PROBLEM N°9

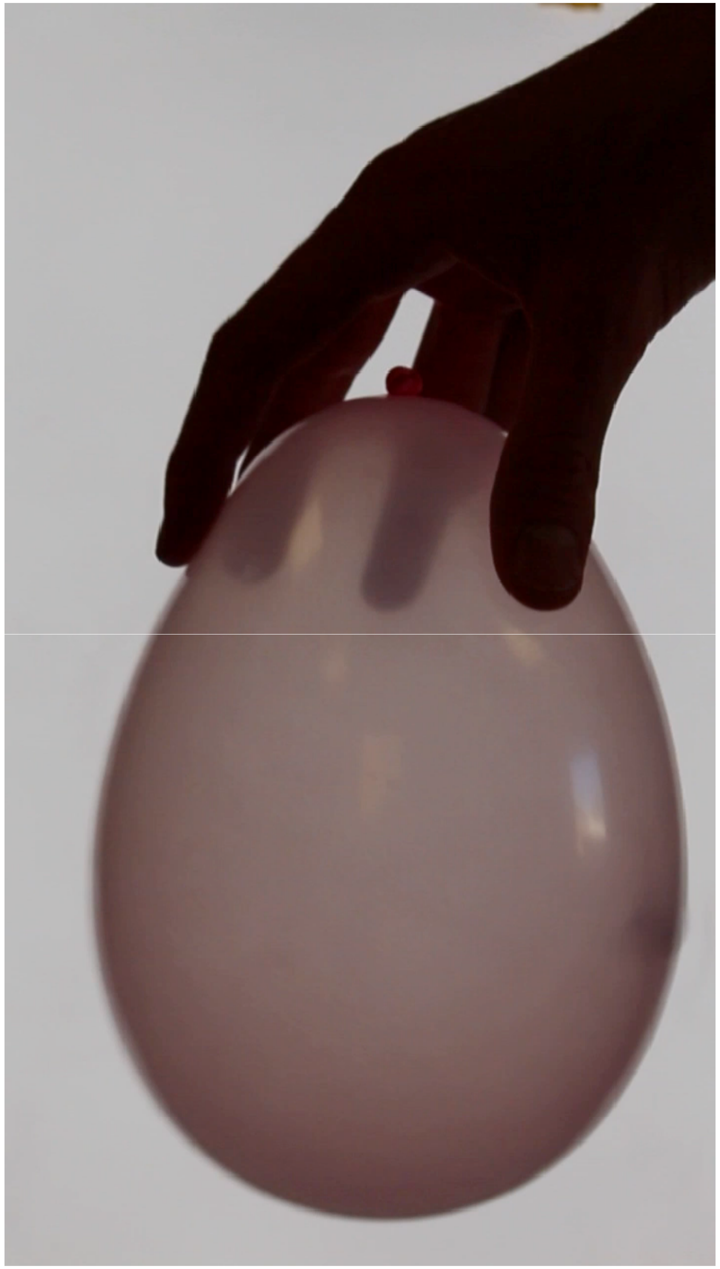
SCREAMING BALLOON

Team Ecole polytechnique

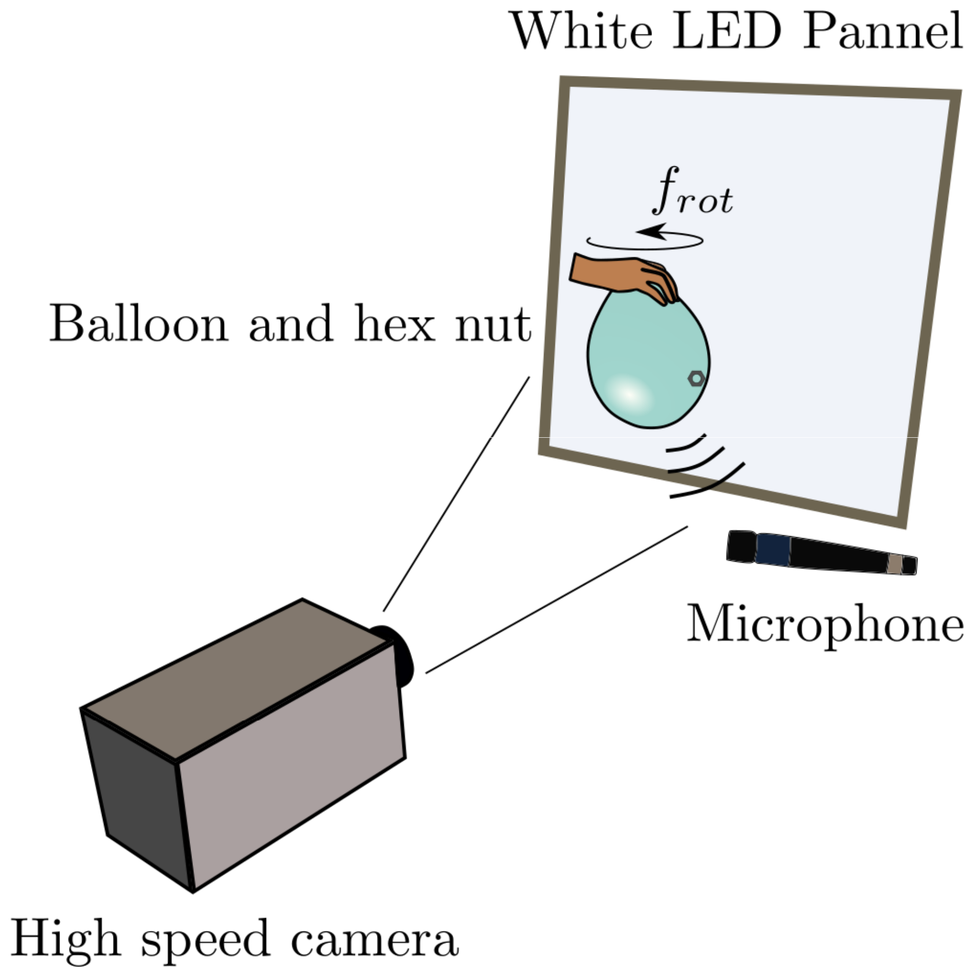
Problem

A **sound** is produced when a **hex nut** is made to **rotate in a balloon**.

How do the **characteristics of the sound** depend on the **parameters of the system** ?



Experimental setup



Frequency range

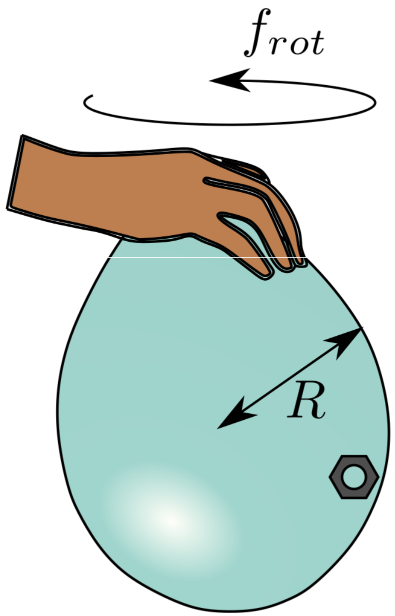
Influence of gravity:

$$mg < m(2\pi f_{rot})^2 R \Rightarrow f_{rot} > 1.6\ Hz$$

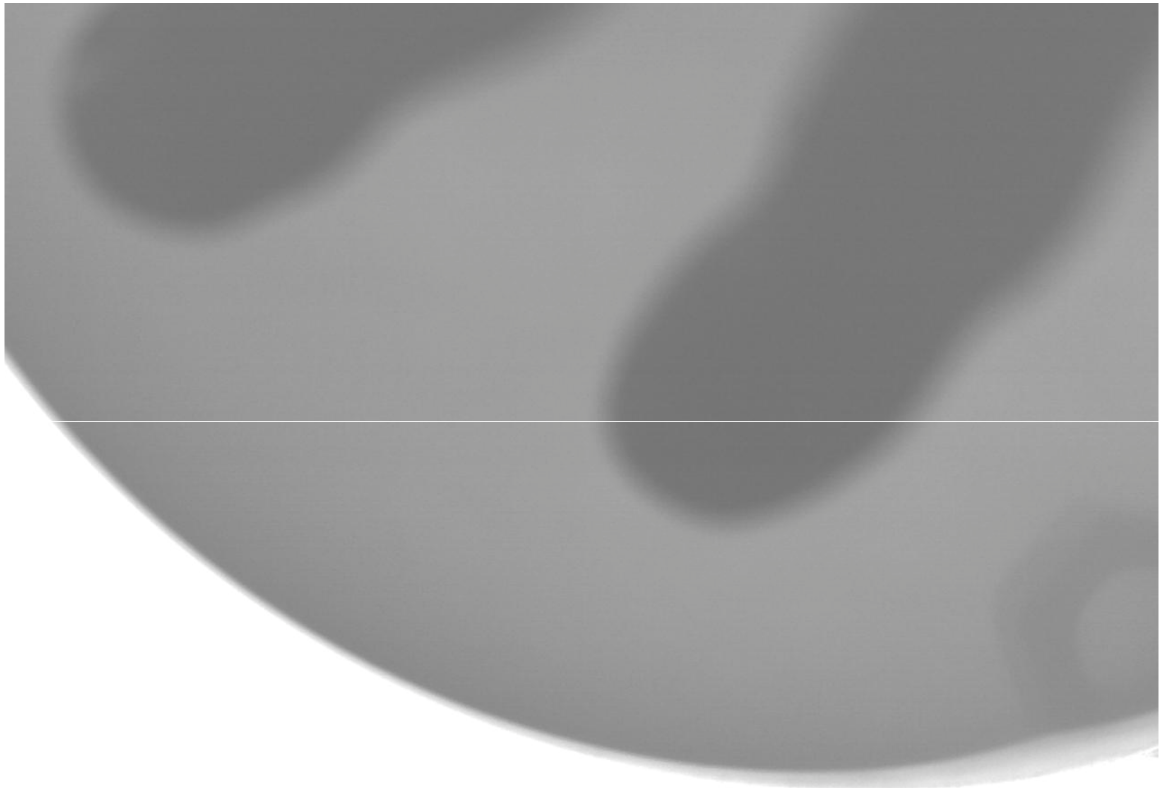
Influence of Doppler effect:

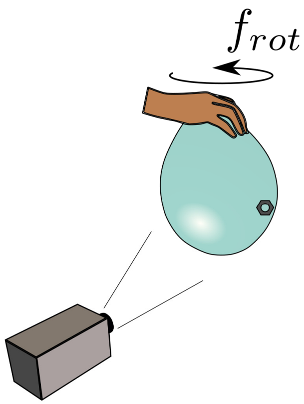
$$\frac{2\pi R f_{rot}}{c} < 0.1 \Rightarrow f_{rot} < 54\ Hz$$

Effective range: $3\ Hz < f_{rot} < 10\ Hz$



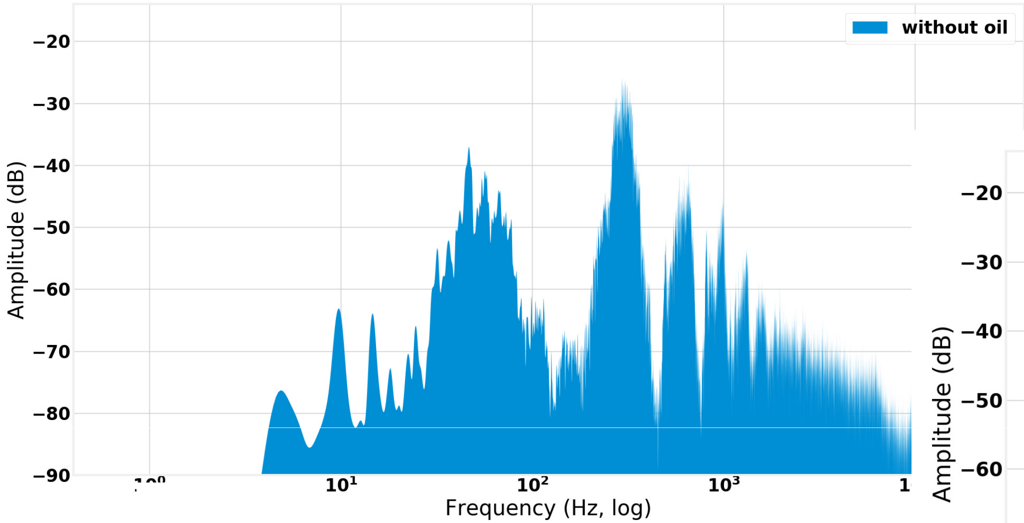
How does the hex move ?

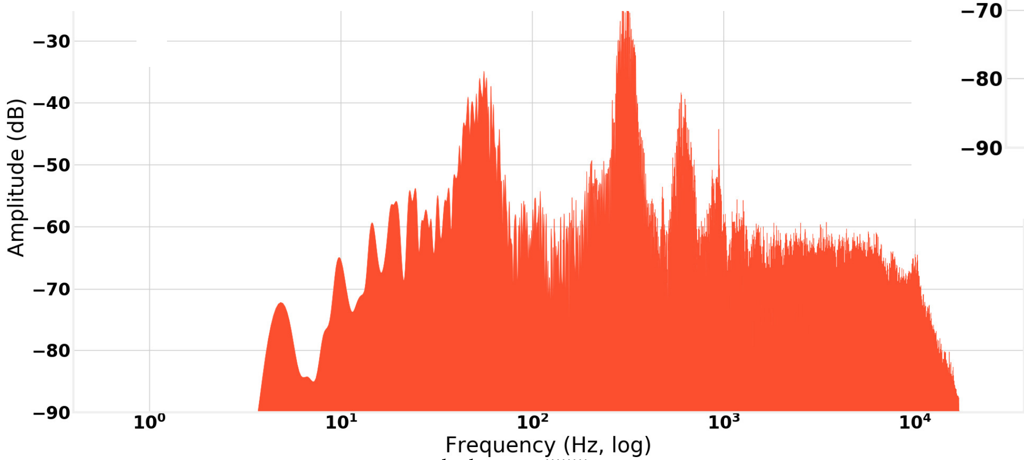


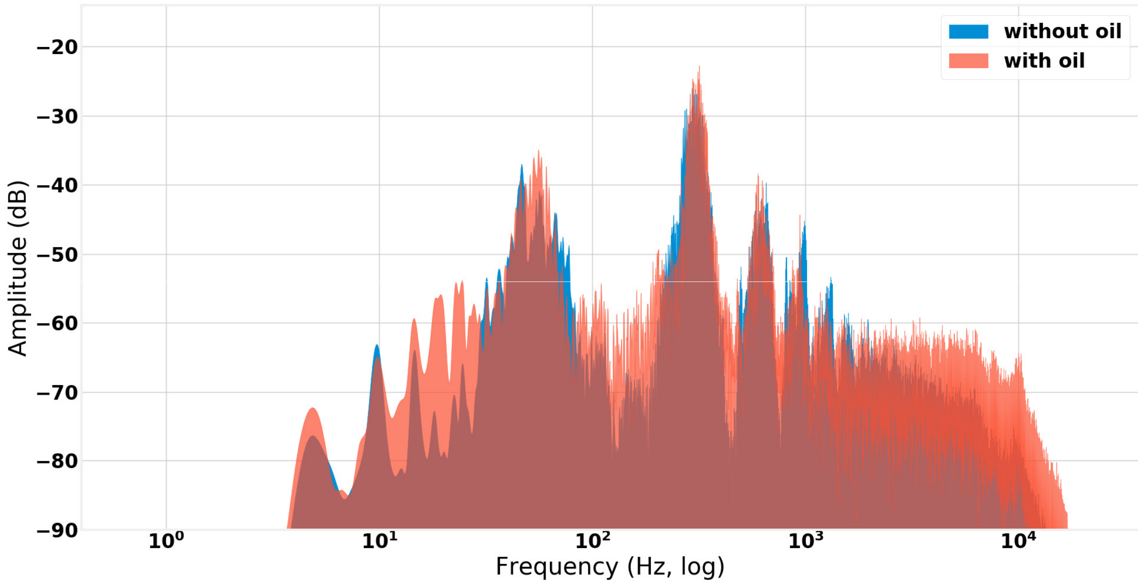


The hex **does not slide**

Influence of friction

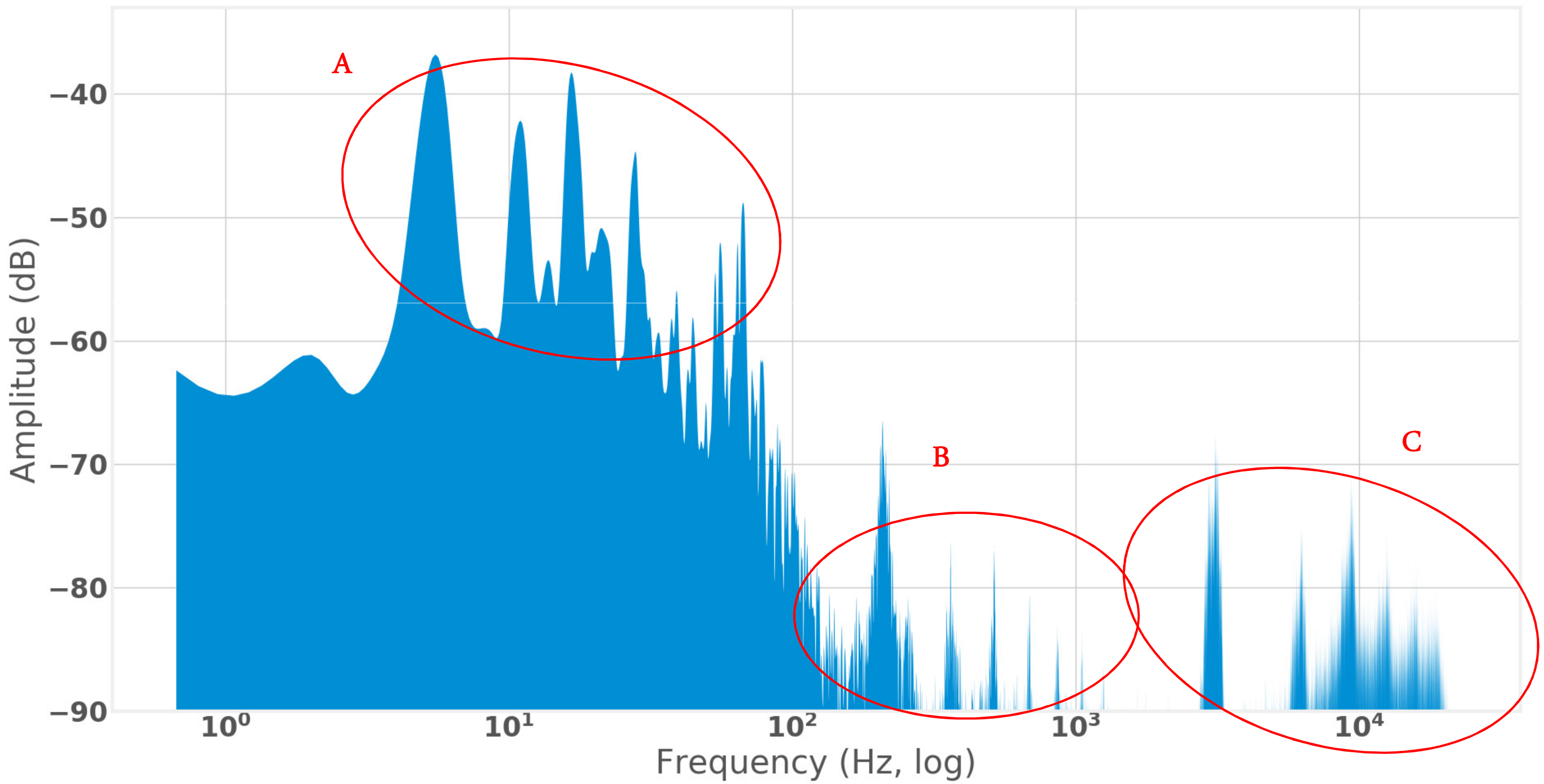






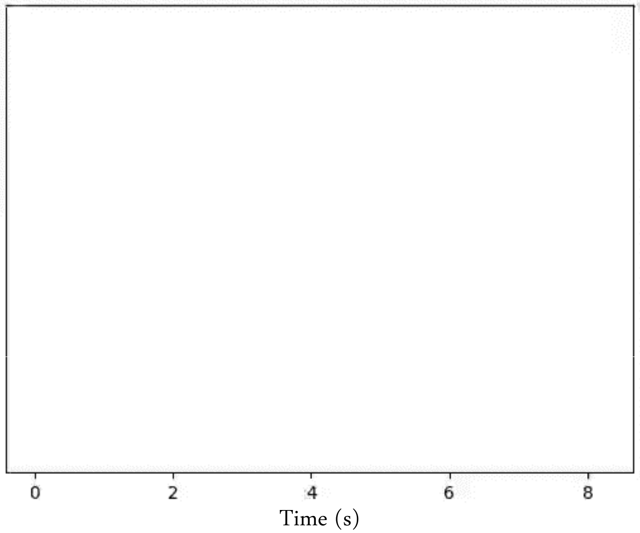
Fourier transform

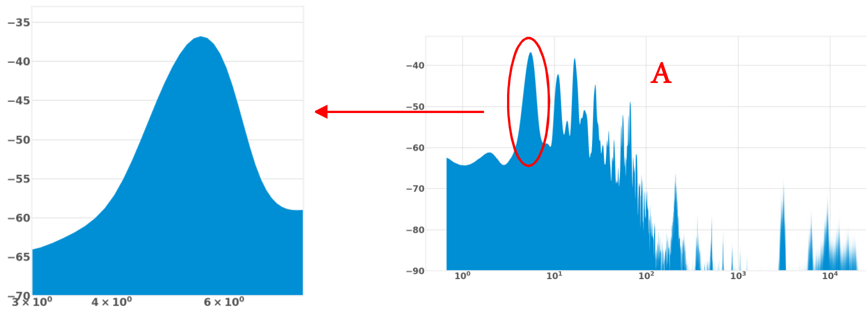
Typical Fourier transform



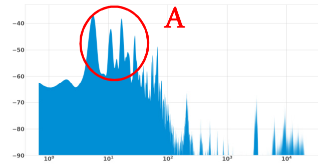
Experiment A

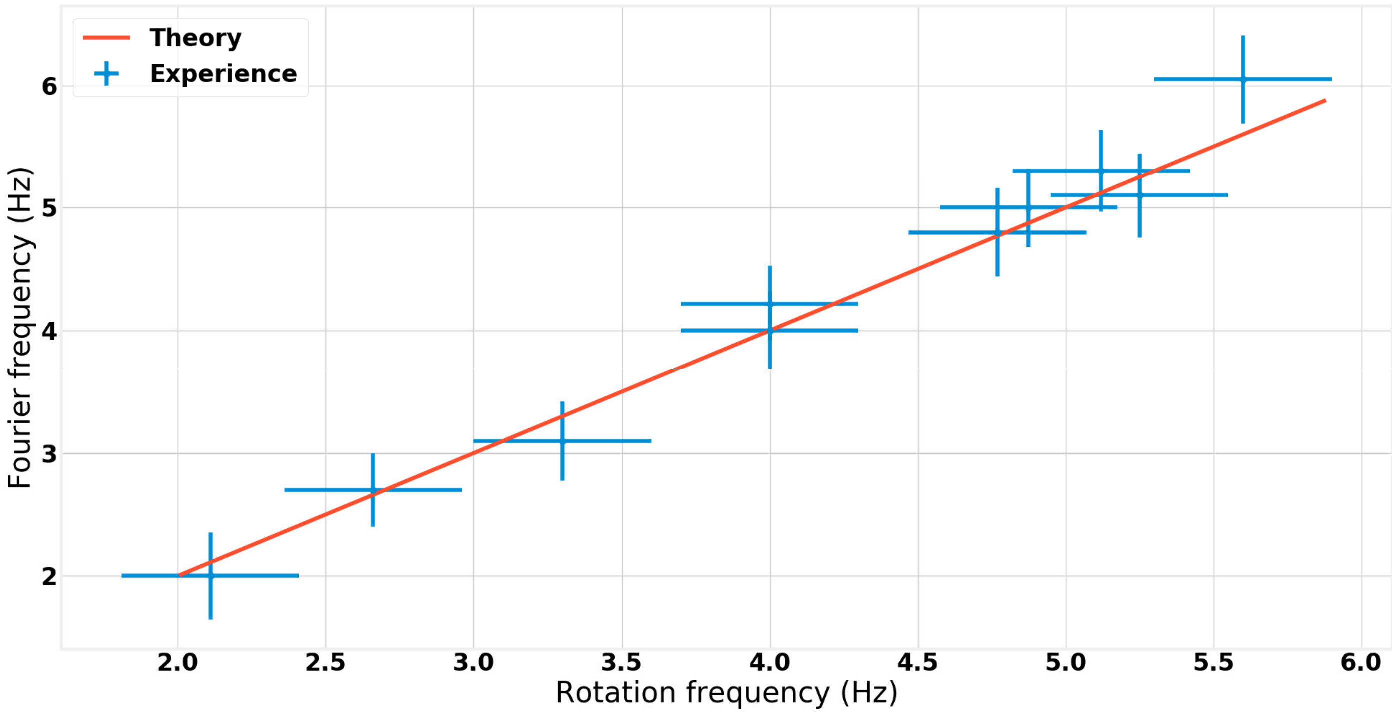
How does the macroscopic rotation speed influence the sound ?





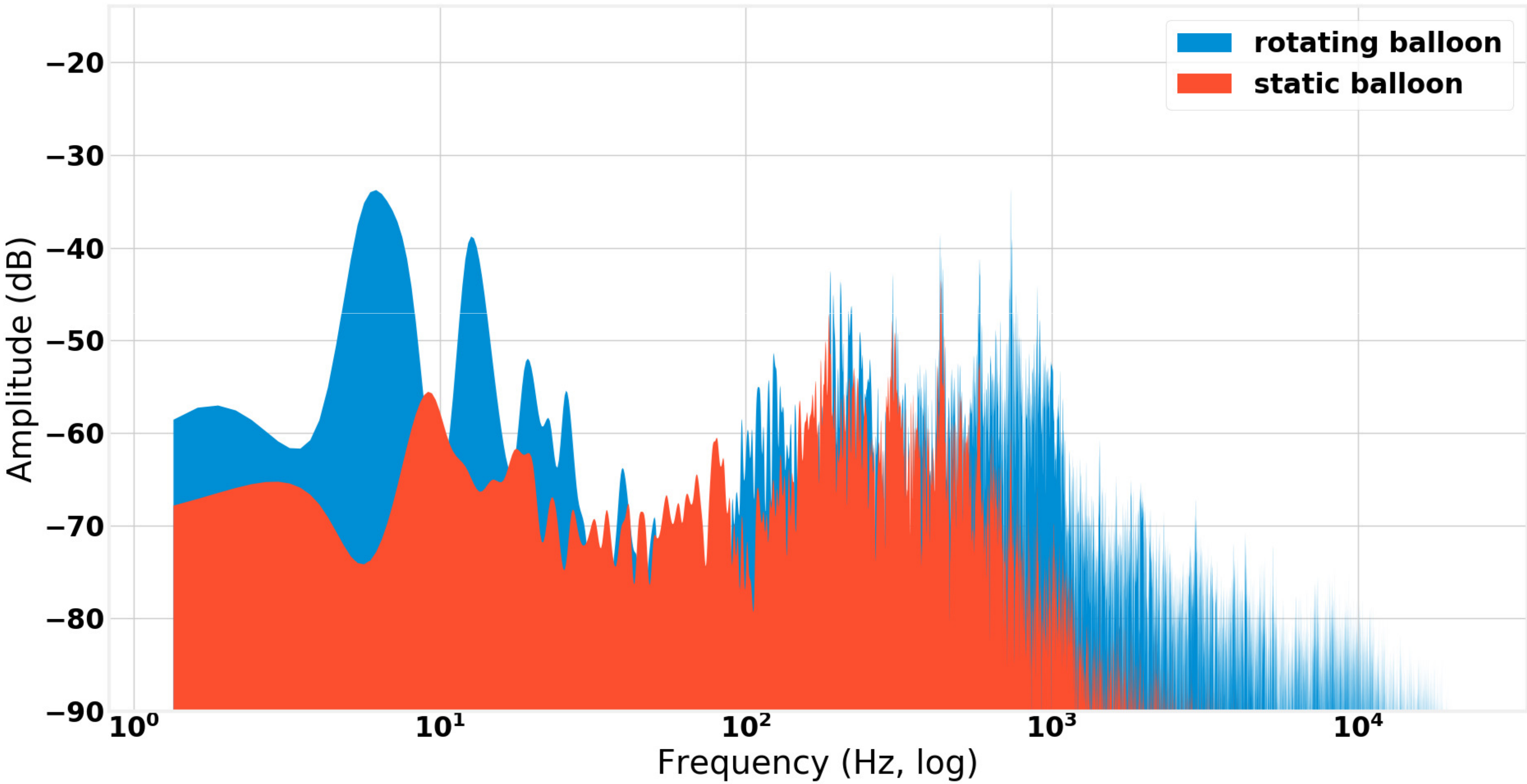
Experiment A



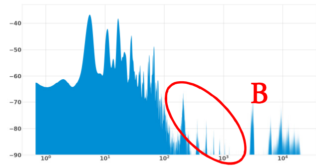


The harmonics of zone A are explained by the macroscopic rotation of the balloon

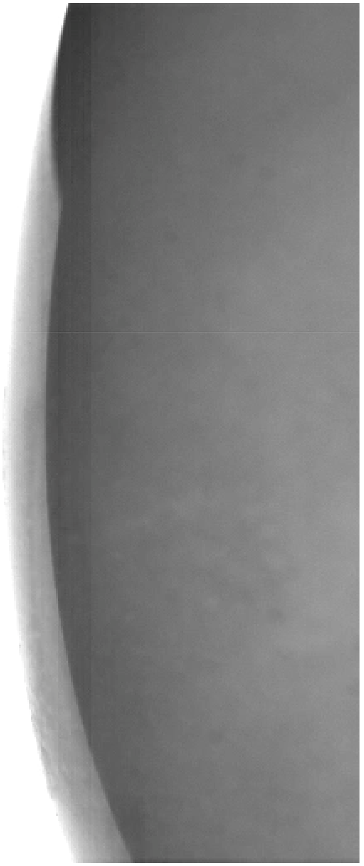
Low frequencies: w/o rotation

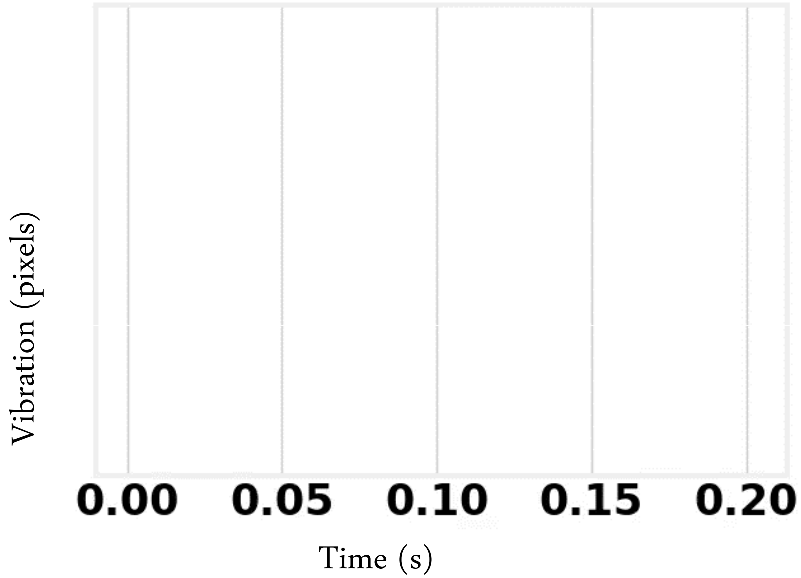


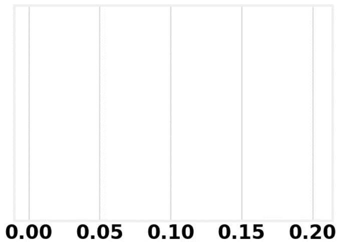
Experiment B



Does the membrane of the balloon oscillate ?





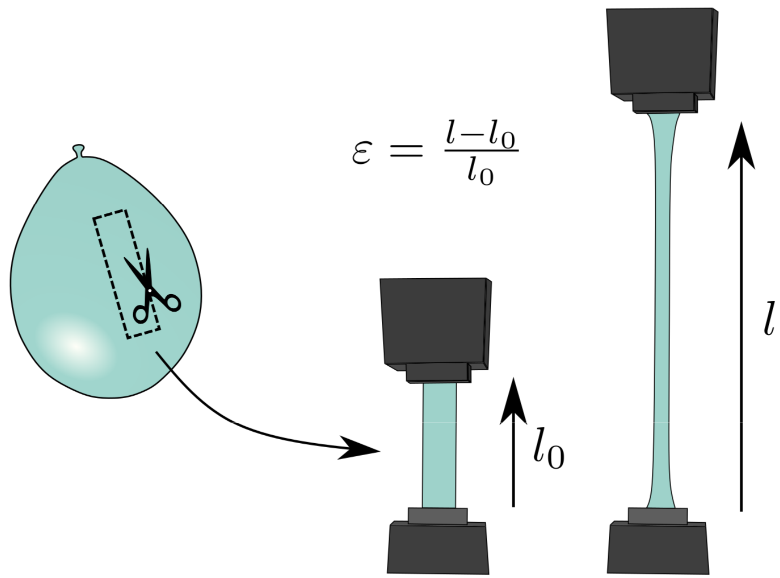


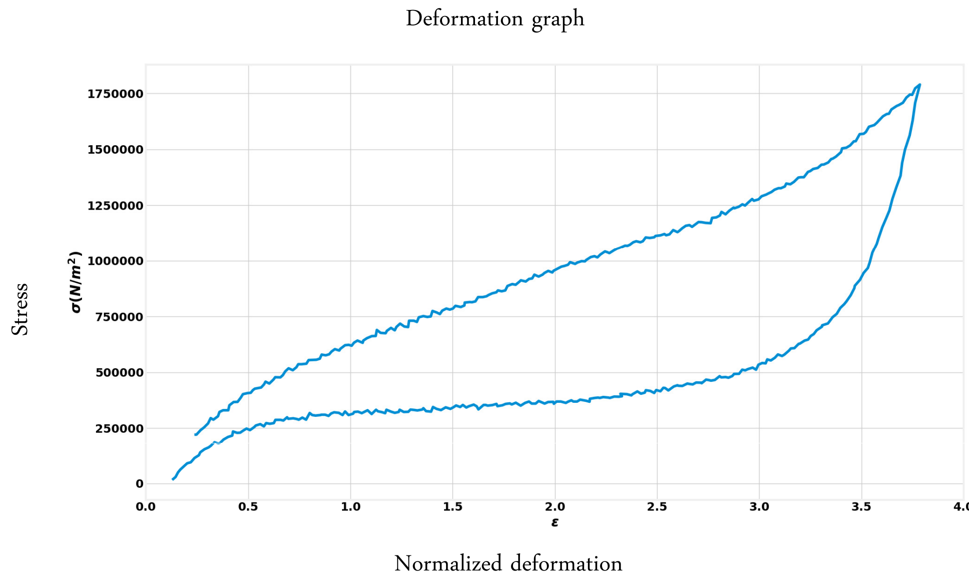
Results :

$$150Hz \leq f_{measured} \leq 250Hz$$

Elasticity is a key factor

Elasticity of the balloon





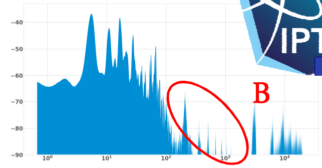
Results :

Elastic parameters

Poissons coefficient: $0.4 \leq \nu \leq 0.5$

Youngs modulus: $1\ MPa \leq E \leq 3\ MPa$

Zone B – Theorical model

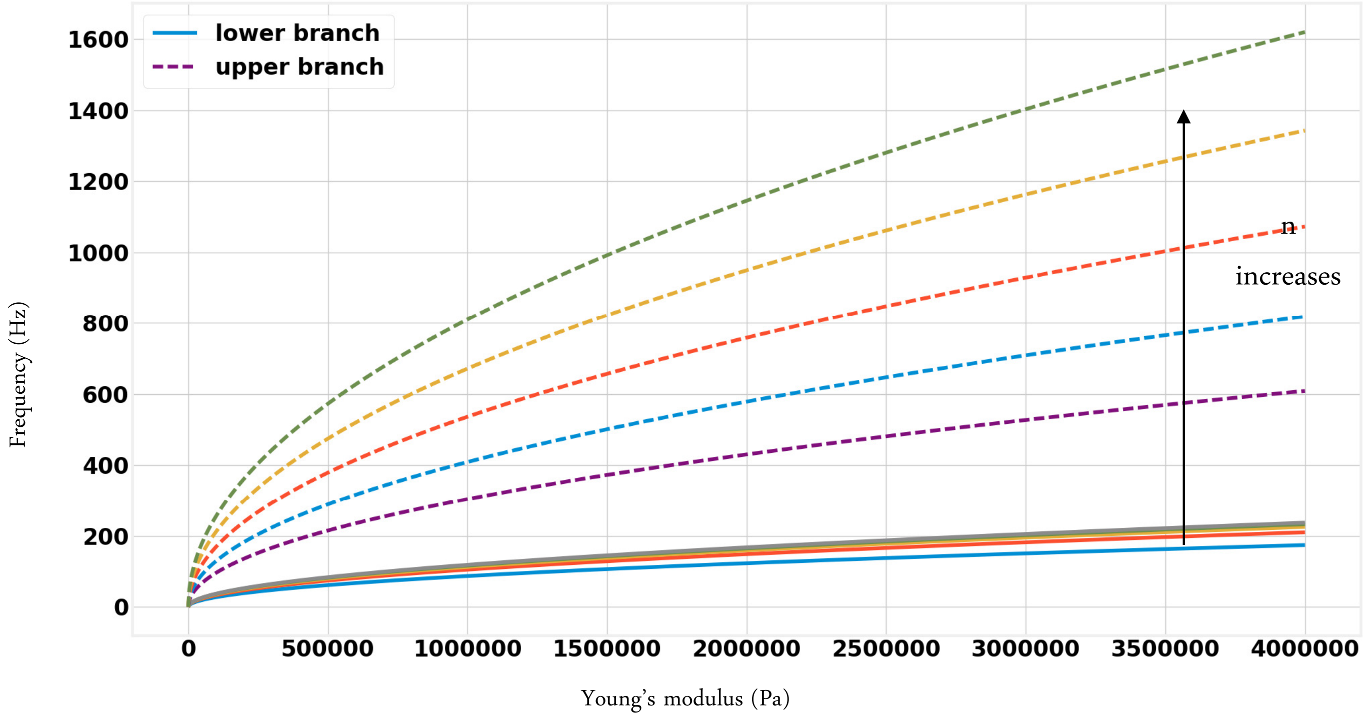


Vibration frequencies of an elastic spherical shell:

$$f_n = \frac{1}{\sqrt{A}} \cdot C_n(\nu)$$

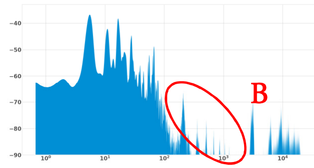
$$A = \frac{1-\nu^2}{E} \rho R^2$$

- ν: Poisson's coefficient
- E: Young's modulus
- ρ: density of rubber
- R: radius of balloon

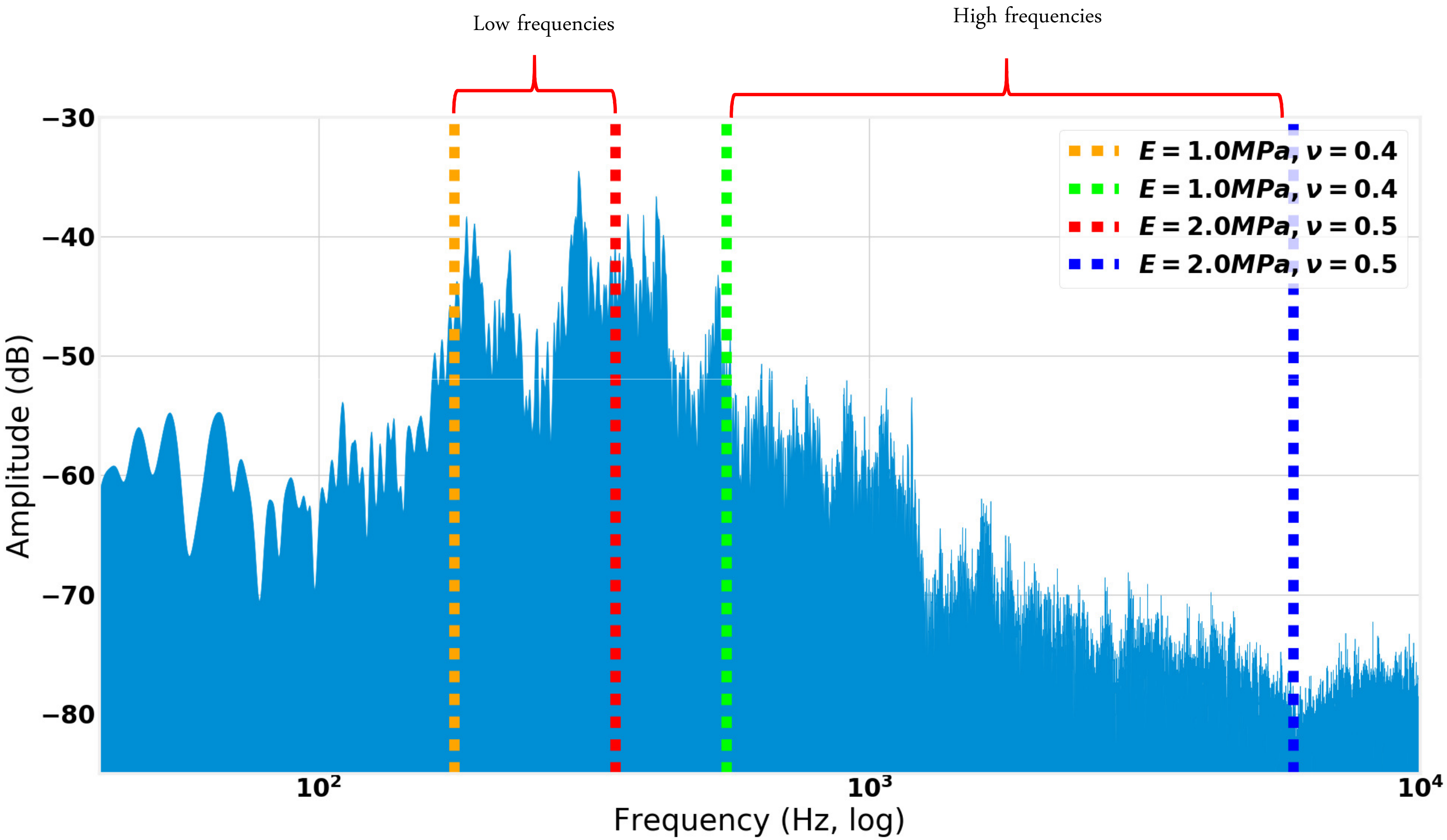


Source: Wilfred E. Baker. Axisymmetric modes of vibration of thin spherical shell. The Journal of the Acoustical Society of America, 33(12): 1749-1758, 1961.

Zone B

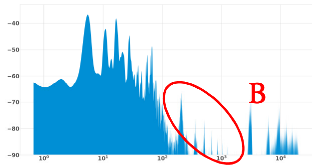


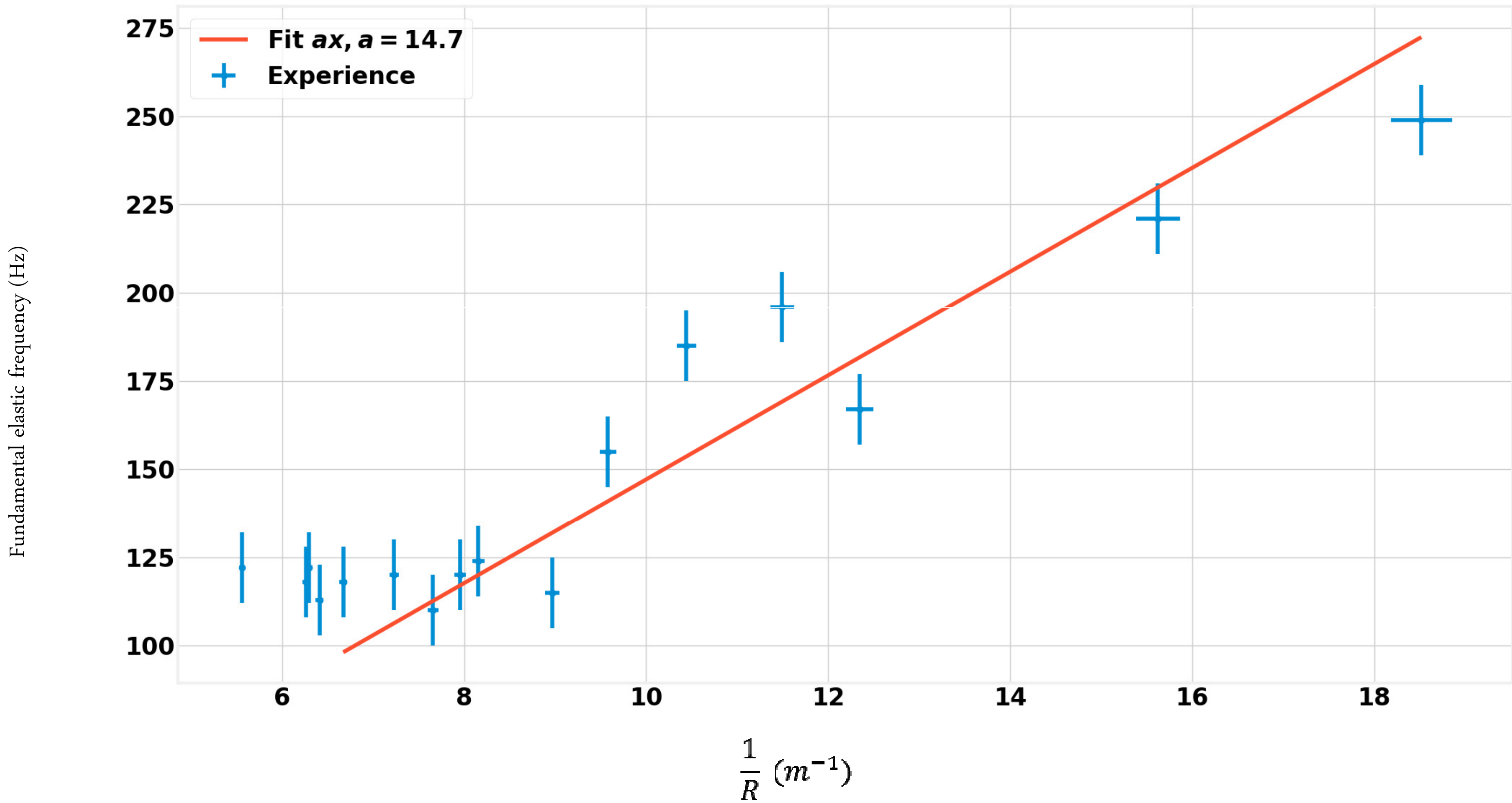
Predicted frequency ranges for n=1 to 15:



The theory is coherent with the experiments

Zone B

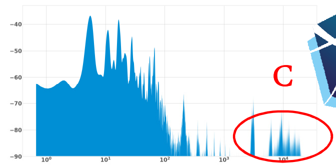




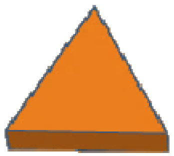
Theory

$$f_0 \propto \frac{1}{R}$$

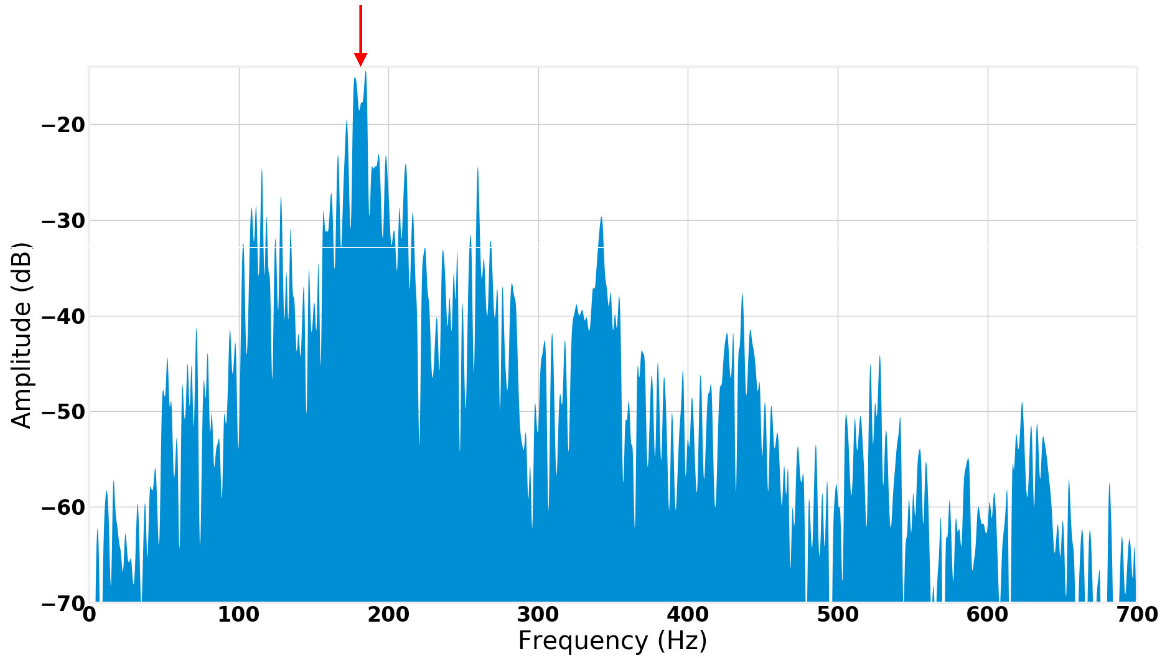
Experiment C



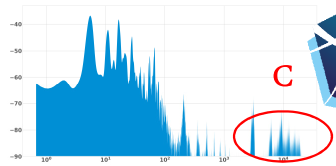
How does the sound of the balloon vary with the size of the hex nut's edge ?



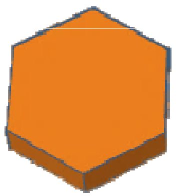
Hex nut with 3 sides



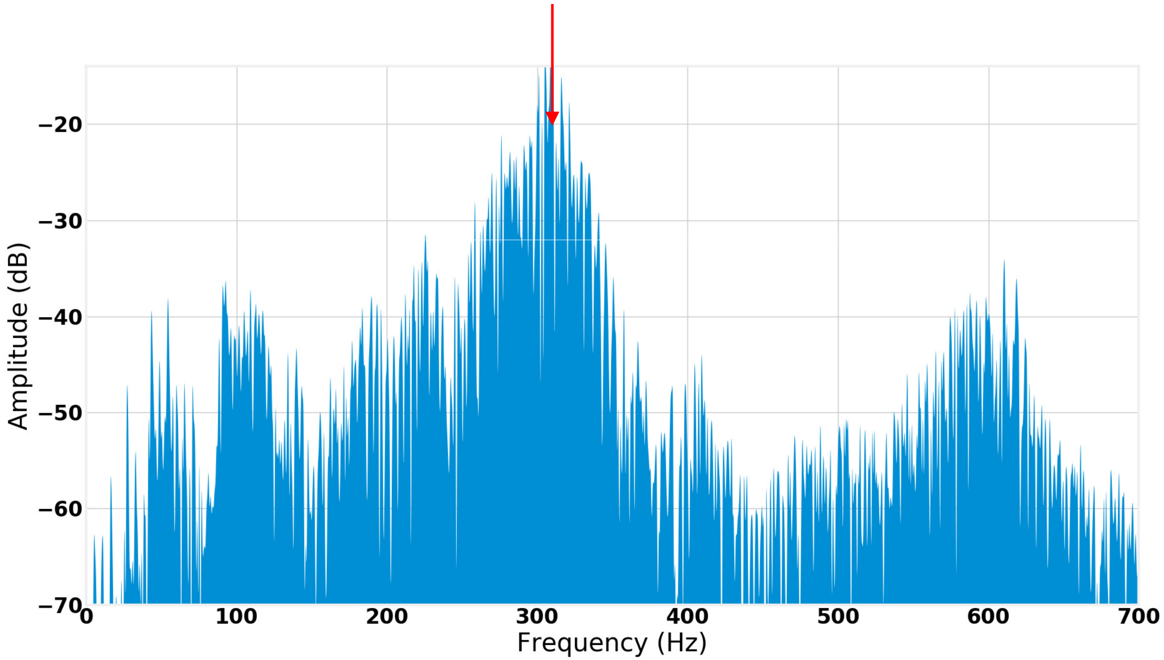
Experiment C



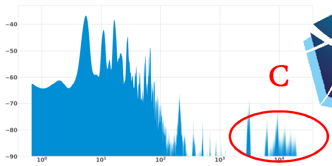
How does the sound of the balloon vary with the size of the hex's edge ?



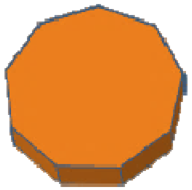
Hex nut with 6 sides



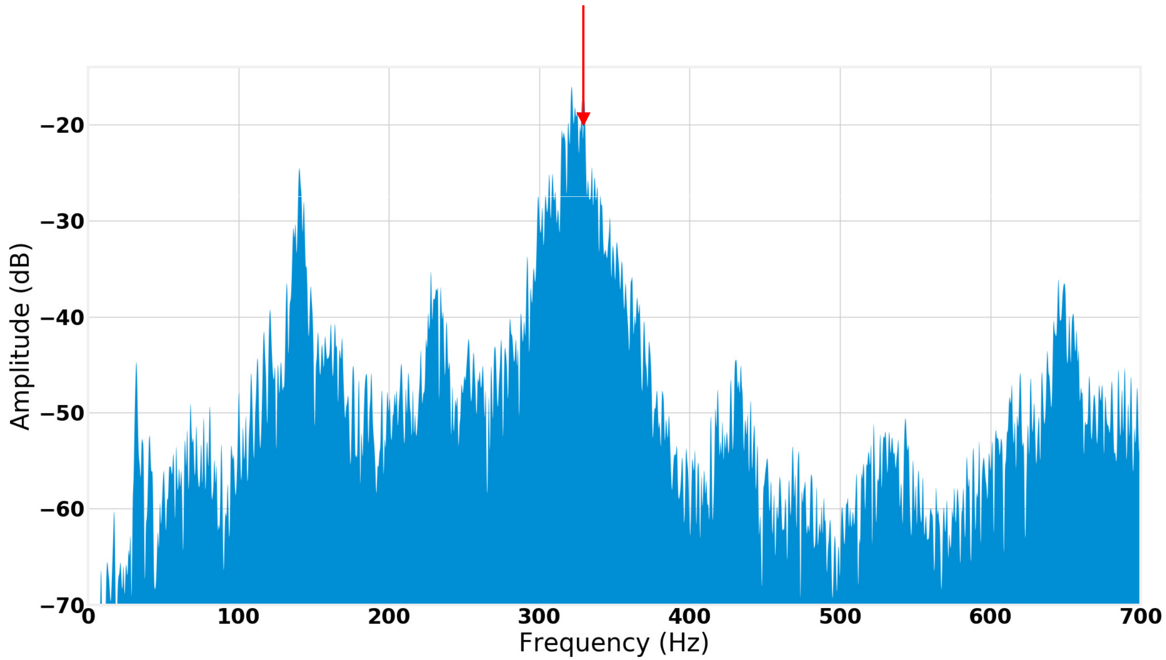
Experiment C



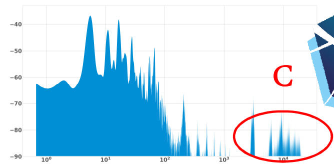
How does the sound of the balloon vary with the size of the hex's edge ?



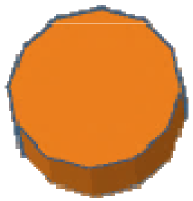
Hex nut with 9 sides



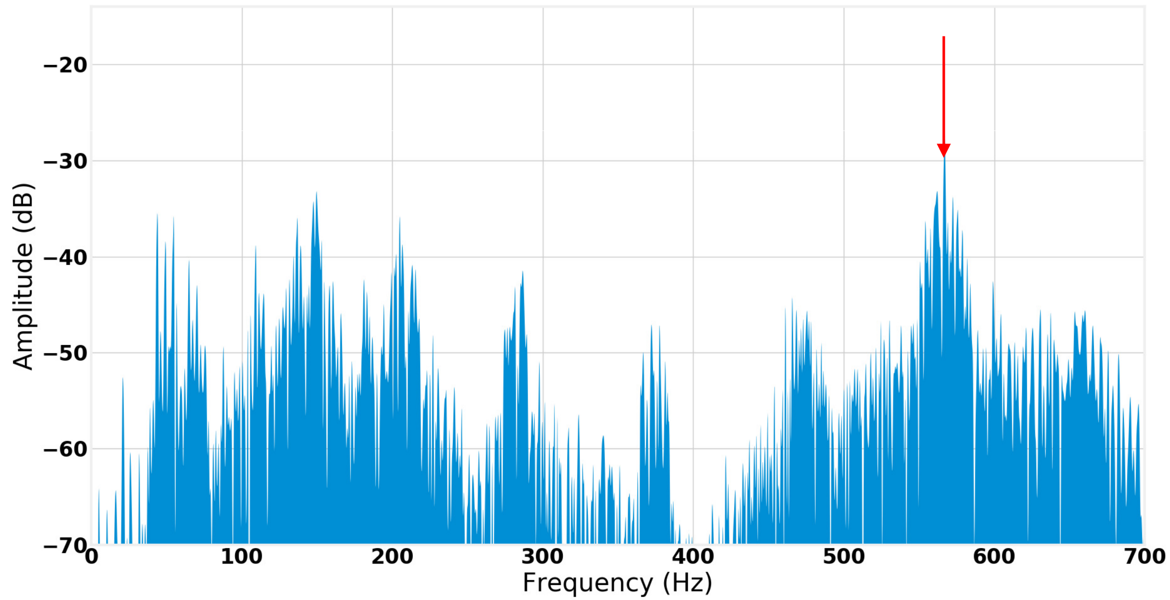
Experiment C



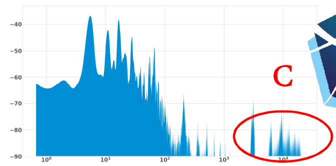
How does the sound of the balloon vary with the size of the hex's edge ?

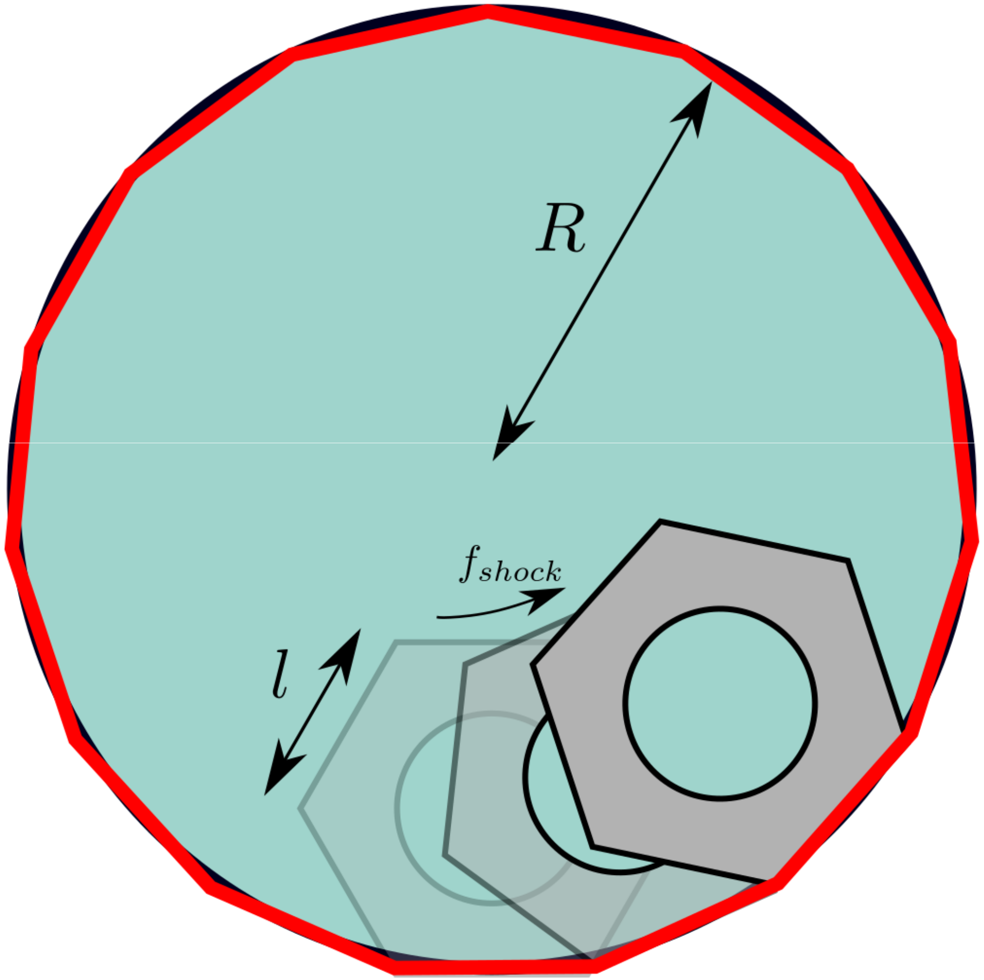


Hex nut with 12 sides



Zone C - Theory





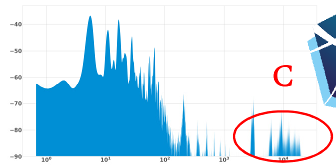
Number of hits per rotation :

$$N = \frac{2\pi R}{l}$$

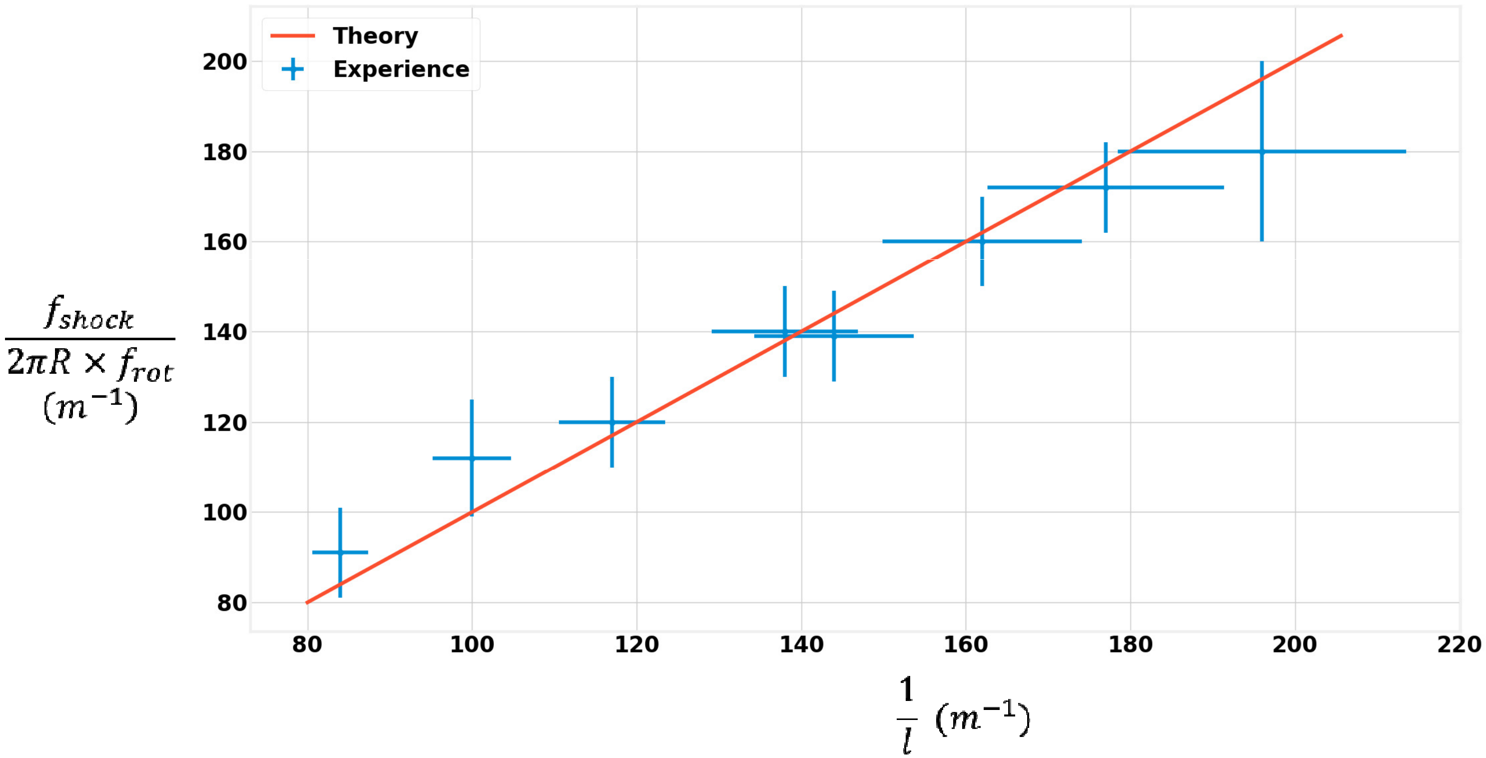
Number of rotation per second : f_{rot}

$$f_{shock} = \frac{2\pi R}{l} f_{rot}$$

Zone C - Results



Sound frequencies for different hex nut's lengths



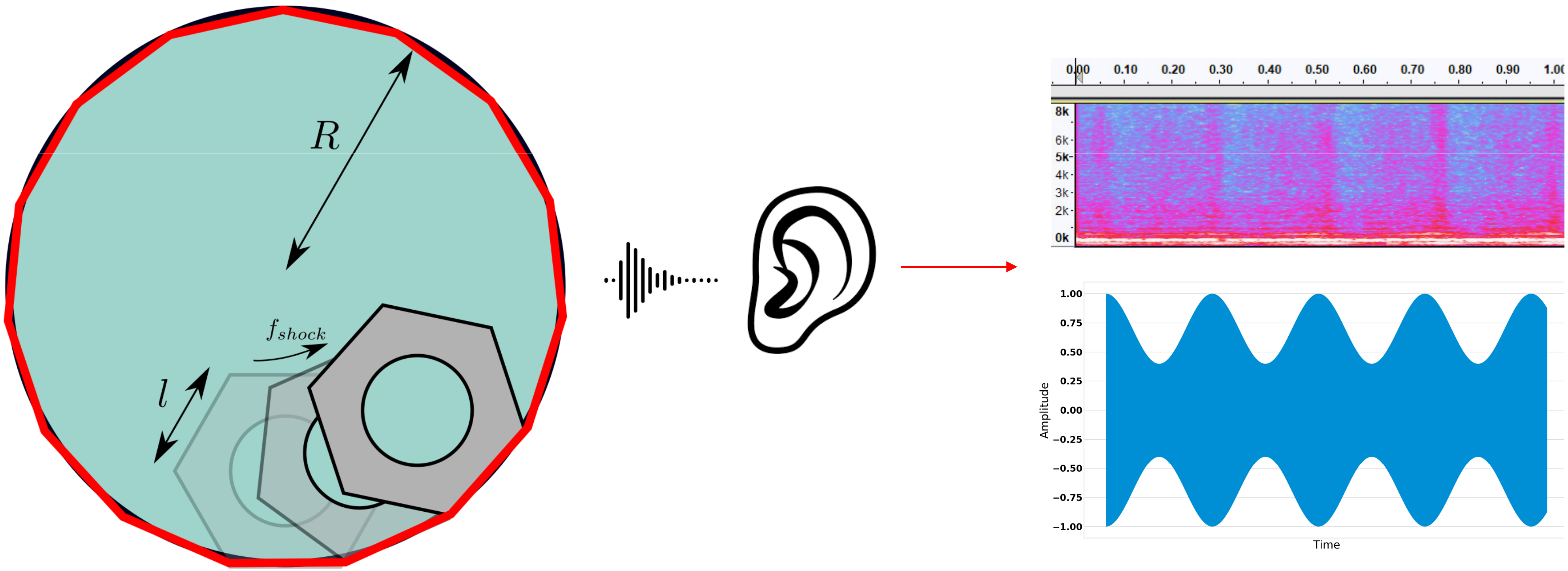
$$\frac{f_{shock}}{2\pi R \times f_{rot}} = \frac{1}{l}$$

The theory matches the experiments

Amplitude

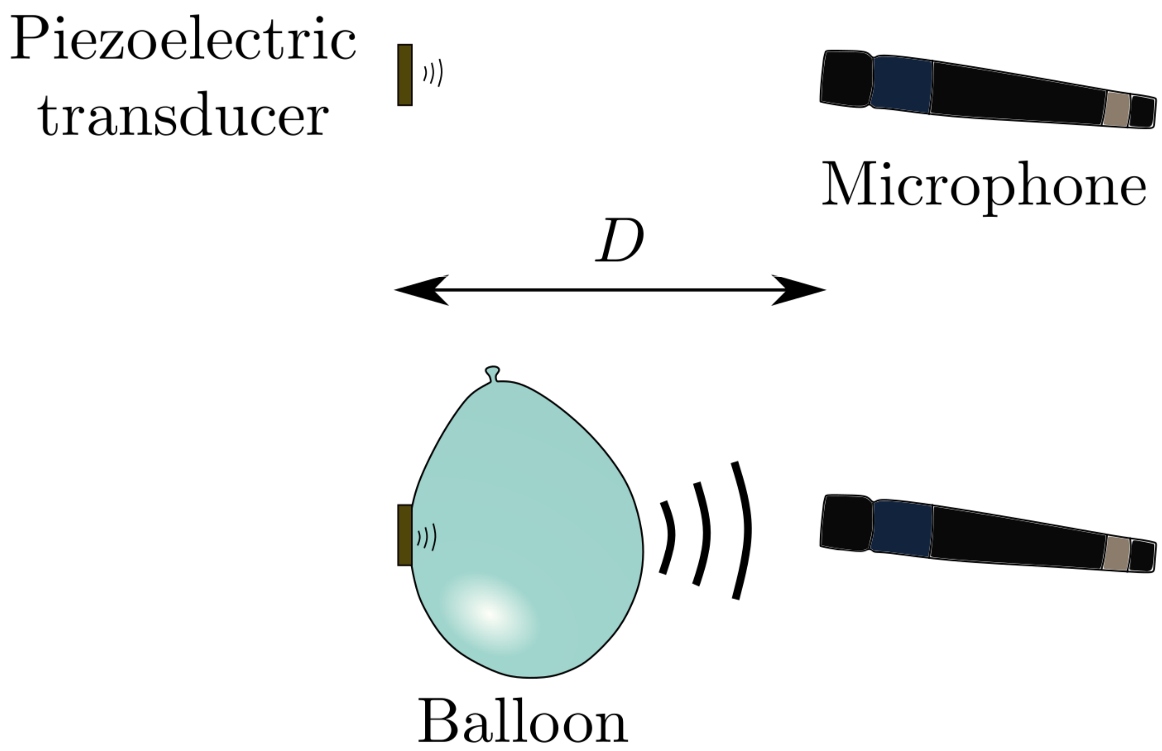
Influence of the rotation

The amplitude is modulated by the varying distance between the ear and the hex nut.



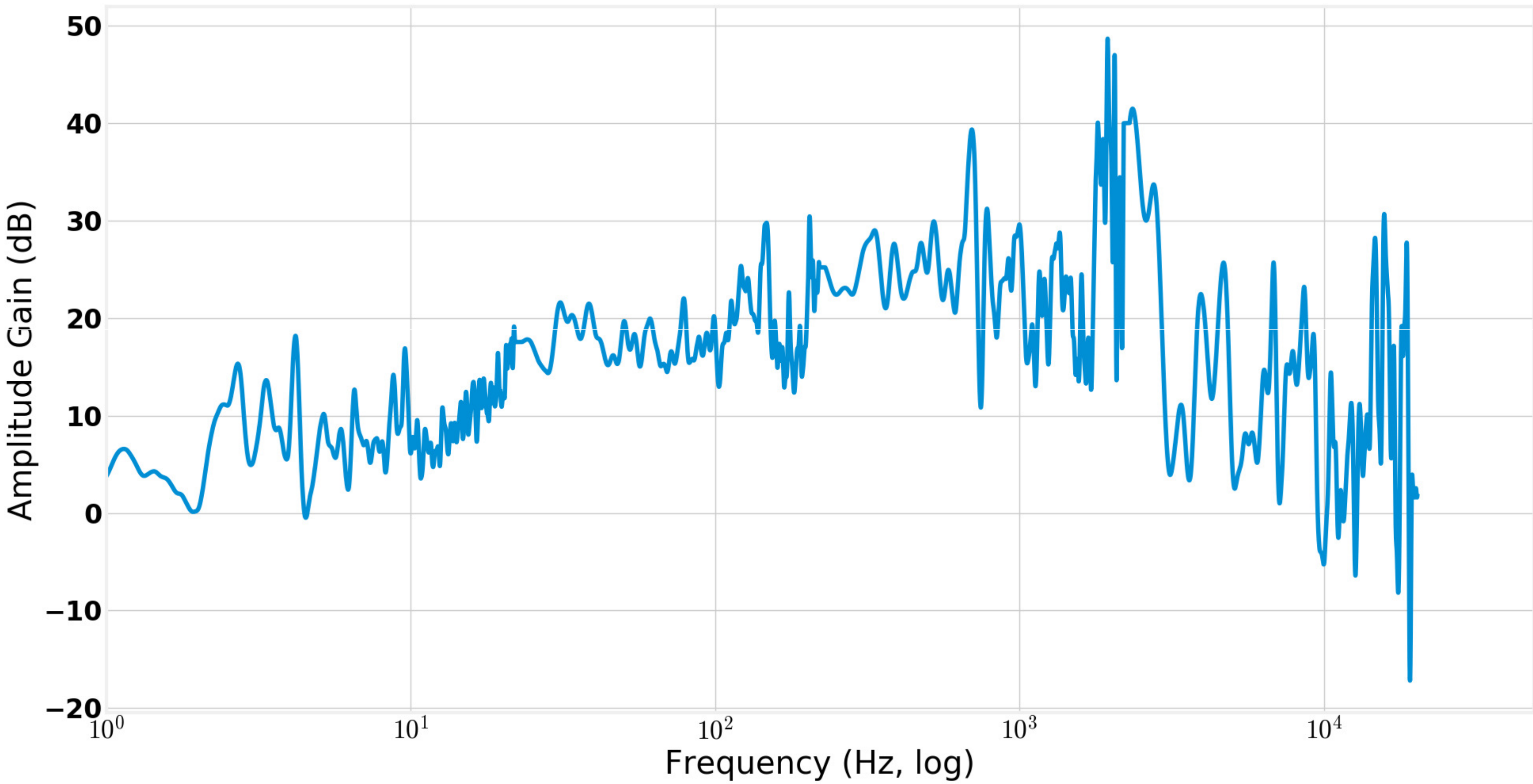
Amplitude

Amplification – Experimental setup



Amplitude

Influence of the sound box



Amplitude gain in function of the frequency

The balloon acts as a sound box

Amplification over audible range≈ 20dB

Conclusion

How do the **characteristics of the sound** depend on the **parameters of the system** ?

Important parameters

3 frequential contributions :

- Movement the balloon

$$f_{sound} = f_{rot}$$

f_{rot}

- **Oscillation** of membrane

$$f_{sound} = f_{resonance}$$

E, ν, R, ρ

- **Shock** (no sliding) of the hex of the membrane

$$f_{sound} = f_{shock} \propto \frac{f_{rot}}{l}$$

f_{rot}, l, R

2 amplitude contributions :

- Movement the hex nut in the balloon

$$f_{amplitude} = f_{rot}$$

f_{rot}, D

- Sound box-like amplification of sound

$$A \approx 20dB$$

R, E, ν, ρ