THE INFLUENCE OF THE FALSE VOCAL FOLDS ON THE PHONATION

by

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ABSTRACT--Some discrepancies have occurred between physiological data for the larynx and the dynamic models which have been proposed in the literature. For instance, recents tomograms of the larynx during phonation has shown the entry angle of the glottis to be more abrupt than that chosen for these models. Also the false vocal folds seem to avoid the assumption of the uniform vocal tract adopted for some models reported. Results presented here show the influence of these figures on the glottal waveforms.

INTRODUCTION

Several researchers have mentioned the importance of the false vocal folds in the laryngeal aerodynamics. Conrad (1983), for instance, has concluded that a supraglottal constriction is necessary for his collapsible tube model of the larynx attains oscillation. Ananthapadmanabha (1983) has reported that a constant exit recovery coefficient cannot be used if a more accurate model of the vocal tract has been adopted. The false folds influence the intra-glottal pressure distribution and act upon the recovery of energy at the glottal exit.

The present study focuses on the three-mass model (Miller, Pereira and Thomas, 1988) for the vocal fold vibration. Two masses are used to simulate the true vocal folds as proposed by Ishizaka and Flanagan (1972) and one mass simulates the false vocal folds. The supraglottic constriction between these folds plays important roles as a source of sound for some particulars cases. The so-called stage whispering arises from an adduction of the false vocal folds. This adduction comes from the decrease in the size of the anterior-posterior dimension of the larynx cavity (Sawashima and Hirose 1983). The adduction of the false vocal folds is considered to contribute to the prevention of the vocal fold vibration by the transglottal air flow, as well as to facilitate the generation of turbulent noise in the laryngeal cavity.

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On the other hand, for pathological cases, the supraglottic constriction (in particular the false vocal folds) play an important role in phonation. Blaugrund (1983) has reported clinical observations of voicing during the post-operative period of subjects who have undergone to partial laryngectomy. He has found that hipertrophy of the false or true vocal folds can be responsible of achieving voice.

The transition between trachea and glottis (conus elasticus) has been adopted to be smooth, generally the entry angle of glottis being about 50 degrees. In a recent research, Rosen and Fourcin (1986) have reported some tomograms of the larynx during phonation which show this angle to be very abrupt, with an average value being about 80 degrees.

THE ADOPTED MODEL

A model presenting the laryngeal air channel have been adopted for the vocal folds vibration. This model is a three-mass formulation of the vocal folds (true and false vocal folds). It is based on the two-mass model proposed by Ishizaka and Flanagan and also incorporates the flow formulation proposed by Miller and Thomas (1982). It presents one mass simulating the false vocal folds and permits displacements in the horizontal and vertical (in the figure) directions.

A complete description of the model has been presented by Miller, Pereira and Thomas (1988). A figure of the model is included here for a concise explanation of it. At the entry of the glottis is proposed to occurs detachment of the flow from the boundary (vena contracta formation). The contraction factor and the place where it is formed are supposed to be function of the entry angle of the glottis and the diameters ratio between trachea and glottis entry. Consequently the pressure drop at this section is not a fixed percentage of the kinetic pressure. In the same way the pressure recovery between the glottis exit and the vocal tract is calculated considering the false vocal folds and is based on the momentum and continuity considerations for the difuser flow.

The horizontal movement is responsible for a modulation in the length of the laryngeal ventricle and this dictates the losses which occur in this section. The vertical movement is quite similar to the masses simulating the true vocal folds. It can be thought as the supraglottal constriction proposed by Conrad (1983), however it is not a unrealistic one for the phonation condition. This constriction is proposed to be variable and have some interaction with the air flow similar to the mucosa membrane of the true vocal fold.

The parameters shown in figure 1 represent the stiffness (s), the damping coefficient (r) and mass, where m1 is the vocalis muscle, m2 is the cover of the true folds as proposed by Hirano and m3 is the false folds. At the left side of the figure is the trachea with radius R and the vocal tract (right side of figure) has a fixed heigth (X4). The sections which composed the model are: trachea and conus elasticus (before station 1 in the figure), the glottis (between stations 1 and 2), the laryngeal ventricle (stations 2 and 3), the false glottis (stations 3 and 4) and the vocal tract (beyond station 4).

Due to the area ratio between trachea and laryngeal channel, the losses incurred in the trachea are regarded as zero. Therefore, the pressure at the entry of the conus elasticus is considered to be constant and equal to the subglottal pressure (lung pressure).

For the phonation condition, the vocal tract is relatively open and consequently the static pressure at the laryngeal channel exit is regarded as atmospheric pressure (P4 in the model).

With the assumptions above and based on momentum and continuity equations the following relationship between static pressure and volume velocity is derived:

$$P_{sg} = \sum_{\substack{i=1 \\ j=i+1}}^{4} \frac{K_v.\mu.L_{(i-j)}\,U}{2.g.W_{glot}.X^3_{min}} - \sum_{\substack{i=1 \\ j=i+1 \\ A_j>A_i}}^{4} \frac{\rho}{2.g.A_j^2}\left[1 - \frac{A_j}{A_i}\right]^2 U^2 \qquad (1)$$

The static pressure at each station is calculated considering the kinetic pressure and the losses up to that station. The equation for the static pressure at each station is given below.

$$P_n = P_{sg} - \frac{\rho .U^2}{2.g.A_n^2} - \sum_{\substack{i=1 \\ j=i+1}}^{n} \frac{K_v.\mu.L_{(i-j)}.U}{2.g.W_{glot}.X^3_{min}} - \sum_{\substack{i=1 \\ j=i+1 \\ A_j>A_i}}^{n} \frac{\rho}{2.g.A_j^2}\left[1 - \frac{A_j}{A_i}\right]^2 U^2 \qquad ...(2)$$

$n = 1.....4$

where:

Pn	pressure at station n	(gm/cm*cm)
Psg	subglottal pressure	(gm/cm*cm)
Kv	constant for viscous losses	
μ	air viscosity	(gm/cm*Sec)
L(i-j)	length between stations i and j	(cm)
U	volume velocity	(cm*cm*cm/Sec)
Wglot	width of the glottis	(cm)
Xmin	minimum laryngeal flow height	(cm)
ρ	air density	(gm/cm*cm*cm)
g	acceleration due to gravity	(cm/Sec*Sec)
Ai	initial area of flow enlargement	(cm*cm)
Aj	final area of flow enlargement	(cm*cm)

RESULTS

The heavy voice (chest register)

In most adjustments for the chest register the ratio of stiffness (stiffness of the vocalis muscle by the stiffness of transition and cover) is relatively high. This results in a marked wave on the mucosa (vertical phase difference between the masses). Figure 2 shows the typical waveform of the chest register, where the ratio of stiffness used was 13:1 and the resultants frequency and open quotient are 125 Hz and 0.625, respectively.

How the vocal fold profile is behaving during a cycle can be extracted from the flow-type pattern. During steady state, the opening of the glottis starts with the vocalis muscle bulk (m1) moving in advance of the cover and transition (m2). This results in m2 being pulled outwards, due to the coupling between them, consequently, the glottal opening occurs as a convergent profile (type 3). When mass1 reverses the movement, mass2 is still moving outward but the profile stays convergent for a small portion of the closure phase of the cycle. As the masses, with their opposite directional movements, change the profile from convergent to divergent, the flow-type changes to type-1 and then closes (type-0) in a divergent shape.

The light voice (falsetto)

In light voice, the ratio of stiffness between the muscle and the mucosa is decreased. The entire vocal fold is stretched and the vocalis muscle is most inactive. The extent of the movement is less in a light voice than in a chest register and little waving is observed in this voice. Figure 3 shows the waveform for a light voice with the ratio of stiffness of 6:1. It can be seen that a complete closure is not reached (open quotient equal 1) and the frequency is higher than the heavy voice (about 200 Hz). The flow-type pattern indicates there is no vertical phase difference. The simulation starts as a convergent profile (flow-type 3) and closes (flow-type 0) without intermediate profiles, as shown in figure 2 for the chest register, and opens again as flow-type 3.

A breathy vocal attack

Dejonckere and Lebacq (1981) have reported that the first deflection of the base line (average of the glottal area variation) reflects sometimes an abduction of the vocal folds and at other times an adduction. The graphs in figure 4 and 5 show that vocal fold oscillation can commence either with vocal fold abduction or vocal fold adduction.

In figure 4 the initial profile is parallel with an area of 20 sq. mm. The resistance offered by the glottis is relatively small and consequently there is a high volume velocity. The conversion into kinetic energy causes a negative static pressure inside the glottis (Bernoulli effect) which then 'sucks together' the folds. This effect causes an adduction of the vocal folds as well as a steadly inward movement prior to steady state oscillation. In figure 5 the initial profile is convergent with a minimum area of 5.6 sq. mm. and the flow velocity is not sufficient to cause an adduction in the small glottal area. As a result the force applied to the masses causes an outward movement (abduction).

CONCLUSIONS

The model has been proved to be suitable for real phenomena which occur in the laryngeal channel. For instance, the vertical phase displacement, as reported by Hirano, is realisticaly reproduced by the model. Also, the movements of the true vocal folds for the falsetto voice fit very well with the graphs produced by Hirano (1977).

Of particular interest to the present work is the simulation of the 'breathy vocal attack' as reported by Dejonckere and Lebacq, particularly at the onset of oscillation. Based on physiological data, results of the simulation show it is possible to obtain almost all characteristics of their glottal wave measurements, as for example, the deflection of the base-line can be an adduction or abduction indistinctly and the number of cycles before the first 'plateau' be reached.

Although a simplistic model has been used it is possible to simulate most of observed phenomena in speech. On the other hand, also for pathological simulation of the laryngeal channel the model can be usefull.

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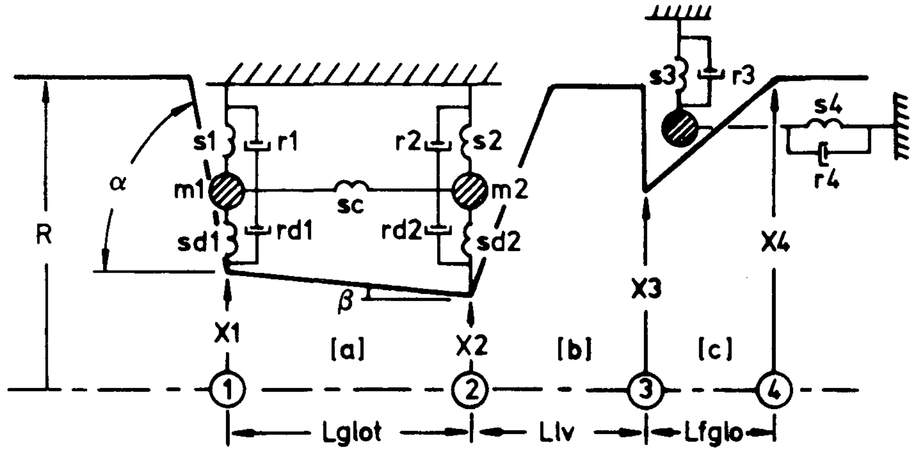

Figure 1 - Three-mass model of the vocal folds. Masses m1 and m2 represent the true vocal folds and mass m3 the false vocal folds.

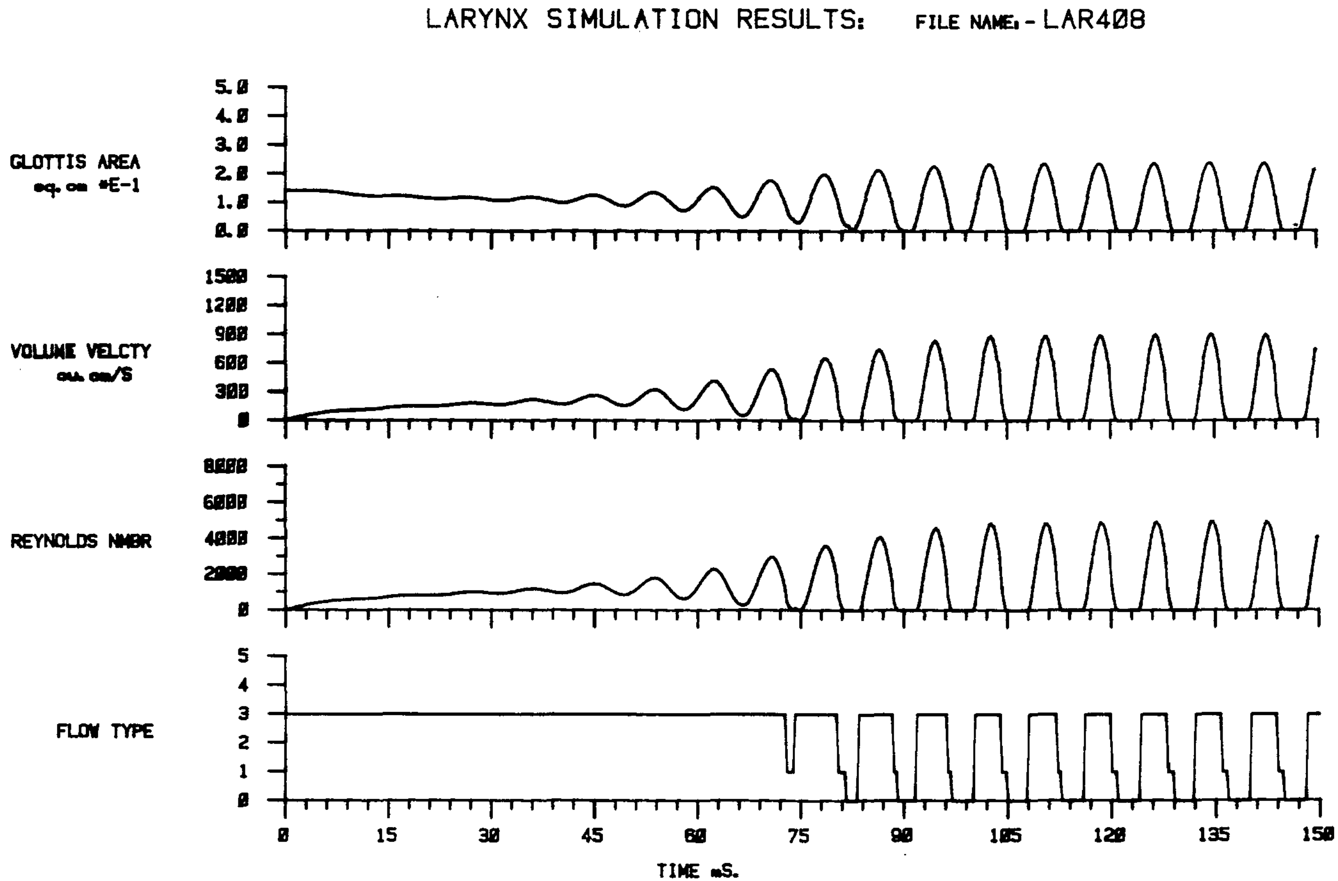

Figure 2 - The heavy voice (chest register) simulation

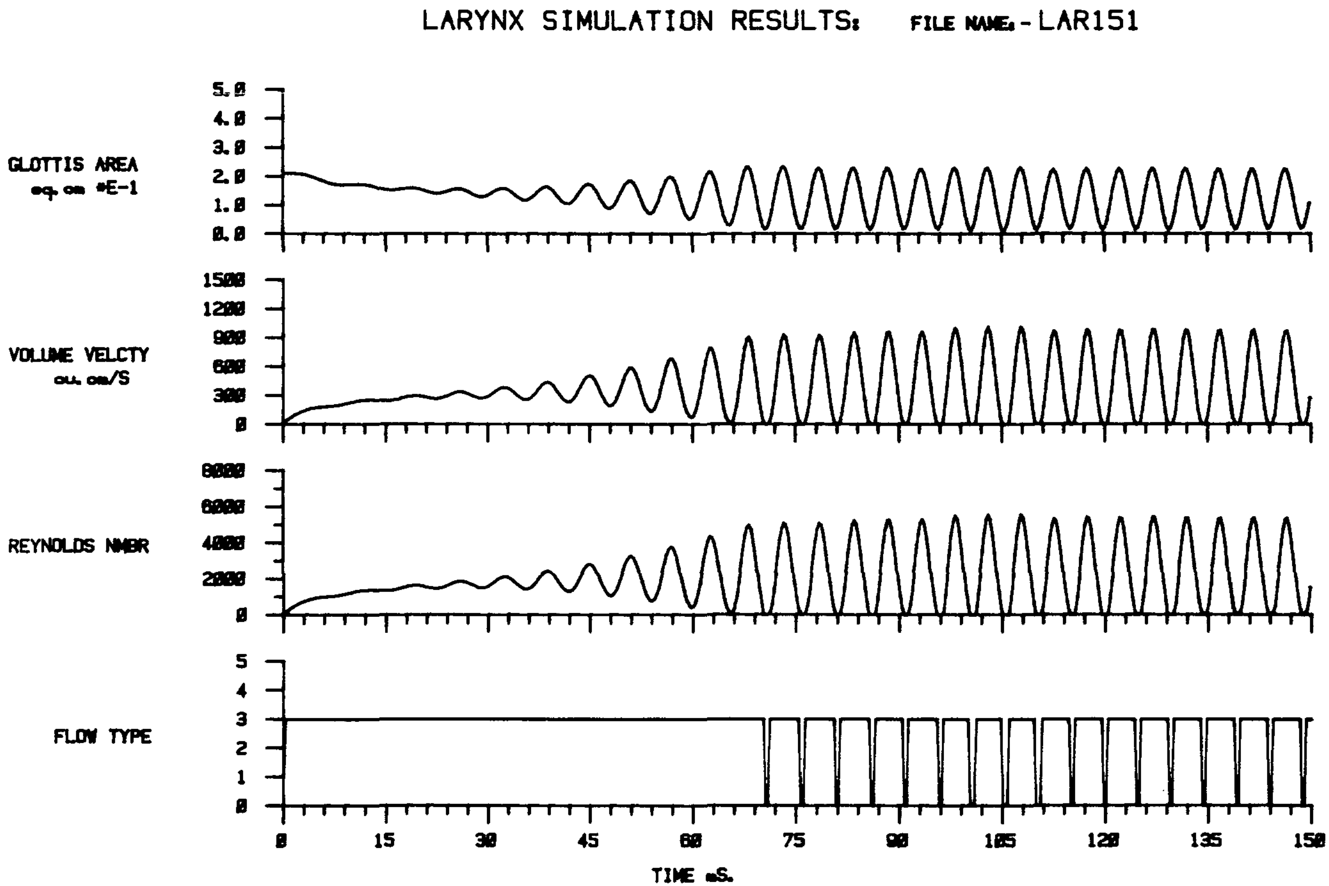

Figure 3 - The light voice (falsetto) simulation

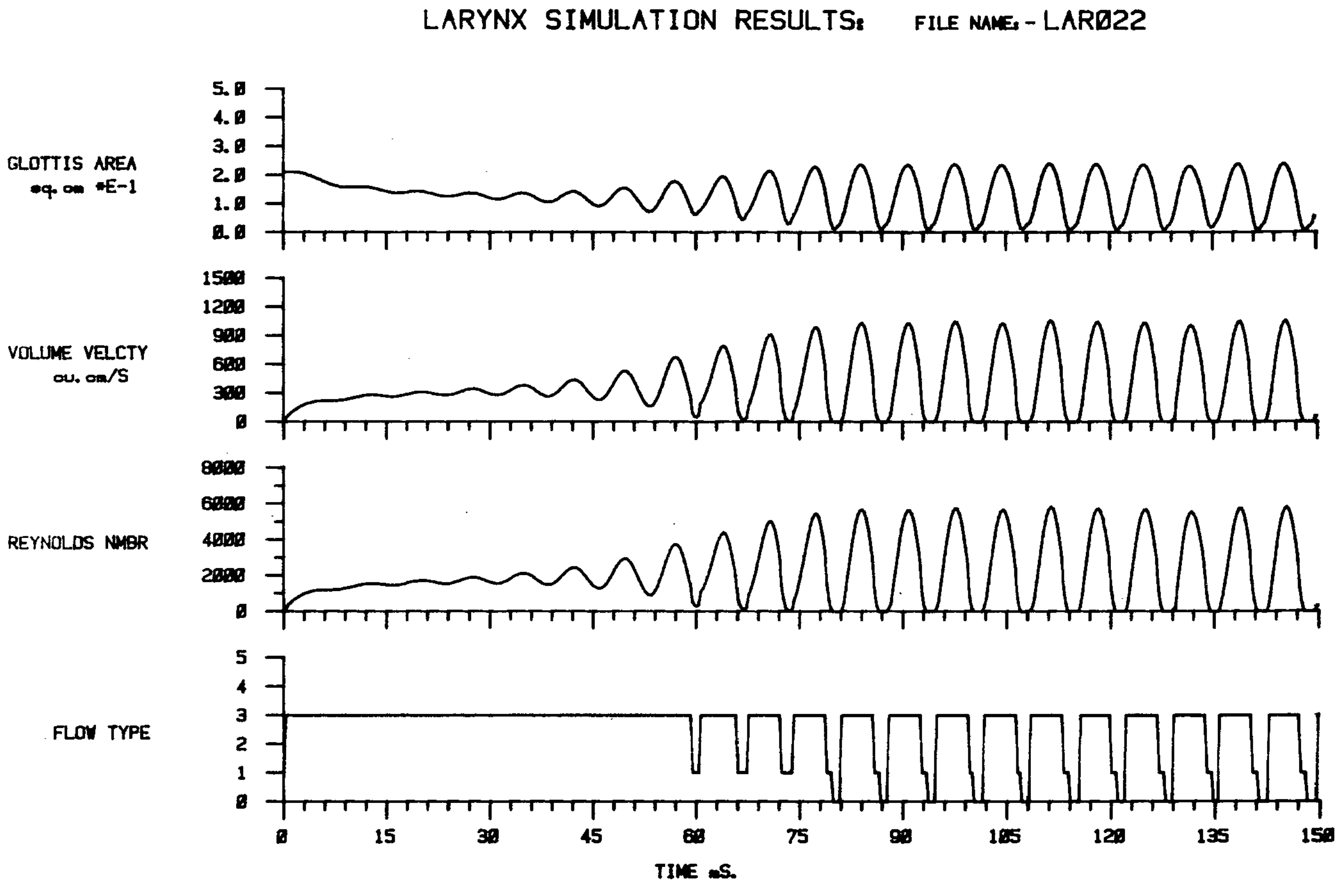

Figure 4 - The adduction of the vocal folds at the onset of phonation as shown in the 'in vivo' experiments of Dejonckere and Lebacq.

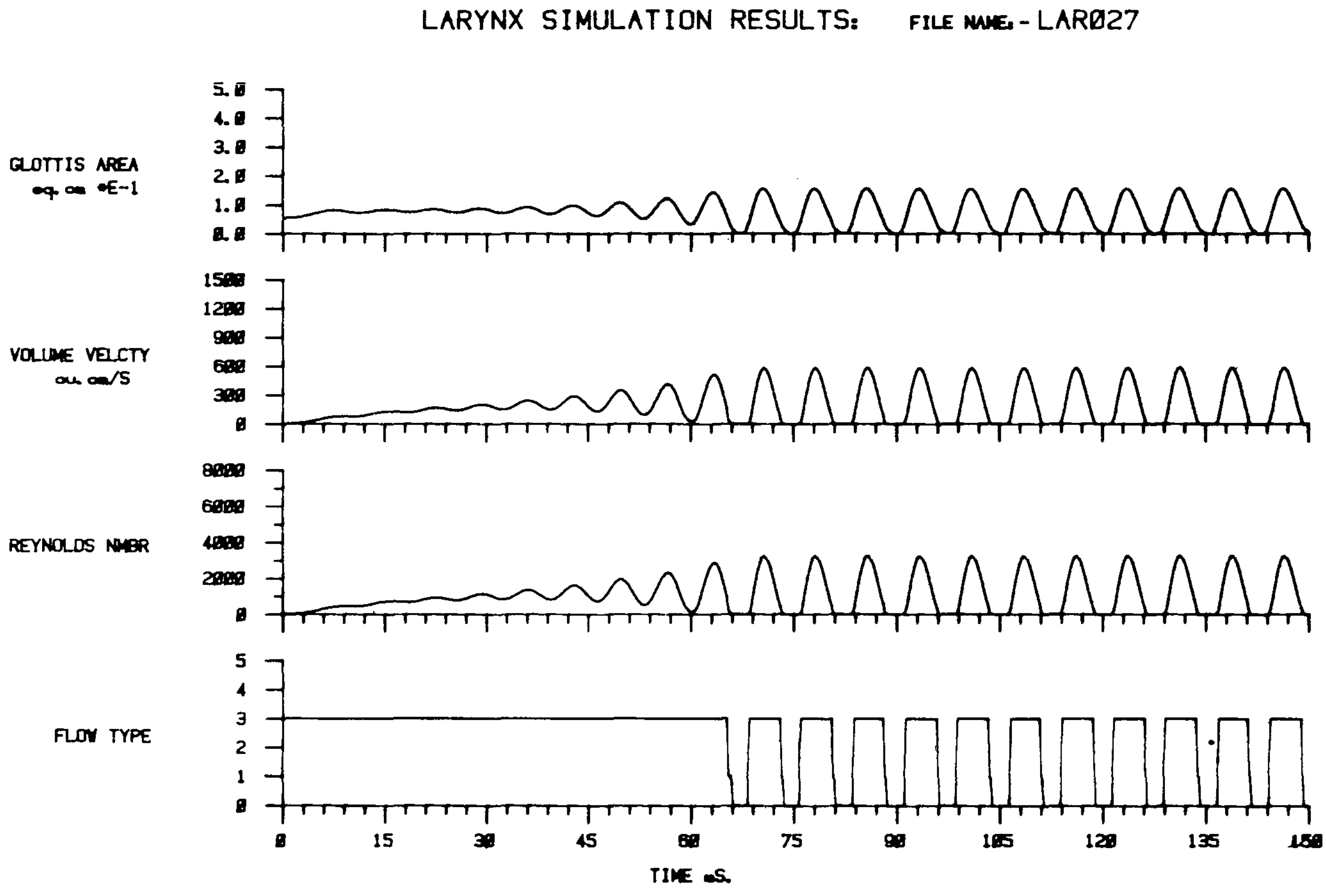

Figure 5 - The abduction of the vocal folds at the onset of phonation.