ShockWaves manuscript No.
(will be inserted by the editor)

A new large cross section shock tube for interface hydrodynamic instability induced turbulent mixing study

L. Houas[1], G. Jourdan[1], L. Schwaederlé[1], R. Carrey[2], and F. Diaz[2]

[1] Polytech' Marseille, Département de Mécanique Energétique, IUSTI, Umr CNRS 6595, Université de Provence Technopôle de Château-Gombert, 5 rue Enrico Fermi, 13453 Marseille Cedex 13, France
[2] Mecathermic Industrie S.A., 13170 Les Pennes Mirabeau, France

Received / Accepted

Abstract. A new large cross section shock tube has been carried out, in order to investigate the different stages of the development of the Richtmyer-Meshkov instability and the induced turbulent mixing. The main interest of such a facility is that it allows, first, to create a free turbulent mixing with the knowledge of the initial conditions and, second, to follow the different transition phases from the beginning to the fully turbulent developed stage.

Key words: Large cross section shock tube, Richtmyer-Meshkov instability, Turbulent mixing

1 Introduction

When an interface between two fluids of different densities is submitted to a shock wave impulsive acceleration, a hydrodynamic instability, known as the Richtmyer-Meshkov instability (RM) (Richtmyer 1960, Meshkov 1969), appears and develops at each initial imperfection of the interface. Vorticity is produced because, locally, both the density and pressure gradients are not collinear. Then, a complex process results leading to the amplification of the perturbations and can evolve to a turbulent mixing zone (TMZ) between the two fluids. The RM instability is of current interest because of its importance to applications such as inertial confinement fusion, supersonic combustion and supernova explosions. Thus, it is widely investigated from experimental, theoretical and numerical points of view. Since Meshkov (Meshkov 1969) first experimentally gave prominence to this phenomenon, all the experimental works within the topic have been focused on the observation of the growth of the initial perturbations in the linear and early nonlinear regimes, or the investigation of the fully, assumed, turbulent phase without knowing the real initial conditions. But, the phase corresponding to the effective process when the shock wave interacts with the thin membrane which initially separates the two fluids and materializes their interface, i.e. the real initial conditions, still remains unknown. Nevertheless it is of fundamental interest. These above related works are well resumed in the eight proceedings of the workshops dealing with the physics of compressible turbulent mixing (Proceedings of the International Workshops on the Physics of Compressible Turbulent Mixing (IWPCTM), 1988, 1989, 1991, 1993, 1995, 1997, 1999, 2001). The principal parameters which characterize the mixing between the two fluids are from one hand, their thermodynamic initial properties, the shock wave intensity and both the experimental facility and rupture mode of the separating membrane, and from the other hand the wave length and the amplitude of the initial perturbations (supposed to be sinusoidal). We believe that the knowledge of the initial conditions of the turbulent mixing creation, i.e. the initial densities of the two fluids, the shock wave intensity, the initial interface acceleration and the interaction process between the shock wave and the interface, but above all both the initial wavelengths and amplitudes of the perturbations, could lead to some predictions of the state of the mixing, and consequently to a better knowledge of the different transition phases to turbulence. The Richtmyer-Meshkov instability induced turbulent mixing is a good way to create free turbulence (without walls) but it requires the perfect knowledge of the experimental initial conditions. Thus, the goal of this new experimental apparatus is to contribute to the investigation of the transition phases to turbulence by the way of the Richtmyer-Meshkov instability study.

Correspondence to:
L. Houas – Lazhar.Houas@polytech.univ-mrs.fr

2 Experimental set-up description

2.1 The T200 shock tube

The new T200 stainless steel double diaphragm shock tube has a total length of 7.04 m. It first includes a movable 1.5 m long and 300 mm internal diameter high pressure

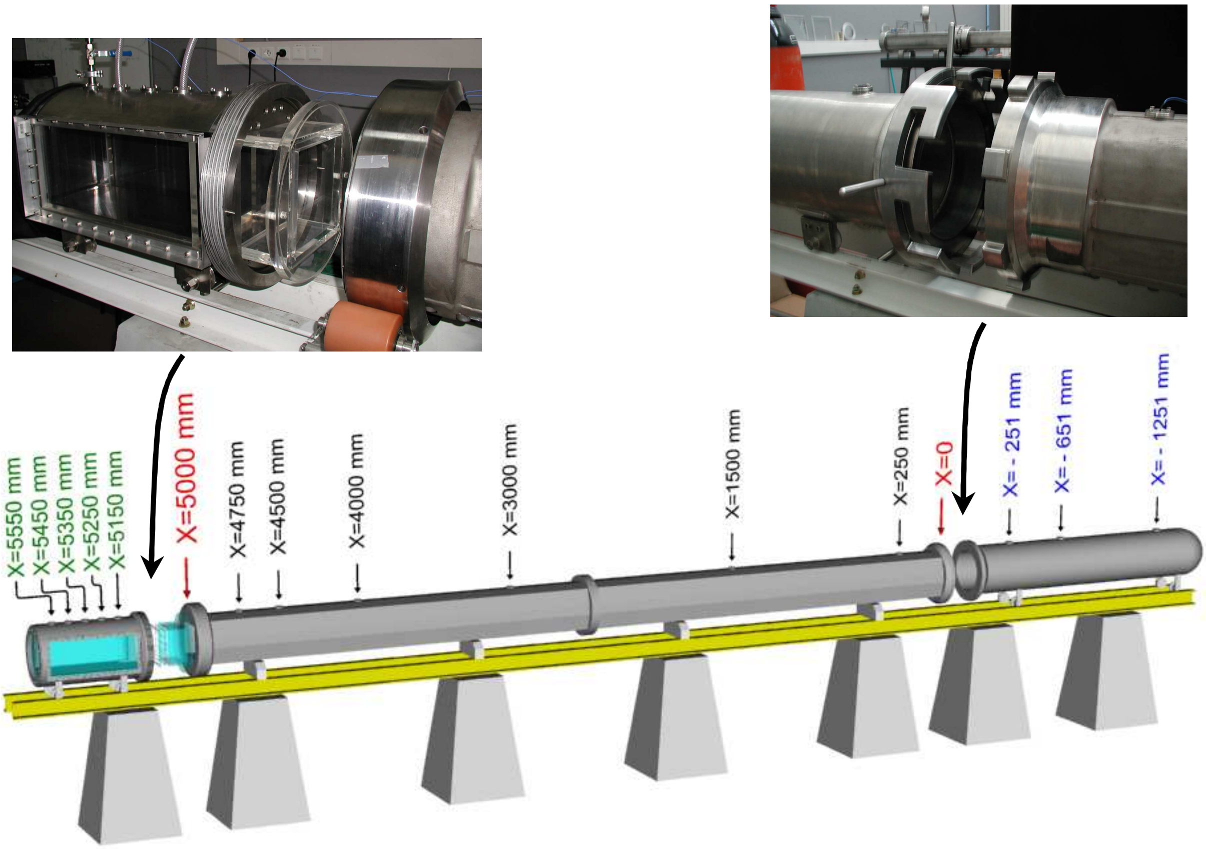

Fig. 1. General scheme of T200 shock tube

chamber, secondly a fixed 5.04 m long and 200 mm square cross section low pressure chamber made with two perfectly aligned 2.52 m long sections and at last a movable 0.46 m long and 200 mm square cross section experimental chamber, as shown in Fig.1. The interest of such a large driven square cross section is that it allows to prevent from wall effects on the studied phenomenon. Two clamps permit the introduction of the two diaphragms. The first, for the shock wave creation, is metallic and positioned between the high pressure and the low pressure chambers. As shown on Fig.1., the joining of the high pressure and low pressure chambers is made with a rapid sixth turn device. The second, a 1 μm less thin membrane is put between the low pressure and the experimental chambers. It materializes the interface initially separating the two gases expected to mix together after the interaction with the shock wave. This set-up simultaneously ensure the perfect alignment and the waterproof joining between the different sections. The experimental chamber is fitted with two 50 cm long visualization windows with a field of view starting from 4 cm before the initial position of the interface to 46 cm after. An original system has been imagined and built in order to introduce the thin membrane which initially separates the two different gases and permit both the control and the knowledge of the initial perturbations imposed on that material interface. Fig.1 shows the principle of the design and Fig.2 the result. The initial wave lengths and amplitudes of the perturbed interface are suitably measurable both before running the experiment and during the development of the perturbations and following mixing process. In concrete terms, the initial perturbations are imposed to the thin membrane, before running the experiment, by a very low pressure gradient between the low pressure and experimental chambers. From the other hand, another Plexiglas window ending the experimental chamber makes possible the use of two dimensional diagnostic technique by crossing it. The first diaphragm which initially separates the high pressure and the low pressure chambers is a beforehand grooved 1 mm aluminium disc and the second is a two layer nitrocellulose 0.4 μm thick membrane. A rotary vane pump (an Alcatel 63 m^3/h Pascal serie) is connected to the three sections. It permits to remove air from one or more sections in order to fill with an other gas and/or to decrease the pressure for high Mach number experiments. The driven section of the shock tube is equiped with ten caps. Four of them are used to flush mount high frequency PCB pressure transducers (113A21 type). They are connected, via a PCB amplifier (48A04 type), to a multicanal digital oscilloscope (Tektronic TDS) and allow, besides the shock wave velocity determination, the triggering of the diagnostic system from the oscilloscope delayed triggering canal. An example of three pressure signals obtained during the calibration process is presented

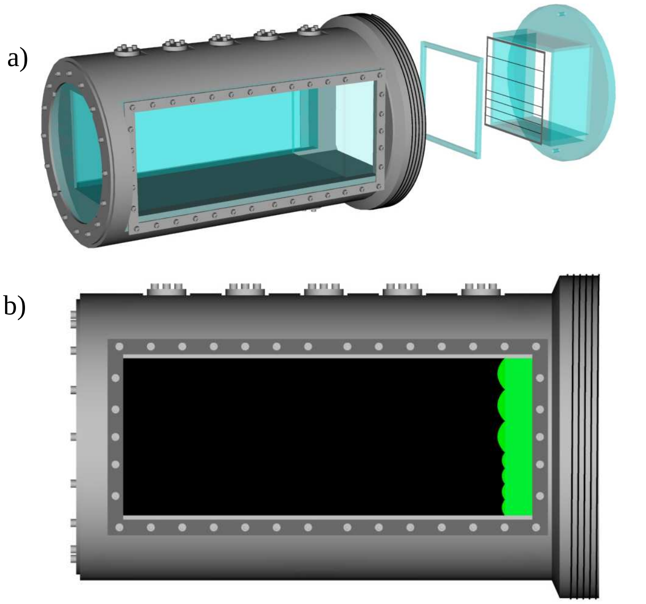

Fig. 2. Scheme of the experimental chamber with the initial condition control and knowledge device: a) detailed view, b) just before running the experiment

in Fig. 3. The first was recorded in the high pressure chamber (651 mm before the metallic diaphragm position), the second in the low pressure chamber (250 mm just after the diaphragm position), and the third at the abscissa of 3 m. The initial conditions were air at atmospheric pressure on the left side of the metallic diaphragm (A1050 aluminum type, 359 mm diameter, 1 mm thick, and 0.3 mm streak depth) and the Mach number of the incident shock wave was about 1.36. We observe on the first signal, the opening membrane process, i.e. the rarefaction waves in the high pressure chamber. The second shows a slowly and strongly perturbed increase corresponding to the formation of the incident shock wave followed by a more abrupt rise illustrating the reflected shock wave after its interaction with the high pressure/low pressure gaseous interface. The third recorded signal gives both the well formed incident shock wave jump and an estimation of the test time, about 5 ms before the coming of the rarefaction waves. Other caps are used to introduce the different test gases. To follow the evolution of the initial perturbations and the development of the mixing of the two gases, several experimental techniques can be developed, as reported in the paper of Houas et al. (Houas et al. 1999). Some of them will give qualitative informations and others quantitative results. But whatever the diagnostic techniques implemented on this experimental device, the phenomenon under study will be followed from the beginning state to the full turbulent regime. Of course, punctual experimental techniques (one measurement at one point during one run) would be out of interest with such a device, but multiple or successive measurements or visualizations would suit very well. For example, at the present time, we are developing a rapid Mie scattering laser sheet technique which allows one measurement each 20 μs during the same run.

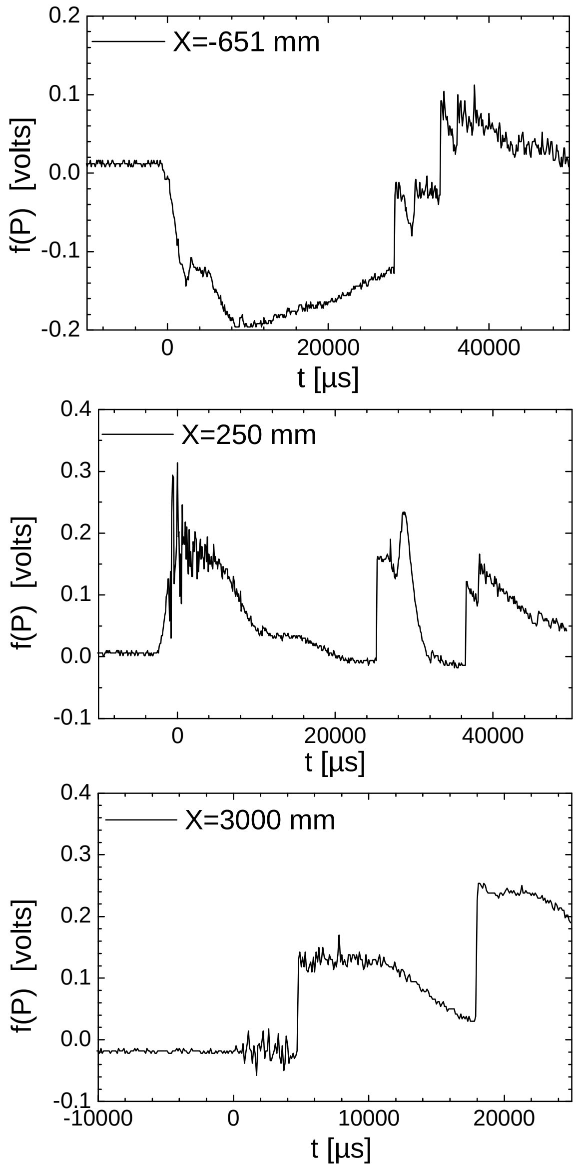

Fig. 3. Example of calibration pressure signals

3 Conclusion

A new shock tube has been developed to study the transition phases to turbulence initiated by the Richtmyer-Meshkov instability. Its 20 cm large cross section prevents from wall boundary layer effects.The special device realized for the control of the initial conditions of the experiments is successfully reached as both the amplitudes and wave lengths of the initial interface are clearly visible and can be easily measured both before and during the run.

We hope that this original type of apparatus will help to progress in the field of hydrodynamic interface instabilities and better understand the different stages of the evolution to turbulence.

Acknowledgement. This device has been realized with special found from Conseil Général des Bouches-du-Rhône and the authors would like to thank Mrs. C. Chauvin and Mr. F. Caccintolo. The authors are also grateful to Pr. J.-C. Loraud, Dr. E. Meshkov, Pr. G. Ben-Dor, Dr. D. Besnard, Pr. S. Zaytsev, Dr. A. Aleshin, Dr. S. Sergeev for their contribution in this project.

References

Richtmyer RD (1960) Taylor instability in shock acceleration of compressible fluids. Commun. Pure Applied Math. 13:297

Meshkov EE(1969) Instability of a shock wave accelerating interface between two gases. Nasa Technical Translation F-13:074

Proceedings of the 1st IWPCTM, Princeton, NJ USA, Ed. A.C. Buckingham (1988) Proceedings of the 2nd IWPCTM, Pleasanton, CA USA, Ed. V.C. Rupert (1989) Proceedings of the 3rd IWPCTM, Royaumont, France, Ed. R. Dautrey (1991) Proceedings of the 4th IWPCTM, Cambridge, UK, Eds. P.F. Linden, D.L. Youngs & S.B. Dalziel (1993) Proceedings of the 5th IWPCTM, Stono Brook, NY USA, Eds. R. Young, J. Glimm & B. Boston (1995) Proceedings of the 6th IWPCTM, Marseille, France, Eds. G. Jourdan & L. Houas (1997) Proceedings of the 7th IWPCTM, St-Petersburg, Russia, Eds. E. Meshkov, Yu. Yanilkin & V. Zhmailo (1999) Proceedings of the 8th IWPCTM, Pasadena, CA USA, under process (2001)

Houas L, Meshkov EE and Jourdan G (1999) Overview of diagnostic methods used in shock-tube investigations of mixing induced by the Richtmyer-Meshkov instability. Shock waves, 9:249-257