Design Optimization & Fatigue Life Prediction Of Aircraft Engine Bracket

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Abstract- *The purpose of this project is to optimize the design, dimensions along with changing in material of the bracket structure to ensure the structural fatigue life increase along with reduction in stress and displacement of the component. Optimization study of components gives a great opportunity for material saving which leads to save cost and man power.*

The major bracket design parameters were explained in detail and the bracket configuration has been described. Different types of loads acting on the aircrafts bracket are determined and the moments, displacements, etc., are also determined. The bracket structure was also explained and functions of each component and their arrangement are also studied.

The methodology of finite element method and the detailed description about various FEM tools have been studied and implemented in this work. The procedure of finite element method was followed to analyse the model. The analysing part of this project is done using CAE tool package and the results were discussed.

In this Project, we designed Aircraft engine bracket using CATIA V5 and carried out linear static analysis using MSC Software. For Pre-Processing used MSC PATRAN and MSC NASTRAN for solving followed by Fatigue calculations.

I. INTRODUCTION

Introduction to Aircraft

Aircraft is a machine which is supported for flight in the air by buoyancy or by the dynamic action on its surfaces. The airframe is the basic structure of an aircraft and is designed to withstand all aerodynamic forces, as well as the stresses imposed by the weight of the fuel, crew, and payload. In an aircraft, there are 4 parts namely Fuselage, wing, empennage and landing gear system. Forces acting on Aircraft are Thrust, Drag, Lift and Gravity. Control surfaces are changing the attitude of Aircraft during flying. The main control surfaces are Ailerons (rolling motion), Elevator (pitching motion) and Rudder (yawing motion).

Aircraft Working Principle

The aircrafts are mainly working on the principle of Bernoulli's theorem and Newton laws of motion which deal with the motion of air and the forces acting on a body moving relative to that air. A propulsion system is a machine that produces thrust to push an object forward. On airplanes, thrust is usually generated through some application of Newton law of action and reaction. A gas, or working fluid, is accelerated by the engine, and the reaction to this acceleration produces a force on the engine.

Aircraft Parts

The airframe of an aircraft consists of the following major units:

1. Fuselage
2. Wings
3. Stabilizers
4. Flight controls surfaces
5. Landing gear
6. Empennage

Fuselage

The fuselage is the main structure, or body, of the aircraft. It provides space for personnel, cargo, controls, and most of the accessories. The power plant, wings, stabilizers, and landing gear are attached to it. It has a sharp or rounded nose with sleek and tapered body so that the air can flow smoothly around it.There are two general types of fuselage construction,

1. Welded steel truss
2. Monocoque designs.

In this construction method, strength and rigidity are obtained by joining tubing (steel or Aluminum) to produce a series of triangular shapes, called trusses. The welded steel truss was used in smaller Navy aircraft, and it is still being used in some helicopters.

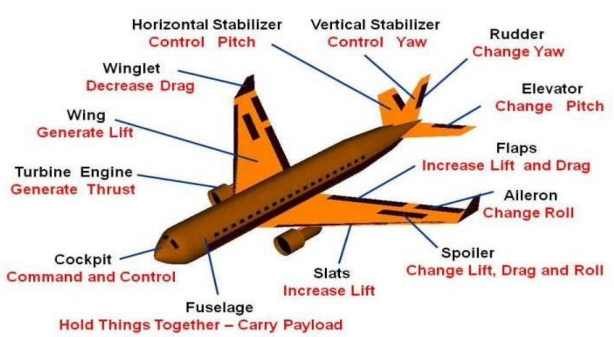
The construction of aircraft fuselages evolved from the early wood truss structural arrangements to monocoque shell structures to the current semimonocoque shell structures.

The monocoque design may be divided into three classes, monocoque, semimonocoque, and reinforced shell. Monocoque (French for "single shell") construction uses stressed skin to support almost all loads much like an Aluminum beverage can. In monocoque construction, rigs, formers, and bulkheads of varying sizes give shape and strength to the stressed skin fuselage. Semi monocoque construction, partial or one-half, uses a substructure to which the airplane’s skin is attached.

Wings

Wings develop the major portion of the lift of a heavier-than-aircraft. Wing structures carry some of the heavier loads found in the aircraft structure. The particular design of a wing depends on many factors, such as the size, weight, speed, rate of climb, and use of the aircraft. The wing must be constructed so that it holds its aerodynamics shape under the extreme stresses of combat manoeuvres or wing loading.

Wing construction is similar in most modern aircraft. In its simplest form, the wing is a framework made up of spars and ribs and covered with metal. The construction of an aircraft wing is shown in figure.



Parts of Aircraft

Stabilizer

The stabilizing surfaces of an aircraft consist of vertical and horizontal airfoils. They are called the vertical stabilizer (or fin) and horizontal stabilizer. These two airfoils, along with the rudder and elevators, form the tail section. For inspection and maintenance purposes, the entire tail section is considered a single unit called the empennage.

Landing gear

The landing gear system is placed in bottom surface of Aircraft. It carries the weight of an aircraft during landing and taxing conditions. It is one of the complicated part in an Aircraft. There are 3 types of landing gear apply to the surfaces are water, earthed and snow or ice (skis type). During landing impact load absorbed by shock absorber (vertical load), when tire touches the ground drag load generated and side load due to the aircraft body. Types of landing gear are fixed and retractable landing gear. Classifications also based on wheels like single, tandem, triple and twin etc. The components of landing gear system mainly include strut, shock absorber, brakes and wheels, torque arm and extraction and retraction system. The function of shock absorber is absorb the impact load during landing in recently oleo pneumatic strut is used. Strut carries the weight of aircraft, placed above the shock absorber (outer cylinder).

Empennage

Commonly known as the "tail section," the empennage includes the entire tail group which consists of fixed surfaces such as the vertical fin or stabilizer and the horizontal stabilizer. The movable surfaces including the rudder and rudder trim tabs, as well as the elevator and elevator trim tabs. These movable surfaces are used by the pilot to control the horizontal rotation (yaw) and the vertical rotation (pitch) of the airplane.

Aircraft Engines

Introduction

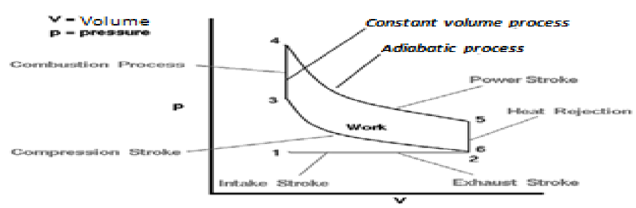
Aircraft engine means an engine that is used for propelling aircraft. A propulsion system is a machine that produces thrust to push an object forward. On airplanes and spacecraft, thrust is generated through some application of Newton’s third law of action and reaction. A gas, or working fluid, is accelerated by the engine, and the reaction to this acceleration produces a force on the engine.

Air-breathing types of aircraft engines use oxygen from the atmosphere to combine chemically with fuel carried in the vehicle, providing the energy for propulsion, in contrast to rocket types in which both the fuel and oxidizer are carried in the aircraft. The main types of aircraft engines are reciprocating, gas turbine, turboprop, fan jets and ramjets, Internal combustion engine, Jet propulsion, Reciprocating aircraft engine, Rocket propulsion.

1. **Internal Combustion Engine**

Airplanes used internal combustion engines to turn propellers, which generate thrust. As the name implies, the combustion process of an internal combustion engine takes place in an enclosed cylinder where chemical energy is converted to mechanical energy. Inside the cylinder is a moving piston which compresses a mixture of fuel and air before combustion and is then forced back down the cylinder following combustion. On the power stroke the piston turns a crankshaft, which converts the linear (up and down) motion of the piston into circular motion. The turning crankshaft is then used to turn the aircraft propeller. The motion of the piston is repeated in a thermodynamic cycle called the Otto Cycle.

In an ideal Otto cycle, as shown on this diagram, the area enclosed between the compression stroke (2– 3) and the power stroke (4–5) is the work done by the engine. To increase the amount of work done this area needs to be made larger. Increasing the volume of the cylinder, having more cylinders, raising the pressure, decreasing the volume during compression, or forcing more air into the cylinder (supercharging) are all ways this can be accomplished. With aircraft engines these changes cause some problems. Increasing the number or size of the cylinders adds weight to the engine and creates more heat that must be dissipated.



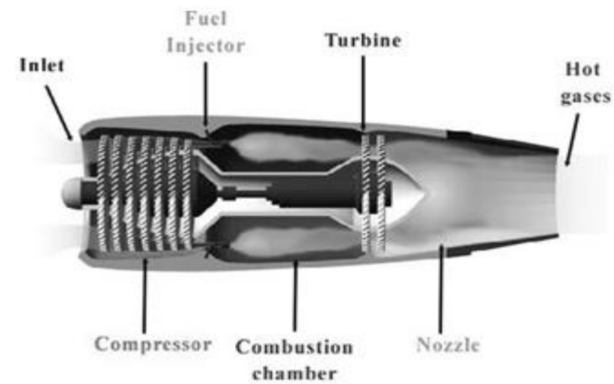
P-V Diagram of Ideal Otto Cycle

2. Turbine Engines

In turbine engines, air is drawn in and compressed, fuel is added and burned, and the hot gases expand out the rear of the engine, pushing the aircraft forward. Some of these exhaust gases turn a turbine, which drives the compressor. A number of different types of gas turbine engines have been developed for use depending upon the specific needs of a particular type of aircraft.

a. Turbojets

All the thrust of these engines comes through the turbine and nozzle, which is called the core of the engine. These are what people commonly refer to as jet engines.

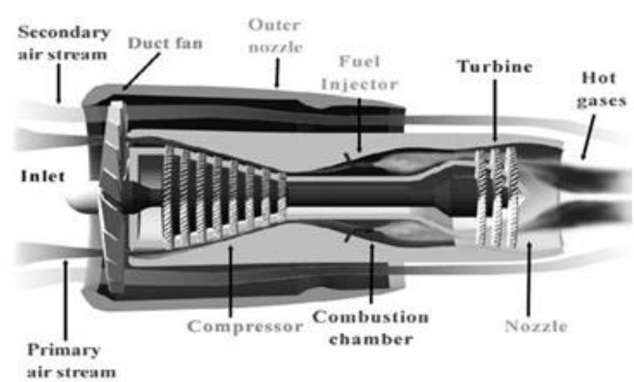


Cutaway view of Turbojet Engine

The turbojet engine, developed for aircraft in the years prior to World War II, was a departure in thinking from the standard piston engine. Instead of burning fuel in a confined space that is dependent upon precise timing of ignition, the turbojet engine is essentially an open tube that burns fuel continuously. According to Newton’s Third Law, as hot gases expand out from the rear of the engine, the engine is accelerated in the opposite direction. The engine consists of three main parts, the compressor, the burner, and the tur- bine, along with the inlet, shaft, and nozzle, as shown above.

b. Turbofans

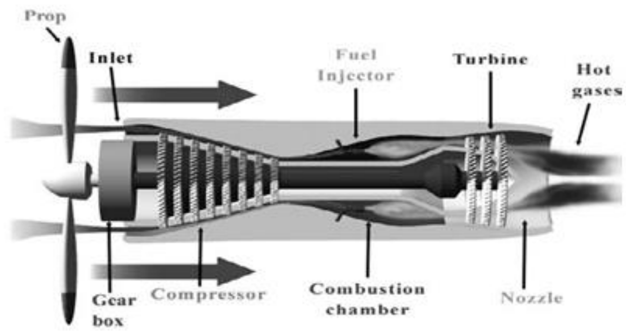
These engines have a central engine core that uses about 10 percent of the intake air while a large turbine powered fan pushes about 90 percent of the intake air around the outside of the core to produce most of the thrust. These are used on most commercial passenger aircraft because they make more thrust for every pound of fuel burned in the core.



Cutaway view of Turbofan Engine

c. Turboprop Engines

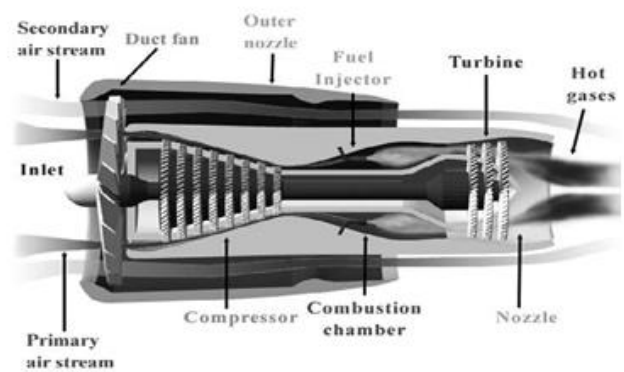
Turboprop engines are aircraft engines with a turbine hot section turning a propeller or rotor. The guts of a turboprop are the same as a jet engine. Turboprop engines allow are used in aircraft similar to those using piston engines, just a few noches bigger and faster. Turboprop engines are used in single, twin and even four engine aircraft like the C-130 Hercules.



Cutaway view of Turboprop Engine

d. Afterburning Turbojets

Afterburners are used only on supersonic fighter aircraft and only for short periods of time. Fuel is injected into the hot exhaust stream to produce additional thrust, allowing for high speed at a cost of high fuel consumption.



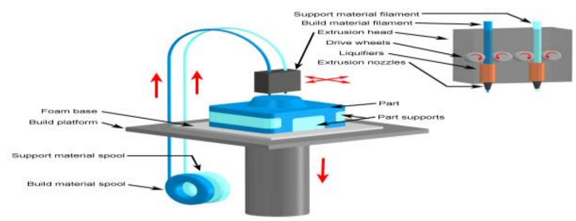
Cutaway view of after burning Turbojets Engine

Additive Manufacturing

Introduction

Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The term "3D printing" is increasingly used as a synonym for Additive Manufacturing. However, the latter is more accurate in that it describes a professional production technique which is clearly distinguished from conventional methods of material removal. Instead of milling a workpiece from solid block, for example, Additive Manufacturing builds up components layer by layer using materials which are available in fine powder form. A range of different metals, plastics and composite materials may be used.

Working Principle



working principle of 3D printing

The system starts by applying a thin layer of the powder material to the building platform. A powerful laser beam then fuses the powder at exactly the points defined by the computer-generated component design data. The platform is then lowered, and another layer of powder is applied. Once again the material is fused so as to bond with the layer below at the predefined points. Depending on the material used, components can be manufactured using stereo lithography, laser sintering or 3D printing.

Additive Manufacturing (AM) Applications in Aircraft

AM applications in aerospace include turbine engine blades, heat exchangers, pumps, structural brackets and a fuel nozzle. Here, metal AM may be effectively applied for novel designs as well in the Maintenance, Repair and Overhaul (MRO). The aerospace specific applications involve rapid and large fluctuations in thermal and mechanical conditions. Therefore, resistance to crack initiation and propagation and resistance to creep are crucial for aerospace applications. The benefits of metal Additive Manufacturing are especially suitable to aerospace, with increased demand on fuel efficiency, greenhouse emissions and buy-to-fly ratios. The buy-to-fly ratio is the weight ratio between the raw material used for a component and the weight of the component itself, commonly between 15 and 20 for CNC produced parts. AM manufactured parts can achieve a buy-to-fly ration of around 2. Additive Manufacturing allows for highly complex structures which can still be extremely light and stable.

Materials used in Additive Manufacturing

The following materials are commonly used for AM in aircraft:

1. Ti-6Al-4V
2. Co-28 Cr-6 Mo
3. Nickel-based alloys
4. Aluminum-based alloys
5. Stainless Steel alloys

Additive Manufacturing provides an opportunity for production with difficult to machine materials, such as Titanium and nickel based alloys. However, Selective Laser Melting and Electron Beam Melting are powder-bed fusion technologies and traditionally powder is used very little in the aerospace industry. Therefore, maintaining a high quality standard proves difficult, as the powder material is one of the main factors to consider when high quality standards are important.

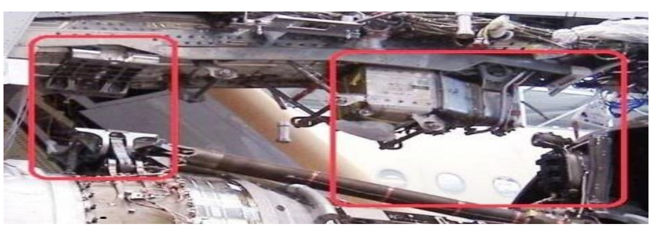
Aircraft Bracket

Introduction

Brackets are connector type elements widely used as structural supports to carry hydraulic and electrical lines used in engines, wings and landing gear links. Failure of brackets may lead to the catastrophic failure of the whole structure.

Bracket is a small fitting or support used to attach system parts as duct, bundle, cable, and blanket keeping them in the intended positions. Generally, the brackets are made from steel sheet strip slit and are cut to size before configured to the required shape by bending operation. The brackets are heat-treated to obtain the desired surface properties.

Aircraft Bracket



Location of bracket in aircraft engine

Bracket Design Requirements

The brackets are to be designed such that they will not damage system, structure and insulation brackets during the life span of aircraft. Their weight shall be minimized asmuch as possible thus reducing the overall aircraft weight leading to indirect cost savings. Brackets are designed for their intended use within the operating temperature of the aircraft. The unique feature of the brackets is that they shall be easy to install with a quick-fix mechanism by one technician, thus saving phenomenal time for the installation and disassembly. The number of feature elements constituting the brackets shall be minimized optimally.

While designing the brackets, care shall be taken on the manufacturing aspects, such as ease of production, machining, tolerances, and manufacturing cost. It is an implied requirement that the sharp edges should be avoided in the design, which would otherwise cause injury to installation engineers. The design shall be adapted to the structural elements shape such as frame section, among others, though minor modifications are allowed on the clip design. The bracket position shall be movable in X, Y, and Z directions. However, it will be locked in the final one. Holes in the structures are strictly avoided for installing the brackets, thus eliminating the use of fasteners for fixation. The indexation function, also called as repeatability or fool proofing, shall be provided in the design. This helps the bracket to be placed easily at its dedicated position. The bracket assembly will not be possible in another location than in the intended position.

Materials used for Brackets

- Aluminum Alloys
- Titanium Alloys
- Steel Alloys

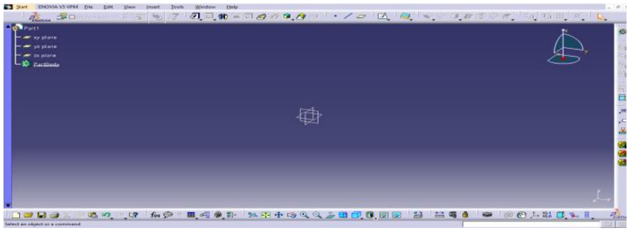
II. DESIGN OPTIMIZED 3D MODEL OF ENGINE BRACKET

Computer Aided Design

Computer aided design helps to assist in the creation, modification, analysis, or optimization of a design using cad software. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

About CATIA

CATIA means Computer Aided Three Dimensional Interactive Application. CATIA is a 3D product Lifecycle Management software suite developed by the French Company Dassult Systems. CATIA facilitates collaborative engineering across disciplines with its 3D experience platform. CATIA allows the user to create parts in highly productive and intuitive environment. CATIA enriches existing product design with basic part and surface design tools, easily establish assembly constraints, automatically positions parts and check assembly consistency.



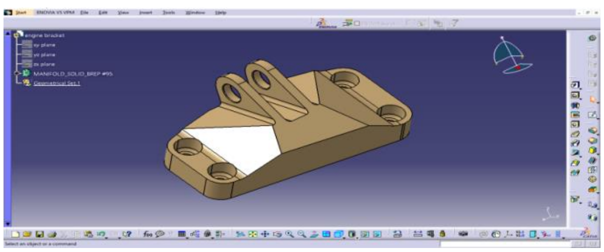
CATIA V5 graphical user interface

Procedure for changing nonparametric model in to parametric model

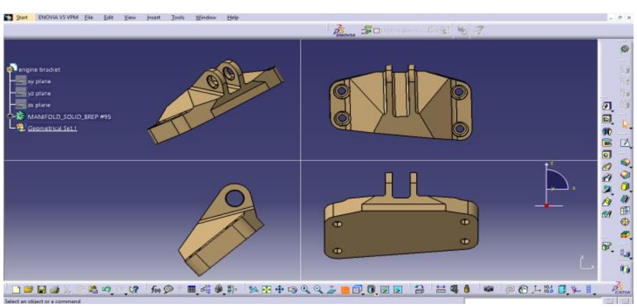
The original 3D model of engine bracket is taken from the below reference 1.

We used Part design & Generative shape design workbenches in CATIA for reverse engineering.

We imported the Step file of original model in to CATIA V5 CAD software.

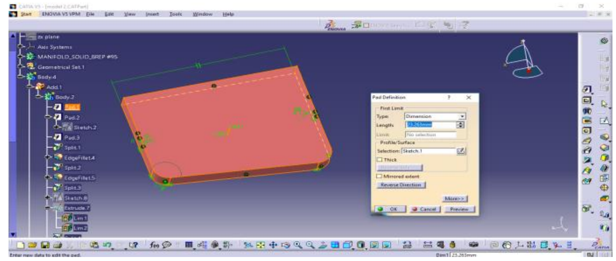


Original 3D model of engine bracket

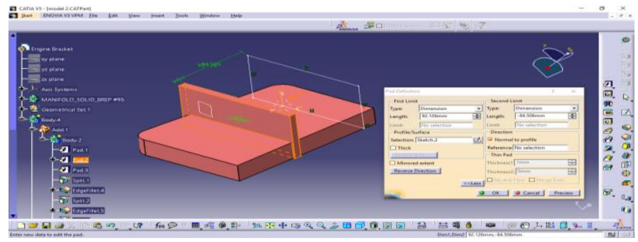


ISO view of original 3D model of engine bracket

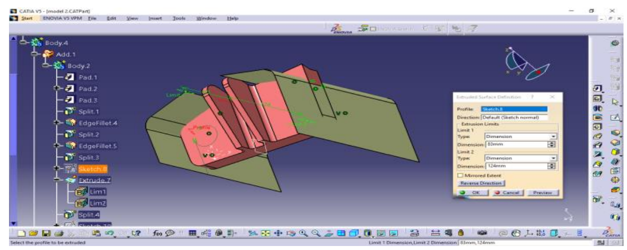
Start -> Mechanical Design -> Part Design -> File -> Open -> Select the .stp of model -> Insert body -> Select the sketch -> created a axis line using points -> using axis system definition created the XYZ positions -> Select the positioning sketch



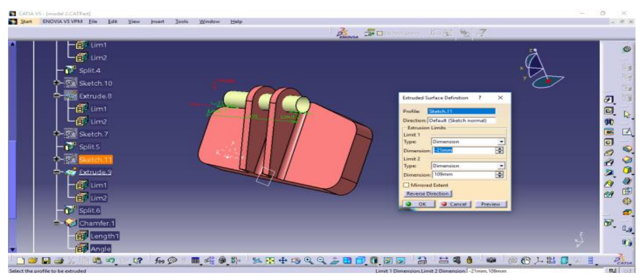
Procedure for design optimization of engine bracket



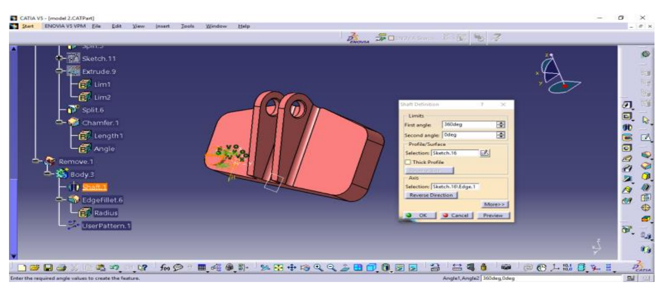
Procedure for design optimization of engine bracket



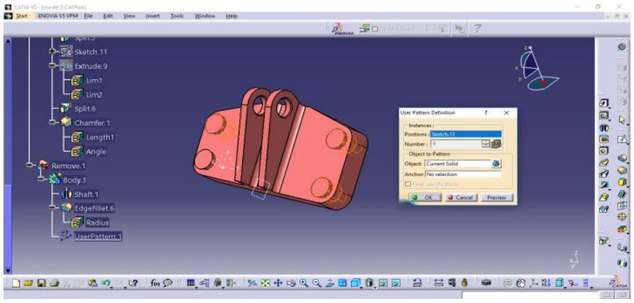
Procedure for design optimization of engine bracket



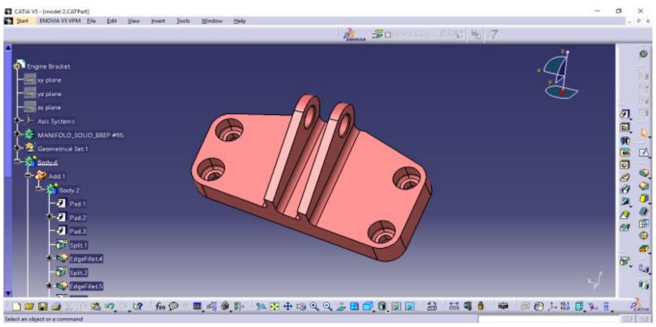
Procedure for design optimization of engine bracket



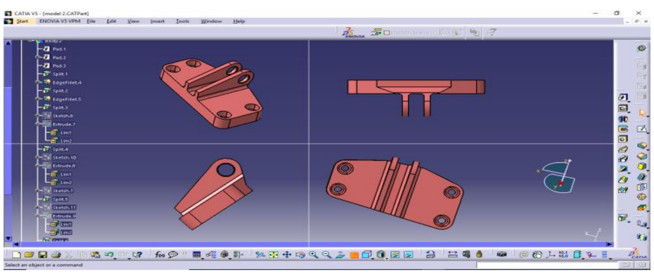
Procedure for design optimization of engine bracket



Procedure for design optimization of engine bracket



Design optimization 3D model of engine bracket



Iso view of Design optimization 3D model of engine bracket

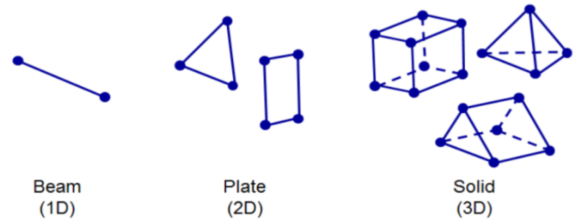
We changed the nonparametric model in to parametric model. The above figures shows the step by step procedure of Design optimization 3D model of engine bracket. Here we are importing this model in to MSC Patran for Linear Static Analysis.

III. INTRODUCTION TO FEA

Engineering analysis can be broadly divided into two categories: classical methods and numerical methods. Following tree diagram shows various methods for solving engineering problems. As shown below, the finite element method is one of several methods for solving engineering problems.

Types of Finite Elements

Finite elements have shapes which are relatively easy to formulate and analyse. The three basic types of finite elements are beams, plates, and solids.

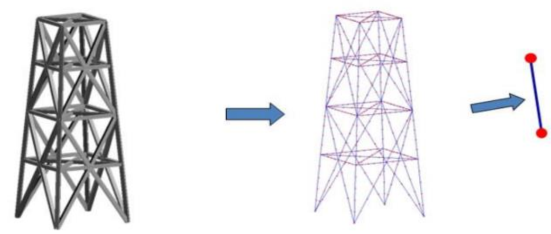


Finite element geometries

Elements are known geometry entities having global equations for calculating its characteristics under working conditions. Based on structural geometry and behaviour we can categorise it into 3 types as shown in the figures.

One Dimensional Elements

A one-dimensional element is one in which the properties of the element are defined along a line or curve. Typical applications for the one-dimensional element include truss structures, beams, stiffeners, and many others.1D beam elements are used to model long, slender structural members as demonstrated in this communications tower finite element model.



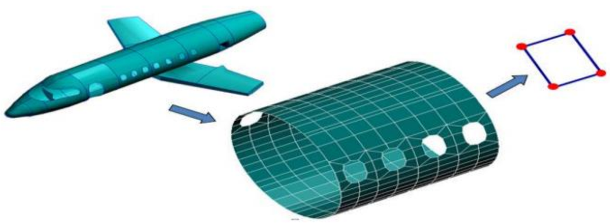
1D elements example-Tower

Two Dimensional Elements

Two-dimensional elements, commonly referred to as plate and shell elements, are used to represent areas in your model where one of the dimensions is small in comparison to the other two. 2D plate elements are used to model thin structural members such as aircraft fuselage skin or car body. In the finite element field, the membrane stiffness of the two-dimensional elements can be calculated using one of two theories: “plane stress” or “plane strain.” In the plane strain theory, the assumption is made that the strain across the thickness t is constant. Note that a two-dimensional element can be in either plane stress or plane strain, but not both.

By default, the commonly used linear two-dimensional elements in MSC Nastran are plane stress elements. Each of these two formulations, plane stress and plane strain, is applicable to certain classes of problems. If you are not familiar with the plane stress and plane strain theories, you probably need to use the plane stress formulation (the default). Most thin structures constructed from common engineering material, such as aluminium and steel, can be modelled effectively using plane stress.

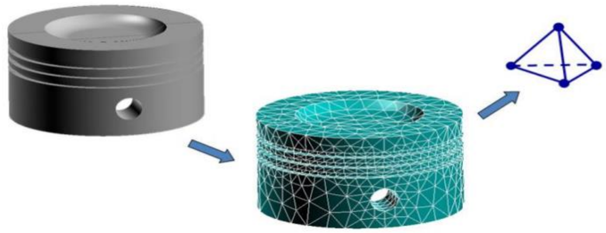
In other words, unless you have reason not to do so, use the plane stress formulation. See example billow how solid body discretized.



2D Elements example-plane structure

Three-Dimensional Elements

Whenever you need to model a structure that does not behave as a bar or plate structure under the applied loads, you need to use one or more of the three-dimensional elements. The three-dimensional elements are commonly referred to as solid elements. Typical engineering applications of solid elements include engine blocks, brackets, and gears.



3D Elements example-piston

As a final comment on all of the elements, the purpose of this chapter is to discuss the commonly used elements and their applications to typical engineering problems. The elements are discussed in order of their size in terms of the number of degrees-of-freedom they are not discussed in order of importance.

About MSC PATRAN, NASTRAN

NASTRAN is a finite element analysis (FEA) program that was originally developed for NASA in the late 1960s under United States government funding for the Aerospace industry. The MacNeal-Schwendler Corporation (MSC) was one of the principal and original developers of the public domain NASTRAN code MSC. Software is pleased to introduce you to the exciting new technologies in MSC Nastran, the premier and trusted CAE solution for aerospace, automotive, medical, defence, and manufacturing industries worldwide. This release includes new features and enhancements in Contact, High Performance Computing, Acoustics, Aeroelasticity, and Explicit Nonlinear SOL 700.
MSC nastran does not have any graphical user interface like other software. It completely communicates by using scripting language or any other pre and post software like Patran, Simxpert and Hypermesh.

IV. ANALYSIS OF BRACKET

Material and Element Properties

We assume that the material is a continuum (contains no gaps or voids) and that all material properties remain constant. Definitions of related material properties are given as follows:

Linear: Deformations are directly proportional to the applied load (i.e., strain is directly proportional to stress).

Elastic: An elastic structure returns to its original, UN deformed shape when the load is removed.

Homogeneous: The material is the same throughout-material properties are independent of location within the material.

Isotropic: Material properties do not change with the direction of the material.

Modulus of elasticity (young's modulus) E:

E is the constant of proportionality relating stress to strain in the linear region. The greater the value of E, is the stiffer the material.

Shear modulus (modulus of rigidity) G:

G is the constant of proportionality relatingshear stress to shear strain in the linear region.

Poisson's ratio v: Poisson's ratio is the absolute value of the ratio of lateral linearstrain to axial linear strain.

In this project we are doing analysis using three different materials. These material properties are taken from MSC Software material library,

1. 2024-T3 Aluminum alloy,
2. Titanium 6AL-4V and,

3. 15-5PH (H1025) Stainless steel.

Chemical Composition of Materials

1. Chemical Composition of 2024-T3 Aluminum alloy

Component	Weight %
Al	93.50
Cu	4.4
Mg	1.5
Mn	0.6
Cr	Max 0.1
Si	Max 0.5
Ti	Max 0.15

Chemical Composition of 2024-T3 Aluminum alloy

2. Chemical Composition of Titanium 6AL-4V alloy

Component	Weight %
Al	6
Fe	Max 0.25
O	Max 0.2
Ti	90
V	4

Chemical Composition of Titanium 6AL-4V alloy

3. Chemical Composition of 15-5PH (H1025) Stainless steel

Component	Weight %
Fe	75
Cr	14.48
Cu	3.5
C	0.07
Ni	4.5
Mn	Max 1
Si	Max 1

Chemical Composition of 15-5PH (H1025) Stainless steel

Material properties of different metals

Titanium 6AL-4V alloy			
Youngs Modulus	E	1.10E+05	Mpa
Shear Modulus	G	4.40E+04	Mpa
Poissons Ratio	Mu	0.342	
Density	Rho	4430	Kg/m^3

Material properties of Titanium

2024-T3 Aluminum alloy			
Youngs Modulus	E	7.00E+04	Mpa
Shear Modulus	G	4.40E+04	Mpa
Poissons Ratio	Mu	0.3	
Density	Rho	2780	Kg/m^3

Material properties of Aluminum

15-5PH (H1025) Stainless steel			
Youngs Modulus	E	2.10E+05	Mpa
Shear Modulus	G	4.40E+04	Mpa
Poissons Ratio	Mu	0.3	
Density	Rho	7.8	Kg/m^3

Material properties of Steel

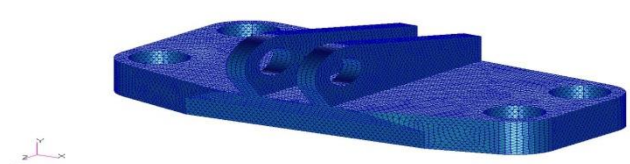
Meshing For Engine Bracket

A. Original Geometrical model

Model Summary:
Number of nodes= 59502
Number of elements= 280218
Number of Rigid Element = 5
Number of RBE2 element = 4
Number of RBE3element = 1
TETRA4: 280213

Original meshed model of engine bracket

B. Optimized Meshed Finite Element Model



Optimized meshed model of bracket

Model Summary:

Number of nodes= 32385
Number of elements= 147000
Number of Rigid Element = 5
Number of RBE2 element = 4
Number of RBE3element= 1

TETRA4: 146995

Loads and boundary conditions

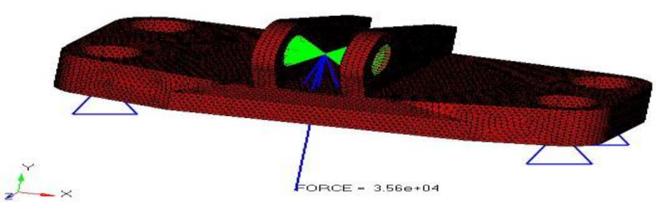
Load conditions taken from below reference 1.For this Linear Static Analysis the following boundary conditions are applied.

Load Case	Applied Load	Units
Vertical	35586	N
Horizontal	37810	N
Angle of 42^0 from vertical	42258	N

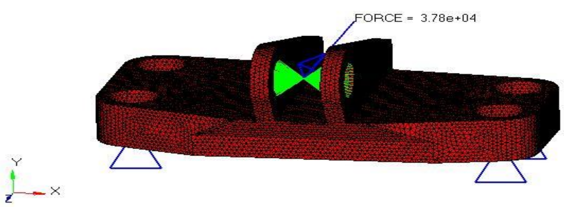
Load conditions for analysis

Here RBE2 elements for four bolts and those are constrained. RBE3 element for apply load.

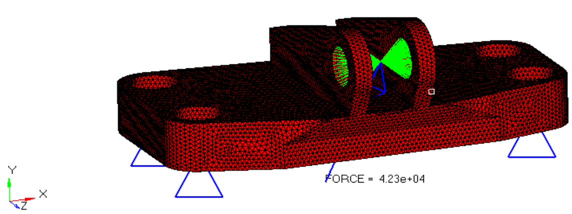
The below figure shows the positions of Loads and boundary conditions. The force value of 35586 N applied at center in downward direction is shown in figure.



Loads and boundary conditions of Vertical load case



Loads and boundary conditions of Horizontal load case



Loads and boundary conditions of Angle of 42^0 from vertical load case

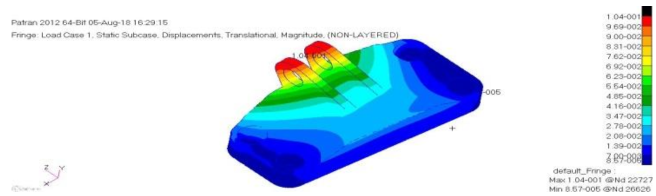
Linear Static Analysis of Bracket

Note: In this project we solved for three load conditions with three different materials such as 2024-T3 Aluminum alloy, Titanium 6AL-4V and 15-5PH (H1025) Stainless steel. Below discussed results for 2024-T3 Aluminum alloy for three load cases of Vertical, Horizontal, and Angle of 42^0 from vertical.

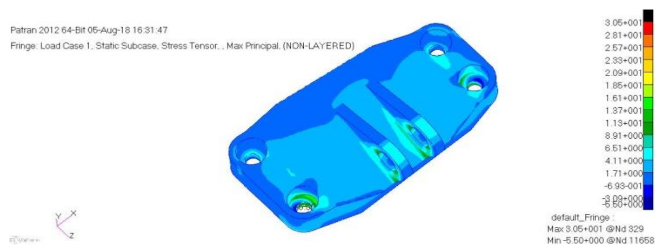
(A) Original Geometrical model

Material type: 2024-T3 Aluminum

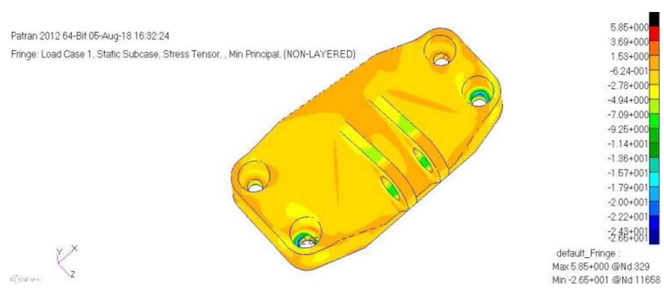
Load case1: Vertical



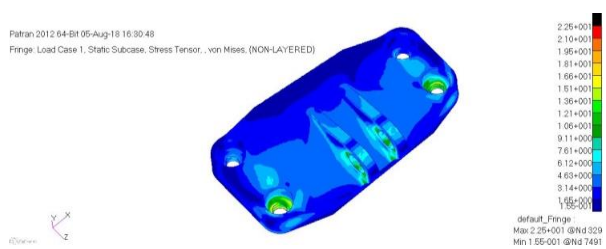
Displacements for vertical load



Max Principal Stress for vertical load

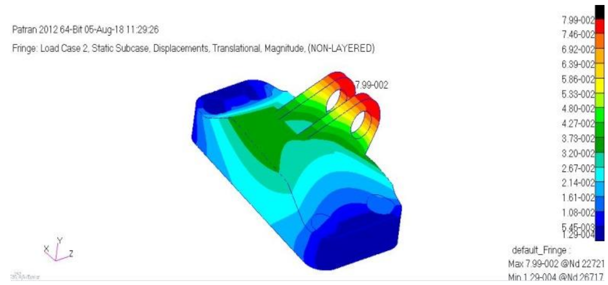


Min Principal Stress for vertical load

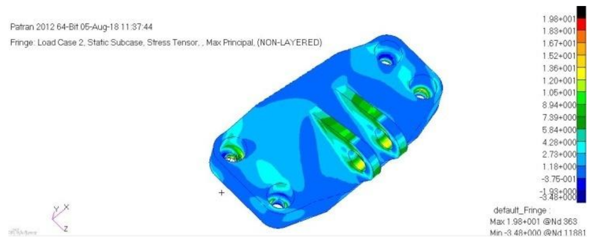


Equivalent (Von-Mises) stress for vertical load

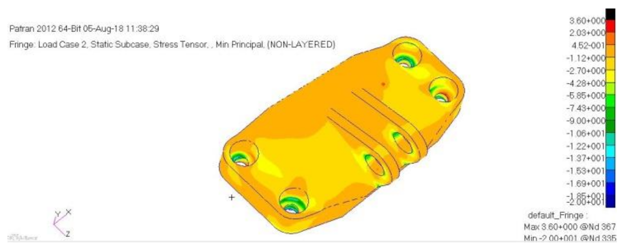
Load case 2: Horizontal



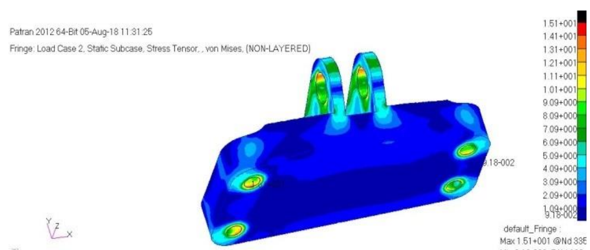
Displacements for Horizontal load



Max Principal Stress for Horizontal load

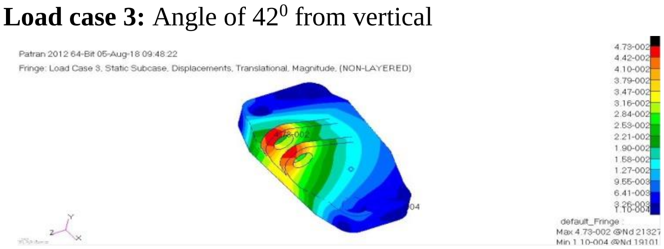


Min Principal Stress for Horizontal load

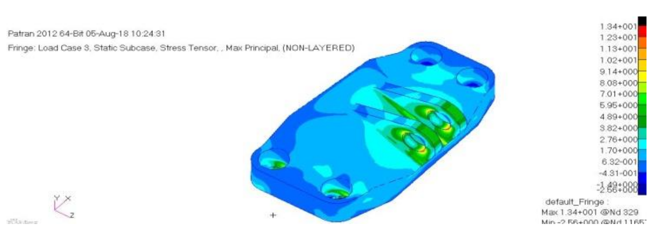


Equivalent (Von-Mises) Stress for Horizontal load

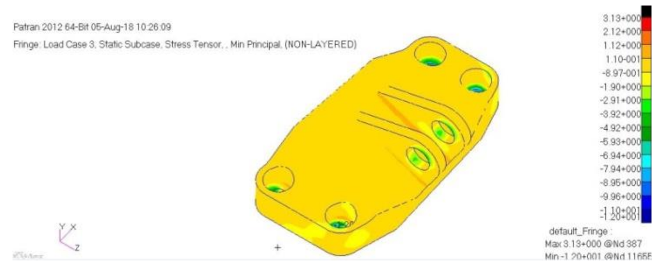
Load case 3: Angle of 42^0 from vertical



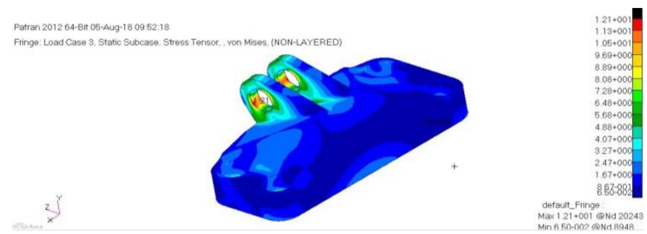
Displacement for Angle of 42^0 from vertical



Max-principal Stress for Angle of 42^0 from vertical



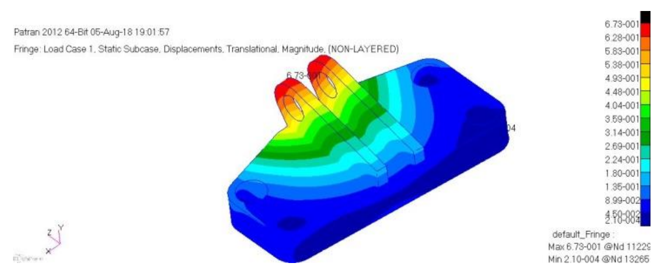
Min-principal Stress for Angle of 42^0 from vertical



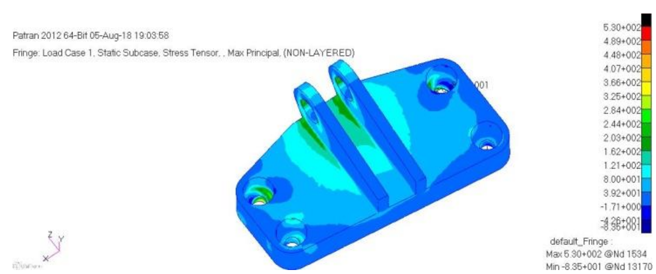
Equivalent (Von-Mises) stress for Angle of 42^0 from vertical

(B) Optimized model

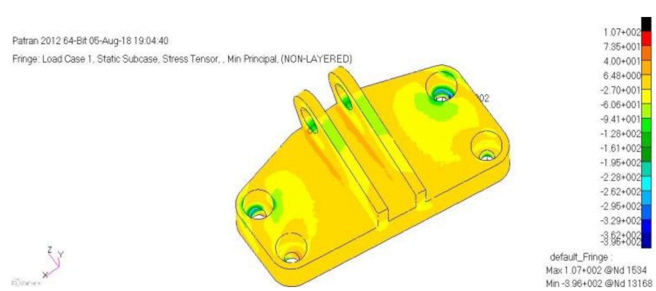
Load case1: Vertical



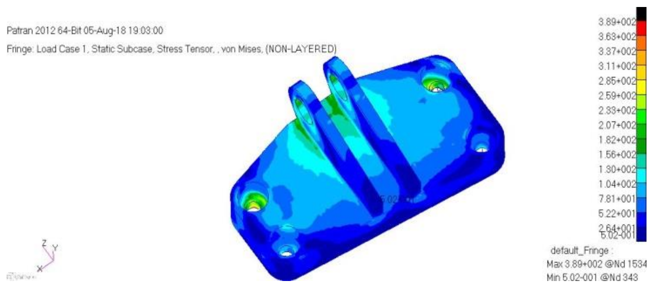
Displacements for vertical load



Max-principal Stress for vertical load

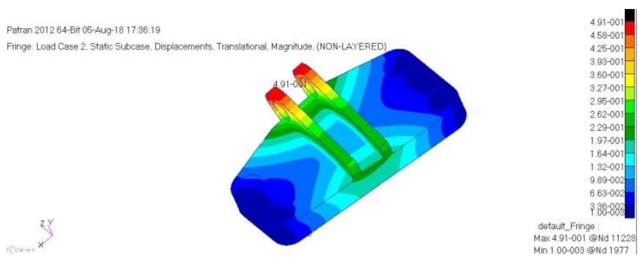


Min-principal Stress for vertical load

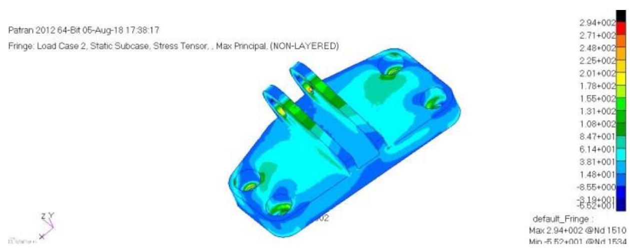


Equivalent (Von-Mises) stress for vertical load

Load case 2: horizontal

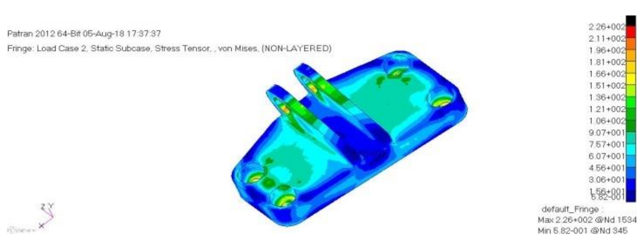


Displacements for horizontal load



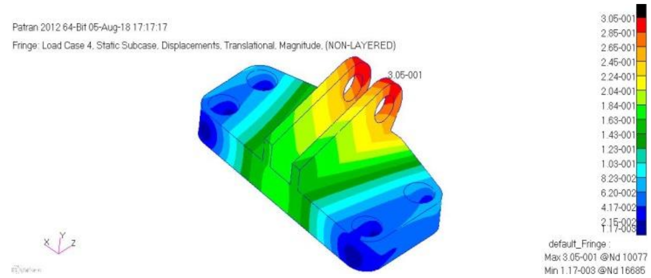
Max-principal stress for horizontal load

Min Principal Stress for horizontal load

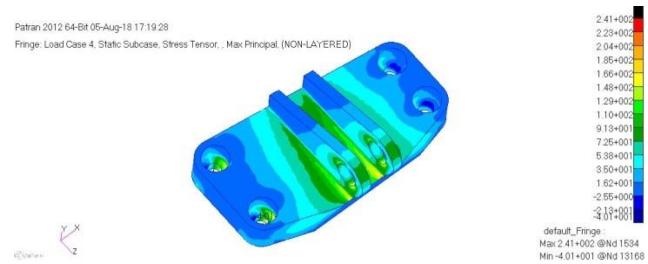


Equivalent (Von-Mises) stress for horizontal load

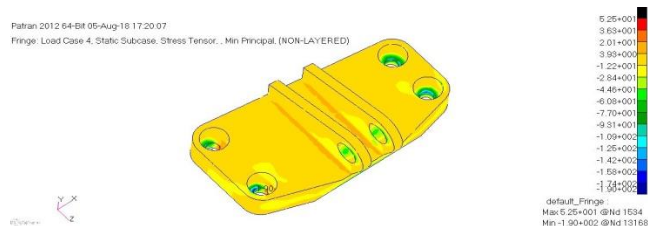
Load case 3: Angle of 42^0 from vertical



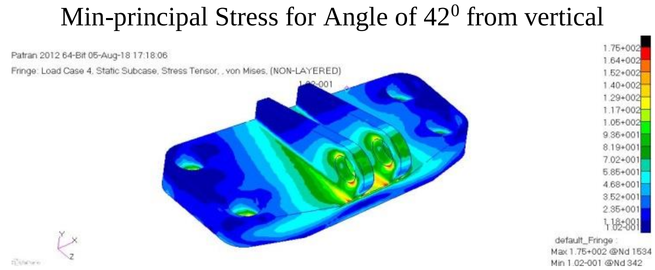
Displacement for Angle of 42^0 from vertical



Max-principal Stress for Angle of 42^0 from vertical



Min-principal Stress for Angle of 42^0 from vertical



Equivalent (Von-Mises) stress for Angle of 42^0 from vertical

V. INTRODUCTION OF FATIGUE

Fracture Mechanics

Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture.

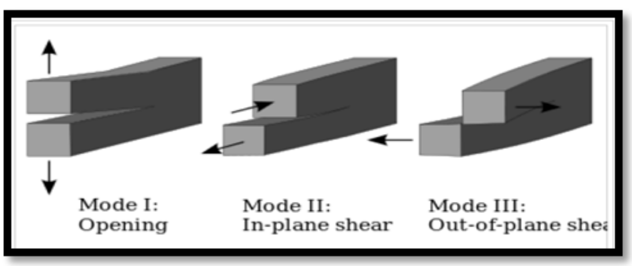
In modern materials science, fracture mechanics is an important tool in improving the mechanical performance of mechanical components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity, to the microscopic crystallographic defects found in real materials in order to predict the macroscopic mechanical failure of bodies. Fractography is widely used with fracture mechanics to understand the causes of failures and also verify the theoretical failure predictions with real life failures. The prediction of crack growth is at the heart of the damage tolerance discipline.

There are three ways of applying a force to enable a crack to propagate:

Mode I fracture – Opening mode (a tensile stress normal to the plane of the crack),

Mode II fracture – Sliding mode (a shear stress acting parallel to the plane of the crack and perpendicular to the crack front), and

Mode III fracture – Tearing mode (a shear stress acting parallel to the plane of the crack and parallel to the crack front).



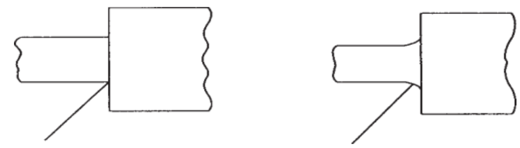
Modes of failure

Fatigue

Fatigue is the failure caused by application of repetitive load by the process of initiation of cracks and growth.

Structural members are frequently subjected to repetitive loading over a long period of time. For example, the members of a bridge structure suffer variations in loading possibly thousands of times a day as traffic moves over the bridge. In these circumstances a structural member may fracture at a level of stress substantially below the ultimate stress for non-repetitive static loads; this phenomenon is known as fatigue.

Fatigue cracks are most frequently initiated at sections in a structural member where changes in geometry, e.g. holes, notches or sudden changes in section, cause stress concentrations. Designers seek to eliminate such areas by ensuring that rapid changes in section are as smooth as possible. At re-entrant corners for example, fillets are provided as shown in Fig.

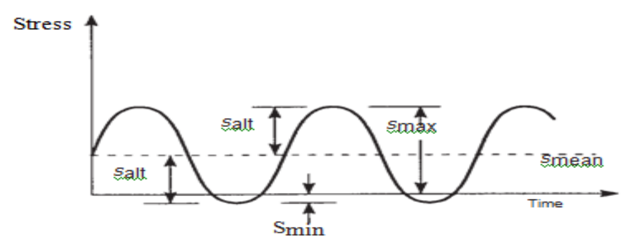


a)Location of stress concentration
b)Provision of fillet minimizes stress concentration

Stress concentration locations

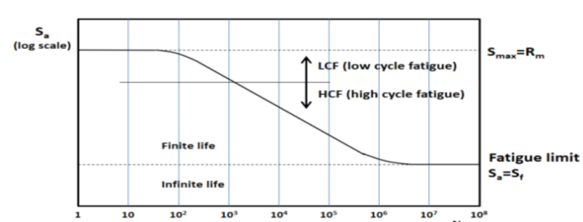
Other factors which affect the failure of a material under repetitive loading are the type of loading (fatigue is primarily a problem with repeated tensile stresses due, probably, to the fact that microscopic cracks can propagate more easily under tension), temperature, the material, surface finish (machine marks are potential crack propagators), corrosion and residual stresses produced by welding.

Frequently in structural members an alternating stress, S_{alt}, is superimposed on a static or mean stress, S_{mean}, as illustrated in Fig.



Alternating stress in fatigue loading.

The value of S_{alt} is the most important factor in determining the number of cycles of load that produce failure. The stress S_{alt} that can be withstood for a specified number of cycles is called the fatigue strength of the material. Some materials, such as mild steel, possess a stress level that can be withstood for an indefinite number of cycles. This stress is known as the endurance limit of the material; no such limit has been found for Aluminum and its alloys. Fatigue data are frequently presented in the form of an S–n curve or stress–endurance curve as shown in Fig.



S-N Curve

Fatigue properties of materials are often described using the fatigue limit or the S-N curve (fatigue curve, Wohler curve). The S-N curve describes the relation between cyclic stress amplitude and number of cycles to failure. The figure below shows a typical S-N curve. On the horizontal axis the number of cycles to failure is given on logarithmic scale. On the vertical axis (either linear or logarithmic) the stress amplitude (sometimes the maximum stress) of the cycle is given. S-N curves are derived from fatigue tests. Tests are performed by applying a cyclic stress with constant amplitude (CA) on specimens until failure of the specimen. In some cases the test is stopped after a very large number of cycles ($N>10^6$). The results are then interpreted as infinite life.

High Cycle Fatigue (HCF): component subjected to less sever loads and life > 10^5 cycles. In this region the material behaviour is fully elastic. On log-log scale the S-N curve can be considered to be linear.

Low Cycle Fatigue (LCF): life of component is less than 100000cycles, applicable for heavy duty application loading. If the maximum stress level in a cycle is exceeding the yield strength, the material behaviour in the net section will be predominantly plastic. Number of cycles to failure will be very small. Usually a strain-life curve instead of the S-N curve is used to describe the fatigue behaviour.

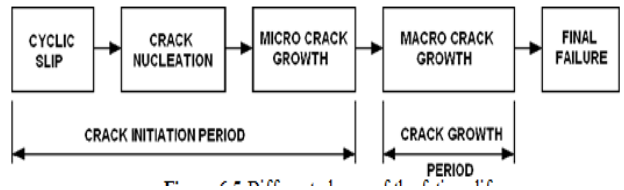
That the actual distinction between HCF and LCF is not defined by a certain number of cycles but by the amount of plasticity in the net section, i.e. the stress level.

Infinite Life: Stress level below which material never fails known as endurance limit or fatigue limit. Never fails or infinite life is a relative term. For steel, test is stooped after $2*10^6$ cycles (in case if till then failure is not detected) and said to have infinite life. This is the point where the S-N curve slop changes and it becomes parallel to x-axis.

Unlike steel, non-ferrous alloys have no specific endurance limit (S-N curve never become parallel to x-axis.The level of the fatigue limit depends on many factors, such as geometry (stress concentration factor Kt), mean stress (stress ratio), surface conditions, corrosion, temperature, and residual stresses.

Different Phases of fatigue Life

The crack starts as a slip band within a grain. The cyclic slip occurs as a result of cyclic shear stress, this slip leads to formation of slip steps, in the present of oxygen, the freshly exposed surface of the material in slip steps get oxidized, which prevents slip reversal. The slip reversal in this case occurs in some adjacent slip plane, thereby leading to formation of extrusions and intrusions on the surface of the material as shown in the figure below.



Different phases of the fatigue life

The fatigue life (N_f) of a component is defined by the total number of stress cycles required to cause failure. Fatigue life can be separated into three stages where:

$$N_f = N_i + N_p$$

Crack initiation(N_i)

This is the number of cycles required to initiate a crack. It generally results from dislocation pile-ups and imperfections such as surface roughness, voids, scratch etc. hence; in this period fatigue is a material surface phenomenon.

The stress concentration factor, K_t is another factor to be considered in crack initiation prediction.

Crack growthN_p

This is the number of cycles required to grow the crack in a stable manner to a critical size, generally controlled by stress level. Since most common material contains flaws, the prediction of crack growth is the most studied aspect of fatigue. Crack growth resistance, when the crack penetrates the material, depends on the material as a bulk property. It is no longer a surface phenomenon. The stress intensity factor is an important factor for fatigue growth prediction.

Rapidfracture

Very rapid critical crack growth occurs when the crack length reaches a critical value. Since rapid fracture occurs quickly, there is no rapid fracture term in the fatigue life expression.

The fracture toughness K_{IC} of the material is the primary factor for rapid fracture prediction or design against fracture.

FATIGUE CALCULATIONS OF AIRCRAFT ENGINE BRACKET

Note: Here we discussed the calculations for 2024-T3 Aluminum alloyof three load conditions.

(A) Original Model

Fatigue life Equation for 2024-T3 Aluminum alloy:

Load case 1: Vertical

$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.56}$
$S_{eq\,=}\,30.50(1\text{-}0.1)^{\,0.56}$
$S_{eq\,=}\,28.75$ Mpa
Log $N_{f\,=}$ 11.1 – 3.97log (S_{eq}- 15.8)
Log $N_{f\,=}$ 10^5*(10 ^ (11.1-3.97*Log (28.75 -15.8)))
Log $N_{f\ =}$4.83E+11 N

Load case 2: Horizontal

$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.56}$
$S_{eq\,=}\,15.10(1\text{-}0.1)^{\,0.56}$
$S_{eq\,=}\,14.23$ Mpa
Log $N_{f\,=}$ 11.1 – 3.97log (S_{eq}- 15.8)
Log $N_{f\,=}$ 10^5*(10 ^ (11.1-3.97*Log (14.23-15.8)))
Log $N_{f\ =}$2.13E+15 N

Load case 3: Angle of 42^0 from vertical

$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.56}$
$S_{eq\,=}\,12.10(1\text{-}0.1)^{\,0.56}$
$S_{eq\,=}\,11.41$Mpa
Log $N_{f\,=}$ 11.1 – 3.97log (S_{eq}- 15.8)
Log $N_{f\,=}$ 10^5*(10 ^ (11.1-3.97*Log (11.41-15.8)))
Log $N_{f\ =}$3.53E+13N

(B) Featured Model

Fatigue life Equation for 2024-T3 Aluminum alloy:

Load case 1: Vertical

$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.56}$
$S_{eq\,=}\,530(1\text{-}0.1)^{\,0.56}$
$S_{eq\,=}\,499.63$Mpa
Log $N_{f\,=}$ 11.1 – 3.97log (S_{eq}- 15.8)
Log $N_{f\,=}$ 10^5*(10 ^ (11.1-3.97*Log (499.63-15.8)))
Log $N_{f=}$ 2.77E+05N

Load case 2: Horizontal

$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.56}$
$S_{eq\,=}\,294(1\text{-}0.1)^{\,0.56}$
$S_{eq\,=}\,277.16$Mpa
Log $N_{f\,=}$ 11.1 – 3.97log (S_{eq}- 15.8)
Log $N_{f\,=}$ 10^5*(10 ^ (11.1-3.97*Log (277.16-15.8)))
Log $N_{f=}$ 3.19E+06N

Load case 3: Angle of 42^0 from vertical

$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.56}$
$S_{eq\,=}\,241(1\text{-}0.1)^{\,0.56}$
$S_{eq\,=}\,227.19$Mpa
Log $N_{f\,=}$ 11.1 – 3.97log (S_{eq}- 15.8)
Log $N_{f\,=}$ 10^5*(10 ^ (11.1-3.97*Log (227.19-15.8)))
Log $N_{f=}$ 7.40E+06 N

Fatigue life Equation for 2024-T3 Titanium 6AL-4V alloy

Log $N_{f\,=}$ 11.75 – 4.45log (S_{eq}- 15.0)
$S_{eq\,=}\,S_{max}(1\text{-}R)^{\,0.62}$

Fatigue life Equation for 15-5PH (H1025) Stainless steel
Log $N_{f\,=}$ 8.72 – 2.56log (S_{max}– 34.9)

VI. RESULTS

Analysed Results

Convergence study for different material for original engine bracket.

Materials	Load Case	Displacemet (mm)	Stress: Von-mises stress (Mpa)	Stress: Max Principal stress (Mpa)	Stress: Min Principal stress (Mpa)	Stress: Max Stress (Smax) (Mpa)	Stress: Seq (Mpa)	High Cycle Fatigue (N)
Aluminum	Vertical	0.01	22.50	30.50	5.85	30.50	28.75	4.83E+11
	Horizontal	0.08	15.10	2.79	-7.64	15.10	14.23	2.13E+15
	Angle_42	0.05	12.10	11.90	-0.09	12.10	11.41	3.53E+13
Steel	Vertical	0.03	22.50	30.50	5.85	30.50	-	1.18E+12
	Horizontal	0.03	15.10	1.29	-9.15	15.10	-	2.51E+10
	Angle_42	0.02	12.10	11.90	0.01	12.10	-	1.75E+10
Titanium	Vertical	0.07	22.10	32.60	8.12	32.60	30.54	2.81E+11
	Horizontal	0.05	14.80	2.50	-7.66	14.80	13.86	3.19E+16
	Angle_42	0.03	12.10	12.10	0.27	12.10	11.33	1.74E+14

Analysed results of original engine bracket

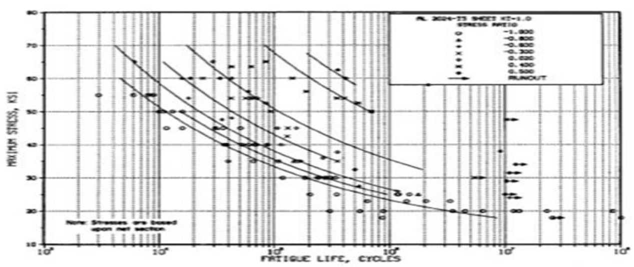
Convergence study for different material for optimized engine bracket.

Materials	Load Case	Displacement (mm)	Stress: Von-mises stress (Mpa)	Stress: Max Principal stress (Mpa)	Stress: Min Principal stress (Mpa)	Stress: Maximum Stress (Smax) (Mpa)	Stress: Seq (Mpa)	High Cycle Fatigue (N)
Aluminum	Vertical	0.67	389.00	530.00	107.00	530.00	499.63	2.77E+05
	Horizontal	0.49	226.00	294.00	46.60	294.00	277.16	3.19E+06
	Angle_42	0.30	175.00	241.00	52.50	241.00	227.19	7.40E+06
Steel	Vertical	0.22	389.00	530.00	107.00	530.00	-	6.63E+06
	Horizontal	0.16	226.00	294.00	46.60	294.00	-	3.48E+07
	Angle_42	0.10	175.00	241.00	52.50	241.00	-	6.25E+07
Titanium	Vertical	0.43	376.00	561.00	149.00	561.00	525.52	5.00E+04
	Horizontal	0.32	218.00	313.00	71.10	313.00	293.21	7.46E+05
	Angle_42	0.19	173.00	256.00	71.40	256.00	239.81	1.92E+06

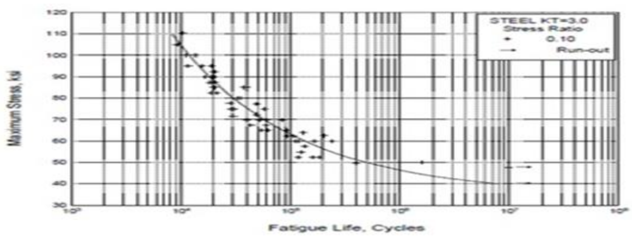
Analysed results of optimized engine bracket

The above tables show the summary of the results for engine mounting Bracket for the various materials, and the observed results are within the allowable limits. Hence the design is safe.

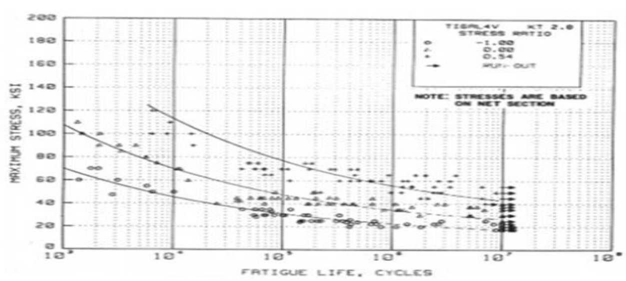
Graphs



S-NCurve for 2024-T3 Aluminum alloy



S-N Curve 15-5PH (H1025) Stainless steel



S-N Curve for Titanium 6AL-4V

VII. CONCLUSION

The engine mount bracket is key important structural member in order to proper functioning of the engine.Various analyses carried out on the mounting bracket to check its strength and stability for different loadings comes from engine and supporting structure. The study was done using various materials which are 2024-T3 Aluminum alloy, Titanium 6AL-4V and 15-5PH (H1025) Stainless Steel. Objective is to study the strength and fatigue life of the bracket with geometry and material change.Based on the study and analysis, in three load cases (Vertical, Horizontal and Angle of $42^0$from vertical) with three materials the life of bracket is> 10^5 cycles. By comparing of mechanical properties, cost and applications,Aluminum is better than all other two materials.

In future studies I am planning to produce my final optimized model and conduct live experiments to understand the quality and stability of the bracket.

As we know that engine components must made up of most heat resistant metals as it create more temperature. I am extending this study for thermo-structural analysis future used case.

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