MARMARA UNIVERSITY

FACULTY OF ENGINEERING

THE EFFECT OF ALTITUDE ON AERODYNAMICS COEFFICIENTS, AEROPLANE STATIC AND STALLIN PERFORMANCE AT 2D AND 3D

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GRADUATION PROJECT REPORT

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by

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Berkay ÖNCEL

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ABSTRACT

The work is focused on numeric analysis of 2D airfoils in different flight conditions, different Re number, AOA and altitude. Several types of airfoil profiles are used in these researches and they were shown according to their efficiency; lift, drag, moment coefficients and forces. The main goal is analyzing and showing up the change in the forces and coefficients at different altitudes and AOA for 3 types of airfoil profiles. Taking the Mach number constant as 0.2 is the main condition of this project. To achieve this goal, numerous analyzes have been made. All of these are shown in this report to examine clearly.

SYMBOLS

Cl	:Lift Coefficient
Cd	:Drag Coefficient
Cm	:Moment Coefficient
F	:Force
C	:Chord

ABBREVIATIONS

M	:Mach Number
Re	:Reynolds Number
Max	:Maximum
Min	:Minimum
AOA	:Angle of Attack
CFD	:Computational Fluid Dynamics
UAV	:Unmanned Aerial Vehicle

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1. INTRODUCTION

In this project, researches were done according to the classical UAV's flight conditions. So, the range of the analyzes are changing between 4-9 kilometers, Mach number is constant and equal to the 0.2 at all altitudes. [1] As the AOA increase, the lift coefficient and drag coefficient increase until a certain AOA and this point is different for different kinds of airfoils although the points are near to each other.[2] The critical point is nearly at 15-16 AOA where the trend changes from increasing to decreasing in terms of lift coefficient. After critical angle of attack, it also denotes maximum value of lift coefficient, lift coefficient decreases because of the separation of the flow from the boundary layer over the surface of airfoil. In terms of altitude and constant Mach number,[3] pitching moment coefficients don't have any dependency on altitude at smaller angle of attack but shows decrease as altitude increase slightly. According to reference 3, pitching moment, drag coefficient and lift coefficients are not changing extremely at constant Mach with respect to altitudes between the 0-10 km altitudes, the changes are really slight and can be neglect according to **purpose of the flight**.[4] But thinking about the lift and drag forces as altitudes increase, forces are dramatically decreases because of the decreasing air density. According to the Nasa,[5] the lift coefficient is not depending on the flight conditions, it depends on AOA and airfoil geometries. At the same time,[6] the vehicles like the planes or UAVs who can flight, if they have the same Mach number, they are going to have the same aerodynamics properties although the same thing can not be said for the lift and drag **forces.**

In addition to these, [7] the k-epsilon model is not widely used in external aerodynamics. The omega-equation offers several advantages relative to the -equation but the use of the standard k-omega model is not generally recommended in Ansys Fluent. The BSL and SST k-omega models have been designed to avoid the freestream sensitivity of the standard k-omega model. The SST model has been calibrated to accurately compute flow separation from smooth surfaces. So, it is recommended to use either BSL or SST models for aerodynamic flows.

2. MATERIAL AND METHOD

In this project, principles of the CFD are used. Ansys Fluent is used for the doing analysis, creating mesh and domain. CFD is the theoretical method to analyze fluid flow and this method is relatively reliable and of course cheaper than the experimental methods.

We have some limitations for this project:

➔Mach number must be constant at 0.2.

➔UAVs generally fly at the altitude of between 4 and 8km.

➔ UAVs must fly at the high value of Angles of Attack. (Between 20^o and 30^o)

We did our analyses based on these limitations.

2.1. What is CFD?

Computational Fluid Dynamics or CFD in short is a case where we use the computer to solve fluid dynamics problems. The people live in a world of motion and every movement that you make interacts with fluid. We need the ability to predict and control fluid dynamics. CFD is one of the main tools that we use for this.

- Analytical

Only works for really simple cases

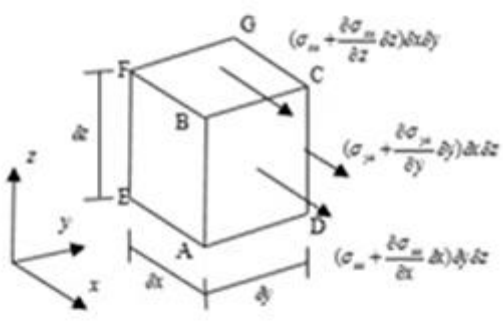

Figure 2.1 Stoke's equations

- Computational

Can be just as accurate as an experiment, plus gives more information cheaper. Gives lots of flexibility.

Figure 2.2 Computers

- Experimental

Accurate, but limited and expensive. We have to build specialized facilities with high construction costs and they have to be very highly calibrated.

Figure 2.3 Fluid Dynamics

The fluid dynamics are hard, they are very complicated. Also, there is a humor that Albert Einstein sat down and tried to work out generalized equations for fluid dynamics all the physics involved. And in the end, he gave up because it was too complicated and went on to do special relativity. It can give a sense how complicated the equations for fluid mechanics.

The full equation for fluid dynamics is what we call the Navier Stokes equations. There is no general analytical solution to solve this equation. So, we have to turn to the computational method to find solutions

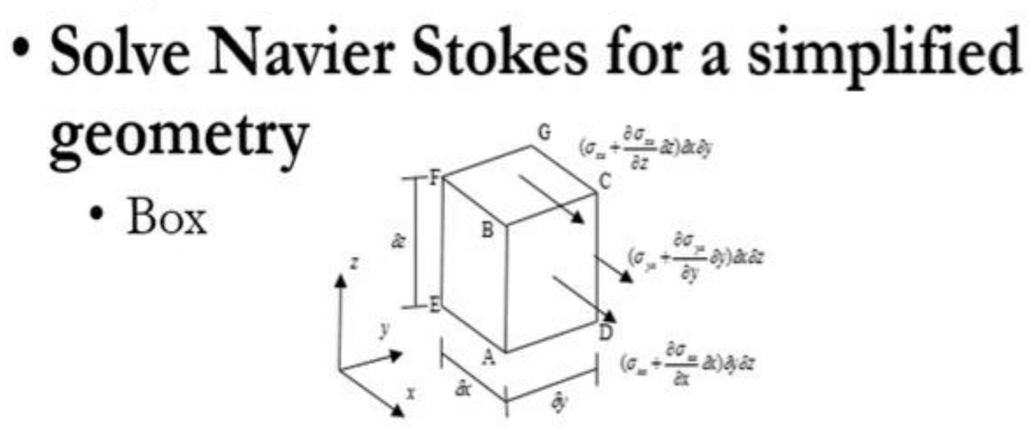

Figure 2.4 Stoke's Equations

We can solve Navier Stoke’s equations if we keep the geometry simple as long as we know the all boundary conditions. So, the main idea of the computers is solving Navier Stoke’s equations for tiny known shapes as box. The program divides your object into millions of little boxes which are called “mesh”. Each cell interacts with its neighbors. The engineers set known values for the boundaries along the edges of the mesh. And then computer uses the power of iteration to balance out all of the cells along the edges and in between all of the interactions.

The steps are listed below basically;

1. Divide your object into millions of tiny little boxes(meshes)
2. Each cell interacts with its neighbors
3. Engineer sets known values for the boundaries
4. Computer iterates to balance all the cells and the edge boundaries

These processes can be applied to any geometry, it works for any situations.

Pros of the CFD;

- Computers are relatively cheap
- Gives extensive detail about results
- Allow simulation of the final product with real world physics
- Allow design optimization and exploration

Cons of the CFD;

- Lack of standardization
- Much misunderstanding
- CFD is an experimental analysis=no working backwards.
- Time cost

Accuracy=User input

- +/- 10%=Easily achieved
- +/-5%=Typical
- +/-2%=Excellent

Proven in two ways

- Validations studies
- Mesh independency studies

There are some different solvers for computational fluid dynamics. In this research, Ansys Fluent is used as solver and mesher.

What is ANSYS Fluent?

Ansys Fluent is a state-of-the-art computer program for modeling fluid flow, heat transfer, and chemical reactions in complex geometries.

Ansys Fluent is written in the C computer language and makes full use of the flexibility and power offered by the language. Consequently, true dynamic memory allocation, efficient data structures, and flexible solver control are all possible. In addition, Ansys Fluent uses a client/server architecture, which enables it to run as separate simultaneous processes on client desktop workstations and powerful compute servers. This architecture allows for efficient execution, interactive control, and complete flexibility between different types of machines or operating systems. Ansys Fluent provides complete mesh flexibility, including the ability to solve your flow problems using unstructured meshes that can be generated about complex geometries with relative ease.

Meshes types supported include 2D triangular/quadrilateral, 3D tetrahedral/hexahedral/pyramid/wedge/polyhedral, and mixed (hybrid). Based on the flow solution, Ansys Fluent also allows you to refine or coarsen your mesh.

Figure below show the interface of the Ansys Workbench. There are too many different modules from modal analysis to fluid flow in this workbench. We interested in with Fluid Flow modules in this project

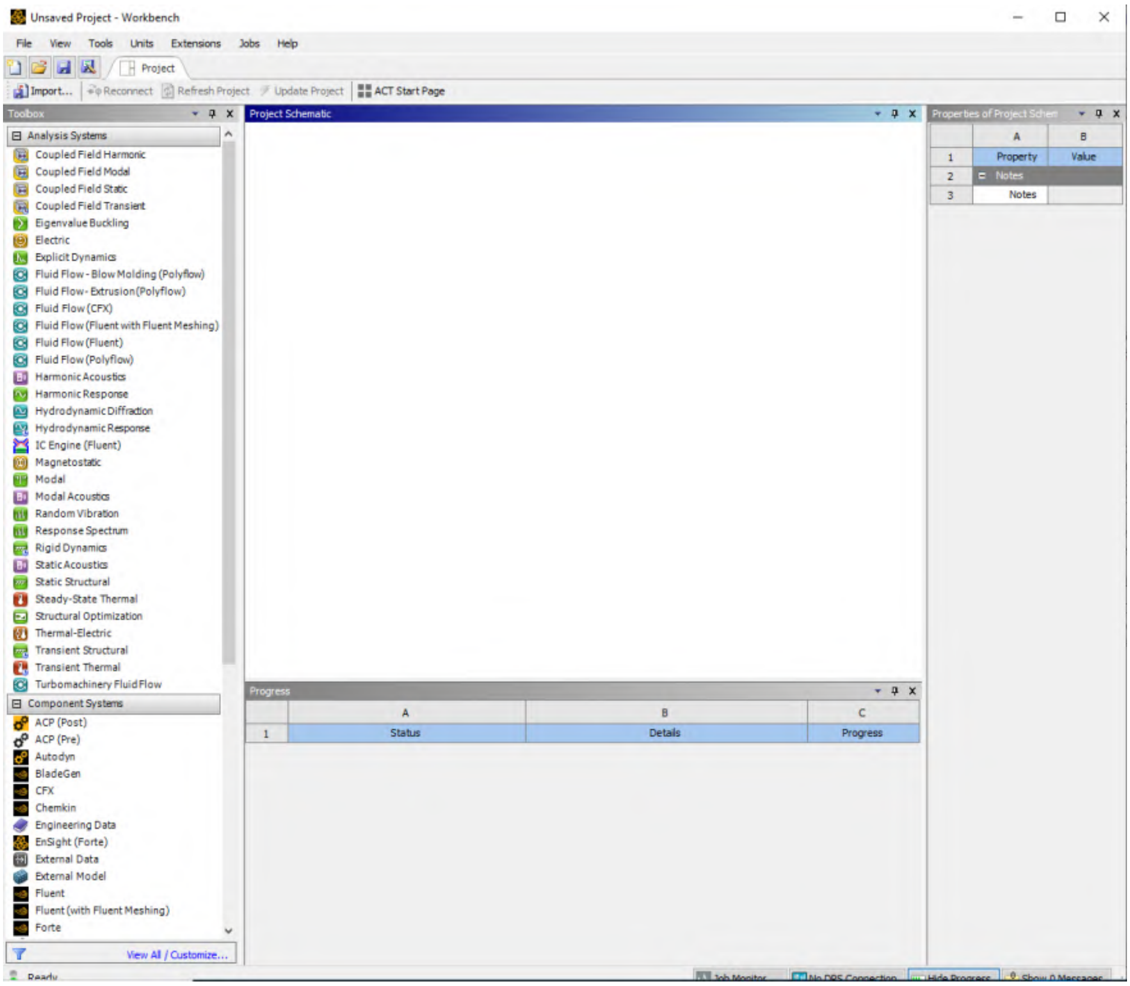

Figure 2.5 The Fluent Module of the Ansys.

There are 5 stages in the fluent module;

Geometry: The geometrical model and fluid domain can be created with the programs called SpaceClaim or Design modeler which are Ansys's own CAD softwares. SpaceClaim is newer than design modeler. The other option is importing the flow domain or 3D model. You can also import your own model created by the other 3D modelling softwares. In this project,design modeler is used for 2D analyses and SolidWorks is used for 3D model.

Mesh: The meshing process is done in this stage. Also, you can import your own mesh model created from another meshers.

Setup: The setting up processes are done in this stage.First of all, the suitable mathematical model for the flow characteristic is selected and then boundary conditions are set up. Also, the details of the calculation and iterations can be organized in this section.

Solution: The generated meaningful datas and specific values can be shown in this stage

Results: The calculated millions of datas collected and visualized to give a meaningful aspect to the observer. There are so many flow visualization methods, for example showing streamlines, vector, pressure & velocity gradients and every conceivable parameter can be visualized in this section.

2.2. Governing Equations

The fundamental [8] laws listed below can be used to derive the governing differential equations used in a Computational Fluid Dynamics (CFD) study. And also, this project was done under the incompressible flow condition so density is not changing with time.

- Conservation of mass
- Conservation of linear momentum
- Conservation of energy

2.2.1. Conservation of Mass

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$$

(1)

$$\nabla * \vec{V} = 0$$

(2)

2.2.2. Conservation of Linear Momentum

$$\rho(\vec{V}.\nabla)\vec{V} = -\nabla \mathrm{p} + \mu\nabla^2\vec{V}$$

(3)

2.2.3. Conservation of Energy

$$\boldsymbol{\rho c_p(\vec{V}.\nabla)T = k\nabla^2 T}$$

(4)

2.3. Geometry and Domain

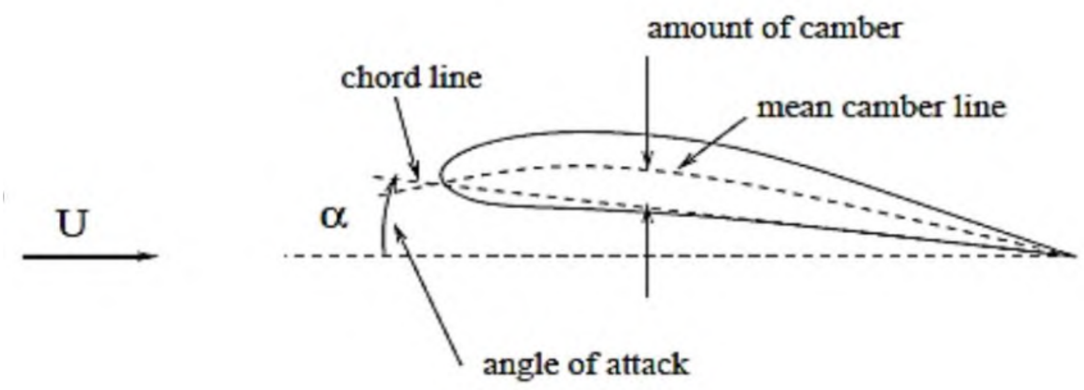

Figure 2.6 Nomenclature of an Airfoil

In this research, C-type domain was used for all kinds of airfoil types while performing analyzes. All types of airfoils are created from at least 150 points in airfoil plotter and exported into the design modeler. The whole domain was divided into 6 different parts. The reason to do this is that achieving to the desired mesh quality and mesh intensity at the desired portion of the domain.

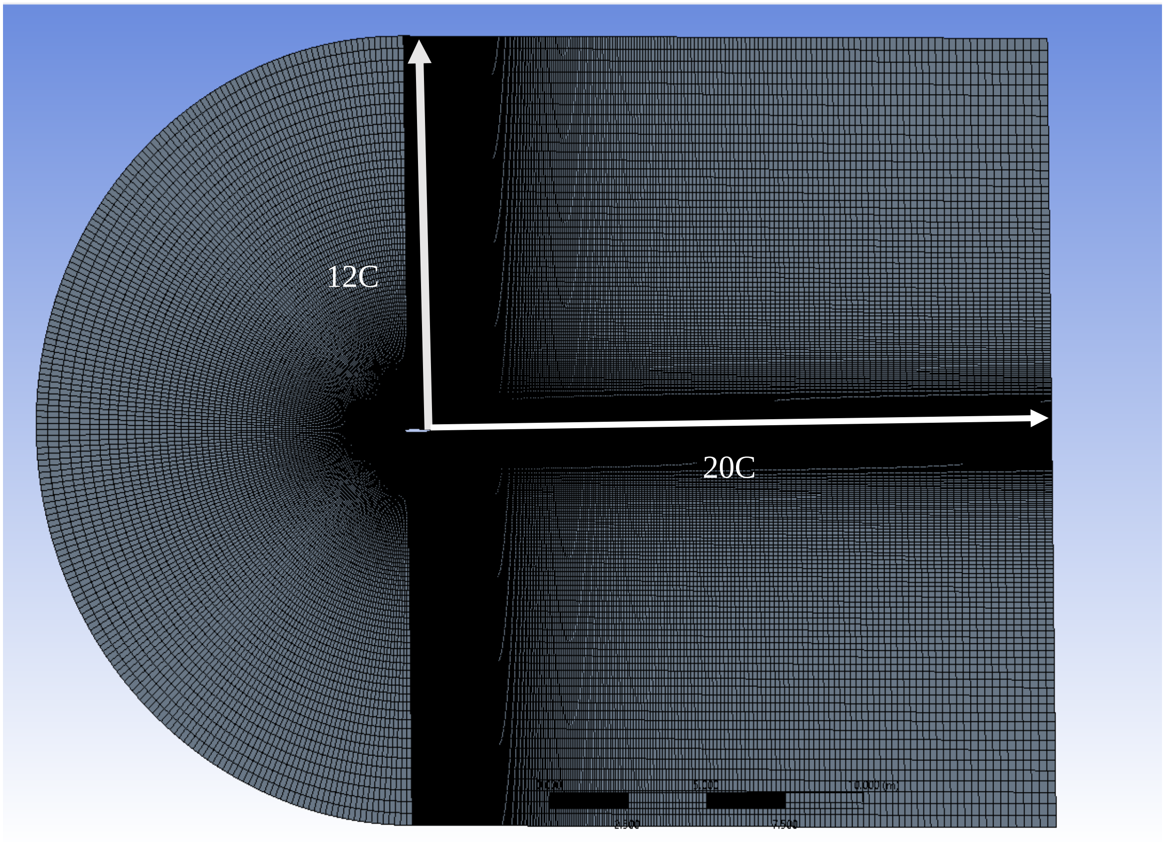

Figure 2.7 C-Type Domain

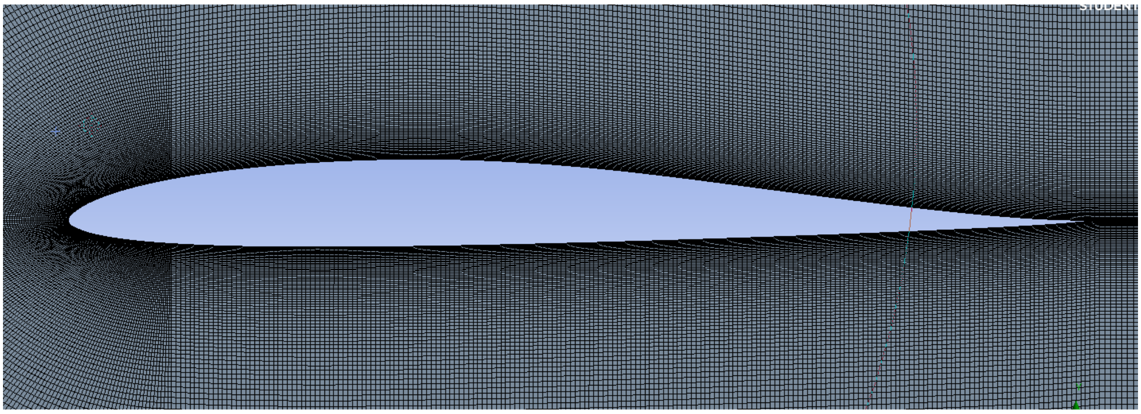

Figure 2.8 Inflation Layers Near to the Walls

2.4. Mesh Quality

Generally, the meshes which are close to the airfoil walls are important for the analyzes. Edge sizing and face meshing applied to the domain to reach appropriate mesh qualities like skewness, orthogonal quality, aspect ratio vs. And also, while using edge sizings,bias factor is applied to create inflation layers on face meshing. Total number of elements are optimized while these processes are applying. Some important parameters about quality of the meshes are listed below with their values;

Skewness: Max 0.41

Aspect Ratio: Max 6.25 at the very close portions to the airfoil walls.

Orthogonal Quality: Min 0.80

2.5. Mesh Dependency

Mesh dependency study is done. The number of elements is optimized for saving the CPU power and the most important is the saving time. After this study, the optimal node number where is the results become independent from the number of elements is found.

The study was carried out for a random steady condition and specific airfoil profile

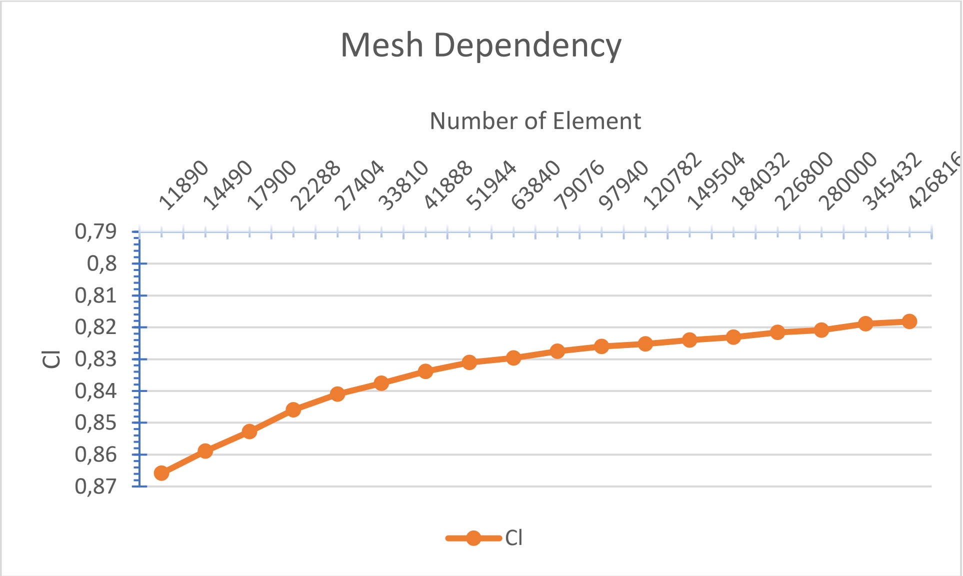

Figure 2.9 Mesh Dependency for a Specific Flow Domain and Mesh Type

Analyzes show that the determinant for the necessary number of elements is size of the flow domain and mesh quality. All of the airfoils are analyzed at same flow domain and mesh quality. So, the mesh dependency is same for all different kind of airfoil profiles. So, according to this study, nearly **240.000** elements are enough for this research.

2.6. Airfoil Profiles

The 3 different kinds of airfoils are used in this project. We choose these 3 airfoils because there are some parameters and formulas for choosing optimum airfoils for UAV's.

Airfoil selection is one of the most important design criteria as it affects the cruising speed, stall characteristics, take-off and landing distances and other aerodynamic characteristics of the aircraft.

The most important factor in airfoil selection is the stall characteristic of the profile. Another important factor in the selection of the wing profile is the thickness ratio of the profile. The higher the thickness ratio, the higher the profile drag coefficient. Finally, statistical data show that; The structural weight of the blade varies inversely with the square root of the thickness ratio.

Thickness: It is the distance drawn perpendicular to the veter line between the upper surface and the lower surface of the profile. It starts at zero on the leading edge and ends very close to zero on the trailing edge. The maximum value along the veter line is called the maximum thickness, and the point of this thickness is called the maximum thickness point.

Stall Characteristic: The lift coefficient shows a linear increase up to a certain angle of attack. After a certain angle of attack, a slowdown or even a sudden decrease in increase occurs. At small and medium angles of attack, the air passing around the wing smoothly and adhering to the wing surface leaves the wing at the trailing edge. At high angles of attack, the air that cannot follow the wing surface separates and causes a loss of adhesion and leaves a swirling flow region behind the wing, causing a decrease in lift.

So, according to these parameters, we chose these 3 airfoils:

➔ NACA0012

➔ NACA4412

➔ E-182IL

2.6.1. NACA0012

Naca0012 is a symmetrical airfoil with 1 m chord length.

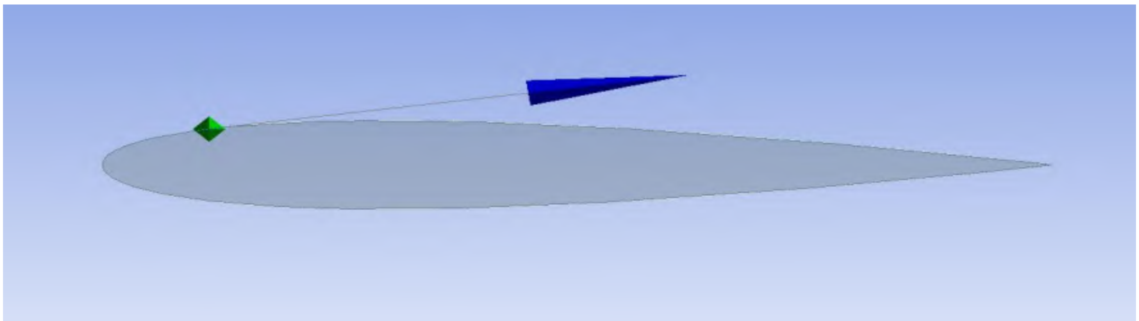

Figure 2.10 NACA0012 Surface

2.6.2. NACA4412

This is one of the most used airfoil which has unsymmetric shape unlike the NACA0012 with 1 m cord length

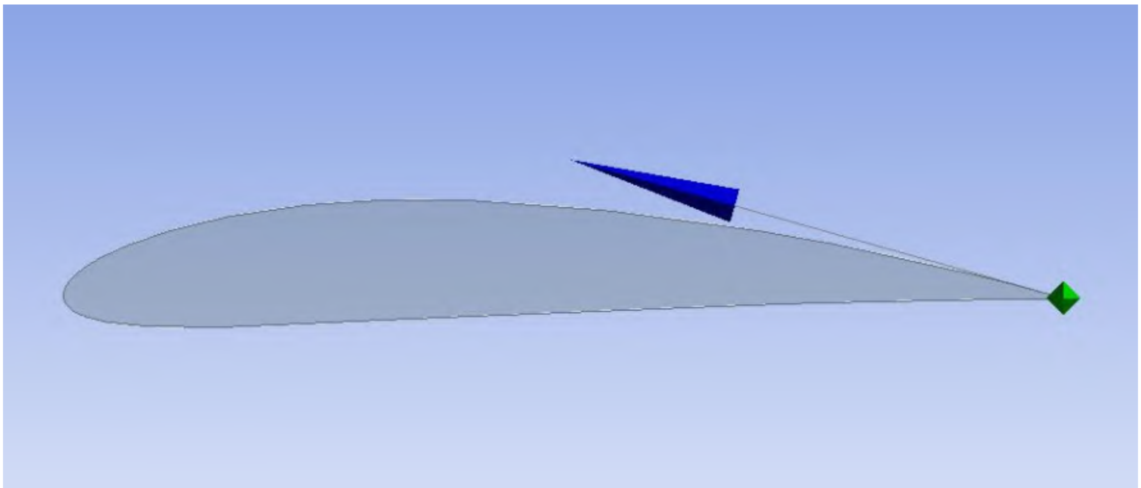

Figure 2.11 NACA4412 Surface

2.6.3. E-182IL

This a low-Reynold numbers airfoil which is generally used for UAV's with unsymmetric shape with 1 m cord length.

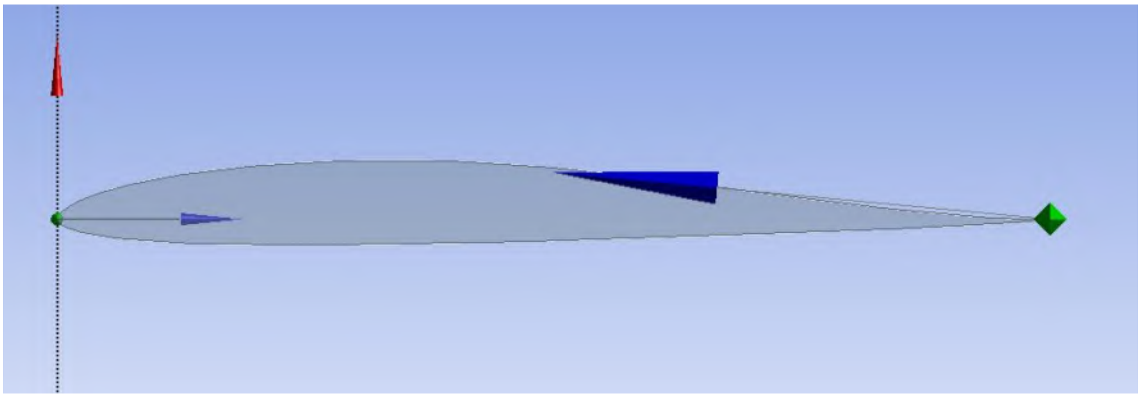

Figure 2.12 E-182IL Surface

2.7. Setup

2.7.1. Model Setup

Because of the cases are in turbulence region, turbulence models should be used while solving the problem. As mentioned in the introduction section, the most suitable model is k-omega-SST for these processes

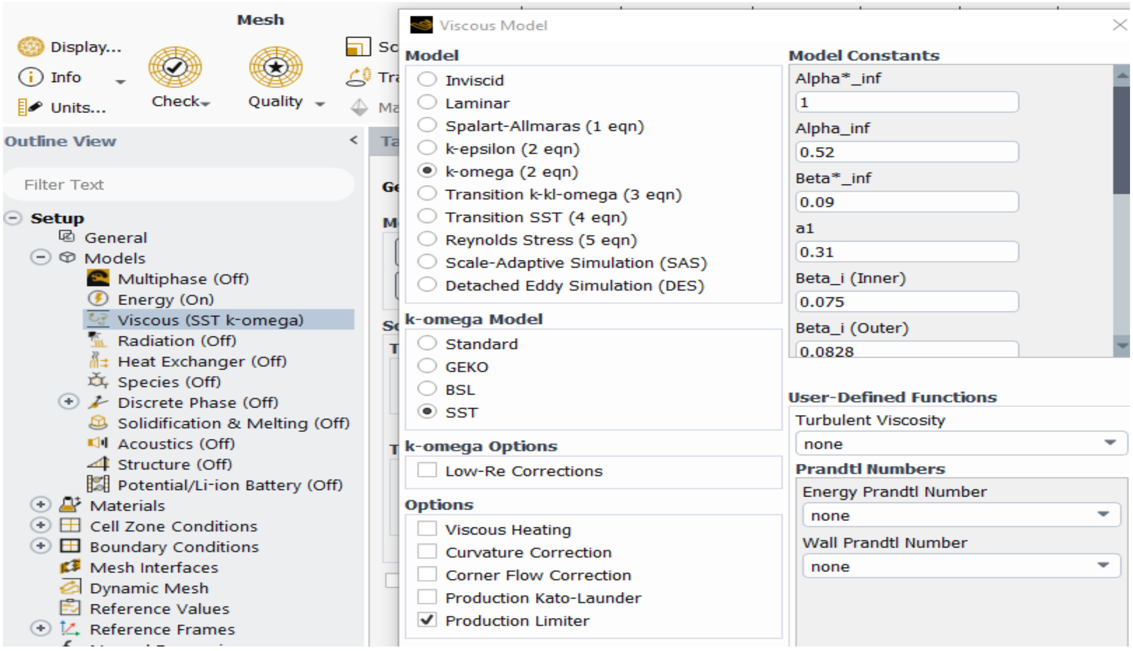

Figure 2.13 Model Setup

2.7.2. Materials

The air is used as working fluid. Since the real ambient and atmospheric conditions are applied, the density, viscosity, temperature and pressure of the air is changing with respect to the altitudes.

2.7.3. Boundary Conditions

In this section of the Ansys, inlet, outlet and wall conditions were defined properly.

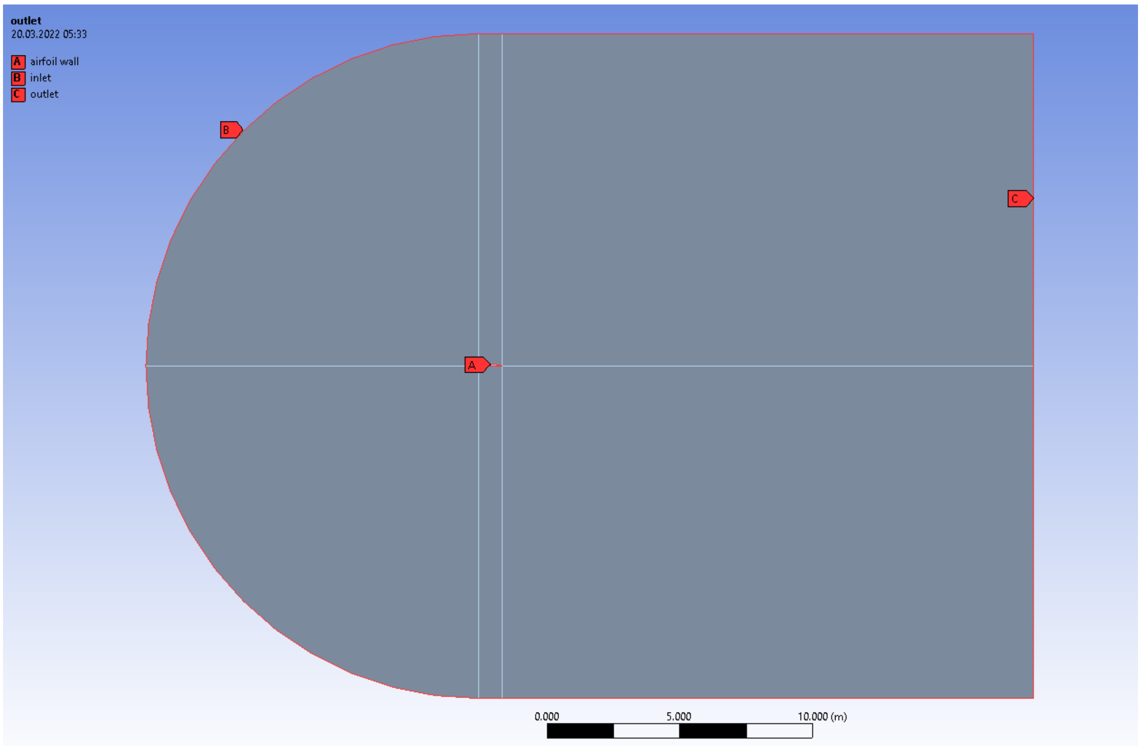

Figure 2.14 Named Selections of Flow Domain

Table 2.1 Boundary Conditions

Inlet	Defined as velocity inlet. Velocity changing with respect to altitude to keep Mach number constant at 0.2
Outlet	Defined as pressure outlet.
Interior	Defined as fluid, domain
Wall	Stationary, no slip condition

2.7.4. Methods

In solution methods momentum, turbulent kinetic energy and specific dissipation rate is discretized with second order upwind. Energy equations are discretized with first order upwind because of the energy is not so important for incompressible flows.

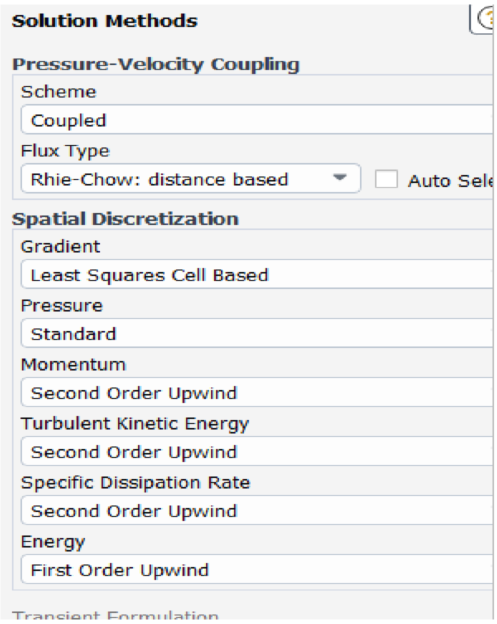

Figure 2.15 Solution & Discretization Methods

(4)

3. RESULT AND DISCUSSIONS

3.1. Validation

From our calculations, we saw that NACA0012 is the best option. Therefore, we decided to compare our theoretical calculations with NASA’s experimental calculations.

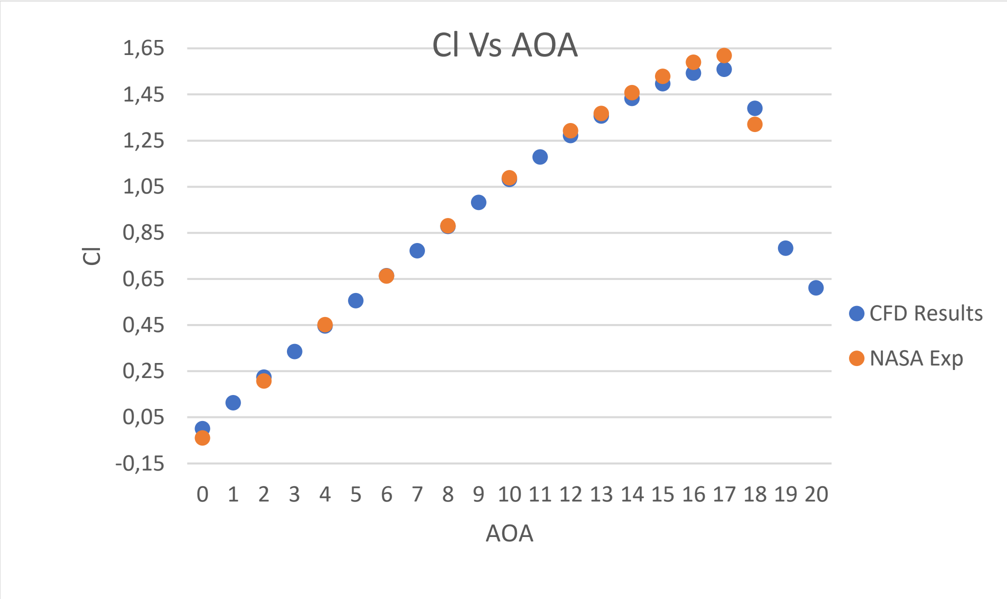

Figure 3.1 Comparing our Cl vs AOA values with NASA's Cl vs AOA values

For Cl (Lift Coefficient), our theoretical values and NASA's experimental values are pretty close to each other. Also, both of the Cl values started to decrease after the angle of 17. We understood from here that our calculations are logical.

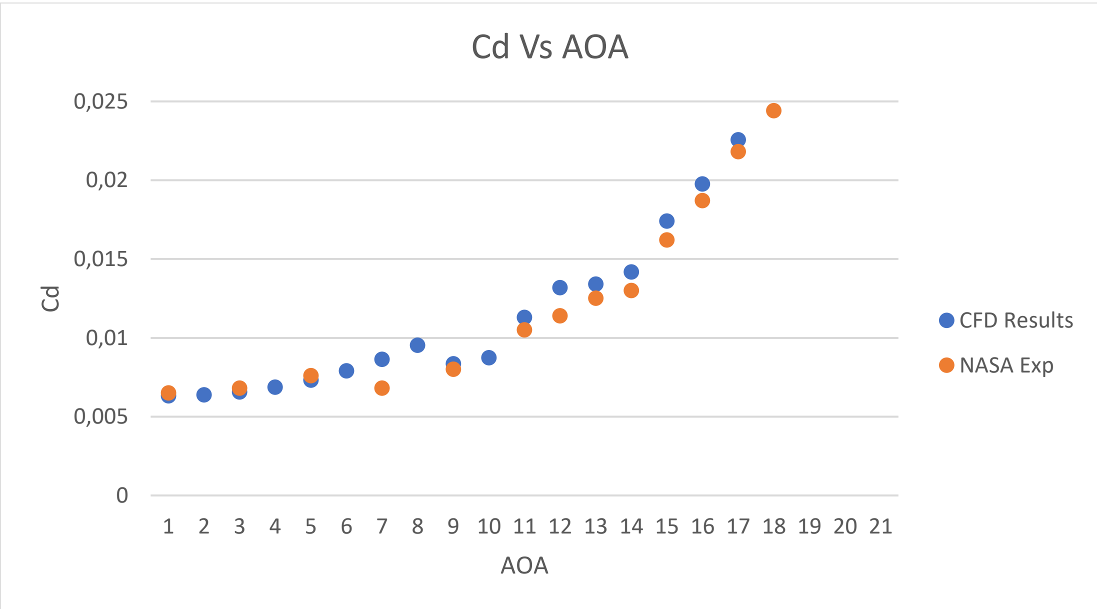

Figure 3.2 Comparing our Cd vs AOA values with NASA's Cd vs AOA values

For Cd (Drag Coefficient), it seems like our theoretical values and NASA's experimental values are similar. There are some differences at some AOA values however, difference is acceptable.

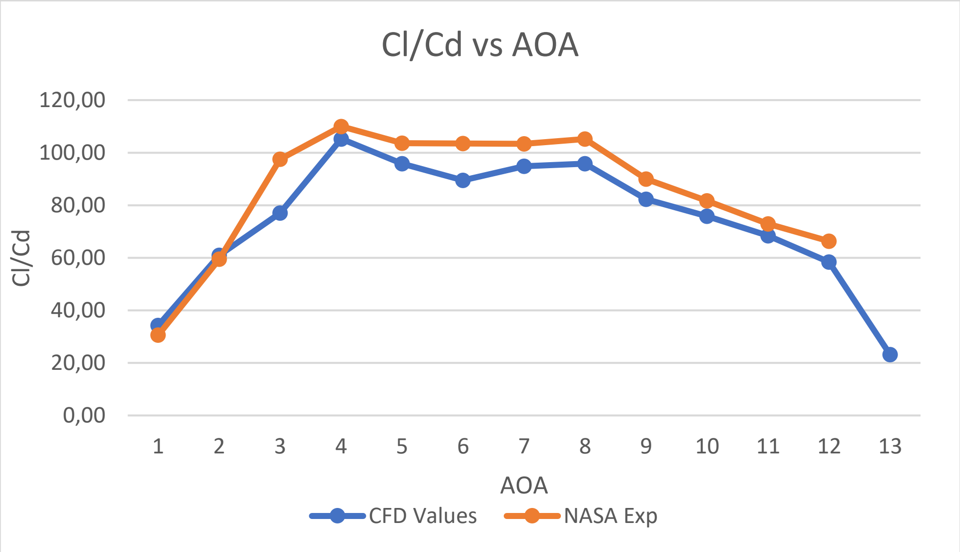

Figure 3.3 Comparing our Cl/Cd vs AOA values with NASA's Cl/Cd vs AOA values

Cl/Cd value is important parameter. So, we decided to compare this value too. After that, we calculated the rate of difference between theoretical and experimental values.

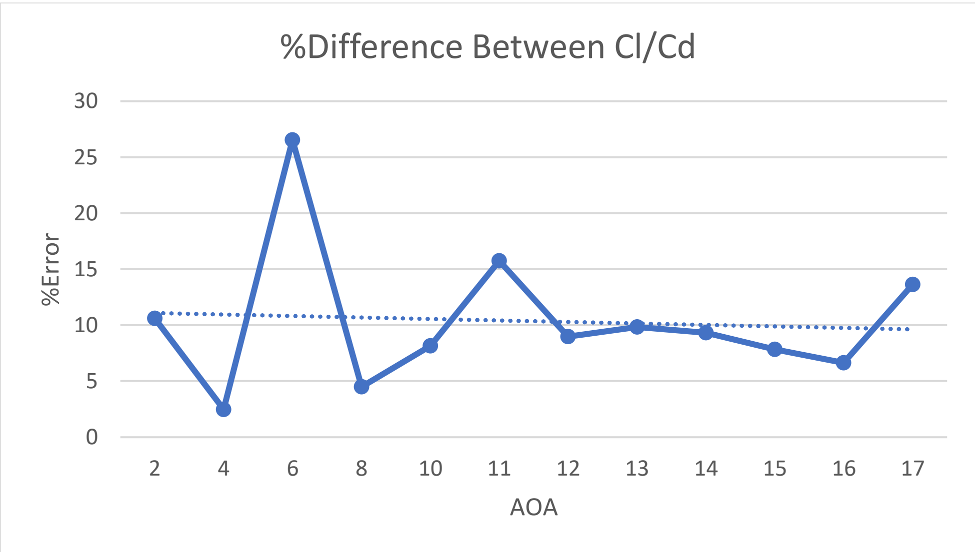

Figure 3.4 Rate of difference between our values and NASA's values

As can be seen from here, rate of difference is between 2.4 percent and 26.5 percent. Average rate of difference is around 10 percent. These differences reasons are mostly about analysis program's errors like discretization errors, mesh errors and solver errors.

3.2. Results

3.2.1. 2D Analysis

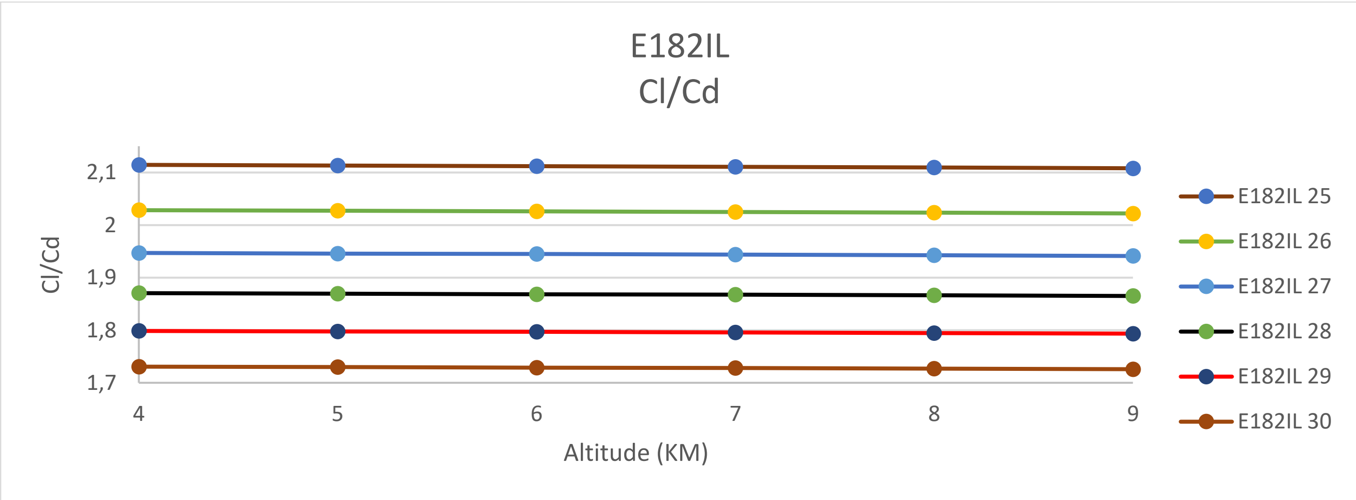

Figure 3.5 E182IL Cl/Cd vs Altitude values

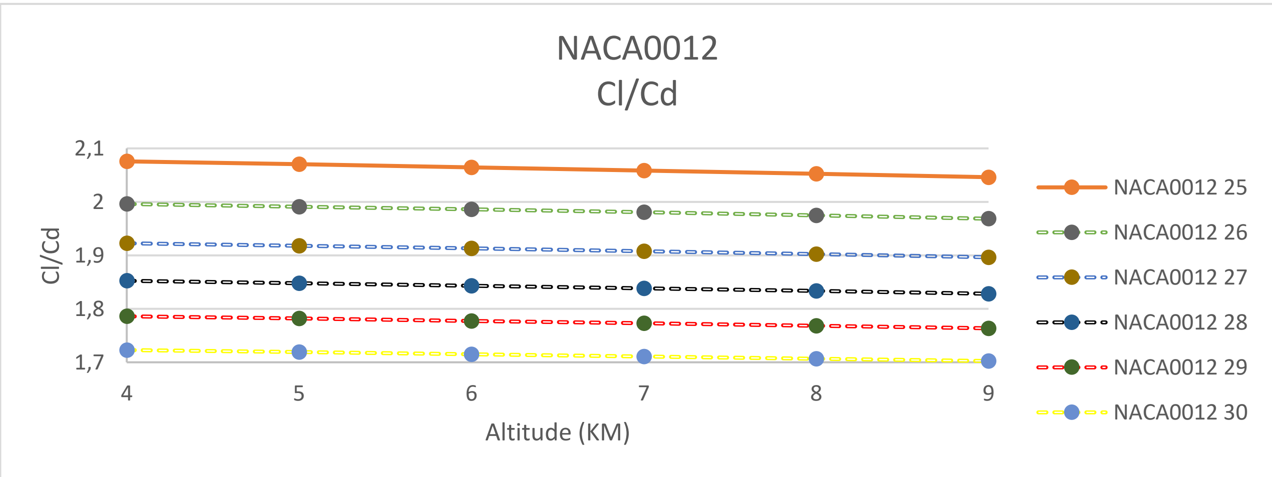

Figure 3.6 NACA0012 Cl/Cd vs Altitude values

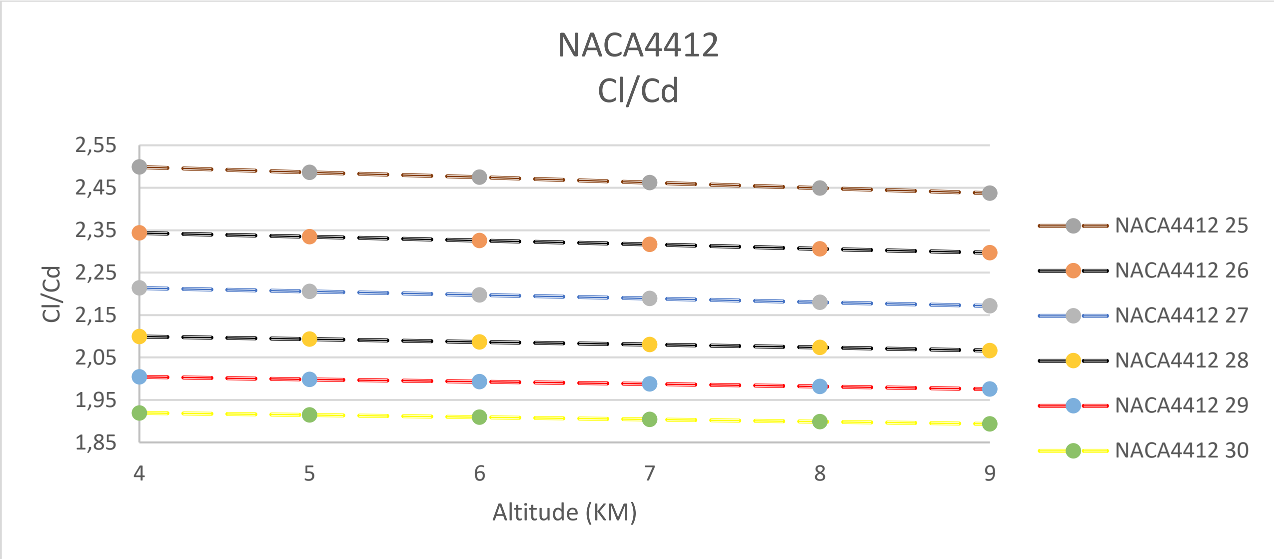

Figure 3.7 NACA4412 Cl/Cd vs Altitude values

Cl/Cd = Lift Coefficient / Drag Coefficient

It is useful to define some non-dimensional coefficients of lift, CL, and drag, CD, in order to characterize the lift/drag behavior of an airfoil. Measurements taken on scale models can be readily transferred to the full-scale situation by using these non-dimensional quantities.

CL = L/qS is the lift coefficient, where L is the lift force, S is the wing area, and q = (rU2/2) is the dynamic pressure, where r is the air density and U is the airspeed. The drag coefficient is expressed as CD = D/qS, where D denotes the drag force and the other symbols denote the same things. These two equations have the dimension of force in the numerator and denominator, hence the equation is dimensionless.

Cl/Cd is one of the best parameter to compare airfoils. We compared 3 airfoils which are suitable for UAV's (unmanned aerial vehicle). First one is E182IL, second one is NACA0012 and the last one is NACA 4412. E182IL and NACA0012's datas are very close to each other. However, as can be seen from the graphs, best option is NACA4412. For the same angle of attack (AOA), NACA4412's values are always higher than other 2 of them.

When the angle of attack starts to increase, Cl/Cd values decrease at the same altitude. Therefore, lower angle of attack means higher Cl/Cd.

Also, altitude has an effect to Cl/Cd value. For the same angle of attack, more altitude means less Cl/Cd.

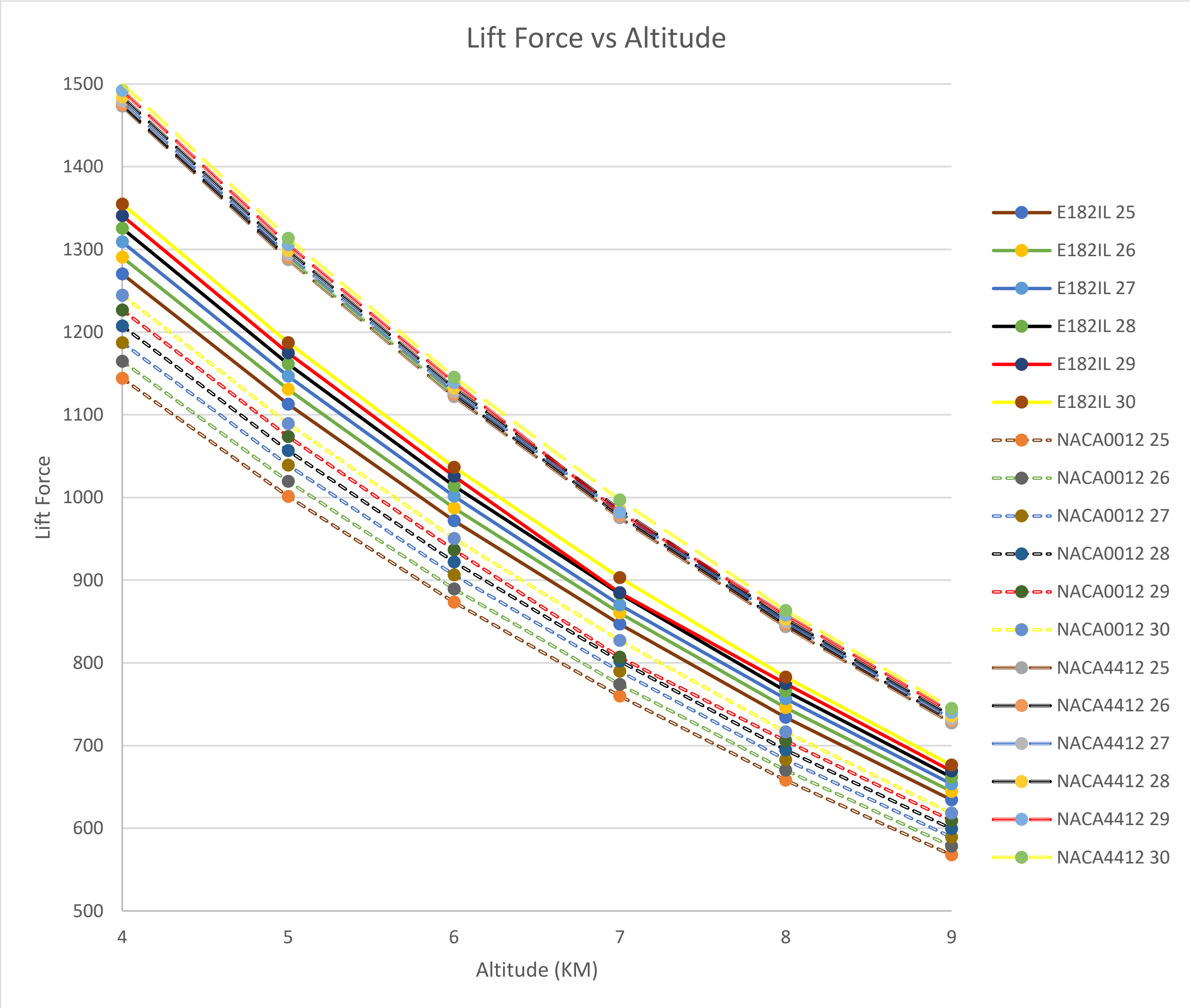

Figure 3.8 Lift Force vs Altitude for all airfoils

Lift varies with altitude, but it's about more than just the distance above sea level. The air density is the physical factor that impacts lift as we change altitude. The density of the air reduces as one rises in height, and it is this decrease that causes the lift to diminish.

From our calculations, we can see that lift force decreases with increase of altitude for all airfoils. Also, lift force is always higher when the angle of attack is greater.

Comparing these 3 airfoils by using lift force graph, it seems like the best option is NACA4412. For all values of angle of attack, lift force is higher than other 2 of the airfoils. Second one is E182IL which is the values of it is very close to NACA0012.

Comparing the values of lift force of NACA4412 by using altitude between 4km and 9km, it seems 2 times less and decreasing is not linear.

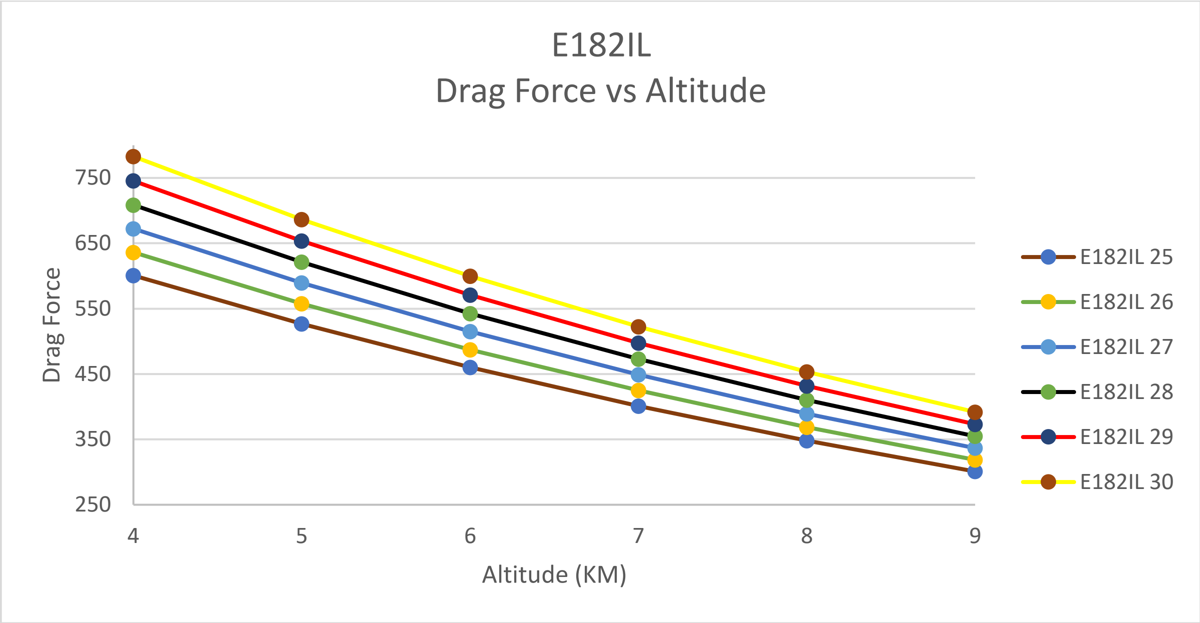

Figure 3.9 E182IL Drag Force vs Altitude

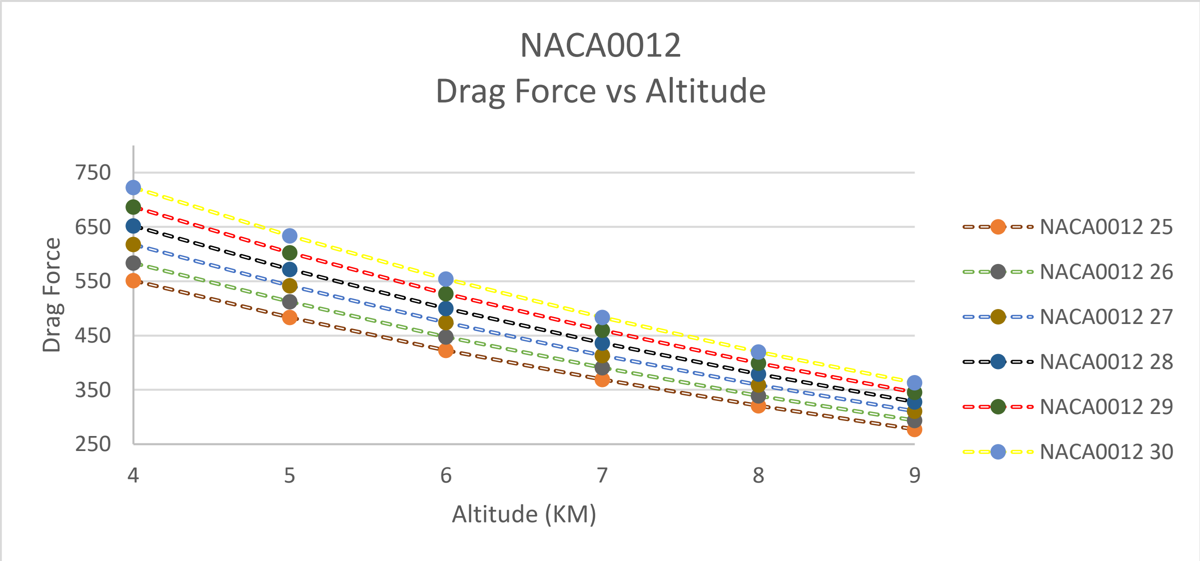

Figure 3.10 NACA0012 Drag Force vs Altitude

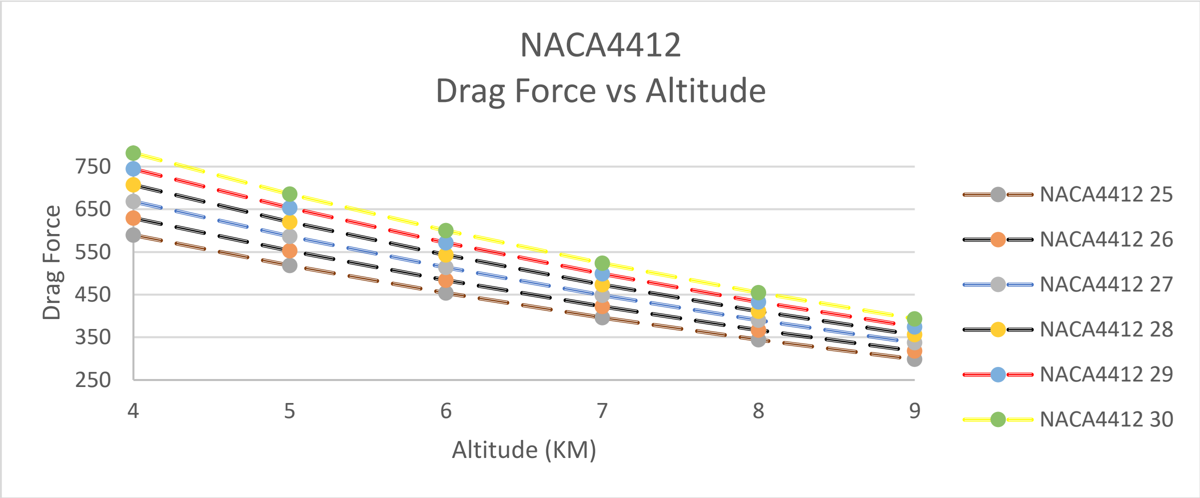

Figure 3.11 NACA4412 Drag Force vs Altitude

FD=(CρAv^2) *0.5

where *C* is the drag coefficient, *A* is the area of the object facing the fluid, and *ρ* is the density of the fluid. (Recall that density is mass per unit volume.) v is speed of the object.

From our calculations, drag coefficient (C) remained almost same with increasing altitude. So, drag coefficient do not have much effect on drag force. However, we formulated density and velocity. Density and velocity affected by altitude a lot. Therefore, drag force is affecting by altitude.

Greater angle of attacks caused greater drag forces for all airfoils. Drag force decreases with altitude. It has decreased to half between 4km and 9km.

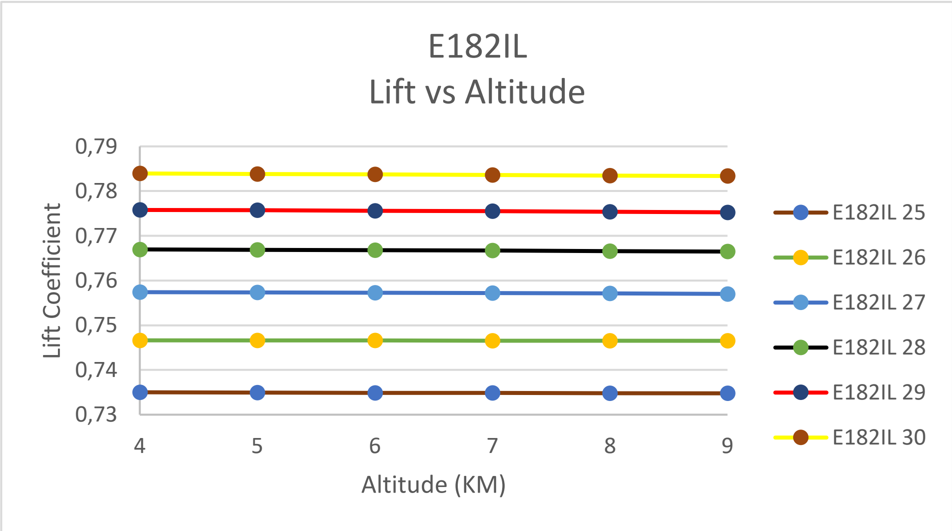

Figure 3.12 E182IL Lift Coefficient vs Altitude

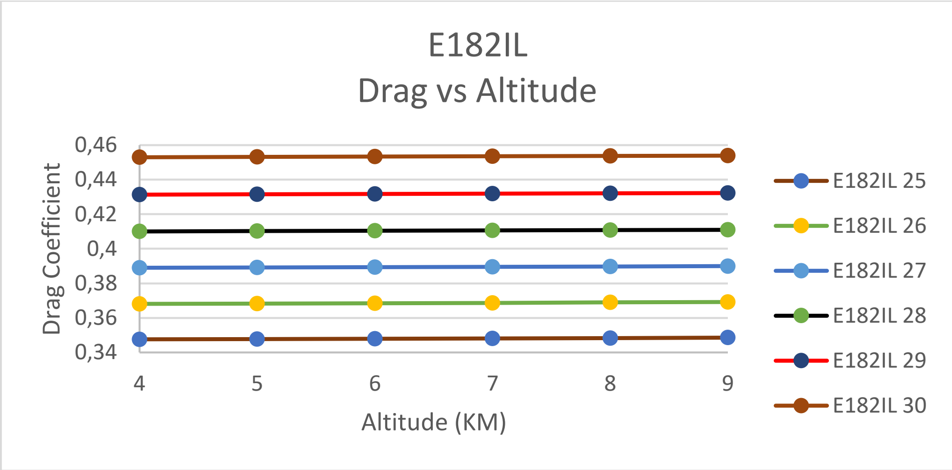

Figure 3.13 E182IL Drag Coefficient vs Altitude

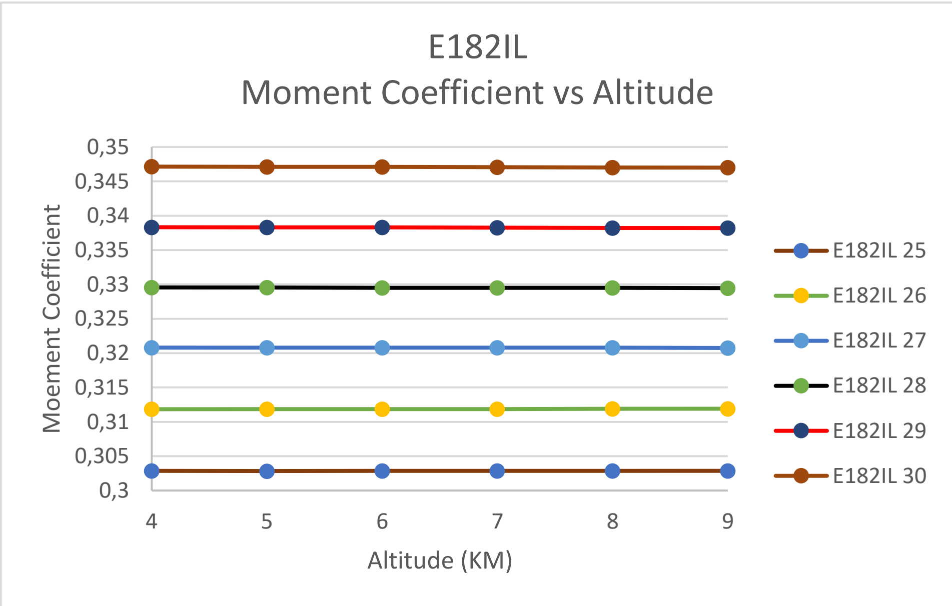

Figure 3.14 E182IL Moment Coefficient vs Altitude

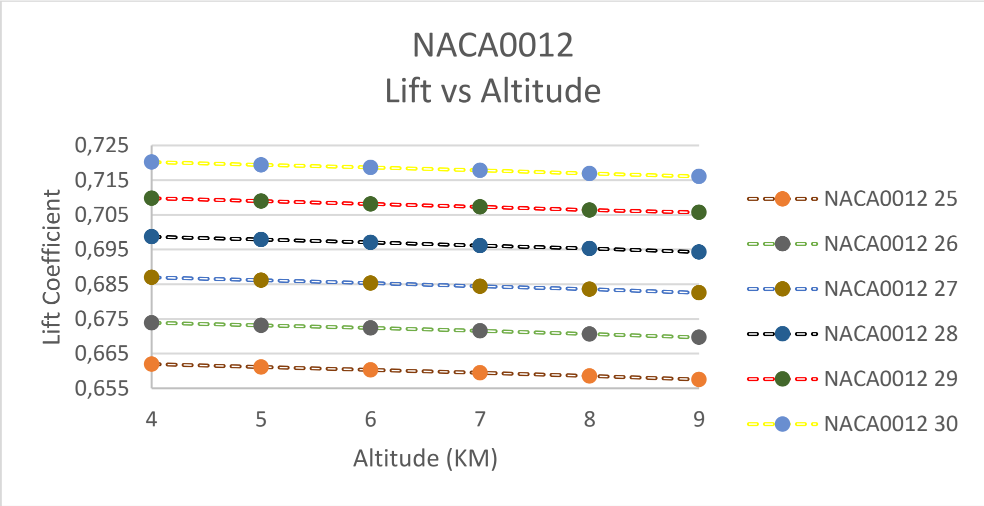

Figure 3.15 NACA0012 Lift Coefficient vs Altitude

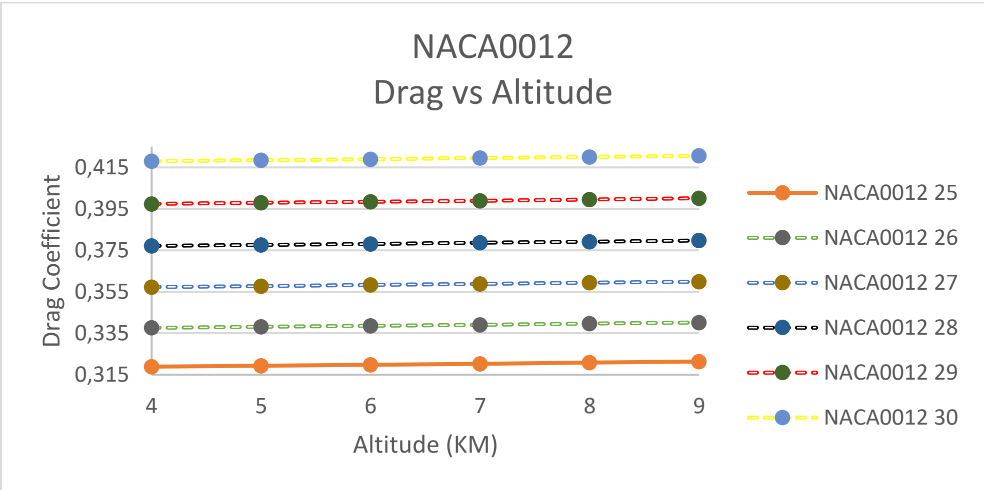

Figure 3.16 NACA0012 Drag Coefficient vs Altitude

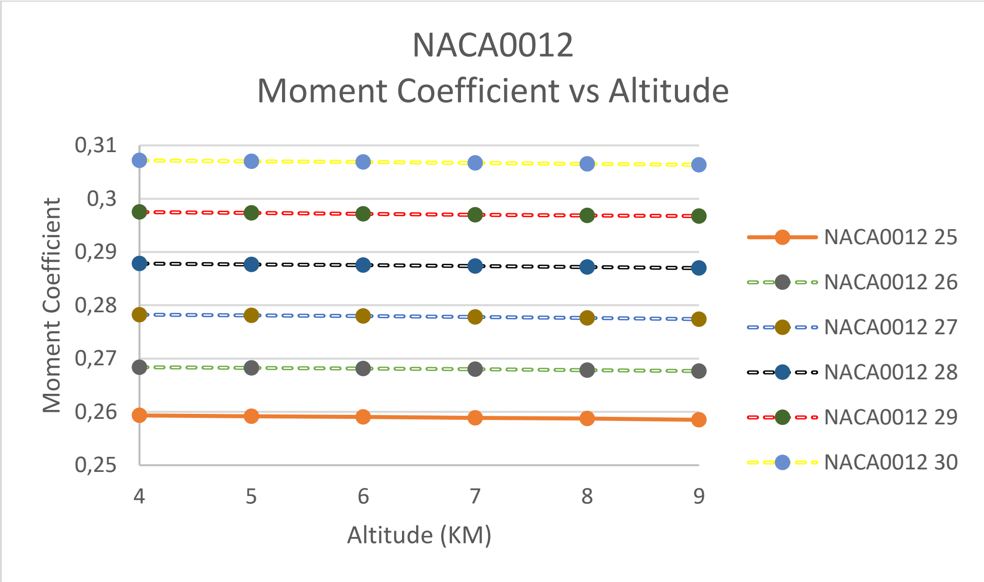

Figure 3.17 NACA0012 Moment Coefficient vs Altitude

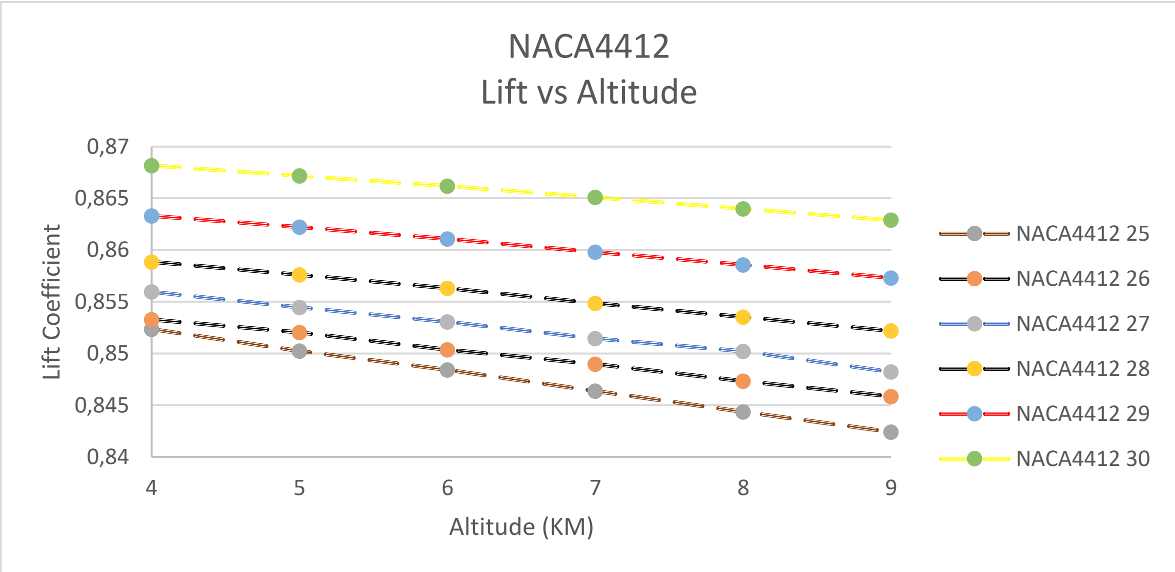

Figure 3.18 NACA4412 Lift Coefficient vs Altitude

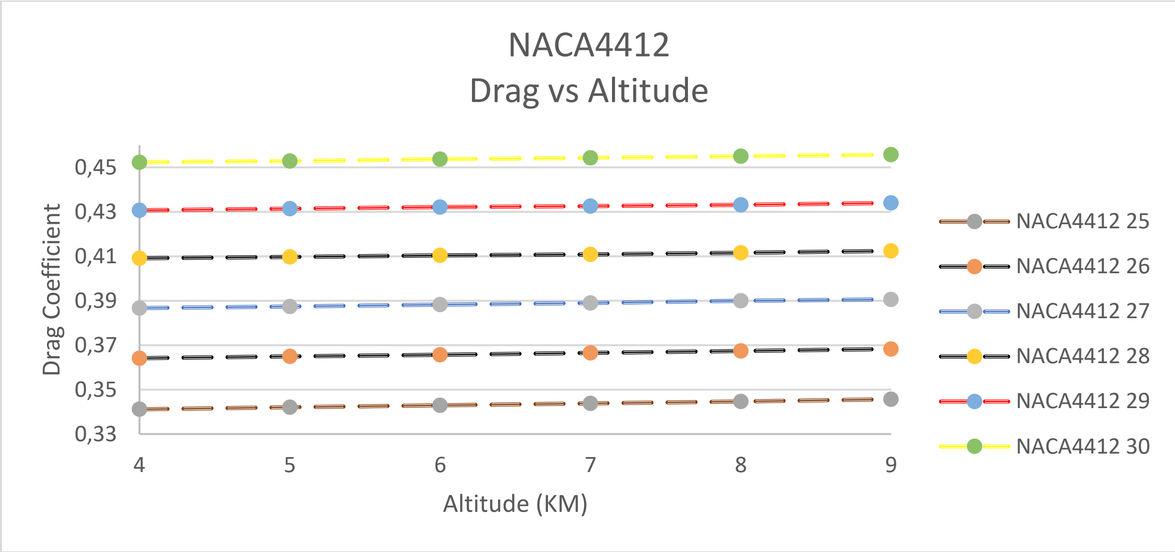

Figure 3.19 NACA4412 Drag Coefficient vs Altitude

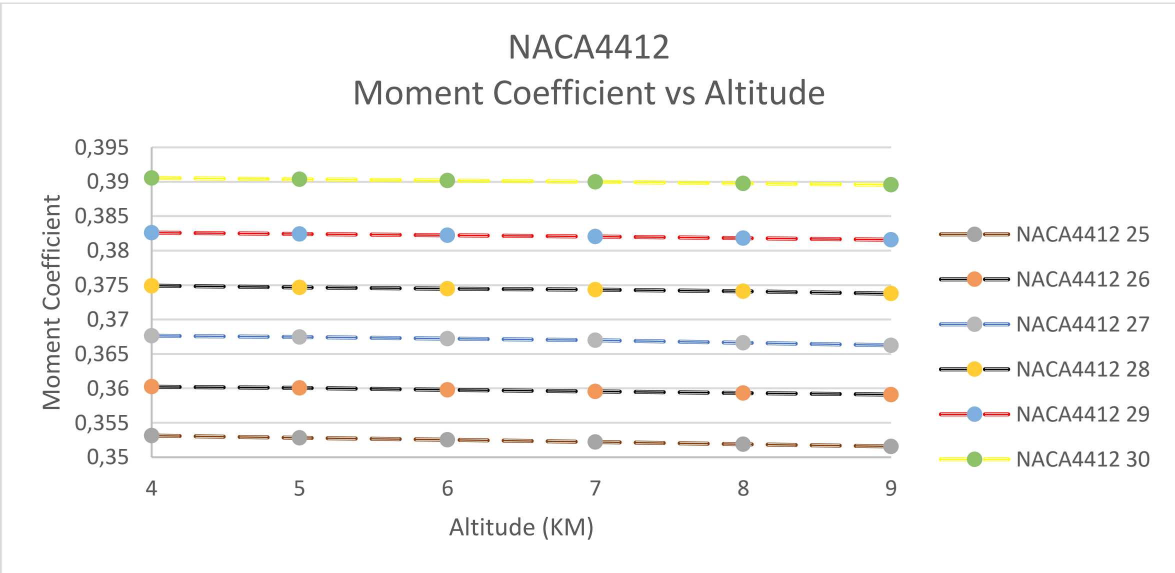

Figure 3.20 NACA4412 Moment Coefficient vs Altitude

All of the Coefficients are one of the most important parameters for flying objects. Higher coefficients cause higher forces.

From the graphs, it seems like coefficients did not change a lot with altitudes. They have been more affected by angle of attack.

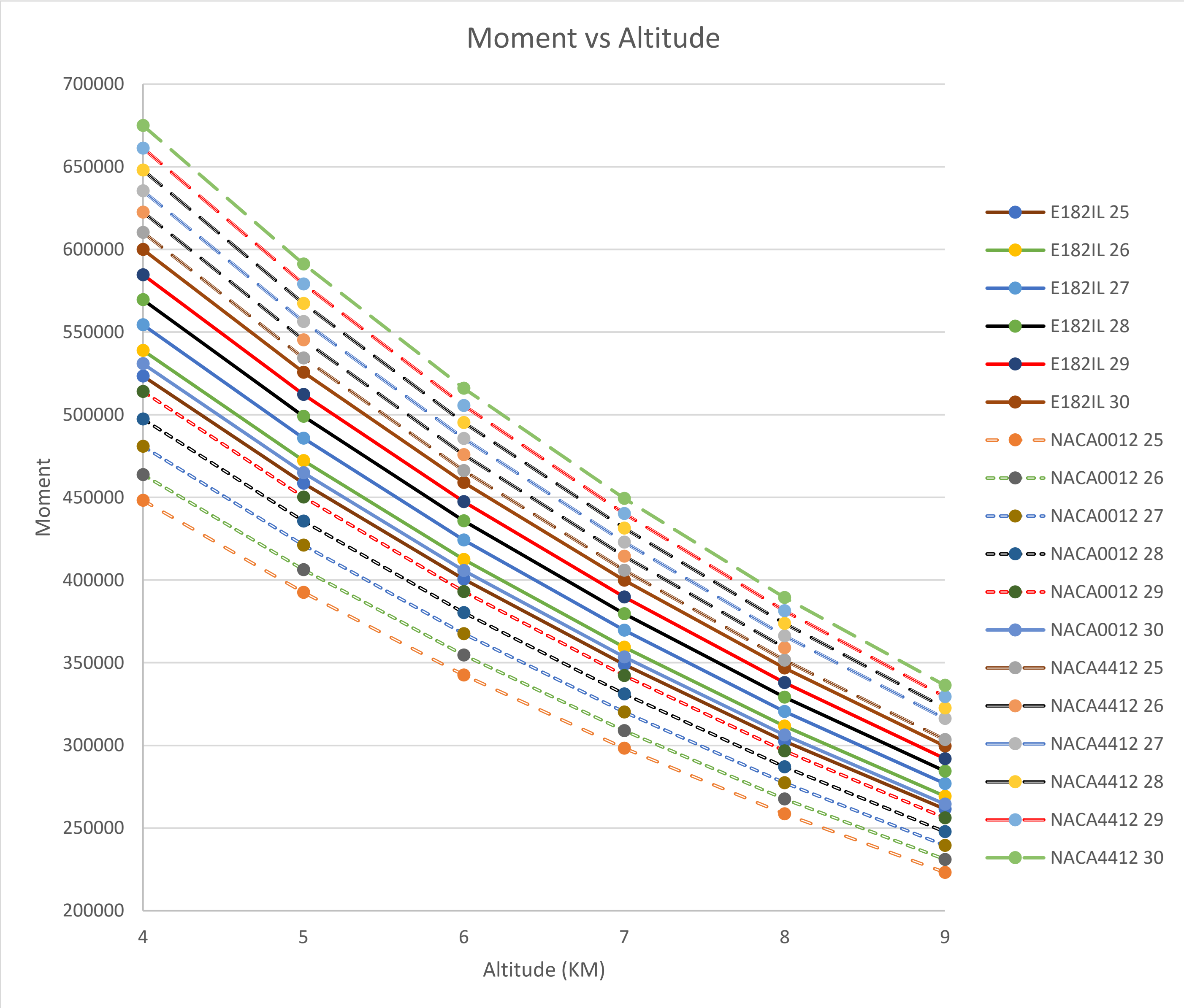

Figure 3.21 Moment vs Altitude for all airfoils

Moments changed same as with the other forces with altitude.

3.3. 3D Analysis

After 2D airfoil profile analyses, 3D UAV CFD analysis are done. In the current analyses, TB-2 Bayraktar 3D CAD model is used which is created from SolidWorks 3D modelling program.

This model's sizes are not its exact size, they are just approximation because of secret of the informations about the defense industry but the sizes used in this project are so close to the real dimensions. So, the analyses should give near results to the reality.

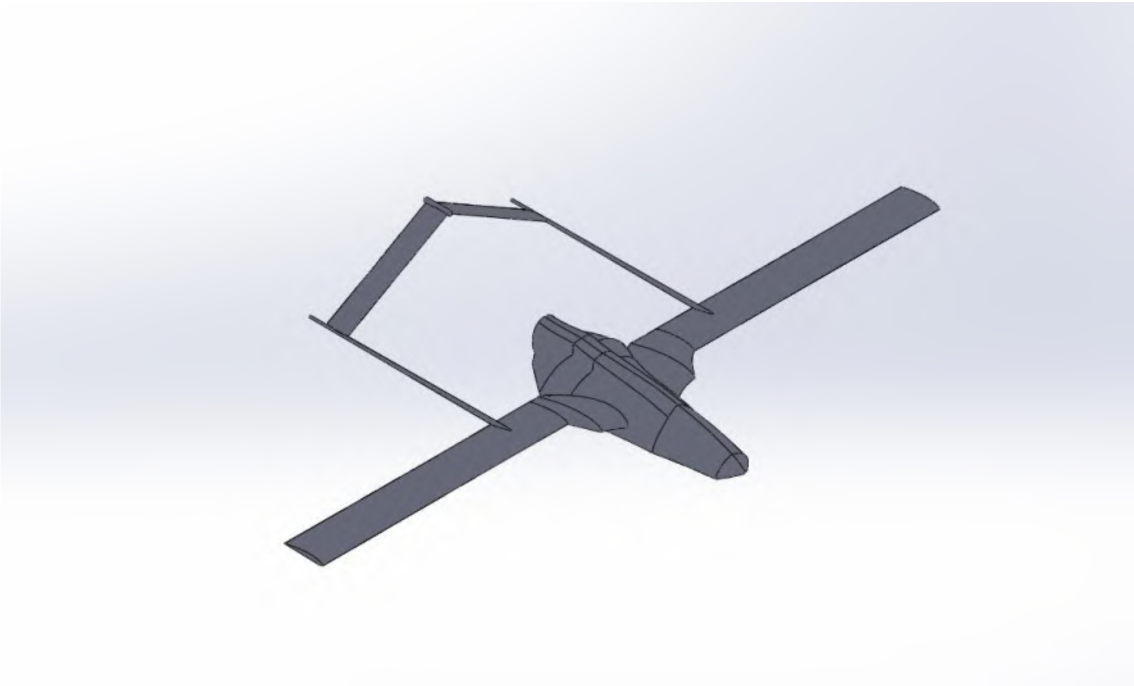

Figure 3.22 Isometric view of the model

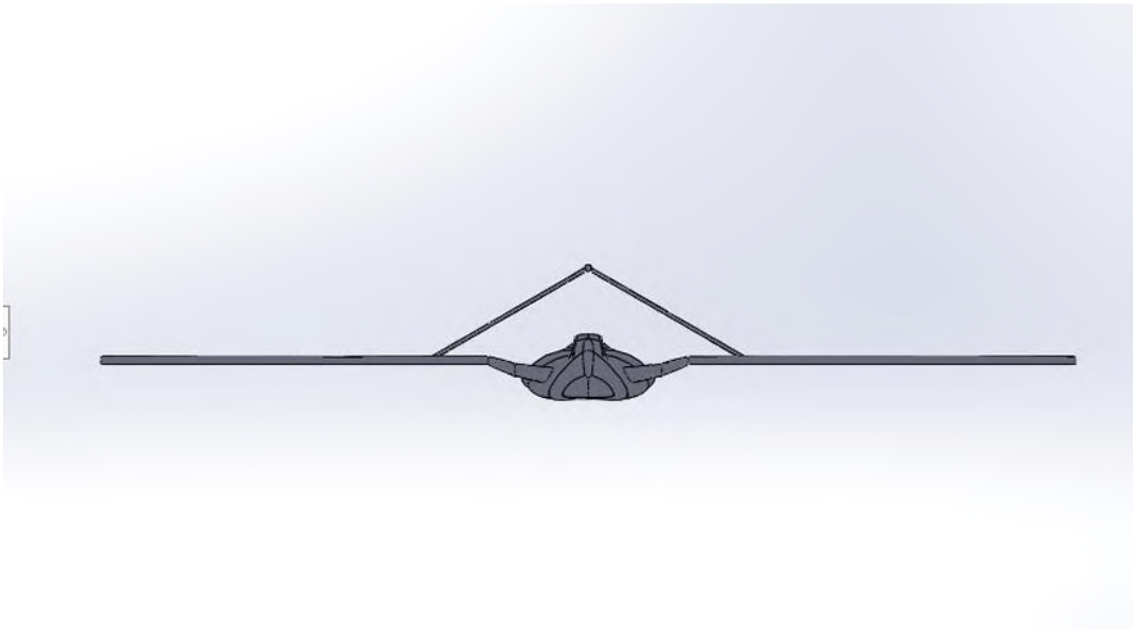

Figure 3.23 Front view of the model

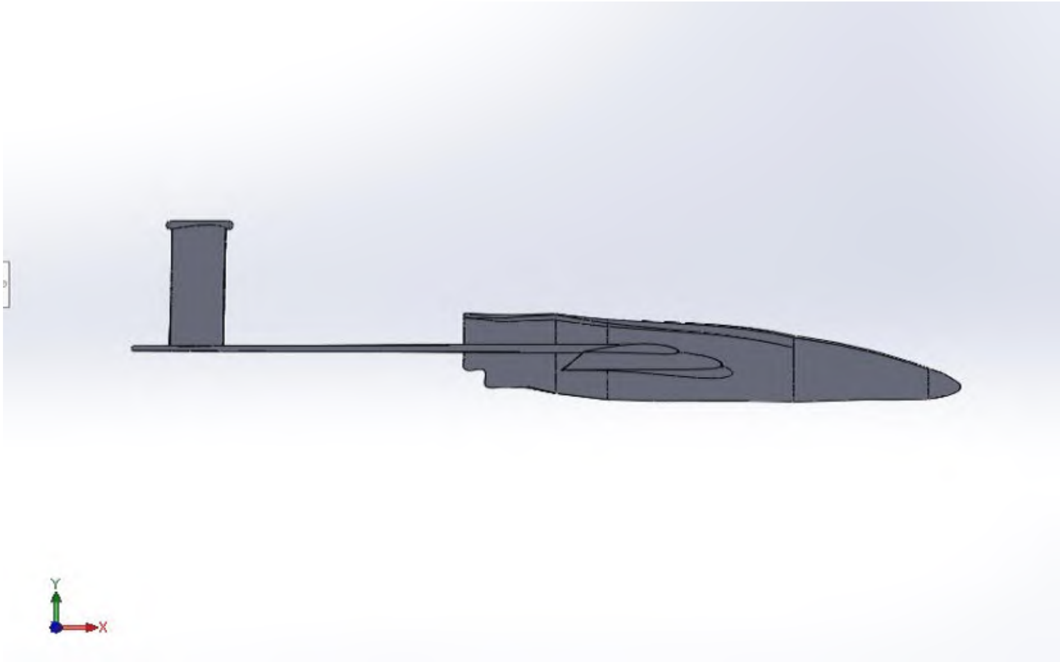

Figure 3.24 Side view of the model

In this model, NACA4412 airfoil profile is used for front and rear wings because of it is the most efficiency one between the profiles that analyzed in 2D for this project.

The figure below shows us the wall of the UAV's whose flow domain was created with subtraction the volume of the body from the far field. The advantages of the symmetry provided an ease to save the time and CPU power. So, the half model is used for prevent presence of huge number of elements. In addition to these, there is a 520.000 elements limitation in the ANSYS version because of that used in this project is free STUDENT version. With limited number of elements, the max mesh efficiency is reached as possible.

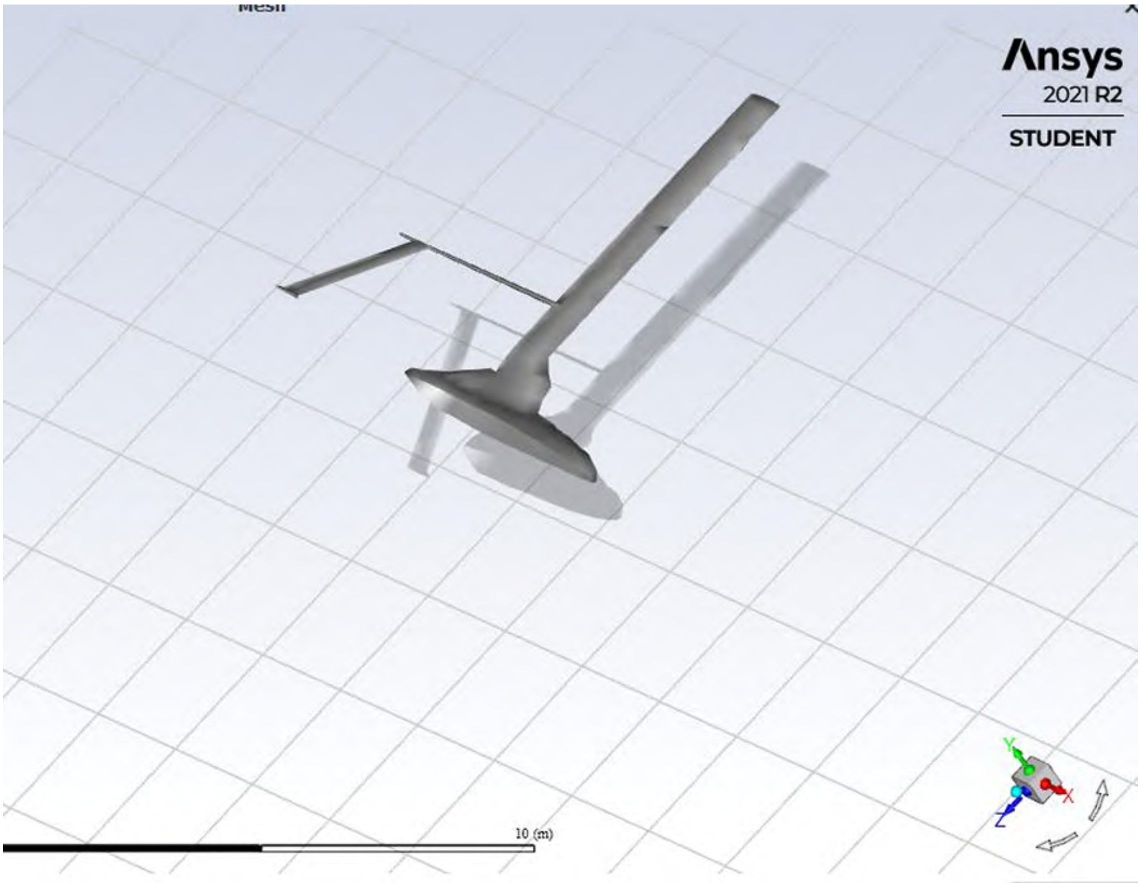

Figure 3.25 Full flow domain and space in the volume identifies the plane body

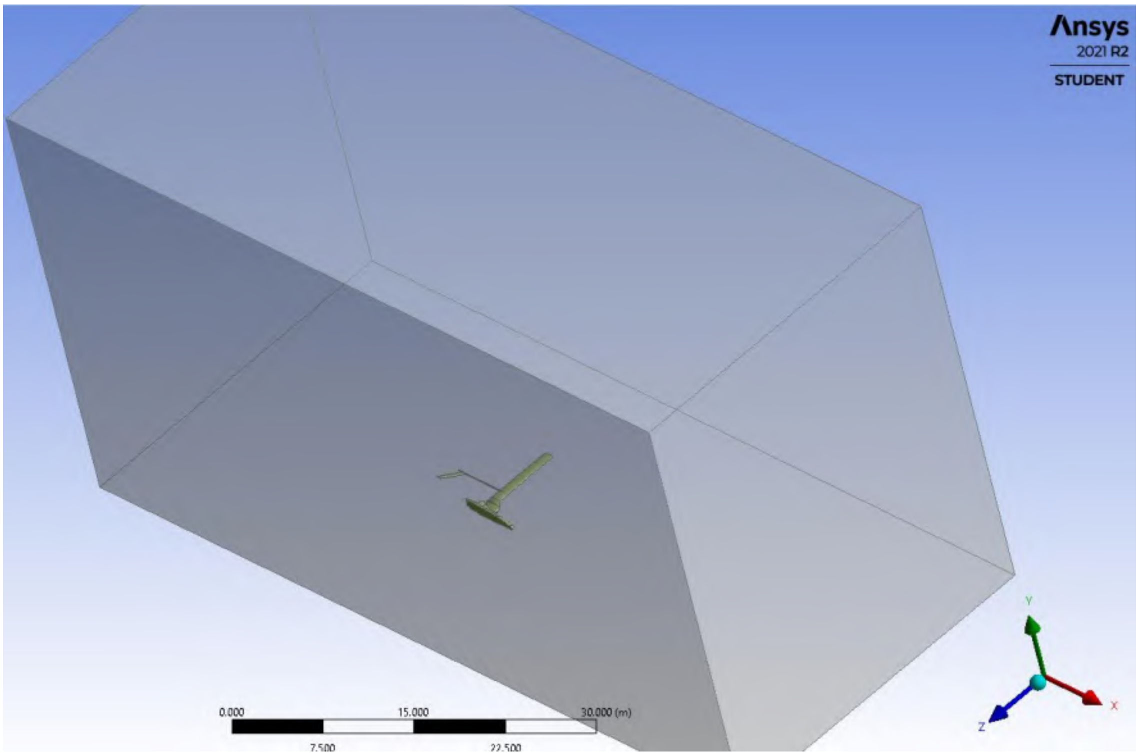

Figure 3.26 Full flow domain and space in the volume identifies the plane body

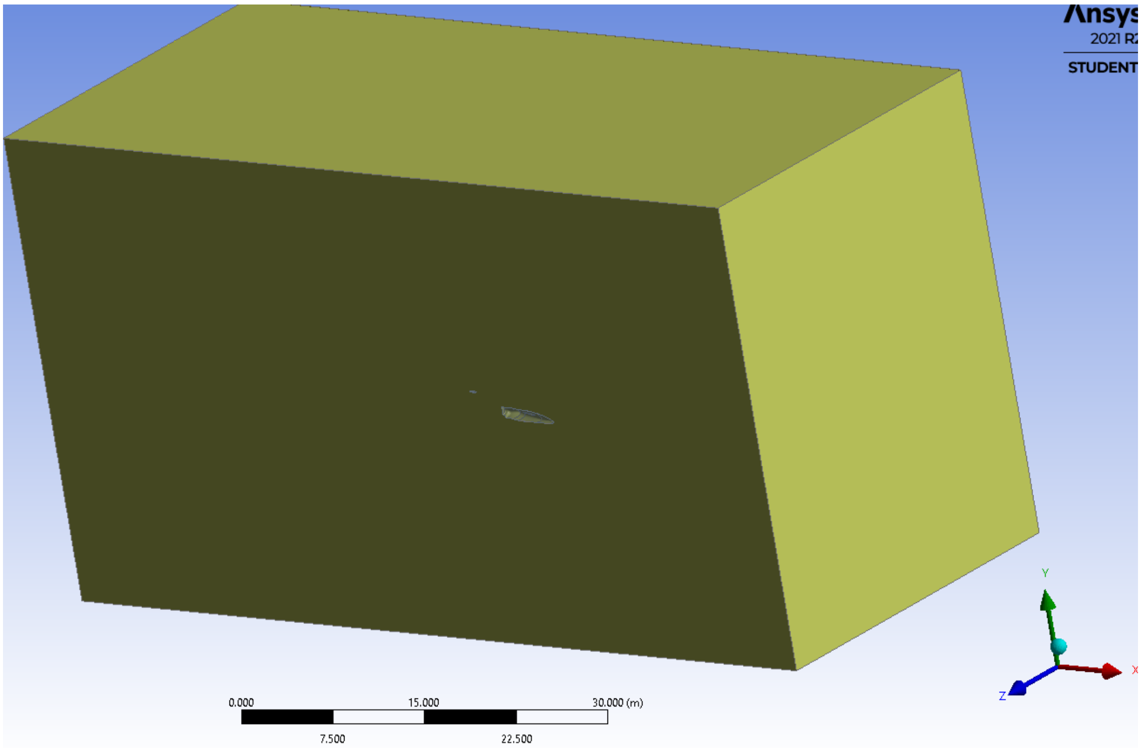

Figure 3.27 Full flow domain and space in the volume identifies the plane body

The flow domain was created very large with respect to the UAV's body for getting fully developed flow region around the wings and back of the UAV and of course, this approach dramatically increases the total number of elements.

3.3.1. Results of 3D Analysis

The 3D whole body and 2D profile flow results are compared to each other in exact same flight conditions in the figures shown below.

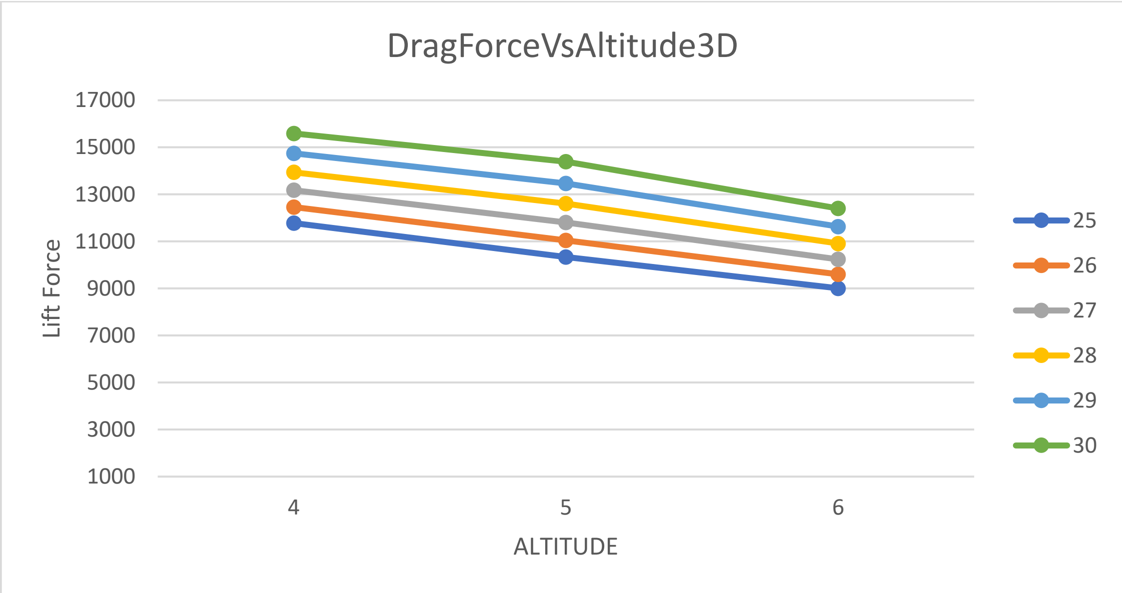

Figure 3.28 NACA4412 Drag Force vs Altitude 3D

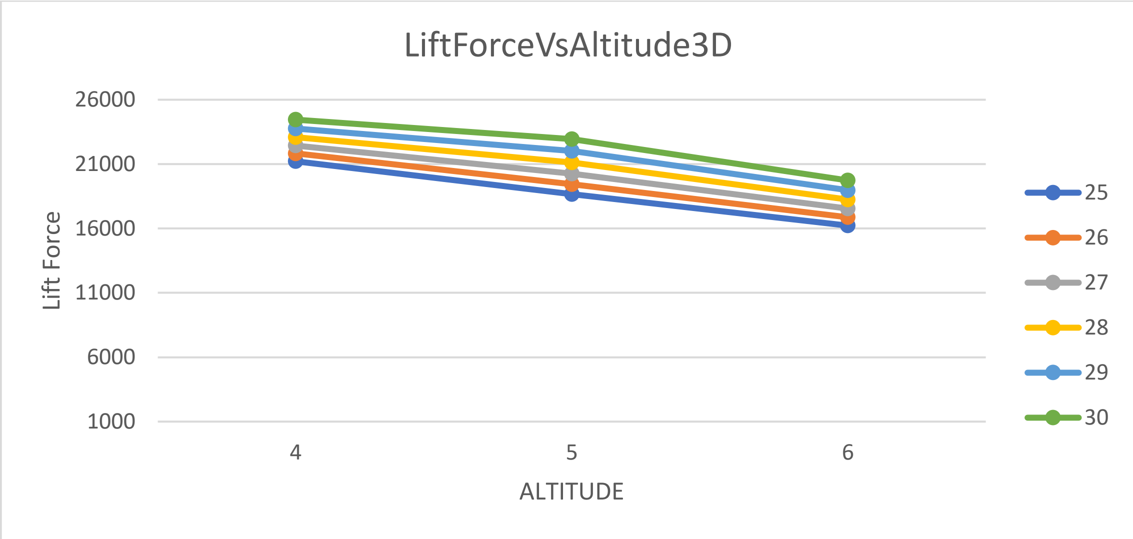

Figure 3.29 NACA4412 Lift Force vs Altitude 3D

We did 3D analyses on NACA 4412's one wing. Then, we multiple it with two because there are two wings on UAV's. Lift Force is between 26000 and 16000 at between 4km and 6km.

So, if we calculate the maximum mass for the UAV basically at 6km;

F = m * a

m = F / a

m= 16000 / 9.81

m = 1630 kg

So, NACA4412 is only suitable for lightweight UAVs. For example, Bayraktar Akıncı is 6000kg. Therefore, NACA4412 is not suitable for Bayraktar Akıncı. But Bayraktar TB2 is 700kg so NACA 4412 is very well suitable for it.

4. CONCLUSION

The work focuses on the numerical analysis of 2D airfoils in various flight conditions, such as different Re number, AOA, and altitude. Several types of airfoil profiles were used in these studies and their efficiency was shown; lift, drag, moment coefficients, and forces. The main goal is to analyze and display the change in forces and coefficients at various altitudes and AOA for three different types of airfoil profiles. The main requirement of this project is to keep the Mach number constant at 0.2. Numerous analyses have been conducted in order to achieve this goal. Following the completion of the 2D analyses, a 3D model analysis is performed. All of these are clearly displayed in this report for examination.

According to the airfoil profile, the behavior of the profiles changes. Some profiles are suitable for low-re number, some are suitable for high number and some are suitable for high AOA. All these properties and behaviors are related with the geometry (chamber, chord length, width etc.) of the airfoil profile.

In this research, generally the coefficients(Cl, Cd, Cm) remain constant with respect to change of the altitude at **same** AOA, but the forces(Lift force, Drag force, Moment Force) are changing with respect to the altitude at **same** AOA. So, the coefficients are only dependent on AOA, the forces are dependent both **AOA** and **altitude**.

In 3D full model analysis, of course, the forces change dramatically because of the shape and aerodynamics effect of the body. In addition to these, in 3D model, there are 4 wings and the UAV’s body has aerodynamics effects itself.

5. APPENDIX

E182IL

9 KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,30286712	261458	0,348561	0,734781	300,9042	634,3187	25	2,108042
1	0,31190765	269262,5	0,369183	0,746519	318,7074	644,4523	26	2,022082
1	0,32074684	276893,2	0,389982	0,75701	336,662	653,5092	27	1,941143
1	0,3294606	284415,5	0,410957	0,766477	354,7693	661,6817	28	1,865104
1	0,33820478	291964,2	0,432265	0,775254	373,1642	669,258	29	1,793468
1	0,3469977	299554,9	0,453915	0,783372	391,8538	676,2663	30	1,725813

Table 5.1 E182IL values at 9KM

8 KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,30285755	302612,5	0,348338	0,734815	348,0566	734,2208	25	2,109486
1	0,31188881	311636,5	0,36894	0,746537	368,6411	745,9332	26	2,023467
1	0,32078199	320522,5	0,38979	0,757147	389,4742	756,5341	27	1,94245
1	0,32949087	329224,3	0,410755	0,766597	410,4225	765,9768	28	1,866313
1	0,33823242	337958,8	0,432055	0,77537	431,7058	774,7425	29	1,794608
1	0,34702958	346748,8	0,453701	0,783494	453,3344	782,86	30	1,726893

Table 5.2 E182IL values at 8KM

7 KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,30285178	349001,2	0,348132	0,734857	401,1819	846,8365	25	2,110854
1	0,31187305	359397,1	0,368713	0,746558	424,899	860,3207	26	2,024765
1	0,32077849	369659,6	0,389571	0,757193	448,9353	870	27	1,943656
1	0,32950915	379720,7	0,410555	0,766693	473,1166	883,5234	28	1,867454
1	0,33826377	389809,4	0,431864	0,775492	497,6722	884,8417	29	1,795687
1	0,3470654	399952,2	0,453508	0,783623	522,6149	903,0336	30	1,727914

Table 5.3 E182IL values at 7KM

6 KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,3028439	400509,3	0,347937	0,734893	460,1447	971,8918	25	2,112144
1	0,31186474	412439,3	0,368507	0,746591	487,3484	987,3621	26	2,025988
1	0,32079708	424252,2	0,389388	0,757286	514,9627	1001,506	27	1,944813
1	0,32952237	435791,4	0,410364	0,766776	542,7038	1014,057	28	1,868528
1	0,33829117	447388,1	0,431682	0,775605	570,8963	1025,733	29	1,796706
1	0,34709619	459032,7	0,453325	0,783741	599,5191	1036,492	30	1,728873

Table 5.4 E182IL values at 6KM

5 KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,30283746	458599,5	0,347754	0,73493	526,6185	1112,935	25	2,113362
1	0,31185195	472250,5	0,368306	0,746614	557,7409	1130,628	26	2,027157
1	0,32079004	485785,8	0,389188	0,757327	589,3637	1146,851	27	1,945914
1	0,32954449	499043,1	0,410192	0,766875	621,1707	1161,311	28	1,869552
1	0,33831671	512327,2	0,431506	0,775711	653,4483	1174,692	29	1,797682
1	0,34712272	525662,5	0,453147	0,783849	686,22	1187,015	30	1,729788

Table 5.5 E182IL values at 5KM

4 KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,30285387	523415,8	0,3476	0,735018	600,7495	1270,315	25	2,11455
1	0,31183726	538941,6	0,368112	0,74663	636,2004	1290,384	26	2,028266
1	0,32080077	554433	0,389016	0,757401	672,327	1308,999	27	1,946968
1	0,32956055	569572,4	0,410024	0,766959	708,6362	1325,519	28	1,870521
1	0,3383267	584722,7	0,431325	0,775781	745,4503	1340,766	29	1,798599
1	0,3471451	599963,4	0,452976	0,783945	782,8683	1354,875	30	1,730655

Table 5.6 E182IL values at 4KM

NACA4412

9KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,25851655	223171,2	0,321373	0,65757	277,4337	567,6646	25	2,046127
1	0,26766888	231072,2	0,340209	0,669696	293,6946	578,133	26	1,968484
1	0,27741187	239483,1	0,359896	0,682527	310,6895	589,2092	27	1,896457
1	0,28698089	247743,8	0,379762	0,694282	327,8393	599,3576	28	1,828205
1	0,29674427	256172,3	0,400144	0,705695	345,4348	609,2101	29	1,763604
1	0,30636222	264475,3	0,420624	0,716057	363,1151	618,1549	30	1,702366

Table 5.7 NACA4412 values at 9KM

8KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,25873659	258527,2	0,320865	0,658613	320,6058	658,0804	25	2,052615
1	0,26783964	267622,9	0,339634	0,670675	339,3592	670,1321	26	1,974698
1	0,277625	277400,4	0,359357	0,683558	359,0658	683,0052	27	1,902173
1	0,28717907	286946,7	0,37918	0,695284	378,8735	694,7212	28	1,833649
1	0,29682624	296586,1	0,399451	0,706401	399,1281	705,8297	29	1,768429
1	0,30653781	306289,8	0,420051	0,716942	419,7113	716,3621	30	1,706797

Table 5.8 NACA4412 values at 8KM

7KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,25887753	298326	0,320342	0,659471	369,1571	759,9629	25	2,058644
1	0,26799607	308834,1	0,339083	0,671576	390,7538	773,9123	26	1,980562
1	0,27778217	320111,4	0,358805	0,684444	413,4812	790	27	1,907564
1	0,28735069	331138	0,37865	0,696168	436,3493	802,2523	28	1,838555
1	0,29700455	342262,9	0,398914	0,707295	459,702	806,9279	29	1,773051
1	0,30671672	353455,1	0,419518	0,717813	483,4451	827,1951	30	1,711043

Table 5.9 NACA4412 values at 7KM

6KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,25904231	342581,9	0,319869	0,660366	423,0255	873,3302	25	2,064486
1	0,26814049	354614,2	0,338566	0,672393	447,7518	889,2357	26	1,986001
1	0,27795691	367596,4	0,358296	0,685357	473,8443	906,3807	27	1,912824
1	0,28751164	380232,4	0,378132	0,697026	500,0774	921,8132	28	1,843341
1	0,29716928	393004,6	0,398401	0,708139	526,8836	936,5092	29	1,77745
1	0,30688393	405852,2	0,419017	0,718635	554,1476	950,3899	30	1,715048

Table 5.10 NACA4412 values at 6KM

5KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,25918815	392499,5	0,319377	0,661189	483,6454	1001,267	25	2,070249
1	0,26826942	406251,6	0,338108	0,673157	512,0113	1019,39	26	1,990951
1	0,27809373	421129	0,357789	0,686161	541,8146	1039,082	27	1,917782
1	0,28767577	435639,5	0,377642	0,697873	571,8798	1056,819	28	1,847973
1	0,29734364	450280	0,39791	0,709	602,5722	1073,668	29	1,781808
1	0,30703331	464953,4	0,418506	0,719425	633,7612	1089,456	30	1,719032

Table 5.11 NACA4412 values at 5KM

4KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,2593359	448204,6	0,318923	0,661995	551,1882	1144,111	25	2,075717
1	0,26838743	463848,2	0,337621	0,673901	583,5029	1164,689	26	1,996029
1	0,2782466	480887,6	0,357329	0,686978	617,5635	1187,289	27	1,922537
1	0,28782839	497447,6	0,377175	0,698675	651,863	1207,504	28	1,85239
1	0,29748651	514139,5	0,397415	0,709782	686,8438	1226,7	29	1,785996
1	0,30718157	530895,2	0,418018	0,720196	722,4522	1244,7	30	1,722882

Table 5.12 NACA4412 values at 4KM

NACA0012

9KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,35157701	303508,1	0,345648	0,842404	298,3896	727,2274	25	2,437174
1	0,35910512	310007	0,368263	0,845851	317,9127	730,2035	26	2,296868
1	0,36625959	316183,2	0,390594	0,848208	337,1909	732,2376	27	2,171581
1	0,37375558	322654,4	0,412401	0,852179	356,0163	735,6659	28	2,066383
1	0,38158726	329415,3	0,433971	0,857312	374,637	740,0968	29	1,975504
1	0,38956336	336300,8	0,455694	0,862896	393,3899	744,9175	30	1,893585

Table 5.13 NACA0012 values at 9KM

8KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,35188236	351597,7	0,344705	0,844357	344,4257	843,6742	25	2,44951
1	0,35931675	359026	0,367402	0,847315	367,1045	846,6295	26	2,306236
1	0,36660956	366313	0,389983	0,850214	389,6675	849,5258	27	2,18013
1	0,37410086	373798,2	0,411615	0,853519	411,2818	852,8283	28	2,073587
1	0,38181357	381504,7	0,433196	0,858558	432,8453	857,8634	29	1,981917
1	0,38976436	389449	0,454994	0,863981	454,6263	863,2822	30	1,898883

Table 5.14 NACA0012 values at 8KM

7KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,35219959	405868,8	0,343775	0,846349	396,1605	975,318	25	2,461926
1	0,35957845	414372	0,366516	0,848981	422,3666	978,3516	26	2,316357
1	0,36696886	422888,6	0,388965	0,851444	448,2367	982	27	2,188997
1	0,37433421	431376,3	0,410872	0,854845	473,4814	985,1088	28	2,080565
1	0,38202674	440241	0,432513	0,859815	498,4203	981,9865	29	1,987953
1	0,38997723	449403,1	0,454319	0,865097	523,5499	996,9233	30	1,904161

Table 5.15 NACA0012 values at 7KM

6KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,35253063	466219,7	0,342851	0,848415	453,4189	1122,024	25	2,474586
1	0,35979723	475829,7	0,365696	0,850351	483,6313	1124,585	26	2,325293
1	0,3672415	485674,7	0,388208	0,853057	513,4034	1128,163	27	2,197421
1	0,3744607	495222,1	0,410449	0,856322	542,8157	1132,481	28	2,086309
1	0,38225312	505527,5	0,432073	0,861076	571,4139	1138,767	29	1,992894
1	0,39019077	516025	0,453656	0,866194	599,9576	1145,536	30	1,909362

Table 5.16 NACA0012 values at 6KM

5KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,35279967	534259,3	0,341988	0,850239	517,8867	1287,553	25	2,486166
1	0,36004639	545233,4	0,364912	0,852022	552,6015	1290,253	26	2,334871
1	0,36744438	556436,4	0,387407	0,854456	586,6662	1293,938	27	2,205578
1	0,37467602	567387,6	0,409745	0,857598	620,4933	1298,697	28	2,093008
1	0,38243544	579138	0,431442	0,86221	653,3502	1305,681	29	1,998439
1	0,39037351	591159	0,452887	0,86719	685,8256	1313,223	30	1,914806

Table 5.17 NACA0012 values at 5KM

4KM	Moment Coefficient	Moment	drag	lift	drag force	lift force	AOA	cl/cd
1	0,35313976	610323,8	0,341118	0,852351	589,546	1473,1	25	2,498702
1	0,36023188	622580,9	0,364126	0,853279	629,3112	1474,704	26	2,343362
1	0,36763469	635375,1	0,386677	0,855959	668,286	1479,336	27	2,213627
1	0,37490891	647946,9	0,409098	0,858861	707,0346	1484,35	28	2,099403
1	0,3826163	661267,4	0,430692	0,863307	744,3558	1492,035	29	2,004465
1	0,39055606	674989,6	0,452296	0,868184	781,693	1500,464	30	1,919506

Table 5.18 NACA0012 values at 4KM

NACA 4412 (3D)

LIFT FORCE	NACA 4412 (3D)		
AOA/KM	4	5	6
25	21214,104	18652,28	16223,21
26	21830,556	19442	16871,16
27	22435,942	20265,16	17544,98
28	23087,89889	21123,18	18245,72
29	23758,80073	22017,52	18974,45
30	24449,19804	22949,73	19732,28

Table 5.19 NACA4412 Lift Forces 3D

DRAG FORCE	NACA 4412 (3D)		
AOA/KM	4	5	6
25	11778,181	10339,52	9007,836
26	12460,1318	11046,12	9602,68
27	13174,8258	11801,01	10236,81
28	13937,64164	12607,49	10912,81
29	14744,62413	13469,08	11633,45
30	15590,3531	14389,56	12401,68

Table 5.20 NACA4412 Drag Forces 3D

Altitude	Temperature (Celcius)	Speed of Sound	Mach=0.2 Speed of Sound	Pressure	Pascal	T/T0	P/P0	p/p0	Temperature (Kelvin)	kg/m^3	Dynamic Viscosity	Kinematic Viscosity
0	15	340,5	68,1	101400,000	1,22670	1	1	1,2E-05	288,15	1,2256	1,81206E-05	1,47851E-05
1000	8,5	336,6	67,32	89929,076	92005,57596	0,97744	0,88687	0,90735	281,65	1,11205	1,77943E-05	1,60013E-05
2000	2	332,7	66,54	79532,429	83292,11688	0,95488	0,78434	0,82142	275,15	1,00673	1,74645E-05	1,73477E-05
3000	-4,5	328,8	65,76	70131,324	75224,62194	0,93233	0,69163	0,74186	268,65	0,90922	1,71311E-05	1,88415E-05
4000	-11	324,9	64,98	61651,114	67769,11653	0,90977	0,608	0,66833	262,15	0,81911	1,6794E-05	2,05027E-05
5000	-17,5	321	64,2	54021,128	60892,64594	0,88721	0,53275	0,60052	255,65	0,736	1,64531E-05	2,23549E-05
6000	-24	317,1	63,42	47174,544	54563,26885	0,86465	0,46523	0,5381	249,15	0,65949	1,61084E-05	2,44254E-05
7000	-30,5	313,2	62,64	41048,273	48750,05083	0,8421	0,40482	0,48077	242,65	0,58923	1,57596E-05	2,67461E-05
8000	-37	309,3	61,86	35582,838	43423,05758	0,81954	0,35092	0,42824	236,15	0,52485	1,54068E-05	2,9355E-05
9000	-43,5	305,4	61,08	30722,254	38553,34813	0,79698	0,30298	0,38021	229,65	0,46599	1,50498E-05	3,22966E-05
10000	-50	301,5	60,3	26413,914	34112,96788	0,77442	0,26049	0,33642	223,15	0,41232	1,46884E-05	3,56242E-05
11000	-56,5	297,6	59,52	22608,471	30074,94146	0,75187	0,22296	0,2966	216,65	0,36351	1,43226E-05	3,9401E-05

Table 5.21 Parameters due to Altitude

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