e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

ANALYSIS OF LIFT AND DRAG W.R.T TO NACA 5-DIGIT SERIES AIRFOILS

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DOI : https://www.doi.org/10.56726/IRJMETS63727

ABSTRACT

This paper presents the analysis of the various aerodynamic properties like lift and drag, with respect to the following airfoils: NACA 22112, NACA 23015, NACA 23018, NACA 23021, NACA 23112, NACA 24112. The objective of this study is to explore the effects of lift and drag at various angles to find out how efficiently it can perform under a wide range of conditions. The Cd, Cl and Alpha for the NACA 5-digit series airfoils are taken from the airfoil tools website. The data is then calculated to evaluate the Cl vs Alpha, Cd vs Alpha, Cl vs Cd and Cl/Cd vs Alpha values, that is then plotted onto their respective graphs for further investigation. This shows us that there are some airfoils that have properties that allow them to perform better under conditions where other airfoils might stagger.

Keywords: Drag, Lift, Airfoil.

I. INTRODUCTION

Airfoils, which are the cross-sectional shapes of wings, fins, and rudders, are a critical component of aerodynamic design. (Irfan Nazir Wani, 2023)

Airfoil produces lift when moved through air. Representing a wing, it generates lift by separating the flow and pushing the air below the surface causing lift to occur due to the pressure being generated. Therefore, we can say that the aerodynamic force (lift and drag) of an airfoil is generated as a result of interaction between the incoming flow and airfoil. (Liu, 2021)

Above the airfoil is high speed and low-pressure flow of air meanwhile below is high pressure low speed air.

The airfoil is the most crucial part of the aircraft, mainly because they are essential when it comes to generating lift and reducing overall drag.

The flow of air over the airfoils is the most important thing that has to be considered during designing an aircraft, missile, sport vehicles or any other aerodynamic objects (Hossain, 2014). It is also key in exhibiting satisfactory handling qualities.

In order to exhibit satisfactory handling qualities, an airplane must possess a certain measure of both stability and controllability. (Dam, 1986)

Understanding airfoils and their theory is important because without the knowledge of the theory of air flow around airfoils it is well-nigh impossible to judge or interpret the results of experimentational work intelligently or to make other than random improvements at the expense of much useless testing. (Theodore, 1932)

The NACA airfoil series is a set of standardized airfoil shapes that was classified by its number system, which was made by NACA (NASA). The numbering system for airfoils of the NACA five-digit series is based on a combination of theoretical aerodynamic characteristics and geometric characteristics. The first integer indicates the amount of camber in terms of the relative magnitude of the design Wit coefficient; the design lift coefficient in tenths is thus three-halves of the first integer. The second and third integers together indicate the distance from the leading edge to the location of the maximum camber; this distance in percent of the chord is one-half the number represented by these integers. The last two integers indicate the airfoil thickness in percent of the chord. The NACA 23012 airfoil thus has a design lift coefficient of 0.3. (Abbott, 1945)

A convenient way of describing the aerodynamic characteristics of a wing/airfoil is to plot the values of the coefficients against the angle of attack, which is the angle between the plane of the wing and the direction of motion. (Ira H. Abbott, 2012). We do this to analyze the aerodynamic properties of an airfoil, which can then be further optimized for the required performance. It can also help us recognize dynamic stalls. The term dynamic stall refers to unsteady flow separation occurring on aerodynamic bodies, such as airfoils and wings, which

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execute an unsteady motion. The prediction of dynamic stall is important for flight vehicle, turbomachinery, and wind turbine applications. (John A. Ekaterinaris, 1998)

Optimized airfoil design influences its wing characteristics. Wrong airfoil might cause a degraded performance to a winged air-vehicle or even unacceptable aerodynamic behavior (Gur, 2022)

The airfoil optimization process, is an iterative process with four discrete steps: updating the airfoil geometry (or starting from an initial design), analyzing the airfoil flow field using CFD analysis, computing the quality of the airfoil by interpreting the flow field, and making changes to the parametric model of the airfoil. (Goel, 1996)

II. METHODOLOGY

Conceptual analysis of lift and drag

To analyze lift and drag, we need to inspect the values- Cl (Lift coefficient) and Cd (Drag coefficient). Cl represent the value that helps the aircraft lift up while the Cd represents the value that determines the amount of resistance/drag the airfoil is going through. In these papers, we compare various Cl and Cd values to different AOAs.

The way we evaluate and analyze it is via plotting graphs for Cl vs alpha, Cd vs alpha, Cl/Cd vs alpha.

Cl vs alpha: Represents the slope for the changing lift with respect to the various angle of attacks the airfoils are put under. It can give us stall characteristics and the lift sensitivity.

Cd vs alpha: Represents the slope for the changing drag with respect to the various angle of attacks the airfoils are put under. It can indicate drag increase at particular angles, as well as indicate stalls.

Cl/Cd: Cl/Cd or the lift to drag ratio, represents the efficiency/ability of an airfoil in producing lift while keeping drag to a minimum.

Cl/Cd vs alpha: This value represents the efficiency, with respect to various angle of attacks to predict the performance of the airfoil under various conditions.

Analysis and collection of data

Data of 5 airfoils taken from the airfoil tools website. There are 5 Cl, Cd and alpha values taken at the Reynolds number of 200000. The data is then calculated and plotted in an excel sheet where it used for further observations.

III. MODELING AND ANALYSIS

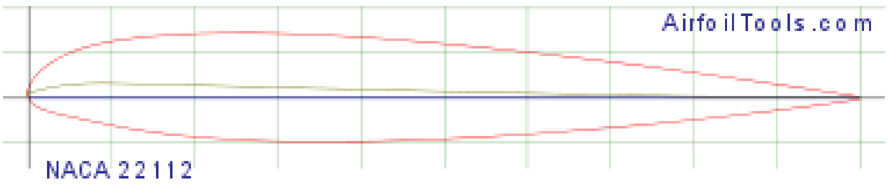

Fig 1: NACA 22112

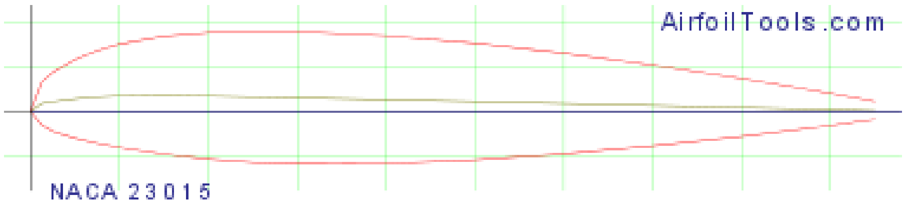

Fig 2: NACA 23015

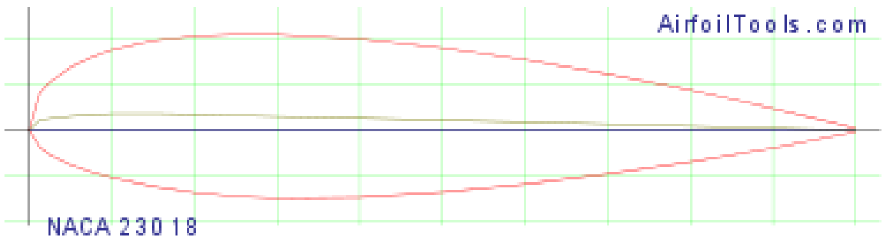

Fig 3: NACA 23018

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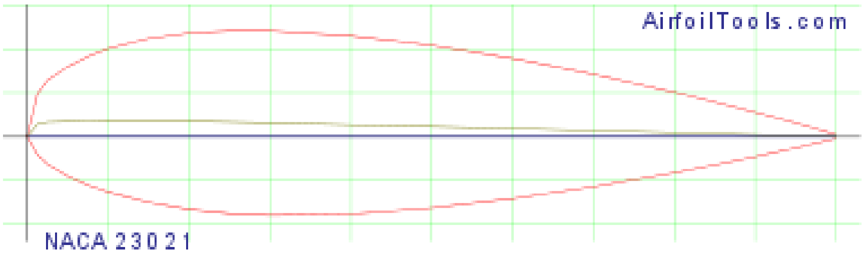


Fig 4: NACA 23021

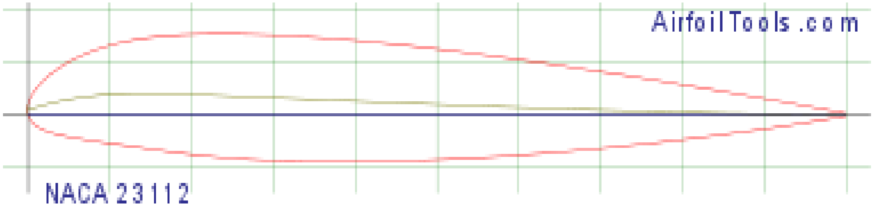


Fig 5: NACA 23112

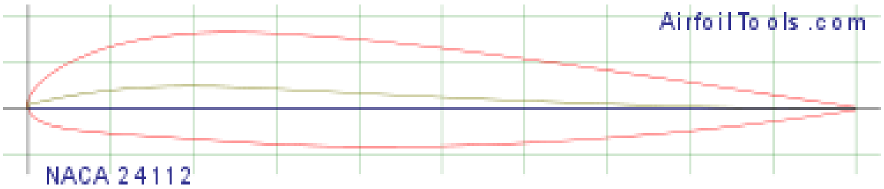


Fig 6: NACA 24112

	alpha	CL	CD
NACA 22112	-5	-0.5159	0.02099
	0	0.1262	0.01063
	5	0.6918	0.01539
	10	1.1285	0.02753
NACA 23015	-5	-0.4929	0.01814
	0	0.1187	0.01187
	5	0.7047	0.01592
	10	1.1632	0.02415
NACA 23018	-5	-0.4218	0.01434
	0	0.1211	0.01225
	5	0.8058	0.01784
	10	1.1615	0.02458
NACA 23021	-5	-0.3949	0.01509
	0	0.1232	0.01358
	5	0.6979	0.01851
	10	1.0361	0.02512
NACA 23112	-5	-0.5029	0.02251
	0	0.1716	0.01126
	5	0.7215	0.01525
	10	1.1604	0.02304
NACA 24112	-5	-0.4792	0.02256
	0	0.2078	0.01218
	5	0.7511	0.01496
	10	1.1866	0.02067

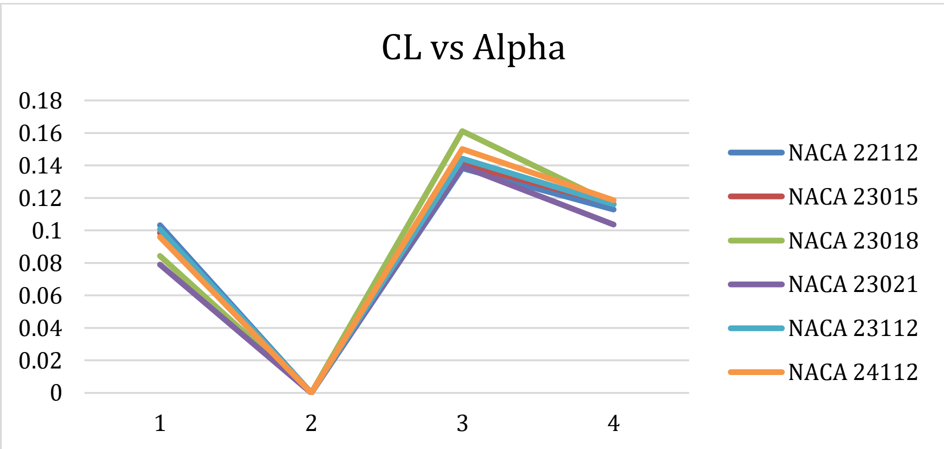
Fig 7: Chart of various values under different conditions

IV. RESULTS AND DISCUSSION

CL v CD	CL v alpha	CD v alpha	CL/CD v alpha
-24.57837	0.10318	-0.004198	4.915674131
11.87206	0	0	0
44.951267	0.13836	0.002753	8.990253411
40.991645	0.11285	0.002753	4.099164548
-27.172	0.09858	-0.003628	5.434399118
10	0	0	0
44.265075	0.14094	0.003184	8.853015075
48.165631	0.11632	0.002415	4.816563147
-29.41423	0.08436	-0.002868	5.882845188
9.8857143	0	0	0
45.168161	0.16116	0.003568	9.033632287
47.253865	0.11615	0.002458	4.725386493
-26.16965	0.07898	-0.003018	5.233929755
9.0721649	0	0	0
37.703944	0.13958	0.003702	7.540788763
41.246019	0.10361	0.002512	4.124601911
-22.34118	0.10058	-0.004502	4.468236339
15.239787	0	0	0
47.311475	0.1443	0.00305	9.462295082
50.364583	0.11604	0.002304	5.036458333
-21.24113	0.09584	-0.004512	4.24822695
17.060755	0	0	0
50.207219	0.15022	0.002992	10.04144385
57.40687	0.11866	0.002067	5.740686986

Fig 8: Chart of calculated values

After plotting the values, we get the following graphs:



Cl vs Alpha:

NACA 22112 – Middle of the pack, can generate a decent amount of lift effectively while still keeping a relatively smaller stall angle.

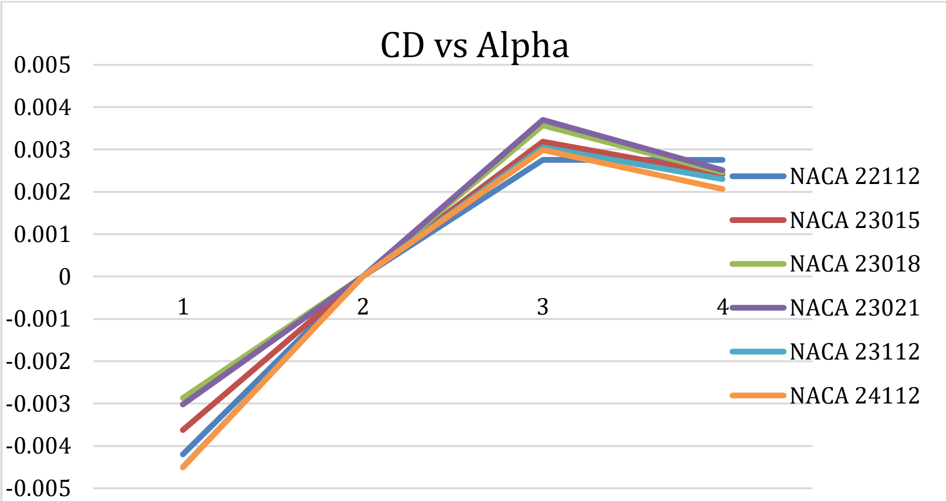
NACA 23015 – Has a progressive slope which indicates that it might be slightly less efficient as NACA 22112 in generating lift but reaches stall angle later. This means that it can generate almost the same amount of lift and not stall.

NACA 23018 – Generates the most lift under the given angle of attacks. Also has the steepest slope which means that while it can generate tons of lift, it can also induce stalls much quicker than the other airfoils.

NACA 23021- Generates the least amount of lift and has the gentlest slope. Indicates that it will not reach the stall angle as fast as the others but will not gain lift as efficiently either. Making it more stable.

NACA 23112 – Just like NACA 23015, generates lift less efficiently than NACA 22112 but is more stable.

NACA 24112- Generates the lift very efficiently while still keeping relative stability.



CD vs Alpha

NACA 22112 – Probably the most efficient at moderate angles but can be prone to stalls at higher angles. Making it suitable for low angle maneuvers.

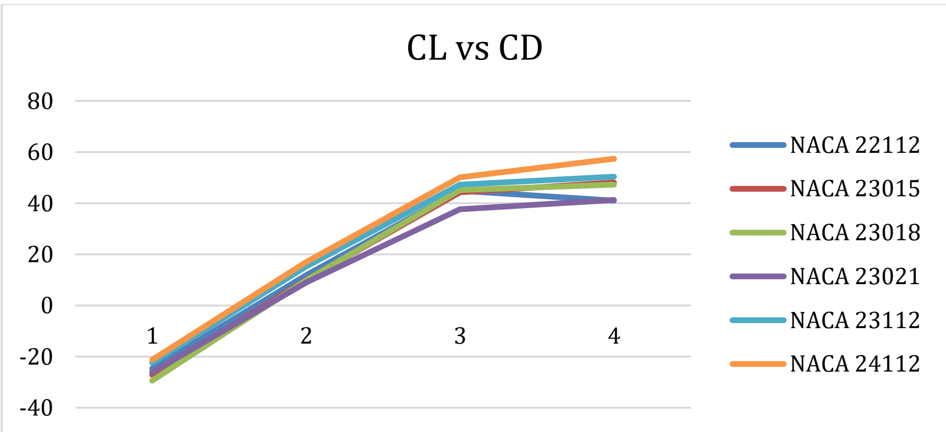
NACA 23015 – Almost the same as NACA 22112 but it does not stall as much in higher angles, making it suitable for high angle maneuvers.

NACA 23018 - Really inefficient drag at lower and moderate angles. Sharp slope suggest that it is definitely not suitable for low-moderate angle maneuvers.

NACA 23021 – Definitely the least efficient out of the bunch, making it just as unsuitable as NACA 23018 for low-moderate angle maneuvers.

NACA 23112 – The most well rounded of the bunch, being decently efficient in all three types of angles making it suitable for all types of movements.

NACA 24112 – Best for low and high angle maneuvers and is pretty good for moderate angle maneuvers while also being really efficient.



CL vs CD

NACA 22112 – Middle of the pack with below average efficiency at higher points.

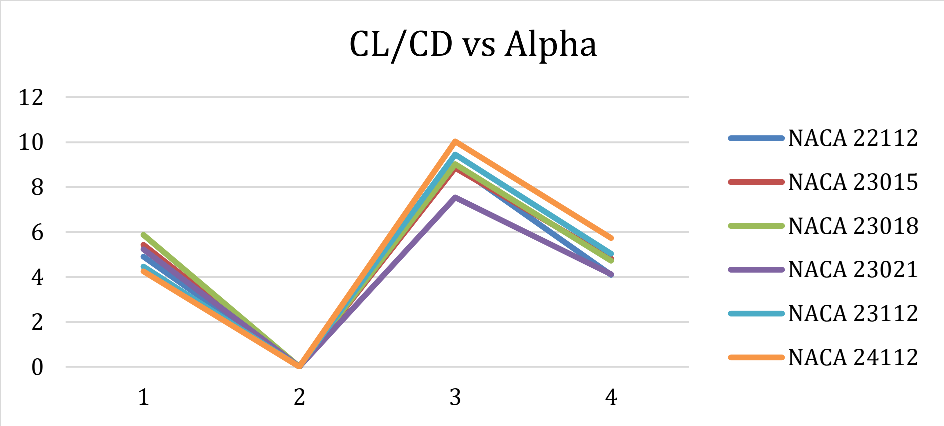
NACA 23015 – Decent efficiency with decent values across the slope, making it a viable choice.

NACA 23018 – Slightly worse than NACA 23018. Decent values across the slope.

NACA 23021 – The least efficient out of the bunch. Its slope shows that it's a highly unsuitable choice if you're looking for efficiency.

NACA 23112 – Great efficiency with good values across the slope. Making it a good choice when looking for efficiency.

NACA 24112 – The most efficient out of the bunch with the highest lift to drag ratio values across. Making it the best choice when it comes to efficiency.



CL/CD vs Alpha

NACA 22112 – Decent efficiency across various angles with a slight dip in the end.

NACA 23015 – Middle of the pack with good efficiency across all angles the board making it viable.

NACA 23018 – Almost identical to NACA 23015 with minor improvements at smaller angles.

NACA 23021 – Mediocre efficiency at smaller angles of attack. Highly inefficient in moderate-high angles of attack.

NACA 23112 – Sub-par efficiency at lower angles but efficient in moderate-higher angles.

NACA 24112 - Great for producing lift with short increments in angle of attacks. Makes its viable for high and low speed maneuvers.

V. CONCLUSION

From the graphs, we can get some unique insights into the properties of some airfoils.

NACA 23021 performs the worst, having higher Cd vs alpha values, lower Cl vs alpha values and having below average efficiency. NACA 24112 performs the best in most categories, having great efficiency and maneuverability at all angles, making it viable for all situations.

From NACA 23021 and NACA 24112, we can see that a airfoil that an airfoil that is incredibly rounded and thick (NACA 23021), akin to a sphere, performs much worse than airfoils that are much more slimmer, elliptical and has slight dents on their surface (NACA 24112).

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