THE EFFECT OF WATER QUALITY CHARACTERISTICS ON CAVITATION NOISE

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Abstract

This study investigated the effects of seawater on cavitation noise using a water jet test, a two-dimensional wing test, and a three-dimensional wing test. A model propeller cavitation test was conducted in a cavitation tunnel using seawater, in order to determine the effects of propeller cavitation more precisely. In the cavitation tests, measured propeller performance for both cavitation noise inception and desinence, as well as the cavitation noise spectrum (see, for example, figure 7). On the basis of the results of the present propeller cavitation test and tests that were carried out previously, we discuss how to control the water quality in the cavitation tunnel to reproduce the cavitation phenomena, especially cavitation noise, in seawater (see, for example, figure 9).

1 Introduction

Generally full-scale propellers operate in seawater, while, cavitation tests on model propellers have been carried out in cavitation tunnels using freshwater with an adjusted air content rate. This is because cavitation tests have mainly been conducted to investigate macroscopic phenomena, such as cavitation pattern and pressure fluctuations on a hull. However recently, there have been requests to simulate not only a propeller cavitation noise, but eddy making noise, boundary layer radiated noise, etc. in the cavitaion tunnel.

As is well known, cavitation occurs when microscopic air bubbles, called cavitation nuclei, that do not dissolve in water are exposed to a negative pressure field. Due to ambient pressure recovery, the cavitation collapses and generates a lot of noise at the same time. Therefore, nuclei distribution is an important parameter to simulate full-scale cavitation noise in a cavitation tunnel.

It is recognized that cavitation noise characteristics are different between seawater and freshwater. An example of typical nuclei distribution for both seawater and freshwater is shown in figure 1. It can be seen that the size of nuclei in seawater is smaller than that in freshwater.

Therefore, using freshwater in a cavitation tunnel to simulate full-scale propeller cavitation noise, without considering the effects of nuclei distribution is questionable.

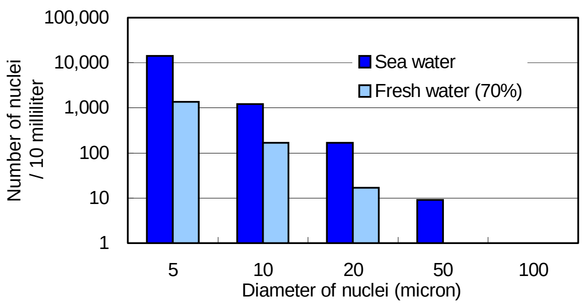

Figure 1: Comparison of measured nuclei distribution between seawater and freshwater, with an adjusted air content rate of 70%.

From our previous research it was found that cavitation noise inception, as well as noise levels are different between seawater and freshwater. The effects of

water quality on cavitation have been investigated by Shen (1994), Kamiirisa (1996), Ceccio (1997), Gindroz (1997), however, the effects are not yet clear.
Under these circumstances, a model propeller cavitation test was carried out using seawater in the cavitation tunnel. Cavitation inception and noise characteristics were measured at different air content rates and nuclei distribution conditions.

2 Model propeller cavitation test

The size of the measuring section in the cavitaion tunnel was 0.5m x 0.5m x 2.0m. A conventional type model propeller, with a diameter of 250mm, was used. The measurement items were (a) propeller open characteristics, (b) cavitation noise and (c) bucket chart. Table 1 shows the test conditions, wherein X means a condition that was carried out.
The cavitation noise was measured using a hydrophone B&K 8103 in an acrylic chamber, which was set on the window of the measuring section. The gap between the window and the chamber was filled with water. The sensitivity of the hydrophone was set as same as for the calibration test performed previously in the free field.
The nuclei distribution was measured in a real time by a particle counter set in the bypass between the contracted section and the measuring section of the cavitation tunnel. The particle counters used were KS62 and KL11 made by RION. The device was determined to be able to measure the bubbly nuclei more accurately than other instruments.
Before and after each test sample water was pulled out from the tunnel and the air content rate of the water was measured using a dissolved oxygen meter UC-12, made by the Central Science Company. A DO meter was available for seawater.

Table 1: Test conditions in the model propeller cavitation test

Fluid	Test items	Air content (%)		
		100	70	40
Freshwater	POT	X	X	X
	Inception & Noise	-	X	X
Seawater	POT	X	-	-
	Inception & Noise	X	-	-

Figure 2 shows the typical cavitation pattern for both seawater and freshwater. On the basis of these test results we discuss the effect of water quality characteristics on cavitation noise in the next.

Figure 2: Typical cavitation pattern in seawater (Left) and in freshwater (Right) for water with 40% air content during the cavitation inception test.

(a) As shown in figure 3, the propeller open characteristics are not different between freshwater and seawater for a conventional type propellers, and are independent of the air content rate.

(b) The cavitation noise inception in freshwater is nearly same as that in seawater when the air content rate of the freshwater is adjusted to about 70%, as shown in figure 4.

(c) The inception of the tip vortex cavitation (TVC) in freshwater is nearly same as that in seawater when the air content rate of the freshwater is adjusted to about 70%, as shown in figure 5. It is remarkable in heavy loaded propeller operating conditions.

(d) The inception of sheet cavitation in seawater is earlier than that in freshwater with its air content is adjusted to about 70% and 30%, as shown in figure 6.

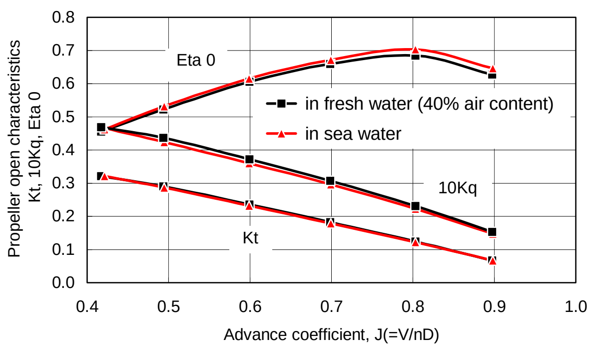

Figure 3: Propeller open characteristics in freshwater and seawater.

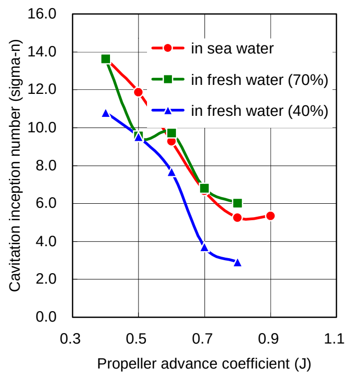

Figure 4: Cavitation noise inception in seawater and freshwater with 70% & 40% air content

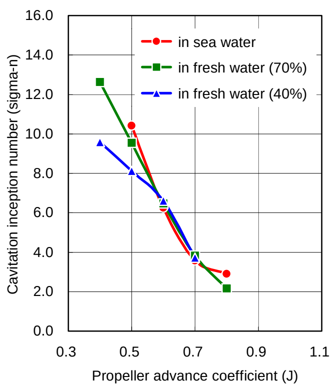

Figure 5: TVC inception in seawater and freshwater with 70% & 40% air content

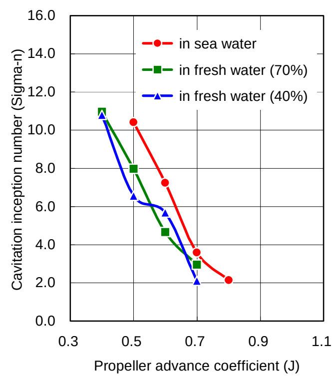

Figure 6: Sheet cavitation inception in seawater and freshwater with 70% & 40% air content

(e) From the above discussion it is proposed that noise inception characteristics can be simulated by adjusting the air content rate of freshwater up to 70% for a conventional propeller in which TVC occurs earlier than other types of cavitation. However, it may be difficult to simulate noise inception characteristics for a highly skewed propeller or a tip unloaded propeller in seawater in which sheet cavitation occurs earlier, even if the air content rate of the freshwater is adjusted up to 70%.

(f) In both air saturated (100%) freshwater and seawater, noise levels above 5 kHz frequency range decrease in spite of an increase in cavitation volume, as shown in figure 7. It is necessary to investigate, if this phenomenon is caused by an acoustic masking due to a lot of air bubbles.

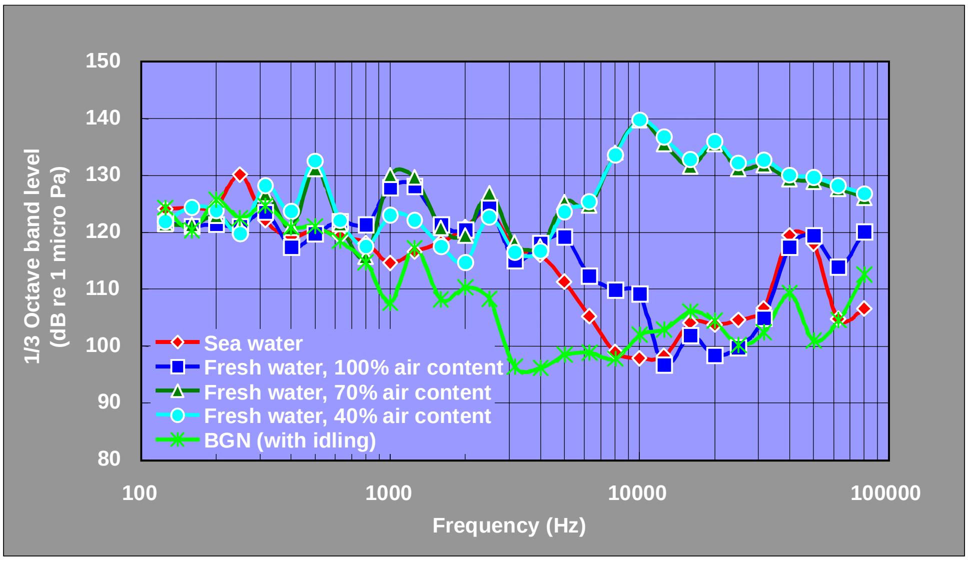

Figure 7: Comparison of the cavitation noise spectrum in seawater and freshwater under the test condition corresponding to full scale (Kt=0.21, J=0.65, Sigma-n=3.1).

(g) As indicated in figure 1, the size of nuclei in seawater is smaller and the number is larger than those in freshwater. However, nuclei distribution varies every time, and it is necessary to monitor the nuclei distribution during the test. The transparent seawater in the tunnel changed to a thin green color during the present test, which was caused by plankton growing. The size of the plankton was about 20 microns and they numbered between 10^3 – 10^5 / milliliter, so that the particle counter did not detect the plankton. On the other hand, the size and number of solid particles were analyzed using a microscopic examination, and it was found that their size was below 10 microns and they numbered about 9 / milliliter. From these results, the particle counter measured only bubbly nuclei. Table 2 shows the summary of the above discussion.

Table 2: Summary of present research regarding the effect of water quality on cavitation noise

POT Characteristics	Seawater = Freshwater			
Cavi. pattern / Characteristics	TVC	Sheet cavitation	Bubble cavitation	Cloud cavitation
Cavi. inception	Seawater = Freshwater (70%)	Seawater = Freshwater (100%)	Seawater Sigma-I > Freshwater Sigma-I	Unknown
Cavi. pattern	Seawater = Freshwater (70%)	Seawater = Freshwater	Unknown	Unknown
Noise inception	Seawater = Freshwater (70%)	Unknown	Seawater Sigma-I > Freshwater Sigma-I	Unknown
Noise level	Seawater = Freshwater (70%)	Unknown	unknown	Seawater = Freshwater (100%)
Spectrum	Unknown	Seawater =Freshwater (50 & 100%)	Unknown	Unknown
Nuclei distribution	The size of nuclei in seawater is smaller than that in freshwater. The effect is so large that keeps it constant during a test.			

Remarks [red box]: Item to be reproduced as in seawater by controlling freshwater quality, Unknown: Item not to be resolved yet, Sigma-I: Inception cavitation number, (%): Air content rate.

3 Two dimensional wing model test

From the above discussion, it will be possible to reproduce cavitation noise inception in seawater by controlling both the air content and nuclei distribution of freshwater in the cavitation tunnel. Therefore, in order to make the effect of nuclei distribution on cavitation noise characteristics clearer, a two-dimensional wing test was carried out by controlling both the nuclei distribution and the air content of the freshwater. The model section was NACA0015. Figure 8 shows the typical test results of the measured cavitation noise spectrum for freshwater and seawater under several air content conditions. From the results of this test the following conclusions were drawn.

(a) The effect of nuclei distribution on the cavitation noise changes at the frequency of 10 kHz. The large number of nuclei makes the cavitation noise level lower below the 10 kHz frequency range, and vise versa for frequencies above 10kHz.

(b) Higher air content levels produce higher noise levels below 10 kHz range, and vise versa for frequencies above 10kHz. This is opposite of the effect of nuclei distribution.

(c) To reproduce the same noise spectrum in freshwater as that in seawater, it is necessary to control not only the air content but also the nuclei distribution. For example, the case on the right side of figure 8, as the number of nuclei in the freshwater is increased the noise level decreases below 10 kHz range, and as a result the spectrum in the freshwater agrees with that in the seawater.

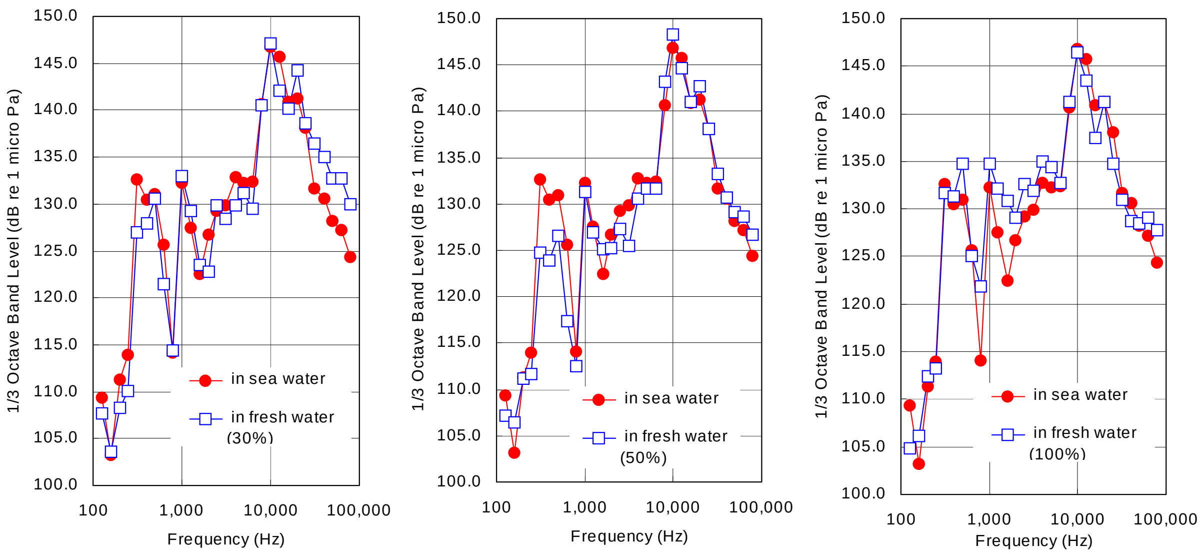

Figure 8: Cavitation noise spectrum of seawater and freshwater for a two dimensional NACA0015 section wing model at several air content conditions. From left to right, the air contents are 30%, 50% and 100%. The attack angle is 8 degrees and cavitation number (Sigma-v) is 2.0.

4 Conclusion

From the present research it was found that both the air content and the nuclei distribution are important parameters for cavitation tests. Table 3 shows the possibility of reproducing cavitation noise in seawater by controlling the water quality in the cavitation tunnel. The following conclusions were made.

(a) It is difficult to reproduce the cavitation noise inception and spectrum in seawater by only adjusting the air content rate of the freshwater to 30% as a conventional way in the cavitation tunnel.

(b) The TVC and sheet cavitation noise inception in seawater can be simulated by adjusting the air content rate of freshwater up to 70%.

(c) By controlling both the air content rate and the nuclei distribution properly in freshwater, it is considered to be possible to reproduce the cavitation noise spectrum in seawater. Figure 9 shows a concept for the control of air content and nuclei distribution.

(d) A study to control the nuclei distribution properly, as well as research the acoustic masking problem in air saturated water at higher frequency ranges must be continued in future.

Table 3: Possibility of reproducible cavitation characteristics by control of freshwater quality in the cavitation tunnel

Control	Cavi. phenomenon / How to control		Inception				Noise	
	Air content	Nuclei distribution	TVC	Sheet	Bubble	Cloud	Level	Spectrum
Conventional	About 30%	Free	Impossible	Impossible	Impossible	Unknown	Impossible	Impossible
Present	Over 70%	Free	Possible	Possible	Impossible	Unknown	May be possible	May be possible
			Conclusion					
Future	Proper control	Proper control	Possible	Possible	May be possible	May be possible	Possible	Possible

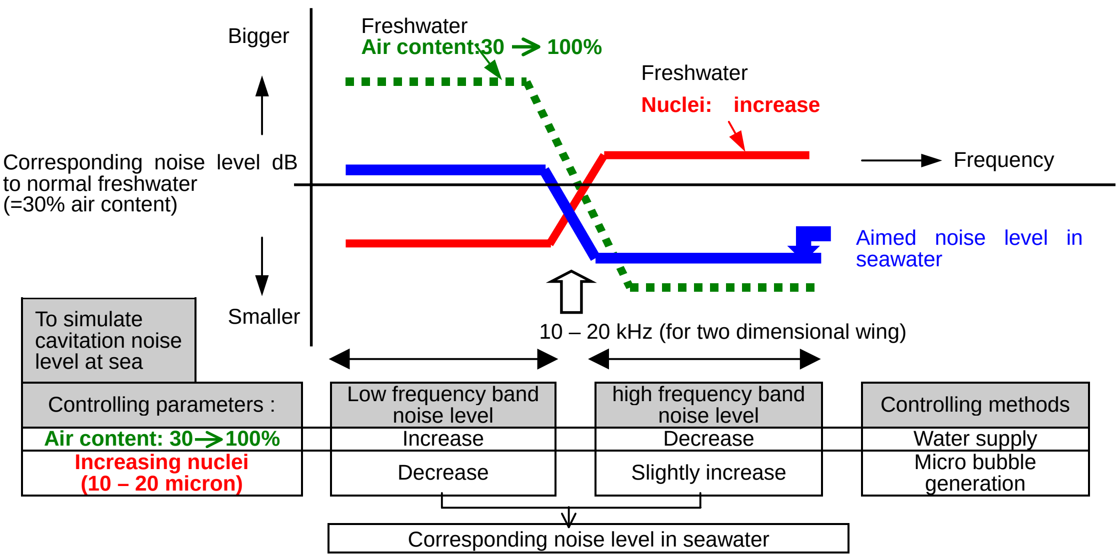

Figure 9: How to control the air content and the nuclei distribution of the freshwater in the cavitation tunnel to reproduce the cavitation noise characteristics at sea.

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