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The Method of Air-Fuel Mixture Preparing in the Front Module of Low Emission Aviation Combustion Chamber

M.V. Siluaynova and O.G. Chelebyan
Institute of Moscow Aviation, National Research University,
Volokolamskoye Ave 4., A 80, GSP 3, 125993 Moscow, Russia

Abstract: In this research, the experimental study results of designed front device with liquid fuels pneumatic atomization in relation to the, low emission combustion chamber are presents. The preparing method of uniform liquid fuel-air mixture in the front device with fine-dispersed spray in swirl flow conditions is observed. Autonomous tests of the front device have been developed and conducted. The basic characteristics of fine-dispersed fuel-air spray in the open space were examined by means of non-contact laser diagnostics method. According to the results of cold tests the average zauter diameter of the fuel droplets in the idle mode is about 23 μ. The wide and intense backflow zone is formed near the device axis. To test the device developed and the method of fuel-air mixture preparation fire tests in the model 3-Burner compartment under high pressure environment have been conducted. The ignition and blowout points under earth conditions have been obtained as the result of tests conducted. The efficiency of lean fuel-air mixture combustion technology has been confirmed.

Key words: Atomizer, swirler, front device, spray, pneumatic, air-fuel mixture, combustion chamber, toxic species

INTRODUCTION

The main research tasCC directed to developing combustion chambers of the perspective TFE intended for use in civil aviation is ensuring competitive level of emission characteristics for these engines. Emission characteristics of a number of the latest engines by American firms "General Electric" and "Pratt and Whitney" supplied with combustion chambers with the scheme of the working process organization which is in essence differing from traditional form for assessment of this level base. The last was based on process of diffusion combustion in which actually chemical reaction of oxidation of fuel happens near formed in the course of hashing of fuel and air of a zone with ratio of mixture the close to stoichiometric and respectively at the close to stoichiometric temperature (Kuznetsov and Libby, 1990). Realization of combustion at this temperature (it as is well-known is close to greatest possible for the given fuel and an oxidizer) causes intensive oxidation of nitrogen air and despite small reference time for realization of this process, larger emissions (emission) of nitrogen oxides (EASA, 2016).

The new scheme of the organization of process of combustion in combustion chambers of TFE most of which sequentially is realized in combustion chambers like TAPS of general electric (Fig. 1), assumes combustion of the most part of fuel at the under temperature as a part of "poor" (α>>1) uniform fuel-air mix which has to be formed in the front device of the camera. The emission characteristics of engines presented in the databank show that use of this process flow diagram provides at least, double decrease in an emission of nitrogen oxides on similar duties of the camera in relation to the best combustion chambers with the traditional (diffusion) organization of process of combustion and surely guarantees compliance of these engines to existing and perspective rules by ICAO (2008).

Formation of the liquid fuel of a stream of air which is evenly "sowed" by drops behind the front device of a combustion chamber represents the complex scientific and technical challenge. This circumstance becomes apparent even in the analysis of a design of that part of the front TAPS device which provides air delivery and fuels to the main combustion zone (Fig. 1). Let's begin with the fact that in the modern literature there are no fundamental ideas of processes of transfer of solids and drops in gas streams with extremely high level of turbulence, the characteristic of streams in combustion chambers of gas turbines. Also, computational methods of liquid fuel

Corresponding Author: M.V. Siluaynova, Institute of Moscow Aviation, National Research University, Volokolamskoye Ave 4., A 80, GSP 3, 125993 Moscow, Russia

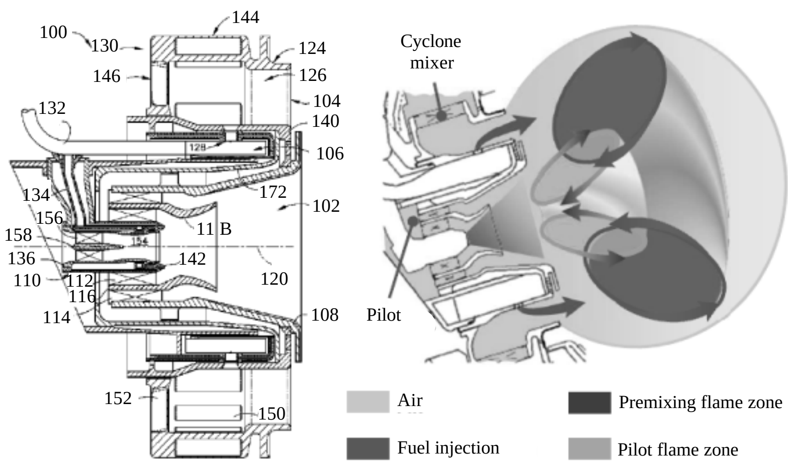

Fig. 1: Frontline module TAPS combustion chamber GE company and the fuel supply circuit

diffusion processes in these cameras as well as unfortunately and the experimental research techniques of these processes are insufficiently developed. In these conditions there is reasonable a huge volume of the efforts, in particular, the experimental spent by foreign firms and the research centers for developing such front devices (Change *et al*., 2013; Foust *et al*., 2011; Mongia, 2003).

Problem definition: Ensuring necessary level of cumulative characteristics of the gas-turbine engine such as sure start, the wide range of operational stability, completeness of combustion of fuel and low emission of harmful substances depend, in particular on reliable research of CC. At the same time, most of researchers in the field agree in opinion that achievement of a high level of the listed characteristics in CC is caused not least by quality of process of subdivision of liquid fuel and its preliminary hashing with air in the front device (Lefebvre, 1986). One of the ways recognized in the world for diffusion is the pneumatic method at which a dispersion of a stream (film) of liquid a high-speed gas current. Effectiveness of application of pneumo sawing was shown in research (Siluyanova and Chelebyan, 2016) at a research of influence of properties of liquid alternate fuels on characteristics of an aerosol.

It is known that combustion beforehand of the prepared homogeneous mixture of liquid fuel with air in model thermal generators allows to receive low emission of harmful substances at the exit (Baessler *et al*., 2007). However in actual CC CCD there is neither place, nor time for exercise of such preparation. From here, it is clear that it is necessary to use most fully the available space and a response time for aspiration of characteristics of fuel-air mix to homogeneous structure. It should be noted that for preliminary warming up of fuel it is necessary to increase as much as possible time of contact it with air on the initial site that is to cut air consumption in the front device and to remove from a fuel injection point exit. At the same time air consumption has to be sufficient for efficient subdivision of fuel. By the results of the pilot studies of front devices (Vasilyev *et al*., 2016) received earlier, the relation of mass of air to fuel has to be not <3. For formation evenly on a circle of an aerosol of a mass fraction of fuel, points of injection has to be the distributed a little. Depending on diameter of an arrangement of points of injection, installation of sprays has to be on one radius and in distance between axes to make about 20-25 calibers of diameter of fuel nozzles. Providing the uniform distribution of the given fuel on diameter of dispersion jet requires use of several air channels with different degree of a turning of a stream. Air swirlers have to form the main and pilot combustion zone, each of which has to be evenly sowed by fuel. The external airflow (without fuel addition) limits a departure of drops abroad of a jet and splits up the separate large drops separating on the periphery of an aerosol. The fineness of drops in the aerosol created behind an exit of the front device has to approach a mono dispersible aerosol and maximal diameters should not exceed 40 μ and average to be about 20 μ. On an axis of the device there has to be a wide and intensive zone of reverse currents for stabilization of a flame (the required extent of its enrichment has to be specified by fuel). And the last: distribution in a jet of mass streams of fuel and air has to be in coordination and be related in each point the close to constant (>3). Apparently, it is also necessary to coordinate the volume of fresh fuel-air mix with volume and a thermal rating of zones of stabilization of a flame (perhaps about 20-30%) but in this direction carrying out padding amount of research is required. Thus, realization of these conditions as much as possible will bring closer mix parameters to homogeneous structure without use of separate specialized devices.

In these conditions for the solution of an objective, first of all it is expedient to make use of the experience accumulated during developing front devices of traditional combustion chambers. These devices are characterized by rather small sizes and mainly central (axile) supply of fuel (We will notice that model operation of front devices which at first sight, could provide increase in their sizes and increase in air consumption via them is impossible because of preservation approximately to constants of one of principal dimensions which has to be used at geometrical model operation of the reference size of drops of fuel). Thus, when using of the developed earlier front devices of traditional cameras for formation of "poor" uniform fuel-air mix with $\alpha \approx 1.5\text{-}2$ in the header of the camera absolutely natural is use the multinozzle (more precisely-multijet) the front devices allowing to increase air consumption to the header of the camera. It is of course, about use of very perfect jets providing the uniform distribution of shallow drops of fuel in the air stream passing through them.

MATERIALS AND METHODS

Method description: On the basis of the given reasoning and for their approbation, the front module for model CC was designed and its separate tests are carried out. The design of a jet represents a one-channel compressed-air atomizer with distribution of fuel on an axis (2 points of injection) and the periphery (4 points of injection), the double pro-thinned-out nozzle and three air sawirlers.

The method of preparation of the uniform fuel-air mix consists in the following: the brought fuel fills the ring channel formed of the external and internal plug and is distributed through 4 and 2 openings diametrically located on an external and internal surface of a spray. Interaction of air channels of the device and points of injection of fuel are designed so that to provide formation of the uniform fuel film on all surface of the cylindrical plug and further subdivision with a velocity head of air on separate drops. One of key components of a method of preparation is maintaining of the constant pressure put from the express pro-thinned-out air jet in points of injection and upon a surface of the formed fuel film, providing the given thickness and the uniform distribution it on diameter of the plug. The received concept of a film, moving with a small speed to dispersion edge break the high-speed twirled stream of air and to be split up for separate drops and intensively mixes up with air from a radial sawirlers, providing distributions of fuel particles in district section and forming evenly prepared mix of liquid fuel with air. The received fuel-air mix is being dispersed from an edge of an output nozzle, forming a steady jet of dispersion with the given expansion angle about 90°C and mono dispersible aerosol.

Thus, the designed front module has to provide preparation of the uniform fuel-air mix with characteristics of an aerosol the most close to homogeneous mixture. As a result of the conducted preliminary calculated researches, it is established that behind a jet the intensive zone of reverse currents on a device axis for stabilization of the flame front and the steady high-speed flow of air at the exit and a nozzle part of a spray is formed. For approbation of the developed front device and a method of preparation the pilot studies of characteristics of the jet of dispersion generated behind an output nozzle in the conditions of open space are conducted.

Experimental technique: The pilot studies were conducted on the test stand of laser diagnostic of characteristics of jets of diffusion behind front devices of combustion chambers in the conditions of open space. Possibilities of the stand and the used equipment allow to receive characteristics of the field of a fineness of dispersion, the field of concentration and their pulsations, corners of a jet of diffusion and a velocity distribution of air and fuel particles in space. Also, the stand is supplied with the equipment for measurements of expenses, pressure, temperatures and physical properties of liquid fuels and air. Fuel consumption of GT and its density is measured by krohne flowmeter, GB air consumption-promass flowmeter. Tonometer is performed by ADZ1 sensors. Digital photographing is carried out by the three-matrix color canon XL-H1 video camera. Optical part of the stand is equipped with 2 methods non-contact measurements of dispersible characteristics of diffusion, speed of drops and their concentration in a stream. Well-known and widespread method of Phase Doppler Anemometer (PDPA) and new unique method of a Shadow anemometer of Particles (PSV). In the real research physical researches were conducted by the PDPA method at 3 options of assembly of the front module, modeling a jet duty in the conditions of confidants to small gas.

RESULTS AND DISCUSSION

Results of the pilot study: The first stage of tests consisted in definition of the account characteristic of the front device on the fuel channel at supply of kerosene of brand CU-1 and on channels of air delivery in the block of

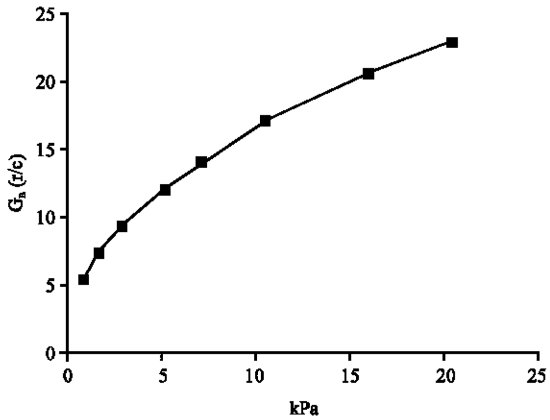

Fig. 2: Air flow characteristic

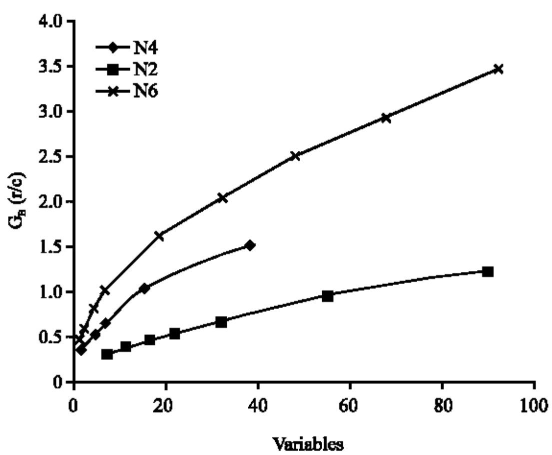

Fig. 3: Fuel flow characteristi; N2: fuel injection through 2 central nozzles; N4-fuel injection through 4 external nozzles; N6: fuel injection through 2 central and 4 external nozzles

sawirlers. Lower on Fig. 2 and 3 schedules of the received account characteristic by air and by three options of supply of fuel are provided. On schedules dependence of an expense on the received pressure drop in channels of air delivery and fuel is presented. Hereinafter CPT and CPB mean difference of pressure according to fuel and air. In a design of the front module in the external air canal there is a preload in the form of a cone. The gas counter-pressure was measured in the place of injection of fuel. This size Fig. 4 was considered further at model operation of the modes of tests for preservation of the required fuel consumption through a nozzle of nozzles.

Measurements of parameters of dispersion were taken on the mode brought closer to small gas. The air pressure drop on a front-line unit was established by 20 kPa that corresponds to 4% of loss of the total

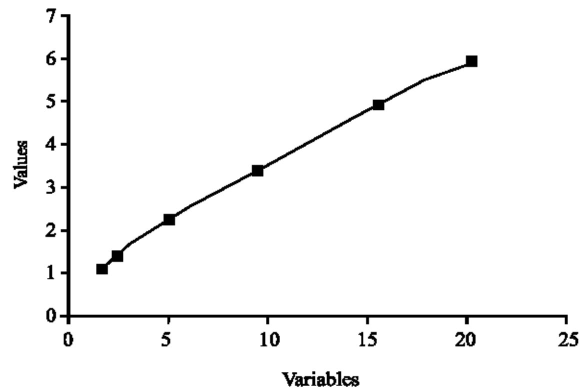

Fig. 4: The dependence of air pressure in the outer channel of the air-fuel inlet pressure drop

pressure on a wall of a heat pipe. Fuel consumption moved 0.3 g with and was distributed on number of points of injection from 2-6. In test data schedules of distribution of effective and medium diameter of fuel particles, axial speed and a volume concentration of fuel were received. Also, district nonuniformity of dispersion jet in a transverse section by method of the fluorescent and polarizable relation, photography in a laser knife and further processing of pictures was investigated. All measurements of parameters of dispersion were taken apart 30 mm from a cut of an air jet at the following duty of the front module: N2, N4, N6, -rv = 20.0 kPa, Gv of = 23.0 g with, Gt of = 0.3 g/page.

On escaping of a nozzle part of a spray the twirled stream of mix begins to extend, forming dispersion jet. The received aerosol can be considered as a combination from two zones: primary (stabilization) and secondary (main) zone, differing both on intensity of a current and by the sizes of drops. Usually, in primary zone the Inverse Flow Zone (IFZ) which serves for stabilization of a flame is formed. In this zone there are most shallow particles which are continuously circulating within IFZ borders. A delivery fuel comes as from a secondary zone by tightening of drops and from the central fuel-air nozzle. In a secondary zone more dense stream sowed by fuel particles, larger on diameter which size with increase in radius of a jet increases is formed. Also, it should be noted existence on border of a jet of local pulsations of concentration of fuel. The mechanism of their education consists in padding adulteration of external air from a surrounding medium. Such pulsations have some frequency depending on the speed of the main fuel-air stream. The general view of a jet of diffusion behind the CC front device and the photo of a transverse section in a laser knife is given in Fig. 5. The received district nonuniformity of distribution of fuel particles in a transverse section of dispersion jet makes <10% that is a good indicator and allows to claim about formation of the

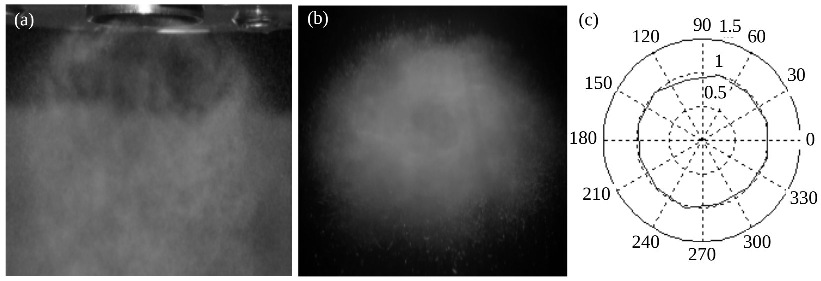

Fig. 5: Photos of the aerosol burner with fuel and pneumodispersion photograph of a cross section of the laser knife and circumferential fuel uneven

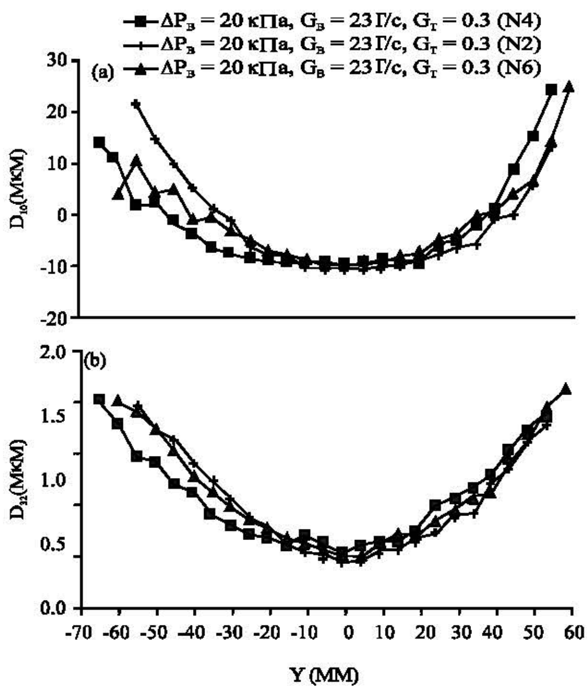

Fig. 6: Distribution medium D10 and medium Zauter D32 fuel particle diameter in the spray; MkM: TyT далее; MM: mkm; kпa: mm: kPa

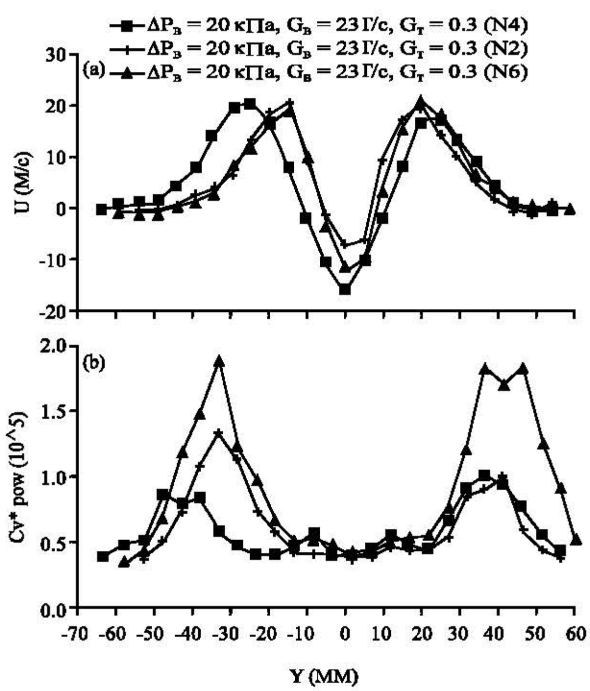

Fig. 7: The distribution of the axial velocity of the air at 5 μ particles of a front-line unit and the volume concentration of the fuel by the diameter of the spray

uniform fuel-air mix behind a jet. On Fig. 6 and 7 schedules of distribution of parameters of an aerosol behind the front module with pneumodis persion.

Schedules of dispersible characteristics distribution of an aerosol show that change of quantity and the place of supply of fuel in a spray design has practically no significant effect on particle size in a stream behind the module. It is explained by the fact that fuel injection openings, being on different surfaces and in different conditions form a fuel film which at an incident flow of air moves dispersion edge and break from it. At the same time, the structure of the film can differ on external and internal the surfaces of the cylindrical plug. Moving on the outer side with larger fuel consumption, thickness of a film increases and on its surface waves which gradually lose stability are formed and in the place of transition with a corner 15°C to a cut of dispersion edge break the twirled air stream. The further trajectory of driving of such drops will be to veil from their sizes. The largest particles will take off further and to be separated on edges of an output air jet and shallow particles are fond of an incident flow of the twirled air. From schedules it is visible that the formed fuel-air mix under different conditions of supply of fuel provides the uniform subdivision and distribution of drops of fuel in a stream at model operation of the mode of diffusion with a pressure drop Crv at the front = 20 kPa which corresponds to reference value in 4% of losses of the total pressure for CC in the conditions of small gas. Behind the front module with pneumodispersion fuels the zone of reverse currents which intensity apart 30 mm from a cut of a nozzle reach to -16 m/sec (that is close to calculated values) and 20 mm wide is formed. Extent of this zone will depend on a design of CC and distance from a front plate to the first row of the main openings. But it is possible to tell that the received values of speeds behind the presented jet will provide the acceptable range of operational stability and a good fineness of diffusion sure start of CC. A volume concentration of fuel as one would expect is most received for option during the operation of all 6 channels of supply of fuel (N6).

Thus in the course of the pilot studies it is shown that increase in intensity of a turning of air allows to raise extent of homogenization of mix (to improve dispersion and hashing of fuel with air). For process of pneumatic subdivision it is important to have the steady high-speed flow of the twirled air at low speed of supply of fuel in it-as it is reached in the device. Disintegration of a fuel film happens in several stages: failure of drops from a film surface, subdivision of a film on dispersion edge, failure of fuel from a transversal crossbeam in the central channel, subdivision of separate large drops around a device nozzle. These schedules show, effectiveness of process of a mass transfer of fuel particles in the twirled stream at the exact selection of a ratio of components, points of injection and a way of dispersion.

For confirmation of operability of the front module with pneumodispersion and technology of the grown poor combustion tests fire at positive pressure of the environment were carried out. For working off of stability of combustion the model option of rectangular three jet compartment CC with the punched cooling of walls of a heat pipe was chosen. Tests were carried out at the CIAM stand in conditions at Pk of = 0.5 MPas and Tk = 680 K on an entrance to a combustion chamber. Distribution of air in volume of a heat pipe was chosen in the ratio 40% through cooling and 60% through 3 jets established in a front plate.

By results of tests fire control and swirl characteristics of the experimental CC with the developed front modules in conditions at H = 0, M = 0 are received. Ignition points of mix are received at αzt = 1.4 and side-altars of steady combustion on the mode of small gas at Shopping mall = 682 K and Rk = make 0.53 MP as αzt = 4.5.

CONCLUSION

As a result of the conducted pilot researches of the developed device and the offered method of preparation it was established: effectiveness of process of subdivision and hashing in twirled stream depends on a way of interaction of streams of fuel and air. It is possible to achieve the uniform distribution of fuel at input of fairings or installation of the padding block of sawirlers that will improve process of mixture-forming. Most the steady and monodispersible flow of diffusion is provided behind the front device with a multistage pneumatic dispersion of fuel. The method of preparation of fuel-air mix provides formation of the uniform aerosol with a corner of dispersion 90°C and the effective zauter diameter of drops on diameter of a jet makes 23 μ that will allow to evaporate evenly drops and to achieve the homogeneous flame front. Thus, tests fire of the front device in the three jet compartment CC and the method of preparation of mix confirmed the serviceability and ensured start and operational stability of a combustion chamber in the range from α zt =1.4-α zt = 4.5.

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