Today, we will:

- Discuss **Tunnel Ventilation** in **Section 5.14**
- Do some example problems – tunnel ventilation

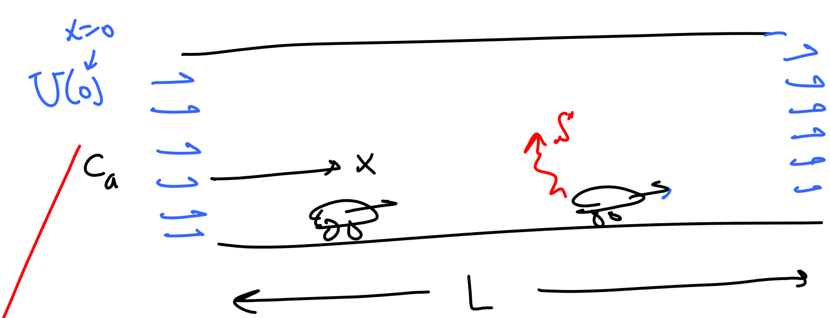
Sec. 5.14 TUNNEL VENTILATION (automotive tunnels only)

- Biggest problem is CO from vehicle exhaust
  ($\dot{S}$ is fairly large)
- CO level is not of great concern when driving through
  even if CO level > PEL, you are in tunnel for a short time
- Concerns:
  - Traffic jams
  - collisions & fires $\dot{S}$ is huge
    ↓
    Special fans that kick on for emergencies
  - tunnel workers → OSHA is concerned about air quality

We will discuss general tunnel ventilation

Classification of tunnel ventilation

1) Natural ventilation → no fans or anything



Good only for short tunnels

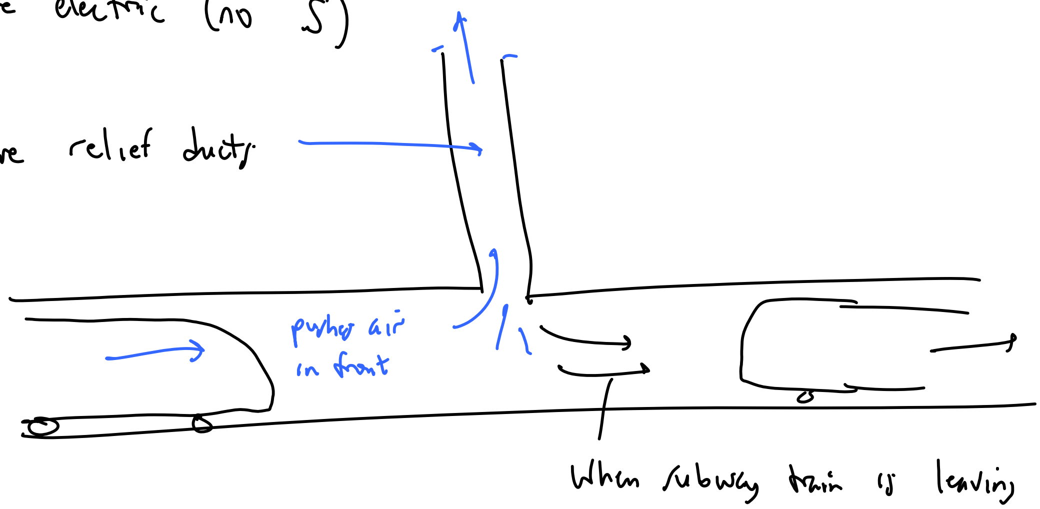
$L \lesssim 300$ m

$U(L) = U(0) = U$
= constant

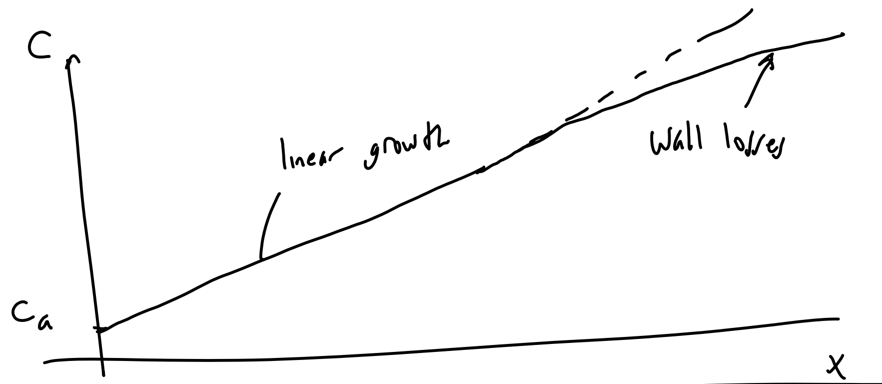
due to entrained air from the moving cars.

Subway tunnels also use natural ventilation usually because subway trains are electric (no S)

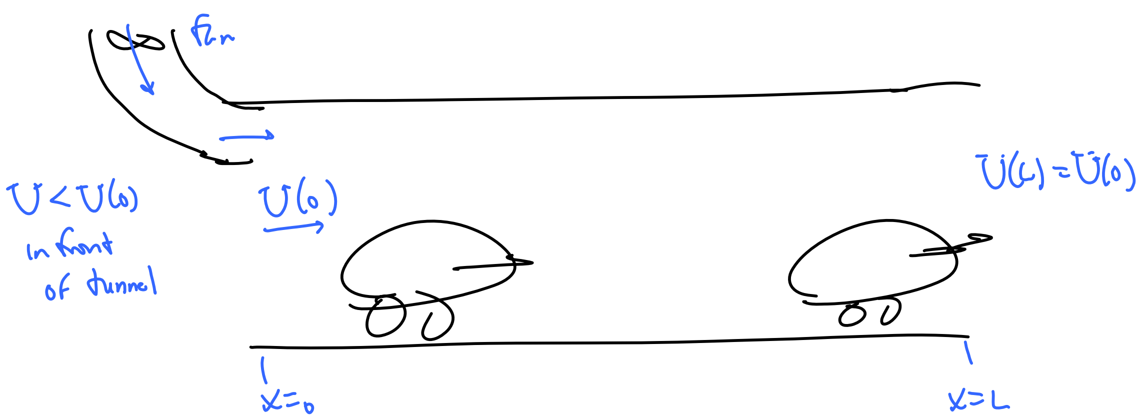
have relief ducts



Natural ventilation



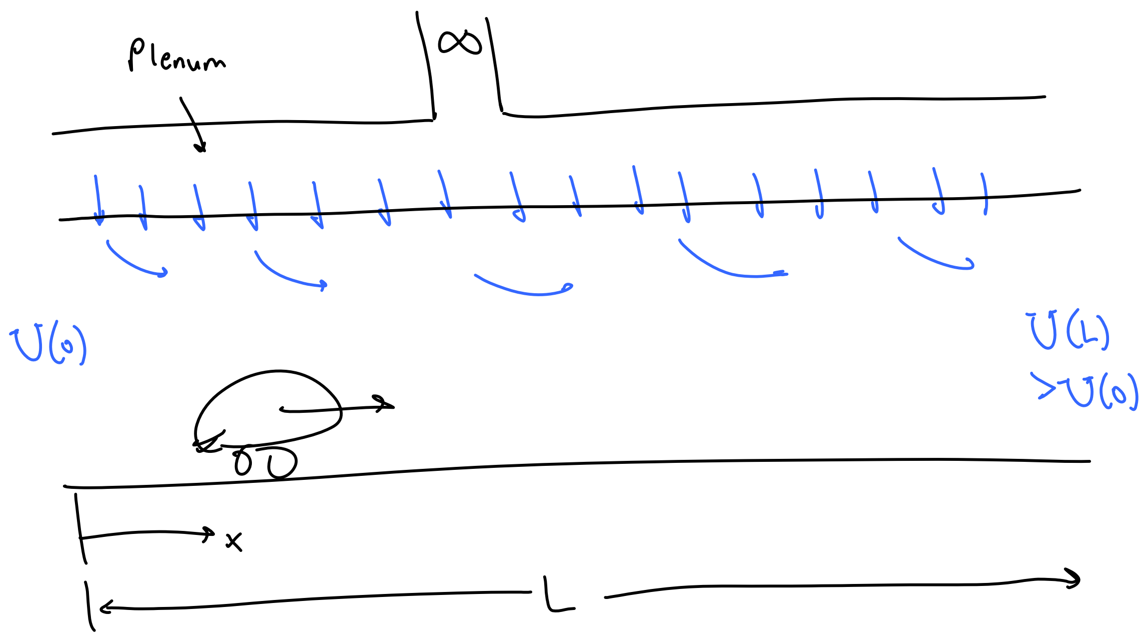
2) Local make-up air ventilation



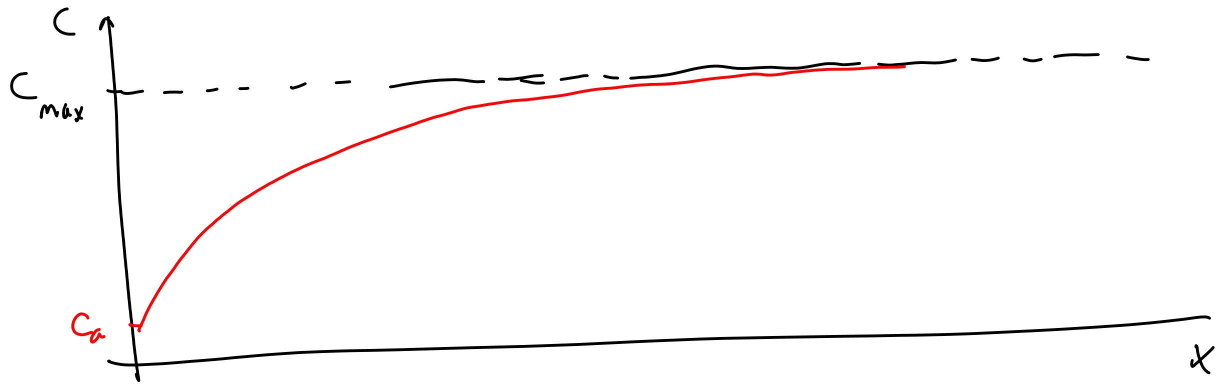
Same eqn & everything as natural case except $U(0)$ is bigger

Good for L up to ≈ 600 m

3) Uniform make-up air ventilation



C levels off eventually, since we are continuously supplying fresh air

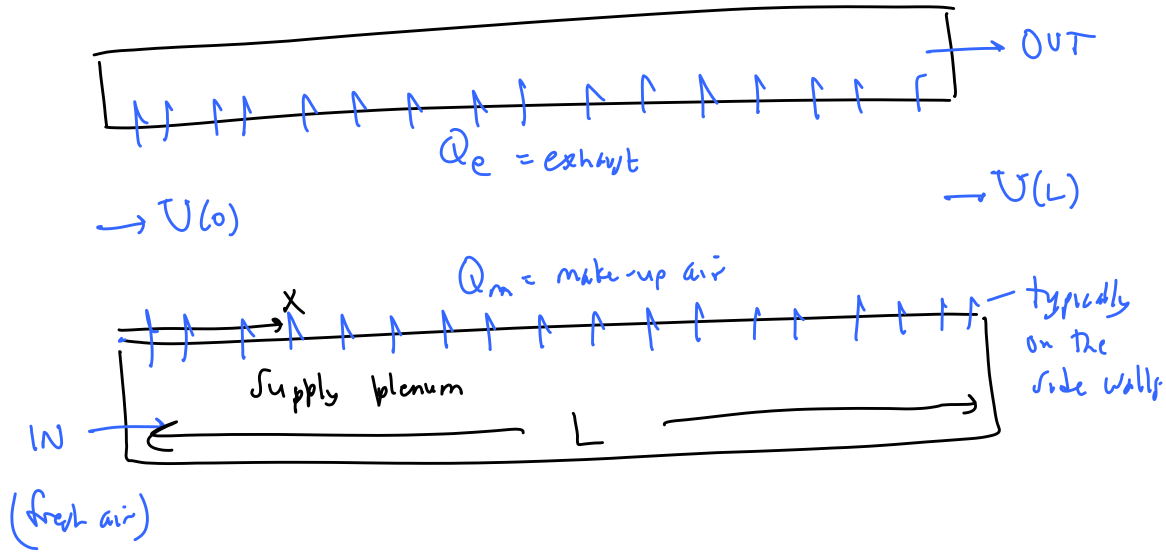


Good for $L \lessapprox 1500$ m

↓ U(x) keeps increasing with x (linearly)

U gets too big for safety

4) <u>Transverse Ventilation</u> (distributed supply (make-up air) <u>and</u> distributed exhaust air)



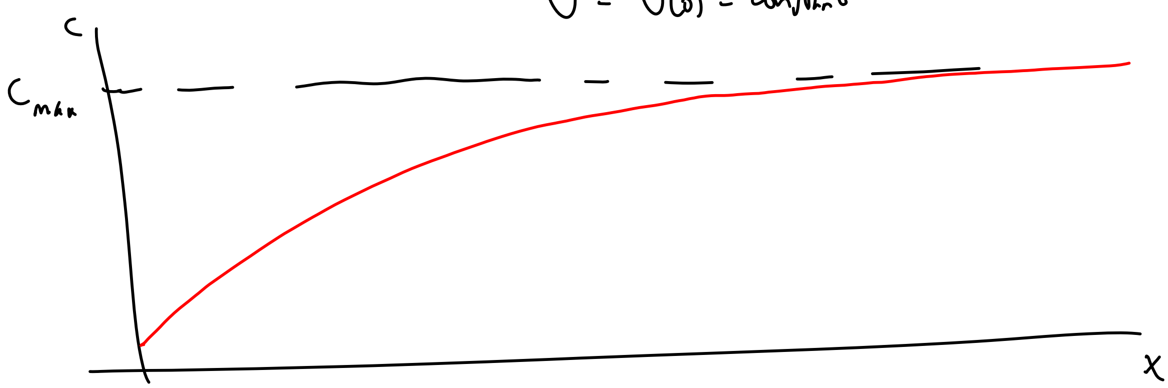
<u>Balanced</u> or <u>Unbalanced</u> transverse ventilation

* Balanced → $Q_e = Q_m$ → No limit to L

Unbalanced → $Q_e \neq Q_m$

$C = C(x)$, but levels off as before

$U = U(0) = \text{constant}$



Analysis of tunnel ventilation:

- $\dot{S}$ = func. of $(EF)_c$ — emission factor for a car $\left(\frac{mg}{car \cdot km}\right)$

Clean air act amendment of 1990 → limit ⟶ $\frac{9 \text{ g of CO}}{\text{mile}}$

$$(EF)_c = \frac{5600 \text{ mg}}{car \cdot km}$$

→ Think of as an upper limit

- n_c = traffic density $\left(\frac{cars}{km}\right)$
- L = tunnel length (km or m)
- V_c = car speed (km/hr)

$$\therefore \quad \dot{S} = \dot{m}_{pollutant} = \dot{m}_{CO} = (EF)_c \, n_c V_c L$$

$$\frac{mg}{car \cdot km} \; \frac{car}{km} \; \frac{km}{hr} \; km = \left(\frac{mg}{hr}\right)$$

Note: As $V_c \uparrow$, $n_c \downarrow$

In a traffic jam, this eq. does not hold

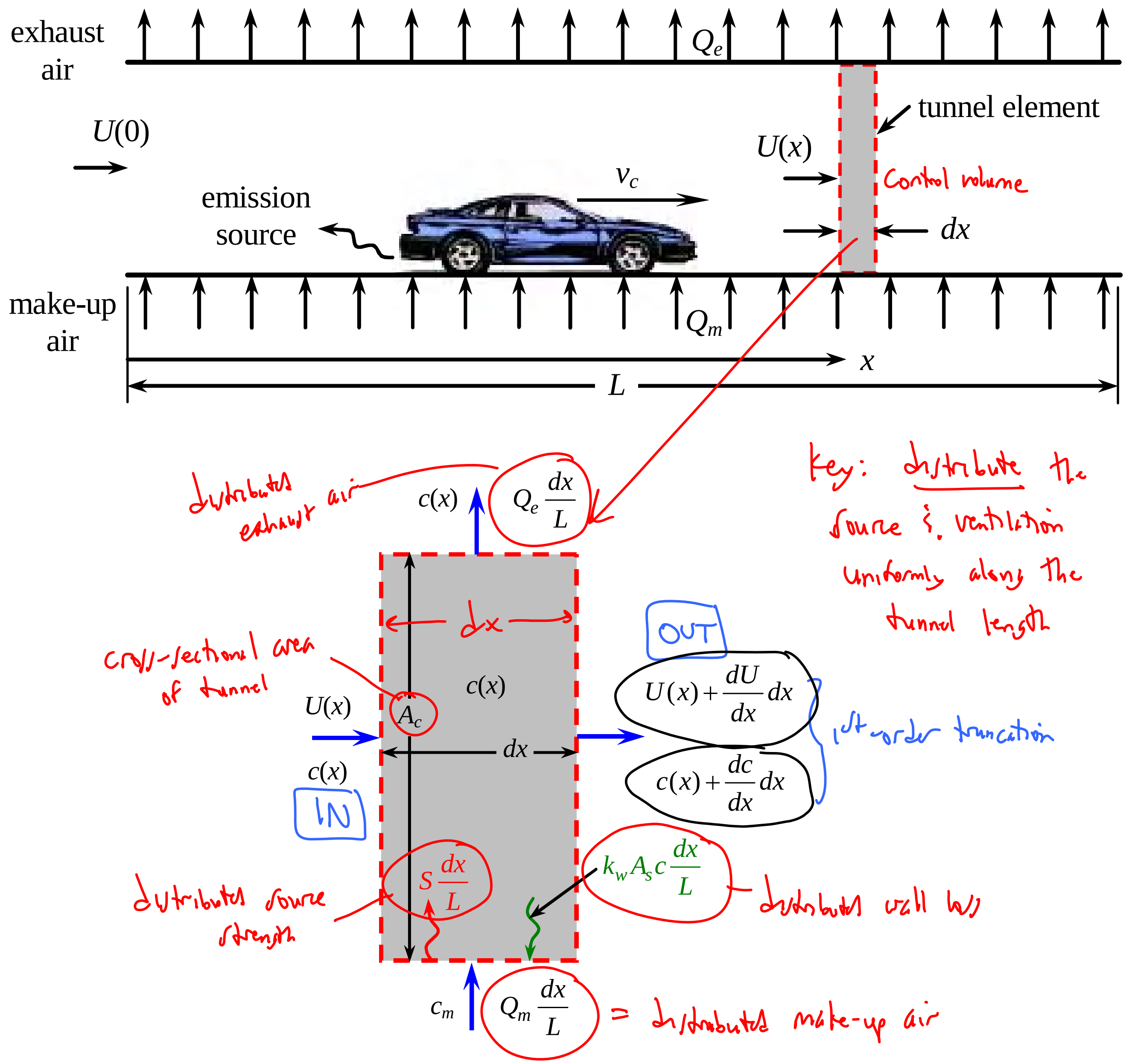
Use instead $\dot{S} = (EF)_c \, n_c L$

[Use a different $(EF)_c$ here]

$$\frac{mg}{car \cdot hr} \; \frac{car}{km} \; km = \left(\frac{mg}{hr}\right)$$

Let's look at a control volume analysis of a tunnel of length L

Automobile Tunnel Analysis: (General case)



* Assume CO is well-mixed vertically, but changes with x (horizontally)

  i.e. $c = c(x)$ only

  Also, $U = U(x)$ only (bulk air flow)

* Assume steady flow $c \neq c(t)$

Cons. of mass of the contaminant (in our CV)

$$\sum_{in} \dot{m}_j = \sum_{out} \dot{m}_j$$ (but let's drop the "j" subscript)

Positive or inflow terms = Negative or outflow terms

$$U c A_c + S \frac{dx}{L} + Q_m \frac{dx}{L} c_m$$

$$= \underbrace{\left(U + \frac{dU}{dx} dx\right)\left(c + \frac{dc}{dx} dx\right)}A_c + k_w A_s c \frac{dx}{L} + Q_e \frac{dx}{L} c$$

neglect the higher order term $\frac{dU}{dx}\frac{dc}{dx} dx^2 A_c$

ignore since dx is small