EXPLANATION OF THE VELOCITY GROWTH OF SELF-SUSTAINED DETONATION DURING ITS UPSTREAM PROPAGATION ALONG A DUCT WITH BOUNDARY LAYERS

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Abstract: The gasdynamic structure of a detonation wave propagating against a supersonic flow in a duct with boundary layers is studied using numerical simulation. The study is based on the classical experiments by J. C. Bellet and G. Deshayes (1970) who showed that in the case of the formation of a structure with boundary layer separations and with a detonation Mach stem, the velocity of the detonation wave with respect to the fresh fuel mixture significantly exceeds the velocity of the one-dimensional Chapman–Jouguet detonation. The gasdynamic structure of the detonation wave is analyzed and the mechanism of increasing the detonation velocity is revealed and explained. The combined effect of the boundary layer separation zone and of the secondary detonation wave leads to the formation of a gasdynamic Laval nozzle with flow chocking behind the detonation Mach stem. It is shown that the considered flow can be attributed to the class of two-layer self-sustaining detonations. The influence of heat fluxes, three-dimensional effects, and turbulence on the wave velocity is considered.

Keywords: detonation in a duct; boundary layer separation; gasdynamic Laval nozzle; chocking

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Figure Captions

Figure 1 Schematic of Bellet & Deshayes test facility [10]

Figure 2 Geometry of the computational domain and the initial field of the longitudinal velocity u for the basic series of calculations of the experiment by Bellet & Deshayes [10]. Scale in vertical direction is increased by a factor of 2. Dimensions are in meters

Figure 3 Flow structure in the reference frame of the detonation wave: (*a*) field of temperature for the regime with $\varphi = 0.3$ and $\mathrm{M}_{\mathrm{inlet}} = 3.5$ with streamlines and sonic line ($\mathrm{M} = 1$); and (*b*) gasdynamic scheme of the flow (*1* — Mach stem with detonation wave; *2* — oblique shock wave; *3* — recirculation zone; *4* — reflected shock wave; *5* — rarefaction wave; *6* — compression wave; *7* — streamline; *8* — sonic line; *9* — secondary detonation wave; *10* — region of heat release in the mixing layer; and *11* — secondary recirculation zone near the moving wall)

Figure 4 Details of static pressure fields [Pa] in the reference frame of the detonation wave in the region of interaction with the boundary layer, with streamlines and sonic lines ($\mathrm{M} = 1$). Left picture — regime with $\varphi = 0.3$, $\mathrm{M}_{\mathrm{inlet}} = 1.7$, right picture — $\varphi = 0.3$, $\mathrm{M}_{\mathrm{inlet}} = 3.5$

Figure 5 Dependences of the longitudinal coordinate of the detonation Mach stem upon time in three calculations for the regime $\varphi = 0.3$ and $\mathrm{M}_{\mathrm{inlet}} = 3.5$: *1* — RANS, burning between the layers of inert gas; *2* — RANS, burning in the whole channel; and *3* — Euler, burning in the whole channel

Figure 6 Temperature fields at successive time moments during the propagation of detonation between layers of nonreacting gas (regime $\varphi = 0.3$ and $\mathrm{M}_{\mathrm{inlet}} = 3.5$): (*a*) $t = 0.115$ ms; (*b*) 0.159; (*c*) 0.217; and (*d*) $t = 0.250$ ms. The isolines $\mathrm{M} = 1$ and the streamlines separating the nonreacting gas layers in the wave reference frame are also shown

Figure 7 Fields of Mach number ($\tilde{\mathrm{M}}$) in the reference frame of the detonation wave obtained in LES and URANS calculations of the regime with $\varphi = 0.3$ and $\mathrm{M}_{\mathrm{inlet}} = 3.5$. (*a*) instantaneous field in LES calculation; (*b*) the same field, averaged over 100 cells in side direction; and (*c*) instantaneous field in URANS calculation. The isoline $\tilde{\mathrm{M}} = 1$ is also shown

Table Caption

Parameters of experiments and results of calculations for $\varphi = 0.3$

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