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A THEORETICAL METHOD FOR THE DESIGN OF MARINE TANDEM PROPELLERS

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ABSTRACT

The propulsive efficiency is reduced with increasing propeller power absorption and the consequent risk of propeller cavitation and induced vibration. By fitting tandem propellers better performance can be achieved. In this paper a procedure is described which was basically developed for calculating the self and mutually induced velocities of the two-propeller system. The typical examples of the two-propeller system are tandem propellers and contra-rotating propellers. The main difference between double and single propeller is the calculation of the mutually induced velocities which vanishes for single propeller. The tandem propellers can be described as a pair of conventional propellers fitted on the same shaft in series and rotating in the same direction. The lifting line theory is applied for the calculation of the velocity field. For the calculation of the induced velocities the circulation theory of propeller action based on Biot-Savart Law is used. Radial distribution of the self and mutually induced velocities are calculated on the lifting line in such a way that each propeller is handled like a single propeller. For optimization of the design the axial distance between the two propellers and angular spacing of the blades of the two propellers are taken into consideration. The performance characteristics such as thrust, torque and efficiency of individual and combined system as calculated are compared with the available results.

Key words: Tandem propeller, propeller efficiency, lifting line theory, Biot-Savart Law.

1. INTRODUCTION

The tandem propellers can be described as a pair of conventional propellers fitted on the same shaft in series and rotating in the same direction. The well known trend of reducing propulsive efficiency with increasing propeller power absorption and the consequent risk of propeller cavitation and induced vibration means that the role of the conventional propeller is virtually exhausted in some applications. The tandem propeller can then be regarded as a practical means of extending this difficult operating range [1,2,7].

By fitting tandem propellers the variable hydrodynamic loads transmitted to a propeller shaft can be decreased [4].

The tandem propeller would utilize the same turbines, reduction gears and shafting as any other single screw installation and consequently would be less expensive and complex than contra-rotating and twin-screw installation.

2. THE IMPORTANT DESIGN CHARACTERISTICS

The following additional characteristics are to be considered compared with those in the case of a single screw propeller system.

- thrust distribution between the forward propeller and the aft propeller.
- distance between two propellers.
- diameter of two propellers.
- angular displacement.
- wake field of the forward propeller and the aft propeller.

2.1 Thrust distribution

In order to investigate the effect of thrust distribution between the forward and aft propellers on the overall propulsion efficiency, it was planned to design the tandem propeller system according to various thrust combinations. The combinations may be 40:60, 50:50, 60:40, 70:30 and so on. However, only the thrust combination 50:50 for the forward and aft propellers is considered for the present calculation.

2.2 DISTANCE BETWEEN TWO PROPELLERS

The ratio of the axial spacing between the planes of the forward propeller and aft propeller and the diameter, L / D is the axial spacing ratio. It is thought that the conventional propeller is more efficient than the tandem propeller and that since in the limit when the axial spacing ratio is zero the tandem propeller becomes a conventional propeller i.e., the tandem propeller would be more efficient as axial spacing is smaller. According to various studies [5] the value is between 0.2 to 0.25. In the present case it is taken as

$L / D = 0.2$

2.3 DIAMETER OF TWO PROPELLERS

In some studies it is suggested that the diameter of the aft propeller be smaller than the forward propeller, which is true for contra-rotating propellers. In contra-rotating case the diameter of the aft propeller is reduced to absorb more rotational energy in the slipstream and to avoid interference between the tip vortex of the fore propeller and aft propeller. As tandem propeller is different due to the fact that in general tip vortices does not disturb each other and also when the diameter of aft propeller is same as forward propeller, the loading of the blades will be reduced and the efficiency of the tandem propeller improved. For the present case, the diameter of both the propellers are considered the same.

2.4 ANGULAR DISPLACEMENT

The angular displacement, θ denotes the angle between the aft propeller blade reference line and the neighbouring forward propeller blade. The best angular displacement of the aft propeller to the forward propeller is that which allows the vortex sheets of the forward propeller to pass midway between the after propeller blades. This angular displacement is determined by considering the angle at which the flow left the forward propeller blades at the 0.7 radius and the axial spacing between the blades [5].

According to circulation theory the best angular spacing is approximated by

$$\theta = (L / D) / (P_1 / D) \times 36^0 \pm 180^0 / z$$

where, P_1 / D at $0.7R = \pi . x . \tan \beta_i$ for forward propeller

z = number of blades

2.5 WAKE FIELD OF THE FORWARD AND AFT PROPELLER

It is estimated [8] from the induced velocity field by each propeller on the other i.e., interference velocity.

3. DESIGN STEPS

The following design procedure is adapted,

- A propeller producing half the required thrust is calculated.
- The induced velocities at selected control points of the forward and aft propellers are calculated using a field point velocity program based upon lifting line theory using Biot-Savart Law. The computer program for the said purpose is prepared by Ullah [8] and used for the present calculation. The induced velocities on the forward propeller are the interference velocities of the after propeller on the forward propeller. Conversely, the induced velocities on the after propeller are the interference velocities of the forward propeller on the aft propeller.
- The physical parameters of each propeller in the tandem set are now determined.

3.1 CALCULATION OF PROPELLER INDUCED VELOCITY

The induced velocities by the vortex system defining the propeller at any field point are calculated by using the Biot-Savart law.

The velocity dv induced at a field point at a distance d by a vortex filament of length dl and of circulation Γ is given by Biot-Savart law as,

$$dv = (\Gamma / 4\pi) . (dl \times d) / | d |^3$$

3.2 THE VELOCITY DIAGRAM

In calculating the performance of a tandem propeller, the main flow features present are taking into account, namely the interference between the propellers.

In this method it is assumed that

- the vortex sheets of the forward and aft propellers are independent
- the forward and aft propellers have the same blade number, diameter and hub diameter
- both the propellers are moderately loaded and wake adapted. As moderately loaded, the slipstream contraction effect is not considered in the calculation.

The blades of a tandem propeller experiences the self induced velocities $u_a / 2$ (axial) and $u_t / 2$ (tangential) and additionally the interference velocities u_{ai} (axial) and u_{ti} (tangential) induced from one set of blades on the other.

The self induced velocities should be equivalent to those induced by an isolated conventional propeller in presence of velocity components $V_{Af,a}$ and $2\pi nr$.

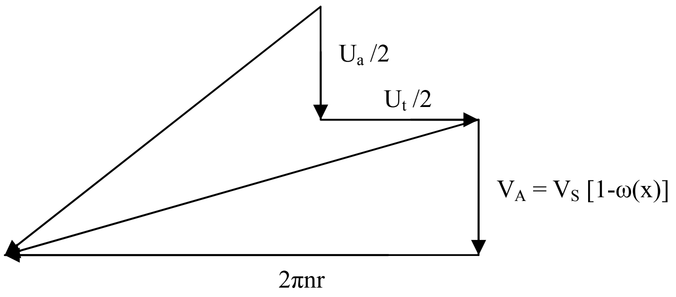
The inflow velocity $V_{Af,a}$ can be expressed at any radius r as follows.

$$V_{Af,a} = V_A + u_{ai}$$

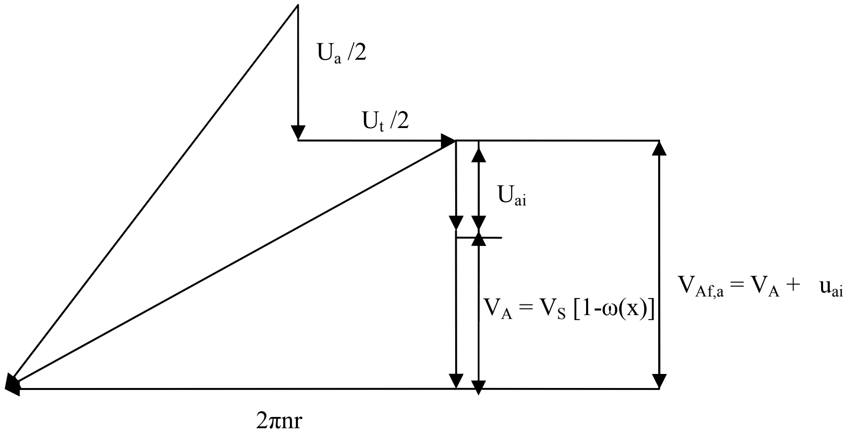
In Figure 1, the velocity vector diagram is presented for single propeller and tandem propeller system.

4. A TYPICAL CASE STUDY

Design conditions have been selected according to the discussion made in the previous section. The selected design conditions and the circumferentially averaged axial nominal wake distribution [3] are shown in Table 1 and Figure 2 respectively.



Single Propeller System



Tandem Propeller System

Figure 1. Velocity diagram related to single and tandem propeller system.

Table 1. Design conditions for the propeller system

Effective horse power	30,800 HP
Ship speed	19.25 Knots
RPM	105
Number of blades	5 forward and 5 aft
Diameter of propeller	6860 mm forward and 6860 mm aft
Thrust deduction fraction	0.143
Wake fraction	0.335
Thrust ratio	50% by forward propeller and 50% by aft propeller
Distance between two propellers	L/D = 0.2 or 1372 mm
Angular displacement	61.1267 degree at 0.7 radius

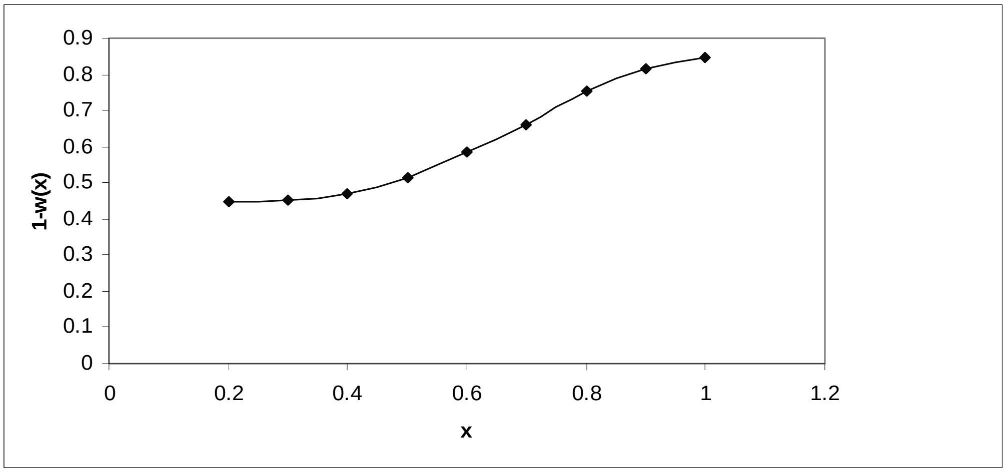


Figure 2. Circumferentially averaged nominal axial velocity distribution (single propeller)

First a propeller producing half the required thrust is calculated. The forward and aft propellers are designed, taking into consideration the design of this single propeller producing half the total thrust. The radial distribution of hydrodynamic pitch angle and the circulation of the single propeller is provided in Table 2.

Using field point velocity program the axial induced interference velocities are calculated and the calculated velocities are provided in Figure 3. These velocities in Figure 3 and the velocities of Figure 2 providing the inflow velocity to the forward and aft propeller are presented as wake velocities for the forward and aft propeller and presented in Figure 4.

Now the hydrodynamic design procedure is followed for the forward and aft propellers separately and the important design parameters are provided in Table 3.

5. CONCLUSION

In this paper, some calculation results of the author's recent study on the design of the tandem propeller system have been briefly presented and discussed together with specific example. Propulsive efficiency is significantly improved by a tandem system, and hence the same amount of fuel-saving could be achieved. For the single propeller design with half the total system thrust, the efficiency achieved is 0.6106. Whereas, for the tandem propeller system this efficiency achievement is 0.624 for forward propeller and 0.6411 for aft propeller. Both the propellers delivered half the total thrust. Thus the performance of individual propeller can be observed.

Table 2. Radial distribution of hydrodynamic pitch angle and circulation of the single propeller

x	β_i (deg.)	G
0.2	46.9666	0.0325
0.3	35.5995	0.0455
0.4	28.4378	0.0507
0.5	23.8880	0.0477
0.6	20.8934	0.0387
0.7	18.6286	0.0296
0.8	16.9563	0.0189
0.9	15.4459	0.0114
1.0	14.0907	0.0000
$1 - \omega = 0.6650$ T = 1350.24 KN $C_T = 1.6304$ $\eta = 0.6106$		

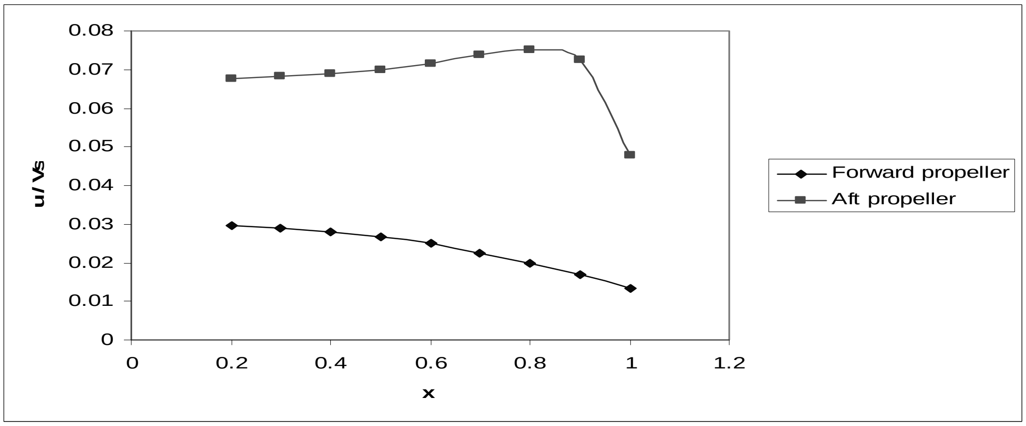


Figure 3. Axial induced velocity distribution at the forward and aft propeller plane.

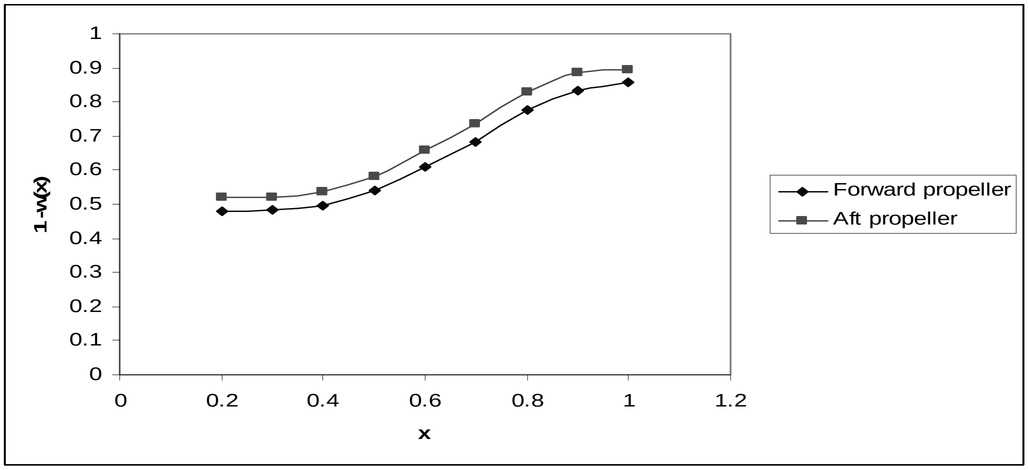


Figure 4. Nominal axial wake velocity distribution at the forward and aft propeller plane.

Table 3. Important Design Parameters

x	Forward propeller			Aft propeller		
	β_i (deg.)	$C.C_L / D$	G	β_i (deg.)	$C.C_L / D$	G
0.2	47.9758	0.1059	0.0304	49.3636	0.1035	0.0283
0.3	36.5519	0.1088	0.0432	37.9105	0.1098	0.0409
0.4	29.2537	0.0969	0.0487	30.4756	0.0991	0.0464
0.5	24.5706	0.0803	0.0464	25.6516	0.0824	0.0443
0.6	21.4659	0.0623	0.0381	22.4165	0.0634	0.0362
0.7	19.1198	0.0464	0.0296	19.9820	0.0465	0.0277
0.8	17.3799	0.0299	0.0192	18.1556	0.0290	0.0175
0.9	15.8100	0.0177	0.0119	16.5132	0.0167	0.0106
1.0	14.4106	0.0000	0.0000	14.9642	0.0000	0.0000
	$1 - \omega = 0.6870$ T = 1349.62 KN $C_T = 1.53637$ $\eta = 0.6240$			$1 - \omega = 0.7360$ T = 1349.64 KN $C_T = 1.3386$ $\eta = 0.6411$		
Required thrust to be produced by each propeller, T/2 = 1352.46 KN Required thrust to be produced by both propeller, T = 2704.92 KN Actual thrust produced by both propellers = 1349.62 + 1349.64 = 2699.26 KN						

REFERENCES

[1] Denny, S. B., "A procedure for the design of tandem propellers," AD – A039027 (1974).

[2] Glover, E.J.. "Contrarotating propellers and tandem propellers," *Proceedings of Symposium, Advance in propeller research and design,Gdansk,* (1981).

[3] Hadler, J. B., Morgan, W.B. and Meyers, K. A., "Advanced propeller propulsion for high-powered single-screw ships," *Transaction of SNAME,* pp. 231-293 (1964).

[4] Meyers, K.J., "Characteristics and performance of tandem propellers," *Thesis, Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology* (1961).

[5] Qin, S. and Yunde, G., "Tandem propellers for high powered ships," *Transaction of RINA,* pp. 347-362 (1991).

[6] Rahman, N.A. and Islam, M.S., "Parametric design and comparison of non-cavitating and fully-cavitating marine propeller in uniform flow," *B.Sc.Engg. Thesis, Bangladesh University of Engineering and Technology* (2009).

[7] Titof, I. A. and Biskup, B. A., "Investigation into the possibilities of tandem propeller application with the aim of decreasing the variable hydrodynamic loads transmitted to a propeller shaft,*"The 11th ITTC Proceedings* (1966).

[8] Ullah, M. R., "A method for the calculation of performance characteristics of the two-propeller system: Part 1- Tandem propeller," *A Report, Department of Naval Architecture and Marine Engineering, BUET,* pp. 1-41 (2000).