DRAG FORCE CONTROL FOR HEMISPHERE-CYLINDER UNDER THE ACTION OF LASER ENERGY DEPOSITION

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INTRODUCTION

Unsteady interaction of a space distributed energy source with a shock layer provided by a sphere in supersonic flow was studied numerically in [1]. Laser energy deposition into supersonic flow was suggested for the purposes of flow/flight control in [2, 3]. Now the investigations of an energy deposition impact onto supersonic flow are a wide area of interests of aerospace engineering (see surveys in [4-6]). In [6] the experimental data are presented for the interaction of the laser discharge plasma with a supersonic body "hemisphere-cylinder". The details of the similar flows are examined numerically in [7]. In [8] it was shown that the perfect gas Euler simulations with the assumed spherical shape of a laser "heated spot" were incapable of accurately predicting the experimental stagnation pressure dynamics. In [9] the shape of the laser "heated spot" as a combined filament was shown to provide qualitative accordance with the experiment in the stagnation pressure dynamics.

In this paper the dynamics of frontal drag force together with the stagnation pressure are studied numerically during the interaction of a laser produced "heated spot" with a shock layer provided by the hemisphere-cylinder under the conditions of the experiments [6]. The models of a heated rarefied filament and a combined filament are used for the approximation of the shape and parameters of the "heated spot". Details of the drag force dynamics for the flows past the hemisphere-cylinder are analyzed for a wide range of flow parameters: Max number, rarefaction degree and sizes of the "heated spot".

METHODOLOGY

Numerical simulations of an interaction of a laser impulse with a supersonic shock layer are based on the Euler equations for an ideal gas for cylindrical flow symmetry with $\gamma=1.4$. The axis of the hemisphere-cylinder is parallel to the oncoming flow. At the inflow boundary the parameters of the oncoming flow are set and slip boundary conditions are used on the body's boundaries. No-reflection conditions in the direction normal to the boundaries are applied on the exit boundaries. Reflection conditions are used on the axis of symmetry.

Energy source is supposed to arise instantly in front of the bow shock wave in the steady flow. The parameters at the stagnation point differ from the theoretical ones by 1-2% at this moment. Energy deposition is specified via the entrance boundary condition using two simplest models: non-combined or combined filament. Non-combined filament is supposed to be an infinite or bounded heated channel (layer) of low density[10], $\rho_i=\alpha_\rho\rho_0$, for $0 \le r \le 0.5d$. The combined filament[11] consists of two heated channels (layers). The density inside the external part of it, ρ_i, is defined as $\rho_i=\alpha_\rho\rho_0$ for $0.5d_1 \le r \le 0.5d$ and in the internal one $\rho_i=\alpha_{\rho 1}\rho_0$ for $0 \le r \le 0.5d_1$, subscript "0" is referred to the freestream parameters (the calculation area is bounded by the axis of symmetry). The static pressure and velocity in the filaments are equal to those of the undisturbed flow. A schematic sketch for the flow with energy deposition
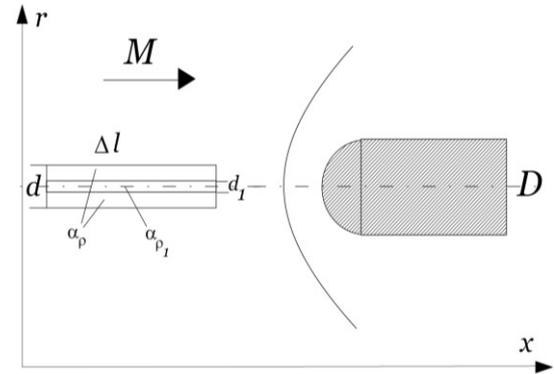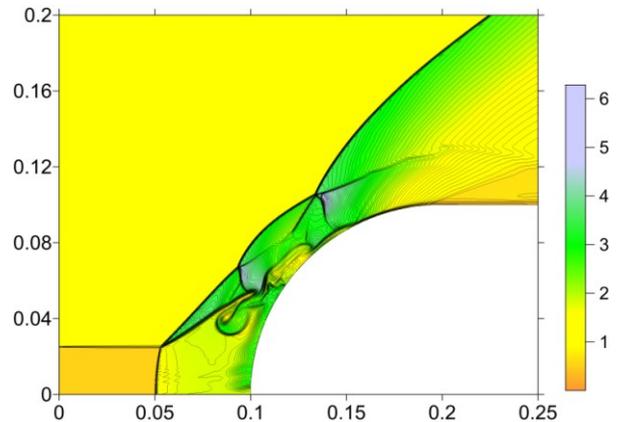

Figure 1: Flow past a hemisphere-cylinder (schematic).

Figure 2: Interaction of an infinite non-combined filament with the shock layer, density, M=3.45, α_ρ=0.5, t=0.68.

and applied notations are presented in figure 1. Complex conservative difference schemes[12] are used in the simulations.
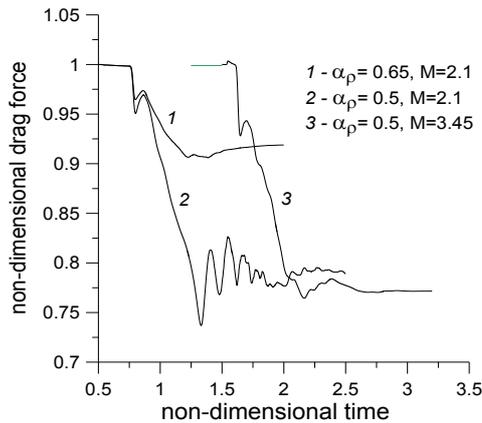

Figure 3: Dynamic of the front drag force for different M and α_ρ for infinite non-combined filament, d/D=0.25.
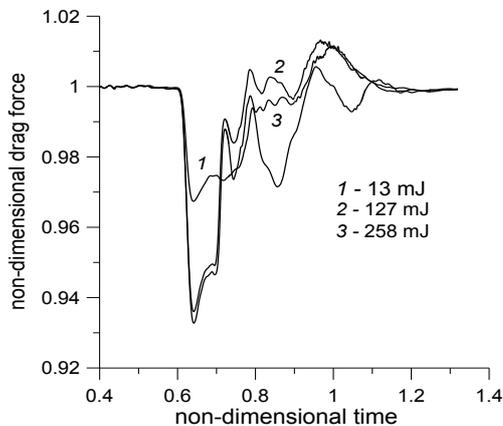

Figure 4: Dynamic of the front drag force for the laser impulses 13 mJ, 127 mJ and 258 mJ [6] on a base of the combined filament model.

RESULTS

The supersonic flows past a hemisphere-cylinder under the action of an infinite energy deposition are shown to characterize by generation of vortices and complicated shock-wave structures (figure 2). Analysis of the drag force dynamics for different Mach numbers, rarefaction degree α_ρ, radius and length of the filament will be presented (figure 3). Details of the flow past a hemisphere-cylinder and mechanisms of stagnation pressure and drag force decrease under the action of laser energy deposition are evaluated for the conditions of the experiments [6]. In this case the optimal shapes of the energy sources using the combined filaments obtained in [9] for the laser impulses 13 mJ, 127 mJ and 258 mJ are applied in the simulations (figure 4).

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