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DESIGN AND CFD ANALYSIS FOR AN AIRCRAFT TURBINE BLADE FOR SEVERE LOAD CONDITIONS

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Abstract: *This work presents the design and CFD analysis of an aircraft turbine blade. Aircraft turbine blade is inherently a multi-disciplinary design process which involves a large number of disciplines and expertise. In this project, it is investigated how high-end CAD software's can be used in the early stages of an aircraft design process, especially for the design of an aircraft turbine blade and its structural entities. In order to perform Computational Fluid Dynamics on the turbine blade geometry, the process of finite element mesh generation is automated. The finite element mesh is updated based on any changes in geometry and the shape of the turbine blade and ensure that all the mesh elements are always properly connected at the nodes. The automated FE mesh generated can be used for performing the CFD analysis on an aircraft turbine blade. In order to maximize the overall performance and efficiency of all modern turbines, it should operate at high temperatures and speeds. Due to high operating temperatures and speeds, failure of the turbine blades is inevitable. Hence there is a pressing need for analysis of turbine blades. The design of the Turbine Blade is done in Catia, and CFD analysis is carried out using Ansys. This investigation has to be done for the varied resolution analysis like; pressure, velocity, temperature, etc.*

I- INTRODUCTION

1.1 General Description

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator. A turbine is a turbo machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and waterwheels.

Gas, steam, and water turbines have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to Anglo-Irish engineer Sir Charles Parsons (1854–1931) for invention of the reaction turbine, and to Swedish engineer Gustaf de Laval (1845–1913) for invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery. Hero of Alexandria demonstrated the turbine principle in an aeolipile in the first century AD and Vitruvius mentioned them around 70 BC.

Uses

- A large proportion of the world's electrical power is generated by turbo generators.
- Turbines are used in gas turbine engines on land, sea and air.
- Turbochargers are used on piston engines.
- Gas turbines have very high power densities (i.e. the ratio of power to mass, or power to volume) because they run at very high speeds.

The Space Shuttle main engines used turbo pumps into the engine's combustion chamber. The liquid hydrogen turbo pump is slightly larger than an automobile engine.

- Turbo expanders are used for refrigeration in industrial processes.

II-LITERATURE SURVEY

A turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling that can be categorized as internal and external cooling, and thermal barrier coatings. Blade fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect blades from these high dynamic stresses, friction dampers are used.

Blades of wind turbines and water turbines are designed to operate in different conditions, which typically involve lower rotational speeds and temperatures.

In a gas turbine engine, a single turbine section is made up of a disk or hub that holds many turbine blades. That turbine section is connected to a compressor section via a shaft (or "spool"), and that compressor section can either be axial or centrifugal. Air is compressed, raising the pressure and temperature, through the compressor stages of the engine. The temperature is then greatly increased by combustion of fuel inside the combustor, which sits between the compressor stages and the turbine stages. The high-temperature and high-pressure exhaust gases then pass through the turbine stages. The turbine stages extract energy from this flow, lowering the pressure and temperature of the air and transfer the kinetic energy to the compressor stages along the spool. This process is very similar to how an axial compressor works, only in reverse.

The number of turbine stages varies in different types of engines, with high-bypass-ratio engines tending to have the most turbine stages. The number of turbine stages can have a great effect on how the turbine blades are designed for each stage. Many gas turbine engines are twin-spool designs, meaning that there is a high-pressure spool and a low-pressure spool. Other gas turbines use three spools, adding an intermediate-pressure spool between the high- and low-pressure spool. The high-pressure turbine is exposed to the hottest, highest-pressure air, and the low-pressure turbine is subjected to cooler, lower-pressure air. The difference in conditions leads to the design of high-pressure and low-pressure turbine blades that are significantly different in material and cooling choices even though
the aerodynamic and thermodynamic principles are the same.[7] Under these severe operating conditions inside the gas and steam turbines, the blades face high temperature, high stresses, and potentially high vibrations. Steam turbine blades are critical components in power plants which convert the linear motion of high-temperature and high-pressure steam flowing down a pressure gradient into a rotary motion of the turbine shaft

A turbine blade with thermal barrier coating

Another major improvement to turbine blade material technology was the development of thermal barrier coatings (TBC). Where DS and SC developments improved creep and fatigue resistance, TBCs improved corrosion and oxidation resistance, both of which became greater concerns as temperatures increased. The first TBCs, applied in the 1970s, were aluminide coatings. Improved ceramic coatings became available in the 1980s. These coatings increased turbine blade temperature capability by about 200 °F (90 °C). The coatings also improve blade life, almost doubling the life of turbine blades in some cases.

Most turbine blades are manufactured by investment casting (or lost-wax processing). This process involves making a precise negative die of the blade shape that is filled with wax to form the blade shape. If the blade is hollow (i.e., it has internal cooling passages), a ceramic core in the shape of the passage is inserted into the middle. The wax blade is coated with a heat-resistant material to make a shell, and then that shell is filled with the blade alloy. This step can be more complicated for DS or SC materials, but the process is similar. If there is a ceramic core in the middle of the blade, it is dissolved in a solution that leaves the blade hollow. The blades are coated with a TBC, and then any cooling holes are machined.

III - OBJECTIVES AND METHODOLOGY

The objective of this project work is to successfully develop a design and CFD analyze of a Aircraft Turbine Blade. The mechanism is to be reliable, simple, cost-effective and practically feasible. The aim of this Aircraft Turbine Blade is to provide constrained thermodynamic optimization, so as to enable the required measurement in the Aircraft Turbine Blade. This system is also supposed to enhance the comfort temperature and the favorable conditions.

The methodology adopted to use standard and presently used components in design rather than to design all components from ground up. The advantage of this method is that, you do not have to spend ridiculous amount level in testing the integrity of each part as they have already proved their worth in real world applications.

Initially the design was adopted from an already existing Aircraft Turbine Blade and minor changes were made to suite our purpose, first devised was based on using the fluid between the wall, This mechanism was later taken in testing phase due to following conditions.

1. Heat transfer of an Aircraft Turbine Blade has been obtained for proper material.
2. Pressure on the Aircraft Turbine Blade has been obtained.
3. Carry out design and optimization of counter flow Aircraft Turbine Blade.

Due to these conditions, the design was changed and a fully new design was defined. The model also uses the same mechanism setup. The software to be used in design is Catia V5 and testing of design is Ansys.

3.1 Summary of capabilities

Like any software it is continually being developed to include new functionality. The details below aim to outline the scope of capabilities to give an overview rather than giving specific details on the individual functionality of the product. Catia Elements is a software application within the CAID/CAD/CAM/CAE category, along with other similar products currently on the market. Catia Elements is a parametric, feature-based modeling architecture incorporated into a single database philosophy with advanced rule-based design capabilities. The capabilities of the product can be split into the three main heading of Engineering Design, Analysis and Manufacturing. This data is then documented in a standard 2D production drawing or the 3D drawing standard ASME Y14.41-2003.

3.2 Engineering Design

Catia Elements offers a range of tools to enable the generation of a complete digital representation of the product being designed. In addition to the general geometry tools there is also the ability to generate geometry of other integrated design disciplines such as industrial and standard pipe work and complete wiring definitions. Tools are also available to support collaborative development. A number of concept design tools that provide up-front Industrial Design concepts can then be used in the downstream process of engineering the product. These range from conceptual Industrial design sketches, reverse engineering with point cloud data and comprehensive freeform surface tools.

3.3 CFD Analysis

Ansys Elements has numerous analysis tools available and covers thermal, static, dynamic and fatigue FEA analysis along with other tools all designed to help with the development of the product. These tools include human factors, manufacturing tolerance, mould flow and design optimization. The design optimization can be used at a geometry level to obtain the optimum design dimensions and in conjunction with the FEA analysis.

IV - GEOMETRICAL METHODOLOGY OF THE PROJECT

The aircraft gas turbine engine is based on deterministic calculations of low-cycle fatigue and previous field experience with similar engines. It is probable that no two engine companies determine the life of their engines in the same way or apply the same experience and safety factors to their designs. Davis and Stearns and Halila et al. discuss the mechanical and analytical methods and procedures for turbine engine and high-pressure turbine design. The designs of the engine components are based on life predictions by using material test curves that relate life in cycles or time (hrs.) as a function of stress. Six criteria for failure were presented:

(1) Stress rupture
(2) Creep
(3) Yield
(4) Low-cycle fatigue (LCF)
(5) High-cycle fatigue (HCF)
(6) Fracture

Mechanics. Not mentioned as probable failure modes and/or cause for removal of rotating engine components in Refs. And are oxidation, corrosion, and erosion (wear).

Turbine blade metal temperatures frequently reach 1040 to 1090 °C (1900 to 2000 °F), only a few hundred degrees below the melting point of the alloys used. Only because of oxidation-protective coatings and internal forced cooling is it possible for metals to be used under such harsh conditions. All commercial aircraft gas turbine engines use some form of nickel- or cobalt-base super alloy that has been intentionally strengthened and alloyed to resist high stresses in a high-temperature oxidizing environment.

V - DESIGN METHODLOGY OF AIRCRAFT TURBINE BLADE

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite. CATIA competes in the high-end CAD/CAM/CAE market with Cero Elements/Pro and NX (Unigraphics).

The 3D CAD system CATIA V5 was introduced in 1999 by Dassault Systems. Replacing CATIA V4, it represented a completely new design tool showing fundamental differences to its predecessor. The user interface, now featuring MS Windows layout, allows for the easy integration of common software packages such as MS Office, several graphic programs or SAPR3 products (depending on the IT environment).

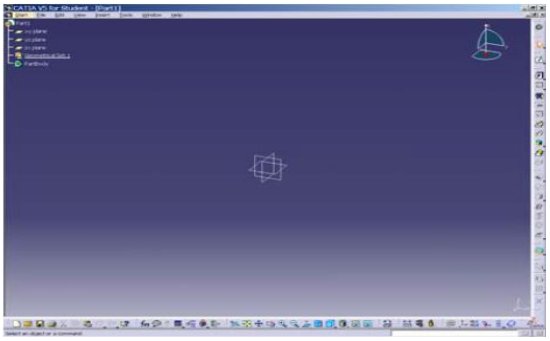


Fig: 5.1: Home Page of CatiaV5

Modeling of Aircraft Turbine Blade in CATIA V5

This **Aircraft Turbine Blade** is designed using CATIA V5 software. This software used in automobile, aerospace, consumer goods, heavy engineering etc. it is very powerful software for designing complicated 3d models, applications of CATIA Version 5 like part design, assembly design. The same CATIA V5 R20 3d model and 2d drawing model is shown below for reference. Dimensions are taken from. The design of 3d model is done in CATIA V5 software, and then to do test we are using below mentioned software's.

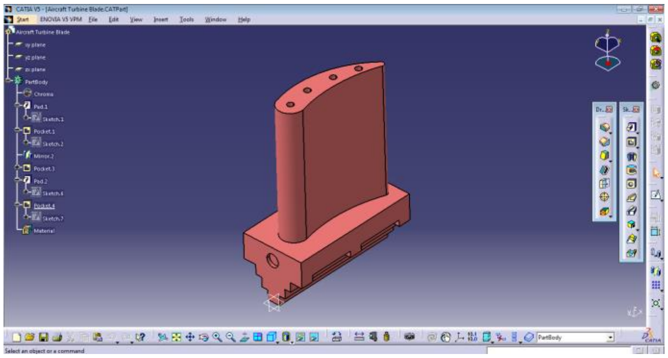


Fig: 5.2: Model design in CATIA-V5

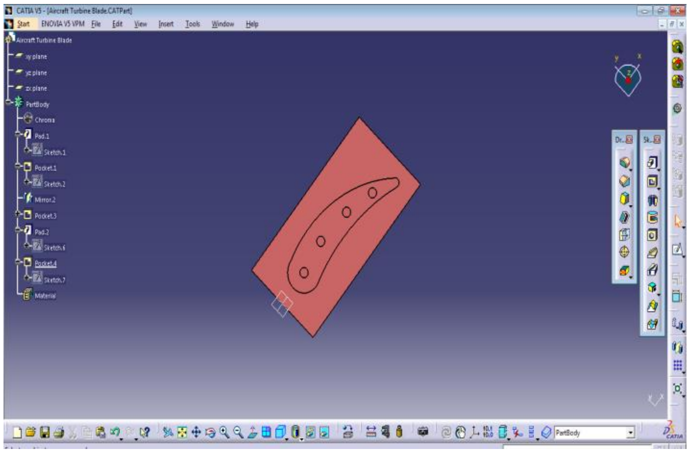
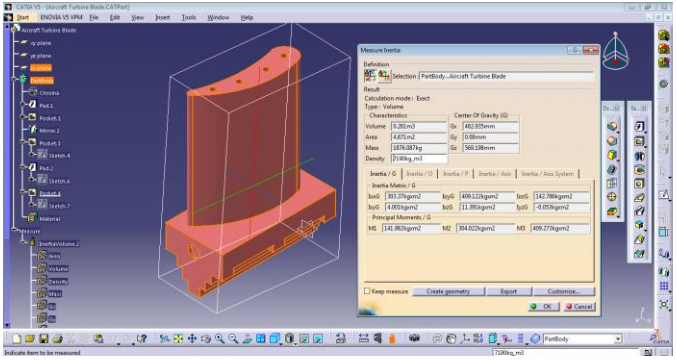


Fig: Model arrangement of working area / mechanism in CATIA-V5

Measure Inertia: Here we get all the values of the material by which the properties were applied; like Mass, Area, Moment of Inertia, Young's Modulus, etc.



Measure Inertia

Definition

Selection: PartBody...Aircraft Turbine Blade

Result

Calculation mode : Exact

Type : Volume

Characteristics

Volume 0.261m3

Area 4.671m2

Mass 1876.087kg

Density 7190kg_m3

Center Of Gravity (G)

Gx 482.935mm

Gy 0.08mm

Gz 569.198mm

Inertia Matrix / G

IoxG 303.37kgxm2 IoyG 409.122kgxm2 IozG 142.786kgxm2

IxyG 4.001kgxm2 IxzG 11.391kgxm2 IyzG -0.053kgxm2

Principal Moments / G

M1 141.982kgxm2 M2 304.022kgxm2 M3 409.273kgxm2

Fig:: Using Measure Inertia

VI - CFD ANALYSIS OF AIRCRAFT TURBINE BLADE

Procedure for CFD Analysis Using ANSYS: The CFD analysis of the Aircraft Turbine Blade is done using ANSYS. For compete assembly is not required, is to carried out by applying moments at the circulation of the fluid location along which axis we need to mention. Fixing location is bottom legs.

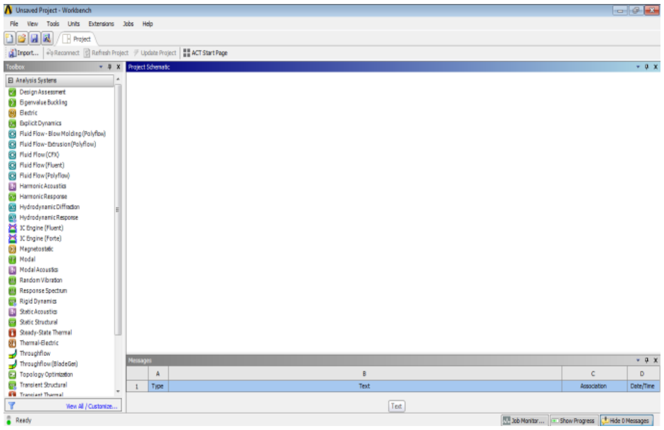


Fig.6.1: Import panel in Ansys Fluent.

6.3 CFD Analysis Procedure

Tetrahedral element that has a quadratic displacement behavior and is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

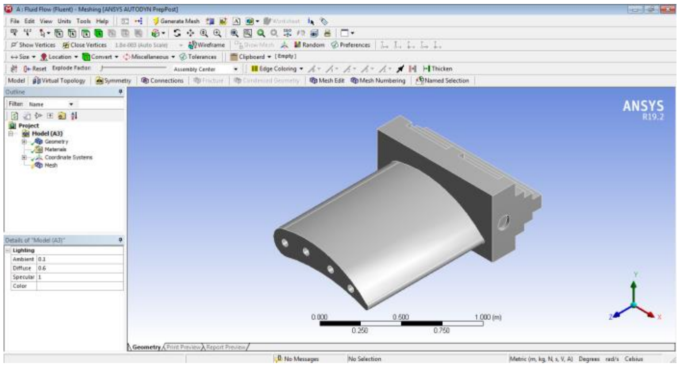


Fig 6.6: Meshing of Model in the Workbench

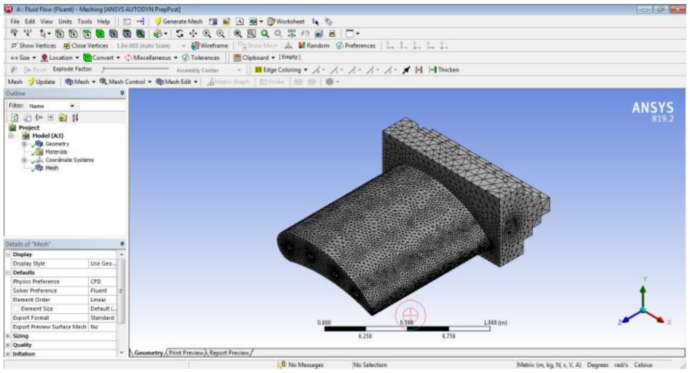


Fig 6.7: Meshing of Model is done

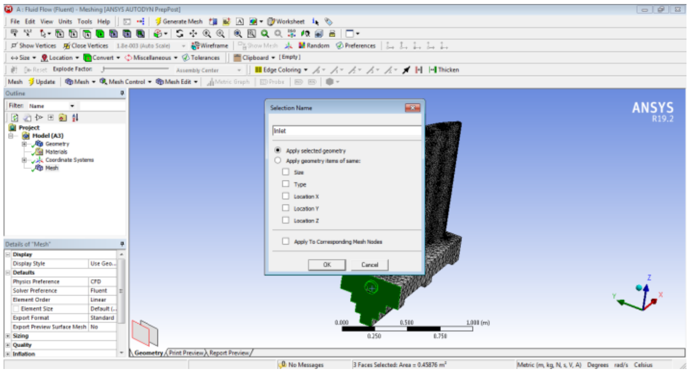
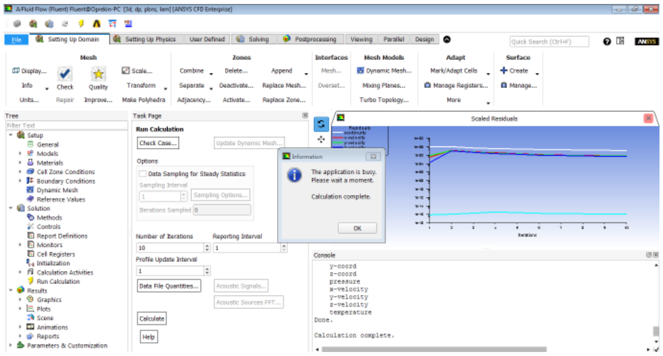


Fig 6.8: Selection of Face – Inlet



The application is busy.
Please wait a moment.

Calculation complete.

```
    y-coord
    z-coord
    pressure
    x-velocity
    y-velocity
    z-velocity
    temperature
Done.

Calculation complete.
```

Fig 6.16: Calculation is done

VII - DISCUSSION ON CFD ANALYSYS RESULT

7.1 Vector Results:

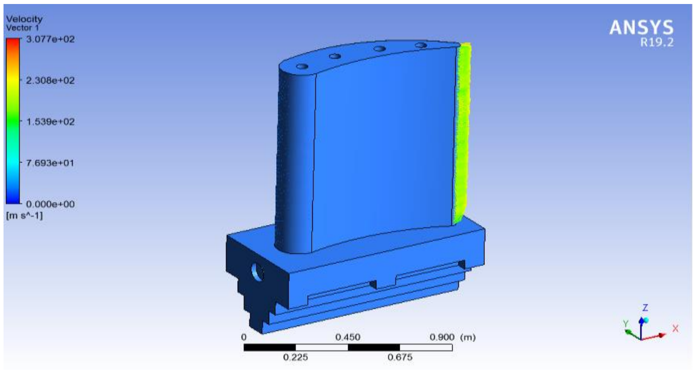


Fig 7.1: Vector – Velocity Result

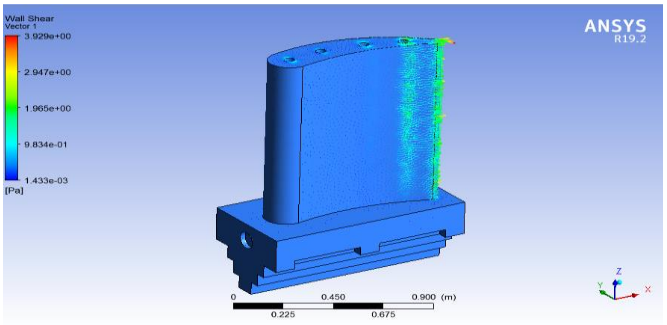


Fig 7.2: Vector – Shear Wall Result

7.2 Contour Results:

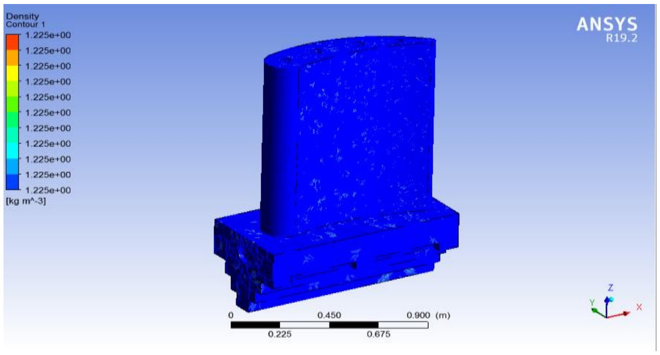


Fig 7.3: Contour – Density Result

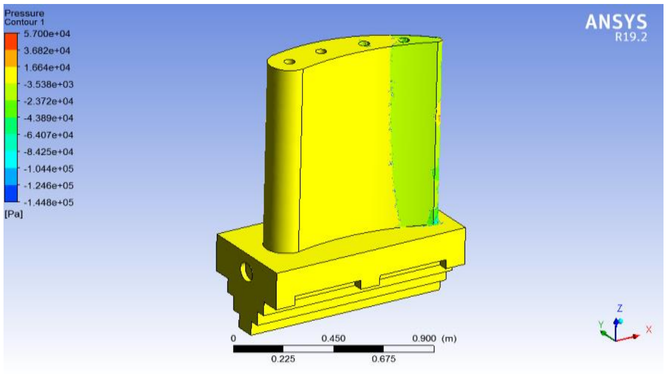


Fig 7.4: Contour – Pressure Result

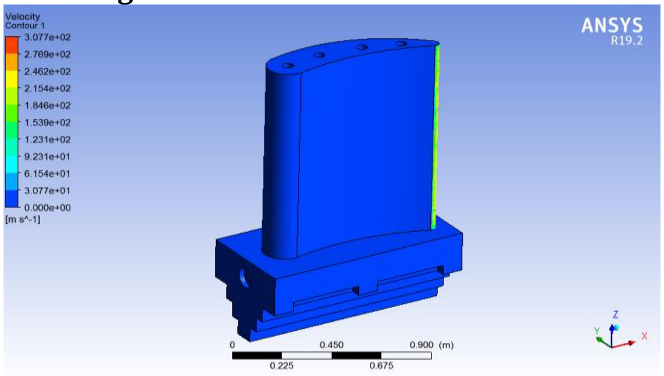


Fig 7.5: Contour – Velocity Result

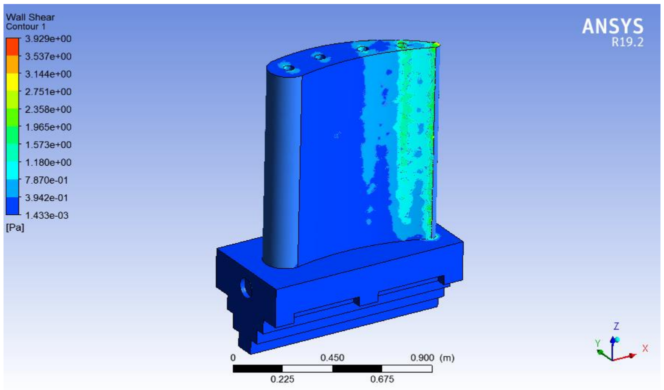


Fig 7.6: Contour – Shear Wall Result

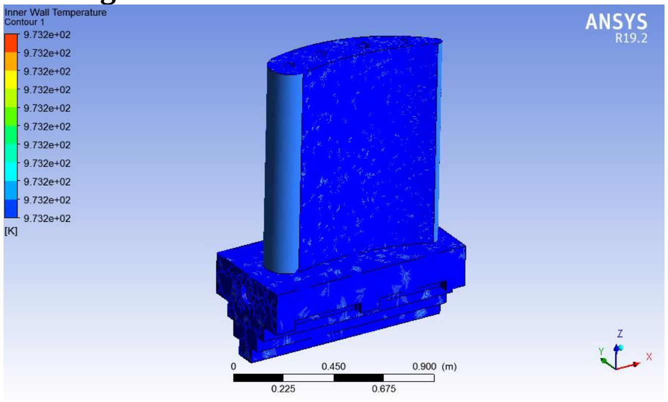


Fig 7.7: Contour – Inner Wall Temperature Result

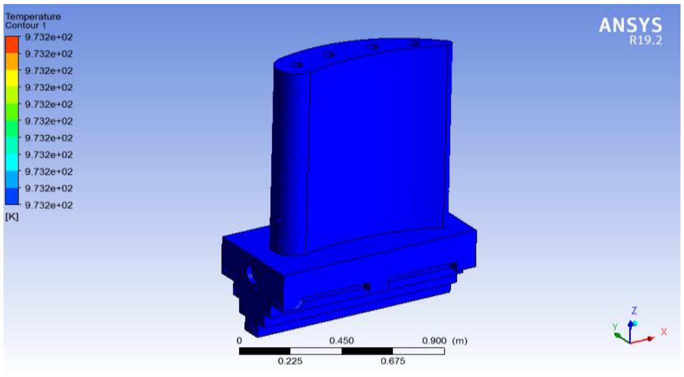


Fig 7.8: Contour – Temperature Result

6.3 Volume Rendering Results:

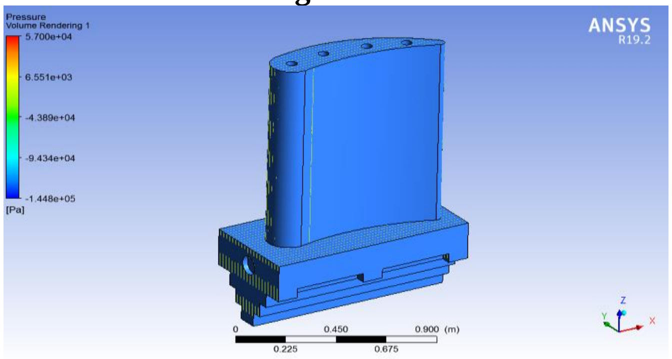


Fig 7.9: Volume Rendering – Pressure Result

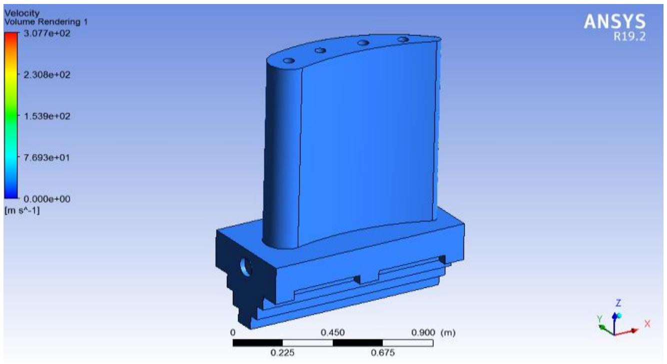


Fig 7.10: Volume Rendering – Velocity Result

VIII - CONCLUSION

It can be seen from the above result that, our objective to design and CFD analysis of Aircraft Turbine Blade using constrained thermodynamic optimization which has been successful. As shown above figures of the design is meshed and solved using CFD Ansys. This is showing us that design is having better results in the case of temperature, velocity and pressure. Pressure is at the fixing location (Pressure which is acceptable). The value is very less compared to yield value; this is below the yield point. The temperature and velocity is coming, this solution solving with the help of Ansys software. So we can conclude our design parameters are approximately correct.

The design of the Aircraft Turbine Blade mechanism and transferring of mechanism worked flawlessly in CFD Analysis as well. Hence, higher percentage of the time spent at center has improved the efficiency of the blade. All these facts point to the completion of our objective in high esteem. The design of the Aircraft Turbine Blade worked flawlessly in CFD analysis as well, all these facts point to the completion of our objective in high esteem.

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