Review and Analysis of Bird Deflection System for Turbofan Engines

V.P.JOSEPH ARUN PRASATH[1], K.CHANDRASEKARAN[2*],
K.RAGUL[3], N.PANDIMEENAL[3], K.PRIYADHARSHINI[3]
[1]*Assistant Professor, Department of Aeronautical Engineering, M.AM. School of Engineering, Siruganur, Trichy.*
[2]*Professor, Department of Aeronautical Engineering, M.AM. School of Engineering, Siruganur, Trichy. Email ID: kchandrusekaran1984@gmail.com*
[3]*U.G.Students, Department of Aeronautical Engineering, M.AM. School of Engineering, Siruganur, Trichy.*

Abstract - The aviation sector continually seeks advancements for safer and more efficient air travel, with bird strikes posing significant risks. This paper introduces the Bird Deflection Screen (BDS), a specialized apparatus aimed at mitigating bird strike impacts on jet engines. By utilizing advanced materials and aerodynamic principles, the BDS diverts birds away from critical engine components. Aerodynamic optimization through Computational Fluid Dynamics (CFD) simulations minimizes drag, preserving fuel efficiency. Integration of sensor technologies enhances safety by detecting bird threats and triggering rapid BDS deployment. Additionally, data analytics enable predictive maintenance, reducing downtime and expenses. The BDS enhances passenger safety, operational efficiency, and environmental sustainability by mitigating engine failures, emergency landings, and carbon emissions. In summary, the BDS offers a pioneering solution to the persistent challenge of bird strikes on jet engines, emphasizing innovative design and collaboration for future development and testing.

Key word: Bird Deflection System, Engine Inlet Screen, Birds Strike

I. INTRODUCTION

Bird strikes, also known as bird-aircraft collisions or bird ingestion incidents, occur when birds collide with aircraft in flight or during takeoff and landing. These incidents pose a significant safety hazard to aviation due to the potential for damage to aircraft components, including engines, windshields, and control surfaces, as well as the risk of injury to passengers and crew.

This paper focuses on collisions involving birds and the term bird strike is used. First, the vast majority of wildlife strikes occur with birds, for example: 98% in Australia, 95% in Canada and 95% in the USA. Second, terrestrial animals can be prevented from entering airport perimeters, for example by installing fences. In contrast, birds can enter airfields regardless. Furthermore, they do not only pose a risk on the airfield, but also in the approach and departure corridors. The related challenges are addressed in this paper.

International Civil Aviation Organization (ICAO) requests its contracting states to report bird strikes. Data are usually collected by the Civil Aviation Authorities (CAA). Its quality relies on consistent reporting by the parties involved in aircraft and airport operations: The pilots, maintenance crews, air traffic control and wildlife control. In recent years, the importance of complete bird strike reporting has been recognized and has since been encouraged or even enforced by many CAAs across the world. Within this context, the European Union (EU), which previously had no consistent reporting regulations among its member states, put into force mandatory bird strike reporting in 2015. All parties involved in air traffic operations within the EU have been obliged to report observed bird and wildlife strikes. In Australia, mandatory reporting has already been in place for several years. Furthermore, in many countries, action has been taken to increase the motivation to report. This has resulted in increasing numbers of bird strike reports.

For example, in the USA, where a mainly voluntary reporting system is in place, the ratio between all reported bird strikes and all bird strike occurrences increased from 41% to 91% for commercial aircraft in the period from 1990 to 2013. When including airports, which handle general aviation and commercial traffic, the share amounts to 47%. In the UK, pilots have been required to report all bird strikes since 2004. Before, only damaging bird strikes had to be reported. The number of reports strongly increased since the implementation of this mandate. Both in the USA and UK studies, the reason for the rise is mainly attributed to better reporting, rather than increased bird strike risk. The authors of both studies reason with the ratio between number of damaging strikes and all strikes.

In case of an increased risk, the rise of reports would be expected to be similar for damaging and non-damaging strikes. However, in both countries, the proportions of damaging strikes fell.

1.1 Probability of Bird Strike:

a. Altitude:
Bird Strike accidents corresponds to the flight phases for which most bird strikes are reported: takeoff, initial climb, landing and approach. However, the share of damaging bird strikes increases with increasing altitude. Contributing factors are a higher kinetic energy due to increasing bird size and rising aircraft velocity. Furthermore, while mitigation measures at airports have been shown to be successful in reducing the number and consequences of bird strikes, outside the airport boundaries, the options for counteracting measures are limited.

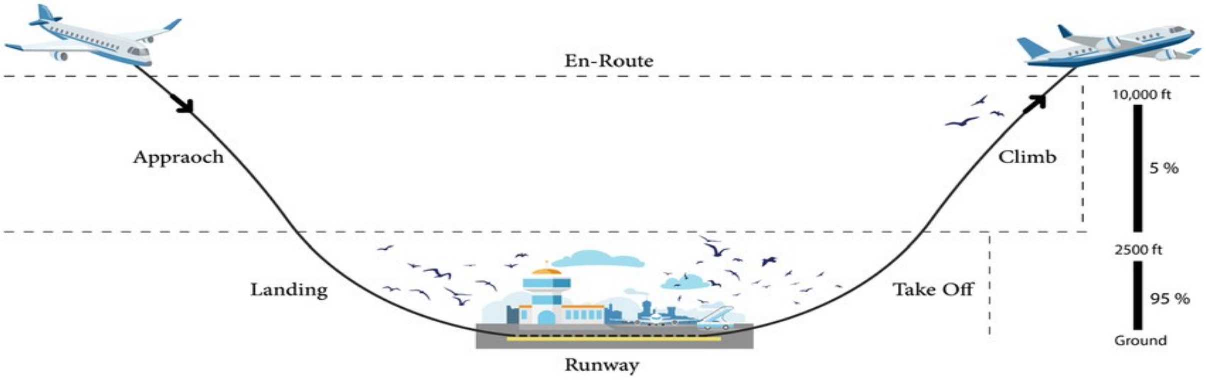

Fig 1: Birds Strike based on Altitude

b. Season:
It can be seen that, during the respective winters, the risk of collisions between birds and aircraft is lowest. In contrast, during summertime, when the juveniles of many bird species fledge especially in the countries in the Northern hemisphere, the highest number of bird strikes is recorded. During spring and autumn, an increased bird activity due to migration between summer and winter residences leads to more strikes.

c. Location and Environmental Conditions:
The probability of bird strikes depends on the geographical location. This is related to the abundance of different bird species with variable behavior, size or tendency for flocking. In the direct airport environment, the landscape characteristics are a determining factor. In regions situated along a migratory flyway, the danger of collision remarkably increases during migration seasons.

d. Aircraft Characteristics
Individual aircraft characteristics are another determining factor in the probability of bird strike. Due to their large size and high suction effect, turbofan engines are more likely to ingest birds than other engine types. Moreover, due to their higher speeds during take-off and landing, turbofan aircraft are more difficult to avoid than other aircraft types. Over the last years, turbofan engines increased in diameter, which increases the risk of ingestion even further.

II. BIRD DEFLECTION SYSTEM:

2.1 Active Deflection System:

Active deflection systems for bird strike prevention represent an innovative approach to mitigating the risks posed by bird strikes in aviation. These systems utilize real-time detection and response mechanisms to detect bird threats and actively deflect or deter birds from aircraft flight paths. Here's an overview of active deflection systems for bird strike prevention:

a. Avian Radar Systems:
Avian radar systems utilize radar technology specifically designed to detect bird activity in and around airports. These systems can track bird movements in real-time and provide early warnings to air traffic controllers and pilots. By identifying areas of high bird activity, avian radar systems help inform bird strike prevention strategies, such as adjusting flight paths or implementing bird deterrent measures.

b. Laser Deterrence Systems:
Laser-based deterrence systems use directed laser beams to deter birds from approaching aircraft flight paths. These systems emit laser pulses or beams towards approaching birds, creating a visual disturbance that encourages birds to alter their flight paths and avoid aircraft. Laser deterrence systems can be mounted on aircraft or installed at airports to create bird-free zones in critical areas such as runways and taxiways.
c. Acoustic Bird Deterrents:
Acoustic bird deterrent systems emit sounds or ultrasonic frequencies designed to deter birds from approaching aircraft. These systems can generate specific patterns of sound or ultrasonic waves that are disruptive to bird communication and navigation, encouraging birds to avoid areas where the deterrents are active. Acoustic bird deterrents can be integrated into airport infrastructure or mounted on aircraft to provide active protection against bird strikes.

d. Automated Decoy Systems:
Automated decoy systems use decoy birds or other visual stimuli to attract and divert birds away from aircraft flight paths. These systems can employ robotic or remote-controlled decoys that mimic the appearance and behavior of natural predators, such as birds of prey, to deter birds from approaching aircraft. Automated decoy systems can be deployed strategically around airports or installed on aircraft to provide active bird strike prevention measures.

e. Drone-based Solutions:
Drone-based solutions utilize unmanned aerial vehicles (UAVs) equipped with bird detection sensors and deterrent devices to actively monitor and deter birds from aircraft flight paths. These systems can patrol airport perimeters and critical airspace to detect and deter bird activity in real-time, providing proactive bird strike prevention measures. Drone-based solutions offer flexibility and mobility in deploying active bird strike prevention measures, complementing existing airport infrastructure and bird management strategies.

2.2 Passive Deflection Systems:

Passive deflection systems for bird strike prevention are designed to reduce the likelihood of bird strikes by incorporating passive barriers or modifications into aircraft or airport infrastructure. Unlike active systems, which employ real-time detection and response mechanisms, passive systems rely on static measures to prevent or mitigate bird strikes. Here are some examples of passive deflection systems for bird strike prevention:

a. Engine Inlet Screens:
Engine inlet screens are mesh or grille structures installed at the intake openings of aircraft engines to prevent birds from entering and causing damage. These screens act as physical barriers, intercepting birds and debris before they can enter the engine intake and cause ingestion-related failures. Engine inlet screens are typically made of lightweight and durable materials, such as stainless steel or titanium, to withstand the harsh operating conditions of aircraft engines.

b. Winglet Modifications:
Winglets are aerodynamic devices installed at the tips of aircraft wings to improve fuel efficiency and reduce drag. Certain winglet designs incorporate modifications, such as serrated edges or bird-friendly shapes, to deter birds from colliding with the wingtips during flight. These passive modifications help reduce the risk of bird strikes by minimizing potential impact points on the aircraft's wings.

c. Radome Reinforcements:
Radomes are protective enclosures housing radar antennas and other electronic equipment mounted on the nose or fuselage of aircraft. Reinforcing radomes with materials such as Kevlar or composite laminates can help increase their resistance to bird strikes and prevent damage to critical avionics components. Strengthened radomes provide passive protection against bird strikes, reducing the likelihood of radar system failures or structural damage.

d. Bird Deterrent Paints:
Bird deterrent paints contain additives or coatings that make surfaces less attractive to birds, discouraging them from perching or nesting on aircraft structures. These paints may incorporate reflective or repellent properties, as well as visual cues such as predator eyes or silhouettes, to deter birds from approaching aircraft. Applying

bird deterrent paints to surfaces such as wing leading edges, engine nacelles, and landing gear can help minimize the risk of bird strikes by reducing bird activity around aircraft.

e. Bird Strike Resistant Windshields:
Bird strike resistant windshields are designed to withstand the impact of bird strikes without shattering or compromising visibility for pilots. These windshields are constructed using multiple layers of laminated glass or polycarbonate materials bonded together to absorb and dissipate the energy of bird impacts. Bird strike resistant windshields provide passive protection against bird strikes, ensuring the safety of flight crew and passengers in the event of a bird strike incident.

III. BIRD STRIKE ACCIDENTS – CASE STUDIES:

- US Airways Flight 1549 (2009): Commonly known as the "Miracle on the Hudson," this Airbus A320 experienced a bird strike shortly after takeoff from New York's LaGuardia Airport, resulting in dual-engine failure. The crew executed an emergency ditching in the Hudson River, and all 155 occupants survived.

- Eastern Air Lines Flight 375 (1960): This Lockheed L-188 Electra crashed shortly after takeoff from Logan International Airport in Boston, Massachusetts, due to a bird strike. The aircraft lost power in three of its four engines after ingesting a flock of starlings, resulting in the deaths of 62 passengers and crew.

- El Al Flight 1862 (1992): A Boeing 747 freighter experienced a bird strike shortly after takeoff from Amsterdam's Schiphol Airport. The impact caused the separation of one of the engines, leading to structural damage and the eventual crash of the aircraft in an Amsterdam suburb. Four crew members and 39 people on the ground were killed.

- Delta Air Lines Flight 191 (1972): This Lockheed L-1011 Tristar crashed during approach to Dallas/Fort Worth International Airport after encountering severe weather conditions, including a microburst. The investigation revealed that a bird strike had damaged the aircraft's radome, contributing to the crew's inability to detect the microburst. The crash resulted in 137 fatalities.

- Air India Flight 113 (1966): A Boeing 707 operating a flight from Mumbai to Cairo experienced a bird strike shortly after takeoff. The aircraft lost power in two engines due to ingestion of large birds, leading to an emergency landing. All 95 passengers and crew survived the incident.

- Turkish Airlines Flight 1951 (2009): This Boeing 737-800 crashed during approach to Amsterdam's Schiphol Airport after experiencing a bird strike and subsequent loss of engine power. Nine people were killed, and multiple others were injured in the accident.

- Sudan Airways Flight 109 (2003): A Boeing 737 operating a flight from Port Sudan to Khartoum suffered a bird strike during takeoff, resulting in the aircraft's crash shortly after becoming airborne. Seventeen passengers and crew perished in the accident.

- China Eastern Airlines Flight 7863 (2022): A Boeing 737-800 operating a domestic flight in China suffered a bird strike shortly after takeoff from Kunming Changshui International Airport. The aircraft returned to the airport safely, and no injuries were reported among the 133 passengers and crew onboard.

IV. OBJECTIVES:

- To study and gain knowledge on various incidents of accidents caused by bird strike around the world
- To review the existing methods used for mitigation of birds through passive methods and active methods.
- To design a system that to effectively prevent foreign objects such as birds, debris, insects, and other particles from entering the engine intake, ensuring the safety and integrity of the engine and aircraft.

- To design and develop an inlet screen to allow for smooth and uninterrupted airflow into the engine, minimizing pressure losses and ensuring optimal engine performance and fuel efficiency.
- To conduct numerical analysis and CFD to minimize the pressure drop across the inlet screen to maintain efficient engine operation and performance, while still effectively capturing and diverting FOD particles away from the engine.

V.NUMERICAL SIMULATION:

5.1 Bird Strike Simulation on Blade as Flat Plate:

The simulation conditions for the stationary blade case were similar to those of the validation simulations. The blade was kept stationary and was fixed at the bottom. The bird was given a velocity of 150 m/s and the AUTODYN-3D Solver performed the computation, based on the Ogden Model (for Rubber) and Mie-Grüneisen Equation of State (for Ti6A14V), with the same set of material constants provided with the validation simulations. The end time for the simulation was 0.01s and the solver performed 10^7 cycles.

5.2 Bird Strike Simulation on Static Blade:

In order to prove the validation of the numerical model, a bird impact test was performed with the same initial conditions as the simulation, as shown in Fig. The whole system is mainly composed of the bird-launching system, the loading frame system, and the signal processing and receiving system. Different bird speeds can be obtained by adjusting the pressure of the air cannon, and the calibration between the bird speed and the pressure should be performed before the test. The fan blade clamped on the test bench as well as the artificial gelatin bird that weighed 0.64 kg. Strain gauges were attached to the back of the lade, with their specific location and numbering. The final deformation of the fan blade after the bird impact test, during which no material loss or fracture occurred is shown in Fig 3.

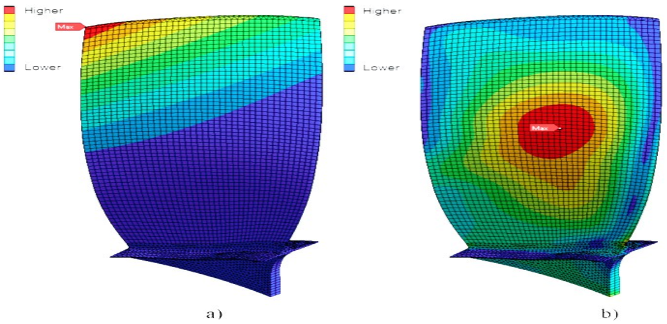

Fig 2: Damage Prediction on Turbofan Blade as Static Plate

5.3 Bird Strike Simulation as Rotating Blade:

The validity of the numerical model of bird impact on a static single blade verified that the bird impact model on a rotating fan assembly was somehow reasonable, since the two models shared the same bird model, contact model, material parameters, blade mesh, and so on. Therefore, it is only necessary to set a typical working condition for the model to verify whether the boundary conditions could work, and observe the dynamic response of the system at the same time. According to the regulations for anti–bird strikes in the 76th clause of “Aircraft Engine Airworthiness Regulations” [FAR 33.76 (FAA 2007)], the mass of the bird impact or is dependent on the area of engine inlet throat, which measures 2.997 m2 for the fan assembly studied. Therefore, a 2.75-kg bird with a velocity of 102 m/s striking on the fan assembly with a rotating speed of 3,500 rpm was simulated.

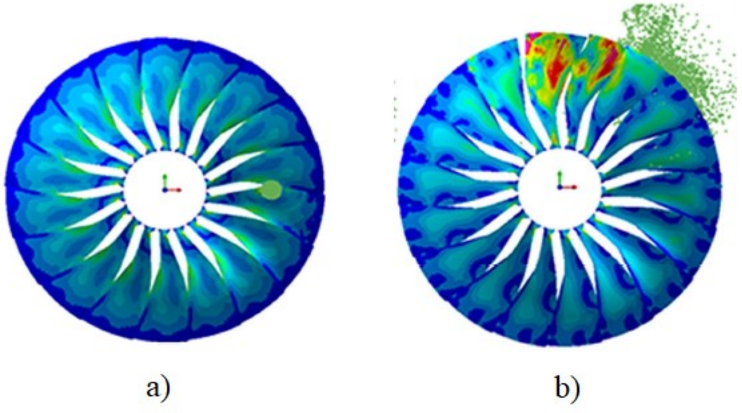

Fig 4: Damage Prediction on Turbofan Blade as Rotating Plate

VI. BIRD DEFLECTION SYSTEM – PROPOSED MODEL:

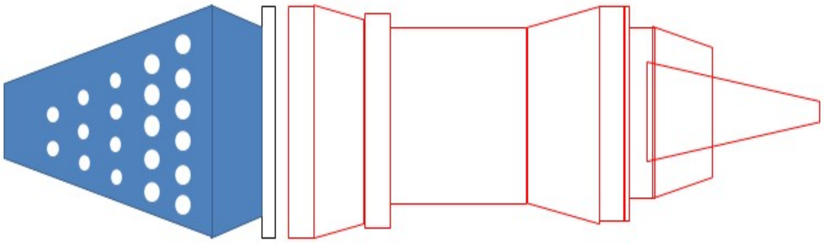

Fig 5: Bird Deflection System attached to Turbofan Engine

The Bird Deflection System (BDS) consists of several key components and operates through a combination of design features and technological integration to mitigate the impact of bird strikes on jet engines. Below is a structured overview of the system's components and its working mechanism:

Structure of the Bird Deflection System:
a. Deflection Screen: The primary component of the BDS is the deflection screen, typically constructed from lightweight yet durable materials such as advanced composites or metals. This screen is strategically positioned in front of the jet engine intake to intercept birds approaching the engine.
b. Mounting Frame: The deflection screen is mounted onto a robust frame, designed to withstand high-velocity impacts without compromising structural integrity. The frame ensures proper alignment and stability of the deflection screen during operation.
c. Sensor Array: Proximity sensors are integrated into the BDS to detect the presence of birds in the vicinity of the aircraft. These sensors provide real-time data to trigger automated responses for deploying the deflection screen when necessary.

d. Control System: A centralized control system manages the operation of the BDS, receiving input from the sensor array and activating mechanisms for deploying the deflection screen. The control system may incorporate sophisticated algorithms for optimizing response times and minimizing false positives.

Working of the Bird Deflection System:
a. Detection Phase: The BDS continuously monitors the surrounding airspace using its sensor array. Proximity sensors detect the presence of birds within a predefined range of the aircraft.
b. Decision Making: Upon detecting a bird or a flock of birds approaching the aircraft, the control system analyzes the data from the sensor array to determine the level of threat posed by the birds.
c. Deployment Activation: If the threat level surpasses a certain threshold, the control system triggers the deployment mechanism of the deflection screen. This may involve pneumatic or hydraulic actuators that rapidly extend the screen into position in front of the engine intake.
d. Bird Deflection: As birds collide with the deflection screen, they are redirected away from the engine intake, reducing the likelihood of ingestion into the engine components. The aerodynamic design of the deflection screen ensures minimal disruption to airflow, preserving engine performance.
e. Reset and Maintenance: After the bird threat has passed, the deflection screen is retracted back into its housing by the deployment mechanism. Routine maintenance and inspection protocols are implemented to ensure the continued effectiveness and reliability of the BDS.

VII. RESULTS & CONCLUSION:

The performance of a turbofan engine can be influenced by the use of an inlet screen, both before and after its installation. As predicted in chapter 8 and pressure, flow and temperature magnitudes at the outlet of the diffuser, at the outlet of the combustion chamber and at the outlet of the engine at different modes can be seen. The following conclusions can be arrived.

FOD Ingestion Prevention:

Without an inlet screen, the turbofan engine is susceptible to ingesting foreign object debris (FOD) such as birds, insects, and other particles.

With the inlet screen installed, FOD is effectively prevented from entering the engine intake, reducing the risk of damage to engine components and maintaining consistent performance.

Airflow Efficiency:

Without a screen, the engine intake may experience disruptions in airflow due to FOD ingestion, leading to inefficiencies and potential performance degradation.

The inlet screen allows for smoother airflow by filtering out debris, maintaining optimal engine performance and efficiency.Pressure Drop:

Ingested FOD can cause turbulence and pressure fluctuations in the engine intake, resulting in increased pressure drop across the inlet.

The inlet screen helps reduce pressure drop by preventing FOD from entering the engine, contributing to more stable airflow and maintaining consistent performance.

Engine Thrust:

FOD ingestion can lead to temporary or permanent loss of engine thrust, impacting aircraft performance and safety.

With FOD prevented from entering the engine, thrust levels remain consistent, ensuring reliable performance during all phases of flight.

Maintenance Requirements:

Without an inlet screen, the engine may require more frequent inspections and maintenance to detect and address FOD-related damage.

The use of an inlet screen can reduce maintenance needs by minimizing FOD-related damage, leading to cost savings and increased aircraft availability.

Overall, the use of an inlet screen can significantly improve the performance and reliability of a turbofan engine by preventing FOD ingestion and maintaining efficient airflow, ultimately enhancing aircraft safety and operational efficiency.

REFERENCES:

[1] Chen, W., Y. P. Guan, and D. P. Gao. 2003. “Numerical simulation of the transient response of blade due to bird impact.”Acta Aeronautica et Astronautica Sinica 24 (6): 531–533.

[2] Chen, W.,W. K. Qi, and D. P. Gao. 1998. “Transient responses of blades tobird impact coupled with deformations of blade.” J. Aerosp. Power 13 (1): 93–95.

[3] China’s Civil Aviation Science and Technology Academy. 2016. 2015 China’s civil aviation aircraft bird strike information analysis report Beijing: China’s Civil Aviation Science and Technology Academy.

[4] FAA (Federal Aviation Administration). 2009. “Advisory Circular No. 33.76-1A, bird ingestion certification standards.” Accessed March 25, 2019. https://www.faa.gov/documentLibrary/media/Advisory Circular/AC_33_76-1A.pdf.

[5] C.Nagarajan and M.Madheswaran - ‘Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter’ - Journal of ELECTRICAL ENGINEERING, Vol.63 (6), pp.365-372, Dec.2012.

[6] C.Nagarajan and M.Madheswaran - ‘Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis’- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011.

[7] C.Nagarajan and M.Madheswaran - ‘Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques’- Taylor & Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011.

[8] C.Nagarajan and M.Madheswaran - ‘Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis’- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.

[9] Nagarajan C., Neelakrishnan G., Akila P., Fathima U., Sneha S. “Performance Analysis and Implementation of 89C51 Controller Based Solar Tracking System with Boost Converter” Journal of VLSI Design Tools & Technology. 2022; 12(2): 34–41p.

[10] C. Nagarajan, G.Neelakrishnan, R. Janani, S.Maithili, G. Ramya “Investigation on Fault Analysis for Power Transformers Using Adaptive Differential Relay” Asian Journal of Electrical Science, Vol.11 No.1, pp: 1-8, 2022.

[11] G.Neelakrishnan, K.Anandhakumar, A.Prathap, S.Prakash “Performance Estimation of cascaded h-bridge MLI for HEV using SVPWM” Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:750-756

[12] G.Neelakrishnan, S.N.Pruthika, P.T.Shalini, S.Soniya, “Perfromance Investigation of T-Source Inverter fed with Solar Cell” Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:744-749

[13] C.Nagarajan and M.Madheswaran, “Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation” has been presented in ICTES’08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007

[14] M Suganthi, N Ramesh, “Treatment of water using natural zeolite as membrane filter”, Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022

[15] M Suganthi, N Ramesh, CT Sivakumar, K Vidhya, “Physiochemical Analysis of Ground Water used for Domestic needs in the Area of Perundurai in Erode District”, International Research Journal of Multidisciplinary Technovation, pp: 630-635, 2019

[16] FAA (Federal Aviation Administration). 2019. "Wildlife strikes to civil aircraft in the United States 1990–2017." Accessed March 25, 2019. https://www.faa.gov/airports/airport_safety/wildlife/media/wildlife-strike-report-1990 -2017.pdf.Gingold, R. A., and J. J. Monaghan. 1977. "Smoothed particle hydrodynamics-theory and application to non-spherical stars." Mon. Not. R. Astron. Soc. 181 (3): 375–389. https://doi.org/10.1093/mnras /181.3.375.

[17] Guan, Y. P., Z. H. Zhao, W. Chen, and D. P. Gao. 2008. "Foreign object damage to fan rotor blades of aeroengine. Part II: Numerical simulation of bird impact." Chin. J. Aeronaut. 21 (4): 328–334. https://doi.org/10 .1016/S1000-9361(08)60043-6.

[18] Heimbs, S. 2011. "Computational methods for bird strike simulations: A review." Comput. Struct. 89 (23–24): 2093–2112. https://doi.org/10 .1016/j.compstruc.2011.08.007.

[19] Huang, J., Y. Z. Guo, D. Y. Qin, Z. X. Zhou, D. D. Li, and Y. L. Li. 2018. "Influence of stress triaxiality on the failure behavior of Ti-6Al-4V alloy under a broad range of strain rates." Theor. Appl. Fract. Mech. 97: 48–61. https://doi.org/10.1016/j.tafmec.2018.07.008.