Abstract

The myoelastic-aerodynamic (MEAD) mechanism, which has been known to drive vocalization in humans, was recently observed in birds across a wide range of taxa. By using high-speed camera to film sound production in syrinx, Elemans et al. (2015) discovered that birds also have mucosal wave propagation on the surface of the lateral vibratory mass (LVM). This new discovery makes birds a very useful model for studying the fundamental mechanism of human vocalization and neural mechanism underlying vocal learning shared by some birds and human. The objective of the current study is to: (a) develop a first-principle based, fluid-structure interaction computational model which can accurately reproduce the vibration of LVM and sound signal; (b) validate the model against experimental measurements on rock pigeon models through subject-specific simulations; (c) use the model to study the detailed vibration pattern as well as the coupling mechanism of airflow and vibration in syrinx.

Keywords: Bird vocalization, fluid-structure interaction

1. Introduction

Recently, by using high-speed camera to film sound production in syrinx, Elemans et al. (2015) discovered that a wide range of taxa of birds might rely on the myoelastic-aerodynamic (MEAD) theory to produce sustained vibrations of their lateral vibration mass (LVM) which is the sound source of their voice. This is the same mechanism of human vocalization known for a long time. Briefly, when applying to human vocal fold, the MEAD theory states that the mucosal wave propagation on the vocal fold surface generates an alternative convergent/divergent glottal shape during the vibration which leads to a temporally-asymmetric aerodynamic force on vocal fold. This temporally-asymmetric aerodynamic force is the key mechanism for net energy transfer from the glottal flow to vocal fold (Titze and Alipour, 2006). In the experiments of Elemans et al. (2015), an alternative convergent-divergent shape of the airway between the two LVMs in birds’ syrinx was also observed. However, different from human vocal fold which is only driven by the subglottal pressure and whose motion is dominantly in the lateral direction, the vibration of the bird LVM presents a more complex coupling mechanism and motion dynamics, such as that the vibration is driven by the combined effect of the air sac pressure and bronchial pressure, an additional tissue called the medial tympaniform membrane (MTM) vibrates together with the LVMs in a lower position, and a strong rotational motion presents during vibration. To elucidate the role and mechanism of these features in bird vocalization, a computational model which can faithfully model these features based on realistic conditions is necessary.
Table 1 Comparison of several key parameters between the numerical simulation and experiment (Elemans et al., 2015).

<table>
<thead>
<tr>
<th></th>
<th>F0 (Hz)</th>
<th>Opening (mm)</th>
<th>SPL (dB)</th>
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<tbody>
<tr>
<td>Simulation</td>
<td>153</td>
<td>1.85</td>
<td>86</td>
</tr>
<tr>
<td>Experiment</td>
<td>140-160</td>
<td>1.8-2</td>
<td>~80</td>
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Figure 1. *The shape of the medial surface of the LVMs at three time instants during one vibration cycle. Each time instant is indicated by the black dot superimposed on the flow rate plot at the bottom right corner of each figure.*

Figure 1 shows the shape of the medial surface of the LVMs at three time instants during one vibration cycle corresponding to the closing, closed and opening LVMs. It clearly shows an alternative convergent-divergent vibration pattern of the LVMs. The LVMs close and open from the beneath, forming a divergent shape during the closing phase and a convergent shape during the opening phase. This is the similar vibration pattern with human vocal fold and the key mechanism of sustained energy transfer from the airflow to vocal folds.

Detailed vibration pattern, such as spatiotemporal variation of the displacement, POD analysis, node trajectory, will be analyzed in future to gain deep understanding of the vibratory dynamics of the LVMs. Aerodynamic pressure and its relationship with the vibration of LVMs will be analyzed and discussed to gain deep understanding of the interaction between the airflow and vibration.

4. Conclusion

The point that human phonation and bird vocalization both apply the MEAD theory is interesting for that it provides one more common phonation/vocalization mechanism between human and birds while the other similarity is that that both songbird and human learn vocalization from a tutor. Thus it provides us more confidence that the study of neural control during bird vocalization may be helpful in understanding the neural mechanism underlying human vocal learning.

5. References

