Glottal Jet Instabilities: Mechanisms, Control and Effect on Primary Acoustics in Voice Generation

Christoph Brücker[1], Michael Triep, Willy Mattheus, Rüdiger Schwarze
[1]*Institut für Mechanik und Fluiddynamik, TU Bergakademie Freiberg, 09596 Freiberg,*
E-Mail: bruecker@imfd.tu-freiberg.de

Introduction

The opening and closing of the glottal orifice is responsible for a complex flow field in the vocal tract as well as for the primary acoustic sources in voice generation.

This paper presents the flow results of an experimental and numerical study on the jet formation, evolution and disintegration in a glottal cam model. The modelled glottal orifices take into account the three-dimensional (3-D) contouring of natural glottal gaps. Instabilities of the jet head and the jet edge are analyzed with regard to the involved mechanisms. The incidence of coherent structures at the jet edge and in part their coalescence is detected. Observed phenomena such as a length-wise vena contracta and axis-switching are supposed to play an important role in controlling the glottal jet. A redistribution of the vortex structures has shown to lead to a different character of the flow-induced primary acoustic sources in the region downstream the glottis. This trend is assumed to be enhanced when the glottal jet also interacts with the vocal tract walls or other supraglottal structures.

Glottal Cam Model

The vocal folds model used in the present study has been extensively described in [1]. The model is used in experiments as well as in numerical simulations in a complementary way. The main physiological parameters of real vocal folds kinematics during phonation are replicated. The characteristic movement of the walls in the glottal region, e.g. the continuous deformation of the mucosal layer (Figure 1) is achieved by means of two 3D contoured cams, which rotate in counter-direction.

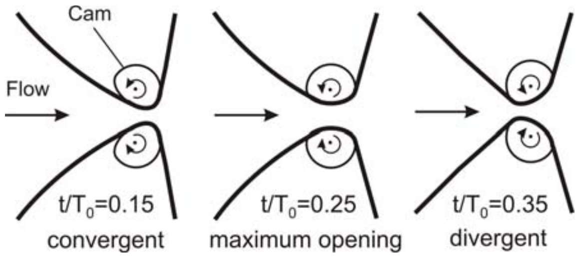

Figure 1: Characteristic open instants of the modelled glottal cycle. Instant $t/T_0=0$ marks the opening instant.

Similarity of geometry, flow dynamics and fluid dynamic forces is kept in the model. Due to very low Mach numbers, the flow is treated as incompressible. In the experiments a pressure head across the glottal orifice is imposed. The resulting glottal volume waveform is given as input for the inlet boundary condition in the numerical model.

Glottal Jet Flow

Temporal and Spatial Character of the Jet

Complex 3D unsteady vortex structures are generated downstream of the glottal orifice as cause of the evolution and break-down of the glottal jet. The jet instabilities are characteristic to the instant they occur in the cycle and are linked to the time-varying 3D contour of the glottal orifice. A Kelvin-Helmholtz instability is responsible for the roll-up of the jet edge. This region of concentrated vorticity is shown in Figure 2. 3D flow phenomena as a lengthwise vena contracta and axis switching occur after the instant of maximum opening when the orifice is already closing.

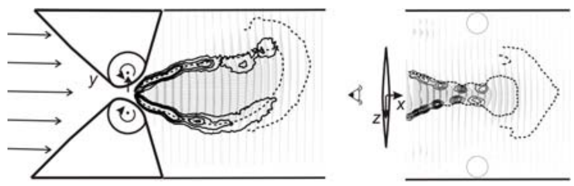

Figure 2: Particle-Image Velocimetry (PIV) measurements of the glottal jet for transglottal pressure of Δp=6 cmH_2O in the midcoronal (left) and midsagittal plane (right) at instant $t/T_0=0.35$. The low-speed jet front (3.5 m/s) and the high-speed jet core (10 m/s) are highlighted.

In order to have a look at the near field character of the jet and study the most energetic large coherent vortex structures, mid-plane visualizations by means of Laser-Induced Fluorescence (LIF) have been carried out and are shown in Figure 4 for the case without and Figure 6 for the case with a second constriction in the channel downstream of the glottal orifice. Three instants in the divergent closing phase are shown, where the vortex topology is most complex and unstable.

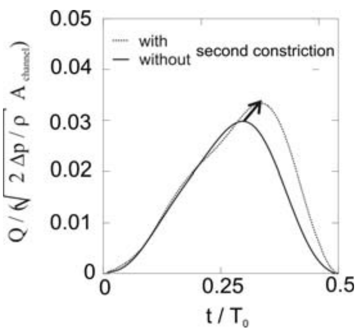

Figure 3: Measured glottal waveforms *Q* for transglottal pressure of Δp=6 cmH_2O. The volume flow *Q(t)* is made dimensionless with the loss-free steady flow rate at the given pressure head.

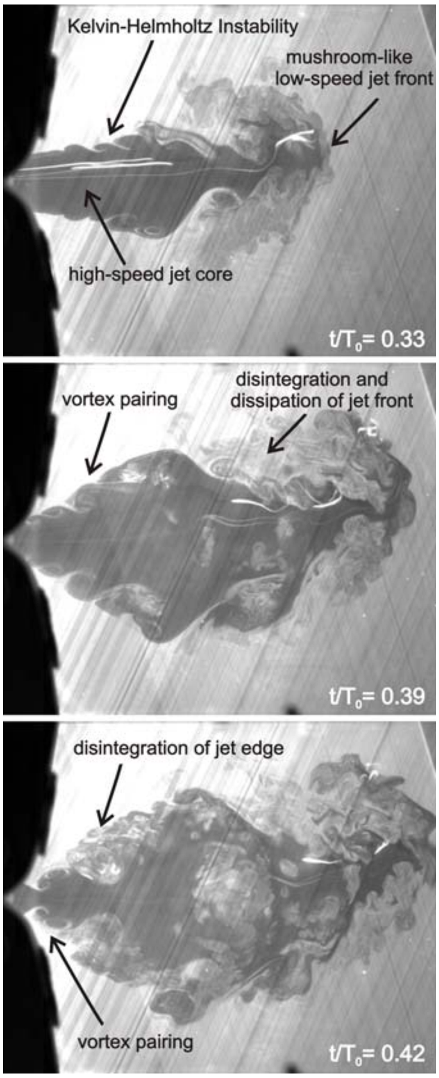

Figure 4: LIF visualization of midcoronal plane for transglottal pressure of Δp=6 cmH_2O (without VFs).

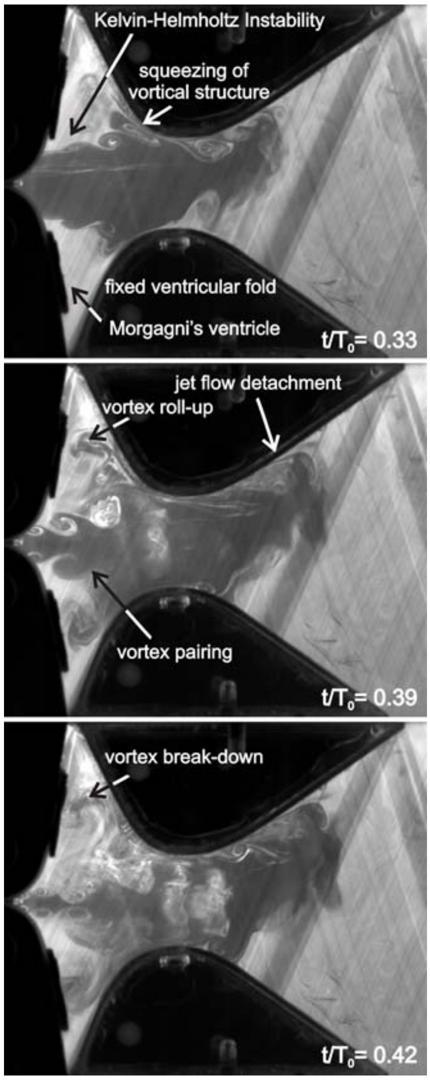

Figure 6: LIF visualization of midcoronal plane for transglottal pressure of Δp=6 cmH_2O (with VFs).

The pulsating jet leads to a characteristic glottal volume waveform, which differs for the case without and with the second constriction downstream of the glottis (Figure 3). The higher net flux and retarding of the maximum volume flow for the latter case is supposed to be due to the complex interaction of the jet edge with the ventricular folds, which act like a second diffuser for pressure recovery. The starting and development of the glottal jet flow is also controlled by any asymmetry of the folds movement (Figure 5).

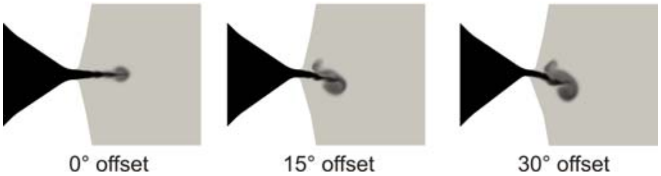

Figure 5: Starting glottal jet flow for different asymmetric cases at instant t/T_0=0.14 and a transglottal pressure of Δp=6 cmH_2O from numerical simulation.

Conclusions and Outlook

Keeping the modulation frequency of the pulsating jet constant, any specific nearby supraglottal structure as e.g. ventricular folds will change the higher harmonics and the noise due to interaction of the jet with these walls. In addition, the second constriction even has an effect on the glottal waveform profile which determines the monopole source term. These observations underscore the highly sensitive feedback from jet instabilities and vorticity/ wall interactionon on the dynamics and acoustics of the pulsating jet generated downstream of the glottis. From the full flow field obtained from numerical CFD-simulations with an implicit LES approach, the distribution of the primary acoustic sources is exactly determined as input for a hybrid CAA approach (Lighthill analogy) to determine the acoustic source spectrum near the glottis.

Acknowledgements

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References

[1] Triep, M; Brücker, Ch.: Three-dimensional nature of the glottal jet. J. Acoust. Soc. Am. 127 (2010)