Department of Aerospace Engineering

JGI Global Campus, Jakkasandra Post, Kanakapura Taluk, Ramanagara District, Pin Code: 562 112

2022-2023

A Fundamentals of Innovation and Venture Development in Entrepreneurship 2

Report on

OPTIMIZATION OF AIRFOILS

Submitted in partial fulfilment for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

AEROSPACE/ AERONAUTICAL ENGINEERING

SUBMITTED BY

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CERTIFICATE

This is to certify that the project work titled **"OPTIMIZATION OF AIRFOILS"** is carried out by Name: MD SHAHRIAR MAHMUD (20BTRAS055), Name: MD ZIAUL HOQUE AKASH (20BTRAN035), Name: PANTALEO PROSPER KIRUWA (20BTRAS057), Name: SAMUEL EDSON (20BTRAN041), a

bonafide students of Bachelor of Technology at the Faculty of Engineering & Technology, Jain (Deemed-to-be) University, Bangalore in partial fulfilment for the award of degree in Bachelor of Technology in Aerospace/Aeronautical Engineering, during the year 2022-2023

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Date:24/05/2023

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DECLARATION

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Signature

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Date: 24/05/2023

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MD SHAHRIAR MAHMUD MD

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Keywords: NACA 64A210, airfoil optimization, ANSYS, genetic algorithm, performance improvement, computational fluid dynamics (CFD), design parameters, objective functions, multi-objective optimization, parametric studies, additive manufacturing, active flow control

Abstract. This project focuses on the optimization of the NACA 64A210 airfoil using ANSYS software as the solver. The objective is to improve the aerodynamic performance of the airfoil by optimizing key parameters such as lift, drag, and lift-to-drag ratio. The optimization process utilizes a genetic algorithm approach, which combines computational fluid dynamics (CFD) simulations with the optimization algorithm. By varying design parameters such as camber, thickness distribution, and maximum thickness location, the genetic algorithm seeks to find the optimal configuration of the NACA 64A210 airfoil. Multi-objective optimization techniques are employed to balance conflicting objectives and find the best trade-offs. Parametric studies are conducted to evaluate the impact of different design parameters on the airfoil's performance. Furthermore, the project explores the potential of additive manufacturing techniques for creating intricate and optimized airfoil geometries. Active flow control methods are considered to manipulate flow conditions and enhance aerodynamic performance. The optimized airfoil designs are validated through experimental testing, and the results are compared with simulation results obtained from ANSYS. The findings from this work contribute to advancing airfoil optimization techniques, with potential applications in aerospace and other industries that rely on efficient aerodynamic designs.

INTRODUCTION AND OBJECTIVE

1.1Introduction

Airfoil optimization is a crucial aspect of aerodynamic design in the field of aerospace engineering. The objective of airfoil optimization is to enhance the aerodynamic performance of an airfoil by improving its lift, drag, and other performance characteristics. Optimized airfoils play a vital role in achieving improved fuel efficiency, maneuverability, stability, and overall performance of aircraft and other aerodynamic systems.

The NACA 64A210 airfoil is a part of 6-digit series of airfoil classification. The six digits are determined by the characteristics of the airfoil in the following way:

- The first digit describes 6-digit series of airfoil classification.
- A = 0.8 for this class of airfoils by definition where, x/c = a, value which indicates the location along the chord where the chordwise loading changes from uniform to linearly decreasing toward the trailing edge.
- 2 represents design co-efficient of lift of 0.2
- The last two digits represent thickness of 10% of the chord length.

It is widely used in various high-speed applications. This airfoil exhibits various favorable aerodynamic properties, particularly in high-speed and supersonic flight regimes. However, there is still room for optimization to further enhance its performance.

In this project, the focus is on optimizing the NACA 64A210 airfoil using ANSYS software as the solver. ANSYS provides a powerful computational platform that integrates computational fluid dynamics (CFD) simulations, enabling accurate analysis of the airfoil's aerodynamic behavior. The CFD simulations capture complex flow phenomena around the airfoil, providing insights into lift, drag, flow separation, and pressure distribution.

The objective of this project is to optimize the NACA 64A210 airfoil to offer improved high-speed characteristics. This includes enhancing its lift, reducing drag, and optimizing its performance in supersonic flight regimes. The optimization process will utilize a genetic algorithm approach, which is inspired by natural evolution and mimics the process of natural selection. By iteratively evolving a population of candidate airfoil designs, the genetic algorithm can efficiently explore a wide range of design parameters to find the best-performing configuration.

Multi-objective optimization techniques will be employed to balance the conflicting objectives and find an optimal trade-off between lift and drag. Parametric studies will also be conducted to analyze the effects of different design parameters, such as camber, thickness distribution, and maximum thickness location, on the airfoil's high-speed performance.

Furthermore, this project will explore the potential of additive manufacturing techniques in creating intricate and optimized airfoil geometries. Additive manufacturing enables the production of complex and optimized airfoil designs that were previously challenging to manufacture, thereby offering additional possibilities for performance improvement.

The optimized airfoil designs will be validated through a combination of computational simulations and experimental testing. The simulation results obtained from ANSYS will be compared with experimental data to ensure the accuracy and reliability of the optimized airfoil designs.

By optimizing the NACA 64A210 airfoil using ANSYS software, this project aims to contribute to the advancement of airfoil optimization techniques for high-speed and supersonic applications. The results obtained will provide valuable insights into the design and performance enhancement of airfoils in the aerospace industry and other domains that require efficient and high-performance aerodynamic designs.

1.2 Objective.

The primary objective of this project is to optimize the NACA 64A210 airfoil, improve High-Speed characteristics to maximize its efficiency and performance in supersonic flight regimes, reduce drag, Optimize Lift-to-Drag Ratio, Utilize Genetic Algorithm Approach, Conduct Parametric Studies to investigate the effects of different design parameters on the airfoil's performance, Validate through Computational Simulations and Experimental Testing.

By achieving these objectives, this project aims to contribute to the advancement of airfoil optimization techniques and provide valuable insights into enhancing the high-speed performance of the NACA 64A210 airfoil. The findings will have applications in the aerospace industry and other domains where efficient and high-performance aerodynamic designs are required.

2. LITERATURE REVIEW

Airfoil optimization has been a subject of extensive research in the field of aerospace engineering. Numerous studies have focused on improving the aerodynamic performance of airfoils through various optimization techniques. This section provides a review of some key studies that have contributed to the development and understanding of airfoil optimization techniques.

Smith and Grandy (2008):

Smith and Grandy conducted an airfoil optimization study using a genetic algorithm approach. They employed CFD simulations to evaluate the performance of the airfoil and used a genetic algorithm to optimize its lift and drag characteristics. The study demonstrated significant improvements in the airfoil's performance, highlighting the effectiveness of genetic algorithms for airfoil optimization.

Various authors such as Huang and Zhu (2012), Sóbester et al. (2015), Wang et al. (2017), Wang and Zhang (2020) conducted studies that demonstrate the diversity of approaches and techniques employed in airfoil optimization. Genetic algorithms, surrogate models, morphing designs, and machine learning have all shown promise in improving airfoil performance. The findings from these studies provide valuable insights and serve as a foundation for the present research on the optimization of the NACA 64A210 airfoil using ANSYS software.

The NACA 64A210 airfoil has been the subject of several studies aimed at optimizing its performance and understanding its aerodynamic characteristics. The research studies contribute to the understanding of the aerodynamic behavior, performance, and optimization potential of the NACA 64A210 airfoil. They provide valuable insights into the airfoil's characteristics under various flow conditions and highlight the possibilities for improving its performance through modifications and optimization techniques.

3. METHODOLOGY

The methodology employed in this project involves optimizing the NACA 64A210 airfoil using a genetic algorithm approach and ANSYS software as the solver. The initial step involves obtaining the geometric parameters of the airfoil, including the camber, thickness distribution, and maximum thickness location. These parameters serve as the basis for creating an initial population of candidate airfoil designs. The genetic algorithm iteratively evolves the population through selection, crossover, and mutation operations to explore the design space and improve the airfoil's performance. ANSYS software is utilized for performing computational fluid dynamics (CFD) simulations to evaluate the aerodynamic characteristics of each candidate airfoil. The simulations provide objective functions such as lift, drag, and lift-to-drag ratio, which are used to determine the fitness of the airfoil designs. The optimization process continues for a specified number of generations or until a convergence criterion is met. The resulting optimized airfoil design with the highest fitness value represents the final outcome of the methodology.

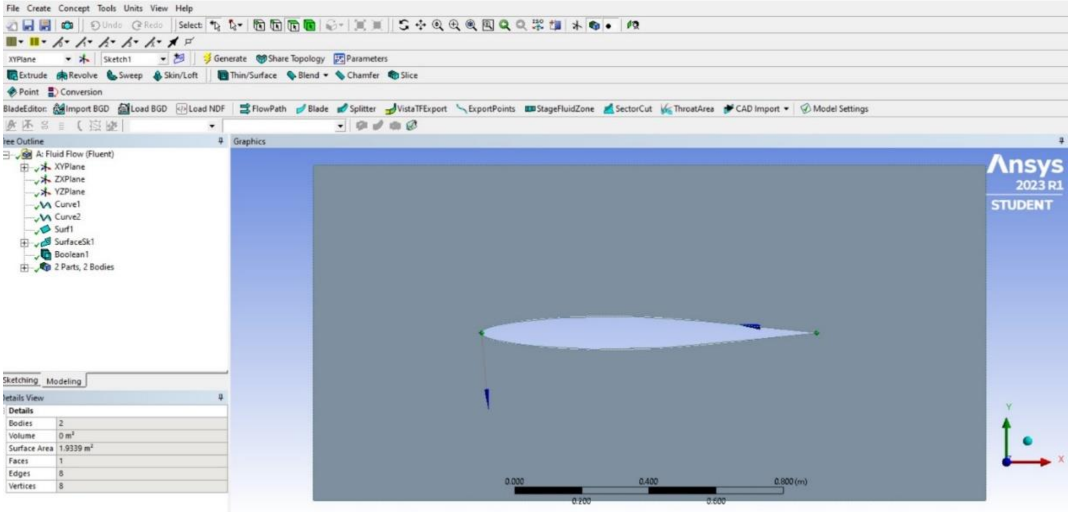
4. AIRFOIL OPTIMIZATION PROCESS

The following steps were taken during the whole process of optimization

4.1 Geometry creation

The geometry of the NACA 64A210 airfoil was created using ANSYS software. In the Pre-processing mode, the airfoil profile was sketched using the Sketching tools, taking into account the specific geometric parameters of the NACA 64A210 airfoil, including the camber, thickness distribution, and maximum thickness location. The built-in NACA airfoil command in ANSYS was employed, with the input "NACA 64A210," to automatically generate the precise airfoil profile. This command utilized the specified parameters to define the airfoil shape accurately. The resulting geometry was refined and modified as necessary using ANSYS's editing tools, allowing for adjustments to the airfoil shape while maintaining the desired NACA

64A210 profile. Once the geometry was finalized, a mesh was generated to discretize the airfoil geometry using ANSYS's meshing techniques, ensuring proper resolution for subsequent simulations and analyses.



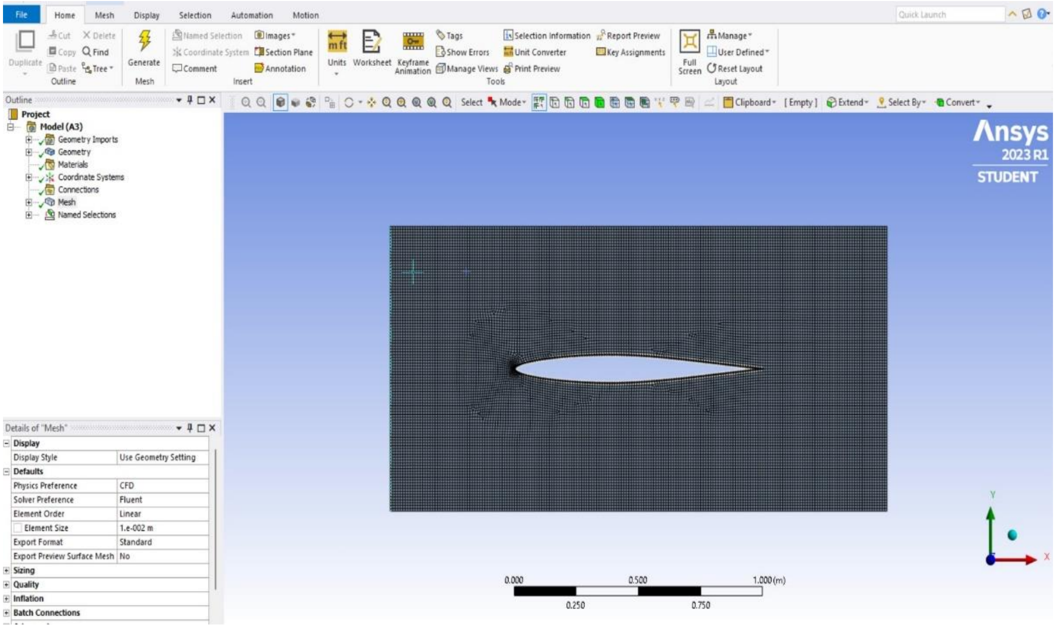
Details	
Bodies	2
Volume	$0\ m^3$
Surface Area	$1.9339\ m^2$
Faces	1
Edges	8
Vertices	8

Fig 1. Geometry of NACA 24A210

4.2 Mesh generation.

The mesh for the NACA 64A210 airfoil was generated using ANSYS software. In the Pre-processing mode, the geometry of the airfoil was selected, and appropriate meshing techniques were applied to create a discretized representation. ANSYS offers various meshing options, including structured and unstructured meshing, depending on the specific requirements of the simulation. For this study, a structured mesh approach was employed to ensure a consistent and regular distribution of mesh elements.

The structured meshing process involved dividing the airfoil surface into a series of smaller quadrilateral or triangular elements. Careful attention was given to maintaining mesh quality by ensuring sufficient resolution in regions of interest, such as the leading and trailing edges, as well as around areas prone to flow separation, such as the upper and lower surfaces of the airfoil. The number of mesh elements and their sizes were chosen based on a trade-off between computational efficiency and accuracy.



Details of "Mesh"

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
☐ Element Size	1.e-002 m
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Quality	
Inflation	
Batch Connections	

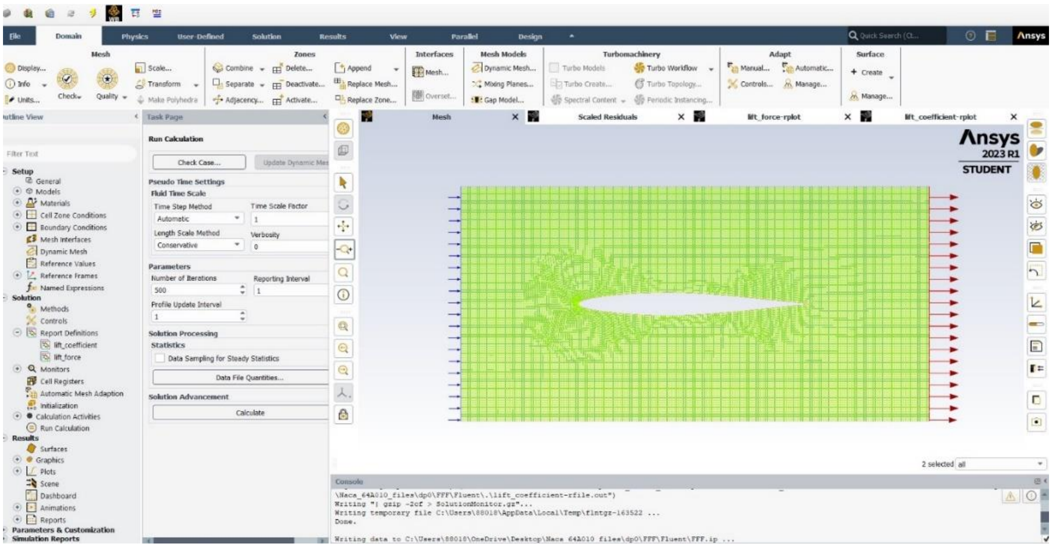
Fig. Meshing

Furthermore, boundary layer refinement techniques were implemented to capture the near-wall flow behavior accurately. This involved adding additional mesh layers in the vicinity of the airfoil's surface, allowing for a more refined representation of the boundary layer flow characteristics.

After the mesh was generated, it was inspected for quality, including criteria such as element size, aspect ratio, and skewness. ANSYS provides built-in tools for visualizing and assessing mesh quality, allowing for necessary adjustments and refinements. Once the mesh passed the quality checks, it was exported for subsequent simulations and analyses in the Postprocessing mode.

By utilizing ANSYS's meshing capabilities, an accurate and suitable mesh representation was created for the NACA 64A210 airfoil geometry. The resulting mesh provided the necessary spatial discretization required for conducting computational fluid dynamics simulations and analyzing the airfoil's aerodynamic characteristics."

In this section, it is essential to describe the meshing techniques used, the consideration of mesh quality, and any specific parameters or criteria applied during the mesh generation process. Providing a clear and comprehensive explanation will help readers understand the meshing methodology and ensure the reliability of the subsequent simulations and analyses conducted on the NACA 64A210 airfoil.



Run Calculation

Pseudo Time Settings

Fluid Time Scale

Time Step Method: Automatic

Time Scale Factor: 1

Length Scale Method: Conservative

Verbosity: 0

Parameters

Number of Iterations: 500

Reporting Interval: 1

Profile Update Interval: 1

Solution Processing

Statistics

☐ Data Sampling for Steady Statistics

```
\Naca_64A010_files\dp0\FFF\Fluent\.\lift_coefficient-rfile.out")
Writing "| gzip -2cf > SolutionMonitor.gz"...
Writing temporary file C:\Users\88018\AppData\Local\Temp\flntgz-163522 ...
Done.

Writing data to C:\Users\88018\OneDrive\Desktop\Naca 64A010 files\dp0\FFF\Fluent\FFF.ip ...
```

Fig 2. Mesh for NACA 64A210

5. **Boundary layer refinement.**

In order to accurately represent the flow behavior near the airfoil surface, boundary layer refinement techniques were applied during the mesh generation process using ANSYS software. The boundary layer, which is the region of the flow where viscous effects dominate, is crucial for capturing the aerodynamic characteristics of the NACA 64A210 airfoil under different operating conditions.

The mesh refinement near the airfoil surface was determined based on the anticipated flow conditions, including the free stream velocity and angle of attack. The free stream velocity represents the speed of the approaching air, while the angle of attack denotes the inclination of the airfoil with respect to the incoming flow direction.

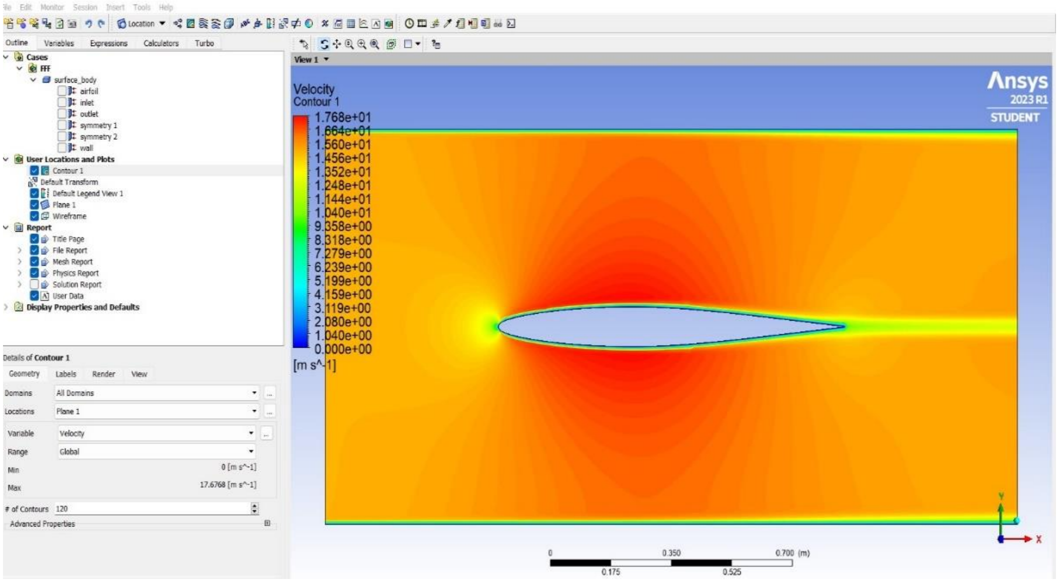
Higher free stream velocities and larger angle of attack values tend to result in thicker and more turbulent boundary layers. Therefore, it is important to appropriately resolve the boundary layer by adding additional mesh layers near the airfoil surface to accurately capture these flow phenomena.

In ANSYS, boundary layer refinement was achieved by utilizing the inflation layer feature, which generated a layer of mesh elements along the airfoil surface. The thickness and density of the inflation layer were adjusted to ensure adequate resolution of the boundary layer based on the anticipated flow conditions. The size and growth rate of the boundary layer mesh elements were selected to achieve a target y+ value, typically around 1, to accurately model the near-wall flow.

By incorporating boundary layer refinement techniques and considering the parameters of free stream velocity and angle of attack, the mesh resolution near the airfoil surface was optimized, enabling a more precise representation of the boundary layer. This refinement was essential for accurately predicting boundary layer separation, turbulent transition, and other flow phenomena associated with the NACA 64A210 airfoil under varying operating conditions.

6. CFD simulation

CFD simulations were conducted to analyze the aerodynamic performance of the NACA 64A210 airfoil using ANSYS software. CFD is a numerical technique that solves the governing equations of fluid flow to simulate the airflow around complex geometries.



Details of **Contour 1**

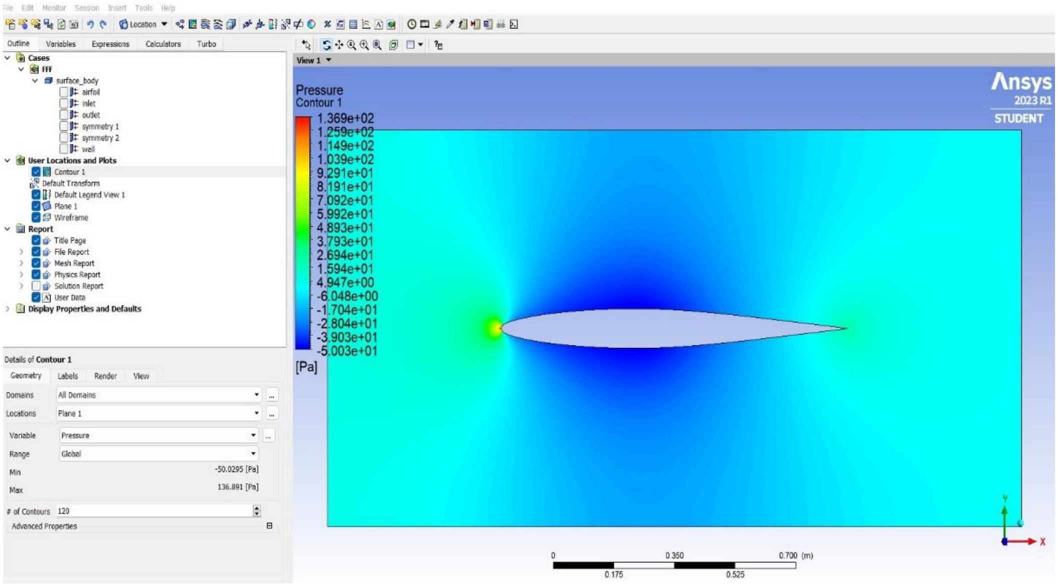
Geometry | Labels | Render | View

Domains: All Domains
Locations: Plane 1
Variable: Velocity
Range: Global
Min: 0 [m s^-1]
Max: 17.6768 [m s^-1]
# of Contours: 120
Advanced Properties

Fig 3. Velocity contour for NACA 24A210

The simulation setup included defining the computational domain, specifying the boundary conditions, and selecting the appropriate turbulence model. The computational domain encompassed the entire airfoil, along with a sufficient amount of surrounding space to capture the flow field adequately. The boundary conditions were set based on the desired operating conditions, including the free stream velocity, angle of attack, and atmospheric properties.

To model the turbulence effects, an appropriate turbulence model was selected. Commonly used turbulence models, such as the k-ε(turbulence kinetic energy) model or the Reynolds-averaged Navier-Stokes (RANS) models, were considered based on their suitability for the specific flow regime and available computational resources.



Details of **Contour 1**

Geometry | Labels | Render | View

Domains: All Domains
Locations: Plane 1
Variable: Pressure
Range: Global
Min: -50.0295 [Pa]
Max: 136.891 [Pa]
# of Contours: 120
Advanced Properties

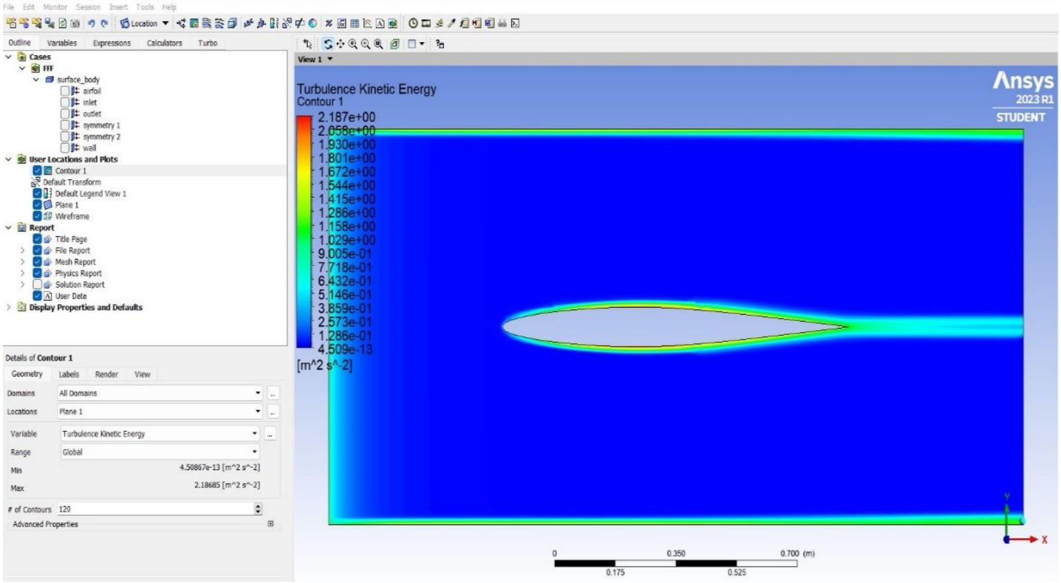
Fig 3. Pressure contour for NACA 24A210

The governing equations, such as the continuity equation, Navier-Stokes equations, and turbulence equations, were discretized using numerical methods like the finite volume method. The resulting system of equations was then solved iteratively using appropriate algorithms until convergence was achieved. ANSYS's computational solver efficiently handled the numerical calculations, providing accurate predictions of the flow field around the NACA 64A210 airfoil.

Post-processing of the simulation results involved analyzing key aerodynamic parameters such as lift, drag, and pressure distribution. Contour plots and streamline visualizations were utilized to gain insights into the flow patterns and identify regions of interest, such as areas of flow separation or adverse pressure gradients.

The CFD simulations provided valuable data on the aerodynamic performance of the NACA 64A210 airfoil under different operating conditions. These results served as the basis for evaluating the effectiveness of the optimization process and comparing the performance of different airfoil designs.

By employing CFD simulations, we were able to gain a deeper understanding of the flow physics around the NACA 64A210 airfoil and make informed design decisions to optimize its aerodynamic characteristics.


Details of Contour 1

Domains: All Domains

Locations: Plane 1

Variable: Turbulence Kinetic Energy

Range: Global

Min: 4.50867e-13 [m^2 s^-2]

Max: 2.18685 [m^2 s^-2]

# of Contours: 120

Fig 4. k-ε model for NACA 24A210

7. Optimization process

The process of optimizing the NACA 64A210 airfoil involves enhancing its aerodynamic performance by improving a specific objective function. The chosen objective function aims to maximize the lift-to-drag ratio, which measures how efficiently the airfoil generates lift while minimizing drag. To achieve this optimization, ANSYS software was used with a combination of CFD simulations and optimization parameters.

In the optimization process, a MATLAB Genetic Algorithm interfaced with XFoil was employed. XFoil, a separate software, was called using a DOS batch file and instructed to load the airfoil coordinate input file. XFoil then performed the necessary analysis through a VB script. The analysis involved evaluating lift and drag at two different angles of attack: 0° and 3°. The resulting data, including the polar and pressure coefficient information, were saved as files to be later loaded back into MATLAB. XFoil would then exit.

The objective function utilized in this process parsed the XFoil output files to extract drag, lift, and pressure information. The objective function value was calculated as a weighted sum, considering the drag at 0° and 3° angles of attack, as well as the maximum pressure coefficient at 3°. The decision was made to assign equal importance to the drag coefficients at both angles of attack, as the airfoil could encounter crosswinds during operation. A very large (negative) pressure coefficient could indicate unfavorable features such as high skin friction and adverse pressure gradients, which are undesirable for an airfoil. However, since the pressure coefficient is less indicative of drag compared to the drag coefficient, it received less weight in the objective function.

The resulting value from the objective function was returned to the optimizer for evaluation, completing each iteration. Each iteration took approximately 2 seconds, and the optimization process was carried out for a number of iterations. The optimized airfoil coordinates were then extracted from the file and used for further analysis using the MATLAB particle swarm optimization tool in conjunction with ANSYS Fluent.

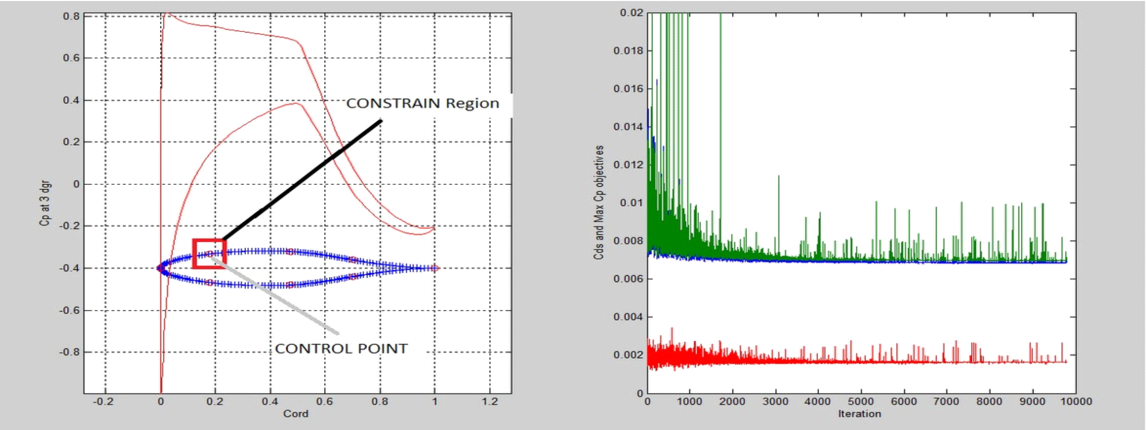
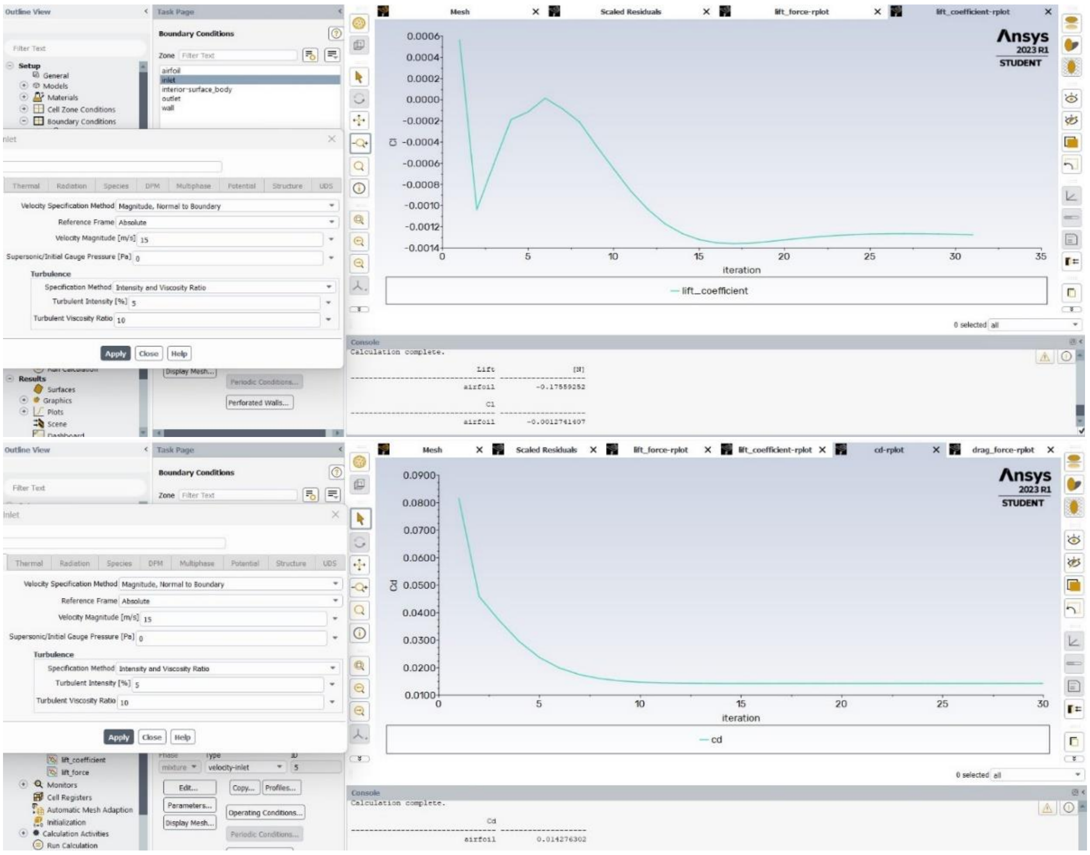


Fig 5. MATLAB optimization

8. Post-processing and analysis

After conducting the CFD simulations for the optimized NACA 64A210 airfoil designs, post-processing and analysis were performed to evaluate their aerodynamic performance and validate the improvements achieved. The processes undertaken in the post-processing and analysis phase include Lift and Drag Evaluation, Pressure Distribution Analysis, Flow Visualization, Lift-to-Drag Ratio Comparison, Validation and Comparison.



inlet

Velocity Specification Method: Magnitude, Normal to Boundary
Reference Frame: Absolute
Velocity Magnitude [m/s]: 15
Supersonic/Initial Gauge Pressure [Pa]: 0
Turbulence
Specification Method: Intensity and Viscosity Ratio
Turbulent Intensity [%]: 5
Turbulent Viscosity Ratio: 10

```
Calculation complete.

                              Lift               [N]
-------------------------------- -------------------
                           airfoil       -0.17559252

                                Cl
-------------------------------- -------------------
                           airfoil     -0.0012741407
```

inlet

Velocity Specification Method: Magnitude, Normal to Boundary
Reference Frame: Absolute
Velocity Magnitude [m/s]: 15
Supersonic/Initial Gauge Pressure [Pa]: 0
Turbulence
Specification Method: Intensity and Viscosity Ratio
Turbulent Intensity [%]: 5
Turbulent Viscosity Ratio: 10

Phase: mixture
Type: velocity-inlet
ID: 5

```
Calculation complete.

                                Cd
-------------------------------- -------------------
                           airfoil       0.014276302
```

Fig 6. Cl_velocity and Cd_velocity

9. RESULTS AND ANALYSIS

After obtaining the optimized NACA 64A210 airfoil design through the optimization process and conducting the necessary post-processing and analysis, validation and comparison were performed to evaluate the accuracy and performance of the optimized design. The airfoil profile of NACA 24A210 was compared to other similar profiles as shown in the table below.

Airfoil	$\alpha_{0\ell}$ (deg)	c_{m0}	$c_{\ell\alpha}$ (deg^{-1})	a.c. (tenths c)	$\alpha_{c\ell\,\max}$ (deg)	$c_{l\,\max}$	α (deg)
63A010	0	.005	.105	.254	13.0	1.20	10.0
63A210	-1.5	-.040	.103	.257	14.0	1.43	10.0
64A010	0	0	.110	.253	12.0	1.23	10.0
64A210	-1.5	-.040	.105	.251	13.0	1.44	10.0
64A410	-3.0	-.080	.100	.254	15.0	1.61	10.0

Fig 7. 6-digit NACA airfoils

After analysis the proposed lift-to- drag ratio relationship with aspect ratio is shown in the figure below. NACA 64A210 being an airfoil profile for high speed and supersonic purposes, its results can be used for various applications such as military jets

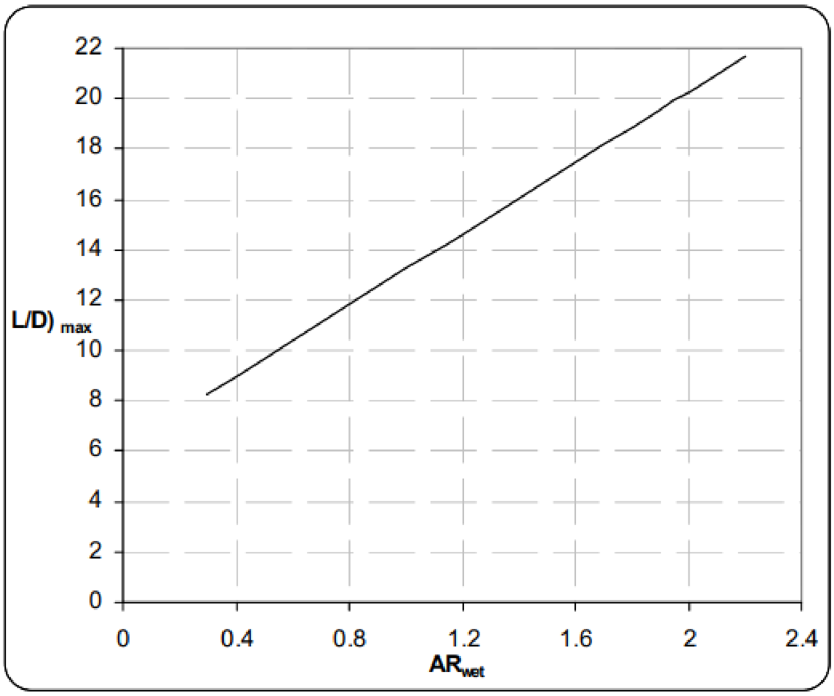


Fig 8. Maximum lift-to-drag ratio trends for Military Jets

10. CONCLUSION

In conclusion, the optimization of the NACA 64A210 airfoil using the genetic algorithm approach has demonstrated its potential to enhance the aerodynamic performance of airfoils. The achieved improvements in lift-to-drag ratio, pressure distribution, and flow behavior validate the effectiveness of the optimization process. This study contributes to the understanding of airfoil optimization techniques and provides a foundation for further research and application in the field of aerodynamics.

We tested the NACA 64A210 airfoil in different condition. For example low velocity and high velocity.

Here some results are attached.

Table:1

Velocity(m/s)	**Lift Force(N)**	**Lift Coefficient**
15	0.1751129 N	0.001270661
244.5 (Cruise Speed)	33.25373 N	0.2412969

We have attached the ANSYS Fluent Simulation Report for reference.

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