MEASUREMENT OF TURBULENCE IN GLOTTAL FLOW

Fariborz Alipour and Ronald C Scherer
University of Iowa, Iowa City, IA 52242
alipour@blue.weeg.uiowa.edu

INTRODUCTION

Glottal flow during phonation exits the glottis as a pulsatile jet that has both a repetitive quasi-periodic portion (called the *deterministic signal*), as well as a more random *turbulence* ripple [1]. Studies have suggested that the glottal jet between the vocal folds typically is laminar before the glottal exit, with transitions to turbulence within a short distance of the glottis [2].

This report discusses three different methods of analyzing the velocity signal of the air exiting the glottis into the deterministic (nearly repetitive) signal and the turbulence residual velocities: smoothing, wavelet de-noising, and ensemble averaging. These will be described following discussion of the excised larynx set-up.

METHODS

Canine larynx was mounted on an air tube with a hot-wire probe placed above the glottis outlet. Airflow was passed through a heater and humidifier to achieve 37?C and 100% humidification. The use of sutures, micrometers, and shims controlled glottal length and adduction. The jet velocity above the glottis was measured with hot-wire or hot film sensors using a constant-temperature anemometer system (Dantec 56C01). Analog signals from the hot-wire probe, EGG, and pressure transducer were monitored on a digital oscilloscope and simultaneously recorded on a DAT recorder. The signals were digitized later at a minimum of 10 kHz per channel for 1 to 5 seconds. **Figure 1** shows typically recorded data, including from top to bottom the following signals: EGG, subglottal pressure (Ps), tracheal velocity (Vs), and glottal exit jet velocity (Vj).

In the interest of flow analysis, it is important to separate the turbulence from the velocity. Thus, by time averaging the instantaneous velocity over time, one can find the mean or time-averaged velocity, and by subtraction, an estimate of the turbulence. This works easily in steady flows where time-averaged velocity becomes time independent. However, in pulsatile glottal flow, simple averaging does not work and other ways of separating turbulence are needed. Once the turbulence is separated, the remaining velocity is still time dependent and is called deterministic velocity.

SUMMARY OF RESULTS

The existence of flow turbulence in the glottal jet flow has been shown to be highly likely. The importance of the turbulence has not been well established, although it may appear obvious that it is part of the noise creation for breathy voicing, whisper, and perhaps secondary dipole sound. Thus, it is important to establish methods to measure turbulence associated with phonation. Turbulence intensity is the conventional measure of choice. But what methods should be used to extract the turbulence from velocity signals? This study attempted to examine three different methods, ensemble averaging, smoothing, and wavelet de-noising.

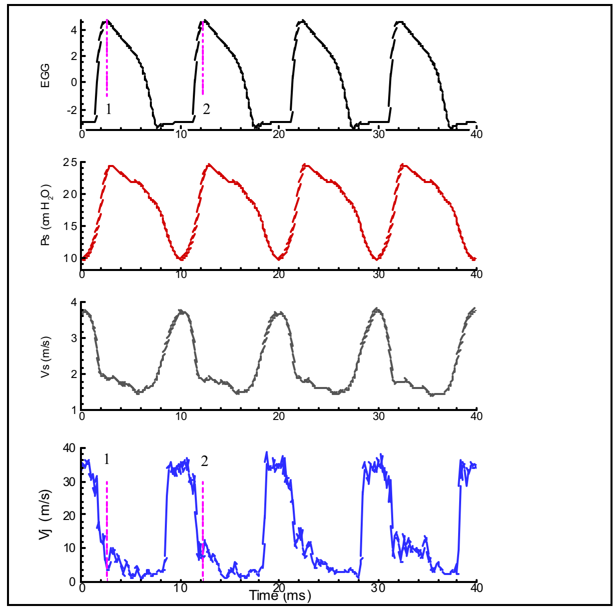

Fig. 1 – Typical waveforms of recorded data

The results suggest that the ensemble averaging is inadequate because it gives the worst representation of the deterministic signal and the lowest cross-correlation between the deterministic signal and the original velocity. It takes away cycle "individuality" by making them all the same (for the chosen group with which to calculate the deterministic signal). The wavelet de-noising scheme would appear to be highly applicable, but the requirement to make a choice of which level of analysis to make lends flexibility for which there is an absence of knowledge. That is, the actual turbulence intensity is unknown, and therefore the level of analysis is not determinable. The smoothing method appears to be a reasonable compromise at this time because of its reasonable calculation of both the deterministic signal and the turbulence intensity, and because of its simplicity.

REFERENCES

1. Alipour F, et al. *J. Fluids Eng.-Trans. ASME*, **117**(4), 577-581, 1995.
2. Hofmans GCJ, et al. *J. Acoust. Soc. Am.* **113**(3), 1658-1675, 2003.

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