ABSTRACT

The decay of laser spark created by non-resonant laser induced breakdown in quiescent air is studied in this work. The flow field immediately after the breakdown, plasma core disintegration, shock wave dynamics, hot kernel deformation and subsequent gas dynamic effects are studied along with an engineering application (flow control around aerodynamic body). A two-dimensional numerical model has been developed in-house to study the above phenomena. The Navier-Stokes equations are solved along with species conservation equations in finite volume framework. Thermal equilibrium and chemical non-equilibrium effects are assumed during the simulation. The validation of the computer program has been performed by comparing numerical data on the variation of shock wave radius with the experimental results conducted in-house.

For single pulse energy deposition with varying pulse energy, initially the shock wave exhibits supersonic speed of propagation momentarily, and then decelerates. The hot plume at the kernel undergoes expansion to form two counter rotating toroidal vortex rings perpendicular to the direction of laser beam. A third lobe is generated at the kernel as the centre line velocity moves opposite to the direction of laser beam. The hot plume expands while changing its shape till it comes to equilibrium with the surrounding. The Jones model is used to fit the trajectory of shock wave in order to find the shock loss. The characterization of energy distribution shows that more than 80% of absorbed energy is carried away by the shock wave and about 16-19% is left in the kernel which could be used potentially for ignition.

Double pulse energy deposition with two combinations of the energy at two different pulse intervals (100 ns and 50 μs) are investigated. For short pulse interval the dynamics of shock wave propagation, third lobe generation and hot plume expansion follows similar mechanism as single pulse deposition case. The energy absorption from the second pulse increases due to high electron density after first breakdown when compared with a single pulse of same total pulse energy. Thus, the life time of plasma kernel is increased by 13.56% due to increase in temperature at the kernel. The characterization of energy shows that the shock loss is slightly higher as compared to same total energy single pulse. Therefore, a single pulse can be replaced by same total energy double pulse at short pulse interval, which is an advantage in prospect of lean limit of combustion. In case

of double pulse deposition at long pulse interval, new physical phenomena are observed, namely multiple layers of shock wave propagation. Two lobes are generated at the plasma kernel in this case: a third lobe opposite to the direction of laser beam and a fourth lobe towards the laser beam direction. The surface area of hot kernel increases, which can help in enhanced mixing in fuel-air mixtures. The Jones model is not best suited to find the shock loss from the trajectory of the shock wave in this case.

Wave drag reduction mechanism over a semi-circular body travelling at supersonic speed by laser energy deposition at various repetition rates and deposition locations are studied. The drag reduction is maximum when the distance between the energy deposition location and the nose of body is kept maximum for single pulse energy deposition under the considered conditions. For repetitive pulse energy deposition, a higher oscillation in drag history is observed. The aerodynamic efficiency of laser energy deposition is found to be 78.7 % at a distance 48 mm from the nose of the body at 50 kHz repetition rate for the flow condition, absorbed energy and geometry considered in the present study.