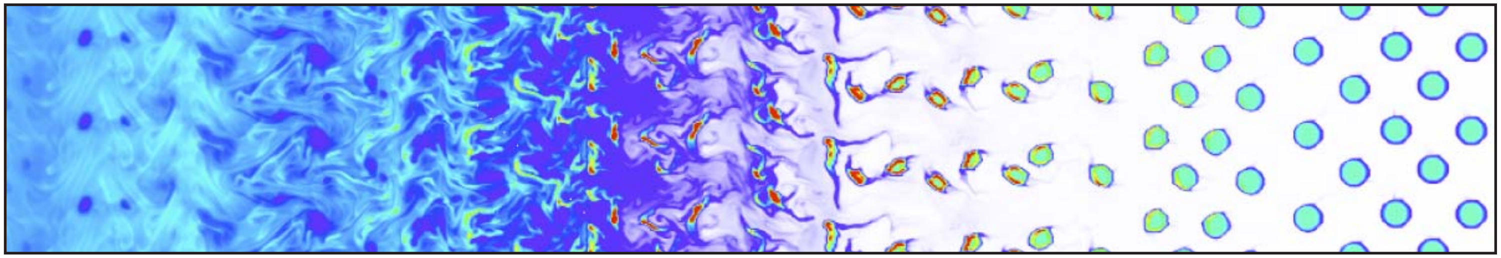
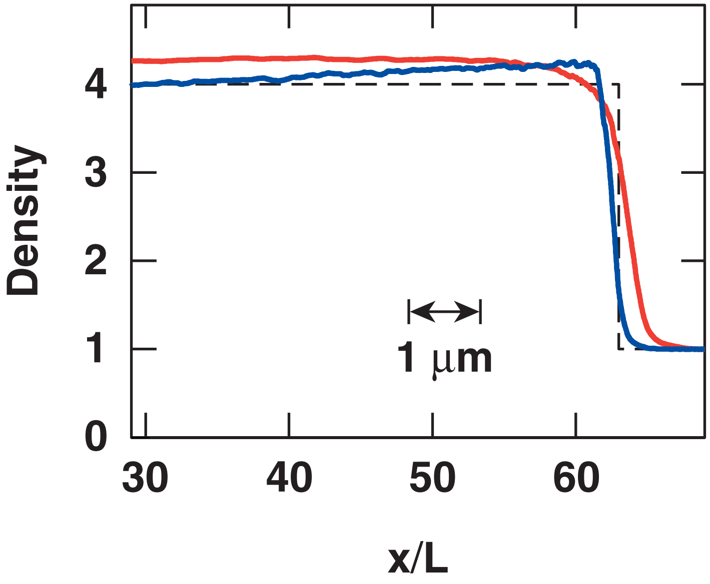
The Role of Viscosity in Simulations of Strong Shocks in Low-Density Foams





- Viscous flows satisfy the Rankine–Hugoniot condition.

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Summary

2-D simulations of strong planar shocks in viscous low-density foams satisfy the Rankine–Hugoniot condition

- Nonviscous 2-D simulations* show deviations from the Rankine–Hugoniot condition.
- These deviations are explained by a slowly decaying 2-D turbulence in the post-shock region.
- Estimated viscosity in ICF foams provides quick dissipation of the post-shock turbulence.
- Low-density foams in ICF shock experiments can be treated as a uniform medium with the equivalent average density.

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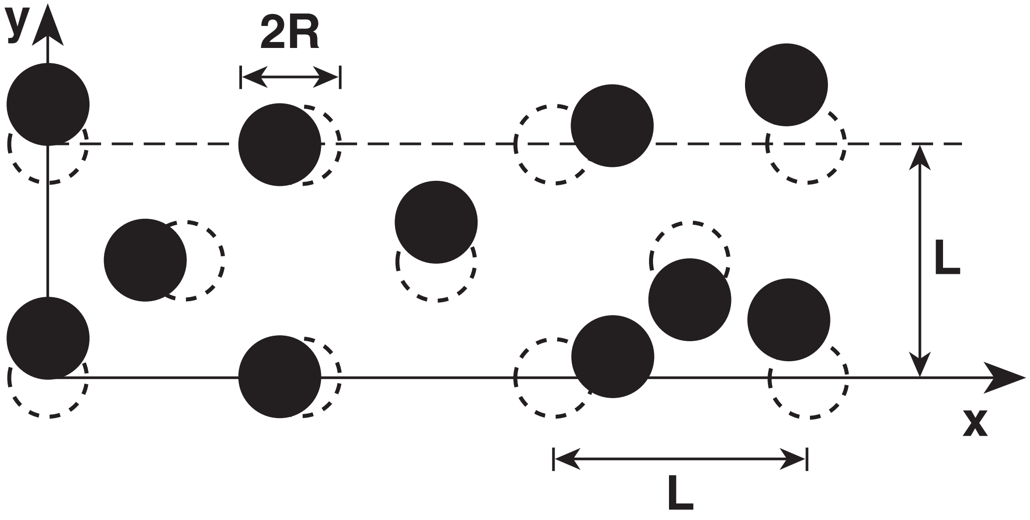
*Kotelnikov and Montgomery (1998); Hazak *et al*., (1998); Phillippe *et al*. (2004).

An idealized 2-D model of low-density foams is used in simulations

Quasi-random foam structures



Dimensionless parameters:

$$\frac{R}{L} \text{ and } \frac{\rho_{\text{fiber}}}{\rho_{\text{i-fiber}}}$$

Dimension parameters:

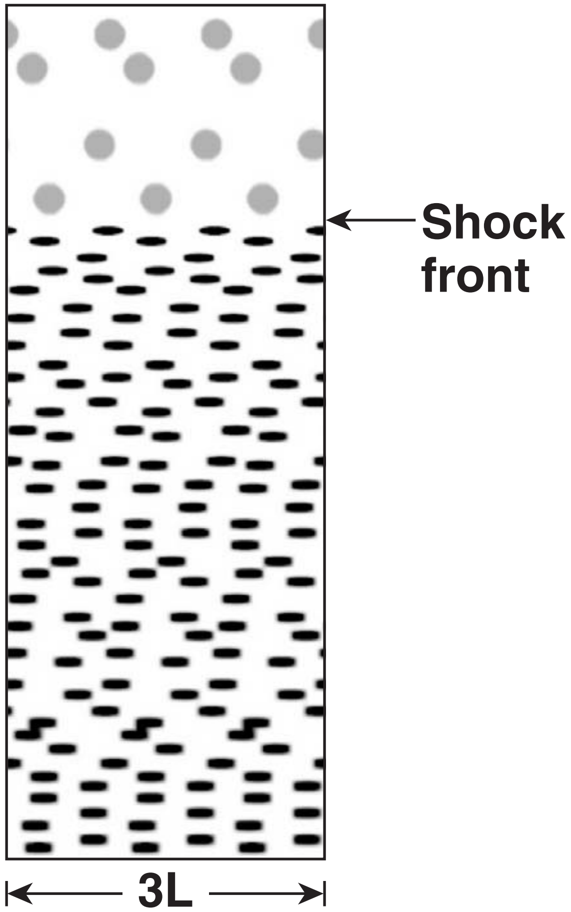
$L = 0.2\ \mu m$

$u_0 = 5 \times 10^6$ cm/s

Simulations were performed using the 2-D Eulerian PPM code

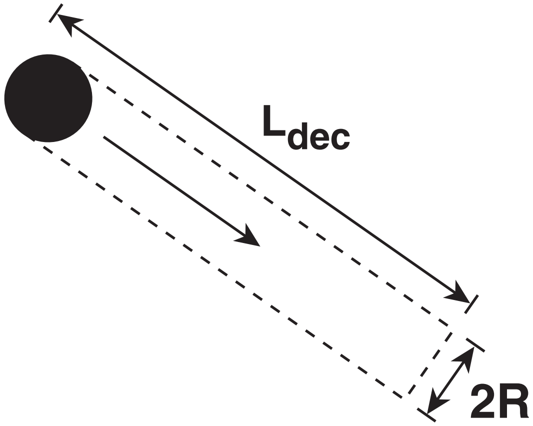
- We solve the system of Navier–Stokes equations
- Explicit/implicit solver for the viscous part
- Multifluid capability (two fluids used).
- Ideal gas equation of state
- 2-D uniform cartesian grid; domain dimension: 1 L × 100 L (100 × 10,000 numerical zones)
- Simulations were performed in the shock reference frame
- Periodic and reflection boundary conditions in the transverse direction

$\rho_{fiber}/\rho_{i\text{-}fiber} = 1$



The structure of the shock front can be characterized by the effective deceleration and collision paths of the fibers

Deceleration path



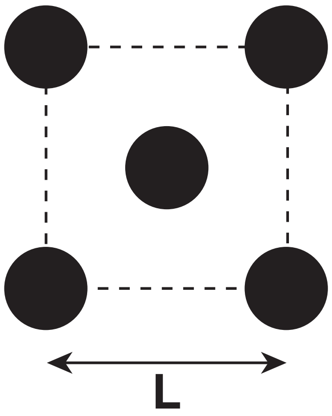
$$\boxed{m_{fiber} = 2R \times L_{dec} \rho_{i\text{-}fiber}} \Rightarrow \frac{L_{dec}}{L} = \frac{\pi}{2} \frac{R}{L} \frac{\rho_{fiber}}{\rho_{i-fiber}}$$

$L_{dec} \sim L$: ICF "wetted" foams

$L_{dec} >> L$: interacting fibers (low-density or "dry" foams)

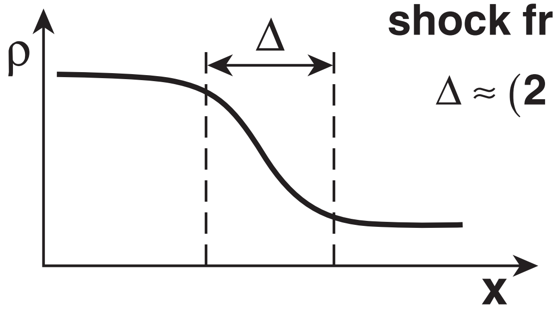
Collision path

$$\boxed{2R \times n_{fiber} \times L_{col} = 1}$$



$$n_{fiber} = \frac{2}{L^2}$$

$$\frac{L_{col}}{L} \approx 0.25 \times \left(\frac{R}{L}\right)^{-1}$$



L_{col} determines "thickness" of the shock front Δ:

$$\Delta \approx (2-3)L_{col}$$

The thickness of the shock front depends on the foam-density contrast and fiber separation

Three basic zones can be distinguished in the shock front:

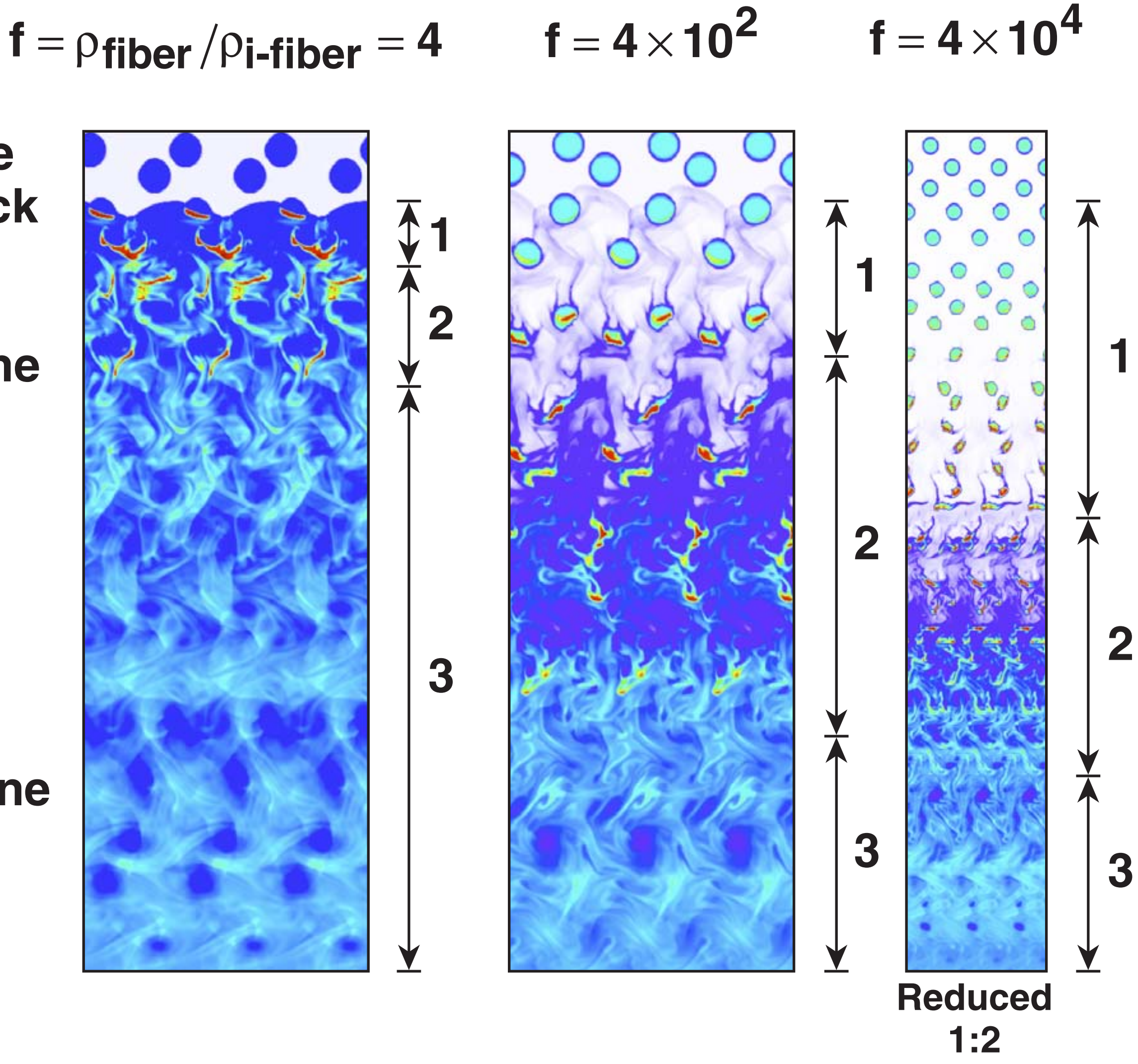
1. Fiber deceleration/zone

   $\approx L_{dec}$

2. Fiber collision zone

   $\approx (2 \div 3) L_{col}$

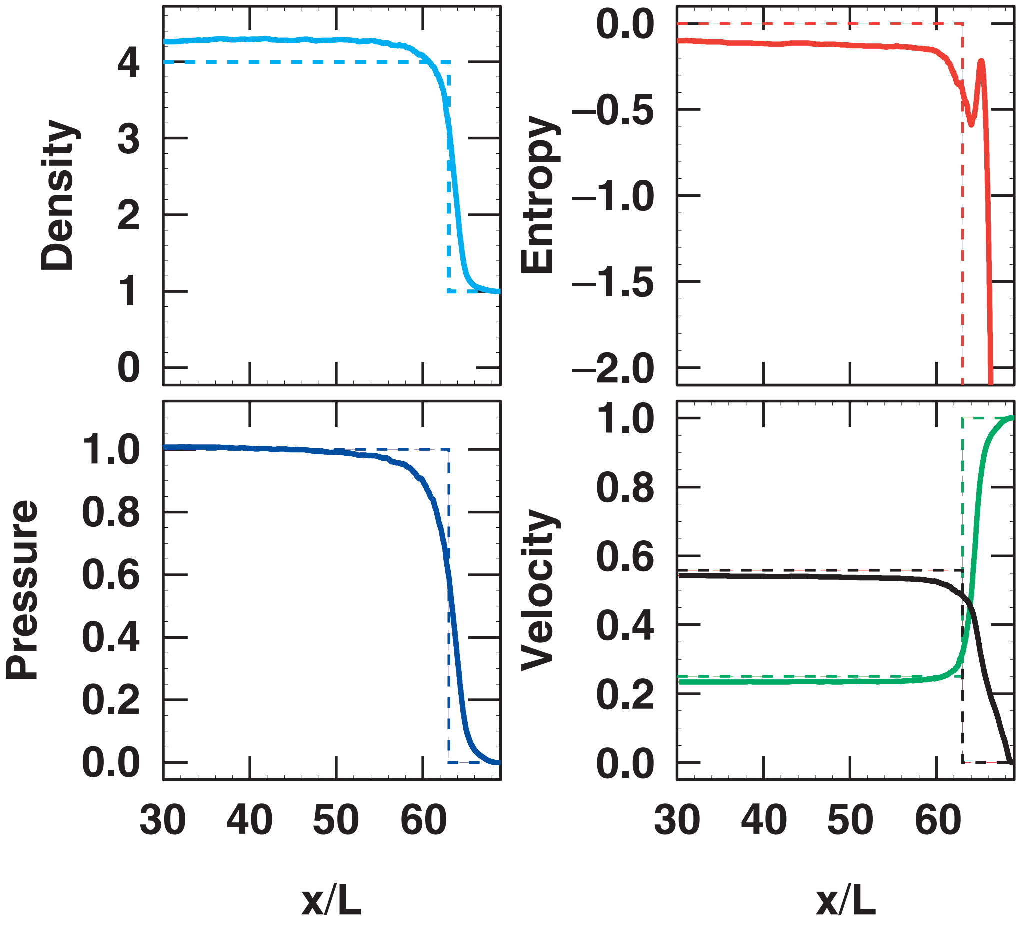
3. Mixing or turbulent zone



Nonviscous simulations show deviations from the Rankine–Hugoniot relation

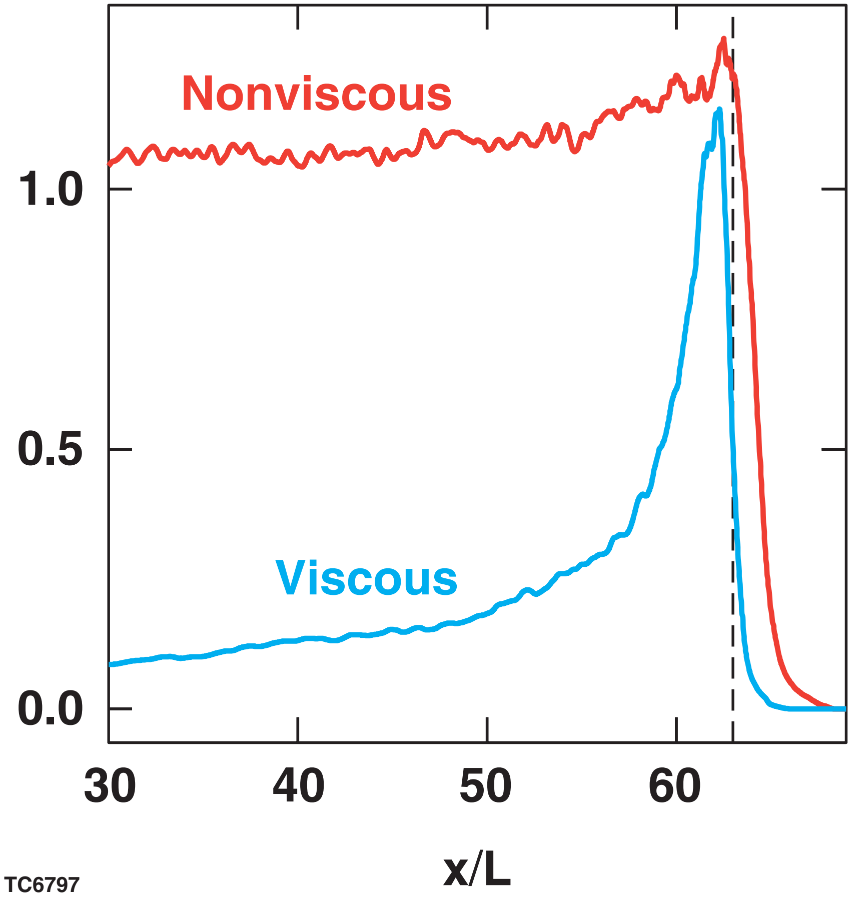
- **The post-shock conditions depend on the assumed transverse boundary conditions:**
  - **post-shock overcompression for periodic boundaries and**
  - **post-shock under-compression for reflection boundaries.**

Time-averaged profiles for the steady-state shock, f = 400.



In 2-D nonviscous simulations, the post-shock turbulent kinetic energy does not dissipate properly

$$\text{Relative turbulent kinetic energy} = \frac{\overline{u^2} - (\bar{u})^2}{(\bar{u})^2}$$



- 2-D turbulence does not provide the correct dissipation of energy through its cascade from large- to small-scale motions.
- Properties of 2-D turbulence depend on boundary conditions.
- Adding appropriate viscosity in 2-D simulations can help to model the properties of real 3-D turbulence in shock-compressed foams.

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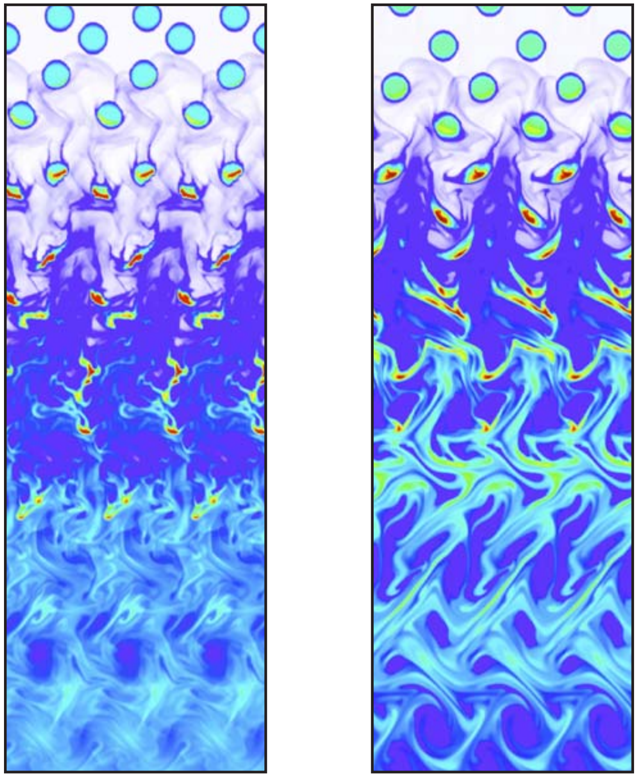
The addition of physical viscosity to the simulation demonstrates good agreement with the Rankine–Hugoniot condition

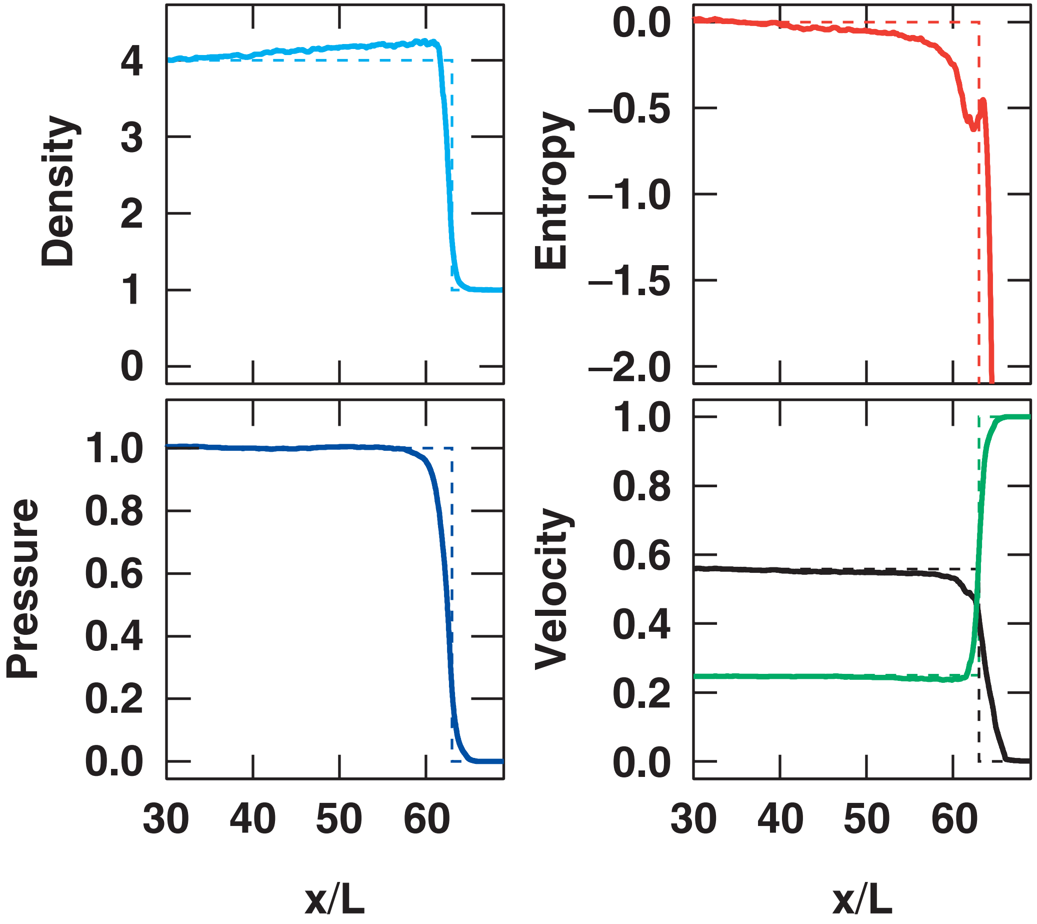
A comparison of the nonviscous and viscous runs clearly shows the effect of viscous smearing.



Re = ∞

Re ≈ 1000

Time-averaged profiles for the steady-state shock in the viscous foam, f = 400 and ν = 0.1 cm^2/s



Summary/Conclusions

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