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Impact Simulation: Comparison of Composite Jet Engine Fan Blade with and without Leading Edge Reinforcement

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Abstract - *Bird strikes are a significant danger to an aircraft particularly at the time of landing &takeoff. Composites have permitted expanded efficiencies by permitting more complex shapes, bringing about less fan blades, and less weight. The present study focused comparing the impact resistance of carbon fiber composite with and without leading edge caused by bird impact on fan blades. Bird modeled as cylindrical geometry with hemispherical ends which is having the properties of Gelatin material and mass of 1.81kg. Cylindrical geometry of the bird model is made to impact on to the leading edge of the actual fan blade model at 90° along with a two different impact velocities of 185 & 200 m/s. The analysis of bird impact was made by simulating impact of the bird model on carbon fiber and carbon fiber with Inconel 792 as leading edge. The results show that the metal leading edge reinforcement has a greater influence in improving the impact resistance.*

Key Words **- jet engine fan blade, bird impact analysis, Ansys, composite fan blade, inconel reinforcement, leading edge, comparison.**

1. INTRODUCTION

Striking of bird on an aircraft may lead to plastic deformations, sudden decrease of thrust, even engine failure. Bird strikes on rotating blades can also cause slices of birds hitting other parts which may lead to greater damage According to various surveys coordinated previously, it has been seen that quitter airplanes are more helpless to avian ingestion, expressly due their absence of caution. Various measures have been taken to shield these strikes from occurring. Both passive and active methods have been utilized. In the passive technique any sight of food, water or shelter is taken out close to the air terminal zone. Bird strike cannot be completely avoided. However, reduction of bird impacting on jet engines can be achieved by suitable design and manufacturing, simulation analysis and practical experiment ofjet engines as indicated by the aeronautical details, with the term bird strike we mean the impact between a feathered creature and an airplane confronting part, which incorporates windshield, nacelles, and wing driving edge and Compressor blade. Two materials have been distinguished to carry on comparative with the conduct of the winged animal upon impact, gelatin and Room Temperature Vulcanized (RTV) rubber. Both of these components have liquid like qualities, which intently reproduces a real winged animal's effect on an engine blade at high velocities [2]. On Fluctuating effect speedvarious kinds of deformation can be obtained: elastic impact, plastic impact, hydrodynamic impact, impact at sonic velocities[4].

1.1 Fan blade

Titanium, aluminum and treated steel have been utilized inthe fan sharp edges, and titanium is regularly utilized due to itshigh strength to weight ratio, corrosion resistance, and creep resistance. For the GEnx motors, the fan edges are made out of Carbon Fiber Reinforced Plastic composite (CFRP) edges and titanium leading edge (Ti-6Al-4V combinations), which was introduced in the GE90 engine, for improving the impact damage resistance in case of bird strikes. (Fig -1). The forward-cleared wing type is embraced because of the most recent three dimensional aerodynamic design technologies. This improves the streamlined exhibition and furthermore can diminish the quantity of fan blades from 22 to 18

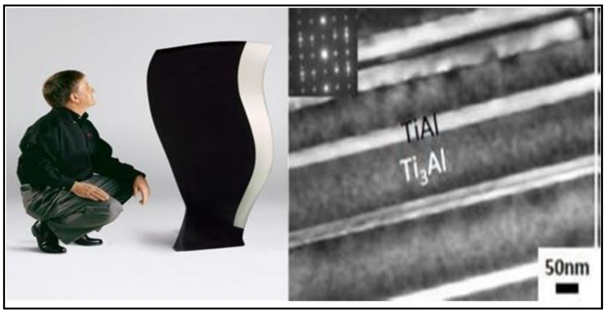

Figure 1: Fan blade in the GE90 and Microstructure ofTi-6Al-4V alloy

1.2 Problem definition

Fowl hits are a noteworthy risk to an aircraft mainly while the plane gets landed or take-off. It may achieve basic loss of human life and property damages worth millions annually. The desire to lessen weight, increment effectiveness and reduction cost has driven engine designers to think about composites, mostly carbon and Kevlar, while picking materialsfor fan edges and cases Exploration started during the 70's and proceeds through today, with manufacturing and analysis toolscontinually improving. The principle contemplations in thedesign of fan sharp edges are proficiency, weight, and durability [8]. The sharp edges must be equipped forwithstanding common debris ingestion with no harm, and be handily fixed maintained. Composites have allowed expanded efficiencies by permitting more unpredictable shapes, bringingabout less cutting edges, and less weight. Composites have been shown to be a very acceptable material choice to construct the single most massive component of an engine.

2. METHODOLOGY

The basic step is to create a fan blade model using design software and meshing the model by importing it to a meshing tool. Solid elements like quadrilateral, hexahedral or tetrahedralare used for meshing and the necessary boundary conditions and loads are applied. Finally the model is imported to simulating software to evaluate the structural response of the blade and static behavior of structure

2.1 Following are the basic steps

Step 1: Geometric model of fan blade is modeled in NX Unigraphics modeling tool with standard dimensions.

Step 2: After creating 3D model of fan blade as per specifications it is imported into HYPER MESH for meshing.
Step 3: Based on the mass the required specifications of thebird is calculated, it is modeled as a solid cylindrical masswith hemispherical ends and appropriate properties wereapplied.

Step 4: Carbon composite material properties applied to fan blade and bird configuration will be considered as load which is hitting on fan blade near the tip leading edge.

Step 5: Static analysis is performed for this assembly using ANSYS.

Step 6: Results are interpreted.

2.2 Geometric Modelling

Composites are used primarily for their high solidarity to- weight extent and significantly versatile properties. According to our necessity, on the off chance that we need 10% of solidarity to be one way and staying 90% toward another path, by masterminding composite handles can fulfill ourprerequisite. Figure 2 shows the geometric model of turbo fan engine fan blade, it's also shows the assembly of fan blade to rotor shaft. The geometric modeling has been done using modeling software Unigraphics. The dimensions of the fan blade are considered from the literature survey. Figure 3 shows the 2D drawing of fan blade it consists of all the required dimensions to develop the 3D model in the design software.

Fan cutting edges are fundamentally airfoils and they have created throughout the long based on the principles of the blade element momentum theory (BEM). It's a one dimensional (1- D) rearranged hypothesis that is ordinarily utilized by fan sharpedge architects reasonably correct prediction of performance. So this hypothesis describes how lift is created on every cutting edge components and it makes a steady measure of lift (the total lift of all blades is the thrust). The BEM theory provides an initial point with regards to the performance of a blade, allowing a designer to select the proper airfoil section, twist, chord, and pitch angle for optimal thrust distribution The jet engine propulsion process begins with fan blades rotating at over 2000 rpm at take-off speed. Normally, a engine is made out of somewhere in the range of 16 and 34 fan edges, contingent upon their aspect ratio, among different components, during propulsion process engine drawing an air at a pace of around 2500 pounds for every second.

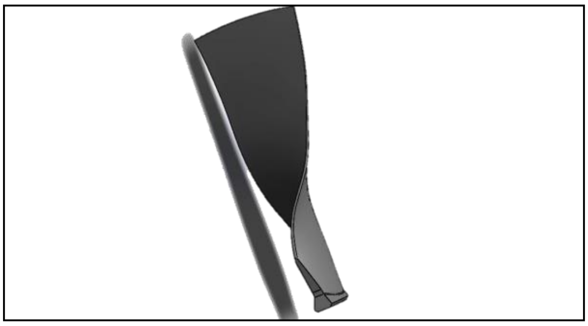

Figure 2: Geometric Modelling of a single fan blade

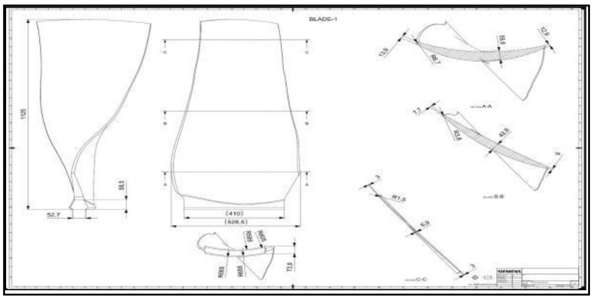

Figure 3: 2D view of fan blade

2.3 Bird Geometry

Bird geometry is created as a solid model with hemispherical ends, which is one of the most used bird model shape for bird impact simulations. Here mass of the bird is taken as 4lb(1.81kg).

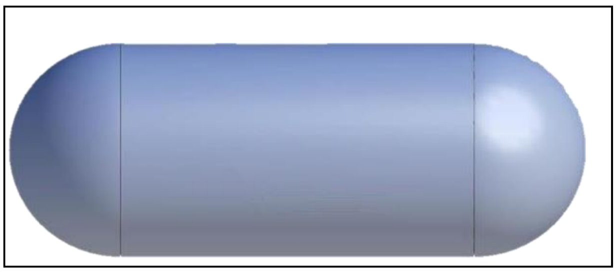

Figure 4: Bird model

Using mass of the bird density, length and diameter are then calculated by using the formulas.

These formulas are taken from a study published by Australiantransportation Safety Bureau [5].

Density = $959 - 63 \times \log_{10}(\text{Mass})$ = 942.7 Kg/m3

Diameter = $0.0804 \times \text{mass}^{0.335}$ = 0.098 m

2.4 Material properties

Bird material is taken as Gelatin, **Density=942.7 kg/m^3**, Young's modulus=0.66 GPA, Poisson's ratio=0.45, Bulk modulus=202 GPA, Shear modulus=0.22759 GPA.

Fan blade material is taken as carbon fiber composites, Density=1760 kg/m3, Young's modulus=159 GPA, Poisson's ratio=0.35.

Reinforced material on the fan blade leading edge is taken as Nickel based super alloy INCONEL IN972DS, Density=8250kg/m3, Young's modulus=220 GPA, Poisson's ratio=0.29.

3. MESHING

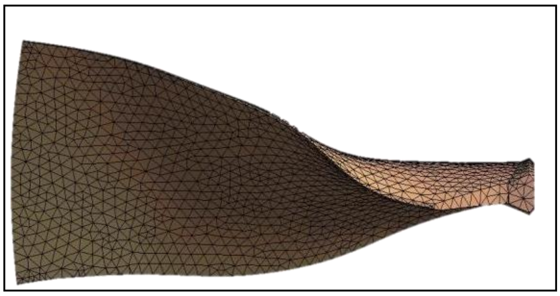

Figure 5: Mesh model of fan blade without leading edge reinforcement

Figure 5 shows the Finite Element mesh generated for the geometric model of the fan blade structure using tetrahedral elements.

Again the blade is meshed with split mesh with two different elements, because impact simulation is performed for two different conditions. One is fan blade without leading edge and with leading edge.

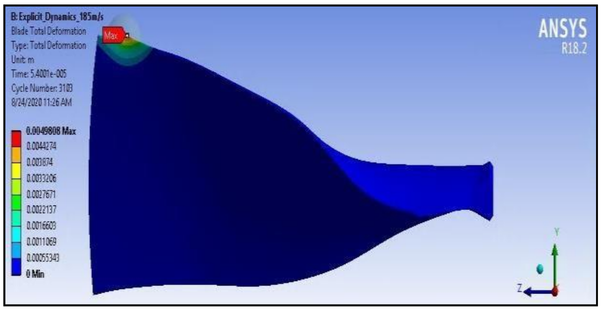

Figure 6: fan blade with leading edge reinforcement

Bird model is meshed with hexahedron element. The accuracyof solutions in hexahedral meshes is the highest.

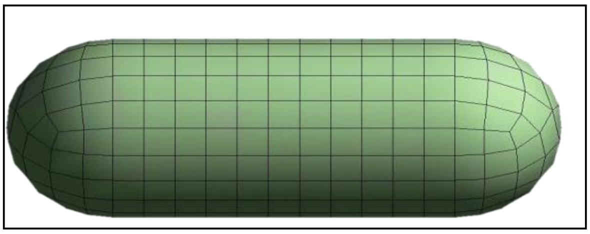

Figure 7: Mesh model of bird

Tetrahedron and hexahedron elements are used to representthe blade and hexahedron is used for bird.

- 94892 & 58383 are the number of Elements and nodes count for first simulation.
- 237675 & 173231 are the number of Elements and nodes count for second simulation.

4. LOADS AND BOUNDARY CONDITION

To study the static behavior of the fan blade, need to fix the fan blade at its root. Stress is induced in the structure due to the application of load. Point load from the solid bird geometry is used as a loading condition for both simulations. Bird geometry is assumed to be strikes on leading edge at the tip of the fan blade. The preferred impact location is selected from the available literature.

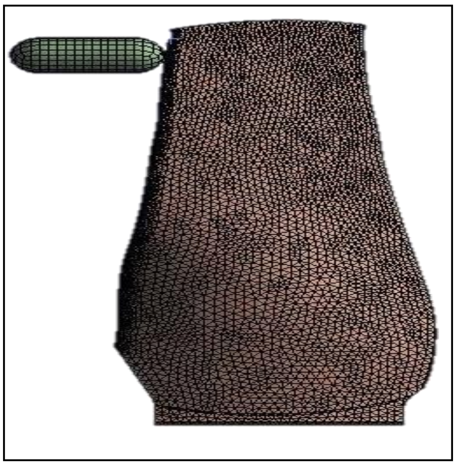

Figure 8: Application of impact load with fan blade root is fixed.

5. RESULTS AND DISCUSSION

The results of bird impact analysis on composite fan blade with and without leading edge reinforcement for impact analysis displacement and stresses are obtained.

5.1 Impact results - blade without leadingedge

Below figure represents the displacement of 4.9808 mm, maximum principle stress of 15.71 MPA and vonmises stress of 31.81 MPA, when a bird of 1.81kg hits the fan blade with a velocity of 180 m/s and impact time of 0.054 mille seconds.

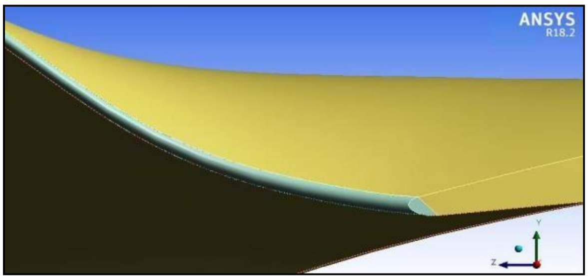

Figure 9: Displacement of 4.9808mm at 180m/s

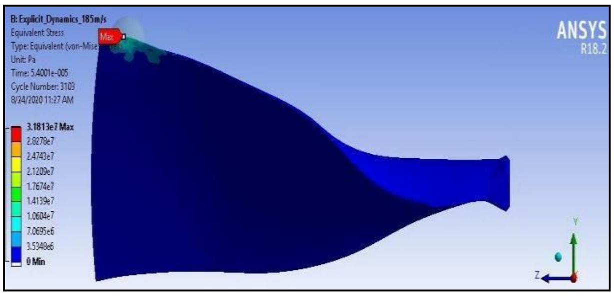

Figure 10: Vonmises stress of 31.8 Mpa at 180m/s

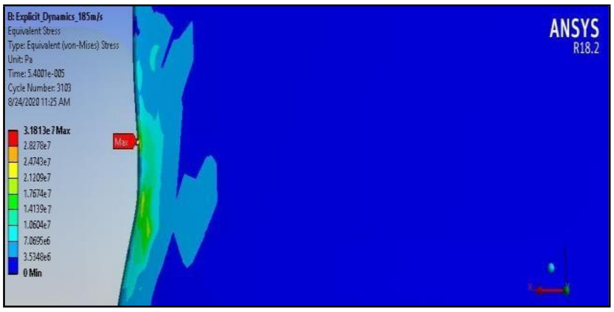

Figure 11: Max principle stress of 15.71 Mpa at 180m/s

When the bird hits the fan blade at a velocity of 200 m/s the observed displacement, maximum principle stress, vonmises stresses are 5.0714 mm, 16.54 MPA, & 38.40MPA respectively

5.2 Impact results - blade with leading edge reinforcement (inconel 972DS)

Below figure represents the displacement of 2.551 mm, maximum principle stress of 11.586 MPA and vonmises stress of 11.968 MPA, when a bird of 1.81kg hits the fan blade with a velocity of 180 m/s and impact time of 0.05 mille second.

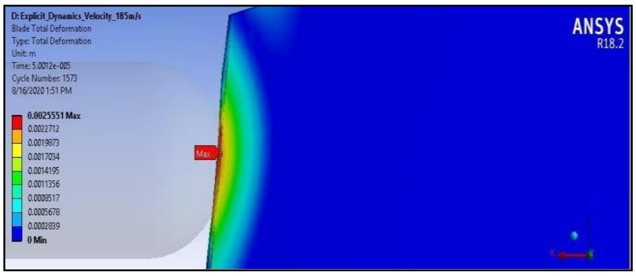

Figure 12: Displacement of 2.551mm at 185 m/s with leading edge

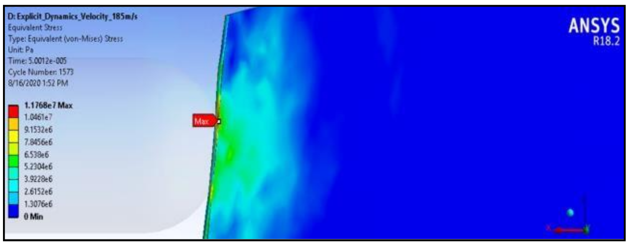

Figure 13: Vonmises stress of 11.968 Mpa at 185m/s

When the bird hits the reinforced fan blade at a velocity of 200 m/s the observed displacement, maximum principle stress, vonmises stresses are 2.8517 mm, 13.784MPA, & 13.71MPArespectively.

5.3 Discussions

The static impact analysis is performed for the fanblade due to an external body impact model is deformed and stressed under bird strike.

The maximum displacement occurs on tip leadingedge of the fan blade without any leading edge reinforcement is 4.9808 and 5.0714 mm at 0.054 and 0.05 milliseconds.
The maximum displacement occurs on tip leadingedge of the fan blade with Inconel 792 integrated with carbon fiber as leading edge reinforcement is 2.555 and 2.851 mm at 0.05 milliseconds.
Displacements obtained for both impact simulations as shown above are relatively small, the one with the leading edge is even small when compare to the blade without leading edge and remain localized at the impact location, which follow the expected pattern and are within acceptable limits.

The main objective of this paper is to compare the simulation results for impact resistance, fan blade with and without leading edge. From the above results it is concluded that the blade with metal leading edge has more impact resistance under bird strike than the one without a leading edge.

An impact analysis result shows the local stress

6. Future scope of research work

The present study is focused on static analysis and the dynamic analysis is not performed. So for the same geometric model of fan blade can be dynamically analyzed and from the obtained analysis results, we can study the fan blade with metal leading edge under dynamic loading condition along with impact load.

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