Performance Study of Micro Vortex Generator Over An Aerofoil

Balaji K[1], Ankit Bhai Patel[1], Saranya S[2], Vishnupriya M[1], Balaji G[3] and Hariharan Thangappan[4]

[1]Department of Aeronautical Engineering, Parul Institute of Engineering and Technology, Parul University, Vadodara, Gujarat, India-391760.
[2]Department of Electronics and Communication Engineering, Sri Bharathi Engineering College for women, Pudukkottai-622303, Tamil Nadu, India.
[3]Department of Aeronautical and Aerospace Engineering, Hindustan Institute of Technology and Science, Padur, Chennai, Tamilnadu, India-603103
[4]Department of Chemical Engineering, Parul Institute of Technology, Parul University, Vadodara, Gujarat – 391760, India .
arobalaji@gmail.com

Abstract. The objective of this study is to improve the aerodynamic efficiency of the aerofoil using novel method of minute vortex generators. The simulation work was carried out using Reynold Average Navier Stokes equation with k omega SST turbulence model to evaluate the aerodynamic performance in terms of lift, drag coefficient. The proposed method is to divide the size of existing vortex generator into small size and same placed in two different locations with small size. The results shows that the lift and stall angle improved by 50% and 26 % at the same time the drag was reduced by considerable amount. This proposed method can replace the existing aircraft vortex generators and improve the aerodynamic performances.

Keywords: Aerofoil, Drag Coefficient, Lift coefficient, Vortex generators, Reynolds Average Navier Stoke Equation

1 Introduction

Nowadays air travel play the major role to transit the people from one place to another place with minimum time durations. The development of the airline industry provides a way to new design. The performance of aircraft wings is enhanced by delaying the boundary layer. To execute this, the most often used strategy is to improve the stall and to maximize the coefficient of lift by using active and passive control mechanisms. However, all existing active methods require the installation of small and complex additional components to achieve the desired flight performance. This increases dead weight and results in high maintenance costs. Moreover, a minor malfunction in these components can potentially cause the entire system to fail. One of the main passive method used to control the boundary layer is vortex generator method, in which the boundary layer is controlled efficiently by inducing a vortex flow at mid of the wing. Mostly, the vortex generators are located at the mid of the wing. The major drawbacks

J. Saxena et al. (eds.), *Proceedings of the International Conference on Sustainable Micro-Nano Materials & Innovative Technology (ICSUMMIT 2026)*, Atlantis Highlights in Engineering 44,
https://doi.org/10.2991/978-94-6239-727-9_23

in this method are, minimum amount of lift coefficient increased with incremental of drag.
Mayuri R. Gore and Balaji K [1] reviewed the existing vortex generators related articles. It reveal that the research gap and development in the vortex generators area. Balaji, K. et al.,[2] conducted the study on vortex generator over an symmetrical and cambered aerofoil. It concluded that the position of vortex generator at 0.2% of chord position is optimum location to enhance the aerodynamic performance of an aircraft wing. Balaji, K. et al.,[3] studied the performance of vortex generator at the midpoint of the wing to study the performance on symmetrical and cambered aerofoil. It reveals that the considerable amount of increment in its performance. Zhenzhou Zhao et al.,[4] studied the vortex generator on the horizontal axis wind turbine and its detailed study about the design and performances. It reveal that the research opportunities and future scope to enhance the performance. Soheila Abdolahipour et al.,[5] conducted study on supercritical aerofoil with pulse jet vortex generator. It concluded that the increment in lift and decrement in drag at various angle of attack. Ali Niknahad and Amir Bak khoshnevis [6] studied the vortex generator with three different shape in order to minimize the total drag of an aerofoil. It proved that the circular vortex generator producing considerable amount of drag reduction with high lift to drag ratio. Vansh Ratna Sharma et al.,[7] performed the triangular vortex generator with heat transfer flow at turbulent flow. It shows that the good amount of aerodynamic performance enhancement with efficient amount of heat transfer. ABDUL QADER HASAN et al.,[8] studied the effect of winglets and vortex generator over an remote control aircraft using numerical study. It reveals the combination of vortex and winglet enhances the aerodynamic performances. Omid Nematollahi et al.,[9] performed the study on vortex generator with delta wing. The results are compared with the smooth wing and efficient enhancement of aerodynamic performances. Sh. Sham Do et al.,[10] study about the vortex generator installed over an solar powered aircraft. It concluded that vortex generators are improved the performance to improve the flight duration. Manthan Patil et al.,[11] performed effect of vortex generator over the delta wing through the flow visualization methods. It proved that the minimize the drag and enhance the lift coefficient at various angle of attack. M. A. Brutyan & Tenzin Tadin [12] studied the vortex generator with transonic aircraft conditions. The study reveals that the effect of aerodynamic performances and temperature .It shows the considerable amount of increment of performances. Hector G. Parra et al.,[13] studied the effect of vortex generator over an rotary wing aerofoil. It shows that the flow visualization over an rotary wing aerofoil and visualize the wake regions. V. G. Tsipenko & V. I. Shevyakov [14] explained the effect of vortex generator depend on the various configuration and its performances to enhance the operations. Arunvinthan, S.,et al.,[15] conducted study on the shark scale-based vortex generators (SSVG) with different configurations. It proved that the proposed SSVG method effectively enhances the aerofoil performance at various angle of attack. Shengxian Huang et al.,[16] implemented the 2D aerofoil with double sided vortex generator. The proposed idea effectively improved the performance and control the flow separation. Putra, W., Hariyadi, S., & Pambudiyatno, N. [17] designed the triangle vortex generator over an swept back wing. The results concluded that the considerable amount of increment of lift coefficient and stall angle with minimization of drag and wake region. Balaji, K., et al [18] and Saranya s et al [19] evaluated active and passive boundary-layer control methods to improve aerofoil

performance across different flight phases using a RANS–SST framework. Results show that inward dimples increase stall angle by about 50%, while the active IBSS method delivers up to a 100% improvement in aerodynamic efficiency over the baseline, making it the most effective approach. Nayak, D., [20] investigated a combined active–passive boundary layer control strategy using injection and vortex generators to enhance wing performance at subsonic speeds. An optimal setup with injection at 20% chord and a vortex generator at 60% chord improves lift by 42% while reducing drag by 44%, demonstrating a practical and efficient approach for aircraft wings. Balaji, K., & Yadav, A.[21] identified the optimal winglet angles for effective boundary-layer control by comparing spiroid, split-scimitar, and blended winglets on a cambered aerofoil using numerical and wind-tunnel tests. Results show that a blended winglet at 95° on a NACA 6321 aerofoil delivers the highest aerodynamic efficiency by significantly reducing induced drag across angles of attack. Balaji, K., et al [22] evaluated the structural safety of a two-seater trainer aircraft's rectangular wing mid-section using both finite element analysis and the K-factor theoretical method. The close agreement between numerical and theoretical results confirms adequate safety margins, offering a reliable approach to improve structural efficiency while reducing aircraft weight. Ruifang Jiang et al.,[23] performed the vortex generator study on the rotary wing aerofoil. It proved that the torque output is enhanced through that output power improved. Nobuo Namura et al.,[24] simulated the multipoint optimization study of vortex generator with different cases. The results concluded that results in the aspects of stability, pitching moment and separation study . Kumar, R., et al.,[25] conducted the vortex generator study with different configuration over an aerofoil. The results compared and concluded that the vortex generator with customized vortex generator can produce higher amount of aerodynamic performances.
The above literature proved that the passive method of vortex generator is effectively control the boundary layer and improved the performances. In all the papers discussed about the VG placed at the single point over a top surface to enhance the behavior of aircraft wing. There are few papers, which are available by placing the VG at multi location over an wing. The objective of the proposed work is to place the vortex generators at multiple location at the separation point to energize the flow which made the flow attachment and performance improvement.

2 Methods

2.1 Geometric Design

Fig. 1 shows the comparison of an existing vortex generator and MLVG configuration. The basic difference between them is the location of vortex generators and the number of rows. MLVG system operated by creating the circulation flow. The NACA 6321 model is designed with the domain size which is specified in the literature [3].The design made for this research is displayed in Fig 2 and specifications are mentioned in Table 1.

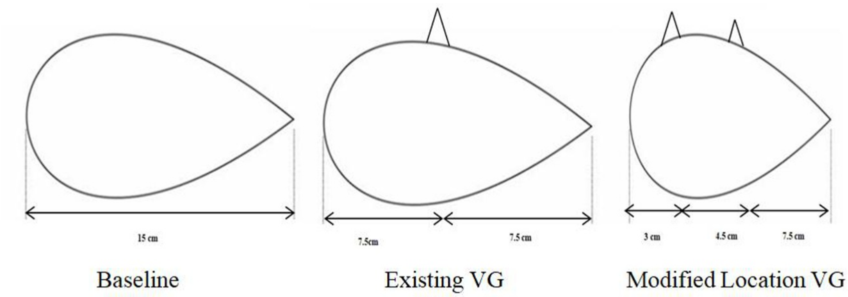


Fig. 1. Comparison of baseline and Vortex generator aerofoils

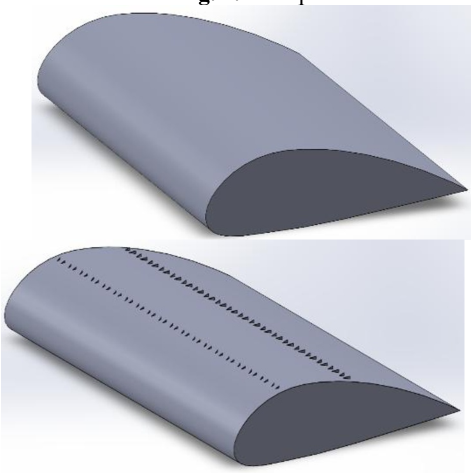


Fig.2. Design of Baseline and MLVG Aerofoil

Table 1.Model specifications

Details	Specification	Parameter
Airfoil	Model	NACA 6321
	span	23 cm
	chord	15 cm
Domain	length	2400 mm
	height	1500 mm
	radius	750 mm
	Length (L)	2.2 mm
	Height (H)	0.8 mm

VG at 0.2c	Vane angle (β)	16deg
	Thickness	0.1 mm
	d	5 mm
	D	11.3 mm
	Total VG pairs	20
VG at 0.5c	Length (L)	4 mm
	Height (H)	1.2 mm
	Vane angle (β)	16deg
	Thickness	0.2 mm
	d	5.8 mm
	D	11.3 mm
	Total VG pairs	20

2.2 Numerical Analysis

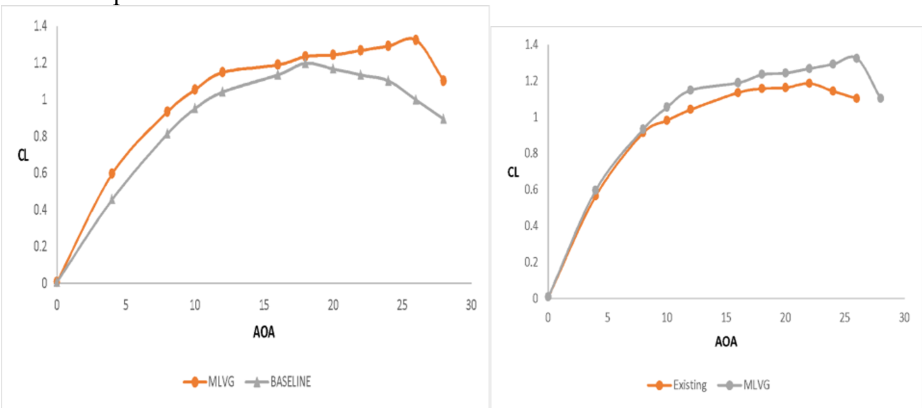
The design is segmented into smaller elements to ensure precise results. Based on the grid independent study conducted through the literature the mesh size is finalized with nodes of 671452 and elements size of 2841542. The turbulence model used for this study is k omega SST and boundary conditions are based on the literature [3]. Finite volume analysis carried out with Reynolds average Navier Stokes Equation used to solve this statement. The non mentioned values of various coefficients are collected based on the different angle of attack.

3 Methods

The computational study was conducted with the velocity of 15 m/sec. In that results of baseline and MLVG are compared and explained in the graphical form as mentioned in below

3.1 Lift Coefficient Curve

Fig. 3 illustrates the lift comparison across various angles of attack for different configurations. The baseline aerofoil experiences stall at an 18-degree angle of attack, whereas with the incorporation of MLVJ, stall occurs at 26 degrees. It is concluded that the performance of the MLVJ method is best suited for all angles as compared to regular aerofoils. Figure 4 presents a comparison between the existing VG method and the MLVG method. It can be concluded that, when compared to the baseline aerofoil, the existing methods improved the maximum angle of attack only by 4 degrees whereas, the MLVG method improved the same to a maximum of 8 degrees, through improved boundary layer control. Another important feature is that the MLVG method performs better not only at higher angle of attack but also at low angle of attack as compared to its counterparts.

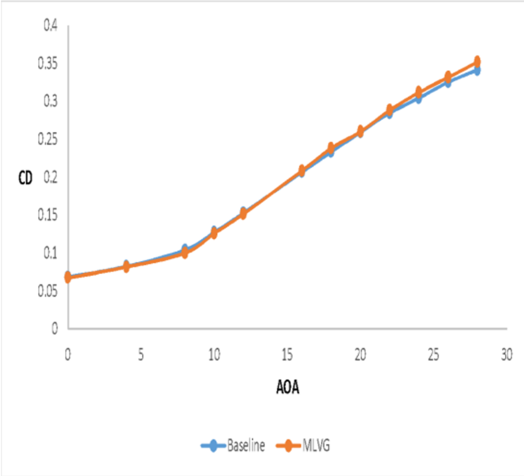


(a) (b)

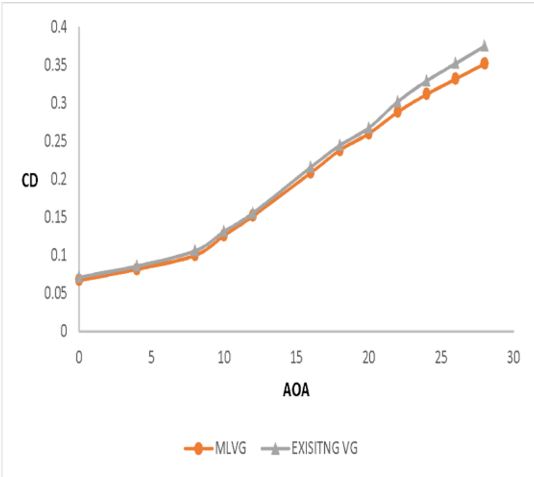
Fig. 3(a) &(b) Co efficient of lift of baseline ,existing and MLVG Method

3.2 DRAG COFFICIENT CURVE

Fig. 4(a) compares the drag coefficient values of the baseline aerofoil and the MLVG method at different angles of attack. The graph indicates that the drag value in the MLVG method remains equal to that of the baseline aerofoil. From this it can be concluded that MLVG method contributes in improvement of lift while maintaining the same drag. In the VG at separation point method, the coefficient of drag value is noted to increase with the increase in lift. Fig. 4 (b) is the comparison of the drag coefficient values of the existing VG method and MLVG method for different angle of attack. The existing method is display to create maximum drag compared to the MLVG system. So MLVG system is used to increase the lift at the same time it reduces the drag which ensures good performance at different angle of attack. In both cases after the maximum angle of attack, the drag value increases abruptly.



(a)



(b)

Fig. 4(a) &(b) Co efficient of drag of baseline ,existing and MLVG Method

3.3 Pressure Coefficient Curve

Fig. 5 shows that the pressure coefficient variation along the surface of an aerofoil at various conditions. It shows that the pressure variation over the top surface of an aerofoil is decreased due to the flow attachment happened. In that the pressure conditions are improved compared to the existing method. It clearly shows that the MLVG system efficiently improve the performance of aircraft wing without affecting any other parameters.

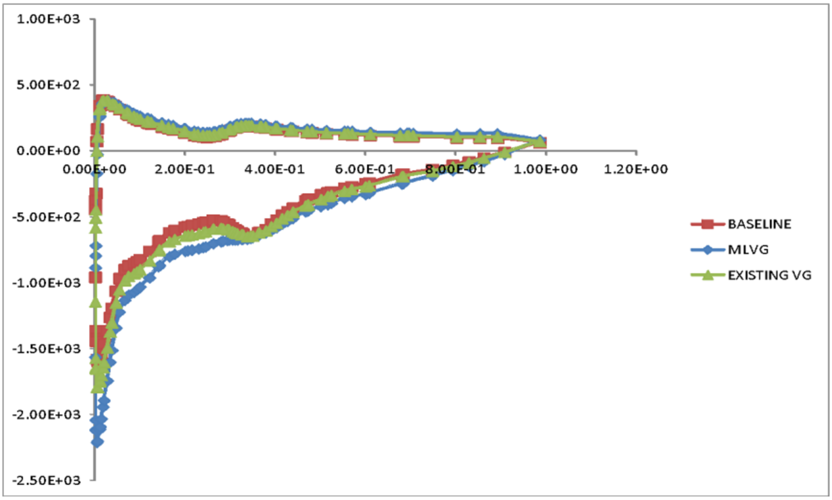
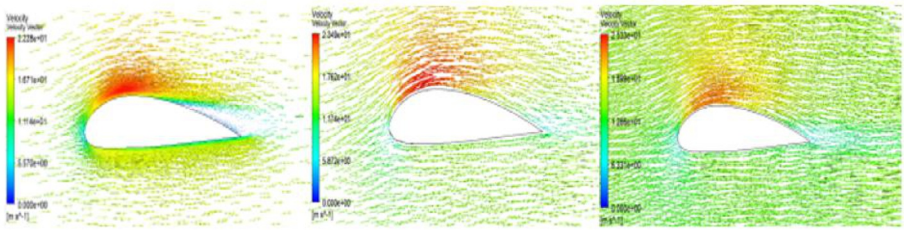


Fig.5. Pressure coefficient of baseline, existing and MLVG Method

3.4 Velocity Contour

Fig. 6 shows the velocity distribution over an aerofoil. In that NACA 6321 baseline aerofoil is having reverse flow due to boundary layer separation. Existing methods and proposed MLVG methods are used to control the separation. Especially in the MLVG method, the flow separation is controlled very effectively and the flow of air particles is close to each other under safe zone conditions compare to existing methods.



a)Baseline b)Existing VG c) MLVG

Fig. 6. Comparison of Velocity distributions

4 Conclusions

An Modified Location of Vortex Generator (MLVG) for the enhanced aerodynamic performance of aircraft wing, comprises of disposing on an aircraft wing, two rows of vortex generators to create circulation flow over aircraft wing without disturbing main flow and effectively controlling boundary layer separation, characterized in the positioning of the said first row at maximum thickness point (separation point) which is the starting point of boundary layer separation in aerofoil and characterized in the positioning of the second row at the point where next circulation is created near mid of aerofoil thereby introducing circulation flow at the exact location of flow separation with the improved stalling angle of attack and increased lift.The Modified Location of Vortex Generator (MLVG) aircraft wing is regular aircraft wing without secondary control surfaces thereby reducing weight, the maintenance cost of secondary control surfaces.The Modified Location of Vortex Generator (MLVG) is used to increase the coefficient of lift and stall angle with the decrement of drag.The Modified Location of Vortex Generator (MLVG) height is fixed based on the boundary layer thickness and position is fixed at two different locations where the flow separation will start. The Modified Location of Vortex Generator (MLVG) at various angles of attack, the stall is improved by about 44% with a decrease in drag. The Modified Location of Vortex Generator (MLVG) is suitable for all aerofoils (Symmetrical and Cambered) in subsonic conditions. The future work of the study is to fabricate the model and conduct the experimental study as well try to apply the similar concept for some other applications.

Disclosure of Interest: The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Gore, M.R., Balaji, K.: Review on vortex generators mounted on airfoil to improve the aerodynamic performance. Shanlax Int. J. Manag. 9(S1), 143–150 (2022). https://doi.org/10.34293/management.v9iS1-Mar.4904
2. Balaji, K., Gore, M.R., Khandal, S.V.: Numerical and experimental study of vortex generator. In: Sharma, R., Kannojiya, R., Garg, N., Gautam, S.S. (eds) Advances in Engineering Design, Lecture Notes in Mechanical Engineering, pp. 1–10. Springer, Singapore (2023). https://doi.org/10.1007/978-981-99-3033-3_22
3. Balaji, K., Gore, M.R., Khandal, S.V.: Investigation on the aerodynamic performance of different aerofoils using vortex generators. SAE Int. J. Aerosp. 16(2), 185–196 (2023). https://doi.org/10.4271/01-16-02-0013
4. Zhao, Z., Jiang, R., Feng, J., Liu, H., Wang, T., Shen, W., Liu, Y.: Researches on vortex generators applied to wind turbines: A review. Ocean Eng. 253, 111266 (2022). https://doi.org/10.1016/j.oceaneng.2022.111266
5. Abdolahipour, S., Mani, M., Shams Taleghani, A.: Experimental investigation of flow control on a high-lift wing using modulated pulse jet vortex generator. J. Aerosp. Eng. 35(5), 05022001 (2022). https://doi.org/10.1061/(ASCE)AS.1943-5525.0001463
6. Niknahad, A., Khoshnevis, A.B.: Numerical study and comparison of turbulent parameters of simple, triangular, and circular vortex generators equipped airfoil model. J. Adv. Res. Numer. Heat Transf. 8(1), 1–18 (2022)
7. Sharma, V.R., Sankalp, S.S., Madhwesh, N., Manjunath, M.S., Pham, D.T.: Enhanced thermal performance of tubular heat exchanger using triangular wing vortex generator. Cogent Eng. 9(1), 2050021 (2022). https://doi.org/10.1080/23311916.2022.2050021
8. Hasan, A., Iqbal, M.A., Azeez, A.A., Khudhiri, N.M., Dol, S.S., Gadala, M.S.: Aerodynamics analysis on wings with winglets and vortex generators. WSEAS Trans. Fluid Mech. 15, 1–10 (2020)

9. Nematollahi, O., Nili-Ahmadabadi, M., Seo, H., Kim, K.C.: Effect of acicular vortex generators on the aerodynamic features of a slender delta wing. Aerosp. Sci. Technol. 86, 327–340 (2019). https://doi.org/10.1016/j.ast.2019.01.002
10. Dol, S.S., Pervaiz, S.S., Uzair, M., Bashir, K., Elzughbi, M.M.: Design of solar-powered endurance glider with vortex generators. Renew. Energy Res. Appl. 2(1), 1–8 (2021). https://doi.org/10.22044/rera.2020.9778.1037
11. Patil, M., Gawade, R., Potdar, S., Nadaf, K., Suresh, S.P., Sahoo, D.: Effect of vortex generator on the flow field over a conventional delta wing in subsonic flow condition at higher angles of attack. FME Trans. 49(2), 395–400 (2021)
12. Brutyan, M.A., Tadin, T.: Numerical simulation of mini-air-jet vortex generators on a supercritical wing in transonic flow and the effect of temperature on its aerodynamic performance. Aerosp. Sci. (2023). https://doi.org/10.1007/s42401-023-00223-8
13. Parra, H.G., Ceron, H.D., Gomez, W., Gaona, E.E.: Experimental analysis of bio-inspired vortex generators on a blade with S822 airfoil. Energies 16(12), 4538 (2023). https://doi.org/10.3390/en16124538
14. Tsipenko, V.G., Shevyakov, V.I.: About the use of vortex generators to improve aircraft aerodynamics. Russ. Aeronaut. 65, 165–172 (2022). https://doi.org/10.3103/S1068799822010184
15. Arunvinthan, S., Raatan, V.S., Nadaraja Pillai, S., Pasha, A.A., Rahman, M.M., Juhany, K.A.: Aerodynamic characteristics of shark scale-based vortex generators upon symmetrical airfoil. Energies 14(7), 1808 (2021). https://doi.org/10.3390/en14071808
16. Huang, S., Wang, J., Hou, L., Wang, Y.: Numerical study on a novel flapping-foil energy harvester with 2D vortex generator. Ocean Eng. 266, 112415 (2022). https://doi.org/10.1016/j.oceaneng.2022.112415
17. Putra, W., Hariyadi, S., Pambudiyatno, N.: Numeric simulation of triangular vortex generator straight on swept-back wing airfoil NACA 23018. In: Proc. ICATEAS 2022, pp. 251–262. Atlantis Press (2023)
18. Balaji, K., Rameshbhai, P.A., Saranya, S., Jamkatel, S., Nayak, D.: Investigation of an aerofoil using improved blowing suction system. In: Proc. ICFAMMTS, pp. 265–279. Springer Nature, Singapore (2024)
19. Saranya, S., Balaji, K., Gore, M., Sulthan, S.: Investigation into active and passive methods to enhance aerofoil aerodynamic performance. Int. J. Aeronaut. Space Sci. 26(2), 517–527 (2025)
20. Nayak, D., Jamkatel, S., Balaji, K., Anbarasan, C.K., Rameshbhai, P.A., Saranya, S.: Investigation of the combined injection and vortex generator method for aerofoil performance enhancement. Int. J. Aeronaut. Space Sci. 26, 1–10 (2025)
21. Balaji, K., Yadav, A.: Design and optimization of winglet shapes for cambered aerofoil. Int. J. Aeronaut. Space Sci. 24(2), 358–365 (2023)

22. Balaji, K., Sulthan, S., Saranya, S., Hunchale, A.D., Bhagat, O.S.: Theoretical and numerical analysis of an aircraft wing mid section. In: **Proc.** BICFLAME**,** pp. 133–143. Springer Nature, Singapore (2024)
23. Jiang, R., Zhao, Z., Liu, H., Wang, T., Chen, M., Feng, J., Wang, D.: Numerical study on the influence of vortex generators on wind turbine aerodynamic performance considering rotational effect. Renew. Energy 186, 730–741 (2022). https://doi.org/10.1016/j.renene.2022.01.026
24. Namura, N., Shimoyama, K., Obayashi, S., Ito, Y., Koike, S., Nakakita, K.: Multipoint design optimization of vortex generators on transonic swept wings. J. Aircr. 56(4), 1291–1302 (2019). https://doi.org/10.2514/1.C035148
25. Kumar, R., Architha, N., Deodhar, R., Tejas, N., Menon, R.: Analytical testing of vortex generators with an airfoil profile**.** Int. J. Eng. Res. Technol. 8, 14–20 (2020)