Sheridan College

SOURCE: Sheridan Scholarly Output, Research, and Creative Excellence

Publications and Scholarship

Faculty of Applied Science & Technology (FAST)

2013

The Effects of Area Contraction on the Performance of UNITEN's Shock Tube: Numerical Study

Ali Mohammed Hussein Mohsen
University of Warith Alanbiyaa

Mohd Zairol Yusoff
Universiti Utara Malaysia

Amir Alfalahi
Sheridan College, amir.alfalahi@sheridancollege.ca

The effects of area contraction on the performance of UNITEN's shock tube: Numerical study

A M Mohsen, M Z Yusoff[1], A Al-Falahi

[1]Centre for Advanced Computational Engineering, College of Engineering Universiti Tenaga Nasional, UNITEN, Jalan IKRAM-UNITEN, 43009 Kajang, Selangor, Darul Ehsan, Malaysia.

E-mail: zamri@uniten.edu.my

Abstract. Numerical study into the effects of area contraction on shock tube performance has been reported in this paper. The shock tube is an important component of high speed fluid flow test facility was designed and built at the Universiti Tenaga Nasional (UNITEN). In the above mentioned facility, a small area contraction, in form of a bush, was placed adjacent to the diaphragm section to facilitate the diaphragm rupturing process when the pressure ratio across the diaphragm increases to a certain value. To investigate the effects of the small area contraction on facility performance, numerical simulations were conducted at different operating conditions (diaphragm pressure ratios P_4/P_1 of 10, 15, and 20). A two-dimensional time-accurate Navier-Stokes CFD solver was used to simulate the transient flow in the facility with and without area contraction. The numerical results show that the facility performance is influenced by area contraction in the diaphragm section. For instance, when operating the facility with area contraction using diaphragm pressure ratio (P_4/P_1) of 10, the shock wave strength and shock wave speed decrease by 18% and 8% respectively.

1. Introduction
A short duration high speed flow test facility is an apparatus used to generate gas flow conditions of high enthalpy and high Mach number for a very short duration (in the order of milliseconds). Such facility includes shock tube, shock tunnel, plasma jet, arc heated tunnel, free piston tunnel, and gun tunnel [1]. Shock tube is one of the most versatile and economical high speed flow test facilities. It is used to generate homogenous, high enthalpy and high pressure gas flow conditions for a very short duration. It allows scientists to perform experimental and numerical studies on shock waves, their interaction, and other Mach number phenomena [2]. Shock tube is an excellent tool for investigating the nature of shock wave propagation in addition to high temperature phenomena in gases [3].

In short duration test facilities, it is quite difficult to fully examine all aspects of flow. This is due to extreme flow conditions and severe time constraint involved. Therefore, numerical studies have become very important tool to provide a quantitative description on the flow field conditions in such facilities [4, 5]. For example, the transient flows in shock tunnel facility have been investigated by Chue et al. [6] using a numerical analysis. Moreover, a numerical study using a finite volume based code was performed by Jacob et al. [7]. In their study, they simulated the shock reflection process in an axi-symmetric shock tube and a high Mach number nozzle using a perfect gas with no boundary layers applied on the shock tube walls. Although, many works were published on the development of shock tubes, it is essential to mention that far too little attention has been paid to the effects of a small area change in the diaphragm section on the transient flow process in a shock tube. The present study involved numerical simulations on the facility with and without area contraction.

2. Two-Dimensional CFD Solver

A two dimensional time accurate Navier-Stokes solver was developed and programmed based on the dimensions and configuration of the test facility which has been recently built at the Universiti Tenaga Nasional (UNITEN) [8]. The solver uses second order accurate cell-vertex finite volume spatial discretization and forth orders accurate Runge-Kutta temporal integration. The current program was developed and validated against exact solution (the Sod's tube problem) and experimental measurements in an earlier work by Al-Falahi et al. [9]. For more details on the solver, refer to References [9, 10].

3. Results and Discussion

The physics of the flow in the shock tube with and without area contraction have been analyzed and presented. In order to study the transient pressure in the facility, two stations have been selected to record and store the data of the interesting parameters as shown in Figure 1.

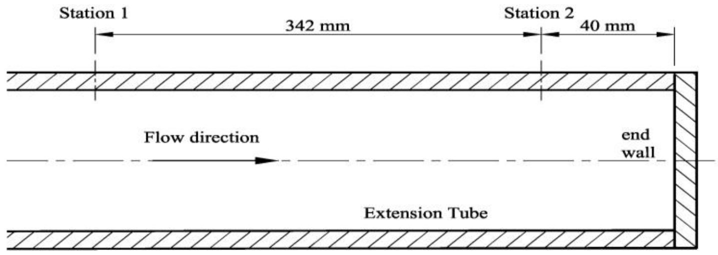
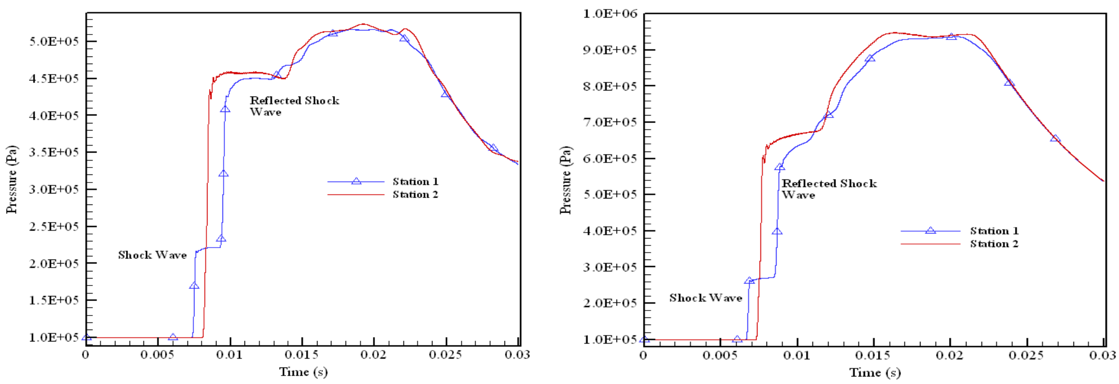


Figure 1. The two stations on the extension tube

3.1. Pressure Transient

The pressure history at station 1 and 2 obtained with area contraction for diaphragm pressure ratio (P_4/P_1) of 10 is plotted in Figure 2(a). From this Figure, it is possible to follow the physics of the flow inside the shock tube. When one traces the pressure history at station 1, the first jump represents the shock wave, while the second jump represents the reflected shock wave. In the first jump, the pressure inside the shock tube increases rapidly from 100 KPa to about 225 KPa. The shock wave compresses and heats the test gas as it is traveling towards the end of the shock tube, and subsequently reflects off at the closed end of the driven section to further compresses the test gas and increases its pressure to around 450 KPa. Following that, the reflected shock wave interacts with the contact surface and this process results in further increase in the pressure until it reaches its maximum value of 520 KPa.

The pressure history at the two stations obtained after removing the bush from the facility is depicted in Figure 2(b). This Figure shows similar trend as for area contraction. The shock wave increases the pressure at station 1 from 100 KPa to around 275 KPa and then reflects and further increases the pressure to 660 KPa. Finally, it interacts with the contact surface to achieve a peak pressure of 800 KPa. It is interesting to note that the shock wave strength, reflected shock strength, and peak pressure are higher than those obtained with area contraction represented earlier.



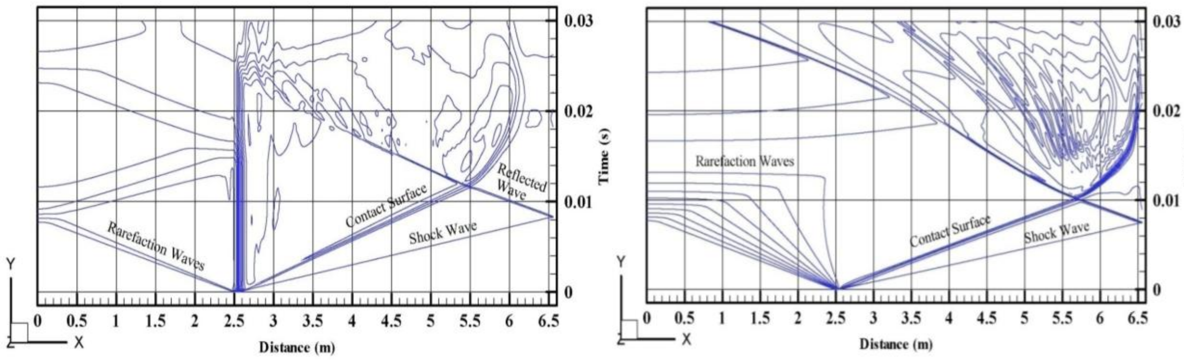
(a) with area contraction (b) without area contraction

Figure 2. Pressure history with and without area contraction (*P_4/P_1=10, Air-Air*)

IOP Conf. Series: Earth and Environmental Science **16** (2013) 012111 doi:10.1088/1755-1315/16/1/012111

3.2. Density Transient

Time-distance diagram is a useful tool used to provide an overall view of the flow process inside the shock tube. Figure 3(a) depicts the x-t diagram for density profile in the facility for shot with area contraction. From this Figure, it can be noted that after diaphragm rupture, a shock wave propagates along the driven section, followed by the contact surface. At the same time, a rarefaction waves are generated and propagate in the compression chamber. Following that, both waves reflect off at the closed ends of the shock tube. The shock interacts with the contact surface. Due to the existence of area contraction in the diaphragm section, the rarefaction wave undergoes another reflection within the driver section of the facility as shown in the same Figure. This process is undesirable since it is useful to examine the flow conditions at the region between the reflected rarefaction wave and the contact surface, which is more commonly known as Region 3.



(a) with area contraction (b) without area contraction

Figure 3. *x-t* diagram for density profile

The x-t diagram for density profile obtained with no area contraction in the diaphragm section is also plotted in Figure 3(b). This shows that removing the bush from the diaphragm section has allowed both reflected waves passing into the other sections of the facility and interacting with each other.

3.3. Shock Wave Mach Number

In order to summarize the effects of area contraction in the diaphragm section on shock Mach number, the obtained values of shock wave Mach number at different operating conditions are gathered in Figure 4. It is shown that higher shock Mach numbers are obtained for shots with no area contraction as the same operating conditions are applied. For example; shock Mach number of 1.6 is obtained for shot with area contraction at diaphragm pressure ratio (P_4/P_1) of 20. While at the same diaphragm pressure ratio, the obtained shock Mach number has increased to about 1.72 when the facility was operated with no contraction. This Figure also shows that the shock wave Mach number has increased by increasing the pressure ratio across the diaphragm.

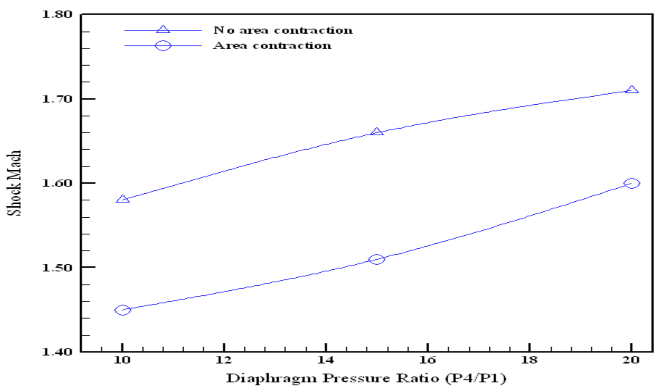


Figure 4. Shock Mach number at different operating conditions

4. Conclusion

The paper reported the flow process inside a short duration high speed flow test facility built at the college of engineering- The Universiti Tenaga Nasional in Malaysia. The effects of area contraction on the facility performance have been investigated numerically. The present code showed good capability of providing the x-t diagram successfully. From this diagram the useful duration or test time can be determined. Results also show that two-dimensional modeling of the high speed flow test facility is an effective way to obtain facility performance data. However, it has been shown that the instantaneous pressure history and shock Mach number are significantly affected by the presence of area contraction in the facility.

References

[1] Lu F K and Wilson D R 1994 Survey of Short Duration, Hypersonic and Hypervelocity Facilities *18th AIAA Aerospace Ground Testing Conference AIAA (Univercity of Texas, Alington)* (vol 94-2491) pp 2-12

[2] Jiang Z and Takayama K 1998 Reflection and Focusing of Toroidal Shock Waves from Coaxial Annular Shock Tubes *J.Computers and Fluids* **27** 553-562

[3] Nagai H, Yang H S, Ueta Y, Murakami M, Takano N and Yanaka K 2001 Application of Super Fluid Shock Tube Facility To Experiments of Highly Transient Low-Temperature Thermo-Fluid Dynamic Phenomena *J.Cryogenics* **41** 421-428

[4] Wilson G J, Sharma S P and Gillespie W D 1993 Time Dependent Simulations of Reflected Shock/Boundary Layer Interaction *Report Number: AIAA 93-0480*

[5] Goozee R J, Jacobs P A and Buttsworth D R 2006 Simulation of a complete reflected shock tunnel showing a vortex mechanism for flow contamination. J.*International Journal of Shock wave* **15(3-4)** 165-176

[6] Chue R S M. and Eitelberg G 1998 Studies of the transient flows in high enthalpy shock tunnels *J.Experiments in fluid* **25** 474-486

[7] Jacob P A 1991 Simulation of transient flow in a shock tunnel and a high mach number nozzle *NASA Contractor Report 187606 ICASE Report* (No. 91-60)

[8] Al-Falahi A, Yusoff M Z and Yusaf T 2008 Development of a Short Duration Hypersonic Test Facility at Universiti Tenaga Nasional *J.Institute of Engineers, Malaysia* **69(1)** 32-38

[9] Al-Falahi A, Yusoff M Z and Yusaf T 2008 Numerical Simulation of Inviscid Transient Flows in Shock Tube and Its Validations *International Journal of Engineering and Natural Sciences* **4** 52-62

[10] Al-Falahi A 2008 *Design, Construction and Performance Evaluation of Short Duration High Speed Flow Test Facility* (Ph.D. thesis, Univesity Tenaga Nasional-Malaysia)