

Design and Fatigue Analysis of Fuselage and Wing Joint

Rudrapala Kirankumar

M.Tech Student

Department of Aerospace
Engineering
MLR Institute of Technology,
Hyderabad.

Mr. M. Ganesh

Assistant Professor

Department of Aerospace
Engineering
MLR Institute of Technology,
Hyderabad.

B.Dinesh Kumar

Assistant Professor

Department of Aerospace
Engineering
MLR Institute of Technology,
Hyderabad.

Abstract:

Fatigue is progressive failure mechanism and material degradation initiates with the first cycle. The degradation/damage accumulation progresses until a finite crack is nucleated, then the crack propagates until the failure process culminates in a complete failure of the structures. The total life from first cycle to the complete failure can be divided into three stages: Initial life interval, Life interval, Final Life interval. The fatigue damage is mainly based on two designs: FAIL-SAFE and SAFE-LIFE. The objective is to design a Fail-Safe Structural component. In this project we have designed a Wing-Bracket interaction which was not yet designed by any of the industry. And we have estimated the fatigue life of our Wing-Bracket attachment model. Here we compared the fatigue life of our model with three materials such as Maraging Steel, Titanium and Structural A36 steel. Among this three we have proved that Maraging steel gives more fatigue life compared to other two materials. For estimating the fatigue life we have made some hand calculations.

Finally we have represented the fatigue life with the help of Goodman Curve. The Structural Component is designed and analysed using CATIA and ANSYS Softwares. In analysis the maximum stress at which the component undergoes degradation/damage is calculated for different End Conditions (loadings and stresses), which determines the fatigue life of the component.

1.1 Introduction

The fuselage is an aircraft's main body section that holds crew and passengers or cargo. In single-engine aircraft it will usually contain an engine, although

although in some amphibious aircraft the single engine is mounted on a pylon attached to the fuselage which in turn is used as a floating hull. The fuselage also serves to position control and stabilization surfaces in specific relationships to lifting surfaces, required for aircraft stability and maneuverability.

Airplanes are transportation devices which are designed to move people and cargo from one place to another. Airplanes come in many different shapes and sizes depending on the mission of the aircraft. The airplane shown on this slide is a turbine-powered airliner which has been chosen as a representative aircraft.

The fuselage, or body of the airplane, is a long hollow tube which holds all the pieces of an airplane together. The fuselage is hollow to reduce weight. As with most other parts of the airplane, the shape of the fuselage is normally determined by the mission of the aircraft. A supersonic fighter very slender, streamlined fuselage from to reduce the drag associated with high speed flight. An airliner has a wider fuselage to carry the maximum number of passengers. On an airliner, the pilots sit in a cockpit at the front of the fuselage. Passengers and cargo are carried in the rear of the fuselage and the fuel is usually stored in the wings. For a fighter plane, the cockpit is normally on top of the fuselage, weapons are carried on the wings, and the engines and fuel are placed at the rear of the fuselage.

The weight of an aircraft is distributed all along the aircraft. The fuselage, along with the passengers and cargo, contribute a significant portion of the weight of an aircraft. The center of gravity of the aircraft is the average location of the weight and it is usually located

inside the fuselage. In flight, the aircraft rotates around the center of gravity because of torques generated by the elevator, rudder, and ailerons. The fuselage must be designed with enough strength to withstand these torques.

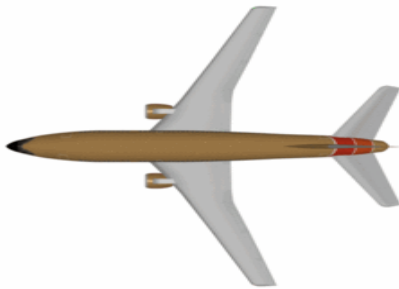


Fig 1.1 Fuselage of a Boeing 737 shown in brown

1.2 Airframe

The airframe of an aircraft is its mechanical structure. It is typically considered to include fuselage, wings and undercarriage and exclude the propulsion system. Airframe design is a field of aerospace engineering that combines aerodynamics, materials technology and manufacturing methods to achieve balances of performance, reliability and cost.

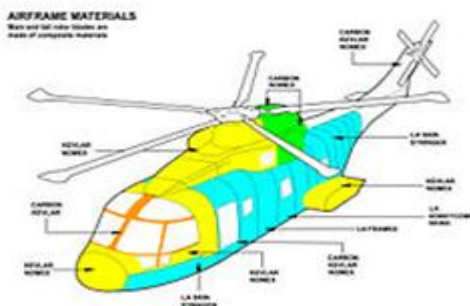


Fig 1.2. Airframe diagram

The empennage, also known as the tail or tail assembly, of most aircraft^{[1][2]} gives stability to the aircraft, in a similar way to the feathers on an arrow the term derives from the French for this. Most aircraft feature an empennage incorporating vertical and horizontal stabilising surfaces which stabilise the flight dynamics of yaw and pitch, as well as housing control surfaces.

In spite of effective control surfaces, many early aircraft that lacked a stabilising empennage were

virtually unflyable. Even so-called "tailless aircraft" usually have a tail fin (vertical stabiliser). Heavier than air aircraft without any kind of empennage are rare.



Fig 1.3 The empennage of a Boeing 747-200

2.1 Literature Survey



Wellington Mark X showing the geodesic construction and the level of punishment it could withstand while maintaining airworthiness

Modern airframe history began in the United States when a 1903 wood biplane made by Orville and Wilbur Wright showed the potential of fixed-wing designs. Many early developments were spurred by military needs during World War I. Well known aircraft from that era include the Dutch designer Anthony Fokker's combat aircraft for the German Empire's Luftstreitkräfte, and U.S. Curtiss flying boats and the German/Austrian Taube monoplanes. These used hybrid wood and metal structures. During the war, German engineer Hugo Junkers pioneered practical all-metal airframes as early as late 1915 with the Junkers J 1 and developed further with lighter weight duralumin in the airframe of the Junkers D.I of 1918, whose techniques were adopted almost unchanged after the war by both American

engineer William Bushnell Stout and Soviet aerospace engineer Andrei Tupolev. Commercial airframe development during the 1920s and 1930s focused on monoplane designs using radial piston engines. Many, such as the Ryan model flown across the Atlantic by Charles Lindbergh in 1927, were produced as single copies or in small quantity. William Stout's designs for the all-metal Ford 4-AT and 5-AT trimotors, Andrei Tupolev's designs in Joseph Stalin's Soviet Union for a series of all-metal aircraft of steadily increasing size, culminating in the enormous, eight-engined Maksim Gorky (the largest aircraft of its era), and with Donald Douglas' firm's development of the iconic Douglas DC-3 twin-engined airliner, were among the most successful designs to emerge from the era through the use of all-metal airframes. The original Junkers corrugated duralumin-covered airframe philosophy culminated in the 1932-origin Junkers Ju 52 trimotor airliner, used throughout World War II by the Nazi German Luftwaffe for transport and paratroop needs.

Types of structures

3.1 Truss structure

This type of structure is still in use in many lightweight aircraft using welded steel tube trusses. A box truss fuselage structure can also be built out of wood—often covered with plywood—as can be seen on this Ibis canard fuselage. Simple box structures may be rounded by the addition of supported lightweight stringers, allowing the fabric covering to form a more aerodynamic shape, or one more pleasing to the eye.

3.2 Geodesic construction



Fig 3.2 Geodesic airframe fuselage structure is exposed by battle damage

Geodesic structural elements were used by Barnes Wallis for British Vickers between the wars and into World War II to form the whole of the fuselage, including its aerodynamic shape. In this type of construction multiple flat strip stringers are wound about the formers in opposite spiral directions, forming a basket-like appearance. This proved to be light, strong, and rigid and had the advantage of being made almost entirely of wood. A similar construction using aluminum alloy was used in the Vickers Warwick with less materials than would be required for other structural types. The geodesic structure is also redundant and so can survive localized damage without catastrophic failure. A fabric covering over the structure completed the aerodynamic shell (see the Vickers Wellington for an example of a large warplane which uses this process). The logical evolution of this is the creation of fuselages using molded plywood, in which multiple sheets are laid with the grain in differing directions to give the monocoque type below.

3.3 Monocoque shell



Fig 3.3 The Van's Aircraft RV-7 fuselage is slender for high speed flight

In this method, the exterior surface of the fuselage is also the primary structure. A typical early form of this (see the Lockheed Vega) was built using molded plywood, where the layers of plywood are formed over a "plug" or within a mold. A later form of this structure uses fiberglass cloth impregnated with polyester or epoxy resin, instead of plywood, as the skin. A simple form of this used in some amateur-built

aircraft uses rigid expanded foam plastic as the core, with a fiberglass covering, eliminating the necessity of fabricating molds, but requiring more effort in finishing (see the RutanVariEze). An example of a larger molded plywood aircraft is the de Havilland Mosquito fighter/light bomber of World War II. No plywood-skin fuselage is truly monocoque, since stiffening elements are incorporated into the structure to carry concentrated loads that would otherwise buckle the thin skin. The use of molded fiberglass using negative ("female") molds (which give a nearly finished product) is prevalent in the series production of many modern sailplanes.

4.1 Introduction to CATIA

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite.

CATIA competes in the CAD/CAM/CAE market with Siemens NX, Pro/E, Autodesk Inventor, and Solid Edge as well as many others.

Developer(s)	Dassault Systems
Stable release	V6R2011x / November 23, 2010
Operating system	Unix / Windows
Type	CAD software
License	Proprietary
Website	www.3ds.com

Table 4.1 Details of CATIA

4.2 HISTORY OF CATIA

4.3 SCOPE OF APPLICATION

Commonly referred to as 3D Product Lifecycle Management software suite, CATIA supports multiple stages of product development (CAx), from conceptualization, design (CAD), manufacturing (CAM), and engineering (CAE). CATIA facilitates collaborative engineering across disciplines, including surfacing & shape design, mechanical engineering, equipment and systems engineering

4.4 Supported operating systems and platforms

CATIA V6: Runs only on Microsoft Windows and Mac OS with limited products.

CATIA V5: Runs on Microsoft Windows (both 32-bit and 64-bit), and as of Release 18 Service Pack 4 on Windows Vista 64, IBM AIX, Hewlett Packard HP-UX and Sun Microsystems Solaris are supported.

CATIA V4: Is supported for those Unixes and IBM MVS and VM/CMS mainframe platforms up to release 1.7.

CATIA V3: Earlier run on the mainframe platforms.

4.4.1 Surfacing & Shape Design

CATIA provides a suite of surfacing, reverse engineering, and visualization solutions to create, modify, and validate complex innovative shapes. From subdivision, styling, and Class A surfaces to mechanical functional surfaces.

4.4.2 Mechanical Engineering

CATIA enables the creation of 3D parts, from 3D sketches, sheet metal, composites, and molded, forged or tooling parts up to the definition of mechanical assemblies. It provides tools to complete product definition, including functional tolerances, as well as kinematics definition.

4.4.3 Equipment Design

CATIA facilitates the design of electronic, electrical as well as distributed systems such as fluid and HVAC systems, all the way to the production of documentation for manufacturing.

4.4.5 Systems Engineering

CATIA offers a solution to model complex and intelligent products through the systems engineering approach. It covers the requirements definition, the systems architecture, the behavior modeling and the virtual product or embedded software generation. CATIA can be customized via application programming interfaces (API). CATIA V5 & V6 can be adapted using Visual Basic and C++ programming languages via CAA (Component Application Architecture); a component object model (COM)-like interface. Although later versions of CATIA V4 implemented NURBS, V4 principally used piecewise polynomial surface. CATIA V4 uses a non-manifold solid engine.

Catia V5 features a parametric solid/surface-based package which uses NURBS as the core surface representation and has several workbenches that provide KBE support. V5 can work with other applications, including Enova, Smarteam, and various CAE Analysis applications.

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CADAM CAD software to develop Dassault's Mirage fighter jet, then was adopted in the aerospace, automotive, shipbuilding, and other industries.

Initially named CATI (Conception Assisted Tridimensionnelle Interactive - French for Interactive Aided Three-dimensional Design) - it was renamed CATIA in 1981, when Dassault created a subsidiary to develop and sell the software, and signed a non-exclusive distribution agreement with IBM.

In 1984, the Boeing Company chose CATIA as its main 3D CAD tool, becoming its largest customer. In 1988, CATIA version 3 was ported from mainframe computers to UNIX. In 1990, General Dynamics Electric Boat Corp chose CATIA as its main 3D CAD tool, to design the U.S. Navy's Virginia class submarine.

6.1 Model Analysis

Preference>Structural

Pre-Processor:

Preprocessor>Element type>Add>Solid>20 node 95

Preprocessor>Material Props>Material

Models>Structural>Linear>Elastic>Isotropic

EX=2.1.e5

PRXY=0.3

Preprocessor>Material

Props>Material

Models>Structural>Density>8.1e-6

Solution:

Solution>Analysis Type>New Analysis>Modal

Solution>Analysis Type>Analysis Options>

No. of modes to extract = 6

No. of modes to expand = 6

Solution>Solve>Current LS

General Postproc:

General Postproc>Results Summary

General Postproc>Read Results>By First Set

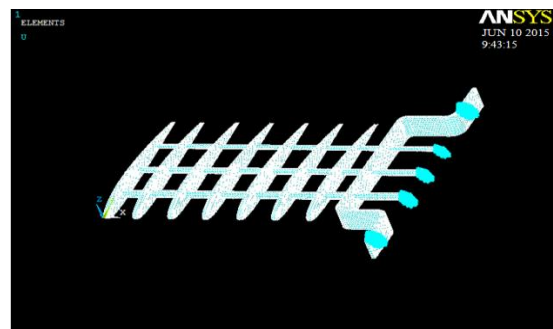
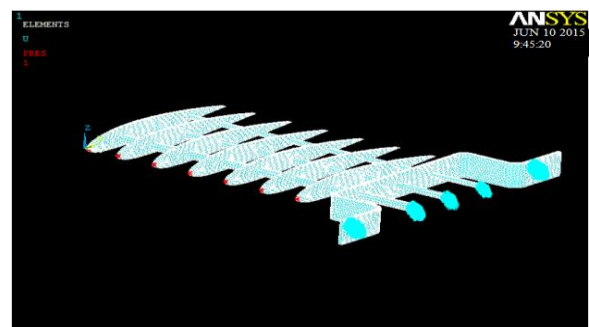
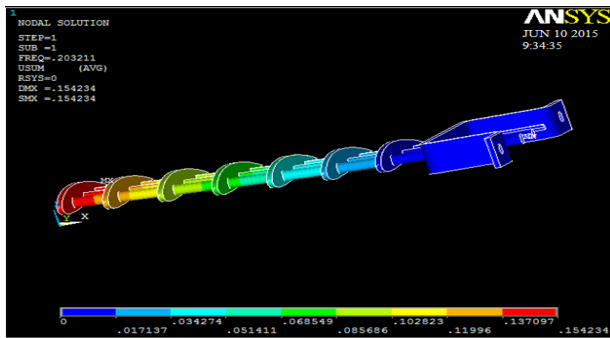


Fig 6.1 Elements Created In Ansys

Fig 6.2 Elements with Loads





First mode of Frequency

General Postproc>Read Results>By Next Set
General Postproc>Plot results>Contour Plot>Nodal Solution>DOF>Displacement Vector Sum

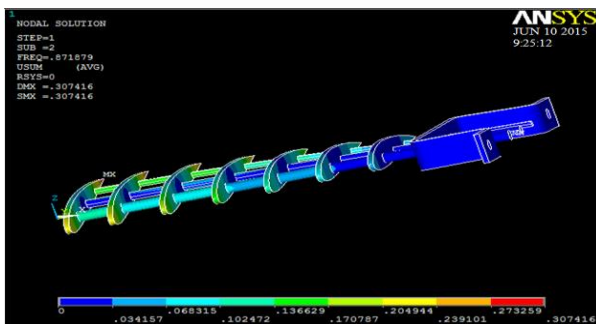


Fig 6.3 Second mode of Frequency

General Postproc>Read Results>By Next Set
General Postproc>Plot results>Contour Plot>Nodal Solution>DOF>Displacement Vector Sum

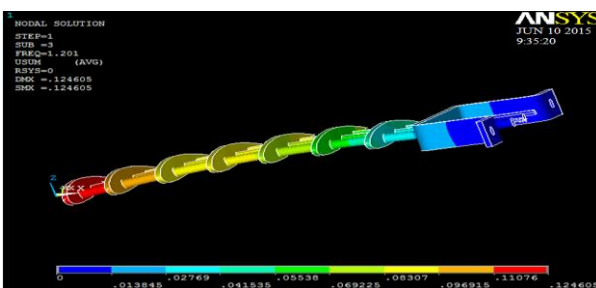


Fig 6.4 Third mode of Frequency

6.2 Maraging Steel

Preferences>Structural

Pre-Processor:

Preprocessor>Element type>Add>Solid>20 node95

Preprocessor>Material Props>Material Models>Structural>Density>8.1e-6
Preprocessor>Material Props>Material Models>Structural>Linear>Elastic>Isotropic>EX=2.1e5
PRXY=0.3
Solution>Define
Loads>Apply>Structural>Pressure>On nodes>Pick all the leading edges of the airfoil and provide pressure value as 1MPa

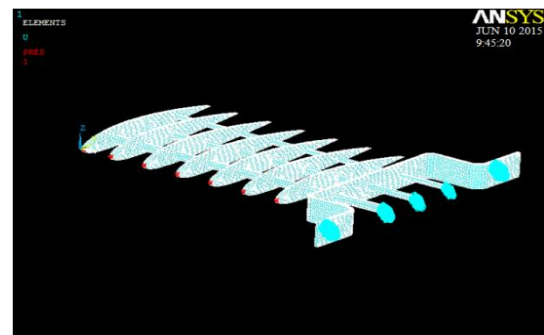


Fig 6.5 Modal with Pressure force of 1Mpa

Solution>Load Step Opts>Write LS file>1
Solution>Solve>Current LS

6.3 General Postproc

General Postproc>Plot Results>Contour Plot>Nodal Solution>DOF>Displacement Vector Sum

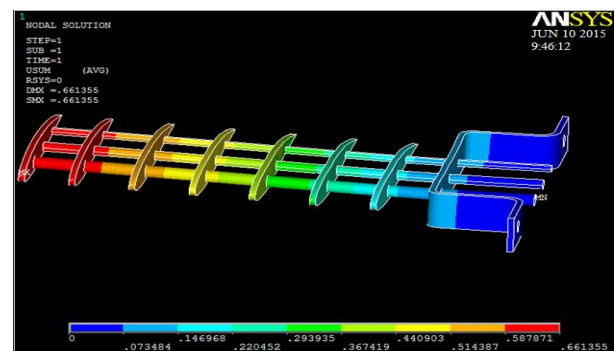


Fig 6.6 Displacement Vector Sum

General Postproc>Plot Results>Contour Plot>Nodal Solution>Stress>1st Principal Stress

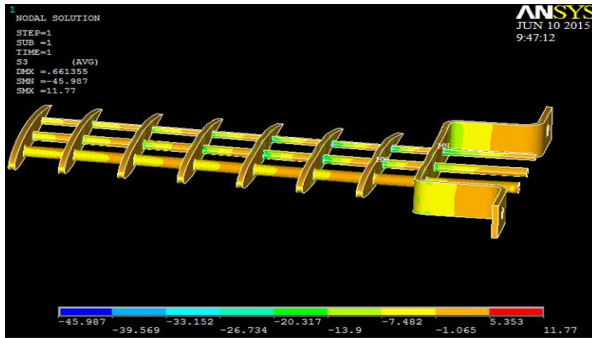


Fig 6.7 Principal Stress

General Postproc>Plot Results>Contour Plot>Nodal Solution>Stress>VonMisesstress

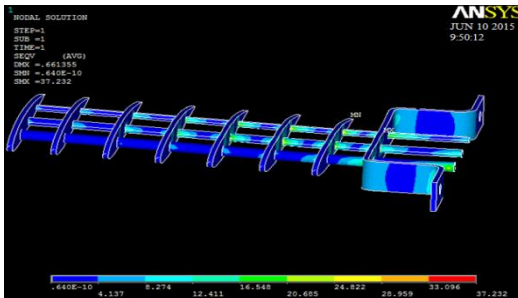


Fig 6.8 VonMises Stress

6.4 Titanium

Preferences>Structural

6.4.1 Pre-Processor:

Preprocessor>Element type>Add>Solid>20 node95
 Preprocessor>Material Props>Material
 Models>Structural> Density>4.4e-6
 Preprocessor>Material Props>Material
 Models>Structural>Linear>Elastic>Isotropic>
 EX=1.1e5
 PRXY=0.32

6.4.2 Pre-Processor:

Preprocessor>Element type>Add>Solid>20 node95
 Preprocessor>Material Props>Material
 Models>Structural> Density>8.1e-6
 Preprocessor>Material Props>Material
 Models>Structural>Linear>Elastic>Isotropic>
 EX=2.1e5
 PRXY=0.3

Solution>Define

Loads>Apply>Structural>Pressure>On nodes>

Pick all the leading edges of the airfoil and provide pressure value as 1MPa

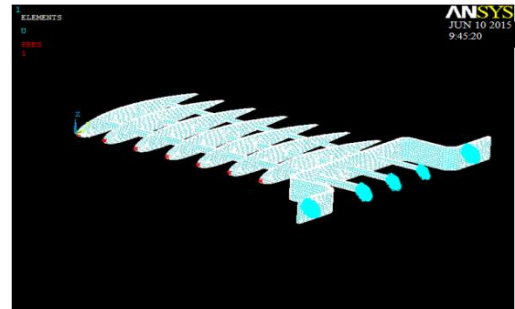


Fig 6.9 Modal with Pressure force of 1Mpa

Solution>Load Step Opts>Write LS file>1

Solution>Solve>Current LS

6.4.3 General Postproc:

General Postproc>Plot Results>Contour Plot>Nodal Solution>DOF>Displacement Vector Sum

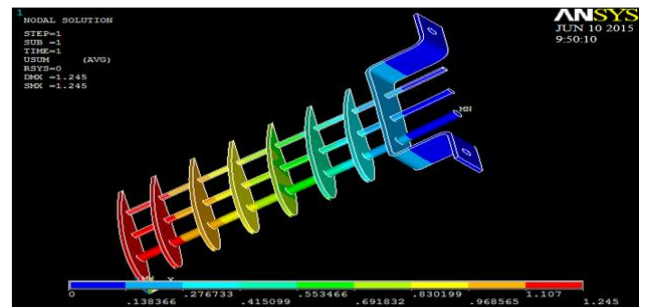


Fig 6.10 Displacement Vector Sum

General Postproc>Plot Results>Contour Plot>Nodal Solution>Stress>1st Principal Stress

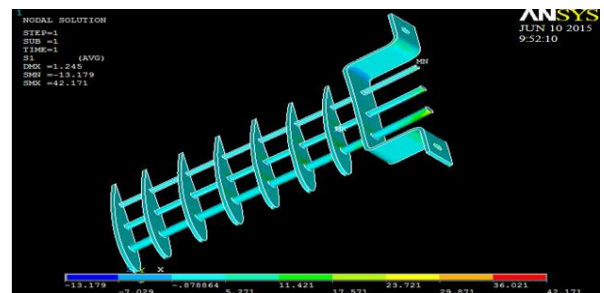


Fig 6.11 First Principal Stress

General Postproc>Plot Results>Contour Plot>Nodal Solution>Stress>3rd Principal Stress

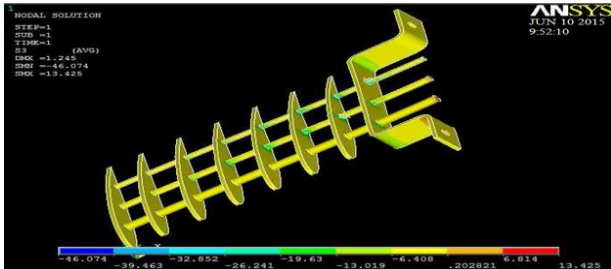


Fig 6.12 Third Principal Stress

General Postproc>Plot Results>Contour Plot>Nodal Solution>Stress>VonMises stress

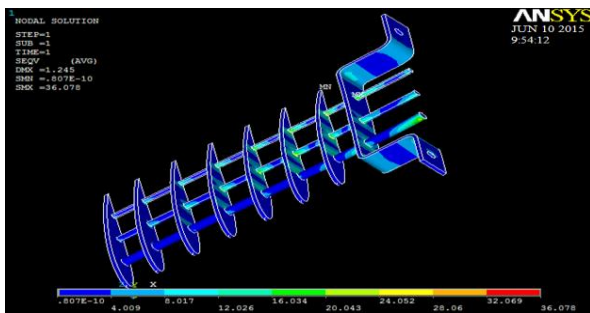


Fig 6.13 VonMises Stress

6.5 Structural A36 Steel

Preferences>Structural

6.5.1 Pre-processor:

Preprocessor>Element type>Add>Solid>20 node95

Preprocessor>Material Props>Material

Models>Structural>Density>7.8e-6

Preprocessor>Material Props>Material

Models>Structural>Linear>Elastic>Isotropic>

EX=2e5

PRXY=0.26

Solution>Analysis Type>New Analysis>Static

Solution>Analysis Type>Sol'n Controls>Basic>Check

Prestress effects

Solution>Define

Loads>Apply>Structural>Displacements>On nodes>

Pick bracket holes and cylinders edges and select All DOF

Solution>Define

Loads>Apply>Structural>Pressure>On nodes>

Pick all the leading edges of the airfoil and provide pressure value as 1MPa

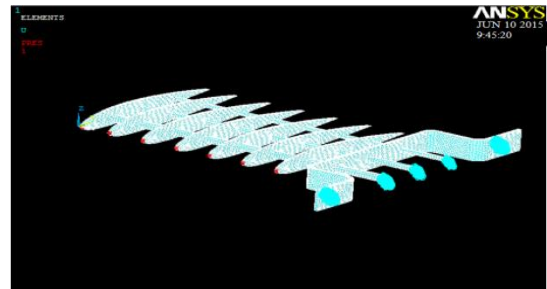


Fig 6.14 Modal with Pressure force of 1MPa

Solution>Load Step Opts>Write LS file>1

Solution>Solve>Current LS

6.5.2 General Postproc

General Postproc>Plot Results>Contour Plot>Nodal

Solution>DOF>Displacement Vector Sum

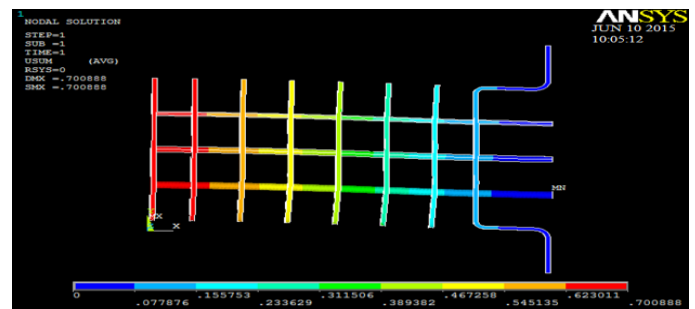


Fig 6.15 Displacement Vector Sum

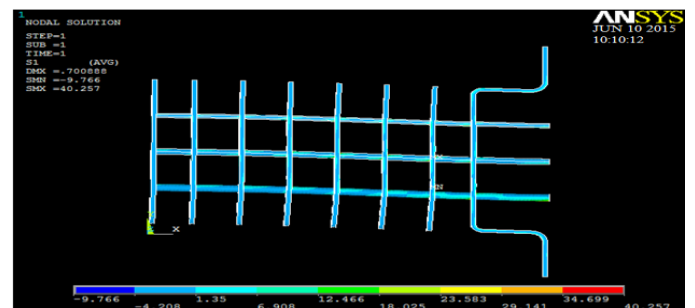


Fig 6.16 First Principal Stress

General Postproc>Plot Results>Contour Plot>Nodal Solution>Stress>VonMises stres

6.6 Calculations

6.6.1 For Maraging Steel

Yield Strength $S_y = 2617\text{Mpa}$
 Ultimate Strength $S_u = 2693\text{Mpa}$
 Endurance limit from guide lines $Se1 = 0.504 * S_u = 1357.272$
 Surface Finish Factor $K_a = a * S_u^b = 0.10507121$
 Size Factor $K_b = (d/7.62)^{-0.1133} = 0.856185089$
 Load Type Factor $K_c = 0.577$
 Temperature Factor $K_d = ST/SRT = 1$
 Miscellaneous effects factor $K_e = 1/K_f = 1$
 Endurance Limit for machine element under investigation $Se = Se1 + K_a + K_b + K_c + K_d + K_e = 1360.810256$

Graph axis
 0 2693
 2617 0
 From analysis

$S_a = 14.605$
 $S_m = 26.375$

6.6.2 Life Cycle Calculations

$\text{Log}(0.9 * S_u) = 3.384478863$
 $\text{Log}(Se) = 3.130434545$
 $\text{Log}(S_f) = 1.421192468$
 $\text{Log}N = 26.18437681$
 $N = 152,889,199,106,666,000,000,000.00$

6.6.3 For Titanium

Yield Strength $S_y = 940\text{Mpa}$
 Ultimate Strength $S_u = 1040\text{Mpa}$
 Endurance limit from guide lines $Se1 = 0.504 * S_u = 524.16$
 Surface Finish Factor $K_a = a * S_u^b = 0.270782586$
 Size Factor $K_b = (d/7.62)^{-0.1133} = 0.856185089$
 Load Type Factor $K_c = 0.577$
 Temperature Factor $K_d = ST/SRT = 1$
 Miscellaneous effects factor $K_e = 1/K_f = 1$
 Endurance Limit for machine element under investigation $Se = Se1 + K_a + K_b + K_c + K_d + K_e = 527.8639677$

Graph axis
 0 1040
 940 0
 From analysis
 $S_a = 14.373$

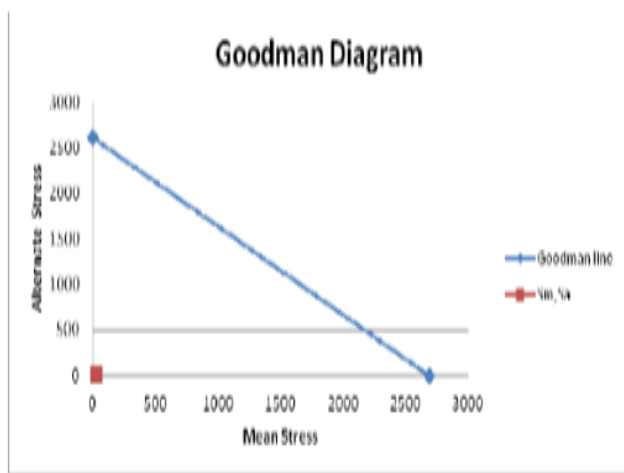


Fig 6.18 Goodman Diagram for Maraging Steel

Conclusion

The model we designed looks very simple and easy to understand. Actually it is not conventional wing Bracket interaction. But we have used new Bracket to wing fuselage interaction. We Compared the Fatigue Life of our Wing Bracket Interaction model with three materials Maraging steel, Titanium and Structural A36 Steel. Our model is based on stress based approach which involves high cycle fatigue. This is clearly explained with the help of S-N curve. Among these three materials Fatigue Life of Wing Bracket Interaction with Maraging steel gives more Fatigue Life Compare to Titanium and Structural A36 Steel. Pressure loads we have applied are 1Mpa.

Finally we conclude that our wing bracket interaction is a SAFE-LIFE structure in infinite safe zone.



Bibliography

1. "Mechanical Engineering Design", "Shigley", "McGraw-Hill", "9th Edition", "2011".
2. "Machine Design- An Integrated Approach", "Robert L. Norton", "Pearson Education India", "3rd Edition", "2000".
3. "Aircraft Structures for Engineering Students", "T.H.G Megson", "Butterworth-Heinemann", "4thEdition", "2007".
4. "Fundamentals of metal fatigue analysis", "J.A. Bannantine, J.J.Comer, J.L.Handrock", "Prentice Hall", "1st Edition", "1989".
5. "Finite Element based Fatigue Calculations", "Dr. N.W.M. Bishop, Dr. F. Sherrat", "Glasgow, U.K :Nafems", "1st Edition", "2000".