Evaluation of Synthetic Self-Oscillating Models of the Vocal Folds

E. P. Hubler, A. B. Hancock, K. S. Weiland, A. G. Apostoli, B. D. Erath, M. W. Plesniak

The George Washington University
Department of Mechanical and Aerospace Engineering

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.
- Voiced speech is produced when a critical lung pressure is achieved, forcing air through the vocal folds. The aerodynamic forces then impart energy to the tissue of the VFs and induce self-sustained oscillations [Titze, 1988].

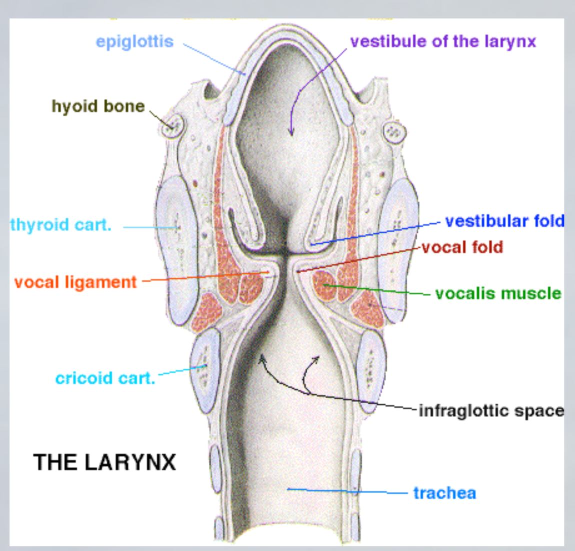


Figure 1.1 - Vocal Fold Schematic [www.yorku.ca]

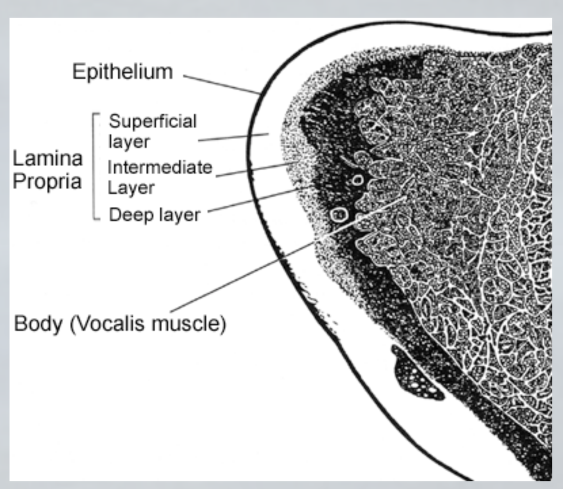


Figure 1.2 - Vocal Fold Layers [http://www.british-voice-association.com/voice-information_vocal-nodules.htm]

- Physiological vocal folds (Figure 1.2) have non-linear stress-strain relationships and exhibit mucosal wave motion.
- 30% of people will suffer from a voice disorder at some point in their lives [Roy et al., 2005].
- Replicating physiological properties of human VFs will enable us to perform bench-top scientific speech investigations using synthetic self-oscillating vocal fold models (Figure 1.3).
- Molds for the samples were designed in ProE and printed on a 3D printer (Figure 1.4).

Figure 1.3 - Silicone Self-Oscillating VF Model

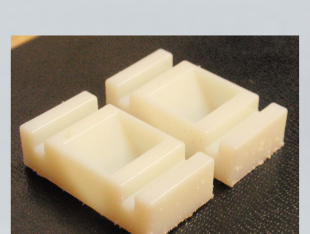


Figure 1.4 - VF Model Molds Created In 3D Printer

- A tensile tester was designed and used to measure stress-strain relationships of silicone samples and stiffness (modulus of elasticity).
- Silicone-based, self-oscillating synthetic VF models were fabricated to produce samples exhibiting material properties representative of the different layers of human VFs.

Objective

The objective of this research is to study and improve synthetic vocal fold (VF) models by evaluating their ability to replicate physiological vocal fold motion and characteristic parameters of human speech within a life-size experimental setup in the Biofluid Dynamics Laboratory. This study will guide the development and improvement of self-oscillating vocal fold models for scientific investigations of voiced speech. This work is in collaboration with the GWU Department of Speech and Hearing Sciences and funded by the GWU IBE and COBRE.

Facility and Methods

- The experimental setup 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).

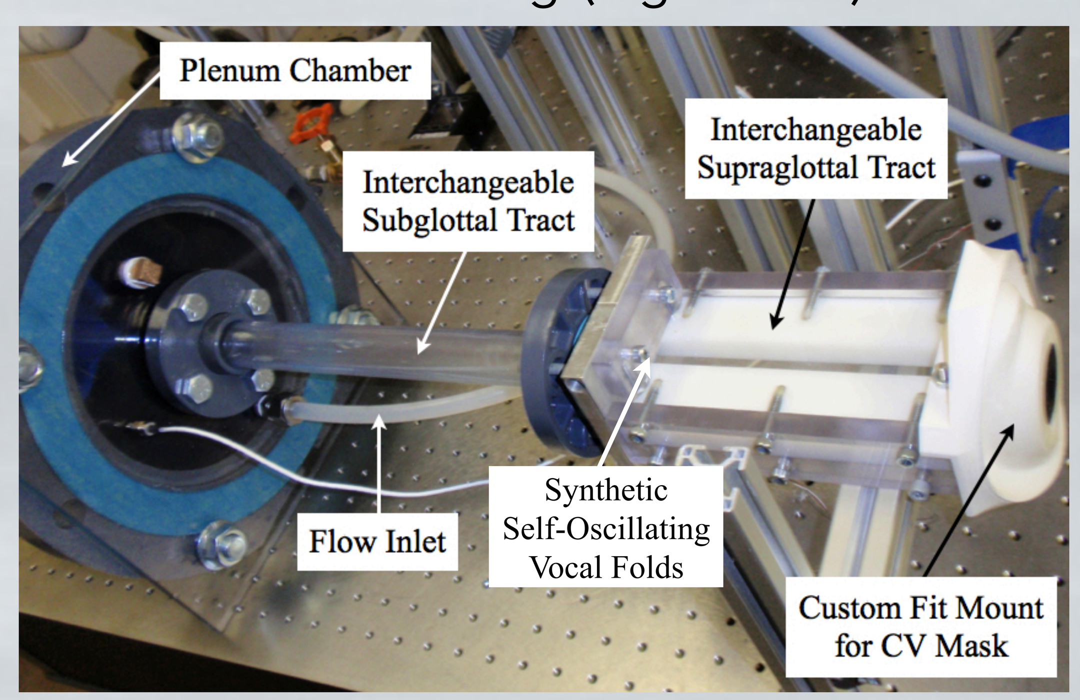


Figure 2.1 - Experimental Setup

- The synthetic, self-oscillating VF models are housed in a versatile positioning mechanism within the experimental larynx.
- Pressure measurements are taken in the subglottal chamber (lung), the subglottal channel, and the supraglottal tract and high-speed images (2500 fps) are captured at varying flow rates during VF oscillation.
- Clinical parameters are calculated from the volume-velocity output of a circumferentially-vented (CV) pneumotachograph (Rothenberg) mask (Figure 2.2).

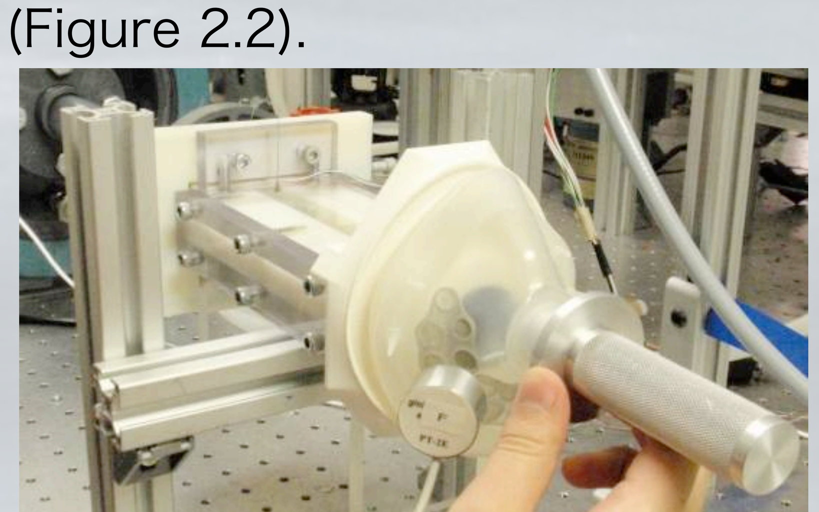


Figure 2.2 - CV Mask With Experimental Setup

Rothenberg Mask Results

- An extensive MATLAB algorithm was developed to calculate clinically relevant parameters from the volume-velocity output of the CV mask (Figure 3.1).

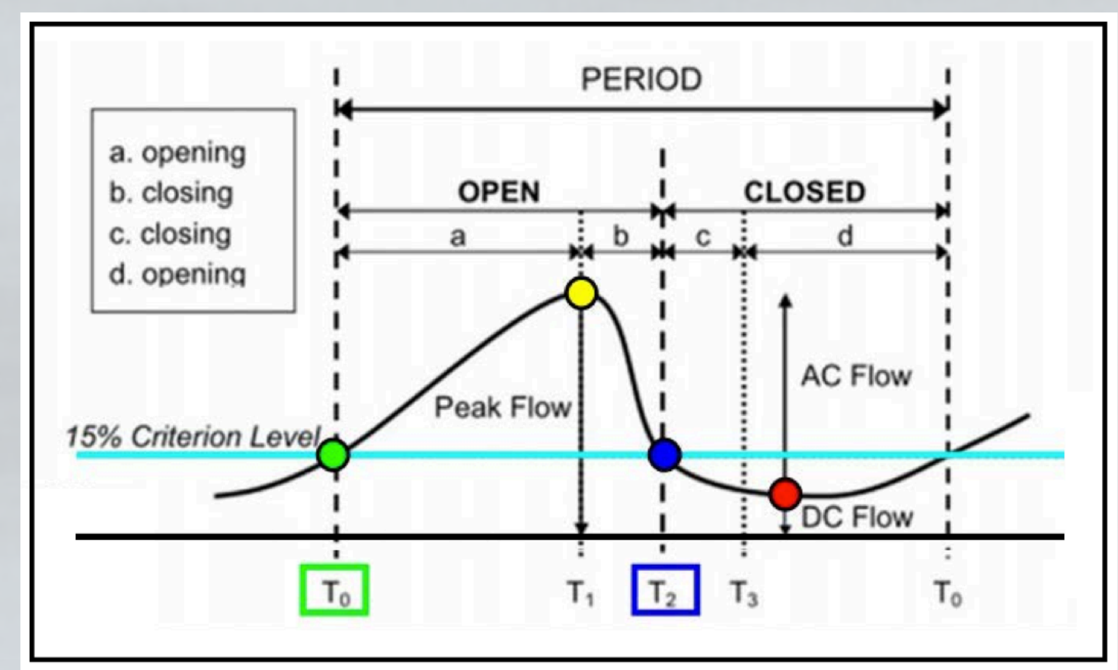


Figure 3.1: Glottal Airflow Signal After Inverse Filtering [Hancock 2011]

- These parameters are compared to clinical data, which was collected from 20 young (18-30) and 10 old (60-80) men using the Rothenberg mask, and analyzed using the MATLAB algorithm (Table 3.1).

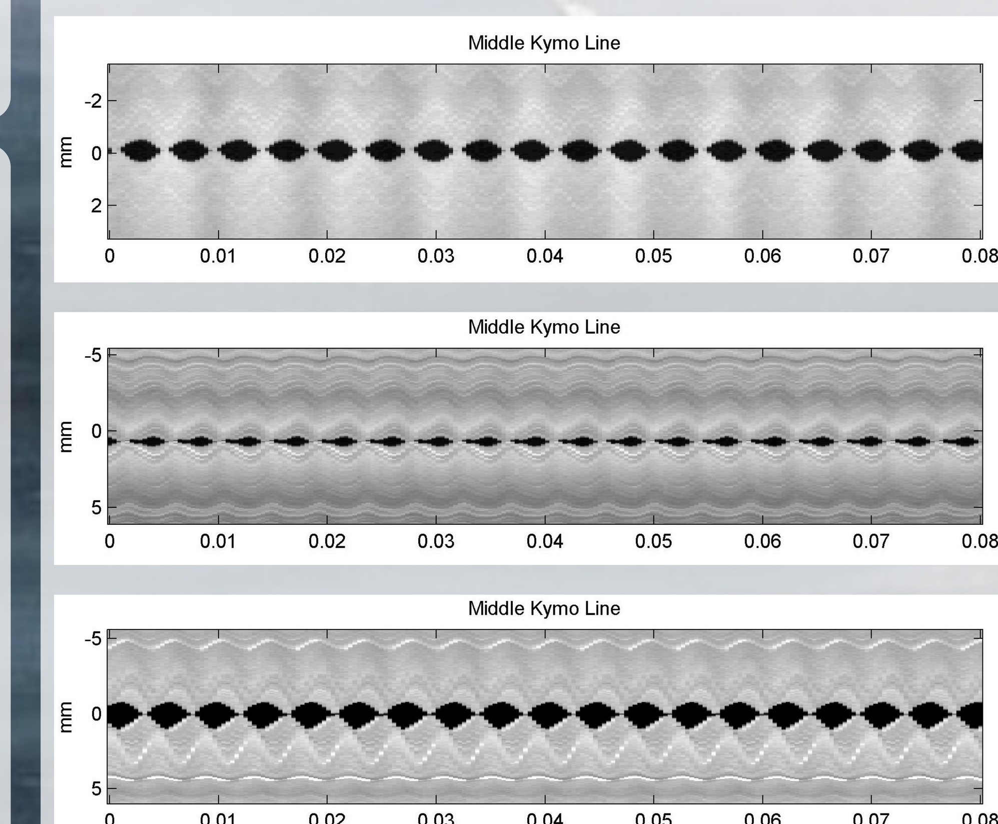
Parameter	Young Mean (SD)	Old Mean (SD)	B&O Mean (SD)
F_0 (Hz)	113 (19.1)	125 (14.1)	112 (11.8)
Peak Flow (L/s)	0.36 (0.11)	0.47 (0.23)	0.41 (0.09)
AC/DC (ratio)	0.67 (0.21)	0.89 (0.42)	0.65 (0.18)
Open Quotient (%)	45.7 (6.58)	48.7 (7.43)	57.0 (10.7)
Speed Quotient (%)	1.46 (0.32)	1.38 (0.24)	1.52 (0.35)
MFDR (L/s²)	320 (134)	444 (322)	337 (127)

Table 3.1: Representative Human Subject Data (B&O Values: Baken and Orlikoff)

- We were able to use Smooth-On EcoFlex Silicone to fabricate synthetic VFs which have modulus of elasticity, E, values of 5.4 kPa, 10.6 kPa, 15.5 kPa, 35.9 kPa, 39.5 kPa, and 88.9 kPa, which are within the range of E values found in physiological investigations.

High Speed Image Results

- The high-speed images are analyzed using a videokymography line-scan technique that has been used to examine VF motion and mucosal wave dynamics *in-vivo* (Figure 4.1).



Homogeneous E = 15.5 kPa

Wool Additive E_{Base} = 15.5 kPa with ⅛ in. wool added

2 Layer Model E_{Base} = 15.5 kPa, E_{Cover} < 5.4 kPa

- The **homogeneous** VF models were found to be symmetric with full closure; the **two-layer** VF models were found to be asymmetric with a mucosal wave; and the VF models with **wool additives** were found to be asymmetric with a slight mucosal wave.

Discussion and Conclusions

- Homogeneous, Two-Layer, and Wool Additive VF models were found to self-oscillate within the range of physiological fundamental frequencies.
- Two-layer and Wool Additive VF models were found to exhibit physiological VF motion.
- These results will guide the development of self-oscillating vocal fold models for scientific investigations of voiced speech.

Future Work

- Synthetic VF models with polyps and nodules will be tested within the same life-size artificial laryngeal setup.
- These results will be compared to clinical data taken in collaboration with the GWU Medical Faculty Associates Voice Treatment Center.