First Test Results of the Transient Arc Plasma Igniter in a Supersonic Flow

Igor Matveev
Applied Plasma Technologies, McLean, VA, USA
*Sergey Leonov**
JIHT RAS, Moscow, Russia

This paper considers the idea and the first test results of a combined cycle plasma torch (CCPT) application for flame holding in high-speed combustors. The CCPT was developed by Applied Plasma Technologies (APT) and is based on a low-power transient discharge plasma pilot [1] with fuel or air-fuel mixture feeding into the arc chamber, so that the main thermal effect is provided by chemical reactions in a plasma-activated medium.

The physical mechanisms of an air-fuel composition processing by electrical discharge for the combustion enhancement are well described during the last few years [2-7]. Two areas are the most important: Molecular kinetics modification (heating, plasma-chemical excitation, active particles generation); and the flow structure control to create local zones of intensive mixing and extended time of the mixture residence. Fig.1 below presents several schemes of the PAC (Plasma-Assisted Combustion) concept's realization in lab-scale tests.

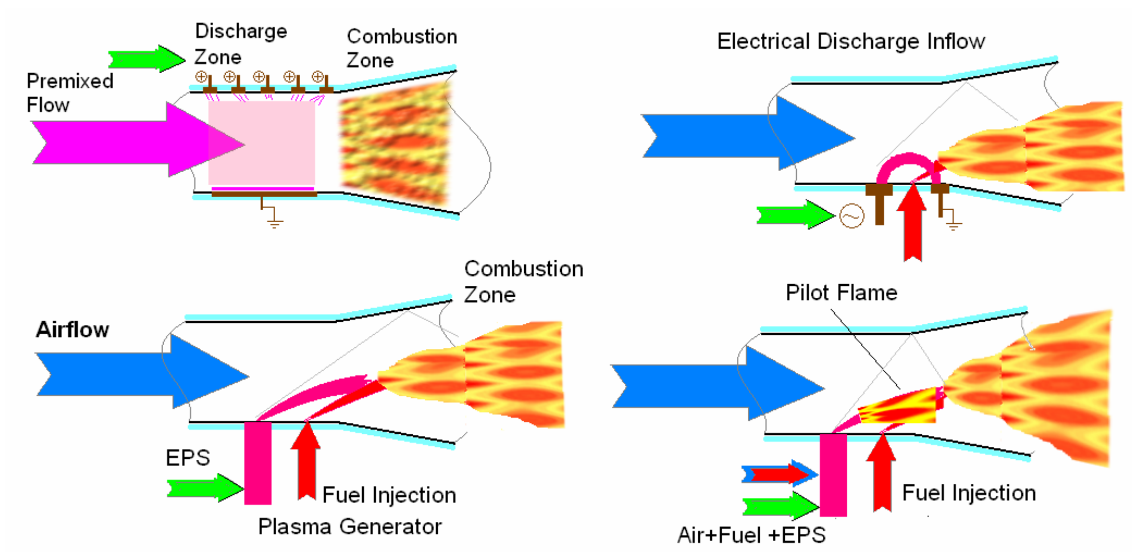

Fig. 1. Experimental schemes of the plasma assistance in high-speed combustion. Red color represents fuel injection, blue – air flow, green – electrical power supply

Two schemes in the first column are quite typical. The first scheme of premixed composition ignition is used in model tests and at theoretical analysis of non-equilibrium plasma effect on the flame propagation [8-9, for example]. The second scheme presents so called "plasma torch" generation for the fuel ignition [5, 10-11]. Torch location can be different: Torch upward, downward, in a cavity, and so on. We consider such a scheme as ineffective due to high power losses and too long a path of excited molecular gas to the zone of interaction for completion of a relaxation. It has to be noted that not only these schemes were tested but others as well. Numbers of interesting works were published, especially with RF and MW types of the plasma excitation.

Two schemes were supposed to avoid the heat loss: (1) the electrical discharge generation just in place of interaction with fuel, and (2) using a small amount of extra fuel as an additive to feedstock gas to increase thermal power of a plasma torch in place of interaction with fuel (active pilot flame). The first approach was tested in [12, 13] and shows exciting results. The forth scheme was tested in the present work.

The experiments were conducted in a short-duration blowdown wind tunnel with closed test section at Mach number M = 1.99 and static pressure P_{st} = 100 - 400 Torr, duration of steady-stage operation 0.4-0.8sec, and typical air mass flow through the duct about $G \approx$ 0.2-1.0 kg/sec. Test section dimensions were 72*60mm or 50*20mm. The experimental set up has been equipped with a Schlieren system with short time exposure, high-speed video camera, a set of fast-response pressure transducers, a spectroscopic system, photo-sensors, current-voltage sensors, thermo-sensors, etc. The air mass flow rate through the plasma generator was $G1_{air}$ = 0.3-3 g/s, the fuel mass flow rate $G1_{fue\ l}$= 0.1-1 g/s. The operation modes permit regimes with combustion or partial fuel conversion [14]. The CCPT, engineered and manufactured by APT is shown in Fig.2.

Fig.2. CCPT with fuel feeding into the arc chamber in operation.

Preliminary test results in the explored configuration can be summarized as follows: (1) The main fuel injected directly to M = 2 airflow can't be ignited by only an electrically powered plasma generator (W_{pl} = 1 kW); (2) small addition of HC fuel into the plasma igniter ($W_{pl} + W_{comb} \approx$ 5kW) sufficiently increases efficiency of flame holding. In some regimes an extra power release was detected due to the main fuel combustion in the high-speed flow. Based on obtained results we can consider such a scheme as very promising for high-speed combustion enhancement.

References

1. I. Matveev, S. Matveeva, Yu. Korolev, O. Frants, N. Landl, *A Multi-Mode Plasma Pilot*, AIAA 2007-822.
2. Leonov S. B., Yarantsev D. A., Napartovich A. P., Kochetov I. V. *Plasma-Assisted Combustion of Gaseous Fuel in Supersonic Duct. IEEE Transactions on Plasma Science*, **34(6)**: 2514-25, 2006.
3. Yu. Korolev, I. Matveev, *Nonsteady-State Processes in a Plasma Pilot for Ignition and Flame Control*, IEEE Transactions on Plasma Science, **34(6)**: 2507-13, 2006.
4. Starikovskaia S. M. Plasma assisted ignition and combustion J. Phys. D: Appl. Phys., **39:** R265–R299, 2006.

5. Takita K. *Ignition and Flame-Holding by Oxygen, Nitrogen and Argon Plasma Torches in Supersonic Airflow*, Combustion and Flame. 2002. V. 128. P. 301.
6. L. Jacobsen, C. Carter, R. Baurie, T. *Jackson Plasma-Assisted Ignition in Scramjet*, AIAA-2003-0871.
7. I. Matveev, S. Matveeva, A. Gutsol, A. Fridman *Non-Equilibrium Plasma Igniters and Pilots for Aerospace Application*, AIAA-2005-1191.
8. Ainan Bao, Guofeng Lou, Munetake Nishihara, Igor V. *Adamovich On the Mechanism of Ignition of Premixed CO-Air and Hydrocarbon-Air Flows by Nonequilibrium RF Plasma*, AIAA-2005-1197.
9. Kochetov I. V., Napartovich A. P., Leonov S. B. 2006. *Plasma Ignition of Combustion in a Supersonic Flow of Fuel-Air Mixture: Simulation Problems*. High Energy Chemistry. **40**(2): 98-104.
10. Naoyuki Abe, Ryuta Ohashi, Kenichi Takita, Goro Masuya, Yiguang Ju *Effects of NOx and HO2 on Plasma Ignition in a Supersonic Flow*, AIAA 2006-7971
11. Billingsley, M.C., Sanders, D.D., O'Brien W.F., and Schetz J.A., *Improved Plasma Torches for Applications in Supersonic Combustion*, 13th International Space Plasmas and Hypersonic Systems and Technologies Conference, AIAA 2005-3423, May, 2005.
12. Sergey B. Leonov, and Dmitry A. Yarantsev *Plasma-induced ignition and plasma-assisted combustion in high-speed flow* // **IOP**, Plasma Sources Science and Technology, **16** (2007), p.132-138, stacks.iop.org/PSST/16/132.
13. A.Aleksandrov, V.Bychkov, V.Chernikov, A.Ershov, V. Gromov, E.Kolesnikov, V.Levin, V.Shibkov, V.Vinogradov *Arc Discharge as a Means for Ignition and Combustion of Propane-AirMixture Supersonic Flow*, AIAA 2006-1462.
14. I.V. Kochetov, S.B. Leonov, A.P. Napartovich, E.A. Filimonova, D.A. Yarantsev. *Plasma-chemical reforming of the hydrocarbon fuel in the air flow*, International Workshop on "Thermochemical and plasma processes in aerodynamics" Saint-Petersburg, 19-21 June, 2006.

**Sergey B. Leonov*
Joint Institute of High Temperature, Izhorskaya str., 13/19, Moscow, 125412, Russia
sleo@oivtran.ru, sleo58@gmail.com, http://www.plasmaero-ivtan.ru
Phone: +7(495) 484 1811 (business hours), Fax: +7(495) 483 2285

Sergey B. Leonov (16 May 1958, Russia)
Education: Master Degree Moscow State University physics - 1981
Ph.D Baltic State University mechanics of gases and plasmas - 1990
DSc Institute for High Temperature physics and mathematics - 2006
Affiliation: Moscow State University - Student (CARS measurements in MW Discharge) - 1976-1981, Institute of Atomic Power Stations - Scientist (Diagnostics of Fusion Plasma) - 1981-1985, State Institute of Aviation Systems- Senior Scientist (Plasma Generation, Gasdynamics) - 1985-1997, Moscow Technical Company - Deputy Director on Science -1996-1998, Joint Institute for High Temperature - Head of Laboratory (Experimental Plasma Aerodynamics) 1998-now
Fields of Expertise: Experimental Plasma Aerodynamics, Weakly Ionised Plasma Generation, Flow Actuation by Electrical Discharges, Diagnostics of Low-Temperature Plasma, Gasdynamics and Aerodynamics, High-Speed Combustion

Present Position: Joint Institute for High Temperature Russian Academy of Science, Head of Laboratory of Experimental Plasma Aerodynamics
Others: AIAA Associate Fellow, Awarded by "Who is Who in Science and Engineering"- 2001, Publications: more than 80

Igor B. Matveev was born on February 11, 1954 in Russia. He received his Master of Science degree in mechanical engineering from the Nikolaev Shipbuilding Institute in 1977 and earned his Ph.D. degree in 1984. The Ph.D. theses were entitled "Development and Implementation of The Plasma Ignition Systems for Naval Gas Turbines". From 1977 to 1990 he was a researcher, teacher and associate professor of the Nikolaev Shipbuilding Institute. In 1990 established a privately owned company Plasmatechnika (Ukraine) for development and mass production of the plasma systems. From 2003 is with Applied Plasma Technologies (USA) as President & CEO. Over 1,200 plasma ignition and flame control systems, developed under his supervision are in operation worldwide.

In 1989 has organized the first in the former Soviet Union conference on Plasma Ignition and Flame Control. From 2006 organizes annual International Workshop and Exhibition on Plasma Assisted Combustion. He is a guest editor for the IEEE Special Issue on Plasma Assisted Combustion from 2004.