Study of Turbulent Mixing Development at the Interface Gas-Gas at Mach Numbers by Shock Wave from 2 till 9

M.V.Bliznetsov, N.V.Nevmerzhitsky, A.N.Rasin, E.A.Sotskov, E.D.Senkovsky, L.V.Tochilina, V.A.Ustinenko

Russia, Sarov RFNC-VNIIEF

Report for the Ninth International Seminar
on Turbulent Mixing Physics of Compressible Media
England, Cambridge, July, 2004

ABSTRACT

The experimental technique for investigation of turbulent mixing is presented in this report. Turbulent mixing (TM) arises at Richtmayer-Meshkov instability at the interface gas-gas accelerated by a shock wave. Helium (He) and air (Air) was used as light gas, as heavy gas - six-fluorine sulfur (SF_6). In all the experiments a shock wave propagated from light gas to heavy gas. Mach number of a shock wave in SF_6 has changed from 2 to 9. The flow was recorded by the use of shlieren method during rapid motion-picture recording.

Introduction

Hydrodynamic instabilities such as Raylegh-Taylor [1], Richmayer-Meshkov [2, 3] play a leading role in many fields of research, for example, in astrophysics, aerohydrodynamics, gas dynamics, in inertial thermonuclear fusion etc. To calculate these instabilities and turbulent mixing (TM) connected with them both numerical methods and semi-empirical models. Both require the testing on experimental data.

A number of experimental works is known, in which development of turbulent mixing was investigated at the interface of gases with different density at Mach numbers by a shock wave (SW) $M \leq 5$ (for instance, [3÷5]). To understand better the influence of compressibility of medium on development of TM it is desirable to obtain experimental data within a wider range of the change of Mach numbers of SW.

In this work SW was formed in a shock tube [6] as a result of detonation of combustible gas mixture (CGM) of acetylene and oxygen. SW Mach number in SF_6 was changed in a range of 2 - 9. Growth of instability and turbulent mixing was studied at the interface of heavy and light gases.

Experimental techniques

Shock tube scheme is presented at Fig. 1. The shock tube consists of chambers with a high pressure (driver) and a low pressure. The chambers are separated from each other by the help of a diaphragm made of lavsan thick up to 100-150 micrometer mcm. A measuring section with a silencer is connected with the low pressure chamber. The measuring section has two windows made of optically clear organic glass. It breaks away from the low pressure chamber by means of polymer film ≈ 0,3 micrometer in thickness, and from a silencer – membrane made of lavsan 50 mcm. thick.

In experiments the low pressure chamber was filled with light gas: helium or air; the measuring section– SF_6 ($\rho_o \approx 6,5$ g/l; $C_0 \approx 129,5$ m/s; $\gamma \approx 1,094$) at atmospheric pressure. There is air in the silencer at atmospheric pressure. The high pressure chamber (driver) length changed within a range of L_1=220÷450 mm, the low pressure chamber length– L_2=800÷1550 mm. The high pressure chamber was filled with CGM at certain pressure P_0 . Detonation of CGM was realized by pulsed electro spark discharge.

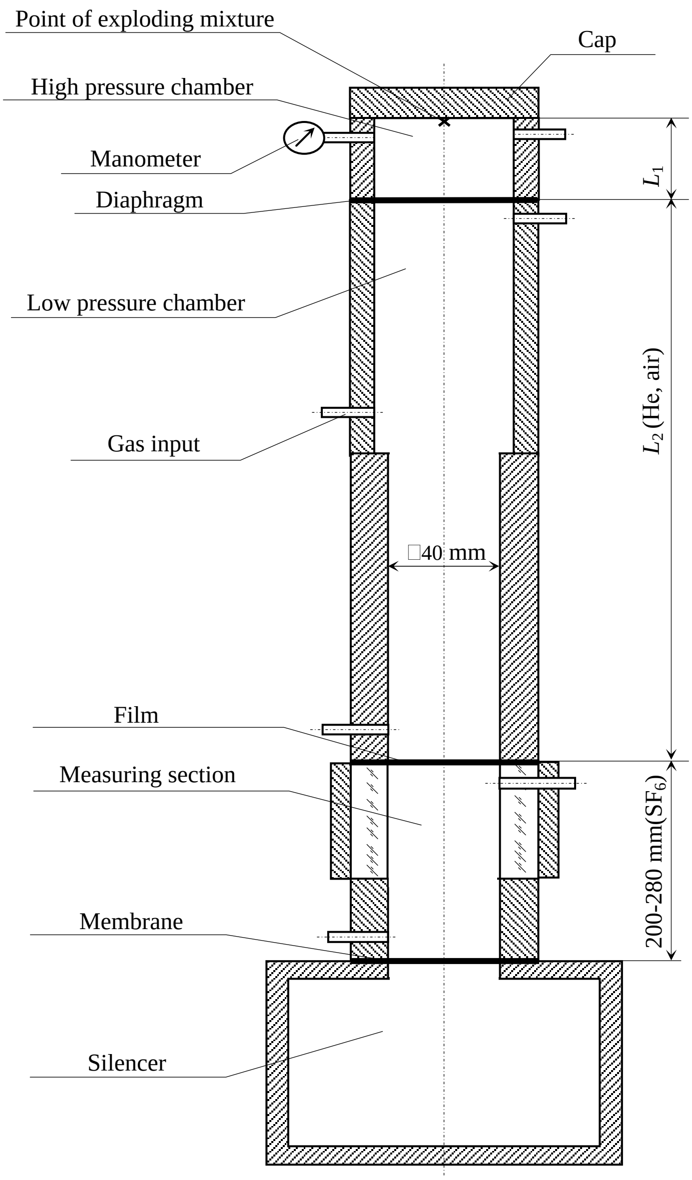


Figure 1 – Shock tube scheme

Operation of the instrument

After initiating CGM a detonation wave propagates on the high pressure chamber. When this detonation wave enters a diaphragm the latter disrupts and a shock wave propagates in light gas. When a shock wave goes toward a contact interface (CI) of light gas with SF_6, two waves are created. A shock wave propagates on SF_6 and a reflected wave outgoes in light gas. After destructing a separating film CI of gases accelerates, with the result that Richmayer-Meshkov instability arises in it, which causes the development of turbulent mixing zone (TMZ) of light and heavy gases.

Variation of CGM composition and CGM pressure has made it possible to obtain shock waves having a varied intensity.

The flow was recorded through the schlieren method by the use of a rapid movie camera in frame-by-frame mode and in slot image scanning mode.

The Results of the Experiments

Figure 2 presents slot moving image frames and frame-by-frame moving image frames of the experiments with helium, Figure 3 – experiments with air, Figure 4 – calculation (without TM) and experimental $X(t)$ diagrams of the flow for some tests. Measuring error of position of TMZ (X_1, X_2) front and SW front in experiments makes up ±0.5 mm, timing error– 0,5%t. Gas dynamical calculations of the flow were conducted by using one-dimensional techniques «VIKHR» [7]. With increase in shock wave Mach number from ~2 to ~9 Atwood number (A) changed from ~0.83 till.99.

From moving image frames and diagrams we notice that with increase in number *M* SW in SF_6: contact interface of gases and, respectively, a front of TMZ approach a shock wave front (due to high compressibility of SF_6); at $M \geq 6,5$ an optical gap is not observed between SW and a forward shock wave front of TM (X_1) in experiments (s. Fig. 2b);

The proximity of the front of TM and SW may cause their mutual influence yet to be studied in subsequent investigations.

The proposed techniques enable us to study TM development at the interface of gases and at higher Mach numbers. In this case a maximum value of Mach number is determined by measuring section strength (toughness).

Conclusions

Experimental techniques were developed to study turbulent mixing development at the gas-gas interface, which is accelerated by the shock wave with Mach number up to 9.

In the near future detailed investigations will be performed into TM development at the interface of gases with different density at M>>5.

Authors are indebted to E.E.Meshkov, V.A.Raevsky, V.I.Kozlov, S.I.Gerasimov for helpful comments and proposals on this work. Authors are grateful to A.E.Egorushkina, O.L.Krivonos, V.I.Dudin, A.A.Nikulin for their assistance in the preparation and the performance of the experiments.

REFERENCES

1. *G.I. Taylor.* The instability of liquid surfaces when accelerated in a direction perpendicular to their planes. I. Proc.Roy.Soc., 1950, v.A201, p.192.

2. *R.D.Richtmyer*. Taylor instability in shock acceleration of compressible fluids. Commun.Pure Appl.Math., 1960, v.13, p.297.

3. *Meshkov E.E.* Instability of the interface of both gases accelerated by shock wave. NEWS AH Soviet Union, MZHG, 1969, № 5, pp.151-158.

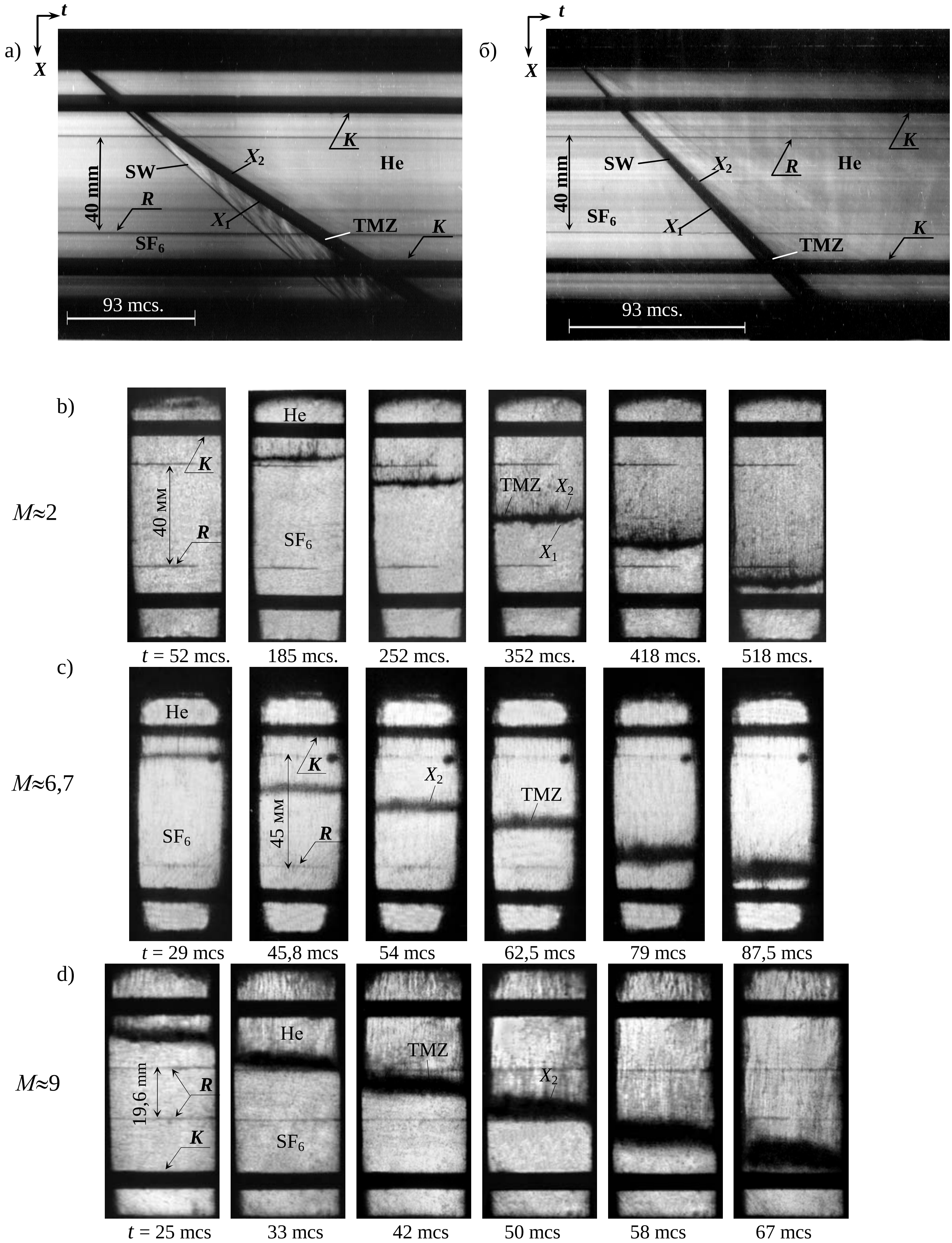
4. *S.G.Zaytsev, E.V.Lazareva, V.V.Chernukha, V.M.Belyaev*. Intensification of turbulent mixing at the interface of media with different density as shock wave passes through it. DAN Soviet Union, 1985 , v. 283, №1, p.94-98.

5. *E.A.Lasareva, A.N.Aleshin, S.V.Sergeev, S.G.Zaytsev and J.F.Haas*. Shock-Induced Intensification of Turbulent Mixing. The Proc of the 6th IWPCTM, Marseille, France, 1997, p.295-300.

6. *Kh.A.Rakhmatulina, S.S.Semionova*. Shock tubes. M.: Foreign literature, 1962 , p.699.

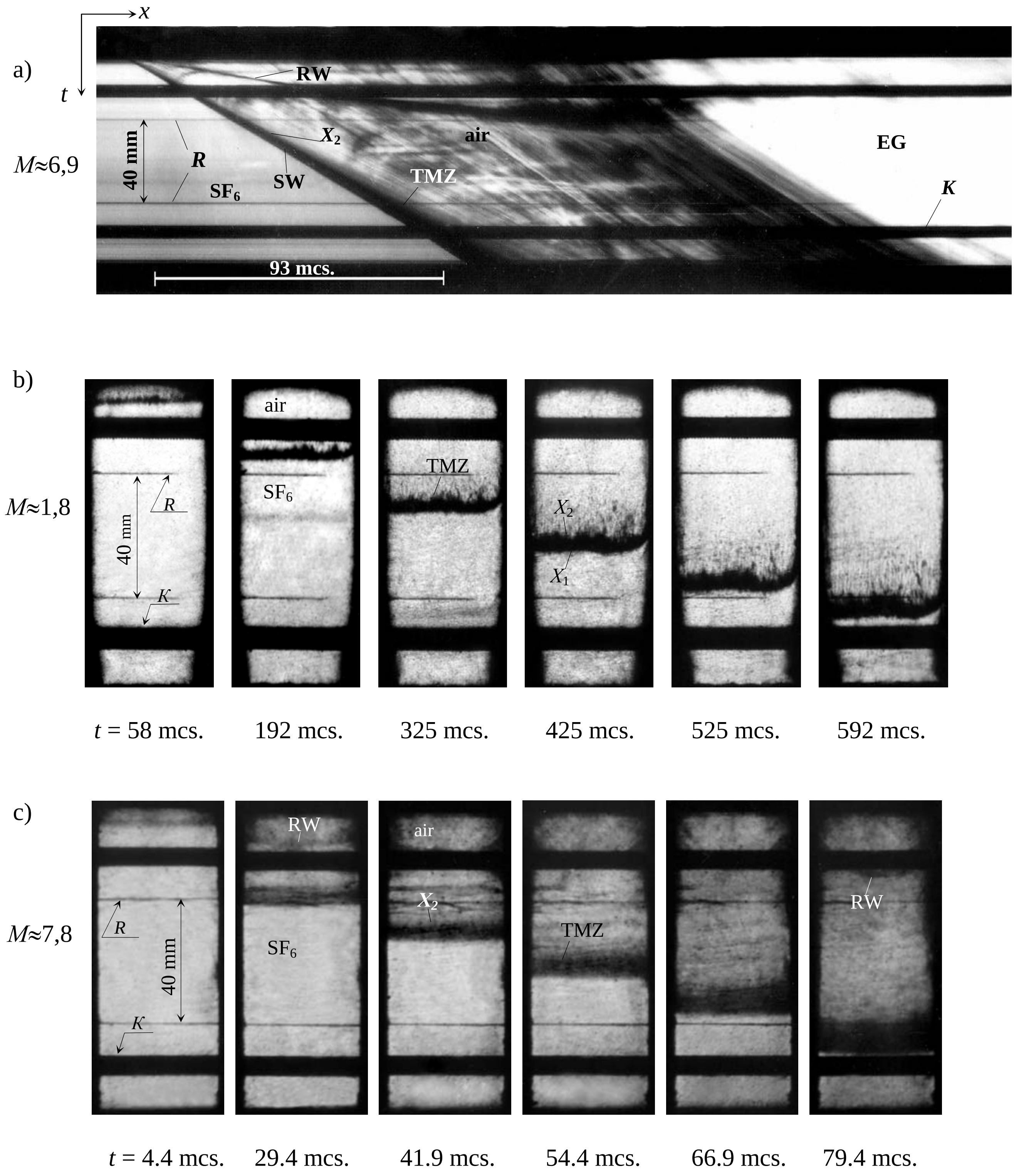
7. *V.A.Andronov, V.I.Kozlov, V.V.Nikiforov, A.N.Razin, Yu.A.Yudin.* Techniques for calculation of turbulent mixing in one-dimensional flows (VIKHR technique) // Questions of Atomic Science and Engineering. Series: Mathematical simulation (modeling) of physical processes. 1994, № 2, p.59.

M=3,9 M=6,6



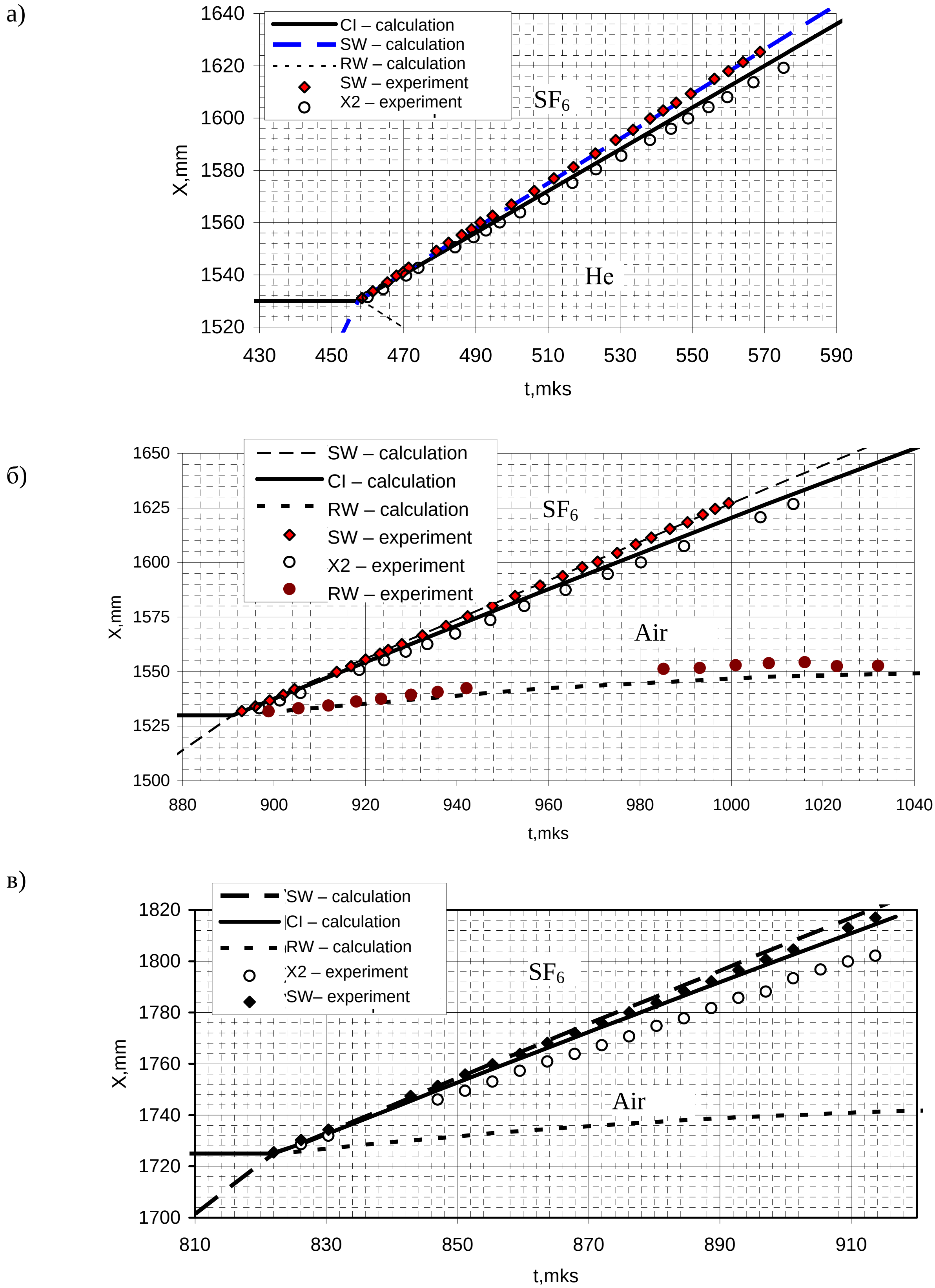
Designations: X_1 – front of the penetration of «light» gas in «heavy» gas; X_2 – front of the penetration of «heavy» gas in «light» gas; t – time is reckoned from output of SW to CI; K – structural element (out of flow); R – reference lines.

Figure 2 – Moving image frames of the experiments on TMZ development at the interface *helium-SF*$_6$: а) experiment №1 (А≈0.95); б) experiment №2 (А≈0.99) – slot moving image frames; в) experiment №3 (А≈0.95); г) experiment №4 (А≈0.99); д) experiment №5 (А≈0.99)



Designations: RW – reflected wave; EG – CGM explosive gases; *R* – reference lines, *К* – structural element; *t* – time is reckoned from the moment of coming SW to the contact interface.

Figure 3 – Moving image frames of the experiments with TMZ development at the interface *air*-SF_6: a) experiment №6 (A≈0.89) – slot moving image frames; б) experiment №8 (A≈0.83); в) experiment №7 (A≈0.89)



Designations: RW – reflected wave; t – time is reckoned from the beginning of CGM detonation; ordinate X is reckoned from the cap of the high pressure chamber.

Figure 4 – $X(t)$ diagrams of the flow in the shock tube. a) experiment №2 (He-SF_6); b) experiment №6 (air-SF_6); c) experiment №7 (air-SF_6 L_1=450 mm; L_2=1275 mm; CGM – C_2H_2+2.5O_2 with P_0=6,8±0,05 atm.)