Twisted Rudder to Make The Ship Energy Efficient

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Abstract: Oil prices climb day by day due to which there should be a reduction in fuel consumption which will also lead to less emission of harmful gases, that can be achieved by modified design of rudders because conventional rudders waste a lot of energy due to cavitation and vibration. The present twisted rudder has profiles along its entire span that are aligned with induced flow angles in the rudder plane. The twist angle of one rudder section varies relatively with the twist angle of adjacent rudder sections due to which the rudders experience zero flow angles induced by the propellers. These rudders are designed computationally with fluid characterstics in self propulsion.

Keywords-: **Cavitation, Navior-Stokes Equation, Reynold's Number, Supercavitation, Drafting, Twenty Foot Equivalent Unit (TEU)**

Introduction-:

This paper contains ship's model which is basically designed to reduce the fuel consumption and increase the speed. Oil price continue to increase due to instability in oil market and higher price of the deep sea oil. The price of bunker-C oil price in 1990 was 90$/mt and currently it is approximately 4 times which is 370$/mt. A container ship that consumes 250mt of oil daily, for that ship effective cost increases by 70,000$. As we all know about 95% ship's emissions is CO2 and it contributes to 3.3% of global CO2 and we need to minimise that by using less fuel**.** International Maritime Organization (IMO) regulates the Energy Efficiency Design Index (EEDI) to cut the emission of CO2. For future ships the CO2 emission is supposed to be decrease. The aim can be achieved by the advanced designing of ship. There is a lot of energy which goes waste during propulsion.

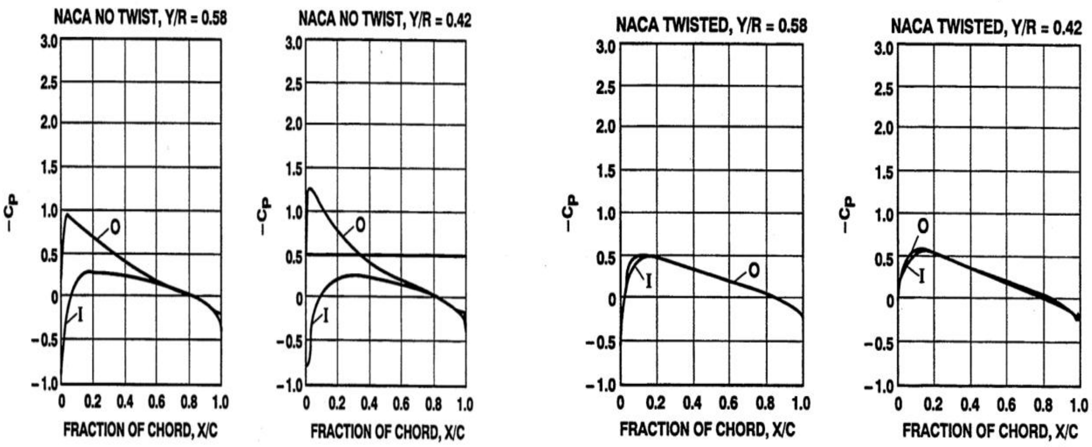
Rotation of propeller generates swirl energy that is partially rectified by the rudder but most of the swirl energy goes in waste. Energy losses in friction and vibration of rudder due to non-zero strike angle of induced velocity by propeller. Some Energy Saving Device (ESD) is required to sort out this problem. This contains rudder designs of present invention. The residual swirl energy at the back of the propeller does not contribute. The bulb of twisted rudder will recover part of swirl energy lost by the propeller, taps the swirl energy of the propeller, due to the profile of twisted rudder viscous loss decreases, and also lowers eddy forces and generates additional thrust to enhance speed.

Background of the invention: -

- Improvement in rudder designing was needed to reduce the vibration and to improve ship's maneuverability.
- Secondly, the propeller rotates the flow into the rudder. As a result, the propeller generates non-zero flow angles, and due to the symmetric profile of conventional rudder it feels non-zero strike angle which results in vibration, viscous losses and decrement in induced velocity.
- Conventional rudders experience this non-zero angles of attack and generates drag. Due to this, the suction pressure peaks occur near to the leading edge of the rudder and early cavitation inception occur which does not improve hydrodynamic and acoustic performances of the ship. The bubbles are formed due to suction pressure peaks on the rudder which on exploding can generate huge shock wave.

Pressure Distribution on the leading edge of the rudder:-

In a twisted rudder profiles are parallel to the onset flow angles and not to the ship centreline. For a conventional rudder coefficient of pressure is -1.25 and in a twisted rudder the computed value of coefficient of pressure is -0.6 which is much lower than conventional rudders.



Theory of twisted rudder:-

The twisted rudder can be made by having a chord-wise profile. Each profile is rotated about a rotation point located on its mean chord-line such that a line drawn tangent to mean chord-line at the rotation point is substantially aligned with the onset flow angle into the profile. Thus, the profile experiences effectively zero angle of attack in the vicinity of the rotation point and very small angle of attack over the entire chord. The effect of shock wave is reduced because the bubbles formed due to suction pressure peaks implode away from the rudder which is termed as supercavitation and this phenomenon can be only successful in asymmetrical rudders.

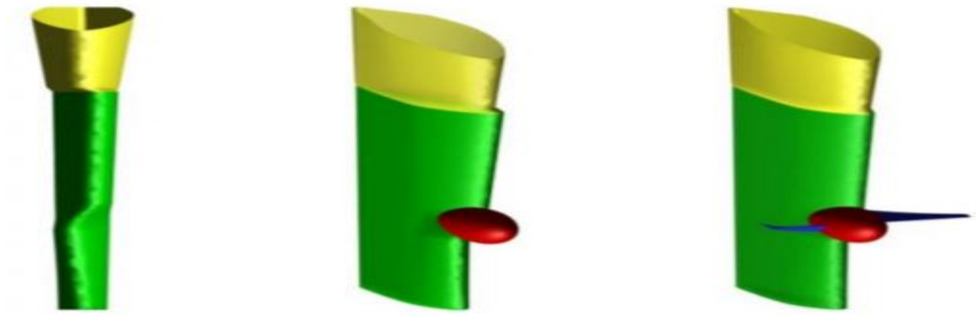
In another type of modification the rudder has profile that are twisted in chord wise direction of the rudder plane such that mean chord-line of each profile is aligned with the onset flow angle into that profile at all points between the leading and trailing edge of the rudder.

There are three types of twisted rudders:-

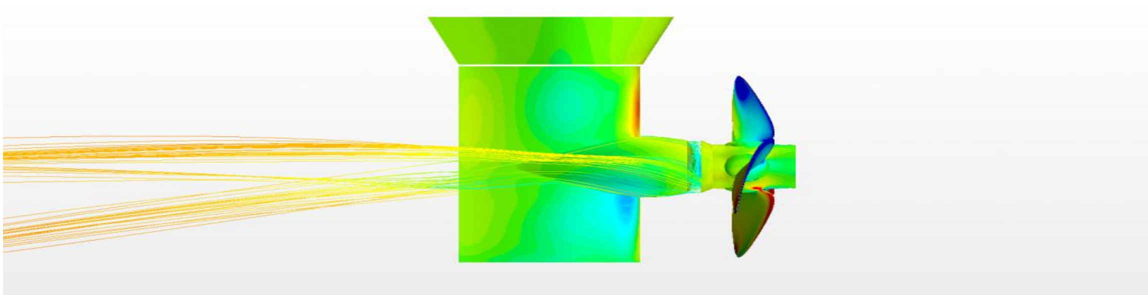
1. Z-Twisted-: It has zero angle of attack of induced flow. In this type of rudder only profile is twisted to make the rudder experience zero strike angle , reducing the early cavitation , viscous loss and vibration.

2. ZB-Twisted- : In addition to the Z-twisted rudder a bulb is placed behind the propeller to avoid the formation of swirl. The bulb distributes the induced flow uniformally over the entire chord. It removes the formation of wake and eddy zone.

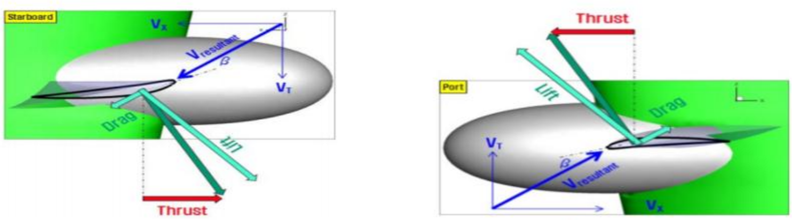
3. ZB-F- Twisted-: This rudder design has a fin placed on the either side of the bulb. Fin's main work is to produce an extra forward thrust by using the drag and lift force due to induced flow.



1. Z-TWISTED 2.ZB-TWISTED 3.ZB-F TWISTED



Rudder bulb preventing the formation of wake in a ZB- twisted rudder

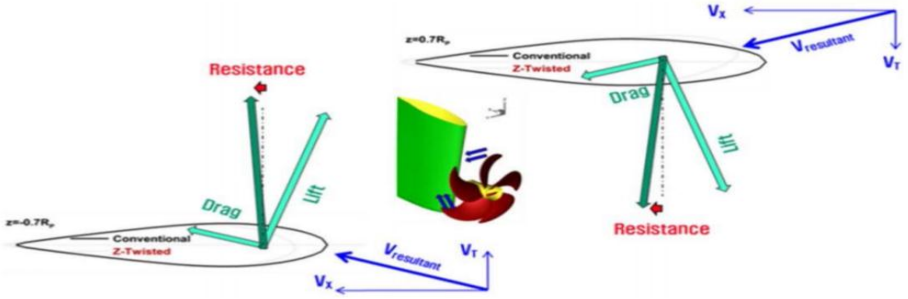


(a) Starboard. (b) Port.

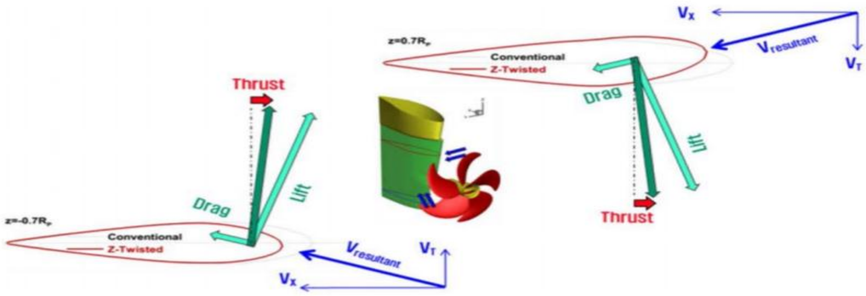
External thrust in a ZB-F twisted rudder.

THE VECTOR APPROACH:-

In conventional rudders, on resolving the forces some drag force in form of resistance is still there after application of lift force.In twisted rudders, due to the curvature drag force gets lessened and lift force is increased due to which we get an additional forward thrust.



(a) Horn-type rudder.



(b) Twisted rudder.

The fluid approach:-

Laminar flow of navior-stokes equation resembles Newton's second law of motion for fluids. Navior-Stokes represents conservation of momentum and continuity equation represents conservation of mass.This type of rudder design requires special designing.

$$\underbrace{\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right)}_{1} = \underbrace{-\nabla p}_{2} + \underbrace{\nabla\cdot\left(\mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}\right)}_{3} + \underbrace{\mathbf{F}}_{4}$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) = 0$$

Now, putting u=0 in above equation, we have:-

Force is equal to rate of change of momentum which is newton second law of motion for fluids. This is for laminar flow in which pressure behind the object is higher. In turbulent flow, the slipstream has a lower pressure than ambient fluid around the propeller due to which slipstream region is formed around the rudder which exerts a force on the rudder to move it in a particular direction. To overcome this problem, a certain force is calculated by navier-stokes equation by slightly offsetting the rudder from propeller's center-line so as to provide an opposing force on the tail cancelling the slipstream force.

The hydrodynamic approach:-

This also follows with Reynolds stress in twisted rudder.Actually, the reynolds stress is the component of total tensor in a fluid obtained from averaging the operation over Navior-Stokes equation to account for turbulent fluctuations in fluid momentum. The net rate of transfer of momentum across a surface in a fluid resulting from turbulence in the fluid. The behaviour of turbulent flow of fluid complicates the flow which is eventually reduced by bulbs and fins present in twisted rudders.

Boundary layer can be laminar or turbulent of the rudder. It can be laminar or turbulent which is calculated by Reynolds number of local flow conditions. Flow seperation is also a major problem in these rudders because of the twist of the rudder. Due to it, there is a loss of lift and stall. Secondly, flow seperation can increase drag in hydrodynamics particularly because of pressure drag which is caused by difference in pressure between leading and trailing edge. The fluid takes form of eddies and vortices which impinge on rudder surface resulting in surface erosion.

This damage can be reduced by making the twist angle smooth. Secondly, in turbulent flow, Reynolds number is higher and because of that seperation resistance of a turbulent boundary layer increases which doesn't allow the flow to seperate.

Hull designing: -

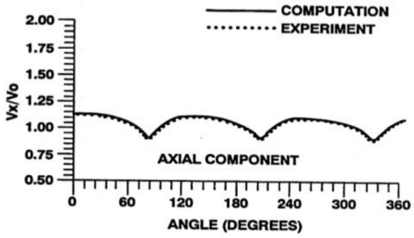
This ship requires hull designing with accurate measurements. It is approximately designed for 13000 TEU or very large container ships. This ship is designed hydro-dynamically and computationally. The governing approaches are vector approach, Navier-Stokes equation of unsteady turbulent flow and the Reynolds stress approach.

This ship has following measurements:-

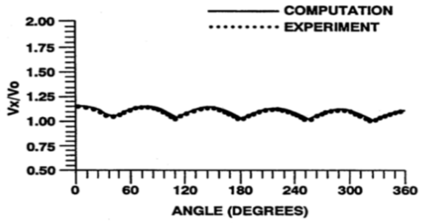
Length between perpendicular (LPP)	– 350m
Breadth (B)	– 48.2m
Draft (T)	-- 14.5m
Propeller Diameter (Dp)	-- 9.9m
No. of propeller blade (Z)	-- 5

This ship is designed very large because if the ship will be large, the size of the propellers will also be large. Large propellers will induce more amount of flow than small propellers, the velocity of induced flow will reduce and the wake or eddy zone will be for very less distance behind the propeller. This ship is designed such that it will have a more aerodynamic body or streamlined body which will provide weak slipstream region and turbulence will also get reduced.

These propellers should have a particular constant speed of 8.02 rps. This is because at that speed ship will move with same speed as that of the slipstream which will lessen the drag on the rudder. This phenomenon is termed as Drafting. As the graph below shows that using five blade propellers instead of 3 blade propeller, there is a five cycle curve in five blade's graph than three cycle curve in three blade's graph. The five cycle curve shows that five blade propellers will attain constant velocity nature more fast than three blade propellers and we need that constant velocity.



Three blade propellor



Five blade propellor

Cavitation test result-:

To validate the effect of twisted angles at the leading edge, cavitation test results for twisted rudders having different twist angles of 0, 3.5, 5.0, 6.0 degrees. In fig 8 it shows that at o degree twist angle cavitation occurs when rudder is deflected by 18 degrees. In fig 9 it shows, at 3.5 degree twist, there is less cavitation at 18 degree rudder deflection. In fig 10 it shows, at 5.0 degree twist there is lesser cavitation at 18 degree rudder deflection. In fig 11 it shows, at 6.5 degree twist there is no cavitation till 18 degree rudder deflection which is very large rudder deflection

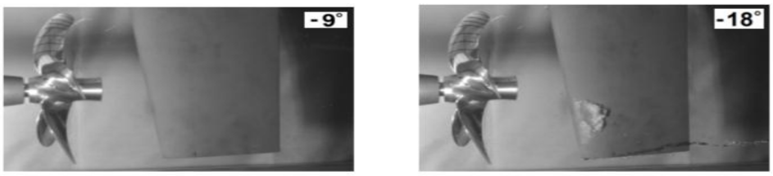


Fig. 8 Cavitation test results of twist angle 0°.

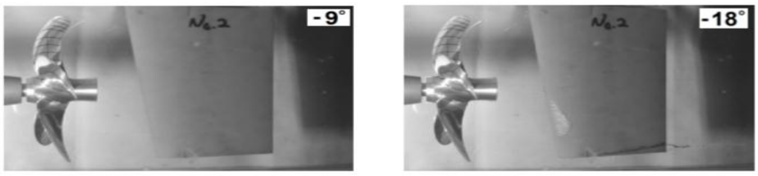


Fig. 9 Cavitation test results of twist angle 3.5°.

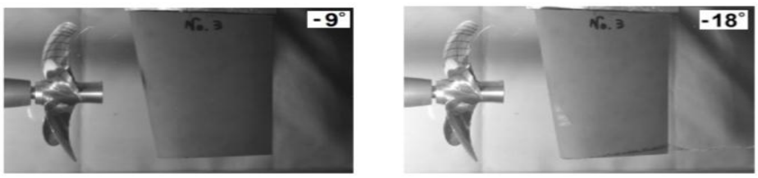


Fig. 10 Cavitation test results of twist angle 5.0°.

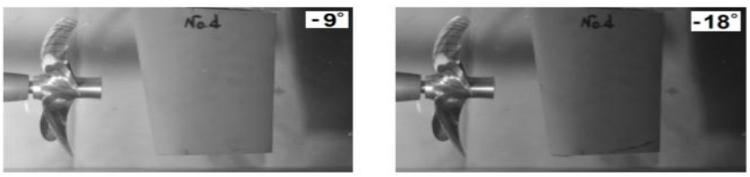
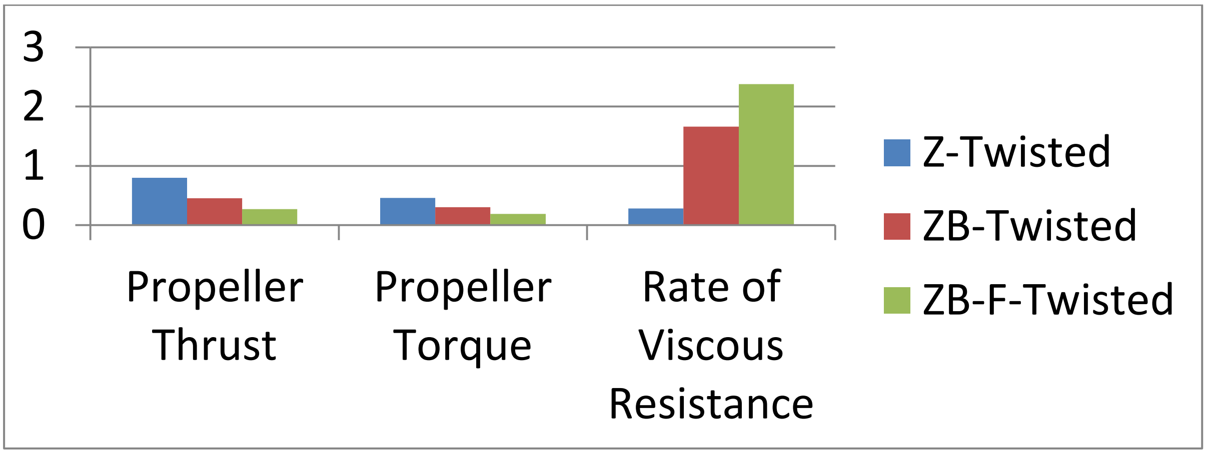
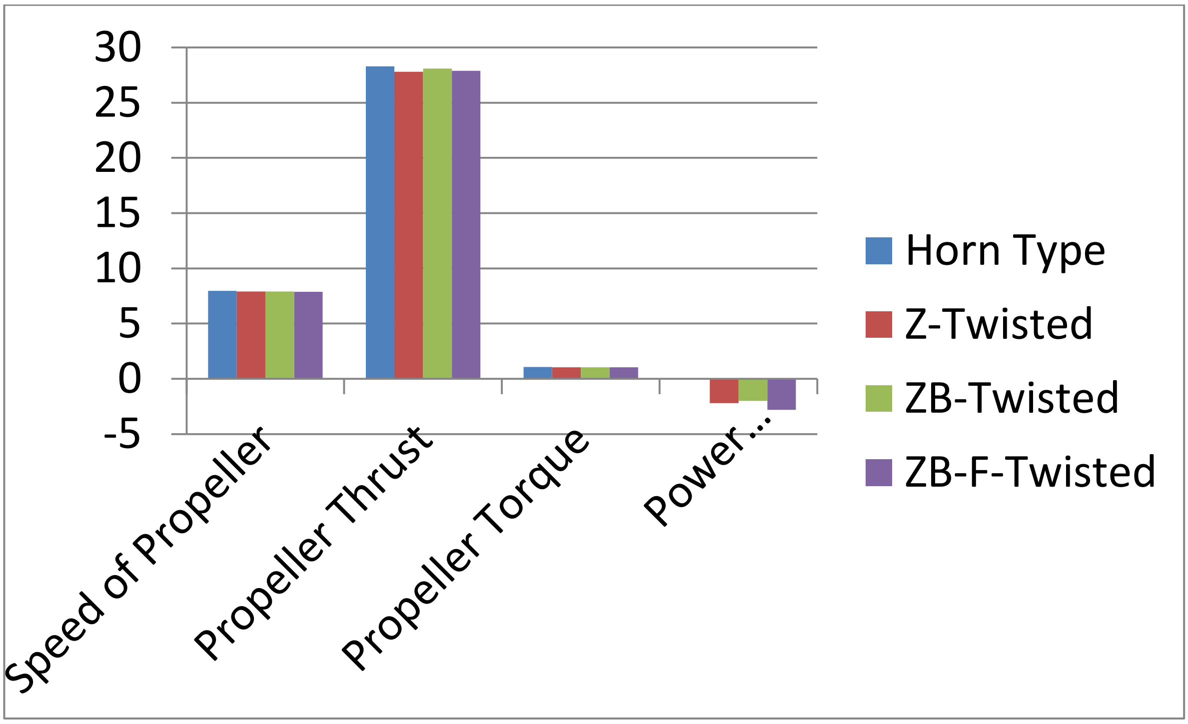


Fig. 11 Cavitation test results of twist angle 6.5°.



Percentage ratio of thrust, torque & viscous resistance.



Speed performance and power delivered.

Conclusion:-

The twisted rudder is an asymmetry type that boosts the propeller's performance by aligning with the direction of propeller slipstream to lessen the drag on the rudder.This rudder increases the ship's speed by 0.35 kmph by reducing drag and increasing the hull efficiency.

The bulb of ZB- Twisted rudder doesnt fulfill the requirement ,bulb are supposed to remove the swirl and hub vortex of the propeller but it doesn't meet the requirement.The bulb fin attached removes the wake zone and and develop an extra thrust to increases the propeller's effciency by 2.95%. This ship's technology meets the EDDI standards of a green ship. These ESD are collectively cut lot of CO2. This ship will save a lot of fuel economy. In case of a 13000 TEU, a container ship that consumes 260 ton per day, a 10% improvement in fuel economy will save 10% 2,886,000 USD a year presuming the bunker C oil to be 370 USD and working days should be 300 in a year.

Refernces:-

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