# ABSTRACT

As there is need of power everywhere, there will be a huge usage of machine to generate, store and use the power. Turbines play a key role in power generation. As the machine is being used, there will be wear and tear of the machine.

In modern aviation, the aircraft turbine engines are considered to be highly reliable in that failures in services are rare. However, research and improvement to the aircraft component seems to be the endless process to avoid the failure during operation of an aircraft engines. This is due to the safety of passengers. Aircraft turbine blades would damage after several years of operation. This blade is identified the most likely component to be failed due to the operating conditions at elevated temperature. The blades profile and behaviour need to be understood to overcome these problems. So, this project deals with mechanical analysis by simulation to find the possible reason of the failure. With the help of ANSYS WORKBENCH software package, simulation of finite element analysis is done. Validation of the FEA results is supported by stress analysis using classical theory of mechanics. Numerically calculated stresses are compared with the FEA results and the blade dimensions are finalised based on it. Also this will eliminate the failure of the blade while functioning and it is structurally stable. Having tested three dimensional symmetric models, the preliminary conclusion is that finite element analysis is an extremely powerful tool when employed correctly.

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# NOMENCLATURE

OD - Outer Dia of the Valve Body (mm) ID - Inner Dia of the Valve Body (mm)

Ts - Thickness of the Shell (mm)

MWP - Maximum Working Pressure (MPa) TP - Test Pressure (MPa)

YS - Tensile Yield Strength (MPa)

YSTP - Yield Strength at Test Pressure (MPa)

Sa.σ.TP - Tensile Allowable Stress at Test Pressure

(MPa)

Sa.τ.TP - Shear Allowable Stress at Test Pressure (MPa) YSWP - Yield Strength at Working Pressure

Sa.σ.WP - Tensile Allowable Stress at Working Pressure (MPa)

Sa.τ.WP - Shear Allowable Stress at Working Pressure

(MPa)

tm (300) - Minimum Wall Thickness of Class 300 Valve (mm)

CA - Corrosion Allowance (mm) BST - Body Shell Thickness (mm) R - Radius of the Shell (mm)

S - Maximum Allowable Stress (MPa) E - Joint Efficiency of Cylindrical Shells

σA - Axial Stress (MPa)

FOS σA - Axial Stress Factor of Safety σT - Tangential Stress (MPa)

FOS σT - Tangential Stress Factor of Safety σR - Radial Stress (MPa)

FOS σR - Radial Stress Factor of Safety σE - Equivalent Stress (MPa)

FOS σE - Equivalent Stress (MPa)

SM - MEMBRANE STRESS INTENSITY (MPa)

FOSSM - Membrane Stress Intensity Factor of Safety SMmax - MAXIMUM STRESS INTENSITY (MPa)

DIAratio - Ratio of Outside and Inside Diameter of the

body

FOSSM - Maximum Stress Intensity Factor of Safety

# CHAPTER 1 INTRODUCTION

Power generation is the major application in now a day. Turbine is one of the key sources for the generation of power using either of the external sources as an input.

# TURBINE

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. 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. A turbine is any kind of spinning device that uses the action of a fluid to produce work. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor.

A working fluid contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Typical fluids are: air, wind, water, steam and helium. Windmills and hydroelectric dams have used turbine action for decades to turn the core of an electrical generator to produce power for both industrial and residential consumption. Several physical principles are employed by turbines to collect this energy. Simpler turbines are much older, with the first known appearance dating to the time of ancient Greece.

# TYPES OF TURBINE

**Steam turbines** are used for the generation of electricity in thermal power plants, such as plants using coal, fuel oil or nuclear power. They were once used to directly drive mechanical devices such as ships' propellers

**Gas turbines** are sometimes referred to as turbine engines. Such engines usually feature an inlet, fan, compressor, combustor and nozzle (possibly other assemblies) in addition to one or more turbines.

# Hydel turbines

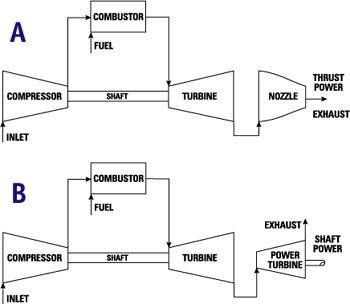
* + - Pelton turbine, a type of impulse water turbine.
    - Francis turbine, a type of widely used water turbine.
    - Kaplan turbine, a variation of the Francis Turbine.
    - Turgo turbine, a modified form of the Pelton wheel.

**Wind turbine**: These normally operate as a single stage without nozzle and inter stage guide vanes. An exception is the Éolienne Bollée, which has a stator and a rotor.

# INTRODUCTION

**CHAPTER 2 GAS TURBINE**

In the history of energy conversion, however, the gas turbine is relatively new. The first practical gas turbine used to generate electricity ran at Neuchatel, Switzerland in 1939, and was developed by the Brown Boveri Company. The first gas turbine powered airplane flight also took place in 1939 in Germany, using the gas turbine developed by Hans P. von Ohain. In England, the 1930s’ invention and development of the aircraft gas turbine by Frank Whittle resulted in a similar British flight in 1941.



# Fig. 2.1 Schematic for a) an aircraft jet engine; and b) a land-based

**gas turbine**

The name "gas turbine" is somewhat misleading, because many it implies a turbine engine that uses gas as its fuel. Actually a gas turbine (as shown schematically in Fig. 1) has a *compressor* to draw in and compress gas (most usually air); a *combustor* (or burner) to add fuel to heat the compressed air; and a *turbine* to extract power from the hot air flow. The gas turbine is an internal combustion (IC) engine employing a continuous combustion process. This differs from the intermittent combustion occurring in Diesel and automotive IC engines. Because the 1939 origin of the gas turbine lies simultaneously in the electric power field and in aviation, there have been a profusion of "other names" for the gas turbine. For electrical power generation and marine applications it is generally called a *gas turbine,* also a *combustion turbine (CT),* a *turbo shaft engine,* and sometimes a *gas turbine engine.* For aviation applications it is usually called a *jet engine*, and various other names depending on the particular engine configuration or application, such as: *jet turbine engine; turbojet; turbofan; fanjet;* and *turboprop* or *prop jet* (if it is used to drive a propeller). The compressor combustor- turbine part of the gas turbine (Fig. 2.1) is commonly

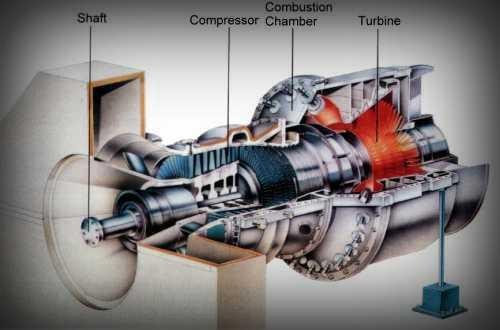
termed the *gas generator.*

The gas turbine in its most common form is a rotary heat operating by means of series of processes consisting of air taken from the atmosphere, increase of gas temperature by constant pressure combustion of the fuel in the whole process being continuous. It is similar to petrol and diesel engines in working medium and internal combustion but is akin to the steam turbines in its aspect of the steady flow of the working medium. Today the steam turbine is preeminent as an aircraft power plant with outputs ranging from a few hundreds of Newton if thrust to over 1000 KN. As a shaft unit the smallest in regular service is 5H.P.

# CHARACTERISTICS OF GAS TURBINE

The outstanding characteristics of gas turbines, which make them eminent of all turbines, are as follows:

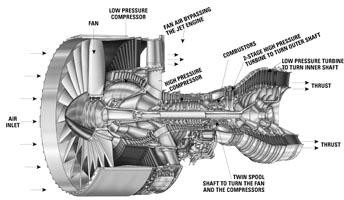
* + 1. It has a very simple mechanism.
    2. It runs at higher speed.
    3. It is very compact engine compared to other requiring less weight and space.
    4. It requires less maintenance cost.
    5. Cheaper liquid fuel can be used, as phenomenon of detonation does not exist.
    6. It is highly situated for peak load and standby power generation and aircraft propulsion.
    7. It works at high operating pressures
    8. It has greater power to weight ration than other engines.
    9. It requires less manpower.



# Fig. 2.2 Parts of Gas Turbine

**Gas Turbine Usage**

In an aircraft gas turbine the output of the turbine is used to turn the compressor (which may also have an associated fan or propeller). The hot air flow leaving the turbine is then accelerated into the atmosphere through an exhaust nozzle (Fig. 2.2) to provide thrust or propulsion power.



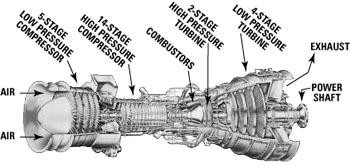
# Fig. 2.3 A modern jet engine used to power Boeing 777 aircraft

A typical jet engine is shown in Fig. 2.3. Such engines can range from about 100 pounds of thrust (lbst.) to as high as 100,000 lbs. with weights ranging from about 30 lbs. to 20,000 lbs. The smallest jets are used for devices such as the cruise missile, the largest for future generations of commercial aircraft. The jet engine of Fig. 3 is a *turbofan* engine, with a large diameter compressor- mounted fan. Thrust is generated both by air passing through the fan (bypass air) and through the gas generator itself. With a large frontal area, the turbofan generates peak thrust at low (takeoff) speeds making it most suitable for commercial aircraft.

A *turbojet* does not have a fan and generates all of its thrust from air that passes through the gas generator. Turbojets have smaller frontal areas and generate peak thrusts at high speeds, making them most suitable for fighter aircraft. In non-aviation gas turbines, part of the turbine power is used to drive the compressor. The remainder, the "useful power", is used as output *shaft power* to turn an energy conversion device such as an electrical generator or a ship’s propeller. A typical land -based gas turbine is shown in Fig.2.3. Such units can

range in power output from 0.05 MW (Megawatts) to as high as 240 MW. The unit shown in Fig. 2.4 is an *aero derivative* gas turbine; i.e., a lighter weight unit derived from an aircraft jet engine. Heavier weight units designed specifically for land use are called *industrial* or *frame* machines.

Although aero derivative gas turbines are being increasingly used for base load electrical power generation, they are most frequently used to drive compressors for natural gas pipelines, power ships and provide peaking and intermittent power for electric utility applications. Peaking power supplements a utility’s normal steam turbine or hydroelectric power output during high demand periods such as the summer demand for air conditioning in many major cities.



# Fig. 2.4 A modern land-based gas turbine used for electrical power production and for mechanical drives.

**Principle Advantages of the Gas Turbine:**

* It is capable of producing large amounts of useful power for a relatively small size and weight.
* Since motion of all its major components involve pure rotation (i.e. no reciprocating motion as in a piston engine), its mechanical life is long and the corresponding maintenance cost is relatively low.
* Although the gas turbine must be started by some external means (a small external motor or other source, such as another gas turbine), it can be brought up to full-load (peak output) conditions in minutes as contrasted to a steam turbine plant whose start up time is measured in hours.
* A wide variety of fuels can be utilized. Natural gas is commonly used in land-based gas turbines while light distillate (kerosene-like) oils power aircraft gas turbines. Diesel oil or specially treated residual oils can also be used, as well as combustible gases derived from blast furnaces, refineries and the gasification of solid fuels such as coal, wood chips and bagasse.
* Greater reliability, particularly in applications where sustained high power output is required.
* Waste heat is dissipated almost entirely in the exhaust. This results in a high temperature exhaust stream
* That is very usable for boiling water in a combined cycle, or for cogeneration.
* The usual working fluid is atmospheric air. As a basic power supply, the gas turbine requires no coolant (e.g. water).
* Low lubricating oil cost and consumption.
* Can run on a wide variety of fuels.
* Very low toxic emissions of CO and HC due to excess air, complete combustion and no "quench" of the Flame on cold surfaces.

# Disadvantages of the Gas Turbine

* In the past, one of the major disadvantages of the gas turbine was its lower efficiency (hence higher fuel usage) when compared to other IC engines and to steam turbine power plants. However, during the last fifty years, continuous engineering development work has pushed the thermal efficiency (18% for the 1939 Neuchatel gas turbine) to present levels of about 40% for simple cycle operation, and about 55% for combined cycle

operation (see below). Even more fuel-efficient gas turbines are in the planning stages; with simple cycle efficiencies predicted as high as 45-47% and combined cycle machines in the 60% range.

* Cost is very high.
* Longer startup than reciprocating engines.
* Less responsive to changes in power demand compared with reciprocating engines.
* Characteristic whine can be hard to suppress.

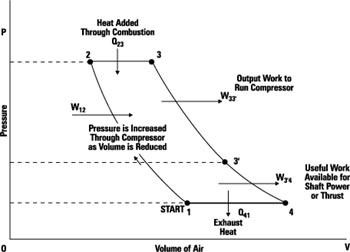
# Gas Turbine Applications

* Locomotive propulsions.
* Central power stations.
* Standby plants for hydro installations.
* Fully automatic booster stations at end of transmission lines.
* Standby and peak load plants for small system.
* Bomb proof power plants.
* At location where water is not available.
* Pumping stations.
* Space applications-
* Turbo jet, Turbo propulsion, marine applications
* Gas turbines are also used in marine application for power generation and propelling. For these applications the gas turbine has to work under high pressure, temperature and critical forces (tangential force, axial force, centrifugal force) .The main part of the gas turbine is blades which have to withstand these forces.

# GAS TURBINE CYCLES

A cycle describes what happens to air as it passes into, through, and out of

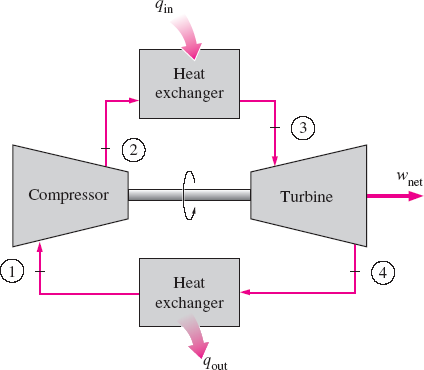
the gas turbine. The cycle usually describes the relationship between the space occupied by the air in the system (called volume, V) and the pressure (P) it is under. The Brayton cycle (1876), shown in graphic form in Fig. 2.5 as a pressure- volume diagram, is a representation of the properties of a fixed amount of air as it passes through a gas turbine in operation. These same points are also shown in the engine schematic in Fig. 2.6



# Fig. 2.5 A Brayton cycle pressure-volume diagram for a unit mass of working fluid (e.g., air), showing work (W) and heat (Q) inputs and outputs.

**Fig. 2.6 Gas turbine schematic showing relative points from the Brayton Cycle diagram.**

Air is compressed from point 1 to point 2. This increases the pressure as the volume of space occupied by the air is reduced.

The air is then heated at constant pressure from 2 to 3 in Fig. 2.5. This heat is added by injecting fuel into the combustor and igniting it on a continuous basis. The hot compressed air at point 3 is then allowed to expand (from point 3 to 4) reducing the pressure and temperature and increasing its volume. In the engine in Fig. 4b, this represents flow through the turbine to point 3’ and then flow through the power turbine to point 4 to turn a shaft or a ship’s propeller. In Fig. 1a, the flow from point 3’ to 4 is through the exit nozzle to produce thrust. The "useful work" in Fig. 4a is indicated by the curve 3’- 4. This is the energy available to cause output *shaft power* for a land-based gas turbine, or *thrust* for a jet aircraft. The Brayton cycle is completed in Fig. 2.5 by a process in which the volume of the air is decreased (temperature decrease) as heat is absorbed into the atmosphere.

# Fig. 2.7 Closed Cycle Gas turbine

Most gas turbines operate in an *open-cycle* mode where, for instance, air is taken in from the atmosphere (point 1 in Figs. 2.5 and 2.6) and discharged back into the atmosphere (point 4), with the hot air being cooled naturally after it exits the engine. In a *closed cycle* gas turbine facility the working fluid (air or other gas) is continuously recycled by cooling the exhaust air (point 4) through a heat

exchanger (shown schematically in Fig. 2.7) and directing it back to the compressor inlet (point 1). Because of its confined, fixed amount of gas, the closed cycle gas turbine is *not* an internal combustion engine. In the closed cycle system, combustion cannot be sustained and the normal combustor is replaced with a second heat exchanger to heat the compressed air before it enters the turbine. The heat is supplied by an external source such as a nuclear reactor, the fluidized bed of a coal combustion process, or some other heat source. Closed cycle systems using gas turbines have been proposed for missions to Mars and other long term space applications.

A gas turbine that is configured and operated to closely follow the Brayton cycle (Fig. 2.5) is called a *simple cycle* gas turbine. Most aircraft gas turbines operate in a simple configuration since attention must be paid to engine weight and frontal area. However, in land or marine applications, additional equipment can be added to the simple cycle gas turbine, leading to increases in efficiency and/or the output of a unit. Three such modifications are regeneration, intercooling and reheating.

*Regeneration* involves the installation of a heat exchanger (recuperator) through which the turbine exhaust gases (point 4 in Fig. 4b) pass. The compressed air (point 2 in Fig. 4b) is then heated in the exhaust gas heat exchanger, before the flow enters the combustor (Fig. 2.8 A).

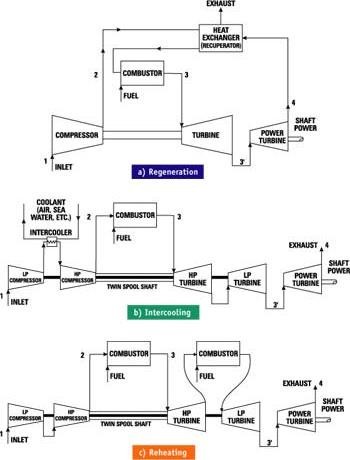
If the regenerator is well designed (i.e., the heat exchanger effectiveness is high and the pressure drops are small) the efficiency will be increased over the simple cycle value.

However, the relatively high cost of such a regenerator must also be taken into account. Regenerators are being used in the gas turbine engines of the M1 Abrams main battle tank of Desert Storm fame, and in experimental gas turbine automobiles. Regenerated gas turbines increase efficiency 5-6% and are even more effective in improved part-load applications.

*Intercooling* also involves the use of a heat exchanger. An intercooler is a heat exchanger that cools compressor gas during the compression process. For instance, if the compressor consists of a high and a low pressure unit, the intercooler could be mounted between them to cool the flow and decrease the work necessary for compression in the high pressure compressor (Fig. 2.8 B). The cooling fluid could be atmospheric air or water (e.g., sea water in the case of a marine gas turbine). It can be shown that the output of a gas turbine is increased with a well-designed intercooler.

*Reheating* occurs in the turbine and is a way to increase turbine work without changing compressor work or melting the materials from which the turbine is constructed. If a gas turbine has a high pressure and a low pressure turbine at the back end of the machine, a reheater (usually another combustor) can be used to "reheat" the flow between the two

Turbines (Fig. 2.8 C).This can increase efficiency by 1-3%. Reheat in a jet engine is accomplished by adding an afterburner at the turbine exhaust, thereby increasing thrust, at the expense of a greatly increased fuel consumption rate.



# Fig. 2.8 Modifications available for the simple Brayton Cycle.

* 1. **GAS TURBINE COMPONENTS**

A greater understanding of the gas turbine and its operation can be gained by considering its three major components (Fig. 1, Fig. 2 and Fig. 3): the

compressor, the combustor and the turbine. The features and characteristics will be touched on here only briefly.

# COMPRESSORS AND TURBINES:

The compressor components are connected to the turbine by a shaft in order to allow the turbine to turn the compressor. A *single shaft* gas turbine (Fig. 1a and 1b) has only one shaft connecting the compressor and turbine components. A *twin spool* gas turbine (Fig. 6b, and 6c) has two concentric shafts, a longer one connecting a low pressure compressor to a low pressure turbine (the low spool) which rotates inside a shorter, larger diameter shaft. The shorter, larger diameter shaft connects the high pressure turbine with the higher pressure compressor (the high spool) which rotates at higher speeds than the low spool. A *triple spool* engine would have a third, intermediate pressure compressor-turbine spool.

Gas turbine compressors are either centrifugal or axial, or can be a combination of both. Centrifugal compressors (with compressed air output around the outer perimeter of the machine) are robust, generally cost less and are limited to pressure ratios of 6 or 7 to 1. They are found in early gas turbines or in modern, smaller gas turbines. The more efficient, higher capacity axial flow compressors (with compressed air output directed along the center line of the machine) are used in most gas turbines (e.g. Fig. 2 and Fig. 3). An axial compressor is made up of a relatively large number of stages, each stage, consisting of a row of rotating blades (airfoils) and a row of stationary blades (stators), arranged so that the air is compressed as it passes through each stage.

Turbines are generally easier to design and operate than compressors, since the hot air flow is expanding rather than being compressed. Axial flow turbines (e.g. Fig. 2 and Fig. 3) will require fewer stages than an axial compressor. There are some smaller gas turbines that utilize centrifugal turbines (radial inflow), but most utilize axial turbines. Turbine design and manufacture is complicated by the need to extend turbine component life in the hot air flow. The problem of ensuring durability is especially critical in the first turbine stage where temperatures are

highest. Special materials and elaborate cooling schemes must be used to allow turbine airfoils that melt at 1800-1900°F to survive in air flows with temperatures as high as 3000°F.

# COMBUSTORS:

A successful combustor design must satisfy many requirements and has been a challenge from the earliest gas turbines of Whittle and von Ohain. The relative importance

of each requirement varies with the application of the gas turbine, and of course, some requirements are conflicting, requiring design compromises to be made. Most design requirements reflect concerns over engine costs, efficiency, and the environment. The basic

design requirements can be classified as follows:

* + 1. High combustion efficiency at all operating conditions.
    2. Low levels of unburned hydrocarbons and carbon monoxide, low oxides of nitrogen at high power and no visible smoke. (Minimized pollutants and emissions.)
    3. Low pressure drop. Three to four percent is common.
    4. Combustion must be stable under all operating conditions.
    5. Consistently reliable ignition must be attained at very low temperatures, and at high

altitudes (for aircraft).

* + 1. Smooth combustion, with no pulsations or rough burning.
    2. A low temperature variation for good turbine life requirements.
    3. Useful life (thousands of hours), particularly for industrial use.
    4. Multi-fuel use. Characteristically natural gas and diesel fuel are used for industrial

applications and kerosene for aircraft.

* + 1. Length and diameter compatible with engine envelope.
    2. Designed for minimum cost, repair and maintenance. 12.Minimum weight (for aircraft applications).

A combustor consists of at least three basic parts: a casing, a flame tube and a fuel injection system. The casing must withstand the *cycle pressures* and may be a part of the structure of the gas turbine. It encloses a relatively thin- walled flame tube within which combustion takes place, and a fuel injection system.

Compared to other prime movers (such as Diesel and reciprocating automobile engines), gas turbines are considered to produce very low levels of combustion pollution. The gas turbine emissions of major concern are unburned hydrocarbons, carbon monoxide, oxides of nitrogen (NOx) and smoke. While the contribution of jet aircraft to atmospheric pollution is less than 1%, jet aircraft emissions injected directly into the upper troposphere have doubled between the latitudes of 40 to 60 degrees north, increasing ozone by about 20%. In the stratosphere, where supersonic aircraft fly, NOx will deplete ozone. Both effects are harmful, so further NOx reduction in gas turbine operation is a challenge for the 21st century.

# TURBINE BLADE:

The rotor blades of the turbo machine are very critical components (Fig. 2.9) and reliable operation of the turbo machine as a whole depends on their repayable operation. The major cause of break down in turbo machine is the failure of rotor blade. The failure of the rotor blade may lead to catastrophic consequences both physically and economically. Hence, the proper design of the turbo machine blade plays a vital role in the proper functioning of the turbo machine as shown in figure.



# Fig. 2.9 Blades mounted on the Rotor of Gas Turbine

A turbine blade (Fig. 2.10) is the individual component which makes up the turbine section of a gas 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, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

So for this application the gas turbine blade must be manufactured with a material which has high chemical and physical properties.

A good design of the turbo machine rotor blading involves the following:

* Determination of geometric characteristics from gas dynamic analysis.
* Determination of steady loads acting on the blade and stressing due to them.
* Determination of natural frequencies and mode shapes.
* Determination of unsteady forces due to stage flow interaction.
* Determination of dynamic forces and life estimation based on the cumulative damage fatigue theories .

# Production of Blades

Blades may be considered to be the heart of turbine and all other member exist for the sake of the blades. Without blade there would be no power and the slightest fault in blade would mean a reduction in efficiency and costly repairs. The following are some of the methods adopted for production of blades.

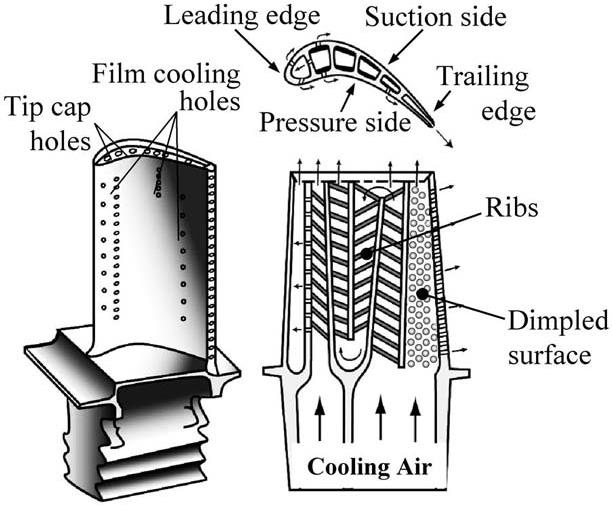
* **Rolling:** Sections are rolled to the finished size and used in conjunction with packing pieces. Blades manufactured y this method do not fail under combined bending and centrifugal force.
* **Machining:** Blades are also machined from rectangular bars. This method has more or less has the same advantage as that of first. Impulse blade is manufactured by this technique.
* **Forging:** Blade and vane sections having airfoil sections are manufactured by specialist techniques.
* **Extrusion:** Blades are sometimes extruded and the roots are left on the subsequent machining. This method is not reliable as rolled sections, because of narrow limits imposed on the composition of blade material.



# Fig. 2.10 Individual Blade

**Turbine Blade Cooling**

Unlike steam turbine bladings, gas turbine bladings need cooling. The objective of the blade cooling is to keep the metal temperature at a safe level to ensure a long creep life and low oxidation rates. Although it is possible to cool the blades by liquid using thermosyphon and heat pipe principal, but the universal method of blade cooling is by cool air or working fluid flowing through internal passage in the blades. The mean rotor blade temperature is about 3500C below the prevailing gas temperature after efficient blade cooling as shown below in figure 2.11.



# Fig. 2.11 Structure of a Blade

Due to corrosion and corrosion deposits turbine blades fail. To protect it from corrosion, the uses of pack-aluminized coatings are used. The main elements used are aluminum, nickel, and chromium .

# 1.4 BLADE MATERIALS

Proper selection of blade material plays an important role in blade design.

The factors that influence the selection of blade materials are: -

1. Method of manufacture
2. Ease of machining
3. The ability to produce blade sections free from flaws.
4. Ductility both allow of rolling of shapes.
5. The capacity for being welded.
6. Ease of forging easily.
7. Condition of operations.
8. Suitable tensile strength at high temperature.
9. Resistance to creep.
10. Cost.

# Turbine Blade Materials

Advancements made in the field of materials have contributed in a major way in building gas turbine engines with higher power ratings and efficiency levels. Improvements in design of the gas turbine engines over the years have importantly been due to development of materials with enhanced performance levels. Gas turbines have been widely utilized in aircraft engines as well as for land based applications importantly for power generation. Advancements in gas turbine materials have always played a prime role – higher the capability of the materials to withstand elevated temperature service, more the engine efficiency; materials with high elevated temperature strength to weight ratio help in weight reduction. A wide spectrum of high performance materials - special steels, titanium alloys and super alloys - is used for construction of gas turbines .The material available limits the turbine entry temperature (TET). The properties required are as follows (a) tensile strength (b) resistance to high frequency vibration fatigue stresses(c) low frequency thermal

fatigue stresses (d) resistance to erosion and corrosion .

# Stainless Steel Alloy

In spite of this there is a group of iron-base alloys, the iron-chromium- nickel alloys known as stainless steels, which do not rust in sea water, are resistant to concentrated acids and which do not scale at temperatures up to 1100°C. It is this largely unique universal usefulness, in combination with good mechanical properties and manufacturing characteristics, which gives the stainless steels their raison d'être and makes them an indispensable tool for the designer. The usage of stainless steel is small compared with that of carbon steels but exhibits a steady growth, in contrast to the constructional steels. Stainless steels as a group is perhaps more heterogeneous than the constructional steels, and their properties are in many cases relatively unfamiliar to the designer. In some ways stainless steels are an unexplored world but to take advantage of these materials will require an increased understanding of their basic properties.

# Titanium Alloy

These titanium alloys are mainly used for substituting materials for hard tissues. Fracture of the alloys is, therefore, one of the big problems for their reliable use in the body. The fracture characteristics of the alloys are affected by changes in microstructure. Therefore, their fracture characteristics, including tensile and fatigue characteristics should be clearly understood with respect to microstructures. The fracture characteristics in the simulated body environment also be identified because the alloys are used as biomedical materials. The effect of living body environment on the mechanical properties is also very important to understand.

# Alpha Structure (α Alloy):

With alpha stabilizer elements present, these alloys possess excellent creep resistance. They are also used largely in cryogenic applications.

# Alpha Beta Structure (α–β Alloy):

This group contains both alpha and beta stabilizer elements. This is the largest group in the aerospace industry.

# Beta Structure (β Alloy):

With beta stabilizers this group has high harden ability and high strength, but also a higher density. Titanium alloys use in aero engines, Automotive, Airframes and road transport, Dental alloys, geothermal plant, Marine and Military hardware.

# Aluminum Alloy

The production of primary aluminum is a young industry - just over 100 years old. But it has developed to the point where scores of companies in some 35 countries are smelting aluminum and thousands more are manufacturing the many end products to which aluminum is so well suited. Alloy A380 (ANSI/AA A380.0) is by far the most widely cast of the aluminum die-casting alloys, offering the best combination of material properties and ease of production. It may be specified for most product applications. Aluminum Alloys use in Electrical Conductors, Transport, Packaging, and High Pressure Gas Cylinders.

# CHAPTER 3

# PROBLEM DEFINITION

The crash of an aircraft during operation may cause by several factors and this includes the failure of its turbine blade. In a research by Carter (2005), unlike automobile engines, aircraft engines run at high power settings for extended periods of time. As a general review, the engine runs at maximum power for a few minutes during taking off, and then power is slightly reduced for climb, and then spends the majority of its time at a cruise setting, that is about 65% to 75% of full power. The power of an internal combustion reciprocating or turbine aircraft engine is rated in units of power delivered to the propeller (typically horsepower). This is actually torque multiplied by crankshaft revolutions per minute (RPM). The propeller converts the engine power to thrust horsepower (thp) in which the thrust is a function of the blade pitch of the propeller relative to the velocity of the aircraft.

Modern gas turbine engines for aviation applications are generally considered to exhibit a high level of reliability, and failure rates are considered low. In reality, this perception is incorrect; with component rejection for incipient failure symptoms during overhaul is quite high. However, the situation is controlled by the rigid inspection team which the engines are exposed, and undergoes very strictly inspection. This is also to ensure that almost all failures are detected in the early stage, and are removed from service for replacement or refurbishment before failure actually occurs. Therefore, it lead to a low rate of actual failure in service occurs.

# PROBLEM STATEMENT

The blade used in aircraft turbine would damage during several years of operation. A major risk in modern aviation is the failure of aero engine turbine blades at very high rotating speed. According to Cowles (1996), the blade is the component that is most likely to be failed due to high cycle fatigue. The failure of turbine blade in aircraft engine could cause aircraft crash. Several cases of

aircraft crash recoded in every years. This should be taken seriously and need to be avoided due to the safety of passengers life. So this project deals with some analysis to find the possible reason of the failure.

Year after years, the engineer and designer have done research on the causes of failure of this aircraft turbine blade. A lot of experiment and examination on the blade behavior have been carried out to determine the causes of failure and the way to preventing it. The simulation using finite element method software package seem to be the most effective way due to the accuracy of the results and the cost saving.





# Fig. 3.1 Failed Blades

The Figure 3.1 above shows the example of failure turbine blade. In order to prevent the problem, the engineer and designer have the option by using several appropriate software packages that related to the finite element analysis. As in this research, the use of MSC Nastran/Patran software will be very helpful in order to simulate and analyze the aircraft turbine blade to find the critical area of the failure, maximum displacement of the blade when exposed to the pressure, and the maximum stress that act on the blade. Theoretical calculation will be use to validate the result obtained from the simulation.

# OBJECTIVES

This project implemented with aim to study and analyze problem those related to the failure of turbine blade. The other objectives that contain in this project are:

* + - To model the blade based on the actual dimensions used in aircraft turbine engine.
    - To simulate the blade using ANSYS Workbench software and investigate the failure of the turbine blade with structural loads for the integrity in the rotor assembly.

# CHAPTER 4

# LITERATURE REVIEW

Extensive work has been reported in the literature of gas turbine blade. In this chapter a review of literature related to design and analysis of gas turbine are discussed. Further, literature related to various single and multiobjective optimization techniques and sensitivity analysis techniques applicable for optimizing the gas turbine blade are presented.

S.Gowreesh et.al[1] studied on The first stage rotor blade of a two stage gas turbine has been analysed for structural, thermal, modal analysis using ANSYS 15.0.which is a powerful Finite Element Method software. The temperature distribution in the rotor blade has been evaluated using this software. The design features of the turbine segment of the gas turbine have been taken from the preliminary design of a power turbine for maximization of an existing The purpose of turbine technology is to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum turbo jet engine. it has been felt that a detail study can be carried out on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses.

Kauthalkar et.al. the purpose of turbine technology is to extract, maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency. That means, the Gas turbine having maximum reliability, minimum cost, minimum supervision and minimum starting time. The gas turbine obtains its power by utilizing the energy of burnt gases and the air. This is at high temperature and pressure by expanding through the several rings of fixed and moving blades. A high pressure of order 4 to 10 bar of working fluid which is essential for expansion, a compressor is required. The quantity of working fluid and speed required are more so generally a centrifugal or axial compressor is required. The turbine drives the compressor so it is coupled to the turbine shaft.

John.v et.al. studied on the design and analysis of Gas turbine blade, CATIA is used for design of solid model and ANSYS software for analysis for F.E.model generated, by applying boundary condition, this paper also includes specific post-processing and life assessment of blade .HOW the program makes effective use of the ANSYS pre-processor to mesh complex turbine blade geometries and apply boundary conditions. Here under we presented how Designing of a turbine blade is done in CATIA with the help of co-ordinate generated on CMM. And to demonstrate the preprocessing capabilities, static and dynamic stress analysis results, generation of Campbell and Interference diagrams and life assessment. The principal aim of this paper is to get the natural frequencies and mode shafe of the turbine blade.

V.Raga Deepu et.al. Studied on a Gas turbine is a device designed to convert the heat energy of fuel in to useful work such as mechanical shaft power. Turbine Blades are most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. The turbine blades are mainly affected due to static loads. Also the temperature has significant effect on the blades. Therefore the coupled (static and thermal) analysis of turbine blades is carried out using finite element analysis software ANSYS.

A.K.Matta et.al. studied the stress analysis for N – 155 & Inconel 718 material. On solid blades it is reported that Inconel 718 is better suited for high temperature operation.

V.Veeraragavan [6] had mainly done the research on the aircraft turbine blades; his main focus was on 10 C4/ 60 C50 turbine blades models. He had used the conventional alloys such as titanium, zirconium, molybdenum, and super alloys were chosen for the analysis. He had analyzed the effect of the temperature on the different material for the certain interval of times. And conclude the molybdenum alloys had better temperature resistance capability.

R D V Prasad, G Narasa Raju, M S S Srinivasa Rao, N Vasudeva Rao had done research on different types of the cooling technique which maintain temperature of the blade to allowable limits, Finite element analysis is used to examine steady state thermal & structural performance for N155 & Inconel 718 nickel-chromium alloys. Four different models consisting of solid blade and blades with varying number of holes (5, 9 & 13 holes) were analyzed to find out the optimum number of cooling holes. They had used two material Inconel 718 and Inconel 155 for their research work and found out Inconel 718 has the better thermal properties as the blade temperature and the stress induce is lesser.

B.Deepanraj et al.[8] (2002) stated that blade failures can be caused by a number of mechanisms under the turbine operating conditions of high rotational speed at elevated temperature. In general, blade failures can be grouped into two categories that are fatigue; including both high (HCF) and low cycle fatigue (LCF) and the second is creep 6 rupture. In the conclusion section he state that the likely cause of blade failure is considered to be a mixture of LCF and HCF as a consequence of blade tip or casing rub strap impact.

S.-g. Kim et al. (2008), in their analysis of failure in J85 engine turbine blades stated that after observing the engine exterior upon landing, cracks and deformations were found in many parts including the fuel inlet manifold and the afterburner fuel manifold. After removing parts and carrying out SEM analysis on cracked parts, the problem was found to be secondary cracks due to overstress.

T.J Carter (2005) in the research about common failures in gas turbine blades stand with the opinion that there are three probable damage mechanisms affect turbine blades, these being mechanical damage through either creep or fatigue and high temperature corrosion. The use of light alloys for the high temperature sections of the engine is not feasible since they cannot generally be design to give acceptable creep properties at the high temperatures needed for efficient turbine operation. In the case of aluminium alloys, the operating temperature is above the melting point. For the most parts, nickel base alloys are

use and the weight penalty is accepted. Under normal conditions, blades should never be operated at excessive temperatures for long enough periods to cause microstructural damage.

E. Silveira et al.(2008) in the journal of study on the root causes for the premature failure of an aircraft turbine blade conclude that the failure of the first blade was attributed to thermal-mechanical fatigue with a significant contribution of creep. This fracture was initiated at one of the cooling holes. Moreover, a noticeable number of elongated particles, whose analysis points were to identify them as brittle intermetallic phases were, observe in this blade. This is a new factor which promotes the failure.

H. Tang et al. (2008) carried out an analysis about fretting fatigue failure of an aero engine turbine blade that focused on two blades which had caused shutdown of an aircraft engine. He stated that apparently the fracture mechanism of blade 1 was high cycle fatigue. The fatigue was attributed to a V-shape notch defect which might be produced by fretting wear. In addition there are some fretting pits and fretting cracks on the surface of blade 1. Therefore it confirms that the failure mechanism of turbine blade 1 was fretting fatigue.

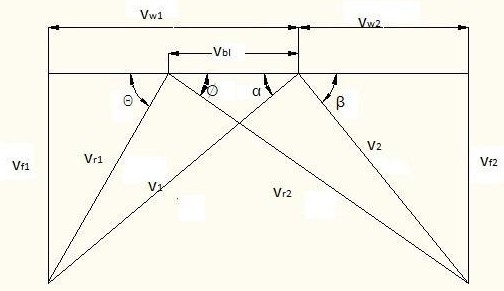
There were numerous researches on this gas turbine blade, but the stress analysis of blade is not clearly defined which eases our project to fix the objective.

# CHAPTER 5

**DESIGN OF GAS TURBINE BLADE**

By using standard assumptions, theoretical calculations are made to obtain the dimensions of the blade geometry. Most of the dimensions are taken from the literature survey.

# DESIGN PARAMETERS



**Fig. 5.1 Velocity Triangle**

|  |  |  |
| --- | --- | --- |
| Inlet flow angle α | = 18 |  |
| Inlet blade angle Ѳ | = 45 |
| Outlet flow angle β | = 36.75 |
| Outlet blade angle | = 13 |
| Diameter of blade mid span | = .15+.60 = | .75 |
| Design speed of turbine | = 4500 rpm |  |
| Blade velocity Vbl | =(π\*d\*n)/60 = | 176.714 m/s |
| Inlet flow velocity V1 | =360 m/s |  |
| Inlet relative velocity Vr1 | = 234.28 m/s |  |
| Inlet whirl velocity Vw1 | = 342.380 m/s |  |
| Inlet flow velocity Vf1 | = 111.246 m/s |  |
| Outlet relative velocity Vr2 | = 234.28 m/s |  |
| Outlet whirl velocity Vw2 | = 51.561 m/s |  |

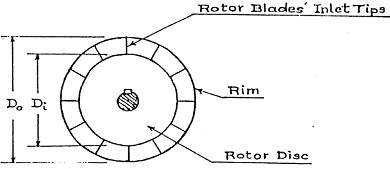
Outlet flow velocity Vf2 = 52.701 m/s

# Finding tangential Force (Fr) and Axial force (Fa) on each rotor

Tangential force in Newton's Ft = M (Vw2 – (-Vw3)] Axial Force in Newton's FA = M (Vf2 – (-Vf3)]

Where m represents mass flow rate of gases through the turbine in kgs /

sec.



# Fig. 5.2 Rotor Assmbly Configuration

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Outer Dia of the Rotor (with blade height) Do  Inner Dia of the Rotor (root of the rotor) Di | | | =  = | 900 mm  600 mm |
| M | = | p2 x π (D0-Di)/4 x V f2 | | |
|  | = | 0.524\*π\*(0.9-0.6) \*52.701/4 | | |
|  | = | 6.506 kg/m3 | | |
| Ft | = | 6.506\*(342.380-(-51.561)) | | |
|  | = | 2563 N | | |
| Fa | = | 6.506\*(111.246+52.701) | | |
|  | = | 1067 N | | |

No of blade passes = 60

For single blade

|  |  |  |
| --- | --- | --- |
| Ft | = | 2563/60 |
|  | = | 43 N |
| Fa | = | 1067/60 |
|  | = | 18 N |

POWER GENERATION:

P = m {Vw1 U – (-Vw2 U)}

= 6.506\*{342.380+51.561}\*176.714

= 456.914 KW

# CENTRIFUGAL FORCE

R1 = 300 mm = 0.3 m R2 = 450 mm = 0.45 m

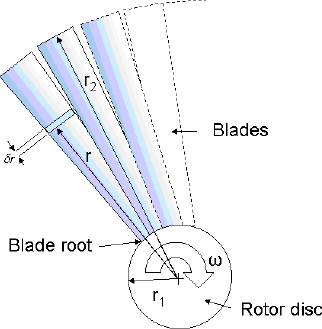
Angular velocity w =π\*d\*n/60 Speed n =4500 rpm

We know that F = mrω2

Consider a small segment of mass *m*δ, of length having width δr at a distance *r* from the centre.

Then the equation for the centripetal force δF on this small segment is given by:

δF = δmw2r



# Fig. 5.3 Rotor Assmbly Configuration

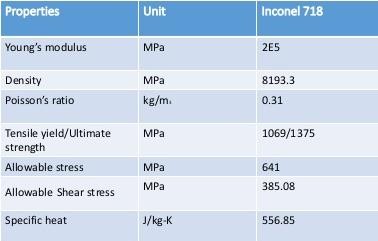
In practice, a blade tapers in thickness towards its tip; but, for simplicity, assuming the blade to have a constant cross sectional area A(m2) and material density ρ (kg/m3), we can write:

|  |  |  |
| --- | --- | --- |
| Δm | = | ρAδr |
| δF | = | ρ\*A\* δr\* w2\*r |
| dF | = | ρ\*A\* w2\*r \*dr on integrating |
| F | = | ρAW2((R2)2-( R1)2)/2 |

# BLADE MADE OF NICKEL ALLOY

Alloy 718 is a high strength, corrosion resistant nickel chromium alloy, initially developed for the aerospace industry and still considered the material of choice for the majority of aircraft engine components. Its excellent strength and corrosion resistance have been recognised by the aviation industry and it is now widely used in this field [9].

# Material Properties f Inconel 718



**Force Calculations for Inconel 718**

|  |  |  |
| --- | --- | --- |
| Area | = | 1.613e-4 m2 |
| Density | = | 8190 kg/m3 |
| Radius R2 | = | 0.46 m |
| Radius R1 | = | 0.30 m |

|  |  |  |
| --- | --- | --- |
| W | = | 4500\*2\*π/60 |
| F | =  = | 471.23 rad/sec  8190\*0.0001613\*(471.23)2\*((0.45)2-(0.3)2)/2 |
|  | = | 17836 N |

So the load acting on each of the blade is very high and seems to be 17836 N.

# CHAPTER 6

**FINITE ELEMENT ANALYSIS**

# INTRODUCTION TO FINITE ELEMENT ANALYSIS

The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions of partial differential equations (PDE) [as well as of integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc. Finite Element Modeling is one of the most robust and widely used phenomenon to virtually Investigating the faults occurring in real time problems which are in general difficult to witness. Here based on available theory (existing formulae) the analysis of thick-walled cylinders is done with finite element modeling, some standard results are being compared.

Finite element analysis (FEA) is a numerical method that models a region by dividing it into small discrete elements composed of interconnecting nodes. Finite element analysis obtains the solution to the model by determining the behavior of each element separately, then combining the individual effects to predict the behavior of the entire model. The interconnecting nodes of the elements make the solution of one element dependent on another, meaning that to reach an accurate solution, FEA must solve each element several times, possibly thousands of times, to reach a solution. The accuracy is also dependent upon the number of elements. More elements will increase the model’s solution

accuracy, but as the number of elements increase, the solution time increases as well. Finite element analysis can be used with either 2-D or 3-D models. 3- Dmodels generally offer a more accurate analysis as they include all three planes of the physical world. A 3-D model is also composed of a great deal more nodes and elements as well, drastically increasing solution time. For this reason, it is often desirable to employ a 2-D model to reduce solution time. A 2-D model estimates the missing third dimension using either axisymmetric or planar geometry. Axisymmetric geometry generates a model using cylindrical components x, r, and θ, where θ is taken as 360°.

Planar geometry generates a model using Cartesian components x, y, and z, where z is specified as some constant value for the entire model. The iterative nature of FEA makes the analysis of models impractical by hand but perfect for computers. Several electromagnetic FEA packages exist, ranging from fully three dimensional packages such as ANSYS and Maxwell 3D, to simpler 2-Dpackages like Maxwell 2D, Quickfield, and FEMM. All FEA computer simulations consist of three parts; the preprocessor, analysis, and postprocessor. The preprocessing consists of constructing the model from nodes, curves, and surfaces, defining boundary conditions and block labels, and generating the mesh. Analysis is the automated process where the model is solved using the prescribed conditions and computational procedures. Postprocessing involves the visualization, study, and analysis of results. In electromagnetic models, this often involves a flux density plot, and the determination of circuit characteristics such as voltage drop, resistance, reactance, and inductance. These 3 steps are done in ANSYS 14.5 tool. **ANSYS Work Bench Analysis:**

The ANSYS Work bench platform is the frame work upon the industry’s broadcast and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex metaphysics analyses with drag– and– drop simplicity. With bi-directional CAD connectivity, powerful highly–

automated meshing, a project– level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Work bench platform delivers unprecedented productivity, enabling simulation

The Work bench environment allows us to solve much more complex analyses, including (as of ANSYS 8.0):

* Multi-part assemblies.
* 3-D solid element, shell elements, and shell-solid assemblies.
* Nonlinear contact with or without friction.
* Small-displacement and large– displacement static analyses.
* Modal, harmonic, and Eigen value bucking analyses.
* Steady –state thermal analysis, including temperature– Dependent material properties and thermal contact.

# MODEL GEOMETRY

In evaluating the geometry, there are several prime considerations. In addition to the necessity to accurately represent the actual geometry of the blade, one must consider the loading and support (boundary) conditions and the mesh to be employed. The extent of the blade modeled is also of prime concern when the decision is made to model only part of an overall system.

# Introduction to CATIA:

Catia-v5 is the industry’s de facto standard 3D mechanical design suit. It is the world’s leading CAD/CAM/CAE software, gives a broad range of integrated solutions to cover all aspects of product design and manufacturing. Much of its success can be attributed to its technology which spurs its costumer’s to more quickly and consistently innovate a new robust, parametric, feature based model. Because that CATIA-V5 is unmatched in this field, in all processes, in all countries, in all kind of companies along the supply chains. Catia-v5 is also the perfect solution for manufacturing enterprise, with associative applications,

robust responsiveness and web connectivity that make it the ideal flexible engineering solution to accelerate innovations.

# Advantages of Catia-V5:

1. It is much faster and more accurate.
2. Once a design is completed. 2D and 3D views are readily obtainable. The ability to changes in late design process is possible.
3. It provides a very accurate representation of model specifying all other dimensions hidden geometry etc.
4. It is user friendly both solid and surface modeling can be done.
5. It provides a greater flexibility for change. For example if we like to change the dimensions of our model, all the related dimensions in design assembly, manufacturing etc. will automatically change.

# Different Modules in Catia:

There are different modules in CATIA using which different tasks can be performed.

The main window and modules of CATIA shown in figure: The main modules are:

1. Part design
2. Assembly
3. Drafting
4. Wire frame and Surface Design
5. Core & Cavity Design

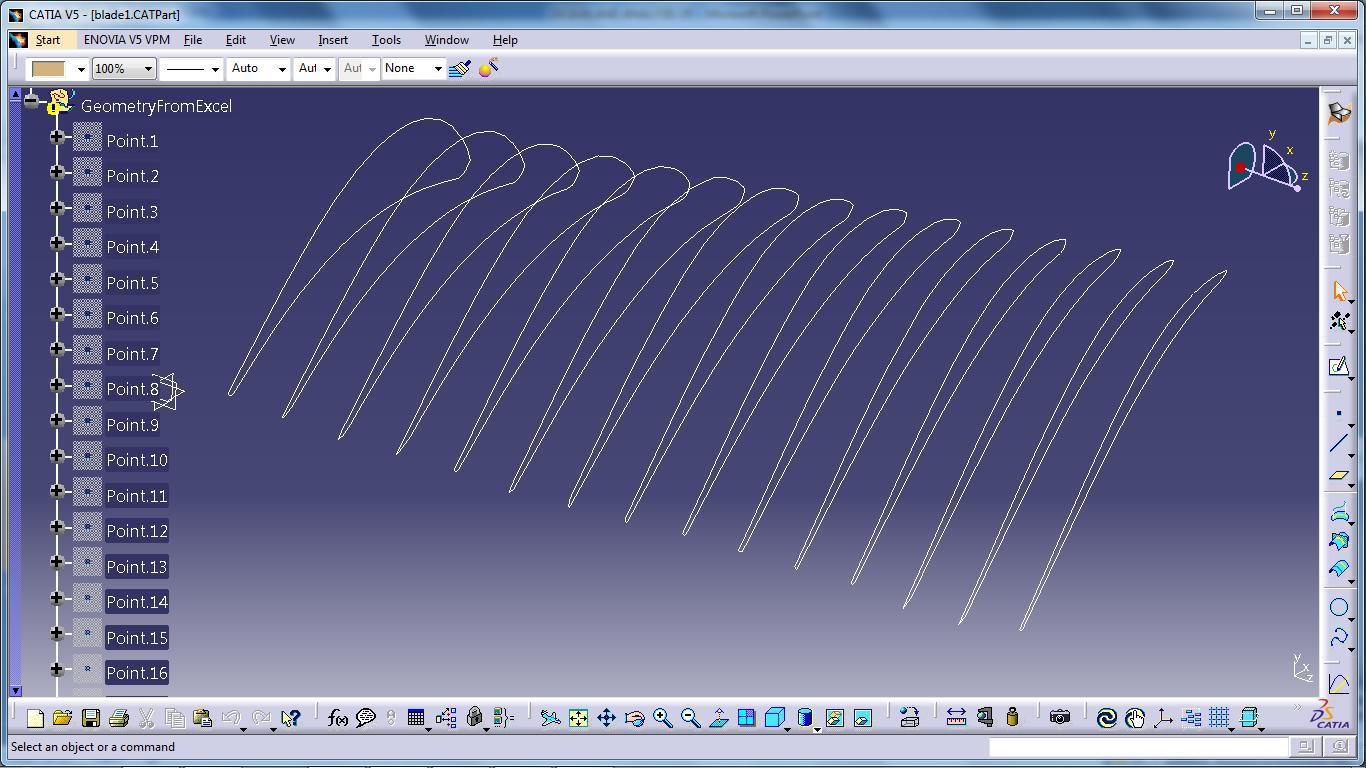
# PART DESIGN:

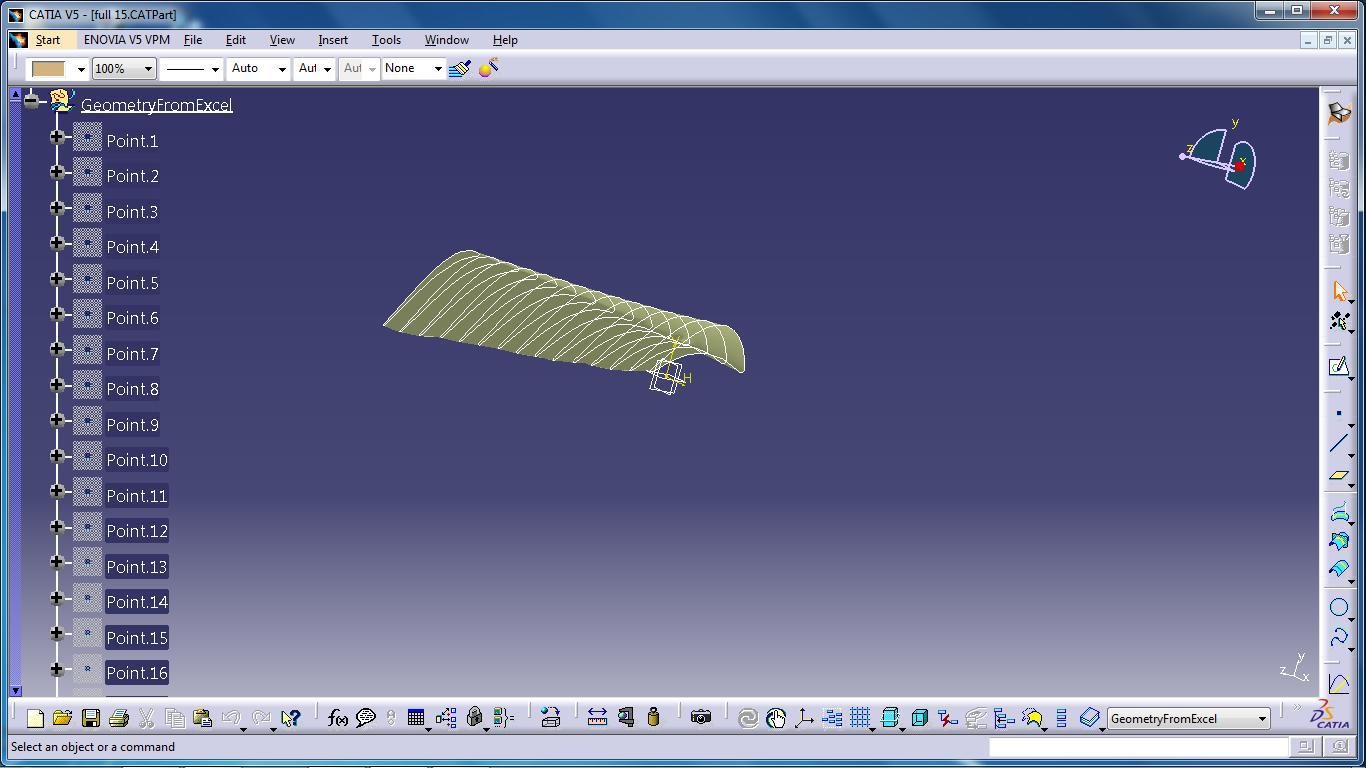
The version 5 part design application makes it possible to design precise 3D mechanical parts with an intuitive and flexible user interface, from sketching in an assembly context to iterative detailed. Version 5 part design application will be enable you to accommodate design requirements for parts of various complexities, from simple to advanced.

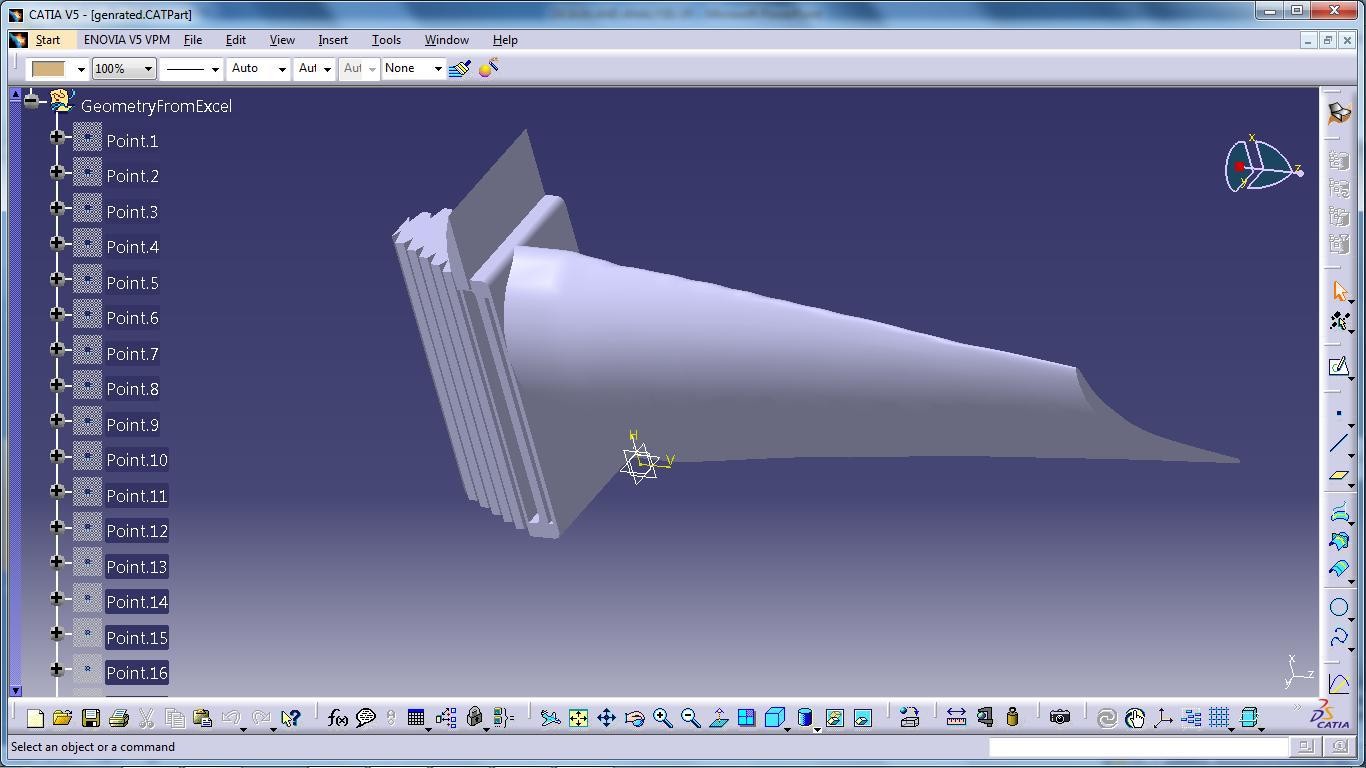
This application, which combines the power of feature– based design with the flexibility of a Boolean approach, offers a highly productive and intuitive design environment with multiple design methodologies, such as post-design and local 3D parameterization.

Select START -> Mechanical Design ->Part Design from the menu bar.

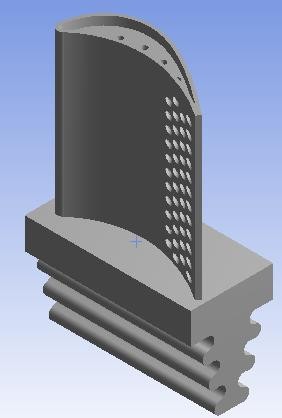
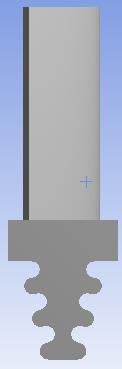
The blade under examination belongs to 1st stage turbine blades of 15 MW gas turbine engine intended for operation in aircraft engine. Dimension data from literatures are taken to develop the profile of the gas turbine blade. The gas turbine blade model profile is generated by using CATIA V5R21software [12]. 3D model of a gas turbine blade with root was done in two stages. First for creating the 3D model of the turbine blade, key points were created along the profile in the working plane. The points were joined by drawing B Spline curves to obtain a smooth contour (Fig. 6.1). This contour was then converted into area and then into volume. Then working plane was rotated by 90º to generate the root part in the same way as the blade. These two volumes were then combined to make a single volume using union Boolean operation.



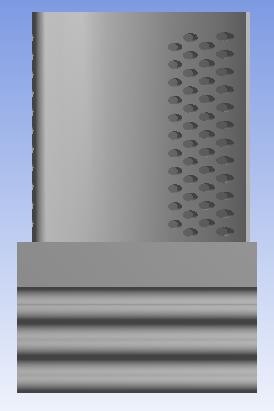


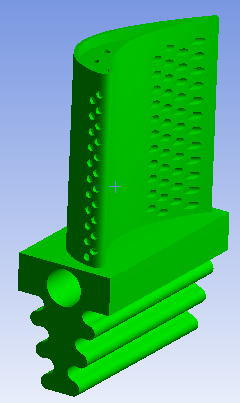


# Fig. 6.1 Development of Blade Profile

# Fig. 6.2 Final blade profile modelled in CATIA (Isometric & Right Side View)





**Fig. 6.3 Final blade profile modelled in CATIA (Front and Left Side View)**

# PREPROCESSING

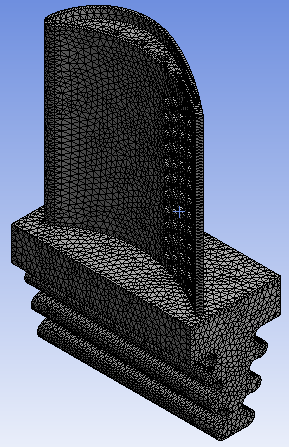
The accuracy of the FE model is highly dependent on the mesh employed, especially if higher order (cubic, quadratic etc.) elements are not used. In general, a finer mesh will produce more accurate results than a coarser mesh. At some point, one reaches a point of diminishing returns, where the increased mesh density fails to produce a significant change in the results. At this point the mesh is said to be‚ converged. This process of refining the mesh and evaluating the results is normally referred to as a mesh convergence study or analysis. Although many FE codes contain ‚error estimates‛ of one sort or another, mesh convergence remains the most reliable means of judging model accuracy. Coarse meshes almost always under-report the stresses in a model. It is not uncommon to have maximum reported stresses on the order of less than 50% of the converged

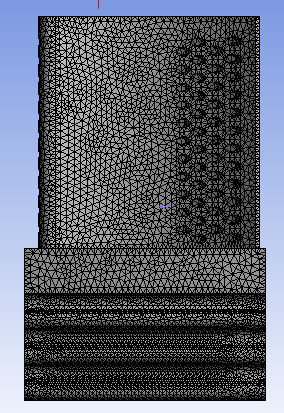
stresses on a coarsely meshed model. Thus, without consideration of mesh convergence, gross errors in stress estimates are quite possible.

Meshing has been done by using the method of fine elements of Tetrahedron. In Tetrahedron method the component is been divided into small triangle on its surface & volume which gives number of nodes and elements of that component (Figure 6.4). The meshing sizing details are given in the Table 1.

|  |  |
| --- | --- |
| **Sizing** | |
| Size Function | Adaptive |
| Relevance Center | Fine |
| Element Size | 1.0 mm |
| Smoothing | Medium |
| Defeaturing Tolerance | Default |
| Minimum Edge Length | 0.2540 mm |
| Nodes | 178054 |
| Elements | 100026 |

# Table 6.1 Mesh Sizing Detail





**Fig. 6.4 Meshing of Gas Turbine Blade MATERIAL PROPERTIES IN ANSYS**

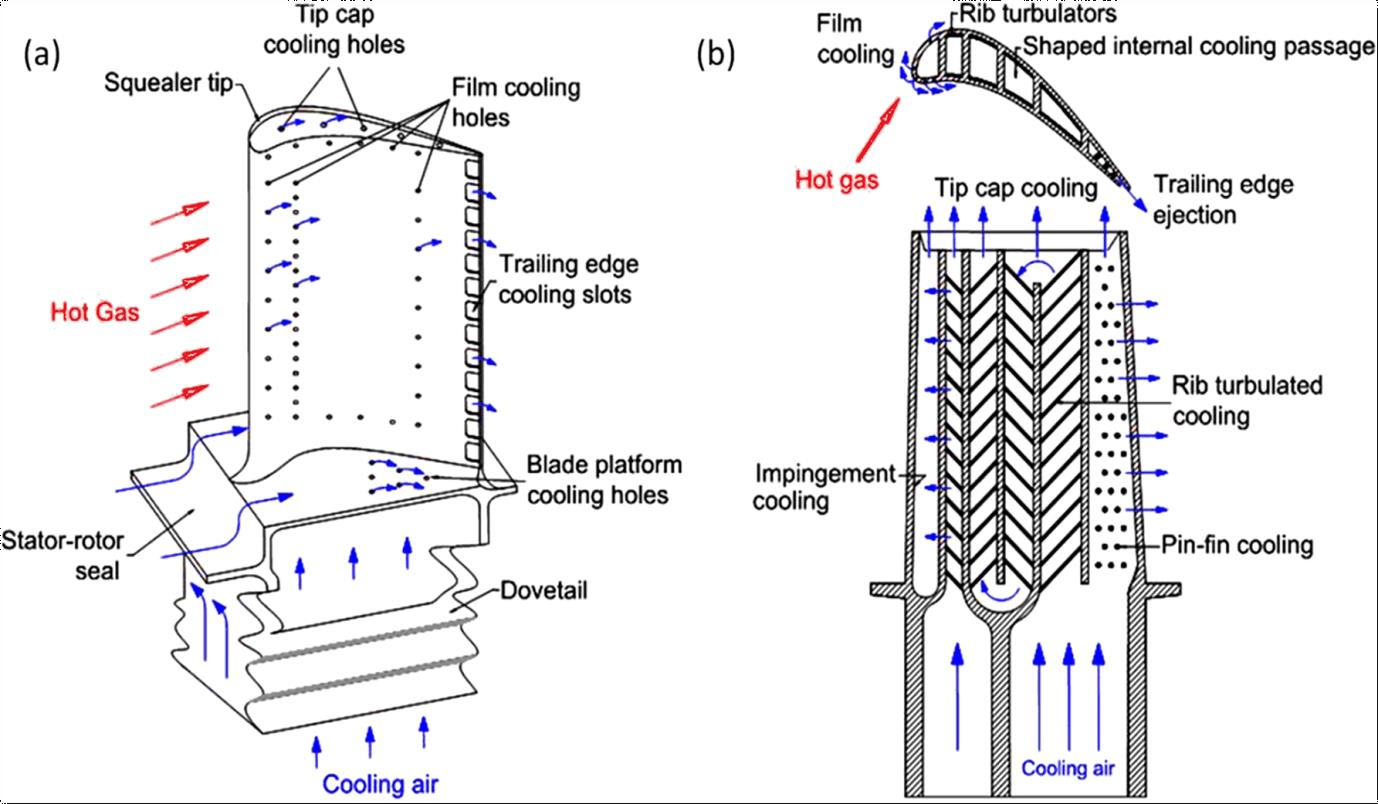
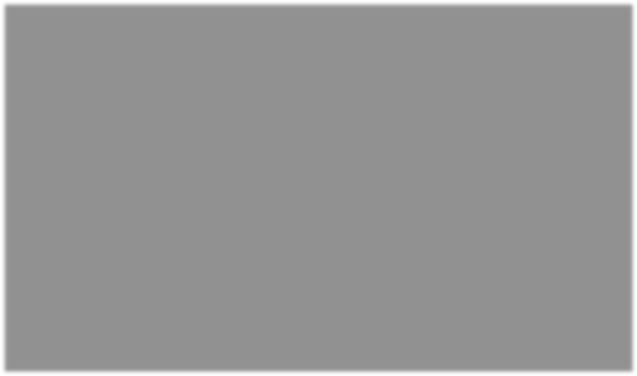
As discussed earlier, Inconel 718 is more suitable based on its superior properties. So in ANSYS, the Inconel 718 material property is added and it is assigned for the Gas Turbine Blade.

# BOUNDARY CONDITIONS

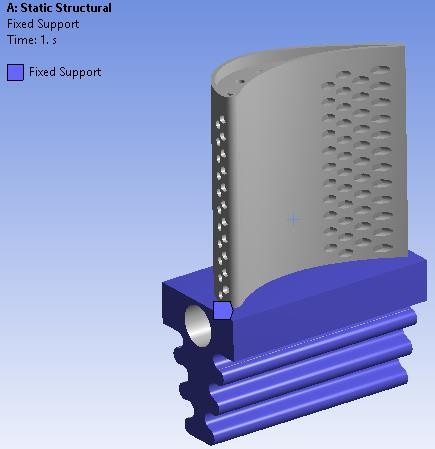
Static analysis was carried out to know the mechanical stresses and elongation experienced by the gas turbine rotor blades, which includes the parameters such as the gas forces which are assumed to be distributed evenly, the tangential and axial forces act through the centroid of the blade. But as per the calculations for a single blade, the force values are less than 100 N. So they are neglected due to minor impact in the structural rigidity.

The centrifugal force also acts through the centroid of the blade and in the radial direction. So the calculated centrifugal force of 17836 N and the pressure developed due to hot gas 1 MPa are applied (Fig. 6.7 to Fig. 6.9). Also the dovetail

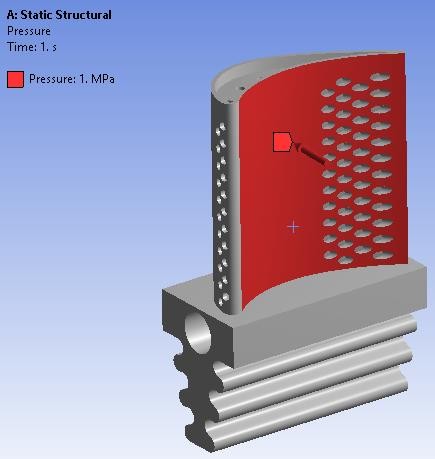
area is assembled in the rotor. Hence it is given as fixed constraint (Fig. 6.6). Below figure 6.5 clearly explains the boundary conditions of the blade.



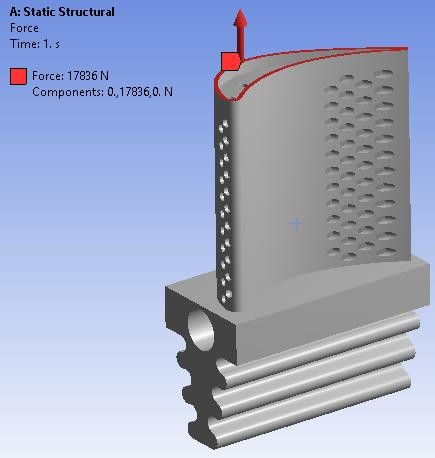
# Fig. 6.5 Loading on Gas Turbine Blade



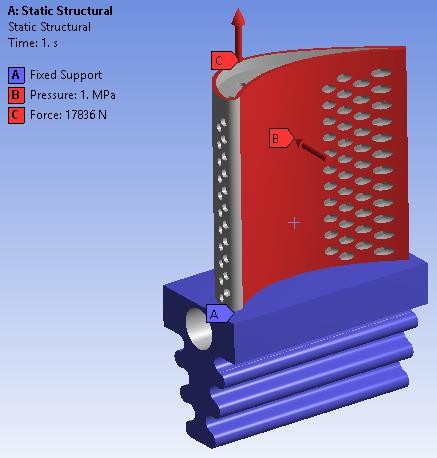
**Fig. 6.6 Fixed Consraint Gas Turbine Blade**



# Fig. 6.7 Loading 1 on Gas Turbine Blade



**Fig. 6.8 Loading 2 on Gas Turbine Blade**



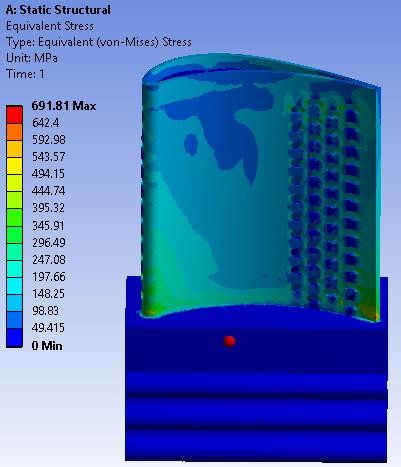
# Fig. 6.9 Combined Loading on Gas Turbine Blade

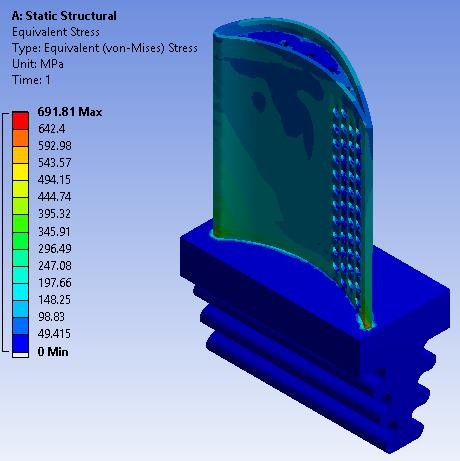
* 1. **POST PROCESSING**

After applying the load and constraints, the blade is analysed for its structural strength. Maximum stresses are observed at the trailing edge of blade near to the root.

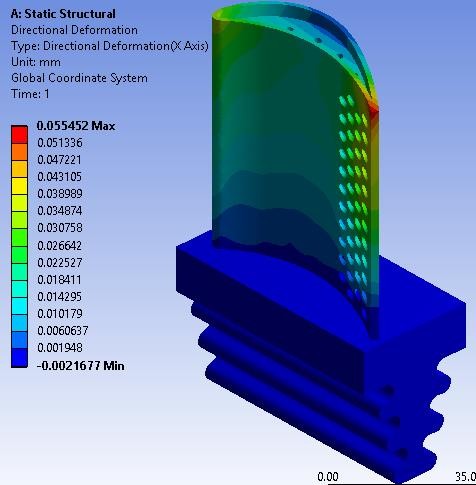
And the results are presented in the figure 6.10 to 6.13 as shown below.

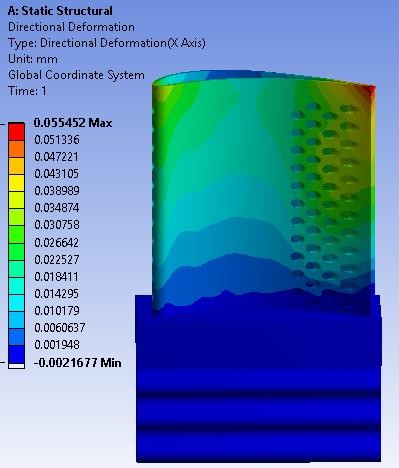
From the below result, it is clear that the stresses [10] are equally distributed along the blade & they are highly concentrated on the upper portion of the hub/root. Also it is evident that the deformation is distributed in an ascending manner from the top of the hub to the tip of the blade.



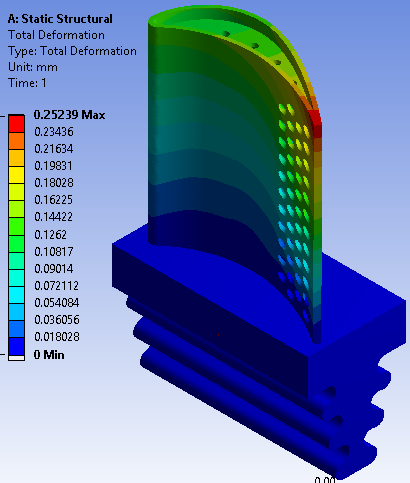


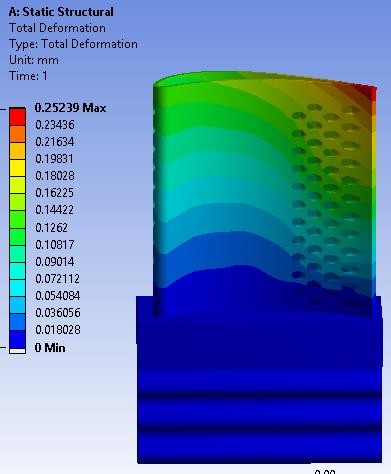
# Fig. 6.10 Equivalent Stress on Gas Turbine Blade



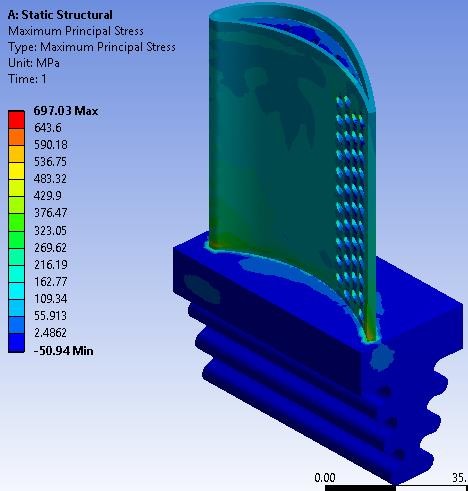


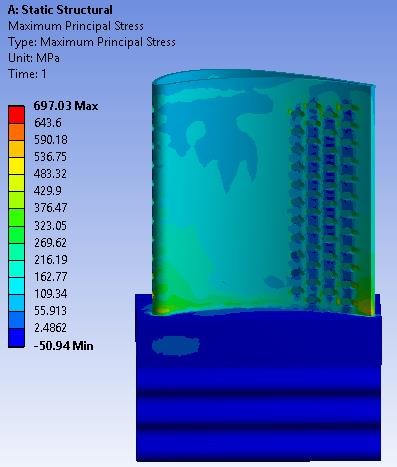
**Fig. 6.11 Directional Deformation on Gas Turbine Blade**





# Fig. 6.12 Total Deformation on Gas Turbine Blade





**Fig. 6.13 Maximum Principal Stress on Gas Turbine Blade**

# CHAPTER 7 RESULTS

This paper presents an efficient design process for gas turbine blade housing.

Both the analysed stress values ie. Equivalent Stress and Maximum Principal Stress values are very less when compared to the Allowable Stress Values & Yield Strength Values as shown earlier in the Table of Material Properties.

Maximum Equivalent Stress Value from the result = 692 MPa Maximum Principal Stress Value from the result = 697 MPa

But the Tensile Yield Strength of the Material Inconel 718=1069

MPa

Factor of Safety (FOS) for Equivalent Stress = 1069/ 692 Therefore FOS = 1.54 for Equivalent Stress

Factor of Safety (FOS) for Maximum Principal Stress = 1069/ 697 Therefore FOS = 1.53

Here the FOS is more than 1.5 in both the cases which is extremely

important in aero space applications.

Also the directional deformations with respect to x, y & z axes are less and total deformation is comparatively less which is less than 1 mm.

These show that the design of the gas turbine blade is extremely safe during operation under maximum loading conditions and having higher degree of structural stability.

This work presented critical design analysis of stress development using 3D CAD models of gas turbine blade and finite element engineering simulation of various stress and deformation tests at high pressure.

# CHAPTER 8 CONCLUSION

Blades are the most important parts of any Gas Turbine in the Aviation Industry. And the design should satisfy the criteria’s given in the international code, ASME Section VIII Division 1. They have to be designed carefully to cope with operating temperature and pressure.

The research work deals with the modeling and analysis of gas turbine blade. The structural finite element analysis was performed for the turbine blade using ANSYS Workbench 17.0 software. The turbine blades are subjected to high mechanical stresses and are operated in aggressive environments. The turbine blades are made of exotic materials to survive in this environment. Material Inconel 718, which is used in the manufacturing of aero turbine blade have been considered for the analysis under same operating conditions and the results are tabulated.

FEA is a powerful tool in analyzing the various structures and the results provided by ANSYS Workbench 17.0 proved once again its reliability. The current capabilities of FE software on desktop computers provide the aero design engineers with the ability to employ FE analysis on a nearly routine basis. Aero design engineers must have a reasonable understanding of FE fundamentals to adequately use this design tool.

The guidelines presented are intended as a starting point for the engineer tasked with conducting an FE analysis of a gas turbine blade component. It is hoped that they will prove helpful. In the end, however, no set protocol of canned, “we solve everything automatically” can guarantee an accurate analysis for every project. CONCLUSION

# CHAPTER 9 REFERENCES

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