# Shockwave Generator using Cavities

1st Shashank Pal
*MME Department*

2nd Sujal Kumar
*MME Department*

3rd Saurabh Gupta
*MME Department*

4th Md Adnaan
*Mining Department*

5th Gopavaram Chakradhar
*Mechanical Department*

6th Uddipan Pathak
*Mechanical Department*

***Abstract*—This study investigates the impact of cavity geometry on shockwave generation and propagation in a supersonic flow. Shockwaves are compression waves that carry immense pressure, temperature, and momentum gradients, typically forming when a source imparts energy to a medium at a speed faster than the speed of sound. Various cavity shapes, including semicircular, elliptical, rectangular, triangular, and combinations thereof, are examined to understand their influence on peak pressure and amplification factors.Computational simulations are conducted using ANSYS Fluent 2023 R2. Results reveal that different cavity geometries lead to variations in peak pressure and amplification factors, with the semicircular cavity demonstrating the highest amplification. This research highlights the significance of cavity geometry in shockwave generation and suggests potential avenues for further investigation, including exploring additional parameters such as cavity dimensions and orientation using advanced computational and machine learning techniques.**

## I. Introduction

A shock front is a compression wave in supersonic flows that affects the flow properties across upstream and downstream locations.Typically, shock is a region where immense pressure, temperature, and momentum gradients occur. The presence of any obstacle in the supersonic flow-field creates oblique shock, strength of which is dependent upon the local Mach number and the ramp angle.These generators harness the energy released within cavities to produce high-pressure shock waves that propagate through surrounding mediums. The principles behind shock wave generation using cavities involve the rapid release of energy, leading to compression waves with immense pressure gradients.A shock wave is a type of propagating disturbance that carries energy through a medium. It is characterized by a rapid increase in pressure, temperature, and density within a very short distance. Shock waves are typically generated when a source imparts energy to a surrounding medium at a speed faster than the speed of sound in that medium. This sudden release of energy creates a compression wave that moves through the medium.

## II. Governing Differential Equations

We analyzed the shock tube problem in 2D with the help of commercial software ANSYS. The following sections describe the governing differential equations solved in ANSYS .

*1) Mass flux:* From the conservation of the mass the mass flow rate across the shock remains constant.

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} = 0$$

### A. Momentum flux

From conservation of momentum the momentum flux of the flow folows

$$\frac{\partial (\rho u)}{\partial t} + \frac{\partial}{\partial x}(\rho u^2 + p) = 0$$

### B. Energy Flux

The component of the energy flux into and out of either side of the shock is

$$\frac{\partial (\rho E)}{\partial t} + \frac{\partial}{\partial x}[(\rho E + p)u] = 0$$

### C. Nomenclature

$\rho$ = Density

$p$ = Pressure

$u$ = Velocity component

$t$ = Time

$x$ = Coordinate

$E$ = Energy

## III. Literature review

There has been significant research and development in the field of shock wave generators. Keep in mind that technological advancements are continuous, and there may have been further progress since then. Here are some key aspects of existing research and technology related to shock wave generators:

### A. Scientific Research:

High-Pressure Physics: Shock wave generators are essential tools for studying materials under extreme pressure conditions, providing insights into the behavior of matter in high-pressure environments.

### B. Shock Tube Experiments:

Shock tubes are widely used in aerodynamics, combustion studies, and fluid dynamics, allowing researchers to simulate and study high-speed gas flows.

The ongoing research in these areas reflects the diverse applications and the continuous effort to optimize shock wave generation techniques for various purposes. Advancements in technology and a deeper understanding of shock wave physics are likely to lead to further innovations in the future.

## IV. Methods

### A. Geometry and Mesh:

We used the Ansys Design Modeler to create the geometry of shocktube with dimensions of 1000 mmx60 mm. The dimensions of the cavities are as shown in Table 1. The mesh grid(discretization of geometry) is generated with Ansys Mesh. Edge sizing and Face meshing techniques are used to mesh the geometry.

TABLE I
Dimensions of Different Cavity Shapes

| Cavity Shape | Dimensions |
|---|---|
| Rectangular | $50 \times 25$ mm |
| Elliptical | Major axis: 50 mm, Minor axis: 30 mm |
| Equivalent Triangular | Side length: 50 mm |
| Semi-circular | Radius: 25 mm |

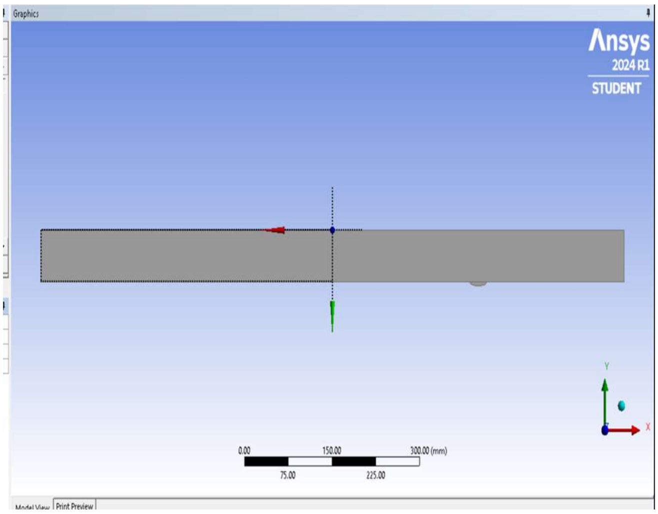


Fig. 1. Enter Caption

### B. Setup condition:

The geometry divided into three parts driver section, driven section and cavity section. 1D unsteady compressible flow and Reynolds averaged Navier-Stokes (RANS) equations have been solved using the commercial software ANSYS fluent 2023 R2. A density-based solver is used to solve the governing differential equations (mass, momentum and energy) in a coupled manner, and the ideal gas equation is used as the state equation. The cell center values are extrapolated to the face center using second order upwind scheme. The gradients at the cell center are computed using the least square method. The fluxes at the faces are calculated using the Roe-Flux difference splitting method. Turbulence modelling has been done using the inviscid model. The working medium is chosen to be air. The boundary conditions for driver section pressure is 500,000 Pa and driven section pressure is 101,325 Pa.

TABLE II
Computational Details

| Category | Details |
|---|---|
| Flux Discretization | Roe-FDS |
| Spatial Discretization | Second order |
| Turbulence Model | Inviscid |
| Working Medium | Air |
| Density Change | Ideal gas equation |

### C. Post-processing:

We extracted the transient pressure data at 5 different points in driven section which are at 300mm, 350mm, 400mm, 450mm, 499mm from the diaphgram for each cavity model. As the test section is at the end of driven section we mainly focused at the 499mm. The pressure contour of semi-circular cavity shocktube is shown in Fig-2.

## V. Results

Data is extracted from all the models with different cavities. We also plotted graphs with time step on x axis and pressure

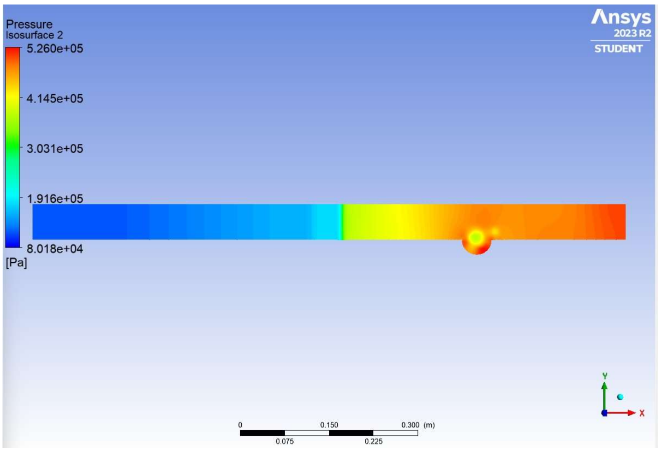


Fig. 2. Pressure contour at 458th time step

on y axis. Pressure distribution along the length of the cavity was measured during shockwave generation at various time intervals.

### *A. Comparison between the pressures obtained at different points in the same geometry:*

We observed that the pressure started to increase as we move from 300 to 499. In semicircular cavity we observed that at 300 the peak pressure didn't reach 500000Pa which is the initial given pressure but as we progress from 300 to 350 we notice that there is a change in peak pressure which is nearly equal to 500000Pa . When we reached 400 the pressure exceeded beyond the initial pressure given and as we move towards the point 499 the peak pressure increased to 514915.90625Pa which is the amplified pressure achieved due to the generation of shockwave.

Whereas in the geometry containing rectangular cavity, given 500000Pa is nearly achieved at point 350 but after 350 there is a gradual amplification in pressure and the final peak value of 511196.28125 is achieved at point 499. For elliptical cavity we observe that the initial pressure is reached at point 300 but as we progress we observe that there is no remarkable changes in peak pressure and finally at point 499 the peak pressure achieved is 504626.28125

The similar and slow amplification is found in both triangular and the geometry containing two semicircular cavities reaching the peak pressure of 503217.9063 and 500539.125 respectively.

### *B. Comparison between the peak pressure values achieved from different geometries:*

Peak pressure is identified in all the models, we observed the following peak pressures for given geometry:

The transient data of pressure vs time steps at a distance of 499mm from diaphragm are shown in Fig-3, Fig-4, Fig-5, Fig-6, Fig-7 for different cavities We find the amplification factor using the following formula:

Amplification factor= (peak pressure observed) / (pressure given)

TABLE III
PEAK PRESSURE

| Geometry of the cavity | Peak pressure at 499mm |
|---|---|
| Tube with no cavity | 495192.15625 |
| Ellipse | 504626.28125 |
| Semicircular | 514915.90625 |
| Rectangular | 511196.28125 |
| Triangular | 503217.9063 |
| Two semicircles | 500539.125 |

TABLE IV
AMPLIFICATION FACTORS FOR DIFFERENT CAVITIES

| Geometry | Amplification Factor |
|---|---|
| No cavity | 0.9903 |
| Ellipse | 1.00925 |
| Semicircular | 1.0298 |
| Rectangular cavity | 1.02239 |
| Triangular cavity | 1.006435 |
| Two semicircular cavities | 1.00107 |

Here, we find that there is no amplification in the pressure when there is no cavity and also observed that when compared among all other geometries chosen the amplification factor is high for the geometry containing semicircular cavity.

## VI. CONCLUSION

### *A. Effect of Cavity Geometry on Shockwave Generation:*

The investigation revealed that the choice of cavity geometry significantly impacts the generation and propagation of shockwaves such that we obtain the pressure greater than the initial driver pressure. Different cavity shapes, such as semicircular, elliptical, triangular, and rectangular, led to variations in peak pressure and amplification factors.

### *B. Amplification Factor and Peak Pressure:*

Analysis of the experimental data showed that the presence of cavities resulted in the amplification of pressure waves compared to scenarios with no cavity. The amplification factor varied across different geometries, with the semicircular cavity exhibiting the highest amplification factor among all cavities.

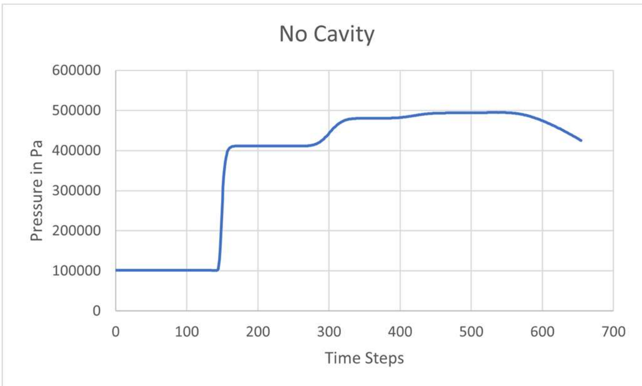


Fig. 3. No cavity at point 499mm

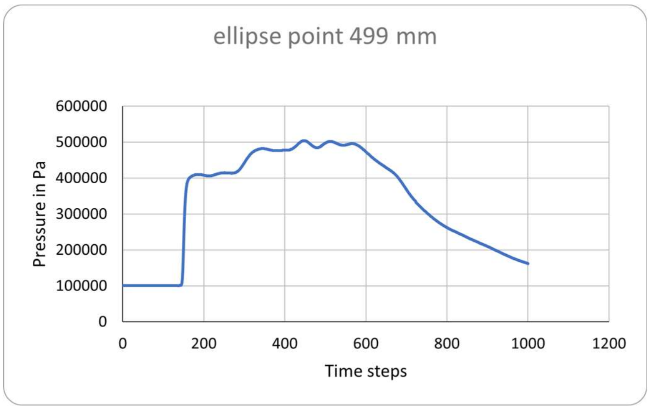


Fig. 4. Elliptical cavity at point 499mm

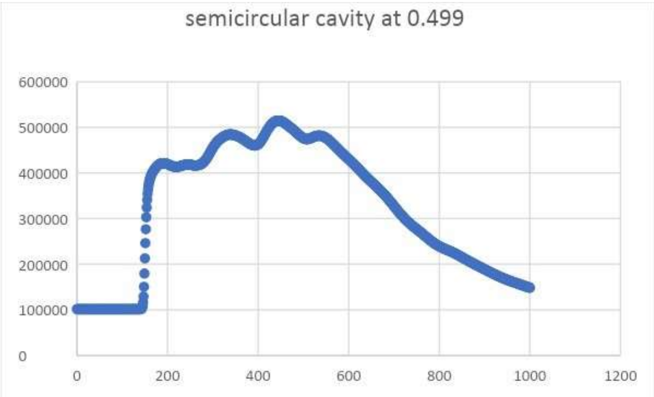


Fig. 5. Semicircular cavity at point 499mm

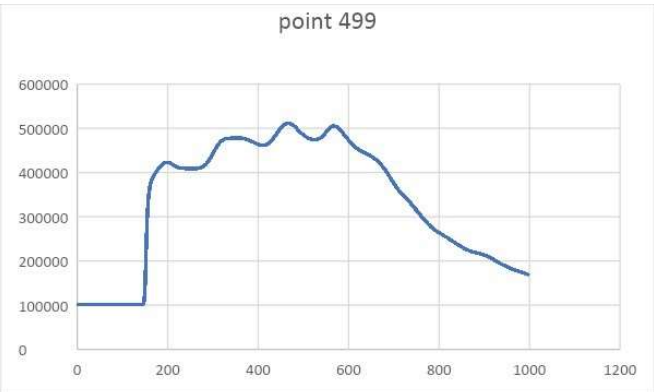


Fig. 6. Rectangular cavity at point 499mm


Fig. 7. Triangular cavity at point 499mm

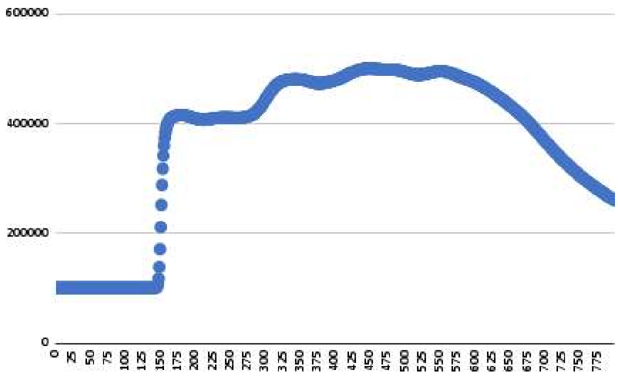


Fig. 8. Two semicircular cavities at point 499mm

## C. Future Open Challenges:

While this study focused on specific cavity geometries, future research could explore additional parameters such as cavity dimensions, and orientation to gain more insights of shockwaves. Furthermore, we can utilise Machine Learning models to predict the peak pressure and amplification factor of different geometries.