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Mini Review

Hand-operated shock tube and hypersonic shock tunnel

Abstract

This manuscript outlines the invention of a miniaturized version of the conventional shock tube and hypersonic shock tunnel that is small enough to be mounted on a table top. The shock tube (named as Reddy tube) works solely with the effect of human force, and the driver gas is pressurized by manual action of a plunger rod. Test can be conducted within a shock Mach number range of 1.2 – 2.0. The extension of the Reddy tube into a table-top, single-pulsed, hypersonic shock tunnel (named as Reddy tunnel) proves to be an important input into the field as it can be established as a fraction of the cost of a full-fledged facility, thereby providing access to such experiments to virtually any person in the experimental aerodynamic community.

Keywords: hand-operated shock tube, hypersonic shock tunnel, high speed aerodynamics, Reddy tunnel

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KPJ Reddy,[1] CS Kumar[2]

[1]Department of Aerospace Engineering, Indian Institute of Science, India

[2]Project Manager, Super Wave Technologies Pvt. Ltd, IISc Campus, India

Correspondence: KPJ Reddy, Department of Aerospace Engineering, Indian Institute of Science, Bangalore, 560 012, India, Tel 91-80-22933162, Email kpjreddy@iisc.ac.in

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Introduction

High speed aerodynamics, gas dynamics and shock waves have been hot topics of research for over a century, and have recently commenced to find application is various fields of science and engineering including biomedical, nanoscience, industrial engineering etc.[1,2] However, large areas of these fields are still plagued with lack of complete clarity. The reason for this is, in large part, owed to the difficult and complicated nature of the field itself, but also due to the 'elitist' character of the field due to expensive equipment involved. The Reddy tube, and its extension, the Reddy tunnel are two instruments targeted specifically at young scientists and engineers who are at the cusp of entering the field. The devices cater to the study of gas dynamics and high speed flow while costing a fraction of that of the conventional systems.

This paper provides the details of some preliminary experiments conducted on both the devices, lucidly proving their capability to handle research level problems in gas dynamics and high speed aerodynamics.

Hand-operated shock tube-the Reddy tube

The Reddy tube is a miniaturized shock tube that can be housed on a table top. It measures a meter in length overall; 400 mm of it the driver section and 600 mm, the driven. The inner diameter of the tube is around 30 mm. Instead of the metal diaphragms that are normally seen on conventional shock tubes, a piece of tracing paper is used. The rupture of the diaphragm is achieved by pushing a plunger along the length of the driver section, towards the diaphragm station. In effect, the Reddy tube is a manually operated version of the free piston shock tube usually employed for high enthalpy studies. Using this instrument, shock waves with Mach number up to 2 can be generated. This opens the door to some serious areas of research. The Reddy tube is, in effect, a miniature version of the free-piston driven shock tube, or Stalker tube.[3]

The Reddy tube is instrumented with two high-speed pressure sensors mounted towards the end of the driven section to enable experimental measurement of shock speed using the time of flight method. A pressure gauge provided at the driver section facilitates the recording of diaphragm rupture pressure. An oscilloscope used in conjunction with the device enables the measurement and recording of pressure signals from the sensors. A photograph of the equipment is shown in Figure 1. Typical pressure signals obtained from the system are shown in Figure 2. It may be observed that an effective test time of up to 500μs can be obtained using the apparatus. A detailed explanation regarding the design and testing of the equipment can be found in Reddy et al.[4]

Figure 1 Photograph of Reddy tube with the associated instrumentation.

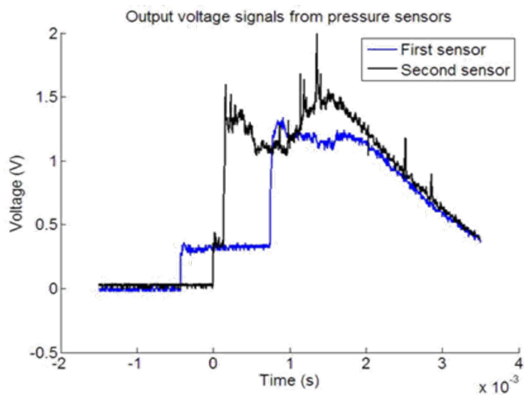

Figure 2 Typical pressure signals from the Reddy tube.

Experiments

The applications of Reddy tube range from gas dynamic study of shock waves to various fields such as chemical kinetics, material studies, biomedical, electronic instrumentation and other industrial areas. Figure 2 depicts typical pressure signals obtained by wall mounted pressure sensors towards the end of the driven section. The shock Mach number can hence be experimentally measured using time of flight method. The calibration curves for the Reddy tube has been generated and are presented in Figure 3 & 4.[5] Currently, research groups are employing the Reddy tube for studies such as combustion of atomized fuel, traumatic brain injury in rats etc.[6]

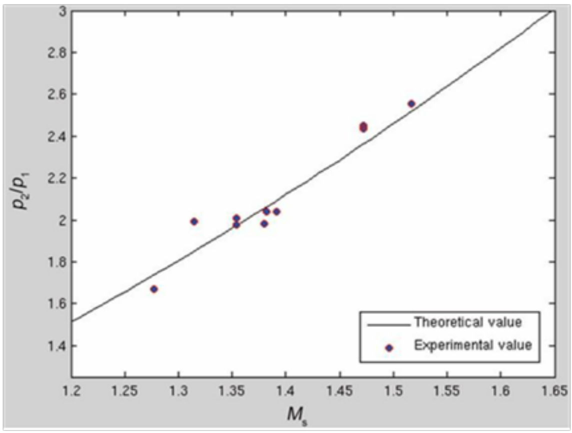

Figure 3 Calibration curve of P2/P1 vs shock Mach number.[4]

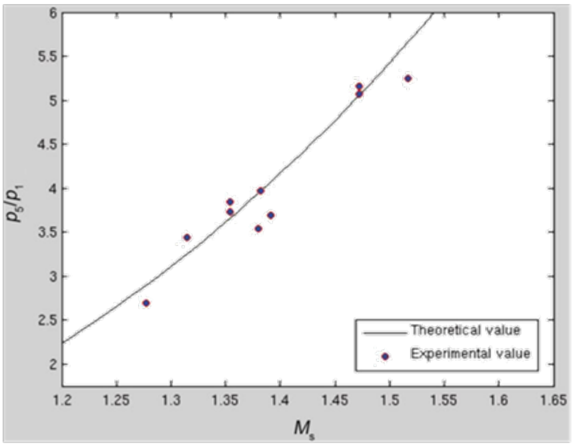

Figure 4 Calibration curve of P5/P1 vs shock Mach number.[4]

Hand-operated hypersonic shock tunnel-the Reddy tunnel

The extension of the Reddy shock tube into a table-top, hypersonic shock tunnel is termed as the Reddy tunnel. A convergent-divergent nozzle followed by a test section–dump tank assembly is attached to the end of the driven section to realize the Reddy tunnel. A thin piece of tracing paper of lesser gauge than the primary diaphragm acts as the secondary diaphragm that separates the driven section from the nozzle. The nozzle may be designed to generate hypersonic Mach numbers within the range of 6 to 8 in the test section, where aerodynamic models can be mounted for testing. The dump tank is attached to a vacuum pump which initially evacuates the tank and test section before the experiment is conducted. The diameter of the exit of the nozzle is 78mm, therefore, test models of cross-wise dimension of up to 50mm can be accommodated in the test section without causing flow blockage. Figure 5 shows a photograph of the equipment, and Figure 6 give a schematic with the different parts of the system. The Reddy tunnel can be effectively used for basic level experiments in hypersonic flow studies including measurement of pressure profiles, heat flux, lift and drag etc. More details of experiments conducted in Reddy tunnel can be found in Kumar et al.[7]

Figure 5 Photograph of Reddy Tunnel.

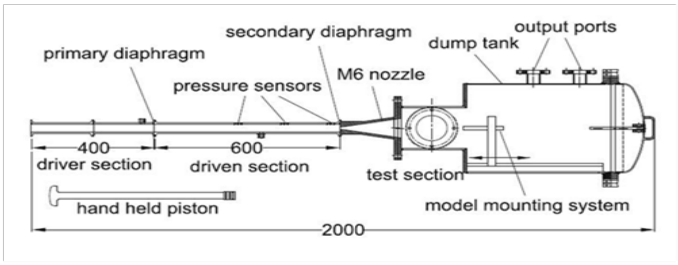

Figure 6 Schematic of Reddy Tunnel.

Experiments

Experiments conducted in the Reddy tunnel are targeted at study of the gross and fine aerodynamic properties over high speed aircraft models. Typical flow Mach number obtained in the Reddy tunnel is around 7. Table 1 gives the various parameters associated with free stream flow in the test section, where M–Mach number; P– pressure, T–temperature, U–flow velocity, ρ –density, Re–Reynolds Number and H–stagnation enthalpy.

Figure 7 depicts the bow shock that is visualized upstream of a hemispherical body mounted in the test section,[8] and shock stand-off distance was compared to published studies by Lobb,[9] with a good quantitative match.

Drag measurement and visualization studies in the Reddy tunnel has been undertaken and data was successfully measured on rudimentary test models and compared to theoretical data.[9]

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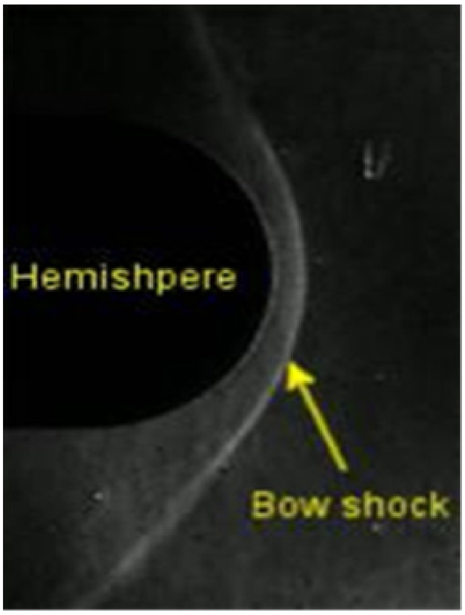

Figure 7 Schlieren picture of bow shock ahead of hemispherical body in Reddy Tunnel.[7]

Table 1 Freestream flow conditions established in the Reddy Tunnel

P_1, kPa	Case1 (90.6)	Case 2 (50.6)
M_∞ $[\pm 1.1\%]$	6.9	6.8
P_∞, kPa$[\pm 5\ \%]$	0. 101	0.095
T_∞, K$[\pm 5\ \%]$	47.4	55.7
U_∞, m/s $[\pm 2.5\ \%]$	955.9	1019.5
ρ_∞, kg/m$^3[\pm 5.5\ \%]$	0.0073	0.0059
Re_∞, million/m $[\pm 7.5\ \%]$	2.29	1.65
H, MJ/kg$[\pm 4.5\ \%]$	0.5	0.58

Conclusion

The Reddy tube and Reddy hypersonic shock tunnels have the potential to become revolutionary devices with the capability of bringing shock waves and high speed flows to the fingertips of aspiring engineers in the field. Their low cost and ease of operation make them uniquely qualified to be used for first cut research into a large number of applications involving shock waves.

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None.

Conflict of interest

Author declares there is no conflict of interest in publishing the article.

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