Trills

Fun Stuff

- Guess the word!
  - https://ericlgame.itch.io/guess-the-word
- Also: Miriam Makeba’s “click song”.

Back to Aerodynamics

- Aerodynamic method #1: Stops

A. start air flow
   - Remember: Boyle’s Law
   - And: Air flows from high to low pressure

B. stop air flow
   - Just bring two articulators together.

C. release air flow
   - Just relax!
   - Not an explosion
   - Air pressure differences do the work
   - Release burst example: Bengali exercises

Another Aerodynamic Method

- What kind of sound is this?
- A **Trill**. A Voiced Bilabial Trill: [ʙ]
- Examples from Kele and Titan
    - (Island of Manus, north of New Guinea)

	KELE		TITAN	
BILABIAL	mʙuɛŋkeiʔ 'fruit' (species)	mʙulim 'face'	mbulei 'rat'	mbutukei 'wooden plate'

How Fast?

- Any volunteers?
- Take a look at the waveform
- (Note: period vs. frequency)
- Do we close and relax our lips each time we do this?
- No?
- When air blows the lips apart, why don’t they stay apart?

Bernoulli Effect

- In a flowing stream of particles:
  - the pressure exerted by the particles is inversely proportional to their velocity
- Pressure = $\frac{\text{constant}}{\text{velocity}}$
  - P = k / v
- $\Rightarrow$ the higher the velocity, the lower the pressure
- $\Rightarrow$ the lower the velocity, the higher the pressure

Daniel Bernoulli

(1700-1782)

Bernoulli Examples

- Airplane wing
- Frisbee

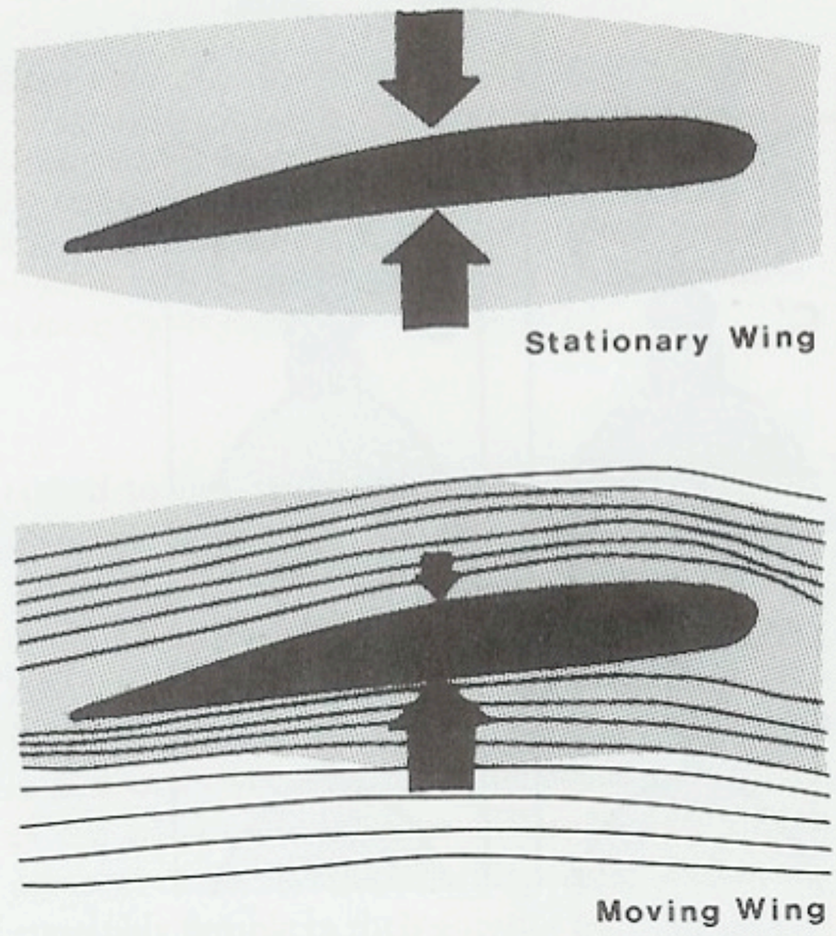
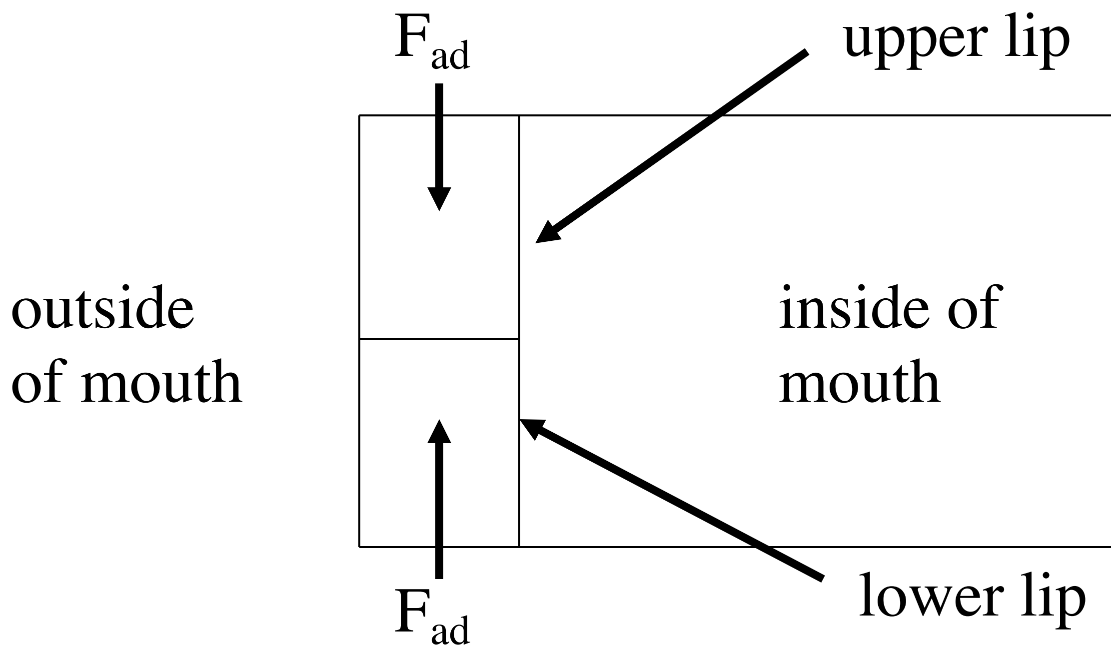


Figure 4.43. Aerodynamic forces on an airplane wing.

- Shower Curtain
- Pieces of paper
- Bilabial trills!
- Reese's Trills

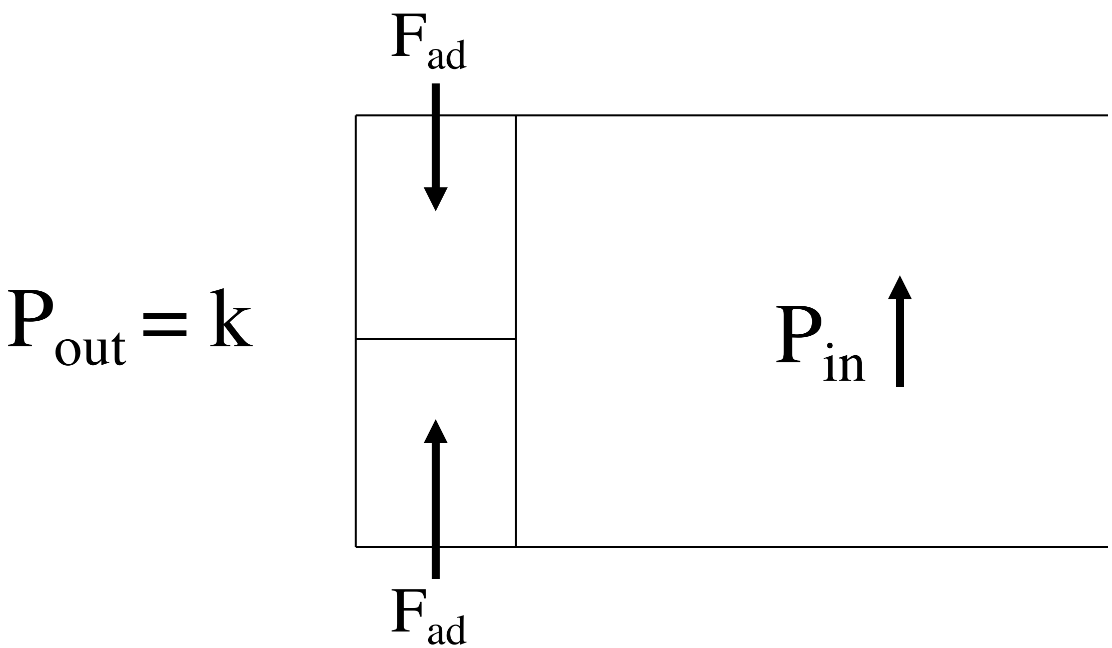
A Trilling Schematic

- Lips are closed
  - **adducted** = brought together
- F_{ad} = adductive force



Trilling: Stage 1

- Pressure builds up inside mouth from compression of lungs
  - P_{in} = Air Pressure inside mouth
- Outside pressure remains constant
  - P_{out} = Air Pressure outside mouth

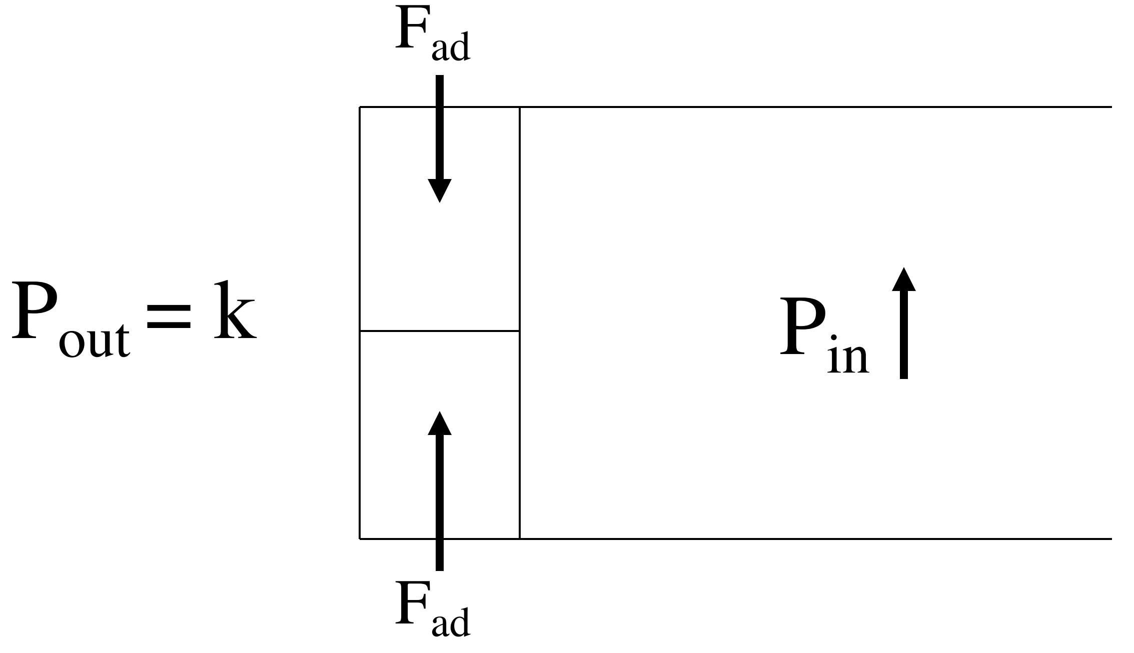


Trilling: Stage 1

- Pressure differential between inside and outside builds up

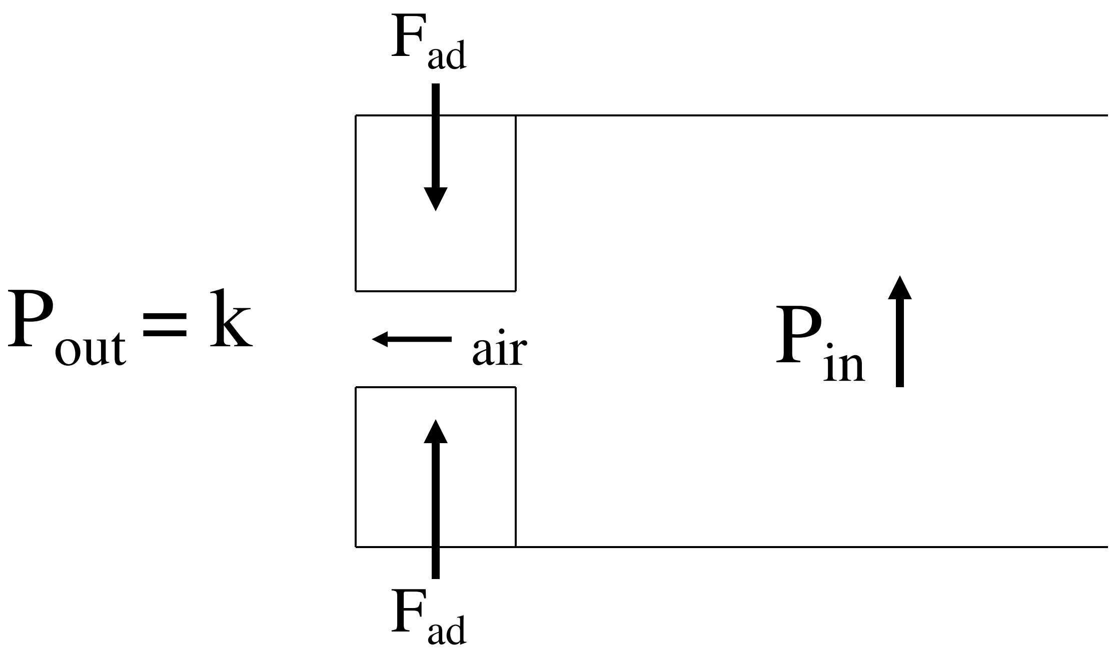
$$\Delta P = (P_{in} - P_{out}) \uparrow$$

- This exerts force against the lips



Trilling: Stage 2

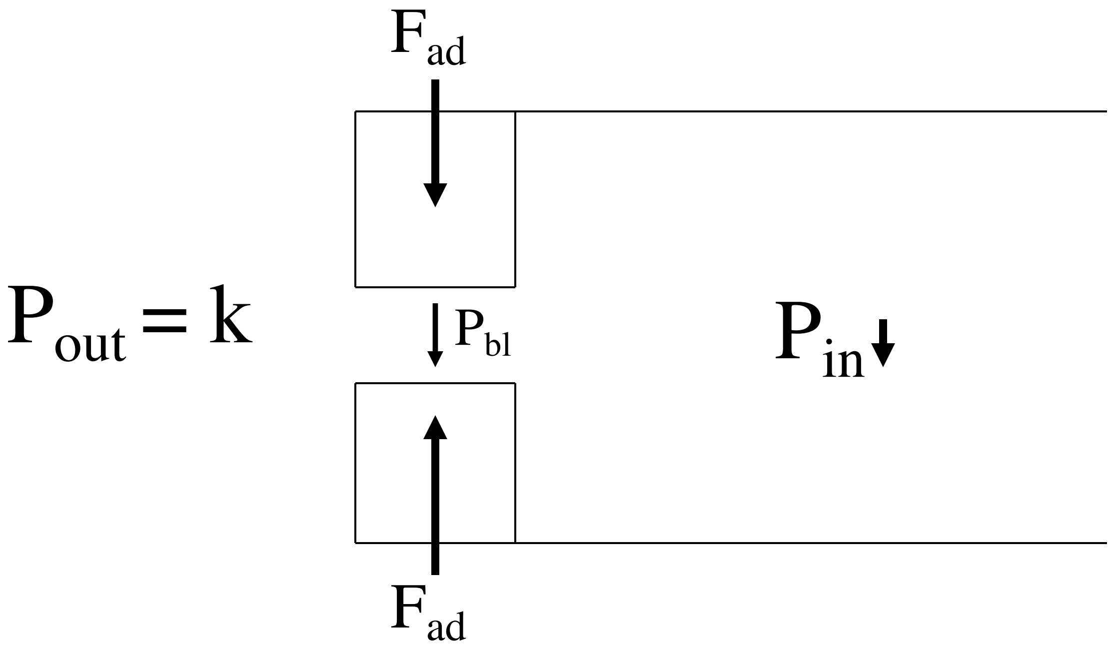
- Pressure differential blows open lips
- Air rushes from high to low pressure



Trilling: Stage 2

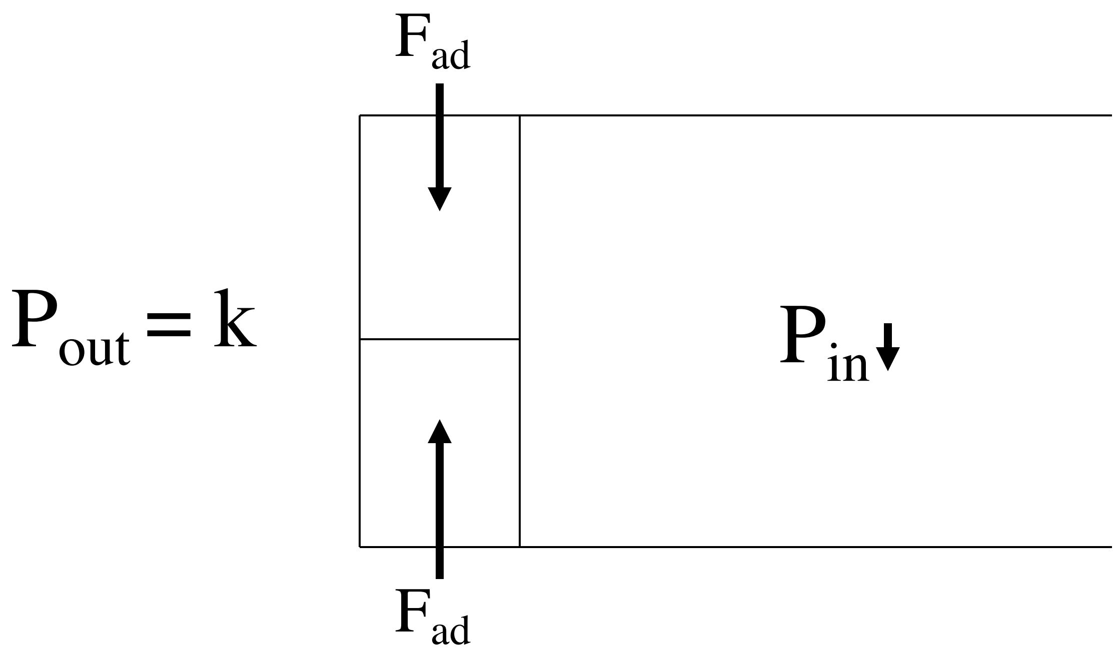
- The opening of the lips means:

1. ΔP decreases slightly
2. High velocity of air flowing between lips
3. Air pressure decreases between lips (Bernoulli Effect)



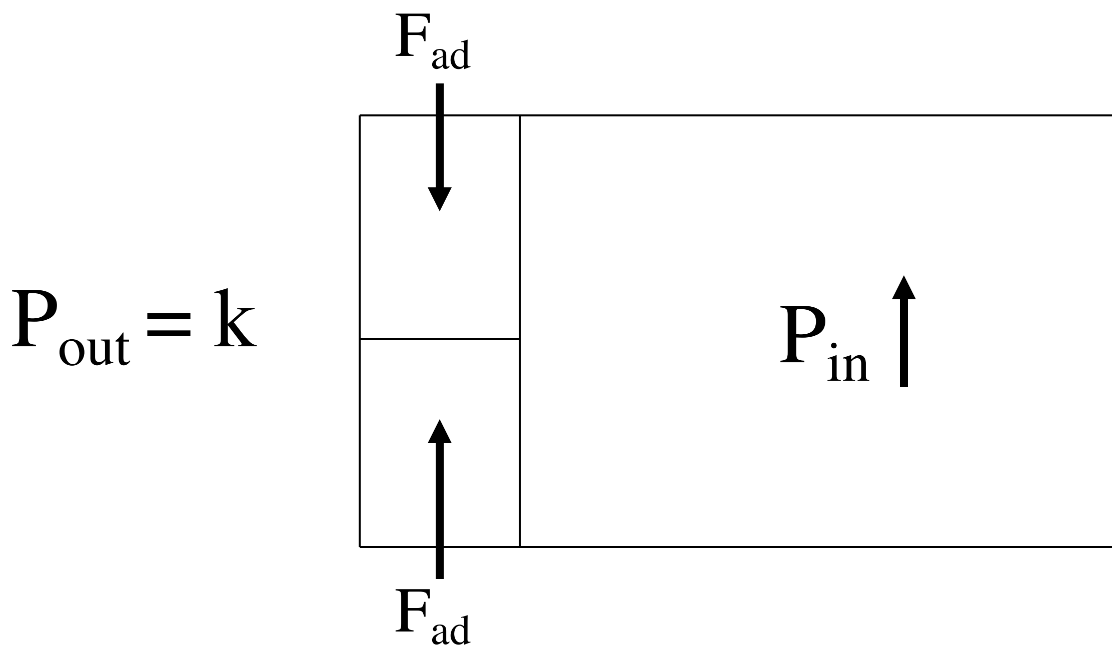
Trilling: Stage 3

- Lips get sucked back together



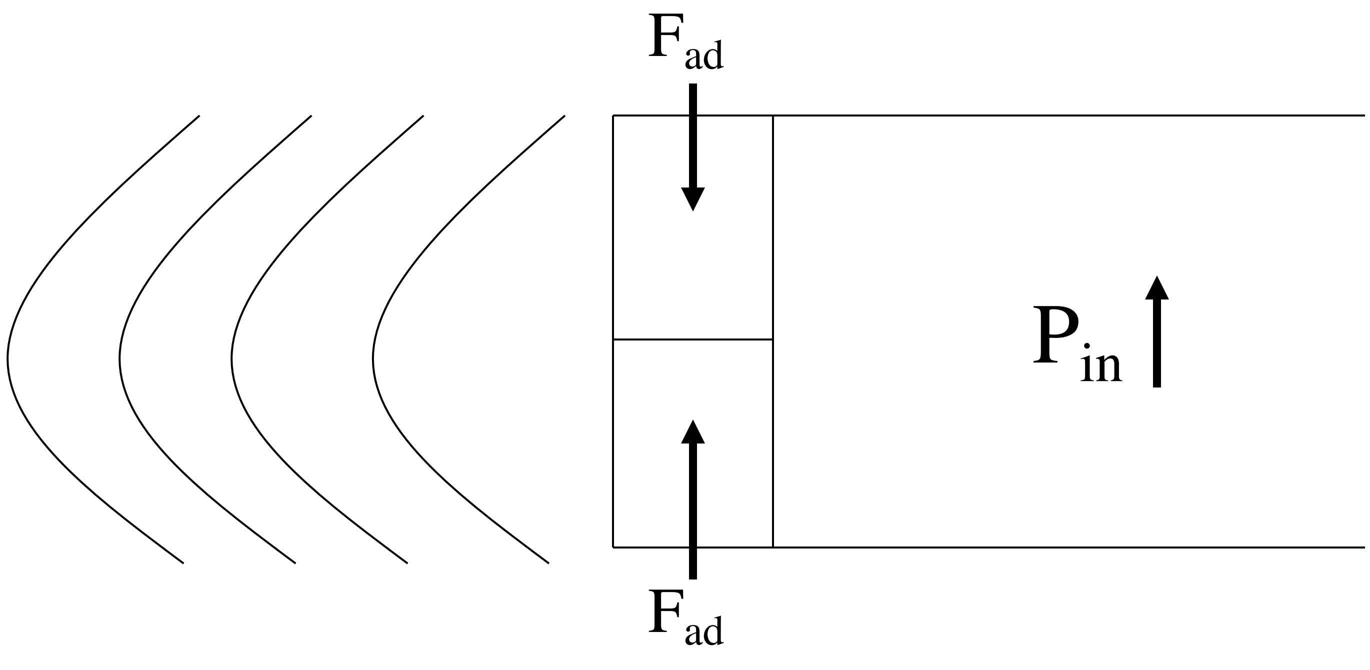
Trilling: Back to Stage 1

- If air is still flowing out of lungs, pressure will rise again within mouth
- Process will repeat itself as long as air is pushed up from lungs and lips are held lightly against each other



Trilling: Back to Stage 1

- Air rushes through the lips in a series of short, regular bursts



Other Trills

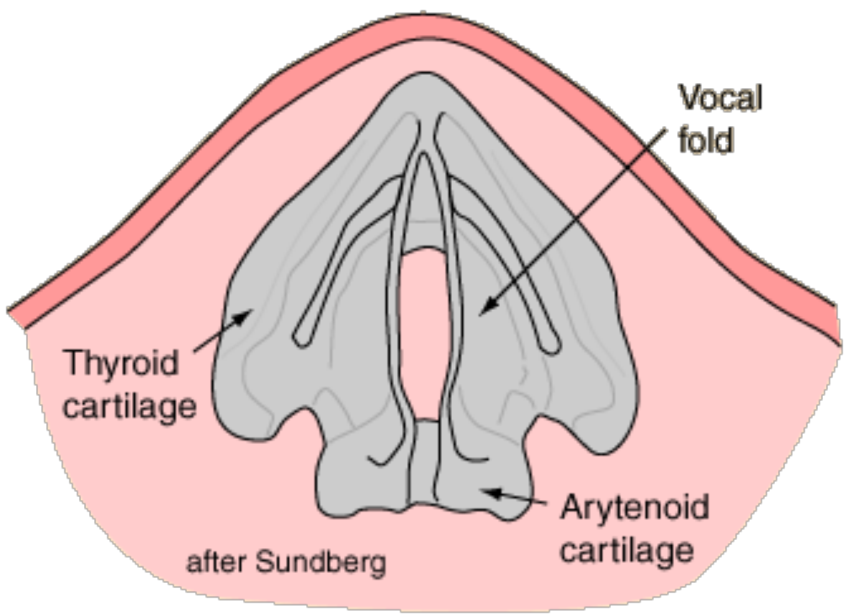
- Alveolar trills: [r]
- Examples from Kele and Titan

	Kele		Titan	
Alveolar	^{n}ruwin 'bone'	^{n}rikei 'leg'	^{n}ruliʔ 'sandpiper'	^{n}rakeiʔin 'girls'

- Uvular trills: [ʀ]
- Pour example: Edith Piaf
- Any other places of articulation for trills?

Voicing = Glottal Trills

- Voicing occurs when:
  1. air rushes up from the lungs
  2. the vocal folds are brought together (adducted)



Creaky Voicing

- The flow of air from the lungs forces the vocal folds to open and close.
- The slowest type of voicing is called “creaky voice.”

Modal Voice

- This is normal, or “modal” voicing. The rate of glottal trilling is considerably faster.

- How fast do you think the vocal folds open and close in normal voicing?

Vocal Fold Specs

- In bilabial trills, lips open and close 20-25 times a second
- In modal voicing, the glottal trill cycle recurs, on average:
- 120 times a second for men
- 220 times a second for women
- 300+ times a second for children

Vocal Fold Specs

- Air rushes through vocal folds at 20 to 50 meters per second
  - Between 72 and 180 km/h or kph (45 ~ 120 mph)
- Due to Bernoulli Effect, pressure between vocal folds when this occurs is very small
- Speed of “glottal trill” cycle depends on:
  - thickness of vocal folds
  - **tenseness of vocal folds**
  - length of vocal folds

Vocal Fold Specs

- In men, vocal folds are 17-23 millimeters long
  - In women, vocal folds are 12-17 millimeters long
- Adult male vocal folds are 2-5 millimeters thick
  - Adult female vocal folds are slightly thinner
- Thicker, longer folds vibrate more slowly
  - Think: violin strings vs. bass strings
- Tenseness of vocal folds can be changed to alter the speed of glottal opening and closing.
  - Like tuning a violin or a guitar…

Terminology

- **Frequency** is the rate at which vocal folds are opening and closing
  - measured in Hertz (cycles per second)
- **Period** is the length of time between cycles
  - Period = 1 / Frequency
- **Pitch** is the perception of frequency
  - Lower frequency = lower perceived pitch
  - Higher frequency = higher perceived pitch

Laryngeal Settings

- We now know of two basic laryngeal settings for any pulmonic egressive sound:

1. Vocal folds are **adducted** (brought together)
   - Air from lungs makes vocal folds “trill”
   - = **voiced** sounds
2. Vocal folds are **abducted** (held apart)
   - Air passes through glottis unobstructed
   - = **voiceless** sounds

Independence

- Stops can be voiced or voiceless.
- Two anatomically independent settings:
    - Place of articulation
    - Voiced/Voiceless
- Are these two settings *aerodynamically* independent of each other?
- Is it easier to make a voiced or a voiceless stop?

Cross-linguistic Data

- From Ruhlen (1976), who surveyed 706 languages
- 75% had both voiced and voiceless stops
- Of the remaining 25%...
- 24.5% had only voiceless stops
- 0.5% had only voiced stops

Upsid Again

- Voiced bilabial stops – 322
- Voiceless bilabial stops - 402
- Voiced alveolar stops – 137
- Voiceless alveolar stops - 195
- Voiced velar stops – 283
- Voiceless velar stops – 438

$\Rightarrow$ voiced stops are hard

One step further

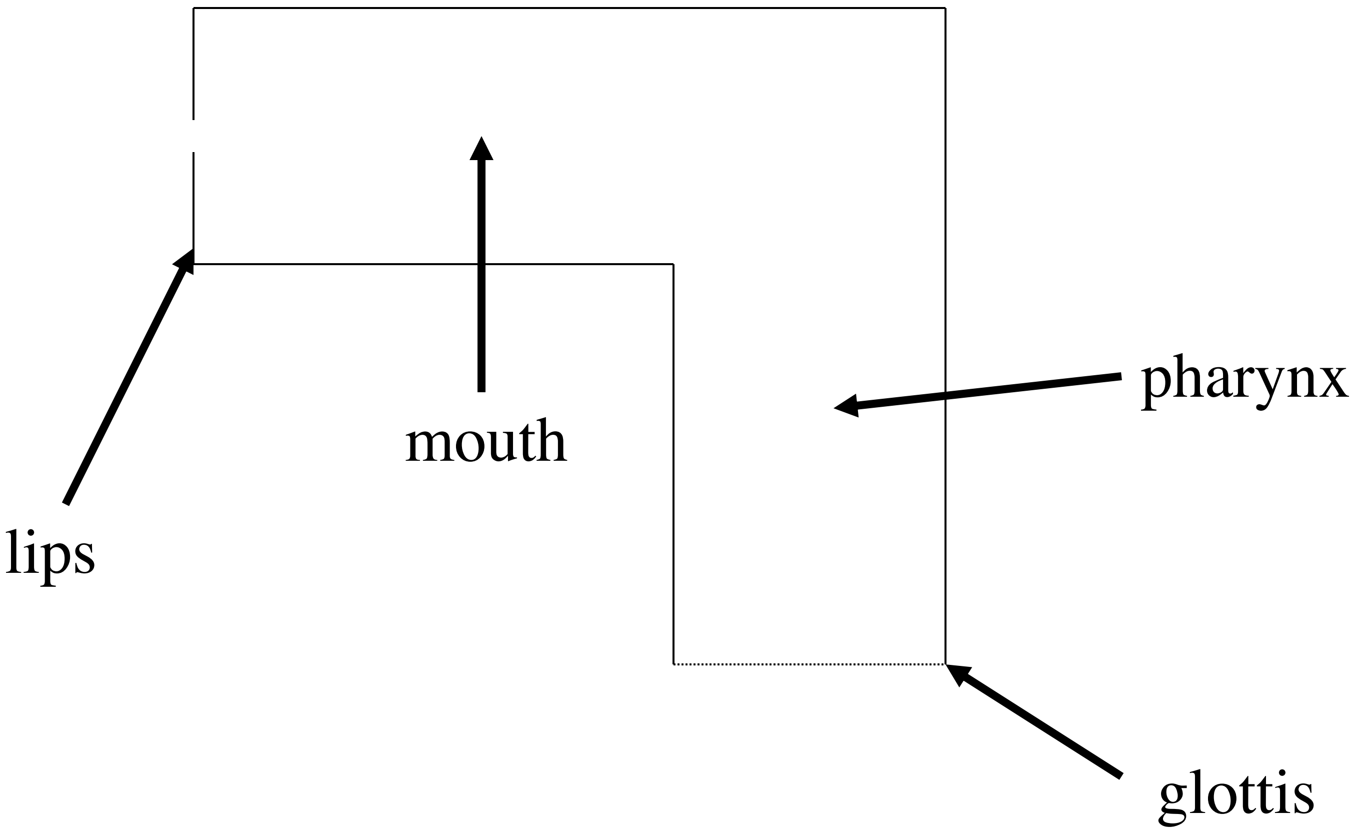
- Are some voiced stops harder than others?
- Stop inventories:

English	p	t	k
	b	d	g
Thai	p	t	k
	b	d	
Efik		t	k
	b	d	

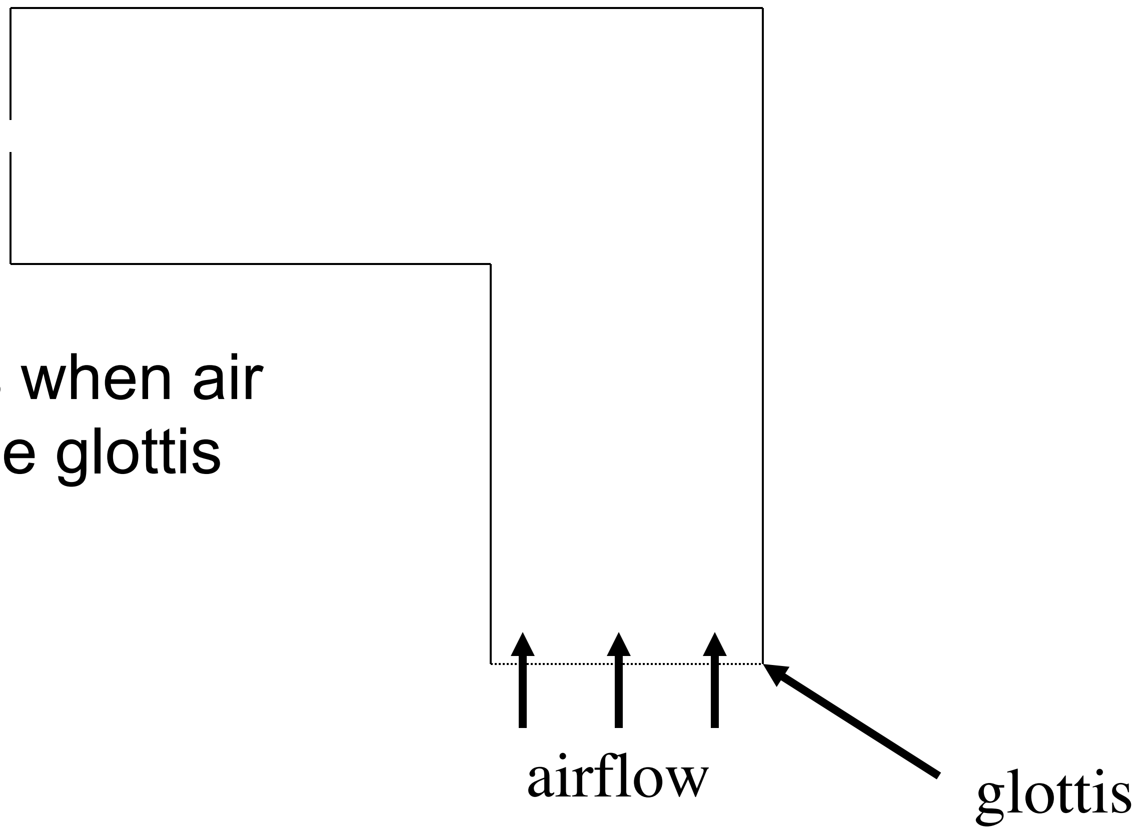
More Cross-Language Data

- From Sherman (1975), who surveyed the stop inventories of 87 languages.
- 2 languages were missing voiced bilabials
- 21 languages were missing voiced dentals/alveolars
- 40 languages were missing voiced velars
- $\Rightarrow$ voiced velars are particularly hard
- Why?

Place and Volume: a schematic

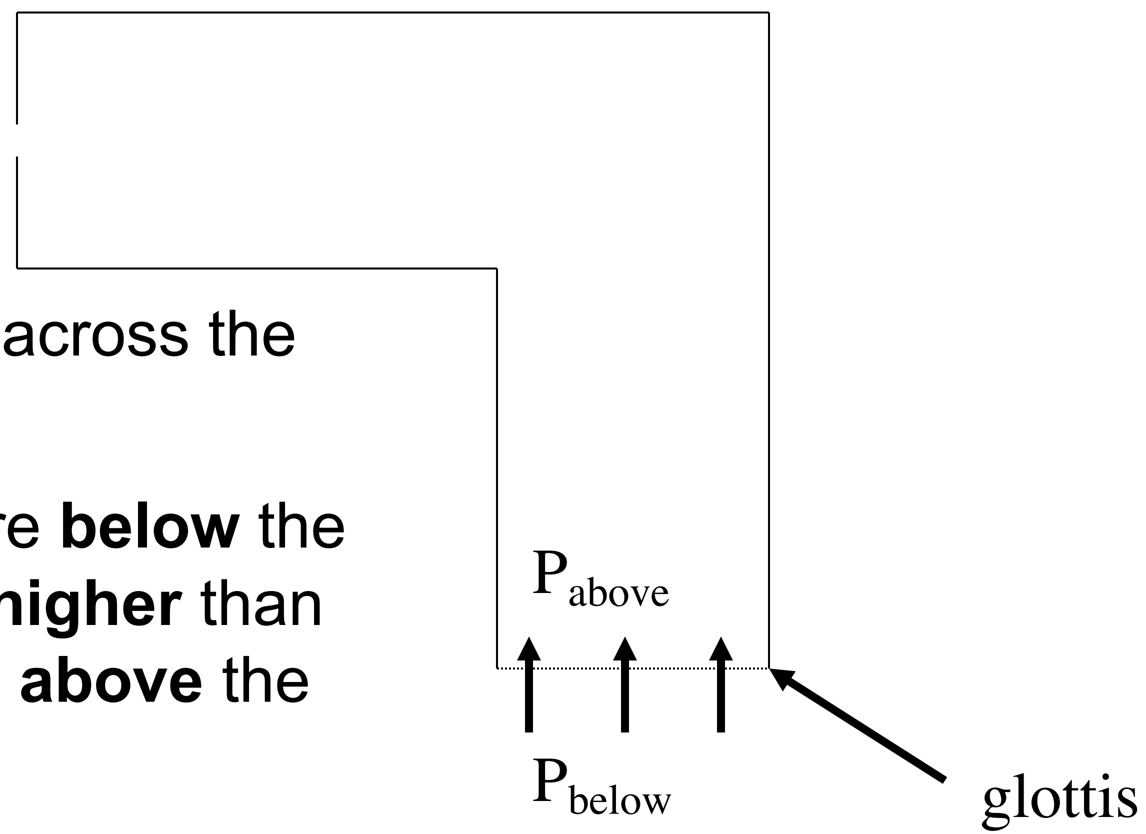


Place and Volume: a schematic



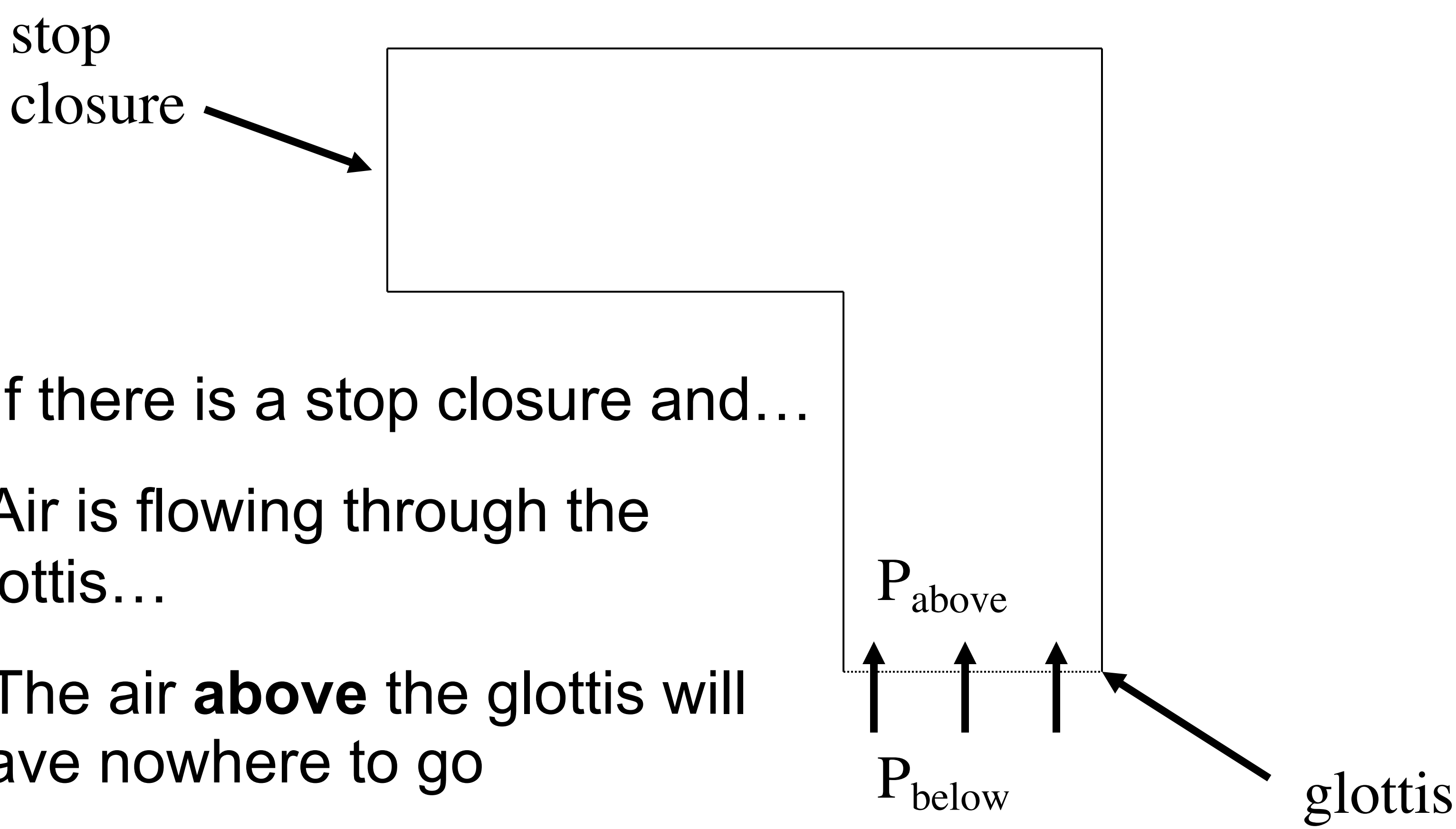
• Voicing occurs when air flows through the glottis

Place and Volume: a schematic



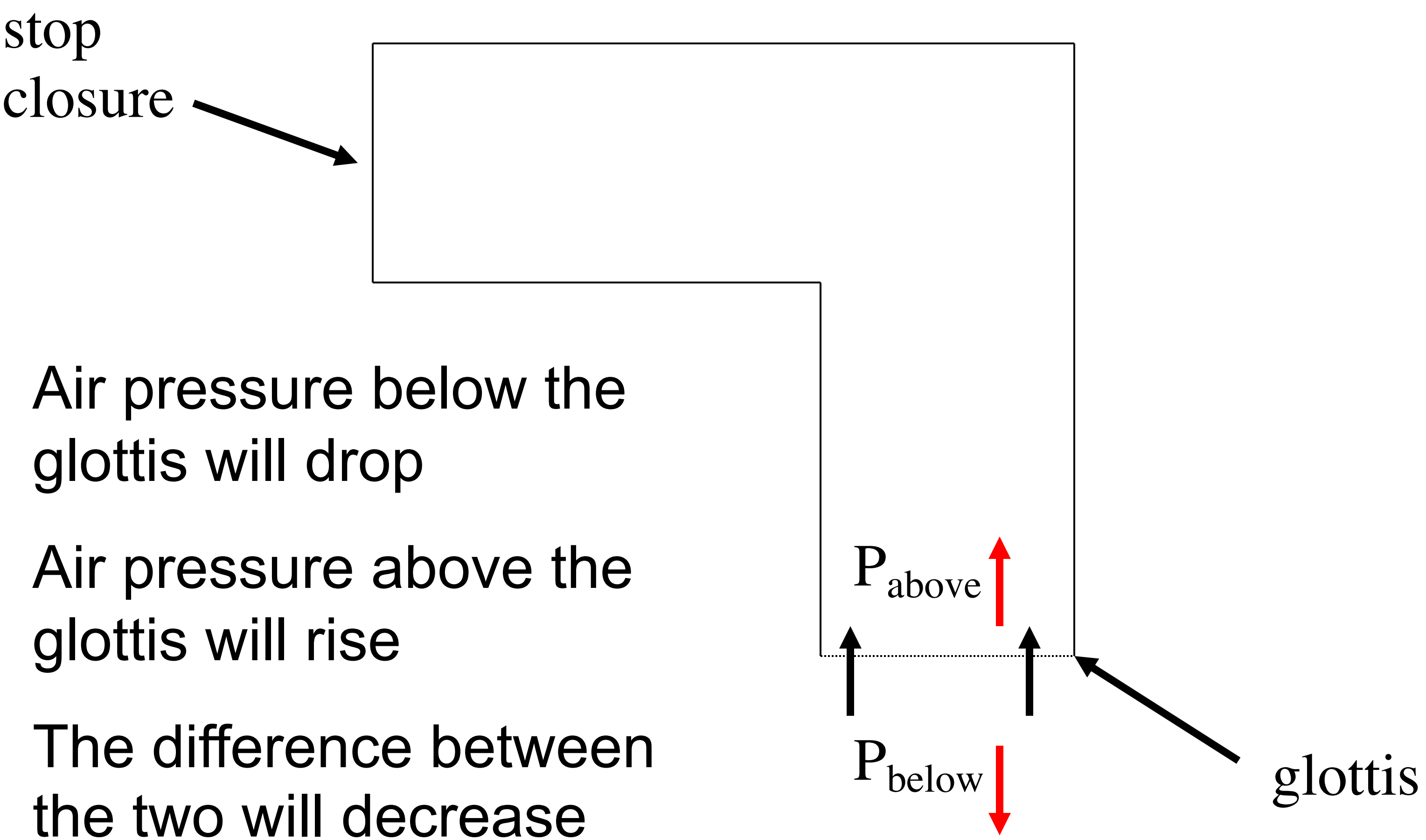
- For air to flow across the glottis…
- the air pressure **below** the glottis must be **higher** than the air pressure **above** the glottis
- $P_{below} > P_{above}$

Place and Volume: a schematic



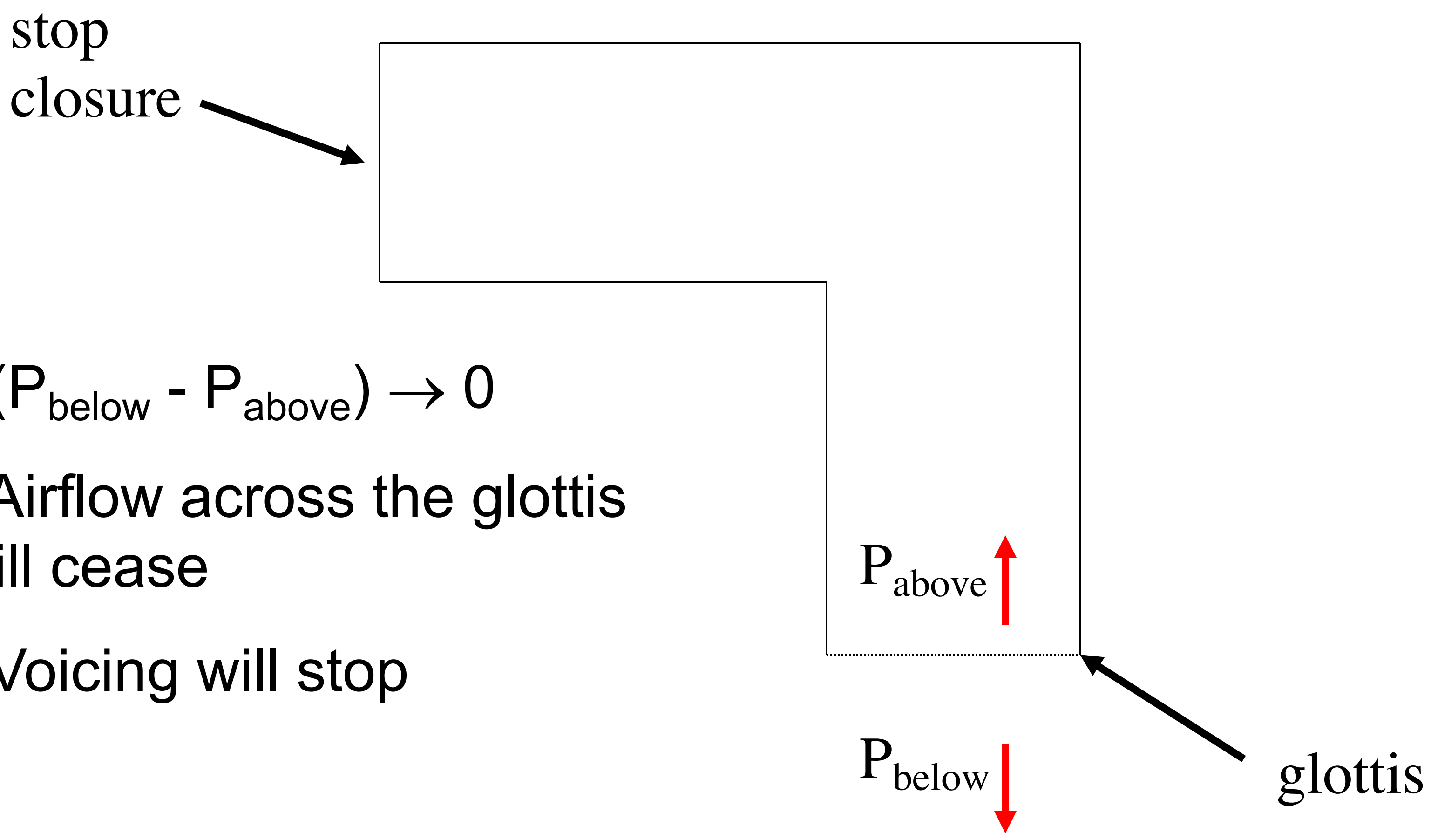
- If there is a stop closure and…
- Air is flowing through the glottis…
- The air **above** the glottis will have nowhere to go

Place and Volume: a schematic



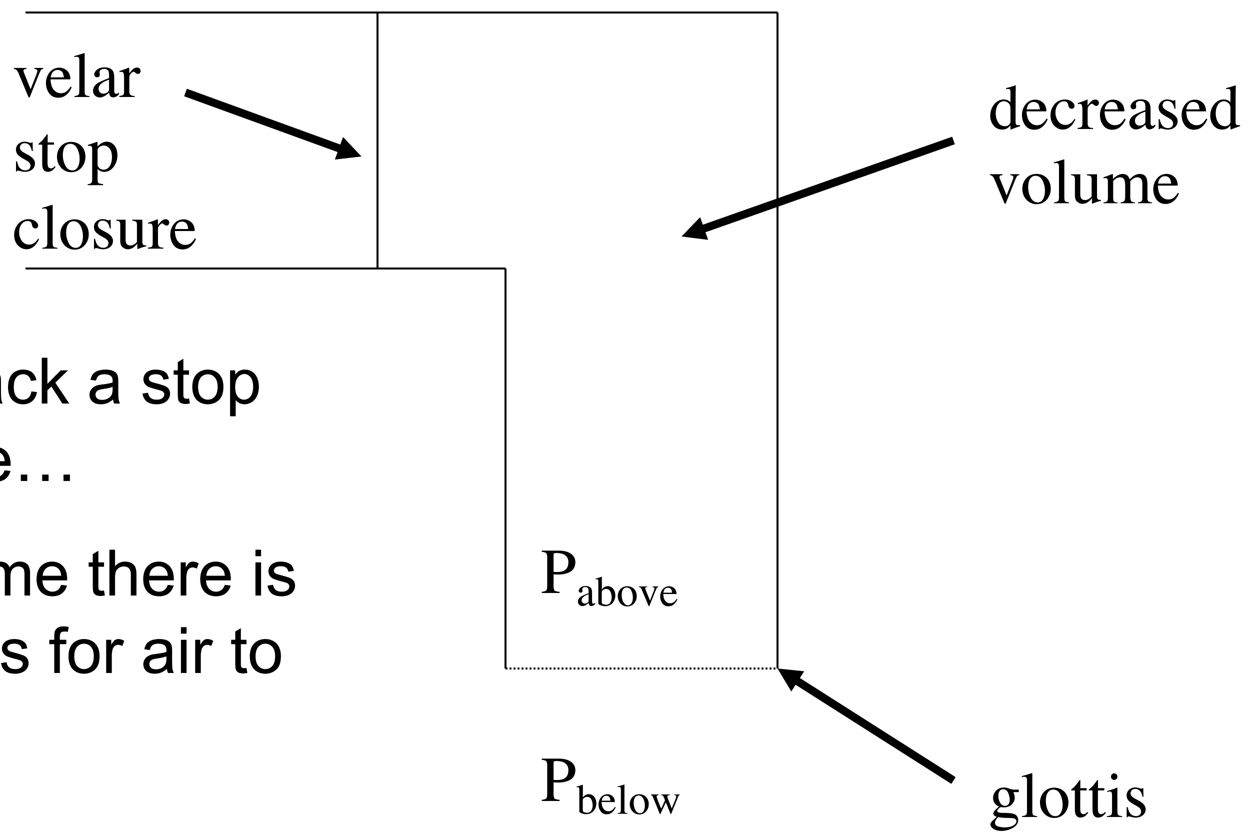
1. Air pressure below the glottis will drop
2. Air pressure above the glottis will rise
3. The difference between the two will decrease

Place and Volume: a schematic



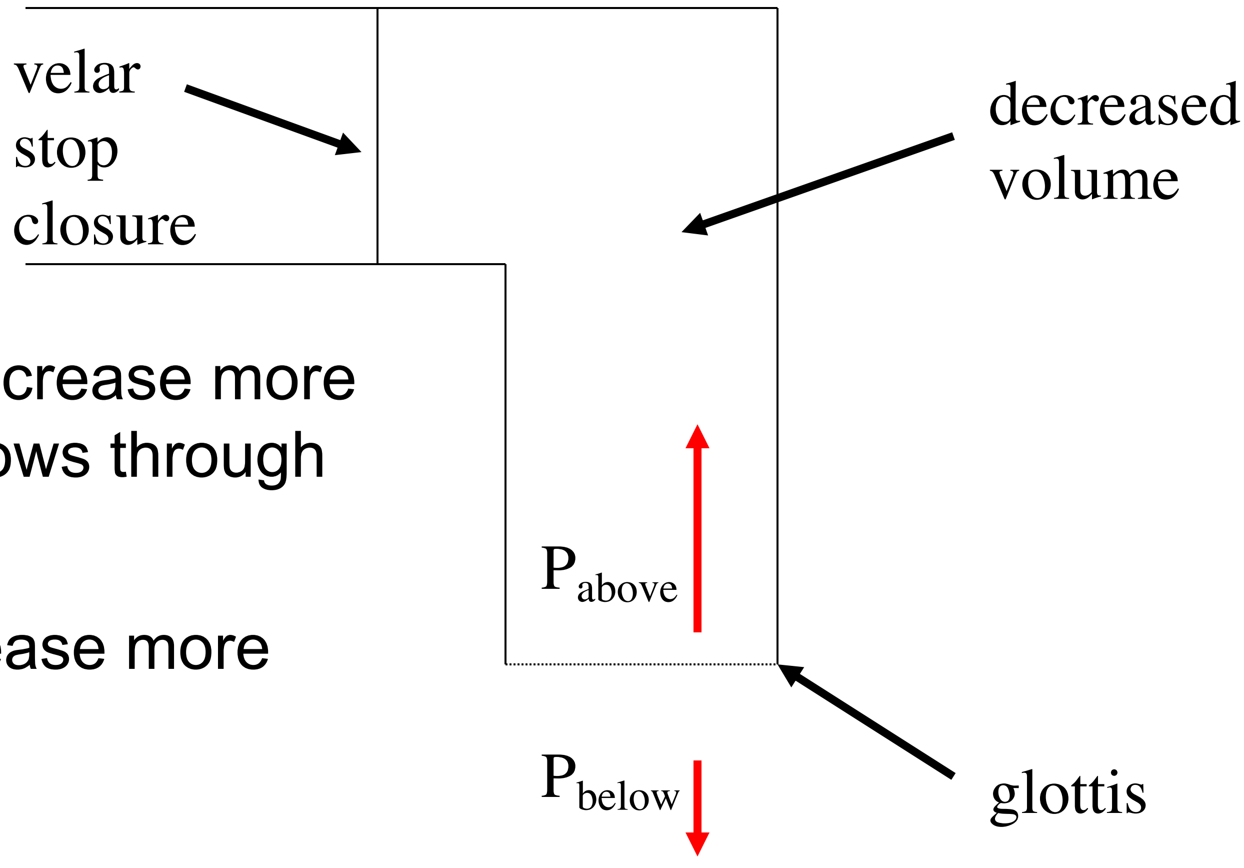
- $(P_{below} - P_{above}) \rightarrow 0$
- Airflow across the glottis will cease
- Voicing will stop

Place and Volume: a schematic



- The further back a stop closure is made…
- The less volume there is above the glottis for air to flow into

Place and Volume: a schematic



- $\Rightarrow P_{above}$ will increase more rapidly as air flows through the glottis
- Voicing will cease more quickly

More Numbers

- From Catford (1982), *Fundamental Problems in Phonetics*
- Lung volume = 1840 - 4470 cm^3
- During inhalation/exhalation, lung volume typically changes 500-1000 cm^3
- Vocal tract volume = space between glottis and oral closure:

1. Bilabials: 120-160 cm^3
2. Alveolars: 70-100 cm^3
3. Velars: 30-50 cm^3

Morals of the Story

- **Voiced stops** are hard because too much air gets pushed into the mouth, behind the stop closure
    - This makes it impossible for there to be a pressure drop across the glottis.
- **Voiced velars** are worse, because the space above the glottis, behind the stop closure, is even smaller.
    - This space gets filled up by pulmonic airflow even faster
- Independent *articulatory* gestures may interact *aerodynamically*
    - They have to share the same stream of air.