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Design of hybrid composite marine propeller for improved cavitation performance

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Abstract

This work aims at understanding the effect of bend-twist coupling in composite materials for improved performance in general and cavitation performance in specific compared to metallic propeller. A four bladed propeller is modeled and analyzed for open water characteristics and cavitation inception. Then, hybrid composite marine propeller is analyzed with the same model along with fluid structure interaction (FSI) using hydro-elastic model. The results of analysis showed, that composite marine propeller can be designed for a greater flexibility in operating range compared to metallic propeller because of inherent couplings exhibited by composite materials. The open water characteristics and cavitation performance of propeller is plotted for NAB and composite propeller.

Keywords: marine propeller; cavitation inception; bend-twist coupling.

1. Introduction

Marine propeller is a component which forms the principal part of ships since it gives the required propulsion. The propeller is an important component of the ship which converts the engine power into the driving force of the ship. These days, conventional marine propellers remain the standard propulsion mechanism for surface ships and underwater vehicles. In general, a propulsor is any device which produces thrust to propel a vehicle, and since the 1800's the most common form of propulsor for ships has been the propeller (or screw propeller, or screw). Nickel-Aluminium-Bronze (NAB) alloy is the most common material for ship propellers but, more recently, composite materials have been used in their construction. Cavitation occurs when the local absolute pressure is less than local vapor pressure for the fluid medium. In fluid power applications the evaporation pressure is reached when flow velocity is increased sufficiently. Cavitation may lead to expensive problems if not acknowledged in an early design stage. The inception of cavitation on hydrofoil is a basic phenomenon in hydrodynamics which refers to the appearance of vapor phase when liquid flows around a hydrofoil. For thin hydrofoils at moderate angle of attack, the first occurrence of cavitation is closely related to the minimum pressure near the leading edge according to [1-5]. Under these conditions the inception of cavitation marks the establishment of relatively large separated flow of vapor on the upper surface near the leading edge commonly referred to as sheet cavitation. Once sheet cavitation is developed, pressure on the upper surface of the hydrofoil is higher than the non cavitating flow. This in turn limits the hydrofoils maximum lift, increases drag, changes the pitching moment. This may also responsible for propeller's noise and vibration as well as efficiency drop and material erosion. The typical design objective is to delay cavitation to higher angles of attack in order to widen the performance of propeller's blades. Minimum pressure coefficient, $(C_p)_{min}$, is used to measure and correlate cavitation inception. For a given hydrofoil at a fixed angle of attack Cavitation inception index $\boldsymbol{\sigma_i}$, tends to increase with flow Reynolds number. Various studies provided the cavitation inception index at various angles of attack. Increasing the angle of attack up to the stall angle at a fixed Reynolds's number also causes to increase in cavitation inception index

[2]. Cavitation inception is dependent on various effects such as surface roughness, cavitation nuclei and transport of non condensable gases [6]. The process of beginning of cavitation is called “Cavitation Inception”. Pure water can withstand considerable low pressure (i.e. negative tension) without undergoing cavitation. For the cavitation inception “the inception pressure” is assumed to be equal to the vapor pressure$\boldsymbol{p_v}$, at the sea. The study of propeller action and design is complex especially the manufacturing of marine propellers is a highly specialized procedure. This complex analysis can be easily solved by numerical techniques. Cavitation inception is of direct importance to Navy vessels, because of the sudden increase in noise levels causes to trouble from stealth point of view at the onset of cavitation.

1.1. Adverse effects of cavitation

The main effects of cavitation are: noise, erosion, vibrations and disruption of the flow, which results in loss of lift and in-crease of drag. Cavitation is known for its violent behavior. That is caused by the fact that vaporization of water and condensation of vapor are very fast processes, much faster than the dynamics of a vapor cavity. As a result the growth and collapse of a cavity is not slowed down by these processes. The violent behavior of cavitation has several adverse effects. Because cavitation is part of the flow, it can move rapidly from regions of low pressure into regions of a higher pressure. This leads to a very rapid collapse. The collapse is so rapid that the local speed of sound in the fluid is exceeded and shock waves occur. The consequence is that cavitation is very noisy and radiates noise over a wide range of frequencies, especially higher frequencies. Also the local pressure rises very strongly at collapse, leading to damage of a nearby surface. This effect is called erosion. When larger amounts of vapor are involved the implosion of cavitation can cause pressure variations in the fluid, which lead to vibration of the cavitating structure. The majority of the adverse effects of cavitation can be related with erosion, noise and vibrations. Cavitation can also alter the flow. This is e.g. the case on propellers when the cavitation becomes extensive. In that case the flow over the blades and the lift of the blades is altered by the cavitation and the thrust of the propeller is strongly reduced. This is the so-called thrust breakdown. Cavitation inception is important for two reasons. The first reason is that the radiated noise level of any form of cavitation is an order of magnitude higher than the noise level of a non-cavitating flow. This is used by Navy ships to detect and locate other ships and by torpedo's to home in on the ship. This is the Navy problem of cavitation inception and the inception speed of a navy ship is very important. In this work cavitation inception speed in calculated both for metallic propeller and hybrid composite propeller.

1.2. Propeller performance

In general, the performance of a marine propeller is measured in-terms of open-water characteristics. The parameters used for this purpose are

$$advance\ coefficient = J = \frac{V_a}{nD}$$

$$torque\ coeffcient = K_Q = \frac{Q}{\rho n^2 D^5}$$

$$thrust\ coefficient = K_T = \frac{T}{\rho n^2 D^4}$$

$$efficiency = \eta = \frac{TV_a}{2\pi nQ} = \frac{K_T * J}{2\pi K_Q}$$

$where\ D = daimeter\ of\ the\ propeller;$

$V_a = axial\ velocity;$

$n = rotational\ velocity(rps);$

$\rho = fluid\ density;$

$T = thrust\ and$

$Q = torque.$

2. Methodology

In this work, a four bladed propeller is modeled and is analyzed for open water characteristics and cavitation inception point. The propeller is modeled in CATIA V5 R17 as shown in fig 1. Fairing caps and shaft are added to the propeller for carrying out the fluid analysis. The fluid analysis is carried out using the general purpose CFD software Fluent 6.3.26 .The inlet was considered at a distance of 3D (where D is diameter of the propeller) from mid of the chord of the root section. Outlet is considered at a distance of 4D from same point at downstream. In radial direction domain was considered up to a distance of 4D from the axis of the hub. This peripheral plane is called far-field boundary. All the boundary conditions are shown in fig 2.

Fig 1. Four bladed propeller.

The mesh is generated with ICEM CFD in such a way that cell sizes near the blade wall were small and increased towards outer boundary. Five prismatic layers are grown on the surface of the blade, hub and shaft to account for the boundary layer as shown in fig 2.

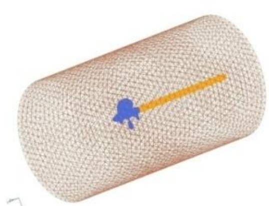

Fig 2. Meshed fluid domain

The pressure obtained from the fluid analysis is mapped to structure for static analysis where in deformed configuration can be obtained. Fluid analysis is carried out again on the deformed configuration to obtain the new pressure distribution on the blades. This process is repeated till the convergence is achieved, i.e. the difference is K_Q between two consecutive iterations is less than 5%. The fluid structure interaction is done as shown in the following fig 3.

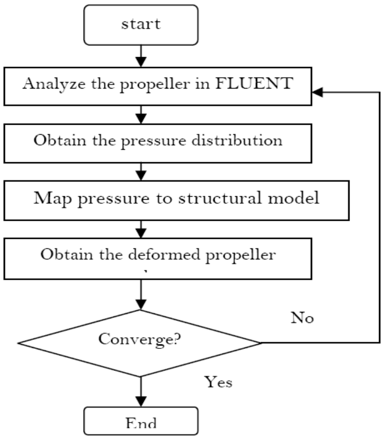

Fig 3. Fluid structure interaction flow-chart.

3. Results and discussion

3.1Metallic propeller

The operating conditions for the analysis are taken as follows: the operating pressure is taken as 14000Pa corresponding to a depth of 1.42m in the water. The vapor pressure is taken as 5000 Pa corresponding to 33^0C of water. The advance velocity is kept constant at 3.83m/s and the rotational speed of the propeller is varied over a range of advance coefficients. The open water characteristics are presented in table 1, and are plotted in fig 4.

Table 1: open water characteristics

Speed(rpm)	J	thrust (T), N	Torque (Q) N-m	K_T	$10K_Q$	Efficiency 'η'
1080	1.038	38.11	2.03	0.067	0.173	0.636
1200	0.934	90.51	3.88	0.128	0.268	0.711
1260	0.890	119.6	4.89	0.154	0.306	0.710
1320	0.849	150.77	5.98	0.176	0.341	0.699
1500	0.747	257.28	9.67	0.233	0.427	0.649
1600	0.701	324.92	12.01	0.259	0.466	0.619
1700	0.659	398.57	14.55	0.281	0.501	0.590
1800	0.623	498.17	17.29	0.313	0.531	0.586
1900	0.590	563.64	20.24	0.318	0.557	0.536
2000	0.560	654.91	23.38	0.334	0.581	0.513
2100	0.534	751.91	26.71	0.348	0.602	0.491
2200	0.510	854.58	30.24	0.360	0.621	0.470
2300	0.487	962.86	33.95	0.371	0.638	0.451
2400	0.467	1076.73	37.86	0.381	0.654	0.434
2500	0.448	1196.15	41.96	0.390	0.668	0.417
2550	0.440	1257.93	44.08	0.394	0.674	0.410
2600	0.431	1321.09	46.25	0.398	0.680	0.402
2650	0.423	1385.62	48.46	0.402	0.686	0.395
2655	0.422	1392.15	48.68	0.403	0.687	0.394
2660	0.421	1398.69	48.91	0.403	0.687	0.393

2670	0.420	1411.82	49.36	0.404	0.688	0.392
2800	0.400	1587.42	55.38	0.413	0.702	0.375
3000	0.374	1875.59	65.26	0.425	0.721	0.351

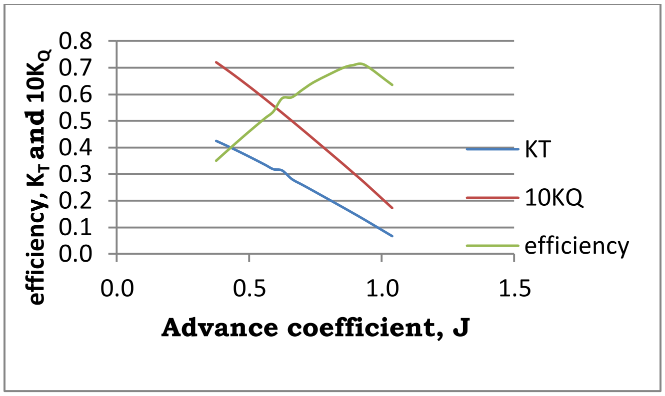

Fig 4. Open water characteristics

The minimum absolute pressure found on the propeller blade is measured at the above advance coefficients to know the cavitation inception, and for metallic propeller the speed of inception is predicted as 1190 corresponding to J=0.940. The pressure distribution in shown in fig 5.

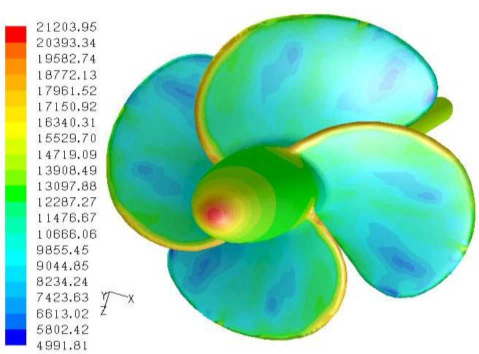

Fig.5 Absolute pressure contours at N=1192rpm

3.2. Hybrid composite propeller

Composite propeller is designed with following three materials as shown in the table 3. The material properties and the stacking sequence is incorporated in Hypermesh 9.0. The stacking sequence adopted for the propeller is $(45_{s2}/45_{s2}/0_c/0_c/0_c/0_c/$ $90Rg/45c/0c/0s2/-45s2/0s2/90s2)s$.

Table:3. Material properties of composites

Property	R glass roving UD/Epoxy	S2 glass fabric/Epoxy	Carbon UD/ Epoxy
E_1 (Gpa)	48.3	22.925	25
E_2 (Gpa)	12.4	22.925	10
E_3(Gpa)	12.4	12.4	10
ϑ_{23}	0.28	0.2	0.2
ϑ_{13}	0.28	0.2	0.16
ϑ_{12}	0.16	0.12	0.12
G_{23}(Gpa)	4.14	4.2	3.8
G_{13}(Gpa)	4.14	4.2	6
G_{12}(Gpa)	6.6	4.7	5.2
$density(g/cm^3)$	2	1.8	1.6

At the same operating conditions as that of the metallic propeller, composite propeller is analyzed and the inception speed is found to be 1298 RPM. The pressure distribution on the propeller is shown in fig 6.

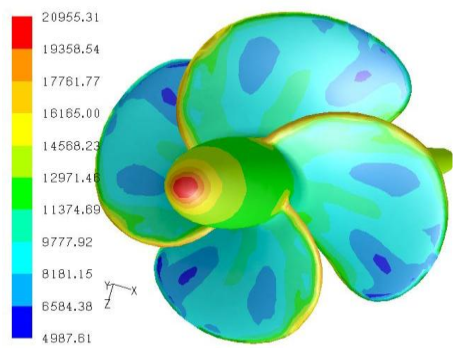

Fig 6. Absolute pressure distribution at 1298 RPM.

4. Conclusions

Composites will give flexibility with regard to design of structures because of the various couplings exhibited by them. Metallic marine propellers can be replaced by composite propellers for enhanced performance with regard to the operating range. In a given range, the metallic propeller inception speed is predicted as 1192 RPM where as the inception speed of hybrid marine propeller is found to be 1298 RPM. The operating range of composite propeller is increased from cavitation inception point of view without compromising the performance. Further, experiments can be done to validate the numerical results obtained for better reliability.

5. References

[1] Taylor, D.w, “The Speed and Power and Ships”, Washington, 1933

[2] J.E.Conolly, “Strength Of composite Propellers”, reads in London at a meeting of the royal intuition of naval architects on dec 1,1960,pp 139-160

[3] Terje sonntvedt, “Propeller Blade Stresses, Application Of Finite Element Methods”, computers and structures, vol.4,pp 193-204,1950

[4] Chang-sup lee, yong-jik kim,gun-do kim and in-sik nho. “Case Study On The Structural Failure Of Marine Propeller Blades” Aeronautical Journal, Jan 1972, pp87-98

[5] M.jourdian, visitor and J.L.Armand. “Strength Of Propeller Blades-A Numerical Approach”, the socity of naval architects and marine engineers, may 24-25,1978,pp 201-213.

[6] G.H.M.Beek, visitor, lips B.V.,Drunen. “Hub-Blade Interaction In Propeller Strength”, the socity of naval architects and marine enginers, may 24-25,1978,pp191-194

[7] George W.Stickle and John L Crigler., “Propeller analysis from experimental data” report No.712, pp 147-164,1989

[8] W.J.Colclough and J.G.Russel. “The Development Of A Composite Propeller Blade With A CFRP Spar” Aeronautical Journal, Jan 1972, pp53-57

[9] J.G.Russel, “Use of reinforced plastics in a composite propeller blade”, plastics and polymers, Dec 1973, pp292-296

[10] Ching-Chieh Lin, Ya-jung Lee. “Stacking Sequence Optimization of Laminated Composite Structures Using Genetic Algorithm with Local Improvement”, Composite structures, 63(2004), pp339-345

[11] Gau-Feng Lin “Three Dimensional Stress Analysis of a Fiber Reinforced Composite Thruster Blade”, the society of naval architects and marine engineers, 1991

[12] Jinsoo Cho and Seung-Chul Lee, “Propeller Blade Shape Optimization For Efficiency Improvement ”,Computer and Fluids, Vol.27, pp 407-419,2002

[13] Charles Dai, Stephen Hanbric, lawerence mulvihill. “A Prototype Marine Propulusur Design Tool Using Artificial Intelligence And Numerical Optimization Techniques ” ,Sname transations, Vol 102, 1994, pp 57-69.

[14] Kerwin,J.E. “Computer Techniques For Propeller Blade Section Design ” International ship building progress, vol 20, no.227,1973,pp 227-251.

[15] C.W.Dekanski, M.L.G.Blor and M.J.Wilson “The Generation Of Propeller Blade Geometries Using The PDE method” Journal of ship research vol 39,no.2, pp 108-116

[16] Wlliam K.Blak, Justin E.Kerwin, E.Weitendorf.J.Friesch, “Deign of Aplc-10 Propeller With Full Scale Measurements and Observations Under Service Conditons”, Sname transitions, vol.98, 1990, pp 77-111

[17] Ansys 11.0, Documentation user Guide.

[18] Fluen 6.2.3, Documentation user Guide.