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REVIEW PAPER ON CFD ANALYSIS OF DIFFERENT NACA AIRFOIL SERIES

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Abstract:

Computational Fluid Dynamics (CFD) has emerged as a powerful tool for analyzing and optimizing airfoil designs. This review paper provides a comprehensive analysis of various NACA airfoil series through CFD simulations. The NACA series, characterized by their unique numerical designations, offer a wide range of aerodynamic characteristics suitable for different applications. Through CFD analysis, this paper examines the performance of different NACA airfoil series in terms of lift, drag, and stall characteristics under various flow conditions. Additionally, the influence of parameters such as airfoil thickness, camber, and angle of attack on aerodynamic performance is investigated. The findings presented in this review paper aim to contribute to the understanding and selection of optimal NACA airfoil designs for diverse engineering applications, ranging from aircraft wings to wind turbine blades.

Keywords: CFD analysis, NACA airfoil series, aerodynamics, computational fluid dynamics, lift, drag, stall characteristics, airfoil design, numerical simulations, engineering applications.

I). INTRODUCTION:

The field of aerodynamics has witnessed remarkable advancements with the advent of Computational Fluid Dynamics (CFD) techniques. Among the pivotal components of aerodynamic analysis, airfoils play a fundamental role in determining the performance and efficiency of various engineering systems, including aircraft, wind turbines, and automobiles. In this context, the NACA airfoil series stands as a cornerstone in aerodynamic research, offering a diverse range of airfoil designs characterized by their numerical designations.

This review paper endeavors to explore and analyze the aerodynamic characteristics of different NACA airfoil series through CFD simulations. By leveraging the capabilities of CFD, researchers can gain valuable insights into the intricate flow phenomena surrounding these airfoils, enabling a comprehensive understanding of their performance under varying conditions.

The NACA airfoil series, developed by the National Advisory Committee for Aeronautics (NACA), now succeeded by NASA, represents a systematic approach to airfoil design. Each airfoil within the series is defined by a unique numerical designation, reflecting its specific geometric parameters such as thickness and camber distribution. This systematic classification facilitates comparative studies and allows engineers to select airfoils tailored to their specific requirements.

A key motivation behind this review paper is the need to elucidate the aerodynamic behavior of NACA airfoils across different series and configurations. By synthesizing existing literature and conducting CFD simulations, this paper aims to provide a comprehensive overview of the performance characteristics exhibited by various NACA airfoil designs. Understanding the intricacies of airflow over different airfoils is crucial for optimizing aerodynamic efficiency and enhancing the overall performance of engineering systems.

Through CFD analysis, researchers can explore a myriad of parameters influencing airfoil performance, including lift, drag, and stall characteristics. Moreover, the effects of parameters such as airfoil thickness, camber, and angle of attack on aerodynamic behavior can be systematically investigated. By scrutinizing these factors, engineers can refine existing designs or develop novel airfoil configurations tailored to specific applications.

Furthermore, this review paper seeks to bridge the gap between theoretical understanding and practical applications of NACA airfoils. While theoretical models provide valuable insights into airfoil behavior, CFD simulations offer a realistic portrayal of airflow dynamics and enable quantitative analysis of aerodynamic performance. By amalgamating theoretical principles with computational methodologies, this paper aims to provide actionable insights for engineers and researchers engaged in airfoil design and optimization.

In summary, this review paper serves as a comprehensive compendium of CFD analysis conducted on different NACA airfoil series. By elucidating the aerodynamic characteristics of these airfoils, this paper aims to facilitate informed decision-making in the selection and optimization of airfoil designs for diverse engineering applications. Through a systematic examination of airflow phenomena and performance metrics, this paper endeavors to contribute to the advancement of aerodynamic research and engineering practice.

II). TYPES OF AIRFOIL

Airfoils, also known as aerofoils, come in various shapes and designs, each tailored for specific applications. Here are a few common types and their applications:

1. Symmetrical Airfoils: These airfoils have identical upper and lower surfaces, generating equal lift at zero angle of attack. They are often used in aircraft wings where aerobatic performance is desired, such as stunt planes and model aircraft.

2. Asymmetrical (Cambered) Airfoils: These airfoils have different upper and lower surfaces, creating lift even at zero angle of attack. They are commonly used in general aviation aircraft, commercial airliners, and military aircraft.

3. High-Lift Airfoils: These airfoils are designed to generate higher lift coefficients at low speeds, enabling shorter takeoff and landing distances. They are often employed in aircraft such as cargo planes, short-haul regional jets, and commuter aircraft.

4. Supercritical Airfoils: Supercritical airfoils are designed to delay the onset of wave drag, making them suitable for high-speed aircraft like airliners and business jets where maintaining efficiency at transonic speeds is crucial.

5. NACA Airfoils: Developed by the National Advisory Committee for Aeronautics (NACA), these airfoils come in various series (e.g., NACA 4-digit, 5-digit) and were widely used in the design of early aircraft. They find applications in a broad range of aircraft types due to their versatility and well-understood aerodynamic characteristics.

6. Natural Laminar Flow (NLF) Airfoils: These airfoils are designed to maintain laminar airflow over a larger portion of the wing surface, reducing drag and improving fuel efficiency. They are commonly utilized in modern high-performance aircraft and sailplanes.

III). AIRFOIL SELECTION

1). NACA 2412

The **NACA 2412** airfoil is an aerodynamic profile developed by the National Advisory Committee for Aeronautics (NACA), the precursor to NASA. The numbers in the designation represent specific characteristics of the airfoil:

- The first digit, "2," indicates that the airfoil has a maximum camber of 2% of the chord length.

- The second digit, "4," represents the location of maximum camber as a percentage of the chord length (in this case, 40%).

- The last two digits, "12," denote the thickness-to-chord ratio of the airfoil (12%).

Application:

The **NACA 2412** airfoil is commonly used in various applications, including aircraft wings and blades for wind turbines, due to its favorable lift and drag characteristics. Its moderate camber and thickness make it suitable for a wide range of aerodynamic purposes.

2). NACA 64A212

The **NACA 64A212** airfoil is another aerodynamic profile developed by the National Advisory Committee for Aeronautics (NACA), now known as NASA. Here's a breakdown of its designation:

- The "64" at the beginning signifies that the airfoil is a 6-series airfoil, indicating its general shape characteristics.

- The "A" indicates that it is a modified form of the basic 64-series airfoil.

- The "2" denotes the location of maximum camber as a percentage of the chord length (20%).

- The "12" represents the thickness-to-chord ratio of the airfoil (12%).

Application:

This airfoil is known for its relatively high thickness and moderate camber. It was designed to provide favorable lift and drag characteristics, making it suitable for applications where a balance between lift and drag is important, such as in aircraft wings and rotor blades for helicopters.

3). NACA 0012

The **NACA 0012** airfoil is a symmetrical airfoil developed by the National Advisory Committee for Aeronautics (NACA), the predecessor of NASA. Here's what its designation signifies:

- The first two digits, "00," indicate that the airfoil has zero camber.

- The last two digits, "12," denote the thickness-to-chord ratio of the airfoil (12%).

Application:

Being symmetrical with no camber, the NACA 0012 airfoil is often used in applications where symmetric lift is desired, such as in certain aircraft tail surfaces like horizontal stabilizers and vertical stabilizers. Its relatively thick profile also makes it suitable for applications where structural considerations are important, such as rotor blades for helicopters and wind turbines.

4). NACA 23012

The **NACA 23012** airfoil is another aerodynamic profile developed by the National Advisory Committee for Aeronautics (NACA). Let's break down its designation:

- The "23" at the beginning indicates that it is a 2-series airfoil, which generally implies a particular set of aerodynamic characteristics.

- The "0" signifies that the airfoil has zero camber.

- The "12" denotes the thickness-to-chord ratio of the airfoil (12%).

Application:

In summary, the NACA 23012 airfoil is characterized by its symmetrical shape (zero camber) and moderate thickness. This airfoil design is often utilized in applications where symmetric lift and moderate thickness are desired, such as in certain sections of aircraft wings, tail surfaces, and even in some marine propeller designs.

IV). METHODOLOGY:

1. Literature Review: The first step in conducting this review paper involved an extensive literature review to gather relevant research articles, conference papers, and technical reports related to CFD analysis of NACA airfoil series. The literature review focused on identifying studies that provided detailed CFD simulations and analyses of different NACA airfoils under various flow conditions.

2. Selection Criteria: The selection criteria for including studies in this review paper were based on their relevance to CFD analysis of NACA airfoil series. Studies that presented detailed CFD simulations, discussed the aerodynamic performance of NACA airfoils, and compared different airfoil designs were given priority.

3. Data Extraction: Relevant data such as airfoil geometries, CFD setup parameters (e.g., mesh type and density, boundary conditions, turbulence models), simulation results (e.g., lift, drag, stall characteristics), and conclusions were extracted from the selected studies. This data formed the basis for the comparative analysis of different NACA airfoil series.

4. Comparative Analysis: The extracted data were used to conduct a comparative analysis of the aerodynamic performance of different NACA airfoil series. This analysis focused on identifying trends and patterns in the CFD results, highlighting the strengths and weaknesses of each airfoil series under different flow conditions.

5. Discussion: Based on the comparative analysis, a detailed discussion was conducted to interpret the findings and provide insights into the aerodynamic characteristics of different NACA airfoil series. The discussion also included a critical evaluation of the CFD methodologies used in the selected studies and their implications for airfoil design and optimization.

6. Conclusions and Recommendations: The review paper concluded with a summary of the key findings from the comparative analysis and a discussion of their implications for future research and engineering practice. Recommendations for improving CFD analysis of NACA airfoil series and directions for future research were also provided based on the review findings.

V). PROBLEM STATEMENT:

The aerodynamic performance of airfoils is a critical factor in determining the efficiency and effectiveness of various engineering systems, including aircraft, wind turbines, and hydrofoils. The National Advisory Committee for Aeronautics (NACA) airfoil series, characterized by their unique numerical designations, represents a significant body of work in airfoil design and aerodynamics. However, despite the extensive research conducted on NACA airfoils, there remains a need for a comprehensive review and analysis of their aerodynamic characteristics using Computational Fluid Dynamics (CFD) techniques.

The existing literature provides valuable insights into the aerodynamic behavior of individual NACA airfoil series. Still, a systematic comparison of different NACA airfoil series through CFD analysis is lacking. Such a comparative analysis is essential for identifying the strengths and weaknesses of various airfoil designs and for informing the selection and optimization of airfoils for specific engineering applications.

Furthermore, while theoretical models and experimental studies have contributed significantly to our understanding of airfoil aerodynamics, CFD simulations offer a powerful tool for conducting detailed numerical analyses of airflow over complex geometries. However, the application of CFD to the analysis of NACA airfoil series is often fragmented, with individual studies focusing on specific airfoil designs or operating conditions.

Therefore, the problem addressed by this research paper is the lack of a comprehensive and systematic review of CFD analysis conducted on different NACA airfoil series. By synthesizing existing literature and conducting a comparative analysis of CFD results, this review paper aims to address this gap in knowledge and provide a comprehensive understanding of the aerodynamic performance of NACA airfoil series across a range of operating conditions.

The findings of this research paper are expected to contribute to the advancement of aerodynamic research and engineering practice by providing insights into the relative performance of different NACA airfoil series and by informing the selection and optimization of airfoil designs for diverse engineering applications. Additionally, this review paper will identify areas for future research and development in the field of airfoil aerodynamics, particularly regarding the application of CFD techniques to the analysis of NACA airfoil series.

VI). DESIGN

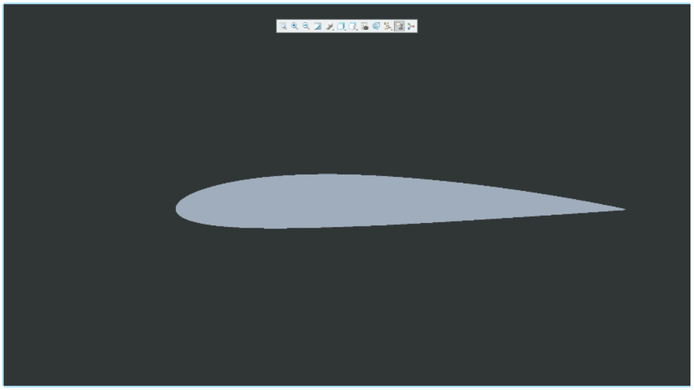

Figure 1 NACA 2412

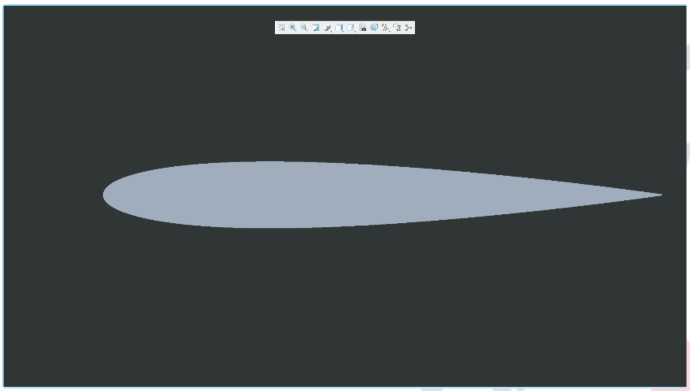

Figure 2 NACA 0012

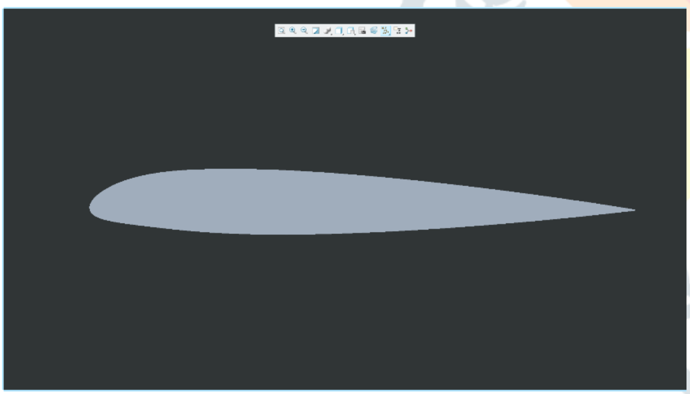

Figure 3 NACA 23012

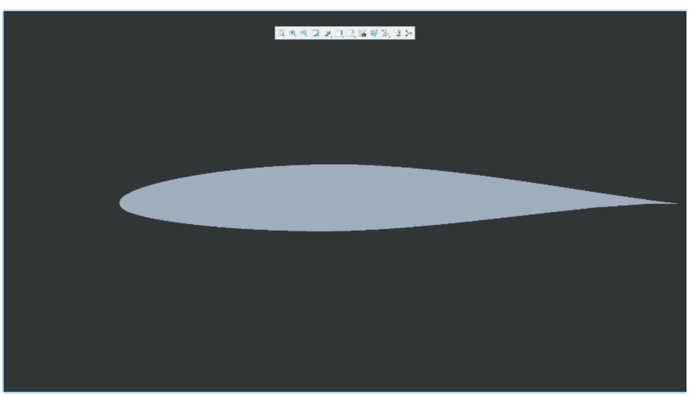

Figure 4 NACA 64A212

VII). BOUNDARY CONDITION

In computational fluid dynamics (CFD), boundary conditions are essential specifications applied to the boundaries of the computational domain to solve fluid flow problems accurately. These conditions define how fluid interacts with the boundaries of the domain and influence the behavior of the solution within the domain and assume mass 50 kg, Weight 500N for thrust required calculation.

Table 1 BOUNDARY CONDITION

S.no	Boundary condition	Value/On/Off
1	Pressure	1.01325 x 10^5 N/m^2
2	Density	1.23kg/m^3
3	Temperature	288.16K
4	Viscous model	k-omega
5	Energy equation	On
6	Air inlet velocity	50m/sec

VIII). RESULT

Table 2 NACA 0012

S.no	AoA	Cl	Cd	Cl/Cd	Thrust Required (T_R) N
1	0	0.00013941384	0.010970047	0.012708590947696	39,343.46475213661
2	5	0.025444258	0.012611615	2.017525749081303	247.8283115978466
3	10	0.056021826	0.018715377	2.993358135398501	167.0364778898853
4	15	0.091926115	0.030336255	3.03023939507365	165.0034650110037

Table 3 NACA 2412

S.no	AoA	Cl	Cd	Cl/Cd	Thrust Required (T_R) N
1	0	0.012535394	0.012787703	0.9802694041298895	510.0638639678976
2	5	0.043328095	0.015936268	2.7188357399612	183.9022463369322
3	10	0.080259573	0.02422714	3.312796021321543	150.9299083861311
4	15	0.12426868	0.039191884	3.170775867779156	157.6901114584946

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Table 4 NACA 23012

S.no	AoA	Cl	Cd	Cl/Cd	Thrust Required (T_R) N
1	0	0.01144321	0.017071818	0.670298265832028	745.9365859754387
2	5	0.069103823	0.021798739	3.170083508041451	157.7245516503479
3	10	0.13584	0.034802161	3.90320589574883	128.0998270023557
4	15	0.22427189	0.06252643	3.586833439874946	139.3987226843275

Table 5 NACA 64A212

S.no	AoA	Cl	Cd	Cl/Cd	Thrust Required (T_R) N
1	0	0.0047659941	0.0080887779	0.5892106519576956	848.5929409774133
2	5	0.026594585	0.0099919005	2.661614274481616	187.8559206695649
3	10	0.05236429	0.016032916	3.266049045600937	153.0901688918154
4	15	0.076651616	0.025649811	2.988389115225839	167.3142220511046

IX). COMPUTATIONAL FLOW ANALYSIS

NACA 0012

Pressure Distribution

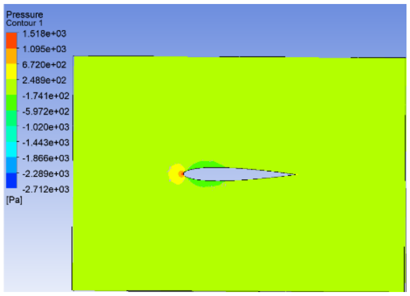


Figure 5 AoA:0

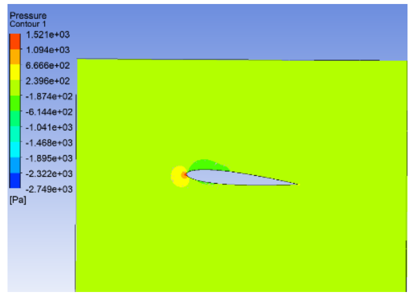


Figure 6 AoA:5

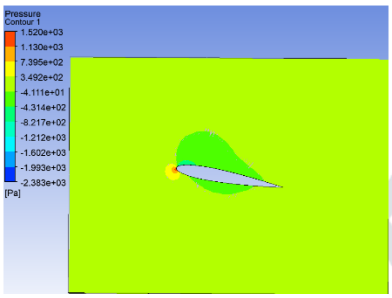


Figure 7 AoA:10

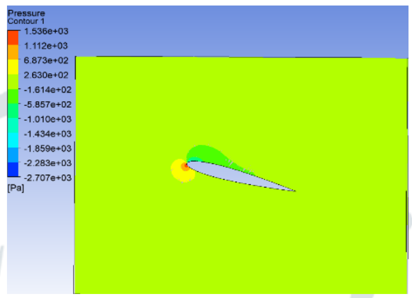


Figure 8 AoA:15

Velocity Variation

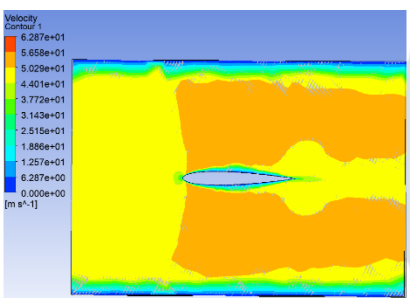
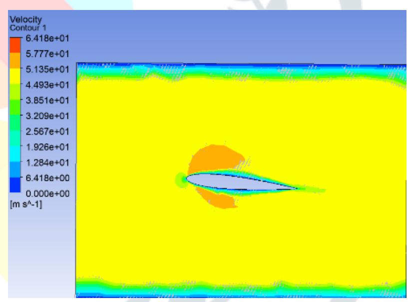


Figure 9 AoA:0



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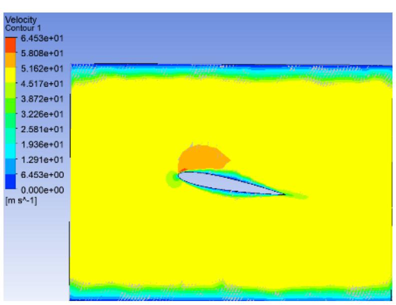


Figure 11 AoA:10

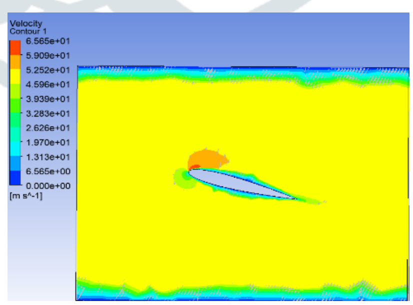


Figure 12 AoA:15

NACA 2412

Pressure Distribution

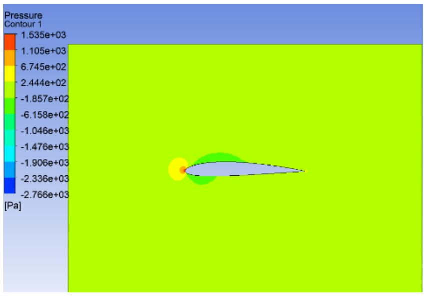
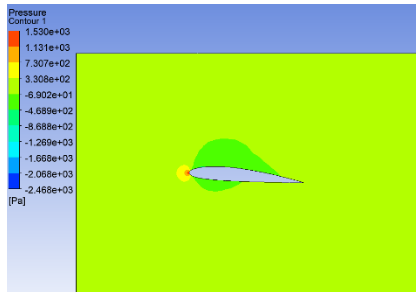


Figure 13 AoA:0



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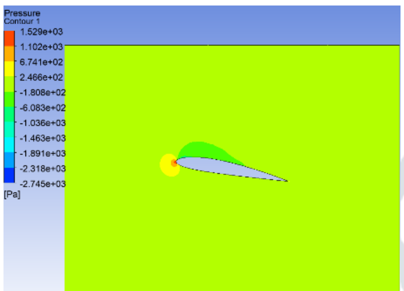

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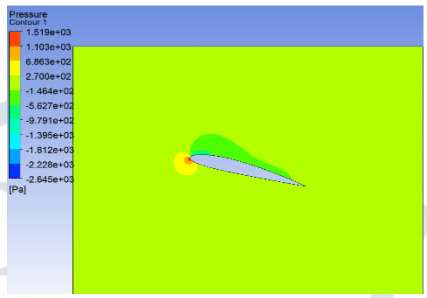
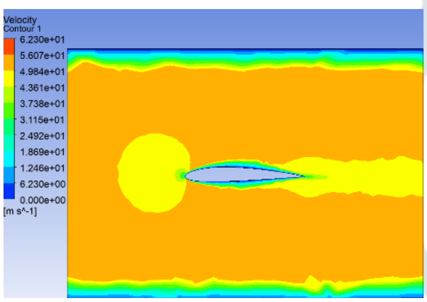


Figure 16 AoA:15

Velocity Variation



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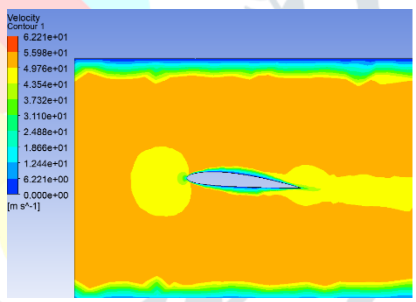

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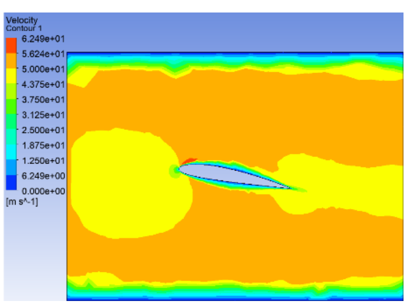

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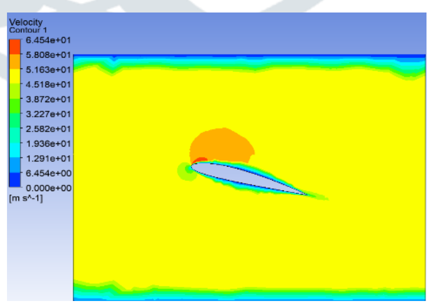
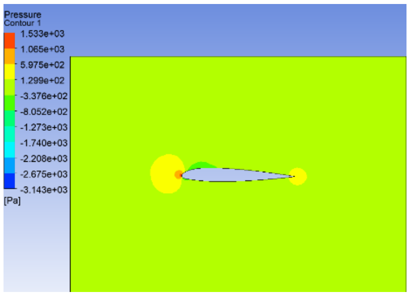


Figure 20 AoA:15

NACA 23012

Pressure Distribution



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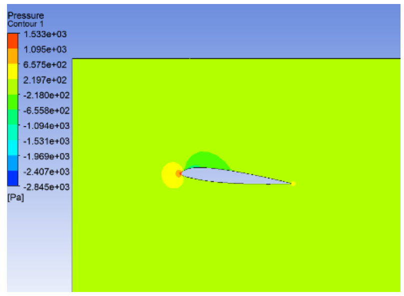

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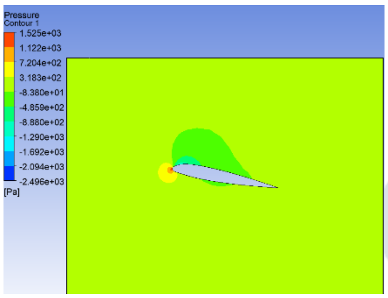


Figure 23 AoA:10

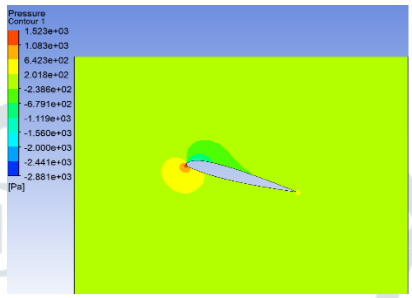


Figure 24 AoA:15

Velocity Variation

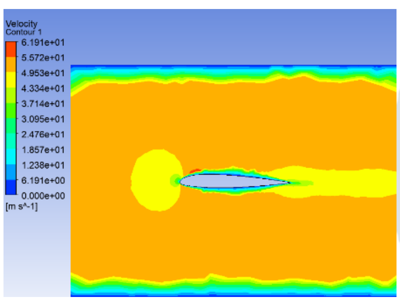


Figure 25 AoA:0

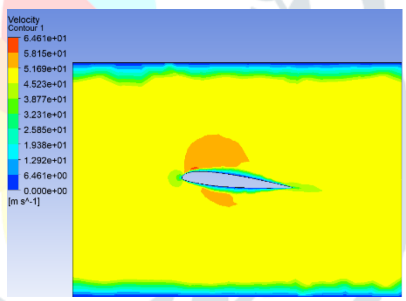
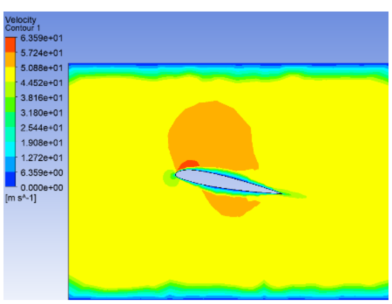


Figure 26 AoA:5



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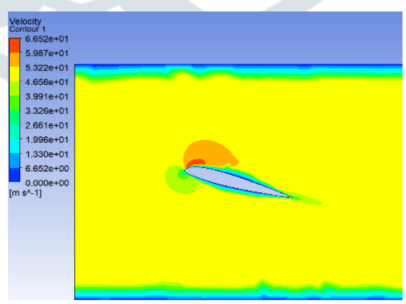
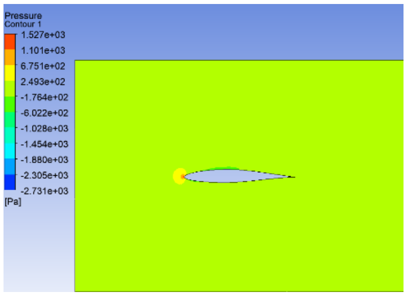


Figure 28 AoA:15

NACA 64A212

Pressure Distribution



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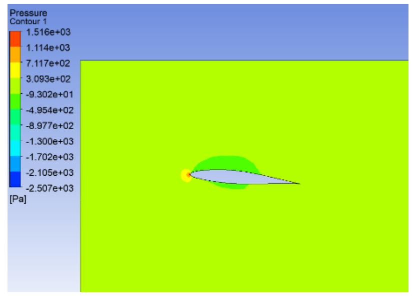


Figure 30 AoA:5

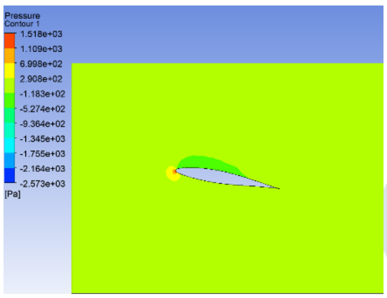


Figure 31 AoA:10

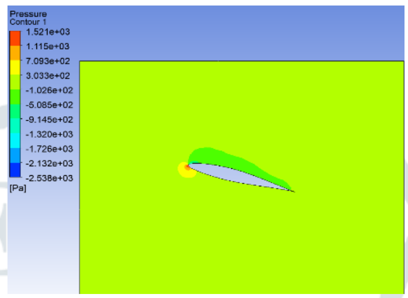


Figure 32 AoA:15

Velocity Variation

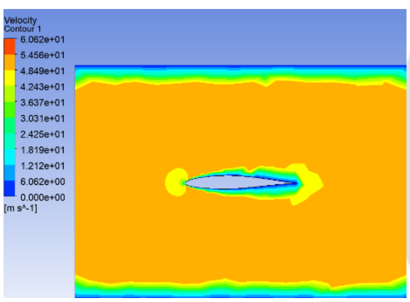


Figure 33 AoA:0

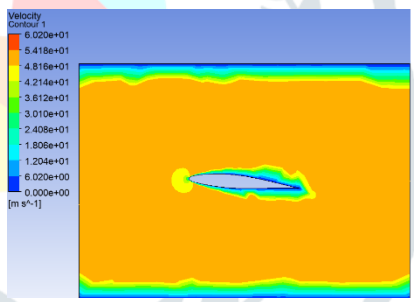


Figure 34 AoA:5

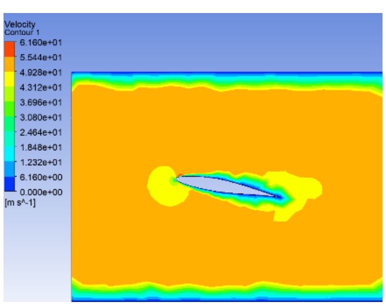


Figure 35 AoA:10

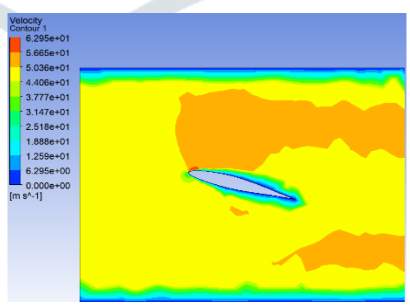


Figure 36 AoA:15

X). AIRFOIL GRAPH

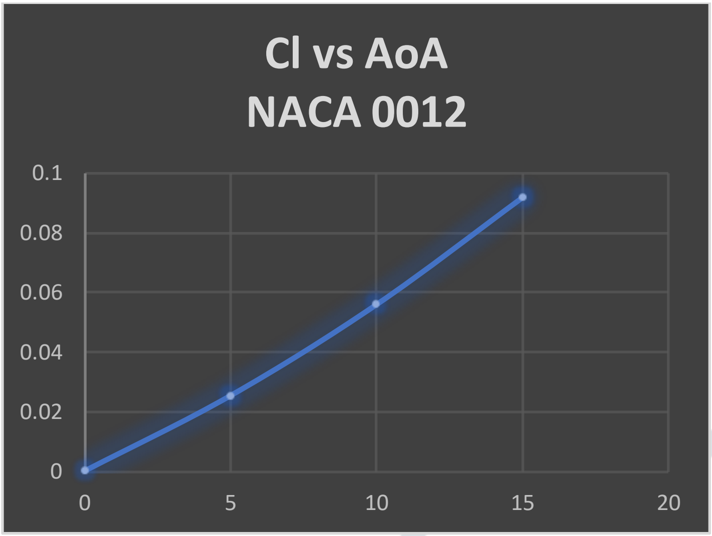


Figure 37

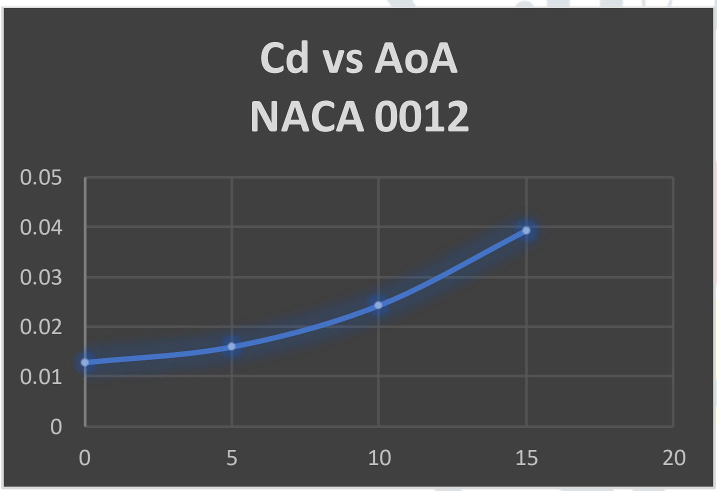
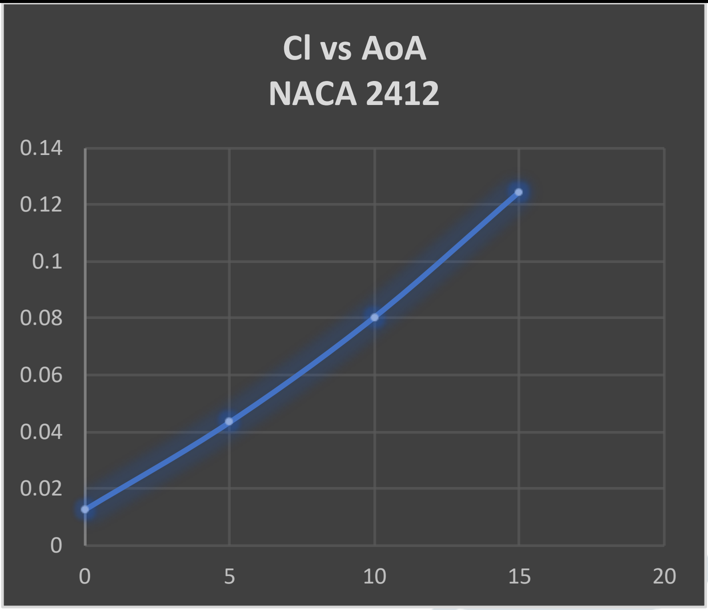


Figure 38

Figure 39



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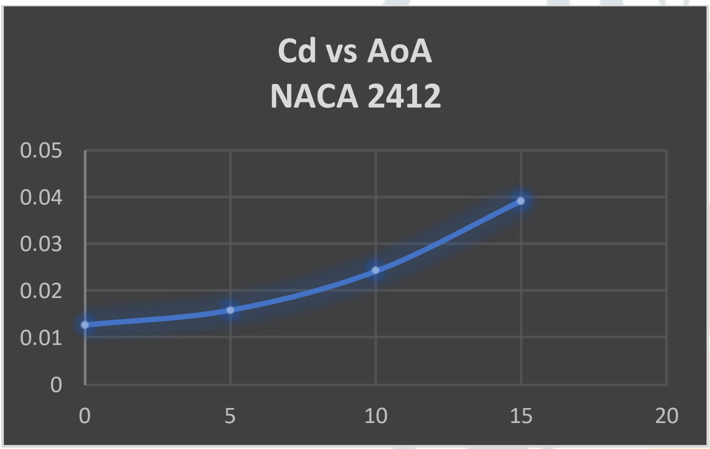


Figure 41

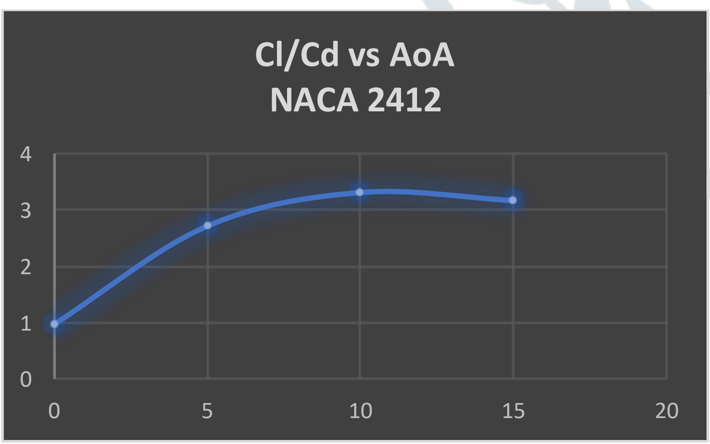
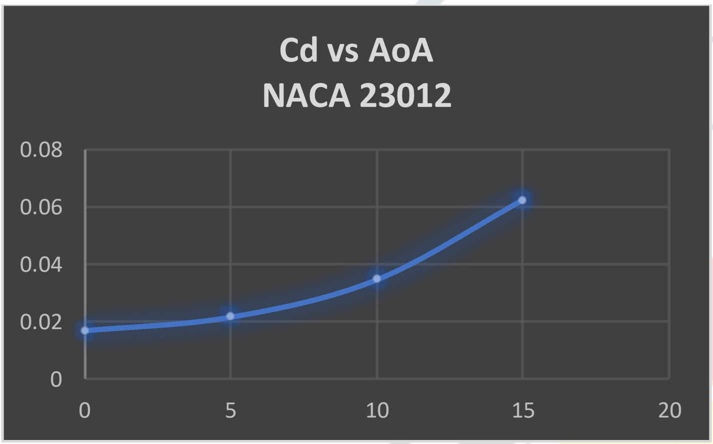


Figure 42

Figure 43



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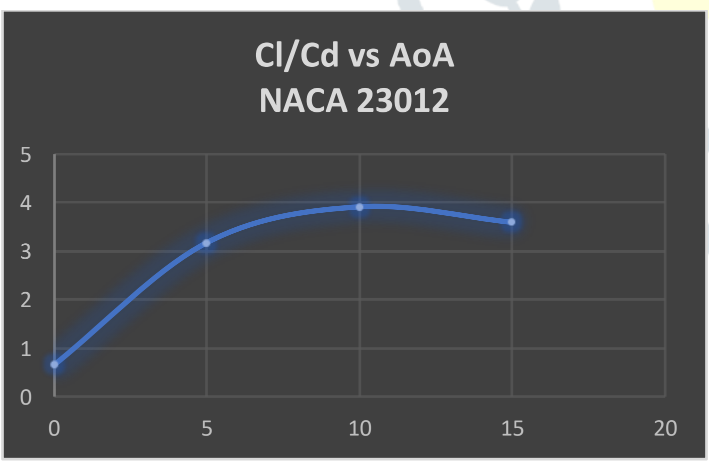

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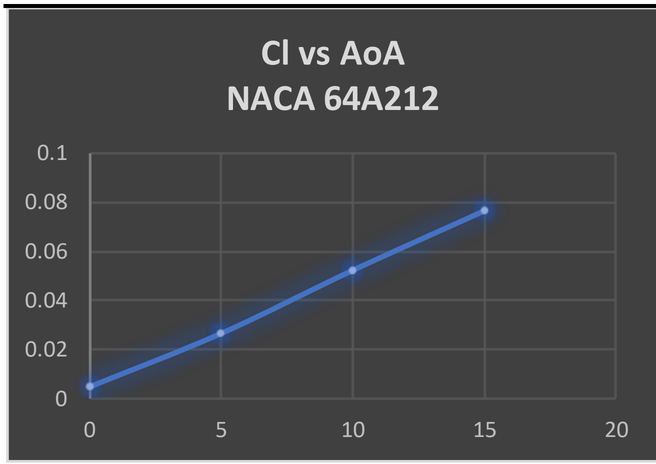

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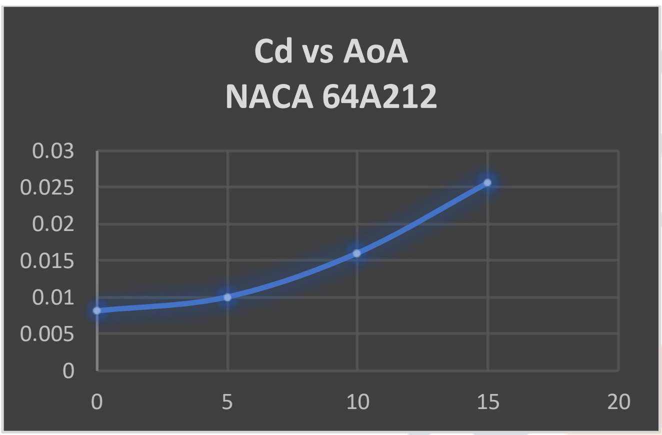

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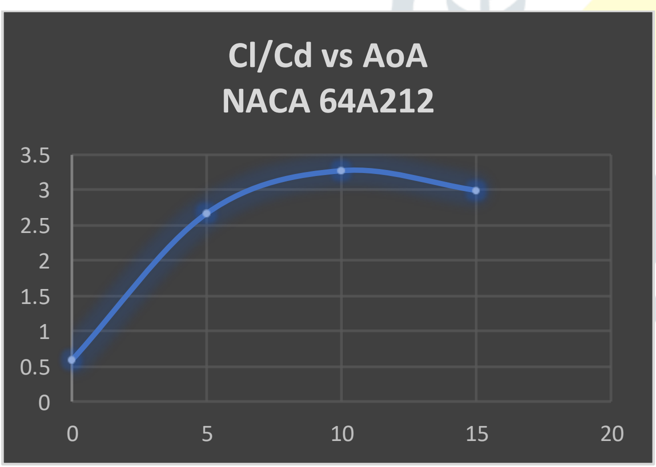

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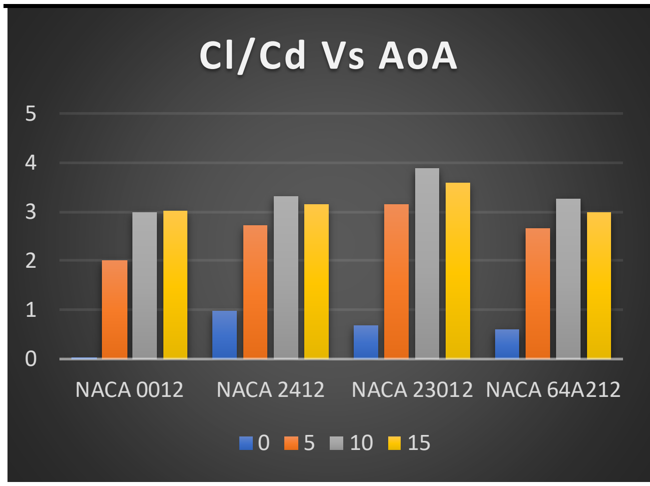


Figure 49

Figure 50

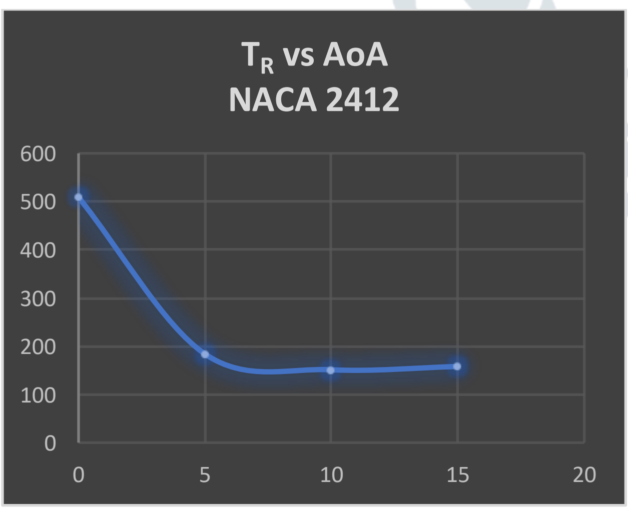
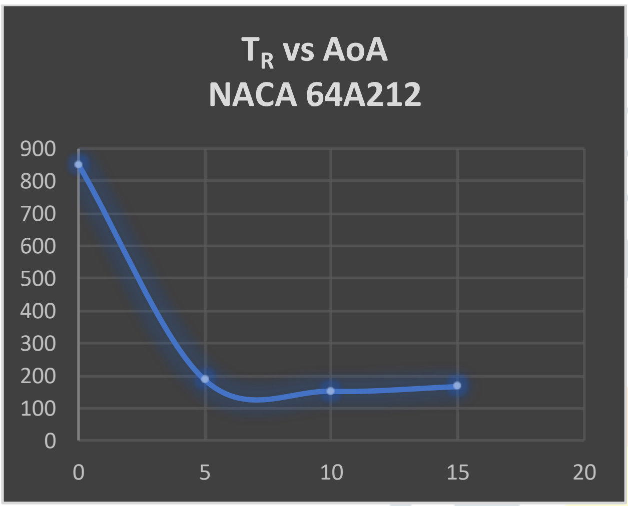


Figure 51

Figure 52



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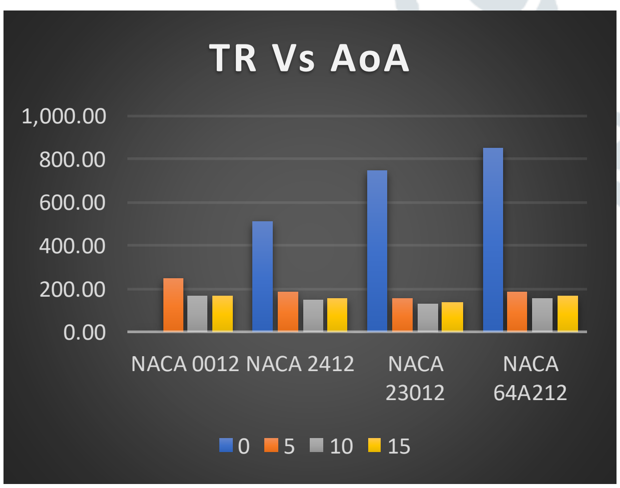

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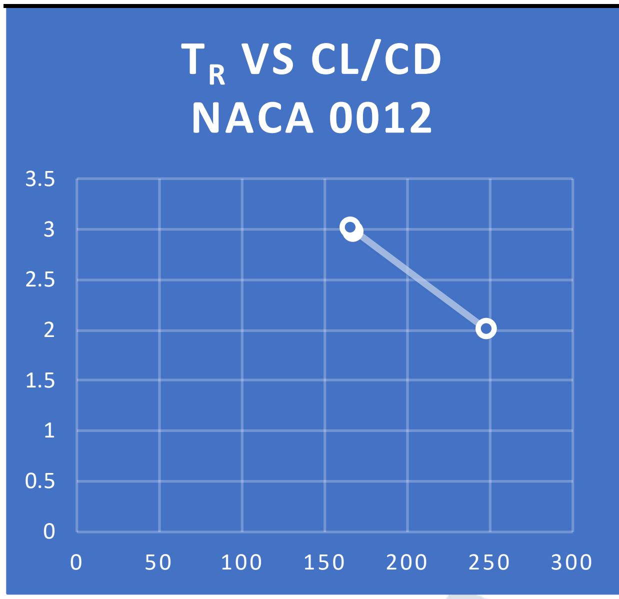

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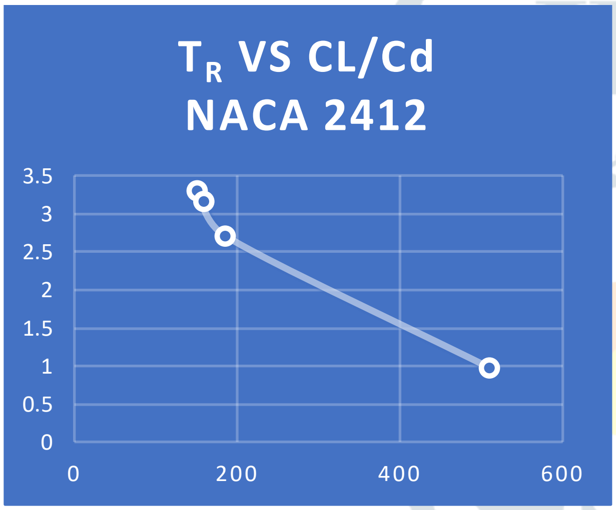

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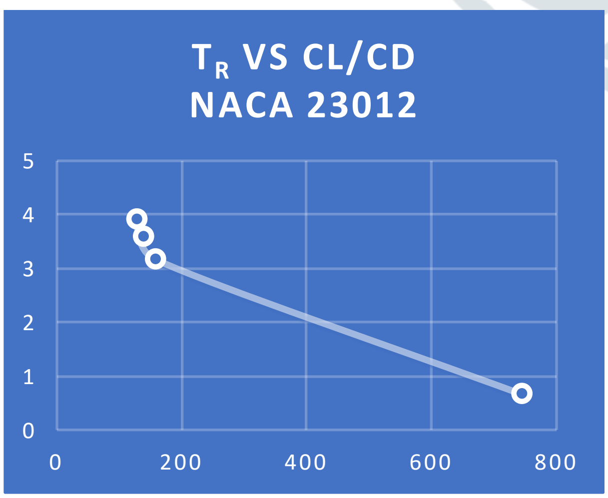

Figure 57

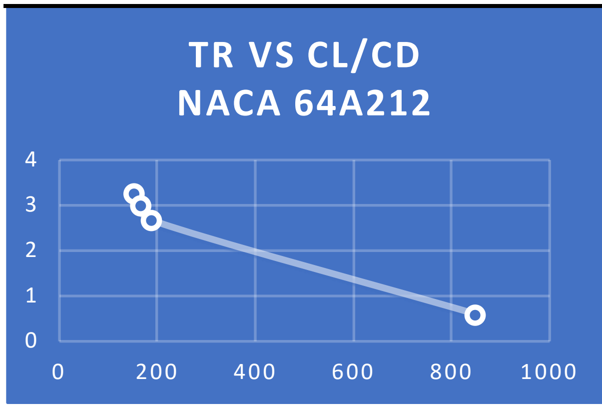

Figure 58

XI). DISCUSSION & CONCLUSION

In Figure 41, we observe that the NACA 23012 airfoil exhibits a higher Cl/Cd ratio at varying angles of attack. This characteristic implies that the thrust required for this airfoil is comparatively lower when compared to other NACA airfoils. According to the thrust-to-weight ratio formula, a higher Cl/Cd value necessitates less thrust, thus enhancing fuel efficiency and aerodynamic performance. This advantage translates into improved aircraft performance, as it requires less energy to maintain flight and maneuver through the air. Consequently, aircraft equipped with the NACA 23012 airfoil can operate more efficiently, achieving greater range and endurance while consuming less fuel. Such aerodynamic advantages are particularly significant in applications where fuel economy and endurance are paramount, such as long-range flights or unmanned aerial vehicle missions requiring extended flight durations. By optimizing aerodynamic efficiency through careful selection of airfoil profiles, engineers can enhance the overall performance and mission capabilities of aircraft, contributing to advancements in aviation technology and sustainability.

Following the success of the NACA 23012 airfoil, the NACA 2412 emerges as another notable airfoil with commendable aerodynamic efficiency and moderate chamber thickness. This characteristic increases its versatility and applicability in the aerospace industry. Both airfoils, NACA 23012 and NACA 2412, find extensive use in wing design applications where achieving a desirable lift value is crucial. However, contrasting with these efficient designs, the NACA 0012 and NACA 64A212 airfoils demonstrate a notably high chamber thickness. While this feature enhances structural stability, it also results in a decrease in aerodynamic efficiency, as indicated by the results. Consequently, these airfoils have limited engineering applications, suitable primarily for scenarios where a lower lift value and enhanced structural stability are prioritized over aerodynamic performance.

The conclusion drawn from the analysis of the NACA 23012 airfoil suggests that it requires less thrust to generate lift compared to other airfoils. This characteristic implies that at lower angles of attack, the NACA 23012 airfoil can achieve higher lift values, making it more efficient in terms of lift production. This efficiency translates to fuel savings, as less thrust is needed to maintain lift, ultimately increasing the fuel efficiency of an aircraft equipped with this airfoil.

Furthermore, the NACA 23012 airfoil's ability to produce higher lift at lower angles of attack can also lead to improved overall aerodynamic performance. This performance advantage can be crucial for various applications, such as reducing take-off distances, improving climb rates, and enhancing maneuverability, all while minimizing fuel consumption. Therefore, the NACA 23012 airfoil's characteristics make it a potentially attractive choice for aircraft design where fuel efficiency and performance are key considerations.

XII). REFERENCE

[1]. Alan Pope, Basic Wing & Airfoil Theory, McGraw-Hill Book Company: New York, 1951.

[2]. National Advisory Committee for Aeronautics: Aerodynamic Characteristics of Aerofoils, NACA Rep. 93, 1920.

[3]. Abbott, Ira H.; Von Doenhoff, Albert E. Theory of Wing Sections. Dover Publ., Inc., 1959.

[4]. Somers, Dan M.: Effects of Airfoil Thickness and Maximum Lift Coefficient on Roughness Sensitivity. Airfoils, Inc., State College, Pennsylvania, 1998.

[5]. John J.Bertin, Aerodynamics for Engineers, 4th edition, Prentice Hall: Upper Saddle River, New Jersey, 2009.

[6]. Anderson, J, Fundamentals of Aerodynamics, 2nd Edition, McGraw-Hill: New York, 1991.

[7]. M.L.J. Verhees DCT 2004.120, Experimental Modal Analysis Of A Turbine Blade, Technische Universiteit Eindhoven, Department Mechanical Engineering, Dynamics and Control Group, Eindhoven, December, 2004.

[8] K. S. Patel, S. B. Patel, U. B. Patel, and A. P. Ahuja, "CFD Analysis of an Aerofoil," International Journal of Engineering Research, vol. 3, no. 3, pp. 154-158, 2014.

[9] M. F. Ismail and K. Vijayaraghavan, "The effects of aerofoil profile modification on a vertical axis wind turbine performance," Energy, vol. 80, pp. 20-31, 2015.

[10] F. Dehaeze, G. Barakos, A. Batrakov, A. Kusyumov, and S. Mikhailov, "Simulation of flow around aerofoil with DES model of turbulence," Труды МАИ, no. 59, 2012.

[11] M. YILMAZ, H. KÖTEN, E. Çetinkaya, and Z. Coşar, "A comparative CFD analysis of NACA0012 and NACA4412 airfoils," Journal of Energy Systems, vol. 2, no. 4, pp. 145-159, 2018.

[12] S. K. Rasal and R. R. Katwate, "Numerical analysis of lift & drag performance of NACA0012 wind turbine aerofoil," International Research Journal of Engineering and Technology, vol. 4, no. 06, pp. 2892-2896, 2017.

[13] F. M. White, Fluid mechanics. Tata McGraw-Hill Education, 1979.

[14] S. J. Juliyana, J. U. Prakash, K. Karthik, P. Pallavi, and M. Saleem, "Design and analysis of NACA4420 wind turbine aerofoil using CFD," International Journal of Mechanical Engineering and Technology, vol. 8, no. 6, pp. 403-410, 2017.

[15] K. S. Rao, M. A. Chakravarthy, G. S. Babu, and M. Rajesh, "MODELING AND SIMULATION OF AEROFOIL ELEMENT," METHODOLOGY, vol. 5, no. 02, 2018.

[16] T. Liu, S. Wang, X. Zhang, and G. He, "Unsteady thin-airfoil theory revisited: application of a simple lift formula," Aiaa Journal, vol. 53, no. 6, pp. 1492-1502, 2015.

[17] H. Yang, M. Fan, A. Liu, and L. Dong, "General formulas for drag coefficient and settling velocity of sphere based on theoretical law," International Journal of Mining Science and Technology, vol. 25, no. 2, pp. 219-223, 2015.

[18] M. S. A. Hakim et al., "The effects of Reynolds number on flow separation of Naca Aerofoil," Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 47, no. 1, pp. 56-68, 2018.

[19] N. Eastman, E. Kenneth, and R. Pinkerton, "The characteristics of 78 related airfoil sections from tests in the variabledensity wind tunnel," NACA-report-460, 1933.

[20] T. A. Johansen, A. Cristofaro, K. Sørensen, J. M. Hansen, and T. I. Fossen, "On estimation of wind velocity, angle-of-attack and sideslip angle of small UAVs using standard sensors," in 2015 International Conference on Unmanned Aircraft Systems (ICUAS), 2015: IEEE, pp. 510-519.

[21] D. Barkley, B. Song, V. Mukund, G. Lemoult, M. Avila, and B. Hof, "The rise of fully turbulent flow," Nature, vol. 526, no. 7574, pp. 550-553, 2015.

[22] S. Eftekhari and A. S. M. Al-Obaidi, "Investigation of a NACA0012 Finite Wing Aerodynamics at Low Reynold's Numbers and 0º to 90º Angle of Attack," Journal of Aerospace Technology and Management, vol. 11, 2019

[23] https://m-selig.ae.illinois.edu/ads/aircraft.html (Accessed: 13-Nov-2022).

[24] https://turbmodels.larc.nasa.gov/naca4412sep_val. html (Accessed: 13-Nov-2022).

[25] https://turbmodels.larc.nasa.gov/naca4412sep_val_ sa.html (Accessed: 13-Nov-2022).

[26] Burton, T., Jenkins, N, Sharpe, D. and Bossanyi, E. Wind Energy Handbook. Chichester, UK: John Wiley & Sons, 2011; 65-67

[27] Panigrahi, D.C., Mishra D.P., CFD Simulations for the Selection of an Appropriate Blade Profile for Improving Energy Efficiency in Axial Flow Mine Ventilation Fans, Journal of Sustainable Mining, 2014; Volume 13, Issue 1, Pages 15-21, ISSN 2300- 3960.

[28] Yılmaz M., Koten H., Çetinkaya, E, Coşar, Z., A comparative CFD analysis of NACA0012 and NACA4412 airfoils. Journal of Energy Systems 2018; 2(4): 145- 159, DOI: 10.30521/jes.454193.

[29] http://airfoiltools.com/airfoil/details?airfoil=naca4 412-il (Accessed: 13-Nov-2022).

[30] http://airfoiltools.com/airfoil/details?airfoil=naca2 3012-il (Accessed: 13-Nov-2022).

[31] Pranto, M.R.I. and Inam, M.I., 2020. Numerical Analysis of the Aerodynamic Characteristics of NACA4312 Airfoil. Journal of Engineering Advancements, 1(02), pp.29-36.

[32] Spalart, P.R., Allmaras S.R., A one-equation turbulence model for aerodynamic flows, AIAA 30th aerospace sciences meeting and exibit, 6-9 Jan 1993.