An Experimental Study of On-blade Active Tab for Helicopter Noise Reduction

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Abstract

This paper presents the experimental results of the active tab (AT) effect on rotor noise reduction. The active tab is installed in a blade of a 1-bladed rotor model and the noise reduction effect is studied by a wind tunnel test measuring sound pressure and blade surface pressure. In this wind tunnel test, the amplitude and frequency of the active tab are pre-set because of the model rotor mechanical limitation.

The wind tunnel test was performed in 2003 and 2004 in the 2.5x2.5m low speed wind tunnel of Kawada Industries, Inc. The active tab effect on rotor noise reduction is studied with respect to the active tab phase angle. About 2dB noise reduction is observed from the base line condition where the active tab is not operated and about 3dB capability to control the rotor noise, which is the difference between the maximum and the minimum rotor noise, is also demonstrated.

Notation

Symbols

c	Blade chord=0.12m
C_p	Pressure coefficient
ΔC_{pmax}	Pressure fluctuation index
R	Rotor radius=1m
SPL	Sound pressure level (dB)
V_W	Wind tunnel speed (m/sec)
δ_{AT}	Active Tab deflection (deg.)
ϕ	Rotor azimuth angle (deg.)

Abbreviations/Subscripts

AT	Active Tab
BVI	Blade/Vortex Interaction
HHC	Higher Harmonic Control
IBC	Individual Blade Control

Introduction

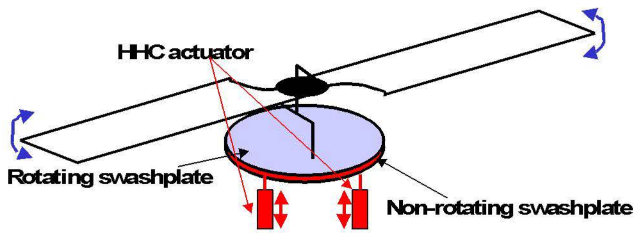
Several active techniques, such as HHC (Higher Harmonic Control) (Refs.1-3), IBC (Individual Blade Control) (Refs.4-7), active flap(Refs.8, 9), active twist(Refs.10-12) and the like, have been proposed, researched and developed for helicopter noise/vibration reduction so far. Some of them were flight-tested and others are in the phase just close to flight test evaluation.

The outlines of each existing active technique, for example on 2-bladed rotor, are depicted schematically in Fig.1.

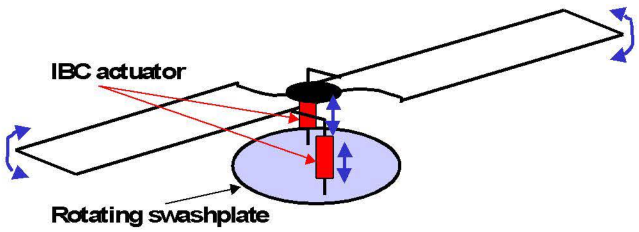
HHC shown in Fig.1 (a) actuates the whole blade by the actuator on the non-rotating frame. This technique has two drawbacks. One is that the actuator is required for high power to drive the non-rotating/rotating swashplates and the inboard portion of the blade as well which are aeroacoustically idle parts. The other is that the higher harmonic pitch frequency able to be appeared on the rotating blade is limited to bΩ and (b$\pm$1) Ω, where b and Ω stand for the number of the blades and the rotor speed, respectively.

IBC shown in Fig.1 (b) drives still the whole blade but by the actuator installed on the rotating frame. This technique improves the former drawback of HHC largely and the latter completely at the price of complicated hydraulic system which transmits actuation fluid with high pressure and large flow rate from the non-rotating frame to the rotating frame.

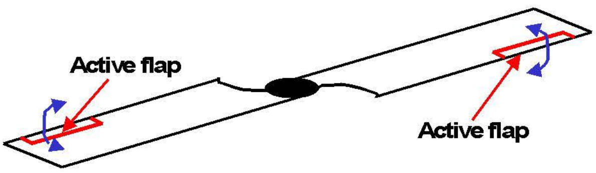
Active flap drives a small flap installed at the trailing edge of a blade tip portion as shown in Fig.1 (c). This technique is power effective compared with HHC and IBC, because only the aeroacoustically useful blade tip part is driven. The flap is actuated by an on-board smart actuator. This technique is materialized by a recent breakthrough in the smart actuator technology area, although the flap drive system still has the challenges in a mechanical component to make enough large flap amplitude with high frequency in high centrifugal force circumstance.



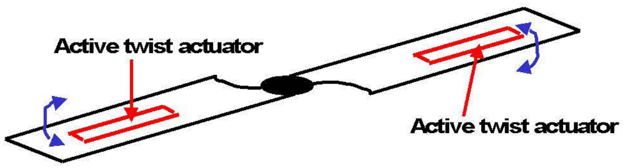
(a) HHC



(b) IBC



(c) Active flap



(d) Active twist

Fig.1 Existing active techniques

Active twist shown in Fig.1 (d) twists a blade directly by an actuator sheet placed along the blade span underneath the skin without any mechanical component standing between actuator and blade, which makes this technique the best power effective among the four mentioned so far. It is supposed that the effort to generate enough large blade tip amplitude for rotor noise reduction is going on.

In terms of noise reduction, these active techniques are efficient for Blade/Vortex Interaction (BVI) noise which is generated during the approach to the landing area and occupies a large part of an issue for the public acceptance of helicopter. But these techniques are either not so useful or not so efficient for the noise reduction during climb and fly-over flight patterns as for approach flight pattern.

JAXA (Japan Aerospace Exploration Agency) and Kawada Industries Inc. have been working together under the joint research program to research and develop a new active technique for helicopter noise reduction which is available to all the flight patterns in order to cope with this problem. This new technique is referred as "Active Tab", which is installed at the airfoil trailing edge of the blade tip portion and is driven back and forth to control the blade lift dynamically. As an initial step, 2D static and dynamic wind tunnel tests were performed to study the fundamental aerodynamic effect of the active tab in the 2m by 2.5m low speed tunnel of Kawada Industries Inc. in 2002 and 2003. These tests showed that the realistic size of the active tab has the sufficient aerodynamic capability with regard to the lift control which is properly related to the potential for the rotor noise reduction (Ref.13).

This paper presents the next step of the wind tunnel testing activity to evaluate the active tab effect in a rotor configuration on BVI condition.

Objectives

The objectives of this study are as follows;

(1) Evaluation for the noise reduction effect of Active Tab in the rotor configuration.

(2) Study for blade aerodynamic influences induced by Active Tab operation.

Description of Active Tab

The schematic view of the active tab is shown in Fig.2. The active tab is installed in the aft portion of the airfoil and driven back and forth dynamically to reduce BVI noise and the vibration by the blade lift control due to the variable blade area effect. The active tab also can be operated statically, such as the active tab is deployed with some displacement and fixed. This way of operation can increase the blade lift during the whole revolution of the blade so that the rotor speed can be reduced by making use of this lift increment, which has the effect on the climb and fly-over noise reduction.

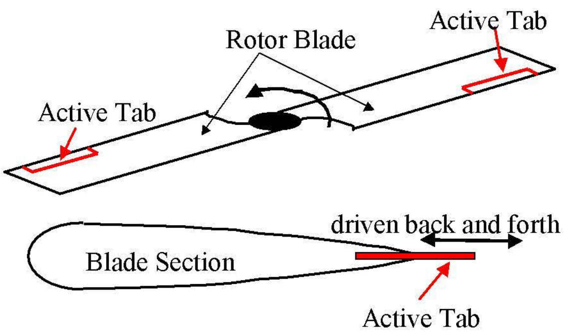


Fig.2 Active tab concept

Wind Tunnel Testing

Model description

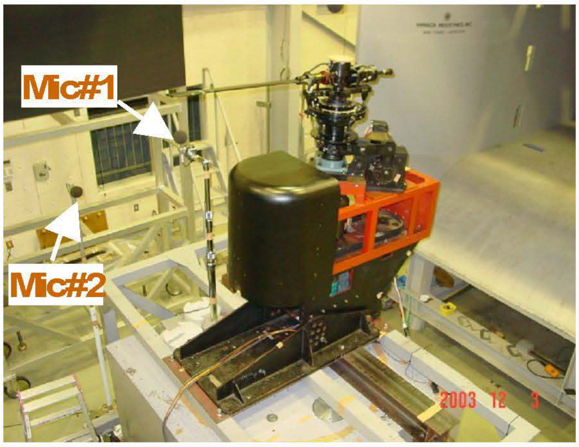
The wind tunnel test was performed to study the noise reduction effect of the active tab by a rotor configuration in the 2.5m by 2.5m low speed wind tunnel of Kawada Industries, Inc. in 2003 and 2004 using a one-bladed rotor system as shown in Fig.3. The main features of this rotor system are shown in Table 1.

The collective and cyclic pitch angles of the rotor blade are pre-set by the collective fitting which connect the blade and the hub.

The active tab installed on the blade and its schematic drawing is shown in Fig.4. The main features of the active tab are also shown in Table 1. The tab is fan-shaped so that the extended area generated by the tab operation is made larger in the outer portion of the blade. A 10deg. anhedral angle is put to the tab so that the tab effect to the blade lift increment is augmented based on the previous work as shown in Ref.13.

The rotor is driven by the electric motor referred as rotor drive motor in Fig.3 and the active tab mechanism is driven by the separate electric motor referred as HHC motor in Fig.3. These two motors are synchronized electrically by the encoder installed in each motor in order to make the proper active tab phase angle shifting with respect to the rotor azimuth angle.

The vertically reciprocating movement of the swash plate is generated by the lever and crank mechanism which is driven by the eccentric disk installed on the end of the output shaft of the HHC motor.



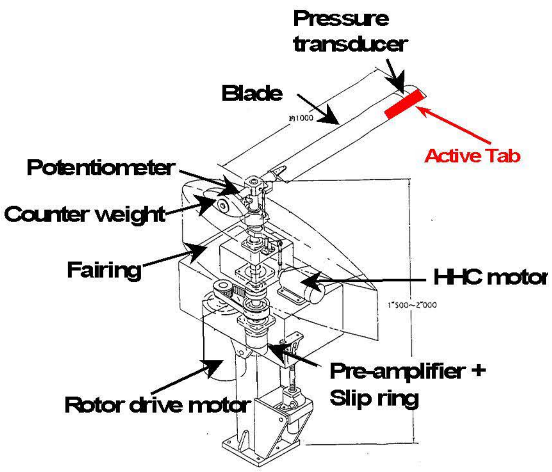


Fig.3 One-bladed rotor system

Table 1 Features of rotor system and active tab

Hub type	rigid in flap and lead-lag
Rotor radius	1m
Blade chord	0.12m
Airfoil	NACA0012
Blade plan form	Rectangular
Blade twist	0deg.
Rotor speed	1200rpm (max)
Collective pitch	-5 to +15deg.
Cyclic pitch	0deg. (fixed)
Active Tab	Amp. : 24mm(max)
	Freq. : 20Hz
	Phase : variable
	Span : 80 ~ 98%R
	Plan form: fan shape
	Anhedral: 10deg.

This vertical movement is transmitted to the push-pull rod which makes the rotary reciprocation of the torque tube via. the crank arm installed at the blade root side so that the active tab installed on the blade tip side of the torque tube is oscillated back and forth by a rack and pinion apparatus.

A fan-shaped active tab is installed on the blade in this wind tunnel test as shown in Fig.4. This active tab is pivoted at its apex to 80%R location of the blade. The end of the rack which makes the active tab move back and forth is fixed to the active tab slightly outboard side of the active tab apex so that the travel of the rack can be made as small as possible to achieve the full amplitude of the active tab motion.

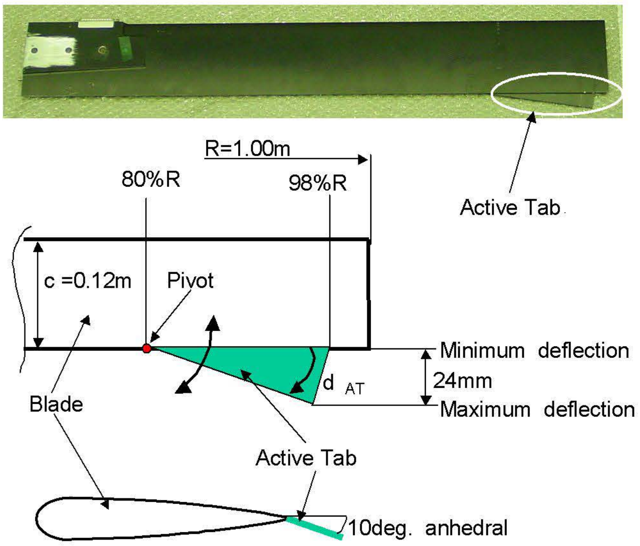


Fig.4 Active Tab installation

The active tab deflection is defined as follows;

$$\delta_{AT} = \theta_{AT}\cos(2\Omega t - \phi_{AT})$$

where

δ_{AT} : active tab deflection (deg.)

θ_{AT} : active tab amplitude (pre-set, deg.)

ϕ_{AT} : active tab phase (deg. or rad)

Ω : rotor speed (rad/sec)

Test condition

The test condition is as follows;

Wind tunnel

Wind speed : 18m/sec

Test section : open

Rotor system

Rotor speed : 600rpm (10Hz)

Collective pitch angle : 4.3deg

Cyclic pitch angle : 0deg

Rotor shaft angle : 2deg. nose up

Active tab

Frequency : 20Hz (2/rev)

Amplitude : 3.8deg.

Phase : 0 ~ 360deg.

Measurement

The blade surface pressure distribution is measured by pressure transducers mainly located on the 85%R position of the upper and lower sides of the blade. Two microphones are set in the wind tunnel as shown in Figs.3 and 5 to evaluate the active tab effect for rotor noise reduction.

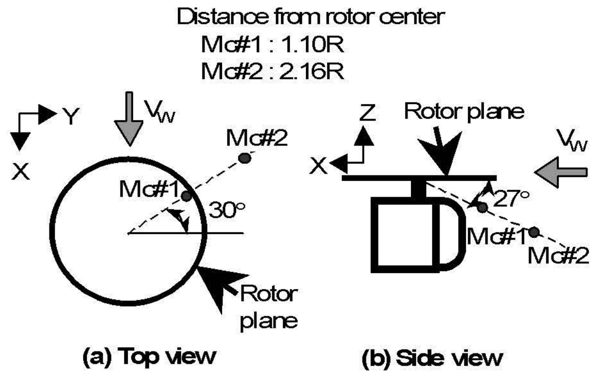


Fig.5 Microphone position

The active tab deflection is detected by a Hall sensor installed just inboard portion of the active tab and a potentiometer installed at the center of the rotor hub measures blade pitch angle.

A pulse encoder generating 1/rev signals is installed beneath the rotor plane at about ϕ =0deg.

The schematic view of the whole measurement system is shown in Fig.6.

Data acquisition/procession

The above mentioned measured items are acquired simultaneously and processed with 1/rev output signals of the pulse encoder in order to be related with the blade azimuth angle.

The sample rate for microphones is set at 10kHz and that for the others such as the blade surface pressures and Hall sensor is set at 4kHz by the limitation of data storage.

All the data acquired in the time domain are ensemble averaged of 40 revolutions equal to

4sec.

Fig.7 Correction for active tab deflection

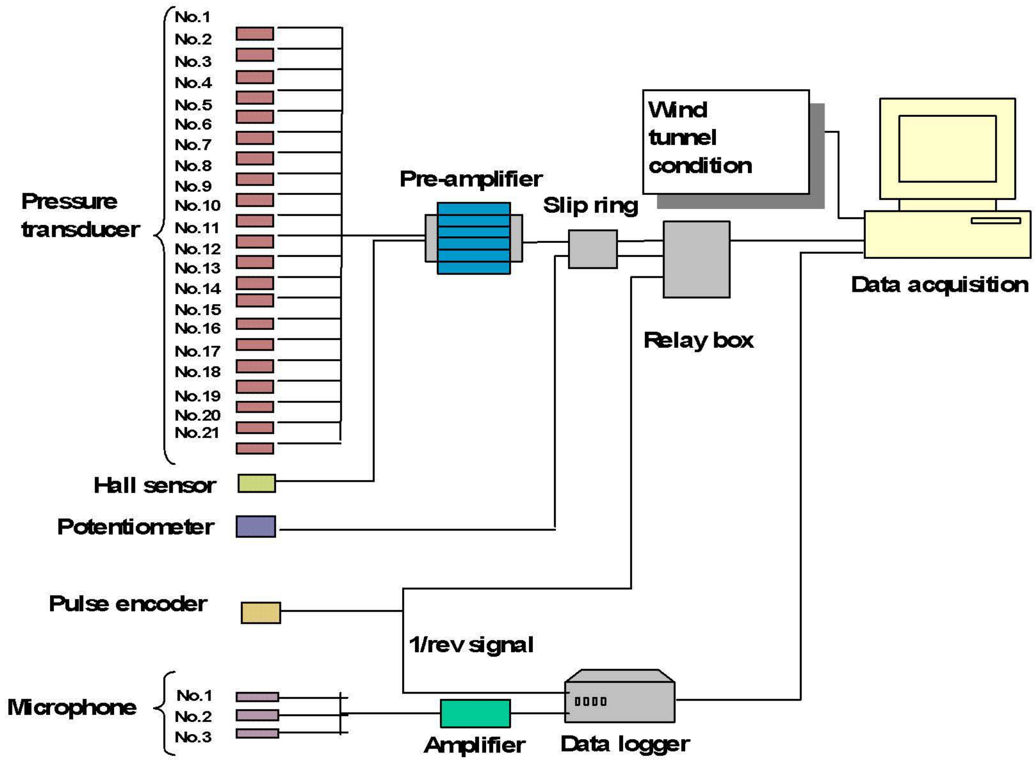
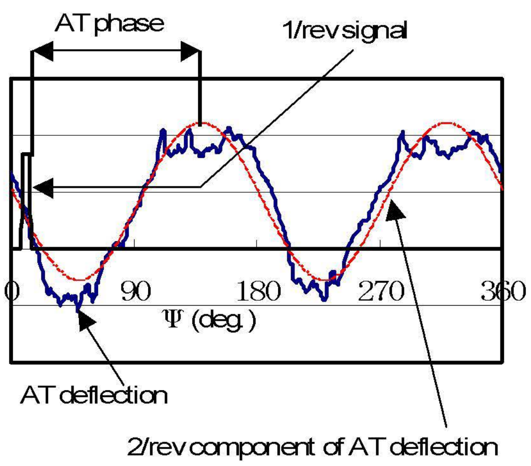


Fig.6 Measurement system

in order to eliminate the random noise from the measured data and to make the periodical aeroacoustic and aerodynamic characteristics caused by rotor revolution clear.

Because of mechanical hysteresis of the crank arm, the dynamic deflection of active tab is distorted shown in Fig.7. The data procession to correct the dynamic tab motion coping with this problem is carried out as follows and as shown in Fig.7;



a) FFT the Hall sensor signal which expresses the actual tab motion.

b) Take 2/rev component which is the dominant and intended tab motion.

c) Replace the actual Hall sensor signal by this 2/rev component.

d) Comparing with 1/rev pulse encoder signal, the amplitude and phase shift of the tab motion are obtained.

Results and discussion

Blade surface pressure

The blade surface pressure at 0, 2.6, 11.2 and 17.4%c positions on both the upper and lower surfaces of 85%R with respect to the rotor azimuth without AT is shown in Fig.8.

In order to closely examine BVI phenomenon, the blade surface pressure at 2.6%c, 90%R on the upper and lower surfaces with respect to the rotor azimuth without AT is shown in Fig.9. It is inferred based on these figures that the effective angle of attack of the blade segment is being decreased by the approach of the blade tip vortex and being increased by the departure,

angle=2.0deg., no AT

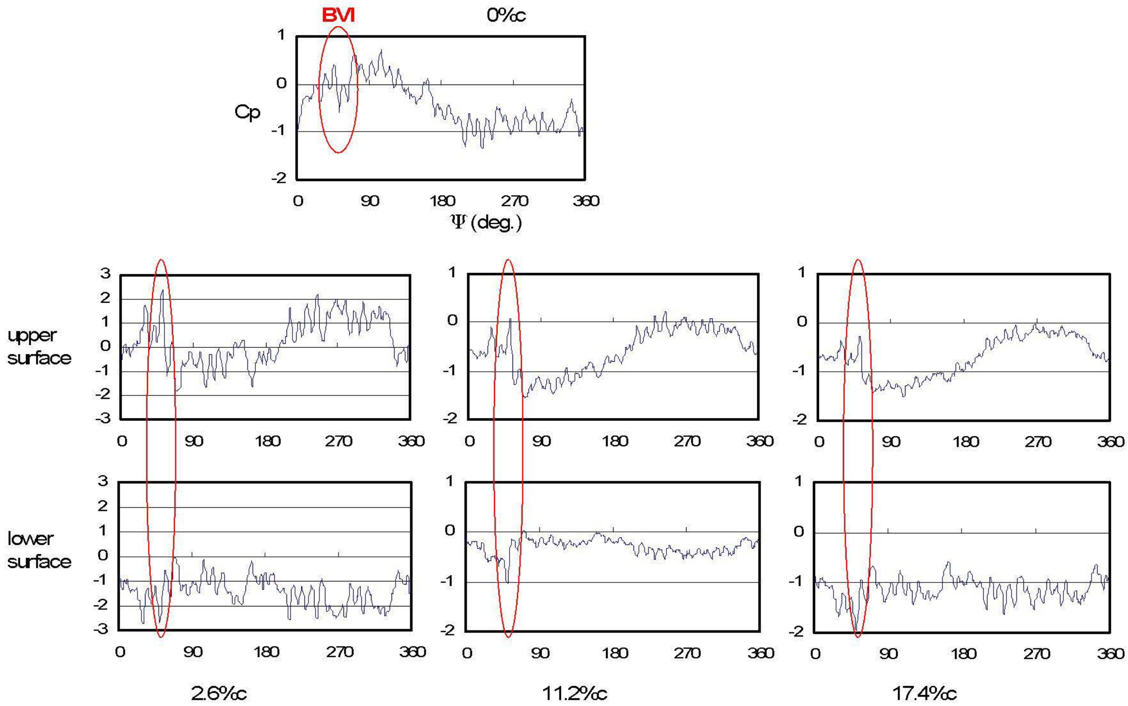


Fig.8 Blade surface pressure at 85%R

V_W=18m/sec, rotor speed=600rpm, collective=4.3deg., cyclic=0deg., rotor shaft angle=2.0deg., no AT

which makes the abrupt temporal change of the blade surface pressure. Fig.8 and 9 clearly show this BVI phenomenon captured as this abrupt pressure change process in a short time of the period at around is ϕ=55deg. for both the upper and lower sides of the blade.

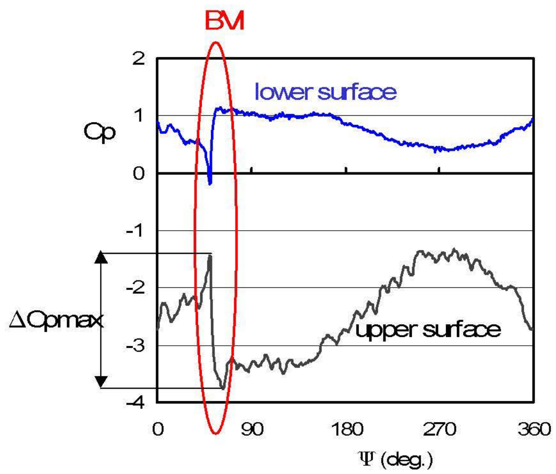


Fig.9 Blade surface pressure at 2.6%c, 90%R

V_W=18m/sec, rotor speed=600rpm, collective=4.3deg., cyclic=0deg., rotor shaft

The magnitude of Cp gap at the BVI region has the difference between AT on and off. There also is this Cp gap difference among AT phases. Therefore, this Cp gap can be an index to express BVI relief effect due to AT phase variation.

In order to evaluate this BVI relief effect with respect to AT phase, the pressure fluctuation index ΔC_{pmax} which physically means the maximum value of the deference in the pressure coefficient between the successive ϕ's (see Fig.9) is introduced and defined as shown in Ref.14, which is repeated below for convenience.

$$\text{Pressure Fluctuation Index}: \Delta C_{p\max} = \max(\Delta C_p(\psi_i))$$

$$\Delta C_p(\psi_i) = C_p(\psi_i) - C_p(\psi_{i-1})$$

$$\psi_i - \psi_{i-1} = 0.9\,\text{deg}.$$

$$C_p = \frac{P - P_s}{q}$$

where

P : measured blade surface pressure

Ps : static pressure

q :dynamic pressure at 85%r/R as
V_W=0m/sec, rotor speed=600rpm

Fig.10 shows the blade surface pressure characteristics reduced in ΔCp over the interested ϕ range around BVI for no AT, AT phase=100deg. and 282deg.

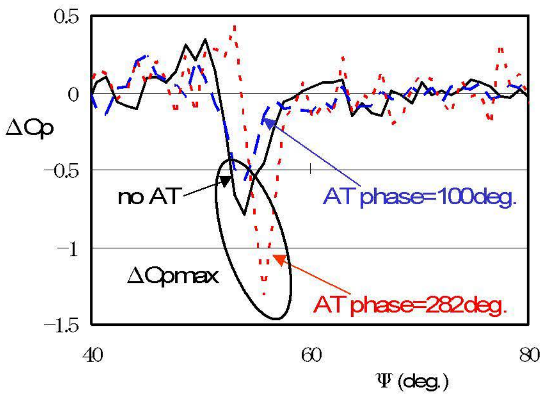


Fig.10 Blade surface pressure fluctuation at 2.6%c, 90%R of upper surface

V_W=18m/sec, rotor speed=600rpm, collective=4.3deg., cyclic=0deg., rotor shaft angle=2.0deg., AT frequency=2/rev, AT amplitude=3.8deg.

ΔCp of AT phase=100deg. case is reduced by about 30% from that of no AT case and ΔCp of AT phase=282deg. case is about 70% larger than that of no AT case. It is noted that ΔCp of the three cases once changes in the positive direction in the beginning of BVI as well as in the negative direction in the middle of BVI process.

ΔCpmax is obtained at ϕ where the BVI takes place. There are some difference in ϕ having ΔCpmax among the three cases. This is mainly inferred that a 0.9 deg. resolution in ϕ which is consequently generated by the combination of the data sampling rate 4kHz and the rotor speed 600rpm of this wind tunnel testing is not enough fine to capture ΔCp's for each case.

More systematic study for the effect of AT phase on ΔCp is shown in Fig.11 as the relationship between ΔCpmax and the whole range of AT phase. The minimum absolute value of ΔCpmax is obtained at AT phase=100deg., which means the maximum BVI relief effect is attained at this AT phase. The opposite happens at AT phase=282deg. where the most adverse influence of AT phase on BVI is observed.

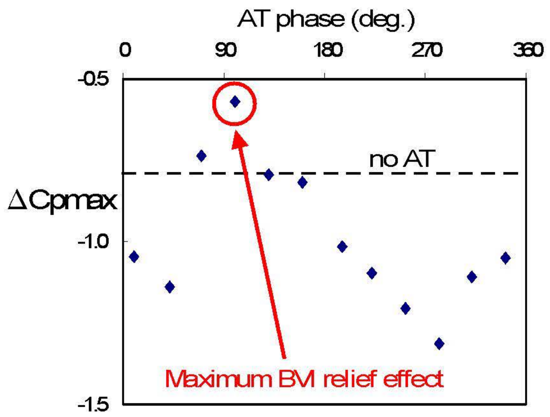


Fig.11 AT phase effect on BVI relief

V_W=18m/sec, rotor speed=600rpm, collective=4.3deg., cyclic=0deg., rotor shaft angle=2.0deg., AT frequency=2/rev, AT amplitude=3.8deg.

Sound pressure

Fig.12 shows the active tab effect for rotor noise reduction measured by Mic#1. The sinusoidal variation of the sound pressure level with respect to AT phase is fairly seen in this figure. The back ground noise caused by the wind tunnel is subtracted from all the data points. Furthermore for AT on cases, the mechanical noise generated during AT operation is subtracted as well to purify the AT effect on rotor noise reduction.

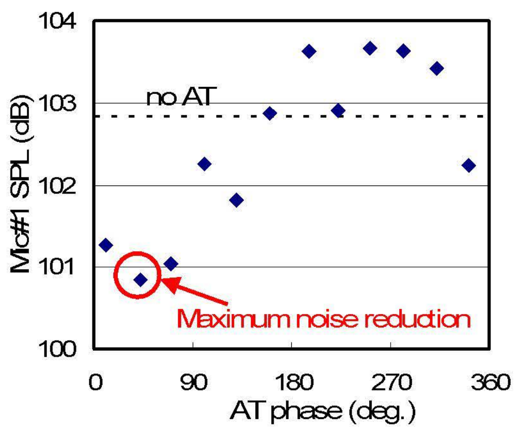


Fig.12 AT effect for rotor noise reduction (Mic#1)

V_W=18m/sec, rotor speed=600rpm, collective=4.3deg., cyclic=0deg., rotor shaft angle=2.0deg., AT frequency=2/rev, AT amplitude=3.8deg.

AT phase=42deg. has the maximum noise reduction effect, otherwise AT phase=252deg. has the most adverse effect. 2dB noise reduction capability from no AT condition and 2.9dB noise controllability, which is the difference between the maximum and the minimum rotor noise, are observed from this figure.

Studying Figs.11 and 12 together, the correlation between ΔC_{pmax} and the sound pressure level with respect to AT phase can be seen. AT phase range around 90deg. simultaneously has the maximum BVI relief effect indicated by ΔC_{pmax} and the largest rotor noise reduction by the sound pressure level. On the other hand, the opposite happens in AT phase range around 270deg.

Conclusions

Summarizing the experimental results, the followings are concluded by this study.

1. It is demonstrated by the wind tunnel test in a rotor configuration that the active tab has the efficient capability to control the rotor noise about 3dB and that the active tab is one of the promising techniques for rotor noise reduction.

2. BVI phenomenon and the effects of the active tab on BVI alleviation are quantitatively evaluated by the measurements of the blade surface pressure and the sound pressure.

3. The correlation between these two measured items is obtained with respect to AT phase. AT phase range around 90deg. simultaneously has the maximum BVI relief effect indicated by ΔC_{pmax} and the largest rotor noise reduction by the sound pressure level. On the other hand, the opposite happens in AT phase range around 270deg.

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