Evaluation of Synthetic Self-Oscillating Models of the Vocal Folds

E. P. Hubler, K.C. Stewart, B. D. Erath, M. W. Plesniak
Department of Mechanical and Aerospace Engineering
The George Washington University

THE GEORGE WASHINGTON UNIVERSITY WASHINGTON, DC

GW SEAS

Background and Introduction

- The vocal folds (Figure 1.1) are two bands of tissue that stretch across the airway and are initially abducted (open). The vocal folds adduct (close) in preparation for speech in order to seal off the airway.
- Voiced speech is produced when a critical lung pressure is achieved, forcing air through the vocal folds.
- The aerodynamic forces impart energy to the tissue of the vocal folds, and incite self-sustained oscillations (Titze, 1988).

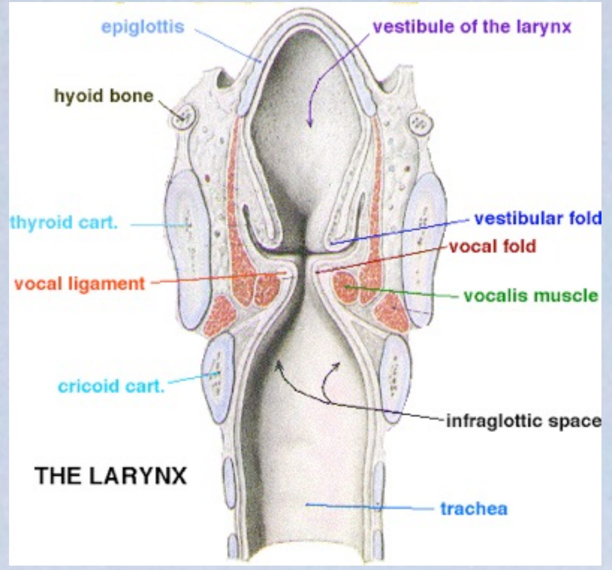

Figure 1.1 - Vocal Fold Schematic (www.yorku.ca)

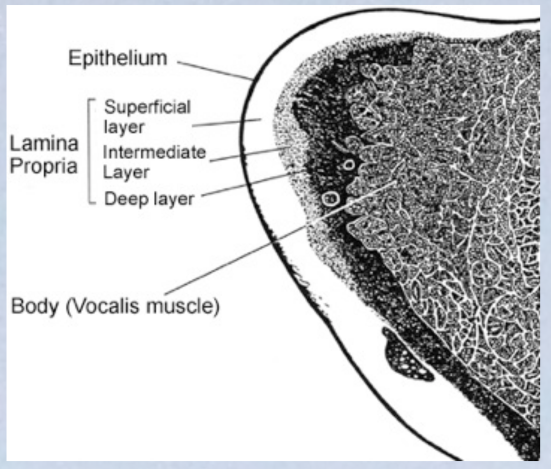

Figure 1.2 - Vocal Fold Layers (http://www.british-voice-association.com/voice-information_vocal-nodules.htm)

- Physiological vocal folds (Figure 1.2) have non-linear stress-strain relationships (Figure 1.3).

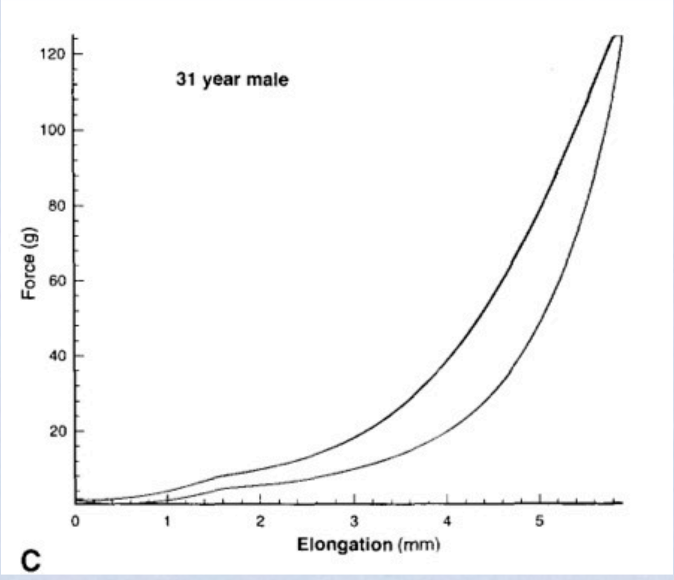

Figure 1.3 - Stress-Strain Curve of Human Vocal Ligaments in a 31-Year-Old Man (Gray et al., 2000)

Figure 1.4 - Silicone Self-Oscillating Vocal Fold Model

- Replicating these properties will enable us to perform bench-top scientific speech investigations using synthetic self-oscillating vocal fold models (Figure 1.4).

Objective

The objective of this research is to study and improve synthetic vocal fold models by evaluating their ability to replicate physiological vocal fold motion and characteristic parameters of human speech within the life size experimental setup in the Biofluid Dynamics Laboratory. This study will help us as we move towards finding a substitute for the complex tissues found in the human vocal folds. This work is in collaboration with the GWU Department of Speech and Hearing Science.

Facility and Methods

- Molds for the samples were designed in ProEngineering and printed on a 3-D printer/ rapid prototyper.
- A tensile tester was designed and used to measure stress-strain relationships of silicone samples and stiffness (Modulus of Elasticity).
- The experimental setup used provides flow from a compressed air line that feeds into an adjustable volume, acoustically-treated, constant pressure chamber which mimics the role of the human lung (Figure 2.1).

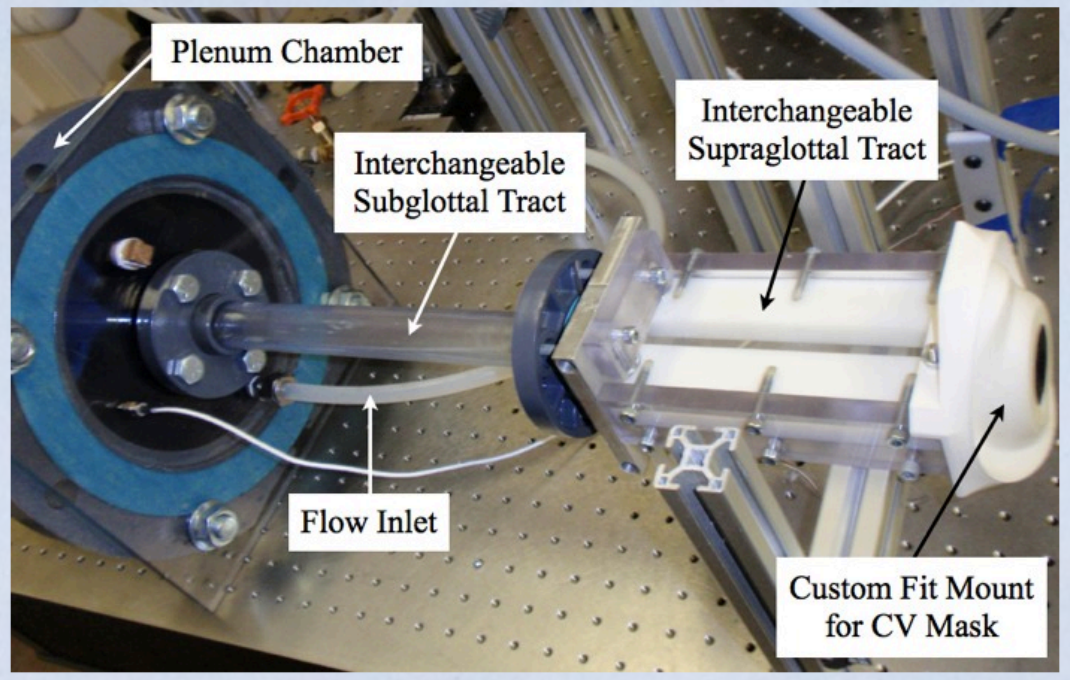

Figure 2.1 - Experimental Setup

- The synthetic, self-oscillating VF models are housed in an experimental larynx.
- Pressure measurements are taken in the subglottal chamber (lung), the subglottal channel, and the supraglottal tract.
- A circumferentially-vented (CV) pneumotachograph (Rothenberg) mask is attached to the experimental setup via a custom mount fit on the end of the supraglottal tract (Figure 4.1)

Results

- We were able to use Smooth-On EcoFlex Silicone to generate synthetic vocal folds which have Modulus of Elasticity, E, values of 5.4kPa, 10.6kPa, 15.5kPa, 35.9kPa, 39.5kPa, and 88.9kPa which are within the range of the E values found in physiological investigations (Figures 3.1).

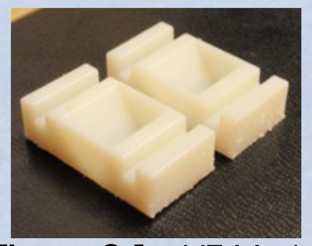

Figure 3.1 - VF Model Molds Created in Rapid Prototyper

- A custom MATLAB algorithm was developed to analyze the pressure measurements acquired from the experimental setup. A representative set of data is shown in Figure 3.2 which was found to oscillate at 235 Hz.

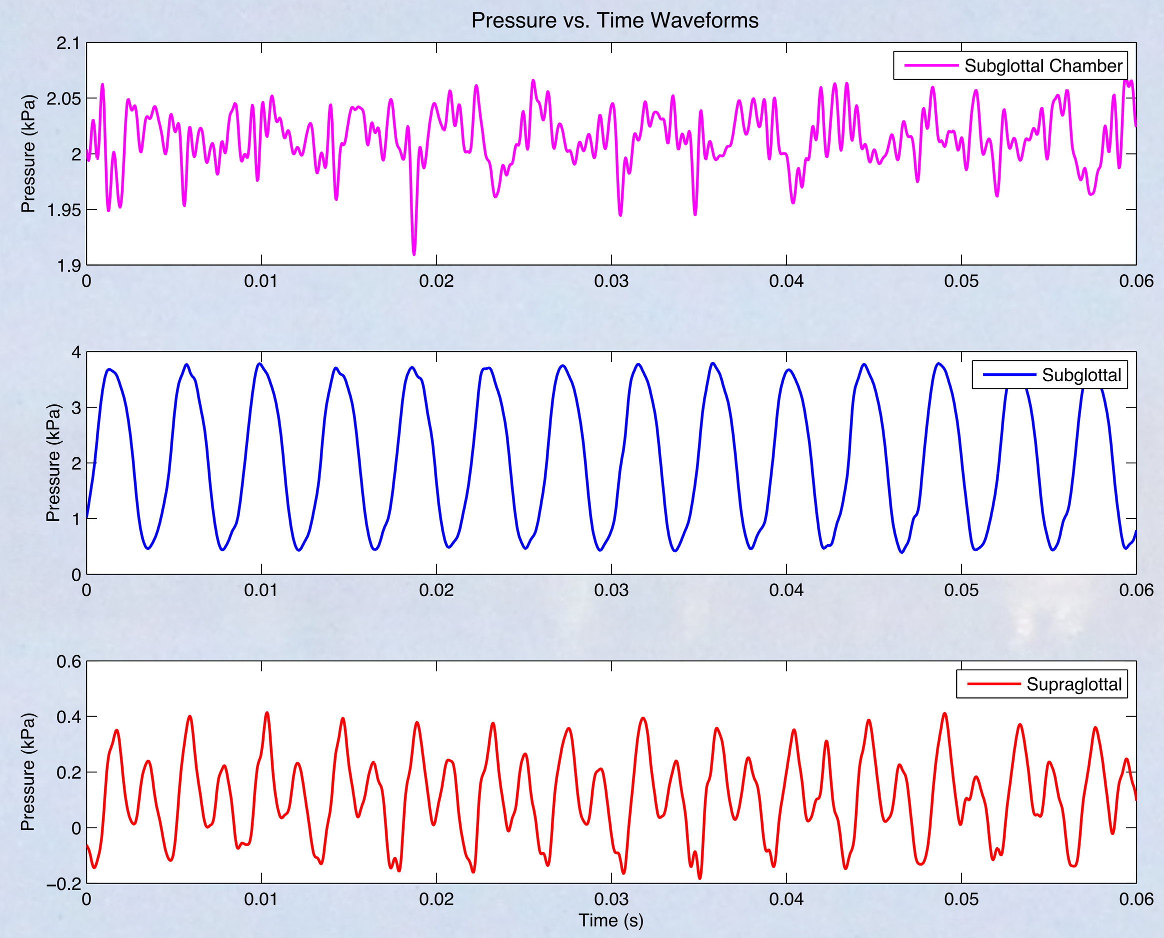

Figure 3.2 - Pressure vs. Time Waveforms Created Using MATLAB Algorithm

- Another MATLAB algorithm was developed to calculate clinical parameters such as AC/DC ratio, peak flow, open quotient, and speed quotient according to the airflow waveforms acquired by the CV mask.

Discussion and Conclusions

- The silicone mixture ratios tested resulted in Modulus of Elasticity values which fell within physiological ranges, therefore we determined that silicone was an effective material for modeling the human vocal folds.
- Homogeneous vocal fold models (E = 10.6kPa, 15.5kPa, and 35.9kPa) were found to self-oscillate within the range of physiological fundamental frequencies.
- Multi-layer synthetic vocal fold models are being evaluated to more closely replicate physiological conditions.
- These results will guide the development of self-oscillating vocal fold models for scientific investigations of voiced speech.

Future Work

- Future work will focus on replicating the non-linear behavior of the vocal folds.
- In addition, a versatile positioning mechanism will be created and implemented to allow for easy adjustments of the models.
- Clinical parameters calculated from the volume-velocity output of the CV mask will be compared to clinical patient data of normal and aging patients to advance the state-of-the-art for synthetic VF models (Figure 4.1).

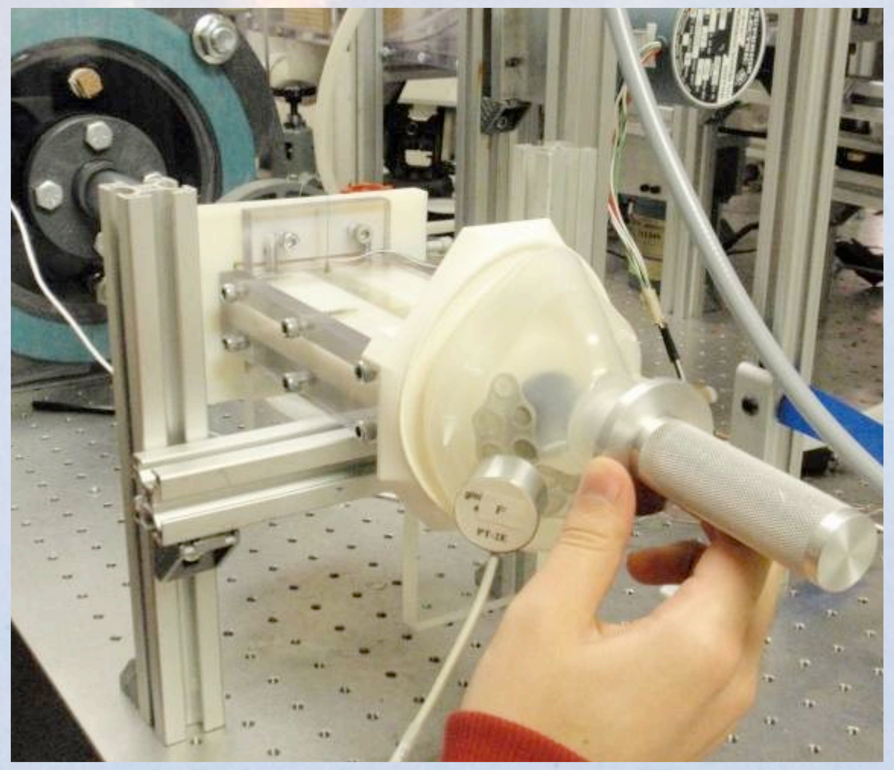

Figure 4.1 - CV Mask With Experimental Setup