NUMERICAL INVESTIGATION OF GRAVITATIONAL TURBULENT MIXING WITH ALTERNATING ACCELERATION

O.Sin'kova, V.Sofronov, V.Statsenko, Yu.Yanilkin, V.Zhmaylo

History

The problem of turbulent mixing under constant acceleration creating unstable conditions at a plane interface between two incompressible fluids has been investigated both experimentally and numerically using DNS method.

In works [Kucherenko et al., 1993, 1997] has been described the experiments carried out with changes of acceleration sign that cause stable conditions at the interface.

The corresponding problem was investigated numerically in [Zhang & Wang (1997)], using the k-ε model. Youngs (1997) carried out direct 3D numerical simulation. None of them observed the effect of the reduced mixing zone during the stability phase.

This paper describes computational investigation of this problem using DNS by 3D code TREK.

Setting up computations

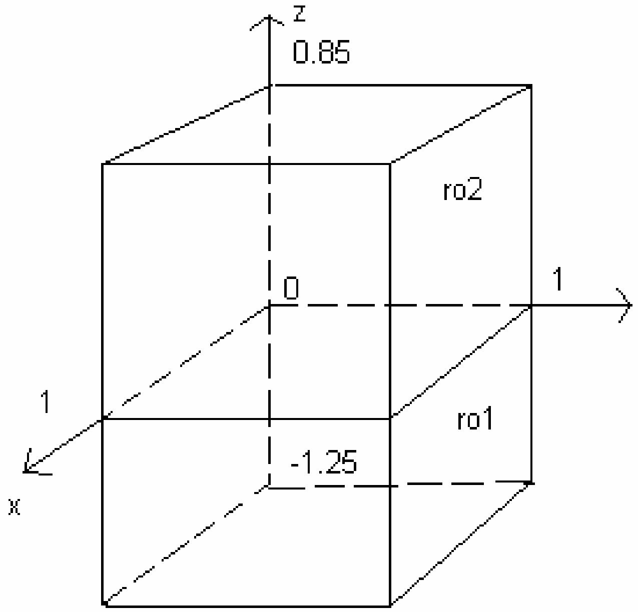
Dr.Youngs simulated the problem in one-fluid approximation (fluids were described as one fluid).

We have assumed that absence of separation was due to the use of the one-fluid approach leading to computational homogeneous mixing of fluids in view of a scheme viscosity.

We have used the two-fluid approach which is free of such a disadvantage at interfaces and mixing, in such a case, is heterogeneous, similar to the experiments. Such approach leads to a significant agreement with the results of measurements.

The problem is also investigated here using the one-fluid approach, both by 3D gas dynamic (GD) code and hydrodynamic (HD) code (providing the flow incompressibility).

Initial data



ρ_1=1, ρ_2=3

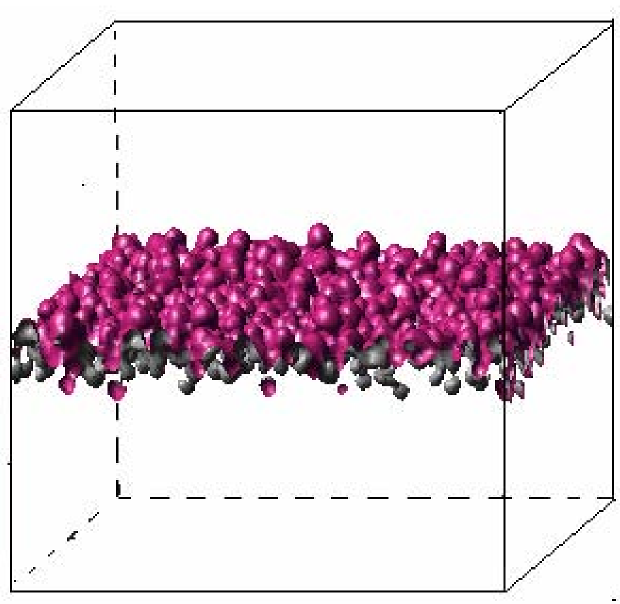
$$p(z) = p_0 - \int_{z_2}^{z} \rho(z) \cdot g \cdot dz, \qquad p_0=20$$

$\delta\rho = \pm\, \rho_1 \delta$, where δ= 0.1

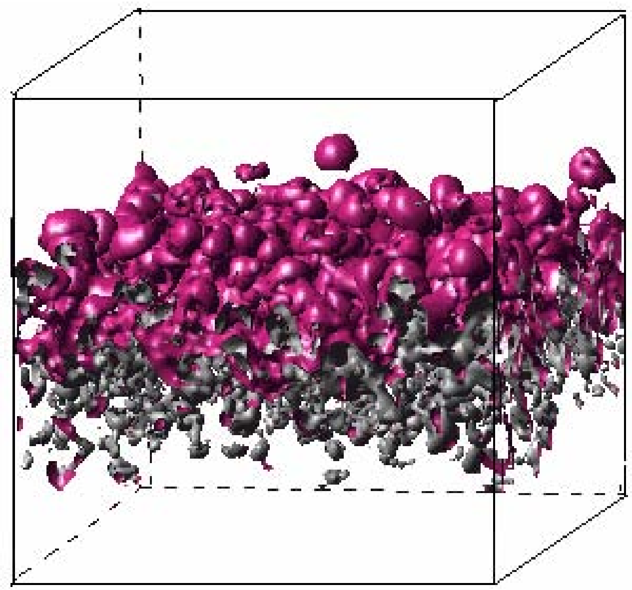
$$g_z = \begin{cases} -1, & t \leq 3 \\ 22/75, & t>3 \end{cases}$$

Grid: N_x=200, N_y=200, N_z=400

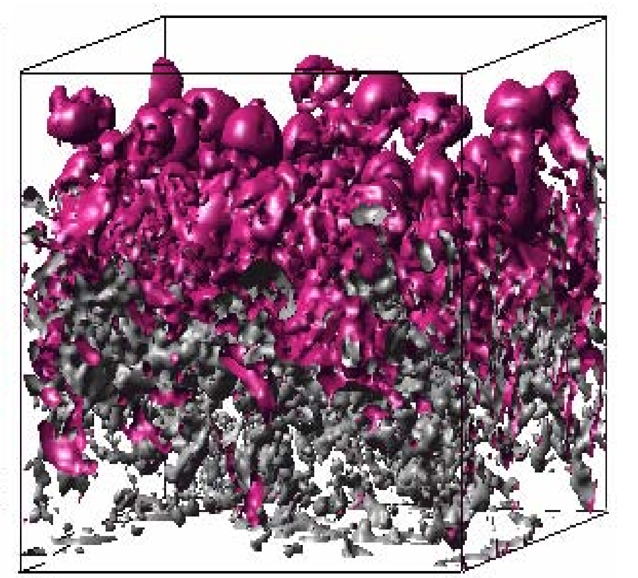
3D raster pictures of volume concentration



t=1.5

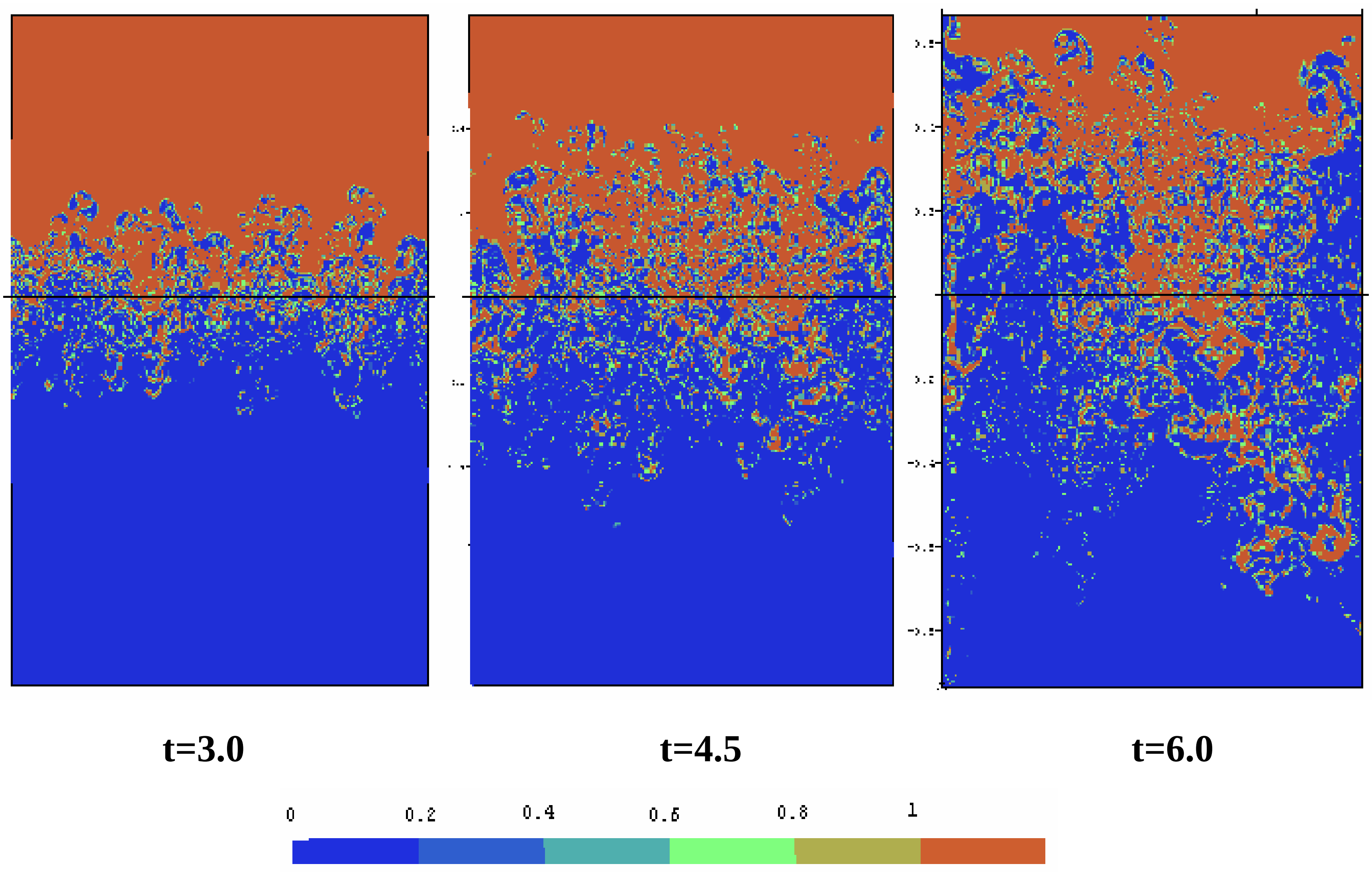


t=3.0

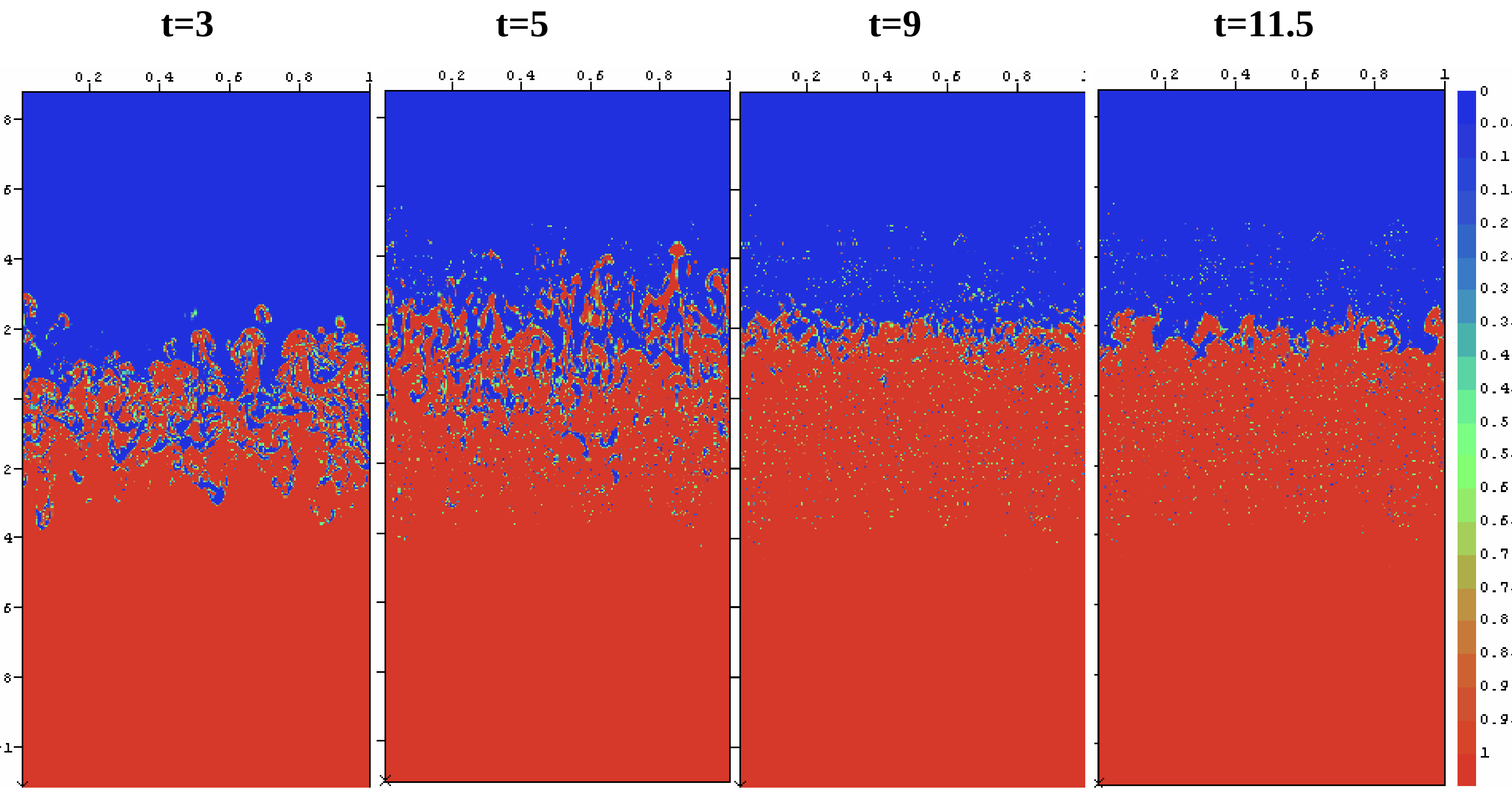


t=4.5

2D section x=0.5

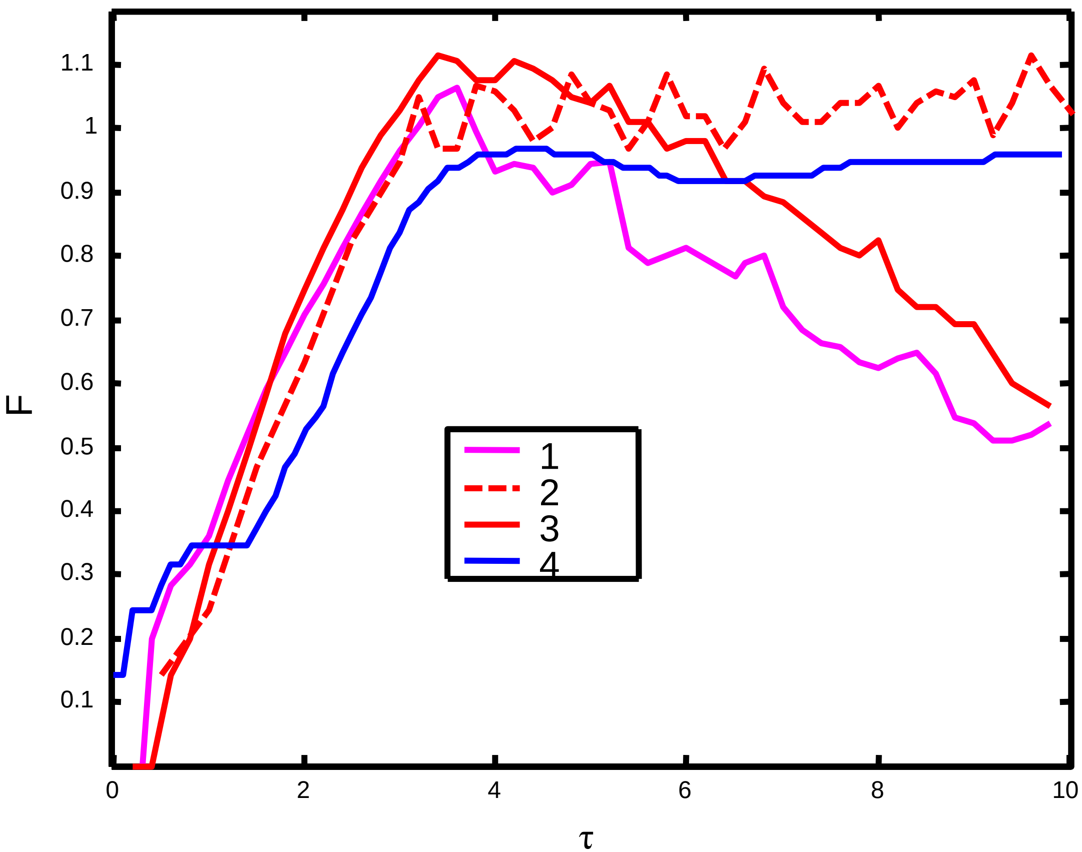


Raster pictures of volume fraction (two fluids, 2D sections y= 0.5)



The TMZ width function dependence on time

1 – GD, N_x=200, two fluids; 2 - GD, N_x=100, one fluid;
3 - GD, N_x=100, two fluids; 4 – HD, N_x=100, one fluid



$$F \equiv \frac{1}{t_0}\sqrt{\frac{L_t}{Ag}}$$

$$\tau \equiv \frac{t}{t_0}; \qquad t_0 \equiv \sqrt{\frac{L_x}{g}}$$

$$\alpha^{(-)} \equiv \frac{dF}{d\tau}$$

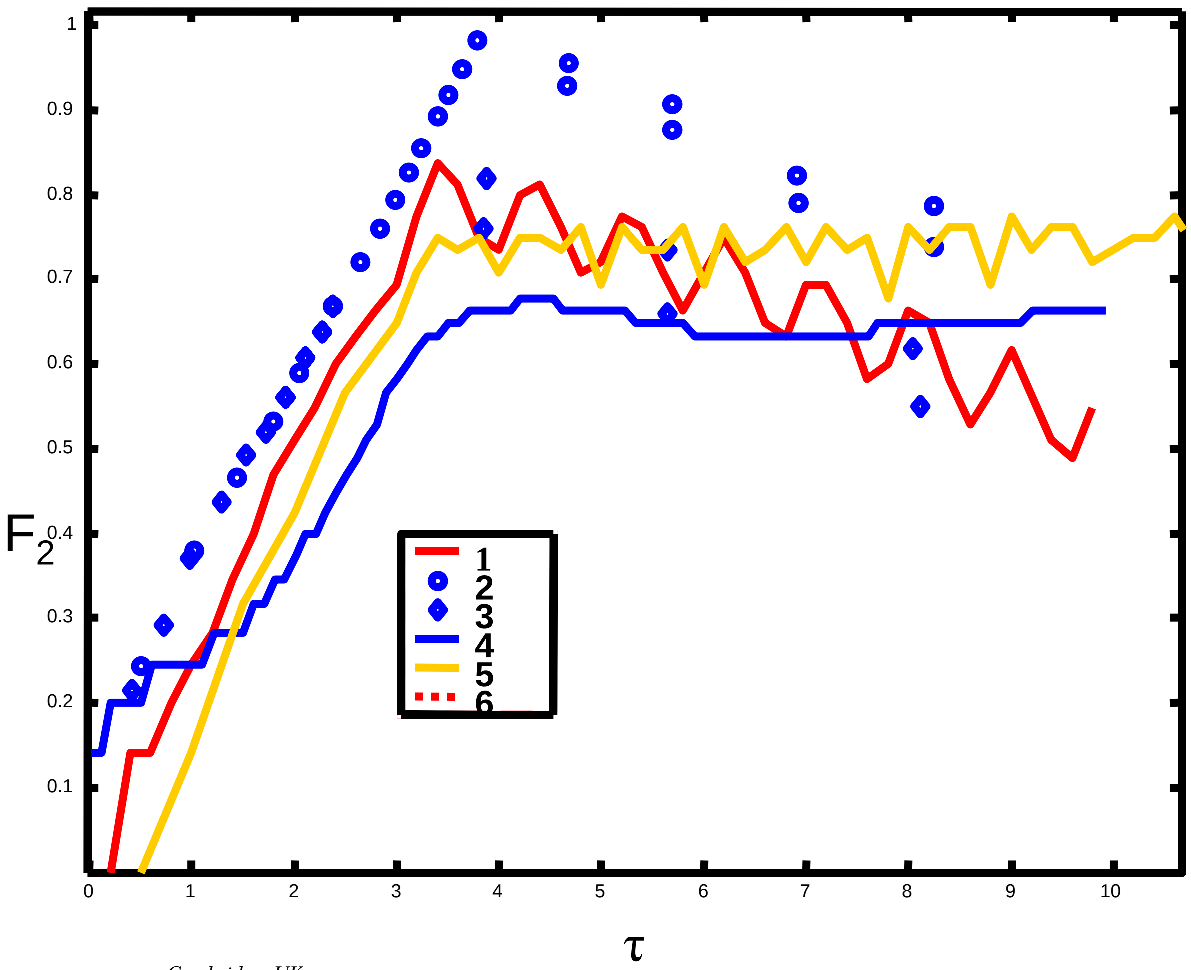
$$L_t \equiv z_2 - z_1$$

$$z_2 : \langle \alpha_2 \rangle_{(x,y)} < 0.98$$
$$z_1 : \langle \alpha_2 \rangle_{(x,y)} > 0.02$$

$$\alpha = (dF/d\tau)^2 \qquad L_t = \alpha A g t^2$$

The dependence on time of the light fluid penetration into the heavy fluid

1 – GD, N_x=100, two fluids; 4 – HD, N_x=100, one fluid; 5 - GD, N_x=100, one fluid;
2 - exp. with S*=360 ; 3 - exp. with S*=140;



$$F_2 \equiv \frac{1}{t_L}\sqrt{\frac{z_2 - z_c}{Ag}}$$

$$\alpha_2^{(-)} \equiv \frac{dF_2}{d\tau}$$

$$\alpha_2 \equiv \left(\frac{dF_2}{d\tau}\right)^2$$

Kucherenko measured

$$f \equiv \frac{d\sqrt{z_2 - z_c}}{d\sqrt{S'}}$$

$$S' \equiv g_{12}\frac{(t-t_c)^2}{2}$$

t_c- is the time of maximum value F_2

Our calculations give us the following value of f:

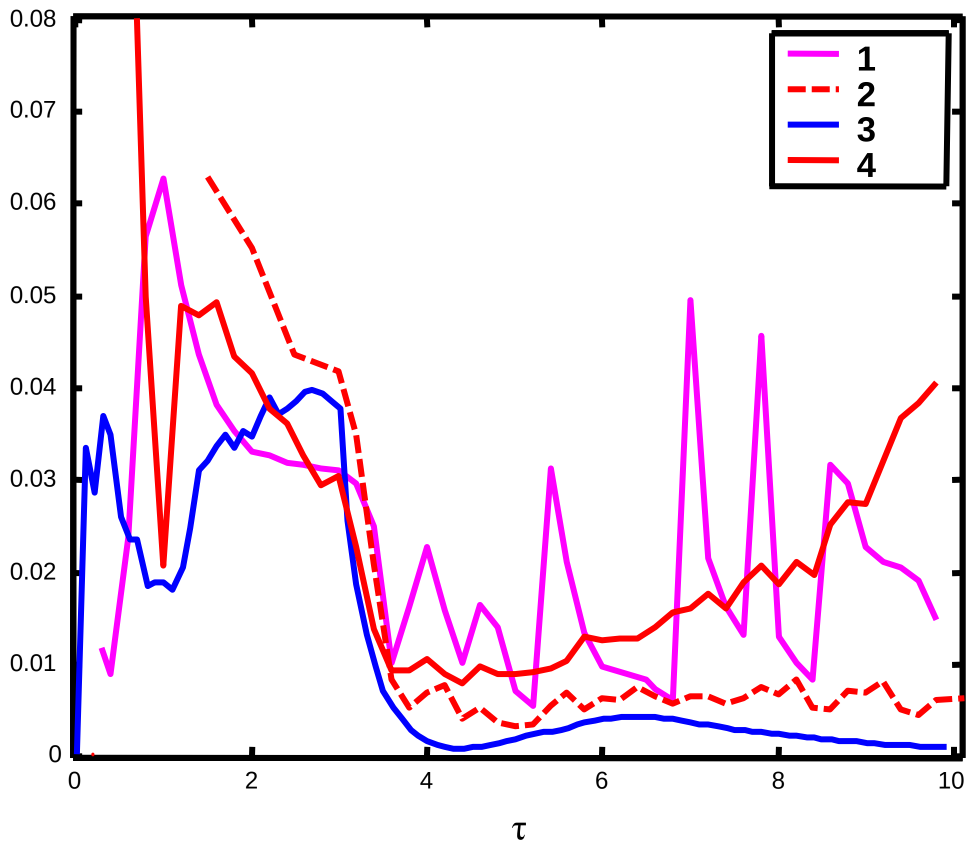
$$f = \frac{dF_2}{d\tau}\cdot\sqrt{A\cdot\frac{2g}{g_{12}}} \approx -0.074$$

From experiments :

$$f \approx -(0.072 \div .082)$$

TMZ maximum scaled turbulent energy versus time

1 – GD, N_x=200, two fluids; 2- GD, N_x=100, one fluid;
4 - GD, N_x=100, two fluids; 3 – HD, N_x=100, one fluid



$$E_m(t) \equiv \max(E)$$

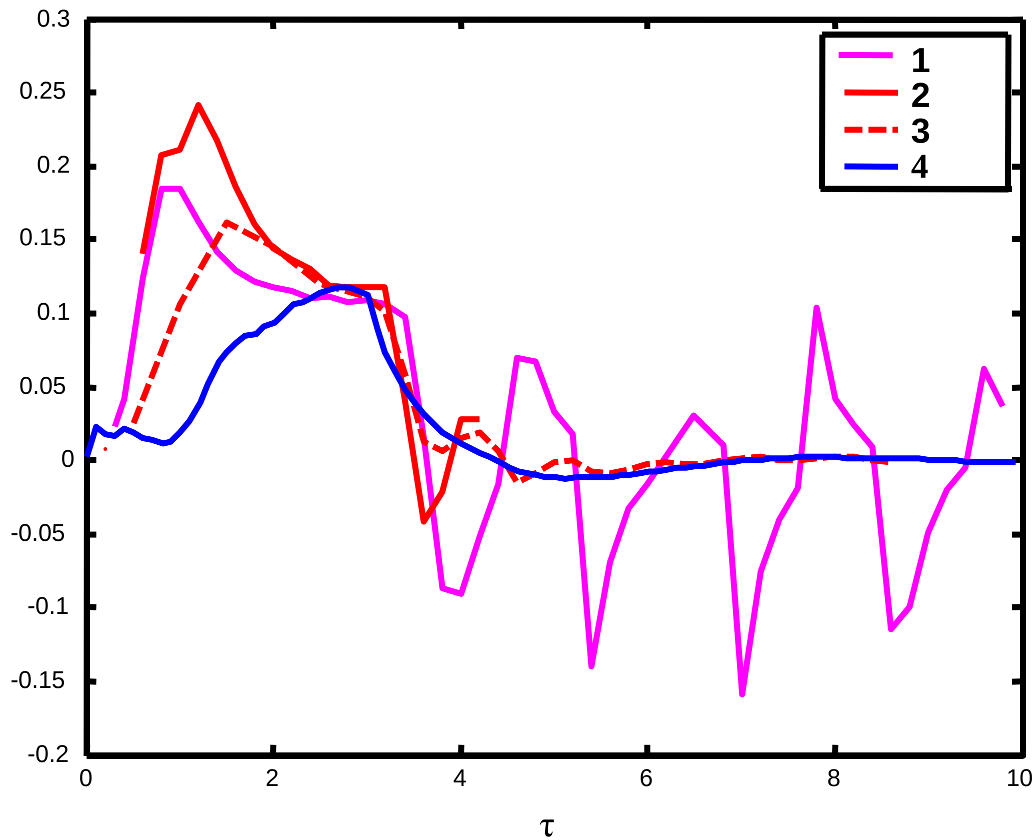
$$E \equiv \frac{k_m}{L_t g}$$

$$k_m(t)=\max(<k>(z,t))$$

$$k(z) = \frac{\langle (u_j)^2 \rangle - \langle u_j \rangle^2}{2}$$

The dependence on time of the scaled turbulent mass flow

1 – GD, N_x=200, two fluids; 2- GD, N_x=100, two fluids;
3 - GD, N_x=100,one fluid; 4 – HD, N_x=100, one fluid



$$R_{zm+} = R_{zm} - R_{zm-}$$

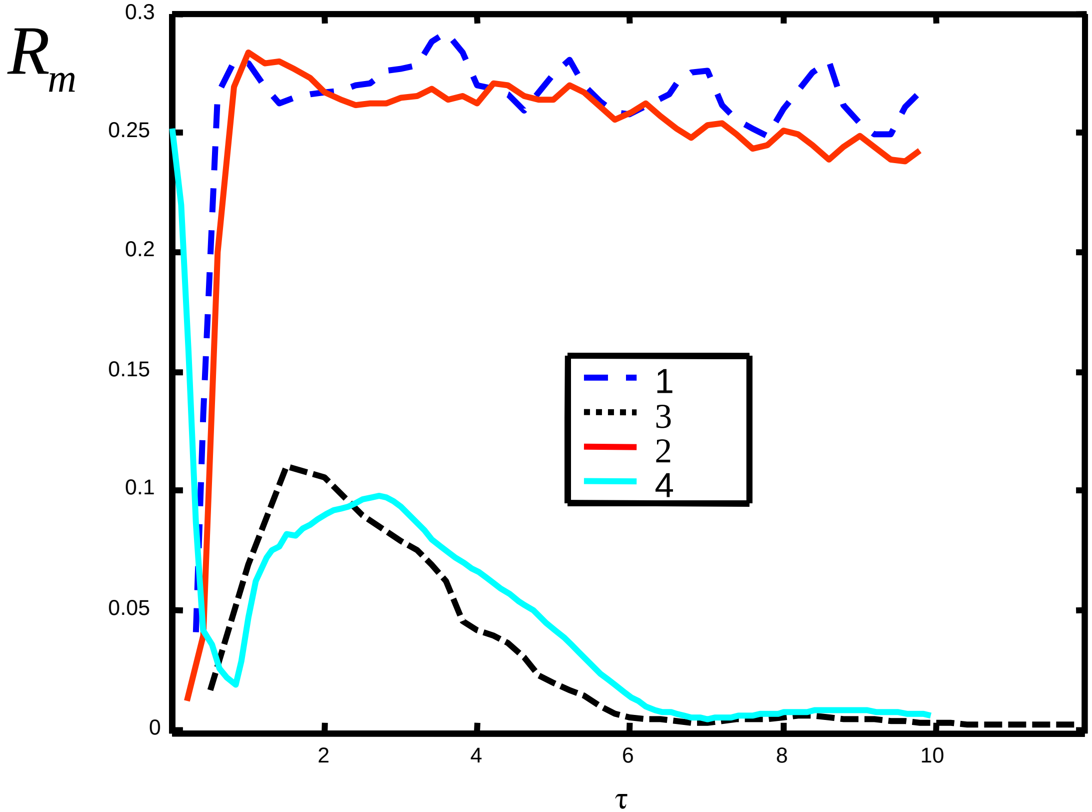
$$R_{zm} \equiv \max\left(-R_z\right)$$

$$R_{zm-} \equiv \max\left(R_z\right)$$

$$R_z \equiv \frac{<\rho' u_z'>}{\sqrt{L_t g}}$$

TMZ maximum density pulsation function versus time

1 – GD, N_x=200, two fluids; 2- GD, N_x=100, two fluids;
3 - GD, N_x=100, one fluid; 4 – HD, N_x=100, one fluid

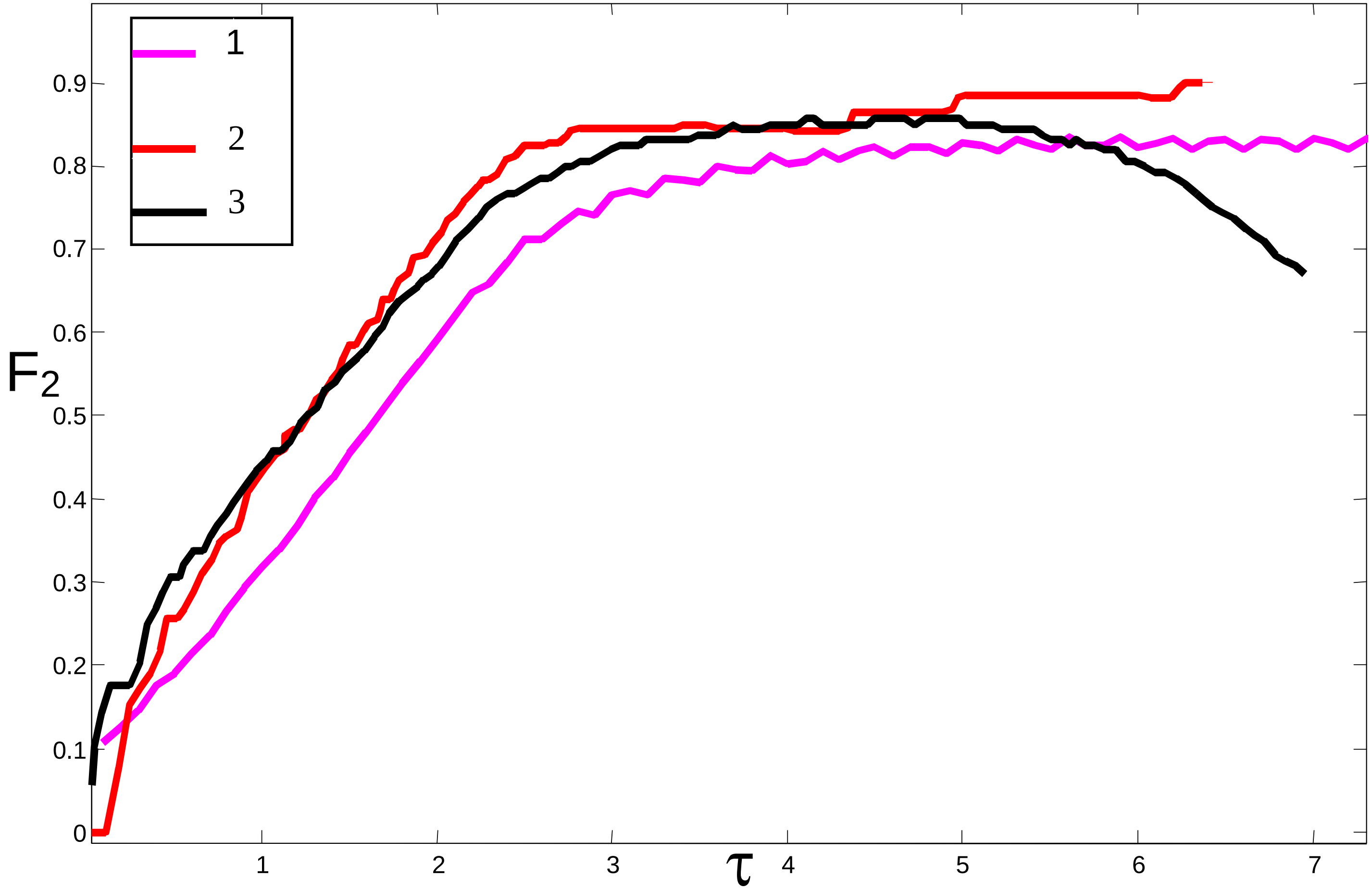


$$R_m \equiv \max(R)$$

$$R \equiv \frac{<\rho'^2>}{\rho^2}$$

The dependence on time of the light fluid penetration into the heavy fluid

1 – k-ε model, 2 – calc. [Zhang & Wang], 3 – experiment.



Conclusions

- In all computations of the first (unstable) phase of mixing, close results concerning changes of TMZ width with time have been obtained.
- The second phase takes place after the acceleration sign has been changed.
- We can conclude that it is impossible to achieve any reduction of the TMZ width using k-ε model of turbulence.
- In 3D DNS with two fluids, linear in time decrease of the TMZ width square root corresponds to this phase that agrees with the known data of experiments.
- Accordingly, the TMZ width decrease, after the acceleration sign has changed, is insignificant in one-fluid 3D DNS computations.
- In general, it should be noted that the use of one-fluid approach to 3D DNS corresponds to mixing fluids, while the multiple-fluid approach corresponds to non-mixing fluids.