The effect of microwave discharge on subsonic gas flow with different power characteristics

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Abstract. The results of the study of the effect on the subsonic flow in the transition microwave diffuser for controlling the boundary layer and restructuring the flow are presented. The effect of various ways of installing antennas in the channel and the power in the discharge from the minimum to the maximum in a pulse-continuous generation mode is shown. Impact assessment was carried out according to the total pressure in the outlet section of the channel.

1. Introduction

Modern trends in the development of aircraft engines are aimed at improving the characteristics of motors with smaller dimensions and increased fuel efficiency. In an attempt to reduce the size of both the engine as a whole and its individual units using optimal design achieve acceptable performance, but not perfect, and only on some of the design modes of flight.

A significant part of the difficulties associated with the change of the parameters of the engine, caused by the mode of gain and altitude, as well as weather conditions even in cruising flight. However, even under conditions of optimal operating parameters of a gas turbine engine, there are frequent cases of flow breaks in the transition channels of blade machines with overall limitations on the engine and the design features of the node when linking paths. In such cases, undesirable negative effects are tried to be eliminated, if possible, by reprofiling the contours of the channels or using passive flow and boundary layer control methods such as installing airworms or interceptors and surface perforation.

The influence of such methods was noted more than once and was extensively developed in the 70s of the last century. The big drawback of passive methods is the impossibility of eliminating the negative impact on the design modes of operation at those moments when control is not required, therefore, active methods of influence, such as blowing and sucking air jets, synthetic jet generators [1, 2], installing dielectric barrier arresters [3] or other plasma formations [4-11]. The choice of control method is often determined by the design features of management requirements.

With the development of technology, more and more attention is paid to the ways of energy impact based on optical methods and gas discharges, for example, spark, glow, pulsating nanosecond, arc and streamer high-frequency (Figure 1).

Over the past two decades, a number of works have been carried out on the application of streamer microwave discharges (MWD) with various energy supply organizations, both for the purpose of fuel
ignition and flow control. The supply of energy to the zone of separation or deceleration in the near-wall region or in the core of the flow can have a different effect on the nature of the flow. So, for example, by bringing energy into the gap near the wall, it is possible to eliminate the vortex formed downstream, thereby reducing the loss of the full pressure of the engine and achieve a more cost-effective mode of operation of the aircraft. Sometimes it is required not only to eliminate the gap, but to restructure the flow structure, for example, to accelerate one part of the flow, but to reduce the speed of the other. In this paper, an attempt is made to influence the flow of air at various microwave discharge powers.

The use of microwave generators for the initiation of plasma discharges is due to a number of their advantages. Virtually all other types of electrical discharges in gas, which are used in research, both in Russia and abroad, have a low efficiency of energy sources in the discharge. It should be noted that the generation of microwave fields and equipment is widespread and highly developed.

2. Experimental setup and conditions
The interaction of the microwave discharge with the air flow in relation to the paths of an aviation gas turbine engine is advisable to explore in channels with similar geometrical characteristics to full-scale ones, therefore a transitional diffuser (Figure 2) with a curvilinear profile characteristic of engines and an open lemniscate inlet is developed to ensure uniform flow in the inlet section. The degree of diffusivity, calculated in relation to the output and input area was 1.76. The vacuum in the output section was created by the compressor.

The gas flow rate in the experiments ranged from 0.1 to 1.7 kg/s, and the Reynolds number calculated from the channel width of 100 mm was from $3 \cdot 10^5$ to $8.5 \cdot 10^5$, which suggests that the flow is turbulent.

All tests were carried out at full inlet pressure $P_0 = 1$ atm and temperature $T^* = 300$ K. The velocity in the inlet section was set using a throttling device and corresponded to Mach numbers M from 0.1 to 0.8.

The channel under study is prepared by pressure samplers (Figure 2). The static pressure was measured along the channel along the three generators, both on the upper and on the lower walls of the channel. In the output section, three Pitot receivers are installed. In addition, in the cross section at a distance of 40 mm from the entrance to the curved channel, two combs are installed to study the flow in the intended separation zone.
A distinctive feature of deep subcritical streamer discharges is the attachment of plasma formations to linear vibrators, i.e. streamers appear on the tip of the antennas located in the electric field of the magnetron and extend a short distance of 5 - 10 mm. However, the discharge will not ignite in the case when the voltage at the ends of the vibrator is not enough to break the medium. The electric field is distributed over the body of the antenna in such a way that the ends have a maximum intensity (Figure 3).

To study the effects of plasma formations initiated by microwave radiation, a complex of equipment was developed for generating microwave radiation and several variants of electrode assemblies were tested (Figure 3), which allow creating microwave plasma formations across the entire width of the channel \( B = 100 \) mm. In order to reduce power costs, a pulse-continuous energy supply mode was implemented with a continuous energy supply \( \tau = 100–200 \) μs and a frequency \( f = 100–300 \) Hz, which allows reducing the power input costs from 6 kW to 360 W. A generator (magnetron) with a wavelength of \( \lambda = 12.4 \) cm was chosen as a source of microwave radiation.

The developed electrode blocks (Figure 3) were installed in the channel as shown in figure 4, i.e. in the straight part of the entrance. Microwave radiation passed through the transparent wall of the channel and excited a discharge on the electrode units installed on the opposite wall.

Figure 5 shows the energy levels that were implemented in pulsed-continuous testing. Estimates show a reduction in power consumption to 60–360 W, depending on the selected duty cycle, which in experiments was \( S = (1–6) \cdot 10^{-4} \). Because results of close energies differ slightly, then we will consider two modes: maximum \( (\tau = 200 \) μs, \( f = 300 \) Hz) and minimum \( (\tau = 100 \) μs, \( f = 100 \) Hz) in comparison with the discharge off and with a channel without electrode units.

3. Results
To assess the contribution of the microwave discharge, tests of the diffuser channel without and with electrode blocks were carried out. Figure 6 shows the relative total pressure \( P^* \) profiles in the intermediate section with high \( h=34 \) mm. The legend schematically shows the method of installation of electrodes in blocks. It is seen that the blocks have a different effect on the flow in the near-all region. The pairwise convergent block significantly reduces the pressure, creating a single vortex that does not have a positive contribution to the characteristics, therefore, it is not considered further. There is no significant difference between the results for the blocks in the output section with high \( H=60 \) mm, although the relatively smooth channel has greatly rebuilt, shifting the area of increased total pressure closer to the near-wall part of the flow (Figure 7).
When igniting a discharge on electrodes arranged parallel and pairwise convergent, neither the minimum nor the maximum mode in the intermediate section of the total pressure profiles do not differ. A greater difference in the profile of the total pressure has time to form to the output section. So, when installing a parallel electrode unit, the differences in total pressure between off, minimum and maximum modes are 1.1 and 2.3%, respectively (Figure 8). An even greater impact on the restructuring of the flow had a pairwise convergent block. The differences were 2.6 and 4.1% (Figure 9).

As a result, at the maximum power consumption mode of the MWD, it was possible to change the total pressure profile in the output section of the relatively smooth case by 5.3 and 7.5% when installing a parallel and pairwise convergent unit respectively (Figure 10). The total pressure in the outlet section exceeds the total inlet pressure, since there is an energy supply in the form of a MWD.
4. Conclusions
As a result of studying the effect of a streamer microwave discharge on a subsonic current in a transition diffuser channel, it is shown that it is possible to achieve flow restructuring both in the entire flow volume and in the wall region using plasma formations with a power of 60 - 360 W. It was found that the maximum value of the total pressure increases by 7.5% when the unit is installed with a pairwise convergent arrangement of electrodes when the power consumption is 360 W in a pulse-continuous mode of operation.

Acknowledgments
The authors are grateful to our colleagues from the MRI RAS, L P Grachev, L G Severinov, and K V Alexandrov for assistance in the formulation of the problem, in carrying out experiments and in analyzing the results.

The reported study was funded by RFBR according to the research project № 18-08-00271.

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