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Numerical Investigation of the Performance of Voith Schneider Propulsion

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Abstract The research explained in this article was carried out to investigate the numerical hydrodynamic characteristics of the Voith Schneider Propeller (VSP) system. The system has four vertical blades connected to the horizontal disk. Each blade has two speeds, one around a disk and second local rational along its axis. The method is finite volume CFD code (Fluent v14) with RNG k-ε turbulence model. For the purposes of this research, a VSP with 4 blades is analyzed at various operating conditions. Hydrodynamic characteristic parameters including moment, thrust and efficiency are presented as functions of advance velocity coefficients at three different pitch rations.

Keywords: *Voith Schneider Propeller, CFD, RNG turbulence model, hydrodynamic performance*

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1. Introduction

VSP was developed as a high performance drive system by Australian engineer Ernst Schneider and came into operation in 1927. It is used primarily for ships that have to satisfy particularly demanding safety and maneuverability requirements [1]. The thrust is generated by separately oscillating, balanced propeller blades. VSP permits continuously variable thrust adjustment through 360°. Thus, the VSP has no preferential direction of thrust and allows infinite variation in the magnitude and direction of thrust [2,3].

A significant difference between the VSP and the screw propeller is the direction of the axis of rotation relative to the direction of thrust. In the case of screw propeller, the axis of rotation and the direction of thrust are identical, on the VSP they are perpendicular to one another. The VSPs operate at a comparatively low rotational speed and are therefore notable for their long service life and very low maintenance [5]. Since the VSP simultaneously generates propulsion and steering forces, there is no need for additional appendages such as propeller brackets, rudders, pods, shafts, etc. Blades of VSP are symmetric. In certain installation conditions, the rectangular swept area of a VSP is approximately twice as large as that of a screw propeller. Thus, generated thrust force in the VSP is more than a screw propeller. The perpendiculars of the chords of the profiles intersect at a single point, the steering center N, as the blades revolve. The pitch of VSP can be varied within a range $e \leq 0.8$. Propellers with a pitch $e>1$ are known as trochoidal propellers. The Kirsten-Boeing propeller is a special casewith a pitch of $e=1$ [5,7].

Rotation speed in VSP is one fourth of typical propellers. Their diameter varies between 1.2 and 3.8 meters and the input power to them is up to 4100 kW. Parameters affecting hydrodynamic performance of VSP are angle of attack during rotation of the rotor, geometry of blades profile, ratio of blade chord length to diameter of rotor, position of blade shafts, relative thickness of blades, tail-end flap of blades and ratio of blade length (span) todiameter of rotor. The tail-end flap in blades can lower the induced drag force [8,9,10].

Assessment of cavitation behavior shows that the sheet cavitation is more common in these propellers. Sheet cavitation has no erosion and corrosion on the blades. VSPs are mainly used in Offshore Support Vessels (OSV), Voith Water Tractor (VWT), Tugs, Mine Countermeasures Vessels (MCMV) and Double-Ended Ferries (DEF) [11,12].

Design improvement is an important phase of the engineering design process. In reference[4],the numerical optimization and Computational Fluid Dynamics (CFD), in particular the Vortex-Lattice Method for the optimization of VSP is used. In reference[21], the Automatic Differentiation method is used for the optimization of the VoithSchneiderPropeller. In reference[22], a new vertical axis propulsion system with orbital paddles which is constituted by a pair of contra-rotating impellers is proposed.Here, the effect of pitch ratio on efficiency and other hydrodynamic characteristics is investigated. It will be shown that the efficiency increases with pitch ratio.

2. Component of Rotor in VSP

The energy required to generate the thrust is supplied to the rotor casing (1) via the flanged-on reduction gear (7) and the bevel gear (6) (Figure 1). Gland bearings or special roller bearing are used to support the blade shaft. The rotor casing is axially supported by the thrust plate (10) and centered radially by the roller bearing (11). Due to the kinematic system (3), the blades (2) perform an oscillating.

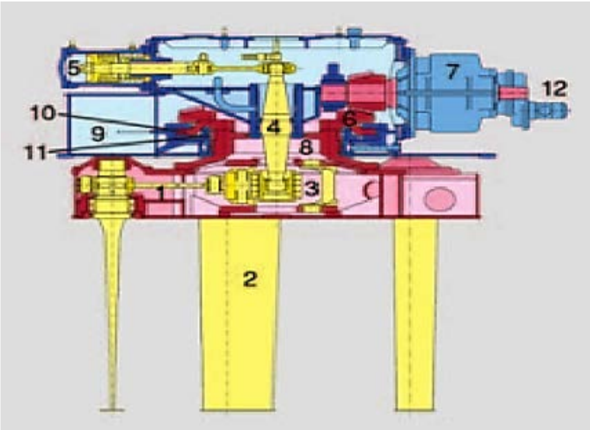

Figure 1. Components of VSP [5]

The amplitude and phase of blade motion is determined by the position of the steering center and hence the magnitude and direction of thrust are varied by means of the control rod [13,14,15].

The control rod is actuated by two orthogonally arranged servo motors (5). The propulsion servo motor (aservo motor is a rotary actuator that allows for precise control of angular position, velocity and acceleration) isused to adjust the pitch for longitudinal thrust (forward and reverse motion of the ship). The rudder servo motor is usedfor transverse thrust(motion to port and starboard). The two servo motorspermit steering according to Cartesian X/Y coordinates (identical with the principal axes of the ship). Controlled changes in thrust are possible via the thrust-free condition. For example, its direction can be changed from full ahead to full astern at a constant speed of rotation without creating disturbing transverse forces [16,17].

Fitting the VSP with mechanical controls for the servo motors and an oil pump (12) flanged to the input gear results in a self-contained propulsion and maneuvering system which, apart from the torque input, requires no other source of power. Various mechanical kinematic systems and hydraulic blade actuating systems were developed and used in the course of development [18].

The blades of the VSP move along a circular path while simultaneously performing a superimposed pivoting motion. The perpendicular of the chord of the profiles intersects at single point, the steering center N.

3. Geometrical Equations in VSP

The eccentricity (e) refers to as pitch of the VSP and is defined as:

$$e = \frac{ON}{D/2}, \quad (1)$$

where D is the blade orbit diameter.Point$N$, as shown in Figure 2, is the control point of the all blades which is related to the pitch angle of the VSP.

The advance coefficient (λ) of the VSP is the ratio of inflow velocity of the propeller (V_A) to the circumferential velocity u of the blades (u):

$$\lambda = \frac{V_A}{u} \quad (2)$$

The circumferential velocity u at the blade circle, with rotor speed (n) and blade orbit diameter (D), is given by

$$u = \pi n D \quad (3)$$

The motion of the blade relative to a stationary observer arises from the superimposition of the rotary movement and a straight line representing the forward motion of the vessel. The blade follows a curve of a cycloid. The rolling radius of the cycloid is $\lambda \cdot D/2$. In one revolution, the propeller travels a distance $\lambda \cdot D/2 \cdot \pi$ in the direction of motion of the ship. Because the blades travel along a cycloidal path, the VSP is also referred to as cycloidal propeller [19].

There is continuous variation in the lift during each revolution owing to the non-stationary inflow to the propeller blades. The force-components acting transversely to the desired direction of thrust cancel each other out, while the force-components in the direction of thrust add up over the circumference of propeller [7].

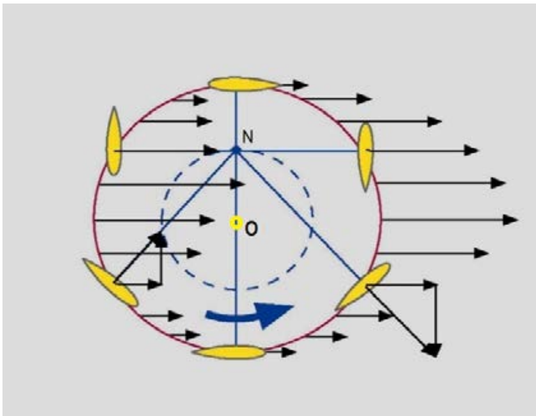

Figure 2. Forces on the blade in various angular positions [7]

4. Hydrodynamic Characteristic of VSP

The hydrodynamic characteristics of VSP are represented by dimensionless coefficients which, as a result of the historical development of the system, differ by constant factors from those of screw propeller [20]. Hydrodynamic equations of the VSP are defined as follows:

$$\text{Thrust} \qquad T = \sum L_i \quad (4)$$

$$\text{Torque} \qquad M = \sum D_i \quad (5)$$

$$\text{Thrust coefficient} \quad K_S = \frac{T}{0.5 \rho D L V^2} \quad (6)$$

$$\text{Torque coefficient} \quad K_D = \frac{4M}{\rho D^2 L V} \quad (7)$$

$$\text{Open - water efficiency} \; \eta_0 = \lambda \frac{K_S}{K_D} \quad (8)$$

where D, ρ , L , λ , $n$are the diameter of the propeller, the density of water, the length of the blades, advance coefficient and the number of revolutions of the propeller, respectively.

The Reynolds number for VSPs, based on the mean chord length c of a profile, is defined as follows [12]:

$$\mathrm{Re} = \frac{c}{\nu}\sqrt{V_A^2 + u^2} \tag{9}$$

where ν and $c$are the kinematic viscosity and chord length, respectively.

The hydrodynamic properties of VSPs are primarily influenced by the following parameters:

- Blade angle of attack during revolution.
- Profile geometry.
- Ratio of chord length c to blade circle diameter D, (c/D).
- Relative thickness of the profile.
- Blade shaft position.
- Ratio of blade length L to blade orbit diameter D (L/D).
- Shape of blade outline.
- Design of the blade ends [14-18].

The thrust coefficient and efficiency are a function of the advance coefficient λ and pitch e. there is a qualitative shift in the coefficients as a function of λ and e, as is familiar from screw propellers with variable pitch. The efficiency increases with pitch. In addition, the fewer the number of blades has higher efficiency. On today's VSPs, the number of blades is much less significant since the hydrodynamic interactions between the blades on the front and rear halves of the rotor are reduced by modification of the blade angle curve.

The side thrust of VSP increases with the advance coefficient. As the advance ratio increases and the propeller speed remains the same, the steering forces also increase, as do the torques [7].

5. Principal Tug Particulars

The main particulars of a tug are shown in Table 1. This will be usedfor estimateof the lift, drag, pressure and velocity distributions in VSPs.

Table 1. Principal tug particulars

	Parameter	Value [unit]
Length of waterline	LWL	14 [m]
Beam	B	3.3 [m]
Draft	T_1	0.9 [m]
Block coefficient	C_B	0.41 [-]
Speed	V	12 [Knot]
Total resistance	R_T	13.29 [kN]

The present VSP has 4 blades and the blade orbit diameter is 1.5 m. The rotor speed is 150rpm. NACA 0012 blade section is selected that has a symmetric section.

The blade dimensions are defined:

Chord length= 1 m, Span length= 1.2 m, Relative thickness = 0.02 m.

6. Numerical Results

This study used the finite volume code FLUENT v14 to solve the incompressible continuity and momentum equation in two dimensions. For the turbulent flow cases, the equations were Reynolds-averaged and the $k-\varepsilon$ model was used for turbulence closure. This study adopted the re-normalization group (RNG) extension of the $k-\varepsilon$ model.

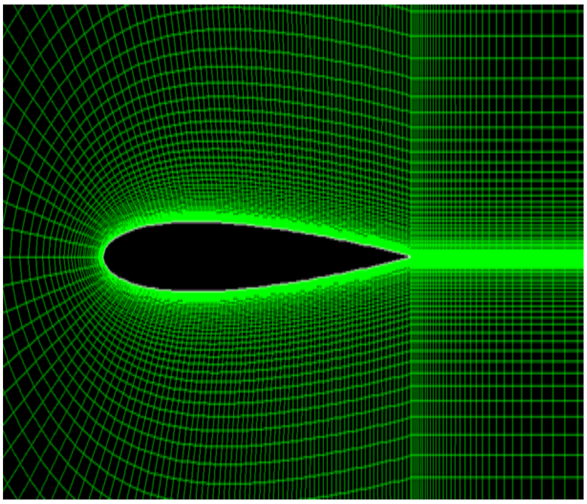

Figure 3. Mesh and details of the profile mesh

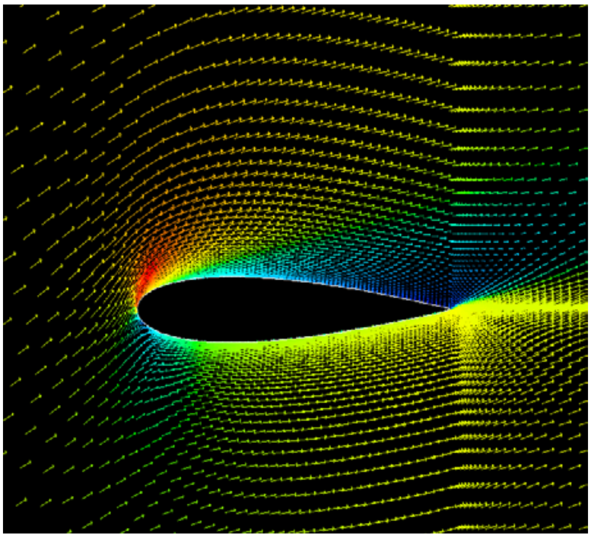

Figure 4. Velocity vector around the blade of the VSP at α=15°

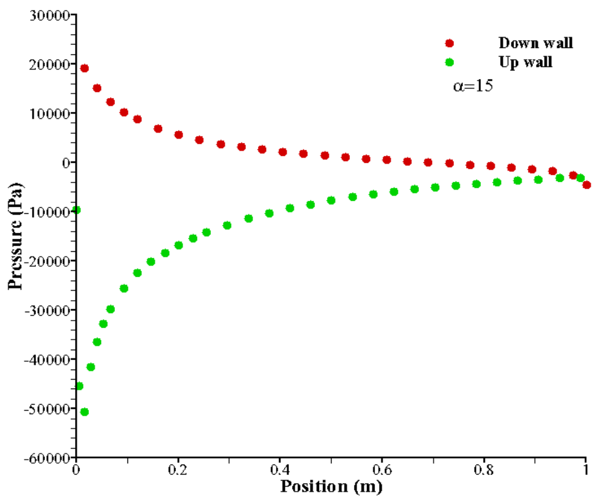

Figure 5. Pressure distribution on blade at α=15°

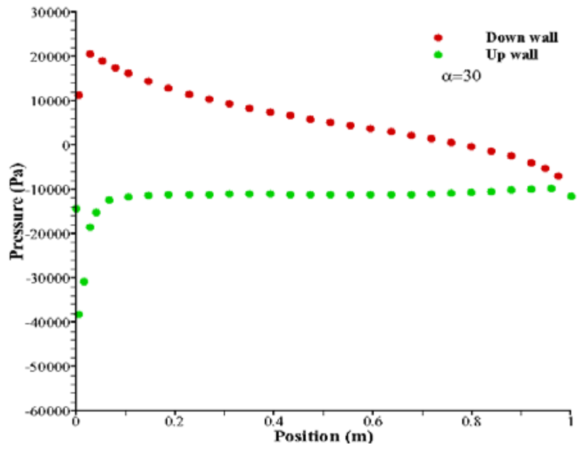

Figure 6. Pressure distribution on blade at α=30°

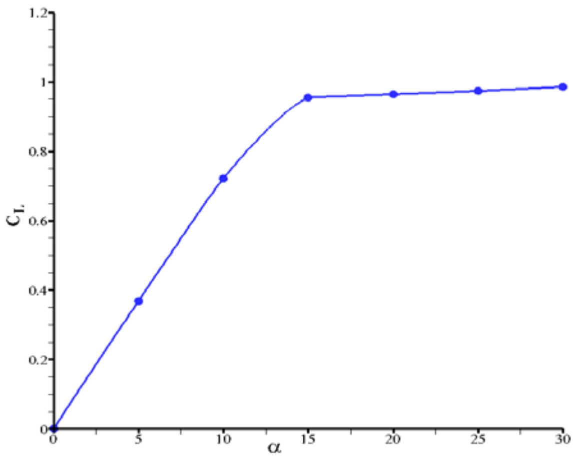

Figure 7. Lift coefficients as a function of α

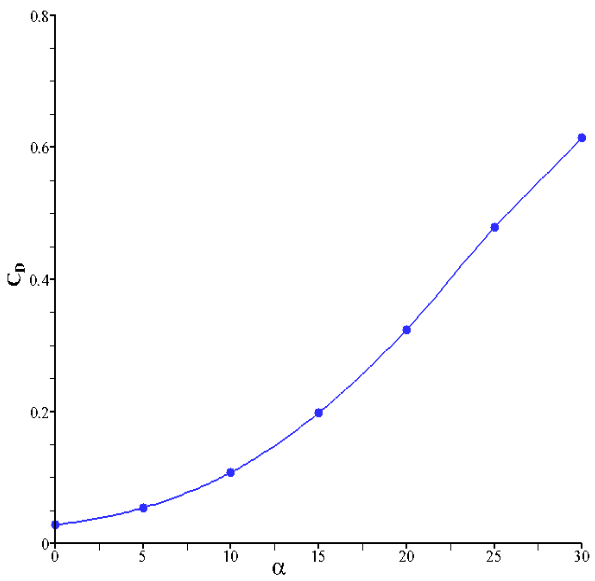

Figure 8. Drag coefficients as a function of α

Here, the numerical results of the blade of VSP are presented. The results are velocity vector, pressure distributions on blade of VSP, lift and drag at various angles of attack (α). Figure 3 shows the mesh and its domain. Numerical results for pressure, velocity, lift and drag are shown in Figure 4-Figure 8.

7. Hydrodynamic Characteristic Results

The most important of VSP characteristics of the VSP are hydrodynamic coefficients. These coefficients are thrust, moment and efficiency. The VSP is a variable pitch propeller. These calculations are carried out for various pitches 0.3, 0.4 and 0.5. Hydrodynamic characteristics (thrust, moment and efficiency) are shown in Figure 9-Figure 11. The efficiency increases with thepitch. Advance velocity coefficient (λ) can play an important role in the hydrodynamic performance. Maximum efficiency is around 70% for pitch ratio of 0.5 at $\lambda = 0.7$ and hasreasonable value based on the experimental data as shown in reference [5].

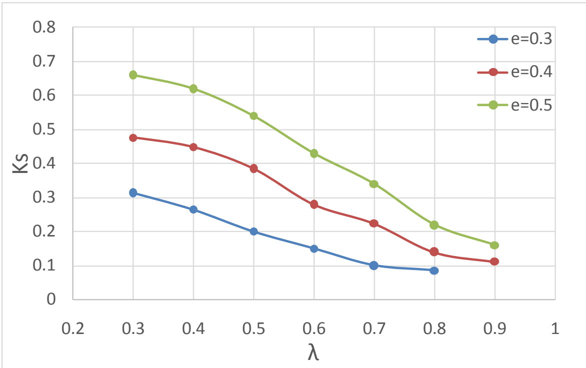

Figure 9. Thrust coefficient at different pitch ratios

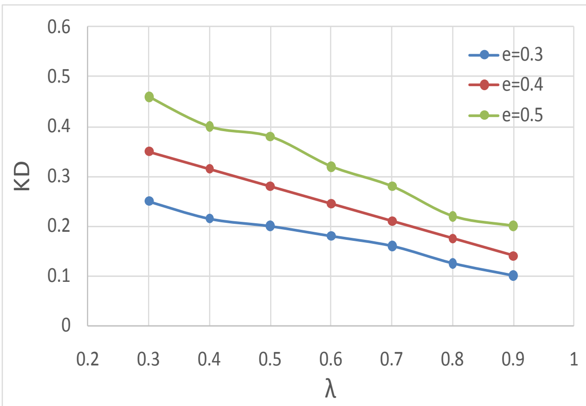

Figure 10. Torque coefficient at different pitch ratios

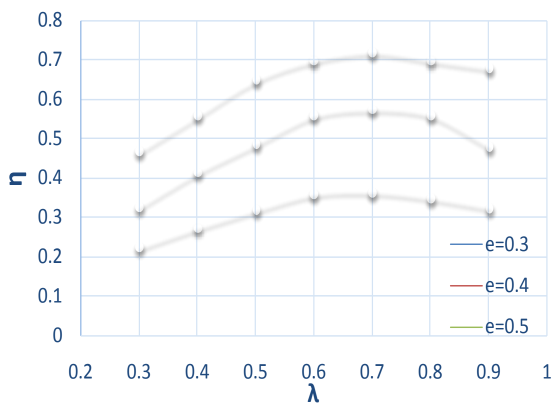

Figure 11. Efficiency at different pitch ratios

8. Conclusions

The hydrodynamic analysis of a VSP at various operating conditions was investigated. A finite volume–

based RANS solver (Fluent) has been used to evaluate the performance of these systems. Based on the numerical results, the following conclusions can be drawn:

1. When the point *N* (means control point) is changed the resultant velocity entering to the blade and its angle are determined. Therefore, especial emphasis should be applied to determine the physical and geometrical blades operating conditions.
2. Physical characteristics of one blade at various angles of attack is investigated in order to get the lift and drag of the blade.
3. Hydrodynamic characteristics of the VSP(K_S, K_D, η) are calculated at three different pitch rations. It is concluded that with increasing the pitch of the blade, efficiency is increased.

Acknowledgement

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Nomenclature

B	Beam, m
c	Chord length, m
C_B	Block coefficient
C_L	Lift coefficient
C_D	Drag coefficient
D	Blade orbit diameter, m
e	Pitch
K_s	Thrust coefficient
K_D	Torque coefficient
L	length of the blades, m
LWL	Length of waterline, m
M	Torque, kN
n	Propeller rotational speed, rps
N	Steering center
O	Center of VSPs
Re	Reynolds number
R_T	Total resistance, kN
T	Thrust, kN
T_1	Draft, m
u	Circumferential velocity, ms^{-1}
V	Speed of ship, Knot
V_A	Inflow velocity of propeller, ms^{-1}
λ	Advance coefficient
ν	Kinematic viscosity, $m^2 s^{-1}$
α	angles of attack, degree
ρ	Density of water, kg m^{-3}

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