Aeroacoustic Source Strength Measurement of Helmholtz Resonator

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Abstract

The characteristics of the aero-acoustic excitation of Helmholtz resonators with different neck geometries have been determined, and the work done to sustain and excite resonance have been studied. 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 the measurement, two Helmholtz resonators have been positioned at opposite sides if a junction in a wind tunnel. The air flowing over the junction openings to the Helmholtz resonators can excite the acoustic resonance of the system. This is similar to blowing over an empty bottle's opening and creating a tone. The effect of the resonator's geometry has been seen in the measured acoustic amplitude and frequency in the resonator. The work done by the aero-acoustic source of sound has been determined through the measurement of the air speed in front of and behind the junction in the wind tunnel, and the energy stored in the resonator has been determined through the measurement of the acoustic pressure inside the resonator's volume.

I. Resonance Frequency

Considering Helmholtz resonators as a mass–spring system, the frequency can be expressed by

\[ f = \frac{1}{2\pi} \sqrt{\frac{S}{\rho V_0}} \]  

where \( S \) is the speed of sound, \( S_{\text{cross}} \) is the cross sectional area of the neck, \( V_0 \) is the volume of the resonator, and \( L \) is the half of the total effective neck length.

II. Strouhal Number

Strouhal 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

\[ St = \frac{f D}{V_s} \]  

where \( D \) is the diameter of the neck, and \( V_s \) is the mean velocity inside the duct before the junction.

III. Acoustic Velocity

The acoustic velocity of the air in the neck can be calculated as:

\[ V_a = \sqrt{\frac{P_{\text{mean}}}{\rho c}} \]  

where \( c = 2f \) is the resonance, and \( P_{\text{mean}} \) is the amplitude of the pressure wave, which can be observed in the oscilloscope's display.

Vac/V1 V.S. St

The above graph shows the results with 6, 7, 16, 25, 29, 27, 29, and 30 (cm) straight replaceable necks. Light (Dark) filled data points are for increasing (decreasing) the flow. The data shows the same general trend for all neck lengths. The acoustic amplitude increases with increased \( V_1 \). However, the ratio Vac/V1 reaches the point where increases in Vac/V1 become moderate. And then, moderately Vac/V1 reaches to the maximum value depending on \( V_1 \) characterized by each neck length. At sufficiently high \( V_1 \), the resonance is extinguished as illustrated by the abrupt end of the data at low St. Additionally, longer necks and the right tails of shorter necks generally have lower amplitude (Vac/V1 ≤ 0.1) indicating the importance of damping and the interaction between acoustic velocity and vortex.

Velocities Before and After the Opening

This graph illustrates the relationship between \( V_1 \) and \( V_2 \) for the 6, 7, 16, 25, 29, and 30 (cm) straight replaceable necks. The gray line has slope 1. Until the point that resonance starts, \( V_1 \) < \( V_2 \), meaning that no work is done. Once resonance starts, \( V_1 \) is slightly less than \( V_2 \), though not much, energy starts to be extracted. And then, there is decrease in \( V_1 \) for increase in \( V_2 \) indicating significant energy extracted from the mean flow going into acoustics. From the characteristic point illustrated as kinks on the above graph, the slope goes back to about 1 though the trend changes based on the velocities. Looking at data taken with longer necks, which has low Vac/V1, we can notice the small deviation from the line with slope 1 indicating we cannot use them to calculate the energy difference because of the low resolution of our pressure sensor.

Energy Dissipated & Q Factor

The first graph shows the measured dissipated energy V.S. St using 6, 7, 16 and 25(cm) replaceable necks. Light (Dark) filled data points are for increasing (decreasing) the flow. This energy is extracted from the main flow and calculated using Eq. (6). The second graph illustrates Q V.S. St with the results using 6, 7, 16 and 25(cm) replaceable neck length. Light (Dark) filled data points are for increasing (decreasing) the flow. The trend corresponds to \( 1+\frac{1}{Q_1} \). This plot indicates the effective conversion of flow energy into acoustic energy.

Examining the second graph, it is nice to see the graph of Edissipated and Q factor using (from) replaceable neck length representing shorter neck's trend. At lower Vac/V1, energy is dissipated for driving resonance insufficiently. Around the maximum Vac/V1, less energy is dissipated from the main flow for driving resonance.

Future Work

We intend to redo this experiment with an improved method to get more accurate flow velocities inside the duct before and after the junction. By this measurement, the quality factors in the low amplitudes’ range can be determined. The ratio, \( 1+\frac{1}{Q_1} \) to \( V_1 \), for each \( V_1 \) is a function of quality factor and frequency in the low amplitude range (Mason and Piero).

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The system is composed of 2 inch OD glass pipe, a cross junction, various lengths of duct pieces and two RAS flasks. In order to measure the quantities required to see the air flow’s behavior, the following are used: a thermometer, an oscilloscope, a voltmeter, two pitot tubes, and two pressure sensors. The one of the pressure sensors is used as a microphone to measure the amplitude of the pressure change, \( P_{\text{mean}} \), and the frequency of oscillation of the flasks. The microphone signal is viewed on the oscilloscope. As the mean flow passes over the junction opening a vortex is created. The creation of a vortex and its behavior influences the acoustic excitation of the flasks. Consequently, the acoustic behavior of the flasks influences the creation of the next vortex. Another pressure sensor is used to measure the mean flow velocities of the air before and after the junction in the duct. \( V_s \) and \( V_t \), via two pitot tubes and switches connected to the two pitot tubes and the sensor; and it is also can measure the pressure difference between the room and the inside of the duct for another pressure measurement. Each pitot tube is calibrated to convert from voltage to pressure or velocity directly.

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