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**Effects of Carbon Dioxide on the Speed of Sound from a Pipe Organ**

**Abstract**

How do environmental factors affect the speed at which sound waves travel in gasses? The way in which sound travels is dependent on the media within which it travels (CITE). In gasses, characteristics such as the molecular composition and temperature and moisture content can alter the frequency, or wave motion, of sound waves.1 Musical instruments, such as pipe organs, depend on sound moving through air at certain speeds to produce desired musical notes at set pitches. Pipe organs particularly depend on their localized environment, as they often reside in large church buildings. Do changes in the environmental conditions in organs’ buildings affect the pitch of the notes? Pipe organs are typically tuned by an organist while the building is empty then played in performance for an audience, whose presence introduces increased temperature, CO2, and water vapour. This investigation focuses specifically on examining the change in pitch from CO2 concentration. Using equations for frequency from CO2 concentration, I will compute predicted pitch and compare measured pitch to see whether, and how much, CO2 concentration affects pitch.

Pitch is ~~dependent on~~ the frequency of sound waves sent out from an instrument.

**OUTLINE**

Abstract:

-introduce main ideas,

-looking at changes in pitch, which is the frequency of sound creating a certain note, as CO2 changes

-will use an equation for frequency from CO2 to predict pitch then look at measured pitch CHANGE (not absolutes)

Introduction:

-air quality affecting sound speed

-pipe organ’s dependency on air quality (location, big building, audiences)

-audience influence of air quality

-lack of other studies ??

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Methods:

-Software used,

-Wrangling (creation of two dataframes),

-calculating median/st error for pitch,

-plotting CO2 vs. time,

-plotting predicted pitch based on CO2 (same plot),

-overlaying measured pitch measurement points on calculated line.

-stats test for significance of correlation relationship

Results:

-statistical significance of the correlation between change in CO2 and change in pitch (expected versus measured pitch at times of high and low CO2 concentration)

Discussion:

-This is the correlation I’ve found

-Further studies include comparing temp and molarity of water from relative humidity

-outdoor temperature

-air pressure

-calculating for expansion coefficient of the lead pipes

-measuring pitch while there is an audience there, for more regular and consistently-timed observed\_pitch values

**Introduction**

Because sound travels via the movement of air, the characteristics and composition of air affect the speed of sound. Therefore, studying the effects of atmospheric conditions such as molecular composition of air can provide insights into the nature of sound travelling in an area.1 This directly applies to musical instrumentation construction, management, and use. Many mechanical instruments are adjusted or tuned to emit certain pitches, or frequencies sound waves, and this tuning depends on knowledge of the rate at which the sound waves will propagate. Since sound waves are affected by the media within which they travel, location and environmental conditions surrounding instruments greatly affects their sound **(CITE).** Cramer has documented the relationship between changes of sound speed and air characteristics such as: temperature, relative humidity (RH), and carbon dioxide concentration.2 **MORE HERE** It has been seen that frequency of sound waves has a calculable relationship to these environmental factors. These calculations can provide insight into how much is musical pitch affected by changing characteristics of ambient air.

Mechanical pipe organs are especially vulnerable to changes in their environment because they are often located in large, heterogeneous buildings, with large audiences, which impact air characteristics.3 Additionally, the pipe and bellow system moves air throughout different parts of their chambers creating mixed air effects. These situational variables can affect tuning of some pipes relative to others making the instrument sound out of tune. Tuning adjustments are completed when the church is empty, however the organ will be played when the building is filled with an audience whose breath produces significant amounts of CO2, which is a heavier molecule than air, mostly comprised of N2 and O2. Therefore, its presence affects calculations of molar mass of air, particularly with high levels of air moisture, as is caused by breathing.4, 5 How much does the frequency of the notes change with environmental differences between conditions during tuning versus during performance? Additionally, will the tuning of different sections of the organ change in relation to others, based on regional differences? This study looks to examine carbon dioxide concentration in the chapel containing a mechanical organ to examine the relationship between CO2 and speed of sound propagated from movement of air through organ pipes.

**Methods**

This study will use data that charts concentration of carbon dioxide (CO2) and pitch of notes played on an organ at St. Paul’s School in Concord, NH USA, collected by Dr. Ian Hoffman. Computational analysis of the data will make use of the mathematical relationship between CO2 concentration and changes to the speed of sound, as described by Cramer.2

Data was collected and recorded using Onset® U12-03 and Telaire 7001 HOBO® data logging devices for temperature and relative humidity (RH) and for CO2 (ppm) readings, respectively. The data was initially converted from .hobo to .csv files using HOBOWare® for analysis in Python. Using Python version 3.4.0, data was arranged for computation, quantitative analysis, calculation of statistical significance, and formation of graphical presentations. Pandas, Numpy and Matplotlib Python libraries **(WHICH VERSION??)** are used for computation and plotting operations. Two types of scripts were created, one for processing

The data was wrangled in Python to create two data frames; one type to house environmental data and another type for pitch measurements. The environmental data files are kept for certain locations and consist of date and time, temperature, relative humidity, and CO2. The pitch data files consist of date and time, division of the pipe whose note is played, musical note played, and frequency values from multiple samplings taken at the same date time value. A mean frequency value for each time stamp was generated, as well as standard deviation.

Measured pitch points are plotted over top of calculated pitch values.

In the environmental dataframes, CO2 data were run through the pitch\_calculator function to generate values for calculated pitch, as per Cramer’s equation for frequency of sound from environmental characteristics.2 A modified version of the equation was used to isolate for CO2 concentration, apart from temperature and humidity. The plotted points of measured pitch come from the average frequency data. To compare measured and calculated pitch values, documented pitches and environmental data was grouped by area in the chapel.

**Results**

Plots of CO2 over time, show spikes where people enter and leave the space (TRACK THIS WITH SUNDAY/MORNING SERVICE TIMES).

We can see how the measured pitch points overlay with the curve of calculated pitch—and see how much they change

This stats test shows the correlation of change in CO2 and change in measured pitch (relationship between measured and calculated pitch)

**Discussion**

**FUTURE STUDIES WITH METADATA?** Useful metadata consists of temperature and RH measurements taken at the same time, with the same sensors, in the same locations as CO2 concentration, as well as temperature readings outside the chapel. Additional meteorological information from nearby weather stations could be used to examine temperature and pressure changes.

Analyzing these data can provide insight into change in pitch of an organ when played in environments of varying carbon dioxide concentration. This can lead to more optimal instrument tuning to account for changes in pitch between CO2 concentrations when the mechanic is adjusting the sound relative to when an organist plays in front of an audience. More broadly, this study will link the change in frequency of sound waves, or the speed of sound, from changes in the amount of COz in partially enclosed environments.

**Works Cited**

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