andlinger center
for energy+the environment

Harvesting energy using piezoelectrics excited by Helmholtz resonance

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-with-

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SOUTHERN COMPANY
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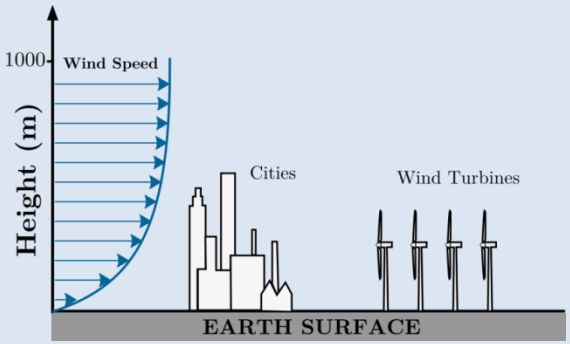
E-ffiliates Partnership | Nov 2016 | Princeton University

SMITS' LAB: ENVIRONMENTAL RESEARCH

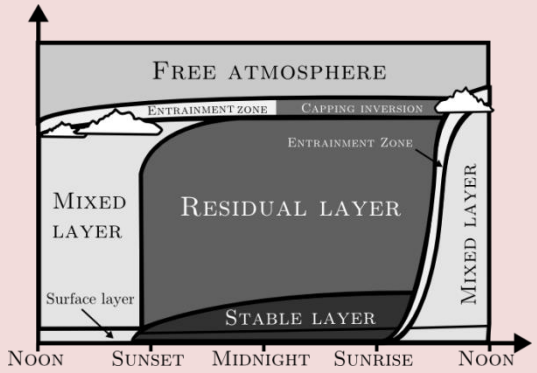
Alexander Smits
Eugene Higgins Professor of MAE

Artificial atmospheric boundary layer



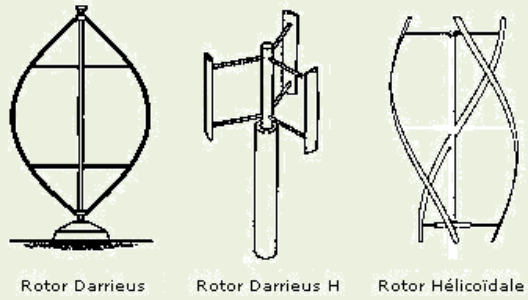
- Development of artificial atmospheric boundary layer generator for wind tunnel testing
- How do model buildings/structures interact with atmospheric flows?

Stratified flows



- Turbulent boundary layers with temperature gradients
- Occurs during transitions between day and night
- On⇄off shore breezes

Vertical axis wind turbines



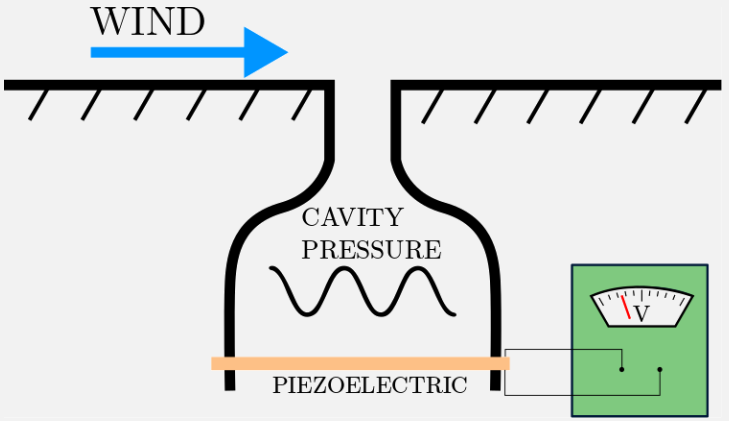
- Many potential benefits
- Some drawbacks (e.g., dynamic stall, scaling to large sizes)
- Better understanding of dynamic stall and performance

ARE THERE OTHER VIABLE WAYS TO COLLECT WIND ENERGY?

Helmholtz resonator and piezo concept

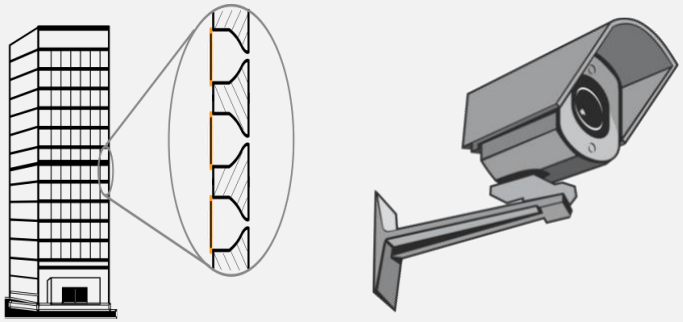
Helmholtz harvester

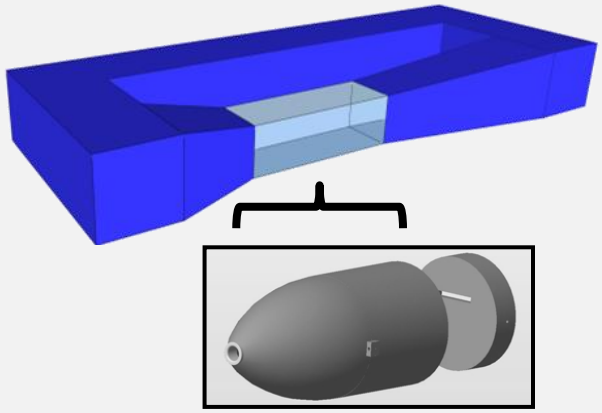
- Fundamentals:
  - Helmholtz resonators
  - Piezoelectric effect
- Harvester design



Applications

- Urban environments
  - Tall buildings, personal houses
- Powering remote sensors

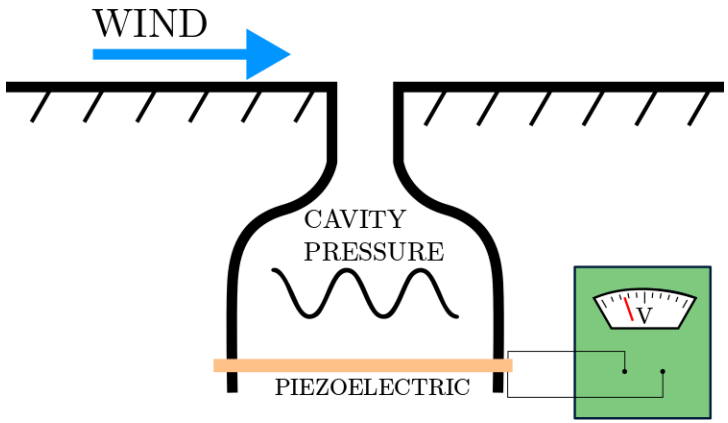




Wind tunnel studies

- Feasibility tests
  - Does it produce meaningful energy?
- Better resonance
  - Can we improve it?
- Effect of geometry

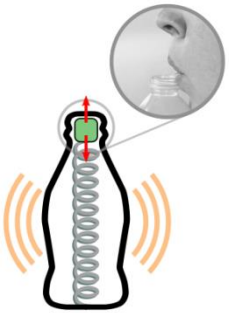
THE CONCEPT



HELMHOLTZ HARVESTER

Turn a surrounding wind into a vibrating pressure field to be converted to electricity and collected

Helmholtz Resonator

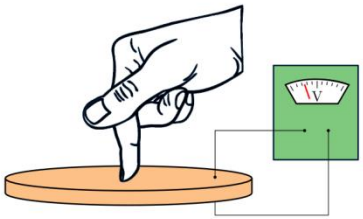


Wind

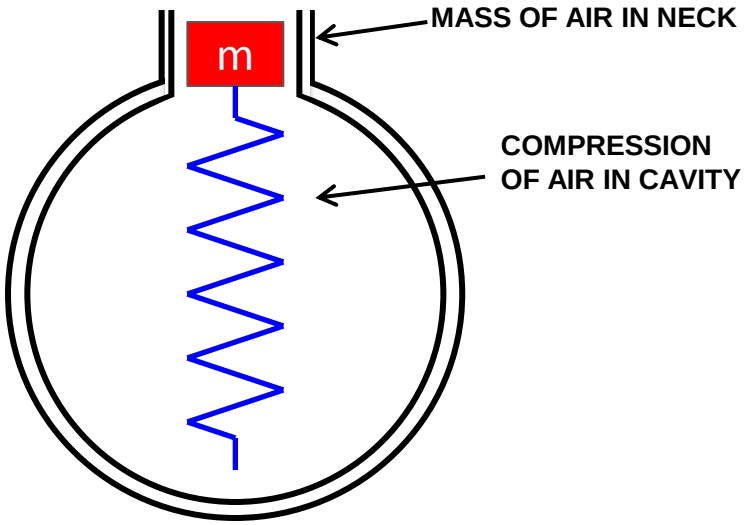
Sound
(oscillating pressure)

Electricity

Piezoelectric Effect



Helmholtz resonator



- Consider a container full of air with a small opening at the top
- The air in the neck acts as a **mass**
- The air inside the container acts as a **spring**.
- Apply a disturbance of pressure

This results in a characteristic frequency based on container geometry and fluid properties

$$f_H = \frac{1}{2\pi}\sqrt{\gamma\frac{P_A A}{\rho V L}} = \frac{c}{2\pi}\sqrt{\frac{A}{VL}}$$

A: Orifice Area
V: Cavity Volume
L: Orifice Neck Length
c: speed of sound in air

Helmholtz resonator

a container full of air

all opening at the top

the neck acts as a mass

side the container acts as

isturbance of pressure

This results in a characteri… …ner geometry and fluid properties

$$f_H = \frac{c}{2\pi}\sqrt{\gamma\frac{P_A A}{\rho V L}} = \frac{c}{2\pi}\sqrt{\frac{A}{VL}}$$

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Helmholtz resonator: origin

Hermann von Helmholtz
1821-1894

"The Helmholtz resonator consists of a rigid container of a known volume, nearly spherical in shape, with a small neck and hole in one end and a larger hole in the other end to admit the sound."

Idealized resonator

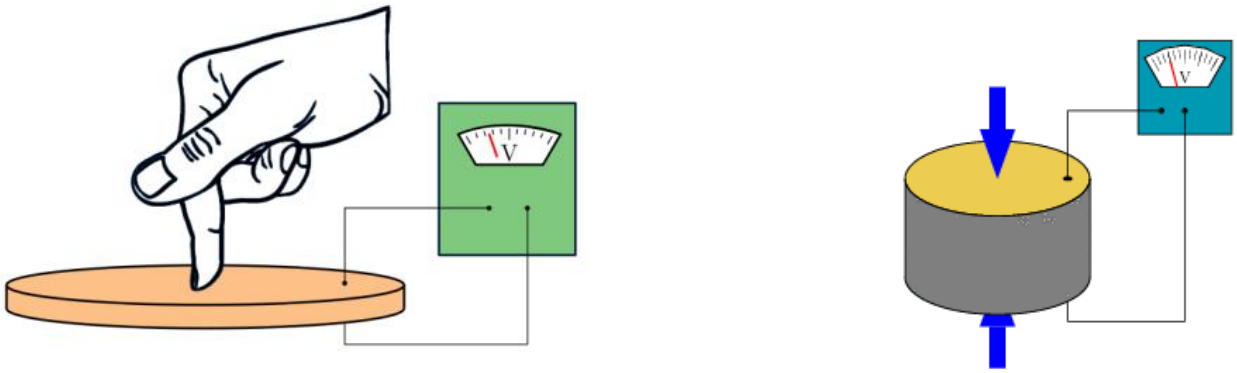
Helmholtz's original design

Now found in:

- musical instruments
- architectural acoustics
- dodge viper/ram engines
- aircraft drag reduction

Piezoelectric effect

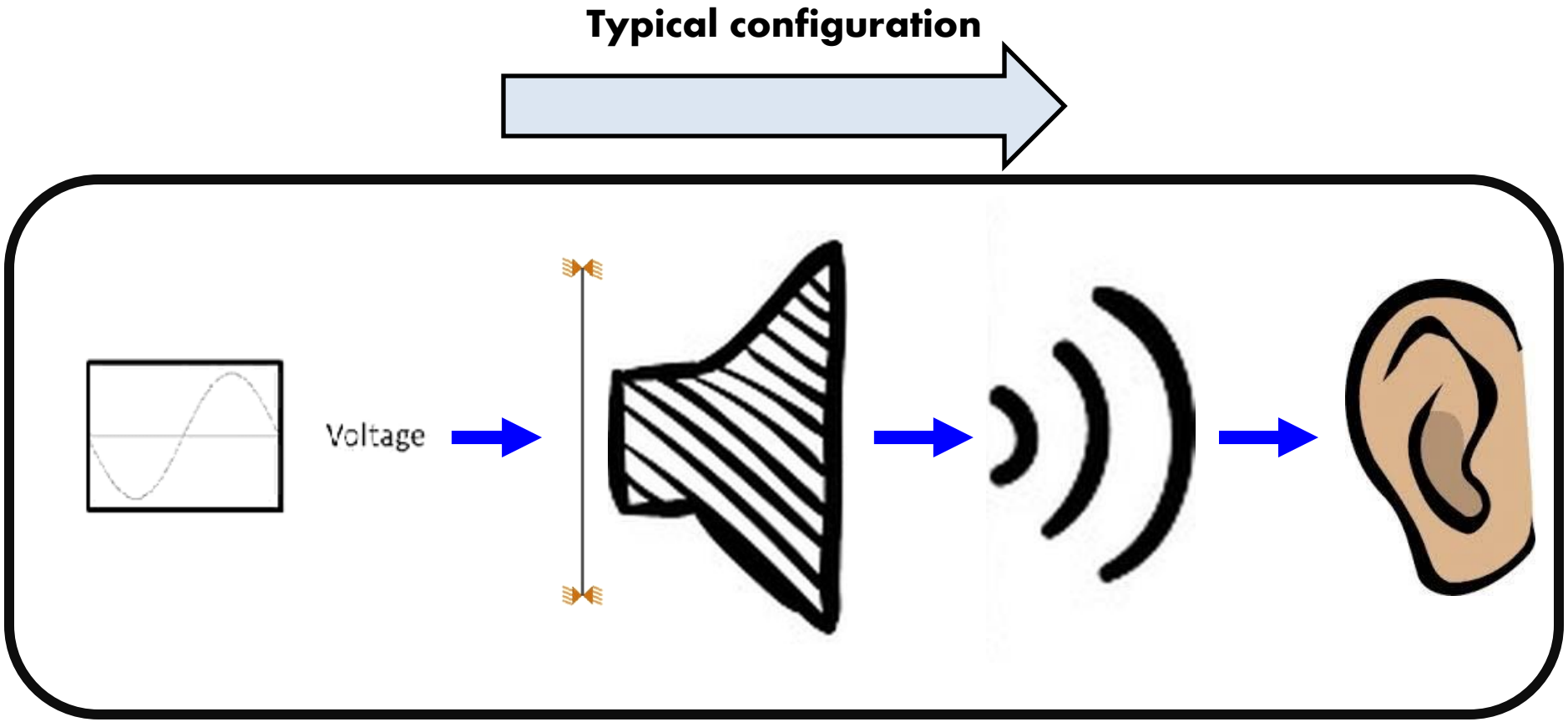
- Piezoelectric crystals generate a voltage when under deformation



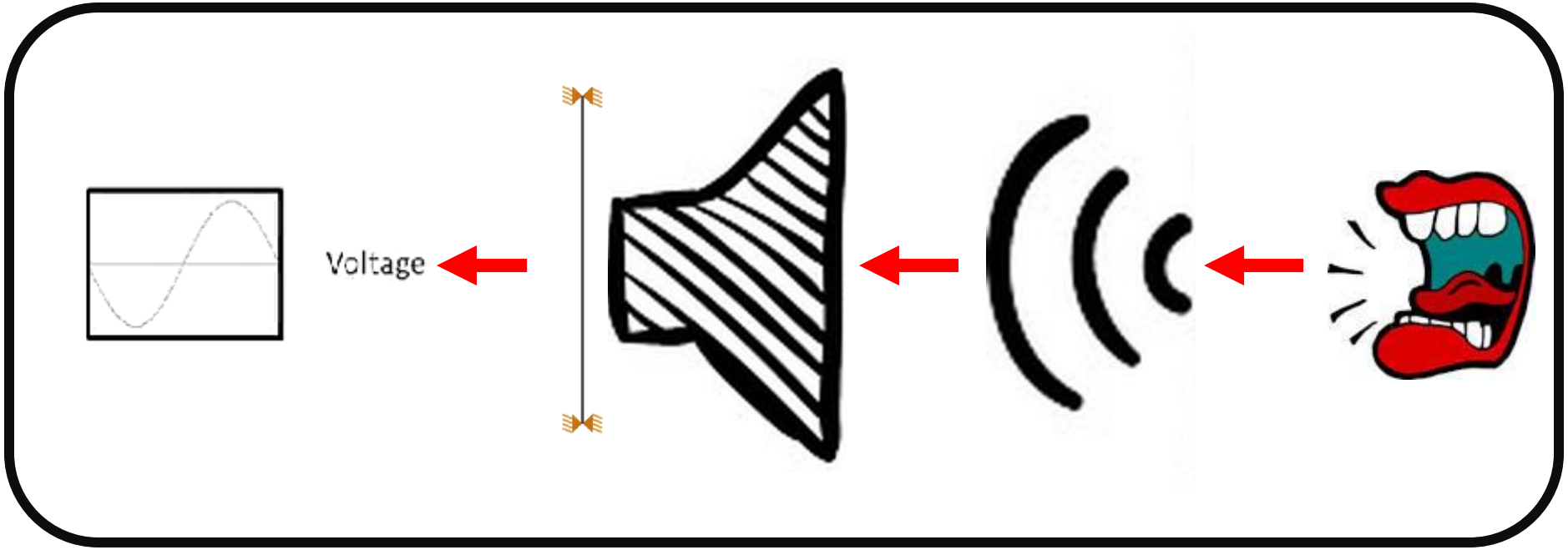
- In our case, a disc shaped piezoelectric is driven by an oscillating pressure field

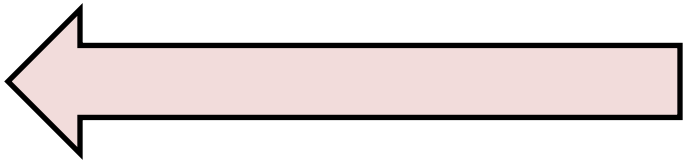
- This disc shape that has a resonance that is a function of the disc geometry, stiffness, and boundary condition

Think reverse speaker



Think reverse speaker





Harvesting configuration

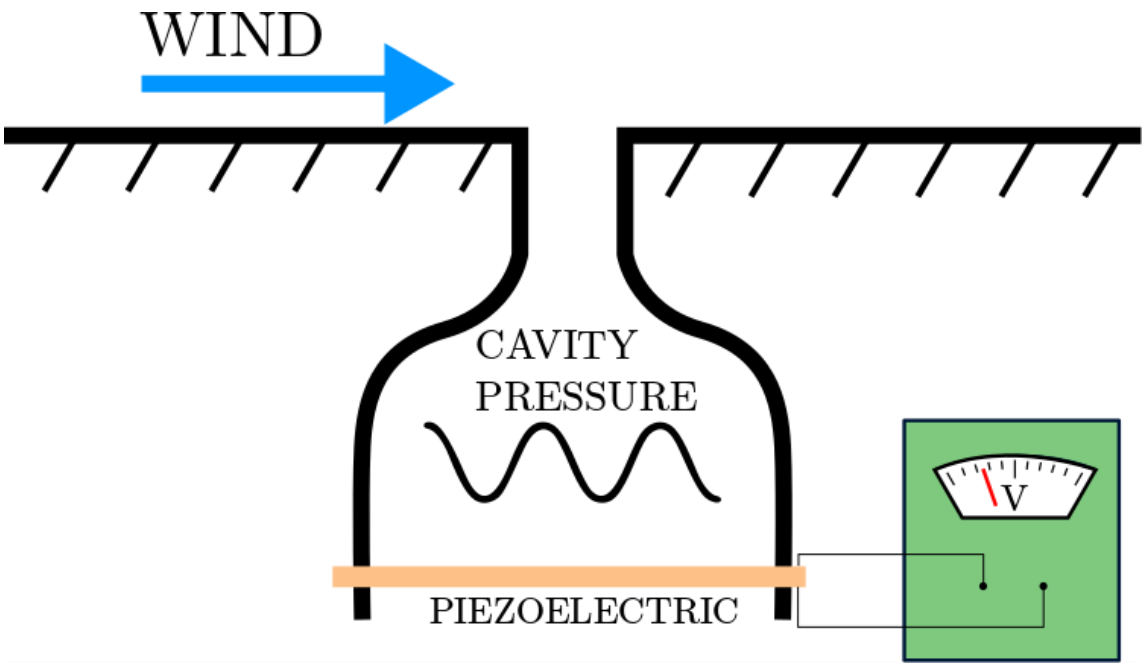
A NOTE ON RESONANCE

One of the most important aspects of this design is that the system frequency is unchanged, thus:

Piezoelectric resonance = **Acoustic resonance**

This **maximizes efficiency** of vibrational to electric energy **independent of flow** condition

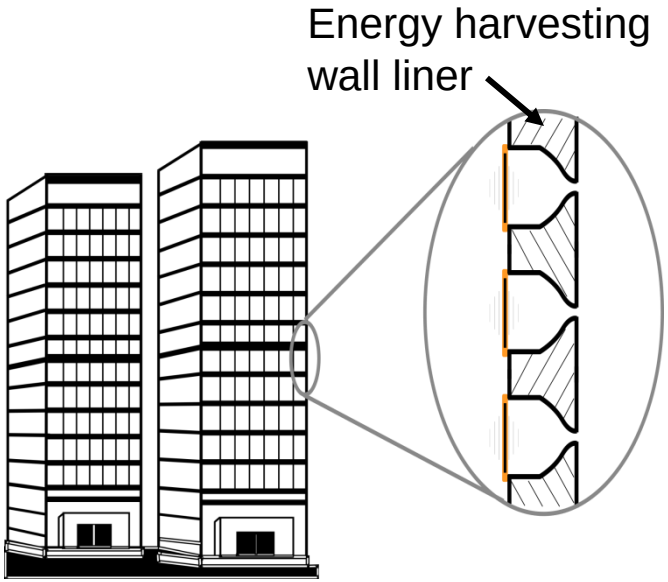
Helmholtz harvester



Potential Application

Green energy solutions

- Provide another distinct technology for harvesting wind energy
- Energy harvesting ability in urban areas (e.g. on city buildings)



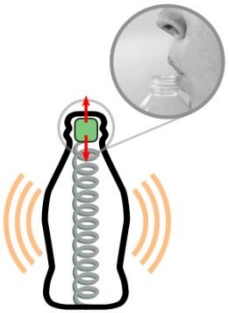
Remote sensor/device powering

- Small device powering for with no alternative power sources
- Small scale harvesters to power devices in remote/impoverished areas
- Support from **The Southern Company**

HELMHOLTZ HARVESTER

To turn a surrounding wind into a vibrating pressure field to be converted to electricity and collected

Helmholtz Resonator



Wind

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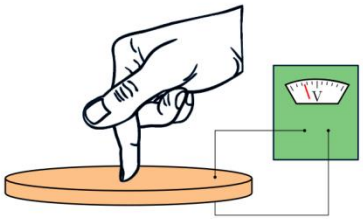
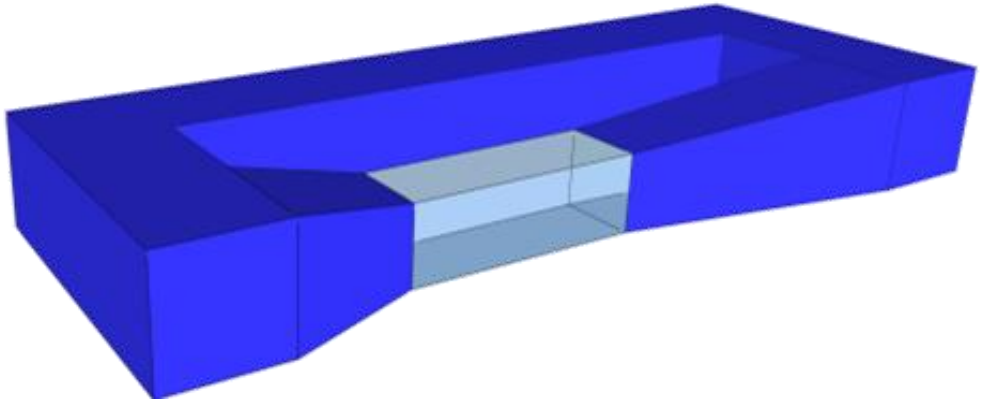
Electricity

Piezoelectric Effect



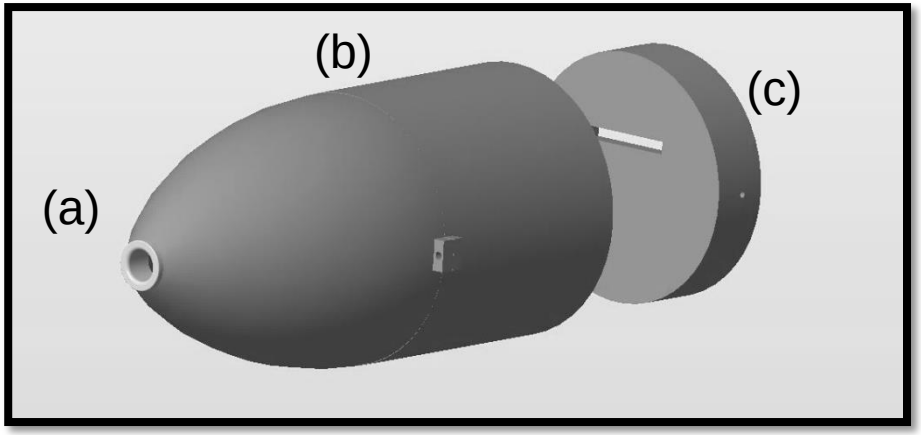
WIND TUNNEL TESTS



Feasibility Testing

A research project by two undergraduate students, Lindsay Graff and Zachary McCourt, explored:

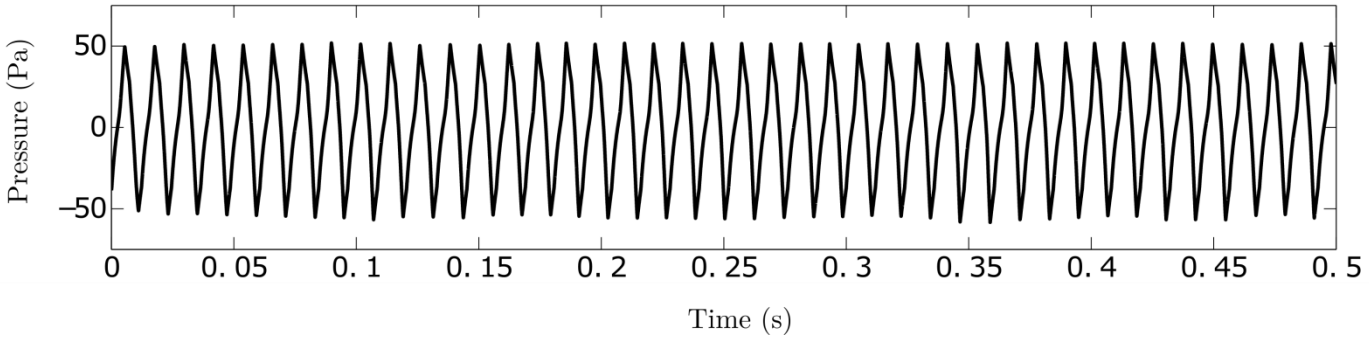
Is there enough energy to bother?



(a) Interchangeable neck designs

(b) Adjustable cavity volume

(c) Access port for pressure measurements via smart phone

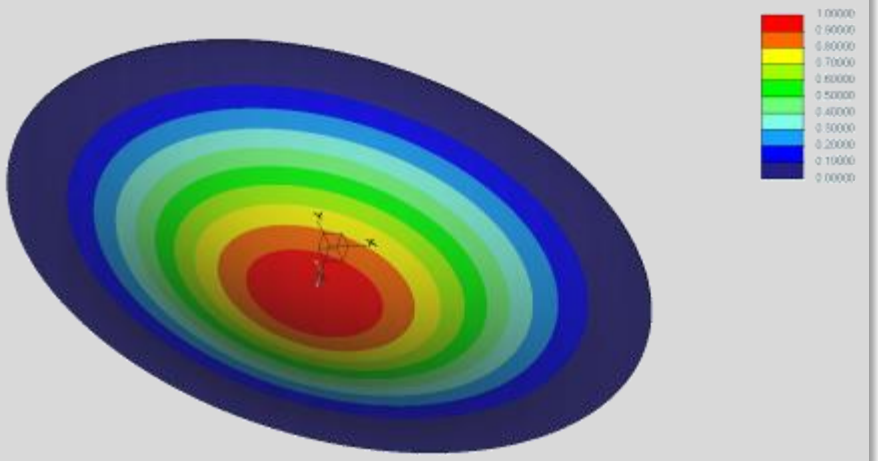


$P_{peak} \sim 50Pa$ $f_H \sim 85Hz\ (theoretical:\ f_H = 96Hz)$

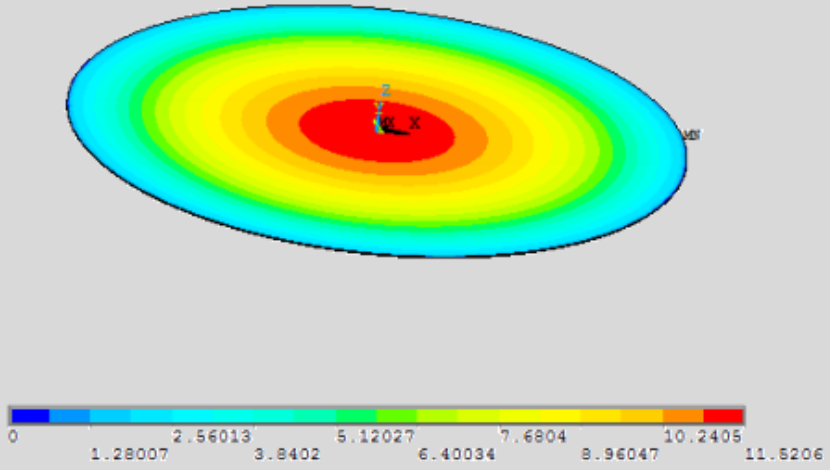
Feasibility Testing

They also showed that they could simulate disk resonance frequencies (useful as a design tool) and predict voltage outputs from the piezo with cavity pressure information.

Piezo Deflection Modelling in Creo

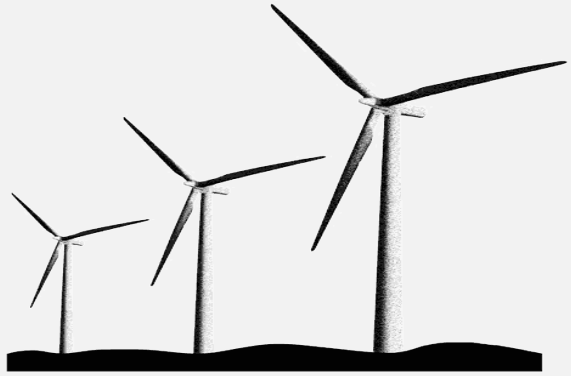


Simulation estimating voltage (FEM)



How does it compare?

WIND TURBINES



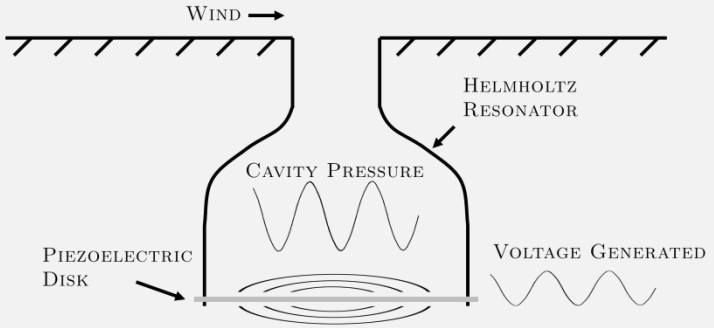
-Power: 1-5 W/m^2 (typical farm values)

-Large

-Limited to open areas

-Don't respond quickly to changes in wind

PIEZO RESONATOR



-Power: up to 6 W/m^2 (so far)

-Small/compact

-Can be utilized in tight spaces (urban environments)

-Omni-directional with quick response

Design improvement study

Emile Oshima and Jason Mulderrig conducted a parametric study trying to answer the question:

Can we improve resonance?

Successful, simple resonance

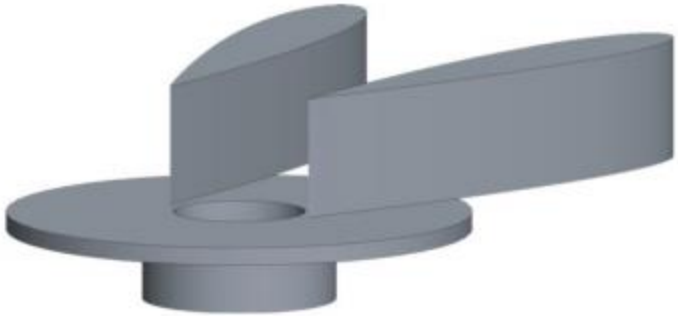
Not good resonance

INDUCING RESONANCE IN WIND

Using specially designed tops to improve resonance

Azimuthally uniform
Vectored
Channeled

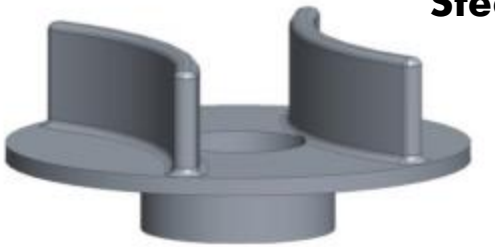
Channeled
Steady



Channeled
Vectored
Unsteady

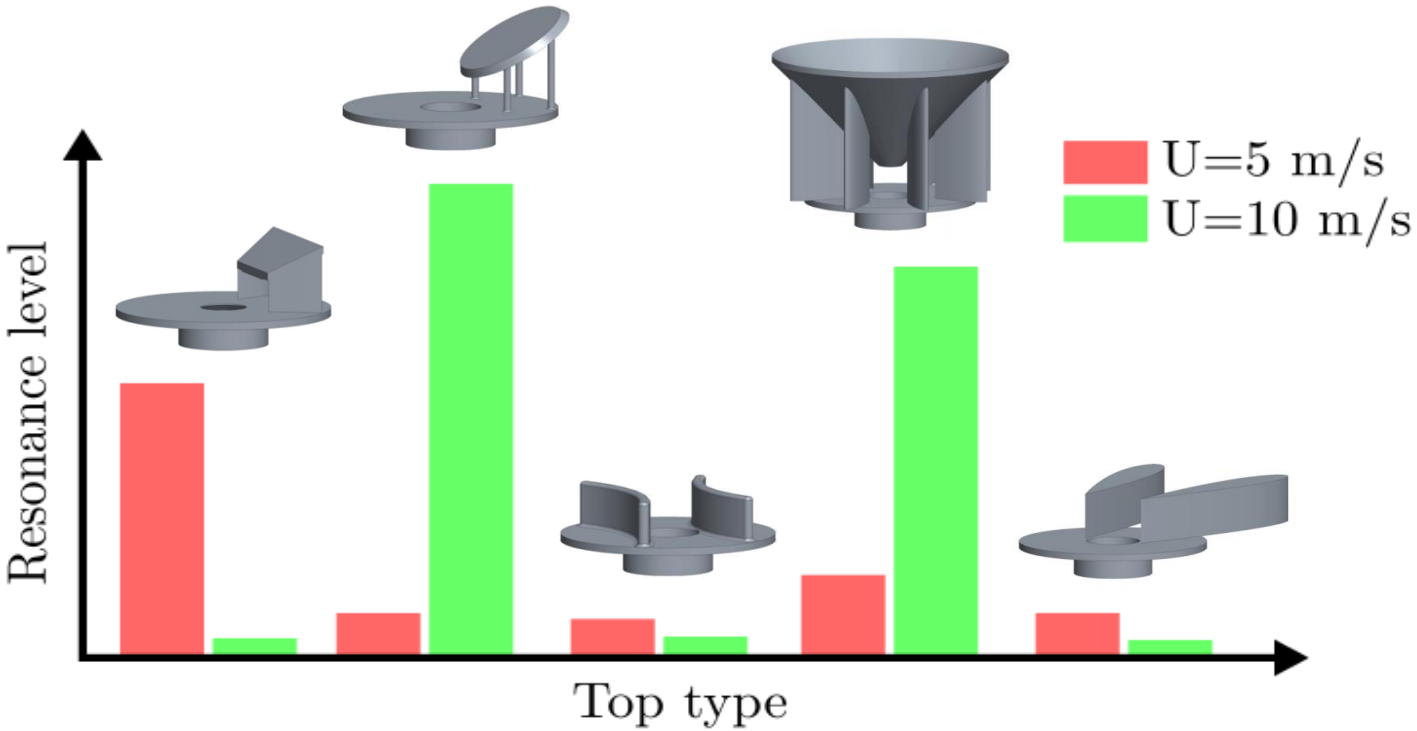
Vectored
Unsteady

Channeled
Steady



Inducing resonance in wind

Using specially designed tops to improve resonance



Keys to success

- Vectoring air into the neck
- Unsteady mechanisms like flow separation (musical instruments)
- Accelerating the flow over the top

Ongoing work

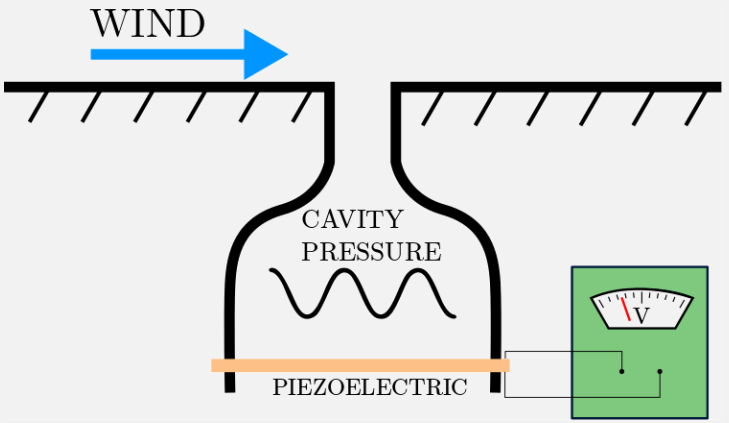
- Study successful tops and redesign based on what we learn
  - Flow visualization and measurement
- Change resonator geometry
  - Is there an ideal geometry or resonator orientation for maximizing resonance?
- Once converged on design, add piezo to collect energy
  - Requires custom piezos (collaboration with Midé Technologies)
  - Matching ideal piezo size/resonator size
- Field tests

Academic achievements

- Undergraduate **senior project**: Zachary McCourt and Lyndsay Graff
- Undergraduate **thesis**: Emile Oshima
- Undergraduate summer **internship**: Emile Oshima
- ACEE summer **fellowship**: Jason Mulderrig
- MAE: John Marshall II Memorial **Award**: Emile Oshima

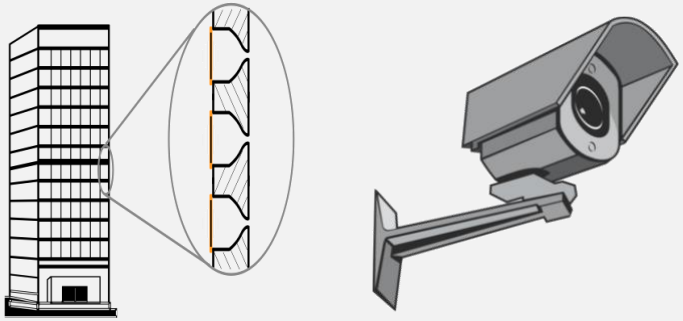
Helmholtz harvester

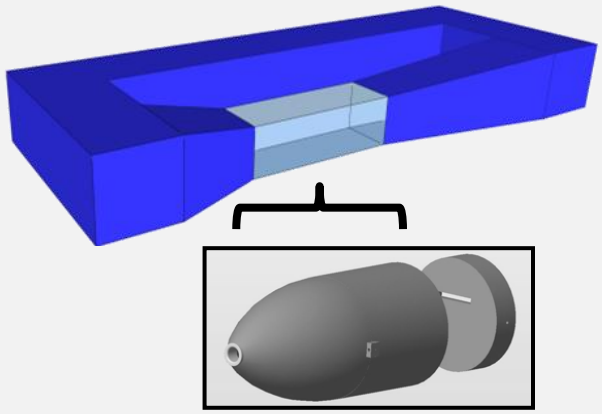
- Fundamentals:
  - Helmholtz resonators
  - Piezoelectric effect
- Harvester design



Applications

- Urban environments
  - Tall buildings, personal houses
- Powering remote sensors





Wind tunnel studies

- Feasibility tests
  - Substantial possible energy available
- Better resonance
  - Resonance can be improved with geometry and neck design

QUESTIONS?