ISSN No:-2456-2165

Investigating the Impact of Bird Strike on Aircraft Wing

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Abstract:- Bird strikes are a continuing challenge in the aviation industry, especially for aircraft with leading-edge structures. This study uses LS-Dyna, a powerful finite element analysis tool, to investigate the effects of bird strikes on these structures. A detailed FEA model representing the receding leading-edge structure is created and simulations are performed under different bird impact. The resulting structural damage can be carefully analysed to identify critical design parameters that influence resistance to bird strikes. To comprehensively understand the influence of wing design on bird strike resistance, we compare the structural damage of different swept leading edge wing designs. Maintaining consistent parameters across all simulations allows us to isolate the effects of wing design and directly compare structural damage. This comparative analysis reveals which designs are most resistant to bird strikes and provides valuable insight into future aircraft designs. The results reveal that bird strikes can cause substantial structural deformations on wing profiles. Additionally, kinetic energy and stress distribution are analysed, demonstrating the impact of bird strikes on aircraft wing leading edges.

Keywords:- *Fea Modelling, Structural Deformation, Swept Wing, Leading-Edge Structures, Ls-Dyna Software, Bird Strike Resistance, Comparative Analysis*.

I. INTRODUCTION

The aviation industry faces the continuing challenge of protecting aircraft from bird strikes, especially on swept leading edge structures. These collisions, which frequently occur during take-off, landing, or low-altitude flight, occur when the leading edge of the wing increases the risk. Investigating the effects of bird strikes requires advanced techniques such as finite element analysis (FEA) and experimental testing. FEA simulations enable detailed investigation of structural responses under different impact scenarios, and experimental tests provide real-world data on the effects of controlled bird strikes. Analysis of FEA and experimental data reveals important design parameters that influence bird strike resistance, such as material properties of the wing structure, leading edge thickness, geometry, and presence of protective layers. This understanding is critical to optimizing aircraft design and improving overall resilience to bird strikes. Additionally, the study goes.

➢ *Leading Edge of Wing*

The leading edge of an aircraft wing is an important aerodynamic component, serving as the leading edge that meets oncoming air during flight. It plays an important role in generating lift and controlling air flow. The leading edge typically features a streamlined shape to minimize drag and optimize wing performance. Modern aircraft often have swept leading edge structures known for their aerodynamic efficiency. This edge is made of a special material and is designed to withstand various aerodynamic forces and external influences, including the potential risk of bird strikes. Design details such as thickness, shape, and incorporation of protective layers have been carefully considered to ensure optimal performance and structural resiliency over the aircraft's operational life.

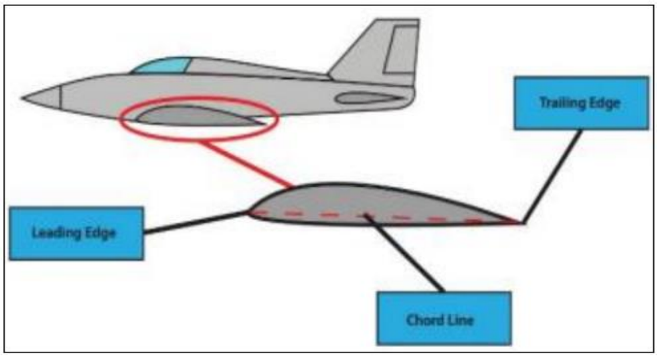

Fig 1 Leading Edge in an Aircraft

➢ *Bird Strike Analysis*

Bird strike analysis is an important aspect of aviation safety and involves a comprehensive assessment of the effects of bird strikes on aircraft structures. This research process uses advanced techniques such as finite element analysis (FEA) and experimental testing to simulate and study the effects of bird strikes. The FEA model allows for a detailed study of the structural response to different impact scenarios, considering factors such as bird size, speed, and impact angle. At the same time, experimental tests expose real aircraft structures to controlled bird strikes, providing real-world data on resulting damage and structural integrity. Beyond structural concerns, the analysis also considers changes in aerodynamic performance caused by bird strikes beyond structural damage and considers the potential impact on aerodynamic performance. Bird strikes can cause dents, tears, or holes in the wing skin, altering airflow and potentially affecting lift production or causing controllability issues. This overall understanding is essential to ensuring safe flight after a bird strike encounter.

➢ *Leading Edge Bird Strike*

Leading edge bird strike analysis is an important aspect of flight safety and focuses on the vulnerability of the wing's leading edge to bird strikes. This study uses advanced techniques such as finite Modelling of Bird Strike on an Aircraft Wing Leading Edge Made from Fibre Metal Laminates – Part 1: Material Modelling[4] this paper by Michael A. McCarthy, C.T. McCarthy gives us the findings as when the model's output is contrasted with actual findings on FML at different strain rates, it becomes clear that the model can adequately represent the majority of the intricate behaviour these materials exhibit that is dependent on strain rate element analysis and experimental testing to evaluate the structural and aerodynamic effects of bird strikes on the leading edge. The study considers factors such as bird size, impact speed, and angle to simulate real-world scenarios. By studying the complexities of these collisions, researchers aim to improve leading edge design and durability to ensure aircraft safety and performance during bird encounters

➢ *Leading Edge Bird Strike*

Leading edge bird strike analysis is an important aspect of flight safety and focuses on the vulnerability of the wing's leading edge to bird strikes. This study uses advanced techniques such as finite element analysis and experimental testing to evaluate the structural and aerodynamic effects of bird strikes on the leading edge. The study considers factors such as bird size, impact speed, and angle to simulate real-world scenarios. By studying the complexities of these collisions, researchers aim to improve leading edge design and durability to ensure aircraft safety and performance during bird encounters. 1.5 Smoothed Particle Hydrodynamics (SPH) Smoothed Particle Hydrodynamics (SPH) is a numerical method that has proven to be a powerful tool for simulating bird strikes. Unlike traditional finite element methods, SPH uses a meshless approach and represents the bird as a collection of particles or liquid elements. This meshless approach has several advantages for bird strike analysis:

- Geometric flexibility: SPH can create complex process geometries, allowing you to Irregular shapes can also be included.
- Large deformations: SPH can effectively simulate the large deformations and material fragmentation characteristic of bird strike events.
- Material Behaviour: SPH can integrate various material models, including bird tissue and aircraft structures, to accurately represent impact behaviour.

II. LITERATURE REVIEW

➢ *Introduction*

Leading edge bird strike analysis is an important aspect of flight safety and focuses on the vulnerability of the wing's leading edge to bird strikes. This study uses advanced techniques such as finite element analysis and experimental testing to evaluate the structural and aerodynamic effects of bird strikes on the leading edge. The study considers factors such as bird size, impact speed, and angle to simulate real-world scenarios. By studying the complexities of these collisions, researchers aim to improve leading edge design and durability to ensure aircraft safety and performance during bird encounters.

➢ *Review of Literature*

Hansen, Kristy Lee[1] study tell us that All tubercle arrangements examined in the investigation have demonstrated that improved lift performance in the post-stall regime results in a decrease in lift performance in the pre-stall regime. It has also been observed that post-stall performance is significantly enhanced and pre-stall lift performance approaches the values obtained by the unmodified air foil when the amplitude and wavelength of the tubercles are optimized. Tatjana Y. Hubel* and Cameron Tropea . [2] paper signifies that it has been established that small vertebrates like hummingbirds, swifts, and small bats have leading edge vortices (LEVs). We have created a simplified goose-sized flapping model for wind tunnel testing to investigate the significance of unsteady effects at the scale of large birds. Measurements of instantaneous net force over the wingbeat cycle clearly showed the influence of the delayed stall and flow separation. J. J. Videler, E. J. Stamhuis, G. D. E. Povel. [3] The findings demonstrate that at small (5- to 10-) angles of attack, gliding swifts can produce stable leading-edge vortices. The paper that most of the birds' arm-wing flow can stay traditionally attached, while the swept-back hand-wings provide lift through leading-edge vortices. Modelling of Bird Strike on an Aircraft Wing Leading Edge Made from Fibre Metal Laminates – Part 1: Material Modelling. [4] this paper by Michael A. McCarthy, C.T. McCarthy gives us the findings as when the model's output is contrasted with actual findings on FML at different strain rates, it becomes clear that the model can adequately represent the majority of the intricate behaviour these materials exhibit that is dependent on strain rate .Part II [5] by the same author here gives other half of study according to reports, aircraft sections that are likely to be subjected to hits like runway debris or bird strikes can benefit from the outstanding impact qualities of Fiber Metal Laminates, which are composed of layers of aluminium alloy and high-strength glass fibre composite. Impact Simulation with an Aircraft Wing Using SPH Bird Model by BogdanAlexandru BELEGA . [6] paper's findings are A shape that is frequently employed in numerical studies of bird striking was represented by the bird model, which was a fluid cylinder with two hemispherical ends. Finding the safe impact velocities at which the wing is not damaged was the major goal. Bird strike analysis on an aircraft aerofoil. [7] paper has the study done over A specified in Part 25 of Federal Aviation Regulations, an airplane must be capable of successfully completing a flight during which likely a structural damage occurs as a result of impact with a 4 lb (1 lb= 0.4536 kg) bird (8 lb for an empennage structure) when the velocity of the airplane relative to the bird along the airplane's flight path is equal to Vc (design cruise speed) at the sea level or 0.85 Vc at 8000 ft (1 ft= 0.3048 m), whichever is more critical. Leading edge topography of blades–a critical review. [8] states the topography changes brought about by blade leading edge maintenance, the impact of form and roughness on performance, and the attempts to forecast and model these changes.

ISSN No:-2456-2165

➢ *Identification of Gaps/Scopes of Work*

- There is less study done over leading edge of wing
- Not much work is done when the weight of bird is increased and observe the difference.
- The mostly used method is Abaqus software but we are using LS-Dyna. 2.6

➢ Objectives

- Impact analysis over leading edge of wing.
- Solver Validation
- Material modelling
- Performing stimulation over a 3D model to observe structural deformation
- Verification & Validation of the results observed

III. COMPUTATIONAL METHODOLOGY

➢ *Introduction*

We are using LS-DYNA for FEA simulations that will show us the structural deformation in leading edge of wing by bird strike. LS-DYNA provides a wide variety of functions, but it is very powerful especially for solving complex nonlinear analysis based on explicit analysis algorithms, providing excellent analysis results in the collision, explosion, and machining fields of automobiles. In general, finite element analysis classes in graduate schools do not have easy access to LS-DYNA because they are assigned to work on programs such as ABAQUS or ANSYS. However, there are few departments that have no other choice than using LS-DYNA for actual design/analysis in branches such as automotive, aviation and shipbuilding.

➢ *Element LS-DYNA*

It is a general-purpose analysis program that can use many elements. It is up to the analyst's experience and know-how to make the right choice of exactly which element to use from among so many element types available. There are many people who think that a very small mesh in 3D element modelling will produce good results without any worries. However, in fact, experienced engineers know that the shell model is much more reliable and effective than solid elements in vehicles and aircraft structures. The element library provided by LS-Dyna.

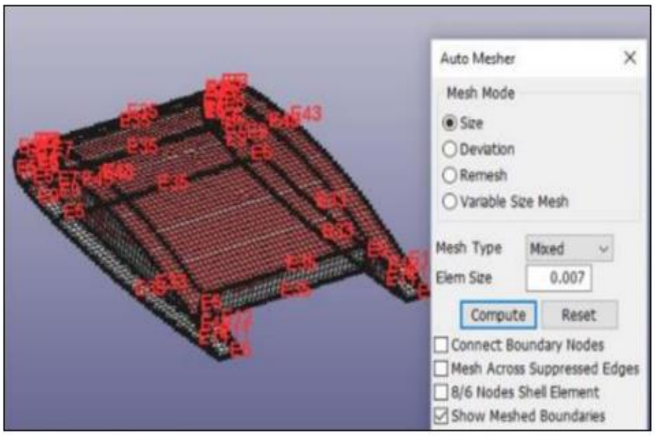

Fig 2 Element Section in LS-Dyna

➢ *Solid Elements:*

Solid elements are used to create mesh directly on the target structure without further processing, including simplification and optimization, but it takes a lot of time to generate mesh, computational CPU time and post-processing.

➢ Shell Elements:

The use of shell elements in the finite element analysis is quite high. This is because many machine components are manufactured using thin panels or sheet metals. In particular, the proper application of shell elements is very important in aviation and shipbuilding

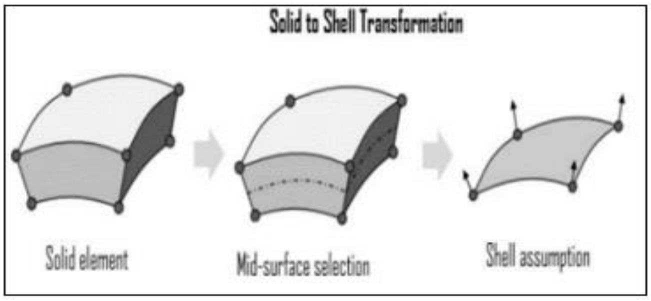

Fig 3 Types of Elements in LS-Dyna

➢ *Mesh Generation*

Mesh generation is a critical step in finite element analysis (FEA), and it is especially important in LS-DYNA, which is an explicit FEA solver used to simulate dynamic events. The mesh is a discretization of the continuous model into a collection of discrete elements, and the accuracy of the simulation results depends heavily on the quality of the mesh. Types of Meshes in LS-DYNA There are two main types of meshes used in LS-DYNA:

- Hexahedral meshes: Hexahedral meshes are made up of six-sided elements, and they are the most common type of mesh used in LS-DYNA. They are generally considered to be the most accurate type of mesh, but they can be more difficult to generate than other types of meshes.
- Tetrahedral meshes: Tetrahedral meshes are made up of four-sided elements, and they are the simplest type of mesh to generate. They are often used for complex geometries where it is difficult to generate a hexahedral mesh.

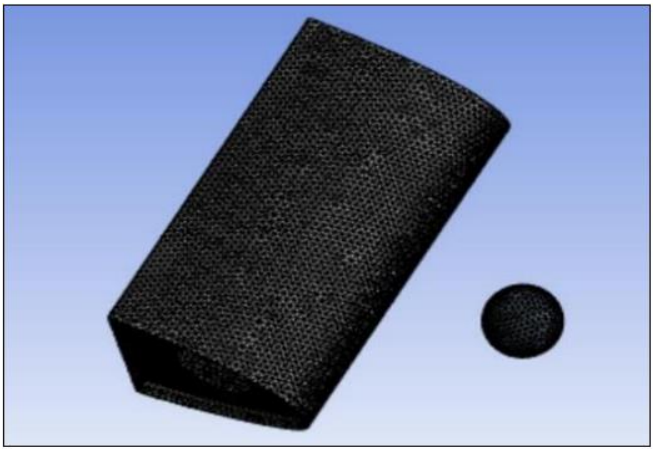

Fig 4 Mesh Generation

➢ *Analysis Condition:*

Matsum This is the process of generating keywords for the analysis model. To check if all the necessary parts of the model are included, use Model checking to check for missing elements. If no error appears, it means that all the necessary elements are included in the analysis model. In this model, two warnings come up and double-clicking them individually confirms detailed information, which can be useful when debugging.

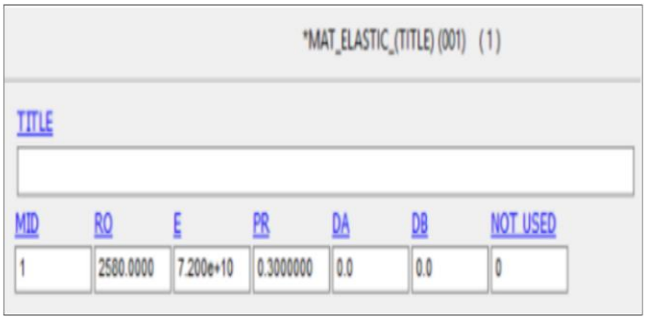

Fig 5 Material Property (Input) in LS-Dyna

➢ *Job Execution*

There are many ways to perform an analysis. There is a method of executing a command directly in the command window. If you are using ANSYS, you can use the command window provided by ANSYS or use LS-DYNA Manager. . If you click File → Run LS-DYNA, a dialog box for solving is displayed below. Here various functions are provided. They are model file, storage location, solver selection, CPU number, and memory allocation options. Selecting the triangle below gives a brief overview of the analysis process. Also, the result file is directly linked and the keyword can be checked directly with the text editor, so use it frequently to familiarize with the working environment.

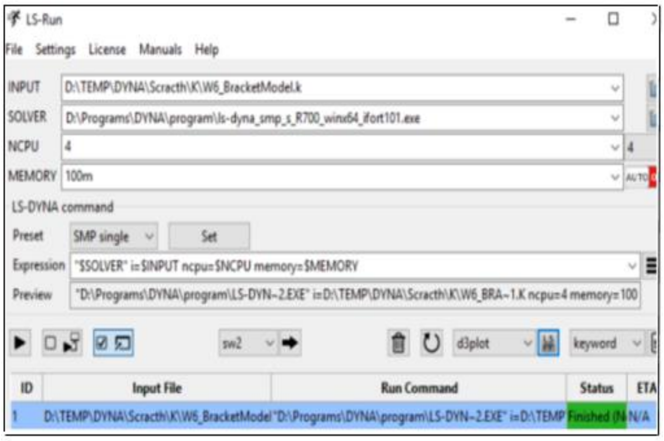

Fig 6 Job Execution in LS-Dyna

➢ *Boundary Conditions & Setup*

This is the process of generating keywords for the analysis model. To check if all the necessary parts oaqf the model are included, use Model checking to check for missing elements. If no error appears, it means that all the necessary elements are included in the analysis model. In this model, two warnings come up and double-clicking them individually confirms detailed information, which can be useful when debugging.

➢ *Post-Processing*

The analysis time will be relatively long compared to the size of the model. As you solve static problems with explicit, the time to find convergence may seem relatively longer than other collision analysis. When the analysis is complete, it will be displayed in green as Finished and you can check the result by selecting the D3plot icon directly above. When the LS-Prepost window opens and the model appears, check out the various results in the Fringe menu of the post-processing option. Since the calculation interval of D3PLOT is set to 0.1sec, a total of 11 frames are generated.

IV. NUMERICAL METHODOLOGY SOFTWARE ANALYSIS

➢ *Introduction*

Bird strike analysis refers to the analysis of any unexpected challenges or risks that may come from a bird hitting the leading components of an aircraft. We are mostly concerned with the analysis of leading edges of wing. When it comes to softwareanalysis we can say bird strike analysis refers to the process of assessing potential risks or issues that may arise when avians meet or damage software application. Much like real life bird strike, the goal here is to mitigate potential threats to software applications' functionality, security, and stability. 4.2 Material Modelling We are using the paper "Application of numerical methods for crashworthiness investigation of a large aircraft wing impact with a tree" authored by Chao Zhang, Wieslaw K. Binienda, Frank E. Horvat, Wenzhi Wang. The entire plane structure is assumed to be V95 aluminium alloy modelled with shell elements. Two material modelling are chosen for the plane: MAT_24 and MAT_15. MAT_24 is modelled as a piecewise plastic isotropic element with an ultimate failure strain of 14%. MAT_15 is modelled as a nonlinear rate-dependent Jhonson Cook model. The parameters of models are given below:

Table 1 Input Piecewise Plasticity Aluminium Alloy Model.

Youngs Modulus (MPa)	Yield stress (MPa)	Tangential Modulus (MPa)	Poisson's Ratio	Density(kg/m^3)
74000	444	573.8	0.33	2850

Table 2 Input Of Jhonson-Cook Aluminium

Young's modulus (MPa)	Shear Modulus (MPa)	Poisson's ratio	Density (kg/m^3)	Yield Stress (MPa)	Strain Hardening Modulus (MPa)	Strain Hardening exponent	Strain rate coefficient
68900	25910	0.33	2700	324	114	0.4	0.002

ISSN No:-2456-2165

- The Johnson Cook model has a lower strength value but a higher failure strain.

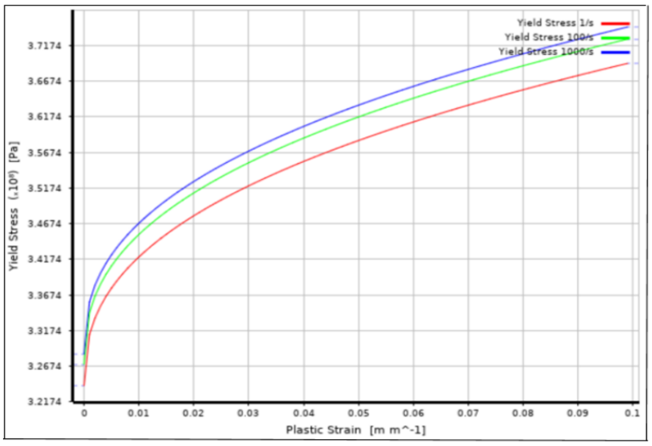

Fig 7 Johnson Cook material model for aluminium alloy.

➢ *Numerical Results/ Validation*

In this experiment we are using the leading edge that is tied to a fixed supporting construction. The leading edge consisted of skin and 4 ribs. The projectile is kept at the distance of 100mm from the leading edge and fired. At the velocity of 153m/s, the leading edge is not penetrated but developed a deformation area where the projectile hit. Two types of contact definitions are used in the stimulation. One is “Automation nodes to surface” between the projectile and the leading edge and the other is “Tied surface to surface” between the components of the leading-edge structure. The load history at the fixed point and displacement history are recorded and compared.

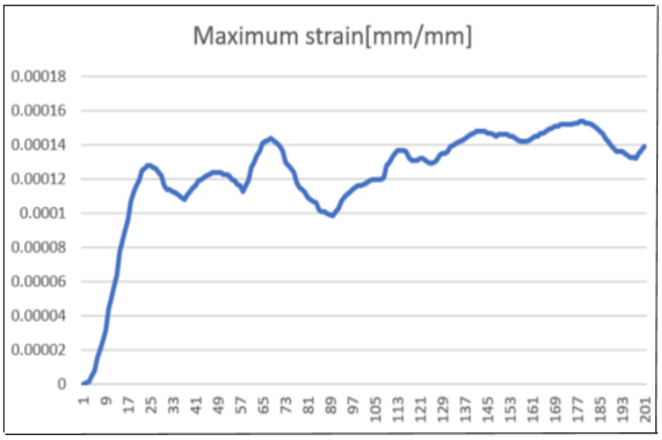

Fig 8The strain graph for validation.

- The graph generated from the points is similar to the graph in the validation paper. The first peak value matches perfectly.

V. RESULTS AND DISCUSSIONS

➢ *Result*

For the study on bird strike, we are using a validation process. For comparison purposes, we use the model and graph that has been verified against the model developed by us for this project. The entire model consists of 7358 nodes and 36038 elements.

➢ *Mesh Generation*

Two types of contact definitions are used in the stimulation. One is “Automation nodes to surface” between the projectile and the leading edge and the other is “Tied surface to surface” between the components of the leading-edge structure. The end time for the stimulation is set at 4e-4 or 0.0004 secs. This is because the velocity of the projectile is taken to be 155 m/s same as for validation. Findings are the total deformation, equivalent elastic strain and maximum principal stress. The model is set fixing the wing and the projectile is kept free to move. The projectile and wing both are kept solid for the stimulation. The other stimulation has the projectile as a smooth particle hydro-dynamic (SPH) element. SPH is a powerful mesh free method and is the most efficient for stimulating a liquid-like material. During the study we find the effects of a bird hitting the leading edge.

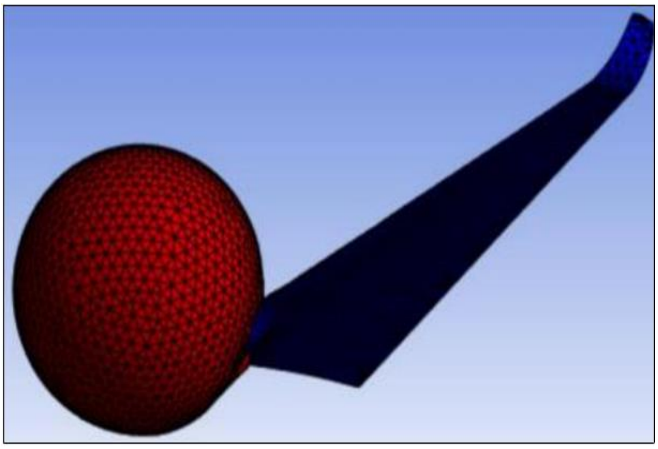
Fig 9 Bird strike and wing FEA model

Total deformation is found to be at the point of impact. The maximum deflection is found to 700.21 mm. this sound to be a small dent but has effects on the flow of air over the wing. The aerodynamic flow is restricted due to these small dents and cause the airflow separation to occur. This makes the aircraft experience more drag and contours to form as the air continues to flow. This will help in the formation of vortices at the trailing edge of the wing.

Table 2 Otal Deformation

Time (secs)	Maximum	Minimum	Average
4.0012e-004	700.21 mm	0 mm	584.26 mm

Table 3 Equivalent Elastic Strain

Time(secs)	Maximum(mm/mm)	Minimum(mm/mm)	Average(mm/mm)
4.0012e-004	1.4104	0	3.7857e-002

Table 3 Maximum Principal Stress

Time (secs)	Minimum (MPa)	Maximum (MPa)	Average (MPa)
4.0012e-004	0	2.4287e+005	2615.9

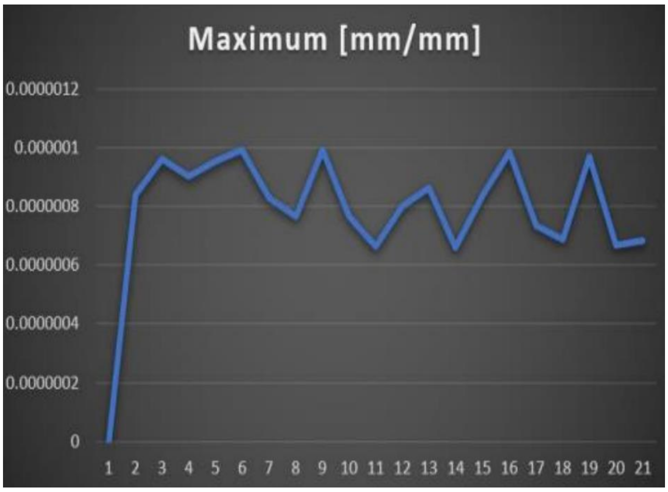

Fig 10 Strain Graph of the Bird Strike Over a Leading Edge of Wing

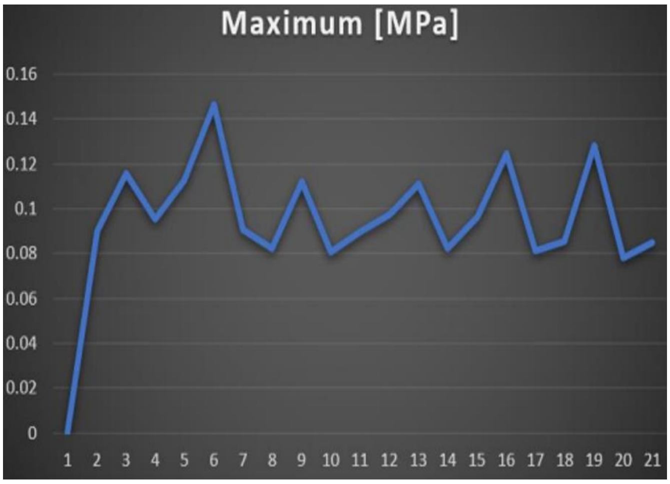

Fig 11 Stress Graph of the Bird Strike Over a Leading Edge of Wing

➢ *Discussion*

The dents caused by the impact disrupt the smooth transition of air over the wing surface, triggering an undesirable phenomenon known as airflow separation. This separation occurs when the airflow is unable to follow the curvature of the wing due to the abrupt change in geometry caused by the dent. As a result, the airflow detaches from the wing surface, creating a turbulent wake that trails behind the wing. This turbulent wake not only increases drag, the force that opposes the aircraft's forward motion, but it also leads to the formation of vortices at the trailing edge of the wing. These vortices are swirling pockets of air that can significantly disrupt the aerodynamic flow around the wing, causing instability and reducing lift generation.

VI. CONCLUSION AND FUTURE SCOPE

➢ *Conclusion*

In conclusion, the total deformation sustained by the wing due to the impact, while seemingly minor, has significant repercussions on the aerodynamic flow. The dents caused by the impact restrict the airflow and induce airflow separation, leading to increased drag and the formation of vortices at the trailing edge. These vortices further disrupt the airflow, exacerbating the aerodynamic consequences of the deformation. Therefore, even minor deformations can have a substantial impact on the aerodynamic performance of an aircraft, highlighting the importance of maintaining structural integrity and minimizing damage.

➢ *Future Work*

Future work involves extending the bird strike analysis to similar wing cases. Additionally, the structural deformation including strain and stress graph will also be studied. In summary, this quantitative analysis has effectively shown using maximum stress and maximum strain. Detailed qualitative investigations further exploring the physics will be undertaken subsequently. Additional research could focus on developing more accurate and comprehensive bird strike models to better predict the impact on aircraft structures. Additionally, investigating the effects of different types of damage, such as dents, cracks, and punctures, on aerodynamic flow would provide valuable insights into the vulnerability of aircraft structures

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