

# **Supersonic Flow: Shock Tube**

ME 83.2

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## **Deviation from Proposed Work**

Several changes in the experimental setup were made from the proposed design. The pipe ends were not flanged but merely connected to floor flanges, and a pipe cap never necessary to use. A small Sears air compressor that could be wheeled around was used instead of the large compressor in the basement since the pressures needed to create a shock wave were less than previously expected (greater than zero psi rather than 28 psi). The quick-release valve was then not needed since the compressor came with one already on the pipeline. The Validyne pressure transducer was replaced by a simple pressure gage that could be screwed into the pipeline.

Shadowgraph imaging was not available due to length of time it took to construct the shock tube and then find a suitable diaphragm. Thus the focus of the lab shifted from visualizing the shock wave as it exited the tube to finding a diaphragm that was both effective and safe.

## **Abstract**

In this project, a simple shock tube was constructed from materials bought at the local plumbing store and found in the fluids laboratory. A shock tube works by raising the pressure on one side of a diaphragm until it ruptures, at which time a shock wave is formed that moves down the remainder of the tube and out the exit.

The shock tube made for this experiment was new and needed to be tested many times. It was checked thoroughly for leaks and any other flaws. A suitable diaphragm needed to be found and many different materials were tested for such. After several test runs it was determined from recorded rupture pressures that clear package tape would make the best diaphragm. Due to the length of time it took for the shock tube to be built and tested, shadowgraph imaging that had been planned to take place did not. Calculations of pressure ratios, mach numbers, and velocities of the shock wave and the air behind it were performed.

## **Introduction**

A shock tube is a relatively simple piece of equipment that can produce a moving shock wave. A large pressure difference is created in the driver section of the tube. This pressure is quickly released when the air ruptures a diaphragm and flows into the lower pressure portion of the tube, called the driven section. Thus a shock wave is produced that moves from ruptured diaphragm down the driven section of the tube and out the exit. Compressible fluid flow effects must be taken into account, of course, when calculating variables such as air velocity and Mach

number of the shock wave. For more information on compressibility effects refer to Lab Number 3 of the Fluids Lab Manual (see Reference 1).

From Table B.2 in Reference 2, if the pressure ratio  $P_2/P_1$  is assumed to be  $P_{\text{driver}}/P_{\text{atm}}$  then it can be seen that a shock wave with Mach number greater than one is produced whenever the driver section pressure is greater than the atmospheric pressure. In other words, any increase in pressure that ruptures the diaphragm of the shock tube will create a moving shock wave. Because of the high pressures that could potentially be attained in this lab, galvanized steel tubes were utilized for safety reasons. As shock waves can be very loud, ear protection was also necessary.

Supersonic flow forms differently around certain geometries than does subsonic flow. In subsonic flow, pressure waves must be sent upstream by an obstruction. These pressure waves influence the flow thus changing its course so that it may more easily pass around the object. Pressure waves travel at the speed of sound, so in supersonic flow pressure waves cannot travel upstream. In supersonic flow, the fluid strikes the obstruction and depending on its geometry, different shock waves are formed around the leading point or edge (see Reference 3). Thus data obtained from shock tube experiments can be useful to engineers involved with rockets and supersonic aircraft, such as the space shuttle, since they need to know how shock waves form around moving vehicles, say, in re-entry to the earth's atmosphere.

### **Objectives**

- Design and build a shock tube that is safe and cost efficient.
- Run various diaphragm materials to failure and determine which will create an optimum shock wave and maintain safety at the same time.
- Use experimentally measured static pressures to calculate the Mach number and various other aspects of the flow field.

### **Experimental Setup**

The shock tube was easily built using some inexpensive supplies from a local plumbing store as well as resources and equipment from the undergraduate fluids laboratory. Purchased equipment included the following:

- 2 twelve-inch sections and 1 two-inch section of one-inch diameter black steel pipe
- 2 one-inch diameter pipe galvanized steel floor flanges with screw holes

- 4 nuts, bolts, and washers
- 1 one-inch diameter black steel pipe T-section
- 1 quarter-inch screw pressure gage (0 to 100 psi)
- 1 quarter-inch to one-inch diameter pipe adapter
- 1 quarter-inch diameter female to one-inch diameter male pipe adapter (consists of one-inch female adapter, quarter to half-inch adapter, and half to one-inch adapter)
- Pipe sealant
- 2 one-inch diameter pipe brackets and screws
- 1 sheet of gasket material

Equipment available in the fluids laboratory included:

- Wooden boards
- Large C-clamps
- Air compressor with quarter-inch hose connection
- Various plastic and foil diaphragm materials
- Screwdrivers, hammers, pliers, wrenches and other necessary tools.

In assembling the shock tube, the following steps were performed:

- \* Pipe sealant was used in every pipe connection made in this assembly procedure.
1. The opposing ends of the T-section were connected to one of the twelve-inch sections of pipe and the two-inch section. The one to quarter inch adapter was screwed into the remaining opening of the T-section and the pressure gage inserted into its other end. One flange was then secured onto the free end of the two-inch pipe. This step completed the assembly of the driver section of the shock tube.
  2. The shape of the other flange was traced onto the sheet of gasket material and cut out with scissors and hole puncher.
  3. This free flange was then connected to one end of the so far unused twelve-inch pipe. This step completed the assembly of the driven section of the shock tube.
  4. The gasket was placed on the driver section flange and the diaphragm to be tested on the driven section. The two flanges were then put together and *tightly* secured so as to prevent high pressure air leaking using the four nuts, bolts, and washers.

5. The shock tube was then tightly secured to a wooden board using the two pipe brackets and screws. This board was latched onto a sturdy table in the fluids laboratory using the large C-clamps provided by the TA.
6. The remaining quarter-inch to one-inch pipe adapter was screwed onto the free end of the driver section. The compressor hose was then tightened onto this open end and the shock tube was ready for experimentation.

See Figure 1 below for a simple visual schematic of the shock tube setup. Figures 2 and 3 are also included for visual aid in constructing the shock tube.

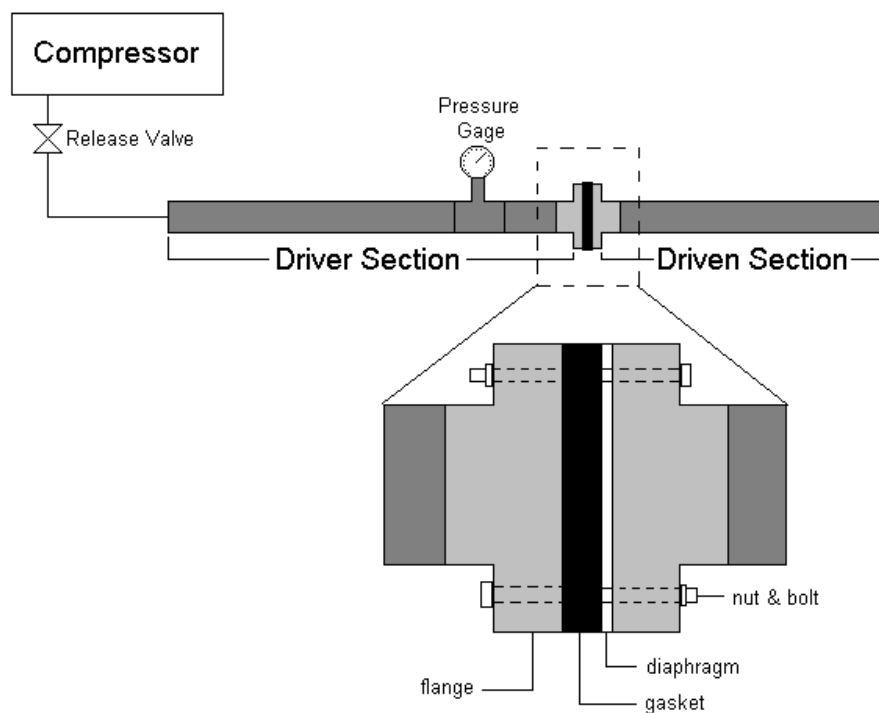


Figure 1: Experimental setup of the shock tube.



Figure 2: Experimental setup in fluids laboratory.



Figure 3: Close-up view of pipe connections.

Some of the various diaphragms that were tested include overhead transparencies, Student Bookstore bags, Ziplock bags, aluminum foil, plastic packaging wrap, Fig Newtons wrapper, and clear package tape. Ear protection was required during all experimentation and was found in the laboratory.

### **Procedure**

1. Assemble shock tube as described above in the experimental setup.
2. If not already done, insert the diaphragm to be tested between the driver and driven sections. Secure the flange connections tightly.
3. Everyone should have ear protection on from this point forward. NO EXCEPTIONS!
4. The professor or TA must be present for all test runs of the shock tube. If they are not present, YOU MUST GO FIND THEM!
5. Check that the supply valve on the compressor is in the closed position. Turn the compressor on.
6. Open compressor valve slowly and only a small amount. Listen for leaks in the driver section of the apparatus. If leaks are found, turn off pressure supply and recheck and/or reseal connections.
7. Open the compressor valve more and observe the pressure gage as pressure in the driver section rises. Note: The pressure will tend to rise quickly once it starts.
8. The diaphragm should rupture soon after the pressure begins to rise. Record the pressure at which the failure occurred. If it for some reason the diaphragm does not rupture and

the pressure exceeds 50 psi, TURN OFF THE COMPRESSOR! There is no need to produce a shock wave that could injure someone or destruct something in the room.

- Repeat steps 2-9 for different diaphragm materials. Make sure to record the pressure of diaphragm rupture for each material. Also, be sure to keep all tested diaphragms for visual analysis later on.

## Results

Table 1: Properties of the flow field at diaphragm rupture

Material	Rupture Pressure	Pressure Ratio	Mach Number	Shock Wave Velocity	Air Velocity behind Shock
Overhead Sheet	> 90 psi	---	---	---	---
Ziplock Bag	7 psi	1.476	1.19	413 m/s	101 m/s
Aluminum Foil	12 psi	1.819	1.30	451 m/s	154 m/s
SBS Bag	10 psi	1.683	1.26	437 m/s	135 m/s
Plastic Wrap	15 psi	2.024	1.37	475 m/s	185 m/s
Fig Newtons Wrapper	> 50 psi	---	---	---	---
Package Tape	30 psi	3.048	1.66	576 m/s	306 m/s

Sample Calculations:

$$1 \text{ atm} = 14.70 \text{ psi}$$

$$\frac{P_2}{P_1} = \frac{P_{\text{rupture}} + P_{\text{atm}}}{P_{\text{atm}}} = \frac{7 \text{ psi} + 14.70 \text{ psi}}{14.70 \text{ psi}} = 1.476$$

Mach number comes from normal shock tables (see Reference 4).

$$M = \frac{V}{a} = \frac{V}{\sqrt{\gamma RT}} \Rightarrow V = M\sqrt{\gamma RT} = (1.19)\sqrt{(1.4)(287 \text{ J/kg} \cdot \text{K})(300 \text{ K})} = 413 \text{ m/s}$$

Density ratio comes from normal shock tables (see Reference 4).

$$\frac{\rho_2}{\rho_1} = \frac{V_s}{V_s - V_g} \Rightarrow V_g = V_s \left( 1 - \frac{\rho_1}{\rho_2} \right) = (413 \text{ m/s}) \left( 1 - \frac{1}{1.342} \right) = 101 \text{ m/s}$$

## **Discussion and Conclusions**

When the experimenters began this lab, the purpose was to take shadowgraph images of the shockwave created in a shock tube. In the course of designing and constructing the shock tube, it was discovered that finding a suitable material to use as the diaphragm was quite a challenge. The construction took too long to be able to use the shadowgraph equipment, so the focus of the experiment shifted from producing shadowgraphs of the shockwave to constructing a shock tube with a suitable diaphragm material.

The original concept for the diaphragm was a piece of overhead transparency plastic. The experimenters wanted to achieve a pressure of near 30 psi in the shock tube before the diaphragm burst. The overhead transparency reached a pressure of 90 psi, and still had not burst so the experiment was stopped. A new piece of transparency was scored in the middle so lower the required yielding pressure, but this transparency also did not burst under 90 psi. At this point, the experimenters decided that a new material for the diaphragm needed to be used.

Various materials were used in the search for a better diaphragm. These materials and the pressure at which they ruptured can be found in Table 1 above. The best options from the materials tried were the Fig Newtons wrapper and the package tape. It was estimated that the Newtons wrapper would have ruptured shortly after 50 psi, judging from the deformation of the wrapper when it was removed from the shock tube, but the experiment was cut off at 50 psi for safety reasons. The best material to use for the diaphragm, therefore, was the packaging tape. This tape ruptured at roughly 30 psi, which was the desired pressure at the outset of the experiment.

Despite not being able to complete the shadowgraph images of the shockwaves leaving the tube, calculations were performed to estimate velocities of the air behind the shock wave and of the shock wave itself. These values are tabulated in Table 1 above. It should be noted that the air coming out the tube exit is not the velocity recorded above due to drag effects of the air present in the driven section of the pipe prior to the occurrence of the shock. The velocity of the air at the tube exit is thus significantly reduced. The velocity reported in Table 1 above is actually the instantaneous velocity of the shock and air at the time of diaphragm rupture.

As explained earlier, shadowgraph imaging did not become available for use in the time frame of this lab. However, below is a description of how such a process was planned to and could be carried out. Perhaps future lab groups will have the time to gather visual images of the

moving shock waves produced by the shock tube. For information on shadowgraph imaging techniques refer to Lab Number 3 of the Fluids Lab Manual (see Reference 1).

For future experimentation, objects of varying geometries such as cones, wedges, and spheres could be placed in the supersonic flow field at the exit of the shock tube. Shadowgraph imaging system could be used to visualize the pattern that the moving shock waves create around the specified objects. These images of supersonic flow fields around different objects could then be compared and analyzed and the effect of shock waves on rockets and supersonic aircraft potentially determined. Figure 4 below is a sample of what the flow field probably would have looked like at the exit of the shock tube if shadowgraph imaging had been available. Note that the bottom frame appears to show the formation of a mushroom cloud. For comparison, see the photo of a mushroom cloud in Figure 5.

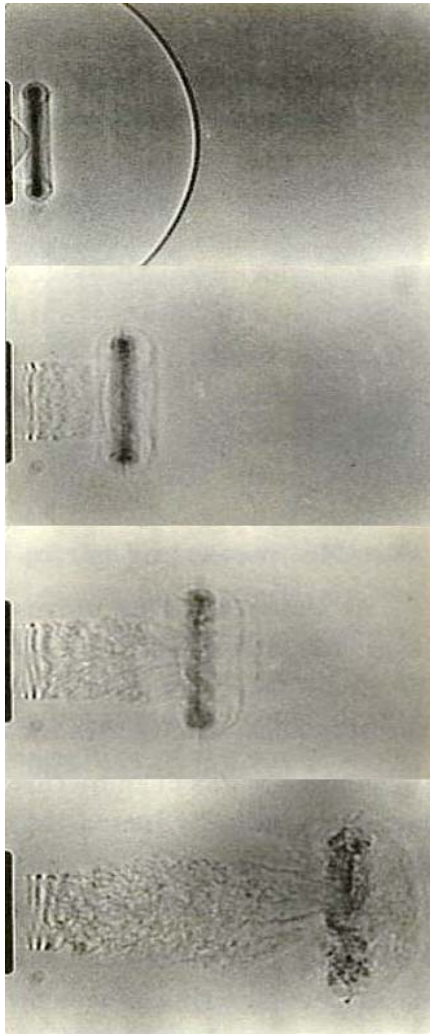


Figure 4: Shock wave and trailing air exiting tube (provided by Dr. Settles)

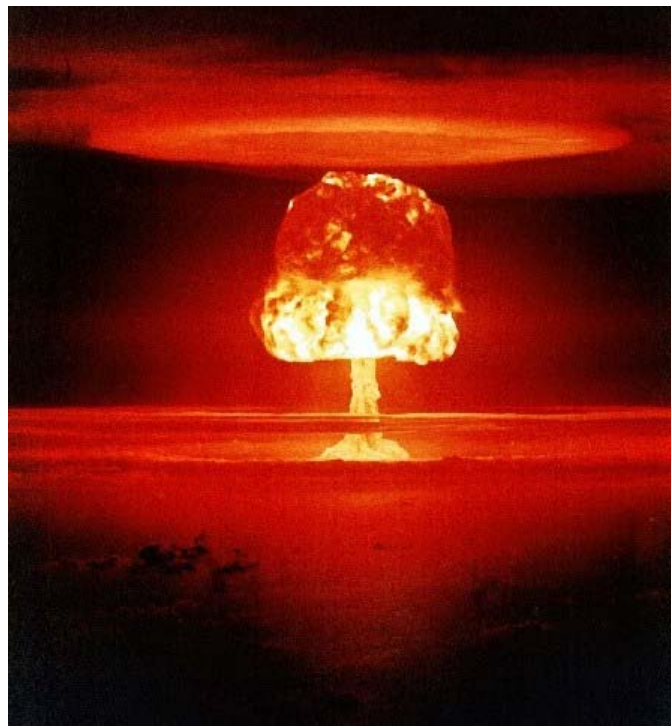


Figure 5: Photo of an actual mushroom cloud (internet picture)

## **References**

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2. White, F. M. *Fluid Mechanics*, Ed. 2. New York: McGraw-Hill, 1986. Appendix B.
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4. John, James E. A. *Gas Dynamics*. Boston: Allyn and Bacon, Inc, 1984. Appendix B.