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Comparative Analysis on CFD Simulations for 4-Digit NACA Airfoils in Formula SAE Car Applications

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Abstract - In simple terms FSAE car aerodynamics have two primary concerns, the creation of down force to help push the car tires on to the track and improve cornering forces and the minimization of drag. A product of air resistance which acts to slow the car down .In this report 2D and 3D performance of NACA airfoils was obtained. Performance of NACA airfoils by using "Xfoil" software for two-dimensional simulation and Solid Works for three dimensional simulations was compared. For two-dimensional analysis there were five airfoils used (NACA 4-digit airfoils) the analysis done by using Xfoil open source software, aimed at obtaining Pressure Coefficient (C_p), Lift Coefficient (C_l) and Drag Coefficient (C_d) graphs. After analysis among five airfoils three airfoils were chosen (NACA: 6318, 9520, 9525) which having higher C_d and lower C_l values. Three dimensional simulations for selected airfoils done by using "Solid Works" software for selecting suitable airfoil and comparing C_l vs. C_d values, which can get from Two-dimensional simulation & three dimensional simulations. The effect of viscosity is not considered in two-dimensional analysis but in three-dimensional analysis viscosity is considered. According to study 3D results are more realistic due to the viscosity inclusion.

***Key Words*: NACA airfoils, Drag force & Lift Force, Reynolds Number, Xfoil, Solid Works, Aerodynamics**

Introduction

The study is done for FSAE car, to improve their better performance. The FSAE car having maximum speed, the car required stability during racing and the important thing is aerodynamic design of the car. Racing car performance depends on elements such as the engine, tires, suspension, road, aerodynamics, and of course the driver [1]. By considering 4-digit NACA airfoil which is having good ability and better parameters like drag, lift forces, which are important to design the FSAE car. So, the NACA airfoils act most important role during design of the car.

The flow over the airfoil is an external flow. The fluid flows outside the body of an object in our case the object is NACA airfoil. These fluid flow moves around airfoil due to which the flow develops forces that are normal and parallel to the flow, and these forces are called drag force and lift force.

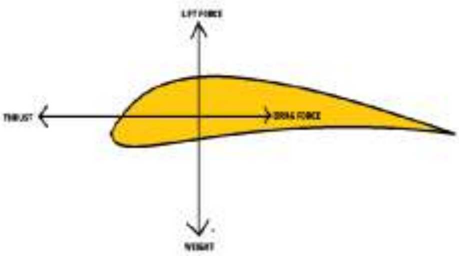

Figure 1- Shape of Airfoil

The (Figure 2) shows aerodynamic shape of airfoil and the forces which develop after fluid flow on the curved shape. This is the basic shape showing parallel and normal forces, the vertical line shows Lift force with weight W and horizontal line shows thrust with Drag force. These forces calculated by using software's like Xfoil & Solid work. Basically, drag force is a mechanical force generated by the airfoil over the fluid flow & the lift force is the force that helps the airfoil to gain altitude. At the starting, consider five airfoils (4-digit NACA airfoil) for study. The NACA stands for the National Advisory Committee for Aeronautics. NACA develops different forms of airfoils and their designs. The five airfoils which we used are NACA: 6318, 9620, 9625, 9520 & 9525. Xfoil is the open source software to obtain the pressure coefficient, lift coefficient & drag coefficient after running the program in the software. Airfoil geometry can be characterized by the coordinates of the upper and lower surface. It is often summarized by a few parameters such as: maximum thickness, maximum camber, position of max thickness, position of max camber, and nose radius. One can generate a reasonable airfoil section given these parameters.

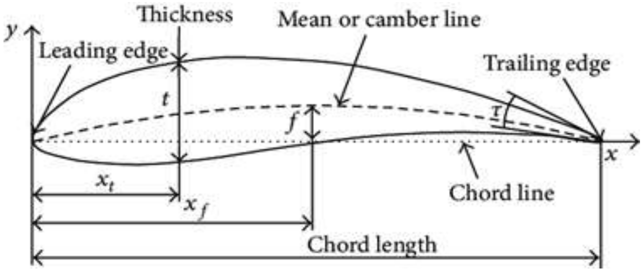

Figure 2- Shape of Airfoil [3]

The 4-digit airfoils having distribution of the each number, the camber line of 4-digit sections was defined as a parabola from the leading edge to the position of maximum camber, then another parabola back to the trailing edge.

Example-

NACAMPXX

NACA9525

Where:

Maximum camber (M) =9

Position of Maximum chamber (P) =5

Thickness (XX) =25

2D simulation in Xfoil get better results for three airfoils which are NACA 6318, 9520 & 9525 having good values of drag, lift and pressure coefficients, at an angle of 0° to 20° for the Reynolds number - 350000. This flow was modeled as an in-viscid and incompressible flow [2]. By using NACA airfoil database tool we got co-ordinates for 3D simulation. For the purpose of 3D simulation we used Solid works which gives better results. The required parameters in drawing were clearly specified.

Literature Review

JOZEPH KATZ [1] - The performance of race cars depends on factors such as engine, tires, suspension, road, aerodynamics, and driver. In recent years, however, automotive aerodynamics has received increasing attention, mainly due to the use of indirect principle (low power), which produces many important performance improvements. This review explains the downside of aerodynamic damage and how it improves race car performance A number of examples that cover a wide range of vehicle conditions (e.g., derived from open-wheel drive racing cars) are presented to illustrate this old line personality Slow-down generation and its effect on lateral stability have a significant impact on race car performance, especially when high speed turns are involved. In the design and design of modern race cars, all aerospace tools are used. Due to the effects such as flow separation, vortex flow, or width boundary changes, over many types of race cars is not always easily predicted.

Dr. Zhexuan Wang [2] - In this report, the low-speed airfoil above the NACA 0012 airfoil at 2 ° and 14 ° angles hits with a given inlet velocity of 0.25 m / s, was model and computational fluid (CFD) analysis done using FLUENT in ANSYS. All setup and procedures are performed following the steps provided by the Cornel University website. However, the mesh independence was obtained at a 2 ° angle, with a 14 ° attack angle; beyond the stall angle, the mesh independence was not achieved. Lift and drag the increase in value as the number of mesh element or angle of attack increases.

Maria E. Ferguson - The aerodynamics of modern boxing has been the subject of a few scientific studies to date. This study uses Computational Fluid Dynamics (CFD) tools to analyse the flow field and aerodynamics of advanced wing, designed using Computer-Aided Design (CAD) modelling.. The solute flow solver ANSYS Fluent is used to solve the Reynolds-Averaged Navier-Stoke (Rans) solid calculations with a confusion model. First, CFD simulations were performed using the k-kl-ω Transition turbulence flow model for the global Gottingen 228 airfoil in 2D at different attack locations. This was done to ensure a closer look at the results from the airfoil software Prof 2.0, ensuring that CFD solutions are similar in lift and drag coefficients. The airfoil had a total height of 1.97 and an angle of 12 °, after validation, 3D RANS simulations were carried out with the overlapping of the wing at various attack locations using the Spalart-Allmaras turbulence model. The wing was thought to fly at a maximum flow speed of 45 m / s, consistent with a Reynolds number of 5.5 × 106.

Angel HUMINIC, Gabriela HUMINIC- -. In this study, the main goal is to investigate the influence of world-class boundary conditions on a fundamental aspect of -aerodynamic open race car using the resources provided by ANSYS CFX, the CFD code. Influence of ground on major vehicle signals, drag and lift, is studied in two ways, widely used in wind tunnels, respectively without ground effect (wheels are stopped and there is no relative movement between car and road), and by road a moving wall.. The flow field around the car is physically complex. Conversely, the efficiency of aerodynamic CFD simulation depends on many factors.

Ying-bin Liang, Li-xun Zhang, Er-xiao Li, Xiao-hong Liu and Yong Yang [3] - The biggest challenge for designers is the choice of blade section, and consequently the color influences details of aerodynamic performance were discussed, including size, camber, lead / trailing and stiffness. The challenge in the design process is to identify the primary design parameters, including the supporting arm, the burned area, and the rigidity, were also investigated in this paper. To aim to shorten the design cycle and increase the power of the coefficient, design the rotor configuration considerations are summarized in this paper. It has been shown that it a good choice for a color the profile and structural parameters are essential for optimum operation, and it is proven that rotor design considerations exist. Balance of aerodynamic performance and mechanical properties.

Methodology

Data was collected for the required NACA AIRFOILS for 2D & 3D simulation and basic requirements like aerodynamics study and airfoil simulation were studied. All the NACA airfoils were thoroughly studied and five airfoils were selected from the generated data for 2D simulation. The simulations were obtained with the aid of Xfoil software. The data of (add the parameter here) about airfoils was fed in the form of input to the program and on executing the program graphs containing drag, lift force coefficient were generated. The graphs of C_l & C_d at different angles from 0 to 20^0 and at Reynolds number 3.5×10^6 for the simulation were plotted. The data thus obtained was collected and compared for the five airfoil graphs. This comparative data is then represented in graphical format. Three airfoils with better comparative results for 3D simulation were selected from the results obtained with higher C_d and lower C_l. The selected airfoil coordinates were imported from NACA airfoil tool website for design purpose. The required airfoil coordinate was downloaded from the website in (dat) file format. The downloaded file was then imported to Solid works and 3D airfoil model was drafted. The design was constrained (if possible specify the constraints) and values of drag and lift coefficient were obtained by flow simulation. The same process was repeated for the other two airfoils. Various graphs were plotted with the help of excel sheet and the three airfoils were compared with each other. The airfoil with better results was chosen from the data.

Experimentation

1. **Two Dimensional Simulation-**

Two dimensional simulations are done in Xfoil. In the Xfoil pressure coefficient, lift coefficient and drag coefficient values for the given airfoil is obtained. The values are in the form of graph. (Figure 3) shows the example of NACA 9520.The following type of graph is obtained for the NACA Airfoils: 6318, 9620, 9625, 9520, and 9525.

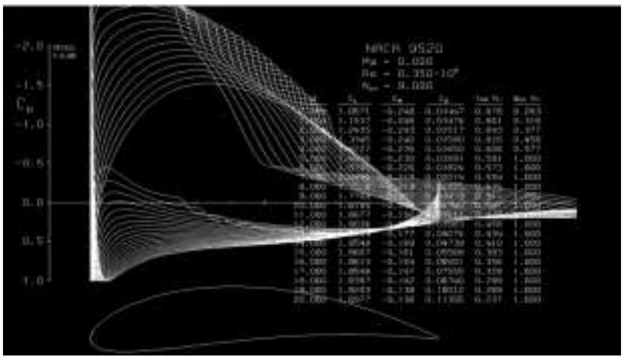

Figure 3- Xfoil Graph for NACA 9520

The values of C_l from the graphs are collected and put in the Excel sheet and the airfoils are compared on the basis of lift force coefficient.

		NACA AIRFOILS				
ALFA	**C_l**	**6318**	**9620**	**9625**	**9520**	**9525**
0	0.1	0.6	0.3869	0.9192	1.0587	0.951
1	0.2	0.6195	1.1216	1.0804	1.1553	1.047
2	0.3	0.7677	1.2236	1.2651	1.2445	1.1441
3	0.4	0.9171	1.4111	1.1898	1.335	1.2232
4	0.5	1.0161	1.4081	1.2683	1.4421	1.3014
5	0.6	1.1171	1.4707	1.3508	1.4451	1.379
6	0.7	1.2201	1.5391	1.4315	1.573	1.4596
7	0.8	1.3212	1.61	1.5013	1.6467	1.4628
8	0.9	1.4423	1.692	1.5969	1.6978	1.502

9	1	1.5151	1.7301	1.6291	1.7657	1.632
10	1.1	1.6055	1.7761	1.6822	1.8169	1.6925
11	1.2	1.7232	1.8176	1.7354	1.8695	1.7413
12	1.3	1.7632	1.8537	1.7769	1.9023	1.7856
13	1.4	1.8264	1.8811	1.7962	1.9235	1.8238
14	1.5	1.8774	1.9025	1.8556	1.9573	1.8559
15	1.6	1.9241	1.9152	1.8808	1.9609	1.8816
16	1.7	1.9062	1.9182	1.9009	1.9579	1.9037
17	1.8	1.8985	1.9115	1.918	1.9519	1.9247
18	1.9	1.8872	1.8979	1.9233	1.937	1.9178
19	2	1.8455	1.878	1.9229	1.9146	1.9241
20	2.1	1.7928	1.87	1.9288	1.8977	1.9388

Table 1- Values of Coefficient of Lift Force

-The data from the table is represented in the form of graph.

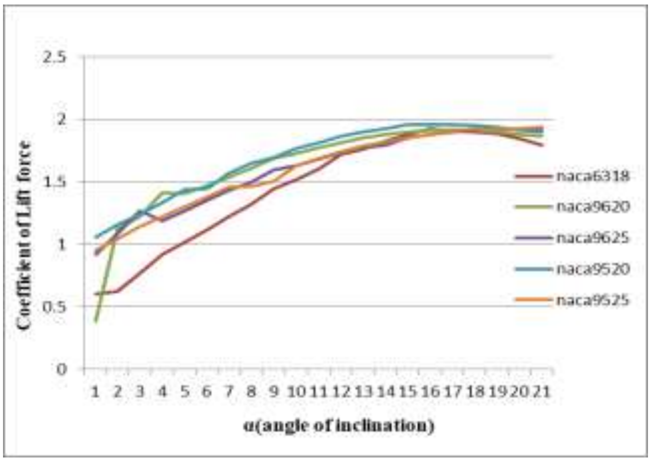

Chart – 1: Comparison of C_l in the form of graph

-The values of C_d from the graphs are collected.

		NACA AIRFOILS				
ALFA	**C_d**	**6318**	**9620**	**9625**	**9520**	**9525**
0	0.01	0.01388	0.01009	0.02042	0.01447	0.0165
1	0.02	0.01398	0.01683	0.01818	0.01474	0.0170
2	0.03	0.01306	0.0193	0.02063	0.01517	0.0177
3	0.04	0.01384	0.0199	0.02214	0.0158	0.0187
4	0.05	0.01475	0.0211	0.02388	0.0165	0.0203
5	0.06	0.01575	0.0212	0.02501	0.01691	0.0213
6	0.07	0.01682	0.0230	0.02707	0.01824	0.0228
7	0.08	0.01797	0.0249	0.02944	0.02014	0.0244
8	0.09	0.01921	0.0279	0.0319	0.02225	0.0270
9	0.1	0.02052	0.0289	0.0339	0.02453	0.0308
10	0.2	0.02193	0.0328	0.0389	0.02753	0.0401
11	0.3	0.02392	0.038	0.04293	0.02853	0.0401
12	0.4	0.0252	0.0439	0.0471	0.03563	0.0418
13	0.5	0.02792	0.0500	0.05283	0.04074	0.0521
14	0.6	0.02998	0.0571	0.05855	0.04799	0.0521
15	0.7	0.033	0.0652	0.06523	0.05568	0.0591
16	0.8	0.03874	0.0747	0.07305	0.06501	0.0671
17	0.9	0.04659	0.0854	0.08145	0.07555	0.0738
18	1	0.05804	0.0975	0.09057	0.0874	0.0844
19	2	1.8455	1.878	1.9229	1.9146	1.9241
20	2.1	1.7928	1.87	1.9288	1.8977	1.9388

Table 2- Values of coefficient of Drag Force

-The data from the table is represented in the form of graph.

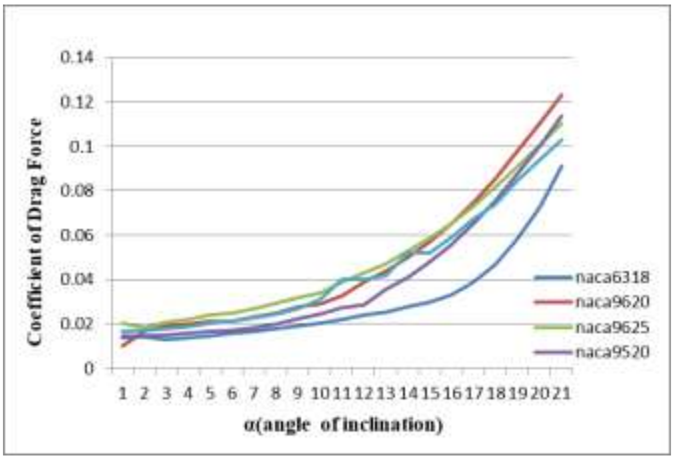

Chart – 2: Comparison of C_d in the form of Graph

After comparison between five NACA airfoils, three airfoils which have higher C_d values and lower the C_l values are selected. The airfoils are NACA 6318, 9525 & 9520.

2. **Three Dimensional Simulation-**

In 2D simulation better results were obtained but for realistic result 3D profile simulation on airfoil design were performed. In 3D simulation one important parameter, viscosity was introduced. Due to viscosity parameter, the results were more realistic than previous. In this study NACA airfoil 9525 was taken into consideration. By using the coordinates from NACA airfoil website, 3D model was prepared and then flow simulation was performed.

-NACA airfoil 9525:

The flow simulation was done by using Solid Works and values of Fx and Fy were obtained. In the software 3D profile was created and flow simulation was performed on it. On applying formulas for the given values of Fx and Fy values of C_l & C_d were calculated. The above (Table 3) shows the value of Fx, Fy, C_l & C_d.

-Mathematical formulas & Calculations:

A. To find velocity for given Reynolds number:

$$Re = v \times l \times \varrho/\mu$$

Where,

V=velocity

L=chord length

ϱ=density

μ=viscosity

For given NACA foils the velocity becomes same

v=13.12 m/s

B. To find C_l & C_d from 3d simulation-

$$C_l = F_y/0.5 \times \varrho \times v^2 \times c$$

$$C_d = F_x/0.5 \times \varrho \times v^2 \times c$$

-For angle of inclination (21^0, 15^0 & 18^0) we calculated Fx, Fy, C_l & C_d.

Angle	Fx	Fy	C_l	C_d
21	11.5874	46.0101	1.1137	0.2804
18	9.3234	34.4037	0.832772	0.225681
15	7.3878	31.4225	0.76061	0.178828

Table 4- Values of C_l, C_d, Fx and Fy for NACA 9525

-Streamline & Velocity Distribution:

The Figure 4 shows the streamline & Velocity Distribution for NACA airfoil 9525 at an angle of inclination 21^0.

The bellows Figure shows Flow Trajectory of the NACA

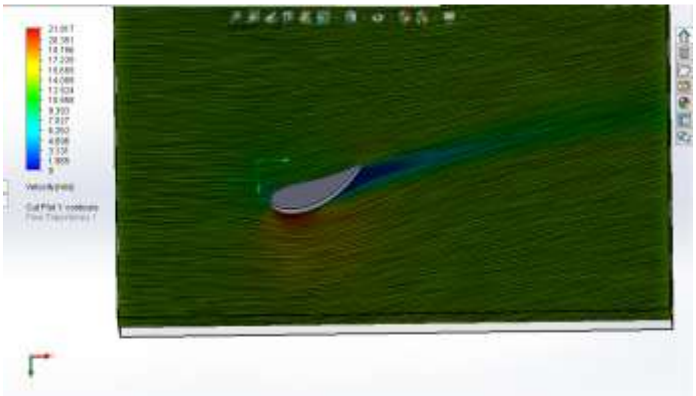

Figure 5- Streamline & Velocity Distribution

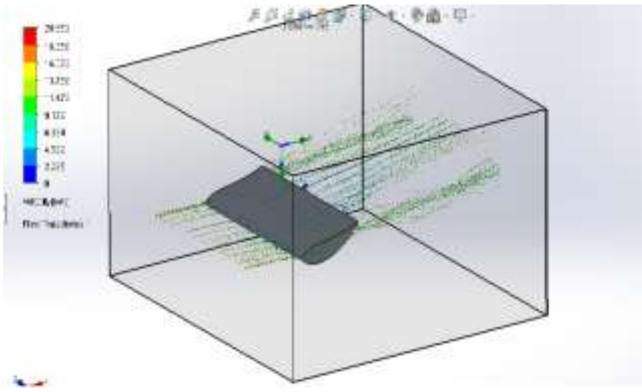

Figure 6- Flow Trajectory

Result & Discussion

For the better results after flow simulation the values for given airfoil were calculated and the values of C_d & C_l from the Xfoil graph and Solid works flow simulation were compared. Comparison was done at angle of inclinations 0^0 to 20^0 respectively. Data was collected in the Excel sheet for better understanding and graph was plotted.

-Comparison for Values of C_l:

Alfa	XFOIL	SFS
0	0.951	
1	1.047	
2	1.1441	
3	1.2232	
4	1.3014	
5	1.379	
6	1.4596	
7	1.4628	
8	1.502	
9	1.632	
10	1.6925	
11	1.7413	
12	1.7856	
13	1.8238	

14	1.8559	
15	1.8816	0.76061
16	1.9037	
17	1.9247	
18	1.9178	0.832772
19	1.9241	
20	1.9388	1.1137

Table 5- Comparison of Xfoil & SFS Values for C_l

-Graphical representation of (Table 6):

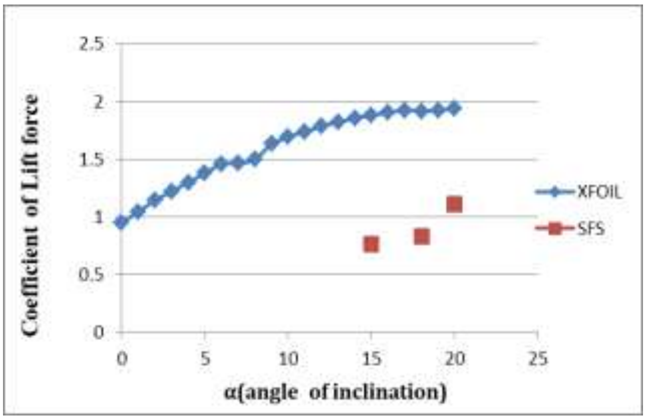

Chart – 3: Xfoil vs. SFS for C_l

Alfa	9525	9520	6318
8			
9			0.526856
10		0.628796	
11			
12			0.590285
13		0.775792	
14			
15	0.76061		0.82628
16		0.860532	
17			
18	0.832772		
19			
20	1.1137		

-Comparison for Values of C_d:

Alfa	XFOIL	SFS
0	0.01655	
1	0.01708	
2	0.0177	
3	0.01879	
4	0.02035	
5	0.02135	
6	0.0228	
7	0.02441	
8	0.02706	
9	0.03085	
10	0.04018	
11	0.04018	
12	0.04189	
13	0.0521	
14	0.0521	
15	0.05918	0.178828
16	0.0671	
17	0.07389	
18	0.08447	0.225681
19	0.09403	
20	0.10284	0.2804

Table 7- Comparison of Xfoil & SFS Values for C_d

-Graphical representation for (Table 8):

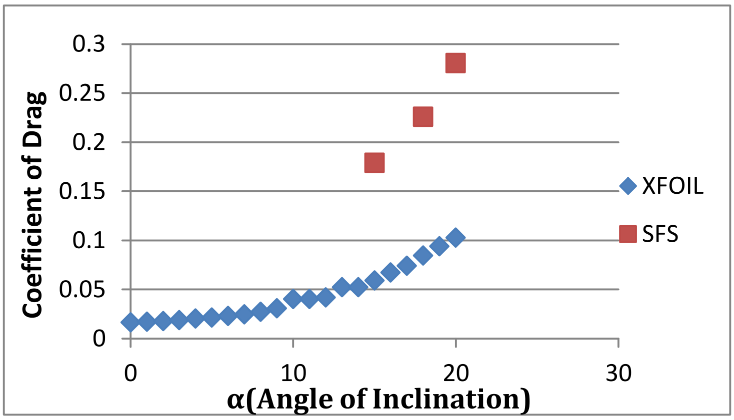

Chart – 4: Xfoil vs. SFS for C_d

Apply this method for NACA 6318 & NACA 9520.

-Comparison between NACA 6318, 9520 & 9525:

The values of C_l for all three airfoils were collected and its values were fed in Excel sheet for comparison. For the values of C_d same procedure was followed and their values with each other were compared and graphs for C_l & C_d were plotted.

Alfa	9525	9520	6318
8			
9			0.526856
10		0.628796	
11			
12			0.590285
13		0.775792	
14			
15	0.76061		0.82628
16		0.860532	
17			
18	0.832772		
19			
20	1.1137		

Table 9- Comparison of C_l Values

Alfa	9525	9520	6318
9			0.08065
10		0.119875	
11			
12			0.10415
13		0.166212	
14			
15	0.178828		0.164746
16		0.200678	
17			
18	0.225681		
19			
20	0.2804		

Table 10- Comparison of C_d Values

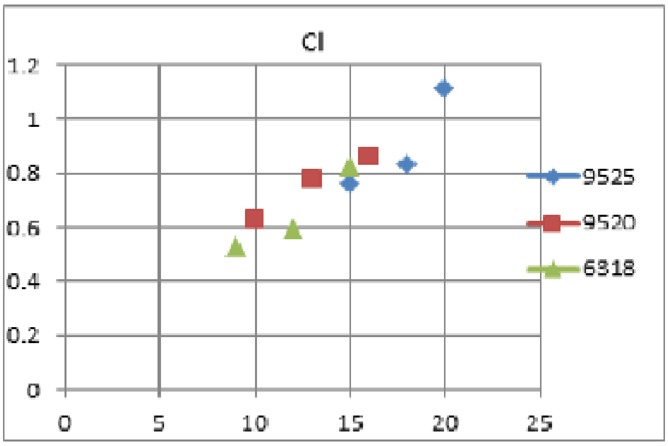

Chart – 5: C_l vs. Alfa for three airfoils

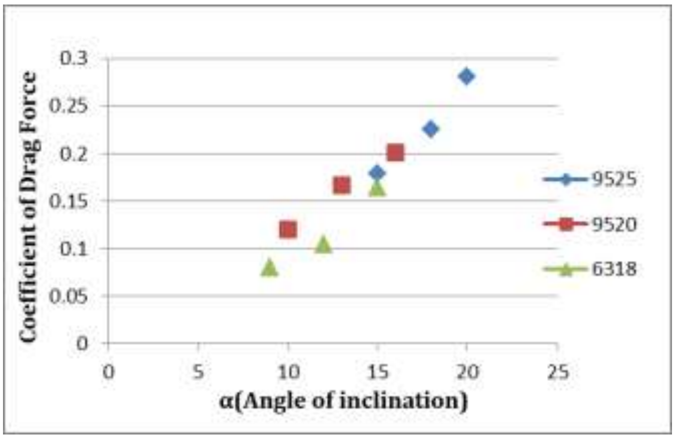

Chart – 6: C_d vs. Alfa for three airfoils

Conclusion

From the comparison between the three airfoils in 2D & 3D simulation it can be concluded that viscosity was not considered in 2D simulation but was considered in 3D simulation. Due to the presence of viscosity stall is produced. From 3D simulations C_l is lower but C_d is higher as compared to 2D simulations. Also due to viscosity the results from the 3D simulation are realistic than 2D simulation. The NACA airfoil 9525 shows better results as compared to other airfoils.

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