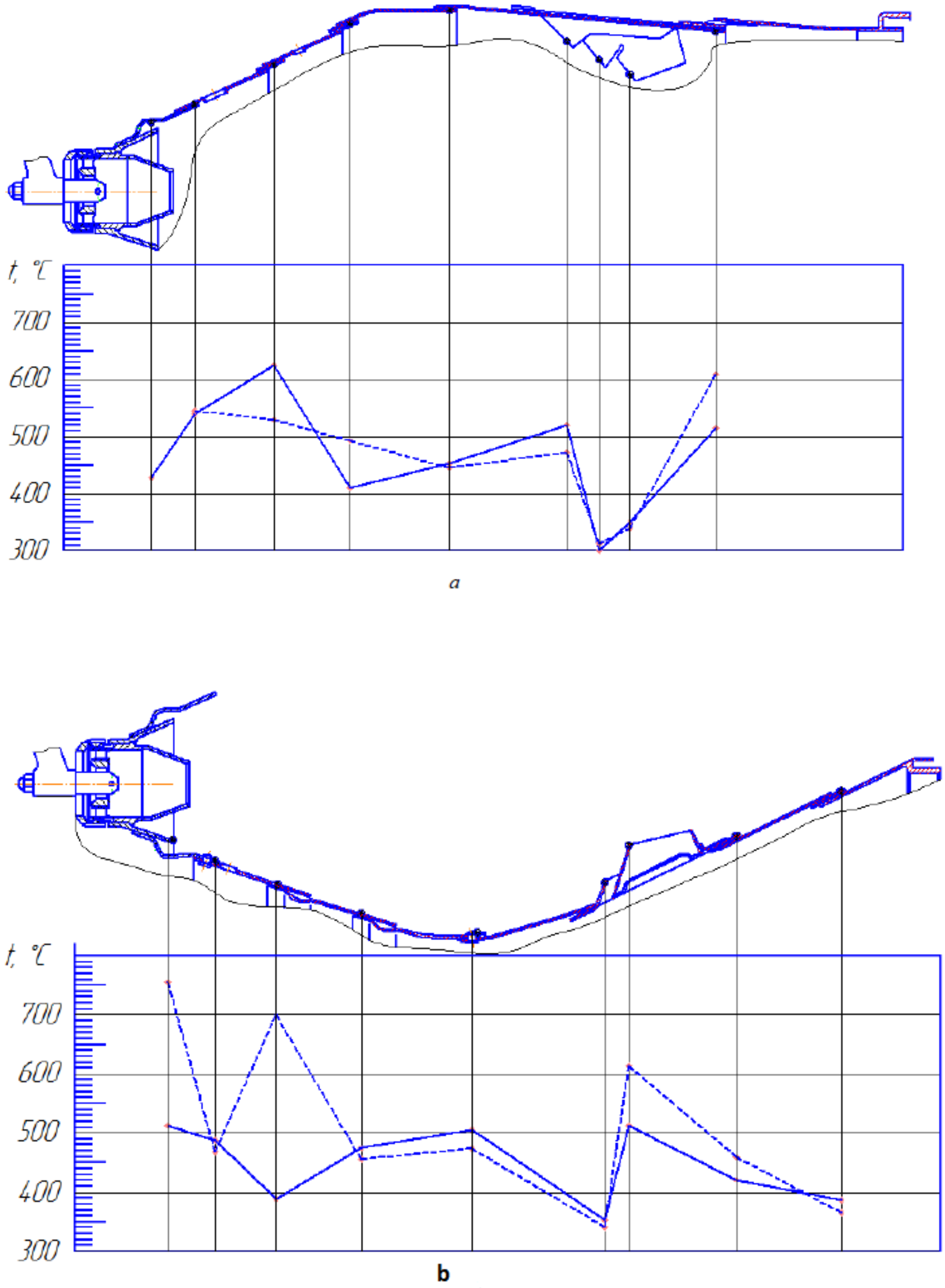
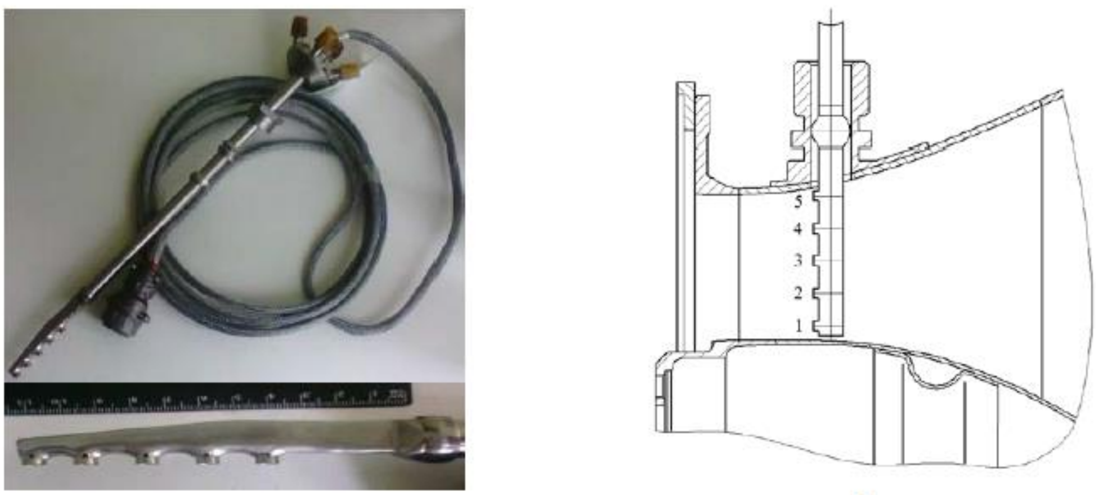


Fig 2.3 - Wall temperature along the length of the flame tube: a - outer casing; b - inner casing

Fig 2.3 shows the temperature distribution for the outer and inner walls of the flame tube at two engine operating modes. The figure shows that with an increase in the engine operating mode, the wall temperature in the combustion zone increases, but does not reach a critical value. Whence it follows that the installation of a new burner device did not lead to the emergence of high-temperature zones near the walls. As a result, there is no need to change the flame tube cooling system.

2.4.1 Combustion chamber temperature determination method

To determine the parameters at the inlet to the combustion chamber under different operating modes of the gas turbine engine, a pneumatic thermo-comb (Fig 2.4) is used.



a b

Fig 2.4 - Pneumatic thermo-comb: a - appearance; b - installation diagram

The comb is mounted by means of a fitting in the combustion chamber diffuser, practically at the inlet to the chamber, so that the pressure receivers are evenly distributed along the channel height. To determine the static pressure, a fitting is installed on the combustion chamber housing. With the help of a comb, such parameters at the inlet to the chamber as: air flow $G_{2air^{r}}$, normalized velocity λ_{ch} are estimated, and the distributions of velocities and pressures along the channel height are determined.

In Fig 2.5 shows the distribution of pressure and flow rate at the inlet to the combustion chamber.

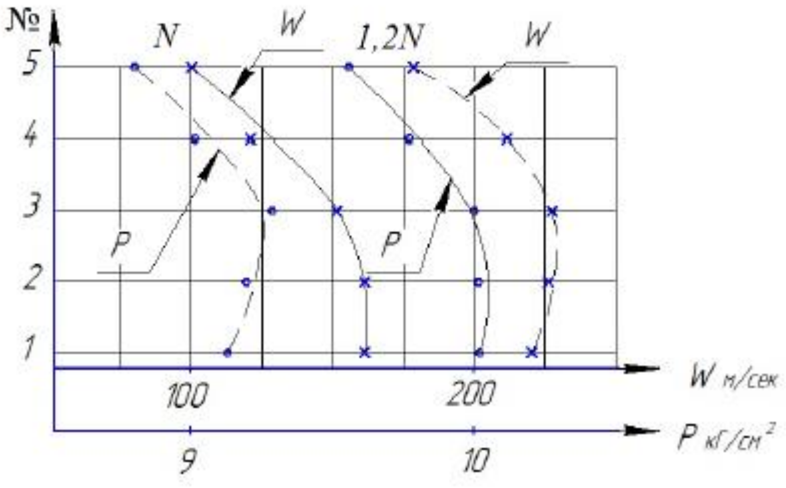


Fig 2.5 - Distribution of pressure and velocity along the height of the chamber diffuser: * - pressure; ● – speed

The figure shows that the maximum value of pressure and velocity is observed in the core of the flow at the outlet of the compressor.

2.5 Combustion stall diagnostics

The use of thermal imaging technology for diagnostics of combustion stall when testing the flame tube of the main combustion chamber of a gas turbine engine. Registration of thermal radiation of a jet of combustion products and internal elements is carried out using a short-wave thermal imaging system AGA-782 using spectral filters in several ranges from 3.2 to 5.6 µm. The thermal imager is installed along the axis of the flame tube. The output signal is recorded and processed on a computer in real time, which allows you to control the combustion process and the thermal state of the object during measurement.

The purpose of the measurement is to test the combustion chamber on hydrocarbon fuel and to determine the boundaries of stable operation with imitation of various flight modes on a gas-dynamic stand. The thermal imaging system is used in measurements to determine the moment of combustion breakdown, as well as to monitor the thermal state of heat-stressed elements in the visibility zone.

The analysis of combustion breakdown is carried out by the thermal imaging, non-contact method and by contact measurement of the stalled flow temperature by a thermocouple installed on the comb at the outlet of the combustion chamber. There is a possibility of application in thermal imaging measurements to determine the optical properties of the flow and the state of protective windows, data from the reference radiation sources.

At the stand (Fig 2.6), heated clean air is supplied through a pipeline through a measuring washer to the inlet of the flame tube or combustion chamber compartment. To characterize the chamber, a turret with combs prepared with thermocouples, total pressure receivers and sampling for chemical analysis is used. The hot choke simulates a turbine and regulates the chamber pressure. The flow of combustion products is preliminarily cooled by blowing cold air into the receiver. Observation of the combustion process and visual control at the place of turning of the outlet pipe is carried out using a thermal imager through a protective CaF2 glass 10 mm thick, which allows measurements in the spectral range of the thermal imaging system and ensures the safety of the scanner under thermal and power loads. The cooling of the glass surface and the blowing off of soot particles in order to reduce the effect of the flow is carried out by a blowing system that supplies air with a pressure drop of 5 ... 7 kg / cm2.

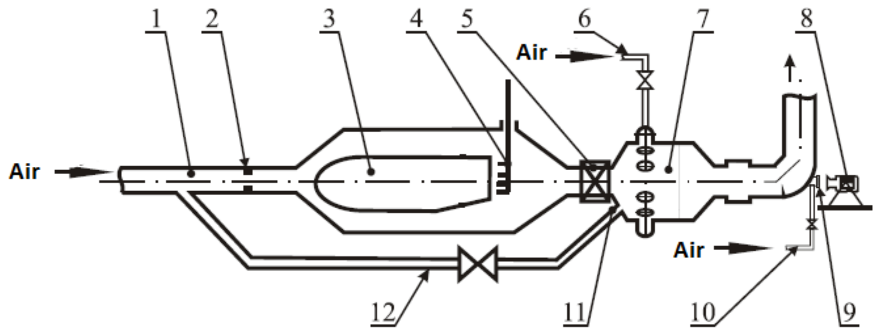


Fig 2.6 - Scheme for thermal imaging studies of the combustion chamber at the stand: 1 - inlet pipeline from the electric heater; 2 - measuring washer; 3 - fire tube of the Combustion chamber; 4 - comb of thermocouples, total pressure and receiver for sampling; 5 - hot choke; 6 - air supply for cooling combustion products; 7 - exhaust receiver; 8 - thermal imager; 9 - porthole with protective glass; 10 - air supply for cooling the window; 11 - reference radiation source; 12 - bypass line

When studying the processes of heat and mass transfer in the flows of combustion products, the spectral characteristics in a number of cases should be determined directly in the measurement conditions. For this, readings from a thermocouple installed in the visibility zone of the thermal imager on the blackened surface of the bypass line are used as a source of reference radiation. Reference radiation sources are a surface with known radiation characteristics and controlled temperature, according to the data from which the absorption and radiation of the jet are calculated in various modes, and the readings of the thermal imager are also corrected.

The radiation power from the flow of combustion products depends on the gradients of the temperature field, pressure, chemical composition, size distribution and concentration of soot particles. The degree of blackness of the jet of combustion products $\varepsilon \approx 0.2 \div 0.3$, and for oxidized metal parts $\varepsilon \approx 0.9$, therefore, with an increase in the excess air ratio, the radiation force from the jet decreases, and from heated metal parts it increases. Thermal imaging monitoring of the thermal state of the elements of the combustion chamber and hot choke was carried out using a spectral filter in the range from 4.76 to 5.6 μm, where the influence of triatomic gases H2O and CO2 is insignificant, and soot and solid particles emit.

2.6 Main gas-dynamic and design parameters of the combustion chamber

We can see the main gas-dynamic and design parameters of the combustion chamber using the example of the AL-31F engine. To compare the organization of the working process in the main chambers and afterburners, some parameters of the afterburner are given in Table 2.1.

The combustion chamber is straight-through, annular. The combustion chamber uses a diffuser with a fixed flow stall and a frontal device with vortex burners. The fixed stall stabilizes the flows in the annular channels of the chamber and the radial diagrams of the gas temperature in front of the turbine nozzle. At the same time, the shortened diffuser made it possible to shorten the overall length of the combustion chamber. Fuel in the combustion chamber is supplied through two fuel manifolds using twenty-eight centrifugal two-nozzle injectors. Fuel manifolds and fuel supply pipelines are thermally insulated with КЛ-11 silica tape and 1X18H9T metal screen.

The combustion chamber is started with the help of two surface discharge plugs installed with a ¼ pitch offset from the axes of the vortex burners.

Table 2.1

№	Parameter name	Value
1	Air temperature behind HPC, K	770
2	Air pressure behind HPC, kPa	237
3	Air flow, %: - through vane swirlers; - through the head of the flame tube	11 – 12 38 – 39
4	Excess air ratio	2,29
5	Combustion efficiency	0,98
6	Total pressure loss coefficient	0,059
7	Combustion chamber relative length	
8	Flame tube relative length	
9	Gas collector relative length	1,1
10	Diffuser opening degree	1,65

2.7 The main parameters of the afterburner

The afterburner combustion chamber of a turbojet by-pass engine contains a housing with a heat shield, forming a cooling channel, and a mixer for the flows of the external and internal circuits of the engine, installed with a gap relative to the chamber housing. The end face of the mixer is equipped with a visor located on its outer surface opposite the heat shield. The height of the visor is 0.5-3.0, and its length is 2.5-7.0 of the height of the cooling channel.

The invention helps to increase the length of the mixing zone of the flows of the external and internal circuits of the engine and to increase the efficiency of their mixing without reducing the cooling efficiency of the housing, which makes it possible to improve the efficiency of the chamber and the engine as a whole.

The afterburner combustion chamber of a turbojet engine containing a housing with a heat shield, forming a cooling channel, and a mixer for the flows of the external and internal circuits of the engine, installed with a gap relative to the chamber housing, according to the invention, the end of the mixer is equipped with a visor located on its outer surface opposite the heat shield, the height of the visor is 0.5-3.0, and its length is 2.5-7.0 of the height of the cooling channel.

The afterburner contains a body, a heat shield forming a cooling channel with the body, a mixer with a visor located on its outer surface opposite the heat shield, and a turbine fairing forming a diffuser with a heat shield in which a front-line device is installed.

The length of the visor should be 2.5-7.0 of the height H of the cooling channel. When the length of the visor is less than 2.5 N, the mixing efficiency decreases due to a decrease in the length of the zone, mixing to the front device, and when it is > 7.0 N, hot gases can be mixed into the cooling path and the mixing efficiency decreases due to a decrease in the radial depth of penetration of the jets air in the pockets of the mixer.

The afterburner combustion chamber of a turbojet bypass engine, comprising a housing with a heat shield, forming a cooling channel, and a mixer for the flows of the external and internal circuits of the engine, installed with a gap relative to the chamber housing, characterized in that the end of the mixer is equipped with a visor located along its outer surface opposite the heat shield , and the height of the visor is 0.5-3.0, and its length is 2.5-7.0 of the height of the cooling channel.

Conclusion to part 2

1) The main combustion chamber operates in a wide range of air and fuel composition, temperatures and pressure of the flow behind the engine compressor.

2) To measure the temperature in combustion chambers chromel-alimel thermocouples are used.

3) To determine the parameters at the inlet to the combustion chamber under different operating modes of GTE, a pneumatic thermo-comb is used.

4) The purpose of the combustion stall diagnostics is to determine the boundaries of stable operation.

5) Main parameters of combustion chamber are: air temperature, air pressure, airflow percentage, combustion fuel efficiency, total pressure lost, air excess coefficient.

PART 3

SCIENTIFIC RESEARCH OF HARMFUL SUBSTANCES EMISSION

3.1 The impact of aviation on the environment

The environmental impact of aviation occurs because aircraft engines generate heat, noise, particles and gases that contribute to climate change and global dimming. Airplanes emit particles and gases such as carbon dioxide (CO2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead and black carbon that interact with each other and with the atmosphere.

Despite the reduction in emissions from cars and more fuel-efficient and less polluting turbofans and turboprop engines, the rapid growth in air travel in recent years has contributed to an increase in overall aviation-related pollution. From 1992 to 2005, passenger traffic increased by 5.2% per year. Moreover, in the European Union, greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.

A comprehensive study shows that despite anticipated innovations in efficiency for airframe, engines, aerodynamics and flight, there is no end, even many decades, for the rapid rise in CO2 emissions from air travel and air travel due to the projected constant growth in air travel. This is because international aviation emissions escaped international regulation up until the three-year ICAO conference in October 2016, aligned with the CORSIA offset system, and with the absence of aviation fuel taxes around the world, lower tariffs are becoming more frequent than otherwise. case, which gives a competitive advantage over other modes of transport. If market caps are not put in place, this increase in aviation emissions would result in sector emissions accounting for all or nearly all of the annual global CO2 emissions budget by mid-century, if climate change is sustained until temperatures rise by 2 ° C, or less.

3.1.1 Air quality

Ultrafine Particles (UFP) are emitted from aircraft engines during near-surface operations, including taxis, takeoff, ascent, descent and landing, and idling at gates and taxiways. Other sources of UFP include ground support equipment operating around terminal areas. A 2014 air quality study found that the area exposed to ultrafine particles from takeoffs and landings on a leeward flight at Los Angeles International Airport is much larger than previously thought. Typical UFP emissions during takeoff are in the order of 1015-1017 particles per kilogram of fuel burned. Emissions of non-volatile soot particles are 1014-1016 particles per kilogram of fuel on a quantity basis and 0.1-1 g per kilogram of fuel on a mass basis depending on engine and fuel characteristics.

3.1.2 Climate change

Like all human combustion activities, most forms of aviation release carbon dioxide (CO2) and other greenhouse gases into the Earth's atmosphere, which contribute to accelerating global warming and (in the case of CO2) ocean acidification. The current volume of commercial aviation and its growth rate underscores this concern. Globally, about 8.3 million people fly daily (3 billion occupied seats per year), which is double the 1999 level. US Airlines alone burned about 16.2 billion gallons of fuel in the twelve months from October 2013 to September 2014.

In addition to the CO2 emitted by most aircraft in flight by burning fuels such as Jet-A (turbine aircraft) or Avgas (piston aircraft), the aviation industry also contributes to greenhouse gas emissions from airport ground vehicles and those used by passengers and staff. for access to airports; and emissions from energy production for airport buildings, aircraft manufacturing and airport infrastructure construction.

While the main greenhouse gas emissions from operating aircraft in flight are CO2, other emissions may include nitrogen oxide and nitrogen dioxide (collectively called nitrogen oxides or NOx), water vapor and particles (soot and sulfate particles), sulfur oxides, oxide carbon (which binds to oxygen immediately after CO2 is released), incomplete combustion of hydrocarbons, tetraethylelide (piston aircraft only) and radicals such as hydroxyl, depending on the type of aircraft used.

Emission Specific Gravity, the factor at which aviation CO_2 emissions must be multiplied to obtain CO_2 emissions equivalent to the average annual fleet status is in the range 1.3-2.9.

In 1999, the share of civil aircraft in flight for global CO_2 emissions was estimated at about 2%. However, in the case of high-altitude aircraft, which often fly near or in the stratosphere, altitude-insensitive CO_2 emissions can significantly increase the overall impact on anthropogenic (anthropogenic) climate change. A 2007 report published by the Institute for Environmental Change / University of Oxford found a range close to a 4 percent cumulative effect. In flight, supersonic aircraft contribute to climate change in four ways.

3.1.3. Carbon dioxide (CO_2)

CO_2 emissions from aircraft in flight are the most significant and most understood element of aviation's overall contribution to climate change. Currently, the level and consequences of CO_2 emissions are generally considered to be the same regardless of altitude (i.e. they have the same atmospheric effects such as emissions from soil). In 1992, CO_2 emissions from aircraft were estimated at about 2% of all such anthropogenic emissions, and this year, the concentration of CO_2 in the atmosphere attributable to aviation has accounted for about 1% of the total anthropogenic increase since the Industrial Revolution over the past 50 years.

3.1.4 Nitrogen oxides (NO_x)

At high altitudes, where large jet airliners fly around the tropopause, NO_x emissions are particularly effective in generating ozone (O_3) in the upper troposphere. Emissions of NO_x at high altitudes (8-13 km) lead to an increase in O_3 concentration compared to surface NO_x emissions, which, in turn, causes greater global warming. The effects of O_3 concentrations are regional and local (as opposed to CO_2 emissions, which are global).

NO_x emissions also reduce levels of methane, another greenhouse gas, resulting in climate cooling effects. But this effect does not compensate for the O3 effect of NOx emissions. It is now believed that atmospheric sulfur and water emissions in the stratosphere tend to deplete O3, partially offsetting the increase in O3 caused by NOx. These effects have not been quantified. This problem does not apply to aircraft that fly lower in the troposphere, such as light aircraft or many commuter aircraft.

3.1.5 Water vapor (H_2O) and bridges

One of the products of combustion of hydrocarbons in oxygen is water vapor, a greenhouse gas. Water vapor generated by aircraft engines at high altitudes, under certain atmospheric conditions, condenses into droplets, forming condensing trails or webs. Contraindications are visible linear clouds that form in cold, humid atmospheres and are believed to have a global warming effect (although one less significant than CO2 emissions or NOx-induced effects). Contral lines are uncommon (although not rare) from low altitude aircraft, or from propeller driven or rotorcraft aircraft.

Cyrus clouds have been observed to develop after persistent track formation and have been found to have a global warming effect beyond just cracking. There is some scientific uncertainty about the contribution of contour and cirrus cloud formation to global warming, and attempts to estimate the overall contribution to climate change in aviation do not include its effect on increasing cirrus cloudiness. However, a 2015 study found that artificial cloudiness caused by contrasting "flares" reduced the difference between day and night temperatures. The former decrease and the latter increase in comparison with the temperatures on the eve and the day after such outbreaks. On days with flares, the day / night temperature difference decreased by about 6 ° in the southern United States and 5% in the Midwest.

3.2 Greenhouse gas emissions per passenger kilometer

Passenger aircraft emissions per passenger kilometer vary greatly due to various factors such as aircraft size and type, altitude and percentage of passenger or cargo capacity on a particular flight, and travel distance and number of stops. In addition, the effect of a given amount of emissions on the climate (radiative forcing) is greater at higher altitudes: see below. Some representative data on CO2 emissions are provided in the LIPASTO survey of average direct emissions (excluding altitude radiation effects) of airliners, expressed as CO2 and CO2 equivalent per passenger kilometer:

- Domestic, short distances, less than 463 km (288 mi): 257 g / km CO2 or 259 g / km (14.7 oz / mile) CO2e
- Domestic, intercity, over 463 km (288 mi): 177 g / km CO2 or 178 g / km (10.1 oz / mile) CO2e
- Onward flights: 113 g / km CO2 or 114 g / km (6.5 oz / mi) CO2e

These emissions are similar to a four-seater with one person on board; however, flying often covers longer distances than by car, so the total emissions are much higher. For a passenger perspective, a typical New York to Los Angeles economy class round trip produces about 715 kg (1,574 lb) CO2 (but equivalent to 1,917 kg (4,230 lb) CO2 when the high altitude "climate impact" effect is accounted for). In the categories listed above, emissions from scheduled flights are significantly higher than turboprop or chartered jet flights. Around 60% of aviation emissions are from international flights, and these flights are not covered by the Kyoto Protocol and its emission reduction targets.

3.3 General climatic effects

In an effort to summarize and quantify the overall climate impact of aviation emissions, the Intergovernmental Panel on Climate Change (IPCC) has estimated that the total climate impact on aviation is 2 to 4 times greater than its direct CO2 emissions (excluding the potential for cirrus rise).

This is measured as radiation exposure. Despite the uncertainty about the exact level of NOx and water vapor exposure, governments have adopted a broad scientific view of their effects. Globally in 2005, aviation contributed "perhaps up to 4.9% of the radiation exposure." UK government policy statements highlight the need for aviation to address its overall impacts of climate change, not just CO2

The IPCC estimates that aviation accounts for about 3.5% of anthropogenic climate change, which includes both CO2 and non-CO2 effects. The IPCC has prepared scenarios for assessing what this figure might be in 2050. The central assessment of the case is that aviation's contribution could rise to 5% of total contributions by 2050 if no action is taken to tackle these emissions, although the highest scenario is 15 %.Moreover, if other industries reach significant reductions in its own greenhouse gas emissions, the share of aviation as a share of remaining emissions may also increase.

3.4 Control over emissions

In order to control the emission (emissions) of explosives in aviation transport in 1986, the Committee for the Protection of the Environment from Aviation (CAEP) of the International Civil Aviation Organization (ICAO) introduced the first International standards for the emission of NOx (nitrogen oxides), CO, CxHy (unburned hydrocarbons) and smoke. The main goal is to control air pollution in the airport area for the so-called standard take-off and landing cycle of engine operation. The standardization of the explosives emission of by-pass turbojet engines is made according to the value of the emission parameter nNOx ~ the ratio of the mass of the emitted explosives during the standard take-off and landing cycle of engine operation mode to the set take-off thrust of the engine. Since 1986, the practice of consistent tightening of the ICAO International standards for the reduction of NOx emissions from turbofan engines (CAEP / 2 in 1996, CAEP / 4 in 2004, CAEP / 6 in 2008) has been carried out while maintaining the emissions of other explosives at the same level.

The tendency to increase the effective efficiency of the turbojet engine in order to improve its fuel efficiency leads to an increase in the pressure and temperature of the gas in front of the turbine of modern turbojet engines and to a significant acceleration of the NOX formation reaction in the combustion chamber, which aggravates the problem of ensuring future standards for the emission of explosives. GEAE (USA) in 2009 certified the GEnx turbojet bypass engine with a take-off thrust of 255.3 kN for the Boeing 787 aircraft, which has an nNOx reserve of 65.8% in relation to the 2008 standards.

Advanced modern turbofan engines, created in the post-Soviet period, have the following I7NOX reserves in relation to the 2008 norms: D-436-148 (ГП «Ивченко-Прогресс», Ukraine) with a thrust of 68.8 kN - 21%; SaM-146 (НЛО «Сатурн», Russia and Snecma Moteurs, France) with 72.7 kN thrust - 17.4%.

3.5 Review of the mechanisms of formation of nitrogen oxides

Before proceeding with a review of the current state of work on the creation of low-emission combustion chambers, let us explain the ways of generating nitrogen oxides during the combustion of hydrocarbon fuel. Of the seven known nitrogen oxides $N0$, $N0_2$, $N0_3$, H_20, H_20_3, H_20_4 and H_20_5 only the first two oxides are stable in the atmosphere and are formed in sufficient quantities to be considered pollutants. Under the conditions of the combustion chamber operation at high modes, virtually all the emission of nitrogen oxides is N0. In the engine exhaust system and atmosphere, nitrogen monoxide is oxidized to nitrogen dioxide $N0_2$ which is a more stable molecule. Therefore, the emission of N0X = N0 + N02 is considered under the assumption that nitrogen oxides are in the form N02.

It is customary to distinguish four ways of formation of nitrogen oxides, which are called kinetic mechanisms. [4, 5]

1. Thermal mechanism of Zeldovich Y.B .;

2. Fast (super-equilibrium) Fenimore mechanism;

3. Fuel mechanism;

4. N_2O mechanism.

3.5.1 Zeldovich's thermal mechanism

This is a set of endothermic reactions of atmospheric nitrogen oxidation in high-temperature regions of the flame and in the post-flame zone. The mechanism is represented by the following reactions:

$$N_2 + O \rightleftarrows NO + N$$
$$N + O_2 \rightleftarrows NO + O$$

$$N + OH \rightleftarrows NO + H$$

To start the mechanism, atomic oxygen is required, which is formed as a result of the dissociation of molecular oxygen at gas temperatures above 1800 K. The rate of formation of nitrogen oxides exponentially depends on the temperature of the gas - it doubles with an increase in temperature by every 90 K at a gas temperature of more than 2200 K. With characteristic residence times of gas in the combustion chamber of gas turbine engines of the order of several milliseconds, the concentration of nitrogen oxides increases almost linearly with time and does not manages to reach its equilibrium value. Under the operating conditions of the combustion chamber in a gas turbine engine, the thermal mechanism is the dominant mechanism for the formation of nitrogen oxides [6]. An increase in the temperature and pressure of the air flow at the inlet to the combustion chamber leads to an increase in the rate of formation of nitrogen oxides.

3.5.2 Fenimore's Fast Mechanism

In low-temperature flames of an enriched fuel-air mixture (TBC), nitrogen oxides are detected already at very early stages of the combustion process, which contradicts the data on the relatively slow nature of nitrogen oxidation by the thermal mechanism (hence the name - "super-equilibrium"). In the process of dissociation of fuel molecules, radicals are formed in large quantities (CH2, C, C2H, etc.) capable of bonding with molecular nitrogen. Under the conditions of enriched TBC, as exemplified by the reaction with CH, the mechanism appears to be a complex chain of chemical reactions:

$$CH+N_2 <R> HCN+N$$

$$N+0_2 <\hat{}N0+0$$

$$HCN+OH\ CN+H_2O$$

$$CN+0_2 <-> N0+CO$$

Thus, part of nitrogen oxidation in the Fenimore mechanism corresponds to the reaction of the Zeldovich thermal mechanism, but the breaking of the triple bond in the nitrogen molecule is carried out by the fuel radical.

The rate of formation of nitrogen oxides by a fast mechanism is proportional to the concentration of carbon atoms and does not depend on the specific composition of hydrocarbon molecules, since the defining molecule of the mechanism is HCN. As a rule, the fast mechanism is the second most important in the formation of nitrogen oxides in the combustion chamber, but under the conditions of modern combustion chamber operation, its contribution can be up to 5%. With a significant suppression of the thermal mechanism in order to create a combustion chamber with ultra-low emission of nitrogen oxides, the contribution of the fast mechanism becomes decisive. In a lean mixture, the rate of formation of nitrogen oxides by a fast mechanism does not depend on pressure.

3.5.3 Fuel mechanism

Denotes a set of reactions for the oxidation of chemically bound nitrogen in fuel. Depending on the type of fuel used, the mass fraction of chemically bound nitrogen can vary between 0.002% ... 2%. The lower limit corresponds to light distillate fuels, including aviation kerosene. The upper limit corresponds to heavy refined products, certain types of coals and low-calorific gases. When the mass fraction of bound nitrogen in the fuel is less than 0.5% by mass, it is almost completely converted into nitrogen oxide during combustion. The degree of conversion of bound nitrogen into nitrogen oxide during combustion increases slightly with increasing flame temperature. In this case, the composition of nitrogen-containing fuel components does not affect the degree of conversion of nitrogen into nitrogen oxide.

During the thermal decomposition of anilines, pyridines that make up the fuel, radicals (secondary intermediate nitrogen-containing components) can form in the reaction zone. When these radicals interact with oxygen, nitrogen oxides are formed, and when interacting with nitrogen oxides, they can reduce nitrogen. The HCN radical is a fundamental component of the further reaction if nitrogen is contained in the form of aromatic amines. If nitrogen is contained in the form of aliphatic amines, then NH3 becomes a fundamental component for further reactions. In the combustion of aviation kerosene, the fraction of nitrogen oxides formed by the fuel mechanism can be considered negligible.

3.5.4 N_2O mechanism

In this mechanism, nitrous oxide acts as an intermediate component for the reactions of formation of nitrogen oxides. Since the formation of N20 occurs with the participation of an intermediary molecule, but with a change in the number of moles of the substance, this mechanism "works" at moderate pressures. Atomic oxygen is required to start the reactions, so the process goes better with an excess of air. Under the operating conditions of the combustion chamber, the amount of nitrogen oxides formed by this mechanism does not depend on the residence time of the gas in the flame tube. This is the third most important mechanism for the formation of nitrogen oxides in the combustion chamber of aviation gas turbine engines. In combustors with measures to suppress the thermal mechanism, the ratio of the fraction of nitrogen oxide formation by the fast mechanism to the fraction of nitrogen oxide formation by the N20 mechanism can reach 2: 1.

3.6 Review of concepts for reducing nitrogen oxide emissions in the combustion chamber of aviation GTE

Consider the basic concepts for reducing nitrogen oxide emissions in aircraft combustion chambers. The focus of consideration was those of the concepts, the effectiveness of which was demonstrated at the fifth and higher technology readiness level on the NASA scale.

This is due to the fact that it is in practice (according to the results of field tests) that the natural selection of the most adapted low-emission combustion technologies to the real operating conditions on the engine occurs. Thus, only combustion chambers made according to DLE technology are considered, that is, with “dry” methods of suppression of nitrogen oxides emissions (without injection of water and ammonia into the Combustion Chamber), which do not use catalytic methods.

In Section 3.5, it was shown that the main mechanism for the formation of nitrogen oxides in the combustion chamber of aircraft gas turbine engines is the Zeldovich thermal mechanism. Therefore, the whole idea of reducing the emission of nitrogen oxides is reduced to reducing the flame temperature as much as possible in the combustion region inside the flame tube and / or the gas residence time in stoichiometric regions. For further consideration of the principles of the concepts in Fig. 3.1 presents a typical calculated dependence of the combustion zone temperature and the concentration of nitrogen oxides and carbon monoxide depending on the excess air ratio. In the so-called "traditional" type Combustion Chambers, combustion occurs in a diffusion mode in areas with a stoichiometric composition of the mixture. The temperature of the stoichiometric mixture in the traditional combustion chamber is determined by the temperature and pressure of the air flow at the entrance to the combustion chamber and the radiation intensity of the combustion products and, therefore, is not amenable to the desired regulation. Traditional combustion chambers use the following techniques to reduce nitrogen oxide emissions:

1. Depletion of the primary zone, which potentially increases the emissions of CO and unburned hydrocarbons.

2. Enrichment of the primary zone, which potentially increases smoke emissions.

3. Increased spatial homogeneity of the TBC distribution.

4. Reduced residence time in the combustion chamber, potentially leading to an increase in CO emissions.

With the help of the above methods, it is possible to have a small impact on the emission of nitrogen oxides without impairing other characteristics of the Combustion chamber.

Several basic concepts of low-emission combustion have been developed to be able to control the temperature of the flame and combustion products, which are discussed below.

3.6.1 LPP concept

The Lean Premixed Pre-vaporized concept represents the radical and most effective solution to reduce the rate of NOx formation. It is based on the combustion of a lean homogeneous Fuel-Air Mixture, which is prepared in a special device - a mixer (premixer) Fig 3.1.

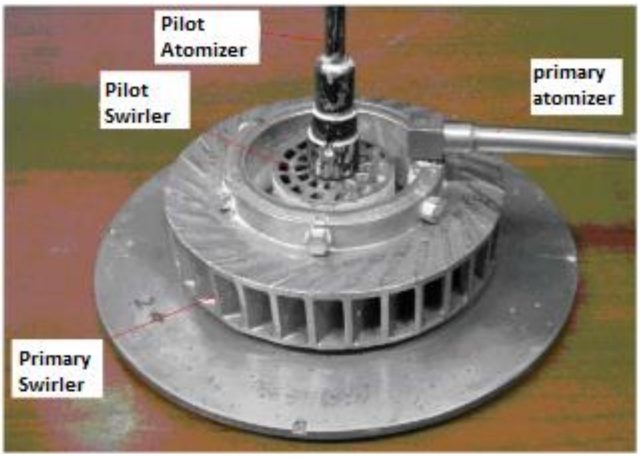


Fig 3.1 – LPP Premixer

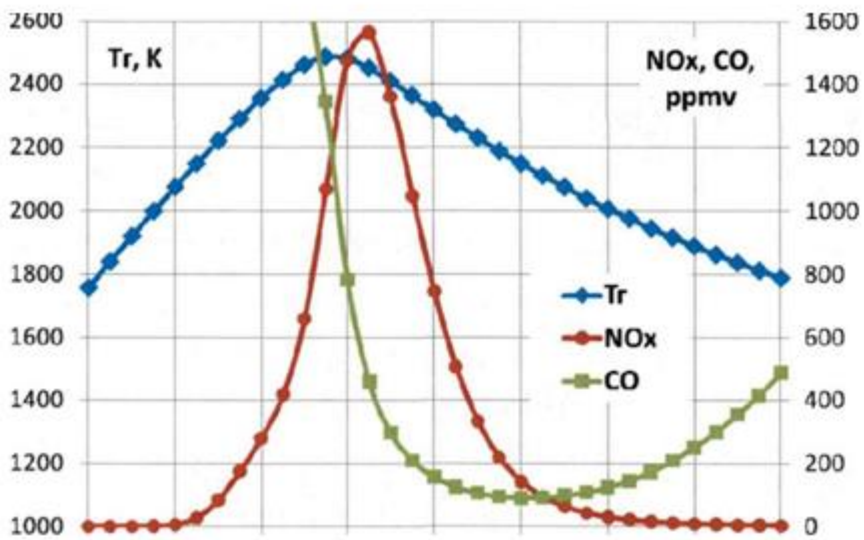


Fig 3.2 - Influence of the excess air ratio in the combustion zone on temperature, concentration of nitrogen and carbon oxides

The preparation involves injection of liquid fuel, evaporation of droplets of fuel (aerosol) and mixing with air until a homogeneous mixture is achieved. Then the homogeneous fuel-air mixture from the mixer enters the flame tube and burns. As seen from Fig 3.2, combustion of a lean mixture significantly suppresses the generation of nitrogen oxides by the thermal mechanism. A significant depletion of the combustion zone leads to an increase in carbon monoxide emission and a decrease in combustion efficiency. Therefore, in each specific case, an optimum is sought between the emission of nitrogen oxides and carbon monoxide. An advantage of this concept is the breakdown of the residence time feedback between NOx and CO when the thermal mechanism of NOx formation is suppressed.

In principle, this concept is similar to the piston internal combustion engine of the carburetor type. There are two possible ways to implement this concept:

• combustion of homogeneous TBC as a result of volumetric reactions in the gas mixture (the so-called "flameless combustion" - FLOX);

• combustion of homogeneous TBC in the flame front.

Flameless combustion can only be used in stationary installations, as it requires a developed recirculation zone of fresh TBC with combustion products and a long residence time, as a result of which stable combustion of poorer air-fuel mixture is possible, allowing to achieve ultra-low NOx emissions [7]. FLOX also has an indirect analogy with internal combustion engines - EGR technology for suppressing the formation of nitrogen oxides in the combustion chamber of gasoline and diesel engines by feeding part of the combustion products back into the cylinder, which are an inert impurity and therefore reduce the combustion temperature and oxygen concentration in the fresh mixture.

In practice, in the Combustion Chamber of an aviation gas turbine engine, it is possible to realize the combustion of a homogeneous mixture only in the flame front. The main problem is precisely the preparation of a technically homogeneous mixture with the required degree of compositional heterogeneity. The main associated problems that inevitably arise with this method of implementing the concept:

1. Low stability of fuel combustion in the flame front;

2. Excitation of vibration combustion modes;

3. Decreased combustion efficiency and increased levels of nitrogen oxide and unburned hydrocarbon emissions at regimes close to idle;

4. High probability of flame breakthrough and self-ignition of the fuel-air mixture in the zone of its preparation;

5. Complication of the fuel supply system and the automatic control system of the combustion chamber.

The described problems in the implementation of this concept in the conditions of the Combustion Chamber of aircraft GTEs did not allow for more than 30 years of development history of the Combustion Chamber of this type to put them into operation.

In the combustion chambers of industrial gas turbine engines, these problems were largely overcome, and already in 1984 the Swiss Brown Boveri Company (after the merger in 1990 with the Swedish ASEA became known as ABB) for the first time in the world put into commercial operation a GT13D gas turbine unit with a low-emission combustion chamber according to the scheme LPP [7]. To date, this concept is increasingly being used to meet the tightening requirements for the emission of harmful substances as developed by developers in different countries.

Investigation of ways to implement the LPP concept in aviation Combustion Chambers led to the understanding that in the case of uniform distribution of fuel droplets with a diameter of 10 ... 20 μm in the volume of the combustion zone, it is possible to implement the so-called "pseudo-homogeneous" fuel [8]. This is a major step forward in the fight against flame slip and self-ignition, especially for engines with high thermodynamic cycle parameters.

3.6.2 RQL concept

Initially, this concept was developed for Combustion Chambers designed to operate on liquid fuel with a high content of chemically bound nitrogen [9]. The concept of "rich and lean" type Combustion Chambers is based on the idea of a two-zone chamber (Fig 3.3).

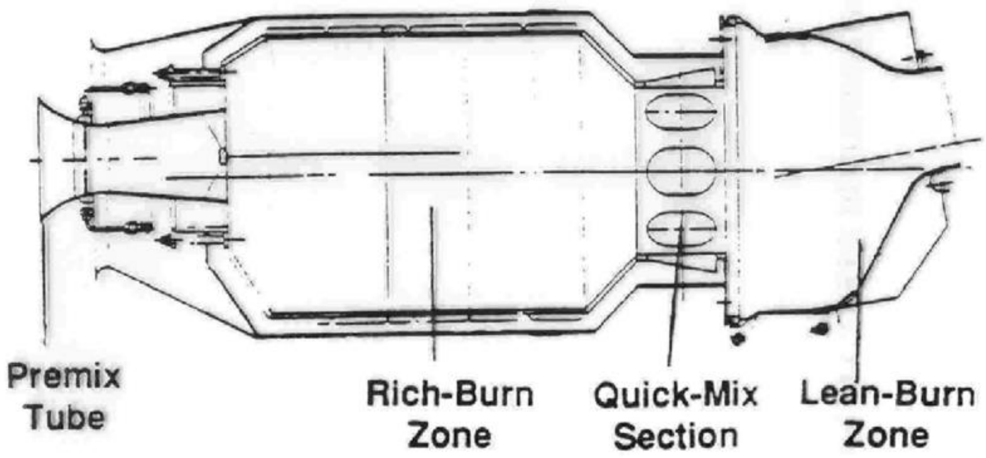


Fig 3.3 – RQL combustion chamber

In the front part of the chamber (primary zone), combustion of a homogeneous fuel-air mixture with an average excess air ratio of less than one (rich mixture) is organized, and in the outlet part (secondary zone) - a homogeneous fuel-air mixture with an average excess air ratio of more than one (lean mixture). Zonal separation is aimed at maintaining the average gas temperatures in the zones below the dissociation temperature of molecular oxygen, after exceeding which a rapid increase in the rate of formation of nitrogen oxide by the thermal Zeldovich mechanism begins (see Fig 3.2).

The main problem of such Combustion Chambers is the difficulty of implementing a quick and inevitable transition through the local stoichiometric zones when supplying air to the secondary zone for the organization of homogeneous combustion of the lean mixture.

In the RQL concept, for mixing the combustion products of the primary zone with air, it is required to ensure that the characteristic time scale of the Kolmogorov turbulent vortex is less than the characteristic time of the chemical reaction of the reactants in the secondary zone. The reagents of the gas mixture in the primary zone are high-temperature radicals of fuel molecules with high reactivity (due to high temperature and low activation energy), as well as products of incomplete combustion. Therefore, it is not possible to fully implement the RQL concept using gas-dynamic methods alone. For the technical implementation of the concept, a heat recuperator is required between the primary and secondary zones of the flame tube. The mixing (or rapid dilution) zone is a critical part of the flame tube for the success of the RQL concept.

In a typical implementation of the RQL concept, most of the fuel in the secondary zone will be combusted in diffusion mode.

Combustion chambers based on RQL combustion organization scheme has its own unique emission characteristic (dependence of the emission index on the excess air ratio in the combustion chamber). The uniqueness is manifested in the fact that the dependence has a minimum at some intermediate point of the compressor station operation according to the excess air ratio. In this work, based on the use of reactor models, the work process in the CC is considered according to the RQL scheme, in which, in particular, an explanation of the form of the emission characteristic is given.

The position of the minimum of the function NO_x = f {ocCC} is determined mainly by the gas temperatures in the rich and lean zones of the CC. By distributing the air flow rates in the combustion chamber zones (ai), it is possible to control the position of the minimum emission characteristic of the combustion chamber in coordinates (NO_x, a_{cc}) and adjust the zones to work with each other in such a way that the minimum of the emission characteristic falls on the required range of operating modes of the combustor along ax. Reducing the proportion of air flow in the rich zone of the combustion chamber allows you to reduce the value of the minimum with a simultaneous shift towards higher values of ax. When the gas temperature in the lean zone reaches 1800 K and more, the emission perfection is entirely determined by the parameters of the lean zone. As a result, all emission characteristics merge into one curve, and the effect of the rich zone is leveled (Fig 3.4).

Often, diffusion-type CSs are unreasonably referred to as "rich-poor" type CSs, because they also have:

• On average, the fuel-air mixture enriched in composition burns up to air jets from the main holes;

• The already lean mixture burns out behind the air jets from the main holes. However, the authors see that the fundamental points are:

• Homogeneity of the fuel-air mixture in the primary zone;

• Fast transition from rich to lean mixture.

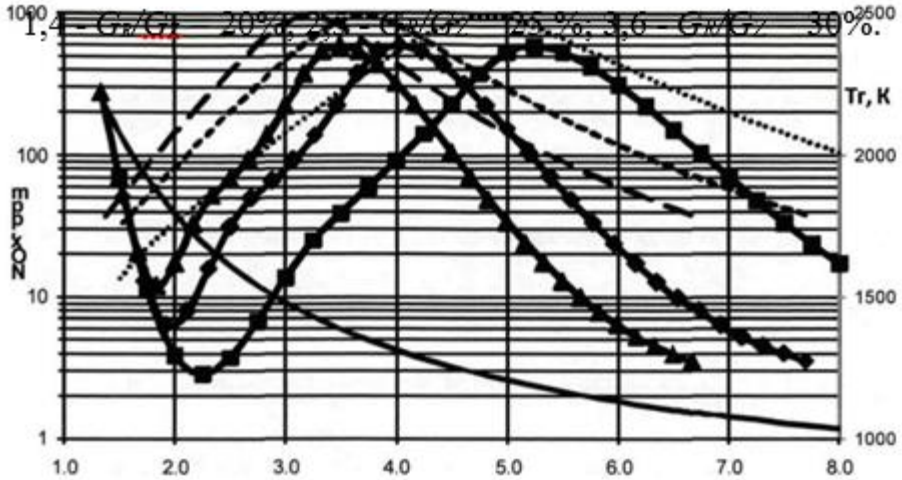


Fig 3.4 - Influence of air distribution between the primary and secondary zones on the NO_x (1,2,3) concentration reduced to 15% O_2, the gas temperature of the primary (4,5,6) and secondary (7) zones.

The thesis about the rate of transition of the mixture through stoichiometry (on average), apparently, does not make any sense at all in relation to fire tubes without heat recovery, because they can be considered equivalent if they have identical systems of main openings on the flame tube and the relative air flow through these openings.

Ultimately, the judgment on the classification of a particular CC design as a "rich-poor" type should be based on the experimental emission characteristic of the CC under consideration.

Benefits of RQL over LPP

1. No problems with combustion stability;

2. Using the Reburn Mechanism to restore nitrogen rich the environment of the primary zone;

3. Low probability of flame breakthrough and spontaneous ignition of the TBC in the area of its preparation;

4. Less stringent requirements for the homogeneity of the mixture composition in the primary zone of the flame tube [10].

5. Operational reliability and simplicity of the fuel supply system.

Disadvantages of RQL over LPP

1. The inevitable transition through the stoichiometric composition of the mixture when the gas moves from the primary to the secondary zone;

2. Significantly more intensive formation of soot particles in the primary zone;

These disadvantages lead to the fact that, in practice, combustion chambers according to the RQL combustion organization scheme have a significantly higher emission of nitrogen oxides and smoke number in comparison with LPP. We also find there that the theoretical estimates of a number of authors prove the emission competitiveness of RQL in comparison with LPP in the ideal case, forcing to focus on the problem of rapid freezing of combustion products of the primary zone. In practice, the RQL scheme is indeed more preferable when burning heavy distillate fuels.

3.6.3 Staged Combustion Concept

The essence of the concept of zoned fuel combustion is to maintain the temperature in the combustion zone between the lean-off limit and the dissociation temperature of molecular oxygen to suppress the thermal mechanism of nitrogen oxide formation.

Zoning is achieved through the optimal distribution of fuel consumption between the zones of the Combustion Chambers of the fixed geometry. Each zone is designed to provide a certain range of characteristics of the Combustion Chamber. In engine-building practice, two-zone Combustion Chambers with an axial (sequential) arrangement of combustion zones and a radial (parallel) arrangement of combustion zones have become widespread. Typical distinguishing features of CC with staged combustion:

1) Weakly forced pilot zone. Combustion in this zone should ensure the efficiency of the combustion chamber in the entire specified range of engine performance (including emissions of CO and unburned hydrocarbons) and serve as fire support for the operation of the main zone. The excess air ratio is about 1.

2) The main zone provides optimal characteristics of low-emission combustion of fuel at high engine operating conditions (first of all, low emission of NO_x). Excess air ratio greater than 1.

The radial arrangement of the combustion zones in comparison with the axial arrangement of the zones allows:

1) Reduce the length of the flame tube and the weight of the entire CC module.

2) It is more efficient to solve the problems of rotor dynamics.

3) Possibility of using fuel injectors of both zones, combined in one body (anti-carbonization).

4) Smaller surface area of the flame tube (economical cooling);

The radial arrangement of the combustion zones in comparison with the axial arrangement of the zones has the following disadvantages:

1. Significant change in the radial profile of the temperature field at the outlet from the combustion chamber when connecting / disconnecting the main zone;

2. The efficiency of the main zone at intermediate engine operating modes is less.

3. Less reliable and faster ignition of fuel in the main zone.

Zoned combustion chambers can significantly reduce nitrogen oxide emissions. The reduction mechanism is not caused by the elimination of stoichiometric regions in the main zone of the combustion chamber, but is caused by the intensification of the mixing process. “Intensification in comparison with the conventional (traditional) combustion chamber became possible due to the combustion of most of the fuel in the main zone, which is a combustion chamber of reduced length. Since the combustion efficiency is high here, the heat intensity of the main zone is higher than the heat intensity of the traditional combustion chamber. This increase was possible for two reasons. First, the combustion products flowing from the first zone enter the frontal device of the second zone, which provides an increase in temperature and an improvement in flame stabilization conditions. Secondly, in the front-line device of the second zone, the excess air ratio is greater than unity. This circumstance leads to an acceleration of mixing in comparison with the traditional combustion chamber, in which the air supply process is greatly extended."

The described Combustion Chambers essentially use diffusion combustion in both zones. Dual Zone Combustion Chambers have been introduced in service by GEAE (radial zoned) for the CFM-56B, GE-90 and Rolls-Royce Deutschland (axial zoned) engines for the BR-715 engine.

Further development of combustion chambers with staged combustion followed the path of the implementation of the LPP concept for the main combustion zone in order to further reduce the emission of nitrogen oxides. At present, Japanese firms are also the developers of this type of combustion chambers [11, 12].

3.6.4 LDI concept

In fact, this concept was a response to the challenges faced by the developers of the LPP and Staged Combustion Combustion Chambers. It is devoid of congenital drawbacks, such as low stability of the flame front, breakthrough and self-ignition of the fuel-air mixture in the mixture preparation module, an increased share of air consumption for cooling the walls of the flame tube with a developed surface area, which significantly hinder the rate of introduction of low-emission combustors into operation.

The technical solution was borrowed from piston internal combustion engines, which were equipped with a fuel injection system back in the 40s. 20th century (DB 601, BMW 801, АШ-82ФН) in order to ensure uninterrupted fuel supply to the cylinders during the evolution of the aircraft. In the 80s, after the adoption of stringent environmental legislation in the United States, and the prevailing preconditions (development of high-pressure fuel pumps, microprocessors), electronically controlled direct injection systems replaced carburetor systems both by increasing the engine's efficiency by accurately controlling the excess air ratio in the cylinders, and by working on poorer mixtures [13].

The LDI concept in aviation Combustion Chambers provides for fuel injection directly into the flame tube and rapid fuel mixing with a high proportion of airflow. This concept makes it possible to reduce the temperature peaks in the flame if the fuel and air have time to mix well to a lean state before the combustion reactions start [14].

Since a sufficiently large relative airflow must pass through the front device (up to about 70%), the airflow through the primary holes and dilution holes must be significantly reduced, or eliminated.

Cooling of the wall and head of the flame tube should be minimized as much as the cooling system used allows. Therefore, the front-line device is additionally assigned the task of providing the required temperature field at the entrance to the HPT.

There are two variations of the LDI concept: macro-scale and micro-scale (Multi-point).

The frontal device in the LDI macroscale concept is developed and, in terms of its geometric dimensions, should occupy most of the area of the front wall of the flame tube. The concept uses the idea of radial combustion zoning. A pilot injector is located in the center of the front module, providing acceptable CO and CH emissions at low engine operating conditions, as well as fire support for the main zone. The main zone provides low emission of nitrogen oxides and complete combustion at high engine operating conditions by rapidly mixing fuel and air, which is achieved through a complex combination of swirling flows. From a technical point of view, the device of the front module in the LDI concept is much more complicated than the front modules of other low-emission fuel combustion concepts and the time for its development and fine-tuning is much longer.

For crushing and mixing the air with the fuel of each circuit, two coaxial air swirlers are used from the inner and outer sides relative to the fuel flame. Fuel atomization system - pneumatic type.

The frontal device in the micro-scale Multi-point concept provides fast mixing due to the scale factor [15] (the turbulent diffusion time is proportional to the square of the characteristic flow size and inversely proportional to the turbulent diffusion coefficient).

NASA's work [16] demonstrates the potential for a significant reduction in nitrogen oxide emissions in the combustion chamber sector, which in the limit reaches the LPP combustion chamber emission levels. The combustion chamber involves the installation of a large number of small diameter nozzles, each of which has its own small air swirler, which creates a recirculation zone.

Due to the narrow range of operation of each nozzle in terms of the composition of the mixture, at least 4 fuel manifolds must be used to ensure the operability of the combustion chamber in the entire range of engine operation. About 80% of the total airflow passes through the air swirlers in the front wall of the flame tube. The rest of the air is used to cool the walls of the flame tube. Fast and homogeneous mixing of fuel with air, combined with short residence times in the recirculation zones, ensures low levels of nitrogen oxide emissions. The significant design difference of the Multi-point appearance from the rest, more traditional in the configuration of the combustion chambers, makes it less suited to work in real operating conditions.

3.7 Measures taken to limit harmful emissions

Since 1986, when the first international standards were adopted to limit levels of emissions of harmful substances (gaseous and smoke) from gas turbine engines of aircraft in the mode of a standard takeoff and landing cycle, the values of the emission parameter for carbon monoxide, unburned hydrocarbons and smoke have not been revised. Limit levels for these values have been adopted.

An increase in the parameters of the thermodynamic cycle of the engine operation and a more rational distribution of air in the Combustion Chamber have a beneficial effect on reducing the formation of these harmful substances.

Since 1986, the standard takeoff and landing cycle, the limit value of the nitrogen oxide emission parameter has been progressively reduced by revising the current level. The history of tightening the standards for the emission of nitrogen oxides of aircraft gas turbine engines with a takeoff thrust of more than 89 kN for subsonic aircraft, depending on the degree of increase in the total pressure in the engine. Over 28 years of operation, CAEP has managed to halve the engine emissions parameter for a standard takeoff and landing cycle.

At present, the most acute issue is the provision of established norms for the emission parameter of nitrogen oxides under the conditions of a standard takeoff and landing cycle.

Leading foreign companies, individually and in cooperation with each other, create joint projects to develop advanced engines and their individual units [17]. Each of the companies, within the framework of its design school, adheres to a certain main direction of the development of combustion chambers.

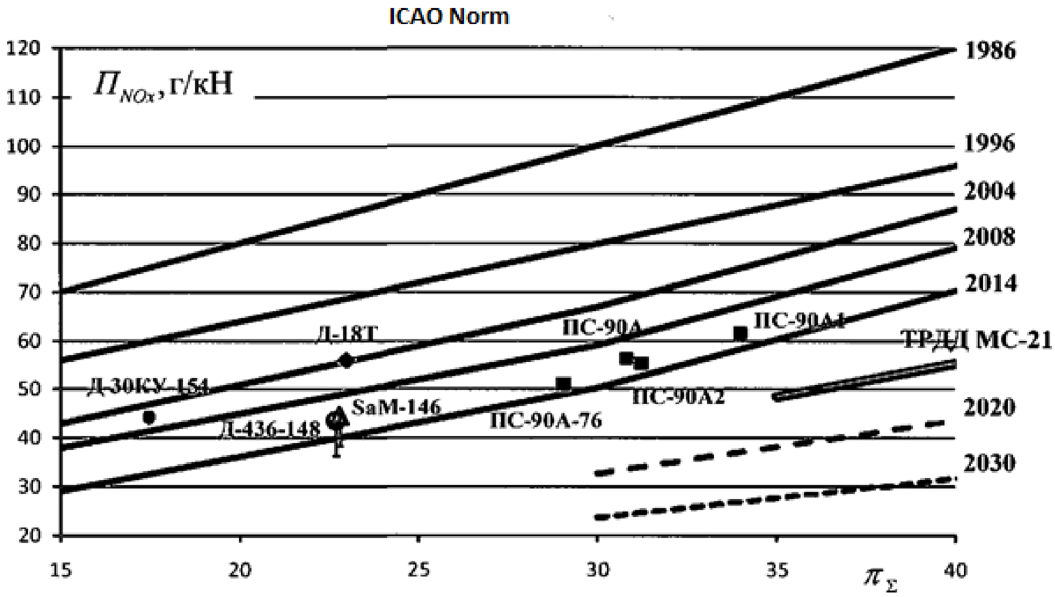


Fig 3.5 - Parameter of nitrogen oxide emission of domestic by-pass turbojet engines

For some products, it was possible to provide a margin of 50% to the CAEP6 standards, that is, to come close to the long-term target technological level of nitrogen oxide emissions.

At the same time, the confirmation of low-emission technology is provided at a high level of technological readiness for the serial production of combustion chambers, which makes it possible for foreign companies, through representatives of their countries in international organizations, to lobby for a constant tightening of international standards, while continuing to ensure their dominant role in the market.

It should be noted that most of the foreign engines of the fourth and fifth generations shown in Figs 3.4 and 3.5 have a bypass ratio from 4.5 to 8.2 on takeoff. The bypass ratio of serial post-Soviet (Russia and Ukraine) engines of the third and fourth generations in takeoff mode is in the range of 2.3 ... 5.6. When compared in terms of the emission parameter, the latter are at a disadvantage in comparison with foreign competitors.

Thus, foreign companies, through the introduction of advanced low-emission technologies and better fuel efficiency of engines, demonstrate the possibility of ensuring the target technological level of emission of NO_x in the long term. In this regard, we will consider what directions of development of low-emission technologies are planned for implementation on engines, first of all.

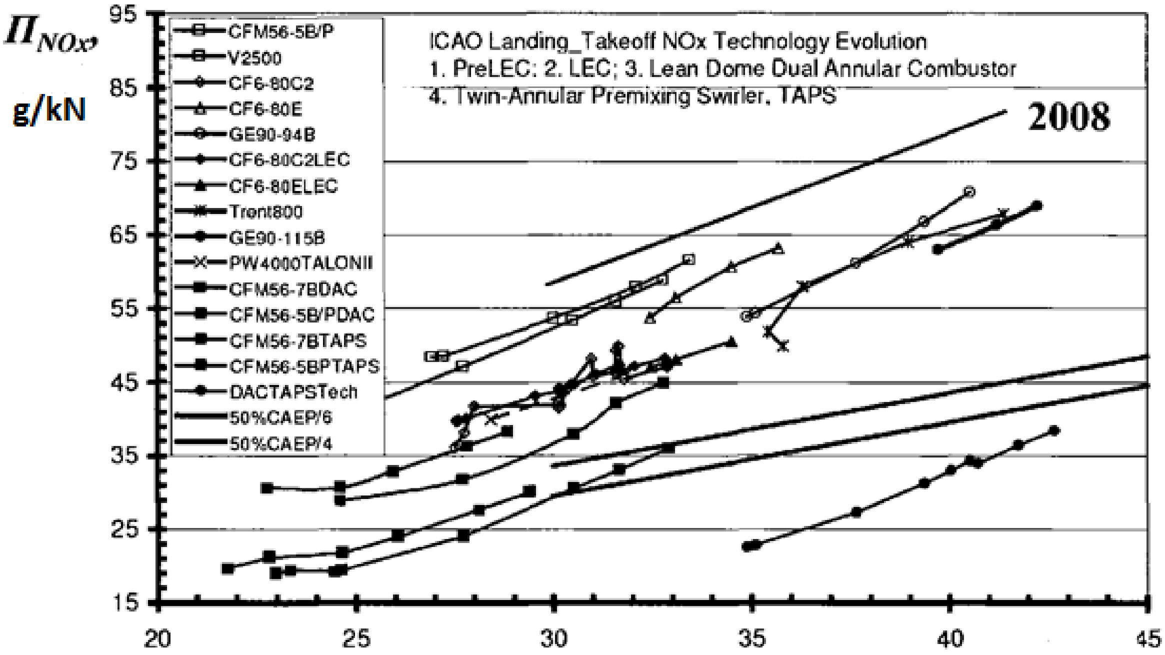


Fig 3.6 - Parameter of nitrogen oxide emission of foreign turbofan engines at

H = 0, M = 0.

Conclusion to part 3

1) Airplanes emit particles and gases such as carbon dioxide (CO2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead and black carbon that interact with each other and with the atmosphere.

2) CO2 emissions from aircraft in flight are the most significant and most understood element of aviation's overall contribution to climate change.

3) Emissions of NO_x causes greater global warming

4) This part considers a range of combustion chamber types to increase a fuel combustion coefficient which leads to reduced emissions.

PART 4
LABOUR PRECAUTION

4.1 General Information

Safety measures during maintenance and repair of aircraft are regulated by: state and industry standards of the System of labor safety standards; instructions on flight performance, technical operation and repair of aircraft; maintenance regulations; repair technology; manual and instructions on occupational safety, etc.

The peculiarity of the operation and repair of aircraft is that a number of technological processes are general processes for these technologies (washing and painting parts, cargo work, operation of pressure vessels, welding, operation of electrical installations, etc.). Therefore, the classification of hazardous and harmful production factors during the operation of the aircraft is suitable for repair processes of the aircraft. Such factors are:

- aircraft, special vehicles and self-propelled moving mechanisms;

- products, blanks and moving materials; unprotected moving elements of aircraft (ailerons, shields, interceptors, trimmers, chassis, rotating propellers, turbines, descending ladders, etc.), special vehicles (cabins that rise and fall, cradles, bodies, stairs, turntables), mechanisms (loading and unloading winches of aircraft, cranes) and production equipment;

- fragments, elements, parts of production equipment that fly away;

- aircraft products, tools and materials that fall during maintenance work on aircraft on the planes, stabilizers, fuselages when working at height with the use of mechanical lifts;

- shock wave (explosion of pressure vessels, flammable liquid vapors);

- jets of exhaust gases of aircraft engines and objects that got into them;

- flowing jets of gases and liquids from vessels and pipelines operating under pressure;

- high-speed air intake streams (aircraft engine nozzle area);

- the plane which is overwhelmed (from lifts or at wrong cleaning of the chassis);

- structures that are destroyed (side stairs, stepladders and other production equipment);

- highly placed parts of the aircraft;

- increased sliding due to freezing, wetting and oiling of aircraft surfaces, ladders, stepladders, ladders and floor coverings, where workers move;

- increased dust and air pollution in the area of aircraft maintenance;

- increased or decreased surface temperature of aircraft, equipment and materials;

- increased or decreased temperature, humidity and air mobility in the area of aircraft maintenance;

- increased noise, vibration, ultrasound and infrasound;

- increased voltage in the electrical circuit, the circuit of which can occur through the human body;

- increased level of static electricity;

- increased level of laser radiation in the work area;

- location of the workplace at a significant height relative to the ground (floor);

- sharp edges, burrs and roughness on the surface of aircraft, equipment and tools;

- lack or lack of natural light;

- insufficient artificial lighting of the working area;

- reduced contrast of objects of distinction with the background;

- increased brightness of light;

- direct brilliance (floodlighting of parking lots, light of headlights of airplanes and special vehicles) and reflected brilliance (from spilled water and other liquids on the surface of parking lots and platform);

- increased pulsation of light flux;

- increased levels of ultraviolet and infrared radiation;

- chemicals (toxic, irritating, sensitizing, carcinogenic, mutagenic, those that affect reproductive function), which are part of the materials used;

- fuels and lubricants, special liquids and pesticides that enter the human body through the respiratory system, gastrointestinal tract, skin and mucous membranes;

- pathogenic microorganisms and products of their vital activity;

- physical (static and dynamic) and neuropsychological overload (emotional, overload analyzers).

4.2 Labour precaution during disassembly and assembly work and machining

Collapsible work during the repair of the aircraft is very voluminous and contains most of the above dangerous and harmful production factors.

Disassembly of the aircraft is preceded by a number of operations, which largely guarantee the further safety of work: thorough flushing of the entire aircraft, cleaning of fuel tanks and systems from fuel residues; installation of safety devices under the appropriate elements of the aircraft for safety during dismantling of the chassis, etc.

Disassembly is performed using various devices, the proper use of which usually guarantees safe operation. However, injuries still occur due to violations of disassembly technology, neglect of safety rules.

Lifting vehicles are used during the disassembly of the aircraft, so the personnel performing work with their help must be trained accordingly. When disassembling air, hydraulic and other aircraft systems, it is necessary to follow the safety rules for handling vessels and devices operating under pressure. All kinds of metalwork tools must be in good working order and correspond to the type of work being performed. Subsequent to disassembly detailed washing and cleaning of aircraft elements and, in particular, aircraft engines are performed in specially designed installations. It is very important that normalized meteorological conditions are created in the workplace, there are no (or did not exceed the MPC) vapors and gases of toxic substances used in these works.

A radical method of eliminating these industrial hazards is to seal flushing baths and installations for cleaning parts of aircraft and engines, as well as the replacement of detergents with harmless and flammable.

Ultrasound is often used during washing, so it is necessary to comply with the requirements of safe work in the area of its action. Now the main factor in creating safe work at the site of washing and cleaning is the reliable operation of ventilation systems. Therefore, the control of their work must be given constant and systematic attention. Compliance with personal hygiene rules by employees in this area of production also plays an important role in the set of measures that create occupational safety. Prevention of injuries during the repair of aircraft is mainly to take precautions when repairing their specific elements and units, in the process of which such work as stretching holes, scraping, grinding, polishing, turning holes, welding and soldering, riveting, machining , restoration of details by galvanic and chemical coverings, painting, tests of units and a fuselage on tightness and other works. A special place is given to occupational safety when performing work on metalworking equipment. Here it is provided by performance of a complex of actions according to standard rules of safety and industrial sanitation at processing of metals. These rules regulate the general provisions, general and special requirements for metalworking equipment, hand tools, organization of workplaces and equipment placement.

The main ones are:

- machines, presses and other equipment are installed on solid foundations or foundations, carefully calibrated and securely fastened;

- workplaces of repair locksmiths are equipped with appropriate cabinets, machines, racks, as well as lifting devices for moving parts and components of large mass;

- parts of machines and mechanisms that move and can cause injuries to workers, protect the appropriate reliable fence;

- workers working on machines that structurally or otherwise cannot be provided with protective devices, the administration is obliged to issue comfortable goggles that do not interfere with work, and constantly monitor their use when working on machines;

- installation and removal from machines, presses and transport devices of workpieces, parts, devices and tools weighing more than 16 kg is performed using lifting devices and mechanisms;

- the design of all devices for fastening of the processed details and the tool should provide their reliable fastening and exclude a possibility of self-unscrewing of devices during work;

- persons who work on machines with the use of cooling parts with emulsions, oils, turpentine, kerosene, give preventive ointments, pastes for lubricating hands; on the recommendation of the medical institution for this category of workers equip the device for early hand washing with special liquids;

- machines on which fragile materials (cast iron, brass, bronze, as well as non-metallic materials) are processed, equipped with dust collectors connected to group or individual devices (suction) for removal of dust and shavings from the places of their formation;

- electrical equipment and live parts must be securely insulated and hidden in the machine body or in other places equipped with a blocking device; the machine itself is securely grounded and equipped with an emergency STOP button;

- when working with hand tools (chisel, beard, core, etc.) workers are given goggles, hand tools must be serviceable;

- assembly of materials and details (products) at workplaces is performed in a way that ensures their stability and convenience for slings when using lifting mechanisms;

- to use compressed air for blowing of products of the equipment in working rooms, as a rule, is forbidden (it is allowed in specially equipped cases or chambers with local exhaust ventilation);

- to protect workers from flying metal particles (for example, during chopping), on metalwork machines install solid mesh-boards with a height of at least 1 m; the machines themselves must have a rigid and strong construction and be sufficiently stable.

4.3 Labour precaution during operation of pressure vessels

During operation and maintenance of aircraft, the energy of compressed air and gases is widely used. For example, compressed air is used to mechanize labor-intensive processes, as well as to perform a number of technological operations (operation of pneumatic tools, blowing and drying of parts and components, application of paints and varnishes, etc.). The source of energy for compressed air is often a compressor unit. For the convenience of operation of compressed air and liquefied gases, special cylinders are used, where these gases are under high pressure.

Compressor units, as well as vessels operating under high pressure, are objects of increased danger, and in cases of safety violations during their operation, low quality of material and malfunction of control and measuring devices can explode and lead to serious injuries to others, as well as in some cases cause poisoning by harmful substances. The power during the rupture of a vessel filled with compressed gas reaches large values. So, for example, at a rupture of the vessel with a capacity of 1 m in which there is a gas under pressure of 980 kPa, for 0,1 with power of 9800 kW develops. This is enough to partially destroy the production building.

Due to the increased risk of pressure vessels, the design, manufacture, installation, adjustment, operation and repair of this equipment, except in certain cases, are governed by the rules of construction and safe operation of pressure vessels and the rules of construction and safe operation of stationary compressor units, air ducts and gas pipelines.

These rules apply to the following containers:

- vessels operating under water pressure with a temperature above 115 ° C or other liquid with a temperature exceeding the boiling point at a pressure of 0.07 MPa (0.7 kgf / cm2) without taking into account the hydrostatic pressure;

- vessels operating under steam or gas pressure higher than 0.07 MPa (0.7 kgf / cm2);

- cylinders designed for transportation and storage of liquefied, compressed and dissolved gases at a pressure higher than 0.07 MPa (0.7 kgf / cm2);

- tanks and barrels for transportation and storage of liquefied gases, the vapor pressure of which at a temperature up to 50 ° C exceeds the pressure over 0.07 MPa (0.7 kgf / m2);

- tanks and vessels for transportation and storage of liquefied, compressed gases, liquids and bulk bodies, in which the pressure above 0.07 MPa (0.7 kgf / cm2) is formed periodically for their emptying; - pressure chambers.

The rules also include a list of vessels to which they do not apply. These are, for example, vessels with a capacity of not more than 0.025 m3 (25 l), regardless of pressure, which are used for scientific and experimental purposes; vessels and cylinders with a capacity not exceeding 0.025 m3 (25 l), in which the product of the pressure in megapascals (kilograms of force per square centimeter) per capacity in cubic meters (liters) does not exceed 0.02 m3 (200 l); vessels that are installed on the aircraft, etc.

Depending on the operating conditions (pressure, temperature, medium, volume), all vessels are divided into four groups (Table 4.1).

Table 4.1

A group of vessels	Estimated pressure, MPa (kgf / cm2)	Wall temperature, ° C	The nature of the working environment
1	Over 0,07 (0,7)	Regardless	Explosive or flammable, or 1st, 2nd hazard classes accorind to ГОСТ 12.1.007
2	Under 2,5 (25)	Below -70, above +400	Any, except for the specified for the first group of vessels
	Over 2,5 (25) under 4 (40)	Below-70 above +200	
	Over 4 (40) under 5(50)	Below -40 above +200	
	over 5 (50)	Regardless	
3	Under 1,6(16)	From-70 to-20 From +200 to +400	Any, except for the specified for the first group of vessels
	Over 1,6(16) under 2,5 (25)	From-70 to +400	
	Over 2,5 (25) under 4 (40)	From-70 to +200	
	Over 4 (40) under 5(50)	From -40 to +200	
4	Under 1,6 (16)	From -20 to +200	

4.4 Engine start and test safety

During the maintenance of aircraft engines, all work is performed in accordance with the operating instructions of the engine of this type. During work on the engine, all power supply that ensures its start is turned off. Inspection of the turbine blades of the gas turbine engine should be performed only if the possibility of scrolling the propeller is excluded. Work in the exhaust pipe can be performed if communication with employees is provided. It is recommended to use a respirator.

Replacement of engines and their transportation are very labor-consuming works, therefore they are carried out, as a rule, under the direction of the foreman. Before starting such work, it is necessary to remove the batteries, insulate the disconnected wires, plug the sockets and pipes. Starting and testing of engines should be performed in accordance with the requirements for flight operation of this type of aircraft and instructions for safe starting and testing of aircraft engines. The work is performed in specially designated and equipped parking lots for this purpose.

Starting the engine for testing has the right to perform (with the permission of the chief or shift engineer) crew commander (pilot), flight engineer (flight engineer), as well as an employee of the aircraft who has undergone special training and allowed by order of the chief of aeronautical technical base to start engines . Safety requirements oblige them to perform the preparatory work provided for this type of aircraft, to take safety measures for service personnel who are at work, as well as precautions against damage to aircraft.

4.5 Fire protection

Fire safety of aircraft production is practically guaranteed by compliance with the rules and other regulations of its provision. According to the laws of Ukraine "On fire safety", "Rules of fire safety in Ukraine" general requirements for fire safety are established, which apply to enterprises, institutions, organizations and other facilities (buildings, structures, production lines, etc.), as well residential buildings that are in operation, are being built, reconstructed, technically re-equipped and expanded, except for underground structures and vehicles, the requirements for which are defined in special regulations.

Ensuring fire safety should also be guided by standards, building codes, rules of installation of electrical installations, standards of technological design and other regulations, based on their scope, regulating the requirements of fire safety.

Fire safety is guaranteed by carrying out organizational, technical and other measures aimed at preventing fires, securing people, reducing possible property losses and reducing negative environmental consequences in the event of their occurrence, creating conditions for rapid call of fire departments and successful firefighting. Fire safety of ground facilities is provided by fire prevention and fire protection systems, organizational and technical measures.

Fire prevention and fire protection systems must prevent people from being exposed to fire hazards that exceed the permissible values. The probability of action of these factors should not exceed the normative equal to 10 per year per person. The cost-effectiveness of systems that ensure its fire safety must be established for each facility, taking into account the probability of fire, the cost of the facility, capital contributions and current costs of fire prevention and fire protection systems.

According to the standard, fire hazards that affect people are classified as follows: open fire and sparks, high ambient temperature, objects, etc .; toxic combustion products, smoke, low oxygen concentration, falling parts of building structures, units, installations, etc. Necessary calculations of fire prevention and fire protection systems and determination of initial data are performed by ministries and departments in accordance with the normative and technical documentation approved in accordance with the established procedure. The data on the main indicators of fire safety of the substance required for the calculations are given in the reference appendix to the relevant standard. The creation of explosion safety is established by the norms of explosion prevention and explosion protection, organizational and organizational and technical measures. Production processes shall be designed in such a way that the probability of an explosion at any explosive site during the year does not exceed 10. In cases of technical or economic inexpediency of ensuring the specified probability of explosion, production processes are designed so that the probability of action of dangerous factors of explosion on people during the year does not exceed 106 per person.

In this case, dangerous and harmful factors are: shock wave, at the front of which the pressure exceeds the allowable value; flame; collapsing structures; equipment, communications, buildings and structures and their parts, which disintegrate and which were formed during the explosion and (or) separated from the damaged equipment; harmful substances, the content of which in the air of the working area exceeds the maximum allowable concentration.

4.6 Fire extinguishing means and rules of their application

All facilities should be provided with primary fire extinguishing means. All workers must know the location of the fire extinguishers and know how to use them.

One of the most effective primary means of extinguishing is the fire extinguisher.

Extinguishers, as a primary means of fire fighting, take one of the main places in the system of fire protection. On the effectiveness and reliability of fire extinguishers, as well as their skillful using depends not only on the nature of the further development of the fire, the amount of damages that they can cause, but also people's lives. Fire statistics show that most fires are usually extinguished before the arrival of fire brigade units.

There such fire extinguishers:

1) ОХП–10, ОП–М, ОП–9ММ – hand chemical foam fire extinguishers. ОХП-10 is intended for extinguishing of inflammation and small fires of hard materials and combustible liquids. ОХП-10, is shown in the figure 4.1, it is the steel welded cylinder the mouth of which is closed with a plug-forming device. The charge of fire- extinguisher consists of acid and alkaline part. Distance of stream is 6 – 8 meters. For

applying of fire-extinguisher it is needed to bring him to the place of inflammation, to turn the handle of the valve on 180 degrees completely, to invert a fire-extinguisher upwards by a bottom and to point the stream of foam to the fire. It is strictly forbidden to extinguish by foam fire-extinguishers to the electrical wiring and electrical equipment;

2) ОУ–2, ОУ–5 and ОУ–8 – hand carbon dioxide fire extinguisher. They are intended for extinguishing of small initial inflammation of different matters and materials, except that matters burning of which takes place without access of air. Carbon-dioxide fire-extinguishers, shown in the figure 4.2, are steel cylinders, in the mouths of which the

brass valves are screwed with siphon tubes, the fly-wheels of valves must be sealed. For extinguishing of fire it is necessary to direct the fire- extinguisher to the fire and unscrew completely the valve anticlockwise. During work of fire-extinguisher it is not recommended to hold a balloon in horizontal position because such position obstructs the output of carbonic acid through a siphon tube;

3) ОВП–10 and ОВП–5 – hand air-foam fire extinguishers;

4) ОУБ–3 and ОУБ–7 – hand ethyl bromide, carbon-dioxide fire extinguishers are designed to extinguish small sources of fire of fuel materials.

ОХП-10 ОУ-8 ОУ-2

Figure 4.1 – Different fire extinguishers types

Primary means of extinguishing fire may be placed on boards. Manual fire tool on the boards should be periodically cleaned from dust, dirt and traces of corrosion and repair needs sharpening angles and painting tool for use after fire or during practice.

All requirements used in this chapter meet the standards ДСТУ 2272–93, ДСТУ 2273–93.

4.7 Labor protection instructions for aircraft technician

Individuals who are at least 18 years of age, have special training, have passed a medical examination and have no contraindications for health reasons, who have undergone introductory and primary labor safety briefings at the workplace, trained in safe methods and techniques of work, have been trained in workplace and testing knowledge of labor protection requirements, as well as training in fire safety rules and testing knowledge of fire safety rules in the scope of job duties; training in electrical safety rules and testing of knowledge of electrical safety rules in the scope of job duties with the assignment of an appropriate group.

Professional requirements for a person are presented in professional charts, which reflect a set of social, technical and organizational factors that characterize the profession and professionally important human qualities. Professiograms also determine anthropometric components, medical and psychophysiological contraindications. Medical examinations for professional selection are carried out in accordance with the rules of the Ministry of Health of Ukraine.

There is an official list of jobs for which you need to make a professional selection. On the basis of this list are lists of professions for which it is needed. During the professional selection it is necessary to take into account the lists of work with harmful and dangerous working conditions, in which the work of minors and women is prohibited. In some intersectoral and sectoral safety rules there are requirements for qualifications, work experience, age, educational level, etc.

Conclusion to part 4

1) The different harmful and dangerous production factors for the mechanic in were identified and described. The measures of fire and explosion safety were considered.

2) On the basis of carried out analysis of dangerous and harmful factors that can take place during work on the engine, the measures are developed for increasing the labour safety during work.

PART 5
ENVIRONMENTAL PROTECTION

5.1 Basic notions and importance of the environmental protection

Pollution is the introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem, i.e. physical systems or living organisms [24]. Ecological problems become more vital in connection with the existence of harmful consequences of interaction between the person and nature.

An ecological problem is of very important, because the condition of environment directly influences on the processes of human organism, its normal functioning. The presented ecological situation in Ukraine is possible to describe as the complicated that formed during the protracted period through ignoring the objective laws of development. The high specific weight of resource intensive and power-intensive technologies, introduction of which was carried out by the most "cheap" method – without building of the proper cleaning installations – is inherent to the economy of Ukraine.

Considerable contaminant of the environment is a transport industry, in particular, is its mobile facilities (cars, locomotives, marine and river ships, air transport), which use the different types of petroleum as fuel. The significant harm causes the exhaust gases of aviation transport, drain water after washing of cars, aircraft and their aggregates, vapors of different harmful matters, acids, materials which are utilized in the technological processes of repair.

5.2 Laws requirements in Ukraine in ensuring of environmental protection

Environmental protection, rational use of natural resources, environmental safety of human life – is an essential condition for sustainable economic and social development of Ukraine. For this purpose Ukraine carries on its territory environmental policy aimed at the preserving for the existence of living and inanimate nature safe environment, for protection the lives and health from the negative impact, caused by the environmental pollution, achieving of harmonious interaction between the nature and society, protection, rational use and reproduction of natural resources.

At present, the main regulations governing the organization of environmental protection in Ukraine are:

1) the Law of Ukraine “About Environmental Protection”;
2) Agrarian Code of Ukraine;
3) Water Code of Ukraine;
4) Law of Ukraine “About Air Protection”;
5) Law of Ukraine “On objects of assigned risk”;
6) Law of Ukraine “On State Program of Toxic Waste”;
7) Law of Ukraine “On the area of environmental emergency”;
8) Law of Ukraine “On Wastes”;
9) Law of Ukraine “About management Radioactive Waste Management” and many others.

Unfortunately, all these legal documents have a serious drawback. They are formed for the separate regulation of land, water, mining, forestry, atmosphere protection. This approach does not provide the regulation of relations on the environment as a single organism.

Ukraine's Law “About Environmental Protection” is the fundamental legal act, it defines the concept of environmental protection and measures for their security, environmental requirements for the disposition, designing, engineering, reconstruction, putting into the operation of enterprises and other objects, on the application of fertilizers; provides measures for protecting the environment from harmful biological effects, harmful effects of physical factors and radioactive contamination, from contamination by industrial, household and other wastes. This law not only states, but also provides the guarantee system of human ecological protection, makes certain orderliness in the management system in branch of the nature use, and it affirms the right of Ukrainian citizens on safe for human life environment. This inherent right is realized by the participation in discussion of draft laws and other decisions in the branch of environmental protection; participation in the development and implementation measures for environmental protection, rational use of natural resources; unification in public organizations for environmental protection; receiving full and reliable information about the state of the environment [25].

In the Declaration on State Sovereignty of Ukraine in the section VII “Environmental Security" it states that Ukraine has the right to prohibit the construction or stop the operation of any enterprises, institutions, schools, facilities that threaten the ecological safety. Ukraine concerned about the environmental safety of citizens and the gene pool of people.

In the Law of Ukraine on economic independence among the main objectives of achieving economic independence are listed security achievements, creating healthy and safe living and working conditions.

In the Law on Enterprises in Ukraine the next position is fixed – all businesses must perform nature-conservative measures. Enterprises are responsible for the compliance with the requirements and regulations on environmental protection, rational use and restoration of natural resources.

The one of the main laws that has to be followed by the aviation enterprises is the Law of Ukraine “About Air Protection”. This Law is directed on the protection and renewal of natural atmospheric air condition, creation of favorable terms for vital functions, providing of the ecological safety and prevention of harmful influence on atmospheric air on people health and environment.

Standardization and rating of norms in the sphere of atmospheric air are held with the purpose of establishment of obligatory norms system, rules, requirements to the protection of atmospheric air against contamination and providing of ecological safety. Standardization and rating of norms in the sphere of atmospheric air protection are directed on:

1) providing of safe natural environment and prevention of ecocatastrophes;
2) realization of single scientific and technical policy in the sphere of atmospheric air protection;
3) establishment of the unique requirements to the equipment and installation in relation to the air protection from the contamination;
4) ensuring of household objects safety and prevention of technogenic catastrophes;
5) introduction and usage of modern ecologically safe technologies.

5.3 Environmental aspects

The urgency of the topic is due to the fact that in the global world the role of civil aviation in the economy of modern countries is growing steadily, but with increasing air traffic, areas cultivated from aircraft agricultural land, the intensity of aircraft operation, it became clear that such technology significantly affects pollution environment. In this regard, it should be emphasized that among the constitutionally enshrined human rights in Ukraine, the right to a safe environment for life and health occupies a prominent place.

It is assumed that it must be properly implemented. It is clear that there is an objective need for additional legislative guarantees. At the same time, it should be noted that scientists still pay insufficient attention to both a comprehensive study of the problem of civil aviation safety in Ukraine and its environmental component. Some issues were covered only in the works of N.V. Bondarchuk, V.V. Kostytsky, A.V. Filippov. Thus, this may explain the fact that Ukrainian legislation not only does not yet define the concept of environmental safety of civil aviation, but also does not distinguish the environmental safety of civil aviation as an independent area of legal regulation. Given the above, the author of the article aims to conduct a scientific analysis of intersectoral legal mechanisms governing the environmental aspects of civil aviation safety in Ukraine. Based on the above, it should be noted that in Ukraine, environmental security as one of the most important priorities of our state was declared in the "Declaration of State Sovereignty"

Among Ukraine's important international achievements is Ukraine's signing of the UN Framework Convention on Climate Change and ratification of the Kyoto Protocol. Thus, Ukraine has made certain commitments to implement a policy of reducing greenhouse gas emissions. Ukraine is one of the twenty largest polluters on the planet and bears its share of responsibility for the negative effects of economic activity. Among the existing economic activities related to the creation and operation of air transport is characterized by large-scale and environmentally hazardous to the environment and health impact: civil aviation companies affect the environment in a comprehensive way - ie simultaneously on various components of the environment: air, land and water country resources.

That is why the analysis of the operation of air transport pays great attention to international organizations that consider the safety of civil aviation in a comprehensive manner, including the safety of the impact on the natural environment of aviation activities of economic entities. Thus, the main international standards and recommended ICAO practices in the field of environmental safety of civil aviation are contained both in Annex 16 to the Chicago Convention and in separate recommendation documents. Accordingly, the number of norms aimed at minimizing the environmental risks of air transport has increased in the national legislation of the world. Adopted in 2003, the Law of Ukraine "On the Fundamentals of National Security of Ukraine" took into account the established international legal requirements, directly stating the importance of providing environmentally and technogenic favorable living conditions for citizens and society, environmental protection.

5.4 state of legal protection of atmospheric air

Analyzing the state of legal protection of atmospheric air from the negative impact of civil aviation should also be borne in mind that one of the main factors of the negative impact of civil aviation on the environment is aviation noise. In this regard, it should be noted that the regulation of harmful physical effects on the atmosphere, in particular noise reduction, is one of the areas of legal measures to protect the atmosphere. Air transport occupies a significant place in the noise regime of settlements. Sources of noise on the territory of the airline and adjacent areas are aircraft power plants with gas turbine and piston engines; auxiliary power plants of aircraft and launch units; special aerodrome maintenance machines for various purposes, including heat and wind machines, created on the basis of aircraft engines that have exhausted the flight resource. The acoustic situation in the area of the airport is determined by the mode of operation of the airline; types of aircraft operated at the airport; current routes of arrival and departure of aircraft; the location of residential buildings relative to the runway, as well as measures taken by the airport to reduce the adverse effects of aircraft noise on the environment.

Thus, the object of the negative impact of civil aviation is not only the environment but also the population. It should be noted that increasing attention to this important issue in the air law of Ukraine. Thus, the new Air Code of Ukraine clearly states that the maximum permissible noise level during aircraft operation, emission of aircraft engines and electromagnetic radiation of aviation objects should not exceed the maximum permissible level established by the aviation rules of Ukraine; and if the noise level during the operation of a civil aircraft exceeds the established maximum permissible noise level, the authorized body for civil aviation has the right to restrict or prohibit the flights of such aircraft. Measures aimed at reducing noise levels at and near the airport through a balanced approach to aviation noise management may include: spatial planning of the area around the airport, taking into account aviation noise conditions and other adverse environmental factors; introduction of operational measures during take-off and landing of aircraft; appropriate organization of air traffic in order to reduce the impact of aircraft noise, etc.

5.5 Noise

Noise at protected facilities during any activity should not exceed the levels established by sanitary norms for the relevant time of day. With regard to aerodrome owners, operators, commanders and crew members, they are obliged to prevent or minimize noise when operating aircraft on the ground and in the air. In this regard, it should be noted that in modern conditions in the normalization of aviation noise there are two different approaches:

- when the permissible levels are set taking into account the sanitary and hygienic requirements in the absence of adverse effects of noise on humans (sanitary and hygienic rationing);

- when noise standardization establishes aircraft noise standards taking into account modern researched and technically substantiated methods of noise reduction in air transport processes.

As the adverse effects of aviation noise during the day and night differ, the permissible values are set separately for day and night in the direction of reducing the noise level in the residential area at night.

The current legislation provides for administrative liability for violation of this norm. The noise of modern subsonic aircraft with jet engines is regulated primarily by ICAO international standards, as well as national standards. The current noise standards clearly regulate not only the permissible noise levels, but also the methods of measuring it, flight modes for certification tests, as well as processing the results and bringing them to baseline in order to protect environmental rights and prevent violations in the use of airspace by air.

5.5.1 Modern ways to reduce the negative impact of aviation noise

The main direction of environmental activities of European airports (about 66%), including large airports in Ukraine, now and in the near future - reducing aircraft noise. In some cases, the problem of noise prevents the increase of airport capacity. Aviation noise has a negative impact not only on the population living on the outskirts of the airport, but, above all, on the airport staff directly involved in the operation of the airline. Thus, noise is both an environmental and an industrial production factor. The problem of the impact of aviation noise on the outskirts of the airport is exacerbated by the continued approach of residential areas to airports, the expansion of existing and the introduction of new routes of aircraft in the aerodrome area, which are often located above residential areas. At the same time, the socio-economic significance of the problem is constantly growing due to the growing number of people working under the influence of aviation noise, and the severity of the consequences of this impact, which manifests itself in occupational morbidity, reduced productivity, increased risk of error work in hazardous conditions. Solving the problem of protection of the population and airport staff from harmful effects is relevant for Ukraine in the context of insufficient financial support for measures for labor protection and emergencies and should be one of the priority areas of state activity.

The International Civil Aviation Organization (ICAO) is currently setting requirements for aircraft in the field of environmental protection. Regulatory documents governing aviation noise and aircraft engine emissions include:

- Annex 16 to the Convention on International Civil Aviation "Environmental Protection";

- aviation rules “AP-36. Certification of aircraft for noise in the field ”;

- ICAO document DOC 8168. “Regulations - Aircraft Flight”, Volume I, Part 5, Appendix to Chapter 3 “Guidance material on noise reduction during take-off at take-off”. Environmental protection is a very important issue and on June 8, 2010 the second international conference Greener Skies Ahead 2010 was held within the framework of the Berlin ILA, dedicated to the issues of reducing the environmental impact of future air transport. The conference addressed issues of improving the environmental efficiency of air transport, achieving environmentally neutral development of air transport, reducing harmful emissions and compliance with restrictions on harmful effects on the environment while maintaining the technical and economic performance of aircraft.

5.6 Work to reduce the impact on the environment

The world's leading manufacturers of aircraft are constantly working to reduce the impact on the environment in the following main areas:

- reduction of engine fuel consumption;
- reduction of emissions of harmful gases (carbon dioxide, nitric oxide);
- noise reduction for passengers, crew and settlements;
- reducing the use of harmful materials;
- reduction of waste in aircraft production.

Conclusion to part 5

1)) Based on legal provisions, it can be stated that the purpose of ensuring the environmental safety of civil aviation is essentially to minimize the harmful effects of its activities by balancing the damage caused to the environment due to aviation activities and the environment in self-healing.

2) According to the law of Ukraine on Environmental protection (from 26.06.1991) the work meets all requirements and proposals concerning reduction of hazardous influence on ecosystem.

3) The current legislation provides for administrative liability for violation noise norm.

4) An ecological problem is of very important, because the condition of environment directly influences on the processes of human organism, its normal functioning.

GENERAL CONCLUSIONS

1) Combustion chambers are designed to convert the chemical energy of the fuel into thermal energy of the gas stream by combustion.

2) All combustion chambers ensure stable combustion basically in the same way, by creating a stream of hot gases in the chamber moving towards the main flow of air and atomized fuel.

3) Combustion chambers can be classified by: the type of fuel-air mixture formation (evaporation, spray), by direction of flow of air and combustion products (direct-flow, counter flow), by design and layout (tubular, annular, tubular-annular), by fuel combustion scheme (two-zone, two-tier).

4) Despite difference in design of combustion chambers they all have such ellements as: diffuser, fire tube, combustion stabilizers, mixers, starting ignitors, drain valves, fuel manifold and fuel injectors.

5) The most important of them are the characteristics of the completeness of fuel combustion and stall characteristics, since fuel efficiency, emissions of pollutants (CO and CH) and engine performance depend on them.

6) The combustion chamber volume is divided into characteristic zones. The primary zone is located between the front device and the first row of large openings through which secondary air is supplied. Further, there is a secondary zone, which ends in the section.

7) Main parameters of combustion chamber include: air temperature, air pressure, airflow percentage, combustion fuel efficiency, total pressure lost and air excess coefficient.

8) Since international standarts of emission were adopted in 1986, they got stricter and plan to reduce the emission of harmful substances by a large margin.

9) By the combination of properties, the dominant concepts of reduction of harmful particles emissions are the concept of LDI and Staged Combustion.

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