

THE IMPORTANCE OF PHYSICAL MODELS OF THE HUMAN VOCAL TRACT FOR EDUCATION IN ACOUSTICS IN THE DIGITAL ERA

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ABSTRACT

Although this is commonly seen as the digital era in acoustics, it is still important to incorporate analog systems into education. Specifically, it is our contention that people learn the basic concepts in acoustics better when they have access to physical models, not only computer simulations. Formerly, we proposed mechanical vocal tract models for education in speech science. In this study, we further developed the mechanical models and compared the characteristics of two types of models: plate and cylinder. Several acrylic plates with holes formed an acoustic tube in the former, whereas hollowing out a cylinder created an acoustic resonator in the latter. When their configurations are the same, the two models produce nearly the same output in the lower formant frequencies, except that the two had different formant bandwidths. In the higher frequencies both the formant frequencies and bandwidths were different. We concluded the plate type is also useful as the cylinder type.

1.INTRODUCTION

The widespread use of computers along with increased processing speed has brought with it a rapid development in digital signal processing. Yet, even though advances in the digital arena (such as more general accessibility to spectrograms) are valuable prospects, we should not forget the importance of analog systems in education. Analog systems, and more specifically, physical models, are useful for teaching acoustics in the classroom. Previously, we reported on mechanical vocal-tract models we developed for intuitive learning [1], [2], [3], [4]. We recently showed these tools to Japanese high-school students who had just finished studying acoustics, and we received positive feedback. Experience shows the tools to be particularly suitable for teaching the mechanism of vowel production [5].

Chiba and Kajiyama measured the area functions of the human vocal cavity and produced artificial vowels by using mechanical vocal tract models in the 1940's [6]. Using Chiba and Kajiyama's measurements of the oral cavity, Arai et al. reconstructed their vocal tract models with an acrylic cylinder to make the models suitable as the educational tool [3]. In this model, the radius at every position was approximated with a polygonal line. Their models each have an opening at each end corresponding to the mouth and glottis, and are made of transparent materials so the shape of the cavity can be seen.

We have also developed several sets of square acrylic plate models [1], [2]. Each plate has a hole in the center, and the holes are various diameters. A set of 16 disks simulates the vocal tract by forming an acoustic tube where the holes line up. Through rearrangement of the plates, students can learn the importance of the position of constriction for vowel production and the perturbation theory [4], [7].

In the previous study [8], we made four cylinder models of the Japanese vowel /a/,

which are different in step size of approximation. The simulations for these 4 cylindrical models were found that the step sizes did not influence the formants of the outputs. In this paper, we compare characteristics of a plate type model with the cylinder type which has the same configuration as the plate type to see the difference between the two.

2.COMPERATIVE EXPERIMENT

The cylinder models have external diameters of 50mm and are 160mm long. The plates in the plate models are made of acrylic, and each plate is 75x75mm square by 10mm thick. When all 16 plates were placed adjacent to one another, the tube measured 162mm long. Therefore, there seems to have been a slight variation in the thickness of each plate.

Fig. 1. shows vocal tract models for cylinder and plate models. In this figure, left is the cylinder model with polygonal approximation [3], the middle is the plate type, and right is the cylinder model that has exactly the same configuration as the plate model.

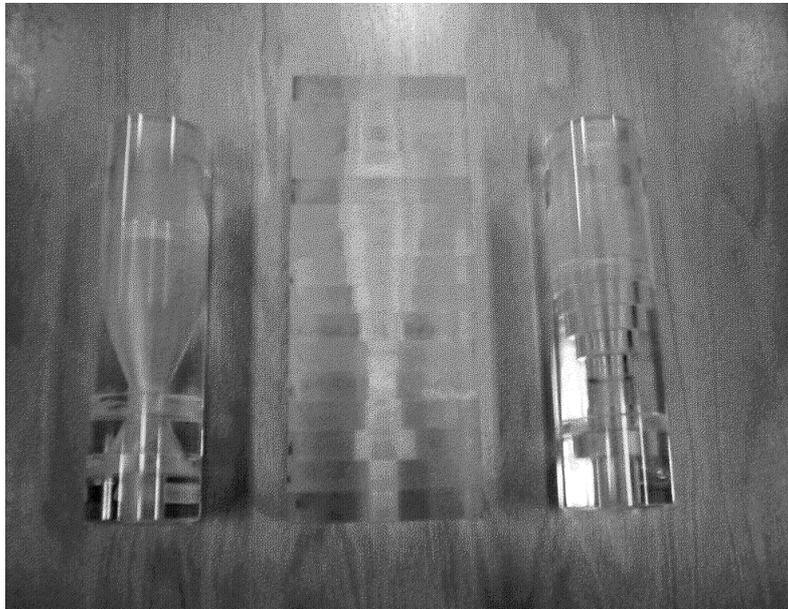


Fig. 1. Vocal tract models for cylinder and plate models (vowel /a/)

We compare characteristics of the plate type model with the cylinder type which has the same configuration as the plate type for vowel /a/. After conducting a perceptual experiment, both models conclusively produced an /a/, but there were some differences in sound quality which we wanted to investigate further. We examined the spectra of the output of the two models by linear predictive coding (LPC) analysis. Fig. 2 shows two spectral envelopes; a heavy line shows the plate model, a fine black line shows the cylinder model, and a fine gray line shows the cylinder type with polygonal approximation.

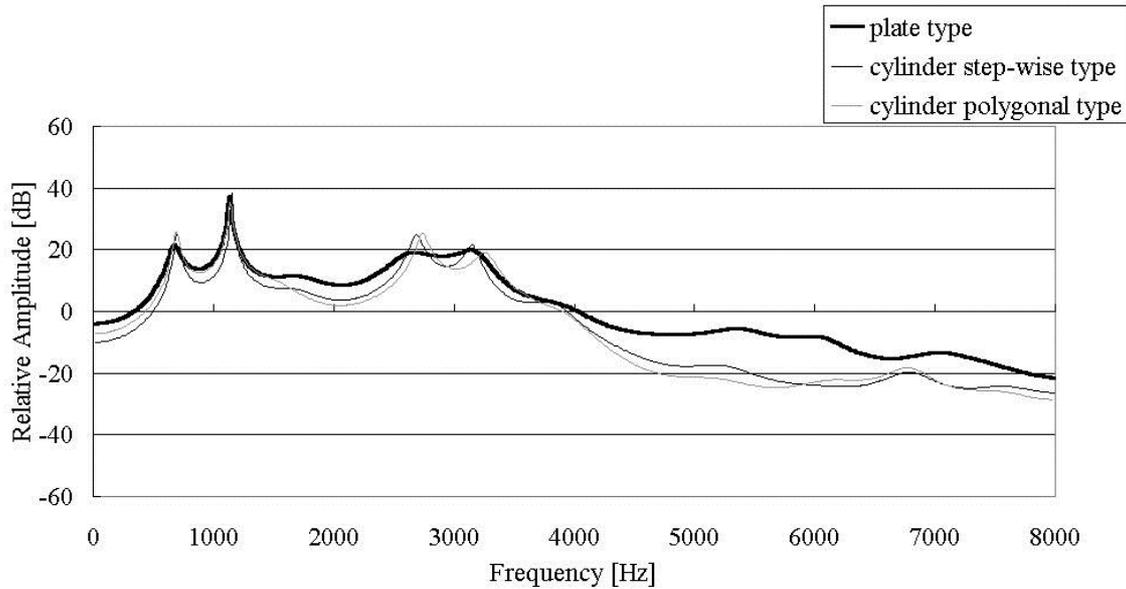


Fig. 2. Spectral envelopes of vowel /a/

3.DISCUSSION

Using LPC analysis, we calculated the frequency and bandwidth for each type as follows;

$$\text{Formant frequency } F = \frac{\arg z}{2\pi\Delta T} \quad [Hz] \quad (1)$$

$$\text{Bandwidth } B = -\frac{\log|z|}{\pi\Delta T} \quad [Hz] \quad (2)$$

$$\text{Quality factor } Q = \frac{F}{B} \quad (3)$$

Table 1. The frequency, bandwidth and quality factor for each type

	Formant [Hz]			Bandwidth [Hz]			Quality Factor		
	Cylinder		Plate	Cylinder		Plate	Cylinder		Plate
	polygon	step-wise		polygon	step-wise		polygon	step-wise	
F1	675	680	648	41	30	84	17	23	8
F2	1128	1141	1108	25	12	23	45	94	50
F3	2727	2675	2564	85	93	361	32	29	7
F4	3257	3146	3128	159	105	231	21	30	14

Table 1 shows the results. From this table, the formants in the lower frequencies, those governing vowel quality, are almost identical. Because of this, the outputs produced from both the plate and cylinder with same configuration had nearly the same vowel quality, although some differences were perceived. The plate type had wider bandwidths compared to the cylinder models. In the higher frequencies, plate models

are also different with respect to relative amplitude. This difference seems to result from the loss of acoustic energy when we lined up each plate. We think these are the main factors accounting for the different acoustic impression between model types.

SUMMARY

In this paper, we have emphasized the need for analog systems in education, even in a digitally oriented society. We further developed mechanical models and compared the characteristics of our two types of models: plate and cylinder. We confirmed that the vowel quality of both types were almost the same. By the spectral analysis, we found that the differences were due to formant bandwidth in the lower frequency range, and relative amplitude in the higher frequencies. The plate type has the greater advantage for education in that the students can arrange them in arbitrary order, and experiment with them individually. They can also test perturbation theory [2] by placing a plate with a narrow hole in various locations. Because the plate-type models have sufficient characteristics, we concluded that they are also useful for education in acoustics.

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