Isentropic Flow Through Nozzles

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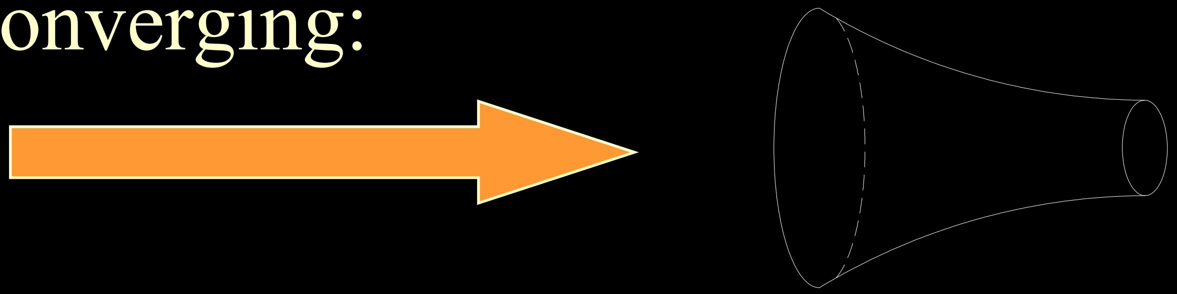
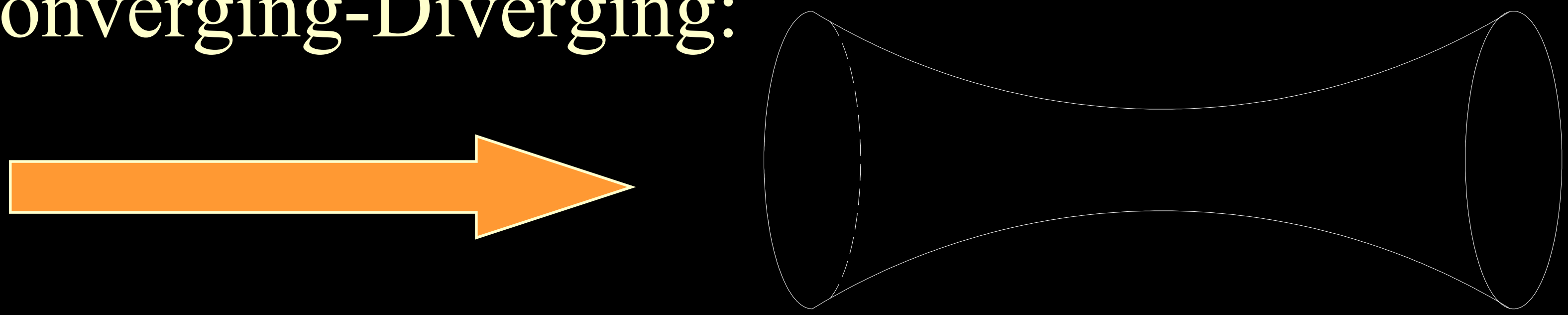
Type of Nozzles

- Converging:



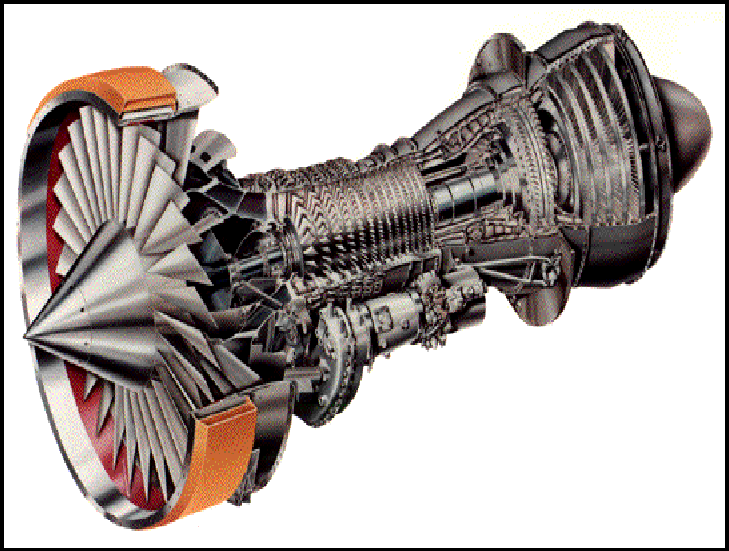
- Converging-Diverging:



- Focus: Converging-Diverging

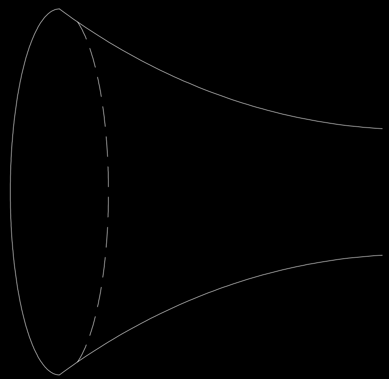
What Makes a Converging-Diverging Nozzle So Special?

- Why not use just an ordinary nozzle? After all an ordinary nozzles are used in turbines, jet engines, and hoses.

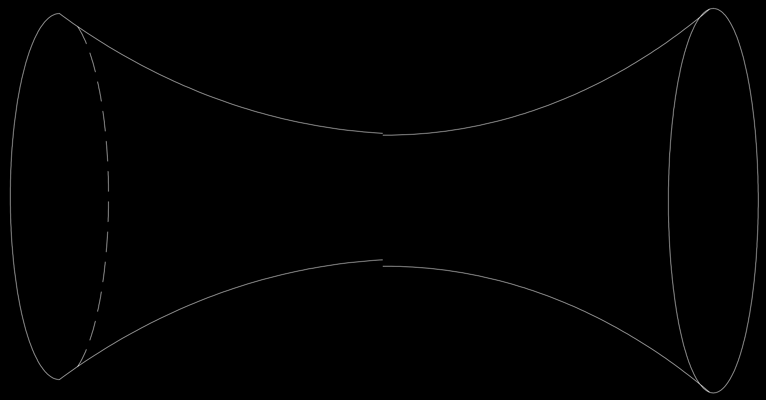


Limitations

- M=1 for



- M>1 for



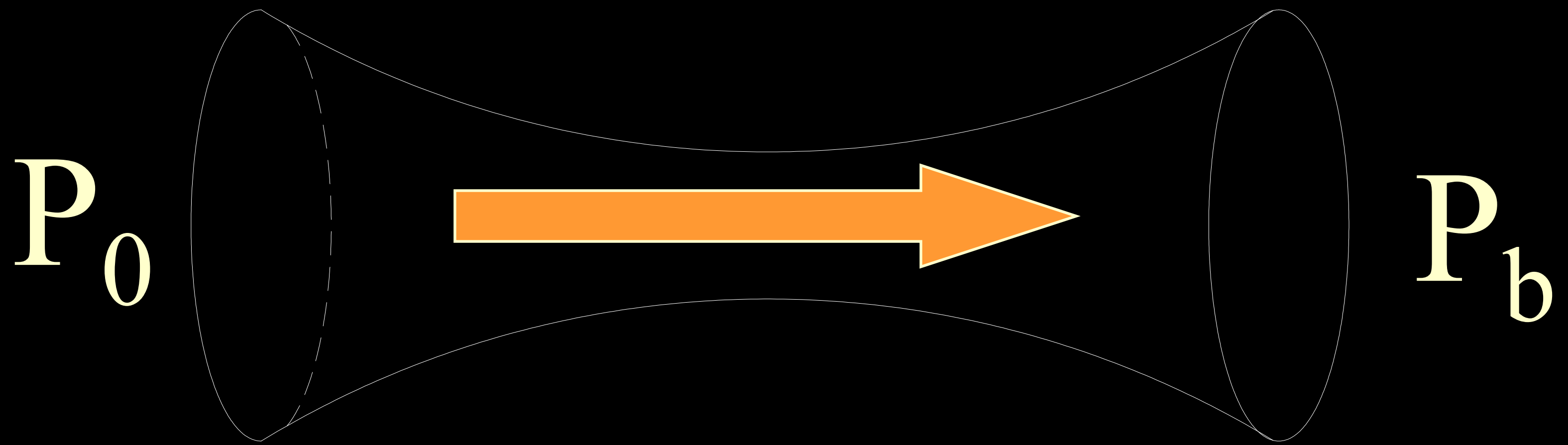
- Standard on all supersonic aircraft

The Resulting Combined Flow Section

- Is a converging-diverging nozzle which is standard equipment on all supersonic aircraft.

This Is Not a Guarantee

- If the back pressure is not in the correct range the fluid might decelerate instead of accelerate.



P_o = Initial Pressure

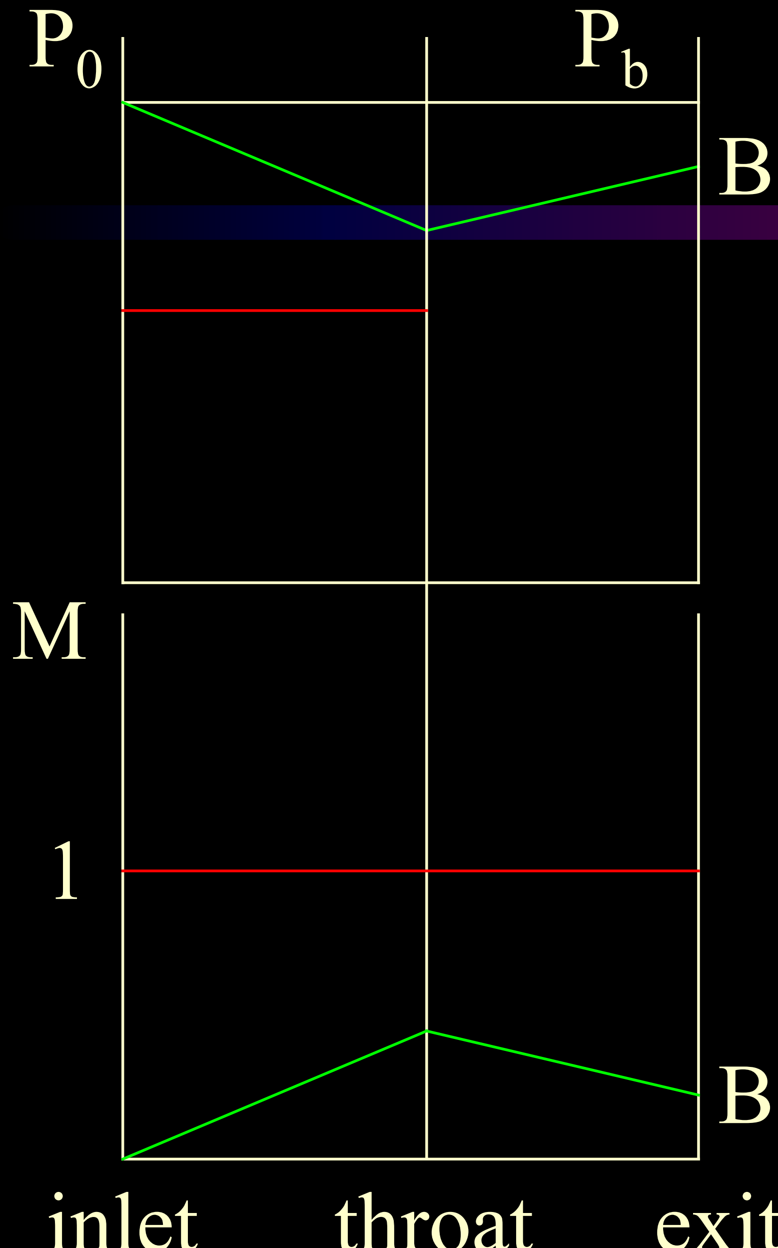
P_b = Back Pressure

Let's Begin

- As before we begin by changing the nozzle to increase velocity and lower pressure.

For $P_b = P_0$ there is no flow.

When $P_b = P_B$



Flow Begins

Velocity Rises

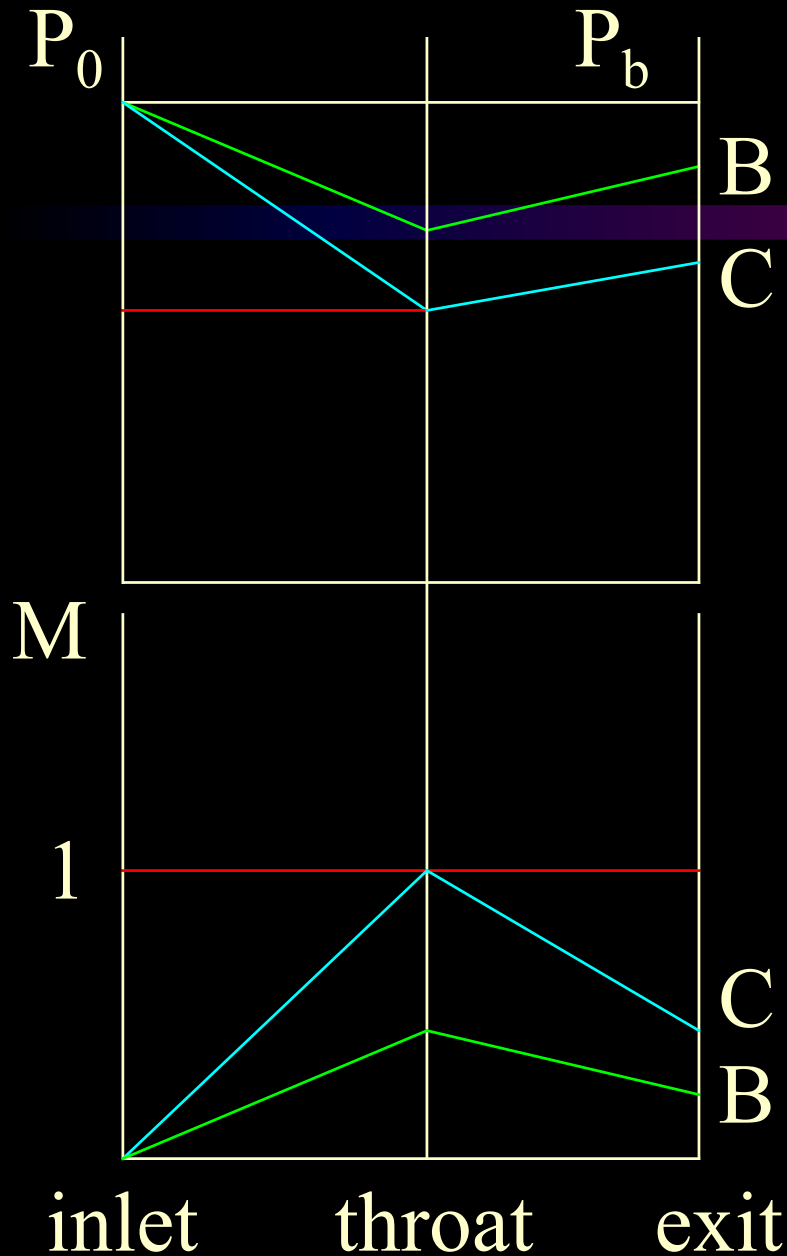
Pressure Drops

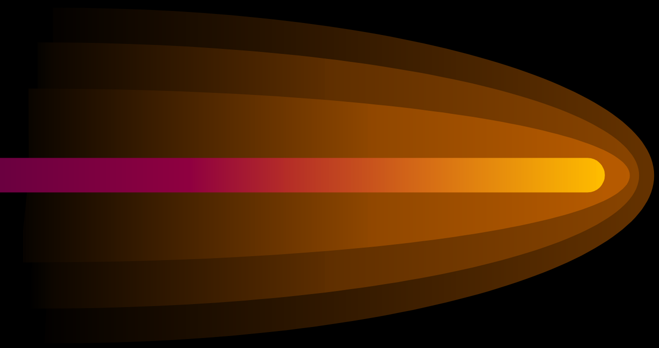
Diffuser Kicks In

Velocity Drops

Pressure Rises

When $P_b = P_C$





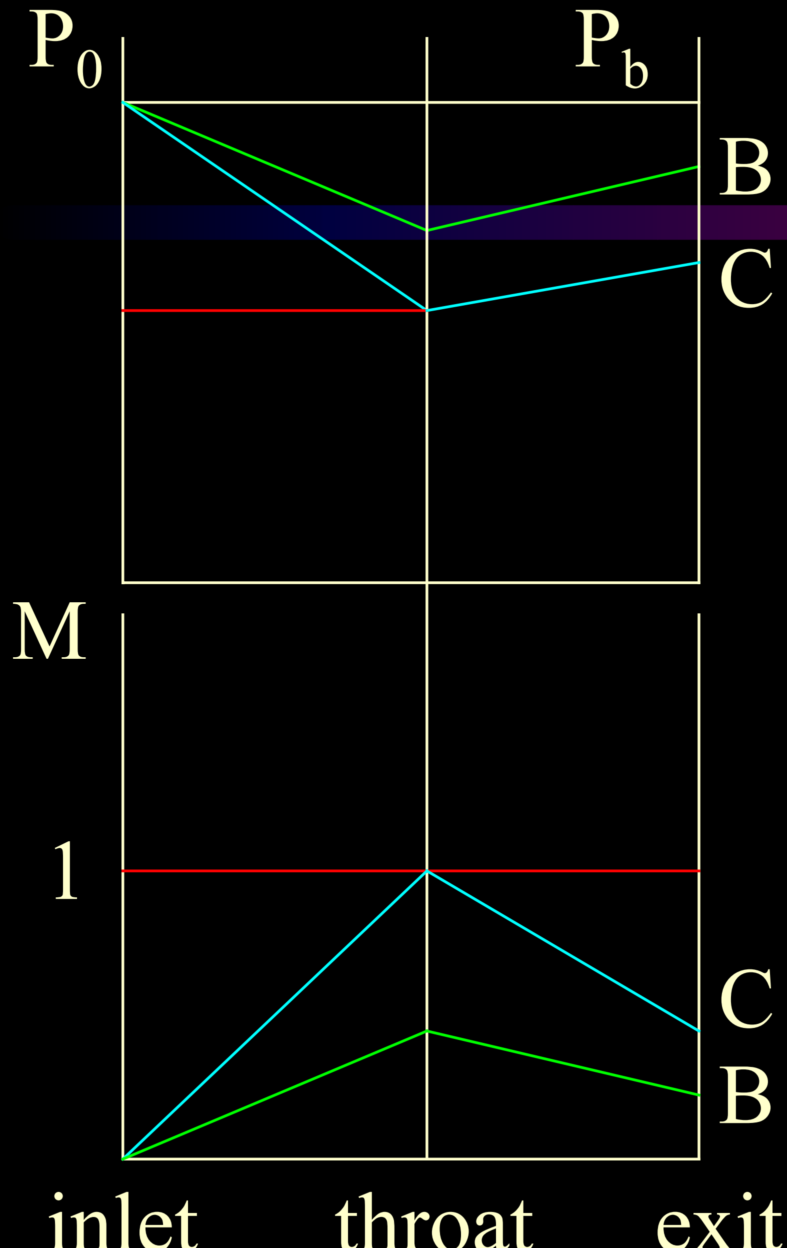
Sonic Velocity

Diffuser Kicks In

Velocity Drops

Pressure Rises

Remember When…



Nozzle at throat:

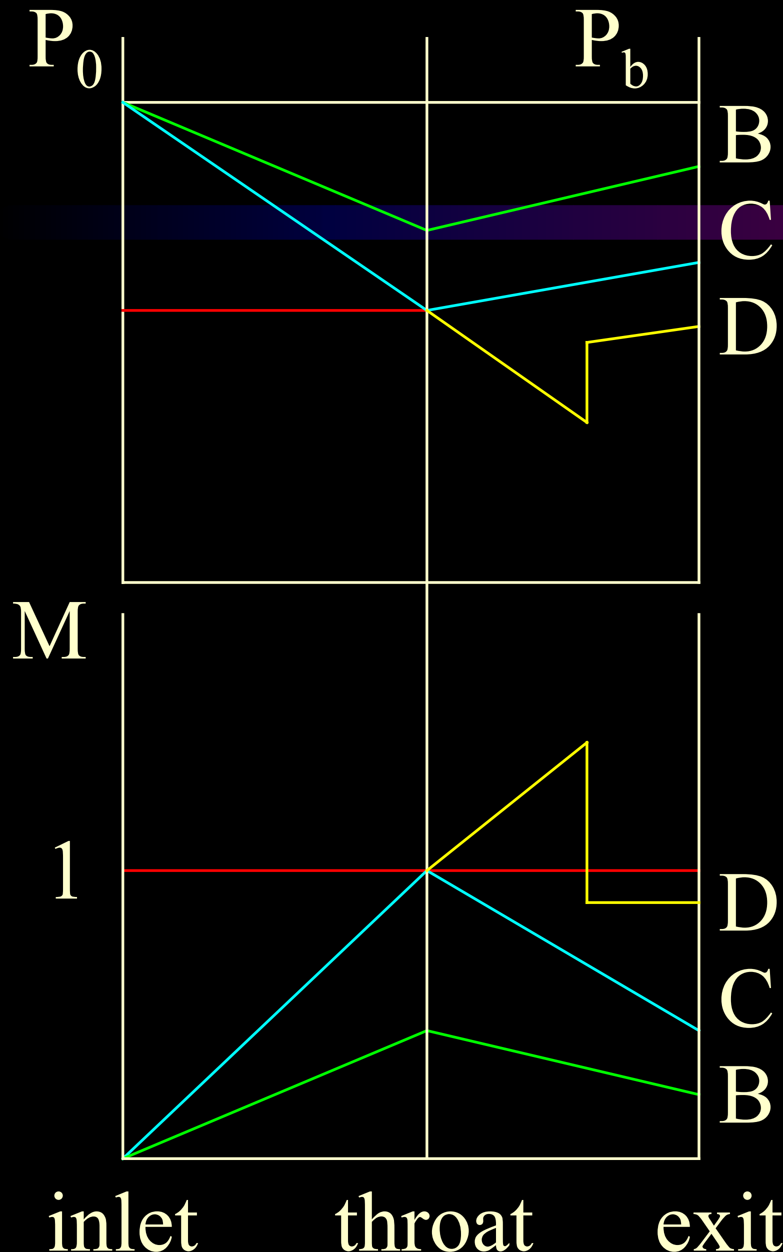
Lowest pressure

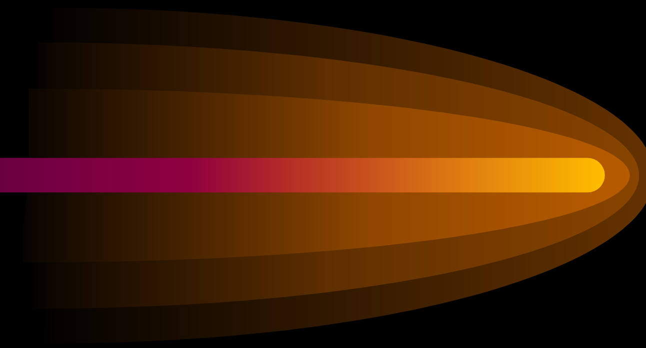
Velocity max at sonic

Reduce pressure more means nothing to me.

But it does in diverging

When $P_b = P_D$





Pressure drops

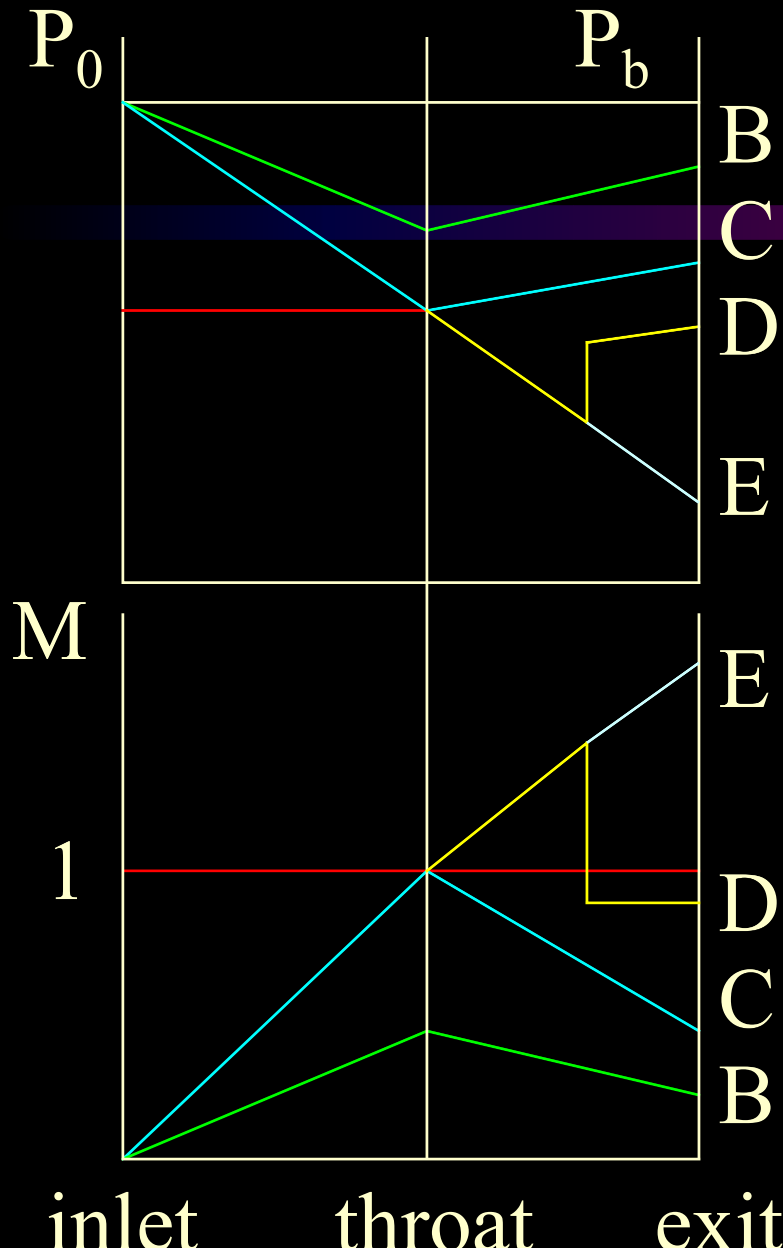
Velocity supersonic

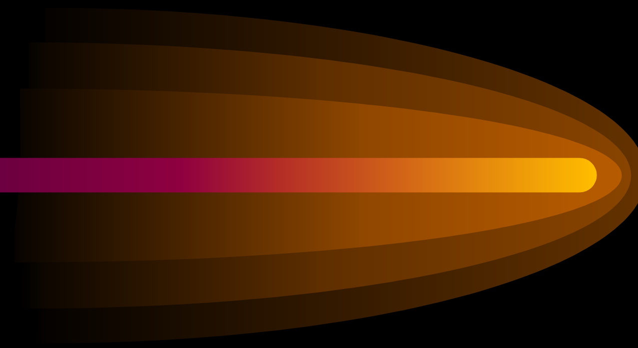
Normal Shock STOPS!

Velocity drops

Pressure rises

When $P_b = P_E$



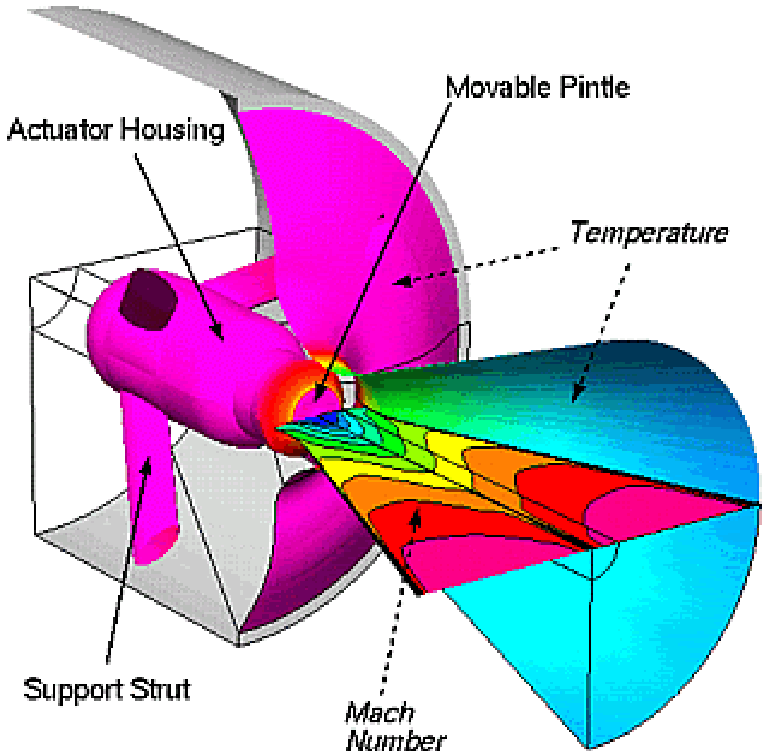


Pressure drops

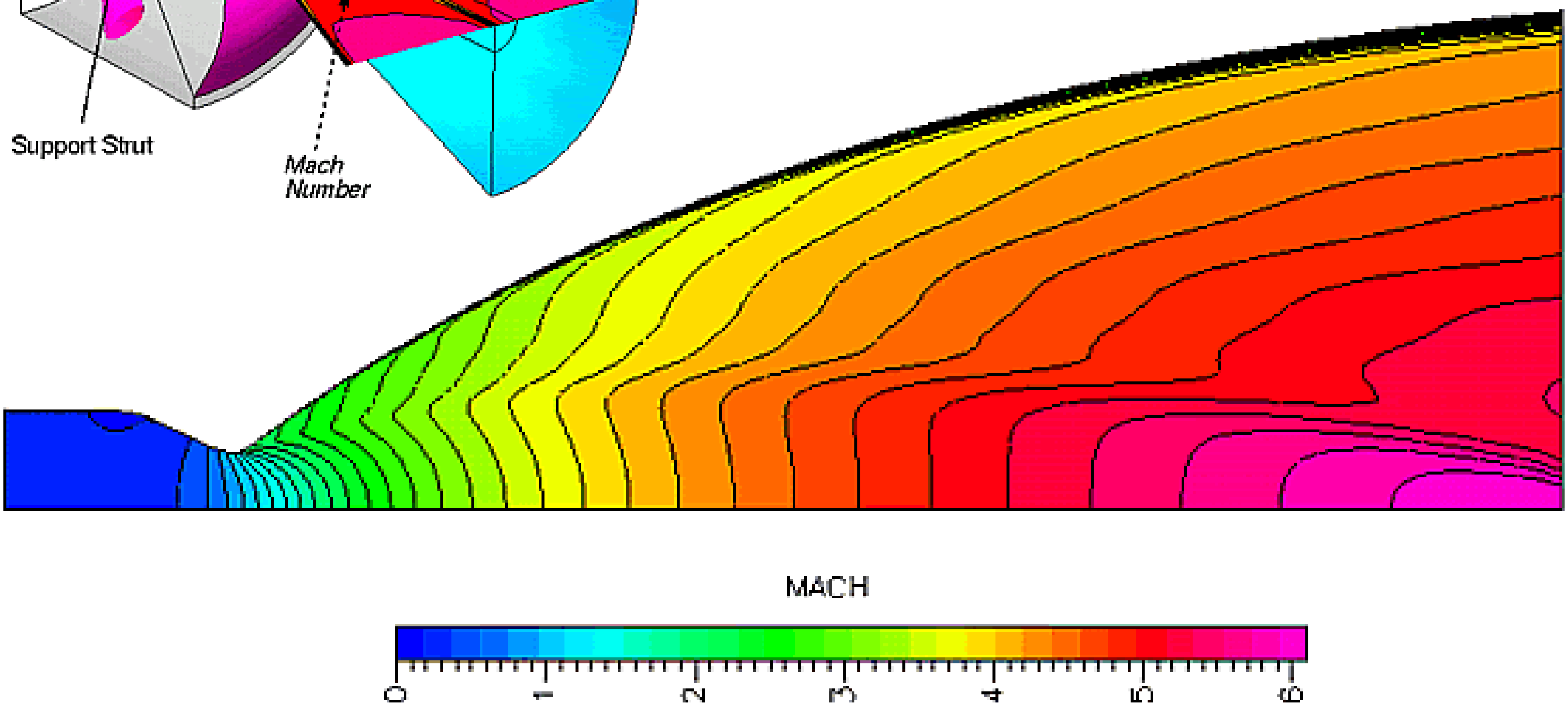
Normal Shock moves away

Supersonic all the way

Example

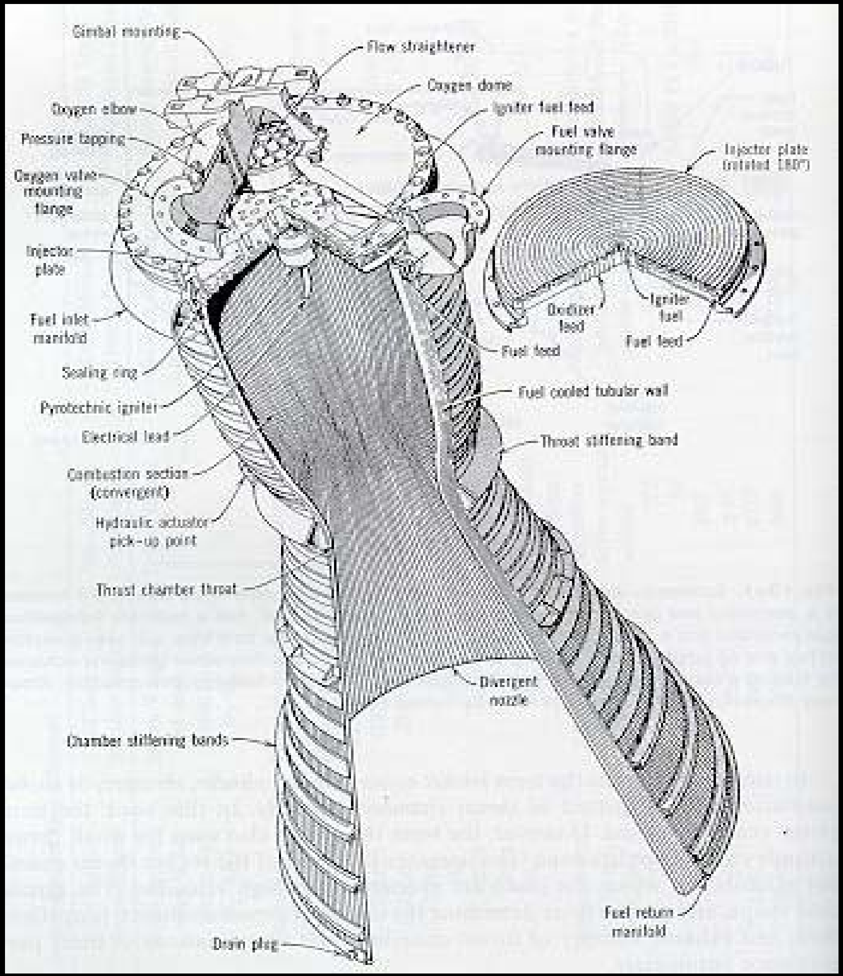


Movable Pintle
Actuator Housing
Temperature
Support Strut
Mach Number



MACH
0
1
2
3
4
5
6

Example

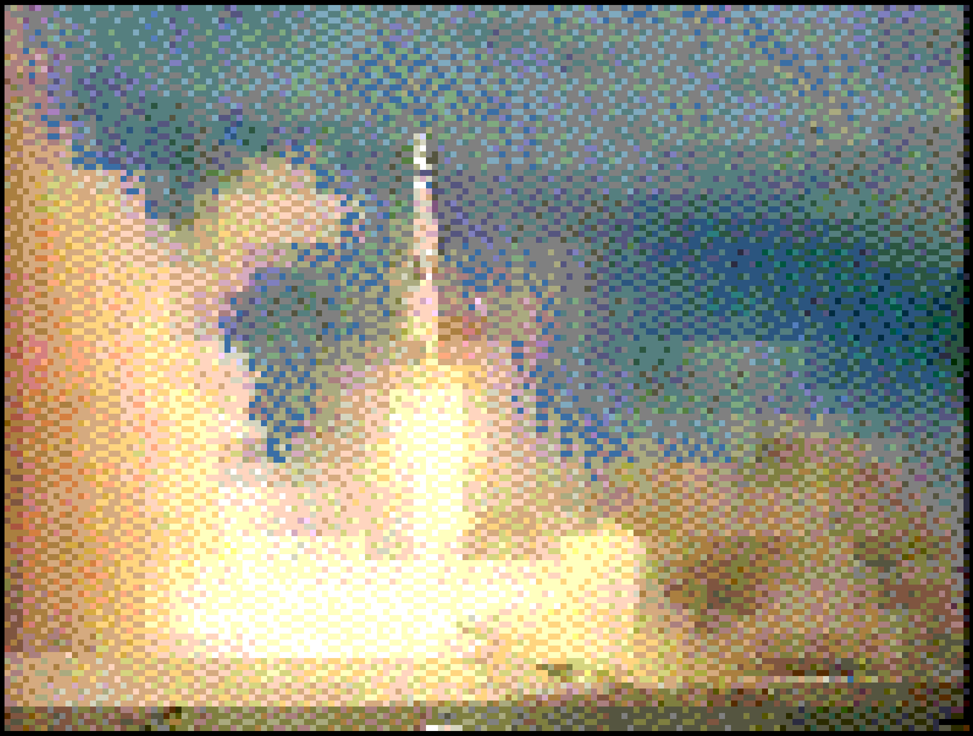


Gimbal mounting
Flow straightener
Oxygen dome
Igniter fuel feed
Oxygen elbow
Pressure tapping
Fuel valve mounting flange
Injector plate (rotated 180°)
Oxygen valve mounting flange
Injector plate
Fuel inlet manifold
Oxidizer feed
Igniter fuel
Fuel feed
Fuel feed
Sealing ring
Pyrotechnic igniter
Fuel cooled tubular wall
Electrical lead
Throat stiffening band
Combustion section (convergent)
Hydraulic actuator pick-up point
Thrust chamber throat
Divergent nozzle
Chamber stiffening bands
Fuel return manifold
Drain plug

http://www.engapplets.vt.edu/fluids/CDnozzle/cdinfo.html

Check It

Check It Out



aplaunch[1]

Yo Yo Check It Out

shuttle[1]

Table A-15

- A relation for :
- flow area A vs. throat area A*
- pressure P vs. initial pressure P_0
- density ρ vs. initial density ρ_0
- temperature T vs. initial temperature T_0
- as a function of the Mach number.

Variables:

V^* = Throat Velocity

A^* = Throat Area

P^* = Throat Pressure

T^* = Throat Temperature

ρ^* = Throat Density

V_e = Exit Velocity

A_e = Exit Area

P_e = Exit Pressure

T_e = Exit Temperature

ρ_e = Exit Density

m_{dot} = Mass Flow Rate

k = Specific Heat Ratio

R = Gas Constant

M = Mach Number

P_0 = Initial Pressure

T_0 = Initial Temperature

ρ_0 = Initial Density

Equations:

- $P = \rho TR$
- $V = M\sqrt{(kRT)}$
- $m_{dot} = \rho AV$

Problem:

- m_{dot} = 13.111 kg/sec
- $k = 1.4$
- $R = 0.287$ kJ/(kg K)
- $P_0 = 1.0$ MPa
- $T_0 = 880$ K
- $A^* = 20\ cm^2$
- $M_e = 2$
- Flow is steady, one-dimensional, isentropic.

Determine:

- Throat conditions.
- Exit plane conditions, including the exit area.
- Mass flow rate through the nozzle.

Analysis:

- Exit Mach number = 2:
  - sonic at the throat
  - supersonic in the diverging
- Inlet velocity is negligible:
  - throat pressure = inlet pressure
  - throat temperature = inlet temperature.

Solution to throat conditions:

- Using $P = \rho TR$ and solving for

$\rho_0 = 4.355 \text{ kg/m}^3$

- From Table A-15 for $M = 1$, $P^*/P_0 = 0.5283$, $T^*/T_0 = 0.8333$, $\rho^*/\rho_0 = 0.6339$.

$P^* = 0.5283$ Mpa

$T^* = 666.6$ K

$\rho^* = 2.761 \text{ kg/m}^3$

- Using $V^* = M^*\sqrt{(kRT^*)}$

$V^* = 517.5$ m/s

Please calculate exit conditions:

- From Table A-15 for M=2, P_e/P_0 = 0.1278, T_e/T_0 = 0.5556, ρ_e/ρ_0 = 0.2301, A_e/A^* = 1.6875.

P_e = 0.1275 Mpa

T_e = 444.5 K

ρ_e = 1.002 kg/m^3

A^* = 33.75 cm^2

- Using $V_e = M_e\sqrt{(kRT_e)}$

V_e = 845.2 m/s

Please calculate m_{dot}

- Steady flow:
  - m_{dot} is the same at all sections of the nozzle
  - calculated by using properties at any cross section of the nozzle.
- Using $m_{dot} = \rho AV$

$m_{dot} = 2.858$ kg/s

Questions