Aeroacoustics Analysis of Propeller Blade

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Abstract - *Aeroacoustics analysis of propeller blades is a crucial aspect in the field of aerospace engineering, aiming to understand and mitigate the noise generated by rotating propellers. This study delves into the complex interactions between the aerodynamic forces acting on propeller blades and the resultant acoustic emissions. The analysis involves a comprehensive examination of the flow patterns, pressure fluctuations, and vortex shedding that contributes to the noise generation. Key factors influencing propeller noise include blade geometry, rotational speed, and tip Mach number. Understanding these parameters allows for the development of noise reduction strategies, including modifications to blade design, materials, and operating conditions. Additionally, advancements in active noise control systems may be explored to further attenuate propeller noise in real-time. The findings of this aeroacoustics analysis not only contribute to the design and development of quieter propeller systems but also have implications for environmental considerations and regulatory compliance. As the aerospace industry continues to evolve, minimizing the impact of aircraft noise becomes increasingly important, making aeroacoustics analysis an integral component of propeller design and optimization.*
Kewords*: Aeroacoustic, Aerodynamic, Noise reduction strategies, Propeller*

I INTRODUCTION

For the majority of modern aircraft, there are two propulsion options, jet propulsion and propeller propulsion. The primary benefit of propeller propulsion over jet propulsion is the ability to convert fuel energy into kinetic energy efficiently, or improved fuel economy. Simultaneously, for propeller aircraft, the propeller slipstream can also greatly boost lift during takeoff and landing, boosting the takeoff and landing performance of the aircraft. The significant aerodynamic noise and vibration that the propeller causes have gained attention during the development of propeller aircraft. Bodie's integrity will be impacted by the transmission of external noise sources near the propeller to the interior of the cabin through structural elements. As a result, it is critical that the propeller's design minimize aerodynamic noise while maintaining the propeller's good aerodynamic efficiency. The majority of conventional techniques for designing propellers are based on the well-known work of Betz. This method is based on improving the propeller's geometry at a certain operating condition in order to reduce the power needed to provide a specific propulsive force under these conditions. Betz's approach simply takes into account the propeller's aerodynamic performance. The noise characteristic of the propeller is not taken into account. Then this propeller is modified in order to reduce its acoustic signature.

Advancements in computational fluid dynamics (CFD), computational aeroacoustics (CAA), and form optimization techniques have revolutionized aerodynamic shape design for propellers. These technologies offer a robust theoretical framework and sophisticated technical tools, enabling precise modeling of airflow and noise generation. CFD allows detailed analysis of fluid behavior, CAA predicts aerodynamic noise, and form optimization techniques refine propeller shapes for optimal performance. Together, they facilitate efficient and innovative propeller designs, enhancing aerodynamic efficiency, reducing noise, and improving overall performance. This rapid development fosters continual improvement in propeller design, contributing significantly to advancements in aerospace engineering.

A. Theoretical Background

Fluid Dynamics: Fluid dynamics forms the foundation of aerodynamics, which is the study of the motion of air and other gases and the forces acting upon objects moving through them. The principles of fluid dynamics, such as Bernoulli's principle, conservation of mass, and conservationof momentum, are crucial for analyzing the aerodynamics of ancient aircrafts. These principles help in understanding how air flows around the aircraft, the generation of lift, and the impact of various design factors on the aircraft's performance.

Design: The design and shape of aircraft play a crucial role in determining aerodynamic performance. Analyzing the design of ancient aircrafts can provide insights into their stability, maneuverability, and efficiency.

Computational Fluid Dynamics (CFD): Computational Fluid Dynamics is a numerical analysis technique widely used in modern aerodynamic research. Applying CFD to the analysis of ancient aircrafts can provide valuable insights into the airflow patterns, pressure distribution, and other aerodynamic characteristics. By simulating the aerodynamic behavior of these aircrafts, researchers can evaluate their flight capabilities, optimize designs, and gain a better understanding of their performance in different flight conditions.

II PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

1. The primary problem lies in the generation of significant noise during the operation of propellers, impacting both passenger comfort and environmental noise pollution.
2. This noise leads to vibration in the System.
3. Vibration cause to loss in stability of the aircraft body and effects on structural Integrity.

B. Objectives

1. Explore various noise reduction techniques, such as modifying blade geometry, adding acoustic treatments.
2. Find a propeller design that emits lower noise, without a high penalty on performance.

III METHODOLOGY

The commencement of any new project underscores the critical significance of adopting an effective methodology, as it significantly contributes to the successful completion of the endeavor. Methodical planning and execution play pivotal roles in ensuring project management within specified timelines. In the context of designing and developing propeller blades for a turboprop engine, the ensuing work plan outlines the fundamental steps that will be adhered to throughout the entire process. The method of performing aeroacoustics analysis on propeller blades in a turboprop engine using ANSYS includes preparing the geometry, meshing, establishing boundary conditions, solving the acoustic and fluid flow equations, and post-processing the output. A thorough approach for this analysis is provided below:

A. Geometry Preparation

Taking reference of the dimensions of ATR 42 aircraft's propeller blade designed the propeller 3D model. To design model 2d sketches are important, after studying many reports on propeller blades draw the sketches. The propeller blade has the total diameter of 4.2 meters, and it's a variable pitch propeller and the sketch of the propeller is represented in Figure 1. During the takeoff the pitch angle propeller is consider as 25 degree and the propeller at 25 degrees is shown in Figure 3. Its idle pitch is consider as 15 degrees and it's 3D image is shown in Figure 2 [1-3].

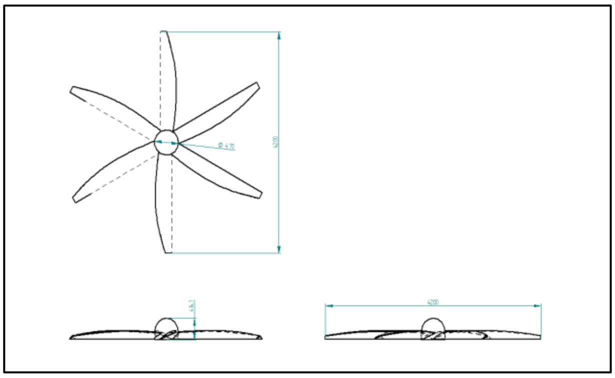

Figure 1 Sketch of the Propeller (in mm)

3D modeling involves constructing a virtual model with geometric shapes, textures and other visual attributes that mimic the appearance and behavior of physical world objects. From reference of the 2d sketch the 3D model is designed using **solid edge** CAD software with different pitch angle as model shown below:

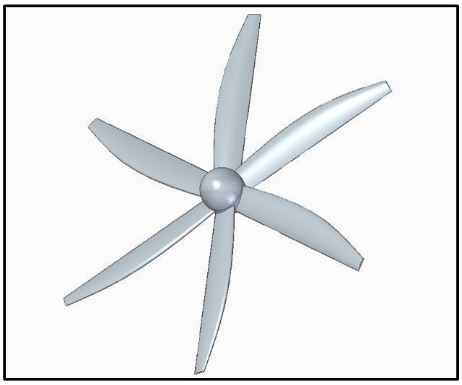

Figure 2 Propeller with Pitch 15 Degree

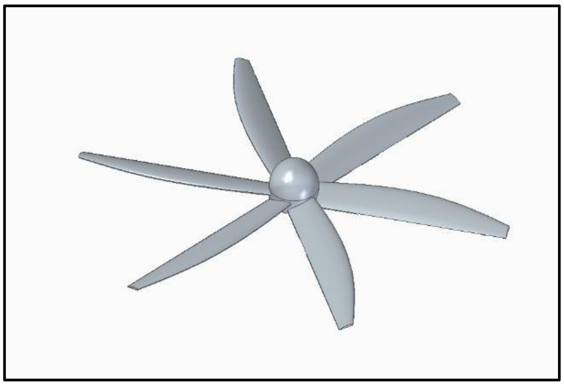

Figure 3 Propeller with Pitch 25 Degree

B. Meshing

Meshing is a crucial step in the field of computational modeling and simulation, particularly in Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD). It involves dividing a complex geometry or domain into discrete elements or cells to create a mesh. This mesh serves as a computational representation of the physical object or domain and enables the numerical analysis of its behavior. The process of meshing involves geometry preparation, element selection, mesh generation, quality checking, etc.

Here the 3D model which was prepared earlier in the solid edge software is imported to ANSYS workbench software for meshing. As a first step a cuboidal and cylindrical envelope is created around the model to create domain which facilitate desired environmentand it is represented in Figure 4. Then the elements size of elements is mentioned. Later the mesh is generated for further analysis and it is shown in Figure 5.

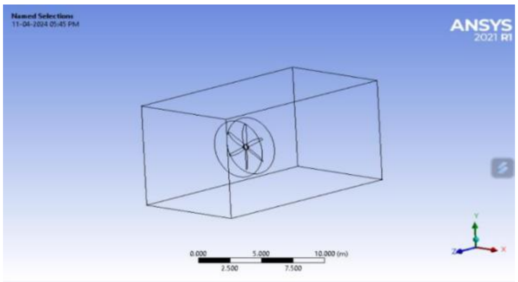

Figure 4 Encloser around Propeller Model

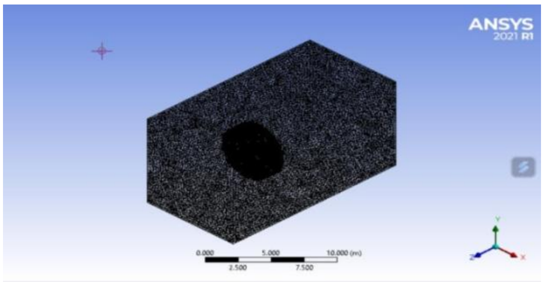

Figure 5 Meshing

C. Boundary Conditions

Boundary conditions and setup are critical aspects of numerical simulations and computational modeling. They define the constraints, environmental factors, and interactions that are applied to the model or system being analyzed.

Setting up appropriate boundary conditions is essential for obtaining accurate and meaningful results. The specifics of boundary conditions and setup can vary depending on the type of analysis being performed. It is crucial to ensure that the chosen boundary conditions and setup accurately represent the real-world scenario being simulated. Careful consideration should be given to boundary condition selection, appropriate material properties, and the impact of simplifications or assumptions made during the setup process.

In general setup turn on the energy equation. The energy equation is a fundamental equation in fluid mechanics and thermodynamics that describes the Conservation of Energy in a fluid flow. Then setup k-epsilon model which is a turbulence model commonly used for turbulent flows. And also turning on Acoustic Broadband Noise source model for acoustic analysis. Then the inlet velocity is given to both different angle of pitch differently.

D. Solution and Data Analysis

Once the numerical simulation or computational model is setup with appropriate boundary conditions the analysis process involves solving the governing equations and analyzing the obtained results. The specific steps involved in the solutions and data analysis phase can vary depending on the typeofanalysisbeingperformed.Theobtainedresults are compared with experimental data, analytical solutions to the accuracy and reliability of the numerical solutions.

Here the thrust force of both propeller with different pitch angles is monitored and also the acoustic values in Decibel Levels (dB).

IV RESULTS AND DISCUSSIONS

For Aerodynamic analysis and Acoustic analysis of both propeller blade with different pitch angle need some parameters those are the air velocity, pitch angle and the rpm of the propeller blade. For pitch angle 15 degrees the air inlet velocity is taken as 15 m/s and the rpm of the propeller is1000 rpm. For pitch angle 25 degrees the air inlet velocity is taken as 6 m/s and the rpm of the propeller is 1200 rpm.

A. Results of Propeller with Pitch Angle15 Degrees

To get the thrust analyzed the pressure and velocity over the propeller blade and studied the pressure and velocity contours as shown below figures:

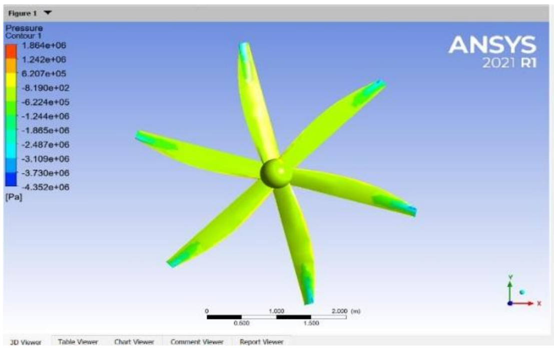

Figure 6 Pressure contours over propeller front

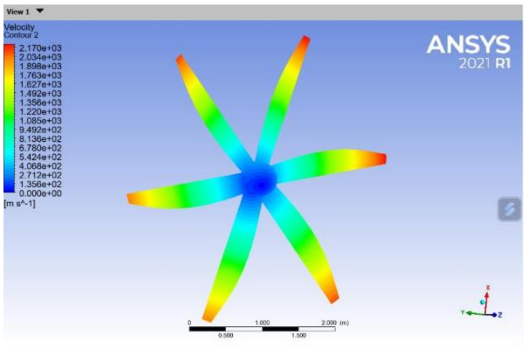

Figure 7 Velocity Contour over Propeller

As expected, after analyzing the pressure and velocity obtained desired results. From Figure 6 can the pressure distribution in front of propeller is less than back of the propeller. Also, from Figure 7 velocity distribution is maximum at the tip of the propeller.

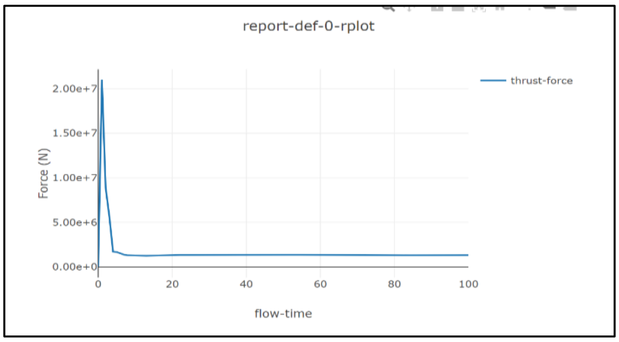

Figure 8 Thrust Force Plot against Flow Time

From above Figure 8 can get the thrust force with respect to flow time by analyzing the thrust force can get the thrust force of the 1324877 N.

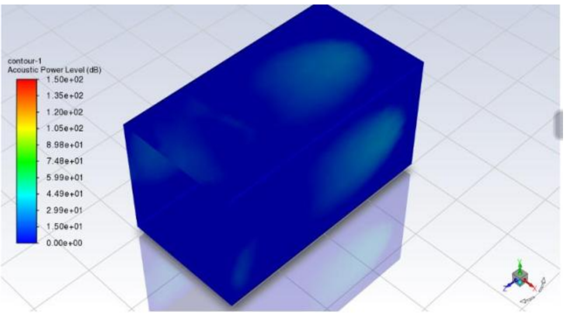

Figure 9 Acoustic Counter Around the Propeller

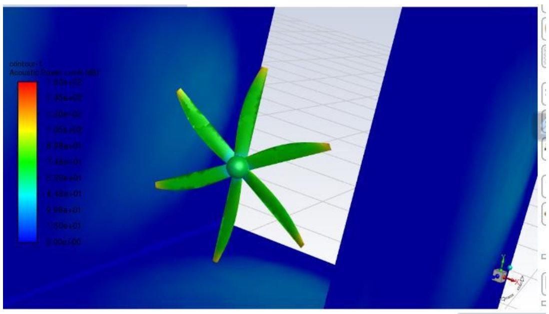

Figure 10 Acoustic Contour over the Propeller

From Figure 9 acoustics around the propeller is ranges from 50dB to 70dB and from the Figure 10 acoustics over the propeller blade is ranging from 70dB to 90dB.

B. Results of Propeller with Pitch Angle 25 Degrees

The pressure and velocity over the propeller blade with pitch 25degrees is analyzed and studied the pressure and velocity contours as shown below Figures 11 to 13:

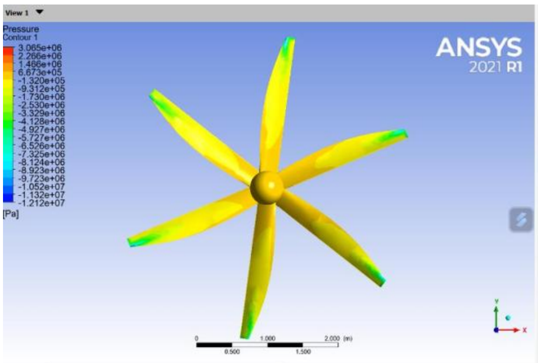

Figure 11 Pressure Contours over Propeller Front

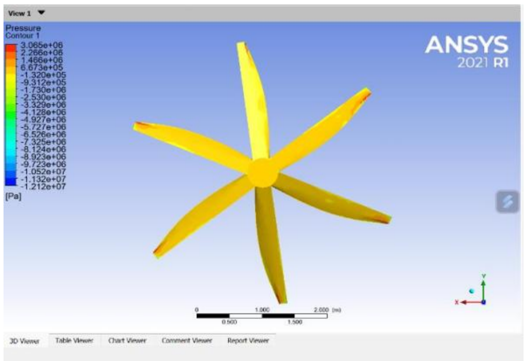

Figure 12 Pressure Contours Over Propeller Back

To calculate Thrust force the analysis of the pressure and velocity is important from the contours of pressure and velocity we can determine the aerodynamic property of propeller blade [4].

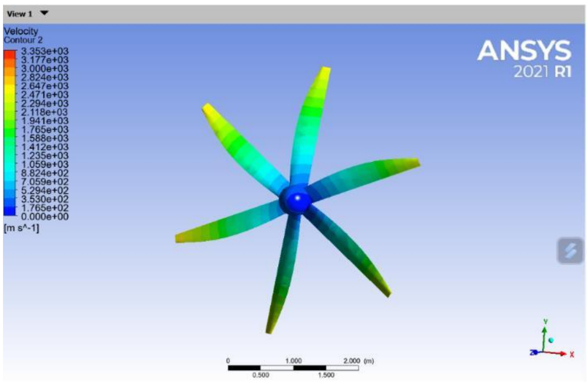

Figure 13 Velocity Contour over Propeller

After analyzing the pressure and velocity obtained desired results. From Figure 11 can the pressure distribution in front of propeller is less than back of the propeller. Also, from Figure 13 velocity distribution is maximum at the tip of the propeller.

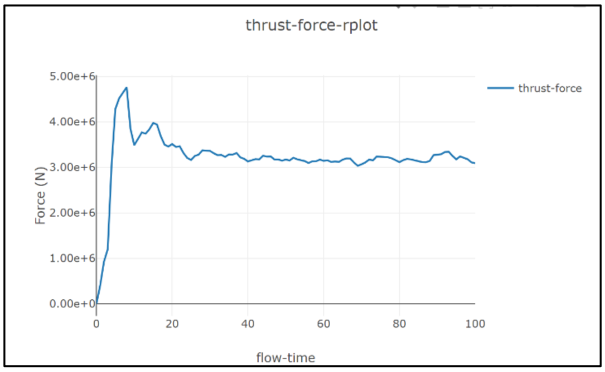

Figure 14 Thrust force plot against flow time

From the above Figure 14 can get the thrust force with respect to flow time by analyzing the thrust force can get the thrust force of the 3089993 N.

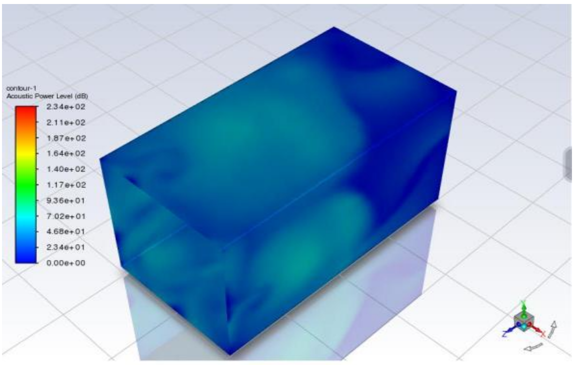

Figure 15 Acoustic Counter around the Propeller

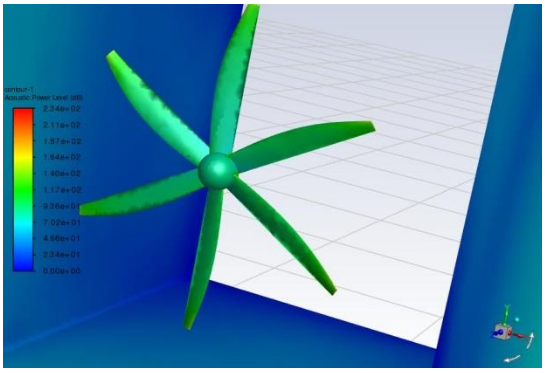

Figure 16 Acoustic Contour over the Propeller

From Figure 15 acoustics around the propeller is ranges from 80dB to 110dB and from Figure 16 acoustics over the propeller blade is ranging from 100dB to 130dB [5].

V CONCLUSION

The analysis of aerodynamics coupled with aeroacoustics has been performed. And the result is obtained. The thrust of the propeller which has the pitch angle 15degree is 1300kW but the actual thrust of the ATR 42 aircraft's propeller is1100kW. Obtained thrust is more than actual propeller.

And the noise produced by the designed propeller is 50dB to 70dB, Actual acoustic valve of blade is 70dB to 90dB. It is greater than obtained values. The thrust of the propeller which has the pitch angle 25degree is 1800kW but the actual thrust of the ATR 42 aircraft's propeller is 1300 to 1500kW. Obtained thrust is more than actual propeller. And the noise produced by the designed propeller is 100dB to110dB, Actual acoustic valve of blade is

100dB to 120dB. Obtained values are pretty much same as the actual values. These may affect on the efficiency of Engine.

VI REFERENCES

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