Explicit representation of glottal flow as a function of transglottal pressure and geometry

by

Lewis P. Fulcher and Guangnian Zhai
Department of Physics and Astronomy

and

Ronald S. Scherer
Department of Communication Disorders
Bowling Green State University
Bowling Green, Ohio 43403

CONTACT: Lewis Fulcher, fulcher@bgnet.bgsu.edu, (419) 372-2635

An extensive set of volume velocities has been collected with a static Plexiglas model of glottal shapes (the model is known as M5, e. g., Scherer et al., 2002). Because these flows are the empirical results of a wide range of glottal geometries and transglottal pressures, and because the changing glottal flow creates the primary acoustic excitation of the vocal tract, these data present an attractive prospect for enhancing the realism in computer simulations of voice and speech. The need is to have an analytic equation that can easily carry their content in a form suitable for input to a computer simulation. This project provides a generalized equation with this need in mind.

Because of the variety incorporated in the design of the vocal folds of M5, 267 volume velocities at 6 different transglottal pressures, 8 glottal diameters and 9 glottal angles (converging, uniform, and diverging shapes) were collected. The data contain several qualitative features not found in models often used to determine the volume flow, such as that developed by Ishizaka, Matsudaira, and Flanagan (IMF72). In the case of the smaller diameters, for example, the small-angle behavior of the data is much more pronounced than the IMF72 model would suggest. Further, the data include subtle flow maxima at small diverging angles, which are not present in the IMF72 model calculations, and the angular variations of the data at the large diameters are much less than the IMF72 model would suggest.

The goal of the present calculation is to capture these qualitative features with sufficient precision so that their implications for an improved understanding of human phonation can be examined. To this end, a formalism for representing the volume velocity as a sequence of nested analytic functions of 3 parameters, the angle, the pressure, and the diameter, has been developed. The angular distributions are examined first, and it is shown that a nonlinear mapping of the angular variable offers an advantage in simultaneously accounting for the large and small angle dependence. The functional dependence on the flow rates on the mapped angular variable is that of a cubic polynomial.

After the angular fits are made, the pressure and diameter dependence of the M5 flow data is carried by a set of 4 coefficients $C_i(P, d)$. The pressure dependence of each of these coefficients may also be adequately represented by a cubic polynomial, which is constrained to give zero flow at zero pressure. Thus, each of the functions C_i requires three independent functions to carry its diameter dependence. Each of the 12 diameter-dependent functions is required to give an exact fit to the coefficients C_i for all of the diameters at which measurements were made. The most efficient way to achieve this precision with reasonable behavior between the observed points is to break the range of the diameter variable into three subintervals.

The average accuracy of the calculated fit to the entire data set of 267 points is 3.4%. The quality of the present fit is compared with a fit based on the IMF72 model and a fit based on a "pressure coefficient approach", akin to that introduced by Scherer and Titze (1983) and by Story and Titze (1995). The average accuracy of the present fit is about 7 times as good as that of the IMF72 calculation. The "pressure coefficient approach" is shown to miss the main qualitative features of the flow at small diameters, but to give reasonable accuracy (~ 6%) at larger diameters. Implications of the 3-P representation for the shapes and strengths of the volume pulses generated by oscillating motions of the vocal folds will also be discussed.

In summary, the analytic equation derived here is based on empirical data from a Plexiglas model of the vocal folds and the glottis, and predicts the glottal flow well when given the dynamic glottal geometry (glottal angle and minimal glottal diameter) and the applied transglottal pressure. The results can be used in computer models of phonation and speech in which the motion of the vocal folds and the transglottal pressures are given. The resulting flow determines the basic acoustical excitation of the vocal tract.

This research was supported by NIH grant #2 R01 DC03577.

Scherer, R. C., Shinwari, D., De Witt, K. J., Zhang, C., Kucinschi, B. R., and Afjeh, A. A. (**2002**). "Intraglottal pressure profiles for a symmetric and oblique glottis with a uniform duct ," J. Acoust. Soc. Am. **112**, 1253-1256.

Ishizaka, K. and Flanagan, J. L. (**1972**). "Synthesis of voiced sounds from a two-mass model of the vocal folds," Bell Syst. Tech. J. **51**, 1233-1268.

Scherer. R. C. and Titze, I. R. (**1983**). "Pressure-flow relationships in a model of the laryngeal airway with a diverging glottis," *in Vocal Fold Physiology: Current Research and Clinical Issues*, edited by D. Bless and J. Abbs (College Hill, SanDiego), 179-193.

Story, B. H. and Titze, I. R. (**1995**). "Voice simulation with a body cover model of the vocal folds," J. Acoust. Soc. Am. **97**, 1249-1260.