# Physics of Musical Instrument (woodwind instrument)

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# 순서

- 관악기 소개
- Wave equation of sound
- Driven force
- Resonance in the pipe
- Open and closed pipe
- Cut-off frequency
- Tone holes and fingerings
- Resister holes

# 관악기란?

금속·나무·대 등의 관을 입으로 불어서 관 속의

공기를 진동시켜 소리를 내는 악기

- Clarinet
- Oboe
- Flute
- Recorder
- Bassoon

# Wave equation of sound

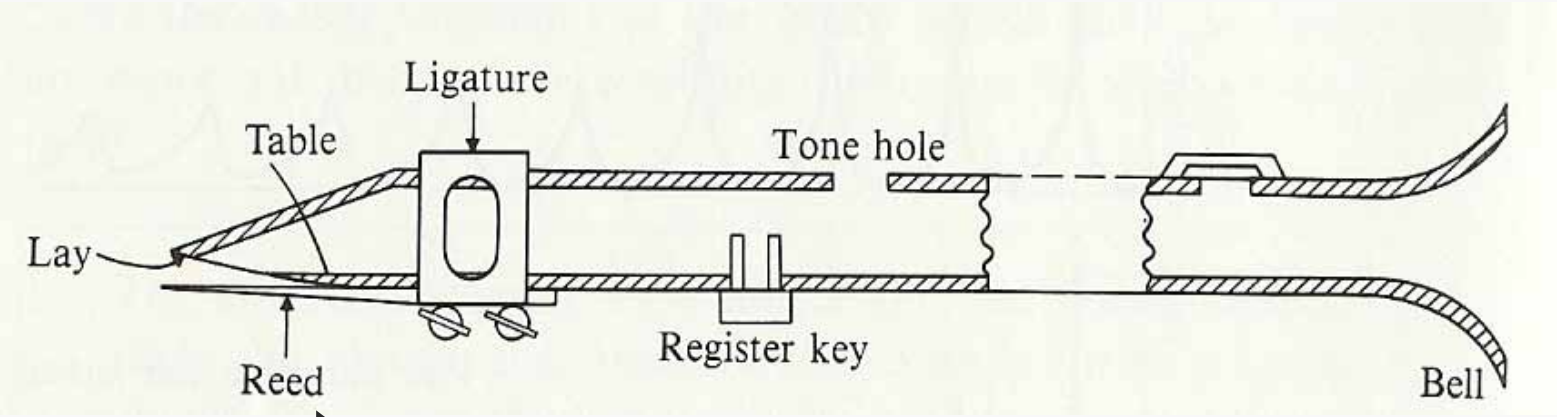
$$\frac{\partial^2 y}{\partial t^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

$$v = \sqrt{\frac{\gamma RT}{M}}$$

# Driven Force

- 관악기 내의 공기가 공명을 하기 위하여 필요한 힘.
- Clarinet, Oboe등은 reed를 이용하여 소리를 낸다.
- Flute이나 Recorder등은 flow-control로 소리를 낸다.

# Clarinet




이 reed의 떨림으로 소리가 만들어 진다.

# Bottle

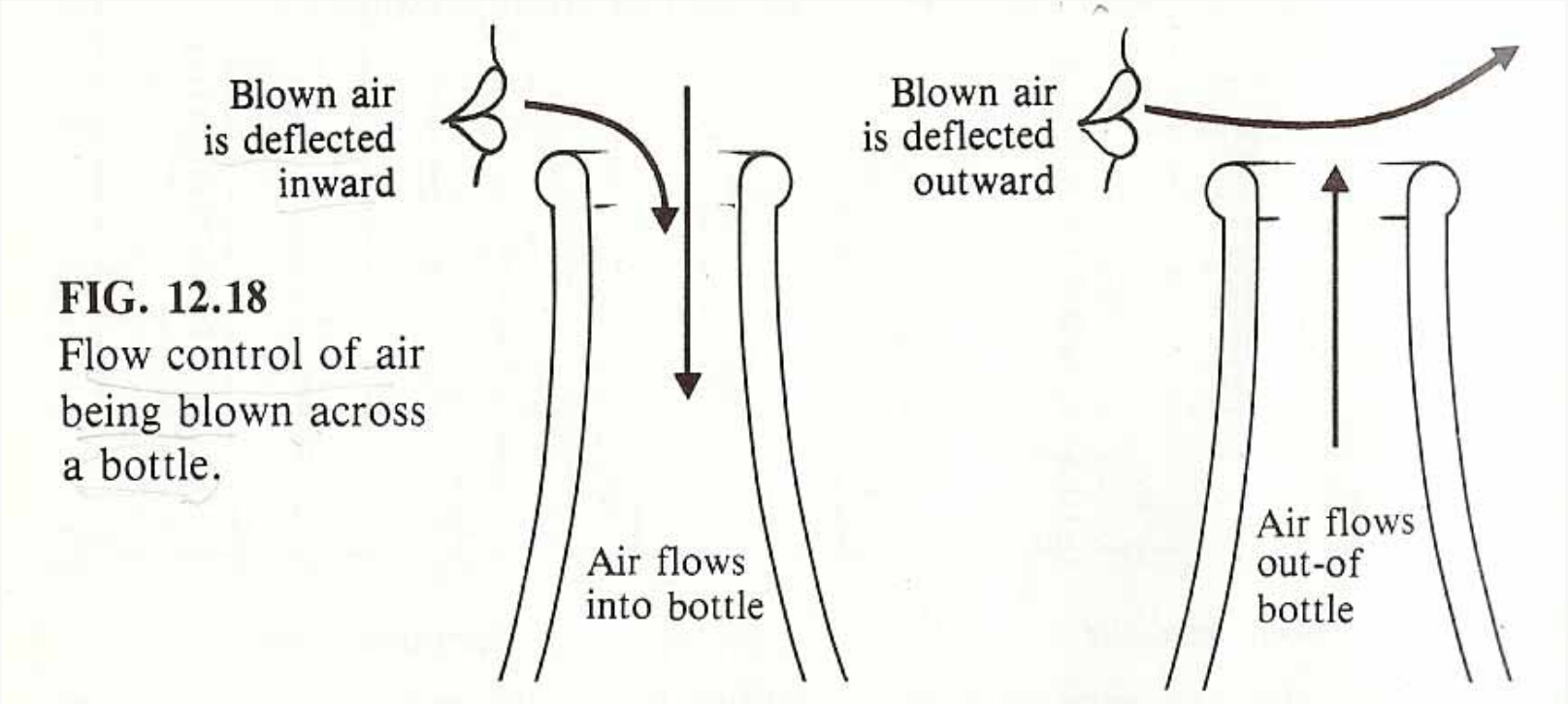
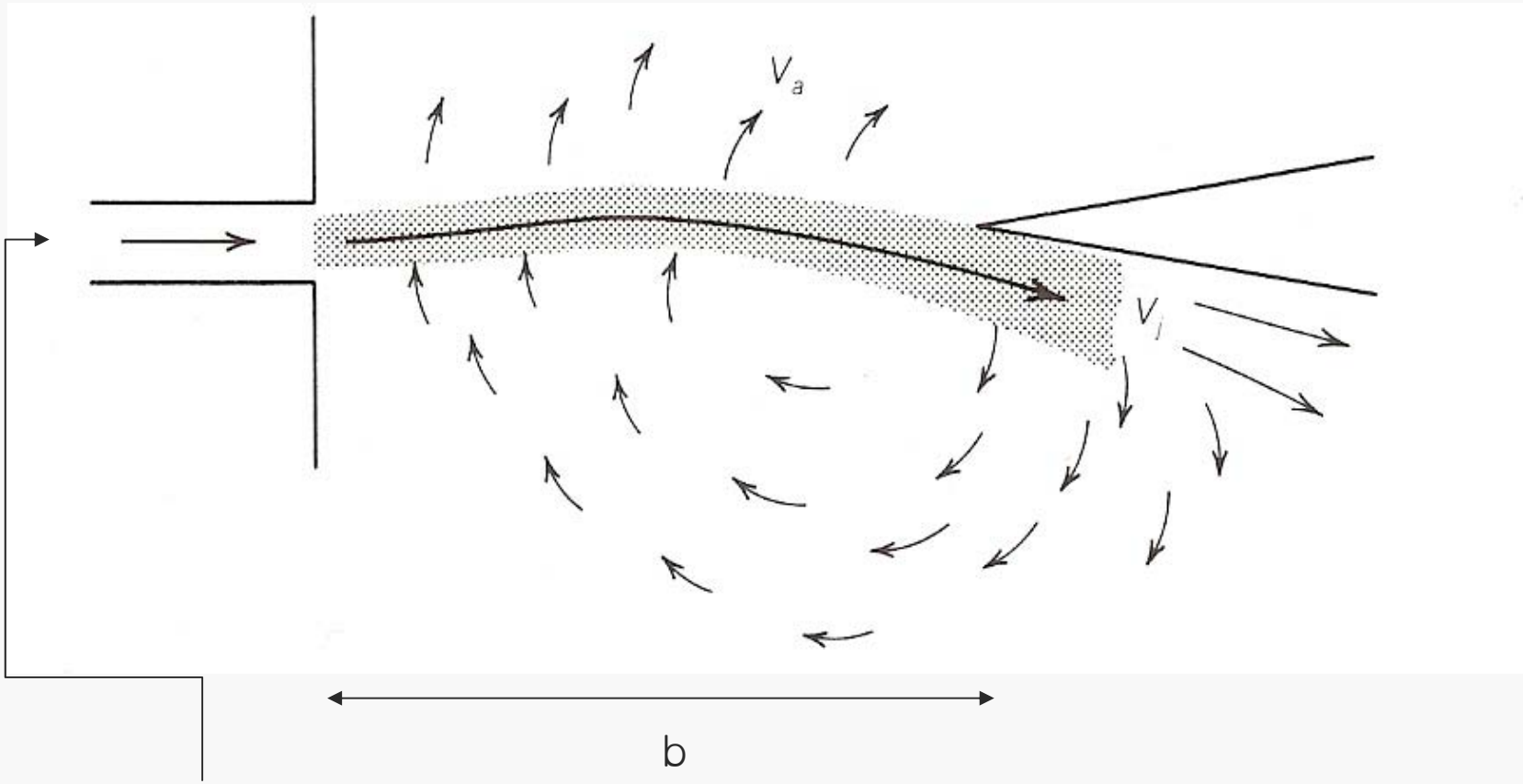
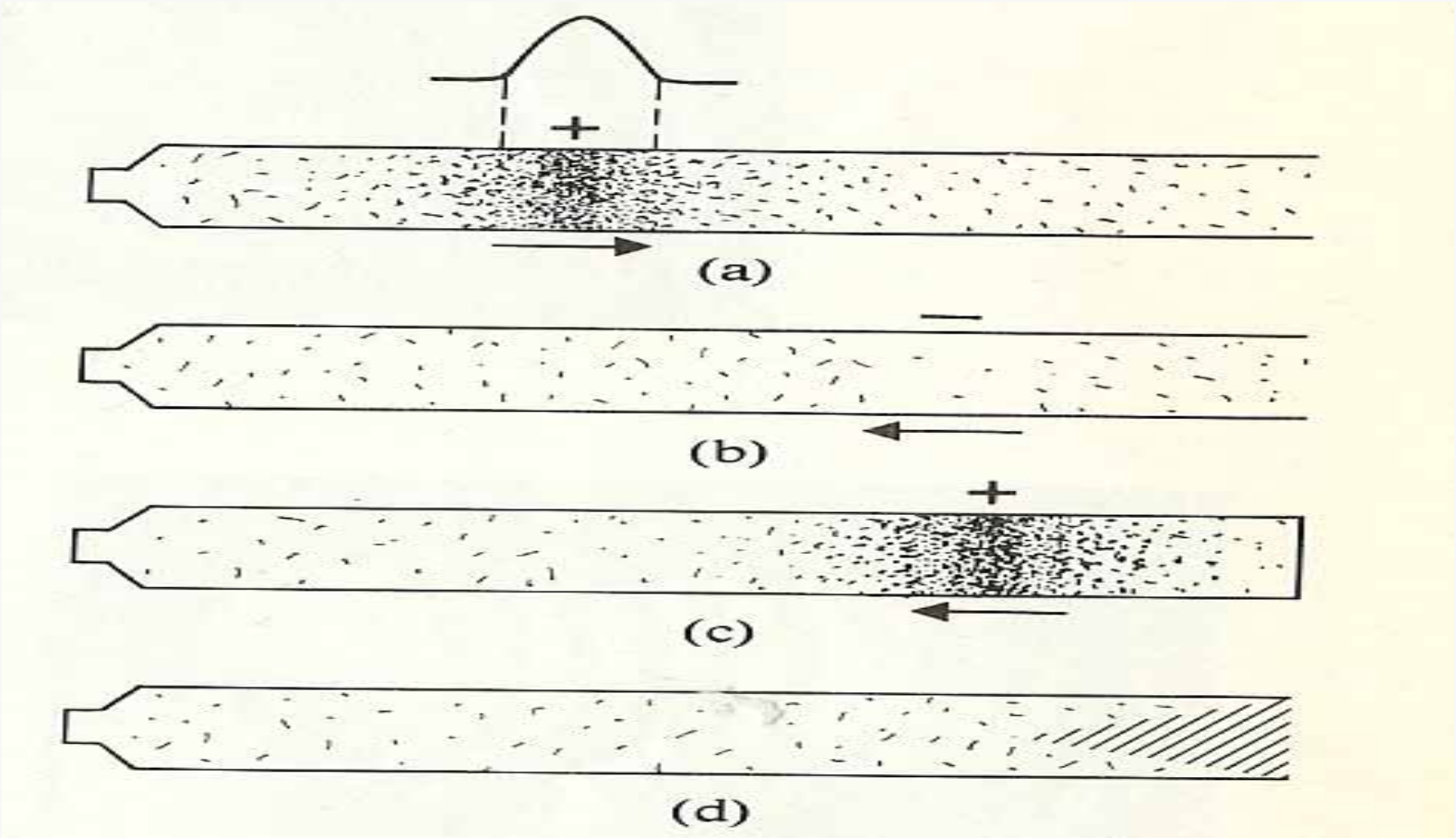



**FIG. 12.18**
Flow control of air being blown across a bottle.




$$f \propto v_j / b$$

# Resonance in the pipe



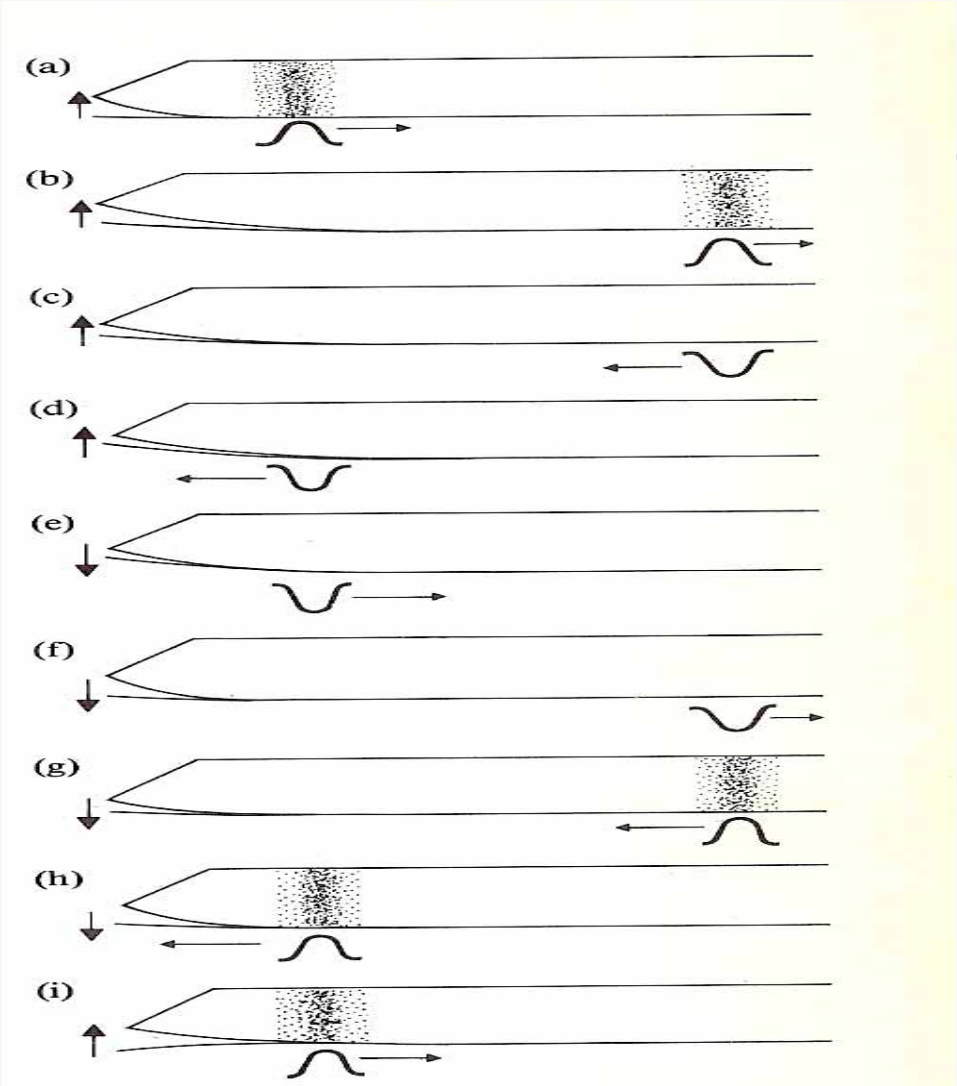
# Open and closed pipe

- Closed pipe-한쪽이 닫혀있고 한쪽이 열린 pipe

  ->Clarinet

- Open pipe- 양쪽 다 열려있는 pipe

  ->Flute, Recorder




$$\lambda = 4L$$

$$f_1 = \frac{v}{4L}$$

# Standing wave in the closed pipe

$P = p_0 \sin(kx + \frac{\pi}{2})$ 이면,

경계조건 : $p(x = L) = 0$

$$kL + \frac{\pi}{2} = n\pi \qquad L = \frac{(2n-1)\lambda}{4}$$

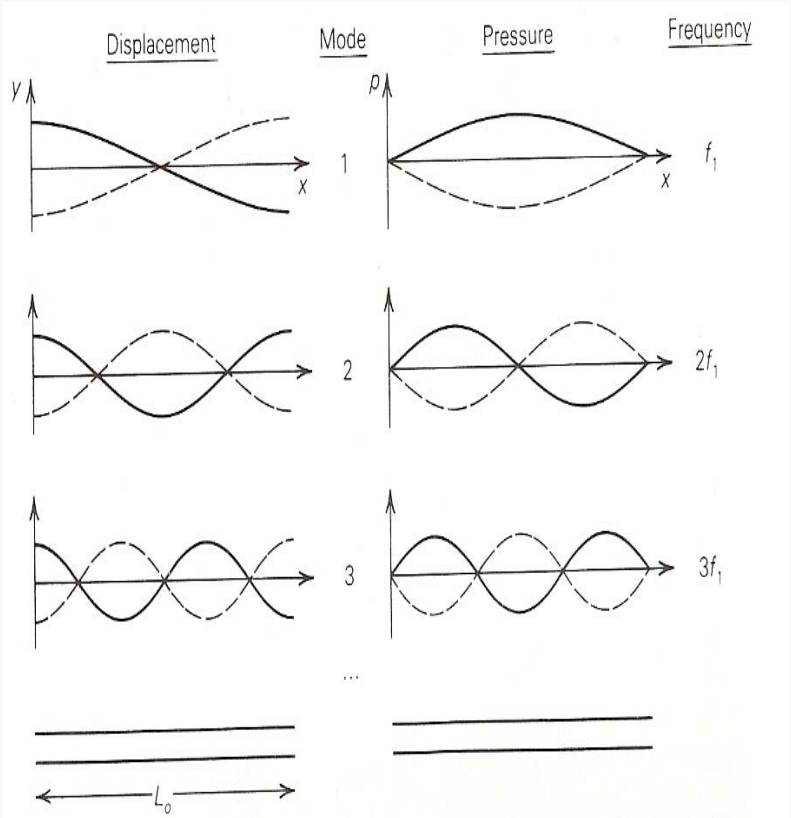
$$f_n = \frac{(2n-1)v}{4L}$$ : 닫힌 관에서의 진동수들

# Standing wave in the open pipe

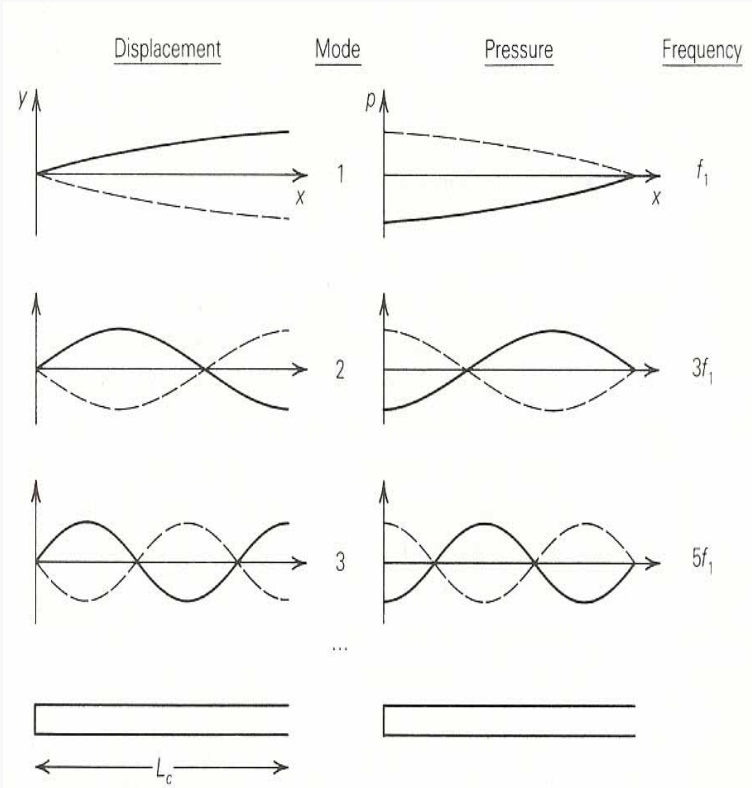
- 양쪽이 고정된 줄의 정상파 조건과 같다.
- 따라서 진동수는

$$f_n = \frac{v}{2L} n$$

# Open & closed pipe




Open pipe




Closed pipe

# Cutoff frequency

- Clarinet과 길이와 너비가 같은 관에 clarinet의 mouthpiece를 끼우고 불면?

-> clarinet과 비슷한 소리가 난다

- 관의 길이를 점점 줄이면?

-> 점점 clarinet과는 다른 음색을 낸다.

# Cutoff frequency

The cutoff frequency of a lattice of tone holes depends on their size, shape, and spacing. The formula for calculating the cutoff frequency (Benade, 1976) is

$$f_c = 0.11 \frac{b}{a} \frac{c}{\sqrt{s(t+1.5b)}},$$

where $c$ is the speed of sound (344 m/s), and $a$, $b$, $s$, and $t$ (expressed in meters) are physical parameters, shown in Fig. 12.5.

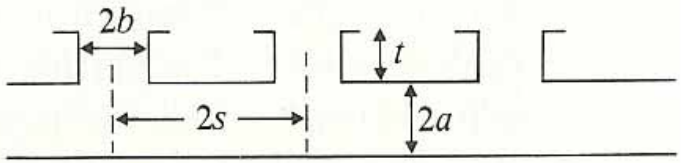
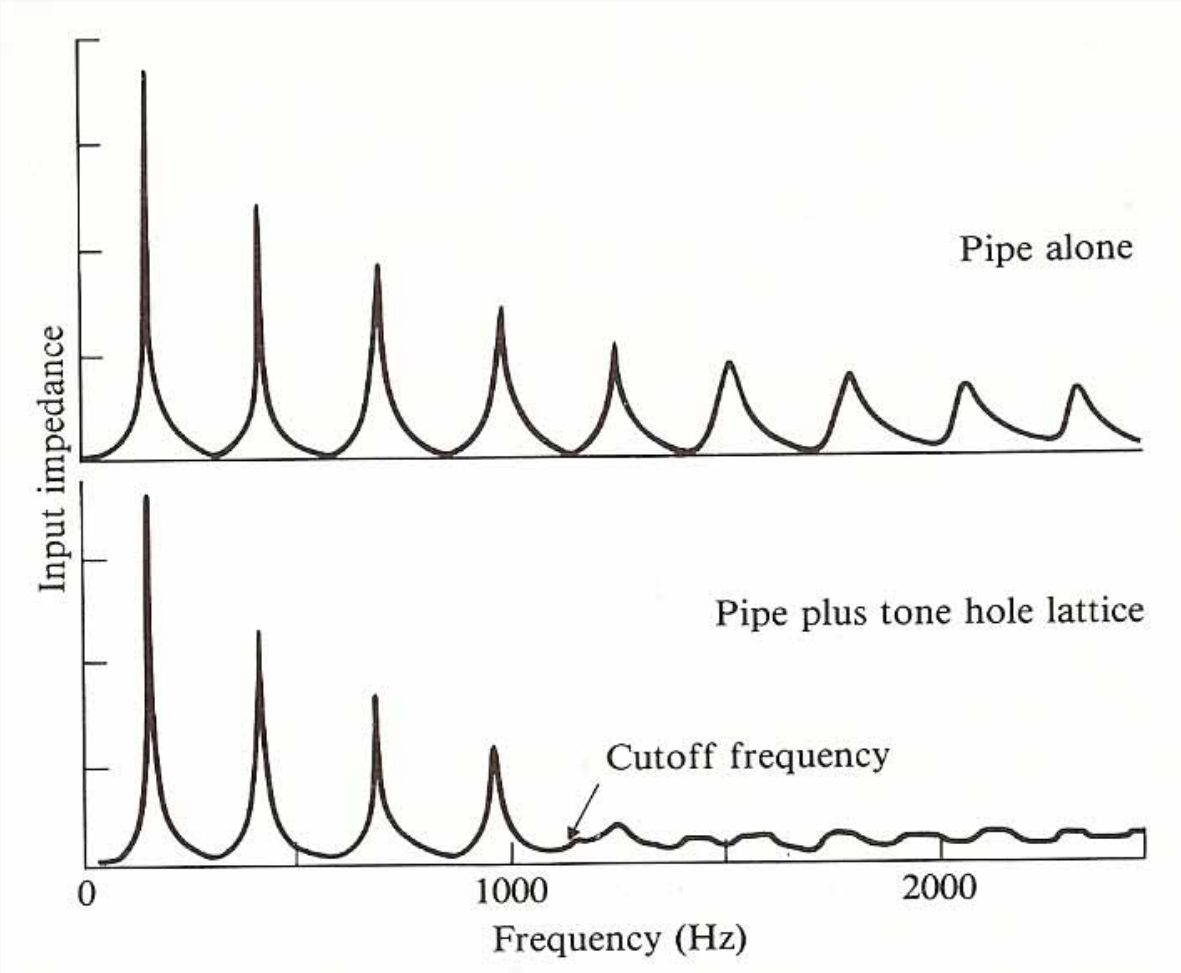



**FIG. 12.5**
An open tone hole lattice indicating the parameters to be used in calculating the cutoff frequency: $a$ = the radius of the bore, $b$ = the radius of the tone hole, $2s$ = the tone hole spacing, and $t$ = the tone hole height.

# Cutoff frequency

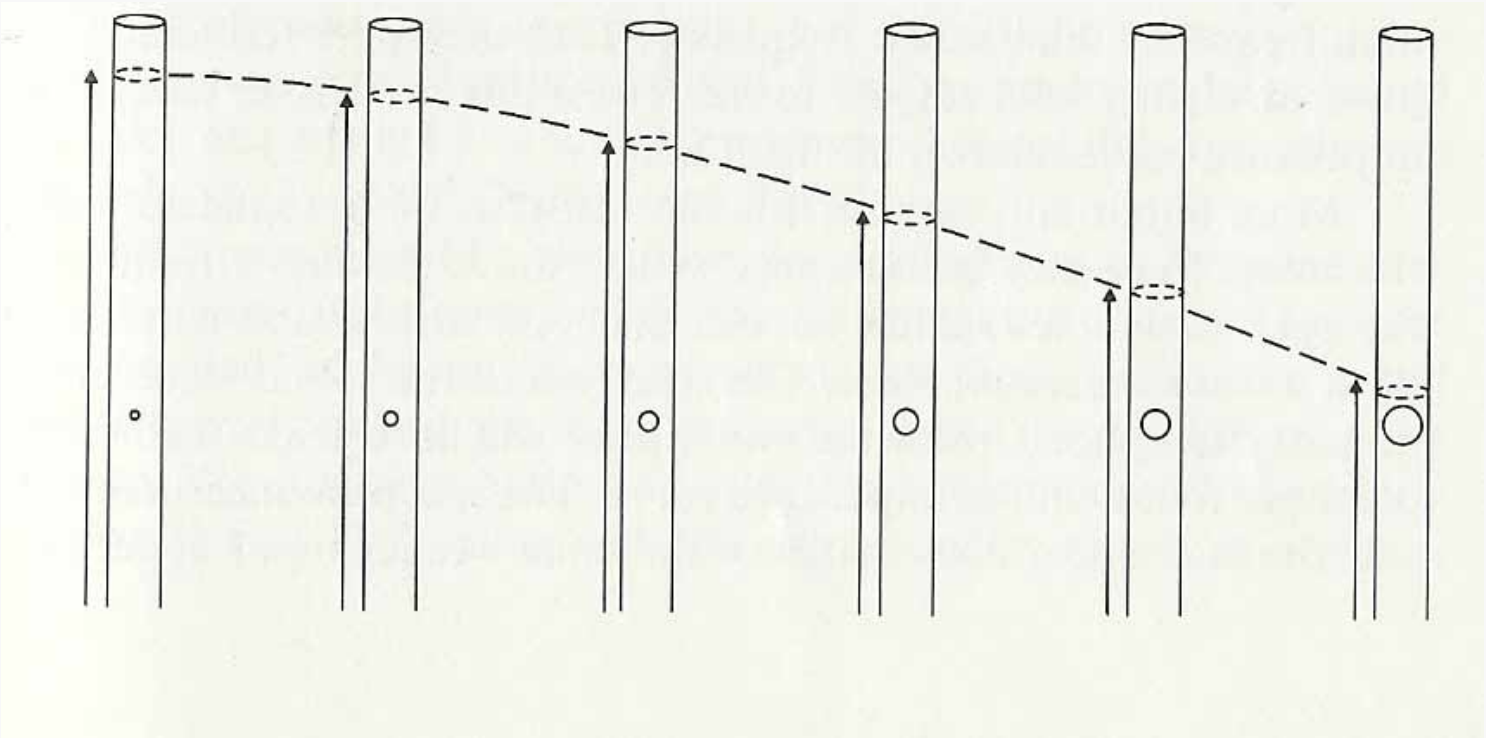


# Tone holes

- As a pressure node : sound radiation at a hole
- Effective length : hole이있을 때 파동이 끝나는 지점까지의 길이

# Tone holes

Hole의 크기에 따른 effective length의 변화



# Tone hole의 배열

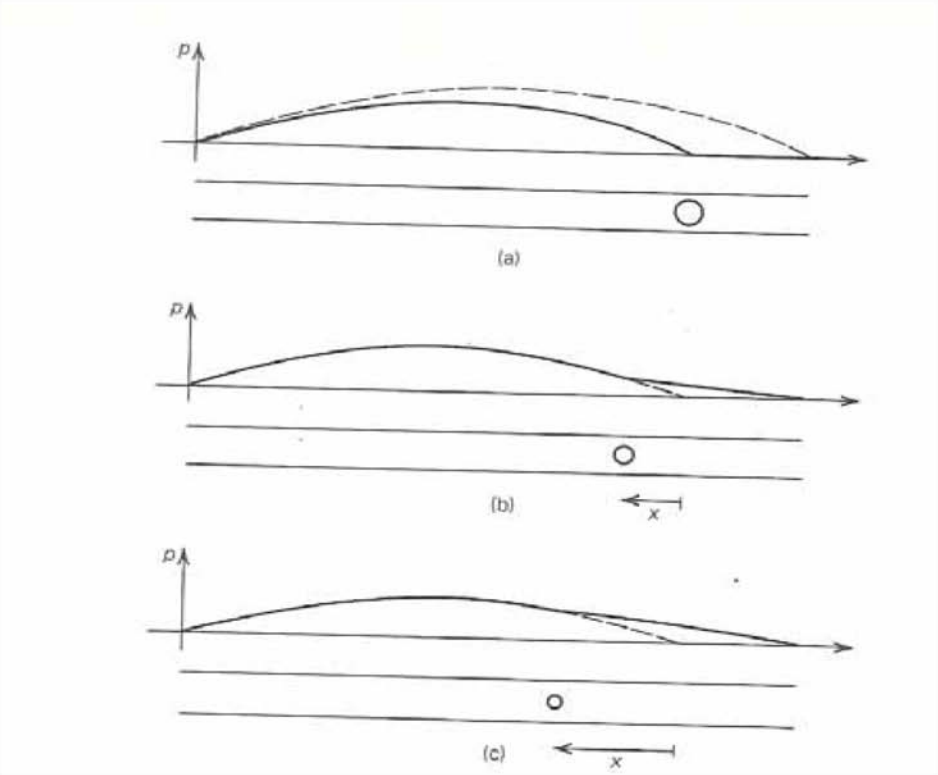
만약 hole의 크기가 충분히 크고 관의 길이가 300mm라면

| L(도) | L(레) | L(미) | L(파) | L(솔) | L(라) | L(시) | L(도) |
|---|---|---|---|---|---|---|---|
| 300mm | 267mm | 240mm | 225mm | 200mm | 180mm | 160mm | 150mm |

이런 식으로 배열 될 것으로 예상할 수 있다. 이와 가장 비슷한 형태가 Flute이다.

http://www.chrysalis-foundation.org/flute_tone_holes.htm

# Tone hole의 배열




점선 : pipe의 길이

실선 : Effective length

점선 : a와 같은 공명

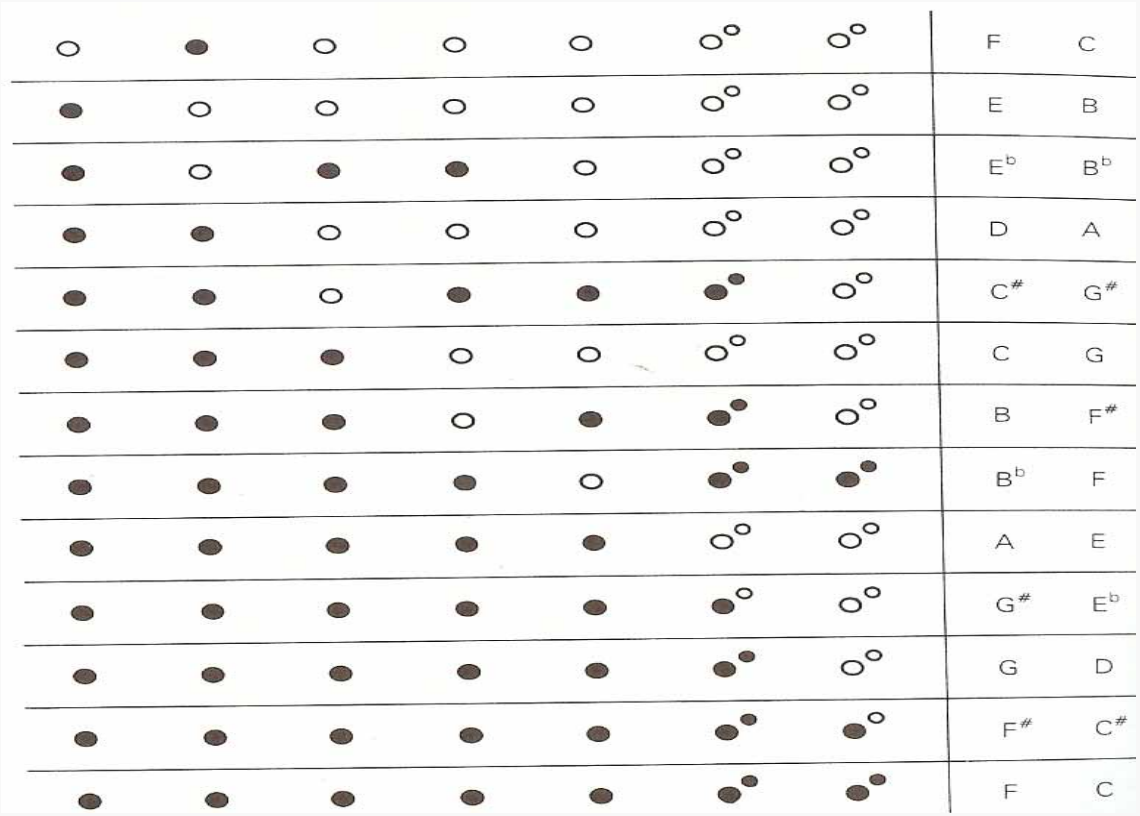
실선 : 실제 파동의 진행

점선 : a와 같은 공명

실선 : 실제 파동의 진행

# Cross-fingering

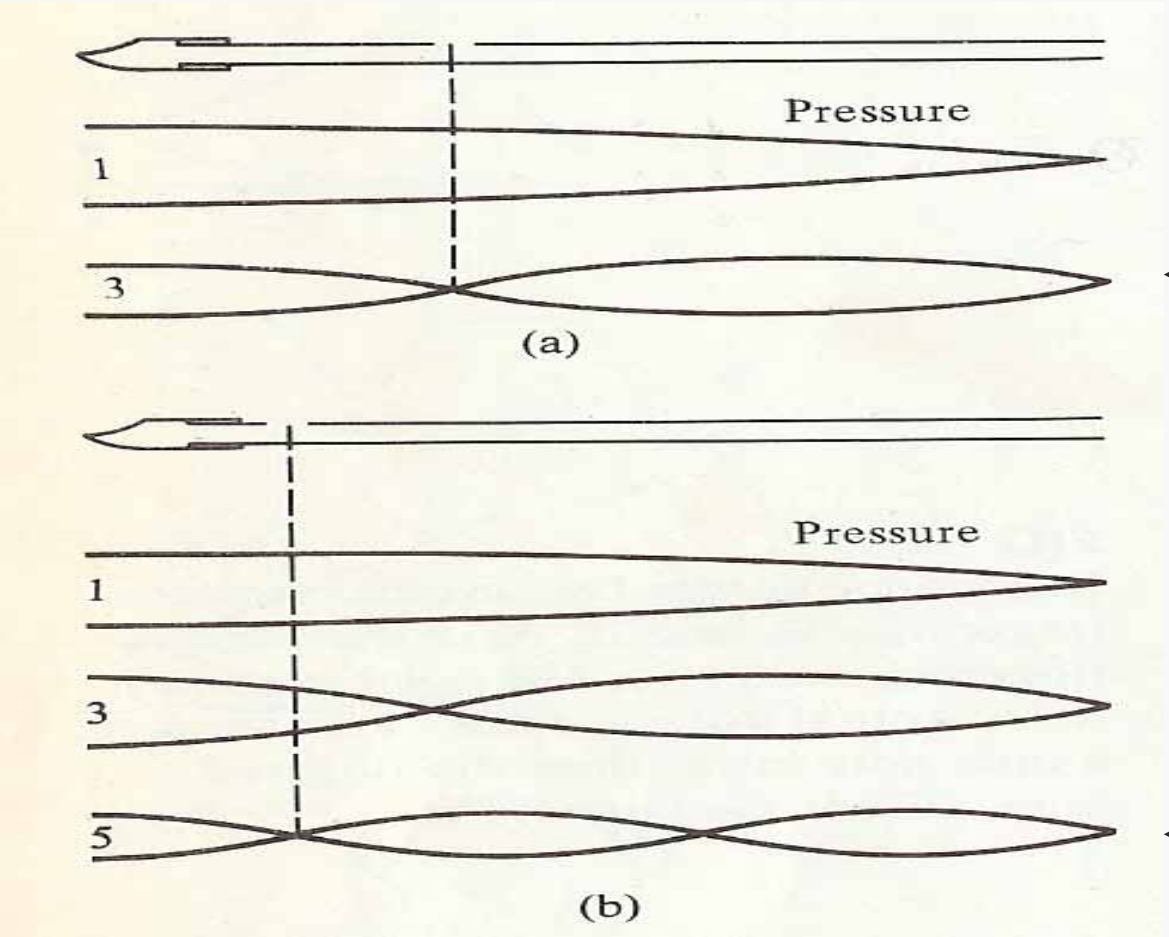
- 첫 번째 열린 hole 이하에서의 fingering



# Register holes

- 옥타브 사이를 조절하는 hole
- Pressure node에 위치

# Resister holes




$\longleftarrow f = 3f_1$

$\longleftarrow f = 5f_1$

# References


- Thomas D.Rossing, The Science of Sound
- Arthur H.Benade, Fundamentals of Musical Acoustics
- Donald E.Hall, Musical Acoustics
- http://www.chrysalis-foundation.org

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