## GROUP DISCUSSIONS

Four Sessions of Group Discussions were arranged in co-operation with the Information Committee, all on topics of current interest to most of the ITTC Member Organizations.

In introducing the subjects the Chairmen had been given the opportunity to invite additional Specialists, and they were assisted by Recorders from the SSPA Research Staff.

## SESSION 1a

## ON FULL SCALE MEASUREMENTS

Discussion Chairman: Dr. B. Della Loggia
Recorder: Dr. O. Rutgersson

### 1a-1. Introduction of the Subject

B. DELLA LOGGIA - Centro per gli Studi di Tecnica Navale CETENA, Genova, Italy.

CHAIRMAN'S INTRODUCTION

First of all, I would like to thank the ITTC Organization which gives us the possibility to discuss Full Scale Measurements and related problems.

In spite of my very limited capacities, ITTC charged me to chair this Session; probably ITTC intended to give this honour to my organization, which has been engaged in Full Scale Measurements since the late sixties.

In any case I'll try to do my best, introducing very briefly two concepts regarding our Session.

In the ITTC world Full Scale Experiments represent, let me say, the other side of the moon, but in this case it represents the real one compared with the simulated one, which is the towing tank part. So it seems very strange to me that a relative little attention has been generally paid to this problem in the ITTC activity, because, after all, it is at sea, this huge tank, where sail full scale models.

A possible explanation could be that, from the ITTC point of view, Full Scale Measurements are only considered as a tool to validate the model-ship correlation methods.

However, it seems necessary to stress that the full scale measurements have a proper significance for the hydrodynamic investigation because they allow to deal with the real ship behaviour and environment, which are very difficult to reproduce completely in the model scale.

On the other hand, it is possible to foresee that in the next future Full Scale Measurements should be used to validate directly the new and more sophisticated theoretical approaches allowed by the continous increase of computer power and speed.

The second point regards the great difficulties generally found in carrying out Full Scale Measurements. In fact, they usually require the employment of large resources, special equipments and skilled technicians.

But, in spite of this, often the experiment could not be considered successful for a large amount of reasons, such as:

- adverse external conditions
- shortage of time
- instrumentation failure
- poor test organization
- unexpected factors, etc.

Then, in my opinion, the few successful and very significant Full Scale Experiments must be carefully considered and used, every time it is possible, as comparison data in cooperative research proposed and sustained by the ITTC.

Only in this way it will be possible to exploit at the best the large amount of information, sometimes not expected, that generally are collected during a successful Full Scale Test.

Finally, I would like to present the program of this Group Discussion, which is divided in two parts:

a) In the first part - Section la-2 - four short reports are presented regarding an overview of the state of the art and a presentation of new testing instruments and methodologies.

   I would like to take this opportunity to thank officially the gentlemen who have accepted my invitation: Mr. Jourdain, from IRCN, the French Ship Research Centre, for the thrust measurement problem, Dr. Takahashi, from Ship Research Institute of Japan, for the propeller cavity thickness and volume determination, prof. Abkowitz, from MIT, for the manoeuvrability and resistance, and Mr. Colombo, from CETENA, for the seakeeping problems.

b) After these presentations, which should take some ten minutes each, the second part - Section la-3 - of this Session will be devoted to floor discussion. Any contributor is welcome, not only to discuss the papers given, but also to present new devices and data analysis methods.

I'd like to thank you in advance for your contribution and I'll start inviting Mr. Jourdain to present his paper.

## 1a-2. Invited Contributions

M. JOURDAIN - Institut de Recherches
de la Construction Navale, Paris, France.

### FULL SCALE THRUST MEASUREMENTS

For many years, naval architects were anxious to get thrust measurements on full scale, because it was a basic data for propeller design.

During the fifties, direct pressure measurements into the thrust block were used, but they required such a care that they were generally unreliable. I shall not insist on more sophisticated devices which did not know some development.

The modern area began in the sixties with the developments of electric strain gauges for general use. On board engines, their first application was the measurement of torque through the shear strain of the shaft. After mastering some troubles inherent to gauges, it proved quite successful and very handy. Now, an accuracy of 1 % is currently obtained on the shaft torque.

Then, it was logical to hope the same result by fitting the gauges in order to measure the shaft longitudinal strain due mainly to the thrust. But, there was a difficulty: this strain is small, of the same order of magnitude that those due to temperature variation and flexure of the shaft between its bearings. Both problems were easily solved.

By associating to the longitudinal gauge a transverse one as close as possible, the temperature effect was compensated. In addition, as the temperature effect is the same in both directions whereas the transverse thrust strain due to the POISSON effect is of the reverse sign to the direct thrust strain, the latter one is majored by about 30 % when the temperature effect is compensated. It may also be seen that, through the elasticity formula, the unique coefficient of shear G, well known from torque measurements, replaces the two coefficients E and $\sigma$ .

Now, the flexure compensation is straightforward by associating to the first bridge a second one fitted on the diametrally opposite generatrix in the same section of the shaft. Thus, the output of the two combined bridges is about 2.6 times the actual longitudinal thrust strain of the shaft.

However, the first tests using this device showed large discrepancies, up to 30 % in worst cases, with the predicted thrust by conventional methods.

Theoretical studies performed in various countries and especially in Italy at CETENA disclosed the origin of this failure. It was the parasitic effect of torque strain due to a defective alignment of the thrust bridges.

At first we thought impossible to improve enough the alignment in order to correct completely this torque effect, and we imagined a double weighting method for taking it in account. Briefly, it consists of, after fitting the shaft of thrust and torque bridges, mounting ashore this shaft on a rig allowing to apply it a pure torque without any thrust. This rig is derived from the one we used thirty years ago for calibrating torsionmeters, but it may be rougher because no external measurement of torque is required. It is sufficient to apply a series of torques and read both bridges. It appears that these readings are proportional and their ratio is the parasitic component of torque on thrust which can be used for correcting thrust readings at the trials.

We think that this process is as perfect as possible, but it is tedious and onerous, with obvious practical hindrances on which I shall not insist.

For these reasons, we revert to investigate the feasibility of a better alignment of the thrust gauges by simple means. In U.K., Shell imagined a sophisticated device that we deem more convenient for laboratory than for daily use on board. At IRCN, we use long gauges (102 mm) and we align them with the help of a machined angle bar put on the shaft along a generatrix. Despite of its simplicity, this process proved to be effective. Various tests on the previous rig and on board allow to estimate the accuracy at about 3 %.

There is little hope to improve this accuracy, due to the smallness of the thrust strain compared with parisitic effects. For scientific research, the best way would certainly be the use of the calibrating rig.

I wish to conclude on a remark which may look as pessimistic, but, for the present, is rather realistic.

The fundamental practical interest of full scale thrust is the improvement of correlation methods such as ITTC 78.

First, as the thrust results from the resistance and the thrust deduction, it is impossible to split it into these two factors. The full scale measurement of the resistance being practically unfeasible, one may at best hope to disclose large errors on its prediction assessing that the scale effect on thrust deduction is small. Another means of exploiting the thrust and torque measurements, proposed by AUCHER, is the check of the scale effect on propeller efficiency. It consists of comparing the plots of $K_Q$ versus $K_T$ on model and full scale: their difference is due to the friction on the blades and allows to evaluate it. This process is theoretically sound but as the previous application to resistance, its interest is limited to the accuracy of thrust measurements.

Anyway, it is not a reason to give up these measurements, and we may hope in improvements by some new process yet to be found.

H. TAKAHASHI - Ship Research Institute, Tokyo, Japan.

# FULL-SCALE MEASUREMENTS ON TRAINING SHIP "SEIUN-MARU"

## 1. Introduction

SR183 Research Panel of the Shipbuilding Research Association of Japan which deals with a study on propellers and stern hull forms aiming at reducing the stern vibration and noise, started on a three-year scheme in April 1980.

As putting a conclusion to study on propeller, full scale measurements on the training ship "Seiun-Maru" were performed in 1982.

(The SR183 Research Panel includes a.o. Prof. Takao Inui, Chairman, Prof. Hiroharu Kato, Head No. 2 Sub-Research Panel on Propellers, and Dr. Hajime Takahashi, Head No. 4 Sub-Research Panel on Full-Scale Measurements.)

At present stage, main topics on screw propeller cavitation are related to the problems on erosion and extreme increase of fluctuating pressures induced by unsteady cavitation. The erosion problem has been investigated for some time. On the other hand, a study on the relationship between unsteady cavitation and stern vibration is rather new, as pointed out by F. M. Lewis and J. E. Kerwin in the paper [1], that is, "It was not until 1970 [2] that attention was given to the influence of transient propeller cavitation on vibratory excitation". Moreover, the attention is paid to the noise problem again for some reasons recently.

## 2. Purpose of Full Scale Measurements

The purposes of full scale measurements are firstly to measure the cavity volume and secondly to investigate the effectiveness of a highly skewed propeller for reducing stern hull vibration.

The information on cavity volume is essential to making progress in the theoretical calculation of fluctuating pressures around a stern. In order to measure a cavity volume, the laser beam system developed for measuring the cavity thickness distribution on propeller models [3], [4], were modified and applied to full scale measurements [5].

The role of the full scale measurements as a part of the whole project is shown in Fig. 1.

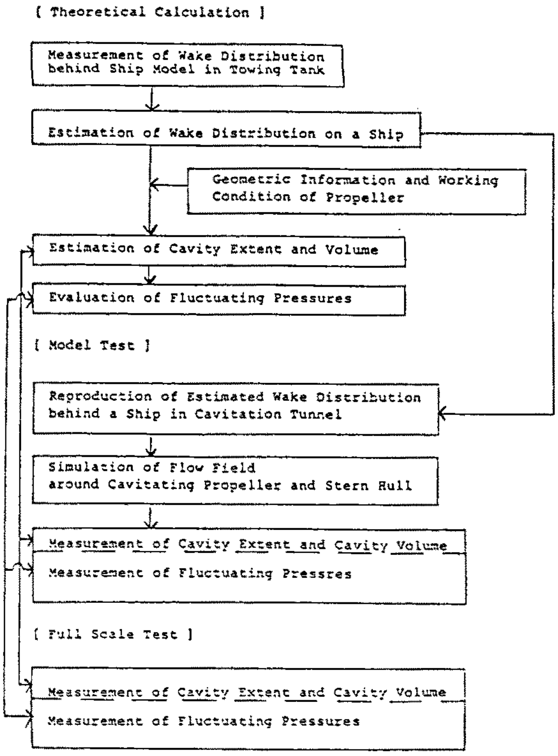

Fig. 1 Role of Full Scale Measurements

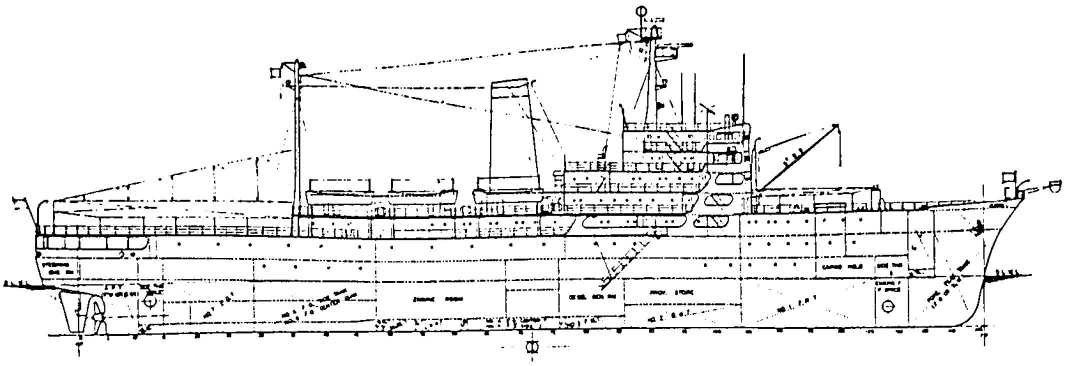

Fig. 2 "Seiun-Maru"

Table 1 Principal Dimensions of "Seiun-Maru"

| | |
|---|---|
| LENGTH b.p. | 105.00 M |
| BREADTH | 16.00 M |
| DEPTH | 8.00 M |
| DRAFT | 5.80 M |
| $C_B$ | 0.576 |
| DISPLACEMENT | 5,781.3 TON |
| MAIN ENGINE: | DIESEL 5,400PS×176 RPM |

CP(M.P.NO.218) HSP II (M.P.NO.220)

Fig.3 Propeller Models

Table 2 Principal Dimensions of Propellers

| Type | CP | HSP II |
|---|---|---|
| Dia. of Prop. (mm) | 3600 | |
| Pitch Ratio (Mean) | 0.950 | 0.920 |
| Exp. Area Ratio | 0.650 | 0.700 |
| Boss Ratio | 0.1972 | |
| No. of Blades (Z) | 5 | |
| Blade Thickness Ratio | 0.0442 | 0.0496 |
| Mean Blade Width Ratio | 0.2465 | 0.2739 |
| Skew Angle (deg.) | 10.5 | 45.0 |
| Rake Angle (deg.) | 6.0 | -3.03 |
| Blade Section | MAU | Modified SRI-B |
| Material | AlBC3(Ni-Al-Bronze) | |

## 3. Full Scale Measurements

Principal dimensions and a side view of "Seiun Maru", which belongs to the Institute for Sea Training, Ministry of Transport, are shown in Table 1 and Fig. 2 respectively. Principal dimensions of propellers (conventional propeller and highly skewed propeller) and photographs of propeller models are shown in Table 2 and Fig. 3. In design of the propeller, the shape of a blade section was changed from MAU type to SRI•B type [6].

Full scale measurements were performed at midnights on 14th~16th May 1982 in the case of CP and on 7th~9th December 1982 in the case of HSP II .

### 3.1 Measuring Items

Ship speed, No. of revolution of propeller, Thrust, Torque, Cavitation extent, Cavity thickness, Fluctuating pressures around the stern, Cavitation noise, Stress on blades, Hull vibration, Noise in Cabin.

This paper mainly describes cavity volume, fluctuating pressures and cavitation noise.

### 3.2 Measuring System

The system structure for cavitation

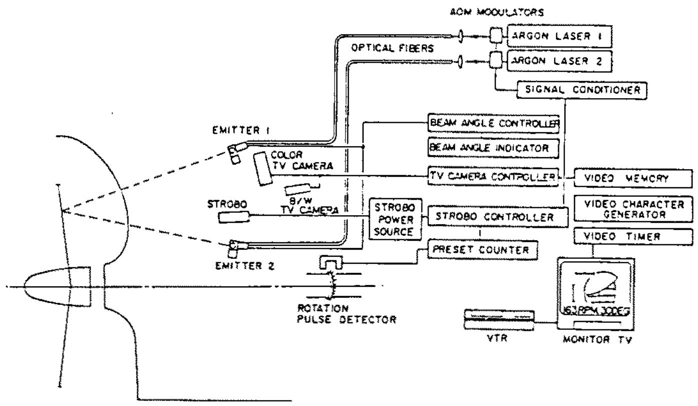

Fig. 4 System Structure for Cavitation Observation

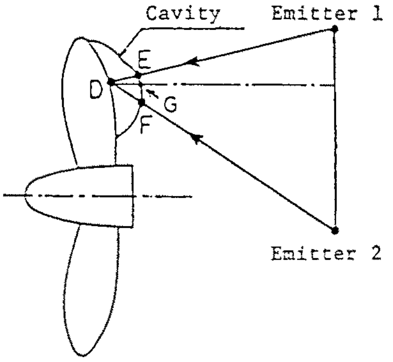

Fig. 5 Principle of Cavity Thickness Measurement

observation and cavity thickness measurements is shown in Fig. 4 and the principle of cavity thickness measurements is shown in Fig. 5. In the case of cavity thickness measurements, two spots of Laser beams from Emitters 1 and 2 are adjusted to be on a single point D in the cavitation free condition. When cavitation occurs, the spot D separates into two spots E and F. Two spots E and F observed by TV camera are shown in Fig. 6. Cavity thickness can then be obtained by

$$\overline{DG} = \frac{1}{b}\,\overline{EF} \quad ,$$

where a factor b is determined from the geometrical locations of the emitters and a TV camera [5].

Arrangements of pressure gauges and hydrophones are shown in Figs. 7 and 8. The measured noise signals were mainly analyzed by 1/3-Octave Band Frequency Analyser in the frequency range from 2 Hz up to 160 KHz.

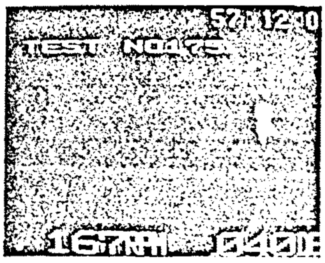

Fig. 6 Two Laser Spots on Propeller Blade (HSP Ⅱ), 163rpm, θ=40°, (0.95R, 0.75c)

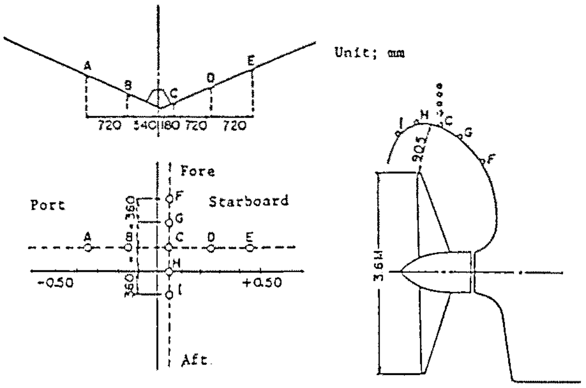

Fig. 7 Location of Pressure Gauges

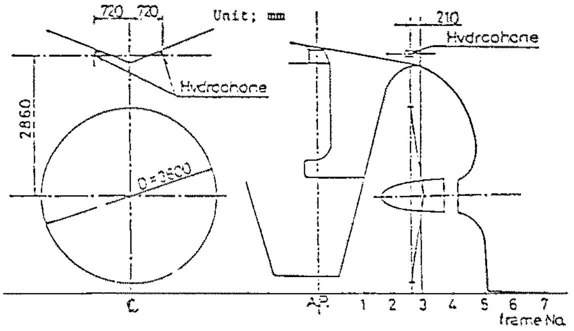

Fig. 8 Location of Hydrophones

## 3.3 Test Results

### 3.3.1 Cavitation Pattern

Tip vortex cavitation occurred at 78 rpm on CP and at 92 rpm on HSP II . Sheet cavitation was dominant on both propellers. Tip vortex cavitation on HSP II was thicker than that on CP.

Cavitation extent on both propellers are shown in Fig 9. No detrimental cavitation was observed.

### 3.3.2 Cavity Thickness

Measuring points

| | |
|---|---|
| Angular Position | $\theta = 30^\circ, 40^\circ, 50^\circ, 60^\circ$ |
| Radial Position | $r/R = 0.85, 0.90, 0.95$ |
| Chordwise Position | $x/C = 0.25, 0.50, 0.75$ |

at 163 rpm

Cavity thickness distribution on HSP II at $\theta=40^\circ$ is shown in Fig. 10. Cavitation near the leading edge is thin and stable. Only few data of cavity thickness on CP were obtained because of damage of the measuring system due to rough sea.

### 3.3.3 Fluctuating Pressures

Fluctuating pressures at point C just above the propeller is discussed.

$$\frac{Kp5(\text{cavitation})}{Kp5(\text{cavitation free})} \doteqdot 2.5 \text{ for CP}$$

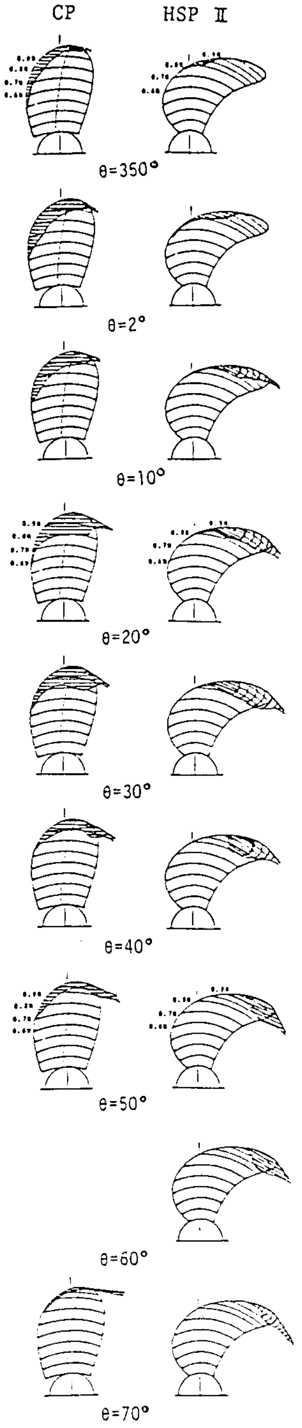

Fig. 9 Cavitation Patterns at 163rpm

$$\frac{\text{Kp5(cavitation)}}{\text{Kp5(cavitation free)}} \doteqdot 2.0 \text{ for HSP II,}$$

$$\text{where Kp5} = \frac{\Delta P}{\rho n^2 D^2} \text{ at Blade Frequency.}$$

The results of Fourier analysis on fluctuating pressures are shown in Fig. 11. 50%~70% reduction in fluctuating pressures was achieved by adopting HSP II .

3.3.4 Noise Measurements

Test results on noise measurements at 163 rpm are shown in Fig. 12. In a range of 100Hz~5KHz, noise of HSP II is smaller by 2~3 dB. Significant differences exist at 1st~3rd components of B. F., which means that the adoption of HSP II is quite effective in reducing fluctuating pressures, but has little effect in the audible range.

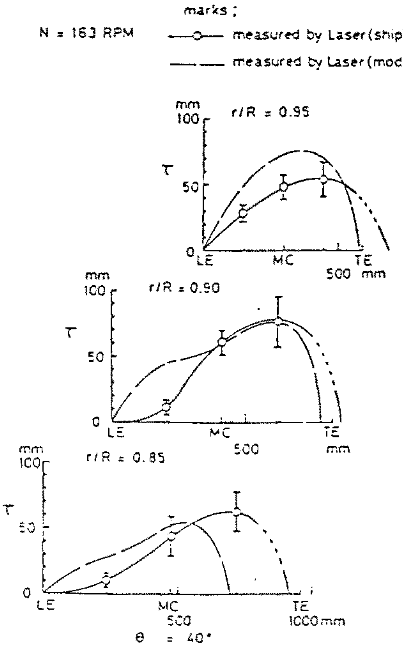

Fig. 10 Cavity thickness at θ=40°, 163rpm (HSP II )

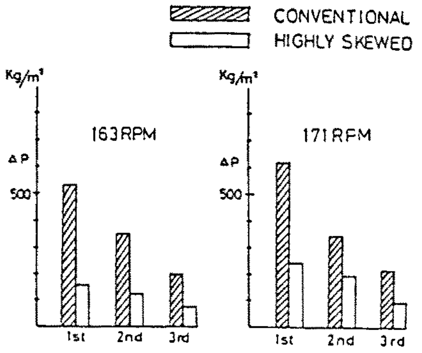

Fig. 11 Amplitute of Fluctuating Pressures at Point C

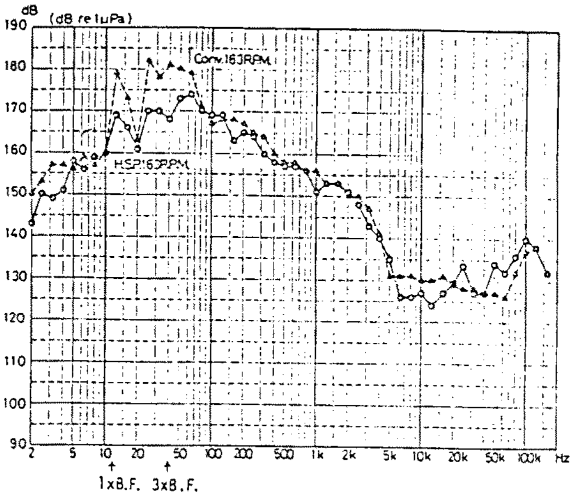

Fig. 12 Noise Measurement on Actual Propllers

## 4. Model Tests

Model tests were carried out in order to estimate stern vibration and noise of the actual ship. Therefore, to confirm the accuracy of experimental estimation, it is very important that comparison of model and full scale measurements is performed carefully. Results of model tests are also used for the evaluation of theoretical calculation.

The measurements of fluctuating pressures induced by cavitating propellers were performed behind the complete ship model in the large cavitation tunnel of SRI.

Table 3 Test Conditions

| | N (RPM) | PS | V (KTS) | Sea State |
|---|---|---|---|---|
| CP | 149 | 2,810 | 14.5 | MODERATE |
| | 163 | 3,700 | 15.5 | |
| | 170 | 4,280 | 16.3 | |
| HSP II | 149 | 2,600 | 15.1 | SLIGHT |
| | 163 | 3,300 | 16.3 | |
| | 171 | 4,000 | 16.6 | |

Table 4 Test Conditions on Models

| Propeller | N(rpm) | $K_T$ | $\sigma_n$ |
|---|---|---|---|
| CP<br>MP No.218 | 149 | 0.200 | 3.66 |
| | 163 | 0.207 | 3.06 |
| | 171 | 0.219 | 2.78 |
| HSP II<br>MP No.220 | 149 | 0.195 | 3.57 |
| | 163 | 0.201 | 2.99 |
| | 171 | 0.212 | 2.71 |

Cavitation noise was measured behind wire mesh screens in the cavitation tunnel of the University of Tokyo.

Scale ratio of the ship model to the actual ship is 1/16.29. Diameter of the propeller model is 0.221m. Test conditions are shown in Table 4.

The estimated wake distribution of the actual ship was realized by using the complete ship model and the flow liner [7] developed for removing wall effect on model wake distribution in the cavitation tunnel [8]. The wake distribution thus realized is shown in Fig. 13.

## 4.1 Cavitation Pattern

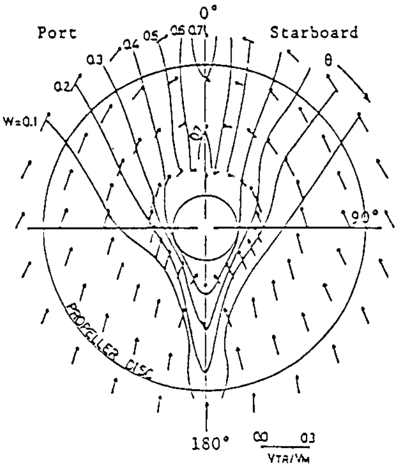

Fig. 13 Realised Wake Distribution of the Actual Ship

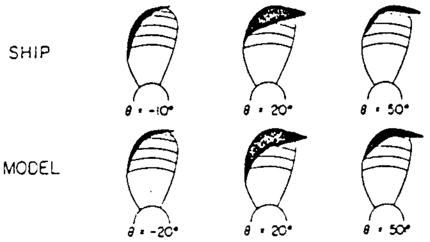

Fig. 14 Cavitation Patterns on CP at 163rpm

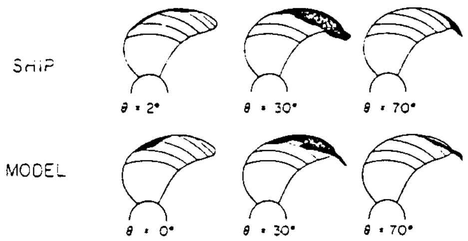

Fig. 15 Cavitation Patterns on HSP II at 163rpm

Cavitation patterns on the propeller models are compared with those on the actual propeller in Figs 14 and 15, which show that the agreement is very good. Quite similar results were obtained in the case of wire mesh method.

## 4.2 Cavity Thickness Distribution

Test results measured by the laser scattering technique [4] are shown in Figs. 10 and 16. Scale of ordinate is five times that of abscissa.

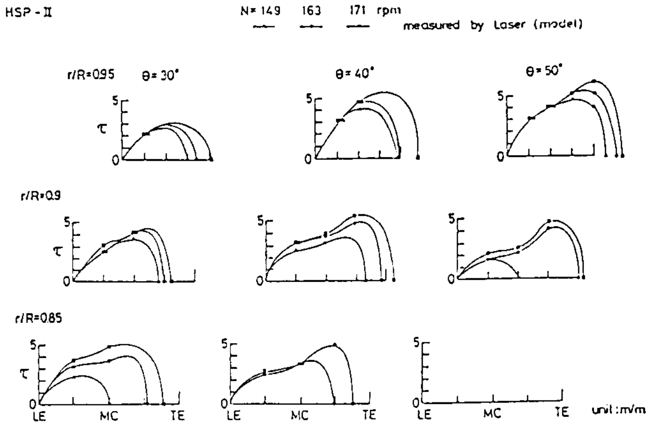

Fig. 16 Measured Cavity Thickness (HSP II )

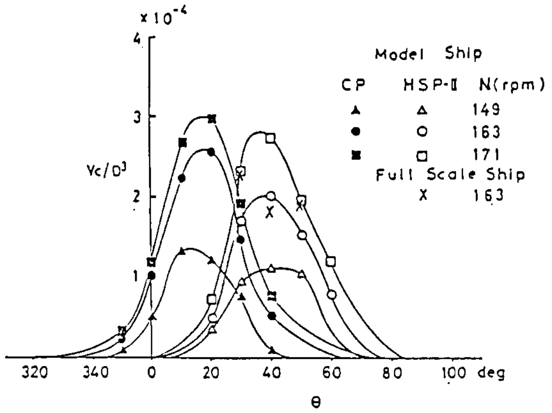

Fig. 17 Variation of Cavity Volume

According to Fig. 10, the correspondence of the model and the actual ship is rather good. It may be said that cavity thickness distribution on an actual propeller is estimated pretty well from model data. Variations of cavity volume estimated from the measured cavity thickness distribution are shown in Fig. 17 including full scale measurements. The agreement of the cavity volume at each angular position between the model and the ship is very good.

### 4.3 Fluctuating Pressure

The distributions of fluctuating pressures both in the transverse and longitudinal directions are shown in Figs. 18 and 19 together with results of full scale measurements.

Kp5 for HSP II was reduced by 50~70% from that for CP. This reduction rate is considerably higher than the reduction rate of cavity volume.

The agreement between model and full scale measurements is rather good. This fact means that fluctuating pressures on a full scale can be predicted quantitatively to some extent from model test results.

### 4.4 Cavitation Noise

The measured results behind wire mesh screen are shown in Figs 20 and 21 together with results of full scale measurements.

In Fig. 20, the results for CP are compared with those for HSP II . There is no difference at 1st B. F. component but noise level of HSP II is lower by 5~7 dB at 2nd and 3rd B. F. component.

The comparison of the measured full scale data and the estimated full scale data based on model test results is shown in Fig. 21. The Levkovskii method [9] is used as a scale correction. There is a trend that the estimated values are slightly higher than the measured values. It is considered that the reason may be reverberation and reflection in the cavitation tunnel.

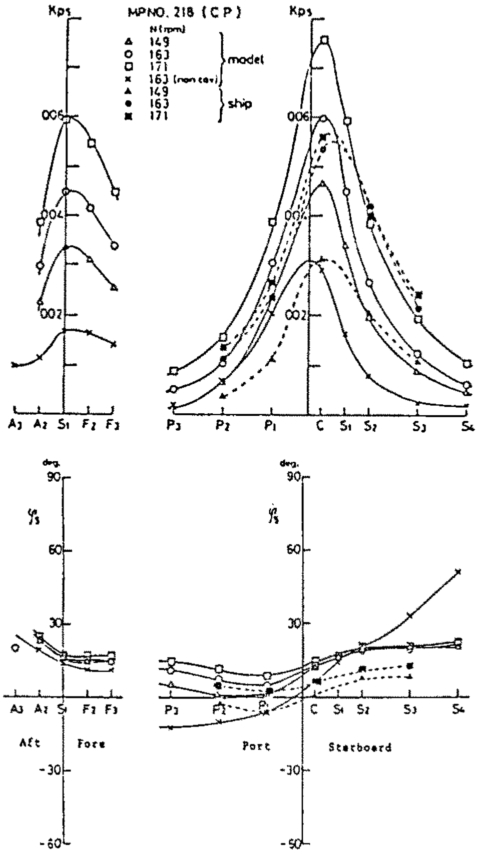

Fig. 18 1st Component of Fluctuating Pressures (CP)

## 5. Concluding Remarks

Summary of conclusions is as follows.

For example, fluctuating pressures at blade frequency at Point C in 163 rpm are

| $\Delta P_5$ | (1)<br>CP<br>$(kg/m^2)$ | (2)<br>HSP II<br>$(kg/m^2)$ | $\frac{(2)}{(1)}$ |
|---|---|---|---|
| full scale measurements | 550 | 170 | 0.31 |
| model tests | 600 | 280 | 0.47 |

There is little difference among values of (2)/(1). This means that the effectiveness in adopting highly skewed propellers can be estimated by model tests

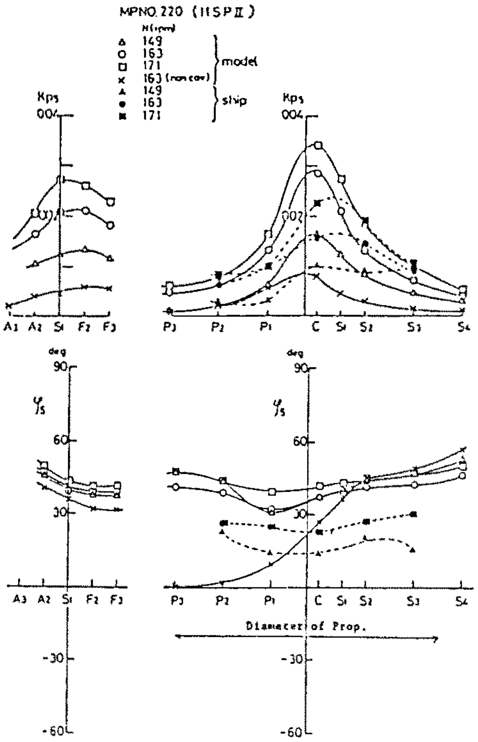

Fig. 19 1st Component of Fluctuating Pressures (HSP II)

Reduction rate of fluctuating pressures in adopting skewed propellers are shown roughly in Fig. 22.

Future tasks concerned are firstly to establish a theory for calculating pressures and cavity volumes precisely by using the data above mentioned and secondly to make measurement of full scale wake distributions.

Future tasks on the measurement of cavity thickness on a actual ship are described in ref. [5].

The author is pleased to acknowledge the considerable assistance of staffs of the following institutes.

University of Tokyo, Osaka University, Kyushu University, Institute for Sea Training, Nippon Kaiji Kyokai, Mitsui

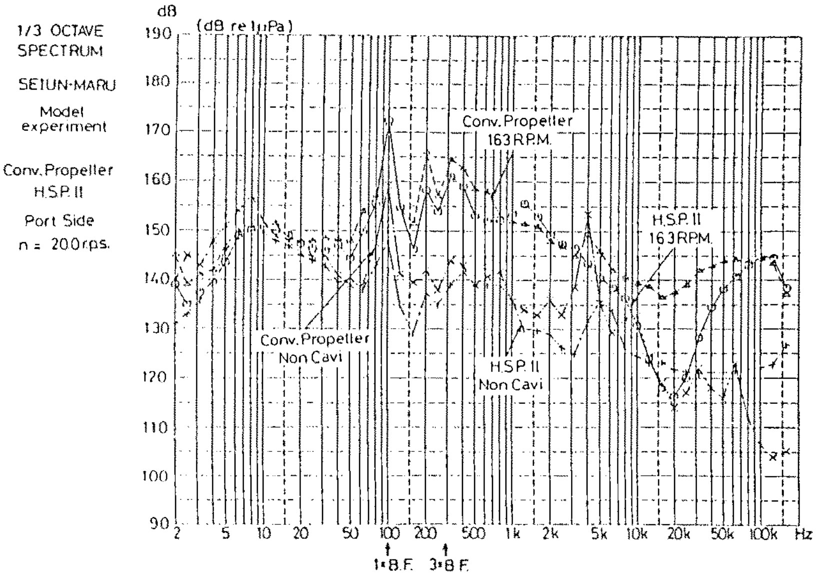

Fig. 20 Noise Measurement on Propeller Models

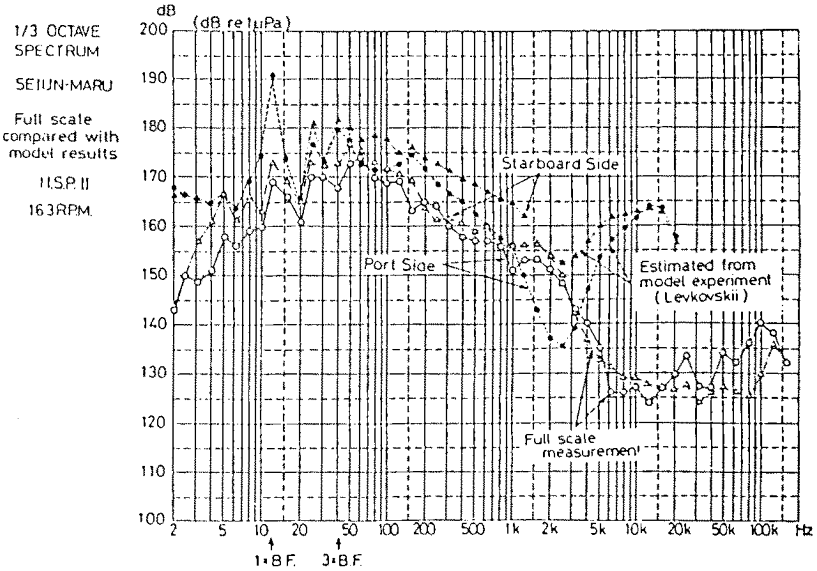

Fig. 21 Comparison of Measured Full Scale Data and Estimated Full Scale Data based on Model Test Results

ΔP : Amp. of fluctuating pressure
⊙ : Model
△ : Ship
with prime : Occurrence of cav.

| No. | Z | TYPE | YEAR |
|---|---|---|---|
| ① | 5(SRI) | Tanker | 1967 |
| ② | 5 | Ore/Bulk/Carrier | 1975 |
| ③ | 4 | Ro/Ro | 1979 |
| ④ | 3(CPP,SRI) | Fishing boat | 1981 |
| ⑤ | 〃 | 〃 | 1982 |
| ⑥ | 4 | Inland vessel | 1982 |
| ⑦ | 5(SR183) | Training ship | 1982 |
| ⑧ | 5 | Car Carrier | 1983 |
| ⑨ | 4(SRI) | Ro/Ro | 1982 |

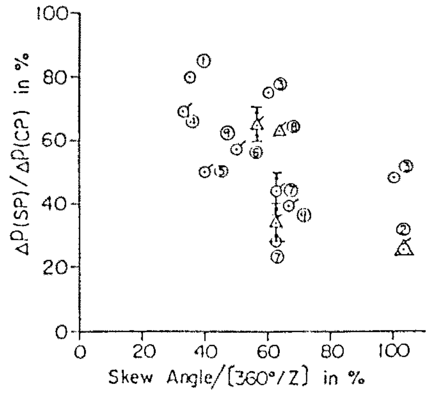

Fig. 22 Relationship between Reduction Rate of Fluctuating Pressures and Skew Angles

Engineering & Shipbuilding Co Ltd, Ishikawajima-Harima Heavy Industries Co. Ltd, Nippon Kokan K. K., Sumitomo Heavy Industries, Ltd, Hitachi Zosen Corp., Kawasaki Heavy Industries Ltd, Mitsubishi Heavy Industries, Ltd, Kobe Steel, Ltd, Nakashima Propeller Co. Ltd.

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[1] Lewis, F. M. and Kerwin, J. E.: "Vibratory Forces on a Simulated Hull Surface Produced by Transient Propeller Cavitation", Journal of Ship Research, Vol. 22, No. 2, June (1978).

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## MEASUREMENTS IN SHIP MANEUVERING

The successful outcome of full scale ship trials greatly depends on sufficient planning and preparation for the trials. Planning should be the major part of the entire trial effort. Poor planning can result in inconclusive results at great cost - time and money essentially wasted. The following are the major items to be considered in the planning process and this sequence was followed in planning and preparing for the successful maneuvering trials of the Esso Osaka trials for "measuring" the maneuvering coefficients through system identification on measurement data obtained during the trials.

1. Establish the need for the trial. What ultimate useful information is to be obtained? At what cost?

2. Establish the necessary maneuvers to obtain the desired information. Make sure the maneuvers do not compromise the safety of the ship. Optimum minimum maneuvers to reduce costs but enough necessary to gain sufficient data with a reasonable amount of backup.

3. Determine what measurements and accuracy are needed. One cannot go back after the trials and obtain information that he/she forgot to get.

4. Determine necessary instrumentation and accuracy required. Consider using as much as possible of the instrumentation already on board.

5. Decide exactly how the analysis of the data is to be carried out. What procedures, computer programs, etc. are to be used in the data analysis. Be sure the analysis technique will work with the data expected to be obtained.

6. Establish the potential for the successful outcome of the trial effort.

7. Assure that the proper instruments are installed on board, tuned up, and properly calibrated.

There have been many trials with poor planning where attempts were made to measure almost everything and the analysis method was tried out after the tests and not before. There was great additional costs in trying to get useful information from the trials.

In case of the Esso Osaka the following was done prior to the trials.

1. "Simulated noisy data" was used to tune up the computer programs used in the system identification process. This led to the development of parallel processing techniques (in which two different maneuvers are simultaneously processed), over and under initial estimates, selected parts of the maneuver for more accuracy, etc.

2. It was established that it would be necessary to measure u (forward speed), v (transverse speed), r (yaw rate) and $\psi$ (the heading angle).

3. It was demonstrated that the linear coefficients could be identified in a $10^o/10^o$ Z maneuver and the non-linear coefficients in a $35^o$ rudder maneuver.

4. The increment of time for updating the identification process could be 4, 8, or 12 seconds. To be on the safe side, measurements were taken every 2 seconds.

5. The Esso Osaka was selected because it was already equipped with a dual axis Doppler sonar log which measured the forward and transverse speed over the ground as well as being equipped with the usual rudder indicator, RPM counter, and gyrocompass. It was only necessary to install an instrument for measuring the yaw rate; the instrument ordered and installed had sufficient accuracy and was comparably inexpensive.

6. Since speed measurements were "over the ground" it was necessary to reformulate the equations of motion to include current and to introduce the magnitude and direction of the current as additional coefficients to identify.

7. Use of simulated noisy data of the specified maneuvers indicated in advance of the trials that there was great potential for successful results.

As a result, the actual trials were very successful giving extremely useful information in the maneuvering predictions of ships. The trials and the results are given in a paper by the author entitled "Measurement of Hydrodynamic Characteristics from Ship Maneuvering Trials by System Identification", Transactions SNAME, November, 1980.

The costs in conducting the trials of the Esso Osaka were significant because the ship had to be taken out of service, instrumentation put on board, etc. Further analysis of the Esso Osaka trial data indicated that the linear and non-linear coefficients can be successfully identified by using just the measurements of u (the forward speed) and $\psi$ (the heading angle) along with the RPM and rudder angle. Since all ships have instrumentation on board to measure RPM, heading ($\psi$) and rudder angle, any ship capable of measuring u becomes a ship of opportunity, on which simple trials during a routine voyage can be carried out with little or no expense to the shipowner. This fact should convince the shipowners to permit their ships to be used in such trials.

Simple full-scale trials conducted during a routine voyage, by which the resistance of the ship can be measured, is described in a contribution to the Report of the Performance Committee by this author.

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FULL SCALE SEAKEEPING TRIALS -
AN INSTRUMENTATION SET FOR SEA AND SHIP MOTION MEASUREMENTS

In spite of the wide developments and improvements in theoretical studies on seakeeping, the experimental full-scale activities are so far limited in number and relevant results are often incomplete due to the lack of a direct measurement of the environmental conditions (sea state) during ship motions trials. In the meantime, the availability of more experimental full-scale data on this topic is essential at least in view of the following scopes, aiming

1) to quantify in a more exact way both the environmental conditions in which a ship operates and the actual behaviour of the ship in terms of motions, accelerations, bottom slamming, deck wetness, etc.

2) to collect data on more similarly sized ships in order to confirm and quantify the expected differences of seakeeping qualities, especially in terms of sustainable

speed in rough seas, to be used in future seakeeping oriented ship design and to derive practically those operational limits to be used in theoretical calculation methodologies

3) to compare experimental data with theoretical results obtained from OS Methods or/and more updated and sophisticated theories, in order to validate them or better understand and quantify the limits and then the range of applicability of such theories, that are extremely useful in an early ship design stage.

On the other hand full-scale seakeeping trials are not easyly performed and moreover they need an unconventional and ad-hoc instrumentation able to provide records of sea state conditions, ship motions and related phenomena.

Concerning wave height measurements the most known instruments are waverider buoys (both unidirectional and directional), even if the adoption of such measuring devices presents many practical problems.

In fact they are difficult to manage, especially in severe sea conditions and often intermittent, and sometimes permanent, loss of the signal transmitted from waverider buoys can be observed. But, mainly, these buoys are subjected to frequent damages or failures, or they may even be lost.

For these reasons environmental data are often obtained by visual observations of the ship crew with some consequent losses of significance in the results and their correlation with theoretical values.

An alternative instrumentation set for seakeeping trials (both for sea state and ship motions measurements) has been well described in Ref. [1], and we are going to shortly describe it as a fully on board installed set-up.

Sea state measuring device consists of an ultrasonic sensor which provides the relative wave height.

The sensor main characteristics are:

SEPA Mod. AS 108/00

| | |
|---|---|
| Ultrasonic Frequency | 24 KHz |
| Scanning Frequency | 10 Hz |
| Resolution | 0.05 m |
| Operation Range | 15-20 m (Full-scale) |

This sensor, which is currently installed on board some Italian Navy Hydrofoils, has been installed on board of some frigates of the Italian Navy during full-scale seakeeping tests, as can be seen from Figs. 1 and 2, and allows the ship to be completely self-sufficient during these trials.

The methodology adopted to correct the measured relative vertical displacement for the angular and vertical ship motions is again detailed in Ref. [1] as well as the mathematical procedure to transform the obtained spectral sea energy distribution versus encounter frequency into an absolute frequency spectrum. The reliability of the SEPA Sensor information is unfortunately limited to sea

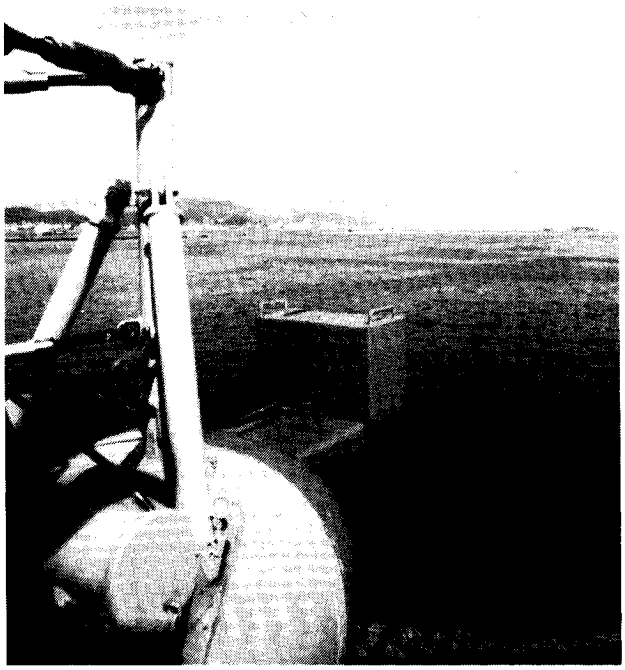

Fig 1

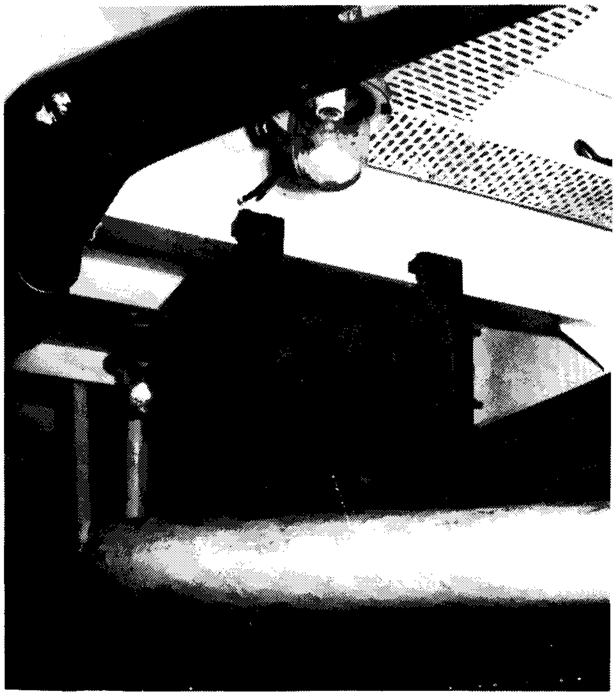

Fig 2

spectra obtained when the ship heading angle ranges between head and bow conditions.

In beam sea the definition of sea spectra is unacceptable while in following and quartering sea it is impossible because there is no one-to-one relation between the encounter and the absolute frequency. This means that to have a correct definition of the sea spectrum, during seakeeping trials, two or more ship runs in head (or bow) sea conditions must be carried out (at the beginning, during and before stopping the trials).

As concerns ship motions measurements, a wide variety of accelerometers and pitch / roll meters has been used.

A more compact and reliable though more expensive device consists of a stabilized platform installed at the ship's center of gravity.

One of the main devices of the platform is an horizontal reference gyro. This allows to measure the accelerations along longitudinal, horizontal and vertical axes of the ship. Furthermore, it measures the changes of the ship's angle with respect to the pitch and roll axes against a ship-motion independent stationary horizon.

A detailed description of the main characteristics of RMS stabilized platform and its use during full-scale seakeeping trials is reported again in Ref. [1]. The following complementary measuring devices are here described as a standard set for such trials:

- bow and stern accelerometers by KISTLER to measure the vertical accelerations of these ship points

- bow bottom and side strain gauges by the Micron Measurement (half bridge with temperature compensator) to investigate the slamming phenomena

- torquemeter and shaft revolutions counter in order to measure the shaft power

- Raydist Radiolocation System for an exact measurement of the ship speed during the trials (see Fig. 3)

All signals are sent to a control central, recorded on F. M. magnetic tape and later on analyzed by a F. F. Analyzer in order to obtain the response spectra and significant heights.

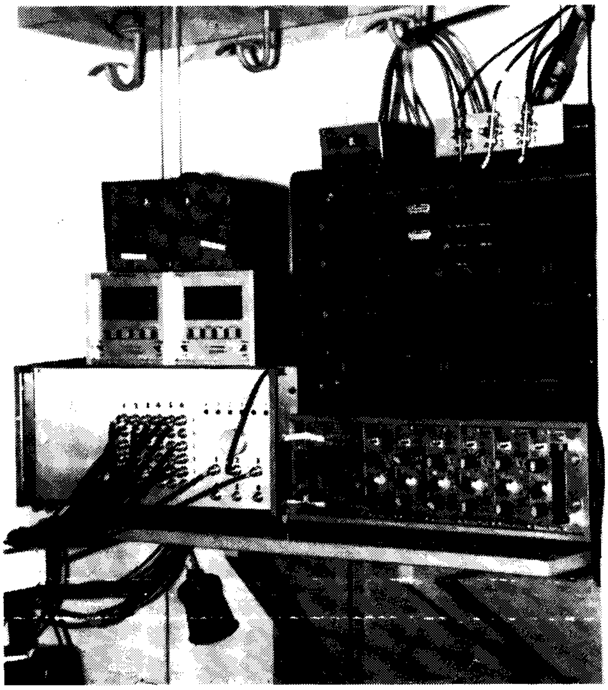

Fig 3

A general arrangement of the instrumentation set employed, for a naval vessel, is shown in Fig. 4.

The main results of a practical application of the full on board instrumentation set, are summarized in Fig. 5.

This figure shows sea spectra, pitch and heave R.A.O.s and a quantification of the error incurred during a sea spectrum mapping due to a wrong estimation of heading angle.

Concerning the adoption of the above described instrumentation, our experience can lead us to the following conclusions:

1) reliable information of long crested sea spectrum can be obtained when the sea ranges from head to bow conditions

2) the definition of sea spectra is unacceptable for beam seas and even impossible for following and quartering seas. However this fact is of little importance because there is always the possibility to perform head-on runs for which the definition of sea spectrum is reliable

3) compared with alternative instrumentation systems our set presents the remarkable advantage of a low cost installation without sacrificing the accuracy of results.

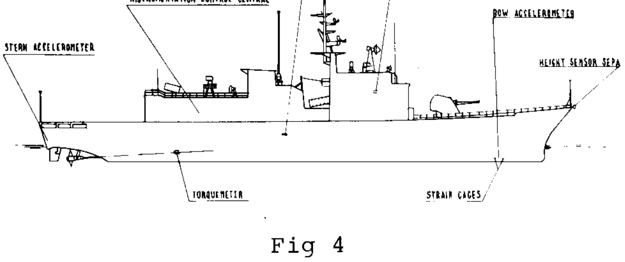

Fig 4

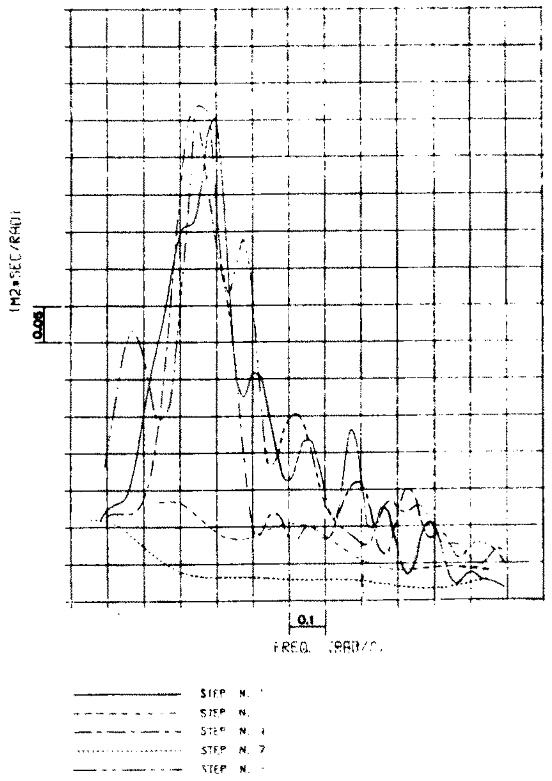

Fig 5a ACV-017 Sea Spectra

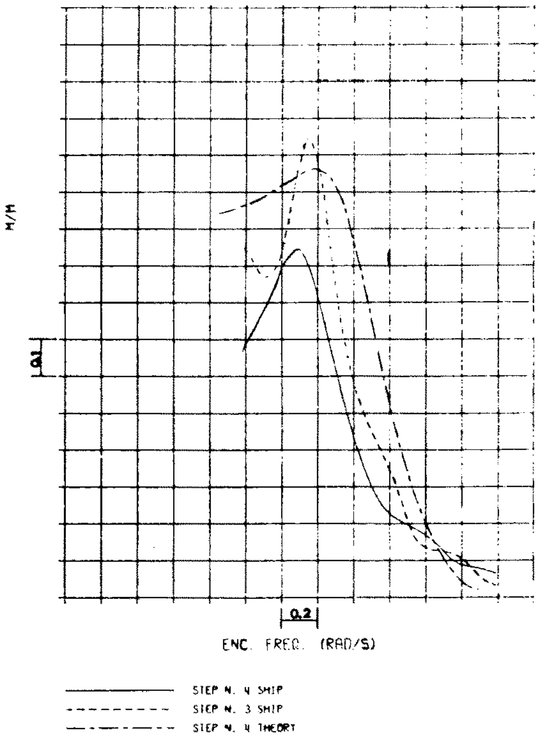

Fig 5b ACV-017 Heave R.A.O.

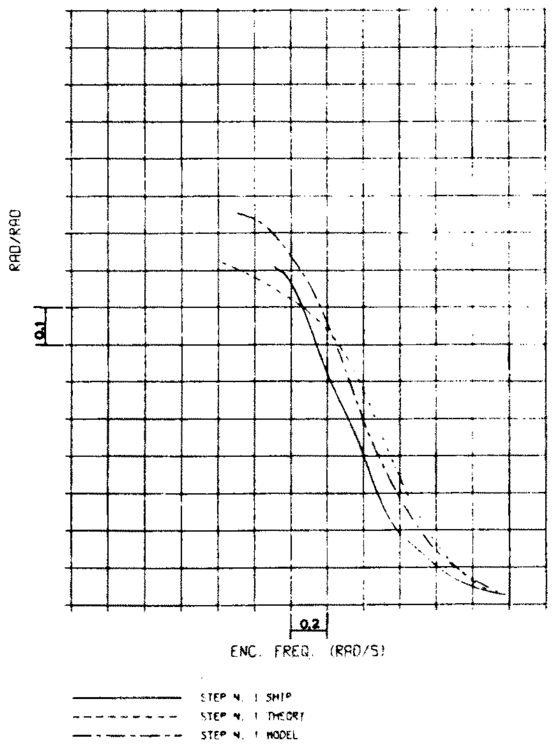

Fig 5c ACV-017 Pitch R.A.O.

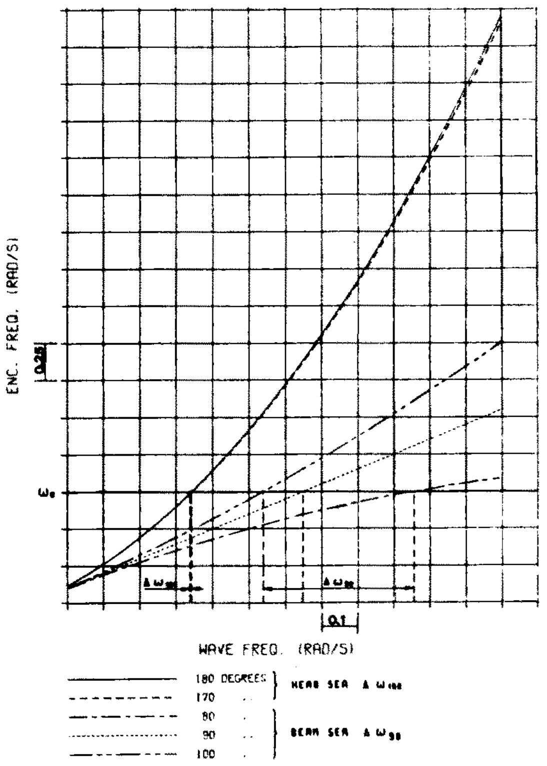

Fig 5d ACV-017 Inaccuracy in wave frequency for an error of ± 10 degrees in heading angle

## Reference

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## 1a-3. Free Discussion

The free discussion that followed was largely related to the above presentations.

*The Chairman* opened the discussion by pointing out that very little was mentioned in the presentations about the accuracy of the different measurements. As the full-scale results often are used as the basis for different comparisons the reliability of the results is very important.

He also commented on Prof. Abkowitz's contribution, saying that it was very interesting but that the equipment seemed to be very sophisticated.

He did not agree with Mr. Jourdain's pessimistic conclusion about thrust measurements. He made reference to the Report of the Performance Committee, in which the necessity of full-scale thrust measurements is stressed.

He finally asked Dr. Takahashi if corrections were made on the pressure amplitudes for the vibrations in the hull plating. *Dr. Takahashi* replied that the vibrations measured were so small that he believed there was no need for such corrections.

*Dr. van Gent* asked Dr. Takahashi if he had considered to measure the velocities of the cavitation bubble dynamics instead of the cavity thickness, and, again, what accuracy would be obtained if the thickness measurements were used to calculate also the cavitation velocity. *Dr. Takahashi* replied that he did not believe it should be possible to obtain the cavitation velocity from the measurements carried out. However new measurements using new equipment is already planned and already next year he hopes to be able to present measurements also of the cavitation velocity.

*Dr. Burcher* asked Prof. Abkowitz if studies had been made of the errors introduced when a redundant number of measuring parameters were used. *Dr. Sharma* asked if studies had been made about the possibility of using filters to avoid systematic errors such as those due to drift in the instrumentation, and if it is possible to identify the current also when measurements of the transverse speed were omitted. *Dr. Choung Lee* finally asked Prof. Abkowitz what was the purpose of his measurements.

In replying *Prof. Abkowitz* stated as follows:

1. Question: Errors introduced when redundant number of measuring parameters were used.

   The measurements made during the Esso Osaka trials were the forward velocity (overground) u, the transverse velocity (overground) v, the yaw rate r and the heading angle $\psi$. The only redundancy might arise from using both the measurements of r and $\psi$. Errors can occur through redundant measurements if the redundant measurement is "noisy". However, in the case of the Esso Osaka, the measurement of $\psi$ had essentially no noise and the measurement of r had very little noise. Therefore no errors due to redundancy were detectable.

2. Question: Were filters used to avoid systematic errors such as instrumentation drift?

   The forward speed (u) and the transverse speed (v) were measured by Doppler sonar and there is essentially no drift involved in the Doppler technique. The heading angle ($\psi$) is measured by the gyro-compass which is a reliable, very stable and essentially no noise instrument. Therefore, over the time of a given maneuver there is essentially zero drift from this instrument. The only measurement which could suffer from drift is the yaw rate (r) measuring device. We checked this instrument for drift during a maneuver through the relationship that

$$\int_{t_1}^{t_2} r dt = \psi(t_2) - \psi(t_1)$$

   In most of the maneuvers there was no drift and in the few that had drift, there was very little drift and the drift was corrected. Therefore, it was not necessary to use filters to correct instrument drift.

3. Question: Possibility to identify the current when measurements of transverse speed are omitted.

   The equations of motion which predict the forward and transverse motion over the ground contain terms involving the magnitude and direction of the current and these two items are subject to identification just like any of the hydrodynamic coefficients in the equations. The probability of identifying the current is improved if the transverse speed is measured but this measurement is not necessary for successful identification of the current. The current magnitude and direction of the Esso Osaka in the $10^o/10^o$Z maneuver and the $35^o$ hard rudder turn were successfully identified by using only the forward speed data (which is affected by the current) and the heading angle data (which was used to give heading rate information) without using the transverse speed data.

4. Question: What was the purpose of your measurements?

   The purpose of measuring the forward speed (u), the transverse speed (v), the yaw angle ($\psi$) and the yaw rate (r) during Z and hard rudder maneuvers was essentially to measure the ship motion response (output) to a known rudder excitation (input) and through system identification techniques, which match output with input, "measure" (determine) the hydrodynamic coefficients of the ship, which appear in the maneuvering simulation model. Whereas system simulation uses a simulation model to predict the response (output) of the ship to a given rudder deflection (input), system identification magnitude predicts the simulation model by matching output to input not only giving the magnitudes of the coefficients (at full size Reynolds number) but also giving information with regard to the validity of the form of the simulation model (equations of motion) which was assumed in setting up the equations. The results of using system identification analyses of the Esso Osaka data indicated that several of the hydrodynamic coefficients measured by scaled model tests suffered from "scale effect" (Reynolds number effects) and the form of the equations, which originally was assumed to be valid if non-linearities through the cubic terms were included, was shown to be inadequate for this ship because the ship lost three-quarters of its speed in a turn and the propeller RPM was maintained at its original value throughout the turn. As a result of these tests the form of the model was altered to take care of very large speed losses and propeller race effects over the rudder and the coefficients in the simulation model (at full-scale Reynolds number) were determined, thereby giving a realistic maneuvering simulation model for the ship.

*Prof. Abkowitz* next turned to Mr.Colombo asking him about the purpose of the seakeeping trials described. *Mr. Colombo* replied like this:

Besides the need to carry out this kind of tests to comply with the design specification submitted by the Italian Navy, such acquisition comparisons are mainly devoted to investigate on the ship roll motion which is the most affected by non linear phenomena, with a particular attention to the effect of antiroll fins.

This last effect was extensively investigated on different frigate classes of Italian Navy and has been estimated on the basis of the significant amplitudes of roll obtained by full scale trials in bow, beam and quartering sea with fins on and off respectively, as shown in the CETENA Report No. 1109.

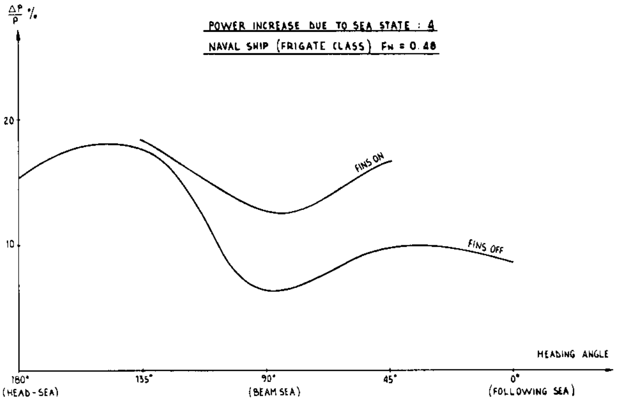
Due to the confidential nature of such data, it is only possible to give the percent decrease of the roll angle significant amplitude, which referring to the above mentioned Trials Report, can be summarized:

| | | |
|---|---|---|
| Bow Sea | 37% | Ship $F_n = 0.48$ |
| Beam Sea | 38% | |
| Quartering Sea | 58% | |

Another most important aspect that can be investigated during such trials concerns the added power due to the sea state.

A result of such an investigation is again summarized in the diagram enclosed here, where, in function of the ship-sea encounter angles, power increase is reported for a frigate in a sea state 4.

Furthermore, such acquisitions enable to quantify in an experimental way he occurrence of undesired effects uch as accelerations in particular



operative ship areas, slamming, green water on deck, etc.

The Chairman thanked the participants for their interest and closed the Session.