Experimental investigation of the sliding electric frequency mode arc discharge in the subsonic and supersonic flow

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1 Introduction

The plasma of the discharge, initiated along a surface of wing or the fuselage, is promising aircraft control facility. Strong shock wave formation at air gap disruption by the sliding discharge (SD) changes a flow over aircraft surface and creates an impulse for changing a trajectory of flight (see Figure 1). Critical existence conditions measurements of the sliding discharge in an air flow are important for its application in supersonic aircraft. These conditions at supersonic flows were investigated earlier [1], [2]. The purpose of this work is to direct measure of efficiency SD to create impulse obtained by wing in the subsonic and supersonic air flow.

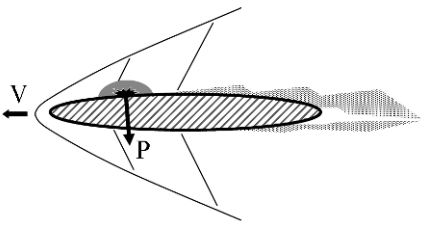

Fig. 1. General diagram of the discharge action to the aircraft wing

2 Experimental setup

The sliding arc discharge was studied in a frequency mode in air flow. Used air flows were created by ventilator or by air outflow to the vacuumed capacity. In this work the investigated discharge is the air disruption between electrodes and a surface of a semiconducting coal-graphite rod (Figure 2a). Direction of discharge is perpendicular to a flow and smooth up with a surface of streamline bodies (wedge with a 10 degree streamlined corner or wing model). The discharged gap between electrodes was 4 cm - 8 cm. The voltage between electrodes was registered. Process of discharge was recorded by video camera. Scheme and photo of investigated wing model are shown on Figure 3. We used two flow-generated modes: flow with velocity 520 m/s (pressure in nozzle 0.16 atm) and flow with velocity 200 m/s (pressure in nozzle 0.24 atm). Investigated wing with discharger and wind tunnel are shown on Figure 4.

For measuring impulse from the discharge, aerodynamic balances were constructed. Own oscillation frequency of balance was of about 100 Hz. The cable and strain gauge were protected from the airflow and heat exchange as minimum for 30 seconds. Strain gauge receives effort to perpendicular of model wing plane. The calibration of aerodynamic balances was produced by falling of calibrated preliminary heated clay ball. Shock from ball was inelastic.

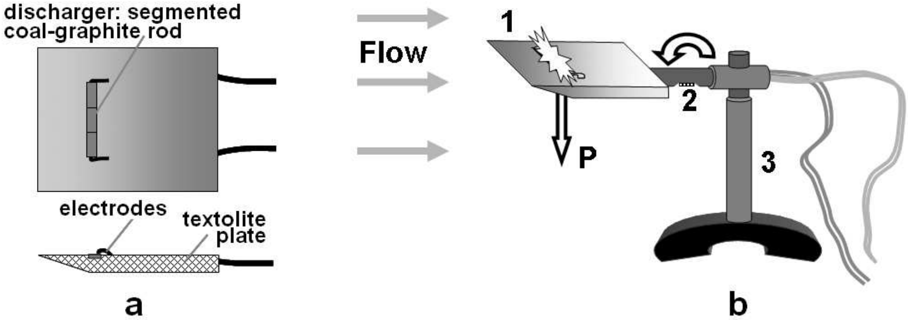

Fig. 2. a - Scheme of supersonic wing model with segmented discharger. Wedge with the sizes of a plane 8 cm x 12 cm. Discharged gap is 4 cm (between electrodes). **b** - Scheme of measuring of discharge impulse using aerodynamic balances in air flow. 1 - wing model with segmented discharger (upper plane of wedge it is parallel to flow), 2 - strain gauge, 3 - the rigid support

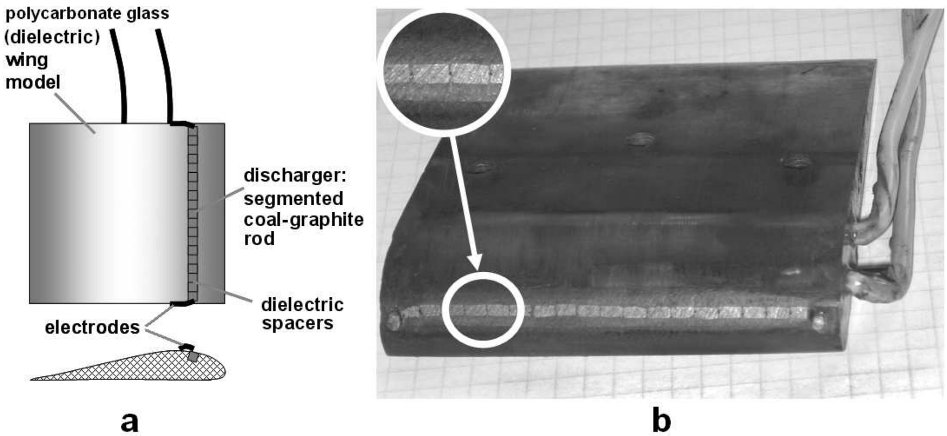

Fig. 3. a - Scheme of wing model. The discharged gap between electrodes is 8 cm. **b** - Photo of investigated wing

3 Experimental results

First experiments with slow air flows (with speed 40 m/s) demonstrated no visible influence of flow on the discharge. It was shown that the major determining factors of stability of the discharge were an intensity of a field on an discharger, size of discharger segments, a warming up of electrodes and pressure (electric durability of air depends on pressure).

All experiments carried out by us confirm the possibility of stable excitation of the sliding discharge in wind tunnel at air flow velocities from 200 m/s up to 520 m/s and intensity of an electric field from 0.5 kV/cm up to 1.0 kV/cm (Figure 5). Frames 1 - 4 on

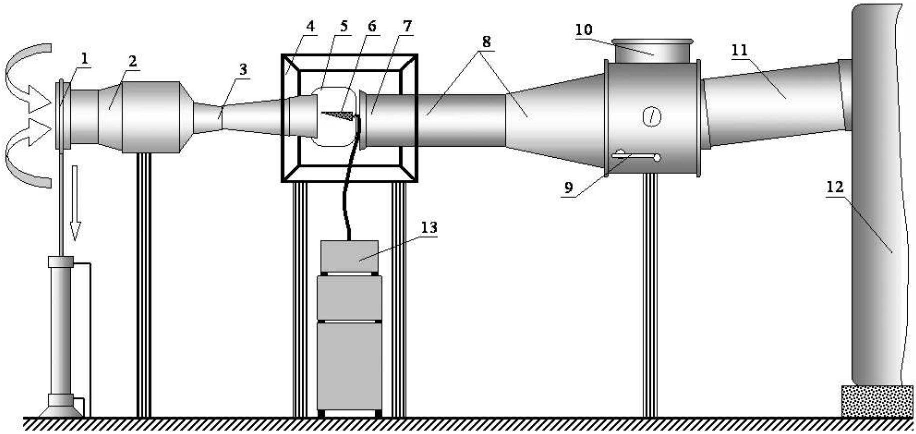

Fig. 4. Experimental setup: supersonic wind tube. 1 - pneumatic cutoff plate-bolt, 2 - receiver, 3 - supersonic nozzle, 4 - Eiffel's camera, 5 - window, 6 - is model wing-discharger, 7 - the entrance of diffuser, 8 - diffuser, 9 - the drive of vacuum lock, 10 - vacuum lock, 11 - connecting conduit, 12 - vacuum gas holder (120 cubic meters, 10 mm Hg), 13 - apparatus counter with the power unit of the discharger

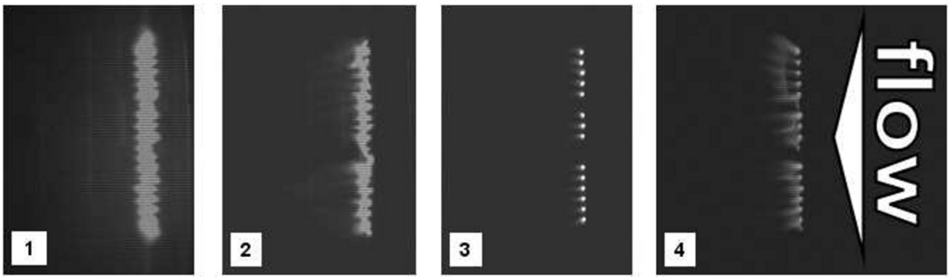

Fig. 5. The frames of wing-discharger work in the airflow with velocity of 200 m/s (frequency - 10 Hz, energy of one discharge - 15 J)

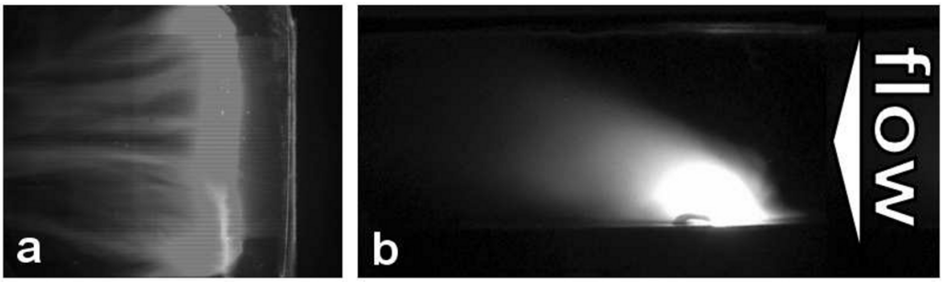

Fig. 6. a - Work of discharger in the wind tunnel. The flow velocity is 520 m/s, frequency - 10 Hz, energy - 150 J. **b** - The work of wedge-shaped discharger in the pulsed operation with the capacity energy 270 J in the airflow 520 m/s, flow direction is from right to left. Wing is located horizontally

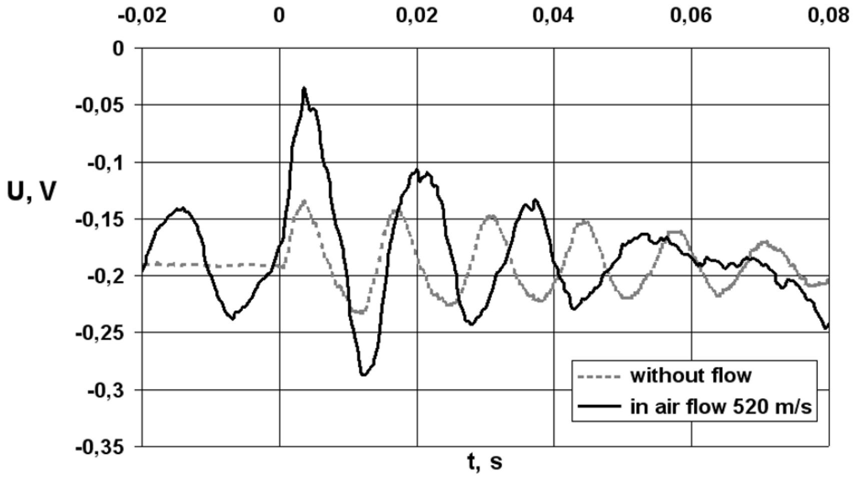

Fig. 7. Oscillogram of the action of the typical discharge with the energy 265 J on the wing in quiescent air and in the supersonic airflow (520 m/s)

Figure 5 - were recorded with exposure time 0.03 s for different discharges. Flow velocity (200 m/s), frequency (10 Hz), energy (15 J) were the same. Frame 1 is typical SD. Frame 2 demonstrates SD with one segment lost. Frame 3 and 4 is work of discharger when three segments were lost by flow, but discharger continued to functionate. Discharger energies were 8 J - 40 J at brought average power from 100 W up to 500 W. Discharges frequency was varied up to 40 Hz. Work of more powerful discharger in the wind tunnel with supersonic flow (520 m/s), frequency - 10 Hz and energy - 150 J is shown on Figure 6. It is well visible (Figure 6a) the removal of the SD plasma by the supersonic flow and the expansion of the erosion products of discharger material.

Action of discharge impulse on wing surface in air flow has been measured according scheme on Figure 2b. These measurements were carried out for various wing profiles and discharge energies. Oscillograms of discharge action with the energy 265 J on the wing in quiescent air and in the supersonic airflow (520 m/s) are shown on Figure 7. Time of one SD was about 5 - 10 μs. Discharge was carried out at the zero time. Dashed line on Figure 7 corresponds to discharge in motionless air. Solid line on Figure 7 corresponds to discharge in supersonic airflow. The difficulty of treatment of oscillograms with the supersonic flow consists in the presence of the strong sustained own oscillations. This is connected with the streamline around the tail end of the wing and knife-holders. As a result we have observed different forms of oscillograms in dependence on the switching moment of discharge relatively to phase of the own system oscillations. We took into account this at obtaining mechanical impulse value.

For the quantitative assessment of pulse action on wing, we had suggested value - efficiency of the discharge:

$$Efficiency = \frac{Impulse}{Deposited\ energy} = \frac{P}{E}, \left[\frac{N \cdot s}{J}\right] \tag{1}$$

where P is mechanical impulse created by SD with energy E. As the energy of the discharge in this work we mean energy of capacity. Energy transferred to the discharge plasma is about 10% - 20% E ([3]).

Obtained experimental efficiency as function of discharge energy is shown on Figure 8. We can see that for all investigated discharges the value of impulse is slightly depended on flow presence. The efficiency of the of discharge action falls with increasing of discharge energy.

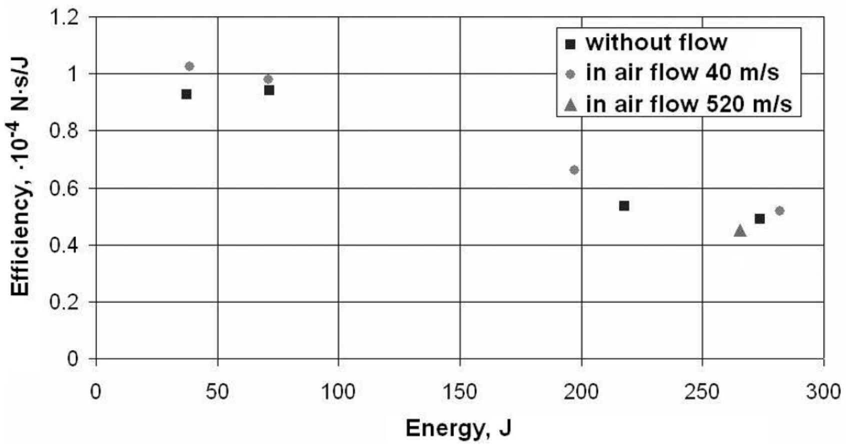

Fig. 8. Efficiency as function of discharge energy

Probably it is connected with the decreasing of the diameter of initial plasma channel of electrical discharge. The more precise interpretation of this phenomenon requires the microscopic examination of the discharge plasma dynamics. But, for investigated range of energies it follows that weak discharges with the energy about 50 J are more preferable than more powerful ones. In the supersonic flow (520 m/s) the measurements were carried out only with the high energy SD about of 265 J. For smaller energies poor relationship between signal and noise was observed. That is action from the discharge was compared with the own wing oscillations.

In perspective applications of the SD, the discharger is proposed to establish directly on the external elements of aircraft. Therefore it is necessary to investigate the possibility of its use in the real weather conditions (increased humidity, fog, rain and etc.) Model wing-discharger was placed into the water-air flow (40 m/s). Discharger functioned both in the the water-air flow and in the water layer on the completely moistened wing surface. Discharges with the energies 10 - 100 J were tested both in the pulse and in the frequency modes (up to 10 Hz during not less than 15 seconds). The flow rate of water from the sprayer was 6 g/s.

4 Conclusions

1. Possibility of the stable excitation of the frequency mode sliding discharge in the wind tunnel with the speeds of airflow to 520 m/s was shown. Necessary electric field was located in the range from 0.5 kV/cm to 1.0 kV/cm. Energies of discharges with a frequency of up to 40 Hz were 8 J - 40 J with the average power input from 100 W to 500 W.

2. Efficiency sliding discharge for creation mechanical impulse as faction of deposited energy is evaluated.

3. The possibility of the functioning of the sliding frequency electrical discharge in the conditions of high humidity in the subsonic flow was tested and verified.

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References

1. V.S. Aksenov, V.V. Golub, S.A. Gubin, V.P. Efremov, I.V. Maklashova, A.I. Kharitonov, Yu.L. Sharov Sliding Electric Arc Discharge as a Means of Aircraft Trajectory Control Tech. Phys. Letters, vol. 30, No. 10,pp. 871-873, 2004
2. V.S. Aksenov, S.A. Gubin, D.V. Blagodatskih, M.V. Bragin, V.V. Golub, V.V. Volodin, I.N. Laskin Active Flow Control by the Sliding Electric Arc Discharge, European conference for aerospace sciences, July 4-7th 2005
3. V.V. Golub, V.S. Aksenov, D.I. Baklanov, V.V. Volodin, S.V. Golovastov, S.A. Gubin, V.P. Efremov, A.S. Savel'ev, V.E. Fortov, Yu.L. Sharov Issledovanie vliyaniya magnitnogo polya na initsiirovanie detonatsii iskrovym razryadom v vodorodo-vozdushnoi smesi, Dokladi Akademii Nauk vol. 404, N 3, pp. 321-326, 2005