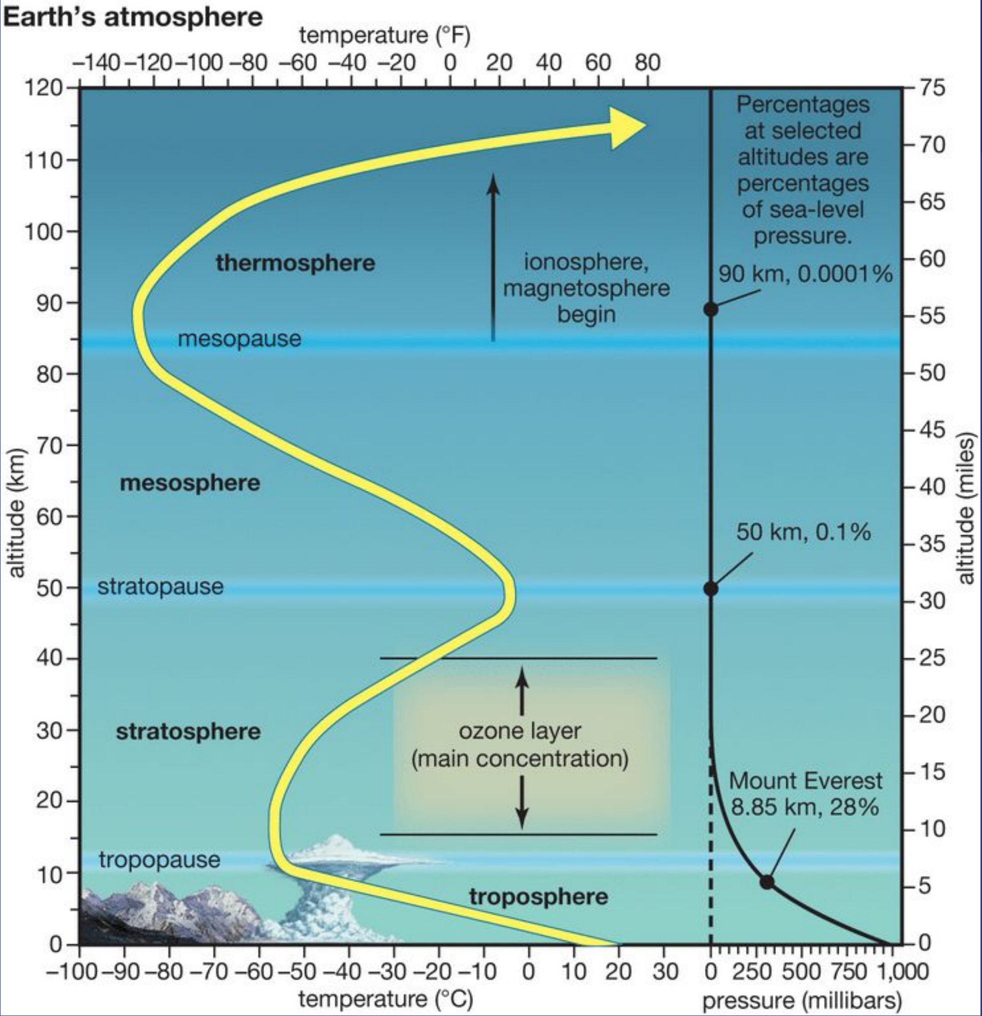


Earth's atmosphere
temperature (°F)
−140 −120 −100 −80 −60 −40 −20 0 20 40 60 80
altitude (km)
120 110 100 90 80 70 60 50 40 30 20 10 0
altitude (miles)
75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
thermosphere
ionosphere, magnetosphere begin
mesopause
mesosphere
stratopause
stratosphere
ozone layer (main concentration)
tropopause
troposphere
Percentages at selected altitudes are percentages of sea-level pressure.
90 km, 0.0001%
50 km, 0.1%
Mount Everest 8.85 km, 28%
−100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30
temperature (°C)
0 250 500 750 1,000
pressure (millibars)

Troposphere:

- Ranges from surface of earth to 8 kms(poles) and 18 kms(equator)
- All kind of weather changes occurs here
- Normal lapse rate: Temperature decreases with increase in height of atmosphere at the rate of 1 Degree Celsius for every 165 m height. “Normal lapse rate”
- 100 Kpa pressure at sea level and 30 Kpa at Mount Everest

Stratosphere:

- Extends to a height of 50 km
- Ozone Layer found here
- This layer aid advantage for powered aircraft as it is above stormy weather and has steady, strong, horizontal winds.
- Layer is dry mostly but contains less rate of water vapour
- Ozone layer absorbs UV rays and safeguards earth from harmful radiation

Mesosphere:

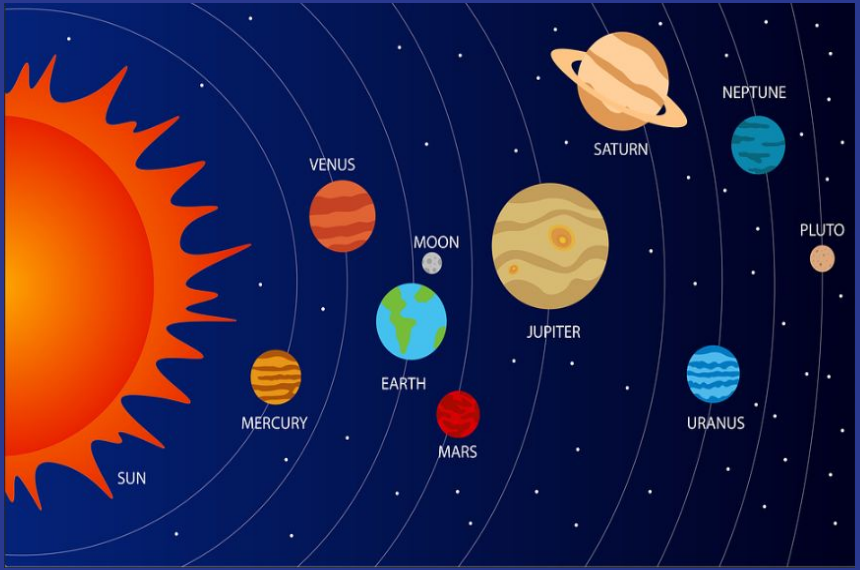
- Coldest layer of atmosphere
- Temperature drops as altitude increases
- By 80 km, layer reaches -100 degree Celsius
- Meteors burn up here

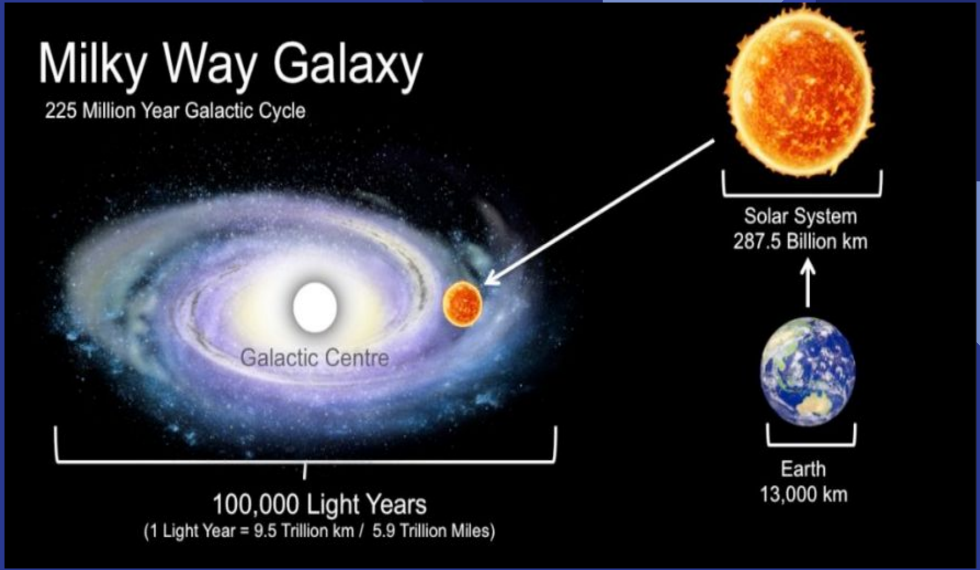
Thermosphere:

- Radio waves are transmitted from the earth are reflected here
- Temp start increasing again as altitude increases
- Lower thermosphere is ionosphere and filled with electrically charged ions due to cosmic and solar radiation
- Ranges between 80 to 400 km
- **The thermosphere** is home to the **International Space Station** as it orbits Earth. This is also where you'll find **low Earth orbit satellite**s. There's a lot going on in the thermosphere.

Exosphere:

- Outermost layer of atmosphere
- The zone where molecules and atoms escape into space
- Extends from top of thermosphere up to 10,000 km.





- 1 LY = speed of light (3x10^8) * 365 days * 24 hours * 60 minutes * 60 sec = approx. 10^11 km
- Pluto is Decommissioned , Not fully grown – Loose gas motion
- Solar system contains 31 moons
- Mass of Earth = 5.974 x 10^24 Kg
- Diameter of Earth = 12,756 km

- Motion of Planets circling the sun influences Newton to discover "**Universal Gravitational Law of Motion**"
- **Kepler and his three laws** was the idea behind Newton's theory

INTRODUCTION TO ROCKET PROPULSION

- Momentum of any moving object = mV

  Where, m = mass of the object

  V = Velocity of the object

- The art of imparting momentum on an object in a space is space propulsion

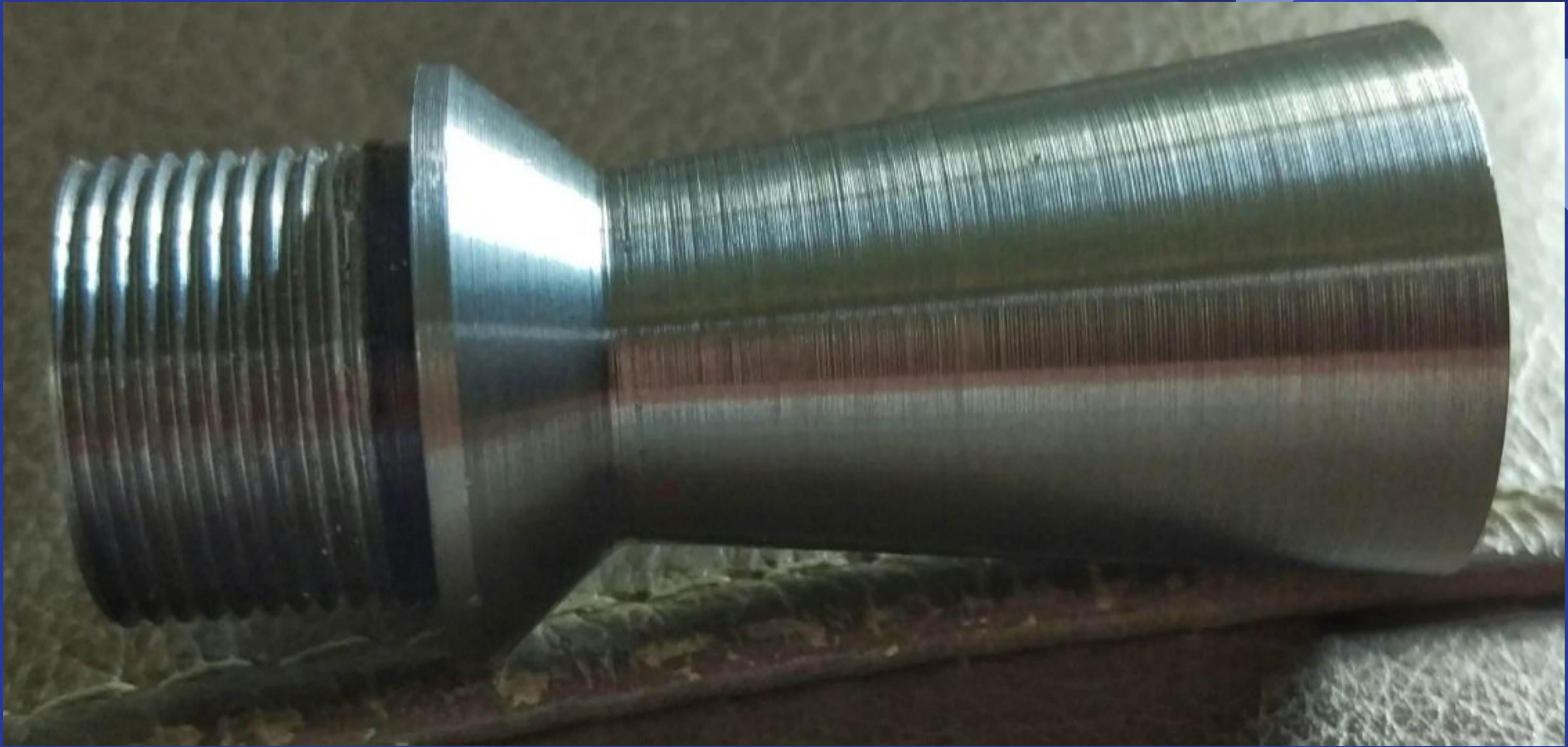
- Propulsion means “Pushing Forward”

How Rockets are differ from Car ??

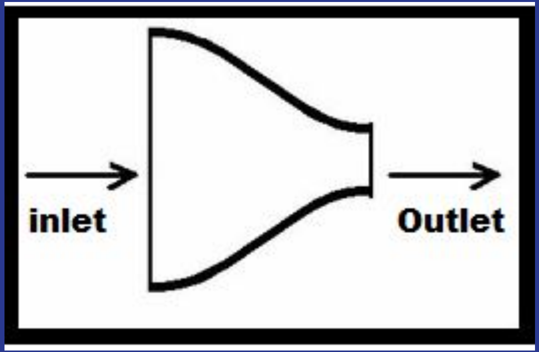
- Car Uses Negligible amount of fuel from fuel tank to push itself with the help of engine.
- During distance coverage, it will not lose its mass significantly

- Rocket uses the propellant to push itself which contribute major part of mass of rockets.
- During distance coverage, it will lose mass significantly

View Of Convergent Divergent Nozzle



Simple Convergent Nozzle



Mass Flow rate at Inlet = Mass Flow rate at Outlet

$$\varrho_i \text{ x } V_i \text{ x } A_i \text{ x } \Delta t = \varrho_o \text{ x } V_o \text{ x } A_o \text{ x } \Delta t$$

(Density x Velocity x Area x change in time)

Density and time difference is same across inlet and outlet.

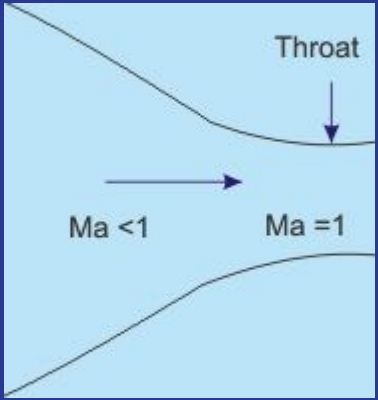
So, $V_o = (A_i / A_o) * V_i$ Area Ratio Between inlet and outlet

- By Decreasing Area of the Nozzle, Velocity can be increased and it Depends on the Mach number of flow.

Regime	Velocity			
	Mach No	mph	km/h	m/s
Subsonic	< 0.8	< 614	< 988	< 274
Transonic	0.8–1.2	614–921	988–1482	274–412
Supersonic	1.2–5	921–3836	1482–6174	412–1715
High-Hypersonic	10–25	7673–19180	12350–30870	3430–8507
Re-entry speeds	> 25	> 19030	> 30870	> 8575

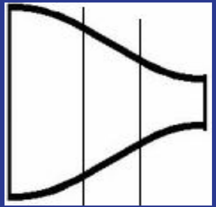
Mach Number = Fluid Velocity / Velocity of Sound

Throat



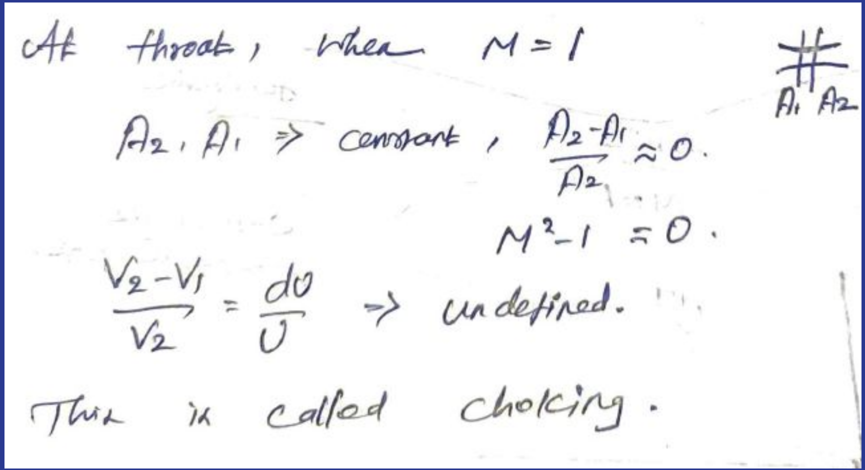
- When the fluid Velocity approaches Mach number 1, Localized separation of fluid molecules happen and the phenomena known as Choking. i.e., Mach number can't be increased further.
- To prevent this, area should be increased .i.e divergence nozzle should be configured after the throat.

At Convergent,



Positive Term

dA/A = [(V2-V1) / V2] (M*2 - 1)



At throat, when $M = 1$

$A_2, A_1 \Rightarrow$ constant, $\frac{A_2 - A_1}{A_2} \approx 0.$

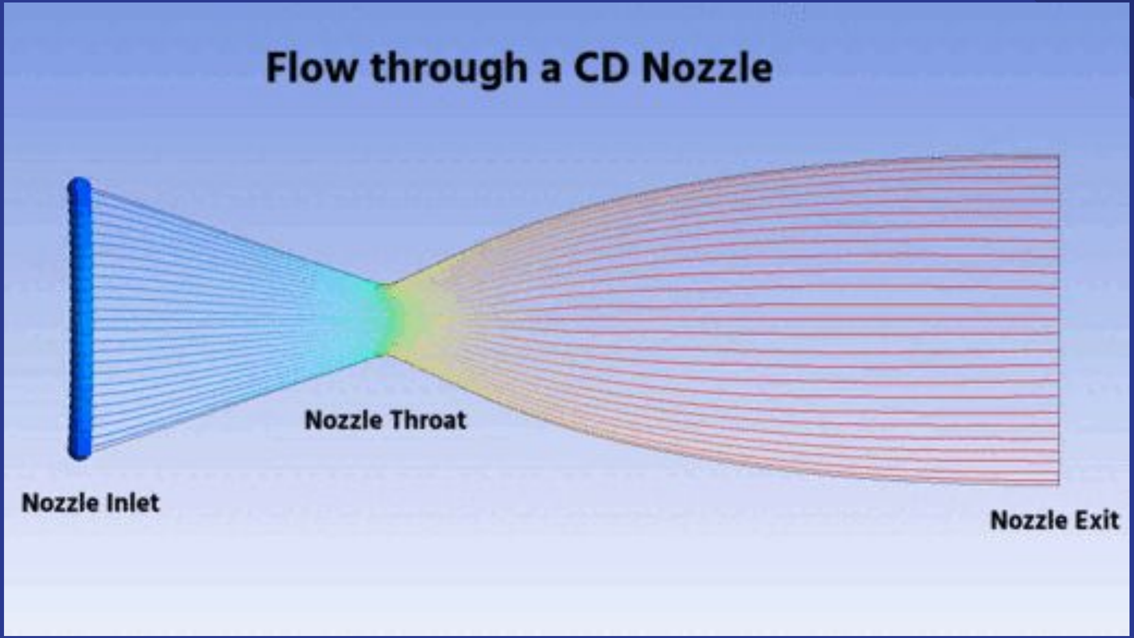
$M^2 - 1 \approx 0.$

$\frac{V_2 - V_1}{V_2} = \frac{d\upsilon}{\upsilon} \Rightarrow$ undefined.

This is called choking.

$A_1 \quad A_2$

Convergent - Divergent Nozzle



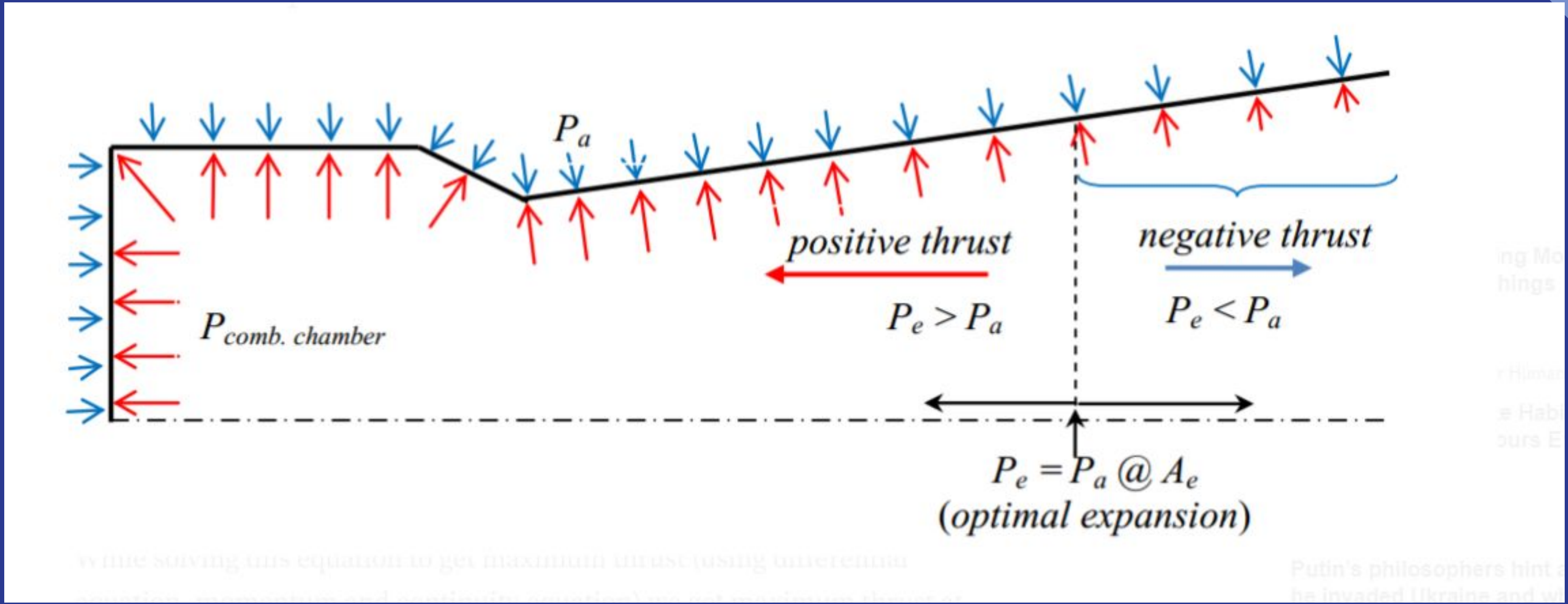
At Divergent , dA/A >> Positive , dV/V = Positive , M*2 -1 = Positive

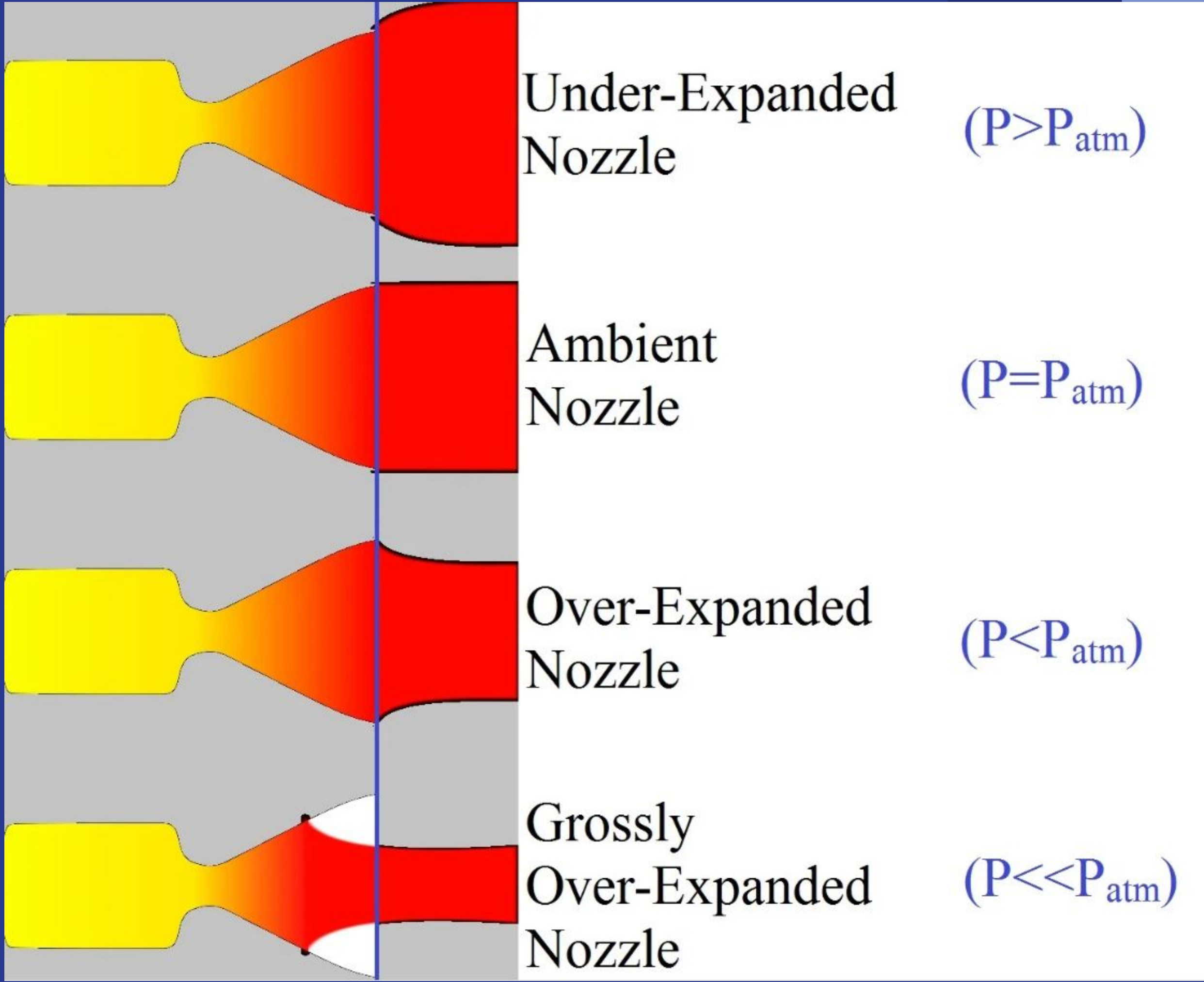
- To increase the velocity from subsonic regime , Nozzle should be converged.
- When the fluid approaches the throat, choking happens, from choking increasing the velocity is done by increasing the area of the nozzle.

Why we can't keep on decrease the convergent Nozzle Area ????

- Due to choking

Why we can’t keep on increase the divergent Nozzle Area for High speed exhaust ????





Under-Expanded Nozzle
(P>Patm)
Ambient Nozzle
(P=Patm)
Over-Expanded Nozzle
(P<Patm)
Grossly Over-Expanded Nozzle
(P<<Patm)

Thrust and Specific Impulse

- The rocket engine will experience that much amount of thrust which will be equal to how much force rocket engine is exerting on the exhaust gases and moving it out.Same force that the exhaust gases will exert on the rocket by using Newton’s third law.

$$F_t = \frac{dP}{dt} = \frac{d}{dt}(m.V_e) = \frac{dm}{dt}.V_e + m.\frac{dV_e}{dt}$$

>>> Rate of change of Momentum

>>> Ve = Exit Velocity

>>> dm/dt = Mass Flow rate (Kg/ses)

- Fuel is ejecting out and mass of the rocket is changing

$$F = \underbrace{\underbrace{\dot{m}.V_e}_{\text{Momentum thrust}} + \underbrace{m.\dot{V}_e}_{\text{Pressure thrust}}}_{\text{"Nozzle is expanding the ejected mass"}}$$

To Obtain Effective Jet Velocity:

$$F = \dot{m}.V_e + (P_e - P_a).A_e$$
$$= \dot{m}.c$$
$$c = \text{effective exhaust velocity}$$
$$= \left[V_e + \frac{(P_e - P_a).A_e}{\dot{m}}\right]$$

>> Rate of change of mass x Effective Jet Velocity

Specific Impulse

Total Number of seconds, a rocket can deliver thrust equal to the weight of the propellant mass when undergoing acceleration due to one g of gravity (unit gravity)

$$I_{sp} = \frac{F_t}{\Delta \dot{m}_p \times g}$$

$$= \frac{\dot{m} . c}{\Delta \dot{m}_p \times g} = \frac{c}{g}$$

(seconds)

Max Q

Moment at which **maximum dynamic pressure and stresses** are occurring on the rocket structure and frames.

$$q = \frac{1}{2}\,\rho\,v^2$$