Gas expansion into low pressure volume – update

Barbara Kedzierska
BGC regular meeting, 2nd November 2018
Outline

Nozzle theory
- Supersonic gas jet into no-vacuum conditions
  - Slightly underexpanded jet
  - Highly underexpanded jet
  - Overexpanded jet
- Supersonic gas jet expansion into the vacuum

Next time:
- Nozzle shape design
Three cases of supersonic gas jet
Basic concepts

1) underexpanded gas jet – the gas leaves the nozzle at pressure higher than ambient (backpressure)
   1) Slightly underexpanded
   2) Highly underexpanded

2) overexpanded gas jet – the gas leaves the nozzle at pressure lower than ambient
Slightly underexpanded jet

1) Gas leaves the nozzle
2) Gas expands and a rarefaction fan emanates from the orifice

Rarefaction fan – a set of infinite number of Mach waves, each of them accelerating and turning slightly the gas flow

Slightly underexpanded jet (2)

3) Gas overexpands
4) At the boundary $p_a$ (backpressure) is present which pushes the jet back
5) Converging conical shock is formed

Incident shock – oblique shock wave before reflection

6) When the incident shock reaches the centerline, it reflects and forms diverging shock

Highly underexpanded jet

Mach disk formation

- Condition: **highly underexpanded** supersonic jet or overexpanded jet
  1) Gas leaves the nozzle
  2) Gas expands and a rarefaction fan emanates from the orifice
  3) Gas overexpands
  4) At the boundary $p_a$ is present which pushes the jet back
  5) Converging conical shock is formed
  6) The incident shock does not converge to a point on the axis
  7) Shock reflects at the perimeter of the Mach disk
  8) When gas goes through a shock, its parameters change
  9) Sometimes when the angle is large, Mach reflections are present

Overexpanded jet

Mach disk formation
- Condition: highly underexpanded supersonic jet or overexpanded jet

1) Gas leaves the nozzle
2) Instead of rarefactions, shocks emanate from the nozzle orifice
3) Oblique shocks are reflected from the disk
4) Flow expansion starts with expansion fans creation
5) The pattern follows the same points as for highly underexpanded jet

Supersonic jet expansion into the vacuum
No Mach disk in the flow


A. Naß, E. Steffens, Direct Simulation of Low-Pressure Supersonic Gas Expansions and its Experimental Verification, Preprint submitted to Elsevier Preprint, 28 May 2018
No Mach disk in the flow

How is it related to space propulsion?

Ion thruster

https://www.nasa.gov/centers/glenn/technology/Ion_Propulsion1.html

University of Michigan, Plasma Science and Technology Laboratory
https://pslab.engin.umich.edu/electric-propulsion-activities/