Technical note

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Fabrication and installation of moderate size shock tube facility – a case study

Abstract

A moderate size shock tube of 7m long with inner diameter of 55mm and thickness of 20mm has been is designed in-house and installed successfully in the Mechanical Engineering Department at Indian Institute of Technology Guwahati (IITG). The shock wave is generatedby rupturing metallic diaphragms instantly with appropriate pressure ratios across the driver (2m) and driven (5m) section of the shock tube. The pressure rise across the across primary and reflected shock is measured by high frequency pressure transducers located towards end of driven section. All necessary shock tube parameters are calculated through one-dimensional shock tube relations and are validated with experimental data.

Keywords: shock tube, shock mach number, primary shock, reflected shock, pressure ratio

Volume 1 Issue 1 - 2017

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Received: May 07, 2017 | **Published:** May 07, 2017

Introduction

Missiles and launch vehicles experience various flow regimes in their flight path. Design of these high speed configurations depend mainly on flow and flight parameters. The more realistic approach to understand the high speed flow physics would be to simulate the high speed flow conditions in the laboratories. During the 1960's considerable research was conducted to establish ground test facilities to simulate such high speed flows. Mainly, the research was focused to understand the aerodynamic data for simple geometries such as cones/slender bodies. Many analytical models were developed to validate the data for understanding aerodynamic behavior.[1,2] But, due to lack of availability of high speed sensors and flow diagnostic instrumentation, these facilities provided limited data and could not be initiated for further developments. With advent of computational power, the new era relies heavily on computational codes to simulate flow parameters for complex aerodynamic body shapes. Again, validation of these codes against experimental test bench plays a vital role to understand flow physics and future development of numerical code. So, ground-based experimentation in high-speed impulse test facilities remains an important component for future developments. In such facilities, the aerodynamic testing is considered as highly specialized activity because short duration flows are produced with test times in the range of few milliseconds. They include small and large scale developments in shock tunnels, free-piston shock tunnel and expansion tubes etc., established over last few decades.[3–7] Main attraction of short duration facilities is that they provide a high-enthalpy slug of test gas at reasonable cost. The test gas is compressed and subsequently expanded with appropriate nozzle to achieve desired conditions in the test section of the tunnel. Though, there are difficulties in the process of data acquisition in the short test times, but the modern days of high-speed instrumentation and flow diagnostics techniques have produced ingenious solutions to take the advantage of short test times.

Shock tube is one of the simple laboratory tools that can generate various flow speeds at different flow regimes.[8–9] However, the penalty paid for these experimental flow field simulations is the test time which is in the order of milliseconds. It leads to sophisticated instruments to gather all experimental information in a short time scale which is quite challenging.[10–11] Extending this facility to shock tunnels, researchers conducted force measurement successfully on a missile shaped configuration at supersonic and hypersonic Mach numbers.[12–13] The surface heating measurements on blunt bodies for variety of interdisciplinary space science applications have also been exhaustively carried out.[14–16]

With the above viewpoint, the authors report about installation of a particular shock tube facility as one of the case study. Being, indigenously designed and fabricated in-house, this modular shock tube facility is very unique in the north-eastern region of the country (India). Apart from aerodynamic experiments at low supersonic speeds, this modular shock tube can also be useful for chemical kinetic studies and other interdisciplinary applications of shock waves. Considering the geographical location of IITG, the major milestone of this facility development are the in-house designed and fabrication of shock tube with allied hardware and integrated effort of the instrumentation for high-speed data acquisition.

Shock tube performance–sample results and discussions

The shock tube performance is based entirely upon the pressure ratios and speeds of sound in driver and driven section. Since, the strength of the shock increases with increase in the ratio of speeds of sound, it is desirable to have a driver gas with a low molecular weight and driven gas with a high molecular weight. So, the strongest shock wave can be obtained by using a heavy driven gas and a light driver gas. While meeting these requirements, the present investigation is aimed for two driver gases (nitrogen and helium) with air in the driven section and the fundamental one-dimensional relations are used to find the performance parameters of the shock tube.[17] The complete schematic overviews along with the components of shock tube are shown in (Figure 1). Initially, an aluminum diaphragm separates the driver and driven section of the shock tube. At the beginning of experiment, the pressure inside the driven section (region 1) is maintained at 0.18bar and all the valves are closed. The driver section is filled with nitrogen through a high pressure cylinder (region 4) and the diaphragm ruptures at a pressure of 20bars. The sudden rupture of diaphragm due to pressure difference across the drive and driven section of the tube creates a shock wave that propagates into the driven section. The gas flow starts as a jet and increases as the diaphragm opens, until the cross section of the tube is filled and the shock wave being formed in this process. The sudden rise in pressures across the shock wave induces mass motion in of the driven gas (region 2). The primary shock gets reflected from the end plate, thus forming the reflected shock propagating into a medium which is already at elevated pressure and thereby forming a further increase in pressure and temperature of driven gas (region 5). The pressure jumps across the primary as well as reflected shock are captured from the pressure transducers (Figure 2). From this pressure signals, the time taken by the shock wave to travel a distance of 500mm (between pressure transducers) is obtained and subsequently, the shock Mach number M_s is calculated. Further, the analytical expressions (Eq-1) are used to compute the pressure and temperature ratios across primary and reflected shocks.[17] the results plotted in (Fig-3) have shown very good prediction within the experimental uncertainty of ± 10%.

$$\frac{p_2}{p_1} = 1 + \frac{2\gamma_1}{\gamma_1 + 1}\left(M_s^2 - 1\right); \quad \frac{p_5}{p_1} = \left[\frac{2\gamma_1 M_s^2 - \left(\gamma_1 - 1\right)}{\left(\gamma_1 + 1\right)}\right]\left[\frac{-2\left(\gamma_1 - 1\right) + M_s^2\left(3\gamma_1 - 1\right)}{2 + M_s^2\left(\gamma_1 - 1\right)}\right]$$

$$\frac{T_2}{T_1} = \frac{1 + \left(\frac{\gamma_1 - 1}{\gamma_1 + 1}\right)\frac{p_2}{p_1}}{1 + \left(\frac{\gamma_1 - 1}{\gamma_1 + 1}\right)\frac{p_1}{p_2}}; \quad \frac{T_5}{T_1} = \left(\frac{\left[2\left(\gamma_1 - 1\right)M_s^2 + 3 - \gamma_1\right]\left[\left(3\gamma_1 - 1\right)M_s^2 - 2\left(\gamma_1 - 1\right)\right]}{\left(\gamma_1 + 1\right)^2 M_s^2}\right) \tag{1}$$

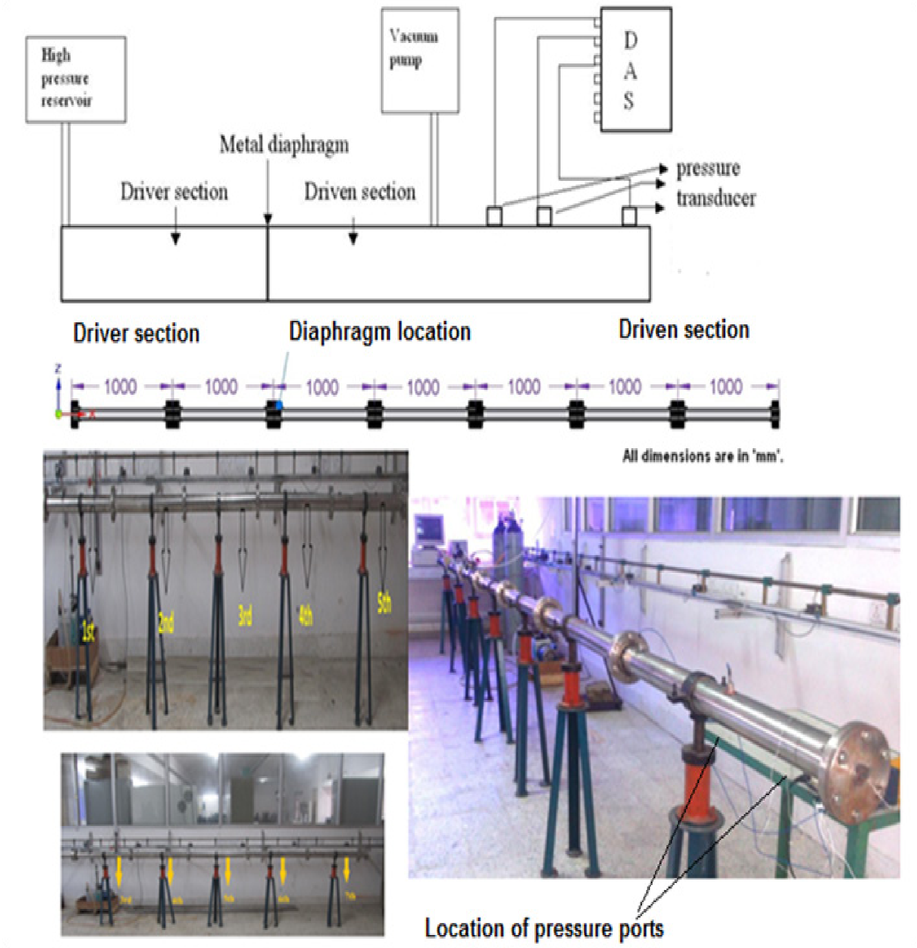

Figure 1 The modular shock tube facility at IIT Guwahati

Citation: Agarwal S, Sahoo N. Fabrication and installation of moderate size shock tube facility – a case study. *Aeron Aero Open Access J.* 2017;1(1):1–4.
DOI: 10.15406/aaoaj.2017.01.00001

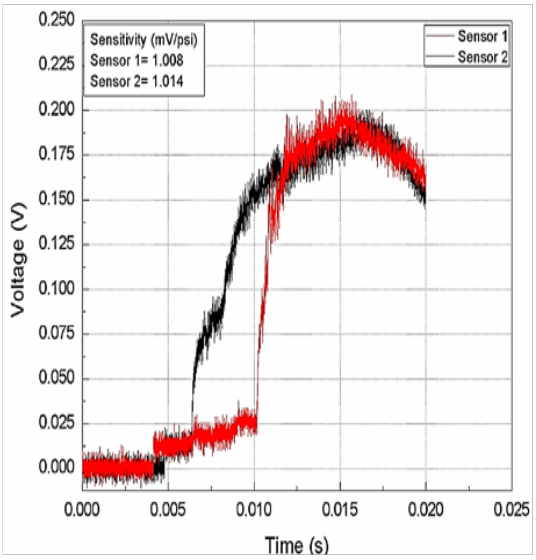

Figure 2 A typical pressure signal from the pressure transducer mounted at driven section of shock tube.

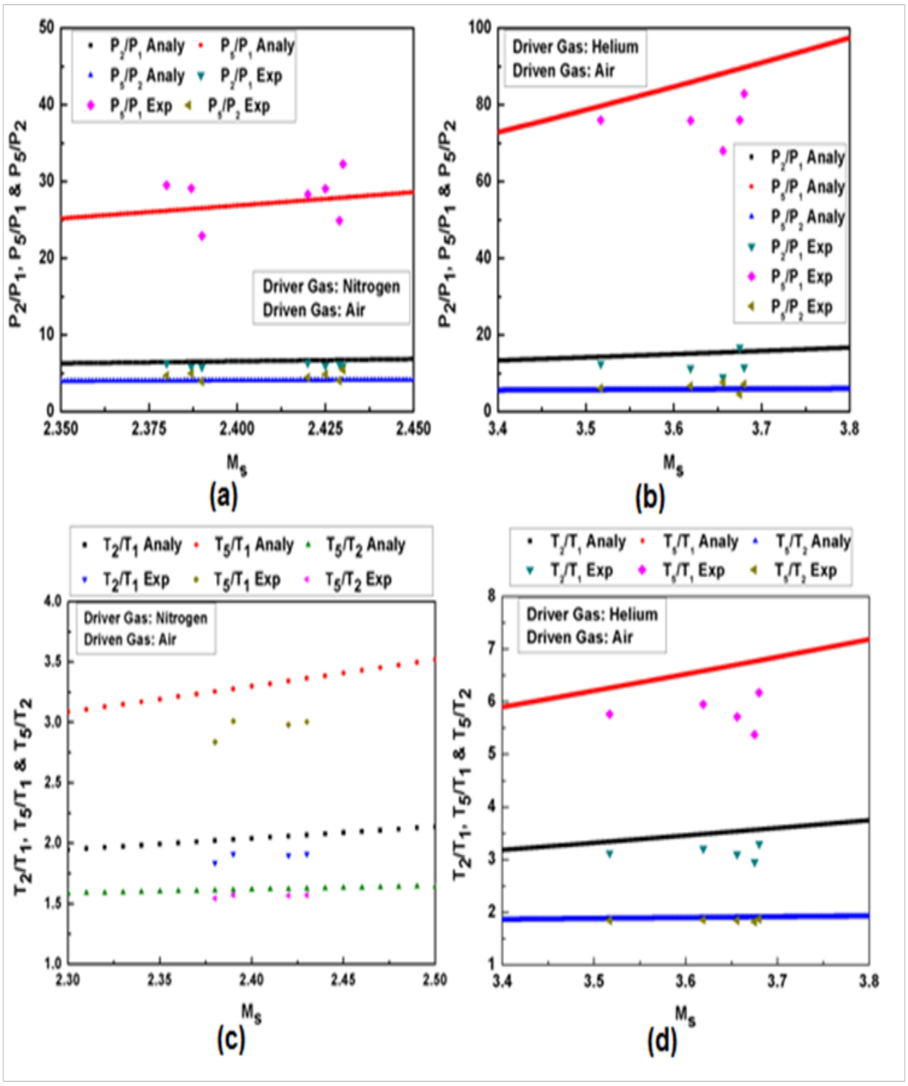

Figure 3 Comparison of pressure and temperature ratios across primary and reflected shocks

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Conclusion

A moderate size shock tube (7m) has been installed in the Mechanical Engineering Department at Indian Institute of Technology Guwahati. It has been calibrated successfully by measuring and estimating shock tube parameters through experiments and analytical calculations with average deviation within ±10%. Most of the components and instrumentations of this shock tube are indigenously designed and fabricated. In the areas of aerospace science and technologies, the attention can be focused to simulate hypersonic flows experimentally through design of suitable convergent-divergent nozzles. The future scope of this facility development is also inclined towards many interesting mechanical applications in the areas of impact assessment on structures and shock assisted deformation studies for metals and composites, chemical kinetics, ignition delay measurements for potential bio-fuels.

Acknowledgements

None.

Conflict of interest

Author declares that there is no conflict of interest.

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DOI: 10.15406/aaoaj.2017.01.00001