The Effect of A Helmholtz Resonator’s Neck Geometry
On The Aero-Acoustic Excitation of Resonance

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Abstract
The aero-acoustic excitation of a Helmholtz resonator with different neck geometries has been examined with an improved measurement technique. A Helmholtz resonator consists of a volume connected to a duct and has a well defined resonance frequency which depends on the length of the duct, the volume of the resonator and the cross sectional area of the duct. In the system used during this experiment, two Helmholtz resonators have been positioned at opposite sides of a junction in a wind tunnel. The air speed in the wind tunnel can be varied over the range 0 to 28 m/s. The air flowing over the junction openings to the Helmholtz resonators excites the acoustic resonance of the system. This is similar to blowing over an empty bottle’s opening and creating a tone. The excitation of the resonators as a function of flow speed in the wind tunnel has been recorded. The effect of the resonator’s geometry has been seen in the measured acoustic amplitude and frequency in the resonator and will be presented.

Pressure Sensor Calibration
A Freescale differential pressure sensor (MPX 5010DP) was used to measure the mean flow, \( \nu_{in} \), in the wind tunnel by use of a pitot tube and as a microphone. The pressure sensor has a response time of 1 ms. This response time is smaller than the period of the fastest signal we measured, 13.4 ms. It was calibrated with a water manometer and a syringe as illustrated in the figure to the right.

Theory
I. Resonance Frequency
Considering the air in the neck as a piston, the thermodynamic equations and the pressure pushing the air into flask,
\[
\Delta P = \frac{2}{3} \frac{1}{\rho} \frac{A_{\text{neck}}}{L} \rho_{\text{air}} \nu_{\text{air}}^2
\]
where \( \Delta P \) is the increased pressure inside the volume, \( \rho_{\text{air}} \) is the air density, \( c \) is the speed of sound, \( A_{\text{neck}} \) is the cross sectional area of the neck, \( \nu_{\text{air}} \) is the volume of the resonator, and \( \nu_{\text{air}} \) is the distance which the air moves into the volume. The frequency can be expressed as
\[
f = \frac{c}{2 A_{\text{neck}}
\]
where \( L \) is the effective neck length. Therefore, the frequency is related to the neck’s neck length plus end corrections.

II. Stroboul Number (St)
The observed in this experiment is unsteady, so the Stroboul Number (St) can be used to characterize the aero-acoustic excitation of the resonator with different neck geometries. St for this experiment can be expressed as
\[
St = \frac{f}{D_{\text{neck}}} \frac{A_{\text{neck}}}{\nu_{\text{air}}}
\]
where \( D_{\text{neck}} \) is the diameter of the neck, and \( \nu_{\text{air}} \) is the mean velocity inside the duct.

III. Acoustic Velocity
For calculation of the acoustic velocity in the neck, the measurable acoustic pressure in the flask’s spherical part works. The velocity of the air mass can be written as
\[
V_{\text{air}} = \frac{1}{\rho_{\text{air}}} \frac{A_{\text{neck}}}{L} \rho_{\text{air}} \nu_{\text{air}}^2
\]
where \( V_{\text{air}} \) = \( \nu_{\text{air}} \) of the resonance. Eq. (4) can also be written as
\[
V_{\text{air}} = \frac{1}{\rho_{\text{air}}} \frac{A_{\text{neck}}}{L} \rho_{\text{air}} \nu_{\text{air}}^2
\]
where \( \rho_{\text{air}} \) is the amplitude of the pressure wave, which can be observed in the oscilloscope’s display.

IV. Pitot Tube
The mean flow, \( \nu_{\text{in}} \), in the wind tunnel can be measured using a pitot tube or in the wind tunnel is related to \( \nu_{\text{in}} \) via
\[
\nu_{\text{in}} = \frac{1}{2} \frac{\Delta P}{\rho_{\text{air}}}
\]
where \( \rho_{\text{air}} \) is the measurable pressure using the Pressure sensor.

Data Trends
The graph above displays the measured resonance frequency at the \( \nu_{\text{in}}/\nu_{\text{flow}} \) maximum for each neck length. The measured frequency agrees well with the theoretical model of Equation (2).

Future Work
We intend to measure the flow velocity before and after the junction to determine the change in the flow’s kinetic energy. This change in kinetic energy should be equal to the work done to excite and sustain the resonance. The acoustic source strength of the vortex driving the resonance is a function of frequency and flow.

Acknowledgement
I would like to thank the UCA Physics department.