A LF-pulse from a simple glottal flow model

Atte Aalto, Paavo Alku, and Jarmo Malinen
Helsinki University of Technology, Finland

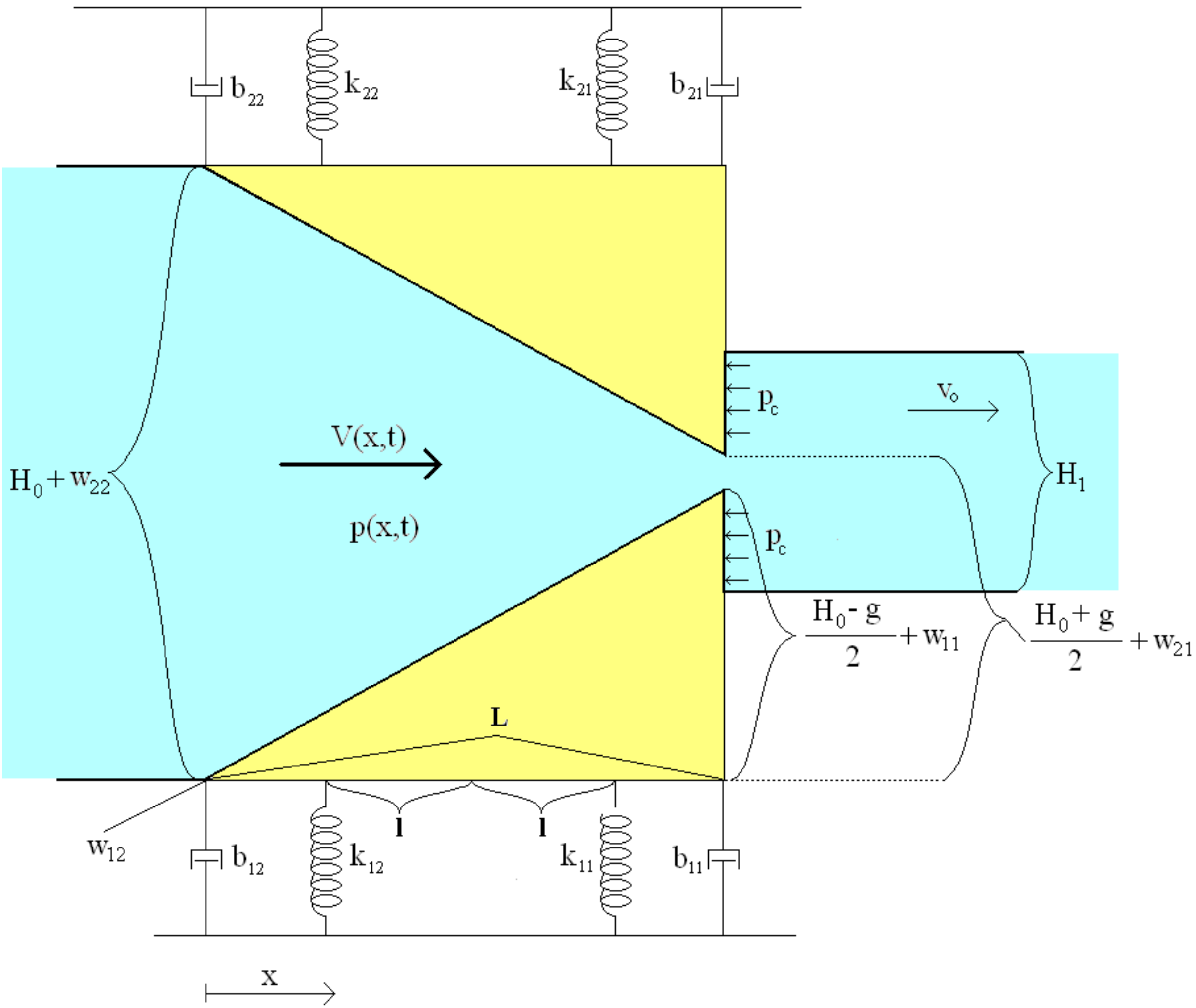
Introduction

- The objective is to obtain validated glottal flow pulse from a simple physically motivated model which we shall later use as a source for a wave equation model.

- The model consists of three subsystems:
  1. a mass-spring model of the vocal folds,
  2. an incompressible 1D flow model, and
  3. a vocal tract (VT) model based on the Webster's equation.

- The flow pulse is validated against the four parameter LF-pulses corresponding to breathy, normal, and pressed phonation.

The vocal fold model (1)



The vocal fold model (2)

The equations of motion are

$$\begin{cases} M_1\ddot{W}_1(t) + B_1\dot{W}_1(t) + K_1W_1(t) = -F(t), \\ M_2\ddot{W}_2(t) + B_2\dot{W}_2(t) + K_2W_2(t) = F(t). \end{cases}$$

Here $W_1 = \begin{pmatrix} w_{11} \\ w_{12} \end{pmatrix}$ and $W_2 = \begin{pmatrix} w_{21} \\ w_{22} \end{pmatrix}$ are the positions of the upper and lower vocal fold and M_j, B_j, and K_j are the corresponding mass, damping, and stiffness matrices.

Load force F

- For the open glottis, F contains the aerodynamic pressure and the counter pressure from the VT.

- When the glottis is closed, F contains a contact force given by the Hertz impact model and the VT counter pressure.

Glottal flow

We assume an incompressible 1D flow through the glottis whose velocity v_o satisfies

$$p_{sub} = \underbrace{\widehat{C}_{iner}\dot{v}_o(t)}_{\text{inertive pressure}} + \underbrace{\frac{C_g}{\Delta W_1(t)^3}v_o(t)}_{\text{viscous pressure loss}}$$

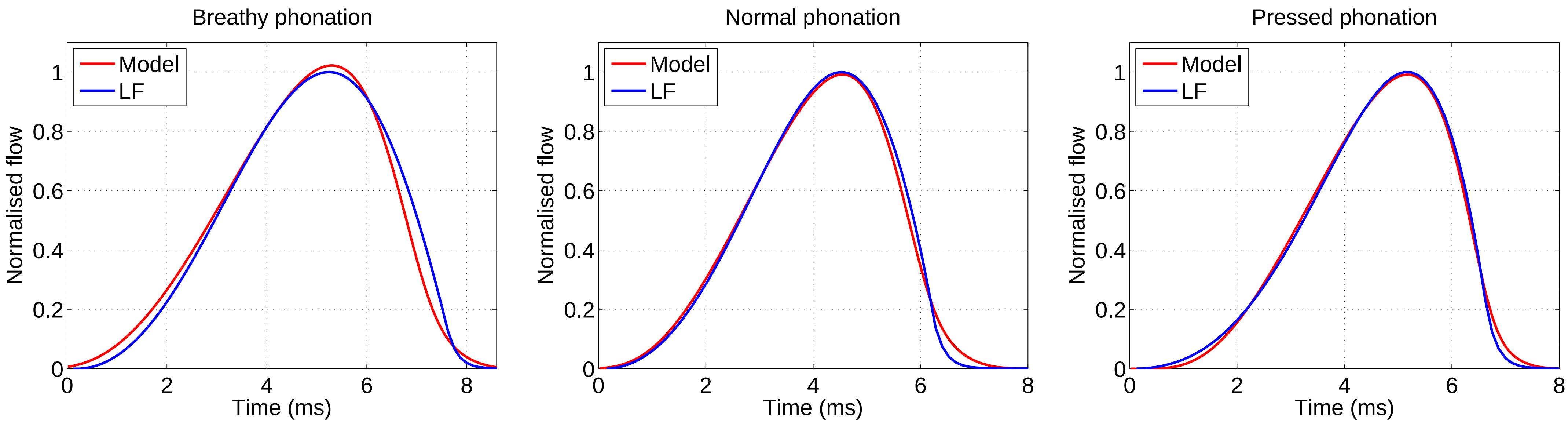
- p_{sub} is the subglottal pressure (above ambient pr.),
- $\widehat{C}_{iner}$ $(= hH_1C_{iner})$ regulates the flow inertia,
- C_g regulates the viscous pressure loss at the glottis,
- ΔW_1 is the glottal opening at the narrowest point.

Flow model parameters

$$\dot{v}_o(t) = \frac{p_{sub}}{\widehat{C}_{iner}} - \frac{C_g/\widehat{C}_{iner}}{\Delta W_1(t)^3} v_o(t).$$

- C_g is fixed because only the relative magnitudes matter.
- Varying p_{sub} only changes the height of the pulse.
- Adjusting C_{iner} changes the pulse inclination.
- The pulse duration is varied by adjusting the mechanical properties of the vocal folds (M_j and K_j).

Parameter estimation



$C_{iner} = 524.8\ kg/m^4s$	$C_{iner} = 530.9\ kg/m^4s$	$C_{iner} = 630.8\ kg/m^4s$
Mean error 1 = 2.93 %	Mean error 1 = 1.45 %	Mean error 1 = 2.09 %
Mean error 2 = 4.14 %	Mean error 2 = 3.07 %	Mean error 2 = 2.14 %

- Instants of maximal flow and total flows are required to coincide.
- Pulse durations and inclinations are optimised.
- Me1 is the integrated error from time 0 to the instant of max. flow. Me2 is the error after the instant of max. flow (% of A_{LF}).

Conclusions

We presented a flow mechanical glottis model to be used as a source for a VT simulator. The model was validated against three LF-pulses whose parameters were obtained by inverse filtering techniques.

- LF-pulses corresponding to different types of phonation can be constructed by our physical model with accuracy of few percents.

- The different phonation types result in different pulse inclinations (values of parameter C_{iner}).