

Modeling and Analysis of Propeller Blade with CFRP Material by Using Finite Element Analysis

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ABSTRACT:

In current years the increased need for the light weight structural element with acoustic insulation, has led to use of fiber reinforced multi-layer composite propeller. The present work carries out the structural analysis of a CFRP (carbon fiber reinforced plastic) propeller blade which proposed to replace the Aluminum propeller blade.

Propeller is subjected to an external hydrostatic pressure on either side of the blades depending on the operating depth and flow around the propeller also result in differential hydrodynamic pressure between face and back surfaces of blades. The propeller blade is modeled and designed such that it can with stand the static load distribution and finding the stresses and deflections for both aluminum and carbon fiber reinforced plastic materials.

This work basically deals with the modeling and design analysis of the propeller blade of a torpedo for its strength. A propeller is complex 3D model geometry. This requires high end modeling CATIA software is used for generating the blade model. This report consists of brief details about Fiber Reinforced Plastic materials and the advantages of using composite propeller over the conventional metallic propeller. By using ANSYS software static structural analysis were carried out for two different materials.

INTRODUCTION

Marine propeller is a component which forms the principal part of ships since it gives the required

propulsion. Fiber reinforced plastics are extensively used in the manufacturing of various structures including the marine propeller. The hydrodynamic aspects of the design of composite marine propellers have attracted attention because they are important in predicting the deflection and performance of the propeller blade.

For designing an optimized marine propeller one has to understand the parameters that influence the hydrodynamic behavior. Since propeller is a complex geometry, the analysis could be done only with the help of numerical tools. Most marine propellers are made of metal material such as bronze or steel. The advantages of replacing metal with an FRP composite are that the latter is lighter and corrosion-resistant. Another important advantage is that the deformation of the composite propeller can be controlled to improve its performance. Propellers always rotate at a constant velocity that maximizes the efficiency of the engine. When the ship sails at the designed speed, the inflow angle is close to its pitch angle. When the ship sails at a lower speed, the inflow angle is smaller. Hence, the pressure on the propeller increases as the ship speed decreases. The propulsion efficiency is also low when the inflow angle is far from the pitch angle. If the pitch angle can be reduced when the inflow angle is low, then the efficiency of the propeller can be improved.

Traditionally marine propellers are made of manganese-nickel-aluminum-bronze (MAB) or nickel-aluminum-bronze (NAB) for superior corrosion

resistance, high-yield strength, reliability, and affordability. More over metallic propellers are subjected to corrosion, cavitations damage; fatigue induced cracking and has relatively poor acoustic damping properties that can lead to noise due to structural vibration. Moreover, composites can offer the potential benefits of reduced corrosion and cavitation's damage, improved fatigue performance, lower noise, improved material damping properties, and reduced lifetime maintenance cost. In addition the load-bearing fibers can be aligned and stacked to reduce fluttering and to improve the hydrodynamic efficiency.

Types of marine propellers

- Controllable pitch propeller
- Skewback propeller
- Modular propeller

Controllable pitch propeller

A controllable pitch propeller one type of marine propeller is the controllable pitch propeller. This propeller has several advantages with ships. These advantages include: the least drag depending on the speed used, the ability to move the sea vessel backwards, and the ability to use the "vane"-stance, which gives the least water resistance when not using the propeller (e.g. when the sails are used instead).

Skewback propeller

An advanced type of propeller used on German Type 212 submarines is called a skewback propeller. As in the scimitar blades used on some aircraft, the blade tips of a skewback propeller are swept back against the direction of rotation. In addition, the blades are tilted rearward along the longitudinal axis, giving the propeller an overall cup-shaped appearance. This design preserves thrust efficiency while reducing cavitation's, and thus makes for a quiet, stealthy design.

Modular propeller

A modular propeller provides more control over the boats performance. There is no need to change an entire prop, when there is an opportunity to only change the pitch or the damaged blades. Being able to adjust pitch will allow for boaters to have better performance while in different altitudes, water sports, and/or cruising.

PROPELLER GEOMETRY

Frames of Reference:

For propeller geometry it is convenient to define a local reference frame having a Common axis such that OX and Ox are coincident but Oy and Oz rotate relative to the OY and OZ fixed global frame.

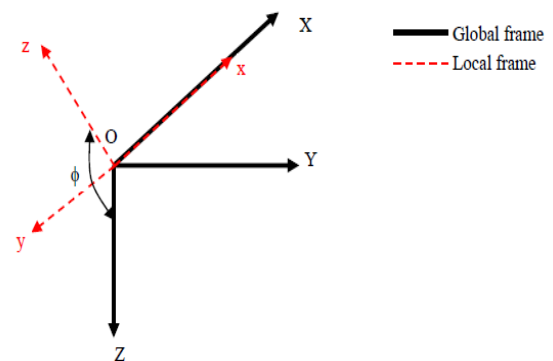


Fig 1: Propeller Reference Lines

The line normal to the shaft axis is called either propeller reference line or directory. In the case of controllable pitch propeller the spindle axis is used as synonymous with the reference line.

Generator line: The line formed by intersection of the pitch helices and the plane containing the shaft axis and propeller reference line.

The airfoil sections which together comprise the blade of a propeller are defined on the surfaces of cylinders whose axes are concentric with the shaft axis.

Face: The side of a propeller blade which faces downstream during a head motion is called face or pressure side (when viewed from aft of a ship to the

bow the seen side of a propeller blade is called face or pressure side).

Back: The side of a propeller blade which faces generally direction of a head motion is called back or suction side (when viewed from aft of a ship to the bow the unseen side of a propeller blade is called back or suction side).

Leading Edge: When the propeller rotating the edge piercing water is called leading edge.

Trailing Edge: When the propeller rotating the edge trailing the leading edge is called trailing edge.

Pitch

Consider a point P lying on the surface of a cylinder of radius r which is at some initial point P₀ and moves as to from a helix over the surface of a cylinder.

The propeller moves forward as to rotate and this movement create a helix.

When the point P has completed one revolution of helix that means the angle of rotation: $\phi = 360^\circ$ or 2π the cylinder intersects the X-Z plane and moves forward at a distance of P.

In the projection one revolution of the helix around the cylinder measured normal to the OX axis is equal to $2\pi r$.

The distance moved forward by the helical line during this revolution is p and the helix angle is given by: θ

The angle θ is termed the pitch angle and the distance p is the pitch.

There are several pitch definitions.

Nose-tail pitch: The straight line connecting the extremities of the mean line or nose and tail of a propeller blade is called nose-tail pitch line. The section angles of attack are defined to the nose-tail line.

Face pitch: The face pitch line is basically a tangent to section's pressure side surface and you can draw so many lines to the pressure side. It is rarely used but it

can be seen in older drawings like Wageningen B series.

Effective or no-lift pitch:

It is the pitch line of the section corresponding to aerodynamic no-lift line which results zero lift.

Hydrodynamic pitch:

The hydrodynamic pitch angle (β_i) is the pitch angle at which the incident flow encounters the blade section. Effective pitch angle (θ_0) = Noise-tail pitch angle (θ , θ_{nt}) + 3-D zero-lift angle where 3-D zero lift angle is the difference between θ_0 and θ .

θ_0 = Hydrodynamic pitch angle (β_i) + Angle of attack of section (α) + 3-D zero lift angle and Pitch values at different radii are called radial pitch distribution.

Slip Ratio

If the propeller works in a solid medium (has no slip), i.e. if the water which the propeller "screws" itself through does not yield (i.e. if the water did not accelerate aft), the propeller will move forward at a speed of $V = p \times n$, where n is the propeller's rate of revolution, as seen in the below figure. The similar situation is shown for a corkscrew, and because the cork is a solid material, the slip is zero and, therefore, the cork screw always moves forward at a speed of $V = p \times n$. However, as the water is a fluid and does yield (i.e. accelerate aft), the propeller's apparent speed forward decreases with its slip and becomes equal to the ship's speed V, and its apparent slip can thus be expressed as $p \times n - V$.

Skew

It is the angle between the mid-chord position of a section and the directrix (θ_s).

The propeller skew angle (θ_{sp}) is defined as the greatest angle measured at the shaft centre line which can be drawn between lines passing from the shaft center line through the mid chord position of any two sections.

The skew can be classified into two types:

Balanced skew: Directrix intersects with the mid-chord line at least twice.

Biased skew: Mid-chord locus crosses the directrix not more than once normally in the inner sections.

Rake

The displacement from the propeller plane to the generator line in the direction of the shaft axis is called rake. The propeller rake is divided into two components: generator line rake (iG) and skew induced rake (is) which are defined as

Propeller Outlines and Areas

There are five different outlines and associated areas of propeller in use these are:

Disc outline (area) (A_0)

Projected outline (A_p)

Developed outline (AD)

Expanded outline (AE)

Swept outline (AS)

Disc area: The area of the circle swept out by the tips of the blades of a propeller diameter.

Projected outline: It is the view of the propeller blade that is actually seen when the propeller is viewed along the shaft centerline normal to $y-z$ plane where Z is the number of blades. r_h is the hub radius of the propeller. R is the tip radius of the propeller.

Developed outline: It is a helically based view, but the pitch of each section has been reduced to zero. The intersection of the blade with the axial cylinder is rotated along the blade reference line into a plane parallel to the propeller. The amount of rotation is equal to the pitch angle at every radius.

Expanded blade outline: It is really not an outline in any true geometric sense at all. It is a plotting of the chord lengths at their correct radial stations about the directrix. Such that the outline is constructed by laying off at each $10 \cdot \text{radius } r$, the chord length along a

straight line. The outline is formed by the locus of the end points of the chord lines laid out in the above manner.

Swept Outline: This outline is swept by the leading and trailing edges when the propeller is rotating. In general, the developed area is greater than the projected area and slightly less than the expanded area.

Blade Sections-NACA Definitions

Mean line or camber line: It is the location of mid-points between upper and lower surfaces when measured perpendicular to the camber line.

Chord length (c): The distance between the leading edge and trailing edges when measured along the chord line is termed as chord length of the section

Camber: is the maximum distance between the camber line and chord line.

Thickness: of a section is the distance between upper and lower surfaces of the section also measured perpendicular to the chord line.

Leading edges are usually circular having a leading edge radius defined about a point on the camber line.

Typical section used for ship propeller is NACA66 series with the mean line $a=0.8$

The upper and lower coordinates of the profile are given as:

$$x_U = x_C, y_U = y_C + y_t$$

$$x_L = x_C, y_L = y_C - y_t$$

Where y_C is the camber ordinate obtained from the table, y_t is the ordinate of the chosen symmetrical thickness distribution

PROCEDURE FOR PROPELLER BLADE

Open CATIA V5 R16

Close the Product Window

Start – Mechanical Design – Wireframe and Surface Design – Enter Part Name as **Propeller Blade** – OK

Now we are in a surface modeling - Select Top (XY) plane – Sketch tool

Now we are in sketcher workbench - Draw a circle with 60 dia – Exit workbench

Extrude it with 50 mm on both sides total 100 mm height as shown in **Fig 2:**

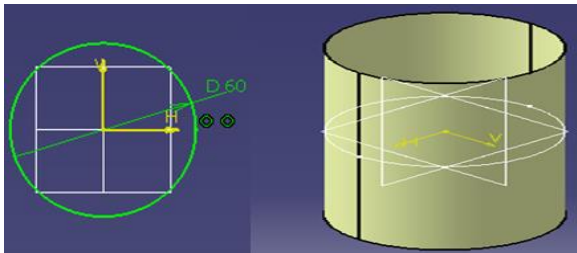


Fig 2 and 3

Create a point on the right plane at a distance of 30 mm from vertical 4 mm from horizontal as, **Fig 3;** Create the helix with 92 mm height and 276 pitches as shown in **Fig 4**

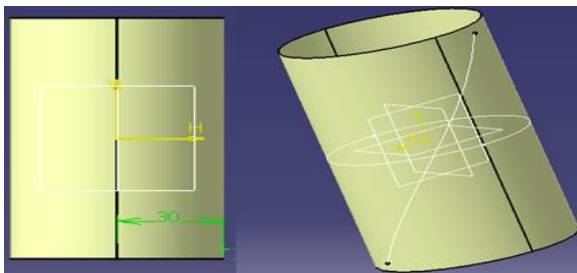


Fig 3 and 4

Create the blade as shown below in Fig 5 by using sweep tool, round the corners with corner tool with R 80 and R 40 as shown below in

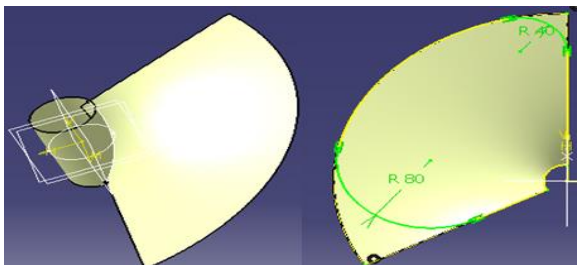


Fig 5 and 6

Extrude the rounded sketch with supports as shown below in Fig 7, split it with split tool as shown below in

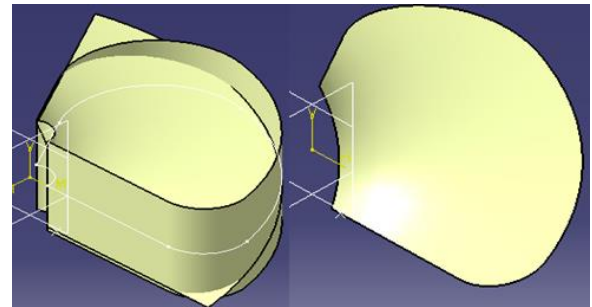


Fig 7 and 8

Now enter into part modeling to add thickness to the blade, by using thick surface tool add the thickness 4 mm (Fig:9), Convert fig:3 surface into solid using close surface tool (Fig:10)

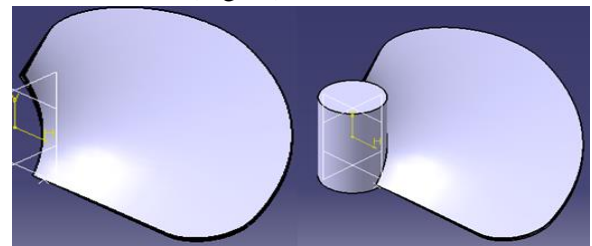


Fig 9 and 10

MODELING OF PROPELLER BLADE BY USING CATIAV5

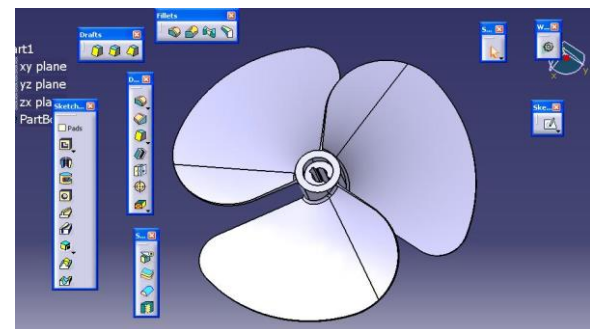


Fig 11: model of a propeller

METALLIC MATERIALS

The most common metals used in marine propeller construction are aluminum, magnesium, titanium, steel, and their alloys.

Alloys: An alloy is composed of two or more metals. The metal present in the alloy in the largest amount is called the base metal. All other metals added to the

base metal are called alloying elements. Adding the alloying elements may result in a change in the properties of the base metal. For example, pure aluminum is relatively soft and weak. However, adding small amounts of copper, manganese, and magnesium will increase aluminum's strength many times. Heat treatment can increase or decrease an alloy's strength and hardness. Alloys are important to the marine propeller industry. They provide materials with properties that pure metals do not possess.

NONMETALLIC MATERIALS

In addition to metals, various types of plastic materials are found in marine propeller construction. Some of these plastics include transparent plastic, reinforced plastic, composite, and carbon-fiber materials.

CARBON FIBER REINFORCED PLASTIC

High-performance marine propeller requires an extra high strength-to-weight ratio material. Fabrication of composite materials satisfies this special requirement. Composite materials are constructed by using several layers of bonding materials (graphite epoxy or boron epoxy). These materials are mechanically fastened to conventional substructures. Another type of composite construction consists of thin graphite epoxy skins bonded to an aluminum honeycomb core. Carbon fiber is extremely strong, thin fiber made by heating synthetic fibers, such as rayon, until charred, and then layering in cross sections.

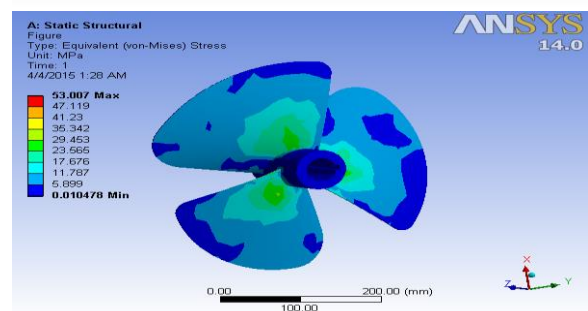
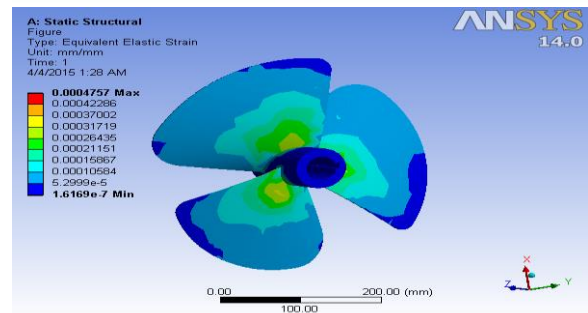
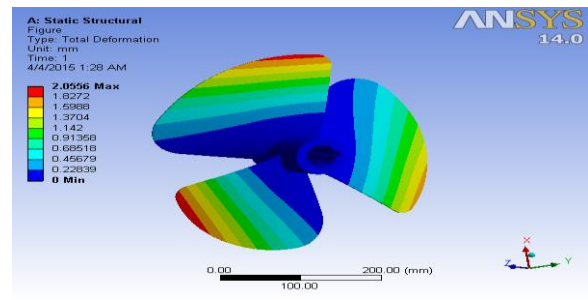
Material Data

Titanium Alloy
Constants

Density	4.62e-006 kg mm ⁻³
Coefficient of Thermal Expansion	9.4e-006 C ⁻¹
Specific Heat	5.22e+005 mJ kg ⁻¹ C ⁻¹
Thermal Conductivity	2.19e-002 W mm ⁻¹ C ⁻¹
Resistivity	1.7e-003 ohm mm

Titanium Alloy > Isotropic Elasticity

Tem C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	96000	0.36	1.1429e+05	35294



Material Data

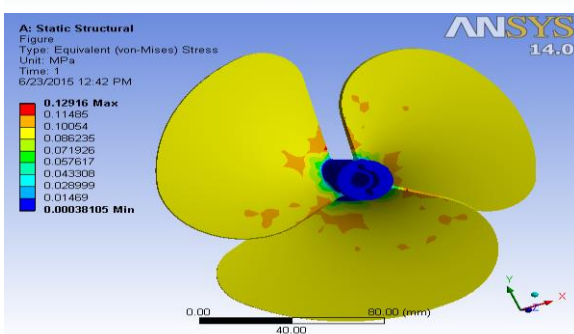
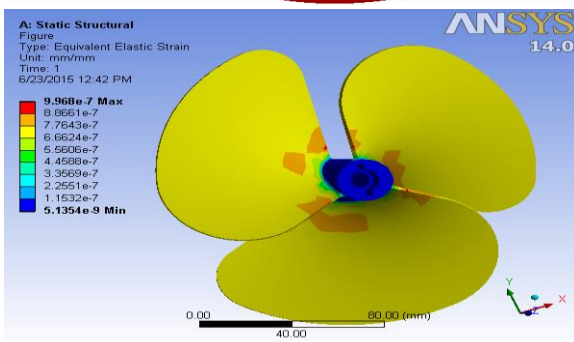
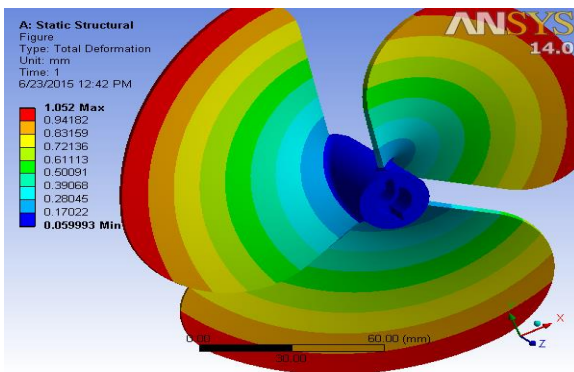
Nibral

nibral > Constants

Density	7.5981e-006 kg mm ⁻³
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nibral > Isotropic Elasticity

Temp C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	1.138e+05	0.29	90289	44094



CONCLUSION

Composite propellers have more advantages over the conventional metallic propellers. We concentrated on the metal and composite strength analysis of the propeller blade carried out by using the finite element method. This report consists of brief details about Fiber Reinforced Plastic materials and the advantages of using composite propeller over the conventional metallic propeller.

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Material Data

CFRP

CFRP > Constants

Density 1.55e-006 kg mm⁻³

CFRP > Isotropic Elasticity

Temp C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	1.3e+005	0.25	86667	52000

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