3aSC5

Experimental observations on the influence of supraglottal flow structures on phonation

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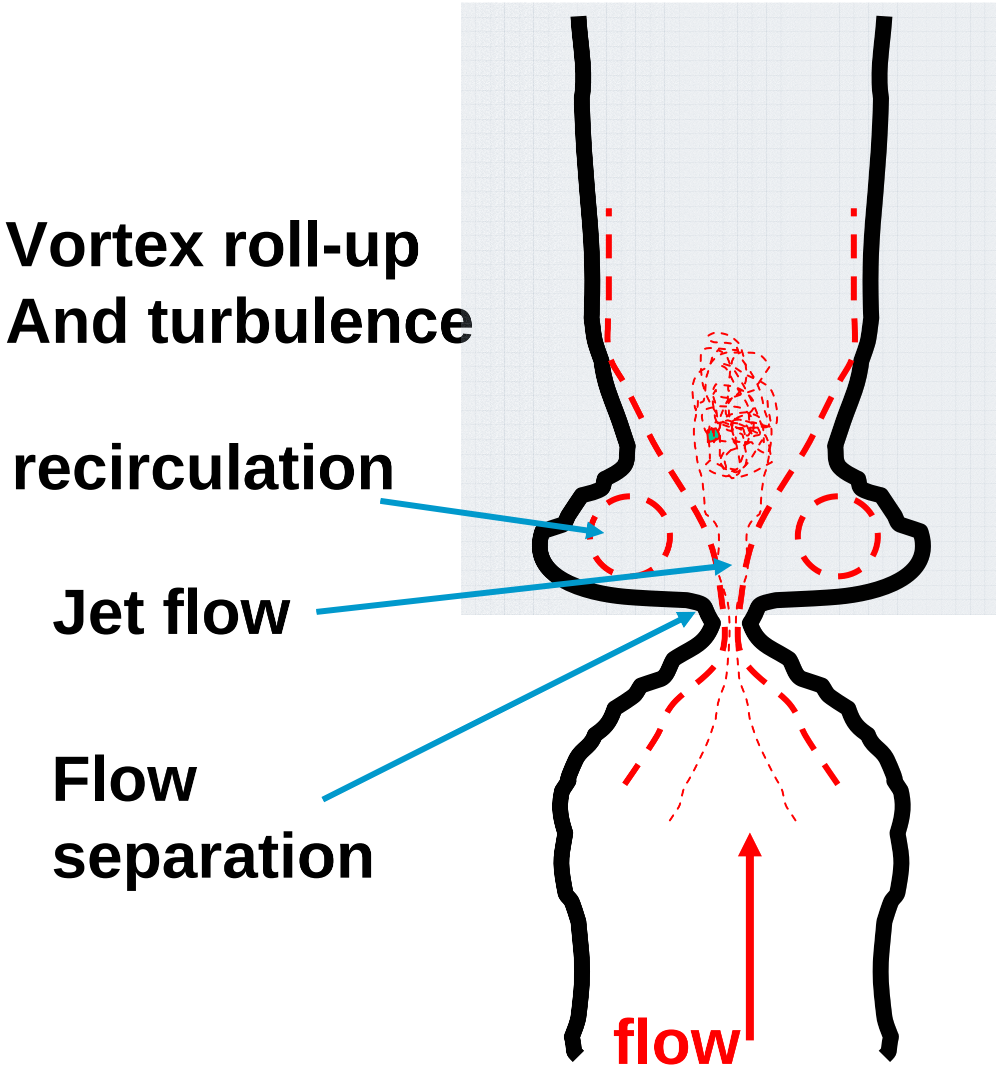
October 28, 2009
158th ASA Meeting, San Antonio, Texas

Acknowledgment:
Research supported by NIH R01-DC009229

Supraglottal Flow Field



- Once separated from the vocal folds, the flow is susceptible to many flow instabilities.
- Highly three-dimensional and complex:
  - Jet attachment to one vocal fold wall (asymmetric jet or the Coanda effect)
  - Recirculation
  - Jet instabilities (vortex shedding and roll-up)
  - Jet reattachment
  - Turbulence

Motivation

- What roles do they play in phonation?

- Practical concern
  - It is computationally expensive to accurately resolve these complex flow features
  - How large an error if some or all of these phenomena are neglected in models?
  - Identify the appropriate degree of complexity for the glottal flow model

Studies on the Supraglottal Flow

- Experiments:
  - Teager and Teager, 1985
  - Pelorson et al., 1994
  - Shinwari et al., 2003
  - Zhang et al., 2004
  - Triep et al., 2005
  - Erath and Plesniak 2006
  - Neubauer et al., 2007
  - Drechsel and Thomson, 2008
- Numerical simulations:
  - Zhao et al., 2002
  - Hofmans et al., 2003
  - Suh and Frankel, 2007
  - Tao et al., 2007
  - Sciamarella and Le Quere, 2008
  - Luo et al. (2009)

Previous Studies

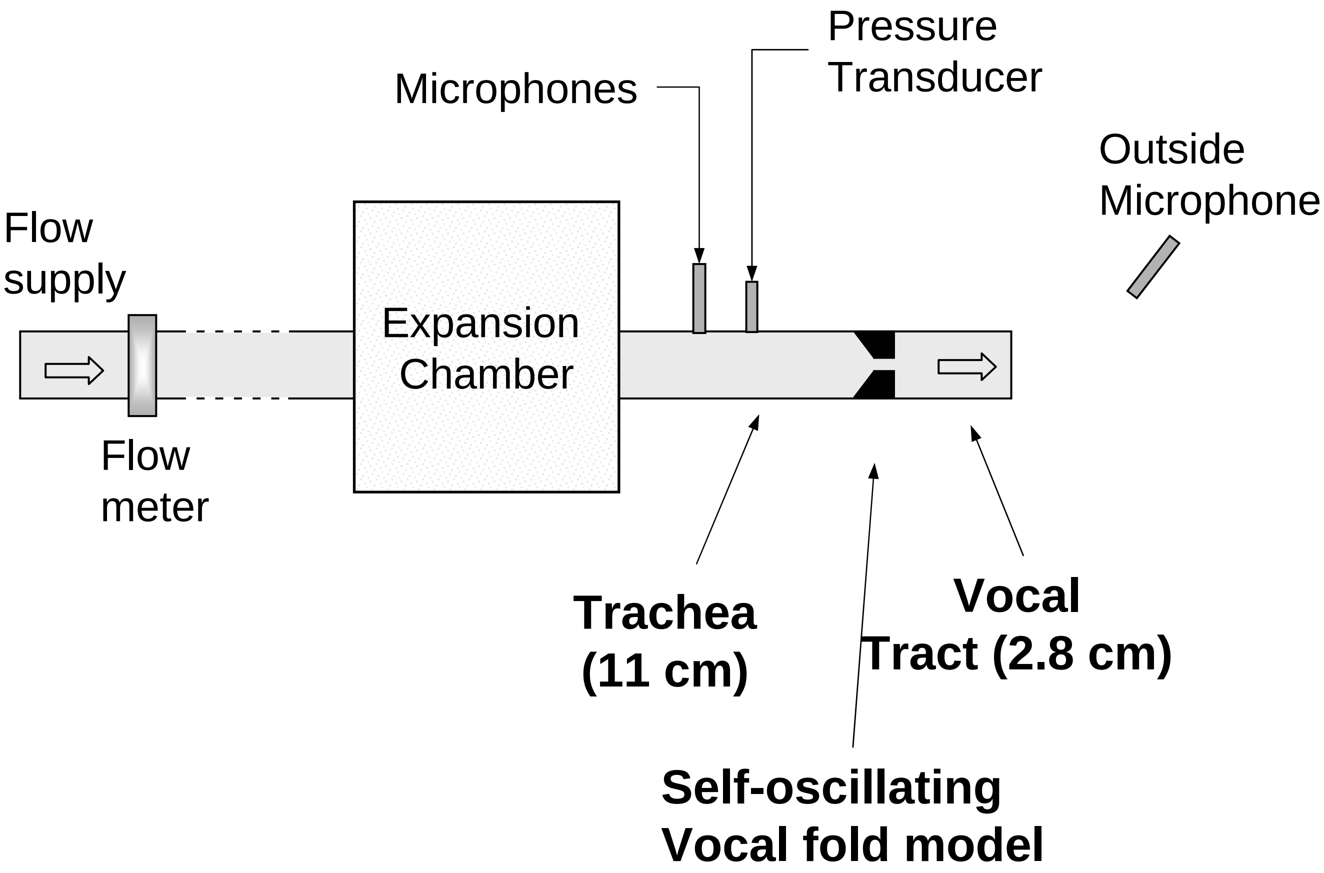
- Most of these studies focused on describing the supraglottal flow field, instead of on its relevance to phonation
- Pelorson et al., 1994; Hofmans et al., 2003
  - Numerical & experimental studies with a static vocal fold model
  - Coanda effect (jet attachment to one glottal wall) and transition to turbulence may not occur in phonation, therefore not relevant.
- Sciamarella and Le Quere, 2008
  - Numerical study; imposed vocal fold motion
  - Unsteadiness (jet instabilities, vortex roll-up) of the fully developed flow past the constriction does not significantly affect the velocity or pressure profiles within the constriction.
- The influence on phonation in a self-oscillating model is essentially unexplored

Objective

- Quantify the effects of supraglottal flow structures on phonation

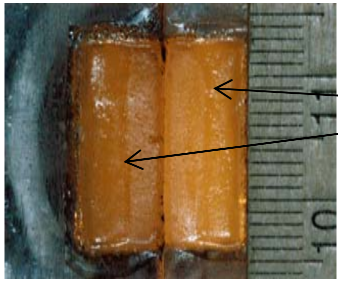
- Approach:
  - Use self-oscillating models
  - Disturb the supraglottal flow field
    - Disturb the flow by traversing a cylinder in the left-right and flow direction
- Variables of interest
  - Sound amplitude and spectral shape
  - Phonation frequency
  - Vibration pattern

Experimental Setup



Two-layer self-oscillating rubber vocal fold model

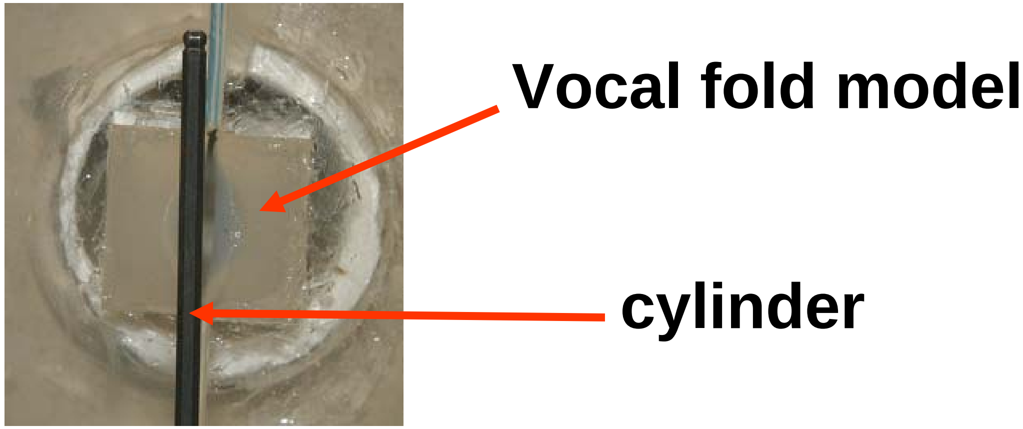
Top View



Side View

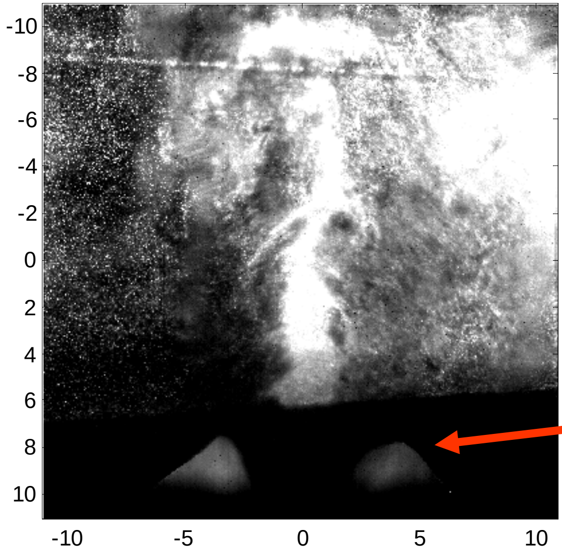
Disturbing the supraglottal flow

- A cylinder aligned in the anterior-posterior direction was traversed in both the left-right and flow directions.
  - The cylinder is long enough to cover the entire anterior-posterior span of the vocal fold model



with vocal tract (2.54 × 2.54 cm and 2.5 cm long)

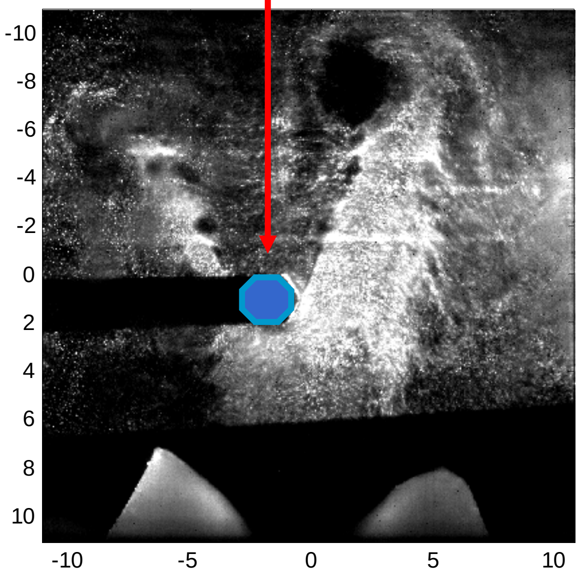
Without cylinder



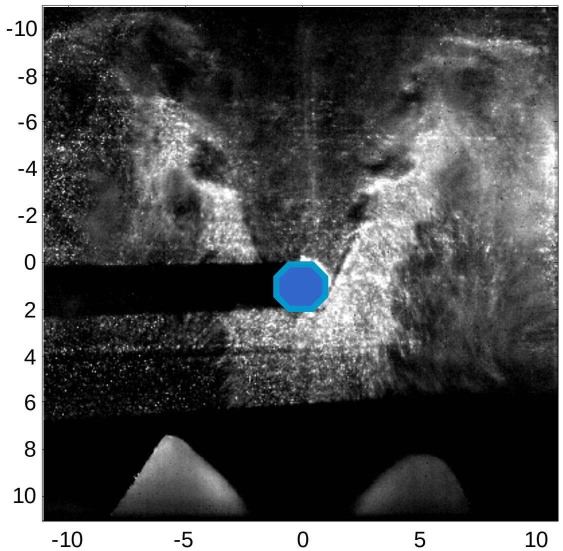
Flow

Vocal folds

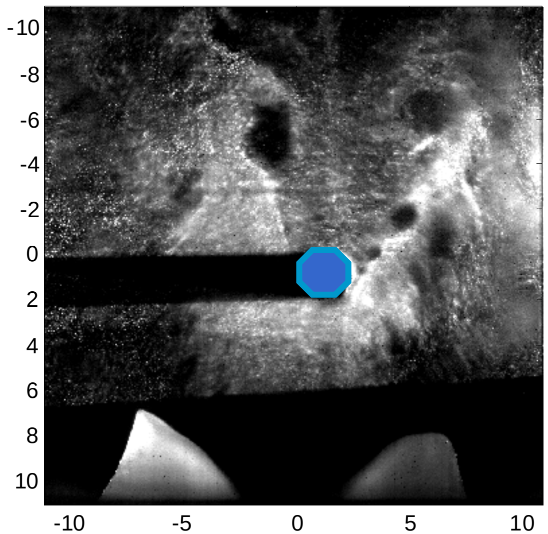
Cylinder on the left



Cylinder at the center



Cylinder on the right

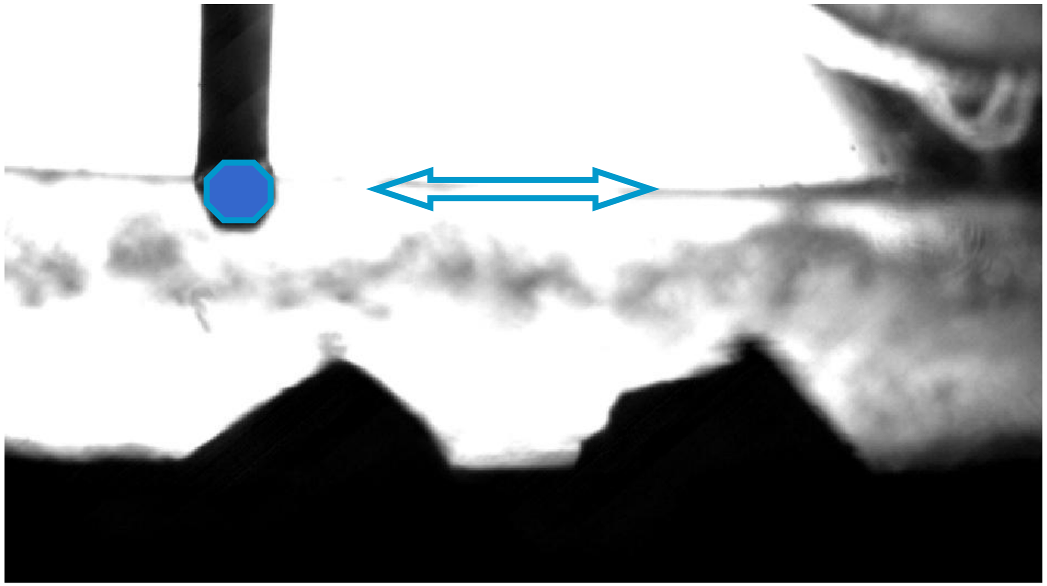


Observation on the disturbed supraglottal flow

- Jet flow was either deflected to one side or split into two jets

- Implications (as the cylinder moved close to the glottal exit):
  - Jet flow may be forced to attach to one vocal fold, leading to asymmetric flow separation within the glottis
  - Asymmetric recirculation between the sides of the jet flow, leading to different pressures on the superior surfaces of the two folds.
  - Pressure recovery associated with jet diffusion/expansion may be significantly altered.
  - Vortex patterns and evolution significantly altered.

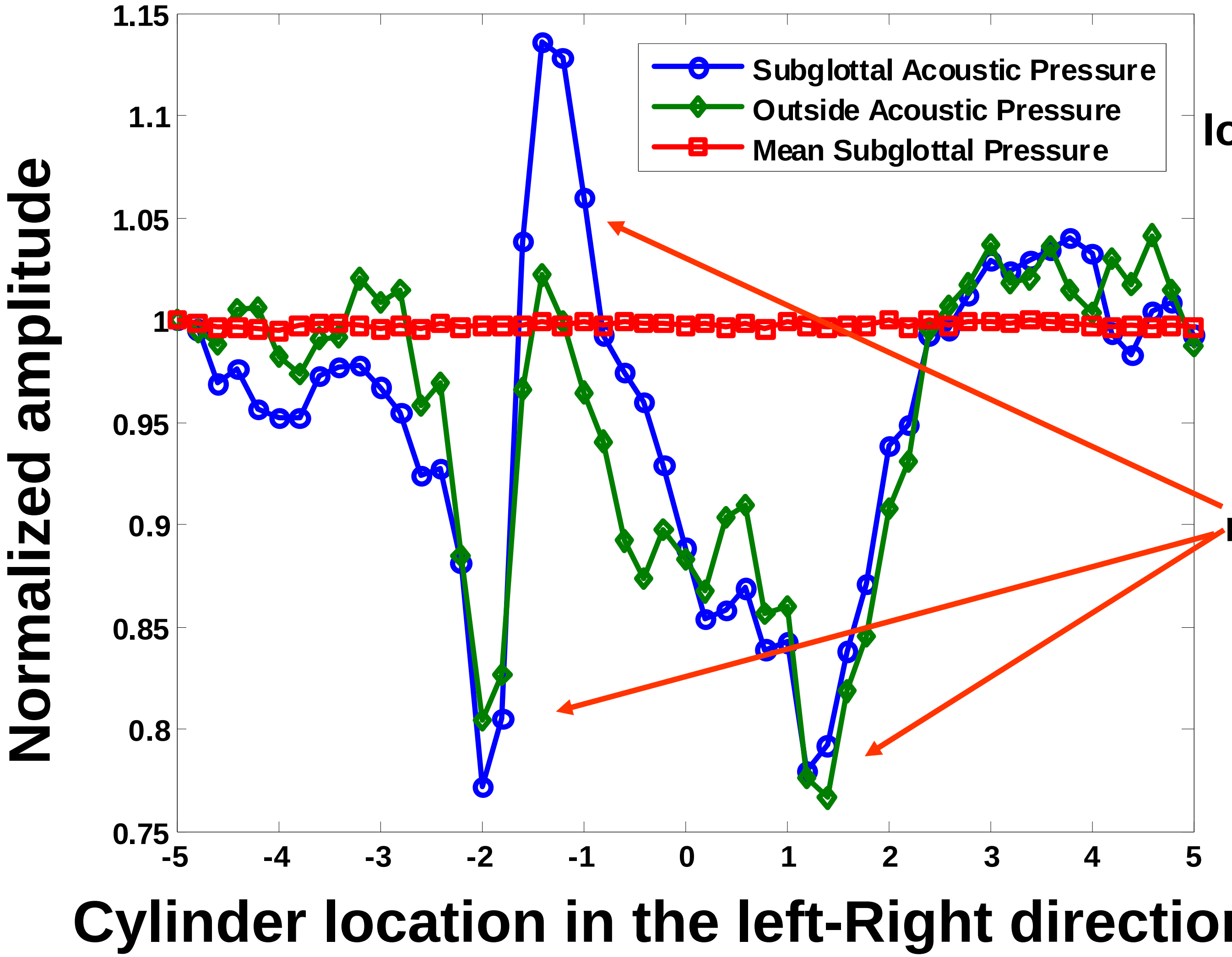
Cylinder traversed in the left-right direction



Cylinder axial location at
x= 1.5 mm

Max(D)= 3 mm

Effect on Phonation: Acoustic pressure amplitude

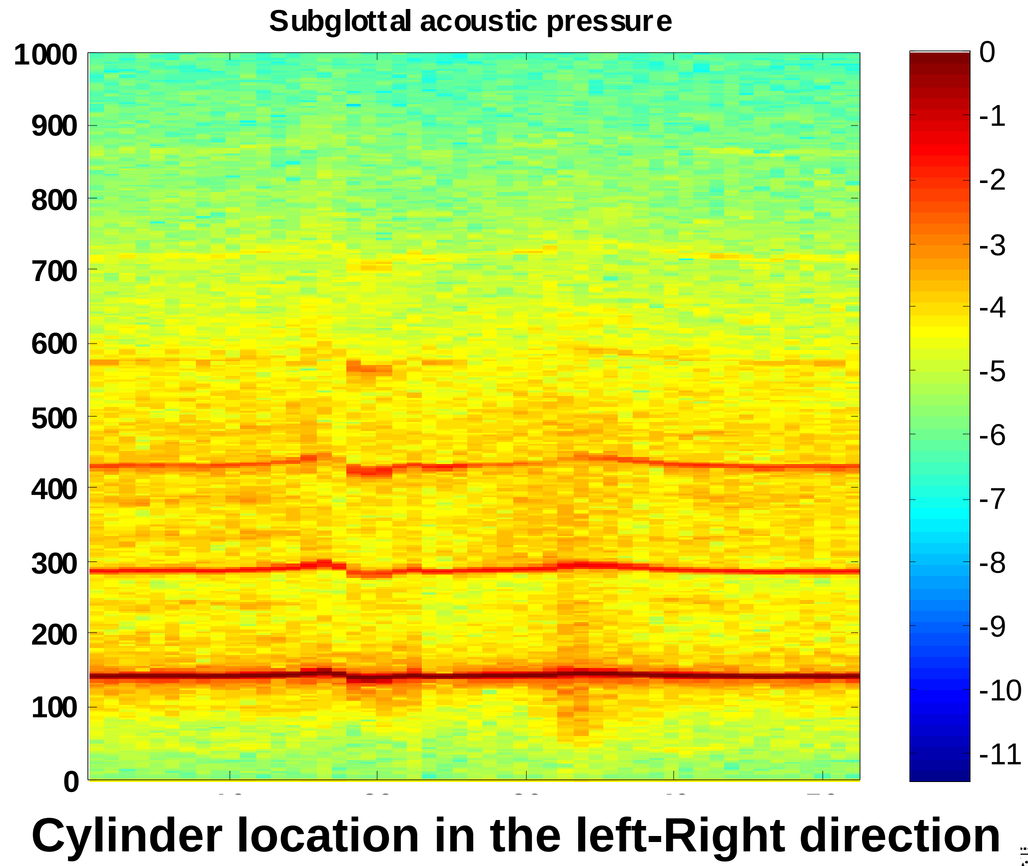


Outside acoustic pressure low-pass filtered with a cut-off of 2.5 kHz

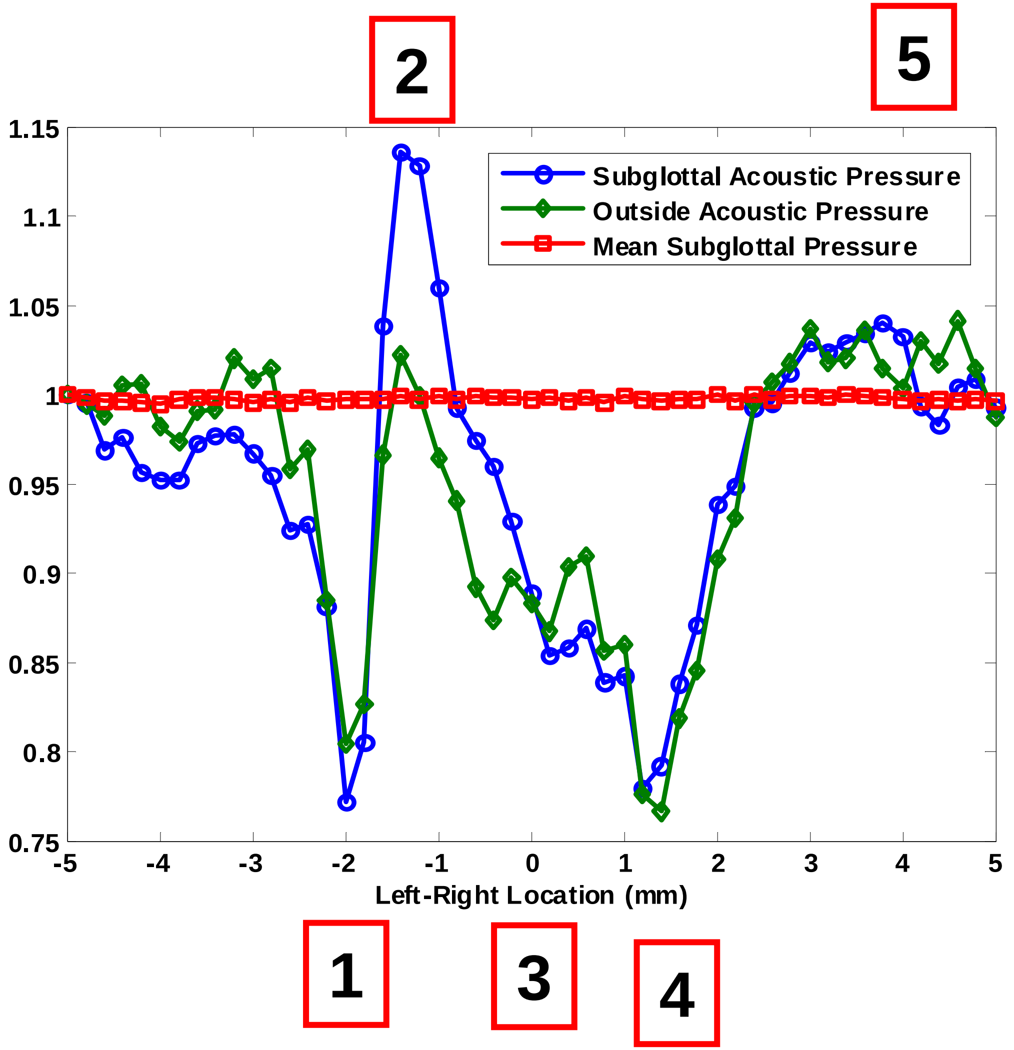
Except for three regions, the change is within 5%

Effect on Phonation frequency F_0

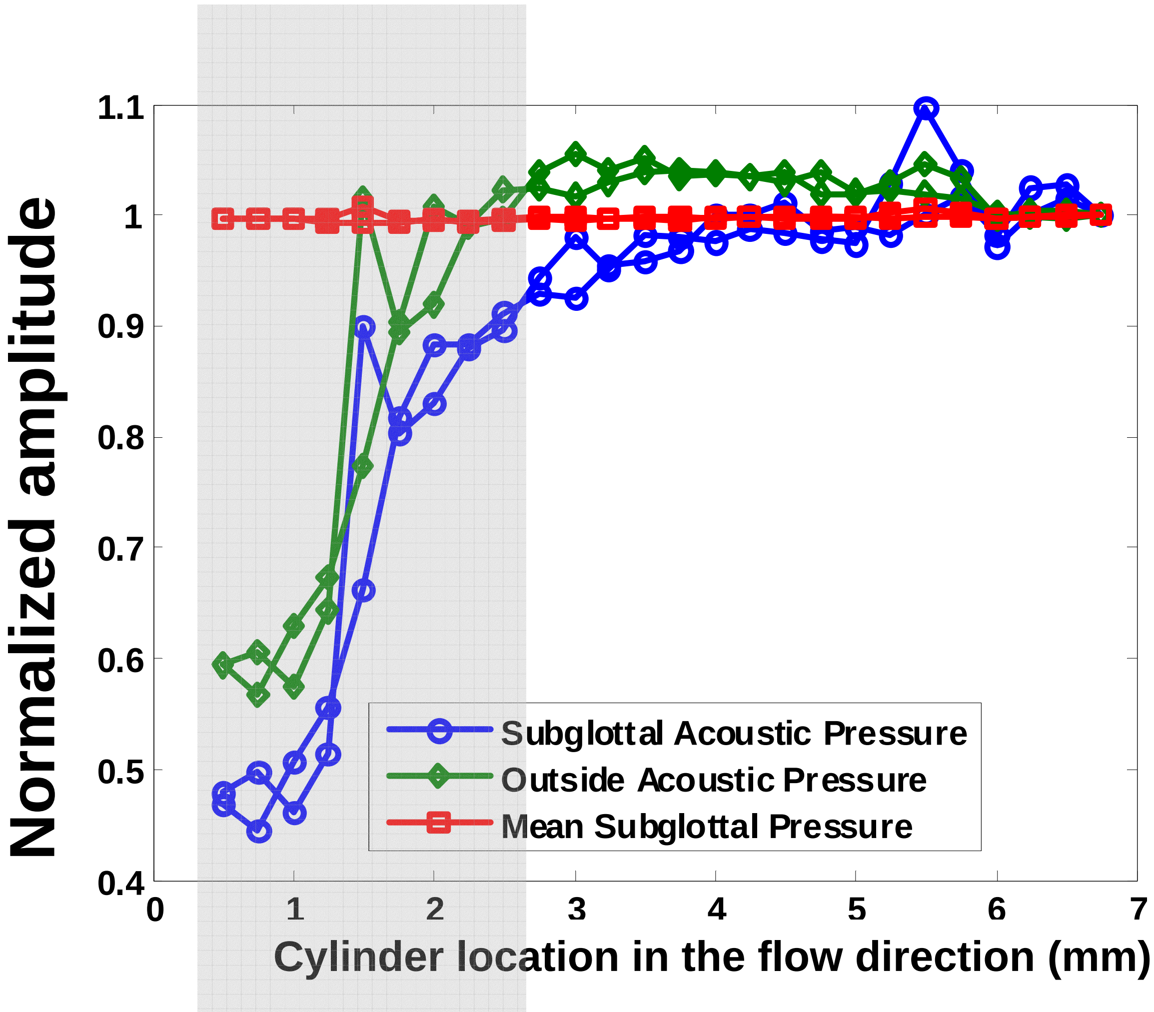
- Phonation frequency F_0 stayed at 144 Hz for most locations as the cylinder was traversed in the left-right direction.
- In regions of significant amplitude change, F0 changed between 142 and 148 Hz.
- No significant changes in spectral shape



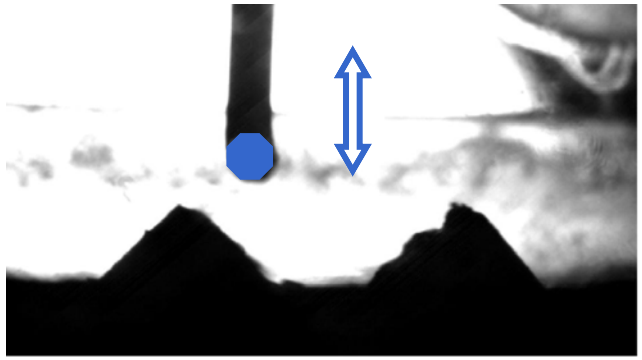
Cylinder traversed in the flow direction



Location 1: on the left
-- Acoustic pressure amplitude



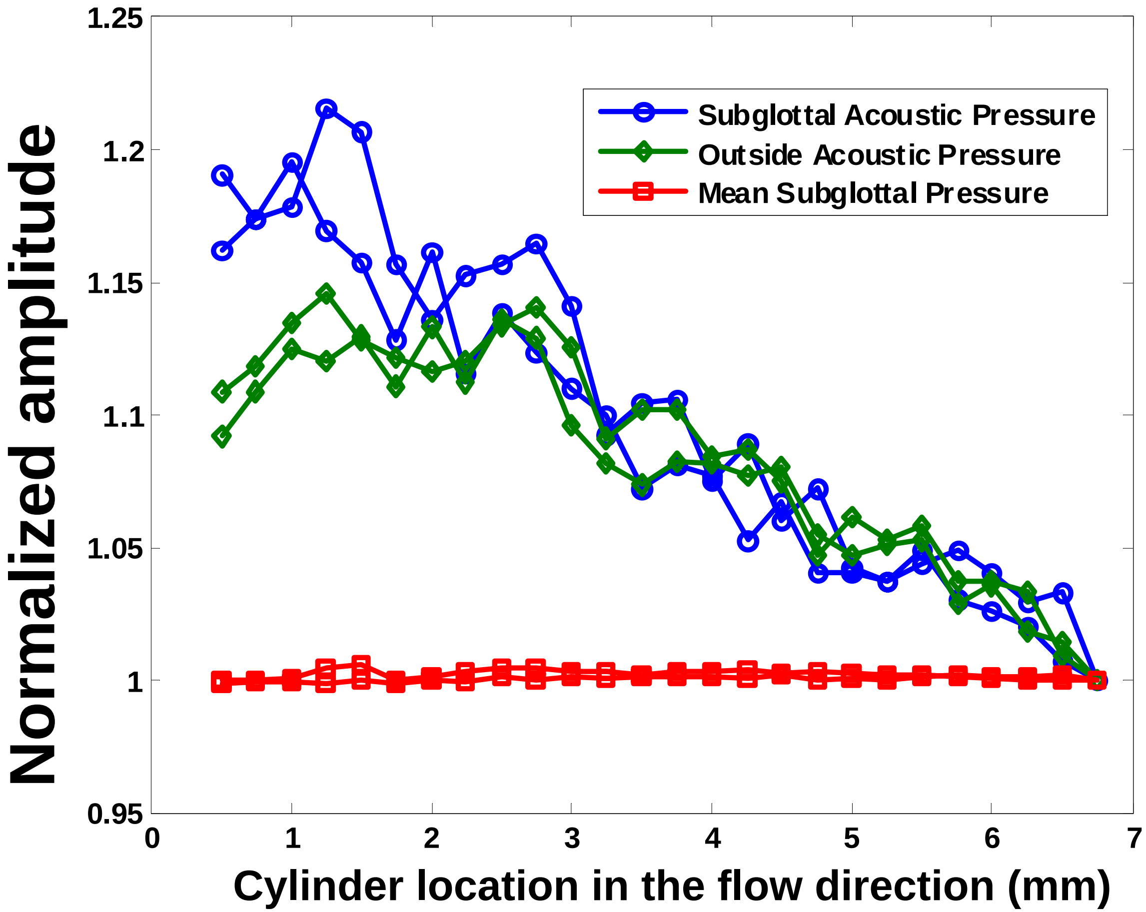
Influence range

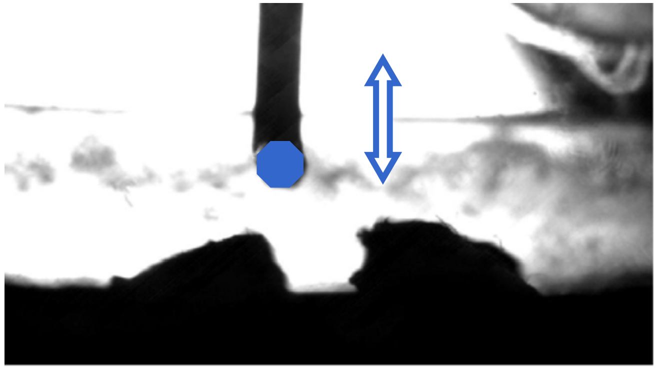


Maximum amplitude change is 55%

Influence range: <2.5 mm

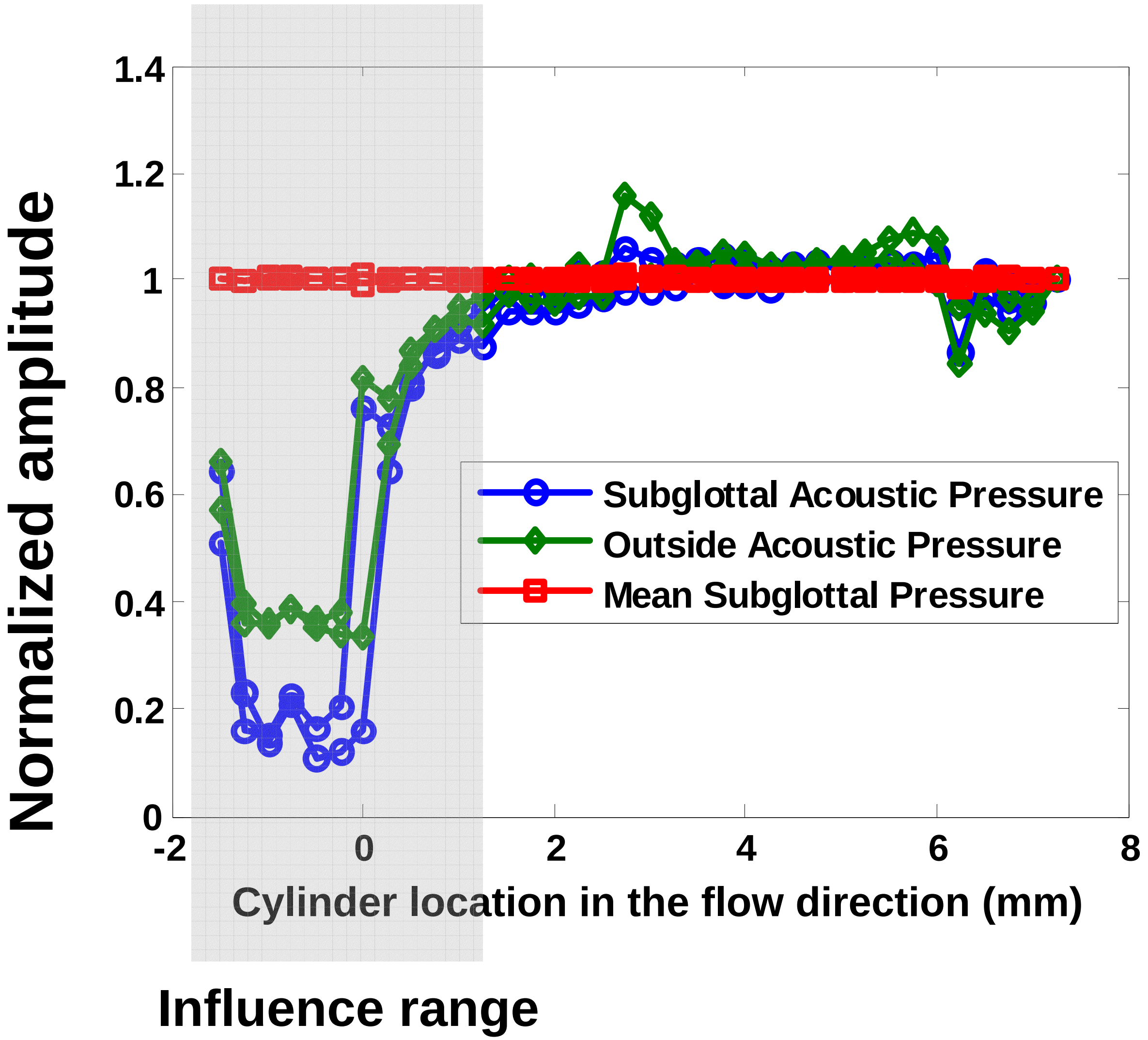
Location 2: slightly left
-- Acoustic pressure amplitude

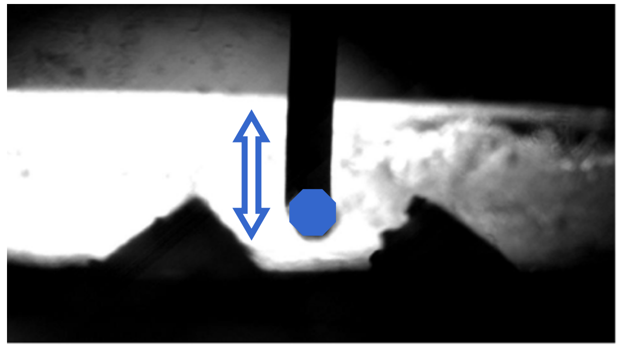




Maximum amplitude change is 20%

Location 3: glottal center
-- Acoustic pressure amplitude

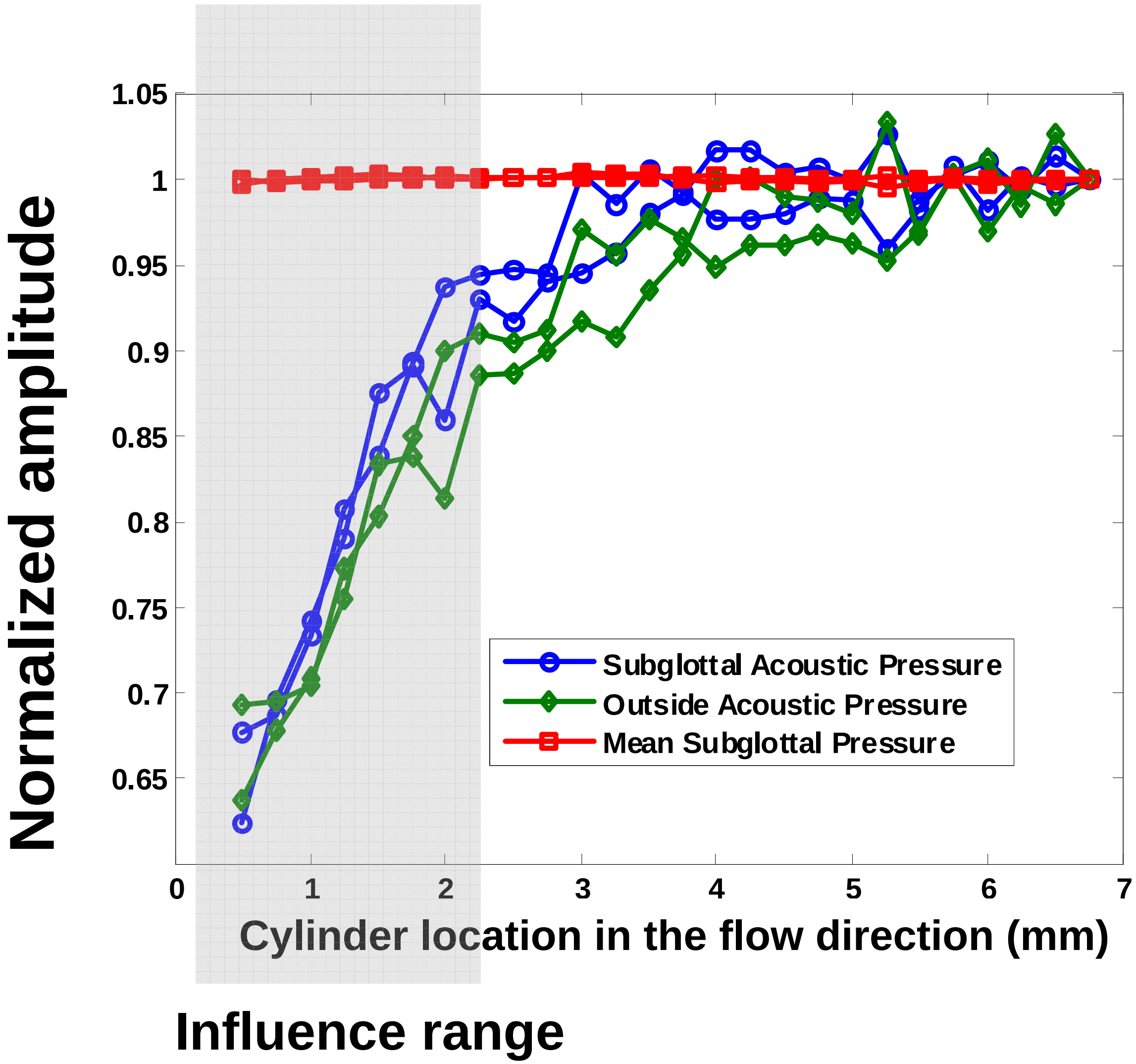


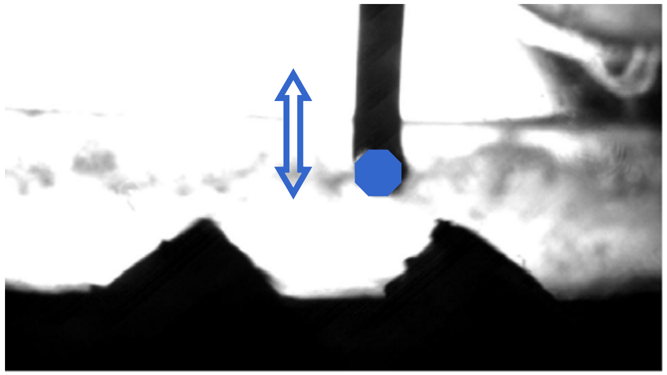


Maximum amplitude change is 80%

Influence range: <1 mm

Location 4: slight right
-- Acoustic pressure amplitude

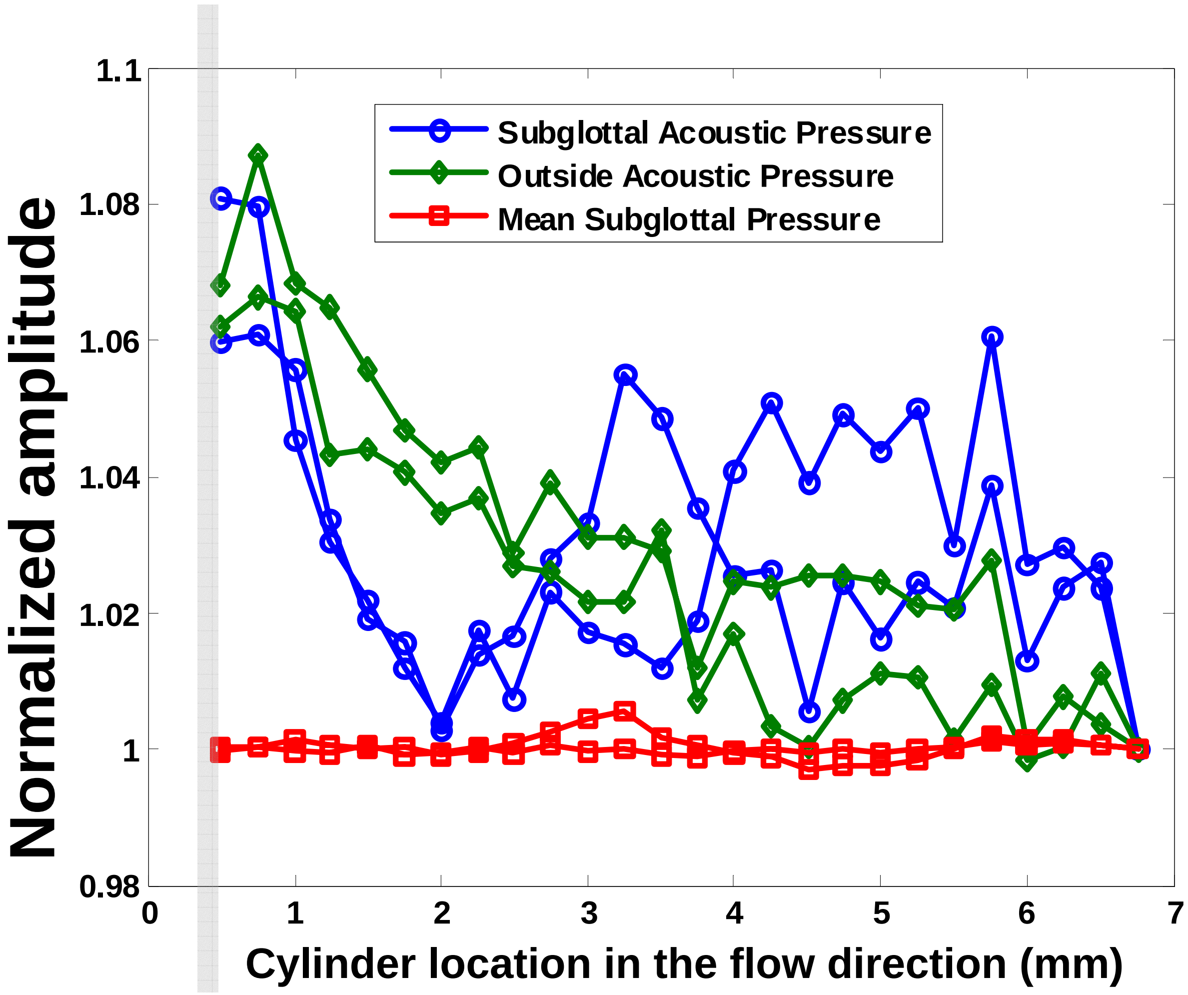




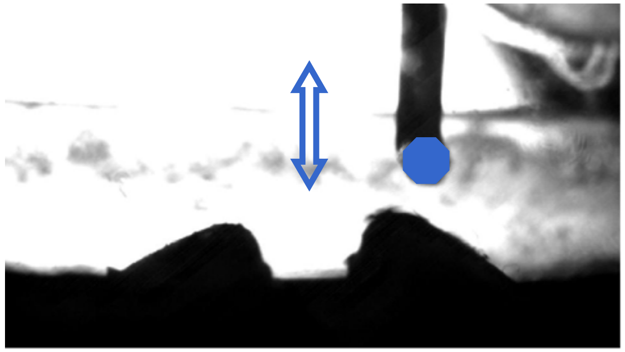
Maximum amplitude change is 35%

Influence range: <2.2 mm

Location 5: on the right
-- Acoustic pressure amplitude



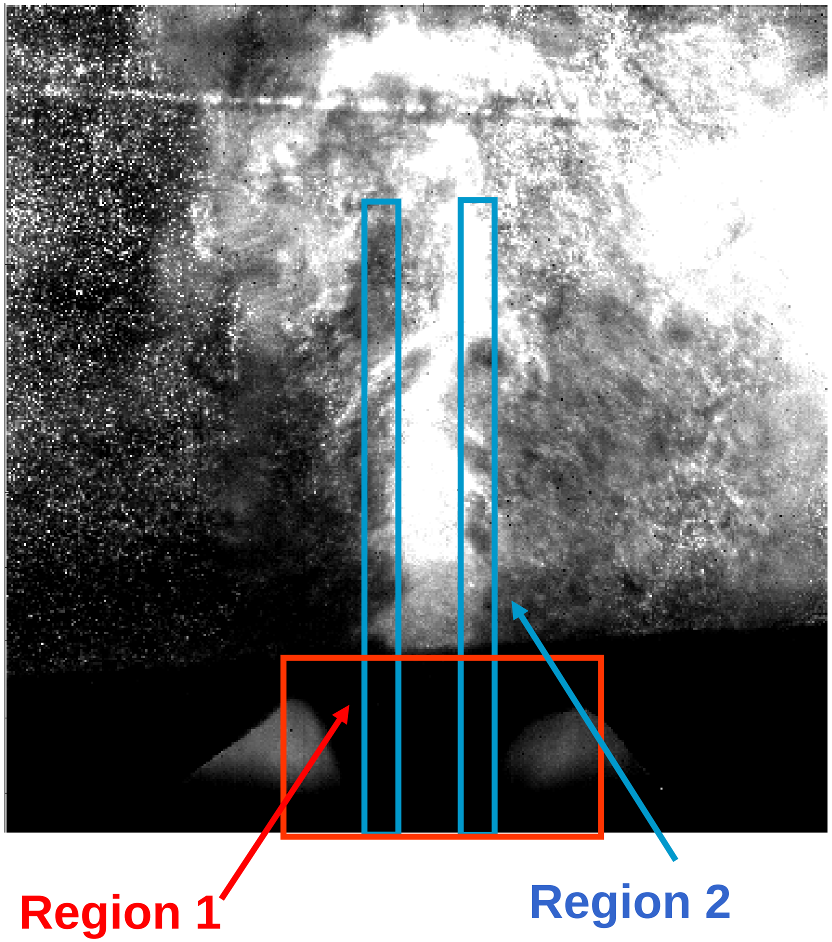
Influence range



Maximum amplitude change is 9%

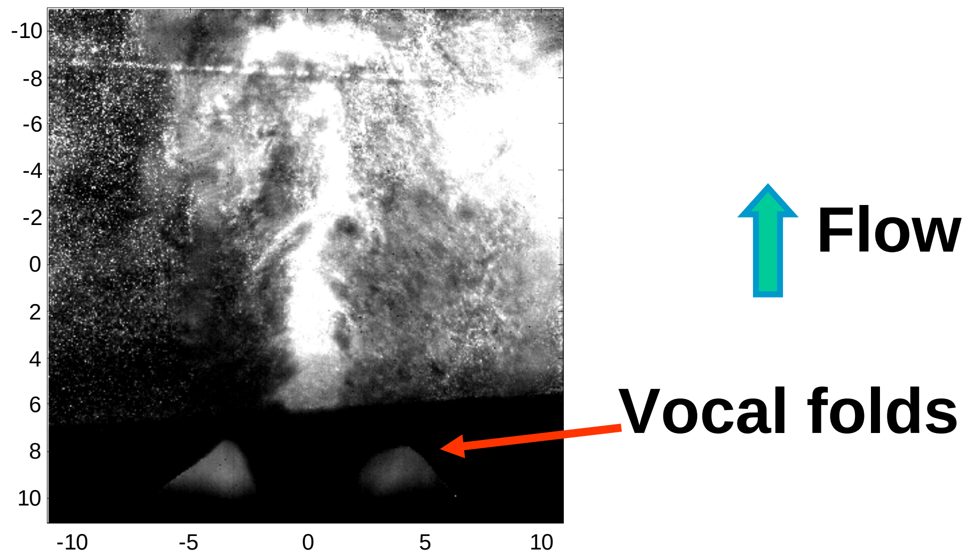
Influence range: <0.5 mm

Regions of significance

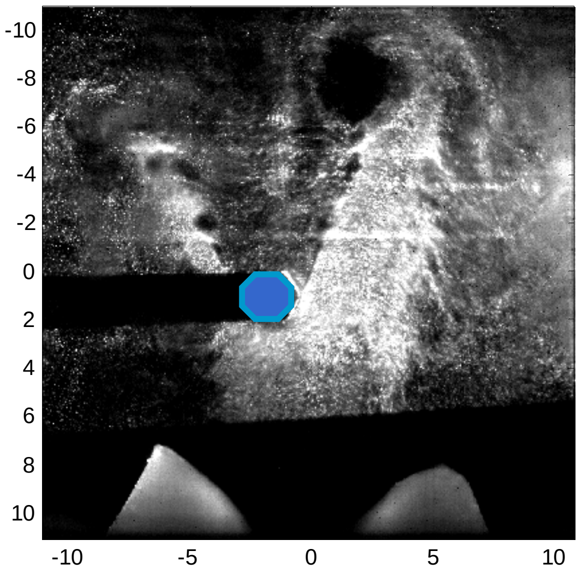


- Region 1: Inside or immediately downstream (< 2mm) of the glottal exit
  - Increased back pressure, and therefore decreased transglottal pressure, due to flow blockage by the cylinder
- Region 2: roughly corresponds to the shear layers of the jet
  - Presence of cylinder caused the jet to change direction
  - Changed the flow separation pattern within the glottis
- Otherwise, phonation is not sensitive to changes in the supraglottal flow.

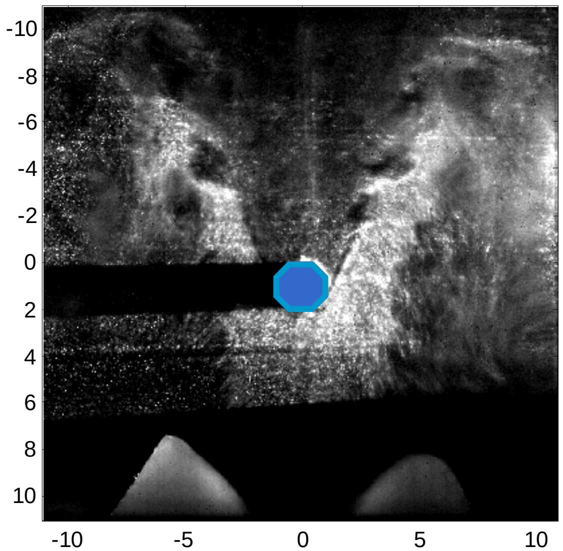
Without cylinder



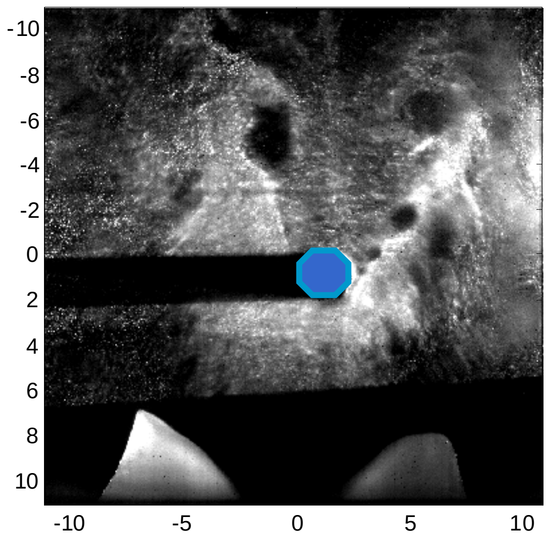
Cylinder on the left



Cylinder at the center



Cylinder on the right



Summary

- Large influence on phonation was observed when the supraglottal flow was disturbed either in the shear layers or a region within 2 mm above the model.
  – Changed back pressure due to flow blockage by the cylinder
  – Changed the flow separation pattern within the glottis
- Otherwise, phonation was not sensitive to changes in the supraglottal flow field,
  – Jet instabilities, recirculation, and transition to turbulence have negligible influence on the low-frequency component of phonation (onset, F0, sound amplitude)

Further Question

- Is there any mechanism in human phonation that can cause significant changes in jet axis, without using a cylinder?
  - Jet instabilities and turbulence have limited influence on jet axis.
  - False vocal folds?
  - Asymmetries in the vocal folds may significantly affect jet axis movement