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ON SOUND GENERATED BY BLUFF BODIES IN AIR FLOW

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1. INTRODUCTION

Simple bluff bodies are studied experimentally in order to have more detailed information about Strouhal number which is a significant parameter with regard to flow sound prediction. A great number of publications on investigations concerning the effect of velocity U which is a component of Strouhal number S have been done up to now. On the other hand, the insufficient knowledge of the size of bluff body corresponding to another important component length d of Strouhal number S may be the reason why Strouhal number has still not been used widely. Attempts to find out the size corresponding to d are made in this study.

2. DESCRIPTION OF BLUFF BODIES

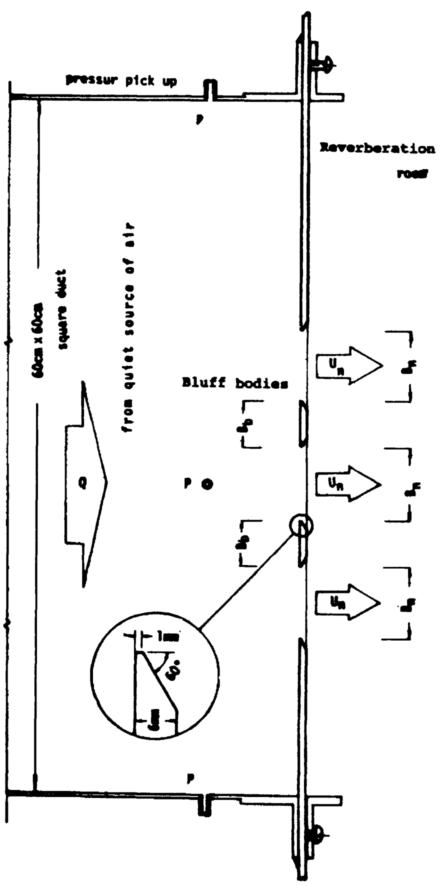


FIGURE 1. Configulation of bluff bodies.

As a simple aerodynamic sound source, bluff bodies used here are shown in figure 1. The varieties of bluff body size B_b tested are of 1 cm, 2 cm, 4 cm and 6.3 cm, besides the flow breadth B_n between the bluff bodies is changed from 0.25 cm to 30 cm. And the number of flows N_n between the bluff bodies is changed from 1 to 5.

3. EMPIRICAL FORMULA

The relationship between Strouhal number S and frequency f (H_z) is,

$$S = fd/U, \qquad (1)$$

where, d : length (m), U : velocity (m/s). Since power spectrum at specified frequency $W_f(f)$ (watt/Hz) is defined in terms of the acoustic power contained within unit of f, in this paper $W_S(S)$ is defined in terms of the acoustic power contained within unit of S. Then,

$$W_S(S) = (U/d) W_f(f). \qquad (2)$$

Meanwhile the total acoustic power of sound generated aerodynamically is proportional to U^{α} (where α is the exponent representing the velocity dependence of the sound) and an area A (m^2) [1, 2]. In this paper, further more, postulating that these relationships hold good as to the power contained within unit Strouhal number,

$$W_S(S) = K_1(S)\, AU^{\alpha}. \qquad (3)$$

From equation (2) and (3),

$$W_f(f) = K_1(S)\, AU^{\alpha} d/U. \qquad (4)$$

Expressing $Q \propto AU$ (m^3/s) for flow rate and $P \propto U^2$ (Pascal) for pressure drop at bluff bodies,

$$W_f(f) = K_2(S)dQPU^{\varepsilon-1}. \quad (5)$$

Where, $K_1(S)$ and $K_2(S)$ represent the distribution functions, and $\varepsilon = \alpha - 3$ is the exponent representing the acoustic effeciency of aerodynamic sound generation and corresponds to Lighthill's parameter. Considering the application to ventilating and air conditioning engineering, the following normalizing values are chosen; $U = 10$ m/s, $d = 0.01$ m, $Q = 0.1$ m^3/s, $P = 60$ Pascal and $f = 1000$ Hz. Putting $W_{SS}(S) = 0.01 \times 0.1 \times 60 \times 10^{\varepsilon-1} K_2(S)$ and rewriting equation (5),

$$W_f(f) = W_{SS}(S)\ (d/0.01)(Q/0.1)(P/60)(U/10)^{\varepsilon-1}. \quad (6)$$

The relation between spectrum level $L_{Wf}(f)$ (dB re 10^{-12} watts) and normalized spectrum level $L_S(S)$ is obtained as,

$$L_{Wf}(f) = L_S(S) + 10\ \log(d/0.01)(Q/0.1)(P/60)(U/10)^{\varepsilon-1}, \quad (7)$$

where, $L_S(S) = 10\ \log W_{SS}(S)\ /\ 10^{-12}$.

4. MEASUREMENT

The equipment used in this experiment consists of a quiet source of air, a measuring section of air flow rate and a reverberation chamber.

In the quiet source of air, absorbers and acoustic filters are installed to reduce high and low frequency noise due to the fan and from outside respectively. Figure 2 shows the sound power spectrum with and without orifice shaped bluff bodies. As compared with the sound by the orifice shaped bluff body which generates the lowest flow sound, provided B_n is less than 30 cm, the noise from test system does not disturb the measurement.

Air flow rate Q is measured by an orifice having the diameter of 12 cm and 24 cm in the center of the square duct of 60 cm x 60 cm cross section and 16 m long. The relations between the pressure drop at the bluff bodies p and Q are obtained. During the measurement of the flow sound by the bluff bodies, the orifice is removed.

The measurement of the acoustic power of the aerodynamic sound produced by bluff bodies is made by means of the reverberation chamber method. Averaging the pressure levels of six microphons in the chamber, an one third octave band pressure level is obtained at each velocity. A $L_{Wf}(f)$ is calculated with the pressure level and the room constant derived from measured reverberation time.

5. EXPONENT REPRESENTING VELOCITY DEPENDENCE α

In order to know the relation between $L_{Wf}(f)$ and U, $L_{Wf}(f)$ of each bluff body configuration is measured with respect to the velocities U_n from 8m/s to 40m/s. Where, $U_n = 10\sqrt{P/60}$ is used for the velocity U in this study. Figure 3 shows the result of such bluff bodies of $B_b = 1$cm, $B_n = 2$cm and $N_n = 5$. The curves represent $L_{Wf}(f)$ calculated from average $L_S(S)$ obtained from measured $L_{Wf}(f)$ at each velocity by means of equation (7). Regarding the variation of velocity, there is little difference between the measured $L_{Wf}(f)$ and calculated $L_{Wf}(f)$ from equation (7) with $\varepsilon = 2$ i.e. $\alpha = 5$ for all frequencies.

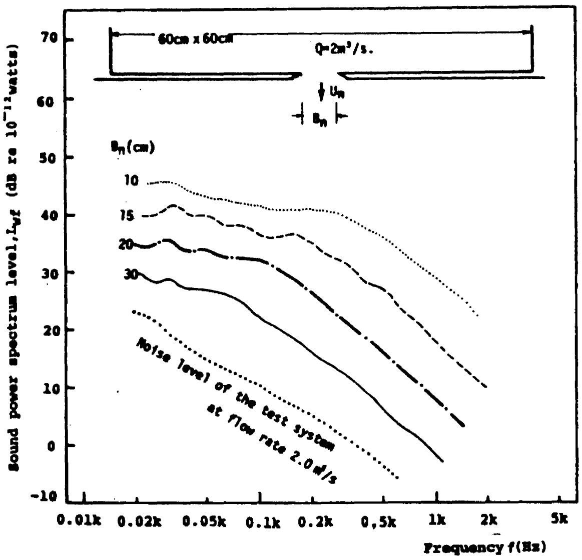


FIGURE 2 Comparison of the sound by the bluff bodies with the sound by measuring duct system, at air flow rate $Q = 2m^3/s$.

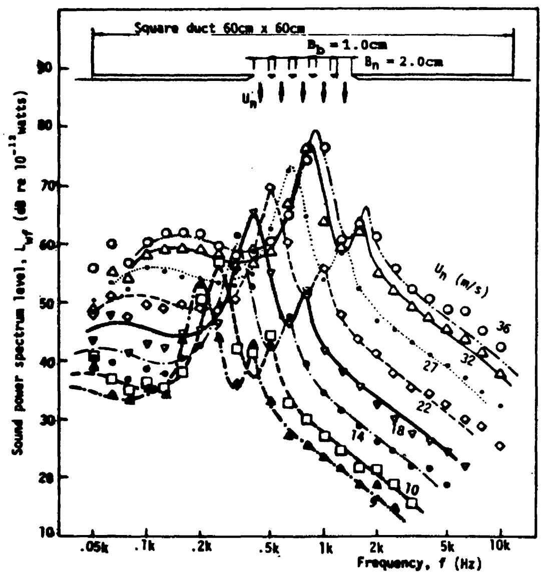


FIGURE 3. Sound spectra change with velocity U_n, at $Bb = 1$cm, $Nn = 5$, $Bn = 2$cm. Curves are calculated using equation(7).

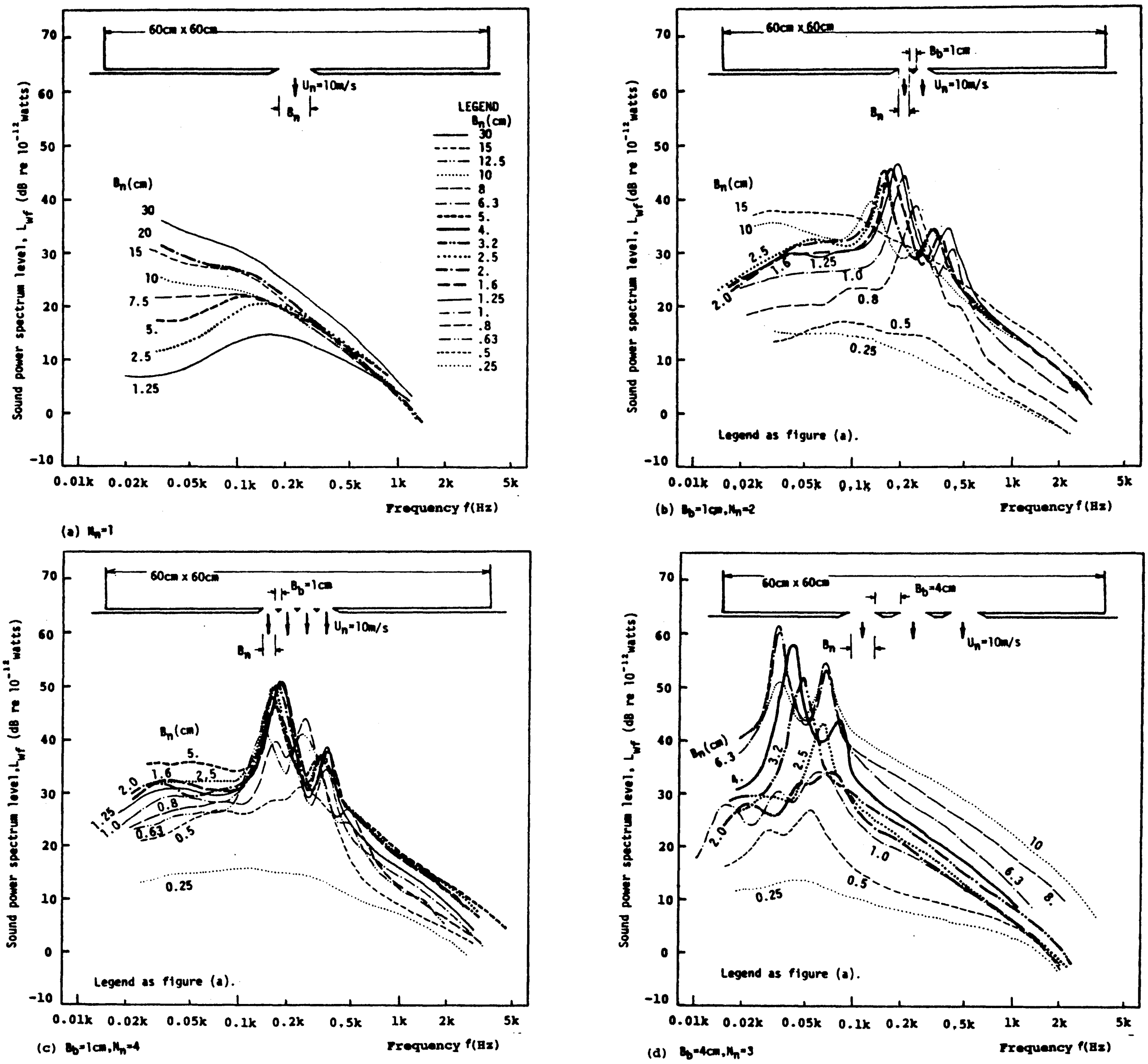


FIGURE 4. Change in sound spectra with sizes of Bb and Bn, at Un = 10m/s.

6. EFFECTS OF SIZE OF BLUFF BODIES ON $L_{wf}(f)$

The values of $L_{wf}(f)$ for bluff bodies having different sizes and number of flows are shown in figures 4 (a), (b), (c) and (d) at velocity $U_n = 10$ m/s.

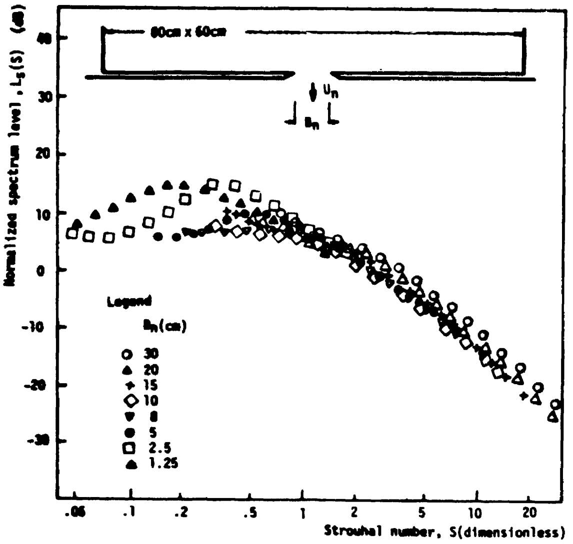
Figure 4 (a) shows the variation of $L_{wf}(f)$ with respect to B_n in the case of single flow $N_n = 1$. The wider the B_n, the higher the $L_{wf}(f)$ becomes and the lower the peak frequency f_p in the spectrum falls to. It is clarified that B_n mainly effects the variation of $L_{wf}(f)$ and may correspond to the length d.

In the range $B_n \simeq B_b$, a discrete tone which is not seen when $N_n = 1$, is prodused followed by a harmonic tone. Figure 4 (b) and (c) show the effect of the number of flows N_n in the case of $B_b = 1$ cm. As N_n increases, see figure 4 (c), this discrete tone has a tendency to appear in wider range of B_n. The peak frequency f_p decreases a little as B_n increases, however the values of $L_{wf}(f)$ are approximately equal in spite of the change of B_n in the range of $B_b \simeq B_n$. B_b is considered to be corresponding size of bluff bodies to the length d.

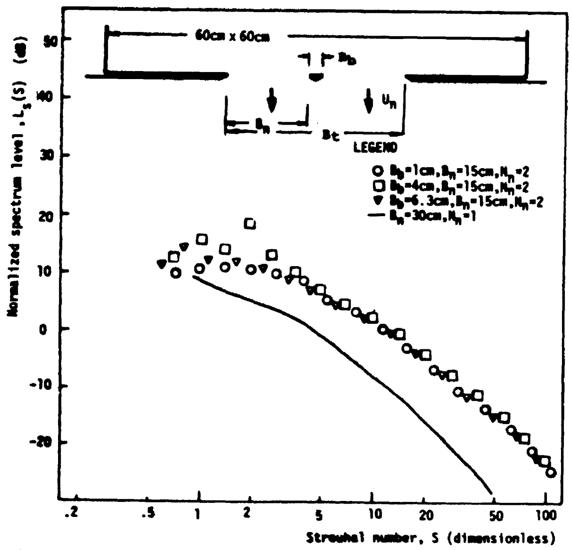
In the range $B_n < B_b$, the variation of $L_{wf}(f)$ is considered to have little dependence on B_n and B_b, but in the range of $B_n \ll B_b$, the shape of $L_{wf}(f)$ may become similar to those of the single flow.

In the range $B_n \gg B_b$, as is seen at $B_n = 15$ cm in figure 4 (b), the discrete tone in the range $B_b \simeq B_n$ disappears and instead a wide spread sound appears.

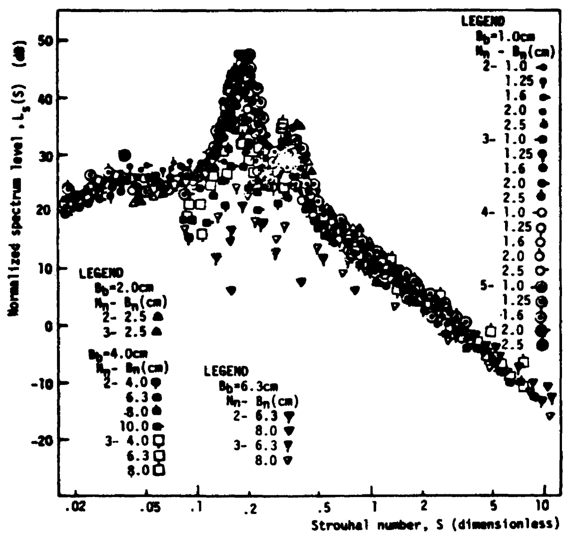
The effects of B_b on $L_{wf}(f)$ are examined in figure 4 (b) and (d) with $B_n = 1$ cm and 4 cm. In the range $B_n \simeq B_b$, the $L_{wf}(f)$ for $B_b = 4$ cm are seen to depend mainly on B_b.



(a) N_n=1,Normalized with respect to opening size B_n.



(b) $B_n \gg B_b$, Normalized with respect to total flow size $B_t = N_n \cdot B_n + (N_n - 1)B_b$.



(c) $B_n = B_b$, Normalized with respect to the breadth of bluff body B_b.

FIGURE 5. Normalized spectra against Strouhal number.

7. NORMALIZED SPECTRUM $L_S(S)$

The normalized spectrum levels $L_S(S)$ by the equation (7) are shown, (1) $d = B_n$ when $N_n = 1$ in figure 5 (a), (2) $d = B_t = B_n N_n + (N_n - 1)B_b$ when $B_n \gg B_b$ in figure 5 (b) and (3) $d = B_b$ when $B_n \simeq B_b$ in figure 5 (c) respectively.

In case of (1), the values of $L_S(S)$ are seen coincident in the wide range of S, but there is some discrepancy in the low frequency range.

In case of (2), $L_S(S)$ in the range $B_n \gg B_b$ is higher than $L_S(S)$ at $N_n = 1$ by about 10 dB for all frequencies.

In case of (3), almost all discrete tones appear at $S \simeq 0.2$, but the discrete tones in case of $B_b = 6.3$ cm have exceptionally low level.

8. CONCLUSIONS

For the prediction of aerodynamic sound generated by bluff bodies at low velocity, the relation between the normalized spectrum level $L_S(S)$ using Strouhal number as a parameter and the sound power spectrum level $L_{Wf}(f)$ is obtaind experimentally as the equation (7).

The exponent of velocity dependence α for each system of bluff bodies is clarified to be constant for all values of S and equal to 5.

The size of bluff body corresponding to a length d of Strouhal number is inferred, as mentioned in paragraph 7 i.e. $d = B_n$ when $N_n = 1$, $d = B_b$ when $B_n \simeq B_b$ and $d = B_t$ when $B_n \gg B_b$ respectively.

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