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# Experimental Study of Internal Flow Noise Measurement by Use of a Suction Type Low Noise Wind Tunnel

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## 1. Introduction

The measurement experiment of the fluid-dynamic noise made from the object placed into the air flow is performed using a low noise wind tunnel, a silent airflow wind tunnel, etc. In the low noise wind tunnel, the measures against silence are taken so that the noise generated with a fan or a compressor may not propagate as much as possible to a wind tunnel test section by an air current. As for the surroundings of the test section of a low noise wind tunnel, acoustic free space is provided. Generally a wind tunnel is classified by the form of the channel of a wind tunnel (blow type, suction type and circulating type), the form of the measurement section (open, half-open and sealed), and the existence of circulation of flow. And the practical wind tunnels are classified into 13 kinds (Mochizuki & Maruta, 1996). Figure 1 illustrates the circulation environment for the airflow between the blower and the measurement section, the types of duct in the wind tunnel (blow, suction and circulating) and the types of measurement section (open, half-open and sealed). The merit of each type of the wind tunnel and the weak point are summarized as follows. In the merit of the blow type, the composition is simple and small the installation space. In the liberating measurement section of jet-type, the usage of use becomes various. The week point is to need big power because the pressure loss is large. Flowing quantity will come to receive the fluctuation easily in turbulence. The measurement section is that the temperature raises more than the temperatures of air in the surrounding. The merit of the suction-type should be able to be composed the rectification part short, and more compactly than the blow-type. The temperature of the measurement section is the same as the temperature of the space in the surrounding. The weak point is to receive the influence of the fluctuation of the outer air flow large. The measurement section must become negative pressure from the atmospheric pres-

sure. An enough space for the rectification is needed on the suction side. The merit of the circulating blow-type is not to receive turbulence. The experiment on all-round is possible in the open-type measurement section. The weak point is to take time until stabilizing and it be easy to rise in the temperature. Merits of the circulating suction-type are that turbulence is not received and the rectification part is short. The weak point is to take time until stabilizing. A very wide space is necessary forward of the suction mouth. Merits of the circulating type to unnecessary big power and not to receive turbulence. The stability of the flow is also early. Especially, efficiency is very good and the pressure loss is a little in the sealed-type measurement section. The weak point is to need noting in the rise's of the air flow temperature becoming remarkable. The object flow must be limited. A wide installation space is needed. In addition, there are a peculiar merit and a weak point respectively by the measurement section shape, and they are summarized as follows. The merit of the open-type measurement section is that the limitation concerning the size and the shape of the test piece is a little. The weak point is to receive turbulence by the suck of air. Merits of the half-open type measurement section are permitted the test piece diversity and are hard of turbulence to receive. The weak point is that the measurement room becomes negative pressure easily. The merit of the sealed-type measurement section is to become the most efficient wind tunnel, and to hardly receive turbulence. The weak point is to receive the limitation to the size and the shape of the test piece. Among these, it is required that the wind tunnel aiming at measurement of a fluid-dynamic noise secures the acoustic free space of silence and a test section. Moreover, it is also required that the spatial relationship of a test model and a microphone can be set up freely. Therefore, many blow-type wind tunnels with the measurement room and half-open type test section by which sound insulation processing was carried out with the sound-absorbing material are used. On the other hand, use of a microphone is difficult in an air flow, and the measurement technique of a fluid-dynamic noise has not been established. Therefore, the wind tunnel with a sealed type test section can scarcely be seen. Accordingly, measurement of the fluid-dynamic noise of internal flows, such as a flow inside a gas turbine or a jet engine, and a pipeline, a flow of the around of the support in a duct, is not in the state which can be performed immediately. As for the present condition, there are also few examples of verification of measurement of the fluid-dynamic noise of an internal flow. So, it is very important to establish the measurement technique of the fluid-dynamic noise of an internal flow in engineering. In measurement of the fluid-dynamic noise using a low noise wind tunnel, when an open-type test section is used, it is reported that there is a case where it becomes impossible for a back ground noise not to be amplified by the large turbulence produced with the edge of the jet stream from a nozzle, or for generating of the sound which is not a measuring object to be observed by interference of a jet and a model sample, or to maintain the two dimensional characteristic of a flow etc. Moreover, when a sealed type test section is used, on the usual surface of a wall, sound reflects, and exact measurement cannot be performed, but if the material which can bear wind pressure that sound tends to penetrate the surface of a wall is used, it is reported that the sealed type test section will probably be better (Fujita, 1994, 1996).

The purpose of this study is examination of the measurement technique of the fluid-dynamic noise of an internal flow. In this study, it proposes carrying out burial setting of the micro-

phone to the test section equipped with a fibered glass. The suction type low noise wind tunnel with such a test section for verification was created, and measurement of the fluid-dynamic noise made from the circular cylinder placed into the air flow was tried. Comparison examination of the measurement result obtained by this measurement technique was carried out with the measurement result obtained in the blow type wind tunnel. As a result, it was shown that the same characteristic is obtained about the change in a sound pressure level or peak frequency. Moreover, since the target acoustic frequency was caught clearly, it was shown that it is convenient for examination of an acoustic effect. This measurement technique showed clearly that usefulness is high to fluid-dynamic noise measurement of the internal flow.

<div>Measurement section</div> <div>Duct type</div>	Open-type	Half-open type	Sealed-type
Blow			
Suction	Non practicality		
Circulating blow			
Circulating suction	Non practicality		
Circulating			

**Figure 1.** Wind tunnel classifications (Mochizuki & Maruta, 1996); the circle represents the blower, the arrow shows direction of the flow, and "M.S" is the measurement section

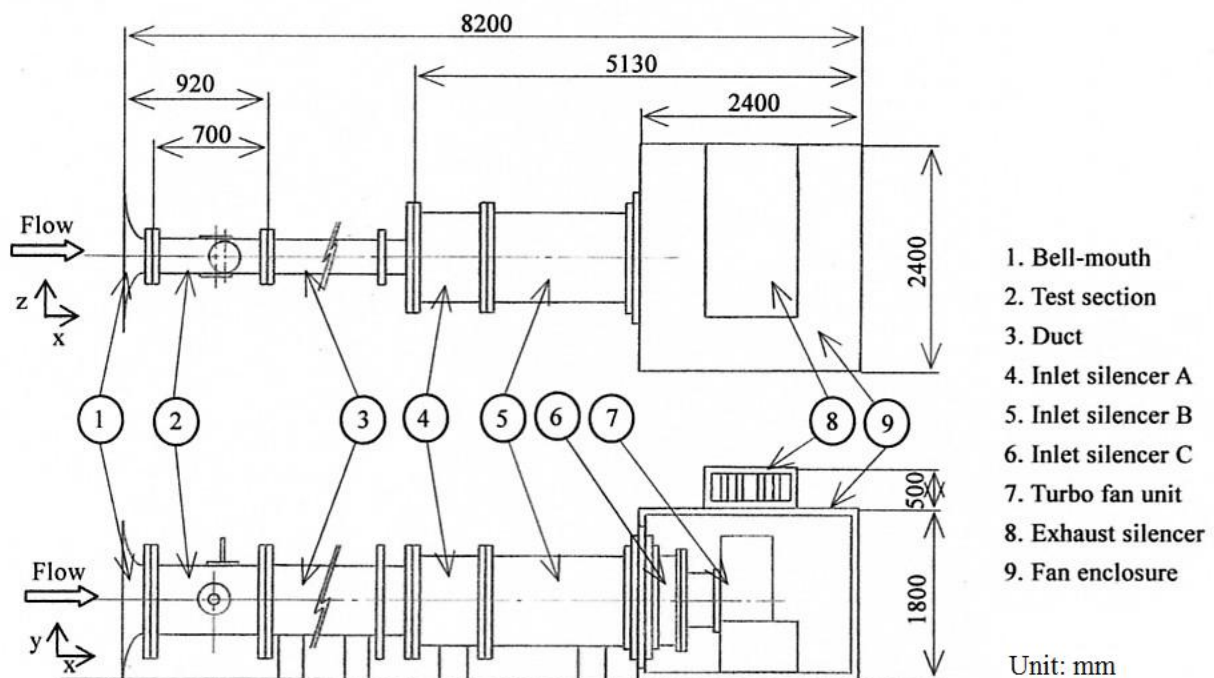
## 2. Experimental apparatus and method

This chapter describes the used equipment, a tool, and the procedure of an experiment.

### 2.1. Outline of the experimental apparatus

The experimental apparatus consists of a low noise wind tunnel and measuring equipment. Figure 2 shows the schematic diagram of a low noise wind tunnel. The low noise wind tunnel is constituted from the bell mouse, the test section, the silence duct, and the fan by the inhaled type wind tunnel with a sealed type test section. In order to reduce fan generating

noise, the inside of a silence duct is divided into four in the shape of a cell, the sound-absorbing material (fiberglass) is stuck on all the surface of a wall, and the fan is installed in the fan room by which interior was carried out with the sound-absorbing material with a silence exhaust port with which three splitter walls were set. Regulation of airflow velocity which passes a test section is performed by carrying out inverter control of the number of rotations of the fan by remote control. A measuring device is divided roughly into fluid-dynamic noise measurement equipment and the air flow velocity measurement equipment. Fluid-dynamic noise measurement equipment consists of directive capacitor microphone (RION, UC-30, hereafter it is called microphone for convenient), precision noise level meter (RION, NA-40), and FFT analyzers (Ono Sokki, CF-5220). The air flow velocity measurement equipment consists of a hot-wire anemometer (DISA, TYPE55) and a digital pressure gauge (Cosmo Instruments, DM-3100B). As for measurement of the turbulence intensity to the flow velocity distribution and a main flow, the hot-wire anemometer was used. The pressure difference between the surface of a wall (static pressure) of a test section and atmospheric pressure was measured with the digital pressure gauge.



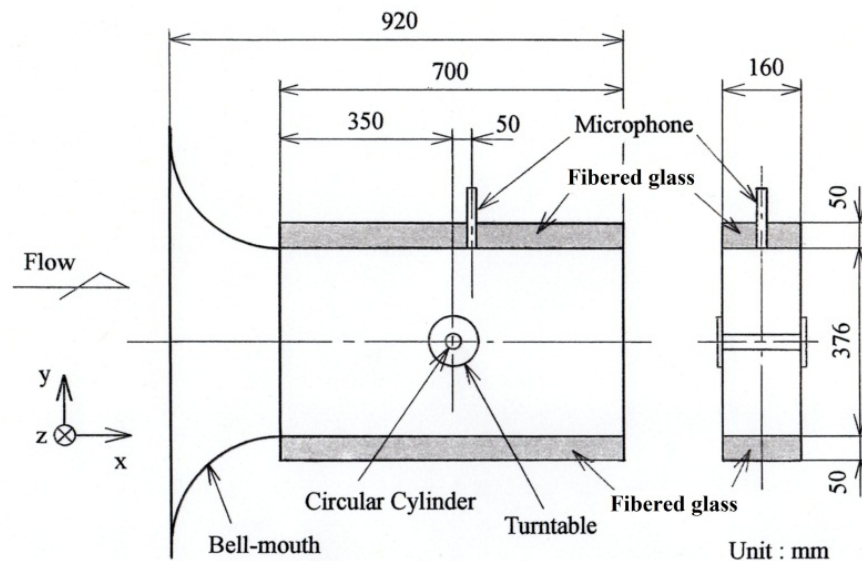
**Figure 2.** The schematic diagram of the wind tunnel

## 2.2. Measurement section and test cylinders

Figure 3 shows the schematic diagram of a measurement section (test section). The measurement section is a rectangular cross-section, 376mm (y direction) in height and 160mm (z direction) in width, with both side walls made of a transparent acrylic resin 700mm (x direction) in length, and a board thickness of 10mm. The turntable installation hole with a



diameter of 100mm was installed from the edge of the measurement section upstream side to the position at 350mm in the centerline. Upper and lower walls act as the sound absorbing walls (fibred glass walls), with 50mm-thick fibred glass placed on a 15mm-thick transparent acrylic board. Half free space is made in acoustics by installing this sound absorbing wall. The microphone and the hot-wire probe are set up from the edge of the measurement part upstream side to the position at 400mm in the centerline. The surface of microphone and the surface of fibred glass are set at the same level. The hot-wire probe can be moved in a vertical direction in the measurement section (y direction) using the traverse device. The test circular cylinder can be set within a range of 5mm-45mm up from the center of the turntable. Here, the center-to-center spacing of the microphone and the circular cylinder make adjustments within a range of 5mm-95mm possible. The test circular cylinder is made from brass, span length is 160mm and the surface is finished smoothly. The test circular cylinder is with seven kind, and each diameter is 6mm, 10mm, 15mm, 20mm, 25mm, 30mm, and 40mm.



**Figure 3.** The schematic diagram of the test section (measurement section)

### 2.3. Experimental method and procedure

In advance of measurement of the fluid-dynamic noise, the flow velocity distribution in the test section is measured by a hot-wire anemometer, and the state of flow is understood. The relationship between the air flow velocity which passes the test section and the static pressure on the surface of wall is previously authorized using a Pitot tube and a digital pressure gauge. Proofreading of a microphone and a precision noise level meter is performed using the piston phone (RION, NC-72, 250Hz, 114dB). The measurement procedure for the sound of flow is as follows. The test air flow velocity is set by operating the rotational speed controller of the blower. The fluid-dynamic noise is measured by the microphone, and the over-

all noise level and frequency analyses are done using the precision sound level meter and the fast Fourier transform analyzer. The flow velocity distribution in the measurement section and the measurement of the disturbance intensity relative to the main flow is as follows. The I type probe of the hot-wire anemometer is inserted detaching the microphone, it traverses in a vertical direction (y direction) at 5mm intervals (the interval of traverse is 2.5mm near the wall), and the air flow velocity is measured at the microphone installation position. The frequency of the oscillating flow due to Karman vortex shedding from the circular cylinder is measured as follows. The I type probe of the hot-wire anemometer is fixed in a position such that a clear shape of the waves can be obtained, and the output signal and frequency are using the fast Fourier transform analyzer. Here, averaging is performed ten times in the frequency analysis.

### 3. Experimental result and discussion

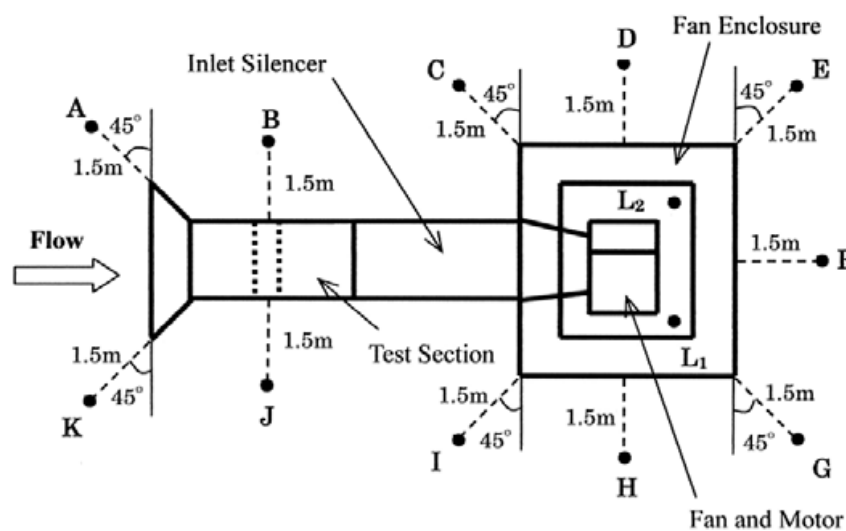
This chapter describes the result of having investigated about the basic characteristic of a producing wind tunnel, and the result of having performed sound verification.

#### 3.1. The fluid-dynamic characteristic and the acoustic characteristic of a producing wind tunnel

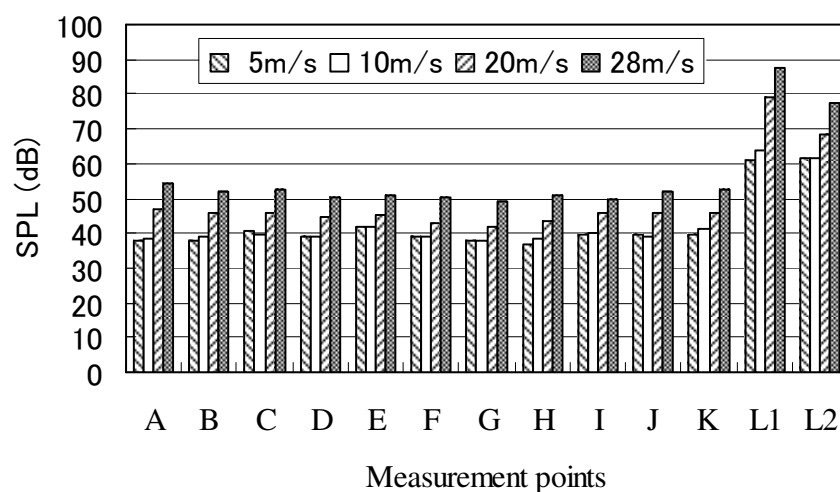
In order to understand the performance of a producing wind tunnel, investigation of the minimum flow velocity and the maximum flow velocity was performed using the Pitot tube. The minimum flow velocity in the test section was 2.5m/s, when the number of rotations of a fan was  $100\text{min}^{-1}$ , and the maximum flow velocity in the test section was 35m/s when the number of rotations of a fan was  $1300\text{min}^{-1}$ .

In a low noise wind tunnel, it becomes important especially to suppress propagation of the operation noise of the fan. Since this wind tunnel is a suction type wind tunnel, it is necessary to make it not accept fan generating noise in a test section. Accordingly, it is important not to leak the operation sound of the fan outside a fan room. So, the noise characteristic of the around of a wind tunnel was investigated. In order to understand the quietness of the wind tunnel, the sound pressure level around the test wind tunnel when it is driven or stopped was measured. Generally, the noise when the wind tunnel is operated is divided into air flow noise, and the operating noise of the blower. It is especially important in the fluid-dynamic noise measurement to suppress the propagation of the operating noise of the blower. The wind tunnel should not accept the blower generation noise in the measurement section. It is important that the operating sound of the blower does not leak outside the fan room. It is necessary, therefore, to understand the noise characteristics around the wind tunnel. The microphone positions for the noise measurement around the wind tunnel are shown in Fig. 4. Microphones are set up outside the fan room at a height of 1m off the ground, at measurement points (A-K). At measurement points (L1, L2) in the blower room, microphones are set up at a height of 1m, and placed a 700mm away from the electric motor and the blower outlet. Figure 5 shows the noise measurements at each measurement point when the circular cylinder is not set up in the measurement

section and when the wind tunnel is in operation. The noise levels around the wind tunnel, almost the same, but differ inside and outside the fan room, and when flow velocity increases, the difference increased. The noise levels inside and outside the fan room were 26dB and 32dB, respectively, when the wind tunnel was not operating. The level of sound intensity is defined by  $L=10\log_{10}I/I_0$  (dB) ( $I_0$  is an intensity of the sound of the standard:  $10^{-12}$  W/m<sup>2</sup>). Here, when the level of intensity of a sound inside the fan room is defined as  $L_{IN}$ , and the level of intensity of a sound outside the fan room is defined as  $L_{OUT}$ , the ratio of the level of sound-intensity  $L_{IN}/L_{OUT}$  is given by  $L_{IN}/L_{OUT}=10^{(L_{IN}-L_{OUT})/10}$ . The air flow velocity range is 5-35m/s, so the ratio of the level of sound-intensity  $L_{IN}/L_{OUT}$  becomes 155 -6760. Therefore, it is clear that the noise in the blower room is intercepted.



**Figure 4.** Sound measurement points around a wind tunnel pressure level

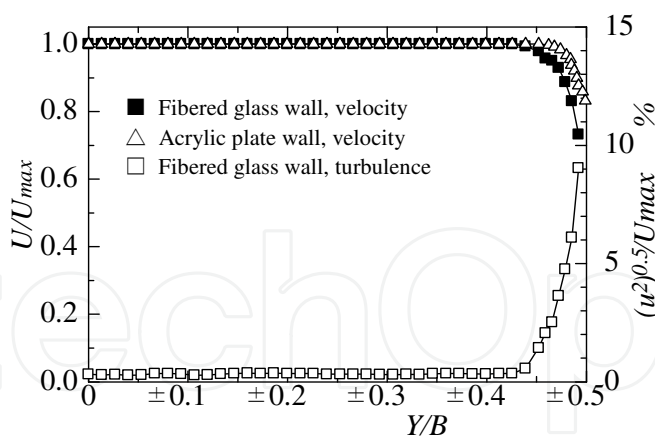


**Figure 5.** Sound pressure level around a wind tunnel with a flow velocity in the test section ranging from 5m/s to 28m/s



### 3.2. Flow characteristics in the measurement section

Flow characteristics in the measurement section where the sound absorbing wall (fiberglass wall) had been used were investigated. The hot-wire probe was inserted in the microphone's installation position; it traversed in a vertical direction ( $y$  direction), and the velocity and disturbance intensity were measured. Figure 6 shows the velocity distribution and the disturbance intensity when the air flow velocity is  $U=28\text{m/s}$ . The velocity distribution ( $\Delta$  symbol) for an acrylic wall is plotted for comparison. Here, the abscissa is a measurement position. The center of width in the vertical direction of the measurement section is assumed to be zero points; the upper side is assumed to be + mark, and the lower side is assumed to be - mark. The measurement position is made dimensionless by width  $B=376\text{mm}$  in the vertical direction of the measurement section. The ordinate shows the velocity distribution and the disturbance intensity, respectively. The symmetry of a flow was good to the center and turbulence intensity was less than 0.5% in the range which is maintaining the equality of a flow. The disturbance intensity to keep the uniformity of the flow was within 0.5%. Here, if uniform flow velocity  $U=28\text{m/s}$  and the measurement point  $x=400\text{mm}$  are calculated by Prantl's exact solution ( $\delta=0.22(\nu/Ux)^{0.167}x$ ), the thickness of the boundary layer is 9.6mm. The thickness of the boundary layer as in Fig. 6 is 10mm for the acrylic wall, and this agrees with the value from Prantl's expression. However, the thickness of the boundary layer above the sound absorbing wall was about 28mm, and was about three times that in Prantl's expression because the sound-absorbing wall was made of fiberglass with a rough surface. It was clarified that the wall was necessary to obtain a wide measurement section and thus improve the uniformity of the flow.

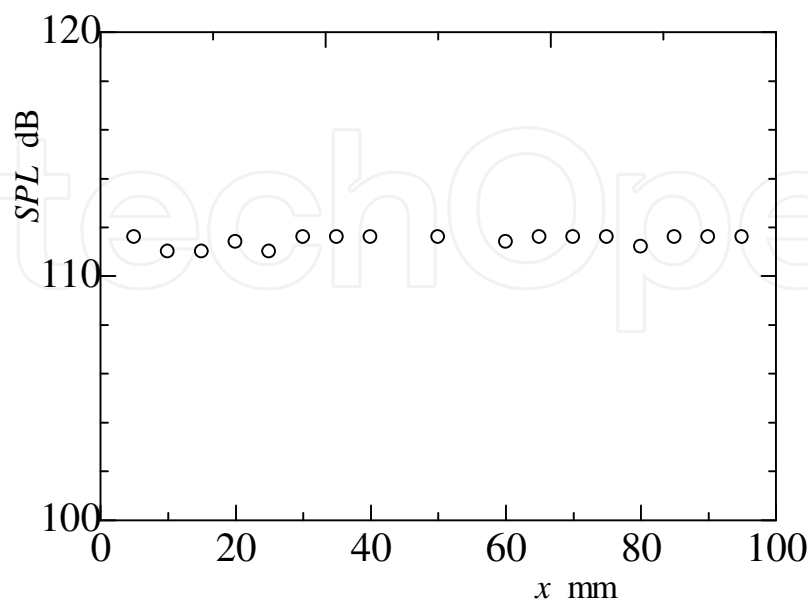


**Figure 6.** Flow velocity distribution and turbulence intensity in the test (measurement) section at a main flow velocity of  $U=28\text{m/s}$

### 3.3. The relation between sound source and measurement position

It is known that the fluid-dynamic noise made from the circular cylinder placed into the air flow is a dipole sound. Since there is single directivity also in a microphone, it is important to understand the influence on the measurement result by the spatial relationship of a sound

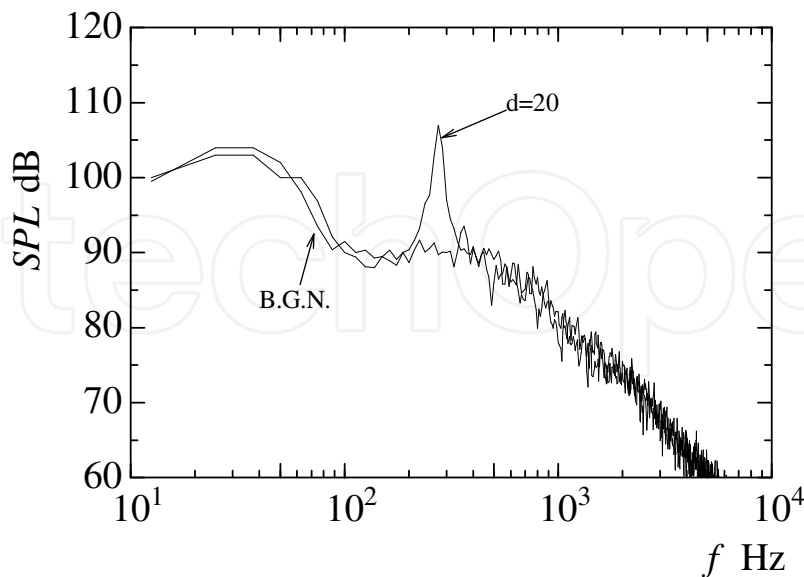
source and its microphone. Figure 7 shows the measurement result of the sound pressure level when varying the distance  $x$  between centers of a circular cylinder and a microphone in the range from 5mm to 95mm. Here, the airflow velocity in a test section was  $U=28\text{m/s}$  and the diameter of circular cylinder was 20mm. It is understood that the measured sound pressure level is almost the same. So, in measurement of acoustic frequency, distance between centers of circular cylinder and microphone was set to 50mm. Here, it is expected that the pressure fluctuation of a short-distance field is included in the sound pressure which will have been measured if the measurement position of sound is generally near from a sound source (circular cylinder). In this study, the distance between the circular cylinder and the microphone was narrower compared with the device arrangement for an ordinary sound measurement. Because the noise measurement of the flow in the fluid machine such as the gas turbines and jet engines is assumed, and the measurement of the fluid-dynamic sound caused by the flow around the object such as the supports and umbones installed in the pipeline and the duct is assumed, it becomes such arrangement. Therefore, the influence of the near field appears to be strong, making a quantitative evaluation of the sound pressure level more difficult. Resolving this is a clear challenge for future studies. The relationship between the position  $r_c$  by which the pressure fluctuation of a short-distance field can be disregarded now, and the minimum frequency  $f$  is given in  $20\log(2\pi fr_c/a) \geq 10 \text{ dB}$  ( $a$  is acoustic velocity) (Iida, 1996). Distance  $r_c$  between the circular cylinder and the microphone becomes 188mm-211mm because the range of center-to-center spacing  $x$  between the circular cylinder and the microphone in this experiment is 5mm-95mm. The obtained lower critical frequency  $f$  becomes 910Hz-812Hz. When the center-to-center spacing is assumed to be 50mm, distance  $r_c$  between two points becomes 194.5mm. The lower critical frequency  $f$  at that time is 880Hz.



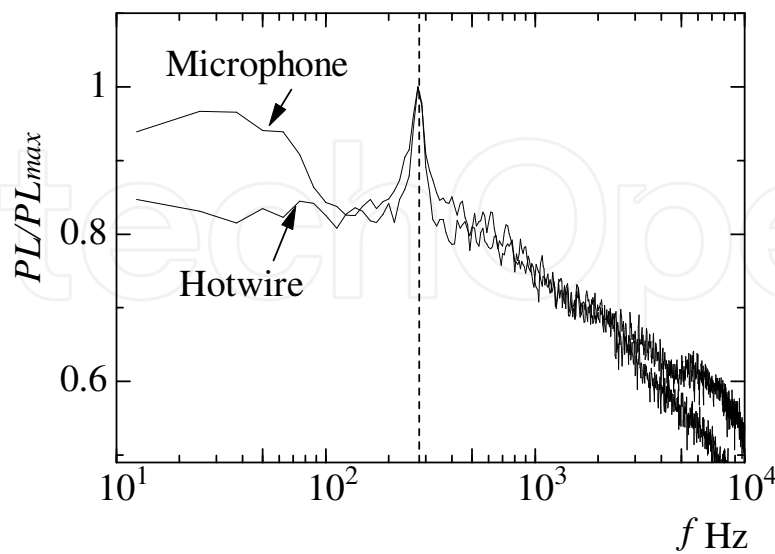
**Figure 7.** Measurement result for sound pressure level with a directivity check

### 3.4. Measurement result and verification of Acoustic frequency

The back ground noise with acoustic half-free space of a test section was measured by making airflow velocity in a test section into  $U=28\text{m/s}$ . The circular cylinder of various diameters was installed in the test section, and frequency of a fluid-dynamic noise (acoustic frequency) was measured. Figure 8 shows the results of the acoustic frequency analysis with back ground noise (B.G.N.) in the measurement section and with a circular cylinder 20mm in diameter. The abscissa is frequency  $f$ , and the ordinate is the sound pressure level  $SPL$  in the figure. When the circular cylinder is set up in the measurement part, a peak at one big sound pressure level is obtained. At this time, the Strouhal number  $S (= f d / U)$  calculated from the frequency  $f (=275\text{Hz})$  and air flow velocity  $U (=28\text{m/s})$  is  $S=0.2$ . It is considered that the microphone measures the acoustic frequency from the fluid oscillation based on Karman vortex shedding. The frequency of the oscillating flow behind the circular cylinder was measured using the hot wire anemometer for verification. Figure 9 shows the result of the frequency analysis using the microphone and the hot wire anemometer. The abscissa is frequency  $f$ , and the ordinate is a sound pressure level made dimensionless by the maximum value. In both measurement results, it is understood that one big peak is seen at the same frequency. Therefore, it was established that the acoustic frequency measured by the microphone was a fluid oscillating frequency based on Karman vortex shedding from the circular cylinder. This means that the fluid sound measured by making the acoustical free space can be measured in an internal flow. And, this measurement technique is considered suitable for the measurement of the fluid sound of an internal flow.



**Figure 8.** The frequency analysis of flow noise,  $U=28\text{m/s}$ ,  $d=20\text{mm}$



**Figure 9.** The relationship between the acoustic frequency and the fluid frequency due to vortex shedding

### 3.5. Comparison of measurement results with a blow-type wind tunnel

Figure 10 shows the variation of the peak frequency of the sound pressure level at the time of varying a circular cylinder diameter. The back ground noise is also shown for comparison. The abscissa is frequency  $f$  and the ordinate is a sound pressure level  $SPL$ . Increase of a cylinder diameter can see the tendency for a sound pressure level to increase and for peak frequency to decrease. The experimental result (Tomita et al., 1982) in the wind tunnel of a blow type with a half-opening type test section is shown in Fig. 11 for comparison with this experimental result. Although the variation of a sound pressure level or peak frequency to the variation of the diameter of the circular cylinder shows the same tendency, in each circular cylinder, one large peak and its harmonics component are seen, and spectrum distribution of the fluid-dynamic noise made when a circular cylinder is installed into an air current constitutes a larger sound pressure level than a back ground noise by the high frequency side which passed over the large peak. This suggests containing other sounds potential in not only the fluid-dynamic sound to be measured but also the flow noise. Therefore, it appears that the use of a blow-type wind tunnel with a half-open measurement section is rather inconvenient for measuring a sound effect. On the other hand, the results from a sealed-type measurement section of a suction-type wind tunnel becomes a sound pressure level that only the section of the frequency of the aimed fluid-dynamic sound is big as shown in Fig. 10, and the other frequency components are the same degree of the sound pressure level as the back ground noise. This is convenient for the examination of sound effects. The suction wind tunnel with a sealed-type measurement section can be expected to be a good measurement technique for examining sound effects.

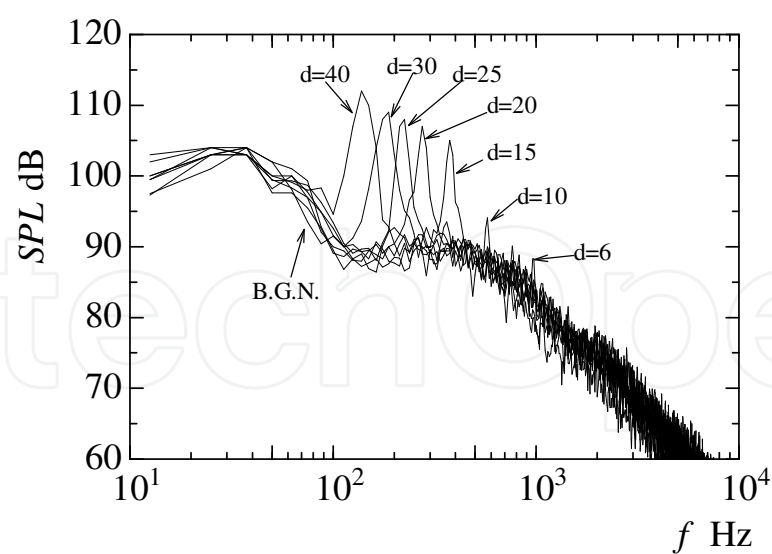


Figure 10. The characteristics of fluid-dynamic noise, in the case of present test section

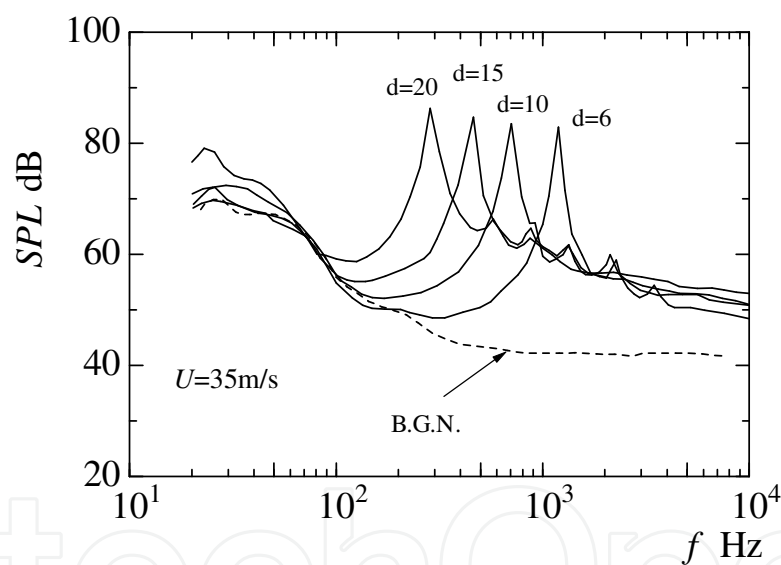


Figure 11. Characteristics of fluid-dynamic noise, in blow-type wind tunnel (Tomita et.al., 1982)

3.6. Effect of acoustic material and sound directivity

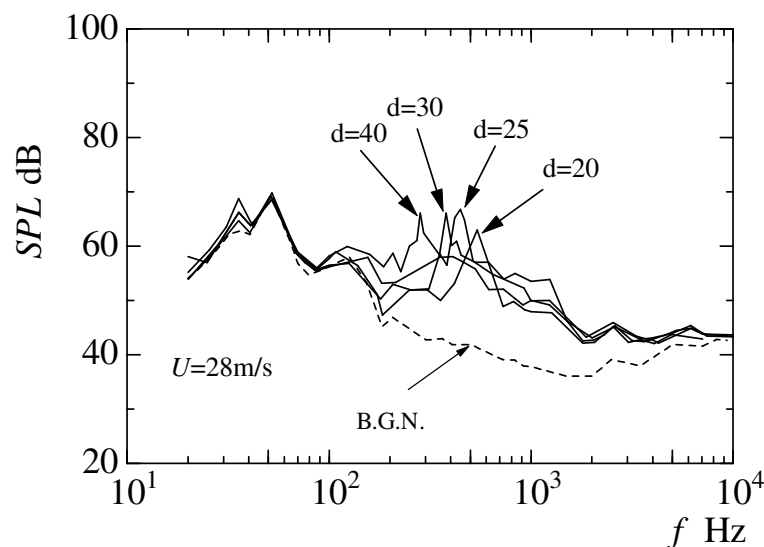
In order to verify the effect of the sound-absorbing material (fiberglass) in the measurement section, the acoustic frequency from the circular cylinder was measured. At this time, the microphone is set up from the bell mouse to 500mm upstream side by equal height to the circular cylinder installation position. The air flow velocity of the measurement section was  $U=28\text{m/s}$ . As a result, the measurement result differed according to the existence of the sound-absorbing material. Figure 12 shows the measurement results for circular cylinders 20mm, 25mm, 30mm, and 40mm in diameter when upper and lower sidewalls made of an



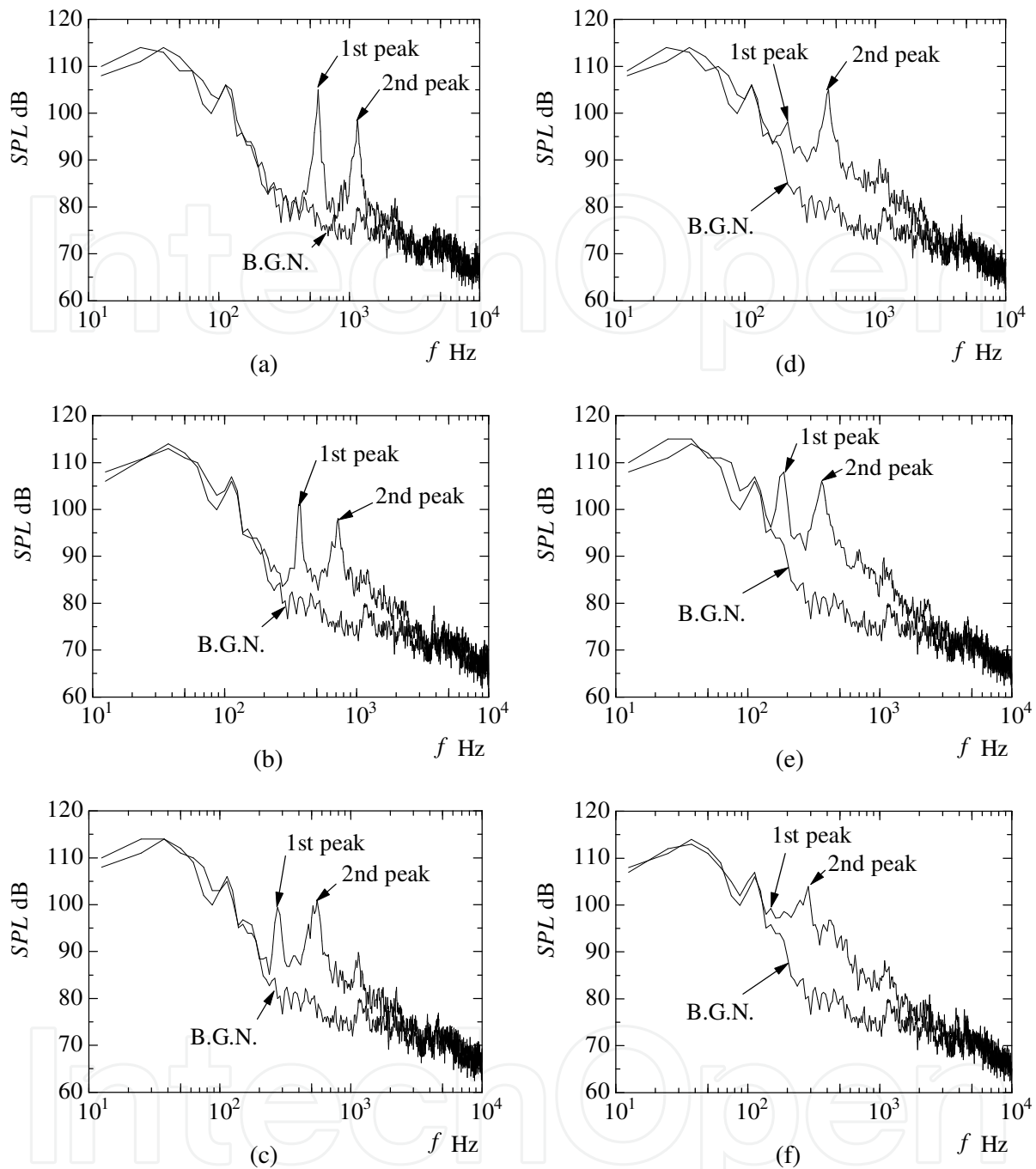
acrylic board are used. Here, the back-ground noise (B.G.N.) is shown for comparison. The sound pressure levels for the peak frequency of each circular cylinder are small, and the peak frequency is twice the value of fluid oscillating frequency, based on the Karman vortex shedding shown in Fig. 10. On the other hand, the measurement result when sound-absorbing material is installed is shown in Fig. 13, relative to back-ground noise (B.G.N.) at circular cylinder diameters of 20mm-40mm. Two sound pressure peaks are seen in each figure. The first peak (1st peak) on the low frequency side is a Karman vortex shedding frequency, and the second peak (2nd peak) on the high frequency side is twice the Karman vortex shedding frequency. Moreover, the magnitude correlation of the two peaks is different in each circular cylinder. In the case of circular cylinders with diameters of 10mm, 15mm, and 30mm, the first peak (1st peak) on the low frequency side is larger. In the case circular cylinder diameters of 20mm, 25mm, and 40mm, the second peak (2nd peak) on the high frequency side is larger. It is shown that there is a change in the interference pattern of the sound wave in a vertical direction in the flow in the measurement section. The two peaks can also be observed in a blow-type wind tunnel with a half-open measurement section as shown in Fig. 11. In this case, however, the microphone is set up at an angle of 45 degrees and positioned 500mm behind the circular cylinder, aiming at the sound around the circular cylinder. The first peak (1st peak) on the low frequency side is always larger than the second peak (2nd peak) on the high frequency side in the magnitude correlation of the peak because of the position of the microphone and the directivity of the microphone. A comparison of the results between a suction-type and a blow-type wind tunnel with sound-absorbing material installed shows that the acoustical free space of an internal flow can become an acoustical free space similar to the case of an external flow. The sound is fluctuation of the pressure which transmits the inside of fluid, the size of the amplitude is the size of sound, and the height of oscillation frequency is the height of sound. The fluid force acts on the circular cylinder by the fluid fluctuation according to the vortex shedding from the circular cylinder. The oscillation of the fluid force can be divided into a lift component and a drag component, at a ratio of 1:2. The circular cylinder placed on the air flow is a source of two kinds of sound waves as two peaks are apparent in the fluid sound. When acrylic upper and lower sidewalls are used, the acoustical free space becomes the only flow direction. The sound by the oscillation in the direction of the lift is canceled by acoustical interference. Therefore, the peak frequencies of each circular cylinder shown in Fig. 12 are considered to be the oscillation a sound from the drag direction. On the other hand, when the sound-absorbing material is installed on the upper and lower sidewalls, the acoustical free space is two directional (a parallel direction and a vertical direction) for the flow. It is an acoustical free space similar to the blow-type wind tunnel with a half-open measurement section. Therefore, the sounds of the lift and drag oscillations are measured as shown in Fig. 13.

In general, because the oscillation amplitude of the lift is far larger than that of the drag, it is expected that the sound pressure level in the direction of the lift is far larger than the sound pressure of the drag direction. However, the sound from the oscillation of the drag direction is easily detected because the directivity microphone is located on the upstream side of the circular cylinder in this measurement, and the fluid-dynamic sound by the oscillation in the direction of the lift is not detected easily. In addition, because the interference pattern of the

sound wave in the direction of the lift is different in each circular cylinder, the sound pressure level in the direction of the lift is small. The sound pressure level of the drag direction has a large value, as shown in Figs. 12(c) (d) and (f). Moreover, when the microphone is set up in the measurement section, only the fluid-dynamic sound in the direction of the lift is measured as shown in Fig. 8. Such a phenomenon suggests that the directivity of the sound source and the directivity of the microphone are at issue, and this is the subject of future investigation.



**Figure 12.** Characteristics of fluid-dynamic noise at the measurement point from the up-stream side of the test section, in the case of solid wall



**Figure 13.** Characteristics of fluid-dynamic noise at the measurement point from the up-stream side of the test section, in the case of fibered glass wall; (a) cylinder diameter  $d$  is 10mm, (b)  $d=15$ mm, (c)  $d=20$ mm, (d)  $d=25$ mm, (e)  $d=30$ mm, (f)  $d=40$ mm

#### 4. Conclusion

This study proposed a technique to measure the fluid-dynamic noise of an internal flow in a wind tunnel, and the fluid-dynamic noise from a circular cylinder placed on the air flow of a

suction-type wind tunnel with a sealed-type measurement section with sound-absorbing material (fibred grass) was measured. The following conclusions were obtained.

1. The acoustic performance and fluid-dynamic performance of a test wind tunnel were good. The following results were obtained for the performance of the test wind tunnel. The noise in the blower room is effectively intercepted. The position of the sound source and the microphone are not influenced by directivity. The uniformity of the flow of the measurement section narrows when sound-absorbing material is used for the measurement section of the test wind tunnel.
2. The following results were obtained from installing sound-absorbing material in the measurement section. The acoustical free space can be made from the closed space. When the surface of the microphone was arranged and set up on the surface of the sound-absorbing material, the measurement of the fluid sound of an internal flow became possible without any disarrangement of the flow-field.
3. The acoustic frequency measured by the microphone was confirmed to have a frequency based on the fluid oscillation caused by the Karman vortex shedding measured with the hot-wire anemometer.
4. The following results were obtained when a comparison was made with the results from a blow-type wind tunnel. The aimed acoustic frequency was measured by the large sound pressure level. Other frequency elements were the same degrees of the sound pressure level as the back ground noise. It has been understood that such a result was convenient when a sound effect was examined.
5. When an acoustical effect was examined, it was understood that the following consideration is necessary. The distance between the sound source and the microphone must be set in consideration of the influence of the pressure fluctuation of the near-field. The lower bound frequency must be understood. The microphone must be arranged in consideration of the sound directivity with the sound source.
6. From the results outlined in (2)-(4), this present measurement technique is considered to be a technique useful for the measurement of the fluid sound of an internal flow.

## Nomenclature

$a$ : acoustic velocity, m/s

$B$ : height of test section, m

B.G.N.: back ground noise, dB

$d$ : diameter of circular cylinder, m

$f$ : frequency, Hz

$I$ : intensity of sound, W/m<sup>2</sup>

$I_0$ : intensity of sound of standard,  $\text{W/m}^2$

$L$ : level of sound intensity, dB

$L_{\text{IN}}$ : level of sound intensity inside fan room, dB

$L_{\text{OUT}}$ : level of sound intensity outside fan room, dB

$PL/PL_{\text{max}}$ : dimensionless sound pressure level, non-dimensional

$r_c$ : critical distance, m

$S$ : Strouhal number, non-dimensional

$SPL$ : sound pressure level, dB

$U$ : main flow velocity, m/s

$U_{\text{max}}$ : maximum flow velocity, m/s

$u$ : component of fluctuating flow velocity, m/s

$x$ : measurement position in test section, m

$x$ : coordinate component (flow direction), m

$Y$ : measurement position in test section, m

$y$ : coordinate component (vertical direction), m

$z$ : coordinate component (horizontal direction), m

$\delta$ : thickness of boundary layer, m

$\nu$ : kinematic viscosity of air,  $\text{m}^2/\text{s}$

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## References

- [1] Fujita, H. (1994). The Present Condition and View for the Basic-study About the Flow and Sound Controls. *Proceedings of the 72nd the JSME Fall Meeting of the Japan Society of Mechanical Engineers*, pp. 360-363, Tokyo, Japan, October, 1994
- [2] Fujita, H. (1996). Experimental Study on Aerodynamic Noise Generated from two-Dimensional Models (1st Report, Study on Wind Tunnel Wall Effect and Wall Mate-



rials), *Transactions of the Japan Society of Mechanical Engineers, Series B*, Vol. 62, No. 593, (January 1996), pp. 187-193

- [3] Iida, A., Fujita, H., Kato, C., & Otaguro, Y. (1996). Experimental Investigation of the Generation Mechanism of Aerodynamic Noise (2nd Report, On Correlation Between Surface Pressure Fluctuation and Aerodynamic Sound Radiated from a Circular Cylinder), *Transactions of the Japan Society of Mechanical Engineers, Series B*, Vol. 62, No. 604, (December 1996), pp. 4160-4167
- [4] Mochizuki, O., & Maruta, Y. (1996). *Introduction of Fluid Sound Engineering*, Asakura-shoten, ISBN 4-254-23088-5, Tokyo, Japan
- [5] Tomita, S., Suzuki, S., Inagaki, S., Yokoyama, T., Kobayashi S., & Tsukamoto, G. (1982). The Study about Fluid Sound from a Cylinder in a Uniform Flow (1st Report, in the Case of Circular Cylinders), *Proceedings of the Thohoku Branch Meeting of the Japan Society of Mechanical Engineers*, Senday, Japan, October, 1984