ME 323: FLUID MECHANICS-II

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Lecture-10

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Wave Propagation
&
Blow Down Process

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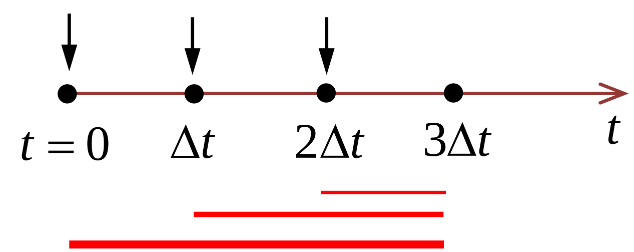
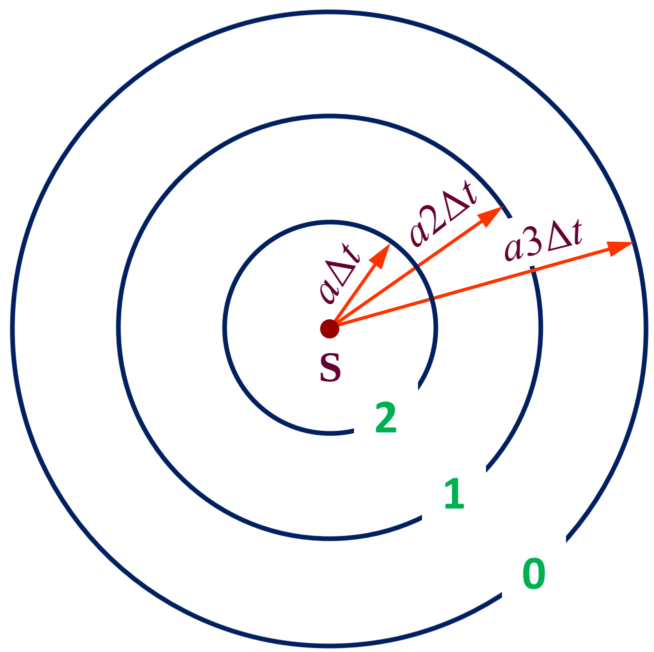
Wave Propagation

Weak pressure changes in the fluid is propagated through the fluid continuum **with the velocity of sound**, ***a*** which is a function of elastic property of the fluid.

Thus, if a periodic pressure disturbance occurs at a stationary point **S** as shown in Figure in a stationary fluid, the resulting pressure waves will travel radially outwards from point **S** as **concentric spheres**. If the period of the disturbance is Δt, then the distance travelled by a wave between the first and second disturbance will be $a\Delta t$.

$$a = \sqrt{kRT} \quad \text{(m/s)}$$





Point **S** is a source (stationary)

Wave propagation with **stationary source**, **S** in stationary fluid continuum

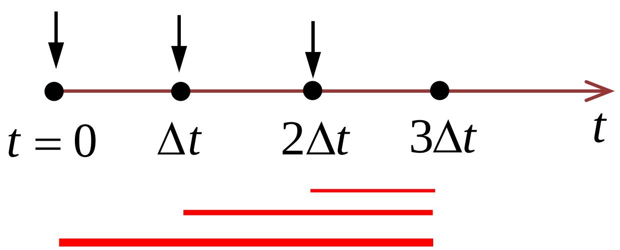
Wave Propagation

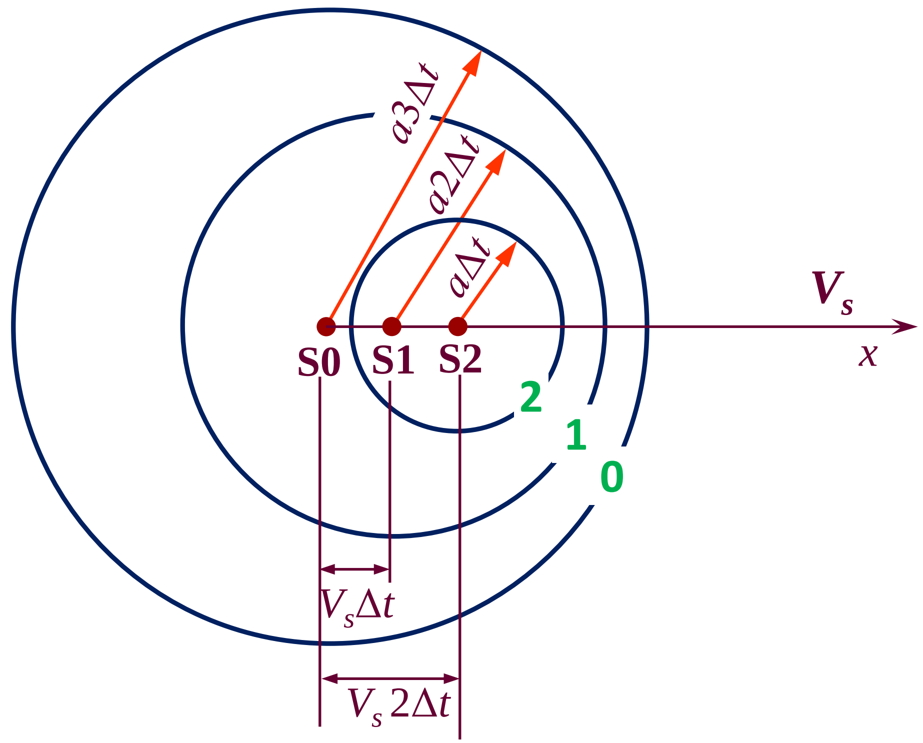
Now if the source, **S** is moving with velocity V_s, what will happen???

Case- I: Source (S) velocity is subsonic (M<1) i.e. $V_s < a$

$$a\Delta t > V_s \Delta t \quad \text{(m)}$$

$$a = \sqrt{kRT} \quad \text{(m/s)}$$





Concentration of spheres' surfaces will increase downstream

Point **S** is a source

Wave propagation with moving source, **S** in stationary fluid continuum
subsonic ($V_S < a$)

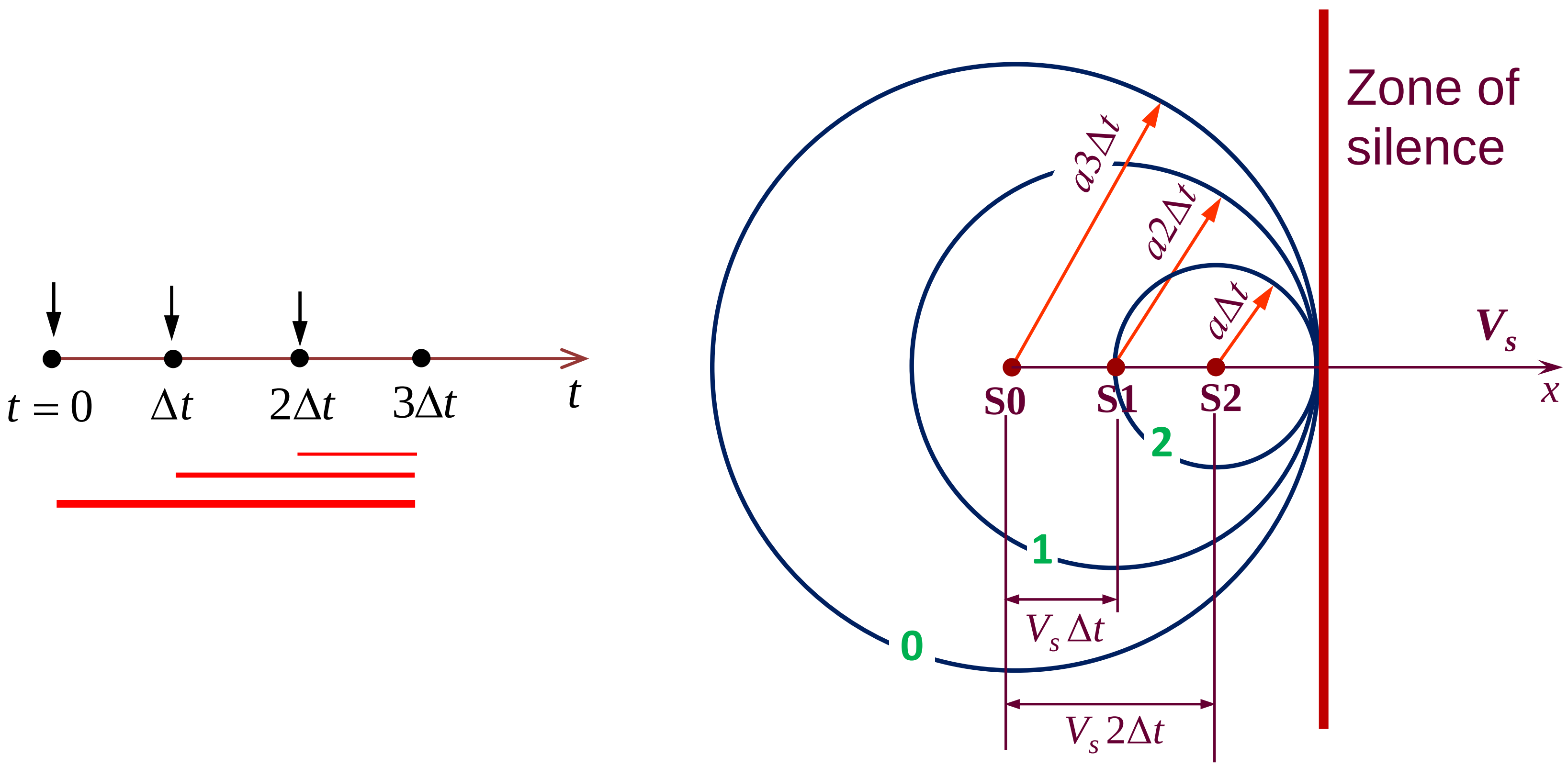
Wave Propagation

Now if the source, **S** is moving with velocity V_s, what will happen???

Case- II: Source (S) velocity is sonic (*M*=1) i.e. $V_s = a$

$$a\Delta t = V_s \Delta t \quad (\text{m})$$

$$a = \sqrt{kRT} \quad (\text{m/s})$$



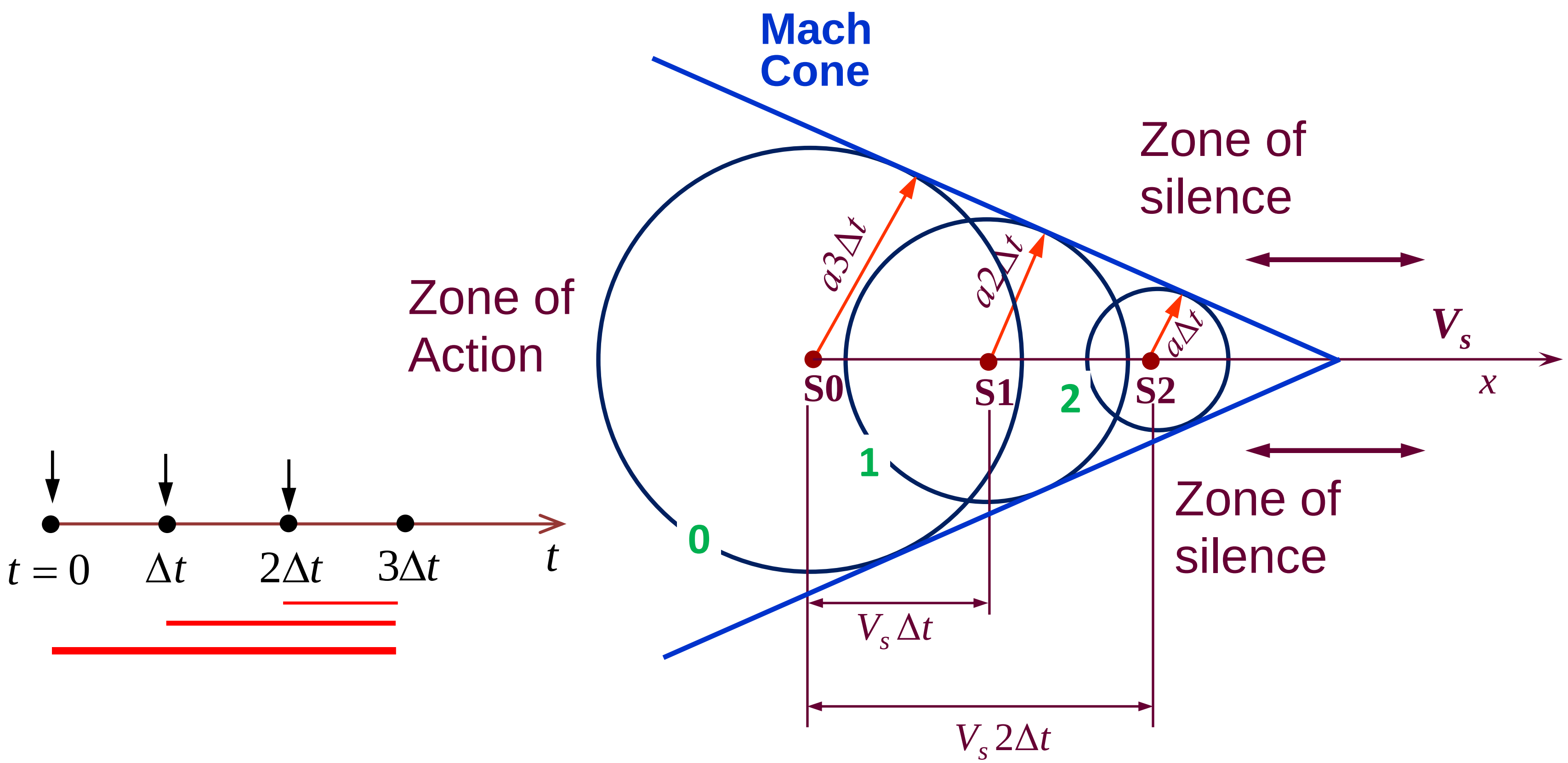
All the spherical waves become tangential to each other and collapse to a certain poin downstream

Point **S** is a source

Wave propagation with moving source, **S** **sonic** **($V_s = a$)**

Now if the source, **S** is moving with velocity V_s, what will happen???

Case- III: Source (S) velocity is supersonic (M>1) i.e. $V_s > a$



$$a\Delta t < V_s \Delta t \quad \text{(m)}$$

$$a = \sqrt{kRT} \quad \text{(m/s)}$$

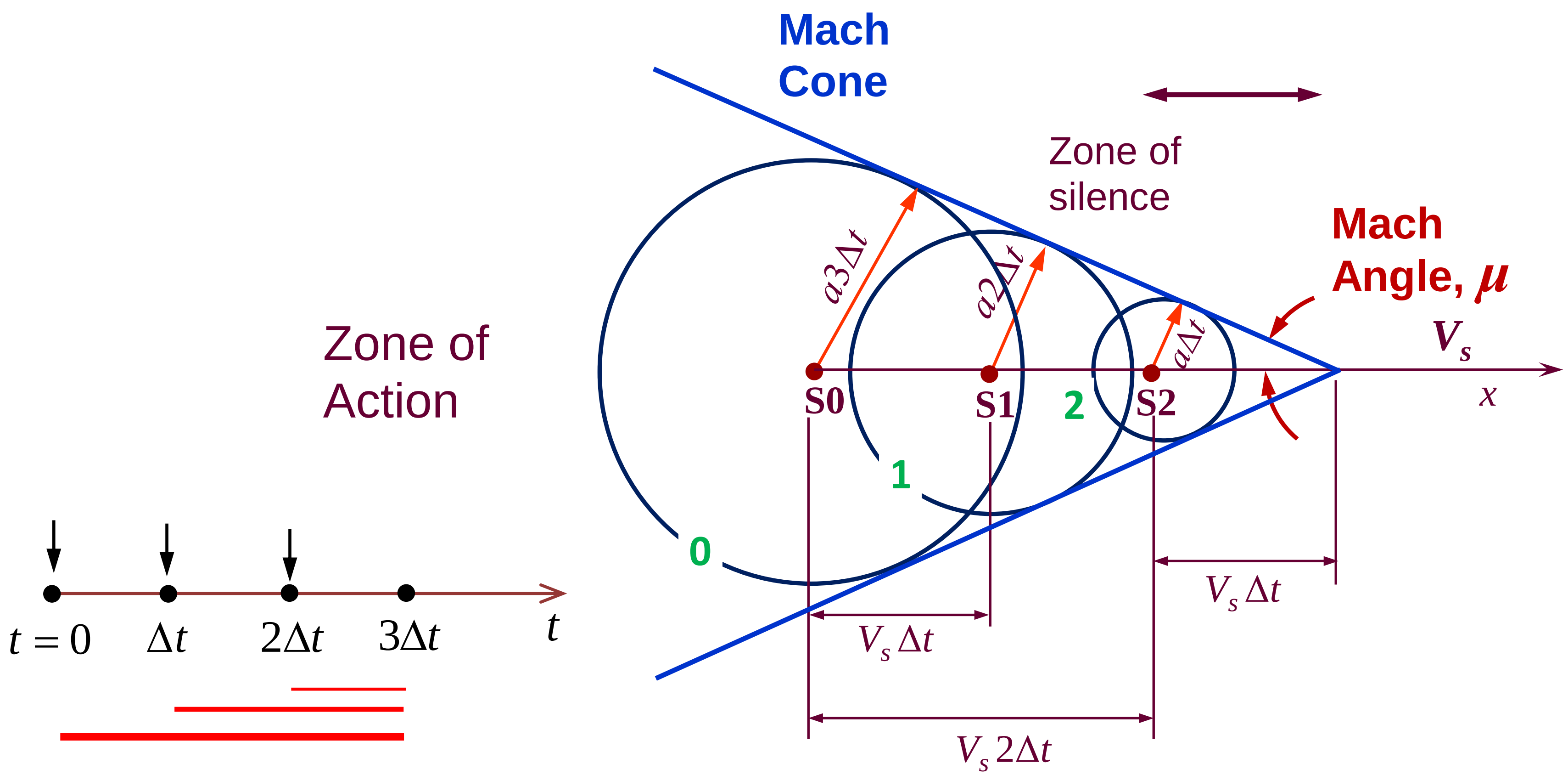
Spheres are swept away faster, then they are generated. The surface tangential to all the spherical waves forms a cone, known as Mach cone

Point **S** is a source

Wave propagation with moving source, **S supersonic ($V_s > a$)**

Wave Propagation

Case- III: Source (S) velocity is supersonic (*M*>1) i.e. V>*a*



$$a\Delta t < V_s \Delta t \quad \text{(m)}$$

Mach Angle: (from triangle)

$$\sin\mu = \frac{a\Delta t}{V_S \Delta t}$$

$$\Rightarrow \mu = \sin^{-1}\left(\frac{a}{V_S}\right)$$

$$\Rightarrow \mu = \sin^{-1}\left(\frac{1}{M}\right) \; ; \quad M = \frac{V_S}{a}$$

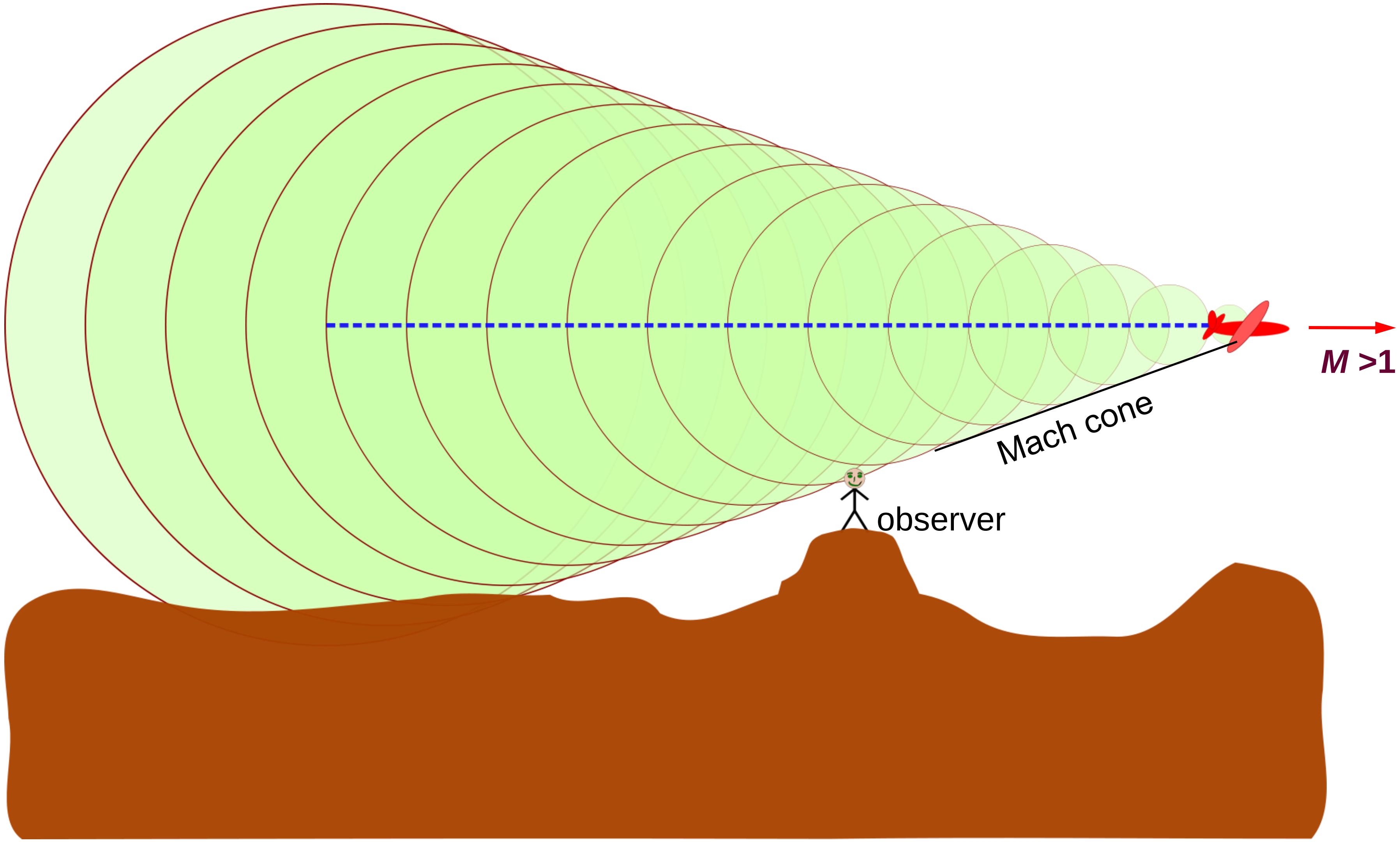
Valid for supersonic flow, *M*>1

Sonic Boom !!

Wave propagation with moving source, **S** **supersonic (V>*a*)**

Point **S** is a source

Sonic Boom

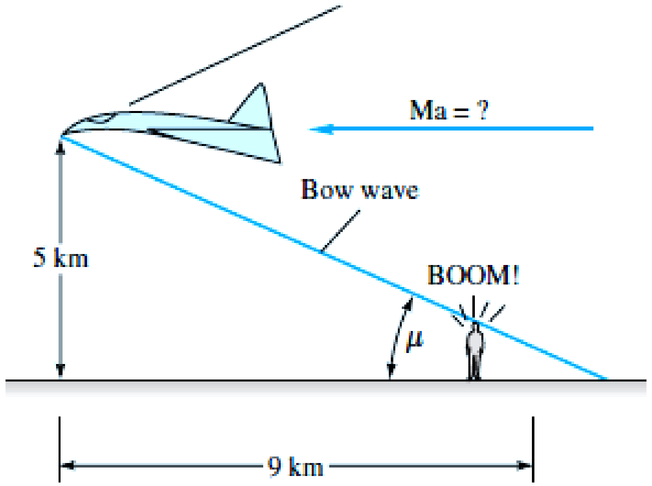


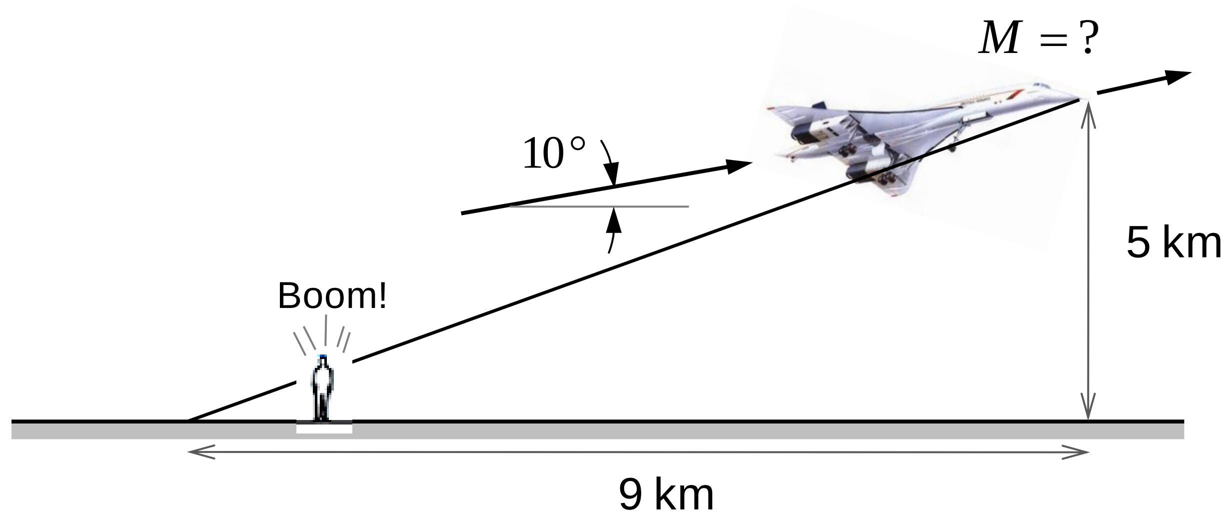
A **sonic boom** produced by an aircraft moving at M = 2.92, calculated from the cone angle of 20 degrees. Observers hear nothing until the shock wave, on the edges of the cone, crosses their location.

*https://en.wikipedia.org/wiki/Sonic_boom

Problem:

An observer on the ground does not hear the sonic boom caused by an airplane moving at 5-km altitude until it is 9 km past her. What is the approximate Mach number of the plane? Assume a small disturbance, and neglect the variation of sound speed with altitude.



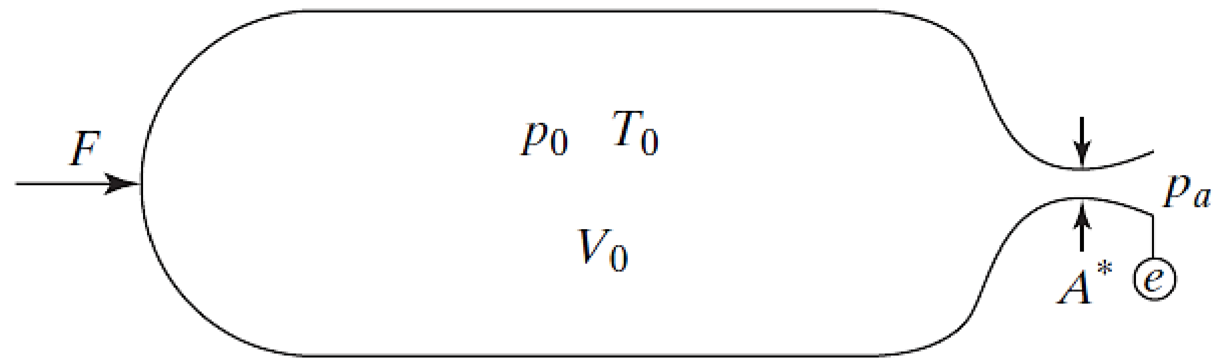


Home work

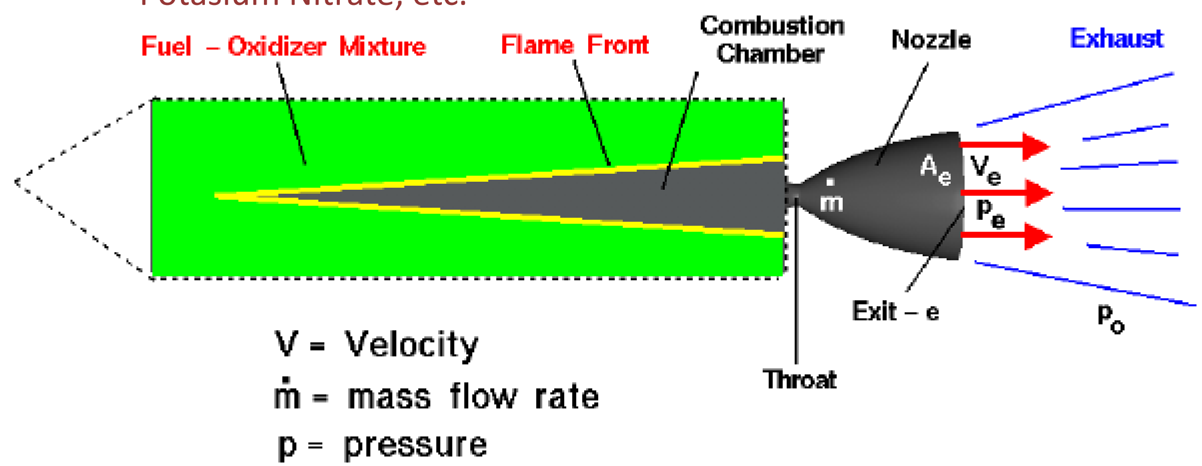
Blowdown Process from A High Pressure Reservoir

High Pressure Tank

- Solid-propellant rocket engine immediately after burnout
- Blowdown wind tunnel
- Pneumatic controls
- Gas venting from high pressure pipeline



Solid oxidizer: Ammonium nitrate, Ammonium dinitramide, Potasium Nitrate, etc.

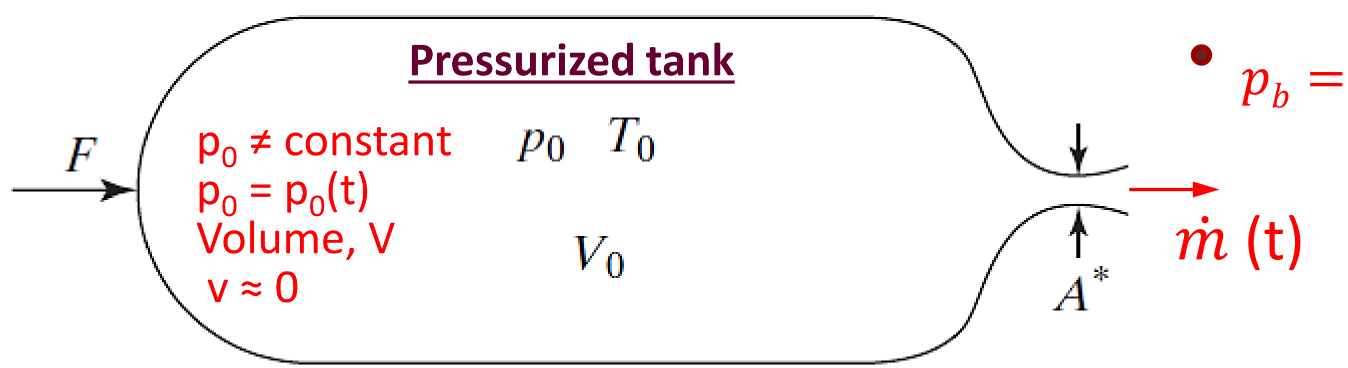


Solid-propellant rocket engine

Blowdown process: an Unsteady Problem

Assumptions:

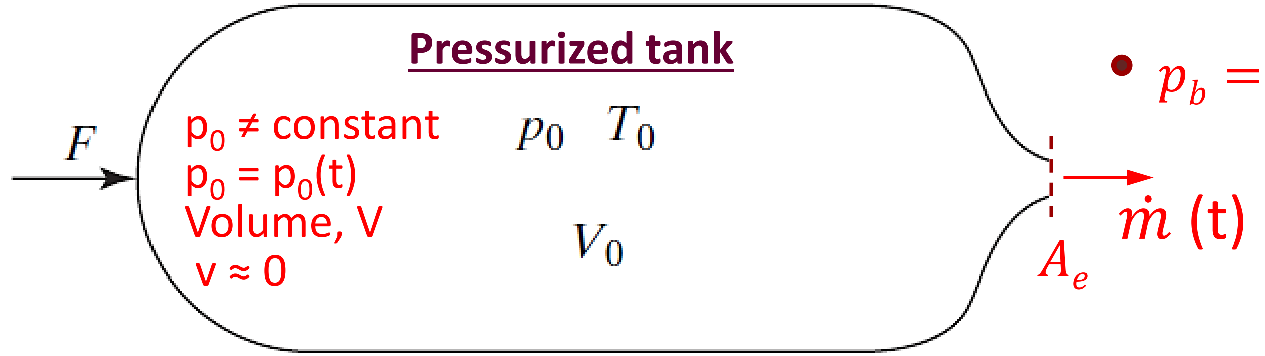
1) 1D flow
2) No viscous effect
3) Fluid behaves as ideal gas
4) adiabatic process (T_0 = const.)
5) Initial pressure ratio is above the critical condition.



- p_b = const.

Blowdown process: an Unsteady Problem

Blowdown from a converging nozzle



- $p_b = \text{const.}$