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Mathematical Modelling and Verification of a Full Scale Naval Training Ship Progressive Power-Speed Trial

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Abstract

A progressive speed trial was conducted on a full scale naval training ship of twin propellers to establish the power-speed characteristics as to fulfill one of the contractual obligations by the shipbuilder to the ship owner. The trial was conducted in Sea State 1 conditions at full load displacement. The readings taken prior and during the trial include; ship speed, engine horsepower, displacement, draft, wind speed, wind direction, wave height, water depth, sea water temperature, sea water density, atmospheric temperature, rotational speed of the propulsion engine and propeller shaft rate of rotation. As usual the trial was performed progressively at about equal speed intervals. The engines brake horsepower at the respective trial speed was measured during the trial. Whereas the effective power available at the propellers corresponds to each trial speed was predicted theoretically based on the measured engine horsepower according to the formulations contained in the relevant Recommended Procedures and Guidelines of the International Towing Tank Conference (ITTC). The calculated or the theoretical effective power derived from the real full-scale trial was then modelled mathematically as a function of speed. The resulting effective power-speed curve generated from the ITTC method and that obtained from the mathematical modelling were cross-plotted to examine their exactness to each other. As indicated by the closeness of the overlapping of the cross-plots of the power-speed curves, it signifies the precision or accuracy of the results. Therefore, the progressive-speed trial of the full scale naval training ship has been successfully modelled mathematically and verified.

Keywords; *Progressive power-speed trial, Sea state 1, Full load displacement, Mathematical modelling, Delivered power, Effective power, International Towing Tank Conference (ITTC).*

I. INTRODUCTION

The main objectives of the study are to mathematically model and verify the actual progressive power-speed trial characteristics of the naval training ship based on the sea trial conducted. The results of the analysis and the mathematical modelling of the actual sea trial results as verified would be very useful and serve as reference for guidance to the captain and the navigation officers of the ship for manoeuvring or handling the ship particularly in open seas and in restricted waters such as canals or rivers and entering or leaving harbours. The data is also important to the marine engineers and the technicians who are the technical operators and maintainers of the machinery on board. The performance data would be treated as the original power-speed performance of the ship of the newly constructed ship and will also be used as

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future reference when the ship undergoes major refurbishments during the service life. The information is normally made available and kept on board as one of the documents of the standard operating procedures for the ship and contained in the ship information book.

Figure 1. Royal Malaysian Navy Training Ship 1

Figure 2. Royal malaysian navy training ship 2

The Royal Malaysian Navy acquired two naval training ships of the same class designed by Daewoo Shipbuilding and Marine Engineering Company Limited (DSME). One of the ships was built by DSME and the other was built by a Malaysian Shipbuilder NGV Tech, however both ships was then contracted out to Grade One Marine Shipyard for the setting to work of the ship equipment and systems, tests and trials and until the commissioning. Both ships are built with a helicopter deck and the operational range is up to 2,500 nautical miles at economical speed with an endurance of 21 days at sea. The ships are fitted with modern air and surface search radar, navigational radar, the up to date necessary communication system and a combat system fitted for but not with modern weapons to be able to perform combat ships when the needs arise.

The total number of crews of the training ship is 45 and capable to accommodate 60 trainees of mixed gender crewing on board with specially allocated compartments for female officers and trainees of up to 12. Each ship is fitted with armaments of one MSI DS30M 30mm cannon and two M2HB Browning 12.7mm machine gun. Missiles and torpedo such as RIM-116 Rolling Airframe Missile (RAM) SAM, Exocet MM40 Block 2 SSM and triple torpedo launcher can be installed instantly when needed with the existing weapon system outfit. Both ships are installed with the same type of aviation facilities to accommodate one medium size helicopter each for anti-surface and anti-submarine warfare. The ships are capable to perform patrolling duties in the Malaysian waters.

The principal particulars of the ship are:

Length Overall, L_{OA}	76 m
Length Between Perpendi,culars L_{BP}	69.6 m
Length Waterline, L_{WL}	69.6 m
Beam, B	11 m
Depth, D	7 m
Designed draft, T	3.15 m
Full Load Displacement, Δ	1323 tonnes
Wetted Surface area, S	692 m^2
Block Coefficient	0.544
Propeller Diameter, d	2.5 m
Propulsion Engines	2 x MAN Diesels

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Maximum Continuous Rating	6570 kW
Range	2500 nautical miles
Endurance	21 days
Number of Propellers	2

The methods of analysis used in the study are based on the Recommended Procedures and Guidelines of the ITTC [1], [2], [3], in specific to the 1978 Performance Prediction Methods effective 2017, Testing and Extrapolation Methods for Resistance and Resistance Tests effective 2002 and Full Scale Measurements Speed and Power Trials Analysis of Speed/Power Trial Data effective 2005. This paper deals with the analysis and verification of the full scale progressive power-speed results of one of the naval training ships**.**

II. THE RECOMMENDED ITTC PROCEDURES AND GUIDELINES

The relevant ITTC Recommended Procedures and Guidelines on the formulation for full scale predictions are described below:

A. ITTC 1978 Recommended Procedures and Guidelines Performance Prediction Methods Effective 2017

The effective power P_E calculated in trial conditions:

$$P_E = ½C_{TS}\rho SV^3.10^{-3}\ (kW) \quad (1)$$

The total resistance coefficient C_{TS} of the full scale ship was predicted from the model test results of the ship, ρ is the sea water density kg/m^3, S is the wetted surface area in m^2 and V is the ship speed in m/s.

$$C_{TS} = (1+k)C_{FS} + \Delta C_F + C_A + C_W + C_{AAS} \quad (2)$$

$$C_{FS} = 0.075/(\log_{10}Re - 2)^2 \quad (3)$$

$$\Delta C_F = 0.044[(k_s/L_{WL})^{1/3} - 10.Re^{1/3}] + 0.000125 \quad (4)$$

$$C_A = (5.68 - 0.6.\log_{10}Re).10^{-3} \quad (5)$$

$$C_W = C_{TM} - (1+k)C_{FM} \quad (6)$$

k is the form factor determined during the model test at Froude number Fn ≤ 0.2, C_{FS} is the ship frictional resistance coefficient, k_s is the roughness of the hull surface taken as 150.10^{-6} m, L_{WL} is the length waterline, Re is the Reynold number, C_A is the correlation allowance, C_W is the wave resistance coefficient determined during the model test, C_{TM} is the model total resistance coefficient and C_{FM} is the model frictional resistance coefficient.

B. ITTC Testing and Extrapolation Methods for Resistance and Resistance Tests Effective 2002

$$C_T = R_T/½\rho SV^2 \quad (7)$$

$$C_R = C_{TM} + (1+k)\ C_{FM} \quad (8)$$

$$C_F = 0.075/(\log_{10}Re - 2)^2 \quad (9)$$

C_T is the total resistance coefficient, C_R is the residual resistance coefficient and C_F is the frictional resistance coefficient of the ITTC model-ship correlation line.

C. ITTC Full Scale Measurements Speed and Power Trials Analysis of Speed/Power Trial Data Effectieve 2005

The definitions in the following paragraphs are applied to the full scale measurements of the speed and power trial.

The ship speed is that realised under the contractually stipulated conditions. Ideal conditions to which the speed should be corrected to maximum wind speed of Beaufort 2, maximum wave heights and wave periods of Beaufort 2, no current, deep water, smooth hull and propeller surface. The hull and propulsors conditions are as from the most recent dry docking report.

The trial protocols or agendas outlining the scope and procedures of the trial. The trial log contains the run number, type of maneuver, approach speed by log, approach shaft speed, times of start and stop of the maneuvers, and any other comments.

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The propeller pitch would be the design pitch for the controllable pitch propeller (CPP). Running pitch is the operating pitch of the CPP. Brake power is the delivered power at the output coupling of the propulsion machinery, shaft power is the net power supplied by the propulsion machinery after the speed reducing and other transmission devices and delivered power is the power delivered to the propeller. The following admiralty formula is recommended to be applied for displacement changes:

$$P_1/(V_1^3 D_1^{2/3}) = P_2/(V_2^3 D_2^{2/3}) \qquad (10)$$

P_1 is the power corresponding to displacement D_1, P_2 is the power corresponding to displacement D_2, V_1 is the speed corresponding to displacement D_1 and V_2 is the speed corresponding to displacement D_2.

III. CONDUCT OF THE TRIAL AND THE MEASURING INSTRUMENTS USED

A series of model tests on the resistance and propulsion were carried out in towing tank at Korea Ocean Research and Development Institute (KORDI) [4]. The tests were carried out with the main objectives to investigate the ship resistance and self-propulsion performances based on the designed hull form and propellers for the full range of the operational speeds of the ship.

The full scale trial had been conducted strictly in accordance with the relevant Recommended Procedures and Guidelines of the International Towing Tank Conference as stipulated in Paragraph II above including the method of analysis of the trial data as well as the necessary instruments or equipment used. The mean draft, displacement, revolutions per minutes (RPM) of port/starboard propellers of the ship at the start of the trial were 3.15 m, 1323 tonnes and 306/306 RPM respectively. The full scale progressive power-speed trial was conducted in Malaysian waters.

The measuring instruments used during the trial are shown in TABLE 1 below. All the measuring instruments used had been calibrated accordingly prior to the trial. The marine environmental conditions are read and recorded before the commencement of the trial are given in TABLE 2. These include the wind speed, wind direction, water density, water temperature, environmental temperature, current speed, significant wave height, wave direction and the water depth in the area of the trial being conducted. These environmental conditions are also taken and recorded for every trial run.

As usual the trial was performed progressively at about equal speed intervals. The engines brake horsepower at the respective trial speed was measured during the trial. Whereas the effective power available at the propellers corresponds to each trial speed was predicted theoretically based on the measured engine horsepower according to the formulations contained in the relevant Recommended Procedures and Guidelines of the International Towing Tang Conference. The standard mathematical approaches such by power law and polynomial curve fitting method are employed in the study.

Table 1. Measuring Instruments Used In The Trial

Parameters Measured	Measuring Instruments Used
Ship Draft	Reading of Draft Marks
Water Depth	Echo Depth Sounder
Sea Water Density	Hygrometer
Wind Speed	Anemometer
Wind Direction	Wind Director Indicator
Ship Heading	Gyrocompass
Ship Speed 1	Measured Miles / Speed Log
Ship Speed 2	Measured Miles / Speed Log
Engine Revolution Per Minute	Engine RPM Sensor
Engine Delivered Power	Strain Gauge / Toque Meter

IV. RESULTS

The measured trial environmental conditions, the effective powers as analysed from the full scale

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trial, as predicted from the model tests, mathematically modelled, by

power law and polynomial curve fitted are presented in the subsequent TABLES. Measurements of the required parameters and the environmental conditions of the trial were carried out using the available fixed measuring instruments and portable apparatus available onboard the ship. One could observe the results of the analysis and mathematical modelling of the power-speed curves qualitatively and objectively.

Table 2. Measured trial environmental conditions at the start of trial (sea state 1)

Environmental Conditions	Measured Quantities	Unit
Wind speed	20	Knot
Wind direction	310	Degree
Water density	1025	kg/m^3
Water temperature	30.3	Centigrade
Environmental temperature	29.0	Centigrade
Current speed	0	Knot
Significant wave height	0.1	Meter
Wave direction	270	Degree

Table 3. The effective power as analysed from the full scale trial

Trial V_s (kn)	PE (kW)
9.99	269.30
14.70	1034.06
15.80	1309.94
17.00	1688.00
18.50	2284.05
20.10	3221.37

Table 4. The effective power predicted from the model test

V_s (kn)	PE (kW)	% Difference
9.99	269.27	-0.01
14.70	1034.06	0.00
15.80	1309.94	0.00
17.00	1688.05	0.00
18.50	2284.05	0.00
20.10	3220.68	-0.02

Table 5. Mathematical modelling of the effective power by power law.

$PE(V_S) = 0.082V_S^{3.512}$

V_s (kn)	PE (kW)	% Difference
9.99	265.64	-0.01
14.70	1031.41	-0.26
15.80	1328.92	1.45
17.00	1718.50	1.78
18.50	2312.71	1.25
20.10	3094.84	-3.93

Table 6. Mathematical modelling of the effective power by 4th degrees of polynomial curve fitting.

$PE(V_S) = 12651.03 - 3709.59V_S + 400.128V_S^2 - 18.676V_S^3 + 0.338V_S^4$

V_s (kn)	PE (kW)	% Difference
9.99	271.51	0.82
14.70	1041.85	0.75
15.80	1327.69	1.35
17.00	1699.90	0.71
18.50	2309.65	1.12
20.10	3253.38	0.99

V. DISCUSSION

The full scale power-speed on the naval training ship was carried out successfully. The main objectives were to establish the power-speed characteristics and to fulfill one of the contractual obligations by the shipbuilder to the ship owner. The trial analysis of the model tests and full scale trial had been conducted in accordance with the relevant ITTC Recommended Procedures and Guidelines. The predicted full scale effective power of the ship at the respective operational speeds based on the model test results are shown in TABLE 4.

The calculated or the theoretical effective power derived from the real full scale trial was then modelled mathematically as a function of speed according to the power law below and the results are given in TABLE 5.

$$PE(V_S) = 0.082V_S^{3.512} \quad (11)$$

The second mathematical modelling of the effective

power-speed curve was by polynomial curve fitting of the

4th degrees below and the results are given in TABLE 6.

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$$PE(V_S) = 12651.03 - 3709.59V_S + 400.128V_S^2 - 18.676V_S^3 + 0.338V_S^4 \quad (12)$$

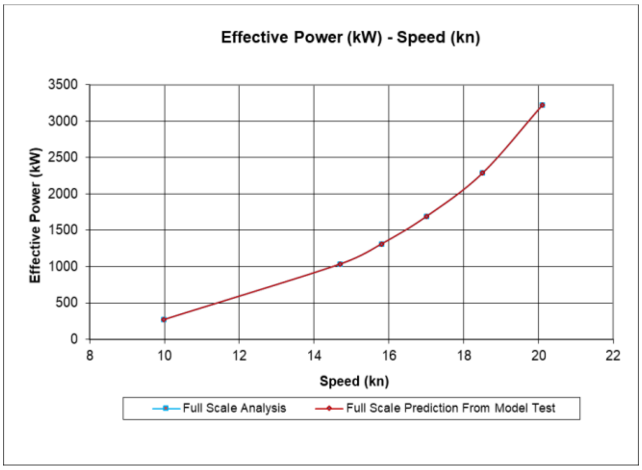

Figure 3. Full scale analysis versus full scale prediction from model test

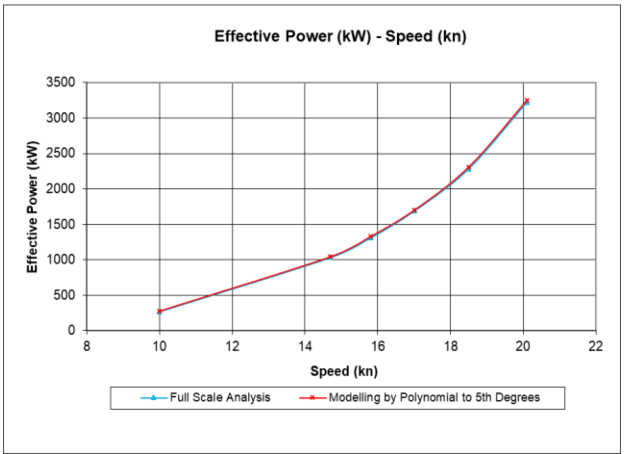

Figure 4. Full scale analysis versus modelling by polynomial to 4th degrees

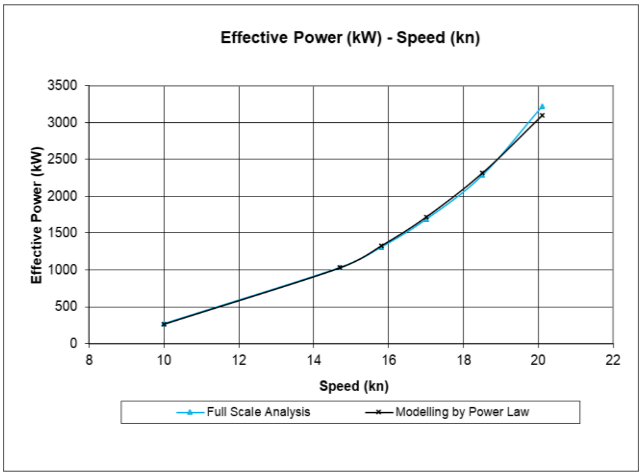

Figure 5. Full scale analysis versus modelling by power law

Figures 3, 4 and 5 show the cross-plots between the full scale power-speed trial results versus the model test results and those mathematically modelled by polynomial of 4th degrees and power law which verified the degree of accuracies of the results and the reliability of the methods.

VI. CONCLUSION

The resulting effective power-speed curves of the full scale ship calculated from the ITTC method and that predicted from the model tests, mathematical modelled by power law and by polynomial curve fittings are cross-plotted to examine their exactness to each other. As indicated by the percentage difference of the computed results of the analysis and the closeness of the overlapping of the cross-plots of the power-speed curves below, it signifies the precision or accuracy of the results. Therefore, the conduct of the progressive-speed trial of the full scale naval training ship has been successfully carried out and fulfilled the objectives. The test results had been analysed, modelled mathematically and verified.

VII. ACKNOWLEDGMENT

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