Effects of an induced asymmetry on the flow through the glottis in relation to voice pathology.

Coriandre Vilain, Xavier Pelorson and Dorothée Thomas
Institut de la Communication Parlée, ESA Q5009 CNRS, INPG, Université Stendhal,
46 avenue F. Viallet, F-38031 Grenoble Cedex 01, France
E-mail: `cvilain@icp.inpg.fr`

Abstract and Introduction:

From the point of view of physical modelling, phonation is the result of a complex interaction between the airflow through the glottis and the mechanical reaction of the vocal folds. During "normal" phonation, one can reasonably assume that both vocal folds are oscillating in phase and thus that glottis forms a symmetrical channel for the airflow. A number of voice pathologies, such as unilateral laryngeal paralyses, or involving tumours or lesions, are however clearly causing an asymmetrical motion of the vocal folds. All existing studies about such pathologies (e.g. [1],[2]) are focussing on the asymmetrical mechanical aspect of the problem whereas the possible effects of this asymmetry on the flow is completely overlooked.

In an attempt to evaluate the relevance of such an assumption, we present in this paper a systematic study of the symmetry of the flow through symmetrical and asymmetrical replicas of the vocal folds.

1. Experimental set-up.

Our mechanical model of the vocal tract, depicted in Figure 1, is made of a cylindrical pipe supplied with dry air, and ended by a replica of the vocal folds (upscaled by a factor of 3) supporting pressure transducers (Kulite XLS dynamic pressure transducers).

In this paper, we only consider divergent profiles of vocal folds with different divergence angles (0°, 10°, 20°, 40°) and different asymmetry degrees. As a measure for the asymmetry of the flow we will use the pressures P_1 and P_2 measured at both sides of the glottal channel as shown in figure 2.
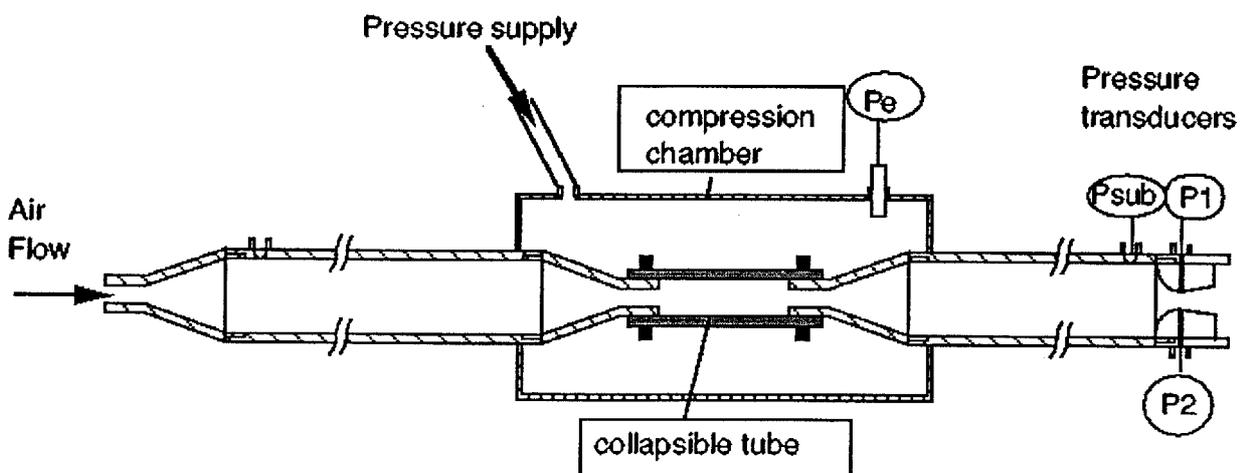

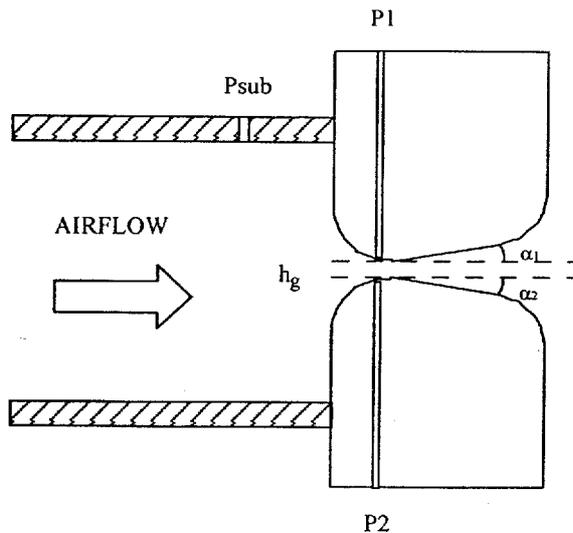Figure 1 : Sketch of the experimental set-up

Figure 2 : View of the glottal model.

The airflow coming through the vocal folds model can be controlled in different ways to produce:

- Steady flow
- Transient flow obtained by opening a gate valve
- Pulsated flow obtained with a Collapsible Tube. (as shown in Figure 1)

2. Asymmetry of the flow in a symmetrical glottis.

Although this might look surprising, an asymmetrical flow can occur even within a perfectly symmetrical channel. Physically this phenomenon is related with the Coanda effect (the tendency for a flow to follow the wall of a channel). This effect has been already discussed formally by Teager et al. ([3]) and observed experimentally using (steady) numerical simulations of the glottal flow by Alipour ([4]).

An example of such Coanda effect is presented in figure 3 for an impulsively started flow. As the subglottal pressure, P_{sub}, increases one can initially observe in Figure 3 a simultaneous decrease of both P_1 and P_2. After about 15 ms, P_1 and P_2 are clearly different due to the establishment of an asymmetrical flow (the Coand effect). This example shows thus that the Coanda effect

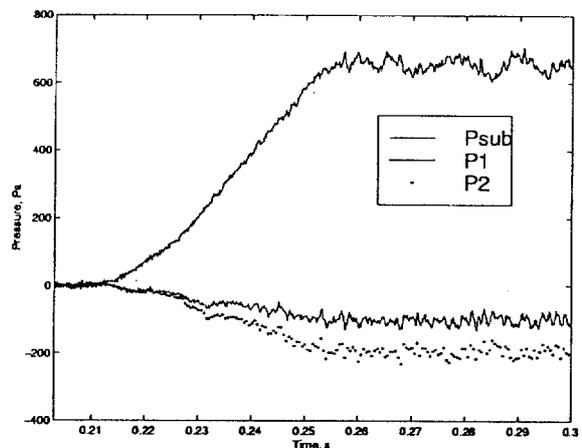needs time to establish and is thus typical of steady flows.

Figure 3 : Transient pressure measurements on a symmetrical (10°,10°) diverging channel.

As a measure for the Coanda effect to occur we define t_{coanda} as the time needed after the opening of the valve to observe a measurable difference between the pressure at both sides of the vocal fold replica: P_1 and P_2. Figures 4 and 5 present two examples of results for different angles of divergence as a function of the Reynolds number:

$$Re = \frac{\sqrt{\frac{2.P_{sub}}{\rho}}.h_g}{\nu}$$

where ρ is the constant air density coefficient and ν the kinematic viscosity coefficient
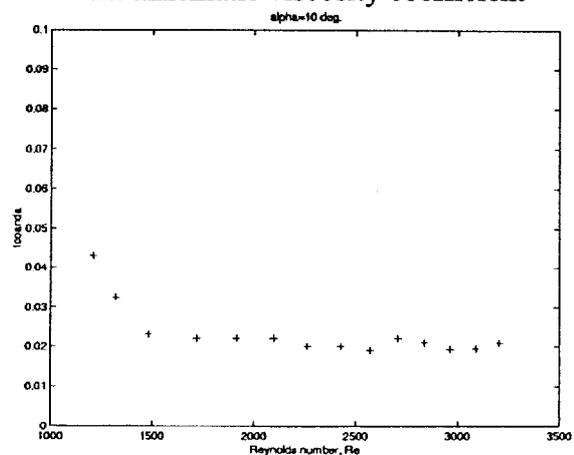

Figure 4 : Time needed for the Coanda effect to appear, t_{coanda}, as a function of the mean flow Reynolds number, Re. Results for $(\alpha_1,\alpha_2) = (10°, 10°)$.
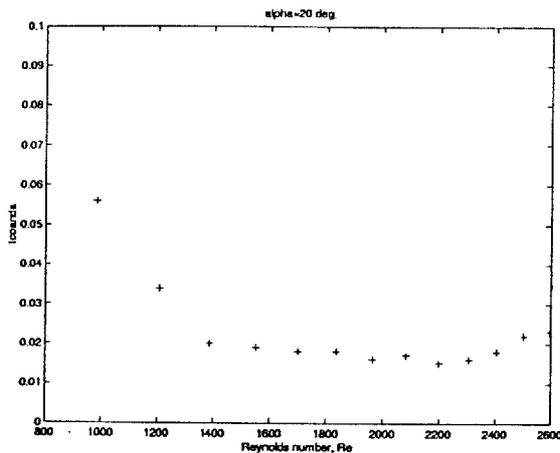
Figure 5 : Time needed for the Coanda effect to appear, t_{coanda}, as a function of the mean flow Reynolds number, Re. Results for $(\alpha_1,\alpha_2) = (20°, 20°)$.

As can be seen from these examples, the time needed for the Coanda effect to occur was always found to be larger that a typical glottal period (of order of 10 ms). Further, it must be noted that the Coanda effect is only expected to occur for a diverging glottis configuration. During phonation such a configuration would occur during the closure of the vocal folds and thus only during a minute part of the glottal period (a few milliseconds). The Coanda effect seems thus not relevant for phonation studies. This conclusion is further confirmed by the measurements obtained using a pulsated flow. As can be seen in Figure 6 and as expected the Coanda effect can hardly be observed in this condition.
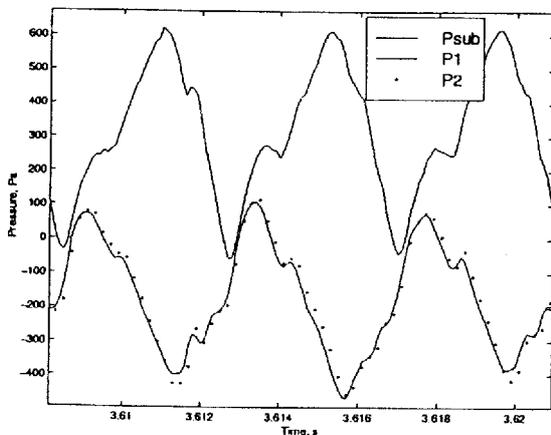

Figure 6 : Unsteady pressure measurements on a (10°,10°) diverging channel.

3. Asymmetry of the flow in an asymmetrical glottis.

We now present results obtained with an asymmetrical glottal configuration ($\alpha_1 \neq \alpha_2$). To avoid possible additional asymmetries due a Coanda effect only measurements obtained using the collapsible tube (pulsated flow) are considered.

3.1. Results for slight to moderate diverging angles.

In this section only asymmetrical configurations with $\alpha_1+\alpha_2$ lower than 30° are considered. A typical example of results is presented in figure 7 for a (0°, 20°) configuration.

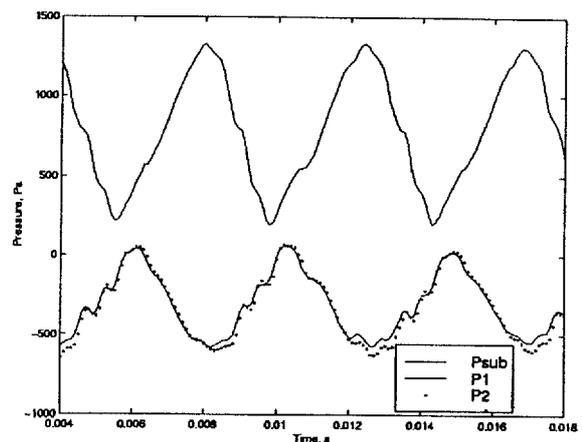**Figure 7** : Example of measured pressures for a (0°, 20°) configuration.

Overall results are summarised in Table I. As a measure for the effects of asymmetries the relative difference between P_1 and P_2:

$$\left| \frac{P_1 - P_2}{P_1} \right| \text{ is taken into account.}$$

Configuration	Mean difference
(0°, 10°)	10 %
(0°, 20°)	10 %
(10°, 20°)	20 %

Table I : Mean relative difference between P_1 and P_2 for different (α_1, α_2) configurations.

As can be seen from table I, the observed differences, although measurable, are quite limited.

3.2. Results for higher angles.

As an extension to the above results we now present results obtained with wider overall angles of divergence. Figure 8 presents an example of results for a (20°, 40°) configuration.
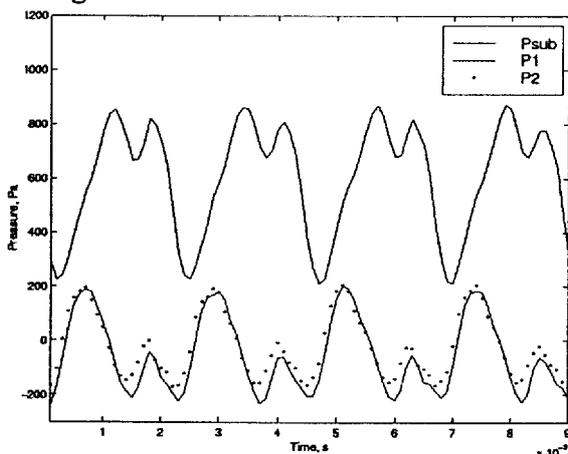

Figure 8 : Example of measured pressures for a (20°, 40°) configuration.

Overall results for the different configurations studied are summarised in Table II.

Configuration	Mean difference
(0°, 40°)	50 %
(20°, 40°)	80 %
(10°, 40°)	70 %

Table II : Mean relative difference between P_1 and P_2 for different (α_1, α_2) configurations.

Discussion and conclusions.

The goal of this research was to justify, or not, the implicit assumption of a symmetrical flow during an asymmetrical motion of the vocal folds. It was shown that the Coanda effect appears indeed meaningless because it is characteristic of steady flows. Under unsteady pulsated flow conditions it was found that this effect did not have time to occur indeed. Concerning the geometrically

induced asymmetries, our first results lead to a less drastic conclusion. Concerning small diverging configurations it was found that asymmetries were only responsible for a limited pressure perturbation (only a few percent of the subglottal pressure). Although measurable it must be noted that these differences are within the degree of accuracy one can expect for the most precise flow theories used in speech modelling. Therefore we can conclude that in this case, neglecting asymmetry effects appears to be a reasonable assumption.

When larger diverging angles are involved, effects on the flow become important and even considerable. It is however not obvious that such configurations have a pathological meaning.

References:

[1]: Ishizaka, K. and Isshiki N. (1974) "Computer simulation of pathological vocal-cord vibration", J. Acoust. Soc. Am., 60, 1193-1198.

[2]: Steinecke I, Herzel H. (1994) "Bifurcations in an asymmetric vocal fold model", NCVS Status and Progress Report, 6, 19-31.

[3] : Teager H. M., Teager S. M. (1985) "Active fluid dynamics voice production or there is a unicorn in the garden", in Vocal Folds Physiology (Titze & Scherer Eds.) 358-386.

[4] : Alipour, F. (1993). "Airflow Instabilities and Asymmetries in the Narrow Glottal Constriction". paper present at 3rd Seminar on Speech Production, New Haven.