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Study on Noise Reduction in Turbofan

(Effects on Performance and Noise by Improving Outlet Angle of Impeller)

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ABSTRACT

A turbofan has been widely used in various industrial fields. In recent years, the need for a turbofan with higher pressure ratio over wider operating flow range under quiet condition is arising. However, the noise usually increases as the increase of the pressure ratio and the widening of the operating flow range. In order to solve these contradictions on the performance characteristics, the impeller with different outlet blade angles were manufactured and tested. When the angle was properly chosen, the aerodynamic performance characteristics developed without the increase of the specific noise level.

NOMENCLATURE

$D/D_2 \times 100$: clearance ratio between tongue and tip of impeller [%]
D_2 : outlet diameter of impeller [mm]
β_1: inlet blade angle [deg]
β_2: outlet blade angle [deg]
ϕ : flow coefficient [-]
η : total pressure efficiency [-]
ψ : pressure coefficient [-]
λ : power coefficient [-]
$L_D(A)$: noise level at point D [dB(A)]
$L_S(A)$: specific noise level at point D [dB(A)]
e : non-dimensional position of hot-wire probe along casing width [-]

INTRODUCTIONS

In recent years, since a turbofan is becoming compact with keeping its performance, the rotating speed of the impeller is increasing. Consequently, the noise from a turbofan is getting louder. Thus, in order to prevent the noise emission, it is important to establish a design methodology for a better aerodynamic performance and a quieter noise at the same time. Aerodynamic noise generated from a fan is generally classified into rotating noise and turbulent noise. The rotating noise becomes predominant at the blade passing frequency and its harmonics occupies a large portion of the overall noise level. The blade angle is an essential design parameter of the impeller and it affects not only the aerodynamic performance but also the rotating noise caused by the periodic fluctuations of the wake. The present study is an attempt to develop the aerodynamic performance of a turbofan by optimizing the blade outlet angle without increase of the noise level. In order to examine the effects on the improvement for the aerodynamic performance and on the noise, and the fluctuations of the relative velocity in the outlet flow were measured.

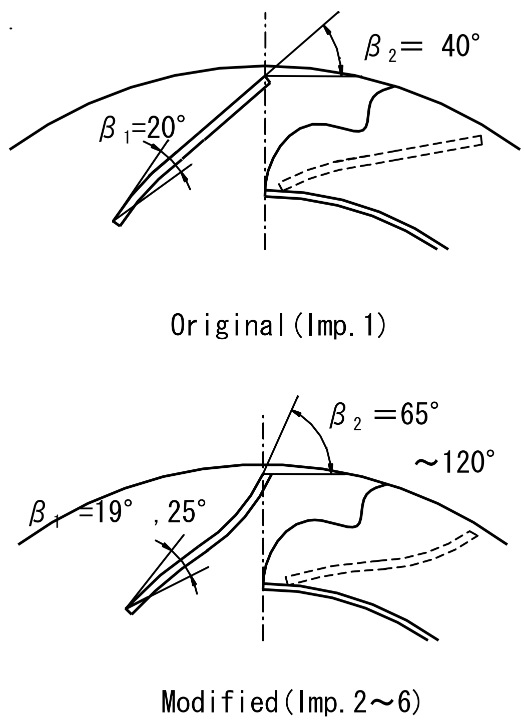

Fig1. Tested Impellers

Table 1 Blade angle of tested impeller

Impeller No.	β_1(deg)	β_2(deg)
Imp.1	20	40
Imp.2	25	65
Imp.3	25	75
Imp.4	19	75
Imp.5	19	90
Imp.6	19	120

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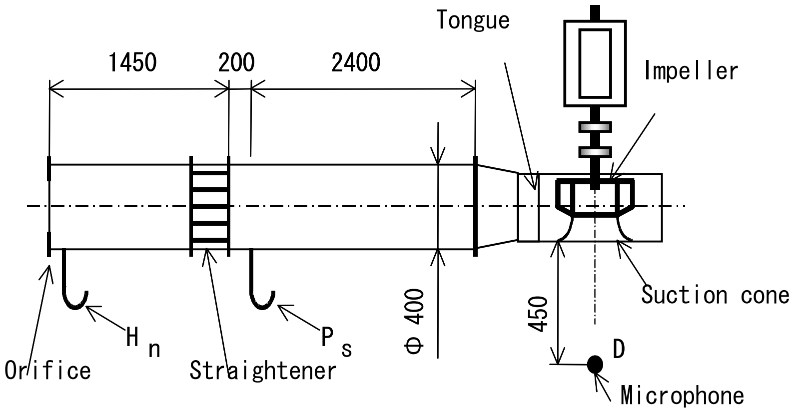


Fig.2 Test apparatus

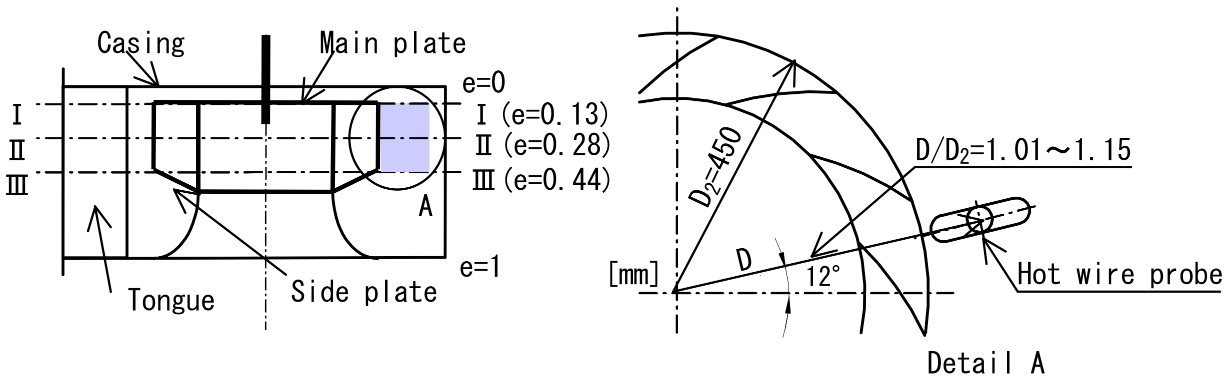


Fig.3 Measurement set up of hot-wire probe

EXPERIMENTAL APPARATUS AND METHOD

The tested fan was a single suction type turbofan having an inlet and outlet impeller diameters of 333mm and 450mm and inlet and outlet widths of 111mm and 151mm with 12 vanes. It was so designed that only the impeller could be replaced. The tested impellers have the circular-arc vanes with the backward-curve as shown in Fig.1. The original impeller (Imp.1) had the blade outlet angle β_2=40° , which was regarded as a conventional value. Generally, the larger blade outlet angle decreases the outlet relative velocity, and as the result, the outlet pressure increases. However, concerning the increase of blade outlet angle, a little work has been reported in a turbofan impeller. In the present study, the modified impellers having larger blade outlet angle than the original one were manufactured (Imp.2-Imp.6). The blade angles of the impellers are shown in Table 1.

The performance tests were carried out in accordance with the JIS B 8330[4] by the apparatus shown in Fig.2. The flow rate was obtained by measuring the pressure difference of the outlet orifice. The rotating speed of the impeller was maintained at 1575 rpm where the specific speed was about 700. The noise level was measured at the point D, 450mm away from the center of the suction cone, and the 1/3 octave band analysis was done by using a FFT analyzer.

It is assumed that, when the blade outlet angle is too large, the high blade loading at the trailing edge will generate the strong flow separation and affect to the velocity fluctuations of the outlet flow, which is becoming a sound source of the rotating noise. In order to clarify the mechanism of the noise generation and the relationship between the strength of the wake and the noise level, the distribution of the relative velocity and the velocity fluctuations of the outlet flow were measured. A single hot-wire probe was inserted into the casing along the width shown in Fig.3. The position of the probe in the direction of casing width and the radial direction were represented by the symbol e and D/D_2, respectively. In order to observe the time dependent velocity synchronizing with the impeller passage, the signal of the probe was triggered by the magnetic pickup attached to the impeller shaft.

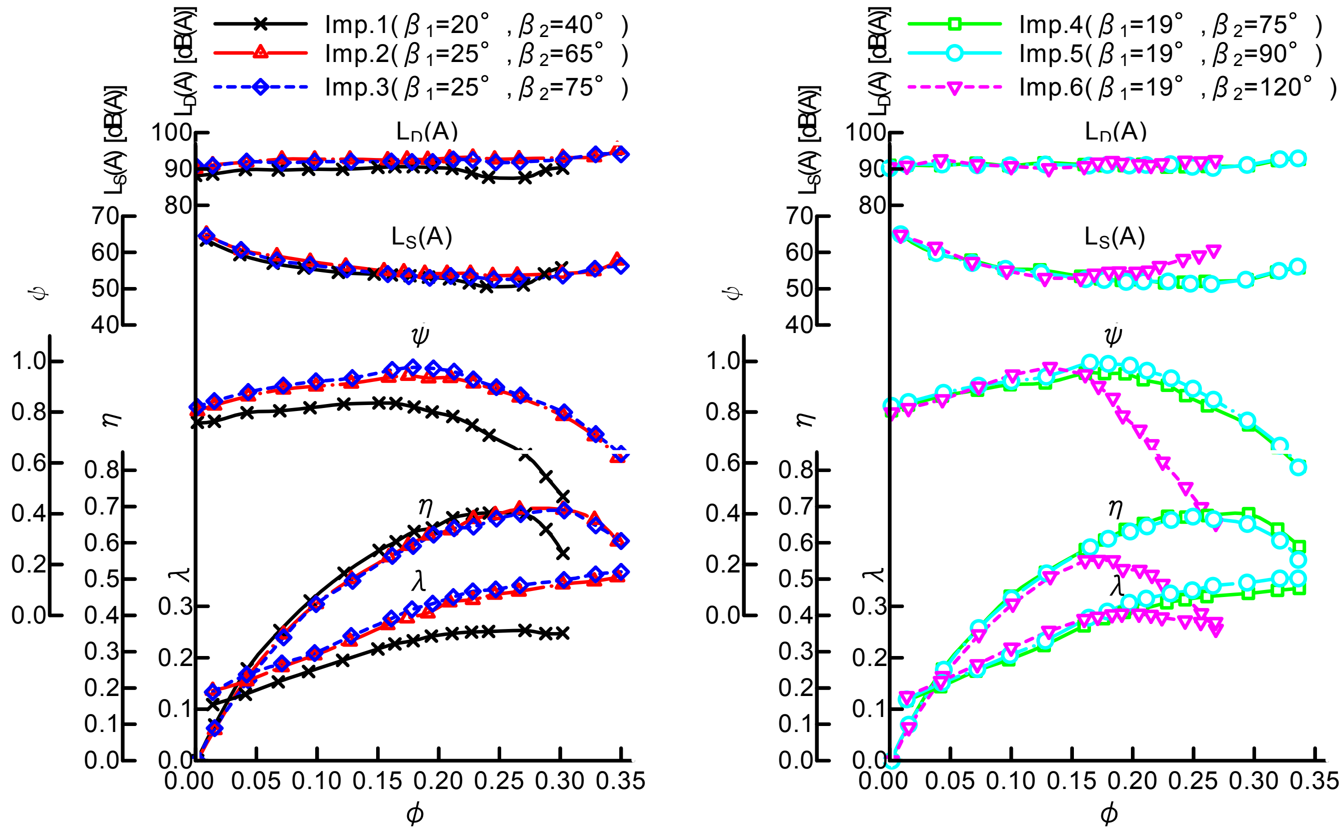
RESULTS AND DISSCUSSION

Performance and Noise Characteristics

Fig.4(a) shows the aerodynamic performance characteristics of the tested impellers. The modified impellers (Imp.2 and Imp.3) have the higher pressure coefficients ϕ than the original one (Imp.1), especially in ϕ>0.15. In addition, the maximum flow rate of the Imp.2 and the Imp.3 were greater than the Imp.1 by 10%. Though the efficiencies of the Imp.2 and the Imp.3 were lower than the Imp.1 at the lower flow rate, these were much higher than that of the Imp.1 at the higher flow rate. It is clear that the higher blade outlet angle than the conventional one can improve the aerodynamic performance substantially. However, the power coefficients λ of the Imp.2 and Imp.3 were increased in proportion to the increase of the pressure ratio.

The curves of the modified impellers having much larger blade outlet angles (Imp.4, Imp.5 and Imp.6) are shown in Fig.4(b). The pressure coefficients increased for the Imp.4 and Imp.5, having the blade outlet angle of β_2=75° and β_2=90° , respectively. However, the Imp.6, having an extremely large blade outlet angle of β_2=120° , decreased its performance significantly. It is assumed that the Imp.6 caused the strong separation due to the steep curvature at the trailing edge.

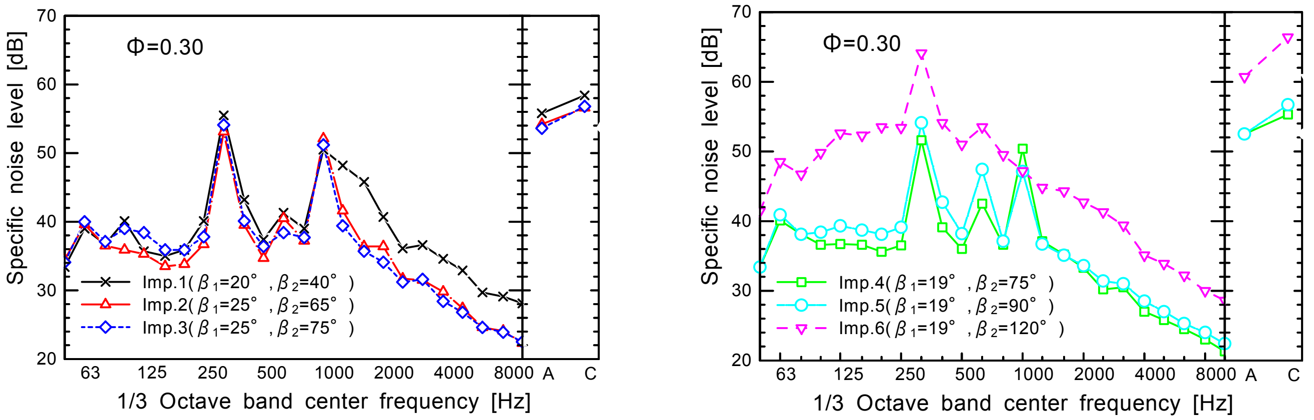
The noise characteristics are also shown in Fig.4(a) and Fig.4(b).



(a) Imp.1, Imp.2 and Imp.3

(b) Imp.4, Imp.5 and Imp.6

Fig.4 Characteristic curves for tested impellers

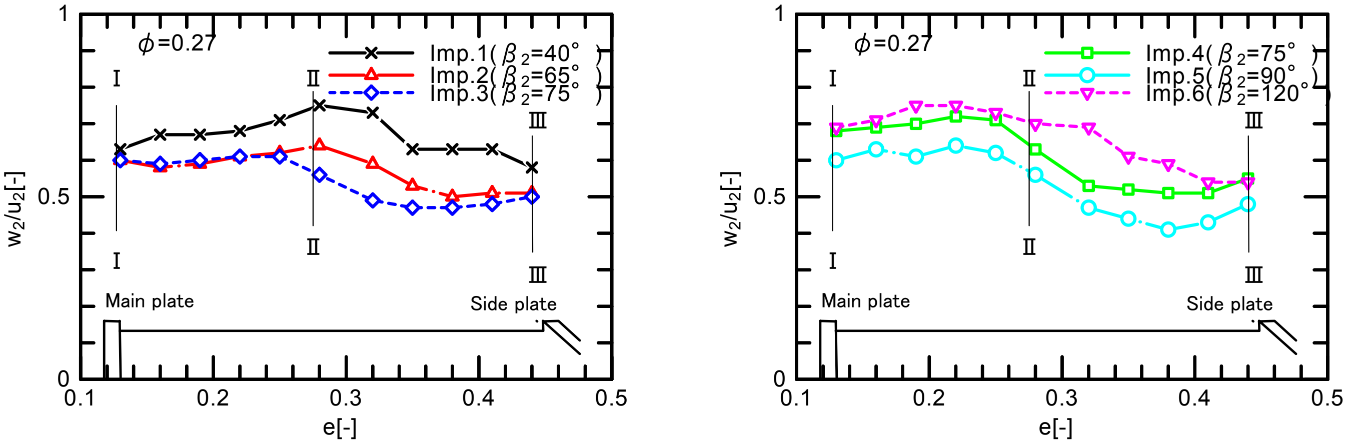


(a) Imp.1, Imp.2 and Imp.3

(b) Imp.4, Imp.5 and Imp.6

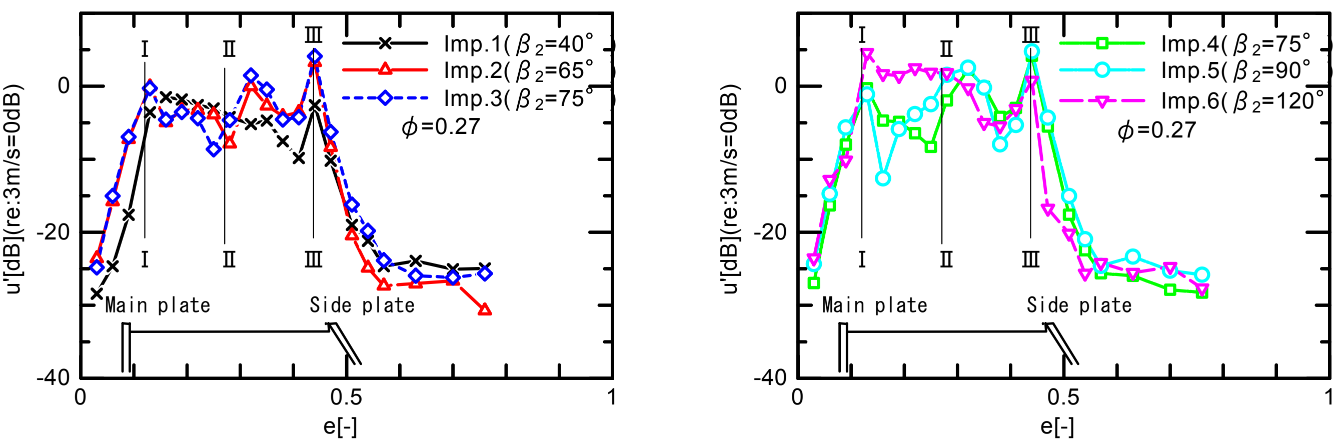
Fig.5 Noise spectra of tested impellers

The overall noise level L_D of the modified impellers with the blade outlet angle of β_2<90° were larger than that of the original one by a few dB. For the specific noise level L_S, taking into account the aerodynamic performance, there was little difference between the original and the modified impellers. Thus, the modified impellers except Imp.6 attained the improvement of aerodynamic performance without deteriorate the noise characteristics. However, only the L_S of the Imp.6 (β_2=120°) became much larger than the others with the decrease of the aerodynamic performance. The specific noise spectra of the tested impellers (Imp.1, Imp.2 and Imp.3) at the flow rate of ϕ=0.30 are shown in Fig.5(a). The rotating noise which has large contribution to the overall noise level appeared at the 315Hz of the 1/3 octave band center frequency including the blade passing frequency. For the modified impellers except Imp.6, noise reductions up to 4dB in the blade passing frequency, approximately 6dB in the broad band component over 1kHz and up to 3dB in the overall noise levels were obtained. As shown in Fig.5(b), Imp.4 and Imp.5 had the same trend as in Imp.2 and Imp.3, in the present experiments. It was not observed a certain relationship between the blade outlet angle and the noise level. However, Imp.6 increased the specific noise level in all frequency range with the decrease of the aerodynamic performance. Thus, it is clear that the larger blade outlet angle up to 90° can improve both the aerodynamic performance without deterioration the noise characteristics.



(a) Imp.1, Imp.2 and Imp.3 (b) Imp.4, Imp.5 and Imp.6

Fig.6 Distribution of relative velocity of outlet flow in a direction to casing width



(a) Imp.1, Imp.2 and Imp.3 (b) Imp.4, Imp.5 and Imp.6

Fig.7 Velocity fluctuations of rotating noise around outlet flow in a direction to casing width

Measurement of Outlet Flow

The modified impellers improved the aerodynamic performance and noise characteristics. That means the larger blade outlet angle is effective. In order to examine the effect of the improvement, the outlet flow of the impeller was measured.

Fig.6(a) and Fig.6(b) show the distributions of the relative velocity of the outlet flow measured by the hot wire probe at the flow rate ϕ=0.27. The horizontal axis shows the position of the hot-wire probe along the casing width, represented by the symbol e. Here, e=0 corresponds to the casing wall on the impeller hub side, and e=1 to the casing wall on the impeller shroud side. The outlet of the blade is located from e=0.12 to e=0.46 as shown in the figure. In case of the modified impellers with the blade outlet angle of $\beta_2 \leqq 90^\circ$, the relative velocity becomes small as the blade outlet angle becomes large. These show the same trend as the pressure coefficient in the aerodynamic performance characteristics.

The velocity fluctuations of the outlet flow at the blade passing frequency are shown in Fig.7(a) and Fig.7(b). The vertical axis indicates the root-mean-squared value of the velocity fluctuation level denoted by dB. The velocity fluctuation levels were large at the region where the outlet flow directly flows, especially at the impeller side plate. It is due to the flow separation generated from the side plate of the impeller, and it becomes the strong noise source. The velocity fluctuation levels at e=0.28 〜 0.44 are corresponding to the increase of the blade outlet angle. On the other hand, Imp.6 showed the different tendency from the other modified impellers as shown in Fig.6(b) and Fig.7(b).

The time histories and the variations of the velocity fluctuation levels in the radial direction at the side plate (e=0.44) are shown in Fig.8 and Fig.9. When the clearance ratio between the tip of the impeller and the tongue is small (D/D_2=1.01〜1.07), the velocity fluctuation levels of the modified impellers were larger than the original one. It means that the modified impellers gave the larger source of rotating noise[1)-3)]. When the clearance ratio became greater, the amplitude of the velocity fluctuations was gradually decreased. When the clearance ratio exceeds 1.07, the levels did not depend on impeller types. The rotating noise is caused by the periodical interference between the outlet flow and the tongue. Thus, it can be estimated that the velocity fluctuations of the modified impellers were larger than the original one, the rotating noise could be reduced by widening the clearance between the tongue and the impeller.

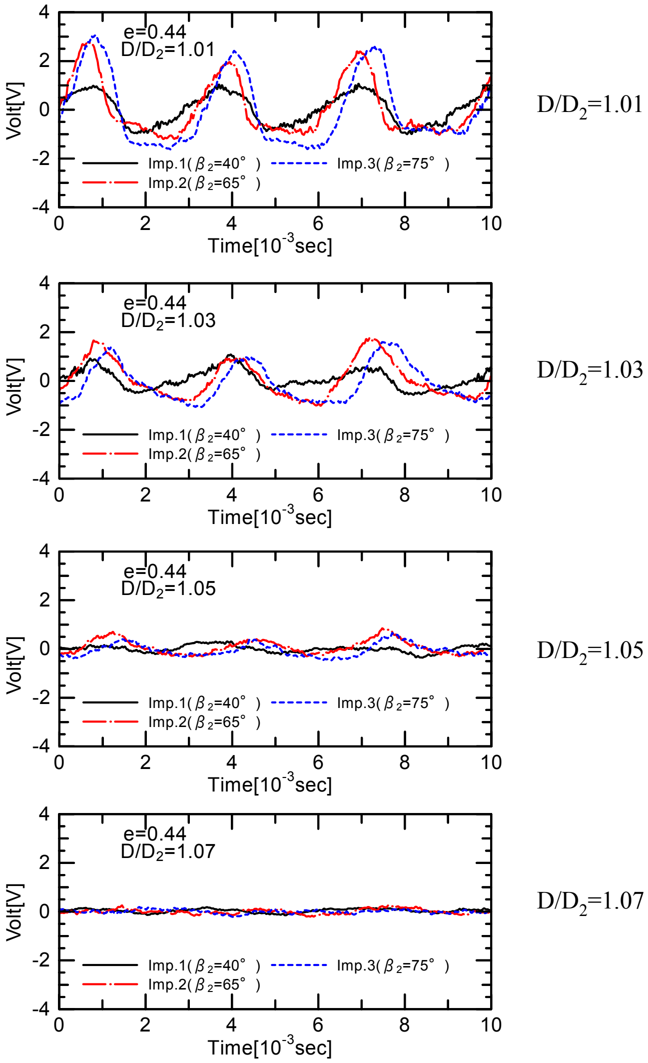
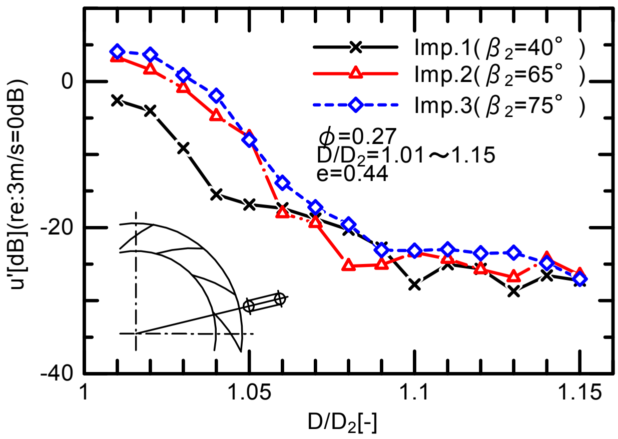
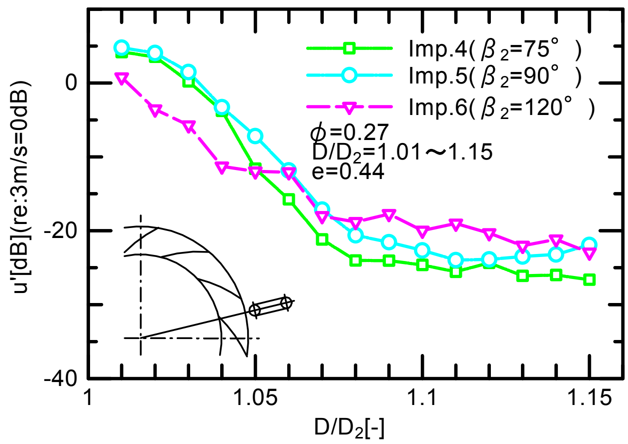


Fig.8 Time histories velocity fluctuations of wakes (Imp.1, Imp.2 and Imp.3)



(a) Imp.1, Imp.2 and Imp.3



(b) Imp.4, Imp.5 and Imp.6

Fig.9 Variations of velocity fluctuation level in radial direction

CONCLUSION

In order to gain a higher pressure ratio in a turbofan, the blade outlet angle of the impeller was modified and tested. When the blade outlet angle β_2 was increased up to 90°, the aerodynamic performance characteristics such as the pressure coefficient and the maximum flow rate were improved. In addition, the specific noise level was almost the same as the conventional one. By the measurement of the velocity fluctuations of the wake, it became clear that the rotating noise can be reduced by widening the clearance $D/D_2 \geqq 1.07$ in the case of the modified impeller, having the strong velocity fluctuations.

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