DEVASTATION TOLERANCE DESIGN OF THE WING SPAR OF A TRANSPORT AIRCRAFT

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ABSTRACT

In a transport aircraft there are normally two competes to take the twisting burdens. The fundamental fight takes a significant bit of this twisting second. It is the major basic auxiliary components in a vehicle wing.
Most assistance auxiliary disappointments in airframes are because of exhaustion breaks. Weakness splitting can't be voided yet can be endured by reasonable harm resilience plan. In enormous vehicle wings the principle fight is an indispensably machined segment which gets precisely affixed to the skin and ribs. The mechanical affixing prompts serious pressure fixation at a couple of clasp gaps. Under help stacking a weakness break can start from the most extreme pressure concentrator. This weariness break will develop under assistance stacking first in the spine and afterward develop into the fight web. This break development can prompt calamitous disappointment if not identified during administration and fixed. This undertaking work will examine substitute basic plan of the fundamental fight to make it harm lenient. The fight development will be in two of discrete parts with one more middle of the road spine and at a stature of 1/third from the base rib. These two pieces can be precisely secured.
In case of weariness breaking the base rib and web may flop however the top rib, web and the middle of the road spine will stay unblemished and can be intended to convey the necessary plan limit load.
A limited component displaying and examination approach will be utilized to contemplate the two kinds of fight narrowing and approve the harm resilience plan idea.
Catchphrases

Keyword*: Transport airplane, Wing, Damage resilience plan, Finite component examination, Fatigue split, Service factor etc…*

1. INTRODUCTION

Air1craft are vehicles which can fly by being upheld by the air, or in general, the atmosphere of a planet. An airplane counters the power of gravity by utilizing either static lift or by utilizing the dynamic lift of an airfoil, or in a couple of cases the down1ward thrust from stream motors. An aircraft is a mind boggling structure, yet a productive man-made flying machine. Airplanes are commonly developed from the fundamental components of wings, fuselage, tail units and control surfaces. Each component has at least one explicit functions and must be intended to guarantee that it can complete these capacities securely. Any little disappointment of any of these parts may prompt a cataclysmic calamity causing tremendous destruction of lives and property. When planning an airplane, it's tied in with finishing the ideal extent of the heaviness of the vehicle and payload. It should be solid and hardened enough to withstand the remarkable conditions in which it needs to work. Durability is a significant factor. Additionally, if a section falls flat, it doesn't necessarily bring about disappointment of the entire airplane. It is as yet feasible for the airplane to glide over to a protected landing place just if the streamlined shape is held basic respectability is accomplished. The essential functions of an airplane's structure are to send and oppose the applied burdens; to give an aerodynamic shape and to secure passengers, payload frameworks, and so forth. from the environmental conditions en-countered in flight. These requirements, in most airplane, bring about slight shell structures where the external surface or skin of the shell is generally supporte1d by longitudinal hardening individuals and transverse casings to empower it to oppose bowing, compressive and tensional loads without buckling. Such structures are known as semi-monologue, while slim shells which depend completely on their skins for their ability to oppose loads are alluded to as monologue.

1.1 Introduction to wing

The wings are the most significant lift-creating part of the airplane. Wings change in configuration relying on the airplane type and its motivation. Most planes are planned so the external tips of the wings are higher than where the wings are connected to the fuselage. This upward point is known as the dihedral and helps shield the plane from moving startlingly during flight. Wings additionally convey the fuel for the plane. The components of aircraft wing are as shown in Figure 1.2. The shape of a wing greatly influences the performance of an airplane. The speed of an airplane, its maneuverability, its handling qualities, all are very dependent on the shape of the wings.

1.2 Introduction to wing spar

An airplane wing is basically exposed to lift, fuel, motor, landing gear, inertial, basic, non auxiliary and other streamlined burdens. The principle load-bearing individuals in the wing are called fights. Fights are solid pillars which run length astute in the wing and convey the power and minutes because of the range insightful lift circulation. The Figure 1.1 shows the schematic outline of the loads acting on the wing.

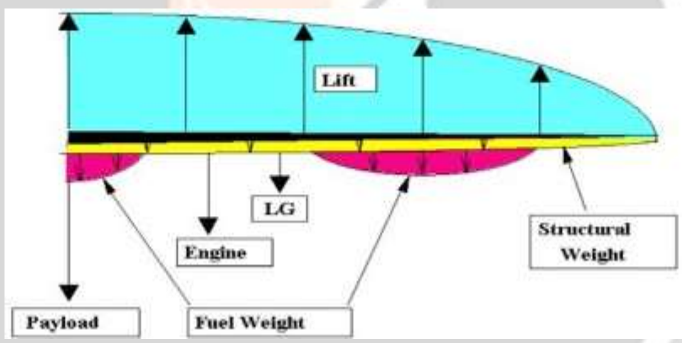

Figure-1.2: loads following up on the wing

Wings of airplane are joined at the root to the fuselage. Subsequently the fight pillars can be considered as a cantilever shaft for the plan reason. The harmony savvy weight and shear dispersions on every airfoil are conveyed to the fights by the wing skin and airfoil-molded auxiliary casings called ribs. The ribs help the wing keep its airfoil shape, and along with the skin and fights structure tubes and boxes which oppose wing winding or twist. The weight and shear circulations on the wing skin are gathered by the ribs and sent to the competes. The heaps on most ribs are generally little, however some may convey concentrated burdens from landing rigging, motors, or outside stores. Wing skins are normally very slender, so they every now and again have extra stiffeners or stringers appended to them. Stringers help send the skin surface burdens to the ribs and fights, and they help shield the skin from bowing a lot under burden. Basic segments of stabilizers and control surfaces are given similar names as comparative segments in wings.

1.3 Structural shapes of wing spar

For bars, for example, wing fights, a straightforward rectangular cross-area is once in a while utilized. For a similar cross-sectional zone and weight per unit range, in any case, C-or I-molded cross segments will have higher estimations of I, since they have a greater amount of their zone farther from their impartial tomahawks where the anxieties are higher. I-molded cross-areas are exceptionally basic decisions for airplane fights. They might be expelled entire or developed from pieces. As appeared in Figure 1.2 the top and base segments of the fight are called fight tops and the moderately meager sheet of material associating them is known as the web. Fight tops are basically stacked in strain and pressure, while the web is planned principally to oppose shear.

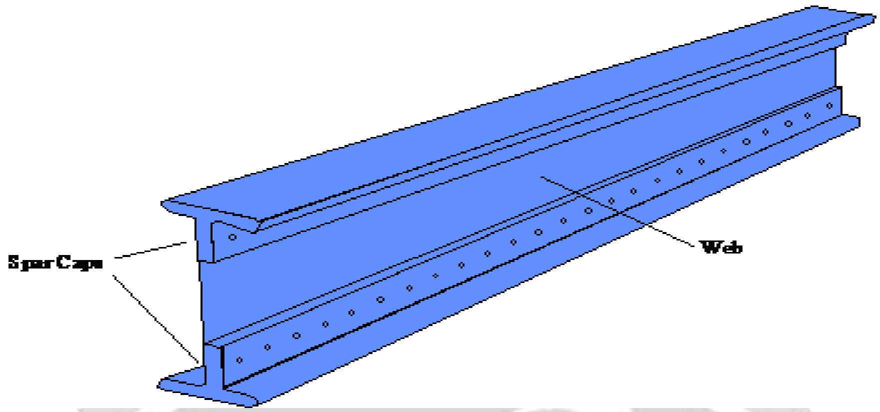

Figure-1.3: Portions of a Built-Up Spar

1.4 Damage tolerance and Fatigue Failure Mechanism

Harm resistance is a property of a structure identifying with its capacity to continue surrenders securely until fix can be influenced. The way to deal with building configuration to represent harm resistance depends on the assumption that imperfections can exist in any structure and such defects proliferate with use. This methodology is normally utilized in advanced plane design to deal with the expansion of breaks in structure through the use of the standards of crack mechanics. In advanced plane design, structure is viewed as harm lenient if a support program has been executed that will bring about the location and fix of inadvertent harm, consumption and weariness splitting before such harm diminishes the lingering quality of the structure under a satisfactory cutoff. Harm lenient plan techniques were built up that expect the structure contains introductory breaks. The underlying split generally dependent on as far as possible. There are two general methodologies, with varieties, that might be followed to ensure that the structure doesn't fizzle in administration. Slow crack growth is the moderate split development plan measures select segment material and sets feelings of anxiety so the accepted previous break won't develop to disappointment during administration and are the typical methodology for single burden way structure. For expanded wellbeing, the permitted administration life as a rule got by separating the all out split development period by a factor of 2. The part would need to be investigated as of now before proceeded with activity would be allowed. Fail-safe design is plan idea accept the chance of numerous heap ways or potentially break capture highlights in the structure with the goal that a solitary segment disappointment doesn't prompt quick loss of the whole structure. The heap conveyed by the split part is quickly gotten by nearby structure and complete crack is evaded. It is fundamental. In any case, that the first disappointment be distinguished and expeditiously fixed, on the grounds that the additional heap they convey will abbreviate the exhaustion lives of the rest of the segments.

1.5 Modified virtual crack closure integral (MVCCI) method

The Modified Virtual Crack Closure integral method, originally proposed in 1977 by Rybicki and Kanninen is a very attractive SIF extraction technique because of its good accuracy, a relatively easy algorithm of application capability to calculate SIF for all three-fracture modes. Although the MVCCI method has a significant advantage over other methods, it has not yet been implemented into most of the large commercial general-purpose finite element codes.

The MVCCI method is based on the energy balance proposed by Irwin. In this technique, SIF is obtained for first fracture mode from the equation.

$$G_i = \frac{K_i^2}{E}\beta \qquad (i=1,2,3\ldots\ldots)$$

Where Gi is the energy release rate for mode I, Ki the stress intensity factor for mode i, E the elastic Modulus, ϑ the Poisson ratio, $\beta = 1$ for plane stress, and $\beta = 1 - v^2$ for plane strain. Calculation of the Energy release rate is based on Irwin assumption that the energy released in the process of crack expansions equal to work required to close the crack to its original state as the crack extends by a small amount of Δa.

Irwin computed this work as

$$W=\frac{1}{2}\int_0^{\Delta a} u(r)\sigma(r-\Delta a)dr$$

Where u is the relative displacement, s the stress, r the distance from the crack tip, and Da the change in virtual crack length. Therefore, the energy release rate is

$$G=\lim_{\Delta a \to 0}\frac{W}{\Delta c}=\lim_{\Delta a \to 0}\int_0^{\Delta a} u(r)\sigma(r-\Delta a)dr$$

2 FINITE ELEMENT ANALYSIS

Software description

Software's used in the present work are,

Geometric modeling – CATIA V5

Finite element modeling – MSC PATRAN

Finite element solver –MSC NASTRAN

2.1 CATIA V5

CATIA V5 is mechanical plan programming, tending to cutting edge measure driven plan necessity of the mechanical business. This device makes it workable for mechanical planners to rapidly outline thoughts, explore different avenues regarding highlights and measurements, and produce models and definite drawings. The accompanying orders are generally utilized in mathematical displaying. One can make mathematical drawing utilizing 2D portrayed calculation just, without reference to existing models or congregations. This outlined math can be constrained by relations (collinear, equal, digression, etc), just as parametric measurements. Expel, utilizing this alternative one can expel base highlights and different highlights utilizing 2D sketch. Spin order can makes a component that includes or eliminates material by spinning at least one profiles around a centerline. Example order can make a direct example, a roundabout example, a bend driven example, or use sketch focuses or table directions to make the example. Mirror, order duplicates the chose highlights or all highlights, reflecting them about the chose plane or face. Round example order used to makes different occasions of at least one highlights, which we can space consistently around a hub. Filet and Chamfer order can be utilized to make filet all edges of a face, chosen sets of appearances, chosen edges, or edge circles and slanted component on chose edges or a vertex. Cut, choice is utilized to manage highlights and 3Dmodel as for a characterized plane. In the current work mathematical models was made by utilizing every one of these orders.

2.2 Introduction to MSC Patran and MSC Nastran

MSC Software Corporation is the biggest single supplier of limited component demonstrating and investigation (FEA) answers for the PC helped designing (CAE) market. MSC's items are advertised worldwide through workplaces in the United States, Europe, and Asia Pacific, and are accessible for use on frameworks extending from PCs to workstations and supercomputers. An overall limited component investigation can be separated into 3 standard undertakings; preprocessing, examination and post handling. The preprocessing task incorporates building the mathematical model, fabricating the limited component model, giving these components the right properties, defining the limit conditions and stacking conditions lastly, amassing these components into an associated structure for investigation. The examination stage basically understands for the obscure degrees of opportunity, just as responses and stresses. In the post processing stage, the outcomes are assessed and shown. The exactness of these outcomes is proposed during this post processing task. The Patran and Nastran programming together play out every one of the 3 of the guideline assignments of a limited component examination. The pre and post processors are interesting to PATRAN itself. Nonetheless, this bundle permits the client to do the genuine arrangement examination on a wide range of bundles. At numerous destinations you have the alternative of utilizing the MSC/Nastran bundle, which is presumably the most broadly utilized solver in industry. A significant number of different bundles generally utilized in modern settings (ABAQUAS, ANSYS, MARC) are additionally viable with PATRAN.

2.3 Finite Element Meshing

Limited component displaying is vital to the capacity to play out a designing butt-centric y sis of a model utilizing a PC. One of the center qualities of Patran is its capacity to assist you with making a limited component model, either from a current math model or through direct limited component activities. The equations expected to decide the conduct of a whole intricate model are frequently so convoluted that it is unreasonable to infer or fathom them. The limited element method takes care of this issue by isolating the intricate model into a collected gathering of limited components, little interconnected pieces normally alluded to as a work. The components in a limited component model have normal mathematical shapes, for example, square shapes, triangles, also, tetrahedral. They likewise incorporate associating focuses called hubs, and doled out material and component prop-erties. When the model is isolated into limited components, the PC examination program would then be able to utilize productive numerical conditions to ascertain the conduct of the individual components, considering the interde-dubiousness of contiguous components and the appointed properties. By changing over the calculation model into a limited component model made out of interconnected pieces, a PC can examine the model's conduct essentially and precisely.

Patran gives the accompanying abilities to limited component demonstrating (FEM):

1. Mesh cultivating apparatuses to control explicit work densities in explicit regions of your calculation.
2. Several profoundly mechanized procedures for work age.
3. Equivalencing abilities for joining networks in neighboring locales.
4. Tools to confirm the quality and precision of your limited component model.
5. Capabilities for direct information and altering of limited component information.

These tools help minimize the human effort needed to reach your most important goal understanding the behavior of a geometric model while providing the flexibility to have as much control over the process as you need.

2.4 Material Modeling

In Patran, a material is characterized as a named gathering of material-related properties that are applicable for a specific limited component investigation. Material properties mention to Patran what your model is made of (steel, a composite, and so on.) and characterize the characteristics of that material, (for example, thickness, firmness, explicit warmth, flexible modulus, Poisson's proportion, etc). Patran provides a materials application form and several sub forms that allow you to create, modify, show and delete materials. When you define a material property, it is not yet associated with the finite element model. Only when the element property is created, is the material is then associated with the model. It is the element property that references both the model and the material.After selecting the type of material model that best represents the behavior of a material, you build the material model by specifying the appropriate material properties. To manually input material property values, you use Patran’s Material Property application forms.

2.5 Assigning Elemental Properties

You can use the Element Properties application to create, modify, delete, and show sets of properties associated with particular finite element types, and to assign these property sets to Geometry or FEM entities in your model. Some element types are a shell, beam, rod, and spring. Examples of element properties are the thickness of a shell, the spring constant for a spring, or an area for a bar element. Materials are element properties, and they are assigned to the model via element property set assignment. The arrangement of element property options is unique for each analysis code and type. You will need to refer to your analysis code documentation for complete information about the supported options. Combinations of element property options are often given special element names within a particular analysis code implementation. For example, a commonly used element in MSC Nastran is the Standard Homogeneous Plate. This element results from choosing a combination of 2D, Shell, standard and homogeneous options, and quad4 topology on the Element Properties form.

2.6 Assigning Load and Boundary Condition

Most analysis problems involve the solution of how a model behaves in response to some action on this model–a force, a pressure, a temperature, or perhaps a magnetic field. In analysis terminology these actions are known as loads. Similarly, most models have certain conditions constraining their behavior. For example, an end of a cantilever beam fixed to a wall, or an adiabatic (non-conducting) boundary in a thermal problem. These constraints are referred to as boundary conditions. There is a great deal of similarity in both of these quantities. Both are applied to portions of your model, and some quantities may in fact be used as both loads and boundary conditions. Hence, a common set of operations is used within Patran to create both loads and boundary conditions.

The specific loads and boundary conditions available to you depend upon the analysis program you are using with Patran. Both load and boundary conditions can be applied to either your geometric model or your finite element model. Both quantities have the important feature of being independent of the finite element model itself. In Patran, loads and boundary conditions are treated as a single type of data to be assigned to portions of your geometry or finite element model. As mentioned above, the specific load and boundary condition data which you can assign is highly analysis dependent.

3 STRESS ANALYSIS OF SPAR BEAM

The wing spar with top and bottom skin model is first prepared in the Catia V5 modelling programming and afterward separated into the product where limited component lattice and investigation is done. The product utilized for examination here is Patran. Limited component fitting is completed for all the parts of the wing fight. The Figure 5.1 shows the subtleties of the limited component work created on each piece of the structure utilizing MSC PATRAN.

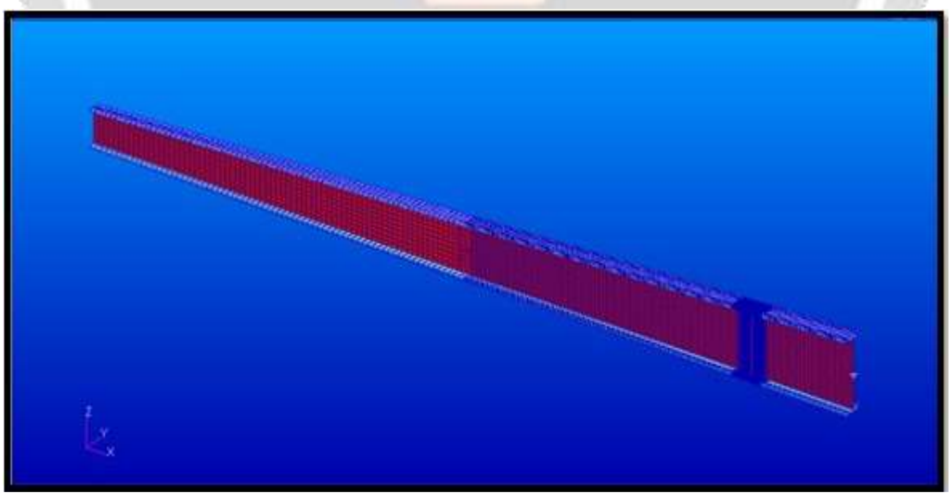

Figure3.1: Finite element meshing of wing spar with top and bottom skin

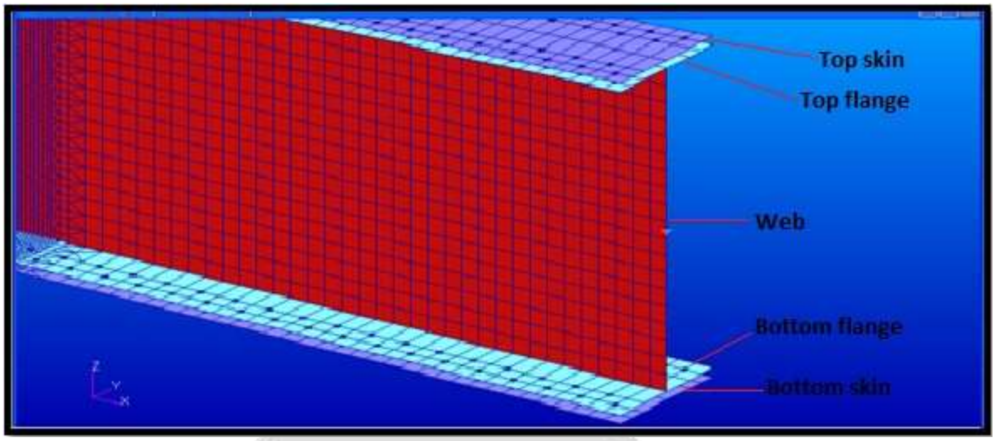

Figure3.2: Close up view of wing spar with top and bottom skin

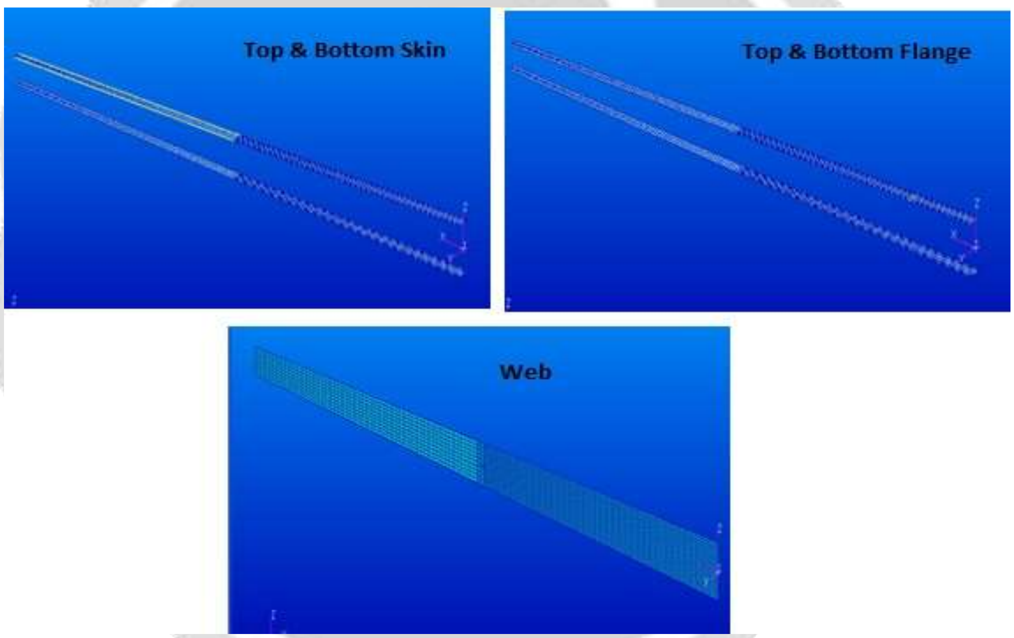

Figure3.3: Finite element meshing of different structural elements of wing spar

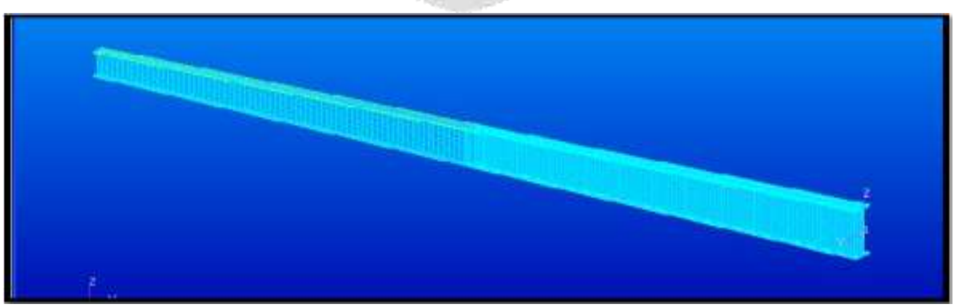

Figure3.4: The 2D mesh display in 3D form to visualize the thickness of the members in the wing spar model

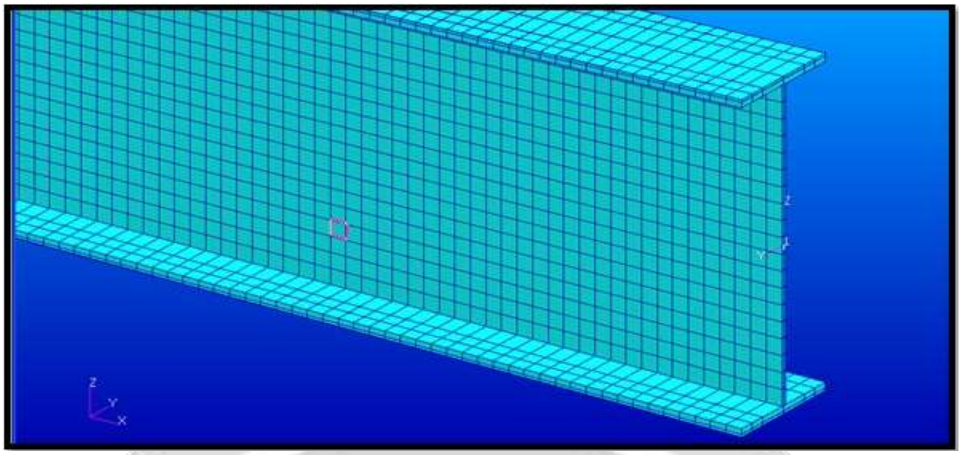

Figure3.5: Close up view of wing spar showing the thickness of the all the structural members of wing spar

Table3.1: SIF calculated by analytical method

Crack length in mm	Elemental length in mm	Nodal Displacements in mm			Forces at nodes in N			Strain energy release rate G in Kg/mm	SIF $\overline{\text{In}}$ *Mpa*
		ΔV1	ΔV2	ΔV	ΔF1	ΔF2	ΔF		
20	1	0.0899	0.0870	0.0028	45.34	46.78	92.1	67.7	2.156
40	1	0.091	0.0868	0.0042	64.09	66.15	130.2	139.97	3.078
60	1	0.0922	0.0870	0.0052	78.96	81.52	160.4	210.8	3.804
80	1	0.0937	0.0876	0.0061	92.08	95.09	187.1	287.66	4.444
100	1	0.0955	0.0885	0.007	104.35	107.78	212.1	370.2	5.041
120	1	0.0976	0.0898	0.0078	116.31	120.14	236.4	461.07	5.626
140	1	0.1	0.0914	0.0085	128.33	132.57	260.9	561.15	6.207
160	1	0.103	0.0936	0.0094	140.75	145.41	286.1	675.55	6.811
180	1	0.1065	0.0961	0.0103	153.92	159.02	312.9	808.34	7.45
200	1	0.1106	0.0993	0.0113	173.8	173.8	342.0	965.92	8.144

4 CRACK ANALYSIS OF WING SPAR

Figuring of pressure power factor utilizing Modified Virtual Crack Closure Integral (MVCCI) technique is accomplished for every single break length beginning from the most extreme pressure got at the bolt opening in the bottom flange where we got maximum stress. Then this SIF calculation is continued to the different crack lengths up to the web of the wing spar when the bottom flange and bottom skin is been fully cracked and opened. Then after once again crack propagation is done up to 1/3rd length of web. In this procedure of crack analysis no of iteration has done for different crack lengths to reach 1/3rd length of web. And at each crack lengths means for each iteration calculate SIF value.

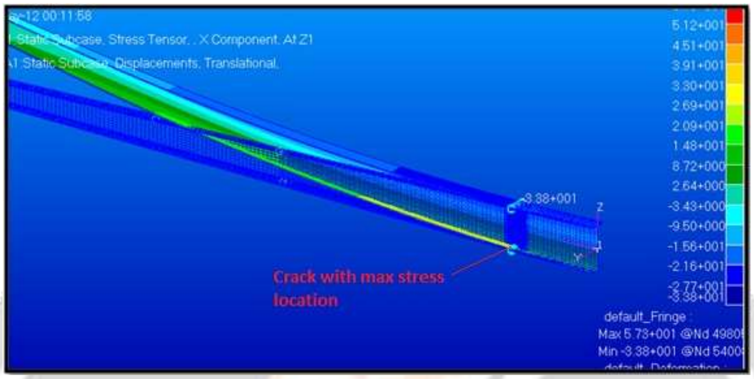

Figure 4.1: Maximum stress at the rivet hole position

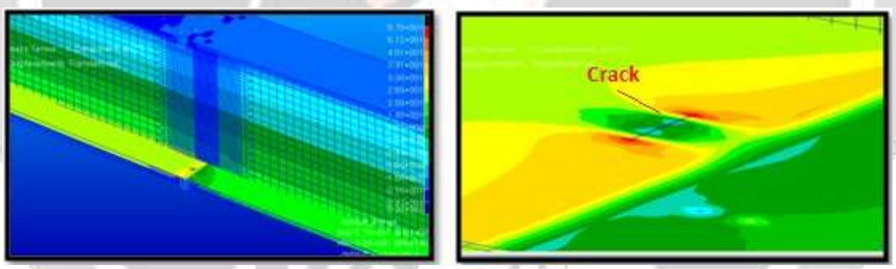

Figure 4.2: Close up view’s of maximum stress at crack tip

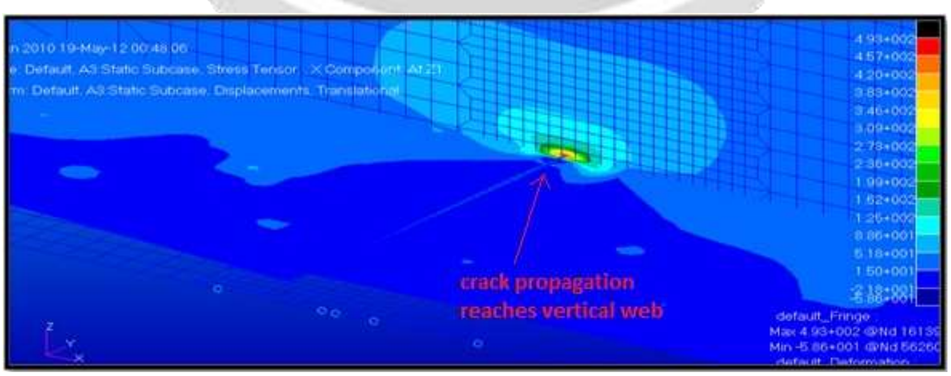

Figure 4.3: Crack propagation reached vertical web of the wing spar beam

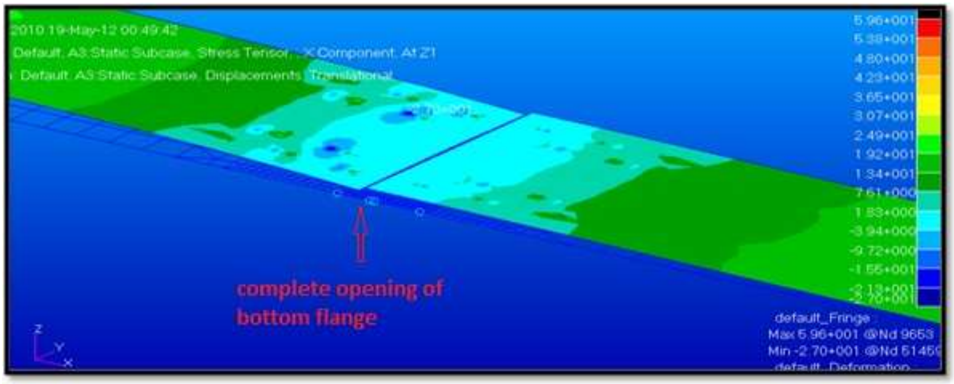

Figure 4.4: Complete opening of bottom flange when crack propagation reached web of spar

Table 4.1: SIF values from 1st to 8th iteration.

Crack length in mm	Elemental length Oc in mm	Nodal Displacements in mm			Forces at nodes in N			Strain energy release rate G in Kg/mm	SIF in $Mpa\sqrt{m}$
		ΔV1	ΔV2	ΔV	ΔF1	ΔF2	ΔF		
7.07	1.64	0.881	0.863	0.018	65.2	64.3	129.51	0.2376	12.65
14.16	1.64	0.888	0.859	0.029	88.6	89	177.64	0.5222	18.75
21.24	1.64	0.896	0.857	0.038	107.29	108.8	216.09	0.8414	23.8
28.3	1.64	0.903	0.856	0.047	124.25	126.95	251.21	1.1929	28.34
35.39	1.64	0.912	0.857	0.055	141.02	145.01	286.04	1.5965	32.79
42.49	1.64	0.923	0.859	0.064	159.42	164.69	324.12	2.0911	37.53
49.57	1.64	0.937	0.864	0.074	183.07	189.99	373.07	2.7798	43.27
56.66	1.64	0.980	0.884	0.095	361.93	361.92	723.86	7.000	68.67

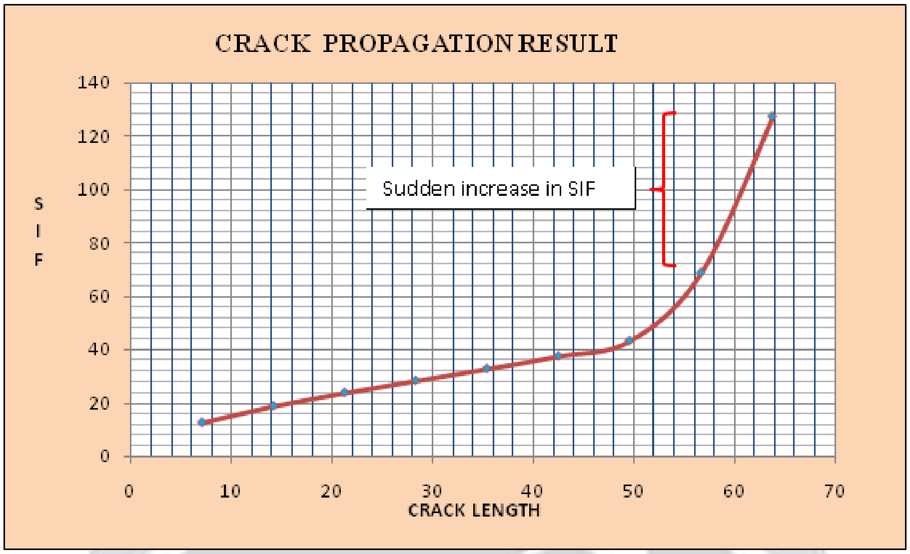

Figure 4.5: The graph of crack length Vs SIF up to 8th iteration

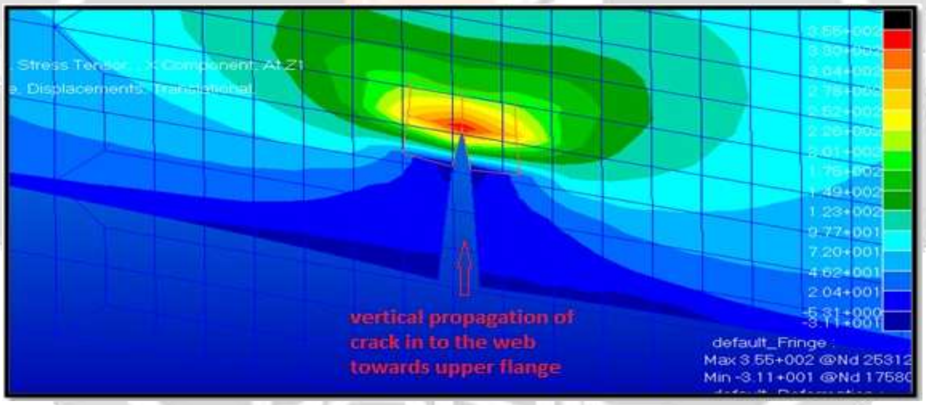

Figure 4.6: Vertical propagation of crack in to the web towards upper flange

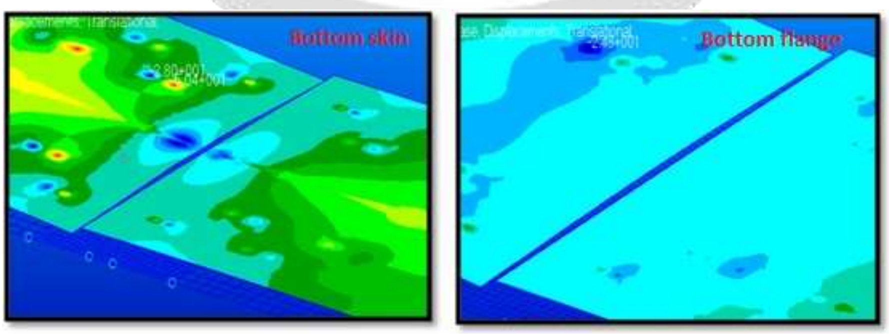

Figure 4.7: Close up view of complete opening of bottom skin and bottom flange

Table 4.2: Crack propagation result of wing spar

Crack length in mm	Elemental length *Oc* in mm	Nodal Displacements in mm			Forces at nodes in N			Strain energy release rate G in Kg/mm	SIF in $Mp\overline{a}$
		ΔV1	ΔV2	ΔV	ΔF1	ΔF2	ΔF		
7.07	1.64	0.881	0.863	0.018	65.2	64.3	129.51	0.2376	12.65
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42.49	1.64	0.923	0.859	0.064	159.42	164.69	324.12	2.0911	37.53
49.57	1.64	0.937	0.864	0.074	183.07	189.99	373.07	2.7798	43.27
56.66	1.64	0.980	0.884	0.096	361.93	361.92	723.86	7.000	68.67
63.77	1.77	1.245	1.009	0.237	892.27	908.2	1800.5	24.005	127.16
70.87	1.77	1.265	1.018	0.247	939.15	949.26	1888.4	26.236	132.94
81.53	1.77	1.284	1.024	0.259	990.21	997.92	1988.1	29.03	139.86
88.64	1.77	1.300	1.029	0.271	1034.08	1042.46	2076.5	31.66	146.05
95.74	1.77	1.317	1.034	0.283	1082.09	1089.73	2171.8	34.63	152.73
102.85	1.77	1.336	1.039	0.297	1133.34	1141.00	2274.3	37.97	159.93
109.95	1.77	1.357	1.046	0.311	1188.25	1196.13	2384.4	41.74	167.78
117.06	1.77	1.380	1.054	0.326	1247.23	1255.69	2502.9	45.99	176.03
124.16	1.77	1.407	1.064	0.343	1310.74	1319.97	2630.7	50.82	185.03
131.27	1.77	1.436	1.075	0.361	1379.33	1389.62	2769	56.31	194.78
138.37	1.77	1.469	1.088	0.381	1453.67	1465.33	2919	62.59	205.35
141.63	1.77	1.497	1.100	0.397	1513.89	1526.31	3040.2	67.91	213.89

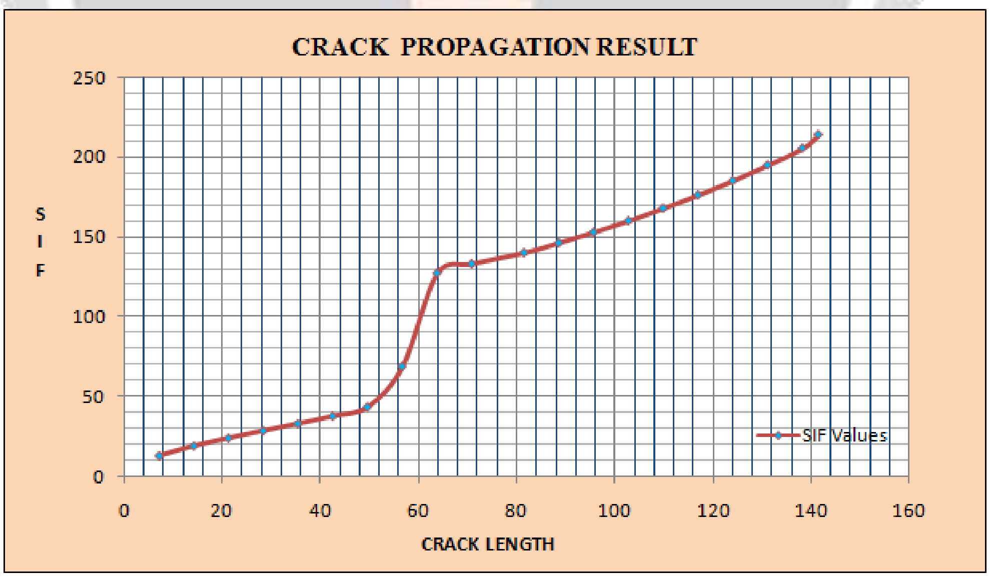

Figure 4.8: Crack propagation result of wing spar.

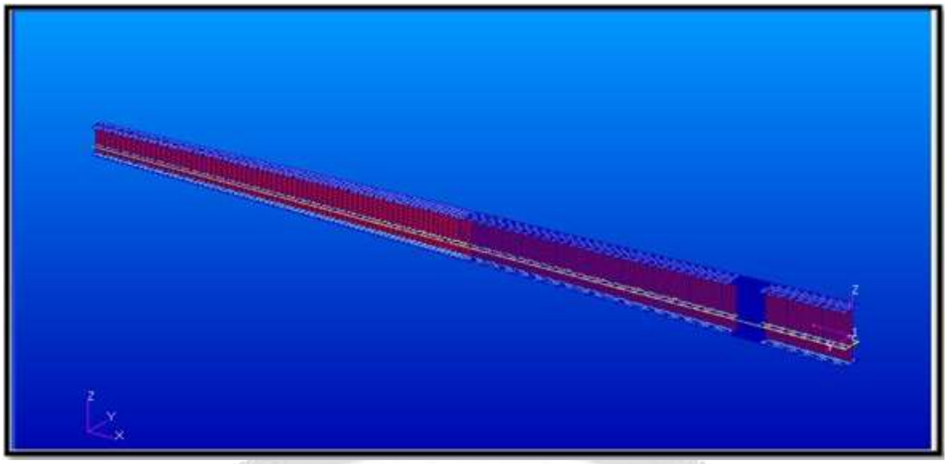

Figure 4.9: Finite element meshing of wing spar beam with intermediate flange

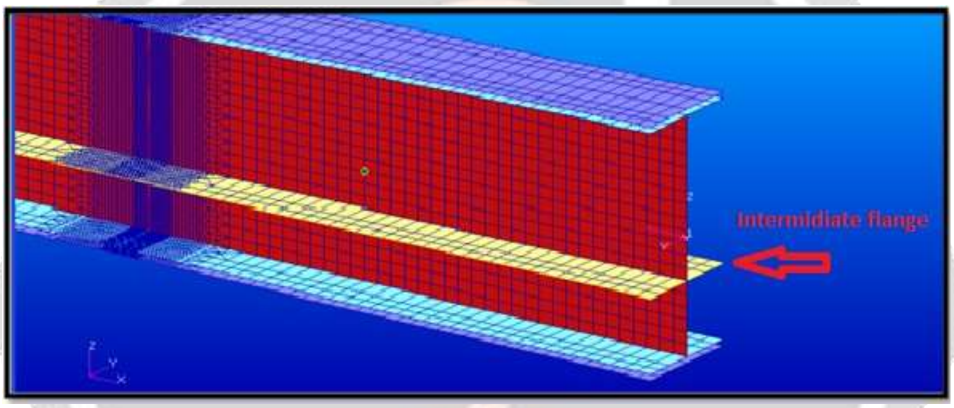

Figure 4.10: Close up view of meshing of wing spar beam with intermediate flange

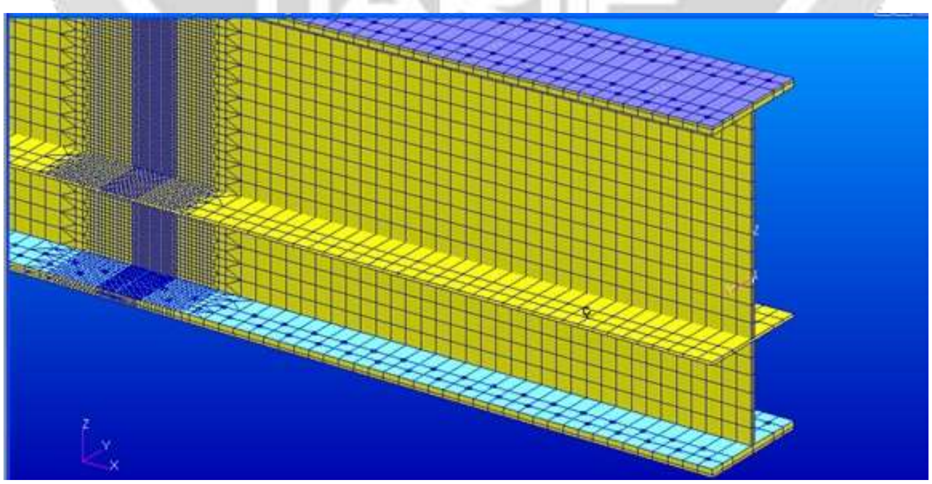

Figure 4.11: Close up view of alternate design of wing spar showing the thickness of all members

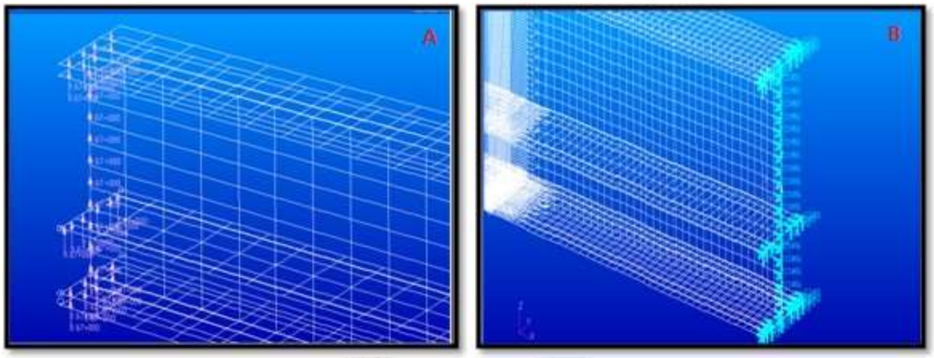

Figure 4.12: Close up view of load and boundary conditions for alternate design of wing spar

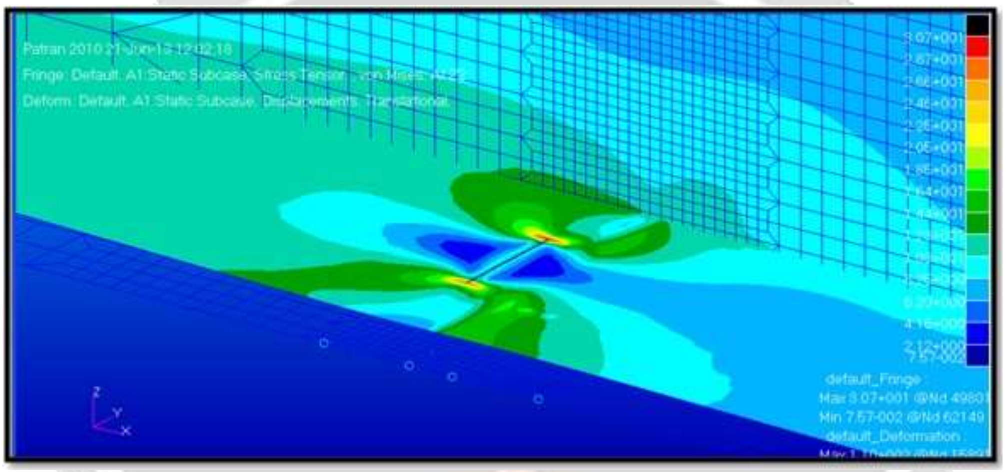

Figure 4.13: Close view of crack at the bottom flange of spar beam in 1st iteration

Table 4.3: SIF values for different crack lengths for crack arresting

Crack length in mm	Elemental length *Oc* in mm	Nodal Displacements in mm			Forces at nodes in N			Strain Energy release rate G in Kg/mm	SiF in $Mpa\sqrt{m}$
		ΔV1	ΔV2	ΔV	ΔF1	ΔF2	ΔF		
7.07	1.64	0.834	0.815	0.019	66.85	67.58	134.44	0.27	13.51
14.16	1.64	0.84	0.812	0.0275	82.99	84.73	167.73	0.46	17.77
21.24	1.64	0.862	0.825	0.0368	102.39	105.23	207.62	0.77	22.87
28.3	1.64	0.853	0.809	0.0441	116.54	120.31	236.85	1.06	26.72
35.39	1.64	0.877	0.824	0.052	134.74	139.59	274.34	1.468	31.44
42.49	1.64	0.871	0.811	0.059	150.05	155.04	305.1	1.855	35.35
49.57	1.64	0.884	0.815	0.069	172.07	178.38	350.46	2.452	40.64
56.66	1.64	1.086	0.846	0.09	343.47	343.46	687.33	6.32	65.25
63.77	1.77	1.138	0.926	0.2115	796.38	811.16	1607.54	19.14	113.55
70.87	1.77	1.133	0.907	0.2256	800.84	825.59	1626.44	20.66	117.98
81.53	1.77	1.128	0.905	0.2227	849.02	856.53	1705.56	21.38	120.02
88.64	1.77	1.122	0.894	0.2279	863.7	881.6	1745.31	22.39	122.81
95.74	1.77	1.114	0.882	0.2326	881.71	899.98	1781.7	23.33	125.38
102.85	1.77	1.104	0.867	0.2367	902.4	909.88	1812.28	24.15	127.55
109.95	1.77	1.091	0.851	0.2396	912.87	920.45	1833.33	24.73	129.07
117.06	1.77	1.074	0.833	0.2406	915.89	923.76	1839.66	24.92	129.58
124.16	1.77	1.051	0.812	0.2387	906.67	914.72	1821.4	24.47	128.41
131.27	1.77	1.02	0.789	0.231	874.4	881.92	1756.34	22.84	124.05
138.37	1.77	0.991	0.779	0.2115	790.88	788.65	1579.54	18.81	112.57
141.63	1.77	0.917	0.772	0.1455	575.25	605.74	1181	9.67	80.73

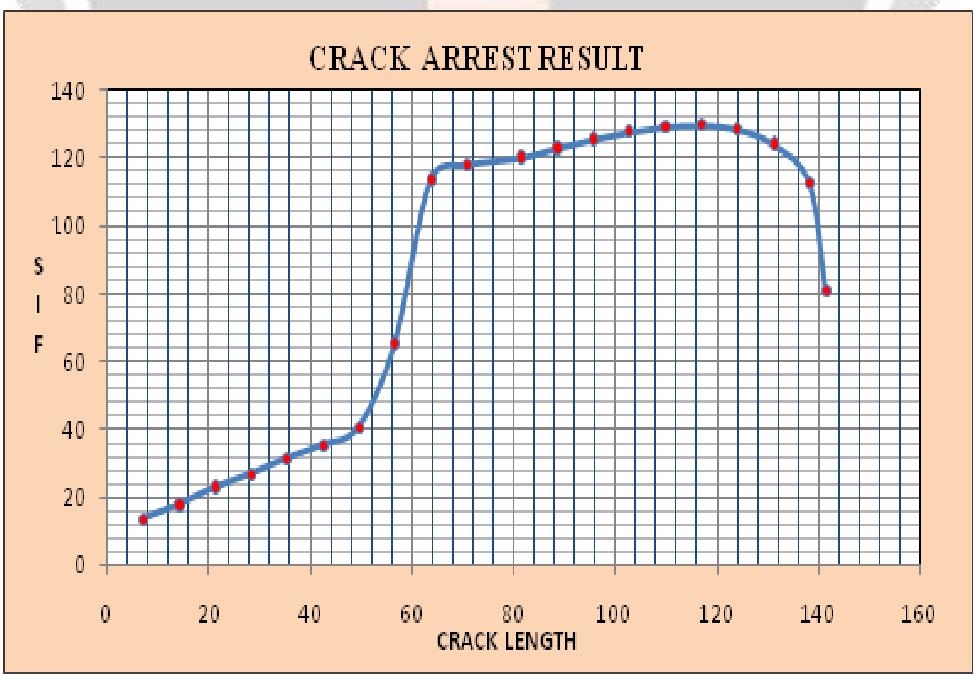

Figure 4.14: Crack arrest result of wing spar

5 RESULTS AND DISCUSSIONS

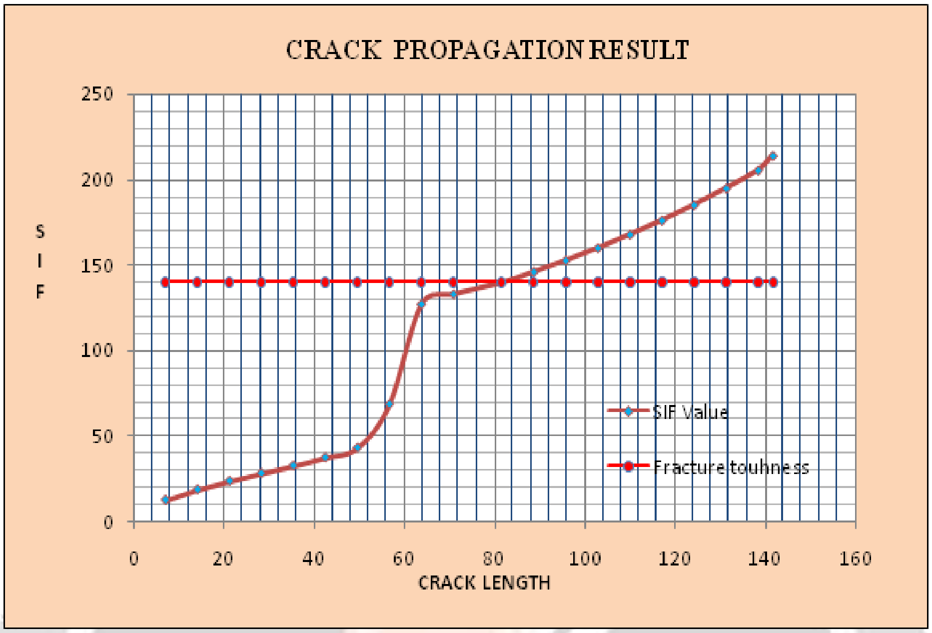

Figure 5.1: Crack propagation result of wing spar

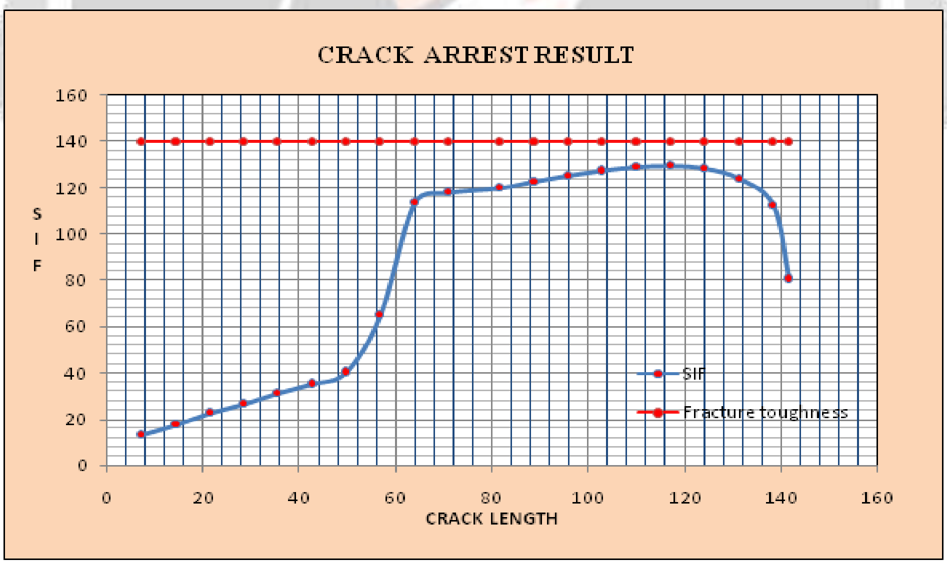

Figure 5.2: Crack arrest result of wing spar

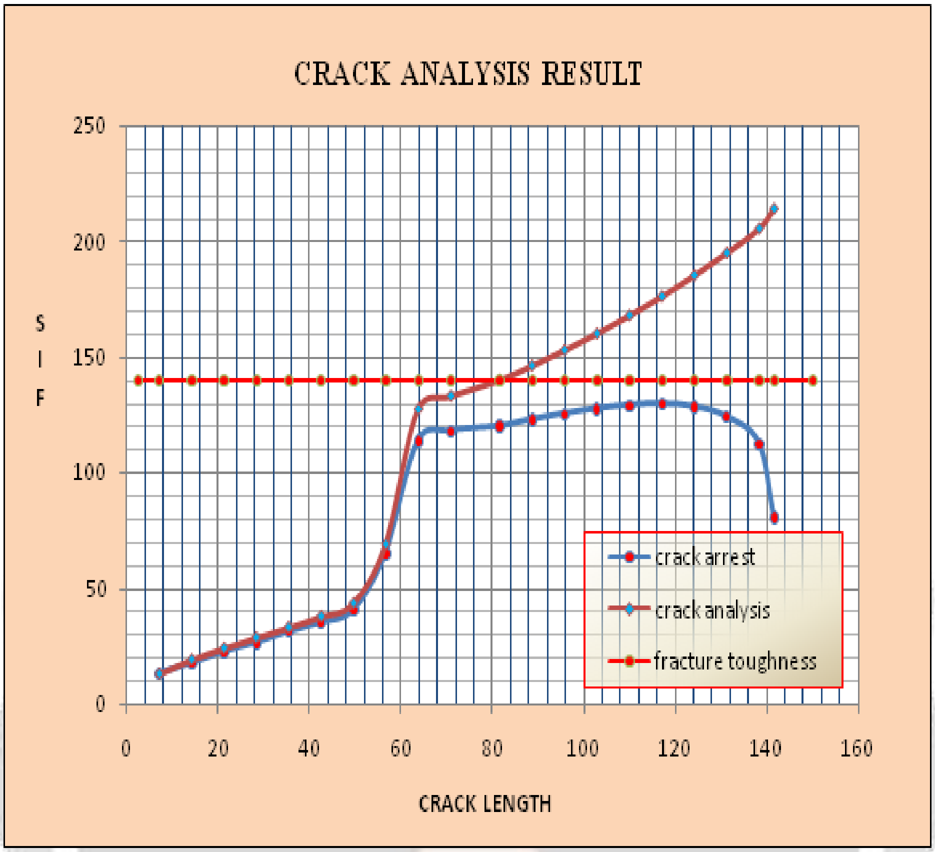

Figure 5.3: Comparative results for crack analysis for both designs.

In the above Figure 5.3 we can observe that crack propagation curve for ordinary design is crossing the fracture toughness curve at some crack length. This results in catastrophic failure of component. And crack propagation curve of altered design of wing spar is well within the limiting range. This concludes that even in presence of crack, spar with altered design or damage tolerant design can carry the design limit load till next inspection. And in this project the fracture toughness value is taken from the book Fracture Resistance of Aluminum alloys published by ASM International.

6 CONCLUDING REMARKS

- Stress analysis of wing spar is carried out and maximum stress is identified at the rivet hole location in the bottom flange of the wing spar.
- Maximum tensile stress of 22.3 kg/mm^2(218.763 N/mm^2) is observed.
- A fatigu crack normally initiate from the location of maximum tensile stress in the wing spar structure as predicted from the stress analysis.

- Crack analysis is done on wing spar by initiating crack at maximum stress location and crack propagated in bottom flange then to the vertically in to the web of spar up to the $1/3^{rd}$ length of web. And stress intensity factor is calculated for different crack lengths using several iterations.
- At 56.66 mm crack length the SIF value crosses fracture toughness and leads to failure of wing spar.
- The structural design of spar is modified to make it damage tolerant by introducing one intermediate flange in between top and bottom flange. And crack analysis is done on this design.
- The maximum value of SIF for this analysis is 129.58 MPa$\sqrt{m}$ for crack length of 117.06 mm after this for next crack length SIF value starts decreasing.
- Comparing this maximum value of SIF 129.58 MPa$\sqrt{m}$ with fracture toughness value of material 140 MPa$\sqrt{m}$. The SIF value is less than fracture toughness of material. With this we can conclude that crack propagation is arrested and it satisfies the fracture toughness criterion and hence design is safe.

By observing the above point we can conclude now the new altered design is damage tolerant. That is even in the presence of crack wing spar is capable of carrying designed limit load at least till next inspection interval.

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