Debris Impact Study Fuselage Panel

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Abstract – *Airline operational costs are increasing constantly for structural component repair due to debris impact. The resulting damage is estimated to cost the aerospace industry $4 billion a year.*

Foreign objects at airport can be anything that positioned inappropriately and cause damage to the aircraft structural components, Aircraft personal and other equipment. Foreign objects can include any material i.e. Inhabitant animals, birds, repair tools, loose hardware, bolts, nuts, and other parts falling from previous aircraft.

Even though the major accidental scenarios like bird strike, Hail stone impact, and lightning strike are considered in Aircraft certification procedure; debris impact damage level on aircraft structural component and its fatigue life requirements are not reported specifically in certification documents.

So debris impact study is an essential part in defining fatigue and threshold life limits of an aerospace components. This helps in defining aerospace certification requirements and avoids major accidental damage.

Key Words: **Debris, Foreign Object Damage (FOD), Low Cycle Fatigue, Stone Impact, Threshold.**

1. INTRODUCTION

During the aircraft life cycle time, commercial and military aircraft parts are subjected to foreign objects like rivet mandrels, parts of ground vehicles, maintenance, stones, hail and bird collisions etc.., other than any part of the aircraft is known as foreign object to that aircraft. The resulting damage is called foreign object damage (FOD). Damage by hard particles mainly occurs, during take-off and landing or during motion of the aircraft on the airfield. Aircrafts on runway are mainly subjected to these foreign objects and damage the aircraft's engine, wing fuselage and nosal region.

Worldwide the FOD costs the aviation sector US$14 billion per year in direct plus indirect costs. Every airline operators are facing million dollars loss due to maintenance of the plane from FOD's. The crash of aircrafts such as Concorde (July, 2000) and Bombardier Learjet 36A (March, 2007) was due to the presence of runway debris. As 90% of FOD's are Bird strike, the other 10% include sand storm, hail-stone, runway debris like lofted stones, nuts, bolts, aircraft parts from previous airplane on runway, etc.

The small lofted stones from tires have major impact on airplane fuselage which creates visible damage, however in some cases only minor scratches or dents with measurable crack may develop, which may be left undetectable. However some lofting stone deflection systems are available, it makes the undercarriage design more complex and it's difficult to maintain in larger aircrafts. So the behavior aircraft fuselage panel to such a stone impact at various velocities and angles is studied and fatigue life is predicted for the component under stone impact at different thermal conditions.

2. Literature Review

The review summarizes the previous effort on the 'Damage tolerance assessment of fuselage and runway debris impact study. There were many researches being carried out on fatigue crack growth behavior of different structures, impact analysis and lofted runway debris. Here are few papers referred below:

J.O. Peters, R.O. Ritchie [1], examined Influence of foreign-object damage on crack initiation and early crack growth during high-cycle fatigue of Ti-6Al-4V alloy. The particle impact on metallic substances subjected to foreign object damage. The objective of this paper is to provide a rationale approach to define the limiting conditions for high-cycle fatigue (HCF) in the presence of foreign-object damage (FOD). This study focused on the role of simulated FOD in affecting the initiation and early growth of small surface fatigue cracks in a Ti±6Al±4V alloy, processed for typical turbine blade applications. Using high-velocity (200±300 m/s) impacts of 3.2 mm diameter steel spheres on the surface of fatigue test specimens to simulate FOD, it is found that the resistance to HCF is markedly reduced due to earlier crack initiation. Premature crack initiation and subsequent near-threshold crack growth is primarily affected by the stress concentration associated with the FOD indentation and the presence of small micro-cracks in the damaged zone (seen only at the higher impact velocities).

SeyedMasoudMarandi [2], explains the foreign object damage on the leading edge of compressor blades. Foreign object damage (FOD) usually happens when objects are sucked into jet engines powering military or civil aircraft. Under extreme conditions, FOD can lead to severe structural damage. More commonly it produces locally impacted sites of the fan and compressor airfoils, reducing fatigue life of these components. FOD is a prime cause for repair in aircraft engines. In this study, the impact on the edge of a thin plate is examined by using the finite element method. The second step in the analysis focuses on the comparison between quasi-static indentation and fully dynamic impact for three critical locations where residual hoop stresses are tensile.

S.N. Nguyen, E.S. Greenhalgh, R. Olsson, L. Iannucci, P.T. Curtis [3], details the parametric Analysis of Runway Stone Lofting Mechanisms. The influence of various factors affecting the severity of runway debris lofting mechanisms was investigated by performing numerical simulations and drop weight impact experiments to assess the likelihoodof a stone impact. Geometrical characterisation of stones collected from airfields led to a generic model of a tyre rolling over stones of various shape with different overlaps, orientations, and densities. In numerical simulations of a 0.4 m diameter aircraft tyre rolling at 70 m/s, a 10 mm diameter spherical stone was lofted at a maximum vertical speed of 35 m/s. For equivalent mass prolate spheroid stones, the loft speeds were 11 to 34% lower depending on the stone orientation. Objects with flat surfaces exhibited different lofting mechanisms and lower angular velocities. The conditions most conducive to stone lofting were very stiff, small diameter, sharp cornered tyres rolling on ground with a high friction coefficient over spherical stones such that just under half the stone diameter was covered by the tyre. The stone loft speed was approximately proportional to the square root of the tyre tread stiffness. Finally, tyre tread grooves could throw stones upwards at the tyre-ground separation speed, which was 17 m/s for the conditions mentioned.

Summary: The literature review clearly stated the significance of impact analysis for the metallic materials. Besides the description of the past work, the survey evidenced the finite element method as the pertinent method to accommodate the analysis of such studies.

3. Methodology

- Analysis of problem statement
- Literature survey
- Identify the fuselage panel geometry and material as per current design
- Geometry creation using CAD software CATIA
- Finite Element modeling and load application using preprocessing tool Hyper mesh or PATRAN
- FE Model solution using solver tool NASTRAN
- Fuselage panel safe life cycle calculation using damage tolerance tool NASGRO.
- Compare the allowable cycle between pristine and damaged (Stone impact) fuselage panels.

4. Objective

- If applied stress level on the fuselage panel due to stone impact is capable of initiating the crack; estimate the life cycle of the component with DTA techniques using NASGRO tool.
- Determine the threshold limit based on crack propagation level
- Perform a comprehensive study between pristine and damage model to know the debris impact levels due to debris

5. Analysis Procedure

5.1 Geometry

Aircraft Fuselage panel considered for analysis is shown in below figure. Considering the complexity of the structure part of the fuselage is considered in analysis with appropriate boundary condition simulation in Finite Element Model.

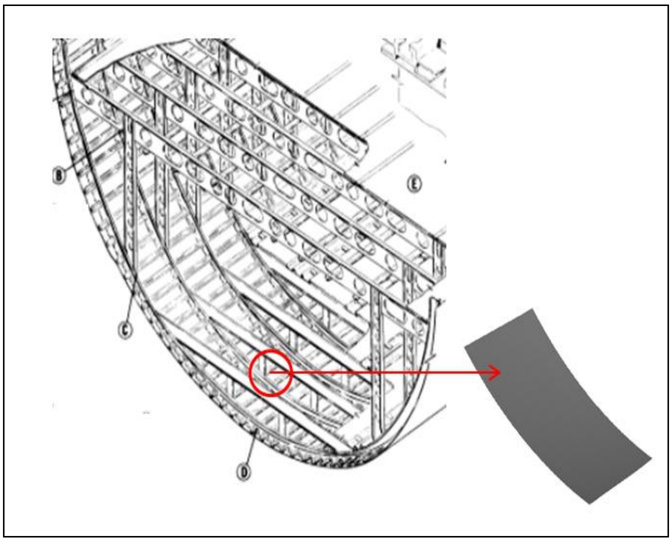


Fig-1: Fuselage Panel Considered For Analysis

5.2 Material Selection

Having better fatigue strength most Aircraft manufactures use Al 2000 series sheet metal in making fuselage panels. Properties for the common usage material Al2219-T62 sheet are given below

Ultimate Tensile Strength	414 Mpa
Tensile Yield Strength	290Mpa
Young's Modulus	73.1Gpa
Shear Strength	255 Mpa
Fatigue Strength	103 Mpa
Poisson's Ratio	0.33

Table-1: Fuselage Panel Material Properties

5.2 Finite Element Model Creation

The finite element model considered for this analysis is shown below

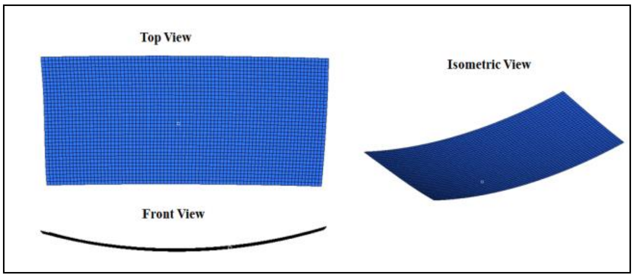


Fig-2: Aircraft Fuselage Panel Finite Element Model

To define the appropriate mesh density in Finite Element Model a trade study was performed with different mesh size by applying a constant magnitude load. Based on results (mesh density Vs von Mises) comparison, mesh convergence is observed to be at 0.5in. Hence mesh density with 0.5in considered in analysis.

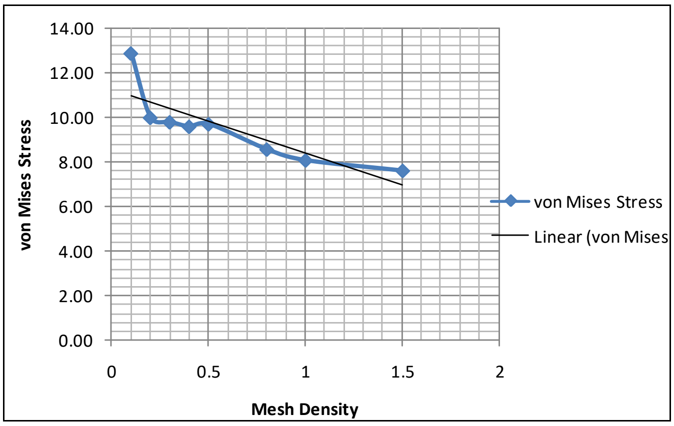


Chart-1: Mesh density Vs von Mises stress

5.3 Impact Load Calculation

From the above mentioned literature the debris stone mass10Kg and acceleration 11.2 m/s2 considered conservatively in this study. From the Newton's second law, Force applied on the structure is directly proportional to its acceleration i.e., F =m x a

Where m is the mass of the hitting body (Kg)
a is the acceleration of the body (m/s2)
So the impact force is F = 10 x 11.2 = 111.2 N = 25 lbs

5.4 FEM Pre and Post Processing:

Stone impact location, Boundary condition, Panel deformation due to applied load and its stress results are shown in following figures:

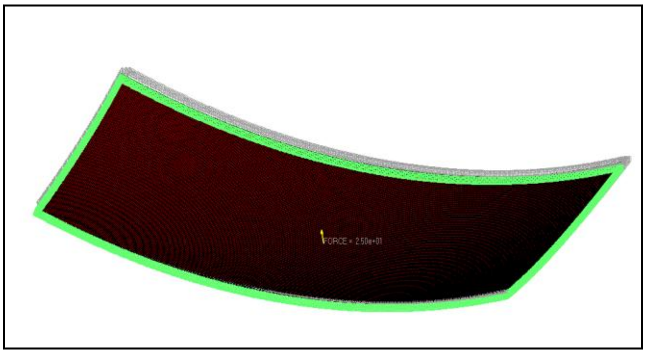


Fig-3: Load application and Boundary Condition

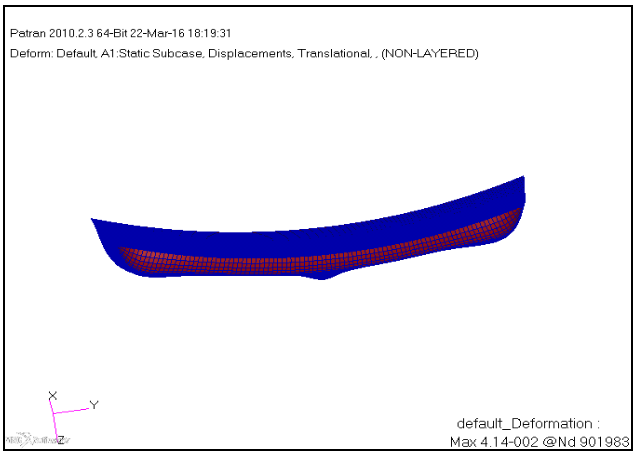


Fig-4: Panel Deformation due to applied load

Analysis performed at different environmental thermal load conditions (ISA day: 163F, Cold day:-65F and Hot day: 500F) and critical thermal load plot mapped on FEM is shown below

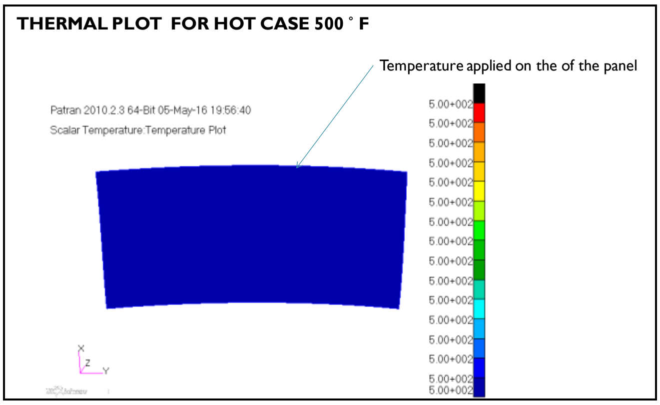


Fig-5: Applied thermal load for hot day scenario

Fuselage panel von Mises plot for the appled load is shown below

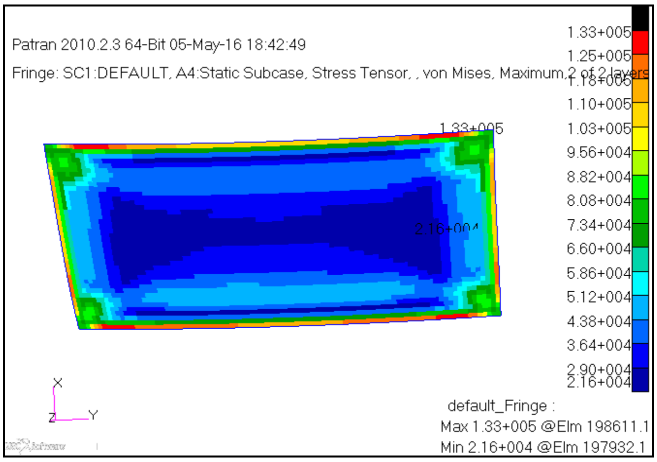


Fig-6: von Mises stress plot for debris impact

Considering the stress level from above graph, a crack growth analysis is performed using NASGRO tool, safe life and threshold number of cycles are determined. Cracks can be grouped in three different length classifications; flaw size, inspectable size, and critical size. These criteria are illustrated in below Figure on the crack growth curve.

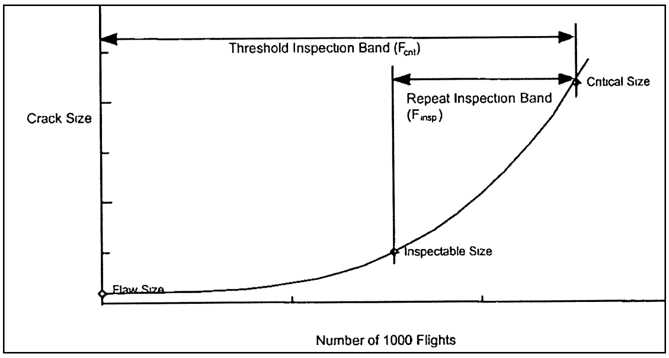


Fig-7: Crack growth curve

Considering the crack growth study is for sheet surface; choose SC02 in NASGRO tool.

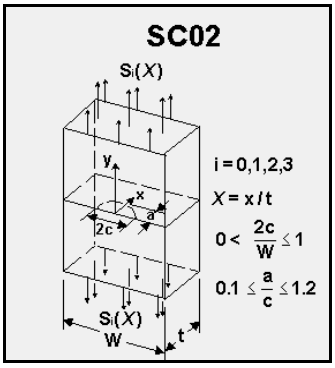


Fig-8: Crack growth model in NASGRO tool

From the above stress contour plot stress gradient along the normalized distance are calculated and provided as input to the NASGRO tool. Also required geometry and material data information is provided in tool.

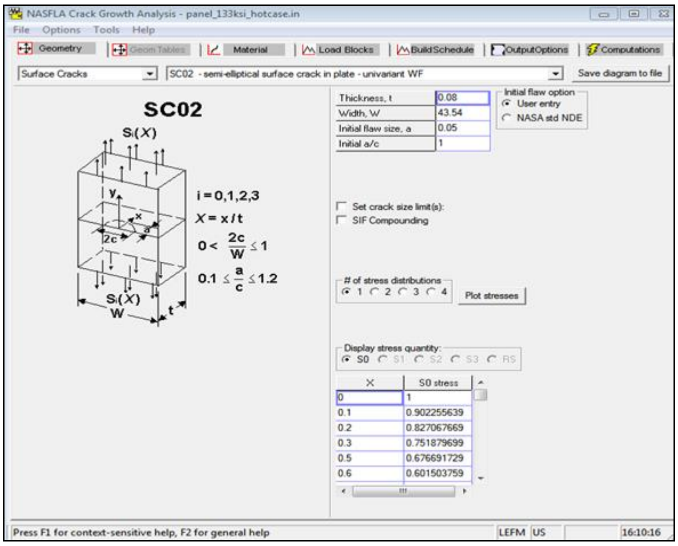
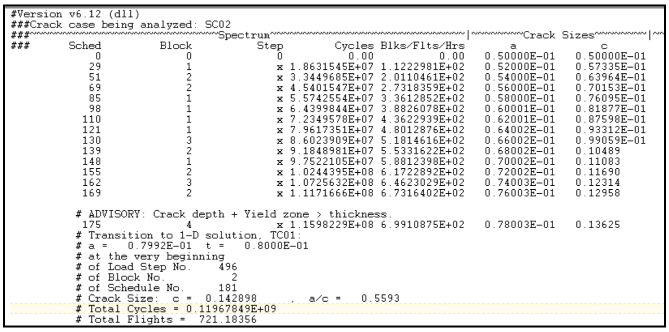


Fig-9: Crack growth model input database

Ouput summary from the NASGRO tool is shown below:



```
#Version v6.12 (dll)
###Crack case being analyzed: SC02
###~~~~~~~~~~~~~~~~~~~~~~~~~~~~Spectrum~~~~~~~~~~~~~~~~~~~~~~~~~~~~~|~~~~~~~~Crack Sizes~~~~~~~~|~~
###      Sched          Block          Step        Cycles Blks/Flts/Hrs        a            c
           0              0              0          0.00           0.00   0.50000E-01  0.50000E-01
          29              1            x 1.8631545E+07 1.1222981E+02   0.52000E-01  0.57335E-01
          51              2            x 3.3449685E+07 2.0110461E+02   0.54000E-01  0.63964E-01
          69              2            x 4.5401547E+07 2.7318359E+02   0.56000E-01  0.70153E-01
          85              1            x 5.5742554E+07 3.3612852E+02   0.58000E-01  0.76095E-01
          98              1            x 6.4399844E+07 3.8826078E+02   0.60001E-01  0.81877E-01
         110              1            x 7.2349578E+07 4.3622939E+02   0.62001E-01  0.87598E-01
         121              1            x 7.9617351E+07 4.8012876E+02   0.64002E-01  0.93312E-01
         130              3            x 8.6023909E+07 5.1814616E+02   0.66002E-01  0.99059E-01
         139              2            x 9.1848981E+07 5.5331622E+02   0.68002E-01  0.10489
         148              1            x 9.7522105E+07 5.8812398E+02   0.70002E-01  0.11083
         155              2            x 1.0244395E+08 6.1722892E+02   0.72002E-01  0.11690
         162              3            x 1.0725632E+08 6.4623029E+02   0.74003E-01  0.12314
         169              2            x 1.1171666E+08 6.7316402E+02   0.76003E-01  0.12958

        # ADVISORY: Crack depth + Yield zone > thickness.
         175              4            x 1.1598229E+08 6.9910875E+02   0.78003E-01  0.13625
        # Transition to 1-D solution, TC01:
        # a =   0.7992E-01  t =   0.8000E-01
        # at the very beginning
        # of Load Step No.    496
        # of Block No.          2
        # of Schedule No.     181
        # Crack Size:  c =  0.142898     ,  a/c =   0.5593
        # Total Cycles = 0.11967849E+09
        # Total Flights =  721.18356
```

Fig-10: NASGRO output summary

Crack growth study performed considering A-tip and C-tip crack approach and results are shown below:

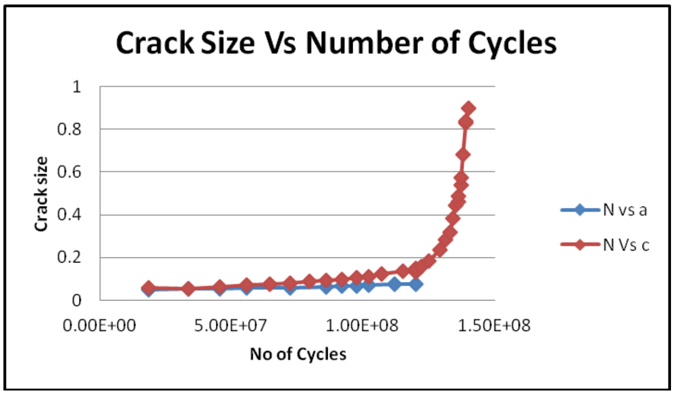


Chart-2 No. of cycles Vs crack size

Resulted critical crack size is 0.9in and obtained safe life cycles before crack propagation is 1.86E+7 cycles. Threshold life calculation details are given below.

$$F_{thr} = \frac{F_{crit}}{K_1 \cdot K_3 \cdot K_4} \leq \frac{Economic\ Life}{2}$$

Where Fthr = Flights to threshold inspection

Fcrit = Number of flights from initial flaw size to critical crack length

K1 = Scatter factor for source of crack growth data

K3 = Scatter factor for environmental effects

K4 = Scatter factor to account for uncertainties in the analysis

Stone impact loads are only considered in this FEM study; a safety factor of 5 and Environmental factor of 4 considered in threshold calculation conservatively.

Life of the component N= 1.86E+7/(4 x 5) =930,000 cycles

Following the similar analysis approach using NASGRO tool pristine panel life cycles are calculated and observed to be infinite.

Allowed cycle for fuselage panel considering Debris Impact		Allowed cycle for pristine panel without Debris Impact
Allowable cycle	Crack Length (inches)	
1.86E+07	0.057	Infinite Life
9.75E+07	0.111	
1.07E+08	0.123	
1.15E+08	0.136	
1.20E+08	0.143	
1.36E+08	0.485	
1.38E+08	0.684	
1.40E+08	0.901	

Chart-3 Pristine Vs Debris impact model life cycle

6. CONCLUSION

From above study debris impact fuselage panel life cycles are low/not infinite compared to the pristine model. So the aircraft certification requirements should include an additional design requirement to meet design life criteria for small debris impact. Also this study can be extended to multi-axial loading with flight loads for more detailed understanding of the damage caused by even the tiniest debris with greater impact force.

REFERENCES

[1] J.O. Peters, R.O. Ritchie 'Infuence of foreign-object damage on crack initiation andearly crack growth during high-cycle fatigue of Ti±6Al±4V' Department of Materials Science and Mineral Engineering, University of California, USA.

[2] SeyedMasoudMarandi and KhosrowRahmani, 'Foreign Object Damage on the Leading edge of compressor blades' from Water University of Technology, USA.

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