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Problem 9
Screaming balloon

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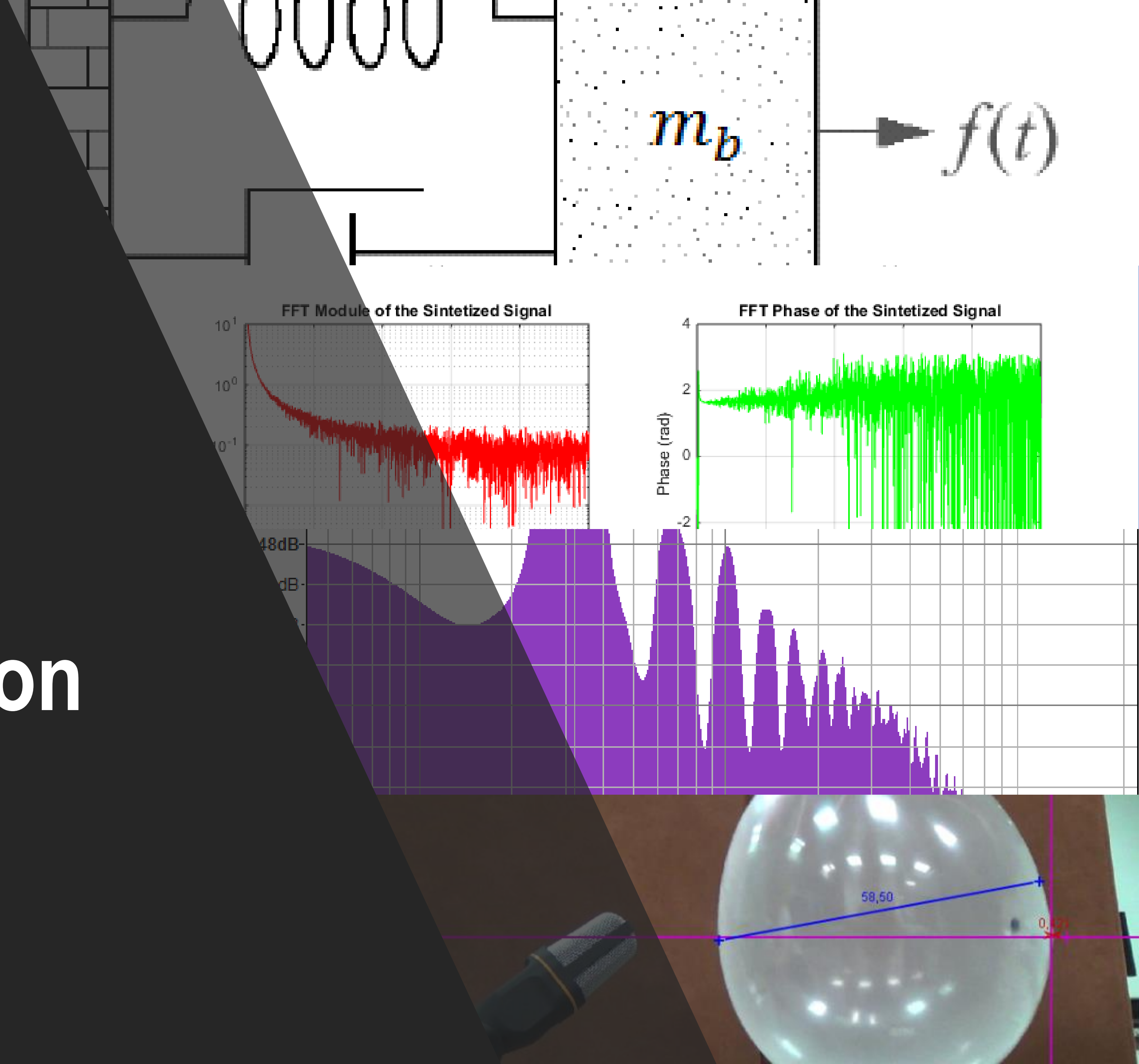

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Screaming balloon

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❑ The problem

- If you put a hex nut in a balloon it is possible to make it **scream by giving a certain rotational movement** to the balloon. How do the **characteristics of the sound produced** depend on the **important parameters of the system**?

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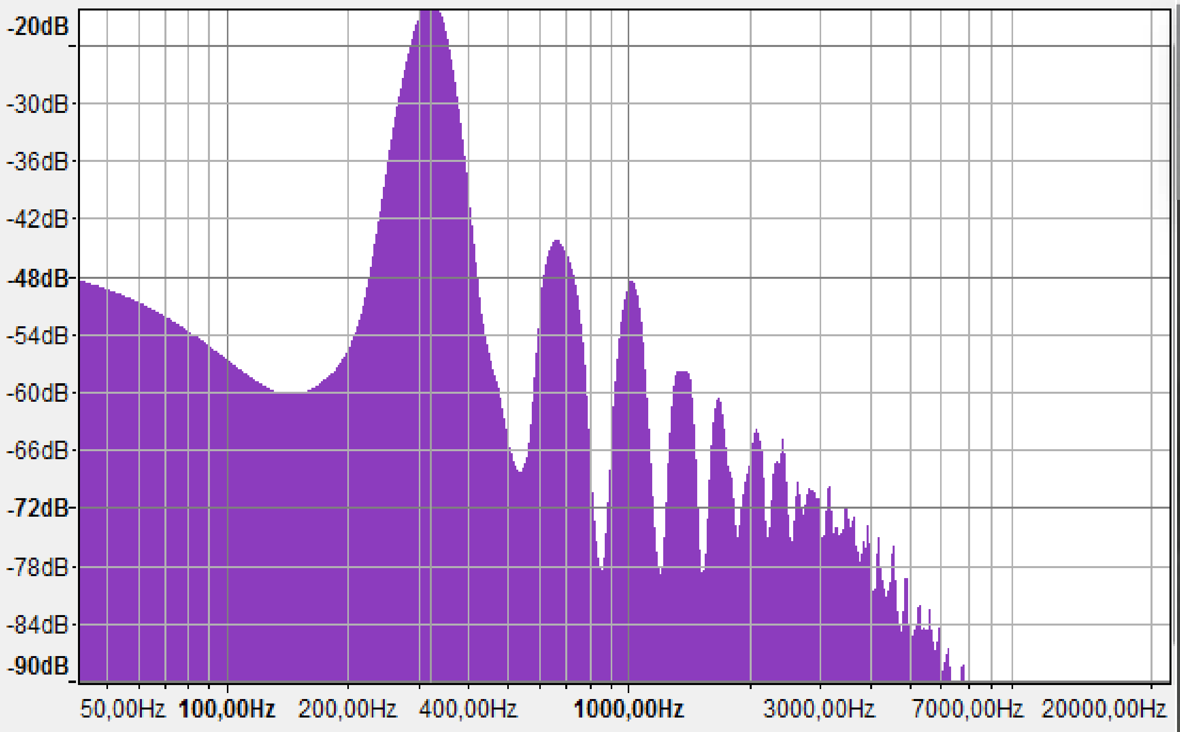
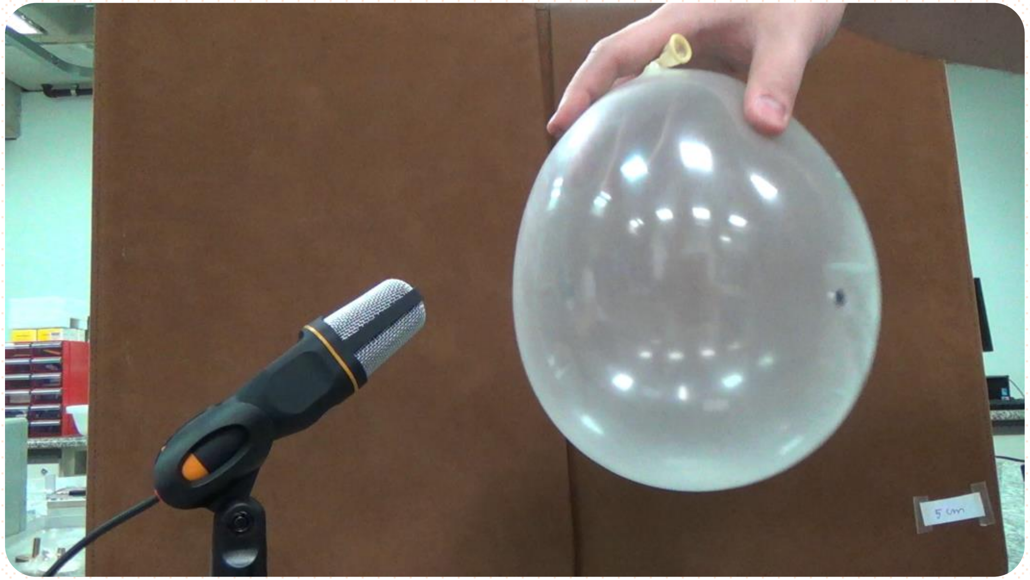
❑ The system



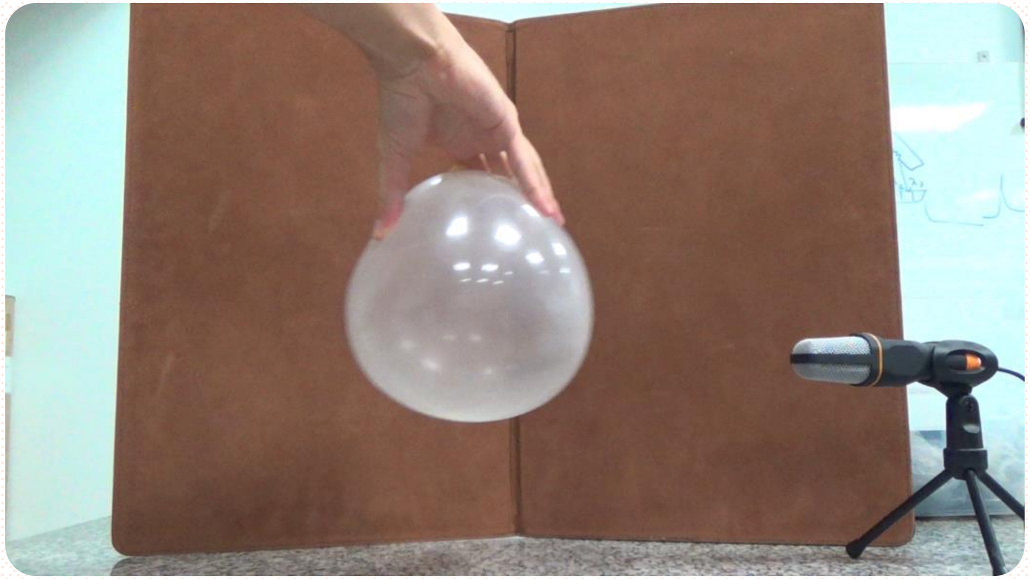
Sound spectrum, hex nuts and balloons

❑ Importance of the edge

- Comparison between hex nut and nut with no edges



- Hex nut



- Nut with no edges

❑ Sound spectrum for both

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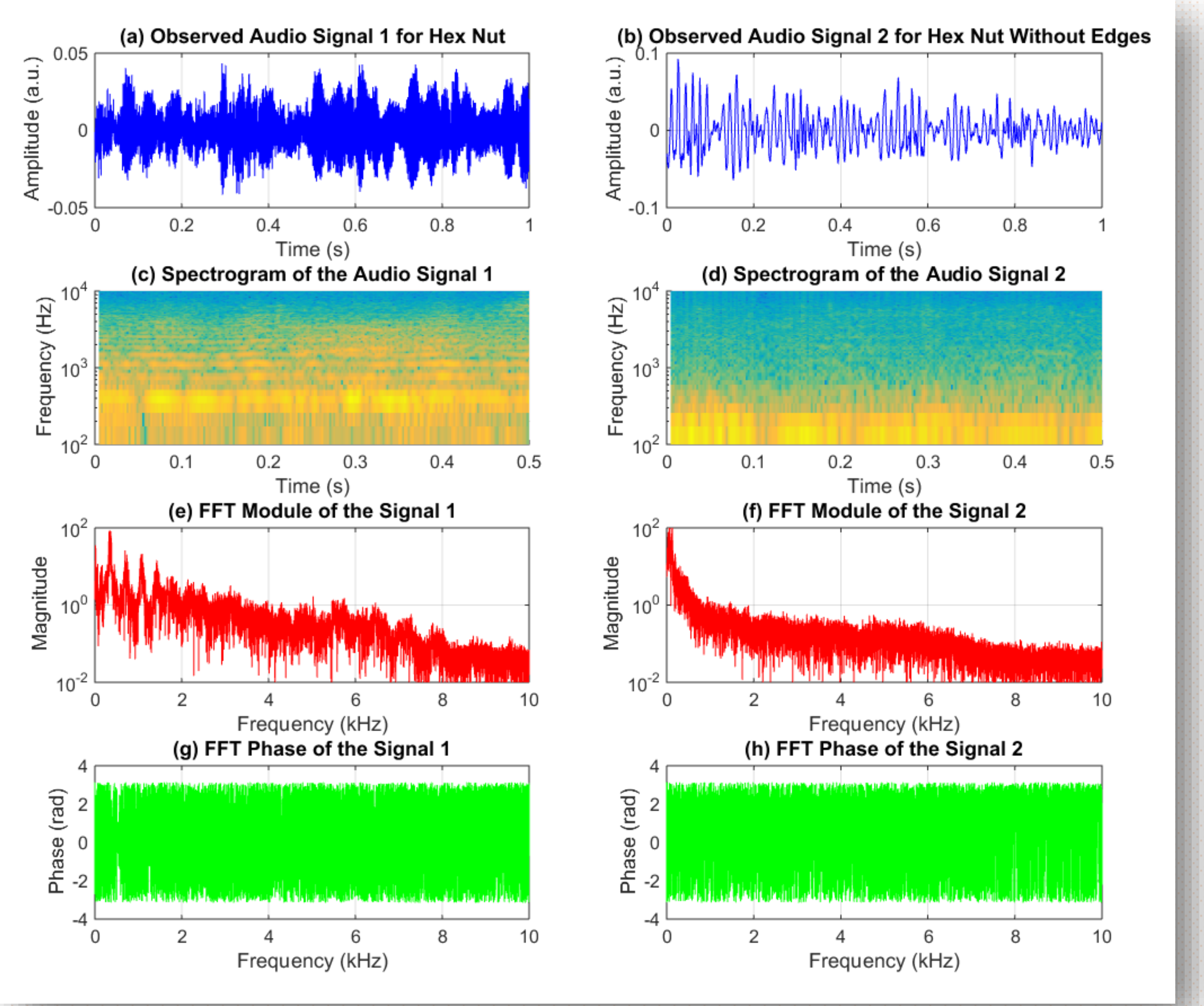
Difference of amplitudes in domain of time

Population of intense frequencies for a same time interval

Similar behavior for magnitudes, except for lower frequencies

Well defined peaks in phase, characteristic of the sound we hear



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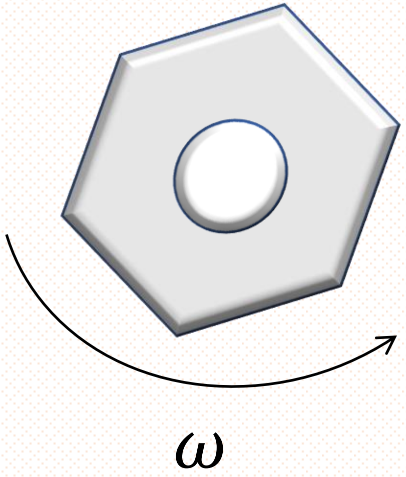
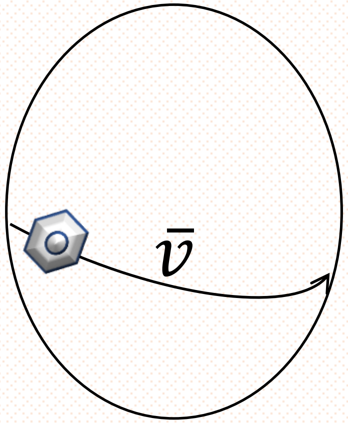
❑ Movement of the hex nut & sound

○ Experimental facts



Nut rotates around itself ω



Nut rotates around the balloon with $\bar{v}$

○ Edge collisions with the balloon creates the **screaming**!

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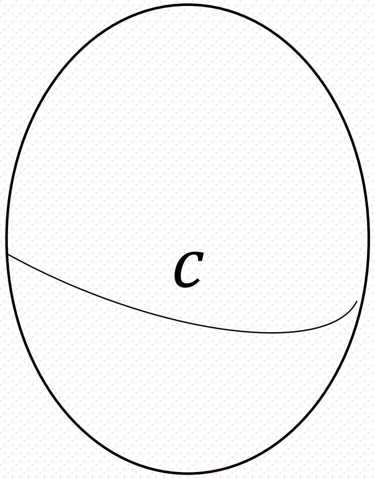
❑ Experimental procedure

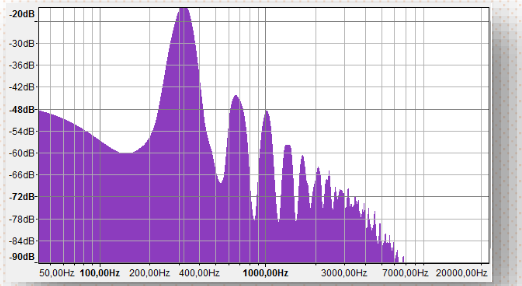


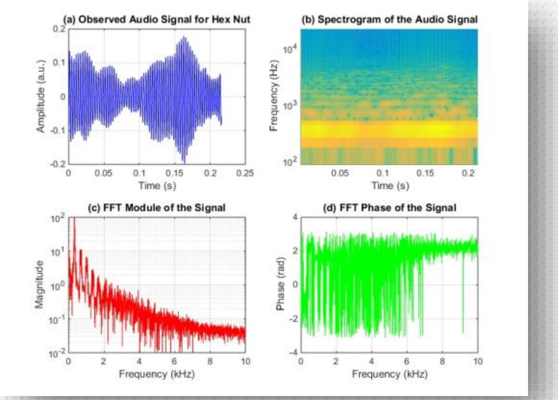
Circumference measurements

Diagonal
Equatorial
Polar

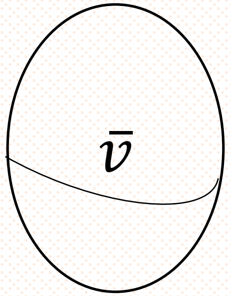
Mean radius

$$c = 2\pi r_b$$





Time Δt to complete 1 turn



$$v = \frac{c}{\Delta t}$$

- With information about the geometry of each balloon and time t we calculated the translational $\bar{v}$!

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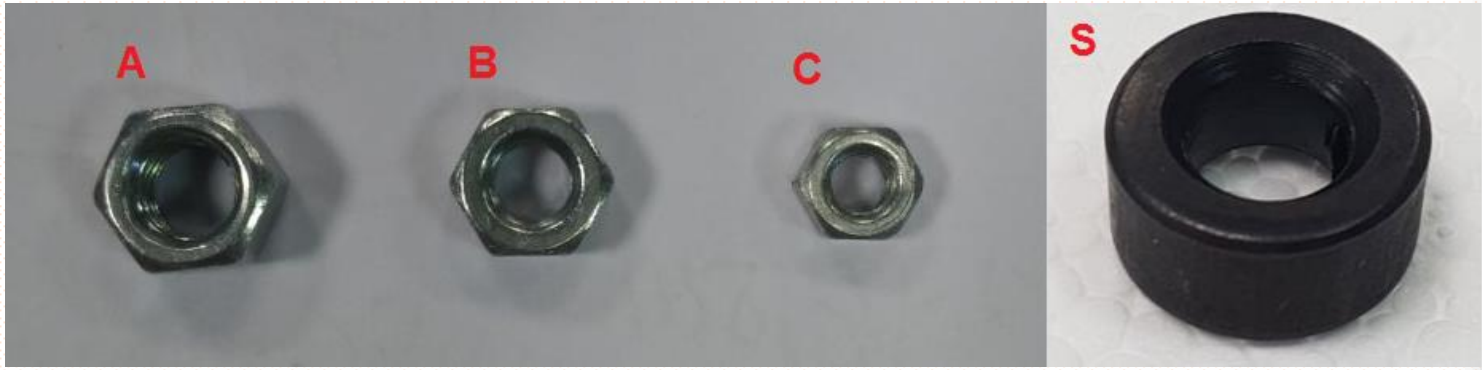
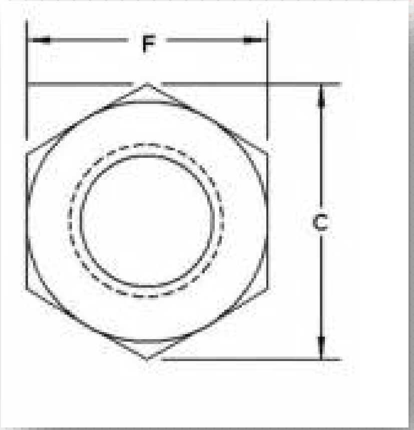
❑ Varied parameters





Mean radius

$$r_{hn} = \frac{1}{6}\sum_{i=1}^{3}(C_i + F_i)$$

Hex Nut	Nominal Size	Mass (g)	Mean external radius (mm)
A	3/8"	6.6270 ± 0.0001	7.5 ± 0.2
B	5/16"	4.7135 ± 0.0001	6.9 ± 0.2
C	M6	2.2122 ± 0.0001	5.2 ± 0.1
S1	--	8.269 ± 0.0001	10.7 ± 0.02
S2	--	3.940 ± 0.0001	16.9 ± 0.02

❑ Sound spectrums

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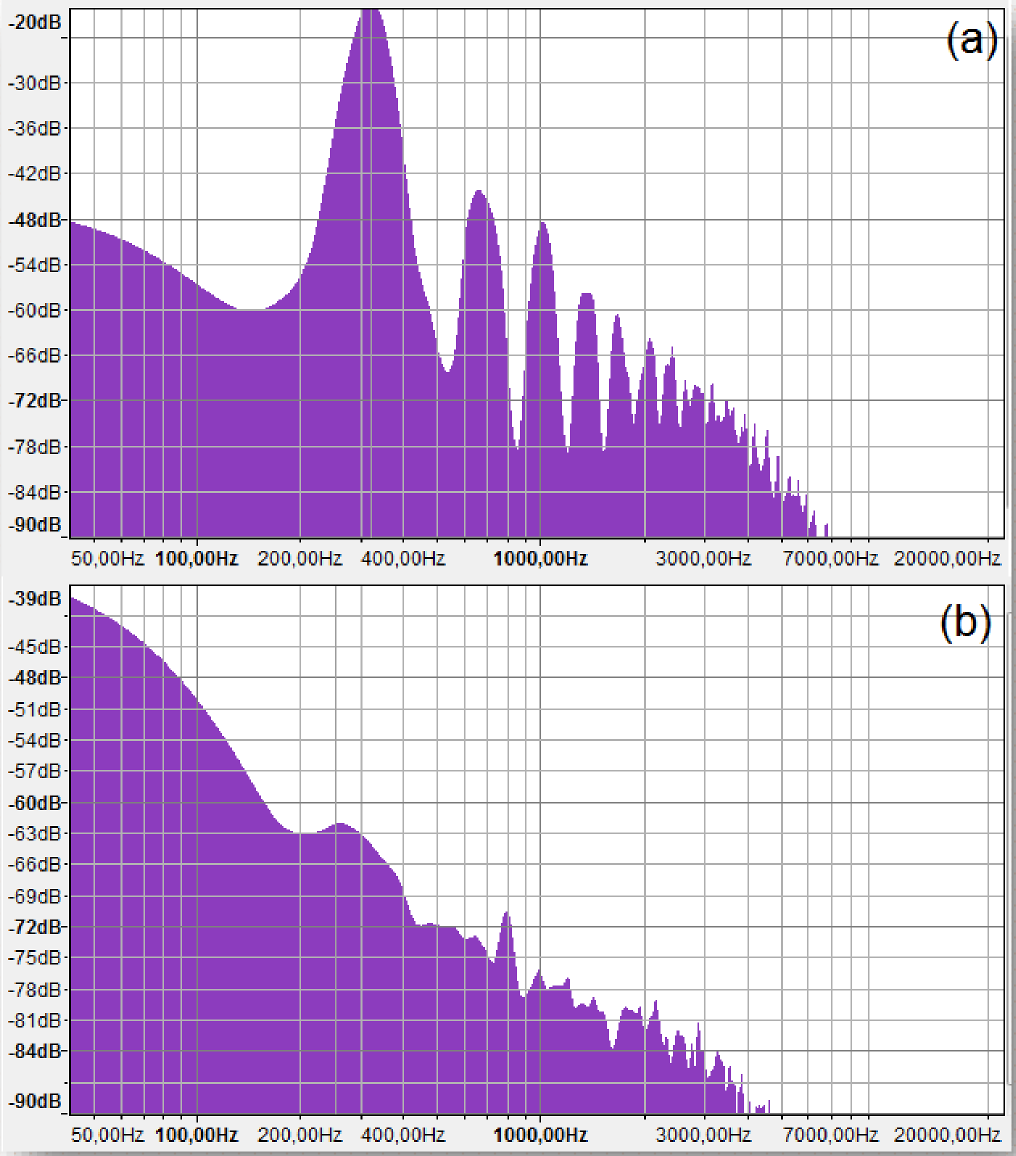

Hex nut *c* with edges (a)

- Well defined peaks with high frequency
- Presence of harmonics

Hex nut without edges (b)

- No defined peaks of intensity!

❑ Results for different hex nuts

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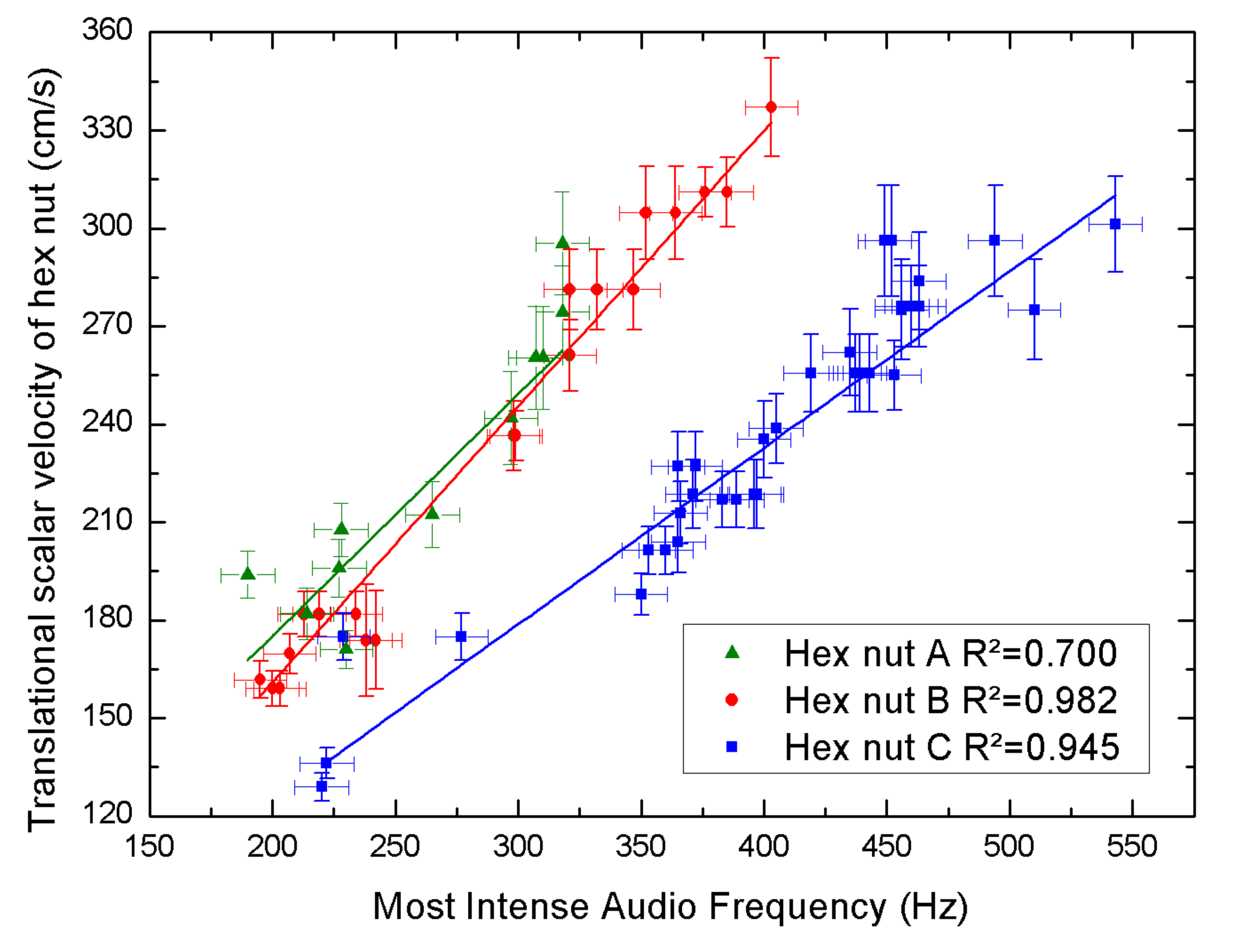

❑ Normalized translational velocities (radius)

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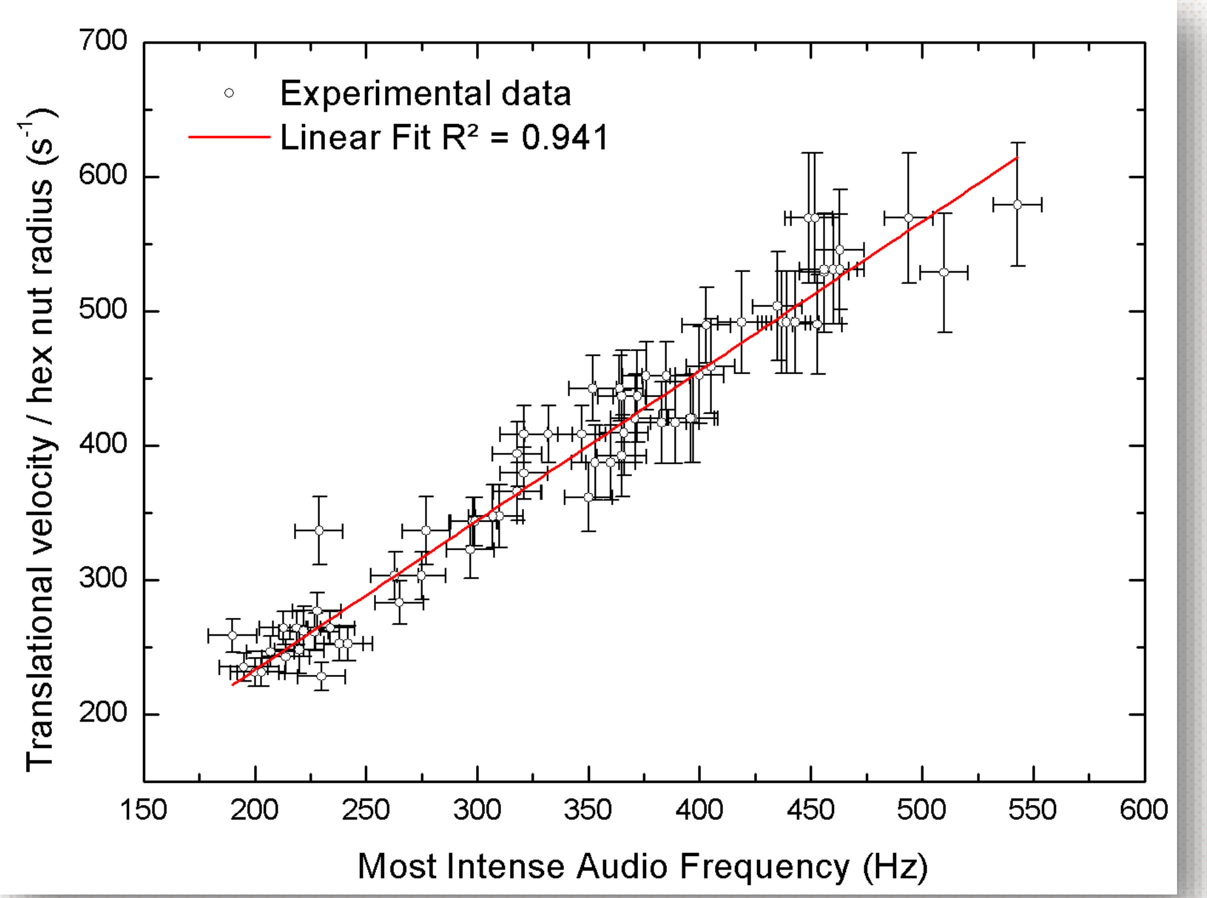
- Considering **all** data for different hex nuts radius and normalizing the results

$$y = ax + b \rightarrow \frac{v_t}{r_{hn}} = af_{MI} + b$$

$$\begin{cases} a = (1.11 \pm 0.03)adm \\ \text{b} = (10 \pm 9)s^{-1} \;\; \textit{experimental error} \end{cases}$$

$$\boxed{\frac{v_t}{r_{hn}} = 1.11 f_{MI}}$$

Relation between nut radius & translational velocity and MIf



❑ So far...

- How do the characteristic of the sound produced depend on the important parameters of the system?

- Characteristics of the sound produced
  - Most Intense frequency in the sound spectrum

- Important parameters of the system
  - Balloon radius + translational period = translational velocity
  - Hex nut = screaming / Nut with no edges = no high frequencies
  - Translational velocity/ hex nut radius = most intense frequency component

- Phenomenological law that relates the sound properties with the system!

❑ Physical model- Reconstructing the screaming

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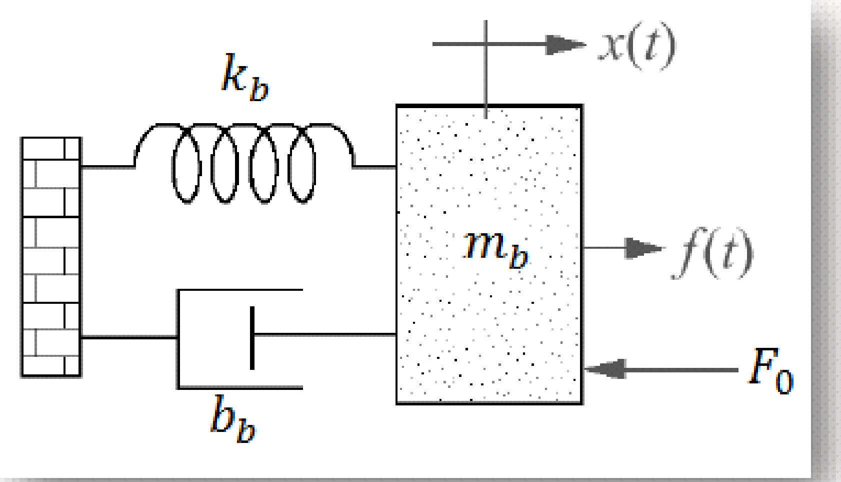
Screaming balloon



Damped spring mass system

$$m_b\ddot{x} = -k_b x - b_b\dot{x} + \cancel{F_o} + F(t)$$

- $F(t)$ is the periodic force by the hex nut, $F(t) = F_0 cos(\bar{\omega}t)$
- $k_b x$ is the balloon's elastic response
- $b_b\dot{x}$ is the damping factor
- $F_o = 4\pi r_b^2 P_b$ is the force due to internal pressure P_b

$$F(t) = F_0 cos(\bar{\omega}t)$$

$\bar{\omega}$ is the frequency of the force $F(t)$ acting on the system

$$\boxed{x(t) = Ae^{-\frac{\gamma t}{2}}\cos(\omega t + \phi) + \frac{F_0}{m_b}\frac{(\cos\bar{\omega}t + \phi')}{\sqrt{(\omega_0^2 - \omega^2)^2 + \gamma^2\omega^2}}}$$

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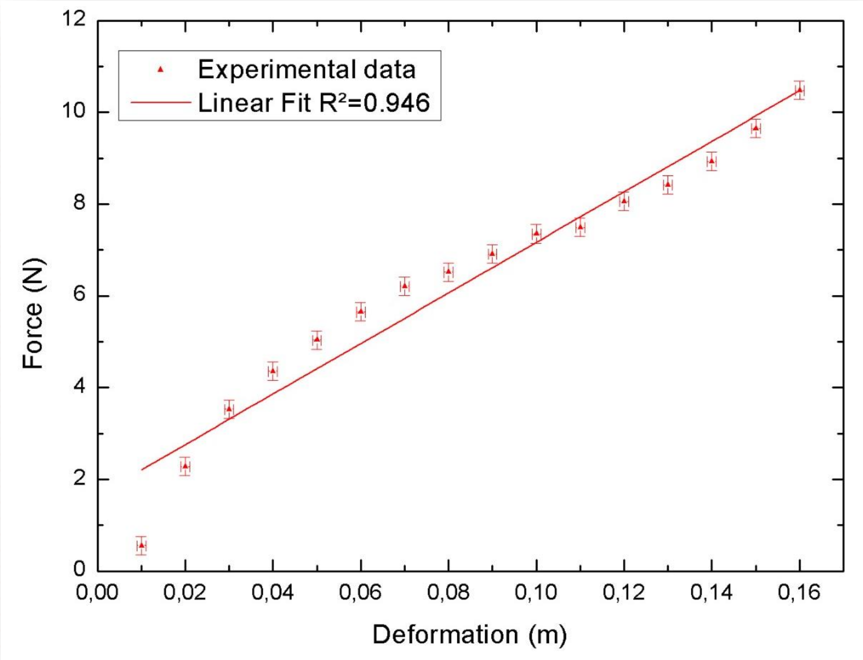
Determining the model constants

- Different balloon masses
  - $m_b \sim (1.3 \pm 0.1) g$
- Balloon's elastic constant
  - $k_b = (55 \pm 1) N/m$
- $F_0 = \dfrac{m_{hn} v t^2}{r_b}$ (cpt. Force)
- $\omega_0 = \sqrt{\dfrac{k_b}{m_b}}$ natural frequency of the system
- $\gamma = \dfrac{b_b}{m_b}$, damping parameter



❑ Results for 1s simulation

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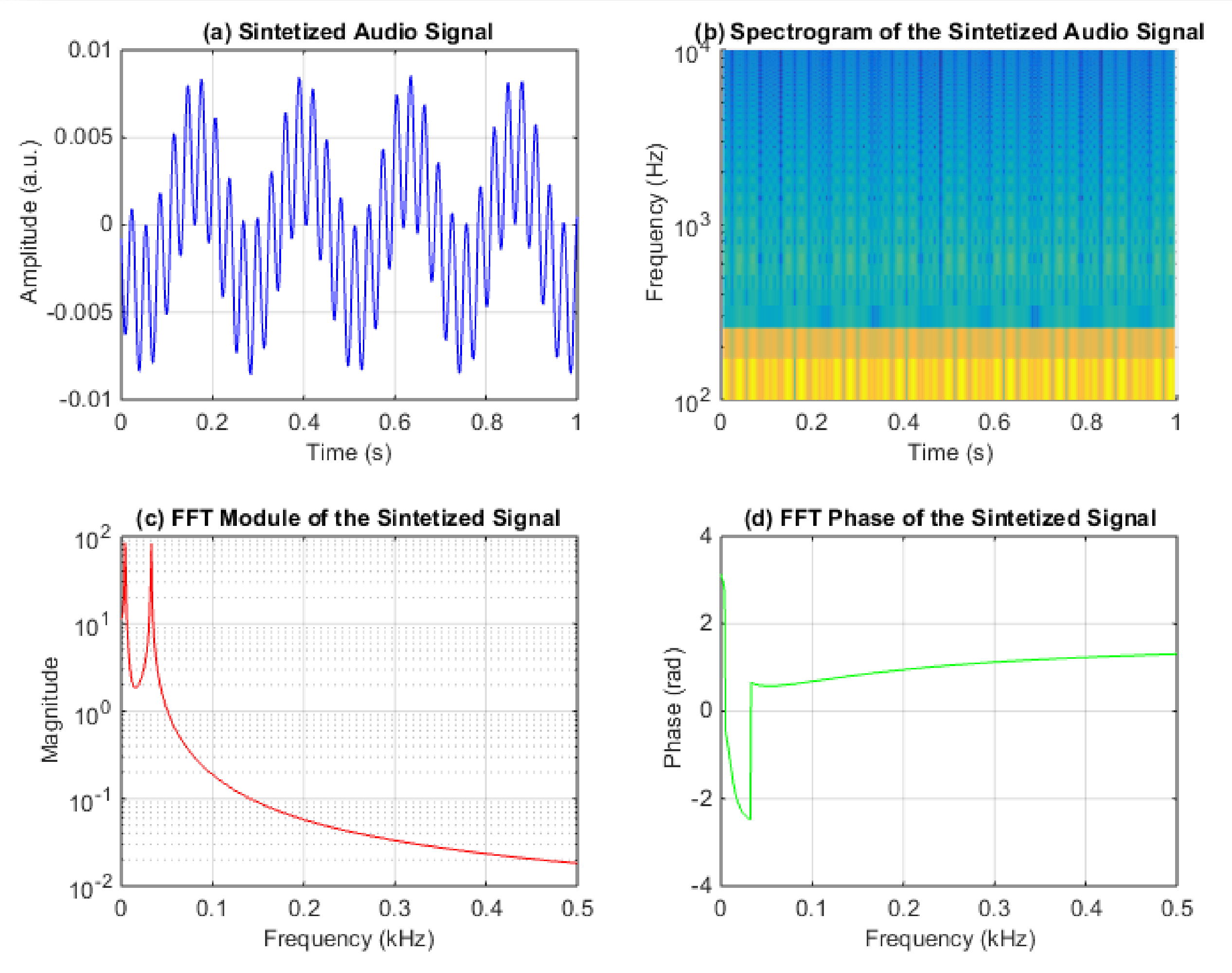
Using the DHO as a 1st approximation to the problem and parameters obtained experimentally to solve the ODE, we get the following behavior we get from a synthesized signal!



Results are similar to the ones with the nut without edges!

❑ DHO x Hex Nut Without Edges (same time for a complete turn)

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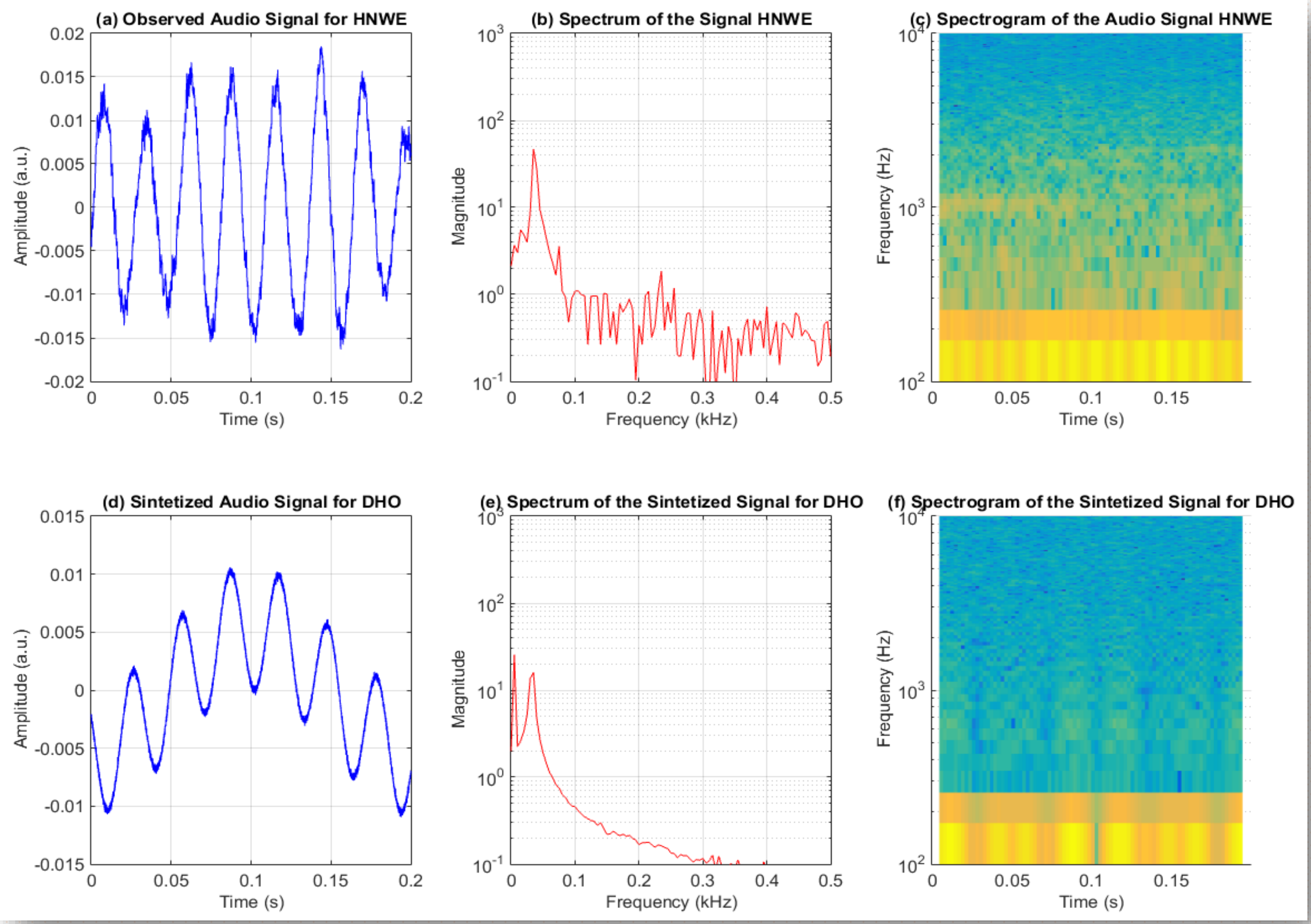

Amplitude modulation for the nux with edges

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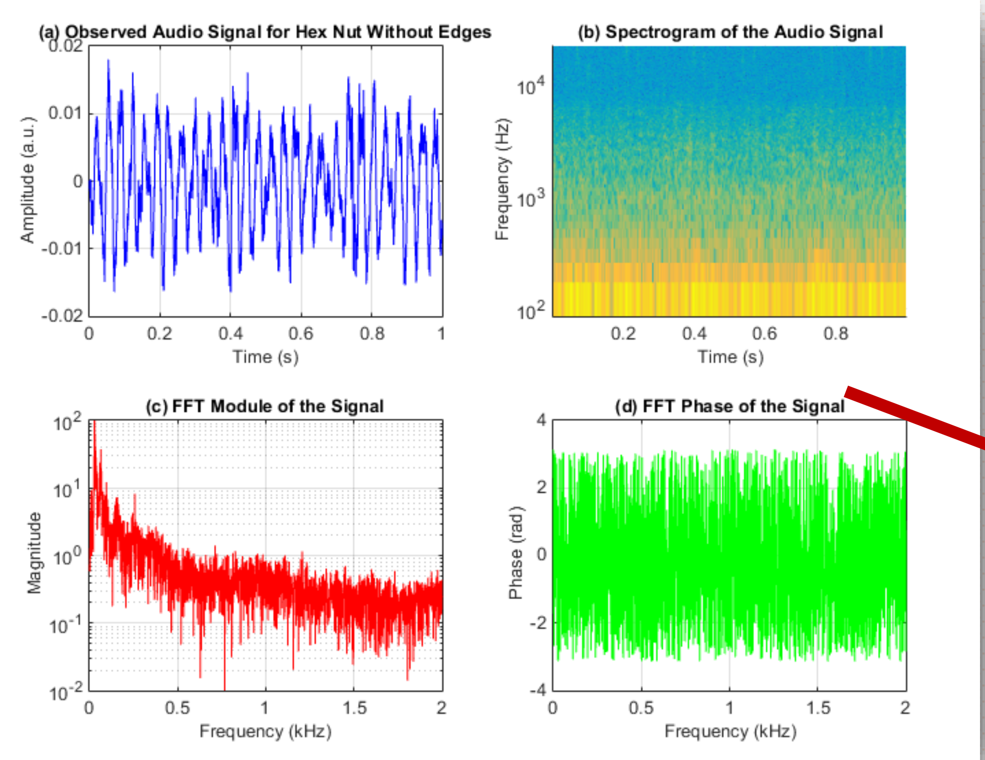
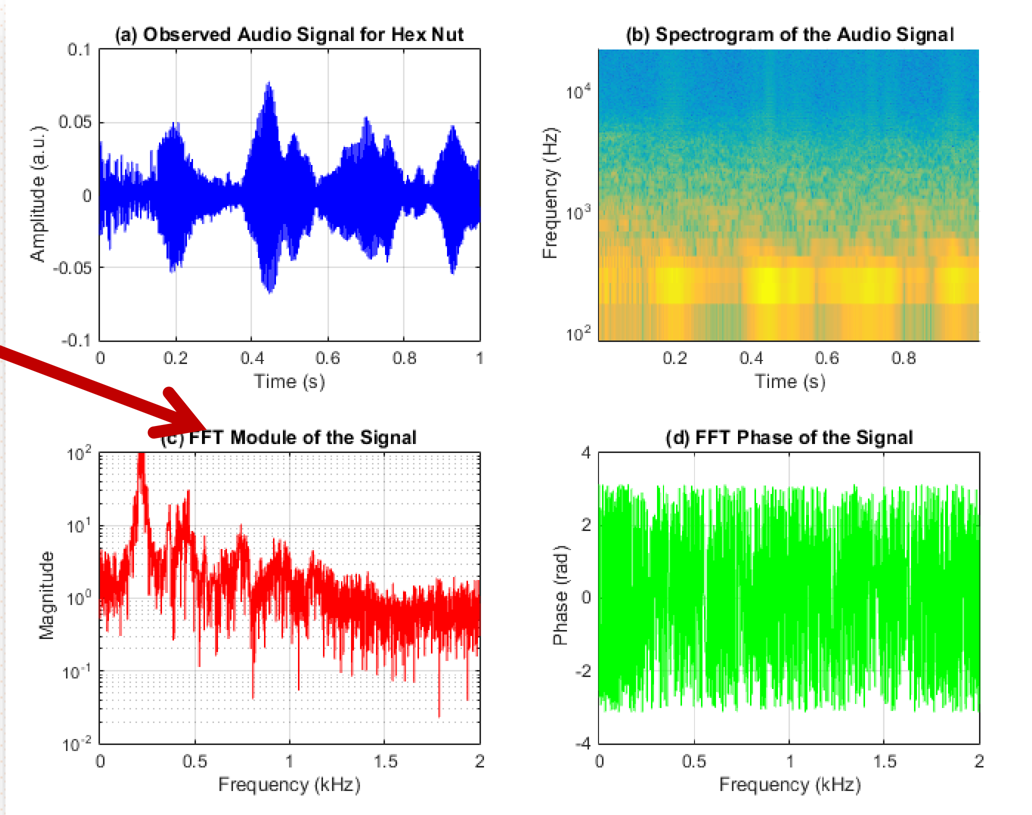
$$s(t) = C\big(1 + k_A x(t)\big)\cos(\omega_r t)$$

- Considering a same $x(t)$ as in the DHO, we applied an amplitude modulation for the HNWE
- $\cos(\omega_r t)$ is the spin over its own axis
- C is the amplitude of the carried signal (free parameter) and w_r is the frequency of each hex nut hitting the balloon's wall!
- $k_A = \frac{E_x}{E_c} = \frac{\int x^2(t)dt}{C^2}$, modulation index, was used with an assumed $C = 0.04$ for a satisfactory approach.
- $\omega_r = \frac{v_r}{r_h} = \frac{v_t r_b}{r_h^2}$ is the rotational frequency

❑ Why use a AM?



(a) Observed Audio Signal for Hex Nut Without Edges
Amplitude (a.u.)
Time (s)
(b) Spectrogram of the Audio Signal
Frequency (Hz)
Time (s)
(c) FFT Module of the Signal
Magnitude
Frequency (kHz)
(d) FFT Phase of the Signal
Phase (rad)
Frequency (kHz)



(a) Observed Audio Signal for Hex Nut
Amplitude (a.u.)
Time (s)
(b) Spectrogram of the Audio Signal
Frequency (Hz)
Time (s)
(c) FFT Module of the Signal
Magnitude
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Phase (rad)
Frequency (kHz)

AM-DHO+AWGN

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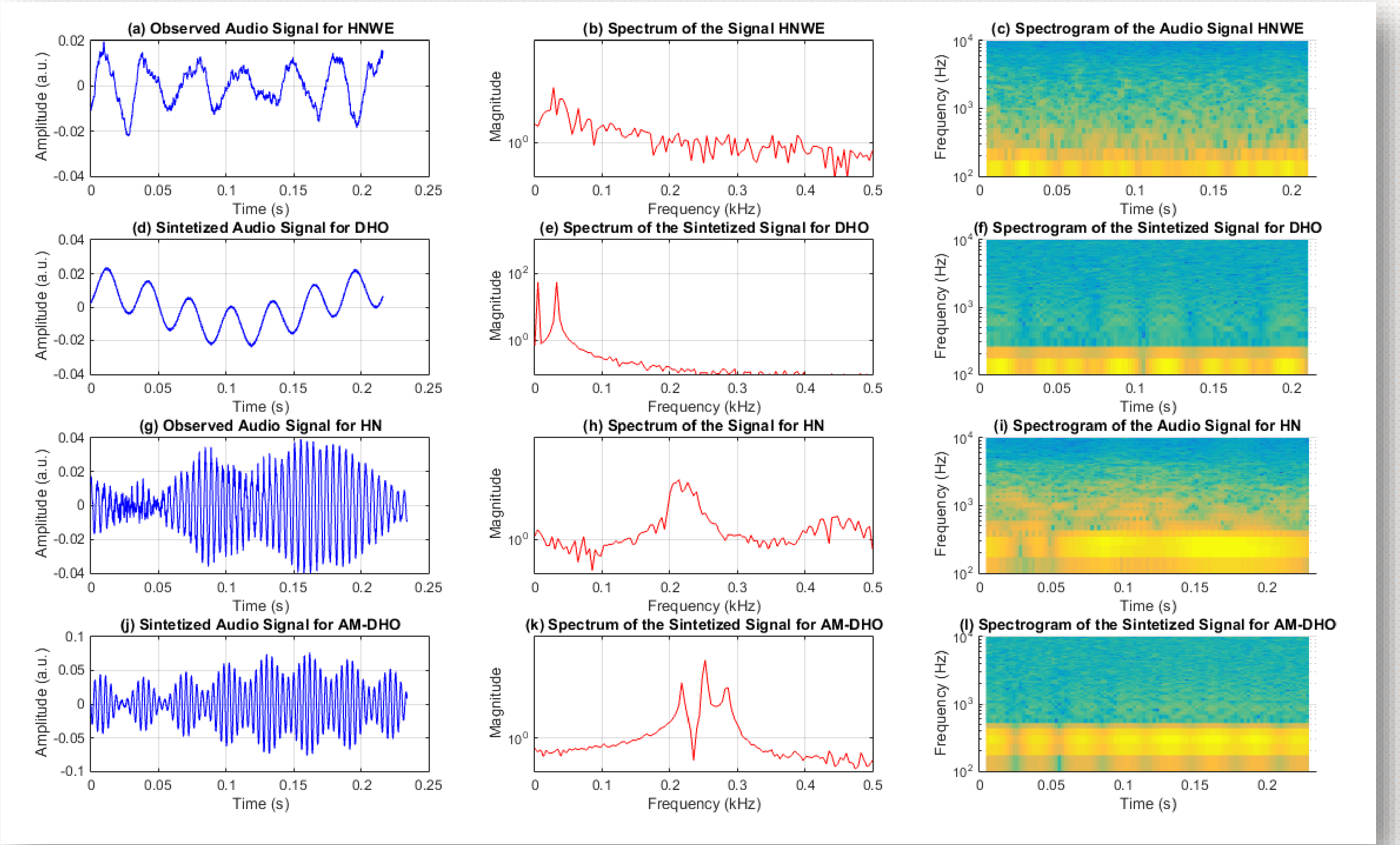

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❑ Conclusion

- We obtained a phenomenological relation to characterize the system's properties with the sound

$$\frac{v_t}{r_{hn}} = f_{MI}t$$

  - Answered the problem experimentally!
- From a physical model, we could explain the problem!
  - DHO simulates the hex without edges translating in the balloon
  - AM -DHO simulates the nut without edges translating in the balloon (DHO) and rotating around its own axis (6 times, one for each edge)
- How to improve the accuracy of the model: improve data collected
- Echoes, balloon's closed surface causing diferente interferences, bidimensional vibration for coupled oscillators, etc.

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Candle Lighting Trick

❑Appendix

❑ Calculating the constants

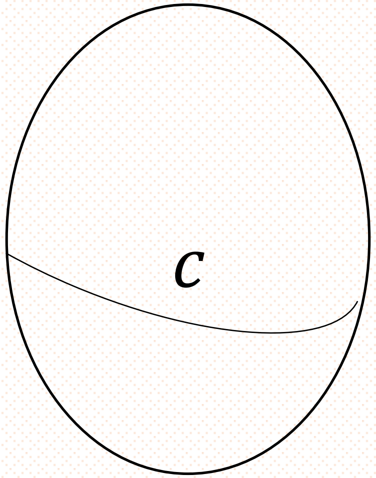
$\gamma = \frac{b_b}{m_b}$ system damping

$\omega_0 = \sqrt{\frac{k_b}{m_b}}$ balloon natural frequency

$\omega_s = \sqrt{\omega_0^2 - \frac{\gamma^2}{4}}$ balloon vibrational frequency

$\omega_t = v_t r_b$ is the nut frequency

$\phi' = arctan \frac{\gamma\omega_r}{\omega^2 - \omega_t^2}$ is the stationary solution phase



$$x(t) = Ae^{-\frac{\gamma t}{2}} \cos(\omega t + \phi) + \frac{F_0}{m_b} \frac{(\cos \varpi t + \phi')}{\sqrt{(\omega_0^2 - \omega^2)^2 + \gamma^2\omega^2}}$$

❑ Physical model- reconstructing the screaming

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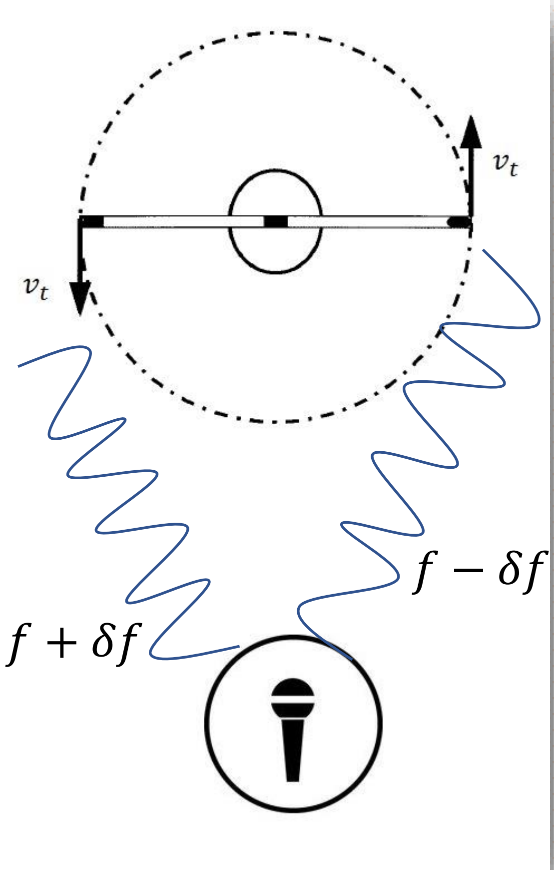
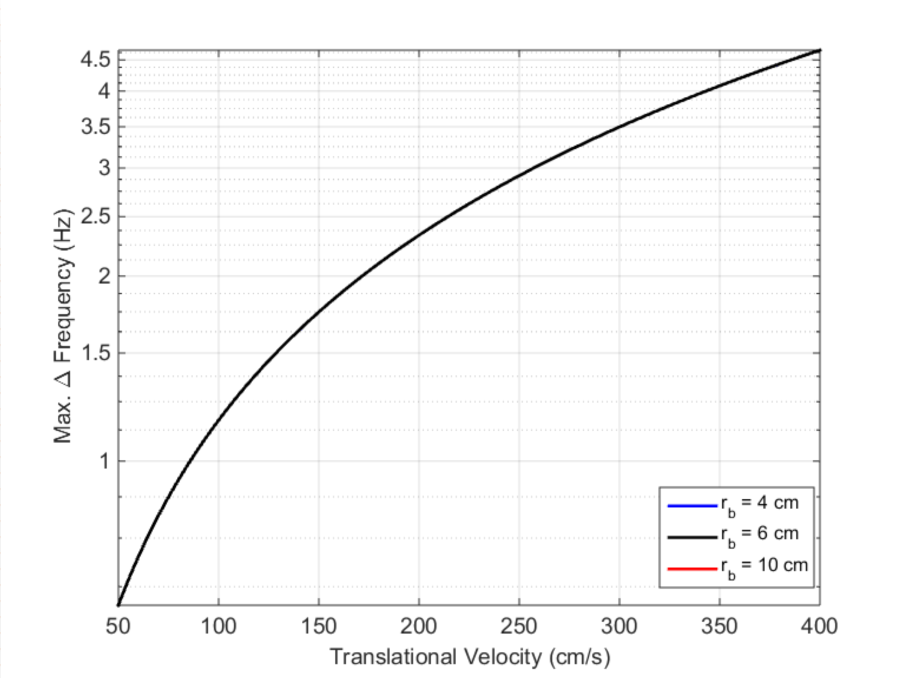


Doppler effect considered by the rotation

$$f(t) = f_0\left(\frac{v_s}{v_s + \frac{2\pi R}{T}\cos\frac{\pi t}{T}}\right)$$



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❑ Distribution for velocities

- Considering all evaluated data