Numerical Study of Mean-Square Velocity Pulsations with Shock Waves Passing through Turbulent Mixing Zone

Yu.V. Yanilkin*, V.P. Statsenko, O.G. Sinkova

RFNC-VNIIEF, ITMF
37, Mira av., Sarov, 607190, Russia

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The paper gives the direct numerical simulation results for turbulence occurring at an interface of various gases in a shock tube during its interaction with shock waves. Computations were carried out by 3D TREK hydrodynamic code /1/ on 125 processors.

The calculated data are compared with the corresponding data of experiments by French researchers /2,3/ and with the results obtained using Nikiforov's model implemented in 2D LEGAK code system. French scientists obtained qualitatively new results: they were the first who measured instant values of the flow velocities in turbulent mixing zone (TMZ). In earlier experiments, the TMZ width dependence on time and the distribution of mean density were only measured.

The idea of the method was as follows: a vertical shock tube of 120 cm in length was filled with two gases (above was SF_6 (sulfur hexafluoride) and below was air), the gases were initially separated by a plastic 0,3 μm membrane. The initial distance between the interface (membrane) of two gases and the rigid wall was 30 cm. Constant pressure 2,15 bar was set at the opposite end of the tube. When a shock wave arrives at the interface, Riemann problem occurs that results in a rarefaction wave propagating in SF6 and a shock wave propagating in air. The shock wave is reflected from a rigid wall and moves towards TMZ, which it is partially reflected from. Thus, TMZ evolutional growth is the result of its interactions with a sequence of shock waves reflected from the tube end.

To form initial perturbations during the experiment, a thin-wire mesh was placed near the membrane; after the shock wave had passed, the membrane moved towards the wire mesh and collapsed on it resulting in formation of the initial zone of turbulence growth.

Three series of computations were carried out (Table 1).

Table 1. Computation variations.

Variant No.	Number of cells $N_X x N_Y x N_Z$	h_X x h_Y	h_Z, $0<z<30$
1	100x100x1002	0.05x0.05	0.05x0.05
2	100x100x1002	0.05x0.05	0.05x0.05
3	150x150x1502	0.03x0.03	0.03x0.03

Fig. 1 shows the curves of the TMZ boundary positions versus time. As one can see, 3D computations are closely approximated to each other confirming that there are no significant effects of the number of computational cells on the positions of boundaries. Good agreement between the calculated and experimental data is also seen.

The same figure shows the R-t diagram for shock waves. Three waves reflected from a rigid wall and propagating through TMZ are seen.

It should be noted that the significant increase of the turbulent mixing zone width takes place when the first shock wave reflected from the rigid wall (t_{r1}≈5.8) propagates through it;

*E-mail: yan@md08.vniief.ru

however, the TMZ width increases even more actively, when the second shock wave reflected from the rigid wall propagates (t_{r2}≈6.4).

Computations gave the resultant pulsations of the longitudinal velocity component for five sensors. Fig. 2 shows the calculated curves for squares of fluctuations of the longitudinal velocity component, $< u_z'^2 >$ versus time that has been obtained for one of the sensors. Averaging is performed over XY plane that corresponds to the shock tube's cross-section. Time is read beginning from the moment of the shock wave arrival at the interface. Generally, good agreement between computation results and the experiment data, both in the TMZ width dependence on time and in the dependences of mean-square fluctuations of the longitudinal mass velocity component on time is seen.

3D computation results are closely approximated, in general, to the experimental data.

It is clearly seen that the number of computational cells insignificantly affects the width of TMZ. Especially emphasize the essentially full coincidence of the TMZ boundaries in SF_6 in all computations. Significant growth of the turbulent mixing zone width can be observed during propagation of the first shock wave reflected from the rigid wall, however, the mixing zone growth becomes even more intensive during propagation of the second reflected shock wave.

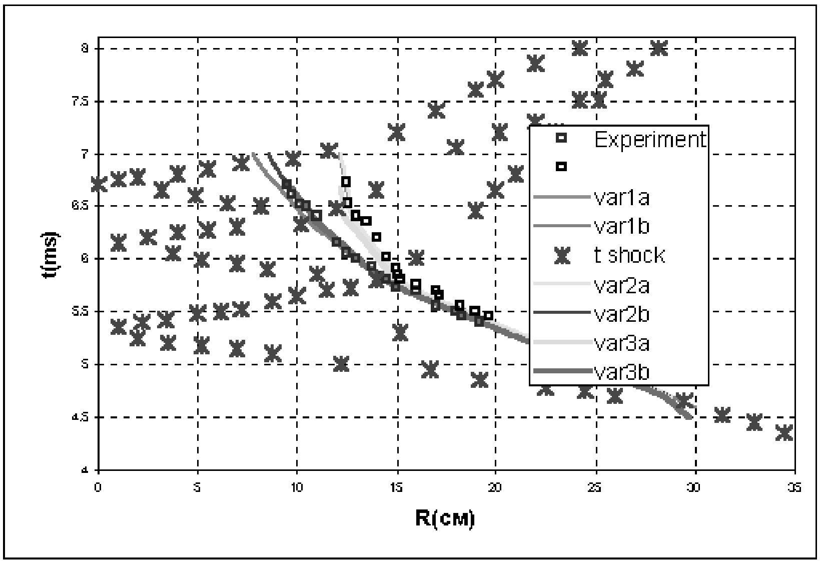

Fig. 1. R-t diagram of the shock wave and the TM zone boundaries.

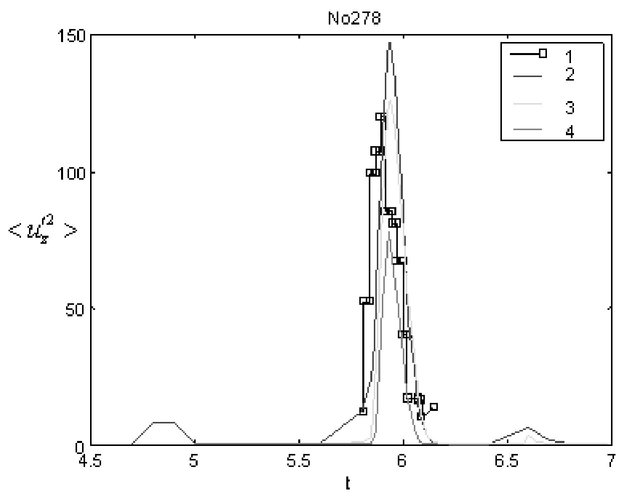

Fig. 2. Square values of the longitudinal velocity component fluctuations versus time for d_278: 1- experiment; 2-4 – results of computations 1-3, respectively.

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