Images of Arc-Heated Supersonic Argon Plasma Jet Impinging on a Flat Plate

Xian Meng, Wenxia Pan, Dongsheng Han, Hai-Xing Wang, and Chengkang Wu

***Abstract*—Low-density flow fields are usually difficult to visualize using ordinary optical methods. However, plasma flows, having high temperature or excited species in them, may show up some features of the flow field in a simple photograph. A dc arc-heated supersonic argon plasma jet impinging on a flat plate under low ambient pressure was photographed. The varying brightness shows features of the flow field which bear some resemblance to the results by numerical simulation of a cold argon jet impinging on a flat plate.**

***Index Terms*—Arc-heated plasma, flow visualization, supersonic impinging jet.**

LOW-DENSITY flow fields are usually difficult to visualize using shadowgraph or schlieren methods due to the weak refractive effects of the gas under such conditions. However, in a low-density plasma, light-emitting particles in the flow might be an indicator of some features of the flow. An example of such a plasma flow is the exhaust of an arc-heated jet (arcjet) thruster. This is a kind of effective electric propulsion system for space applications [1]. In the thruster, gaseous propellant is heated by a dc arc discharge to a temperature over 10^4 K, and subsequently, converted into a supersonic plasma jet through a convergent–divergent nozzle, issuing into the ambient atmosphere, where the pressure is a few pascals or even lower, producing a thrust force. The thrust may be indirectly measured by the impinging force it produces on a normally placed flat plate [2]. It is desirable to know the structure of the flow field in such an arrangement. In this paper, images of such a supersonic argon plasma jet impinging on a flat plate are presented. Numerical simulation result for the flow field of a cold supersonic argon jet impinging on a flat plate is also shown.

The arcjet thruster [3] has a nozzle with a throat of 0.7 mm in diameter, a conical expansion half angle of 15°, and an area ratio of exit to throat of about 240, where supersonic plasma jet flow can be produced. It was placed in a vacuum chamber where the pressure could be kept at lower than 10 Pa with a 5-slm (standard liter per minute) argon flow. A heat-resistant metal plate of 200 mm in diameter is normally placed downstream of the thruster nozzle exit, and the distance between the nozzle exit and the metal plate is 75 mm.

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X. Meng, W. Pan, and C. Wu are with the Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China (e-mail: mengxian@imech.ac.cn).

D. Han and H.-X. Wang are with the Beijing University of Aeronautics and Astronautics, Beijing 100191, China.

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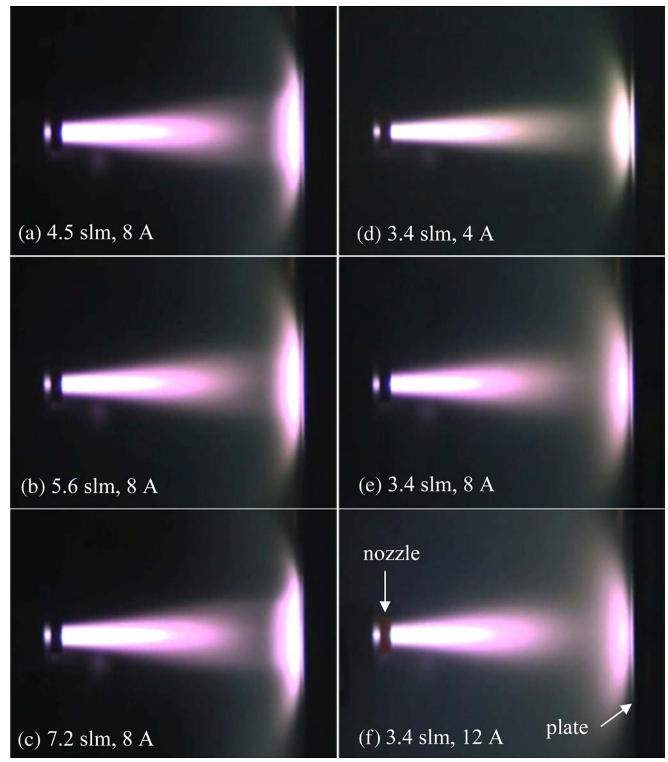

Fig. 1. Images of argon arc-heated supersonic jets impinging on a flat plate at arc current of 8 A with (a)–(c) different gas flow rates and at gas flow rate of 3.4 slm with (d)–(f) different arc currents. The distance between the metal plate and the nozzle exit is 75 mm.

Images of argon plasma impinging on the flat plate at various conditions are shown in Fig. 1, which were taken by a digital video camera (SONY DCR-TRV27E). It is seen from these figures that the size of the luminous region of the plasma jet does not change much with increasing gas flow rate, while it looks much brighter for higher arc current, and the diameter of the plasma jet increases with increasing arc current, particularly in the region near the nozzle exit.

Each image can be divided into three regions according to the jet brightness. The first region is the free jet region, where the jet is exhausting from the nozzle and away from any local interactions due to impingement. Then, the second region is the impingement region, where strong interactions of the impinging jet with the metal plate produce a change in flow directions and lead to significant changes in local jet flow parameters. A slightly curved front can be seen at the

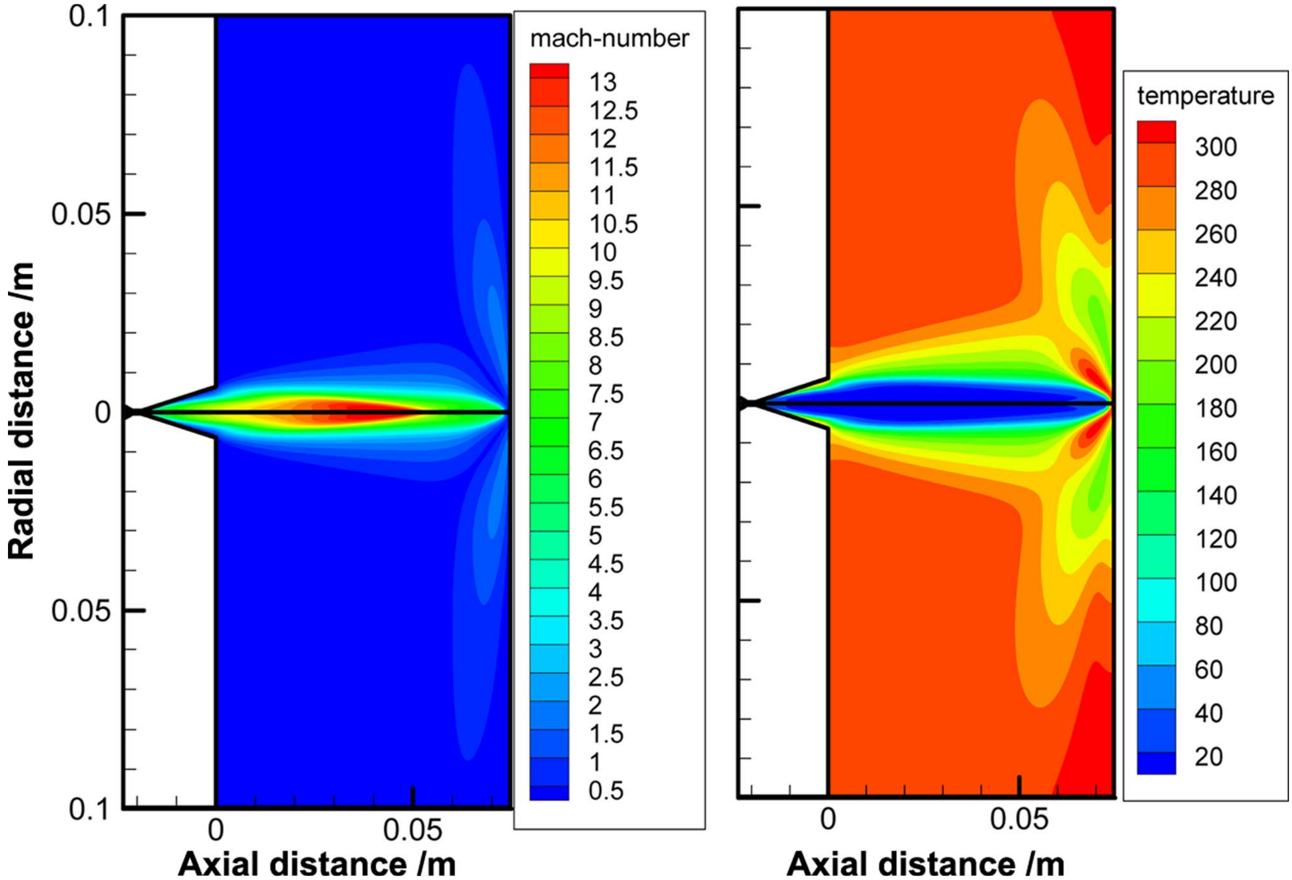

Fig. 2. (Left) Computed Mach number and (right) temperature distributions in the cold argon impinging jet at a gas flow rate of 7 slm. The distance between the nozzle exit and the metal plate is 75 mm. Ambient pressure: 15 Pa. Inlet gas temperature: 300 K.

beginning of this impingement region, more obvious at higher flow rate. This is considered to be a normal shock, and sharp changes of the jet brightness behind the normal shock represent the violent changes of the jet flow parameters, such as the temperature, velocity, and pressure. The third region is the wall jet region, which is essentially the radial flow along the metal plate surface. In this region, although the flow is not as bright as in the impingement region or the core of the free jet, it is still brighter than that of the environment. These three flow regions are consistent with former research [4].

Wave structures of typical underexpanded supersonic jets, such as the expansion and compression/shock waves, are not clearly seen in the free jet region among the images in Fig. 1. The reason could lie in the rarefied nature of the flow under these extremely high-temperature and low-ambient-pressure conditions. However, the brightness of the images may qualitatively indicate the temperature distributions.

Based on the assumptions and governing equations [2], Fig. 2 shows the FLUENT computed results in the cold argon impinging jet with same geometry as the experiments. Though the numerical simulation is a two-dimensional presentation on the central sectional plane of the cold jet, while the photographs were taken from the side of the entire hot plasma, some resemblance of the two representations can still be found, which might be quite interesting and helpful in understanding the flow.

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