

Design and Construction of the Propulsion System of a Modelled Offshore Service Vessel

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ABSTRACT

The paper focuses on the design, construction and testing of a propeller system for a modelled offshore vessel. It will discuss the construction of the hull of a vessel using steel, design calculations and selection of the propeller system which was powered by battery and electric motor. The experimental testing of the vessel propulsion system was conducted in a 3-meter by 3-meter water reservoir with a depth of about 5-meter to mimic a real-life environment. The results of the tests are satisfactory. The contribution of this work is the practically demonstrating of ship movements in water using a propeller system powered by battery and electric motor in order to enhance pedagogy teachings in Nigeria/West Africa. Further work will focus on the development of a controller system to aid maneuverability for the modelled vessel.

Keywords—*Propulsion/propeller system, offshore vessel, ship movement*

I. INTRODUCTION

Ship propulsion is of importance to ship movement and maneuverability. In the last century much work has been done and published in the field of propulsion [1, 2] with focus ranging from control of propulsion system [3, 4], to propulsion performance [5], and more recently, on performance optimization of propulsion [6] and development of innovative propellers [7].

In this paper, our focus is to develop a propeller system for a modeled vessel. This will involve applying basic rules/principle of design (i.e., which is to ensure safety, simplicity and functional ability of the system). The work also includes fabrication and construction of the ship hull structure, shaft, and propeller so that the system can be experimentally tested in a lab environment. This will be useful in practically demonstration of ships movement in water.

The paper is organized into 6 sections comprising of the introduction, design, construction and experimental testing and conclusion sections. The introduction section provides an overview on propulsion system and basic concepts is provided in the methodology section. This is followed by the design section which describes the design process and calculations with the aid of charts to generate propeller characteristics/curve which was modified to match the prime mover. The next section described the construction of the vessel from steel sheet, while the experimental testing followed it. The final section in the paper is the conclusion section.

II. METHODOLOGY

A propulsion system is used to provide thrust to a ship/flight system to overcome resistance. There are various types of propulsion system, such as vertical-axis (or cycloidal), nozzle, jet, fixed pitch, controllable-pitch, contra-rotating propellers and they all have their individual advantages and disadvantages. Our focus is on controllable-pitch propeller (with a 3-blade screw propeller). For a detailed discussion on Marine propulsion, the reader is referred to the literature [1, 2].

There are two main methods used in the design of a propeller. The first method is based upon Charts giving the results of open-water test on a series of model propellers such as pitch ratio, blade area ratio, number of blades and section shapes. The second method is based on the Circulation theory. It

leads to a detailed design of the propeller and is specifically useful for the design of heavily loaded propeller, liable to cavitation.

We used the design based on Charts for this work. It is important to state that Computer design approach using Computation Fluid dynamics could also be used for propeller design.

A transmission system consists of the shaft, the bearings and the propeller and it transmits power from the prime mover (engine) to the propeller to thrust the ship. The propeller comprises of a boss securing the tail shaft with blades of helical form attached to it. The propeller in operation screws or thrust its way via the water by giving momentum to the column of water passing through it. Fig. 1 illustrates the schematics of a propulsion system.

Fig. 2 and 3 show the fabricated screw propeller and propeller shaft coupling (with bearings) respectively.

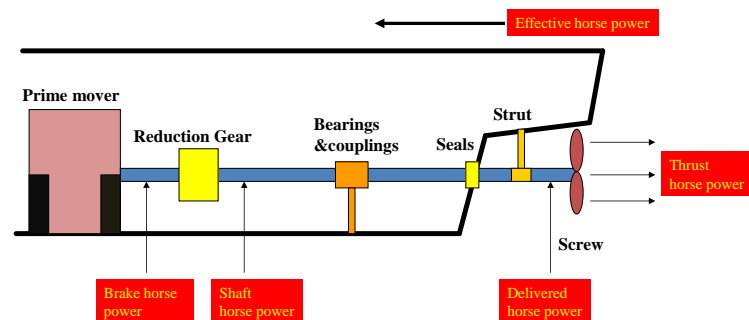


Fig. 1: Propulsion system



Fig. 2: Picture of the propeller

III. DESIGN

The design and construction of a ship is in general expected to satisfy safety, economic, technical and operational requirements. The structural and architectural arrangement of the hull results from the proper consideration of these factors.

In the design and construction of a ship, the most fundamental requirement is to achieve adequate floatation of the ship under the desired loading conditions and the possibility to be moved from one location to another.

A secondary consideration is to achieve efficient operational characteristics such as having minimal resistance to the motion of the ship under varying sea conditions. Other factors such as durability, habitability and maintainability etc. are also considered and the final dimension is expected to conform to the numerous criteria that governed its design and construction.



Fig. 3: Propeller shaft coupling

For this work, the Taylor's series B charts SNAME [2] are used. The charts for the Propeller power coefficient, B_P , – Propeller pitch/Diameter ratio coordinates are presented in [8]. Using the charts, the contours of propeller efficiency circulation, Γ and Propeller speed coefficients, δ Parameters were obtained. The design calculations are also reported extensively in [8].

From the calculations, the values of Speed, n in RPM were used to get the corresponding values of Propeller power coefficient, B_P , that were used in estimating the values of the advance co-efficient (δ) and the Pitch diameter (P/D) ratio for a given blade number and blade area ratio. With this, we generate a table by varying the speed, n from 300 RPM to 410 RPM at an increment of 10RPM so as to generate propeller characteristics/curves (Table 1 and Fig. 4).

Based on the variation of n we obtain Table 1:

TABLE 1: PROPELLER CHARACTERISTICS

Propeller RPM	n	300	310	320	330	340	350	360	370	380	390	400	410
B_P		20.94	21.638	22.336	23.034	23.732	24.43	25.128	25.826	26.524	27.222	27.92	28.618
δ		220	222	223	223	227.5	230	232.5	234	236	239.5	241	243
Corrected δ (6%)		206.80	208.68	209.62	209.62	213.85	216.20	218.55	219.96	221.84	225.13	226.54	228.42
D		6.03	5.89	5.73	5.56	5.50	5.40	5.31	5.20	5.11	5.05	4.95	4.87
η_o		0.61	0.6	0.59	0.58	0.579	0.575	0.573	0.57	0.565	0.564	0.56	0.56
η_h		1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
η_r		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P/D		0.855	0.840	0.836	0.833	0.831	0.829	0.828	0.825	0.822	0.820	0.818	0.815
P_s	BHP	218.87	222.52	226.29	230.19	230.59	232.19	233.00	240.09	242.21	242.64	244.37	244.37
P_s	kW	163.21	165.93	168.74	171.65	171.95	173.15	173.75	179.03	180.62	180.94	182.23	182.23
η_D		0.689	0.678	0.667	0.655	0.654	0.650	0.647	0.644	0.638	0.637	0.633	0.633
D	M	1.838	1.795	1.747	1.694	1.677	1.647	1.619	1.585	1.557	1.539	1.510	1.486

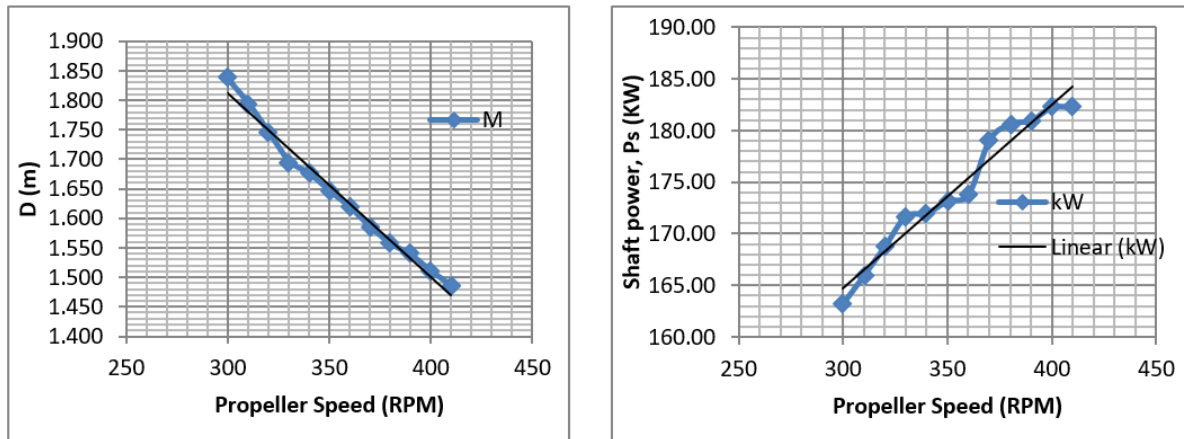


Figure 4: Engine/Propeller Curve

A. Selection of Propeller

The aim of the propeller selection is to choose the propeller with maximum possible diameter. For optimum propeller efficiency, a maximum propeller diameter of 1.48 is chosen and set as a limit.

Results deduced from the two graphs above indicates that the main propulsion engine will supply power output of 166kw (222 B.H.P) to propel the vessel at the given service speed, (corresponding speed is 310 rpm) - for it to operate at its optimum efficiency. The design calculation procedures take the same form as in the previous case are documented in [8].

B. Propeller - Main Engine Matching

For an engine that best suits the propeller to be selected it is often convenient to present the layout diagram on a logarithmic co-ordinate such as log power/log R.P.M. This enables us to obtain the nominal curve on a linearized form, thereby making the work easier. With the relationship that exists between power and speed, we obtained the power for our speed range of speed, n , which is between 250 – 350 rpm. Thus, the propeller curve was determined.

The powers obtained were in the range of 80 – 110% of the design speed (310 R.P.M), i.e., 248 R.P.M to 341 R.P.M is required to obtain the propeller curve.

We obtained the propeller curve (Table 2 and Figure 5) based on the following speed range in RPM: 248, 257, 266, 275, 284, 293, 302, 311, 320, 329, 338.

C. Selection of Main Engine

The selection of the propelling unit (main engine) is based principally on its agreement with the propeller other factors that are considered include the engine's reliability in service, its operational and maintenance cost.

The main factors that are going to be considered in this selection are:

- Specific fuel oil consumption for service power on diesel
- Power required at specific speed
- Weight of machinery
- Reliability and cost of maintenance
- Noise and vibration

TABLE 2: MODIFIED PROPELLER CHARACTERISTICS DATA

PROPELLER MAIN ENGINE MATCHING											
RPM	248	257	266	275	284	293	302	311	320	329	338
Log n	2.394	2.410	2.425	2.439	2.453	2.467	2.480	2.493	2.505	2.517	2.529
P (bhp)	113.664	126.493	140.253	154.977	170.696	187.444	205.253	224.155	244.184	265.372	287.752
P (kW)	84.759	94.326	104.587	115.566	127.288	139.777	153.057	167.153	182.088	197.888	214.576
Log P	1.928	1.975	2.019	2.063	2.105	2.145	2.185	2.223	2.260	2.296	2.332
FIRST ENGINE 3304T (4 CYLINDERS) LOGC = -0.3009											
RPM	248	257	266	275	284	293	302	311	320	329	338
P (kW)	92.494	95.851	99.208	102.564	105.921	109.278	112.634	115.991	119.348	122.704	126.061
P (bhp)	124.037	128.538	133.040	137.541	142.043	146.544	151.045	155.547	160.048	164.549	169.051
Log n	2.394	2.410	2.425	2.439	2.453	2.467	2.480	2.493	2.505	2.517	2.529
Log P	1.966	1.982	1.997	2.011	2.025	2.039	2.052	2.064	2.077	2.089	2.101
SECOND ENGINE 3306T (4 CYLINDERS) LOGC = -0.1627											
RPM	248	257	266	275	284	293	302	311	320	329	338
P (kW)	127.150	131.764	136.378	140.993	145.607	150.221	154.836	159.450	164.064	168.679	173.293
P (bhp)	170.511	176.699	182.886	189.074	195.262	201.450	207.638	213.826	220.014	226.202	232.390
Log n	2.394	2.410	2.425	2.439	2.453	2.467	2.480	2.493	2.505	2.517	2.529
Log P	2.104	2.120	2.135	2.149	2.163	2.177	2.190	2.203	2.215	2.227	2.239
THIRD ENGINE 3306TA (6 CYLINDERS) LOGC = -0.052											
RPM	248	257	266	275	284	293	302	311	320	329	338
P (kW)	164.065	170.019	175.973	181.927	187.881	193.835	199.789	205.743	211.697	217.651	223.605
P (bhp)	220.015	227.999	235.983	243.968	251.952	259.937	267.921	275.906	283.890	291.874	299.859
Log n	2.394	2.410	2.425	2.439	2.453	2.467	2.480	2.493	2.505	2.517	2.529
Log P	2.215	2.230	2.245	2.260	2.274	2.287	2.301	2.313	2.326	2.338	2.349

GRAPH OF LOG P AGAINST LOG N – THIRD ENGINE 3306TA – LOG C = -0.052

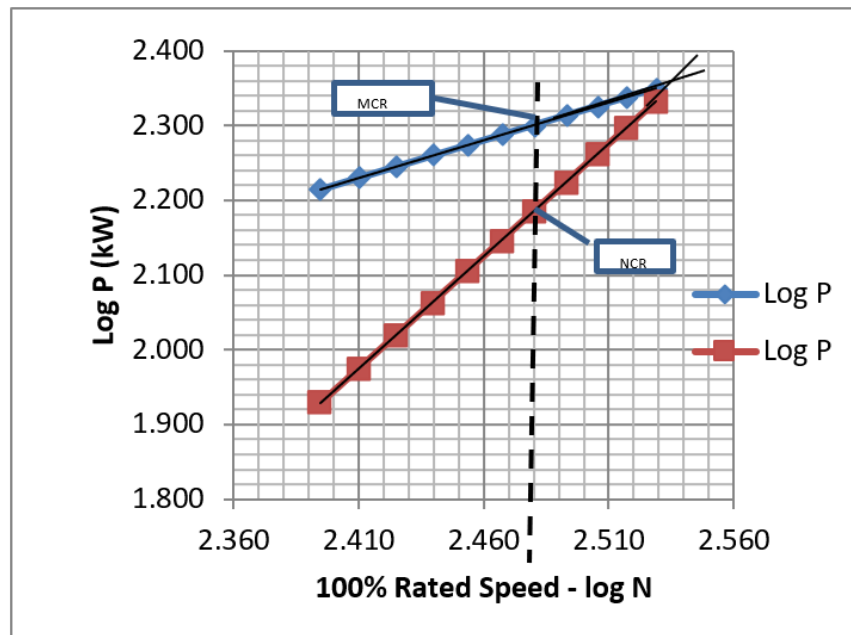


Fig. 4: Engine-Propeller Match for selected Engine

And above all the engine whose data gives a curve at about 10 – 15% below point of maximum power, (i.e. acceptable sea margin).

Based on these factors, and after critical analysis using tables and values read from graphs, for three different engines, the third engines having power capabilities of 162 – 262 kw and R.P.M was found to be having acceptable margin for a successful engine propeller matching.

Therefore, 3306TA caterpillar engine [9] was chosen, and its main/relevant data is given in Table 3.

TABLE 3: PRELIMINARY ENGINE DATA [9]

Engine No.	CAT 3306TA
Cycle	4
No. of Cylinders	6
Bore (mm)	121
Stroke (mm)	152
Mean Piston Speed (m/s)	10.1
Speed (RPM)	2000 – 2200
B.MEP (Bar)	10.7
Output (KW/Cyl)	160 – 265
Specific Fuel Oil Consumption, SFOC (g/kw/h)	214 – 223

IV. CONSTRUCTION

The propulsion system consists of the hull, and the mechanisms for propulsion. The hull is basically the body structure of the ship/vessel that is in contact with water.

The hull was constructed by first, itemizing the required dimensions of the vessel (model) from normalizing the final design parameters data based on the available portable prime mover in Nigeria.

This also necessitated a need for it to be electrically powered by a battery. At the end of the iteration process, bearing in mind of the basic design principle of safety, simplicity and function-ability, the data of the model vessel is given in Table 4.

After specifying the dimensions, a 2mm thick mild steel sheet, was cut into the desired pieces using oxy-acetylene torch. A frame (structure) that divides the vessel into compartments (transverse and longitudinal) was first welded in place. This frame serve as beams and pillars that supports the sheets when they are welded together to withstand all types of load. The keel of the vessel was welded in place, with its location at the basement of the ship.

TABLE 4: MODELLED OFFSHORE SERVICE VESSEL DATA

Parameters	Dimensions (mm)
Length	930
Breadth	470
Draft	335
Metal Sheet Thickness	2
Propeller Shaft Diameter	20
Propeller Blade Thickness	2
Propeller Blade Radius	42

The frame takes the curvature (shape) of the bow (forward) and stern (back side) of the ship. The metal sheets were tagged in position to the frames, and with the aid of clamps, the required angles were gotten. The sheets were fully welded to its respective frame. The heights and curvatures at the bow and stern were checked, the bottom of the vessel was checked for leakage. The vessel was then taken to a pool and tested for stability.

The propulsion system consists of 24-volts powered D.C. motor connected to a shaft (propeller shaft) through a system flywheel to reduce the speed that is eventually delivered to the propeller. The propeller shaft, which is a 20mm, solid shaft, was turned out on a lathe machine, which the front-end fitting into the flywheel, and the end section, having a coupling for the propeller blade (3 – blades). Fig. 6 and 7 show the propeller blade and shaft diagram respectively.

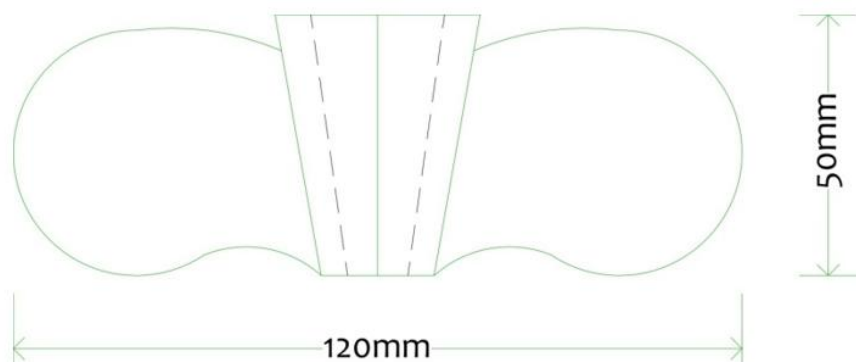


Fig. 6: Propeller Blade



Fig. 7: Propeller Shaft

A bedding (support) was constructed to carry the propulsion system from amidship (middle of the ship) where the engine (motor) is located to the aft of the ship. A 27.5mm hole was bored at the bottom end of the ship where the propeller shaft protrudes out to link the propeller blade via a hollow shaft that has oil seals at both ends to prevent leakage of water into the vessel when the propeller is moving.

The electric motor is connected to two dc batteries (12V, 26amps each), one located at port side, the other at starboard side, amidship. The other end of the motor is connected to a control mini-panel and a switch with three bottoms, one for forward, backward movement and stop.

V. EXPERIMENTAL TESTING

The vessel was lowered into a pool of water, 5 m deep with length and breadth of 3m by 3m, for experimental testing (Fig. 8).

The switch was engaged in the forward direction, and the motor started, propelled the shaft, and eventually rotated the propeller, which eventually moved the vessel forward.

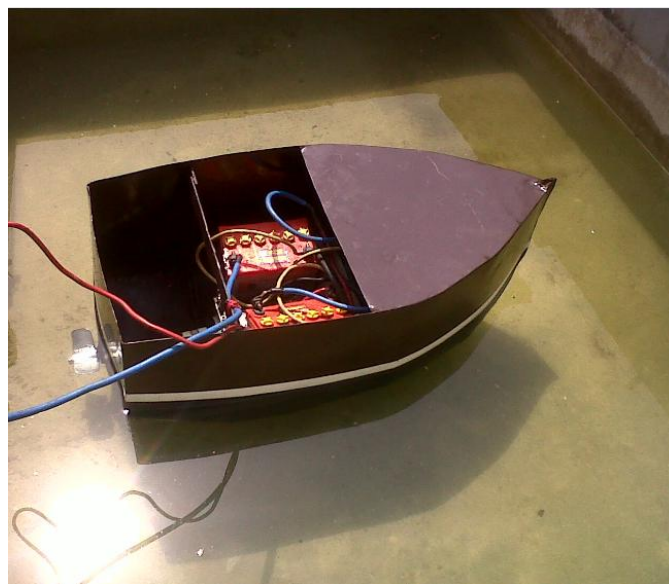


Fig. 8: Modelled Vessel during Experimental Testing

The vessel moved backward when the reverse switch was actuated, and it was stopped when the stop button was pressed. Thus, the experimental testing of the designed and constructed propulsion system of a modelled offshore service vessel achieved the desired results.

VI. CONCLUSION

The results of the experimental tests are satisfactory. Based on the results, we have practically demonstrated ship movements in water using a low-cost propeller system powered by battery and electric motor. This contribution to knowledge will enhance pedagogy teachings in the field of marine propulsion and control in Nigeria/West Africa countries.

Further work will focus on the development of a controller system to aid maneuverability for the modelled vessel.

REFERENCES

- [1] J. SCarlton, "Marine Propellers and Propulsion", Butterworth-Heinemann, Amsterdam, 2007
- [2] SNAME, The Society of Naval Architects and Marine Engineers, Principles of Naval Architecture, Vol. I, II and III
- [3] E.C. Kerrigan and J. M. Maciejowski, "Fault-Tolerant Control of a Ship Propulsion System Using Model Predictive Control" in Proc. European Control Conference, Karlsruhe, Germany, August 1999.
- [4] M. Altosole, G. Benvenuto, M. Figari, and U. Campora, "Real-time simulation of a COGAG naval ship propulsion system" in Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 2009. 223: 47-61
- [5] A. Briant, J. P. Martineau, and J. Y. Hascoet, "Influence of machining paths on hydro propeller performance" in Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 2003 217:1757-1762
- [6] C. Mundt, and J. Lieser, "Performance improvement of propulsion systems by optimization of the mixing efficiency and pressure loss of forced mixers", Paper presented at the 8th European Propulsion Forum Affordability and the Environment – Key Challenges for Propulsion in the 21st Century, 26-28 March 2001 in Nottingham
- [7] W. Han, and L. J. Tao, "A new marine propulsion system" in Journal of Marine Science and Application, 2003, Vol. 2, No. 1, 30-34
- [8] B. Ipa, "Design and construction of the Propulsion System of a Modelled Offshore Service Vessel" M.Sc. Thesis, Dept. of Mechanical Eng., University of Lagos, Akoka, Lagos, Nigeria, 2011.
- [9] Caterpillar Engine Catalogue for 3306TA caterpillar engine