DESIGN AND ANALYSIS OF AXIAL FLOW COMPRESSOR BLADE USING DIFFERENT MATERIALS

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ABSTRACT

Compared to automobile components, the design process for turbomachinery requires thorough consideration of both aerodynamic and mechanical considerations, which raises the cost of manufacture. Production is preceded by extensive study that includes virtual testing using a variety of software tools to guarantee performance and dependability. The delivery of precise pressure and mass flow rates to the combustion chamber by axial flow compressors, essential parts of gas turbine engines, has a direct impact on engine performance. Therefore, to increase overall performance, careful design and compressor blade optimization are crucial. The main focus of this study is the application of standard mean line design process to the design of compressor blades with axial flow. Using stress and model analysis, we examine the material consequences of these blades in dynamic settings. Software tools like as ANSYS and CATIA are used in the modeling and analysis procedures.

KEYWORDS: Axial flow compressors, Material effects, CATIA, ANSYS

1. INTRODUCTION OF AIRFOIL

When a body moves through a fluid or fluid moves over the surface of the body then there is formation of boundary layer. Existence of boundary layer leads to the various forces acting on the body. These forces are Normal force, axial force, Drag force, Lift force. If body is having aerodynamic shape, then the generated lift force will help to lift, up or down the body in the fluid depending on the angle at which the air is striking the body. The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered equations to precisely generate the cross-section of the airfoil and calculate its properties. It is a fact of common experience that a body in motion through a fluid experiences a resultant force which, in most cases is mainly a resistance to the motion.

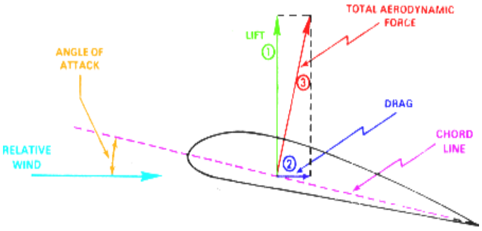


Fig.1 forces acting on airfoil

2. NACA SERIES BLADES 65

The NACA (National Advisory Committee for Aeronautics) airfoil series, including the NACA 65-series airfoils, is a set of aerodynamic profiles developed by the NACA in the early to mid-20th century. These airfoils are widely used in the design of aircraft wings, propeller blades, and rotor blades. The designation "65" in the NACA 65-series refers to the thickness-to-chord ratio of the airfoil.

3. IMPORTANT TERMS-IN THE AERODYNAMIC DESIGN OF AIRFOIL

- Leading Edge - Point at the front of the airfoil which has the maximum curvature and flowing fluid strikes the surface firstly at this point.
- Trailing Edge - The point of maximum curvature at the rear end of airfoil.
- Chord Line - Straight line joining the leading edge and trailing edge is called as chord length
- Chord Length - Simply CHORD is the length of the chord line and is the characteristic dimension of the airfoil section.
- Camber Line - A line on a cross section of a wing of an aircraft which is equidistant from the upper and lower surfaces of the wing.
- Angle of Attack - In fluid dynamics, angle of attack (AOA), or α[1] is the angle between a reference line on a body (often the chord line of

an airfoil) and the vector representing the relative motion between the body and the fluid through which it is moving. Angle of attack is the angle between the body's reference line and the oncoming flow. In aerodynamics, angle of attack specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. Since a wing can have twist, a chord line of the whole wing may not be definable, so an alternate reference line is simply defined. Often, the chord line of the root of the wing is chosen as the reference line. Another choice is to use a horizontal line as the reference line.

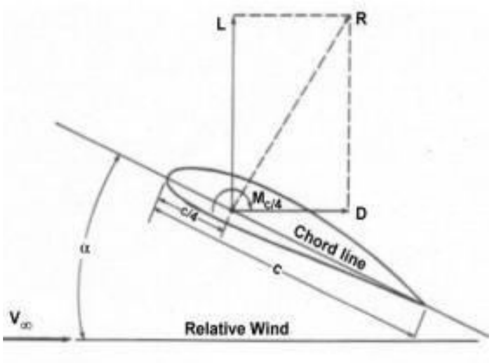


Fig.2 Angle of attack on airfoil

4. LITERATURE SURVEY

F. W. LANCHESTER from the United Kingdom had popularized the conclude plate method to cut induced drag. For that to materialize, Prantdl's (1910) Trefftz-plane theory had been selected to be the optimum choice in determining induced drag. During that time, the thought of this theory being able to determine induced drag was considered as a potential for both domestic and foreign market industries. A wing normally functions to generate plenty of drag (D), lift (L) and nose-down pitching moment (M). Maximizing lift, together with minimizing drag and nose-down pitching movement has been a constant goal for industry players in developing new wing designs. The explanation of wings being regarded as lifting surfaces would be; the production of lift is caused.

LOGSDON, 2006 2D & 3D models of airfoil with far field was created in GAMBIT and analyzed using FLUENT. 3D model consumes much amount of time and requires high memory computer while 2D model gives the identical results. Author tested NACA65 airfoil at different Reynolds Number on 2D and 3D models of airfoil. Accuracy of FLUENT was not up to the mark for values of above 10o angle of attack. Simulation was done with Incised and SpalartAllmaras turbulent models.

KULUNK & YILMAZ, 2009 Blade Element Momentum Theory (BEM) can be used to explore the Horizontal Axis Wind Turbine Blades. Here S-809 Blade was used. (Potter, Barnet, Fisher, & Costas, 1986) Breakaway at a point on the surface is known as separation point & such phenomenon is called separation. In this report author found that detachment location is significantly independent on turbulent intensity & vibration but it is dependent on pressure distribution.

AGRAWAL & SAXENA, JUANMIAN, FENG, & CAN, 2013 There are many turbulent Models available but these three Models were used. (Realizable and RNG k-Reynolds and Reynolds Stress Model (RSM)) Here aerodynamic behavior of the airfoil with different turbulent models has been studied. A symmetrical airfoil was used to study the trailing edge separation on trailing edge. Here the low Reynolds numbers were used. RANS equations were solved with finite volume method on airfoil SD8020. K-ω SST turbulent model were used to simulate the problem. It was noticed at small angles of attack laminar separation happens on both sides of airfoil while at high angles of attack, the separation reattach to the trailing edge.

SQUIRREL CAGE DARRIEUS G. J. M. DARRIEUS has presented two major types of Durries mechanisms. They differ on how they handle the centrifugal force impose on the blade of the turbine, one is called Squirrel cage variant which consists of two disks at top and bottom with the airfoil running straight up and down between their rims. This allows the centrifugal force to be handled by the relatively sturdy construction of the disks. The advantage of turbine is to be able to progressively get into rotation. The disadvantage of it is the low Reynolds number.

H-DARRIEUS S. ROY ET AL in his work have described about H-darrieus turbine. H-Darrieus are breed of vertical axis wind turbine designed by George Darrieus in 1920's. They are capable of producing much power than most typical wind turbine. H-Darrieus rotor is a lift type device having two or three blades designed as airfoils.

DARRIEUS L. J. HAGEN ET AL in his research paper has summarized about Darries turbine. This design of turbine was patented by Georges Jean Marie Darrieus, a French aeronautical engineer in 1931. Darrieus turbine is a vertical axis turbine. It has streamlined blades turning around an axis perpendicular to the flow. The turbine consists of number of curved airfoil blades mounted on a vertical rotating shaft or framework. The curvature of the blade allows the blade to be stressed only in tension at high rotating speeds. It is powered by the phenomenon of lift. There are major difficulties in protecting the Darrieus turbine from extreme speed of fluid and in making it self-starting.

GORLOV A. M. GORLOV has patented information about Gorlov turbine. The Gorlov turbine was invented by Alexander Gorlov in 1995. This turbine is also known as ‘Cross flow helical turbine’. It is similar to Darrieus straight blade style turbine, except airfoil blade profile is swept in a helical profile along its span. One of the advantage of helical blade is that it improves self-starting of Gorlov turbine compared to Darrieus turbine.

K. SORNES in his paper have discussed about various types of blade design used in Hydro-Micro turbines. The two most common small scale hydro-kinetic turbine concepts are axial flow turbine and cross flow turbines. The axial concept has a rotational axis of rotor which is parallel to the incoming water stream. The cross flow concept on the other hand, has a rotational axis of rotor which is parallel to water surface. The advantage of cross flow turbines over axial flow turbine is that they can rotate uni-directional even with bi-directional flow.

5. OBJECTIVE OF THE PROJECT:

The objective of the project is to design and analyze a NACA 65-021 series airfoil using CATIA V5 software. This involves creating a detailed 3D model of the airfoil utilizing CATIA V5's design capabilities. The project also aims to conduct static structural analysis and modal analysis on the airfoil using ANSYS software.

Specifically, the objectives include:

1. Designing a NACA 65-021 series airfoil using CATIA V5, ensuring accuracy and adherence to specified aerodynamic characteristics.
2. Creating a 3D model of the airfoil with precise dimensions and surface finishes.
3. Performing static structural analysis using ANSYS to evaluate the airfoil's structural integrity under various loading conditions.
4. Conducting modal analysis using ANSYS to determine the natural frequencies and mode shapes of the airfoil structure.
5. Utilizing three different materials for the airfoil construction: Ti-6Al-4V, 317 stainless steel, and Carbon Fibber T-800.
6. Comparing the structural performance of the airfoil made from different materials to determine the most suitable material for the intended application.
7. Providing recommendations for material selection and structural optimization based on the analysis results.

Overall, the project aims to enhance understanding of the structural behavior of the NACA 65-021 series airfoil and optimize its design for improved performance and durability in aerospace applications.

6. METHODOLOGY

To achieve the objectives outlined for the project, the following methodology can be followed:

1. Airfoil Design using CATIA V5
2. Static Structural Analysis using ANSYS
3. Modal Analysis using ANSYS
4. Material Comparison and Optimization
5. Documentation and Reporting

7. NACA 65-021 AEROFOIL

The NACA 65-021 airfoil is part of the NACA 65 series, which was developed for aircraft applications. Here are some key characteristics and features of the NACA 65-021 airfoil: The first two digits "65" indicate that the maximum thickness of the airfoil is 65% of the chord length. In the case of the NACA 65-021 airfoil, the maximum thickness is located at 21% of the chord length. The NACA 65 series airfoils typically have moderate camber, meaning there is a curvature along the upper and lower surfaces of the airfoil. The specific camber of the NACA 65-021 airfoil is designed to provide a balance between lift generation and drag reduction. The NACA 65-021 airfoil is known for its good lift-to-drag ratio, making it suitable for a variety of general aviation applications. It offers relatively efficient performance across a range of angles of attack, making it versatile for different flight regimes. Due to its moderate camber and thickness distribution, the NACA 65-021 airfoil typically exhibits benign stall behaviour, meaning it tends to maintain lift relatively well at higher angles of attack before experiencing a stall. This characteristic is desirable for general aviation and sailplane applications.

The NACA 65-021 airfoil can be found in various general aviation aircraft, including light aircraft, training aircraft, and some sailplanes. Its versatile performance makes it suitable for a wide range of flight conditions and missions. Overall, the NACA 65-021 airfoil strikes a balance between lift, drag, and stall characteristics, making it a popular choice for many aircraft designs where efficient performance and predictable handling are essential.

8. MATERIALS USED

The following are the three materials used in this project for the axial flow compressor NACA 65 series blade. The existing 317 stainless steel, titanium alloys (Ti-6Al-4V) and proposed carbon fiber-T800 material.

CARBON FIBER COMPOSITE-T800:

Fiber Type: Selection of high-strength carbon fiber (e.g., T700, T800) is based on their proven performance in aerospace and wind turbine applications, offering excellent strength and stiffness characteristics. Matrix Material: Epoxy resin systems are commonly used as the matrix material in carbon fiber composites due to their high strength, stiffness, and adhesion properties, ensuring effective load transfer between the fibers.

TITANIUM ALLOY (Ti-6Al-4V):

Alloy Type: Titanium alloys such as Ti-6Al-4V (Grade 5) or Ti-6Al-2Sn-4Zr-2Mo are chosen based on their widespread use in aerospace applications, offering a favorable combination of high strength, corrosion resistance, and lightweight properties.

317-STAINLESS STEEL:

Alloy Type: Stainless steel alloys from the AISI 300 series (e.g., 316 or 317 stainless steel) are chosen for their high-strength and corrosion-resistant properties, making them suitable for demanding aerospace and industrial applications.

9. DESIGN PROCEDURE IN CATIA:

Go to the NACA official website and download the co ordinates about NACA 65-021 AEROFOIL profile and open that free shape in sketcher workbench and connect those points as per the dots as per specifications. After create the plane in another plane again go to the wire frame and surface design apply the sweep option as per the dimensions again go the part design work bench create the apply thicken as per the specification as shown below figures

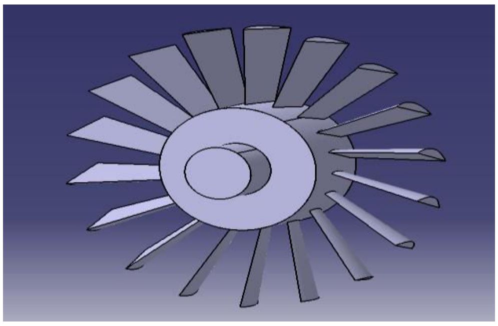


Fig.3 solid 3d model design

10. STATIC ANALYSIS:

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes). Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

11. DYNAMIC MODAL ANLAYSIS

Modal analysis in ANSYS is a crucial tool for engineers and designers to understand the natural vibration characteristics of structures. Here's an overview of how modal analysis works in ANSYS:

1. Model Preparation
2. Setup
3. Solver Execution
4. Results Interpretation
5. Post-Processing
6. Validation and Iteration

Modal analysis in ANSYS is a powerful tool for predicting the dynamic behaviour of structures, which is essential for ensuring structural integrity, avoiding resonance, and optimizing designs for various applications.

12. BOUNDARY CONDITIONS:

The NACA 65-021 series airfoil is subjected to loading test. The boundary and loading conditions are taken from the past references. From the Finite element analysis the normal and shear stress of each ply under the loading, is obtained. The frame is fixed at the hub ends. For the loading test, loads are applied on the NACA 65-021 series airfoil part. Axial Load of 10000 rpm.

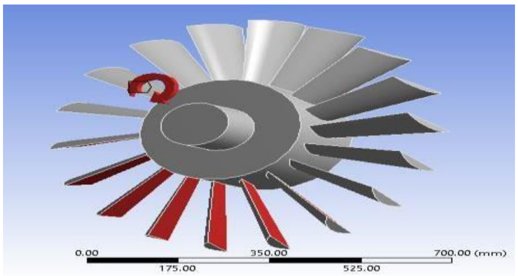


Fig.4 Boundary conditions

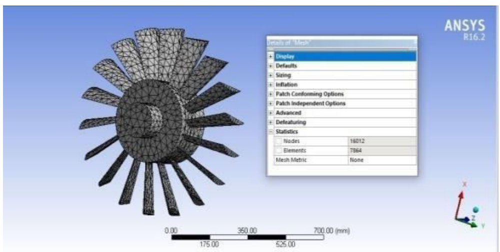


Fig.5 Meshing Nodes: 16012 and Elements: 7864

13. RESULTS AND DISCUSSIONS

In this undertaking, the NACA 65-021 series airfoil is investigated Static and Modal examination strategy with the accompanying materials TI-6Al-4V, 317 stainless steel, and Carbon Fibre T-800 to discover the best material. Working stress applied to the NACA 65-021 series airfoil with 10000 rpm. The arrangement stage manages the arrangement of the issue as per the issue definitions. All the drawn-out work of defining and collecting of lattices are finished by the PC lastly distortions, stress, shear pressure esteems are discover as displayed underneath figures

14. STATIC ANALYSIS

Following are the static structural analysis results of the TI-6AL-4V, 317 stainless steel, and carbon fibre t-800. The von misses stresses, strains and a deformation of axial flow compressor with the NACA 65-021 series airfoil is investigated and their results are mentioned in below.

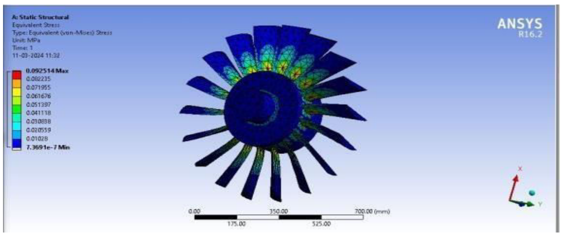


Fig.6 von-misses stress on stainless steel-317

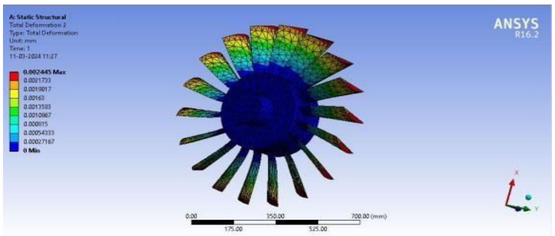


Fig.7 total deformation on stainless steel-317

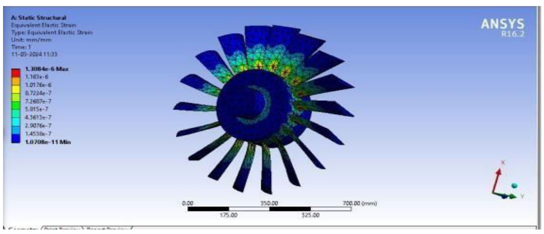


Fig.8 strain on stainless steel-317

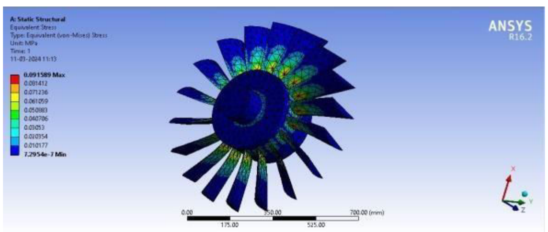


Fig.9 von-misses stresses on TI-6Al-4V

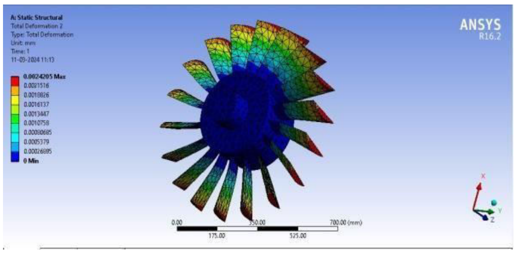


Fig.10 total deformation on TI-6Al-4V

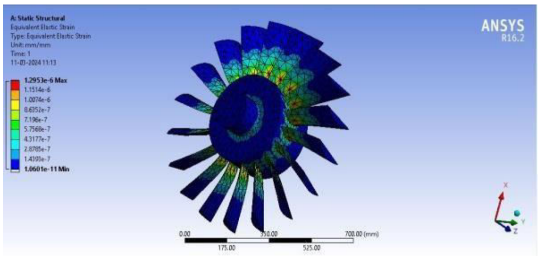


Fig.11 strain on TI-6Al-4V

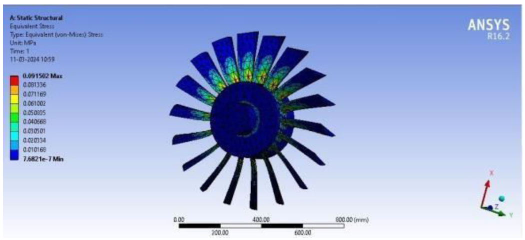


Fig.12 von-misses stress carbon T-800

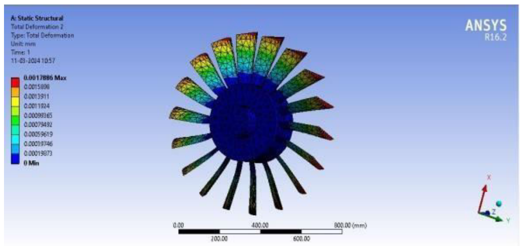


Fig.13 total deformation carbon T-800

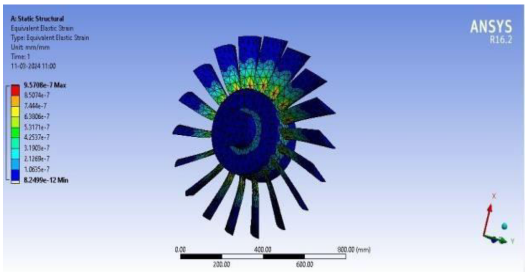


Fig.14 strain carbon T-800

15. MODAL ANLAYSIS OF CARBON T-800:

The modal analysis is conducting on the acting on the proposed favourable material from static structural analysis as carbon fibre t-800 material are investigated at different modes and their final results are given below figures

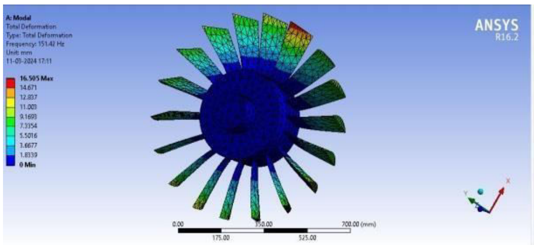


Fig.15 Mode 1

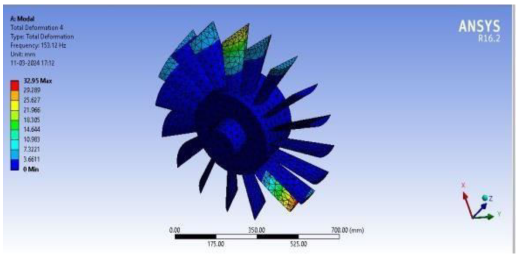


Fig.16 Mode 2

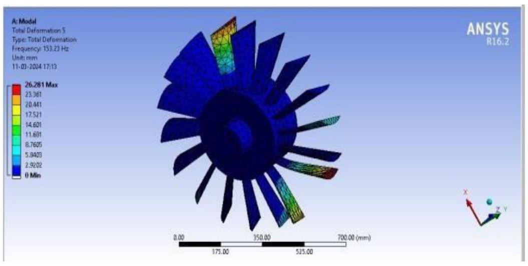


Fig.17 Mode 3

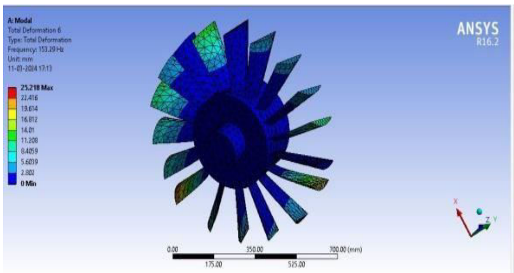


Fig.18 Mode 4

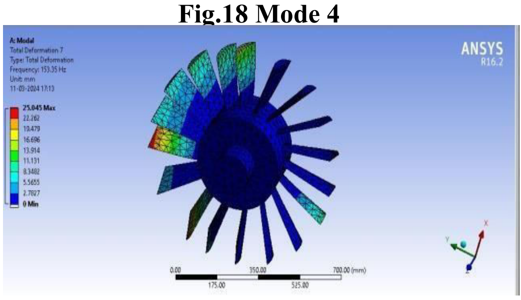


Fig.19 Mode 5

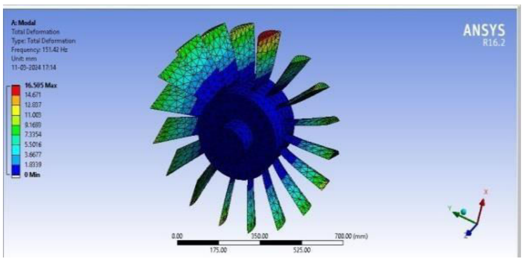
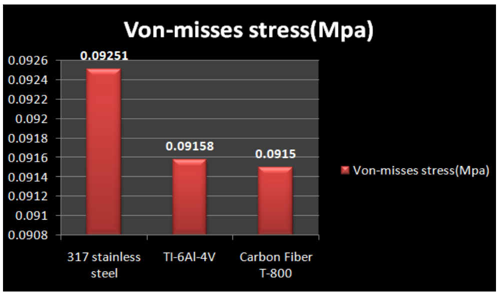


Fig.20 Mode 6

16. VON-MISSES STRESS GRAPH:

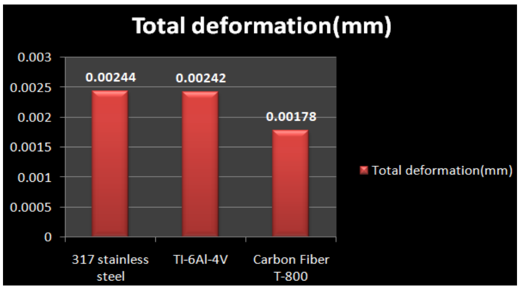
The below graph shows that NACA blade Observed the Von-misses stresses using various materials TI-6Al-4V, 317 stainless steel, and Carbon Fibre T-800. Finally observed the Carbon Fibre T-800 material have less von-misses stress shown below graphs.



Graph.1 Von-misses stress graph between various materials

17. TOTAL DEFORMATION GRAPH:

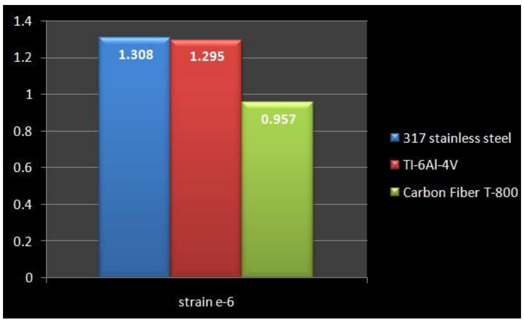
The below graph shows that Helical wind turbine blade Observed the Total deformation using various materials TI-6Al-4V, 317 stainless steel, and Carbon Fibre T-800. Finally observed the Carbon Fibre T-800 material have less Total deformation and highest Total deformation of blade are 317 stainless steel shown below graphs.



Graph.2 Total deformation graph between various materials

18. STRAIN GRAPH:

The below graph shows that blade Observed the strain graph using various materials TI-6Al-4V, 317 stainless steel, and Carbon Fibre T-800. Finally observed the Carbon Fibre T-800 material have less strain shown below graphs.



Graph.3 Strain graph between various materials

19. MODAL ANALYSIS TABLE:

CARBON FIBER T-800	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Total deformation(mm)	16.505	32.95	26.281	25.218	25.045	16.505
Frequency(Hz)	151.42	153.12	153.23	153.29	153.35	151.42

Table.1 Modal analysis results of carbon fiber T-800 material

20. CONCLUSION

Modelling and simulation of NACA 65-021 series airfoil has done using CATIA software. After observing the static analysis values we can conclude that Carbon Fiber T-800, better stress bearing capacity compared with the other material Ti-6Al-4V and 317 stainless steel. Its showing better strength values when loads are applied. A considerable amount of load is produced due to the pressure difference created by the moving blades dynamically. The aim of the project is design the axial flow compressor NACA blade using with three materials Carbon Fiber T-800 materials perform the static and modal analysis finally find out the stress, shear stress, total deformation in static analysis and deformations at different frequencies at modal analysis axial flow compressor NACA blade can be installed on the median of the rotor so that the loads are from both sides of the median will act tangentially in opposite direction on both sides of the blade thereby increasing effective load acting on the blade. On doing static analysis of axial flow compressor NACA blade it is clear that, the maximum Stress, shear stress and deformations are induced .If we compare stress, corresponding deformations of the material Ti-6Al-4V and 317 stainless steel above result finally Carbon Fiber T-800 is concluded as suitable material.

REFERENCES

[1] P. Thiede,(2001) Aerodynamic Drag Reduction Technologies: Proceedings of the CEAS/DragNet European Drag Reduction Conference, 19-21 June 2000, Potsdam, Germany vol. 76: Springer Verlag.

[2] W.Shyy, H. Aono, C. Kang, H. Liu,(2013) "An Introduction to Flapping Wing Aerodynamics", Cambridge University Press, pp. 42.

[3] Sudhir Reddy Konayapalli and Y Sujatha (2015) "Design and Analysis of Aircraft Wing" International Journal and Magazine of Engineering, Technology, Management and Research. Volume No: 2,Issue No: 9.

[4] Nguyen Minh Triet, Nguyen Ngoc Viet, and Pham Manh Thang (2015) "Aerodynamic Analysis of Aircraft Wing" VNU Journal of Science: Mathematics – Physics, Vol. 31, No. 2, 68-75.

[5] Prabhakar A. and Ohri A., (2013)"CFD Analysis on MAV NACA 2412 Wing in High Lift Take-Off Configuration for Enhanced Lift Generation", J Aeronaut Aerospace Eng., 2: 125. doi:10.4172/2168-9792.1000125.

[6] Prakash, G., Darbandi, M., Gafar, N., Jabarullah, N.H., & Jalali, M.R. (2019) A New Design of 2-Bit Universal Shift Register Using Rotated Majority International Journal of Advanced Science and Technology Vol. 28, No. 6, (2019), pp. 100-103 103 ISSN: 2005-4238 IJAST Copyright ⓒ 2019 SERSC Gate Based on Quantum-Dot Cellular Automata Technology, International Journal of Theoretical Physics, https://doi.org/10.1007/s10773-019- 04181-w.

[7] Shi, X., Dini, A., Shao, Z., Jabarullah, N.H. & Liu, Z. (2019) Impacts of photovoltaic/ wind turbine/ microgrid turbine and energy storage system for binding model in power system, Journal of Cleaner Production, 226, 845-857.

[8] Mbella, M. F., & Fonjong, L. (2018). Challenges to Effective Rural-Urban Linkages in Meme Division of Cameroon. Journal of Asian Scientific Research, 8(2), 42.

[9] Mostofi, A., & Erfanian, H. (2018). Multi-Shuttle Automated Storage and Retrieval System. Review of Industrial Engineering Letters, 4(1), 12-20.

[10] Mukadasi, B. (2018). Mixed Cropping Systems for Sustainable Domestic Food Supply of the Smallholder Farming Communities in Nakasongola District, Central Uganda. Canadian Journal of Agriculture and Crops, 3(1), 42-54.

[11] Lakshya Kumar, Dilipkumar B Alone Design and CFD Analysis of a Multi Stage Axial Flow Compressor. 21st Annual CFD Symposium, CFD Division Aeronautical Society of India 08 – 09 August, 2019 Bangalore.

[12] Aniekan E, Owunna Ikechukwu, P. O. Ebunilo2, Ememobong Ikpe Material Selection for High Pressure (HP) Compressor Blade of an Aircraft Engine Ikpe. International Journal of Advanced Materials Research Vol. 2, No. 4, 2016, pp. 59-65 http://www.aiscience.org/journal/ijamr ISSN: 2381-6805 (Print); ISSN: 2381-6813 (Online).

[13] Design and Analysis of Axial Flow Compressor Blade Using Different Aspect Ratios with Different Materials, K. Sravanmathur, R. Murugan, V. S. Hariharan International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE) Vol 3, Issue 2, February 2018

[14] Sang-Yun LeeKwang-Yong Kim, "Design optimization of axial flow compressor blades with three-dimensional Navier-Stokes solver", KSME International Journal, September 2000, Volume 14, Issue 9, pp 1005–1012

[15] Dr. S. A. Channiwala, Nilesh P. Salunke, "Design and Analysis of a Controlled Diffusion Aerofoil Section for an Axial Compressor Stator and Effect of Incidence Angle and Mach No. on Performance of CDA" International Journal of Fluid Mechanical and System, Jan 2010

[16] K. Pandey, K M ; Chakraborty, S ; Deb, "CFD analysis of flow through compressor cascade", International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-2, Issue-1, March 2012

[17] Dr. S. A. Channiwala, Nilesh P. Salunke, "Literature Review On Aerodynamic Design Of Axial Flow Compressor", January 2011, first international conference on sunrise technologies, i-COST 2011

[18] Chan-Sol Ahn and Kwang-Yong Kim, "Aerodynamic Design Optimization of an Axial Flow Compressor Rotor", ASME Turbo Expo 2002: Power for Land, Sea, and Air, Volume 5: Turbo Expo 2002, Parts A and B, ISBN: 0-7918-3610-X, June 3–6, 2002

[19] Horlock, J. H., "Axial Flow Compressors" Butteworth 1958.

[20] Ronald H. Aungier "Axial-Flow Compressors: A Strategy for Aerodynamic Design and Analysis" ASME Press

[21] Nicallas Falck,'Axial Flow Compressor Mean Line Design, Master thesis.Lund University,Sweden,Feb.2008

[22] McKenzie, A.B. Axial Flow Fans and Compressors, Ashgate Publishing Limited,1997

[23] Myat Soe, comWang Yan Rong School of Jet Propulsion Beijing University of Aeronautics and Astronautics Beijing, China Aerodynamic and Structural Dynamics Analysis of Swept Transonic Compressor Rotors