Converging shock calculations and experimental comparisons

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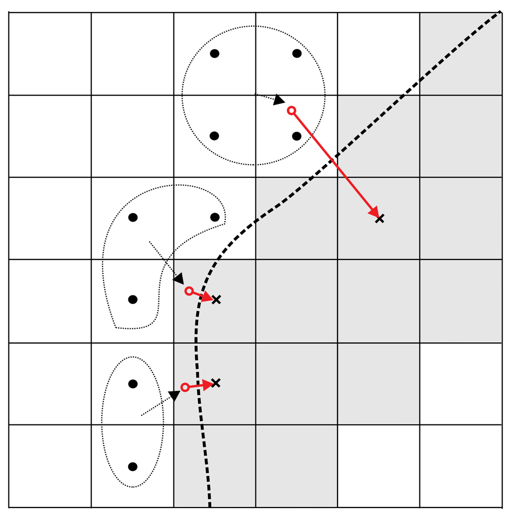
VTF and GFM: Complex boundaries

The design of the Virtual Test Facility (VTF) employs the Ghost Fluid Method (GFM) as a representation of complex boundaries while still computing on regular Cartesian meshes. This approach is used in coupling to either dynamic solids or static boundaries.

- Based on level set that represents distance
- Level set results from Closest Point Transform (CPT) or analytic function supplied by the user at compile time.
- A mirror image of each ghost cell is located in the fluid and appropriate interpolations are used to find the local fluid state.
- A reflection principle is then used to fill ghost cells prior to each timestep

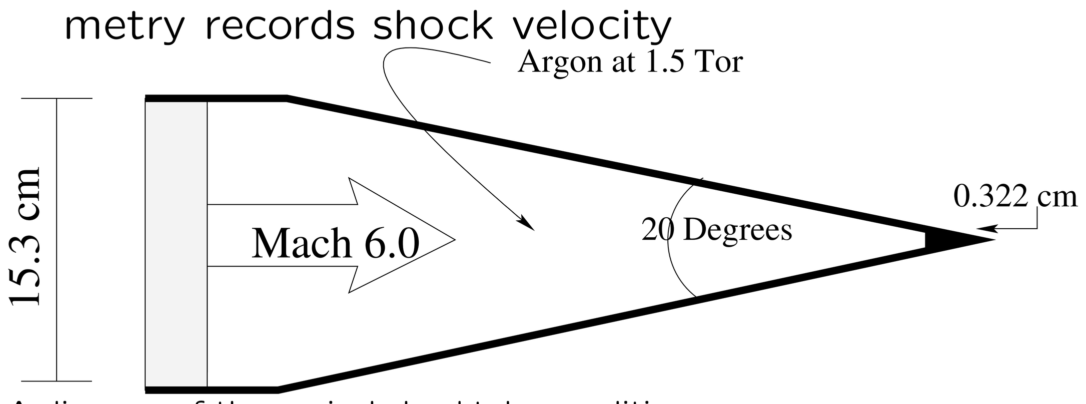


Ghost cell setting in an embedded boundary method for fluid F_i with prescribed velocity derived from a node-centered solid dynamics calculation. Remaining values mirrored.

Strong Shocks in a Conical Shocktube

We have chosen the data from the experimental investigation of shock strengthening a conical convergent channel (Setchell, Strom, Sturtevant, JFM 1972) as a means of code validation. Correct simulation of the structure of the shock, reflected shocks, and Mach stem are crucial for good agreement.

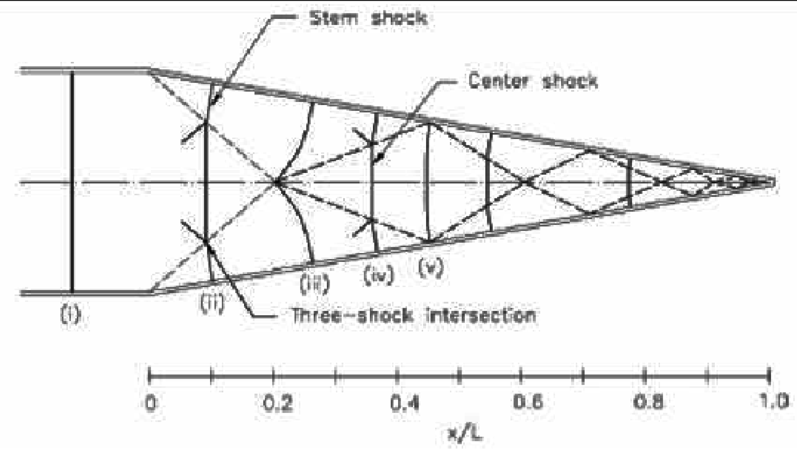
- Mach 6 shock propagates down a 15.3cm diameter shocktube into a cone with half-angle of 10.17^o
- Argon gas is used: $\gamma = 5/3$, molecular weight 39.95
- To achieve a Mach 6 shock, the test section is at 1.5Torr
- A probe (diameter 3.2mm) along the axis of symmetry records shock velocity



A diagram of the conical shocktube conditions

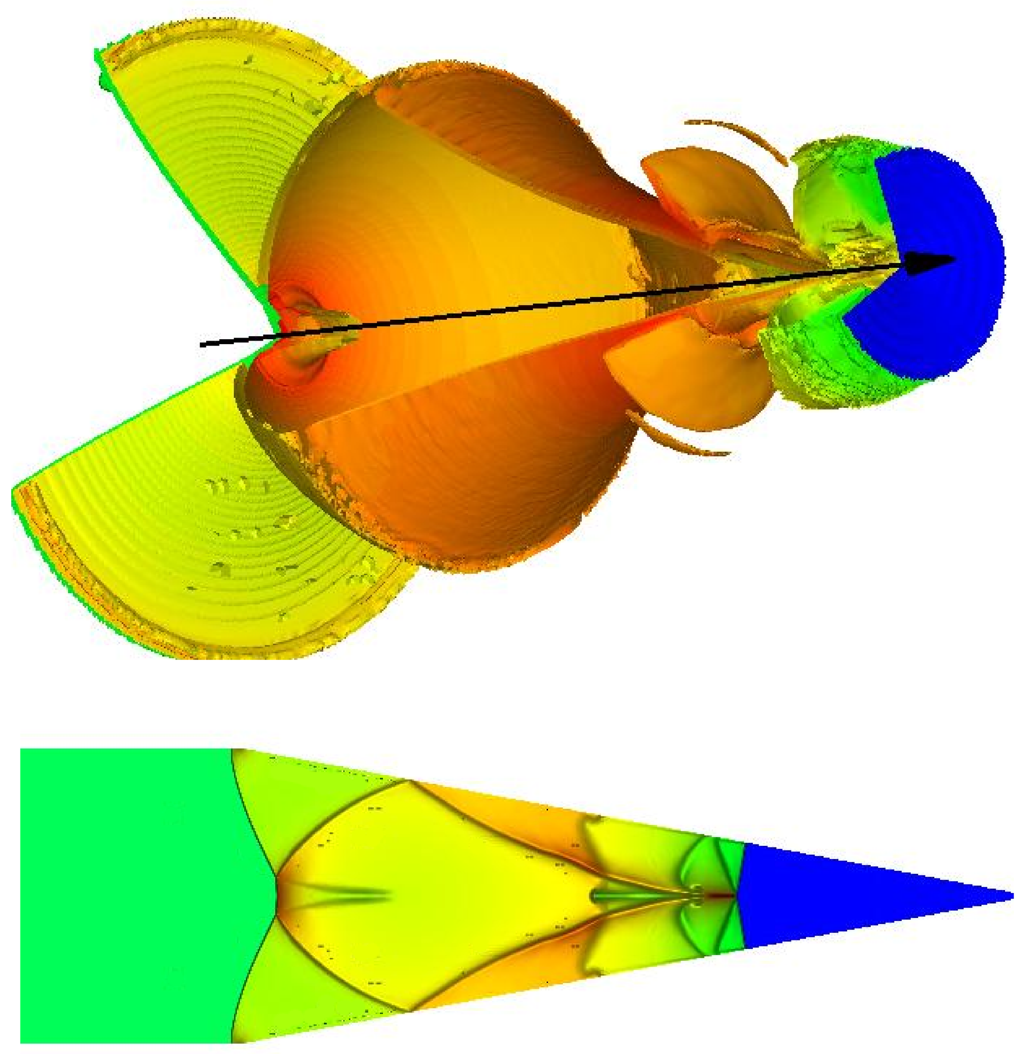
A shock wave propagating into a gradually converging channel experiences a progressive strengthening. For this experiment the geometric information is communicated by the reflected shocks and the triple points. Jumps in the (measured) centerline shock velocity correspond to the arrival of the triple-points at the cone center-line.

Simulation and Validation using GFM



Diffraction of the incident shockwave from SSS JFM '72

To best exercise different aspects of the VTF with the GFM, the AMR simulations of this geometry were conducted with both a fully three-dimensional code and with two-dimensional code.

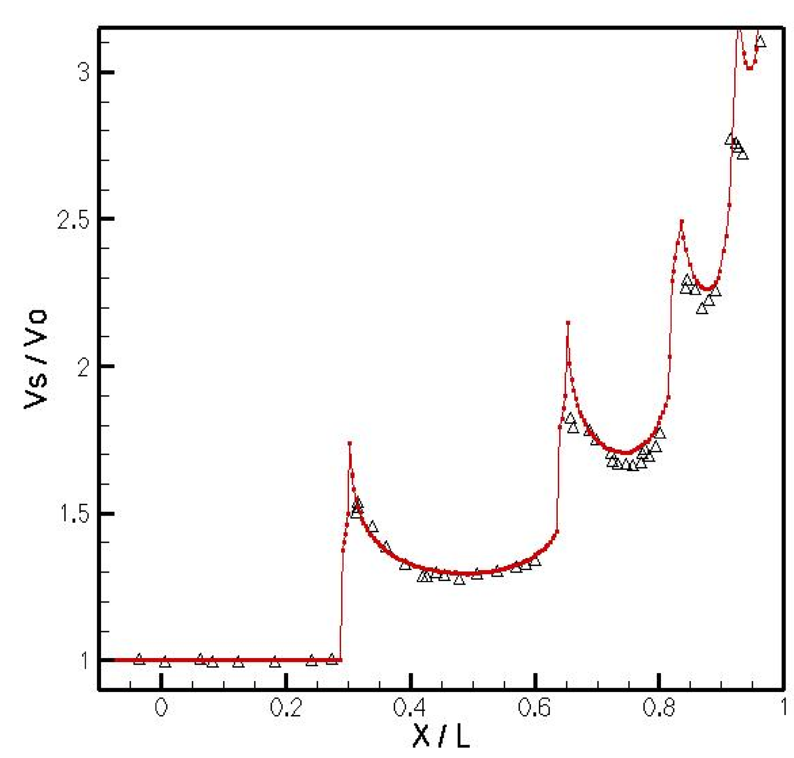


3D and 2D axi-symmetric simulations. The focusing shock and reflected shocks at time $t = 0.0016$ as the shock travels down the conical tube (towards the observer in the 3D case). Simulation done with 3 Levels of refinement and an effective resolution of $744x240^2$ and $1488x480$

In the two-dimensional code, a source term was required to convert a Cartesian 2D solver to an axi-symmetric cylindrical solver.

$$\frac{\partial}{\partial t}\begin{pmatrix}\rho\\ \rho u\\ \rho v\\ E\end{pmatrix}+\frac{\partial}{\partial r}\begin{pmatrix}\rho u\\ \rho u^2+P\\ \rho uv\\ u(E+P)\end{pmatrix}+\frac{\partial}{\partial z}\begin{pmatrix}\rho v\\ \rho uv\\ \rho v^2+P\\ v(E+P)\end{pmatrix}=-\frac{1}{r}\begin{pmatrix}\rho u\\ \rho u^2\\ \rho uv\\ u(E+P)\end{pmatrix}$$

Comparison with experiment



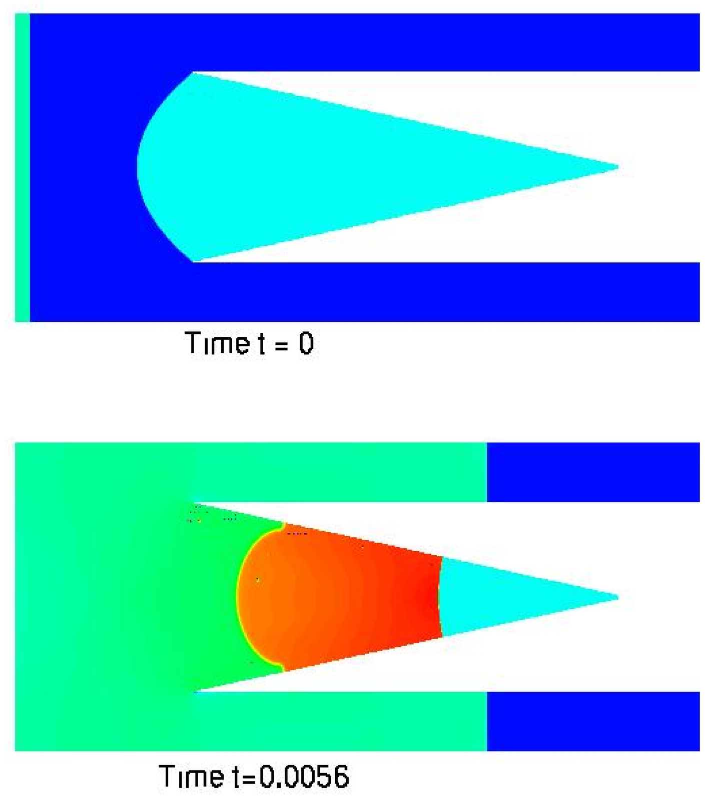
Computed centerline shock speed in red and triangles represent the experimental data from SSS JFM '72. Agreement is seen to be very good although real gas effects not accounted for in the simulation may explain discrepancies near the apex

Shock Focusing by a Wedge

The Caltech ASC center validation experiment of shock focusing is divided into three phases, all use the geometry of a adjustable wedge as a focusing device affixed to the 17inch Galcit shock-tube.

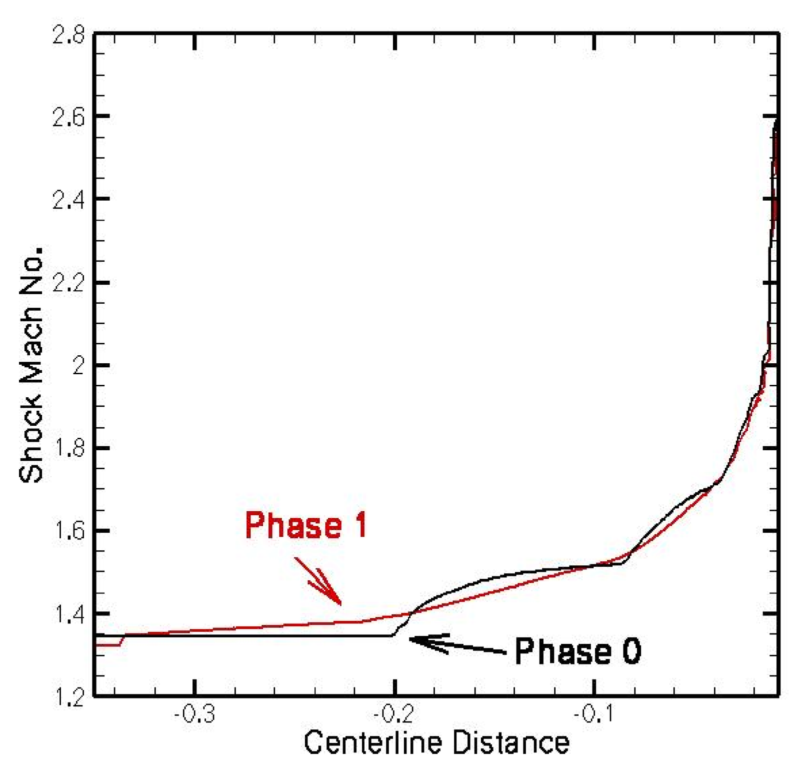
- Phase 0: a planar shock in a single gas focused by the wedge
- Phase 1: a planar shock converted to an angle of a imploding cylindrical shock by a gas lens
- Phase 2: the interaction of the imploding cylindrical shock with a contact

Here we explore the relation between the Phase 0 and Phase 1 experiments. In particular, we compare the shock speed along the centerline for the two cases. The Phase 0 configuration will produce triple points just as the conical experiment did, and the affect of these triple points will be seen in the centerline shock velocity.



A Phase 1 simulation. The incident Mach number is 1.3122 and the two gases are related by a density ratio $\rho_{lens}/\rho_{driver} = 1.4$. The lens gas has a ratio of specific heats $\gamma = 1.4$ and the driver gas has $\gamma = 1.5$ and the wedge angle is 23.234^o

The simulations of the two experiments were related by using the same geometry, using the $\gamma = 1.4$ gas in the Phase 0 simulation, and by matching the initial shock speed in the Phase 0 simulation with the shock speed transmitted into the lensing gas in Phase 1. The shock speeds were then measured along the centerline of the wedge.



The smooth circular shock produced by the Phase 1 geometry focuses smoothly as it accelerates into the wedge, while the Phase 0 shock uses triple point reflection to focus as can be seen by the jumps in centerline shock speed.