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A Study on the Repeatability of Cavitation Tunnel Tests

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Summary

In order to understand the level of the accuracy and the repeatability of cavitation tunnel tests, a propeller model was tested repeatedly in cavitation tunnel and in open-water. The test results were analyzed in terms of the variation of thrust and torque at each set of advance constant and cavitation number. From the test results and the analysis, it can be concluded that

(1) the variation of cavitation test results is, in non-cavitating condition, about the same as the variation of open-water test results, while in cavitating condition the variation of cavitation test results is about three times as large as the variation of open-water test results,

(2) effect of air content on cavitation test results is not so clear for the range tested ($\alpha/\alpha_s \fallingdotseq 15$—$40\%$),

(3) there is a nearly linear relationship between the variation of thrust and torque, thus it is considered that the variation of thrust and torque is mostly due to the variation of the lift on the blade.

1 Introduction

Among many propellers tested in the cavitation tunnel of the Mitsubishi Experimental Tank, some showed fairly different characteristics when the tests were repeated. The variation of test results might be brought about by many causes, such as air content in water, temperature, error in the measurement of thrust, torque and water speed, etc.

In order to understand the level of the accuracy and the reliability of cavitation tunnel tests, a model propeller was tested repeatedly both in cavitation tunnel and in open-water through a year. The test results were analyzed in terms of the variation of thrust and torque at each set of advance constant and cavitation number. It was found that there is a nearly linear correlation between the variation of thrust and torque. Attempts were made to find the possible reasons of the variation of thrust and torque, taking into account the error in the measurement and other sources of variation.

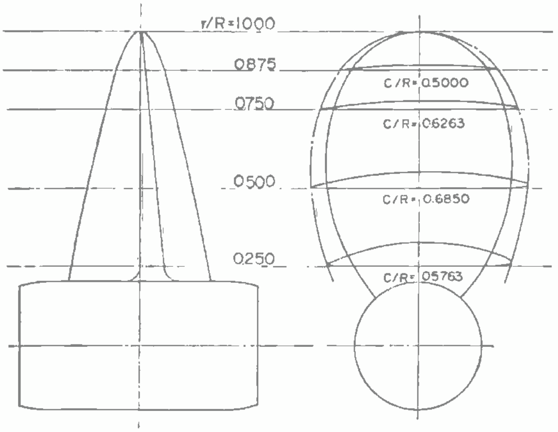

Fig. 1 Propeller P. 1324

Table 1 Particulars of Propeller P. 1324

Diameter	250 mm
Pitch (constant)	250 mm
Pitch Ratio	1.000
Expanded Area Ratio	0.601
Boss Ratio	0.200
Thickness-Chord Ratio at 0.7R	4.08 %
Number of Blades	4

2 Test Procedure

The propeller model used in this series of tests is the ITTC standard propeller (Fig.1). This was used for the ITTC comparative tests, whose results were reported at the 10th ITTC (London) in 1963. The particulars of the propeller are given in Table 1.

The tests were repeated 27 times in the cavitation tunnel and 12 times in the towing tank. The dates

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* Experimental Tank, Nagasaki Technical Institute, Mitsubishi Heavy Industries, Ltd.

Table 2 Dates and Test Conditions of the Repeated Tests

(a) Cavitation Tests

Test No.	Date	Water Temp.(°C)	Air Content α/α_s (%)	Remarks
1	16-1[illegible],May 1964	18.0-18.4	18.9	
2	20,May 1964	19.0-19.3	19.7	
3	1[illegible],June 1964	20.0-20.2	14.[illegible]	
4	2[illegible],June 1964	20.5-20.7	16.[illegible]	
5	[illegible],July 1964	23.7-24.0	15.4	
6	24,25,July 1964	24.9-25.1	16.6-18.9	
7	6,Aug. 1964	27.0	[illegible].1	
8	[illegible],Sep. 1964	23.6-24.0	22.6	
9	3,Oct. 1964	21.0	16.4	
10	17,Oct. 1964	20.4-20.5	29.1	
11	[illegible],Nov. 1964	17.3-19.0	21.2	
12	[illegible],Dec. 1964	14.5-1[illegible].0	15.0	
13	[illegible],Dec. 1964	14.1-1[illegible]	20.5	
14	[illegible] 1965	1[illegible]-11.0	16.6	
15	[illegible] 1965	[illegible]	15.0	
16	[illegible] 1965	1[illegible]	14.3	
17	[illegible] 1965	[illegible]	21.7-22.5	Variation of Air Content (1)
18	[illegible] 1965	25.4	25.1	
19	11,Aug. 1965	25.2-2[illegible].4	25.8-26.5	
20	12,Aug. 1965	25.2-2[illegible].5	26.9-27.8	
21	13,Aug. 1965	25.6-25.9	28.7-30.3	
22	[illegible],Sep. 1965	21.5-22.0	17.3	Variation of Air Content (2)
23	30,Sep. 1965	21.2-21.6	22.4	
24	1,Oct. 1965	21.5	25.0	
25	[illegible],Oct. 1965	21.1-21.3	29.0	
26	6,Oct. 1965	21.4	36.9	
27	7,Oct. 1965	20.3	38.3	

and the test condition of the tests are shown in Table 2.

The cavitation tunnel is K-18 type of Kempf & Remmers with the measuring section of 500mm × 500mm. The water speed was measured with a Venturi meter and the static pressure was measured at the upstream end of the measuring section. In several cases of the series of the tests, the water speed was measured, together with the Venturi meter, with a "midway" pitot tube (mounted at the midway between the propeller tip and the tunnel wall, cf. Fig.2) or a pitot tube on the side wall just beside the propeller (Fig.3), to see whether the method of speed measurement affects the variation of the test results. Propeller revolution was measured with an electronic counter. Air content in the tunnel water was measured with a Van Slyke's apparatus. In general, air content ratio α/α_s was adjusted around 20%. In the last 11 test numbers the air content ratio was varied methodically from 17 to 38% to see the effect of air content on the cavitation test results. Some photographs of cavitation were taken to record the cavitation pattern on the blades.

The cavitation tests were carried out at $\sigma_n = 0.4$, 0.6, 0.8 and atmospheric condition, with the propeller revolution of 40, 35, 30 and 28 r.p.s. respectively. The water speed was changed to vary the advance ratio from J = 0.5 to 1.0 with the interval of 0.1. Table 3 shows "static pressure -vapour pressure" and the water speed measured with the Venturi meter for each set of σ_n and J.

Table 2 [illegible] (continued)

(b) Towing Tank [illegible]

Test No.	Date	Water Temp.(°C)	$\frac{nD^2}{\nu}\times10^{-4}$	$Re(k)\times10^{-5}$
1	[illegible], June 1964	21.1	8.[illegible]	6.52
2	24, July 1964	2[illegible].3	[illegible]	[illegible]
3	[illegible], July 1964	1[illegible].6	[illegible]	[illegible]
4	[illegible], Aug. 1964	[illegible]4.1	[illegible]	7.00
5	[illegible], Sep. 1964	[illegible]	[illegible]	7.[illegible]4
6	22, Sep. 1964	[illegible].0	[illegible]	7.31
7	1[illegible], Oct. 1964	[illegible].0	[illegible]	6.66
8	[illegible], Nov. 1964	17.1	7.[illegible]5	5.93
9	4, Dec. 1964	1[illegible].5	7.6[illegible]	5.[illegible]2
10	5, Jan. 1965	14.6	7.[illegible]	5.[illegible]4
11	19, May 1965	16.4	7.[illegible]	5.91
12	14, Aug. 1965	25.4	9.14	7.21

$$Re(k)=\frac{C_{0.7}}{\nu}\sqrt{V_A^2+(0.7\pi nD)^2}$$

Where V_A is the towing speed at 20% in slip ratio.

In the towing tank, the advance speed was measured with a current meter. Propeller revolution was measured with an electronic counter. Advance constant J was varied, as in the cavitation tunnel, by changing the water speed while keeping the propeller revolution constant. The number of revolution of the propeller was 13.5 r.p.s. which is the maximum for the capacity of the dynamometer to cover the range of advance ratio J = 0.5 – 1.1. The Reynolds number Re(k) based on the resultant inflow velocity at 0.7R was (5.5 – 7.3) × 10⁵ depending upon the water temperature. Propeller immersion was kept constant. It was about the same as the propeller diameter i.e. I/D ≒ 1.

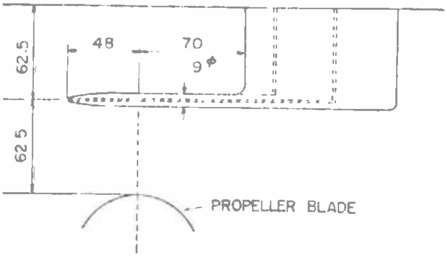


Fig. 2 Midway Pitot Tube

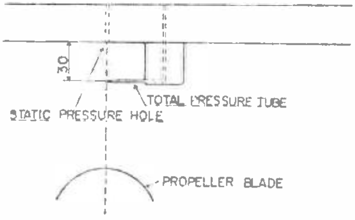


Fig. 3 Pitot Tube on the Side Wall

Table 3 Static Pressure-Vapour Pressure and Water Speed of the Cavitation Tests

(a) "Static Pressure P_s − Vapour Pressure e" and Propeller Revolution in r.p.s.

σ_n	[illegible]	[illegible]	[illegible]	atm.
P_s-e	[illegible]	[illegible]	[illegible]	[illegible]
n	[illegible]	[illegible]	[illegible]	[illegible]

(b) Water Velocity in m/s

σ_n	[illegible]	[illegible]	[illegible]	atm.
J=0.5	5.00	4.375	3.75	3.50
0.6	6.00	5.25	4.50	4.20
0.7	7.00	6.125	5.25	4.90
0.8	8.00	7.00	6.00	5.60
0.9	9.00	7.875	6.75	6.30
1.0	10.00	8.750	7.50	7.00

3. Test Results

3.1 Cavitation Tests

The measured thrust and torque were corrected for the 'idles' and were reduced to the non-dimensional coefficients K_T and K_Q. The water speed measured by the Venturi meter was not corrected for the tunnel wall effect. Figs. 4 and 5 show the example of K_T and K_Q plotted to the base of test number.

As a numerical expression of repeatability, the standard deviations σ were calculated for each set of σ_n and J, viz.,

$$\Delta K_{T,Q}=K_{T,Q}\,(\text{measured})-K_{T,Q}\,(\text{mean}) \tag{1}$$

$$\sigma(K_{T,Q})=\left[\frac{1}{N}\sum_{i=1}^{N}(\Delta K_{T,Q})_i^2\right]^{1/2} \tag{2}$$

In Fig.6 the scattering of the test results are presented with the bands of the standard deviations along the mean lines. In Fig.7 the standard deviations are plotted to the base of advance coefficient J with cavitation

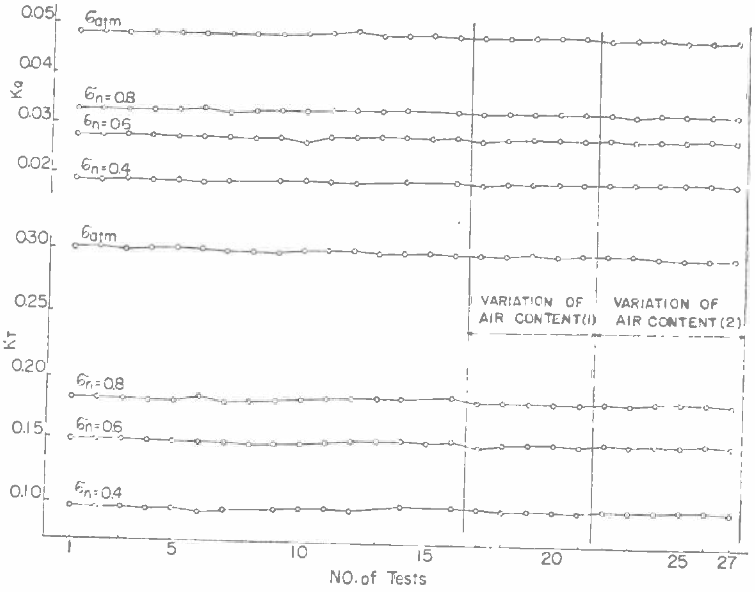


Fig. 4 Plot of K_T and K_Q to the Base of Test Number ($J=0.5$)

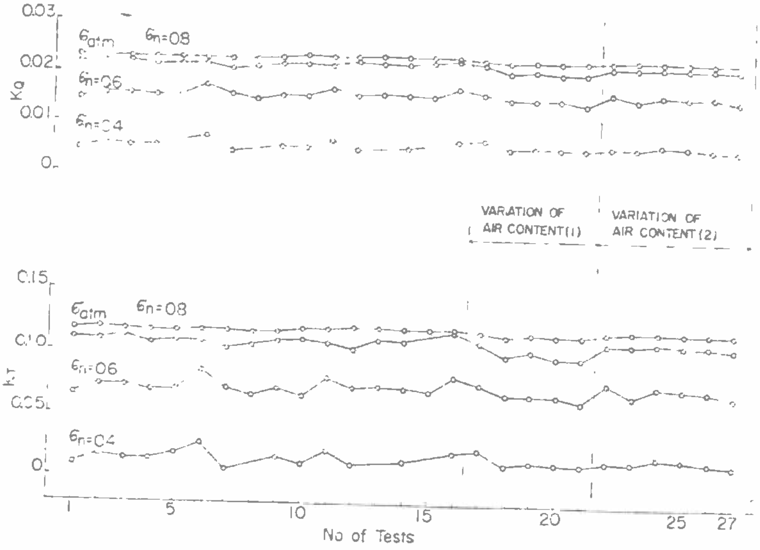


Fig. 5 Plot of K_T and K_Q to the Base of Test Number ($J=0.9$)

number as parameter. They increase gradually with J under atmospheric pressure, while in cavitating conditions they show rapid increase in higher J range and reach their maxima around $J=0.9$. The maximum standard deviation in cavitating conditions is about three times as large as under atmospheric pressure. The relations between $\sigma(K_{T,Q})$ and $K_{T,Q}$ (mean) are presented in Table 4.

3.2 Open-water Tests

In open-water tests, the measurement of thrust and torque was carried out at J which is a little different from the prescribed value, because the time for adjusting the water speed and propeller revolution is much shorter than in cavitation tunnel. Therefore the standard deviations cannot be calculated directly from the measured K_T and K_Q, as was done in the case of cavitation tests. Then all the measured thrust and torque were plotted to the base of J in terms of K_T and K_Q, and their mean lines were drawn. For each group of J the deviations K_T and K_Q were read from their mean lines as shown in Fig.8, and the standard deviations

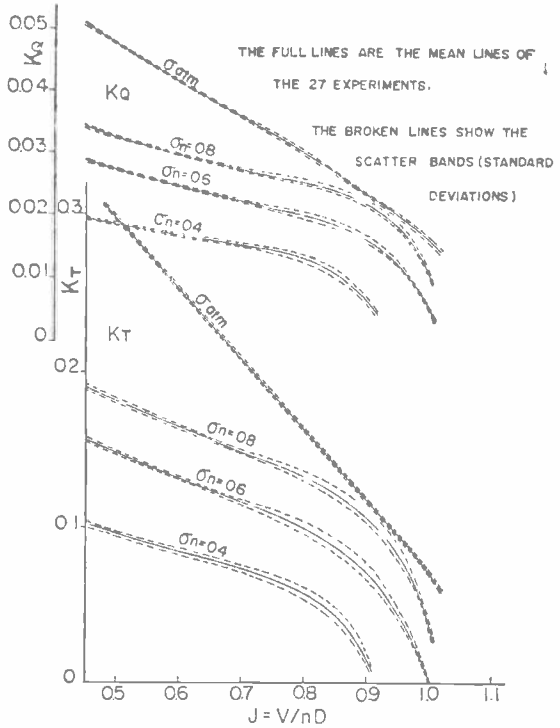


Fig. 6 Results of the Repeated Cavitation Tests

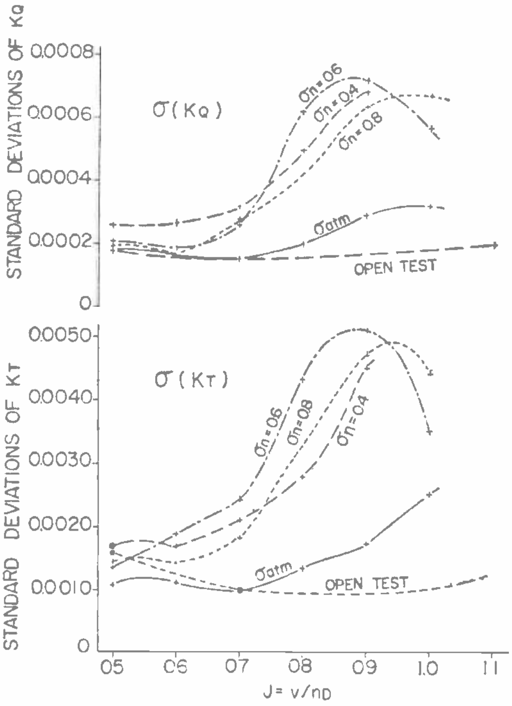


Fig. 7 Standard Deviation of K_T and K_Q

Table 4 Relative Variations $\sigma(K_T)/K_T$ and $\sigma(K_Q)/K_Q$

	$\sigma(K_T)/K_T$ (%)				$\sigma(K_Q)/K_Q$ (%)			
J \ σ	0.4	0.6	0.8	atm	0.4	0.6	0.8	atm
0.5	1.[illegible]	0.9	0.[illegible]	0.4	1.4	0.[illegible]	0.6	0.4
0.6	1.0	1.4	0.9	0.5	1.[illegible]	0.[illegible]	[illegible]	[illegible]
0.7	2.[illegible]	2.1	1.[illegible]	0.5	2.1	[illegible]	1.[illegible]	0.[illegible]
0.8	4.[illegible]	4.4	2.5	0.8	3.9	3.1	1.7	[illegible].7
0.9	[illegible].0	7.2	4.4	1.5	11.4	4.6	3.0	1.[illegible]
1.0	–	–	1[illegible].1	[illegible].6	–	–	[illegible]	[illegible].1

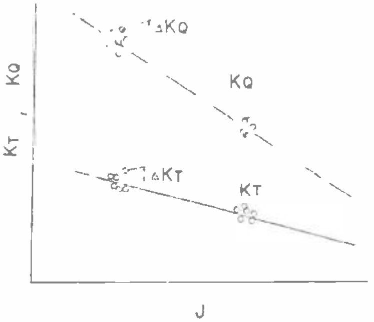


Fig. 8 Deviation of Open-water Test Results

were calculated by eqs. (1) and (2). They are plotted also in Fig.7, in which it can be seen that the standard deviations are almost constant for J, and are about the same as those in cavitation tunnel under atmospheric pressure.

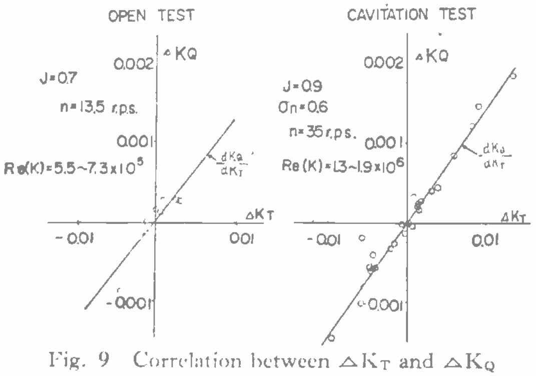


Fig. 9 Correlation between $\triangle K_T$ and $\triangle K_Q$

Table 5 Correlation Coefficient γ between $\triangle K_T$ and $\triangle K_Q$

J \ σ_n	0.4	0.6	0.8	atm
0.5	0.95	0.74	0.[illegible]6	0.55
0.6	0.95	0.90	0.76	0.68
0.7	0.96	0.91	0.[illegible]3	0.57
0.8	0.96	0.80	0.97	0.69
0.9	0.90	0.97	0.[illegible]3	0.85
1.0	–	0.83	0.59	0.84

4. Discussion on the Test Results

4.1 Correlation betweeen $\triangle K_T$ and $\triangle K_Q$

A close examination of the test results suggests that there might be a correlation between the variations of K_T and K_Q; when K_T is larger than the mean K_T, K_Q is in general larger than the mean K_Q. From the cross-plotting of $\triangle K_T$ and $\triangle K_Q$ as shown in Fig. 9, it is found that there is a nearly linear relationship between $\triangle K_T$ and $\triangle K_Q$. The correlation coefficient γ calculated by the equation below are 0.7—0.9 as shown in Table. 5.

$$\gamma=\frac{\frac{1}{N}\sum_{i=1}^{N}(\triangle K_T)_i\cdot(\triangle K_Q)_i}{\sigma(K_T)\cdot\sigma(K_Q)} \tag{3}$$

Referring to the velocity diagram for a blade element (Fig.10) and separating the thrust and torque into the lift and drag element of the blade,

$$T=\int(dL\cos\beta_i-dD\sin\beta_i) \tag{4}$$

$$Q=\int r(dL\sin\beta_i+dD\cos\beta_i) \tag{5}$$

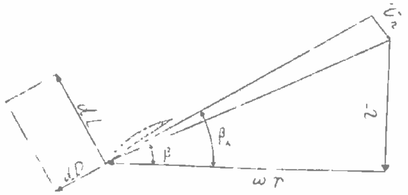


Fig. 10 Velocity Diagram for a Blade Element

we may say that the variations having the correlation between $\triangle K_T$ and $\triangle K_Q$ are caused mainly by the change in lift of the blade section.

It is to be noted that the slope of the mean line through the cross-plotting of $\triangle K_T$ and $\triangle K_Q$ are nearly equal to the slope of the K_T-K_Q curve for each σ_n, viz.,

$$\frac{\triangle K_T}{\triangle K_Q}\doteqdot\frac{dK_T}{dK_Q} \tag{6}$$

The relationship between $\triangle K_T$ and $\triangle K_Q$ described above holds also for the results of open-water tests. Discussion on the source of the variation of the open-water test results is given in Appendix.

4.2 Effect of Air Content in Water

It has been considered that the air content in water is one of the parameters having significant effects on cavitation test results. In the present study, therefore, attempts were made to see the effect of air content by varying it systematically. The variation was tried twice as shown in Table 2 and Figs. 4–5. In the first series of the variation (Test No. 17–21) the measured K_T and K_Q decreased with air content ratio. The tendency was most clear around $J=0.9$ and $\sigma_n=0.6$–0.8, where the standard deviation of K_T and K_Q reach the maxima. In the second series (Test No. 22–27), however, K_T and K_Q were almost constant with respect to air content ratio. Fig.11 shows the plotting of K_T and K_Q at $J=0.9$ to the base of air content ratio a/a_s. There can be seen, in some range, a tendency that K_T and K_Q decrease slightly with air content ratio, but as a whole we can not derive a general conclusion about the effect of air content ratio on the variation of K_T and K_Q. It should be mentioned that the variation of air content was limited to a rather narrow range (a/a_s 17–38%), since with the increase of air content ratio it occurs more often that small air bubbles come into the

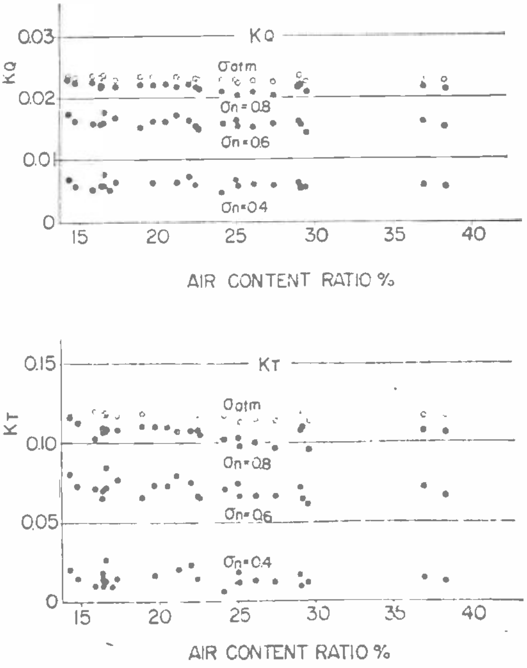
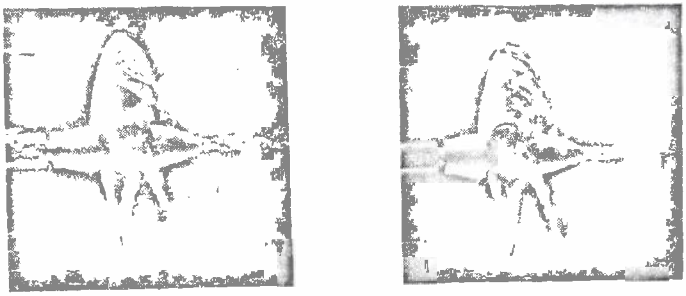


Fig. 11 Effect of Air Content ($J=0.9$)

pressure taps and the tubes connected to the manometers, thus impairing the accuracy of the speed measurement.

Comparison of the cavitation patterns suggests, however, that air content may affect the type of cavitation. As shown in Fig. 12 for example, it can be seen that the amount of bubble cavitation increases with air content ratio in water.



$\alpha/\alpha_s = 22.4\%$ $K_T = 0.0672$

$\alpha/\alpha_s = 38.3\%$ $K_T = 0.0672$

Fig. 12 Effect of Air Content on Cavitation Pattern at $J=0.9$ and $\sigma_n=0.6$

4.3 Effect of Water Temperature

Propeller characteristics are affected by water temperature, mainly through the variation of the drag coefficient of blades with Reynolds number. In the case of cavitation tests, however, the plotting of K_T and K_Q to the base of water temperature did not show a systematic change; the Reynolds number is considered to be large enough so that the variation of drag will be quite little.

4.4 Effect of the Methods of the Speed Measurement

The water speed measured with a midway pitot tube or a pitot tube on the wall showed a slight variation in each test, whereas the water speed measured by the Venturi meter was kept constant throughout the repeated tests. The relation between ΔJ (variation of J due to the variation of water speed measured by a pitot tube) and ΔK_T are shown in Fig.13. In this figure there can be seen no definite relationship between ΔK_T and J. In other words, the variation of K_T and K_Q is little affected by the method of speed measurement.

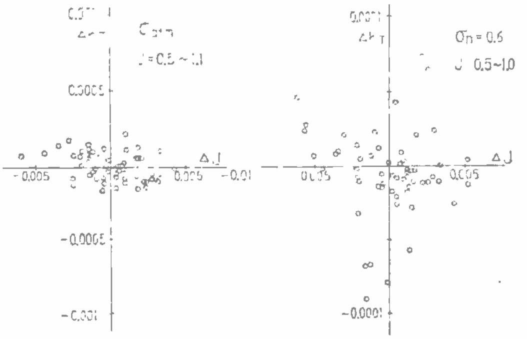


Fig. 13 Variation of Method of Speed Measurement

4.5 Sources of Variation of Cavitation Test Results

We have learned in the previous sections that there exists a correlation between the variation of thrust and torque, and the variations will be ascribed mostly to the variation of the lift of the blades. Effect of air content is not so clear as expected and effect of water temperature can be neglected. In the following, attempts are made to find the possible reasons of the variation of thrust and torque, taking into account the error in the measurements and other sources of variation whether or not influencing the lift of the blades.

(1) Error in the reading of the dynamometer

The scales of the dynamometer of pendulum type for measuring thrust and torque are graduated with the interval of 1.0 kg for thrust and 0.01 kg-m for torque. As the oscillation of pendulum during the measurement was considerably small through the whole range of the tests, the error in the

Table 6 Variations due to the Error in the Measurement of Thrust and Torque

σ_n	0.4	0.6	0.8	atm
$\Delta K_T \times 10^4$	3.1	4.1	5.6	6.4
$\Delta K_Q \times 10^5$	3.1	4.1	5.6	6.4

reading of the dynamometer may amount to 0.2 kg in thrust and 0.005 kg-m in toque. The corresponding $\triangle K_T$ and $\triangle K_Q$ are calculated by

$$\triangle K_T = 0.2/\rho n^2 D^4$$
$$\triangle K_Q = 0.005/\rho n^2 D^5$$

Substitution of propeller revolution for each test condition yields the variations as shown in Table 6.

(2) Error in the reading of manometer

For each test point the water speed and the static pressure in tunnel were adjusted to the prescribed values. As they were measured by mercury-water manometers, the error in the reading of the manometers results in the variation of the measured thrust and torque. The reading of the manometers is affected also by fluctuation of the mercury tubes.

The reading of the manometer connected to the Venturi static holes on the tunnel may be as accurate as 0.2mm in lower speed range and about 0.5mm in higher speed range. The resulting error due to thus measured water speed is estimated by

$$\triangle K_T = \frac{\partial K_T}{\partial J}\triangle J$$
$$\triangle K_Q = \frac{\partial K_Q}{\partial J}\triangle J$$
$$\text{where} \qquad \triangle J = \triangle V/nD$$

Numerical evaluation of K_T and K_Q leads to the results as shown in Table 7.

The reading of the manometer for the static pressure in the tunnel is a little less accurate than that of Venturi-meter. The variation of thrust and torque resulting from the error in the reading can be estimated through the variation of cavitation number and is given by

$$\triangle K_T = \frac{\partial K_T}{\partial \sigma_n}\cdot\triangle\sigma_n$$
$$\triangle K_Q = \frac{\partial K_Q}{\partial \sigma_n}\cdot\triangle\sigma_n$$
$$\text{where} \qquad \triangle\sigma_n = \frac{12.595\cdot\delta h_s}{\rho n^2 D^2}$$

Estimating the accuracy of the reading δh_s to be 1 mm, we obtain the $\triangle K_T$ and $\triangle K_Q$ as shown in Table 8.

Table 7 Variations due to the Error in the Measurement of Water Speed

	$\Delta K_T \times 10^{[illegible]}$				$\Delta K_Q \times 10^{[illegible]}$			
$J \diagdown \sigma_n$	0.4	0.6	0.8	atm	0.4	0.6	0.8	atm
0.5	[illegible]	1.4	1.5	4.4	[illegible]	[illegible]	2.4	6.0
0.6	1.4	1.5	1.5	[illegible]	2.2	[illegible]	2.4	6.6
0.7	1.5	1.3	[illegible]	5.2	2.4	[illegible]	[illegible]	[illegible]
0.8	[illegible]	1.7	[illegible]	5.6	2.6	[illegible]	[illegible]	7.8
0.9	5.0	4.2	[illegible]	5.6	[illegible]	[illegible]	[illegible]	7.3
1.0	–	[illegible]	[illegible]	[illegible]	–	7.5	7.0	3.4

Table 8 Variations due to the Error in the Measurement of Static Pressure

	$\Delta K_T \times 10^{4}$			$\Delta K_Q \times 10^{5}$		
$J \diagdown \sigma_n$	0.4	0.6	0.8	0.4	0.6	0.8
0.5	[illegible]	7.7	7.9	[illegible]	[illegible]	[illegible]
0.6	5.5	7.0	6.6	[illegible]	[illegible]	11.0
0.7	5.3	7.0	6.2	10.0	[illegible]	[illegible]
0.8	6.0	6.4	5.7	[illegible]	[illegible]	11.0
0.9	7.0	7.7	6.2	[illegible]	[illegible]	11.0
1.0	–	7.0	7.0	–	[illegible]	11.0

(3) Error in the number of revolution of propeller

The number of revolution of propeller was adjusted and kept constant for each test condition by means of an electronic control system. The revolution was measured up to two decimals in r.p.s. by an electronic counter connected to the propeller shaft. The difference of the propeller revolution from the prescribed value is less than 0.02 r.p.s. so that its effect on the measured thrust and torque can be neglected compared with other sources of variation.

(4) Other sources of variation

In atmospheric condition, the sum of the aforementioned variations due to the measurement error is a little more than a half of the standard deviations obtained through the repeated tests. Considering the variation of the water speed measured by a pitot tube as mentioned in 4.4, it may be that the variation has resulted also from the variation of the uniformity of the velocity distribution in the measuring section. Assuming that the fluctuation of the velocity distribution can be expressed as $\triangle J=0.002$ with reference to Fig. 13, we obtain the corresponding variation of K_T and K_Q as shown in Table 9. In atmospheric condition, especially in lower J range, addition of these values to the variations due to measurement errors leads to about the same as those obtained through the repeated tests. In higher J range, there remains a little difference between the variations thus estimated and those obtained by the repeated tests. (Fig. 14).

Table 9 Variations due to the Fluctuation of Velocity Distribution

($\Delta J=$ [illegible])

	$\Delta K_T \times 10^4$				$\Delta K_Q \times 10^5$			
J \ σ_n	[illegible]	[illegible]	[illegible]	atm	[illegible]	[illegible]	0.8	atm
0.5	3.	2.[illegible]	3.	8.	7.[illegible]	7.[illegible]	[illegible]	1[illegible]
0.6	3.	[illegible]	3.[illegible]	[illegible]	4.[illegible]	4.4	4.[illegible]	12.[illegible]
0.7	3.0	[illegible]	3.[illegible]	[illegible]	4.	[illegible]	[illegible]	12.0
0.8	3.0	3.	3.0	[illegible].6	4.	4.	[illegible]	1[illegible].0
0.9	6.6	7.0	7.0	[illegible].6	1[illegible].0	1[illegible]	[illegible]	[illegible]
1.0	–	[illegible]	7.[illegible]	[illegible]	–	1[illegible]	[illegible].0	1[illegible]

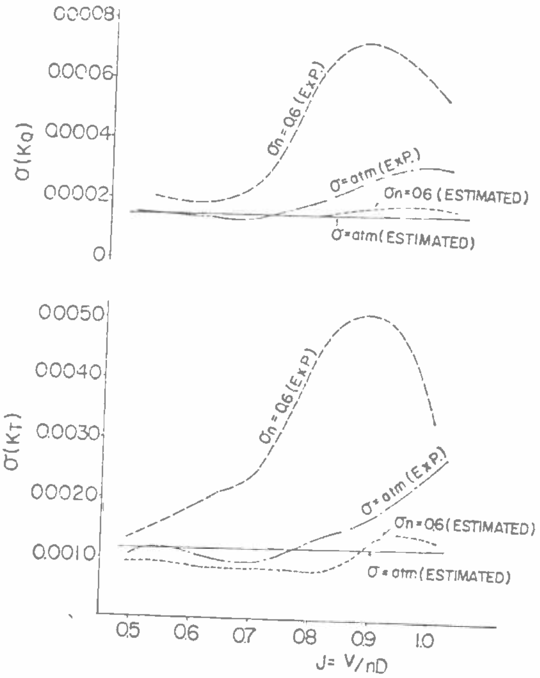


Fig. 14 Comparison of Estimated Standard Deviation and those obtained by Experiments

In cavitating condition, however, the estimated variations are far less than the variations of the test results. In particular, the large peak of the variations around $J=0.9$ can not be explained by the summation of each measurement error. Remembering the correlation between $\triangle K_T$ and $\triangle K_Q$, there will be still other factors influencing the operation of the cavitating blades, which lead to the variation of the lift on the blades.

4.6 Unstable Cavitation of the Blades

In the range where the variation of K_T and K_Q are large, the blades of the propeller operate with bubble cavitation on the after half of the back and with sheet cavitation on the face at the same time. It is expected that the characteristics of the propeller are most unstable in such condition.

The operating condition of the propeller blade will be calculated approximately by the aid of the vortex theory of propeller. Assuming the circulation distribution to be optimum, we obtain the hydrodynamic pitch angle βi and angle of incidence including the effect of downwash for a given set of J and K_T. At $J=0.9$, the angle of incidence is about zero ($\sim \pm 30'$) and the cavitation number $\sigma_{0.7}$ based on the resulting inflow velocity at 0.7R is 0.11 at $\sigma_n=0.6$ and 0.14 at $\sigma_n=0.8$

May be cavitation on the blades at such small angle of incidence and at the cavitation number $\sigma_{0.7}=0.11-0.14$ is more unstable than in the other conditions.

5. Conclusion

The results and the analysis of the repeated cavitation tests may be summarized as follows.

(1) Under atmospheric pressure in the cavitation tunnel, the standard deviations of K_T and K_Q are usually 0.4–1.5% of K_T and K_Q. These deviations are about the same as those in the open-water test results.

(2) In cavitating condition, at $J=0.5-0.6$, the deviation is a little larger than under atmospheric pressure, but it shows rapid increase near $J=0.9$ and amounts to 5–7% of K_T and K_Q.

(3) There is a nearly linear correlation between $\triangle K_T$ and $\triangle K_Q$. The variation will therefore be ascribed mostly to the variation of the lift of the blades.

(4) The estimated variation of K_T and K_Q, considering the error in the measurement and the non-uniformity of the water speed in the tunnel, is in fairly good agreement with the test results under atmospheric pressure. But in cavitating condition, the estimated variation is much smaller than the experiment. The difference may be ascribed to the instability of the cavitation.

(5) The variation of test results is large when the blades operate with a small angle of incidence and with cavitation number $\sigma_{0.7}=0.1$–0.15 (based on the resultant velocity at 0.7R). In such condition, cavitation on the blades is considered to be unstable.

(6) Air content ratio in water does not seem to affect K_T and K_Q for the range tested. But the cavitation pattern may be influenced by air content; it was observed that bubble cavitation increased with air content.

Appendix Variation of Open-water Test Results

The standard deviations of the open-water test results are as follows.

$$\sigma(K_T)=0.0010$$

$$\sigma(K_Q)=0.00015$$

The accuracy of thrust and torque measurement is about 0.02kg in thrust and 0.0008 kg-m in torque. The resulting variations of K_T and K_Q are

$$\Delta K_T=0.0003$$

$$\Delta K_Q=0.00005$$

Considering the correlation between K_T and K_Q, the difference between the water velocity as measured by the current meter and the inflow velocity to the propeller will be a source of the deviations. If we ascribe the rest of the deviations to those of the inflow velocity, the corresponding deviation of the velocity is

$$\Delta v=0.005 \text{ m/s}$$

This variation may be explained by a complex behaviour of the residual current in the towing tank after the run of towing carriage, as has been observed in resistance tests.