Simulations of H_2 supersonic expansion

Renzo Parodi & Gianangelo (Nino) Bracco

INFN & Department of Physics
University of Genoa, Italy

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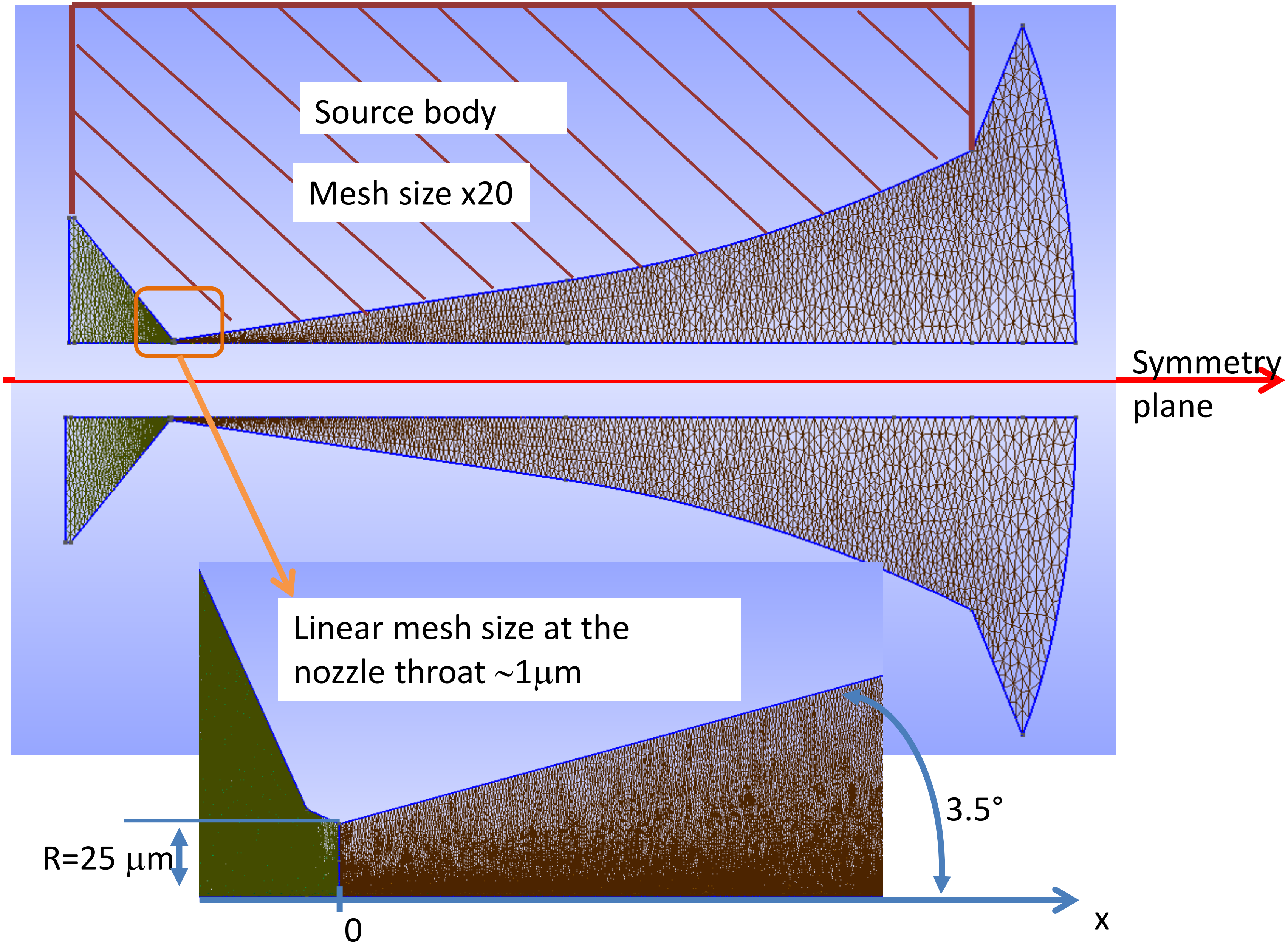
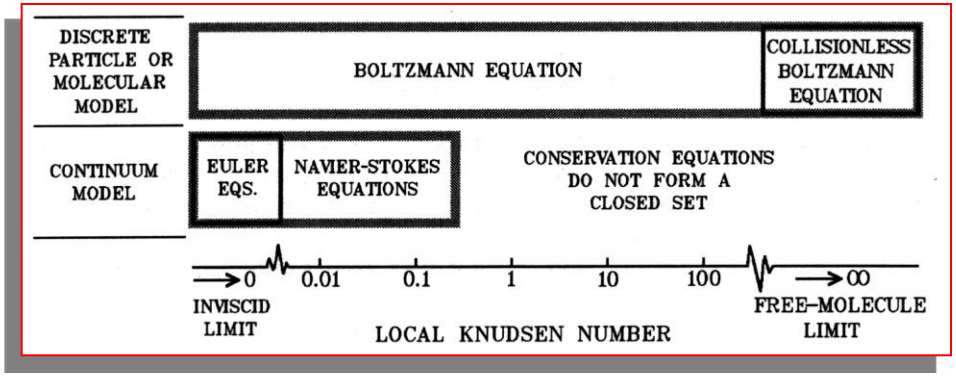
Simulation performed on a CERN nozzle: 2D geometry



$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot \rho \mathbf{U}\mathbf{U} - \nabla \cdot \mu \nabla \mathbf{U} = -\nabla p$$ Navier-Stokes equation

Simulation of gas expansion through a nozzle can be carried out by solving the Navier-Stokes (NS) equations if the flow can be approximated as continuum one. A parameter to check is the Knudsen number Kn=λ/L (λ mean free path, L characteristic length) : Continuous approach is valid if Knudsen number Kn<0.1 (gas is not rarefied)

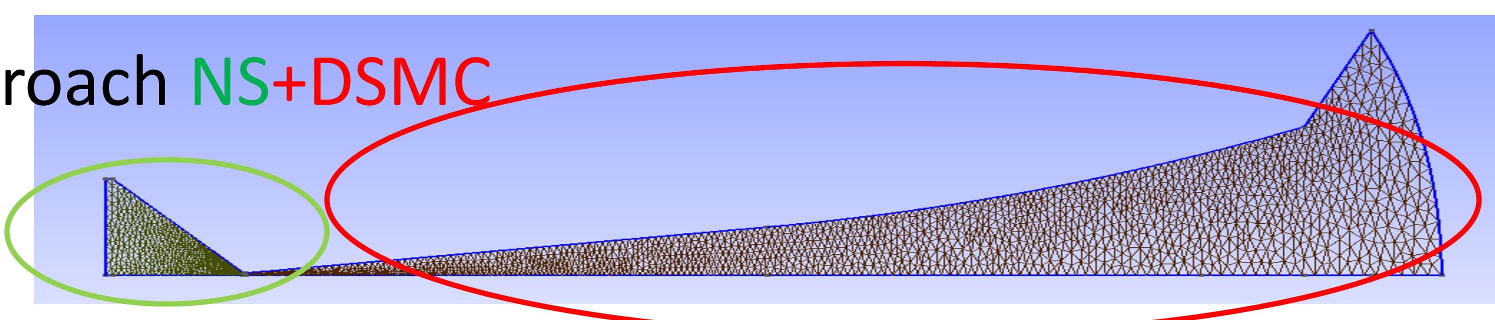


G.A. Bird, Molecular gas dynamics and the Direct Simulation of gas flow, Claredon Press Oxford,1994.

G.A. Bird introduced the local Kn, where the characteristic length L*= ρ/ (dρ/dx) depends on the gradients of the density which set a limit to the variation of the quantities with respect to the mean free path.

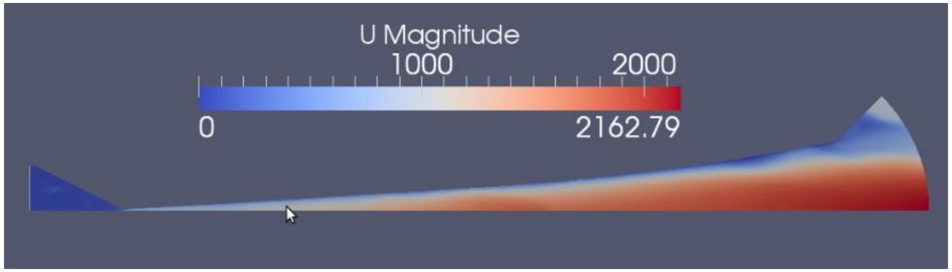
Where the gas is rarefied, the approach to the problem is through particle simulation, for instance with Direct Simulation Monte Carlo (DSMC) methods

-> hybrid approach NS+DSMC



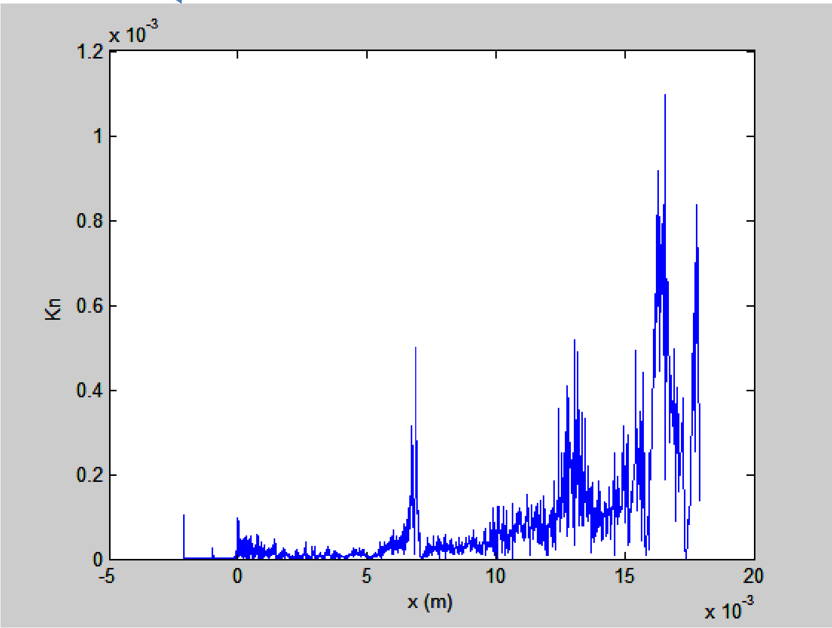
In fact:

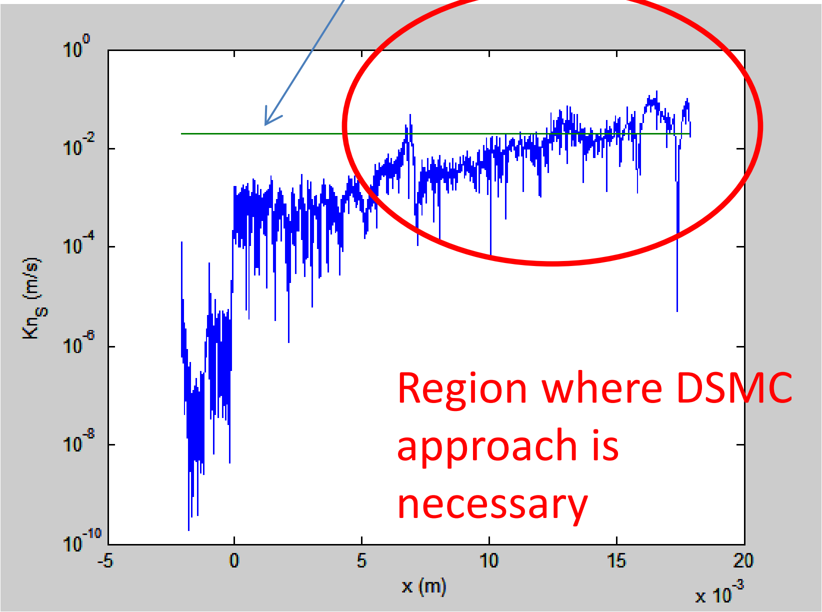
Navier-Stokes solution for hydrogen expansion through a 50 μm nozzle at 30 K along the central streamline (y=0). Nozzle throat position x=0.



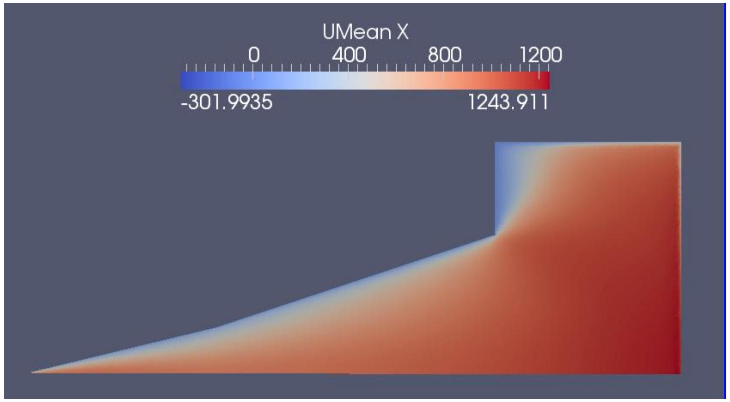
local Kn =(λ/ρ) (dρ/dx)

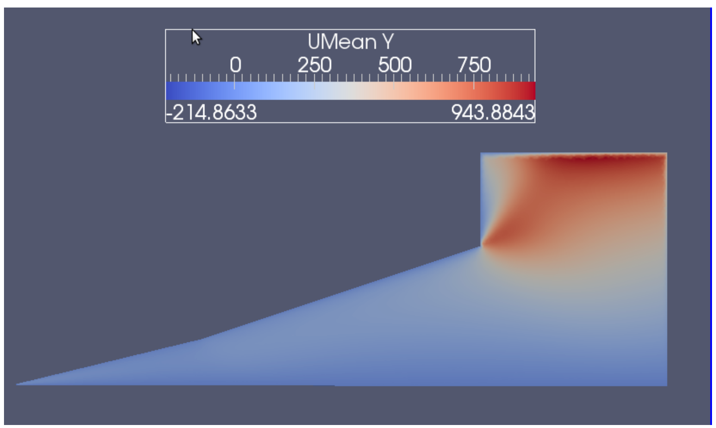
But, for gas expansion, also the speed ratio is important and the corrected Kn_S must be less than 0.02 (green line)

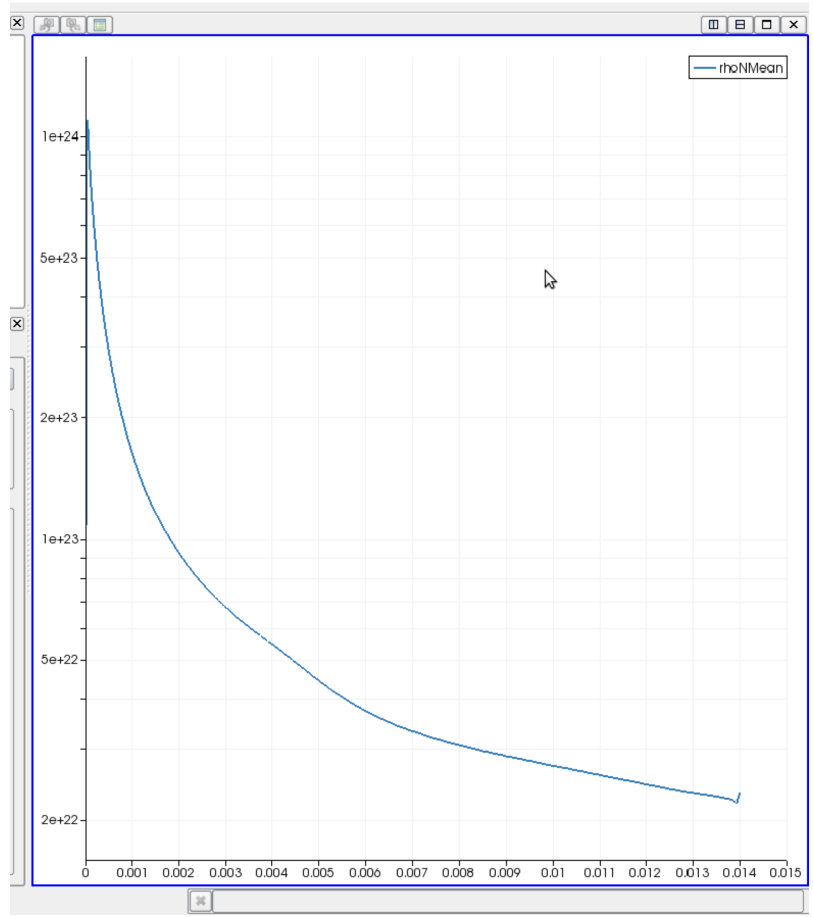




Preliminary DSMC results for hydrogen @ 50 K, 4 x10^6 particle in the domain :
Ux, Uy and particle density along the central streamline







Work to do:

- More statistics for DSMC (increasing particle number)
- Matching between NS & DSMC (hybrid simulation)
- 2D -> 3D simulations