Modal Analysis and Performance Charecteristics of a Typical Quadcopter Propeller

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Abstract— The project aims at performing modal analysis of a quad-copter propeller and to find out its performance characteristics. Quadcopters are classified as rotorcraft, unlike to fixed wing aircraft as their lift is generated by a set of rotors which are vertically oriented.The propeller will be designed using the dimensions of a typical propeller model with Onera HOR07 airfoils at various offset planes,on designing software(Solidworks).

Computational analysis software (ANSYS) will be used to perform analysis on the changes that will happen to the propeller at various operating conditions.The objective is to analyze the performance characteristics of the propeller in ideal conditions.The results obtained from the computational software is compiled and tabulated. Comparison graphs between the characteristics at various rotations per minute are drawn.

Index Terms— Airfoils, Ansys, Computational Fluid Dynamics (CFD),Natural frequency ,Onera HOR07,Static Pressure, Velocity, Vibrations

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1 INTRODUCTION

1.1 PROPELLER

Quad-copters are classified as rotor-craft, unlike to fixed wing aircraft as their lift is generated by a set of rotors which are vertically oriented.

Quad-copters generally use two pairs of identical fixed pitched propellers; two clockwise (CW) and two counter-clockwise (CCW). Both set of rotors have independent speed variation to achieve higher degrees of stability.

Variation in the speed of the various propellers, desired thrust and torque can be produced.

The propeller attaches to the power source's driveshaft either directly or through reduction_gearing. Propellers can be made from wood, metal or composite_materials.

Propellers are only suitable for use at subsonic air speeds mostly below about 480 mph (770 km/h; 420 kN), as above this speed the blade tip speed approaches the speed of sound and local supersonic flow causes high drag, noise and propeller structural problems.

1.2 MODAL ANALYSIS

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. Modal analysis, or the mode-superposition method, is a linear dynamic response procedure which evaluates and superimposes free-vibration mode shapes to characterize displacement patterns. Mode shapes describe the configurations into which a structure will naturally displace. Typically, lateral displacement patterns are of primary concern. Mode shapes of low-order mathematical expression tend to provide the greatest contribution to structural response. As orders increase, mode shapes contribute less, and are predicted less reliably. It is reasonable to truncate analysis when the number of mode shapes is sufficient.A structure with N degrees of freedom will have N corresponding mode shapes.

Each mode shape is an independent and normalized displacement pattern which may be amplified and superimposed to create a resultant displacement pattern.

Modal analysis on the designed propeller was done to find the natural vibrating frequency of the propeller.

By knowing the natural vibrating frequency of the propeller, resonant failure during its application can be prevented.

1.3 INTRODUCTION TO THE SOFTWARE USED

The project majorly focuses on computational analysis of the designed propeller using the required software.

The design is carried out in 3D design software, Solidworks by Dassault Systemes. The constructed design is imported to computational analysis software, ANSYS and the required computation is carried out.

1.4 INTRODUCTION TO SOLIDWORKS

SolidWorks is a solid_modeling computer-aided_design (CAD) and Computer Aided Engineering (CAE) computer program that runs on Microsoft_Windows. SolidWorks is published by Dassault_Systèmes.

SolidWorks is a solid modeler, and utilizes a parametric feature-based approach which was initially developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The software is written on **Parasolid-kernel.**

Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent.

Building a model in SolidWorks usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of SolidWorks means that the dimensions and relations drive the geometry, not the other way around.

The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

In an assembly, the analog to sketch relations are mates. Just as sketch relations define conditions such as tangency, parallelism, and concentricity with respect to sketch geometry, assembly mates define equivalent relations with respect to the individual parts or components, allowing the easy construction of assemblies. SolidWorks also includes additional advanced mating features such as gear and cam follower mates, which allow modeled gear assemblies to accurately reproduce the rotational movement of an actual gear train.

Finally, drawings can be created either from parts or assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards (ANSI, ISO, DIN, GOST, JIS, BSI and SAC).

SolidWorks files (previous to version 2015) use the Microsoft Structured Storage file format. This means that there are various files embedded within each SLDDRW (drawing files), SLDPRT (part files), SLD ASM (assembly files) file, including preview bitmaps and meta-data sub-files. Various third-party tools (see COM Structured Storage) can be used to extract these sub-files, although the sub-files in many cases use proprietary binary file formats.

1.5 INTRODUCTION TO ANSYS

Ansys Inc. is an American public company based in Canonsburg, Pennsylvania. It develops and markets engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties.

Ansys was founded in 1970 by John Swanson. Swanson sold his interest in the company to venture capitalists in 1993. Ansys went public on NASDAQ in 1996. In the 2000s, Ansys made numerous acquisitions of other engineering design companies, acquiring additional technology for fluid dynamics, electronics design, and other physics analysis.

Ansys develops and markets finite element analysis software used to simulate engineering problems.The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys software may simulate how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety.

Most Ansys simulations are performed using the Ansys Workbench software, which is one of the company's main products. Typically, Ansys users break down larger structures into small components that are each modeled and tested individually. A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyzes movement, fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

Ansys also develops software for data management and backup, academic research and teaching. Ansys software is an annual subscription sold on basis.

2 DESIGN

The model of the typical propeller is designed on SOLIDWORKS 2018 CAD software by importing propeller airfoil Onera HOR07 at different offset planes and then lofting them.

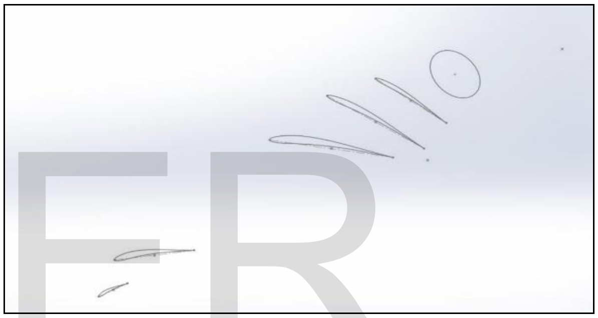


Fig 2.1 AIRFOILS AT VARIOUS OFFSET PLANES

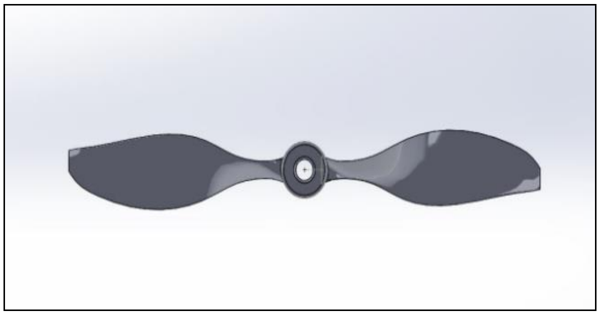


Fig. 2.2 FINAL DESIGN MADE ON SOLIDWORKS 2018

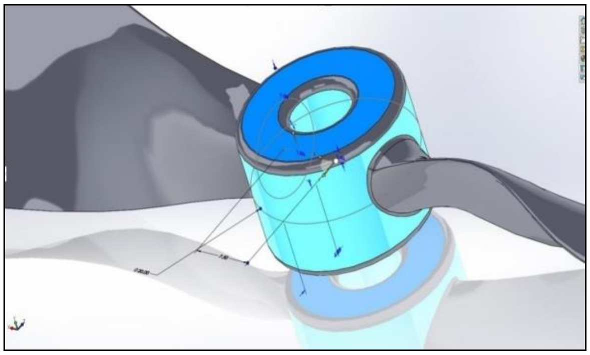


Fig. 2.3 PROPELLER HUB WITH DIMENSIONS

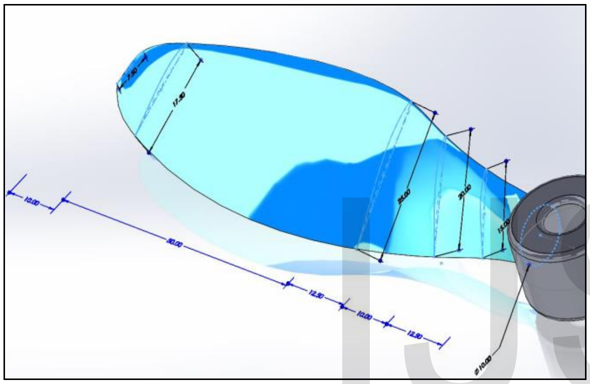
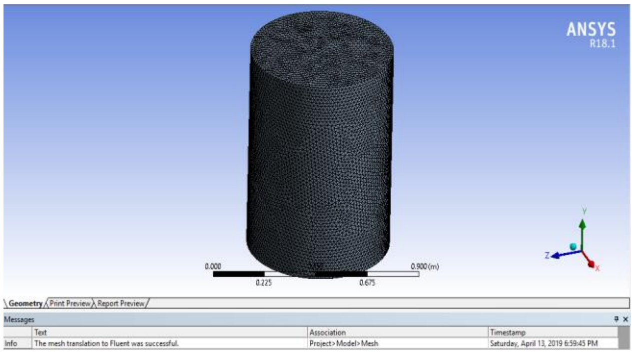


Fig. 2.4 PROPELLER BLADE WITH DIMENSIONS

3 MESHING

MESHING DETAILS:

Sizing	Fine
Relevance centre	Fine Mesh
Relevance	15
No of Elements	1513380
Size function	Proximity and Curvature
Max face size	0.017 m
No of Nodes	274259



	Text	Association	Timestamp
Info	The mesh translation to Fluent was successful.	Project>Model>Mesh	Saturday, April 13, 2019 6:59:45 PM

Fig 3.1 MESHING OF THE DOMAINS WITHOUT WIREFRAME

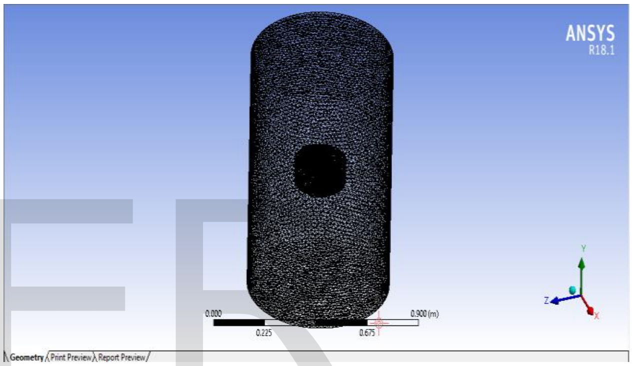


Fig 3.2 MESHING OF THE DOMAINS WITH WIREFRAME

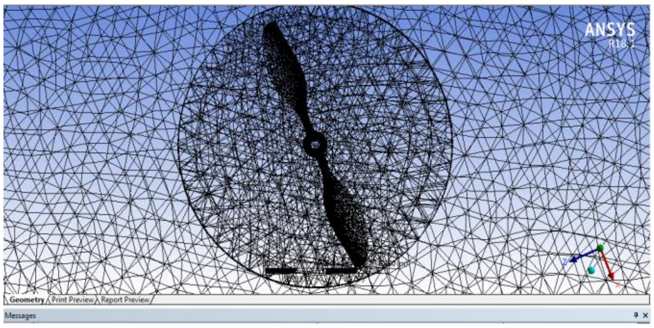


Fig 3.3 CLOSE UP IMAGE OF MESH, OF THE ROTATIONAL DOMAIN

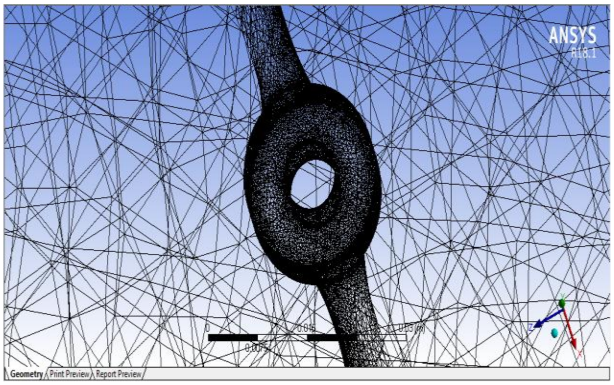


Fig 3.4 MESHING OF PROPELLER HUB

4 ANALYSIS

4.1 COMPUTATIONAL FLUID DYNAMICS (CFD) AND VIBRATIONAL ANALYSIS:

After the design finalization the following procedure was carried out to compute the CFD of the given propeller. Fluid flow (fluent) is selected from the toolbox in workbench and selected. In geometry, the propeller design is imported (igs. format). A cylindrical enclosure (rotational domain) of radius 0.01 m and (-) and (+) directions of 0.03 m is created. Another cylindrical exposure (static domain) of radius 0.2m and (-) and (+) directions of 0.4 m is created. Boolean is done by subtracting the tool body (propeller) from the target body (rotational domain). Geometry is updated and Mesh is opened.

Various inputs are put for mesh and the mesh is generated. Mesh is updated and setup is opened. In setup the various boundary conditions are given properly.

The medium is chosen as air. In cell zone conditions, the rotational axis is chosen as y axis and the various rpm values are put. The inlet is kept as pressure inlet in boundary conditions.

Initialization from the inlet is done and the calculation for 500 iterations for each rpm value was started.

After the calculations are completed, the thrust and torque values on the propeller is noted from the console box.

The various performance characteristics are noted in Excel and graph is plotted between the rpm and thrust values.

The project is saved and a new file is opened on ANSYS.

Modal is selected in the workbench for the vibrational analysis.

The material is changed to polyethylene (plastic) and imported into geometry.

In the Modal analysis, the hub portion is given fixed support and 10 modes are given for 10 natural frequencies of the propeller in Hertz.

The deformation for each and every frequency is calculated and the video is recorded.

The project is saved.

5 PERFORMANCE CHARACTERISTICS OUTLINE

RPM	7000
RADIUS	10.25 cm
DIAMETER	20.5 cm
THRUST	2.562 N
TORQUE	0.0543

Table. 5.

RPM	8000
RADIUS	10.25 cm
DIAMETER	20.5 cm
THRUST	3.359 N
TORQUE	0.071

Table. 5.2 CHARACTERISTICS AT 8000 RPM BLADE SPEED

RPM	9000
RADIUS	10.25 cm
DIAMETER	20.5 cm
THRUST	4.297 N
TORQUE	0.089

Table. 5.3 CHARACTERISTICS AT 9000 RPM BLADE SPEED

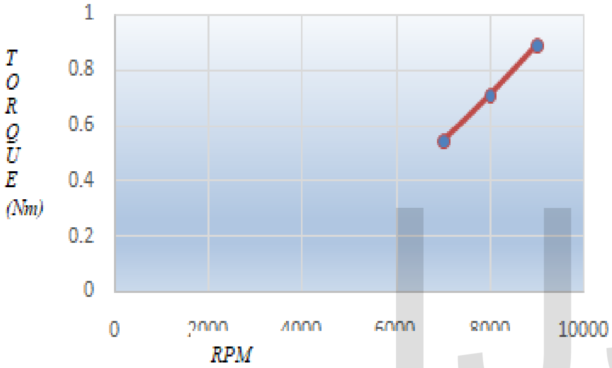


Fig 5.4 GRAPHICAL REPRESENTATION OF TORQUE VS RPM

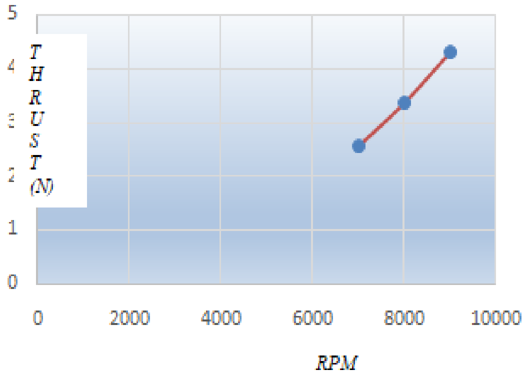


Fig 5.5 GRAPHICAL REPRESENTATION OF THRUST VS RPM

6 CONCLUSION

6.1 PRESSURE AND VELOCITY DISTRIBUTION:

The CFD analysis of the imported propeller model was done successfully on Ansys fluent. Various performance characteristics like thrust, torque is calculated at various rpms and compared. The size of a quadcopter propeller depends on the particular thrust, torque and other characteristics, which further decides various other parameters such as motor size,quadcopter frame size etc. The performance characteristics so found in this project can help for the particular propeller size and decides the motor size and the quadcopter frame size.

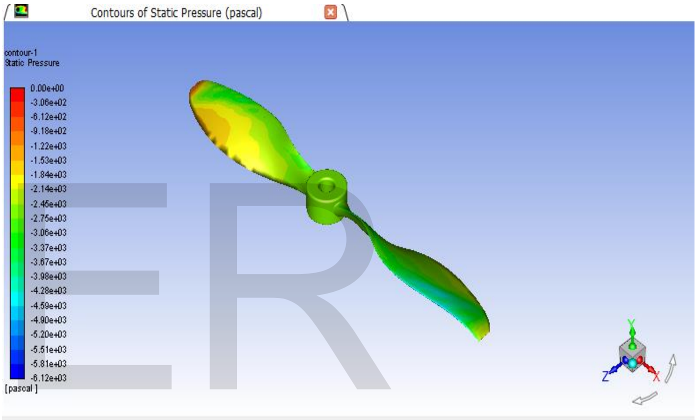


Fig 6.1.1. STATIC PRESSURE VARIATION AT 7000 RPM

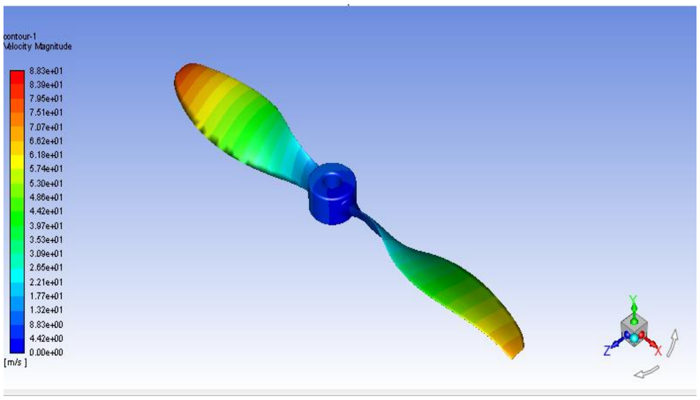


Fig 6.1.2 VELOCITY VARIATION AT 7000 RPM

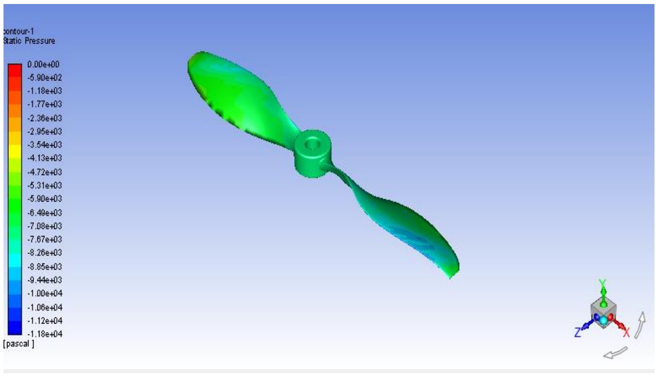


Fig67.1.3 STATIC PRESSURE VARIATION AT 8000 RPM

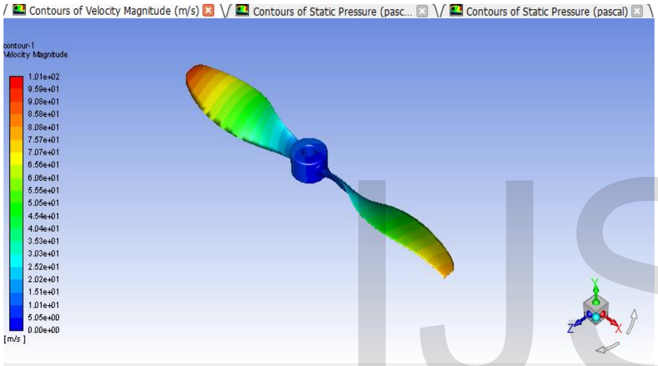


Fig 6.1.4 VELOCITY VARIATION AT 8000 RPM

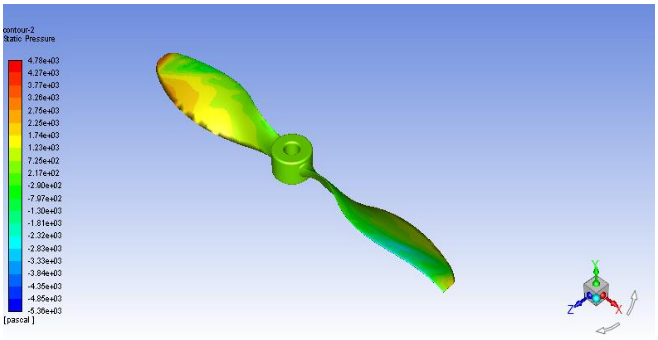


Fig 6.1.5 STATIC PRESSURE VARIATION AT 9000 RPM

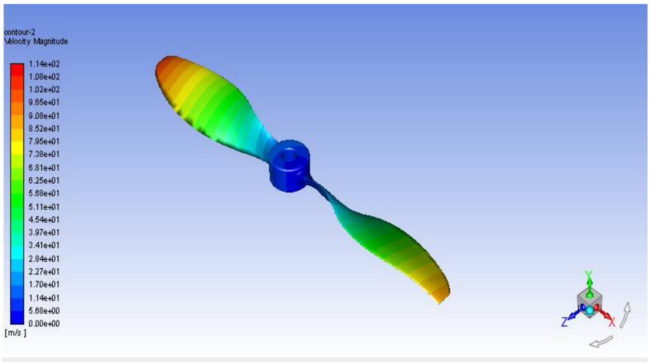


Fig 6.1.6 VELOCITY VARIATION AT 9000 RPM

6.2 MODAL ANALYSIS

The vibrational analysis of the imported propeller model was done successfully on Ansys Modal. The various natural frequencies of the propeller were calculated for twelve modes.They are 27.747 hz, 29.95 hz, 124.95 hz, 128.32 hz, 285..38 hz, 304.21 hz, 403.63 hz, 418.08 hz, 625.67 hz, 661.55 hz, 1012.5 hz and 1016.3 hz respectively. The main reason for finding the natural frequencies of the propeller is to make sure that no vibrational resonance occurs while connecting the propeller to the motor shaft or on the quadcopter. The natural frequencies should not match with the natural frequencies of the motor or the quadcopter frame.

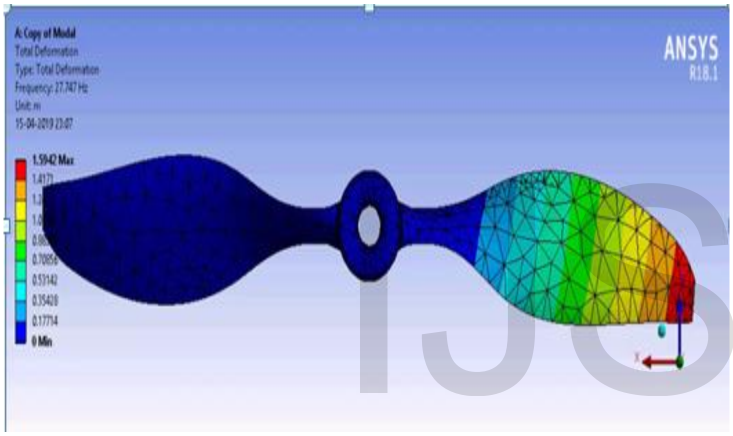


Fig 6.2.1 DEFORMATION FOR 24.747 HZ

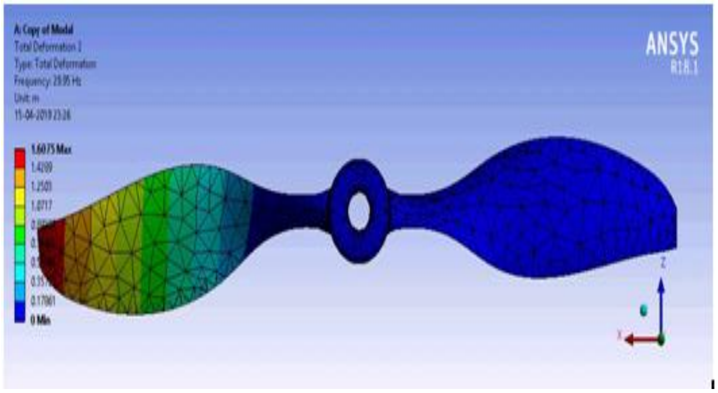


Fig 6.2.2 DEFORMATION FOR 29.95 HZ

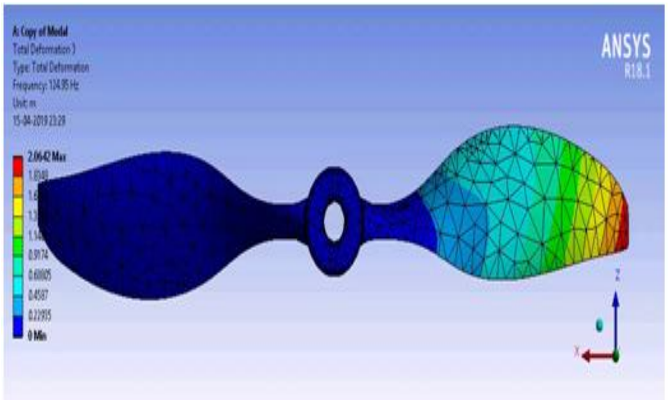


Fig 6.2.3 DEFORMATION FOR 124.95 HZ

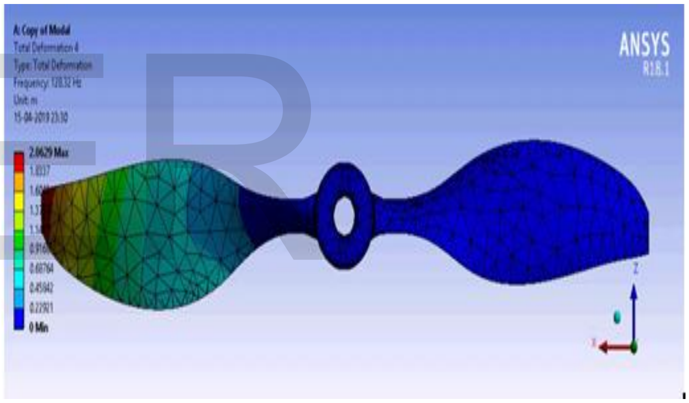


Fig 6.2.4 DEFORMATION FOR 128.32 HZ

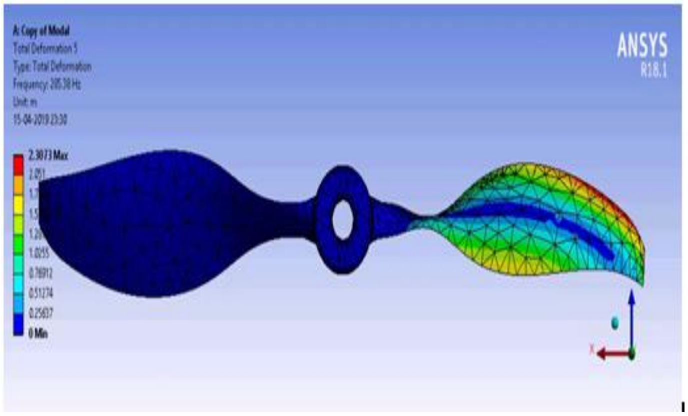


Fig 6.2.5 DEFORMATION FOR 285.38 HZ

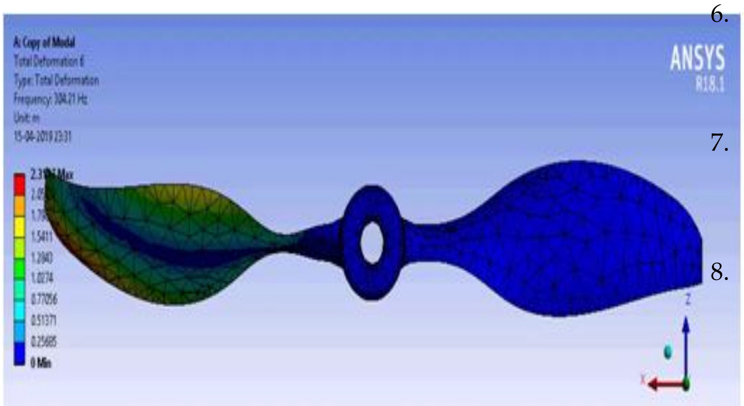


Fig 6.2.6 DEFORMATION FOR 304.21 HZ

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