Analysis of New Model Aircraft Wing Design To Improve Fatigue

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Abstract- *This project is aimed towards addressing certain set of objectives in a realistic manner as possible. In any aircraft, wings are the major lift generating aerodynamic structure. It accounts for carrying major portion of aircraft weight, structural strength, long life, better fatigue life characteristic becomes vital criteria for wing structural design. Any deviation from the set design parameters (structural) may lead to improper functioning of the wing or even catastrophic failure leading to loss of life and property. This project includes a brief concept of materials selection criteria, wing structure optimization and various loads which are supposed to be acting on them. The wing optimization design is carried out by solid edge st8 and the analysis is done by ansys 14.5 workbench. The results have been validated with the variation in the wing structure.*

Keywords- Wing Structure, Solid edge st8, Ansys14.5 workbench.

I. INTRODUCTION

The primary factors to consider in aircraft structures are strength, weight, and reliability. These factors determine the requirements to be met by any material used to construct or repair the aircraft. Airframes must be strong and light in weight. An aircraft built so heavy that it couldn't support more than a few hundred pounds of additional weight would be useless. All materials used to construct an aircraft must be reliable. Reliability minimizes the possibility of dangerous and unexpected failures. Many forces and structural stresses act on an aircraft when it is flying and when it is static. When it is static, the force of gravity produces weight, which is supported by the landing gear. The landing gear absorbs the forces imposed on the aircraft by takeoffs and landings. During flight, any maneuver that causes acceleration or deceleration increases the forces and stresses on the wings and fuselage. Stresses on the wings, fuselage, and landing gear of aircraft are tension, compression, shear, bending, and torsion. These stresses are absorbed by each component of the wing structure and transmitted to the fuselage structure. The empennage (tail section) absorbs the same stresses and transmits them to the fuselage. These stresses are known as loads, and the study of loads is called a stress analysis. Stresses are analyzed and considered when an aircraft is designed.

1.1Tension

Tension is defined as pull. It is the stress of stretching an object or pulling at its ends. Tension is the resistance to pulling apart or stretching produced by two forces pulling in opposite directions along the same straight line. For example, an elevator control cable is in additional tension when the pilot moves the control column.

1.2 Compression

If forces acting on an aircraft move toward each Other to squeeze the material, the stress is called Compression. Compression is the opposite of tension. Tension is pull, and compression is push. Compression is the resistance to crushing produced by two forces pushing toward each other in the same straight line. For example, when an airplane is on the ground, the landing gear struts are under a constant compression stress.

II. AIRCRAFT WING

Wings are airfoils that, when moved rapidly through the air, create lift. They are built in many shapes and sizes. Wing design can vary to provide certain desirable flight characteristics. Control at various operating speeds, the amount of lift generated, balance, and stability all change as the shape of the wing is altered. Both the leading edge and the trailing edge of the wing may be straight or curved, or one edge may be straight and the other curved. One or both edges may be tapered so that the wing is narrower at the tip than at the root where it joins the fuselage. The wing tip may be square, rounded, or even pointed. Figure 1.1 shows a number of typical wing leading and trailing edge shapes.

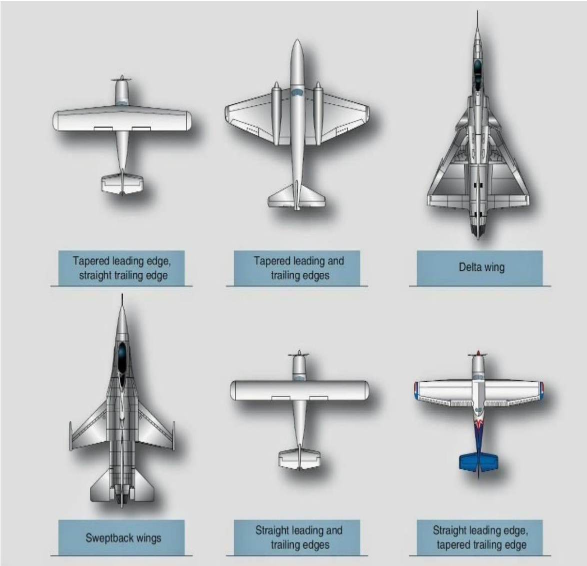


Fig -1: Various Wing Designs.

2.2 Spar

In a fixed-wing aircraft, the spar is often the main structural member of the wing, running span wise at right angles (or thereabouts depending on wing sweep) to the fuselage. The spar carries flight loads and the weight of the wings while on the ground. Other structural and forming members such as ribs may be attached to the spar or spars, with stressed skin construction also sharing the loads where it is used. There may be more than one spar in a wing or none at all. However, where a single spar carries the majority of the forces on it, it is known as the main spar.

Fig-2: Spar

2.3 Introduction to Fatigue

Fatigue may occur when a member is subjected to repeated cyclic loadings (due to action of fluctuating stress, according to the terminology used in the EN 1993-1-9).

The fatigue phenomenon shows itself in the form of cracks developing at particular locations in the structure. Cracks can appear in diverse types of Structures such as: planes, boats, bridges, frames, cranes, overhead cranes, machines parts, turbines, reactors vessels, canal lock \ doors, offshore platforms, transmission towers, pylons, masts and chimneys. Structures subjected to repeated cyclic Loadings can undergo progressive damage which shows itself by the propagation of cracks. This damage is called fatigue and is by a loss of resistance with time.

The physical effect of a repeated load on a material is different from the static load. Failure always being brittle fracture regardless of whether the material is brittle or ductile.

Main parameters influencing fatigue life

The fatigue life of a member or of a structural detail subjected to repeated cyclic loadings is defined as the number of stress cycles it can stand before failure. Depending upon the member or structural detail geometry, its fabrication or the material used, four main parameters can influence the fatigue strength (or resistance, both used in EN 1993-1-9):

III. STRESS-LIFE DIAGRAM (S-N Diagram)

The basis of the Stress-Life method is the Wohler S-N diagram, shown schematically for two materials in Figure 1. The S-N diagram plots nominal stress amplitude S versus cycles to failure N. There are numerous testing procedures to generate the required data for a proper S-N diagram. S-N test data are usually displayed on a log-log plot, with the actual S-N line representing the mean of the data from several tests.

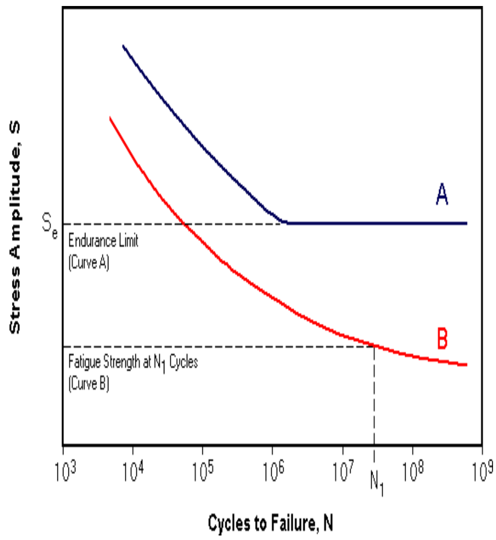


Fig.3. *Typical S-N Curves*

IV. METHODOLOGY

Methodology is the systematic, theoretical analysis of the methods applied to a field of study. Typically, it encompasses concepts such as paradigm, theoretical model, phases and quantitative or qualitative techniques. It is the general research strategy that outlines the way in which research is to be undertaken and, among other things, identifies the methods to be used in it.

The methodology followed for this particular project is shown in a schematic diagram below

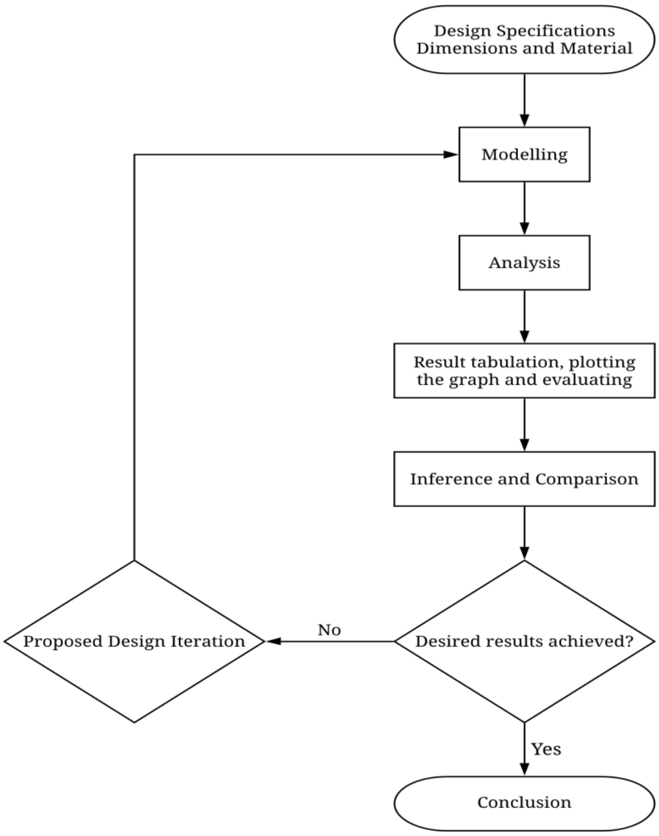


Fig 4. *Flow Chart of Methodology*

V. MODELLING

PROBLEM STATEMENT

Wings are aerodynamic lifting surfaces and carry whole lot portion of aircraft's weight during the flight. Thus the wing is needed to be structurally strengthened with high fatigue life. This is necessarily done by ribs, spars & skin. My problem here is to optimize these structural components to have wing with light weight, good strength & unaffected or better aerodynamic properties.

I need to have ribs with less material, but also maintain airfoil shape of the wing, skin is the main part which increases the weight. Thus i need to have skin with better properties with lesser weight and should also not yield/coagulate easily at expected flight operations.

5.1 MODELLING OF RIBS AND SPARS

Design of the spars and ribs was done using solid edge ST8. This software has been very helpful particularly to carryout design iterations as we progress providing me with more and more wing variants.

The airfoil we have used is NASA GA (W)-1, the name is a nomenclature abbreviation to describe the particular airfoil. NASA stands for National Aeronautics and Space Administration which is pioneer in designing many airfoils till date and providing with the airfoil contour coordinates. And GA stands for general aviation airfoil category.

The airfoil shape is as shown in figure and the various ribs and spars design and assembly is also shown in the subsequent pages.

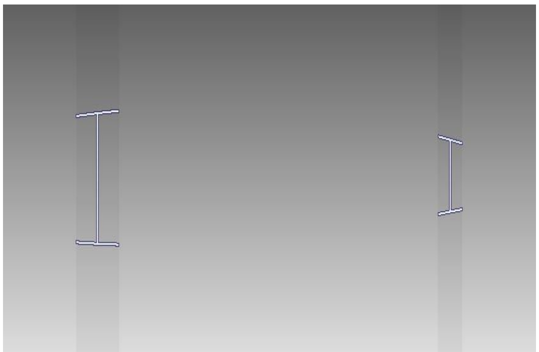


Fig.5.1 *solid edge design of spars of wing variant 1 and 2.*

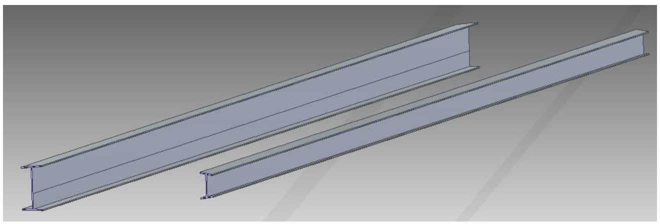


Fig.5.2. *solid edge design of spars of wing variant 1 and 2.*

Fig.5.3. *solid edge design of spars of wing variant 3 & 4.*

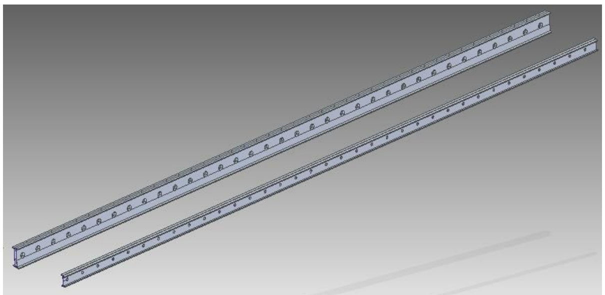


Fig.5.4. *solid edge design of spars isometric view before creating holes.*

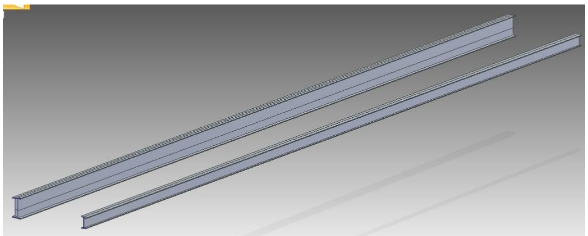


Fig.5.5. *solid edge design of spars of wing variant 4.*

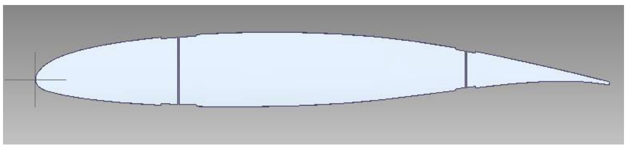


Fig.5.6. *solid edge design of rib of wing variant 1.*

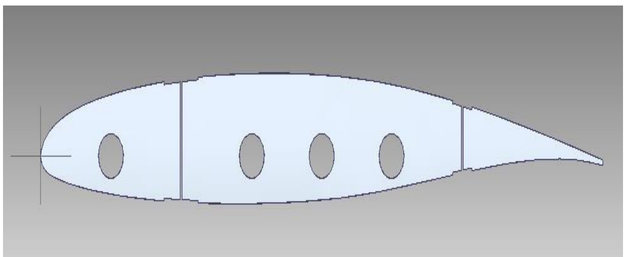


Fig.5.7. *solid edge design of rib of wing variant 2.*

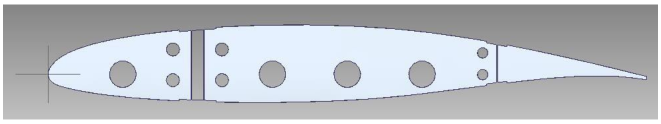


Fig.5.8. *solid edge design of rib of wing variant 3.*

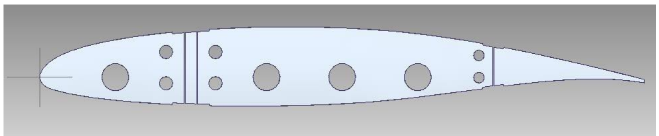


Fig.5.9. *solid edge design of rib of wing variant 4.*

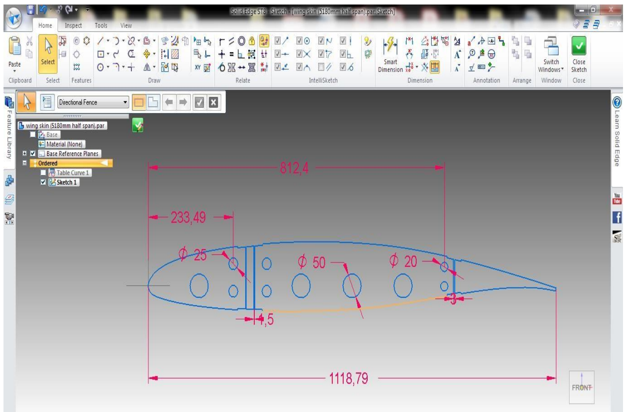


Fig.5.10. *solid edge design of rib of wing variant 4 with dimensions.*

VI. ANALYSIS OF WING VARIANTS

As discussed in the previous chapter on modelling the design models are imported in ANSYS workbench 14.5 where the analysis of the structural behaviour of the various wing models is carried out. We have developed 4 wing models in due course of our project, each exhibiting different behavior under same loading conditions

The analysis in the above mentioned software is done as follows

- The engineering properties of the selected material (CFRP) is first fed to the system and saved for further use.
- The geometry of the wing of first variant is imported, settled to proper axis, is given a fixed support on one face of the starting ribs to make it cantilever.
- Then loading of the wing is done for various load values from 3000N to 6000N in steps of 1000N at front and rear spar.
- The problem is now solved for total deflection, equivalent von misses stress, strain and safety factor.

- The results and behavior are then tabulated and plotted and this steps is repeated for subsequent wing designs to come.

6.1 WING VARIANT 1

Total deflection of the wing variant 1 under various loads

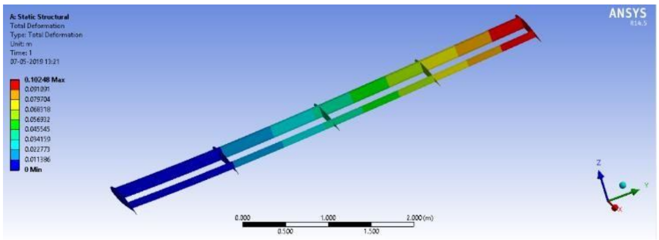


Fig.6.1. *Total deformation under 3000N load.*

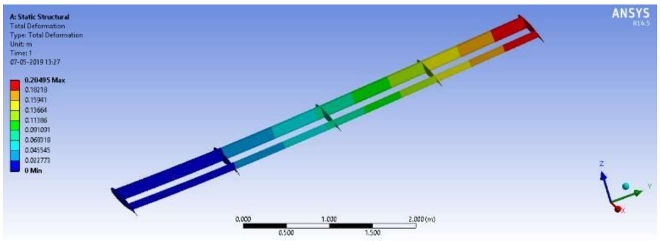


Fig.6.2. *Total deformation under 6000N load.*

Von misses stress of the wing variant 1 under various loads.

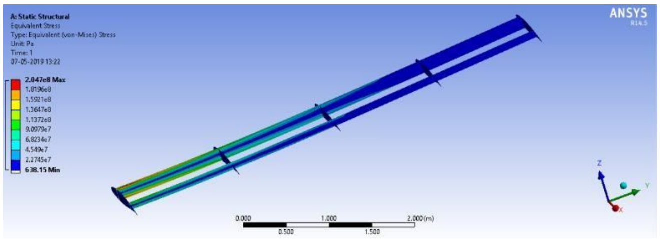


Fig.6.3. *Von misses stress under 3000N load.*

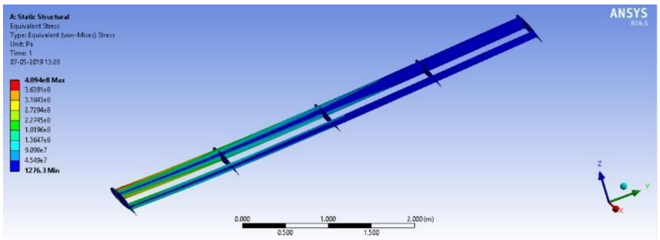


Fig.6.4. *Von misses stress under 6000N load.*

Strain of the wing variant 1 under various loads

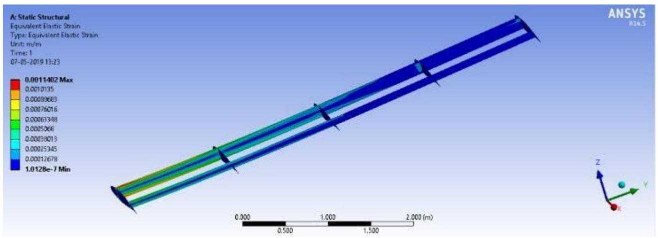


Fig.6.5. *Strain under 3000N load.*

Note:- Similarly wing variant1, 2,3 and 4 and their respective deflection, Von misses stress and stain are plotted in the table below:

Tabulation for Wing Variant 1

Force(N)	Max total deformation (m)	Von misses stress (Pa)	Max total strain (m/m)
3000	0.10248	2.047×10^8	0.001142
4000	0.13664	2.729×10^8	0.00152
5000	0.1708	3.4117×10^8	0.0019
6000	0.20495	4.094×10^8	0.00228

Tabulation for Wing Variant 2

Forces(N)	Max total deflection (m)	von misses stress (Pa)	Max total strain (m/m)
3000	0.10313	1.92×10^8	0.00106
4000	0.13664	2.56×10^8	0.001416
5000	0.1708	3.2×10^8	0.00177
6000	0.20495	3.84×10^8	0.00212

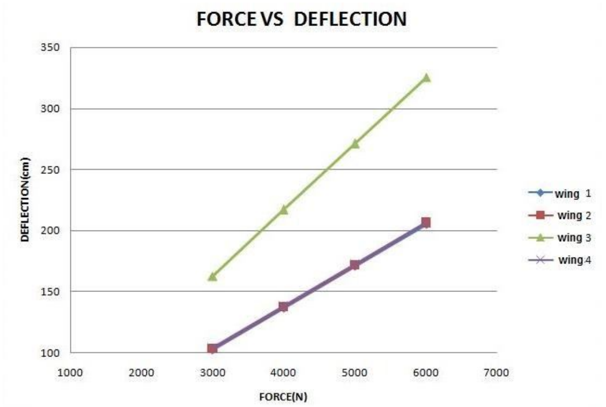
Tabulation for Wing Variant 3

Force(N)	Max total deformation(m)	von misses stress (Pa)	Max total strain (m/m)
3000	0.1626	2.511×10^8	0.001399
4000	0.2168	3.348×10^8	0.001866
5000	0.2711	4.185×10^8	0.00233
6000	0.3253	5.022×10^8	0.00279

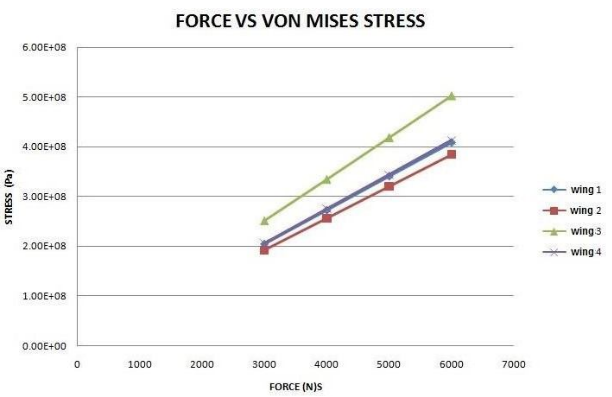
Tabulation for Wing Variant 4

Force(N)	Max total deformation (m)	von misses stress (Pa)	Max total strain (m/m)
3000	0.10346	2.0686×10^8	0.001159
4000	0.13795	2.758×10^8	0.001546
5000	0.17244	3.447×10^8	0.001933
6000	0.20692	4.1372×10^8	0.002319

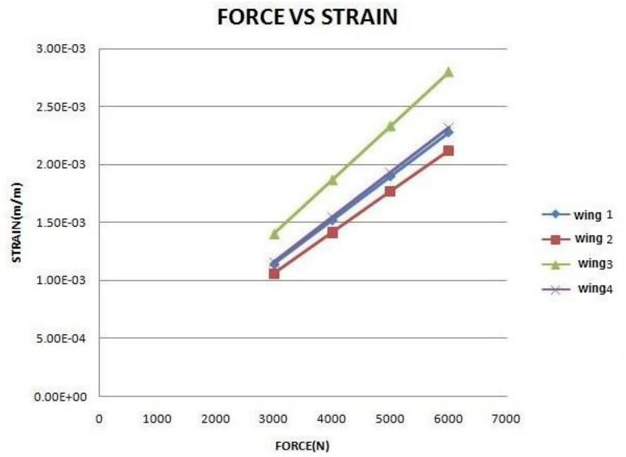
VII. GRAPHICAL REPRESENTATIONS



Graph 7.1. Force v/s Deflection.



Graph 7.2. *Force v/s Von Mises Stress.*



Graph 7.3. *Force v/s Strain.*

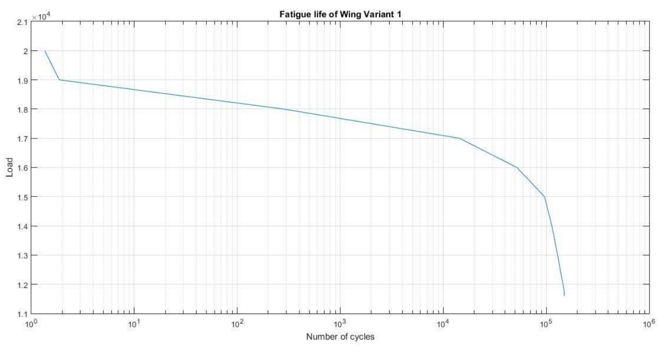
VIII. SAFETY FACTOR TABULATION

Table 8.1. Safety factor of Wing Variants

Wing Model	Safety Factor
Wing Variant 1	**1.9558**
Wing Variant 2	**2.9293**
Wing Variant 3	**2.2375**
Wing Variant 4	**2.7193**

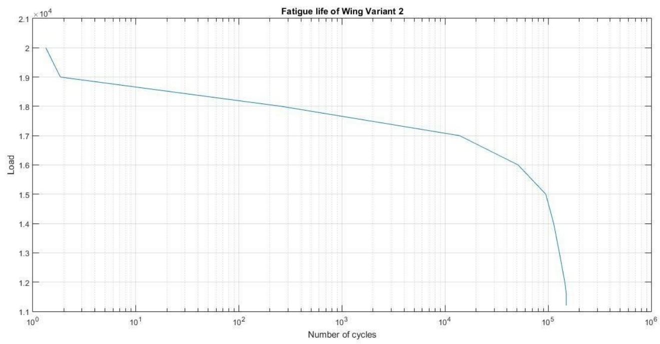
IX. FATIGUE LIFE ANALYSIS

Wing Variant 1



Graph 9.1. *S-N Curve for Wing Variant 1.*

Wing Variant 2

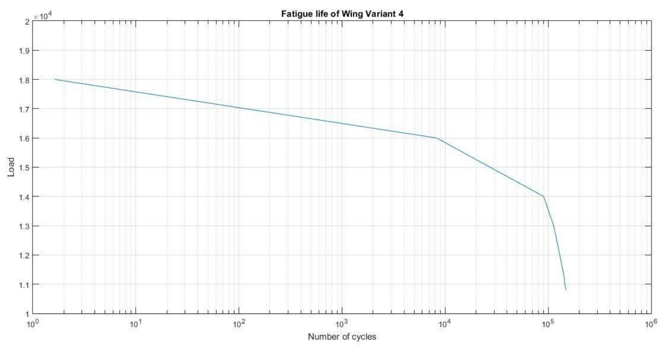


Graph 9.2.*S-N Curve for Wing Variant 2*

Wing Variant 3

Wing variant 3 has shown inadequate results compared to other three variants in Stress, Total Deformation and Strain analysis. This variant has shown higher values in all the three parameters. So it is of mere significance to conduct fatigue life estimation on this variant.

Wing Variant 4



Graph 9.3. *S-N Curve for Wing Variant 4*

X. RESULTS AND DISCUSSION

For the proposed wing design variants, We have carried out analysis for three of the many structural parameters and they are – stress, strain and total deformation. Based on these designs we have carried out fatigue life estimation using S- N curve and determined its safety factor and carried out iterations to improve the same.

Wing Variant 1 was considered to be our basic design, and taking that as reference, iterations were carried out. We have analyzed its behaviour for stress, strain and total deformation for various loads and the values have been tabulated in table and graphically represented in graphs.

Wing variant 2 was then introduced with holes in ribs, which would help reduce weight, which further reduced load at the root of the wing and the same can be confirmed from the data obtained after the analysis. The stress, strain and total deflection for this variant has shown significant decrement as compared to variant 1. This is shown graphically in graphs.

We could further see a scope to reduce weight in wing variant 2. However this time we would split the web of the front spar into two each with thickness halved from the original. This ensured no addition of weight .This wing variant 3 has shown a very negative result with stress, strain and total deformation as compared to variant 1 as can be seen in graphs.

This behaviour can be attributed to the design change introduced where the rib material between the webs of the front spar was eliminated, which left the model weak at that portion and at root region it can be seen to be under high stress and thus more prone to crack initiation.

The wing variant 3 was then rectified for its design problem by extending the rib to fit inside the front spar's web resulting in wing variant 4. It was then analysed and the result can be seen in the table and graphical representations. It can be seen that this small change has significantly improved its behaviour as compared to the previous variant. We see a peculiarity in this variant in that though this wing has significant weight reduction and different spar design compared to variant 1 its structural behaviour is almost close to that of wing variant 1 with wing variant 4 showing a little higher values of the considered parameters.

Further fatigue data was obtained for wing variant 1, 2 and 4 and S-N curve was plotted (see graph). It can be seen that though stress strain and deflection of wing variant 2 was reduced compared to variant 1, the fatigue life of 2 is slightly reduced. This can be attributed to the fact that the holes introduced also caused certain portion of the material to come under higher stress than the rest and this increased the chances of crack initiation in those regions of higher stress. However this design did see an increment in safety factor from 1.9558 of variant 1 to 2.9293, a considerable improvement. This improvement will help wing variant 2 to be used with greater load.

Wing variant 4 however saw a greater reduction in fatigue life compared to variant 1, with an appreciable improvement in safety factor.

XI. CONCLUSION

In this project report various design variants were introduced and analyzed. This process gave me a mixed outcome between my efforts to achieve the desired goal and the efforts to minimizing the chances of failure.

- Wing variant 2 saw highest safety factor, slightly reduced weight as compared to variant 1. Thus variant 2 can be a good replacement for variant 1.
- Wing variant 4 saw a significant increase in safety factor as well as reduction in weight. And it showed closest behaviour to variant 1 structurally. However it saw a considerable reduction in fatigue life. Wing variant 4 can thus replace 1 when weight becomes a major parameter.

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