# Reduction and Validation of Noise levels for Non-Cavitating Marine Propellers

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*Abstract*— Marine propellers are one of the dominant noise sources for under water vehicles. Marine propeller is the one of the major source of noise in marine vehicle. Marine propeller is used to propel the body. Either this body could be a marine vehicle of submarine, ship, boat, torpedo etc. So in any vehicle which ever run on water they all use of this marine propeller. So marine propeller is one of the significant and major part in a water moving vehicles. The purpose of the propeller is to produce the thrust in order to move the body either in forward or backward direction. If the propeller takes the clockwise rotation then the vehicle gets move in forward direction and vice versa. This paper presents investigation of noise levels for non-cavitating turbulent flow around marine propeller by varying pitch angle of propeller using the Eddy Viscosity model of Large Eddy Simulation (LES) which is available in Ansys 16.2 version software. Behaviour of propeller is investigated for hydrodynamic parameters later subjected to Computational Acoustic Analysis (CAA) using Ffowcs Wiliams – Hawkings formulations (FW-H). The analysis is carried out by considering pressure based, unsteady formulation of second order implicit. Noise is predicted with time – domain acoustic analogy along with finite volume method. Sound pressure Levels (SPL) are predicted at fixed position of receiver and these results are verified with static analysis on propellers by performance characteristics.

***Key words:*** Sound Pressure Levels (SPL), Non-Cavitating Marine Propellers

## I. INTRODUCTION

A propeller is a fan of that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airofoil - shaped blade, and a fluid (such as air or water) is accelerated behind the blade. Propeller dynamics, like those of marine propellers can be modeled by either or both Bernoulli’s Principle and Newton’s third law. The name propeller came from the Latin langue. In Latin propeller is called as ―propellare. It means to drive forward. An efficient propeller was designed in the 19th century for the application of power source for the steam engine. The rotating propeller converts its rotation motion into thrust which balances the resistance against to drive forward the marine vehicle at that throttle speed. Generally, the engine revolutions are higher to drive the propeller. Therefore, the engine’s r.p.m. must be reduced by a reverse gear with a reduction. A propeller is the only one propulsion drive on marine vehicles which imparting momentum to the contacting fluid which causes a force to act on ship. General principle to propel the ship is Bernoulli’s principle and Newton’s third law. By these principles when the propeller rotates a pressure difference will be creates on the front and back side the blade and due to this pressure difference water will be accelerated behind the blades. in order to obtain high level of comfort zone and to obtain high efficiency, the propeller design should be carefully designed as per the type of application. Generally the propeller is known by its number of blades, its diameter, its pitch and the direction of rotation (left or right).

## II. LITERATURE SURVEY

Rama Krishna V [1] research paper aims at developing and analyzing the six-bladed torpedo propeller. The designing of torpedo propeller is completed in Catia V5 R16 software and analysis is completed with help of Ansys Fluent software. The analytical results of this analysis got compared with the experimental results obtained from the cavitation tunnel. The fluent analysis conducted at different speeds with different r.p.m’s. The outcomes of this analysis are Overall Sound Pressure (SPL) in dB units. The process adopted is Large Eddy Simulation (LES).

Francesco Salvatore, Claudio Testa et al [2] paper aims at modeling a propeller by hydrodynamic model by potential flow formulation which is valid t study inviscid flows around lifting bodies in arbitrary motion. Sheet cavitation model is applied to estimate transient cavity pattern on the surface of the propeller blades. The acoustic noise levels are studied by Ffowcs- Williams- Hawkings equation.

K.L.Satyavarma, C. Neelima Devi [3] paper deals with the numerical study on noises of underwater propeller for different performance conditions. Numerical analysis of non-cavitatating noise will be evaluated using finite element volume (FEV) method and later acoustics analysis will be done at different operating conditions. With respect to hydrophone positions noise characteristics are presented.

Ch. Suryanarayana, B. Satyanarayana, K. Ramji [4] paper aiming at investigating the performance evaluation of an underwater body and pump jet model of body and propulsor testing in cavitation tunnel. Self-propulsion point for the model of two parts of configurations was determined. And the results are closely got matched with the cavitation tunnel outcomes.

Sakir BAL [5] paper aiming at designing of cavitating ship and analysis on it. This work was carried out in 2 steps. Lifting line model was adopted to optimum radial distribution of circulation over the blades to produce the desired thrust with highest efficiency and second one is shape of blades required to produce the desired distribution of circulation. The design of propeller is carried out on two propellers. They are DTMB 4119and DTMB 481 propeller. And the results are compared with the literature.

S. Subhas, V F Saji, S. Ramakrishna, H.N Das [6] paper deals with measuring the non – dimensional coefficients i.e, thrust coefficient ($K_T$), torque coefficient ($K_Q$) and efficiency ($\eta$). And validation these results with experimental work results. The complete work completed with ansys fluent 6.3 version software. Cavitation phenomenon is also calculated along with non-cavitation condition. The propeller model is INSEAN E779a and the element shape in meshing is hexahedral. The model adopted is K-Б turbulence model.

## III. ACOUSTIC PREDICTION

Lighthill proposed the acoustic analogy in the 1950s. Ffowcs Williams–Hawkings (FW-H) generalized the Lighthill acoustic analogy and included the effects of the general surfaces in the arbitrary motion in 1969. The FW-H equation is an appropriate tool for predicting the noise generated by the complex motion of the solid bodies. Today, almost all deterministic rotor noise predictions are based on the FW-H equation. The analytical solutions were obtained for some important problems by using of the frequency domain analysis with some approximation. In the frequency domain analysis, the blade loading is often distributed on the ideal surface without thickness instead of the true blade boundary surface, and some approximation is also made for the distance between the noise source and the position of observer.

Farassat developed many formulations for the solution of the FW-H equation in the time domain. Mainly, the formulation provides a solution for a given geometry, displacement and aerodynamic loading of the moving objects. The implementation on these formulations are straightforward. The solutions need an estimation solution for the retarded times and an accurate representation for the blade loading.

The theory of hydrodynamic sound was developed by Lighthill. He rewrote the Navier-Stokes equations into an exact, inhomogeneous wave equation whose source terms are important only within the turbulent region. Lighthill acoustic analogy equation is given below

$$\boxed{\frac{1\partial^2 p}{c^2\partial t^2} - \Delta^2 p = \frac{\partial q}{\partial t} - \frac{\partial F_i}{\partial x_i} + \frac{\partial^2 T_{IJ}}{\partial x_i \partial x_j}} \quad (1)$$

The acoustic analogy generalized by Ffowcs Williams and Hawkings is often applied in the prediction of the noise emission generated by the rotors of helicopters, axial fans and propellers.

Ffowcs Williams & Hawkings equation is written in the following form

$$\boxed{\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\nabla^2\right)\left[c^2(\rho-\rho_0)\right] = \frac{\partial^2 T_{ij}}{\partial_{xi}\partial_{xj}}} \quad (2)$$

## IV. METHODOLOGY

In the present paper, propeller consisting of six blades was considered for study. The diameter of propeller is 0.389m and hub to propeller diameter ratio is 0.254. Modeling of the propeller is done using CATIA V5R16. In order to model the blade, it is necessary to have sections of the propeller at various radii. These sections are drawn and rotated through their respective pitch angles. Then all rotated sections are projected onto right circular cylinders of respective radii as shown in Fig. 1. Now by using multi section surface option, the blade is modeled. The surface model is created by enclosing the entire surfaces as shown in Fig. 2. The objective of the present CFD and acoustic analyses are to find the noise sources and overall SPL of a propeller at receiver point. Fig. 3 shows the computational domain used for present study. Three dimensional structural tetrahedral grids are generated to discretize the domain. The domain is discretized by minimum 10 linear elements per source wavelength to increase the accuracy of the acoustic propagation. Commercially available grid generation code GAMBIT is used to mesh the entire domain of propeller. Element size 12 is used for mesh generation. After convergence, there are 95486 tetrahedral elements are formed. Fig. 4 shows the meshed model of propeller. The numerical simulations have been carried out with a finite volume code method using FLUENT. The turbulent nature of the flow is incorporated through the LES. LES is chosen as viscous model because, it needs time dependent solution for hydrodynamic solution. Surfaces that rotate relatively are defined as "moving wall". Moreover, as they are dependent on the fluid around them and as they rotate, they are defined as "relative to adjacent cell zone" and "rotational motion". Cylinder walls are defined as "stationary wall" and the inlet and outlet are defined as "velocity inlet (7.08m/sec)" and "outflow". Fluid zone in the inner volume is defined as "moving mesh" and 780rpm in x-direction. However, fluid in the outer volume is defined as "velocity inlet (7.08m/sec)". Fig. 4 shows the boundary conditions on entire domain of propeller. Analysis is carried out iteratively for angular speed of 780rpm. Solution is stopped when changes in solution variables from one iteration to the next is negligible. The same methodology is used for simulations to predict non-cavitation noise of propeller of different propeller rotating speeds of 840 rpm, 900 rpm, 960 rpm at different vehicle speeds of 7.62 m/s, 8.17 m/s, 8.7 m/s respectively by varying pitch angle of propeller to find out optimum pitch angle with validation of static analysis of the propeller by maintain constant vehicle speed (7.08 m/s) but varying propeller rotating speeds of 900 rpm, 960 rpm, 1020 rpm and 1080 rpm.

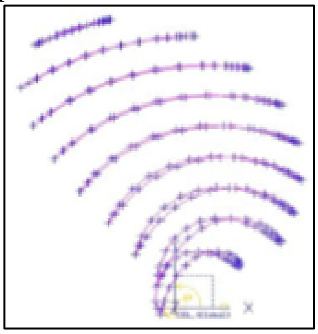

Fig. 1: Points on surface of the blade

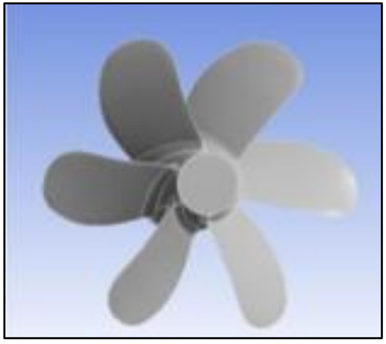

Fig. 2: Solid model for propeller

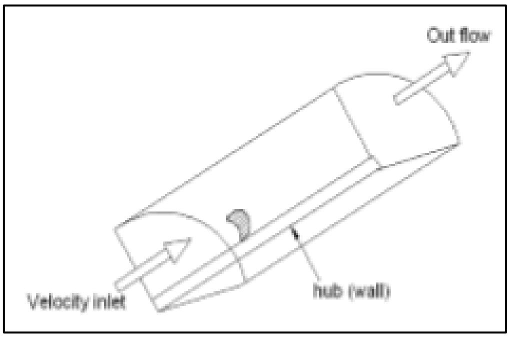

Fig. 3: Computational domain and boundary conditions

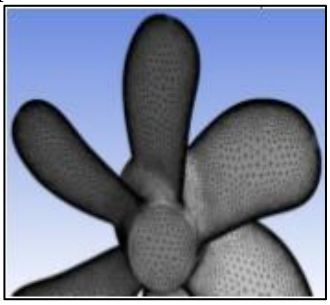

Fig. 4: Meshed model of propeller

## V. RESULTS

In order to reduce the noise prediction levels changing the propeller pitch angle to $51^0$, $45^0$, $43^0$,$41^0$,$38^0$,$35^0$, $33^0$, $28^0$, $23^0$,$18^0$, $13^0$, $8^0$ randomly gives better values on the basis of literature survey. In the view of observing the changes in SPL values note down the values of overall SPL on all these intervals regularly. All these values are tabulated in Table 1

| Pitch Angle (Degrees) | Overall SPL (dB) | | | |
|---|---|---|---|---|
| | $\omega_p$ =780 rpm & V =7.08 (m/s) | $\omega_p$ = 840 rpm & V =7.62 (m/s) | $\omega_p$ = 900 rpm & V = 8.17 (m/s) | $\omega_p$ = 960 rpm & V = 8.71 (m/s) |
| 48 | 127.11 | 127.96 | 128.733 | 129.655 |
| 43 | 110.464 | 110.509 | 109.814 | 112.575 |
| 38 | 104.444 | 105.458 | 108.344 | 109.21 |
| 35 | 106.093 | 107.475 | 107.638 | 107.961 |
| 33 | 107.825 | 108.539 | 109.057 | 111.329 |
| 28 | 105.357 | 109.912 | 110.154 | 110.165 |
| 23 | 108.649 | 109.965 | 110.871 | 112.959 |

Table 1: Pitch angle varying from $48^0$ to $8^0$ (6 Blades)

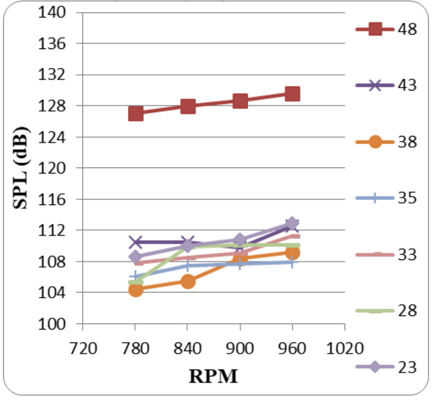

Fig. 5: Six bladed propeller Pitch angle variation

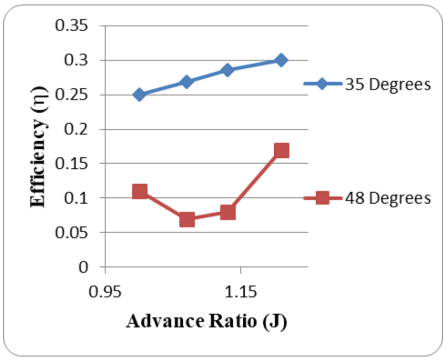

Fig. 6: Efficiency comparison for six bladed propeller with varying pitch angle

## VI. CONCLUSIONS

The non-cavitating noise generated by underwater propeller is investigated by numerical method in this study. The non-cavitating turbulent flow around a full scale marine propeller is simulated with the LES (Large Eddy Simulation) approach. For non-cavitation noise prediction, Ffowcs Williams–Hawkings equation is adopted. Sound pressure levels are predicted and plotted at 1m receiver positions. Optimum pitch angle for the six-bladed propeller is 350. The results are also compared with static analysis and it is verified that 350 pitch angle is optimum for six bladed propeller.

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