Kerosene combustion in a supersonic flow

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Abstract. A new approach is proposed to the initiation of kerosene combustion in a supersonic airflow with the stagnation temperature below 2000 K, which consists of a pulsed-periodic gas-dynamic action on the flow. The experiments have shown that it is possible to implement a quasi-steady pulsed combustion mode by choosing the parameters of pulses: energy, duration, and frequency.

1. Introduction
It is well known that in order to arrange for the kerosene combustion in a supersonic airflow certain conditions must be created that ensure mixing with air in the range of concentration limits for flame propagation, a temperature sufficient to initiate ignition, and the ratios of typical times (for flow and combustion) for a stable process. For the ignition in supersonic flow, a high level of the stagnation temperature is required (for numbers \(M = 2.0–2.5\)) \(\geq 2000\)K (see [1]). To reduce it, the use of chemically active agents ([2]) is considered, the handling of which requires special safety measures.

2. Experiment arrangement
A new approach is proposed in the work to the kerosene combustion initiation in a supersonic airflow with the stagnation temperature below 2000K, which consists of a pulsed-periodic gas-dynamic action on the flow.

Figure 1 shows the diagram of a duct, in which the flow parameters at the inlet after the nozzle are close to the conditions of the flight of a flying vehicle with hypersonic velocity. The experiment conditions: the Mach number \(M = 2.2\); the total pressure \(P_0 = 0.71\) MPa; the total temperature \(T_0 = 1680\) K. The kerosene was fed through an injector on the duct axis. The excess air factor was chosen in such a way that at a complete combustion, the flow mean velocity in the duct remained supersonic. The length of the duct part with a constant cross section was subject to change. A special valve using the air and operating according to a given program was applied as a generator of pulses.

Figure 2 shows the package of gas-dynamic pulses, which is created by the generator. The pulses have constant frequency \((f = 52\) Hz), duration \((10\) ms), and a variable intensity, which is characterized by the air pressure in the generator \((\text{MPa})\). In the cyclogram, the digits identify the regions \((1–3)\), which are typical of different modes of the combustion process. Two combustion modes were observed in the process of experiment.
Figure 1. 1 – the nozzle; 2 – the duct of a constant cross section 50 mm in diameter, which passes to a duct with a sudden expansion 90 mm in diameter (see position 4); 3 is the kerosene supply along the duct axis via the injector; 3 – the introduction of gas-dynamic pulses; 5 – the location of a possible additional supply of the combustible gas; Pi is the pressure on the duct wall.

Figure 2. Cyclogram of the packages of pulses.

Shown in figure 3 relative pressure distributions along the duct length reflect the changing nature of the process from the beginning of the initiation of combustion of kerosene at a high intensity of pulses at the beginning of the package (1) to a gradual reduction of the pressure level (2) and the failure of combustion (3). During some period of time (9.6–9.9 s), there was a pulsating combustion (1). At a reduction of the intensity (10.2–10.4 s), the combustion deteriorated (2), and the flame blowout occurred (3).

Experiments have shown that the selection of parameters of gas-dynamic pulses may exercise quasi-stationary pulsating mode of combustion.

Figure 3. Distribution of relative pressure along the length of the duct.
3. Proof of the combustion effectiveness

A special experiment was made to confirm the feasibility of intensive combustion of kerosene in part of the combustion chamber of constant cross section. The essence of the experiment was as follows. The amount of kerosene was supplied on the basis that when it is completely burned in the part of the duct of constant cross section, the average flow velocity at the outlet of it will be close to the speed of sound (Mach number ≈ 1). It is assumed that it is possible to retain this mode when the supply of the package of pulses is switched off if the combustion process in the expanding part of the channel is organized in such a way that an appropriate backpressure is created. Settings at the nozzle exit are \( M = 2.2 \); total pressure \( P_0 = 0.70 \text{ MPa} \); total temperature \( T_0 = 1680 \text{ K} \). Ahead of the entrance into the expanding part of the duct, ethylene was fed through 32 holes of 2 mm diameter, the combustion of which was stabilized by the recirculation zone behind the sudden expansion. The cyclogram of the mode is shown in figure 4.

![Cyclogram of the experiment](image)

**Figure 4.** Cyclogram of the experiment. a, b, c – the supply in time of the kerosene, package of pulses, and ethylene after the steadying of the flow exhaustion from the nozzle; time intervals within which the pressure distribution on the wall was recorded. The pressure is measured along the ordinate axis in corresponding devices before the supply to the duct.

Parameters of the package of gas-dynamic pulses: frequency \( f = 45 \text{ Hz} \) and duration (12 ms). The coefficient of excess fuel for kerosene \( \varphi = 0.17 \), and ethylene varied within \( \varphi = 0.5–0.33 \).

The results of the experiment are shown in figure 5. From the figure, it follows that in the absence of exposure, the combustion of kerosene is of low intensity, or there is no combustion. The introduction of a package of pulses (modes 2, 3) leads to a noticeable increase in pressure, which indicates the intensive course of the combustion process, and the combustion begins near the injection site of kerosene. At a switch-off of the package of pulses (modes 4, 5), the kerosene combustion process remains intense, the beginning of the combustion is shifted downstream, and the length is approximately four diameters of the duct of constant cross section. Upon termination of the feeding of ethylene, the combustion of kerosene in the duct of constant cross section stops. According to the previously proposed (see [3,4]) quasi-one-dimensional method of estimating the combustion completeness for combustion in a pseudo-shock, the values of the Mach number and the combustion completeness were determined. The Mach number at the end of the section of the duct of constant cross section \( M = 0.9 \), and the combustion completeness is close to 1.
4. Conclusion
The conducted study shows that it is possible to control the combustion process in a supersonic flow by means of a package of gas-dynamic pulses of variable intensity with the implementation of a pulsating combustion mode. The intense combustion mode was experimentally realized in the part of the duct of constant cross section after switching off the external pulsed-periodic gas-dynamic action when creating at the end of it the corresponding backpressure by organizing the ethylene combustion in the expanding part of the duct.

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