Theoretical and experimental investigation of the air-driven free reed

James P. Cottingham

Physics Department, Coe College, Cedar Rapids, IA 52402

Abstract: The free reed is the excitation mechanism for several families of instruments, including the reed organ and harmonium, the harmonica, the accordion and concertina, and the Asian free reed mouth organs. While most studies of reed behavior have concentrated on reeds which are either inward-striking (closing) and outward-striking (opening), free reeds do not fit neatly into either category and can exhibit behavior characteristic of either opening or closing reeds, depending on certain details of the reed configuration. Some characteristics of free reed behavior, in particular the relation between frequency and blowing pressure, have been modeled by adapting Fletcher's analysis of musical instruments driven by a reed mechanism [N.H. Fletcher, Acustica **43**, 63-72 (1979)]. In addition, a variety of measurements of reed motion have been made, including experimental determination of measurements of reed position and phase using proximity sensors. These are compared with observations of the near-field sound as well as with predictions based on theoretical considerations.

FREE REEDS AND THE MODEL

There are two types of free reeds found in musical instruments. In the reeds that can be referred to as "offset," the reed tongue is attached to the frame in such a way that the there is a slight separation between the tongue and the frame, so that there is a positive unblown reed displacement, $X_u > 0$. These reeds, found in the reed organ, harmonium, accordion and harmonica, only sound for one direction of air flow. The reeds that can be referred to as "symmetric" are cut from a single sheet of metal and with $X_u = 0$. These are found in the Asian free-reed mouth organs (*sheng, sho, khaen*) coupled with pipe resonators so as to sound with either direction of air flow.

Fletcher has given a general model for reed behavior in which the reed is modeled linearly as a harmonic oscillator and has obtained for this model an expression for the complex reed admittance Y_r. The equations for the amplitude and phase of Y_r can be found in Fletcher's paper.(1) The notation used here for the reed parameters is that used by Johnston in a paper on the harmonica.(2) A necessary condition for self-sustained oscillations is that Re[Y_r]<0. In the absence of a pipe resonator we expect the operating point to be at the frequency corresponding to the (negative) minimum of Re[Y_r]. Figure 1 shows a plot of Re[Y_r] vs. frequency from a calculation using Fletcher's equations and appropriate parameters for a C_3 reed from a Wolfinger reed organ. It can be noted that this curve resembles that for a "closing" (inward striking) reed, with the minimum of Re[Y_r] below the reed resonance frequency.

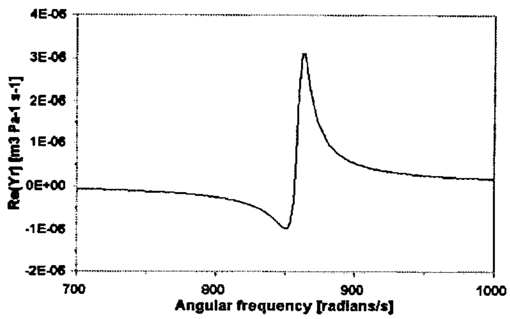

FIGURE 1. Re[Y_r] calculated as a function of frequency for the Wolfinger C reed at P_0 =0.6 kPa.

COMPARISON WITH EXPERIMENT

Considerable experimental work is needed to determine some of the physical parameters needed for the above calculation. Specific values given are those for the Wolfinger C reed. The blowing pressure P_0 and the frequency of vibration ω are variables in the model. The resonance frequency of the reed, ω_r=860 s^{-1}, is easily determined. The constant part of the volume flow U_0 is calculated by fitting empirical data with the relationship $U_0 = cP_0^z$, which also yields the exponent z=0.67. In the model considered the reed is a simple spring mass system. Experimentally, the displacement of the reed tip X is taken as the displacement of the mass, and the spring constant of the system is determined by suspending small masses from the reed tip and measuring the resulting displacement. For the reed in question the relationship is in fact linear with spring constant k=150 N/m and effective mass $M_r = k/\omega_r^2 = 2.1 \times 10^{-4}$ kg.

The damping coefficient D=0.012 is determined experimentally, and the reed width b=4.0 mm is measured directly. The effective area S_r=ab and hence the effective reed length a=8.0 mm, as well as the unblown reed displacement, are determined from experimental data using the relationship $X_0=X_u - (S_r/M_r\omega_r^2)P_0$.

A question of interest is how well this simple linear model reproduces important observed features of free reed behavior. In particular, an attempt was made to see if the model shows the characteristic decrease in frequency with blowing pressure observed in the laboratory as well as by players and tuners.(3) Figure 2 shows a comparison of experimental data for the Wolfinger C reed on the laboratory windchest with calculated values obtained from the model, where the calculated frequency is taken to be that of the minimum value of Re[Y_r]. It can be seen that the two sets of points agree fairly well over the mid-range of pressure values (0.6-1.0 kPa). This range includes typical playing pressures for the reed in an instrument. However, the observed relationship is not reproduced by the model for low or high values of blowing pressure.

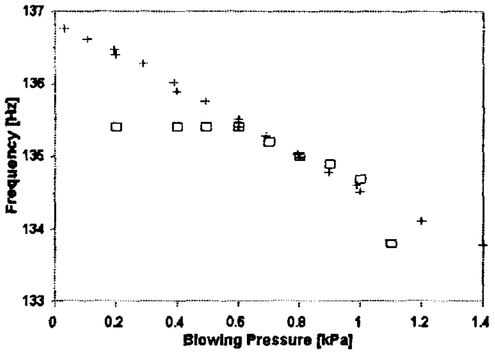

FIGURE 2. Frequency vs. blowing pressure for an organ C reed: experimental data (+) and calculations from the model (□).

A number of aspects of free reed vibration have been studied for reed organ reeds mounted on a laboratory windchest.(3) One not previously reported is the phase relation between air-driven free reed motion and the resulting acoustic pressure waveform. Figure 3 illustrates this using a pressure waveform obtained by a probe microphone located 3 mm from the vibrating reed tip, with a sine wave fit to approximate the reed motion so that the maxima and minima correspond to the measured occurrences of the maximum upward and downward displacements of the reed.

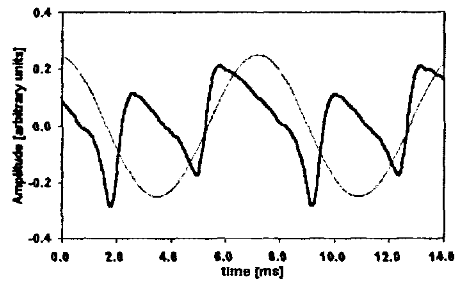

FIGURE 3. Sound pressure waveform near the reed tip (heavy solid) with a sine wave representing reed displacement.

The discussion above involves an example of an offset reed. Results in agreement with observation are also obtained in the case of a symmetric reed by setting X_0=0 in the computation. The results for the symmetric reed resemble those for an "opening" (outward striking) reed in that the minimum of Re[Y_r] is at a frequency greater than ω_r. For a symmetric reed coupled to a pipe resonator the phase relation between reed and air column vibration given in Fletcher's model correctly predicts the sounding of the reed near the pipe resonance, a topic discussed in a forthcoming report.(4)

REFERENCES

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