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A new variable inclination shock tube for multiple investigations

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Abstract. A new variable inclination shock tube has been set up especially for visualization of shock induced high speed flows. This device allows the generation of shock waves of Mach numbers ranging from 1.05 to 4, moving horizontally, vertically from up to down or the opposite, or with any inclination angle. It is coupled with a suitable high speed camera shadowgraph visualization system, and the whole facility has been realized so as to be both very easy to use and movable. We believe this example could be of interest to scientists interested in starting experiments on shock wave induced multi-phase complex flows.

Key words: Variable inclination shock tube, Multi-phase flows, High speed photography

1 Introduction

Shock waves are present in most domains of investigation and have particularly strong influence in understanding of complex flows. The study of the interaction of shock waves with heterogeneous flows such as non-homogeneous gases, gas-particle or gas-liquid media, finds today wide domains of applications which require specific experimental devices and diagnostics. However, the operation of these devices should not add uncessary difficulties to the complexity of the studied phenomenon. Thus, the idea of our group, involved in the domain of multi-phase flows and shock waves, in collaboration with the mechanical designers R. Carrey and F. Diaz, was to design an original simple shock tube set-up in order to study unsteady gas flows with liquid and solid inclusions in many different configurations, with both easiness of operation and mobility.

2 Experimental description

As a main tool of the experimental studies of shock waves, the shock tube has been widely used in the past four decades (Gaydon et al. 1963, Glass et al. 1994). In this conventional shock tube, a high pressure chamber and a low pressure channel are initially separated by a diaphragm and the shock wave is instantaneously generated from the convergence of compression waves after the bursting of the diaphragm due to the sudden increase of the pressure in the driver chamber.

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2.1 The T80 shock tube

The new T80 stainless steel 80 mm square cross section shock tube has a total length of 3.75 m. It first includes a movable 0.75 m long high pressure chamber, secondly a fixed 2.02 m long low pressure chamber and at last a movable 0.98 m long experimental chamber, with a surface finish of the internal walls (polished by hand) of about 2 μm. The complete device is mounted on rail and coupled with a pneumatic system which allows to tilt it with any angle (from -90° to +90°) as shown in Figs.1a and b, in few minutes. The shock tube was designed so that the maximum pressure can reach 20 bars (even in the test chamber) and the pressure in the driven chamber can go down to 0.5 mbar, in order to obtain a pressure ratio adequate for shock wave Mach numbers within the range of 1.05 to 4 in air or any inert gases. In practice, the pressure in the high pressure chamber is increased by a manual valve connected to the driver gas supply until it reaches the pressure required to burst the diaphragm. It generally consists in a 150 mm in diameter beforehand grooved aluminium disc from 12 μm to 0.8 mm thick. This procedure ensures a repeatability of the shock speed typically to within $\pm 2\%$. Note that the closing system between the high-pressure and the low-pressure chambers has been designed so that the diaphragm change was both simple and rapid. It consists in a special safety catch clamp (operating with one 6^{th} of a turn) which provides security and airtightness as shown in Fig.1c. After the bursting of the diaphragm, compression waves are formed in the low-pressure chamber. They rapidly steepen (in less than 1 m) to form a shock front. Simultaneously, an expansion wave fan moves into the high-pressure chamber, while the test and the driver gas make contact and propagate along the tube behind the

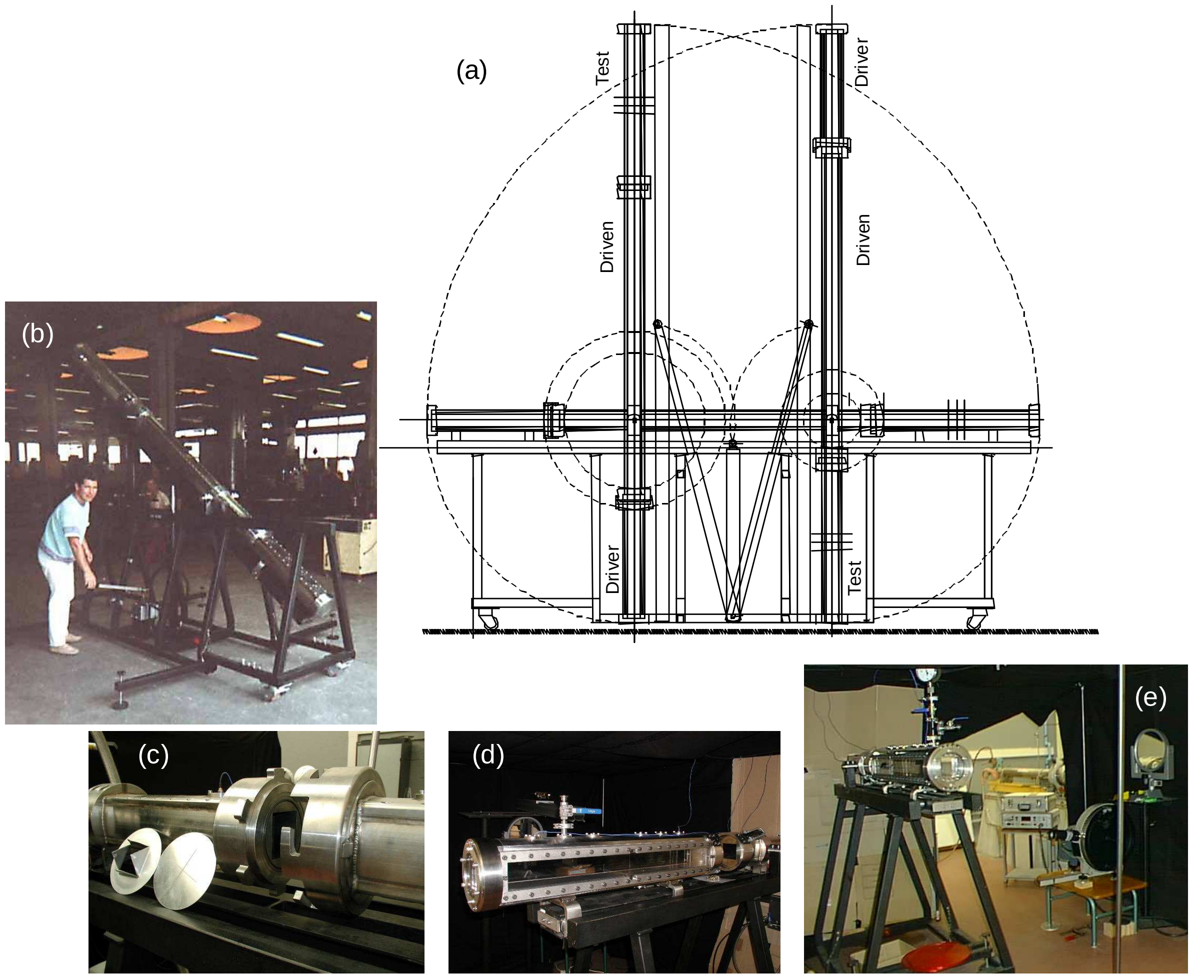

Fig. 1. General scheme (a) and different views of T80 shock tube with the inclination pneumatic system principle (b), the rapid HP/LP chambers closing system (c), the test vizualisation chamber (d) and the shadowgraph imaging set-up (e)

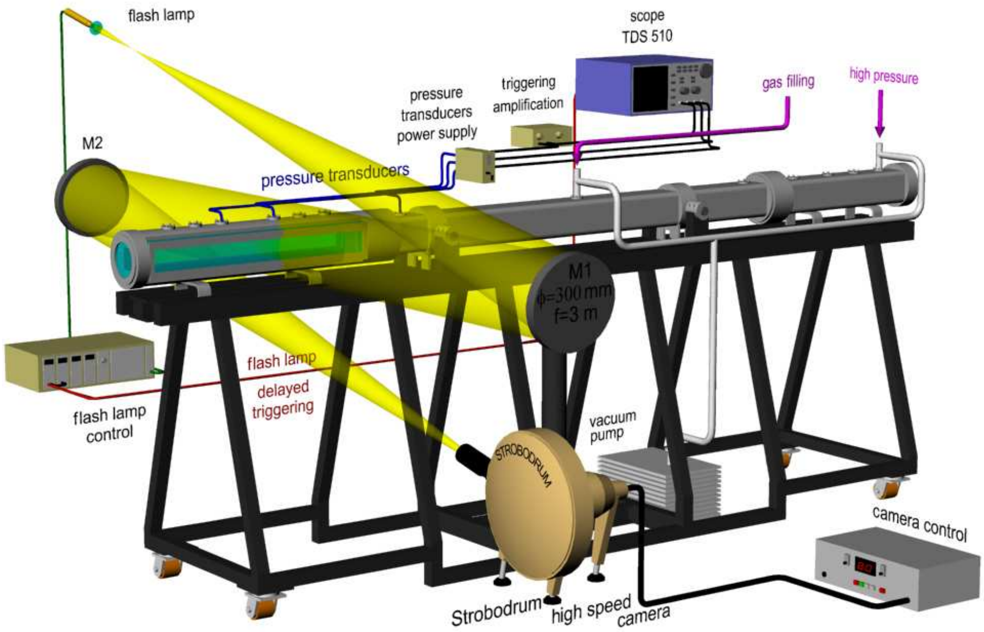

Fig. 2. General diagnostic system

Table 1. Position of the different caps; the zero point corresponds to the beginning of the HP chamber

Caps#	1	2	3	4/4′	5	6/6′	7	8	9	10	11	12	13
Position (mm)	3630	3520	3410	3190	3080	2970	2630	1770	900	615	415	265	115
Chamber	Test	Test	Test	Test	Test	Test	Driven	Driven	Driven	Driver	Driver	Driver	Driver

shock front. The shock-tube length has been optimized in order to stabilize the incident shock wave prior to the visualization section while ensuring enough uniform flow time (from 0.5 to 5 ms) before the return of reflected shock, the expansion waves and contact surface, in different flow regimes (subsonic and supersonic). However, possible extensions of the driver, driven and test sections can be designed in order to increase test time for specific investigations. Parallel Plexiglass windows (30 mm thick) suitable only for shadowgraph or laser sheet visualization, span the entire 80 mm width and 880 mm length of the test section (Fig. 1d). The Plexiglass surface should remain unpolished as provided by the manufacturer. The test section of the shock tube ends with a rigid Plexiglass plate which allows the introduction of a laser sheet. However, Plexiglass can easily be replaced with glass, Carbon or Lexan for windows allowing for other optical diagnostics (schlieren, interferometry or X-ray absorption). Finally, the whole system is set up on rollers in order to move it easily in, or out of, our laboratory and to optimize our work space. This installation has been mechanically well conceived so as to facilitate the preparation and the execution of a simple run (less than 10 minutes) including diaphragm insertion, pressure data reduction and camera loading, even by a novice operator.

2.2 Pressure instrumentation

The driver section is equipped with a compression gauge to measure the pressure of the driver gas just before the release of the shock. Thus it is possible to estimate the deviation of the actual shock tube performance from theory by comparing the experimental shock wave velocity and strength with the calculated one. A rotary vane pump (an Alcatel 20 m^3/h SD serie) is connected both to the driver and driven sections. It permits to remove air from sections in order to fill with an other gas and/or to decrease the pressure of the driven gas (down to 0.5 mbar) for high Mach number experiments. The driver and the driven sections of the shock tube are equipped with 4 and 11 caps, respectively. Table 1 gives their positions along the tube. Note that in the test section, caps #4 and #4′ and #6 and #6′ are facing each others at the same abscissa. Some of them are used to flush mount high frequency calibrated PCB (PCB Piezotronics Inc.) pressure transducers (SM113A26 type). They are connected, via a PCB amplifier (482A22 type), to a multicanal digital oscilloscope (Tektronic TDS) and allow, besides the shock wave velocity and the pressure jump determinations, the triggering of the flow imaging diagnostic from the oscilloscope delayed triggering canal. Only four pressure transducers are needed for a normal run of the shock tube and they can be changed from one position to another one. Other caps can be used to introduce different devices within the shock tube inner section according to the study in progress.

2.3 Shadowgraph diagnostic device

The T80 shock-tube is coupled with a high speed camera shadowgraph system, where a stroboscopic “Nanolite” flash lamp is synchronized with a rotating “Strobodrum” camera (High Speed Photo-Systeme Company). The Nanolite KL-L type insures a flash duration of 18 ns with an energy of 25 mJ which allows the photographic analysis of extremely fast events. The spark discharge can also take place in pressurized chambers using rare gases (Ar, Kr or Xe) in order to increase the light gain. The “Ministrobokin” serves to operate the flash lamp and is designed as a basic unit for external triggering of flashing rates up to 20 kHz. Sequences of pictures can be ontained with the drum streak camera Strobodrum (Fig. 1e). It operates at constant peripheral speeds up to 90 m/s and is loaded with a 1.5 m × 35 mm film. For single flash operation, classic reflex photo cameras can also be used. A scheme of the general experimental set-up is presented in Fig. 2 where a vertical Z-configuration of shadowgraph system using two spherical mirrors is combined with the horizontal arrangement of the shock tube.

3 Performance results

The present installation has been initially designed for low Mach number experiments but nevertheless it can work in stronger conditions. Runs have been conducted for Mach numbers ranging from 1.05 to 4 which gives corresponding flow durations of about 5 to 0.5 ms. In all cases we have verified that the shocks are formed within the first meter of the driven section. This means that a pressure transducer located at the second abscissa 1770 mm (see Table 1) in the driven section always records a steep step-like profile even in the lowest possible initial pressure of 0.1 hPa. An example of a typical pressure signal recorded in the test section at abscissa 3080 mm during an usual run is presented in Figs. 3a. The incident shock wave Mach number was 1.06, obtained in air at atmospheric pressure and the use of a 12 μm thick aluminium sheet. We can observe the well formed incident shock wave jump and an estimation of the test time, about 3.5 ms before the arrival of the rarefaction waves and reflected shock.

Fig. 3b presents the corresponding wave diagram obtained from an one-dimensional simulation. It shows the trajectories of the different calculated singularities of the flow. As we can see, the time interval during which an uniform flow is obtained is limited in this weak shock case by the arrival of the rarefaction waves and the return of the shock wave reflected from the shock-tube end-wall.

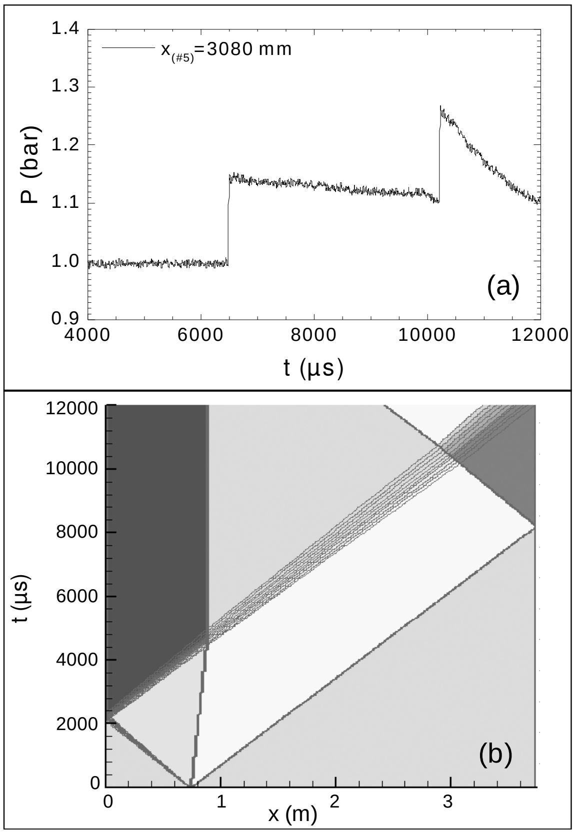

Fig. 3. Example of pressure time trace recorded from a pressure transducer located at 3080 mm (#5) from the end plate of the driver chamber for a 1.06 shock wave Mach number (a) associated with the corresponding (b) wave diagram calculated from one-dimensional simulation

4 Conclusion

A new shock tube was designed and constructed to generate a large range of Mach numbers, from 1.05 to 2 in atmospheric air, up to 4 when the driven chamber is evacuated below the atmospheric pressure. For the several calibration runs, the scatter of the generated shock wave velocity was found to be less than ±2% for all the range of experiments. Its originality lies in the fact that it can work in many configurations, i.e, horizontally, vertically the shock wave moving from up to down or vice-versa, or with any inclination angle. This device has been coupled with a streak camera shadowgraph system, where a stroboscopic flash lamp synchronized with a rotating drum camera allows to capture high speed flow sequence up to a 20 kHz rate frequency. The whole set-up has been thought out for an easy and rapid use and built at a total cost in 1999 of less than 110,000 euros with 45,000 euros for the shock tube and 65,000 euros for the pressure instrumentation and the high speed visualization system. It should be noticed that the price of steel has considerably increased since then. At this time, some investigations have been already undertaken with this facility in different fields such as, Richtmyer-Meshkov instability induced mixing, shock soap bubble interaction (Layes et al. 2003), shock particle interaction (Devals et al. 2003) and shock and solid structure interactions. The possibility to study liquid layers and bed of particles (Rogue et al. 1998) under shock loading at any oblique inclination has been considered. For future Richtmyer-Meshkov studies, it should also be interesting to look at the oblique interaction of shock waves with horizontal diffuse interfaces. Note that these developments require a modification of the present test section. Finally, we hope that the presentation of this original simple set-up will encourage the scientific community to start or continue experiments in the field of shock inducing complex flows.

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