Generating the Coordinates and Graph of NACA 00xx AIRFOIL using PYTHON

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Abstract

Python is a remarkable interpreted level, open-source, and higher-level general-purpose programming language. In this paper, Python is introduced as a regulated programming language as to make use of it to analyze engineering problems and extract results in the form of a document or in a systematic graphical representation. The purpose of this paper is to extract the coordinates of the 4-digit NACA (National Advisory Committee for Aeronautics) 0012 airfoil by solving the airfoil equation using python. The main intention of this spadework is to use python to simplify the calculation, extract the airfoil coordinates in the form of a CSV file, and generate the graph for the respective. The tiny changes in these airfoil designs can alter the overall efficiency of the plane or a turbine or another machine where this is used. Each airfoil has its own advantages and disadvantages depending upon the application of the airfoil. NACA 0012 is one of the basic airfoil shapes used in the airplanes. These airfoil designs help the plane in stability, speed control, and landing of the flight. The designed airfoils are tested for the fluid flow over the airfoil using computational fluid dynamics or simply fluid dynamics through which the efficiency or the suitability of the airfoil is checked.

Keywords: Airfoil, Python, Computational fluid dynamics, Co-ordinates, Aerodynamics.

1. Introduction

An airfoil is a cross-sectional shape of a wing, blade of a propeller, rotor, or sail. It is also called as an Aerofoil. It produces an aerodynamic force when an airfoil body is subjected to moving fluids. The forces are resolved in two directions. The force component perpendicular to the direction of motion is called Lift. The force component which is parallel to the direction of motion is called Drag [1]. An airfoil is defined as the two-dimensional representation of a wing.

The airfoils are classified into two types based on the cross-section, symmetrical airfoil in which the cambered line and chord line are the same and another one is a cambered airfoil. Based on the type of application, they are classified as Symmetrical, Cambered, Flat bottom, Supersonic, and Supercritical airfoils [3].

When the wind is opposed by an object in the opposite direction of the wind, the object experiences aerodynamic uplift forces and also drag forces. Most of the airfoil shapes need a positive angle of attack to create lift, where cambered airfoils can generate lift at zero angles of attack.

The first licensed airfoils were developed by Horatio F. Philips in 1884. He carried out the first far-reaching wind-tunnel experiments on airfoils. Later in 1902, the Wright brothers took the lead of the tests by their methods in a wind tunnel, which resulted in efficient shapes lead to the first successful flight in December 1903 [2].

The incompressible airflow over the airfoils can be analyzed by using computational fluid

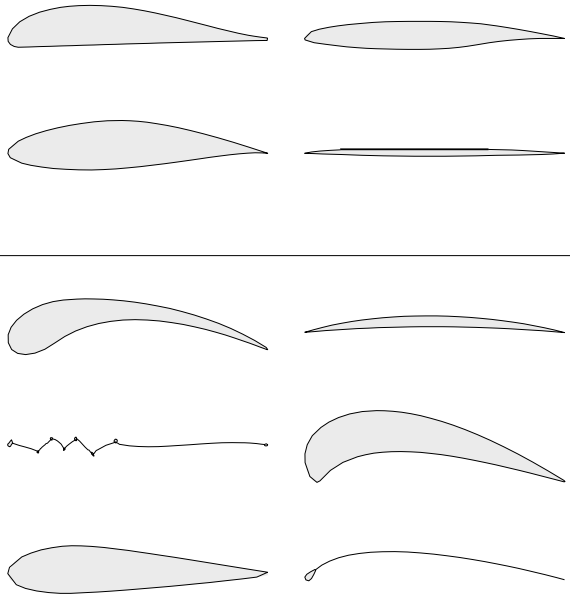dynamics which helps to resolve the equations of airfoils.

Figure 1. Examples of Airfoils in nature [1]

2. Method

This research is descriptive research with direct analysis using python including the libraries Numpy, and Matplotlib. This research uses only one kind of NACA airfoil that is NACA 0012 which is a two-dimensional(2-D) shape. The results are extracted in the form of a CSV document then the graph is plotted for the respective coordinates of the airfoil. This coordinate graph can be imported into designing software to create the actual model of the airfoil.

3. Airfoil Terminology and Nomenclature

There are a few airfoil terminologies that are used to define the parameters of the airfoil. The front point of the airfoil having maximum curvature is called as a Leading edge. The rear point of minimum curvature of the airfoil is known as the Trailing edge. The shortest line joining the leading edge and the trailing edge is called as the Chord line. The locus of point's midway between the upper and lower surface of an airfoil is defined as the Camber line. The angle between the free stream velocity and the

chord is known as the angle of attack. The ratio of a span of an airfoil to the chord length of an airfoil is called as Aspect ratio.
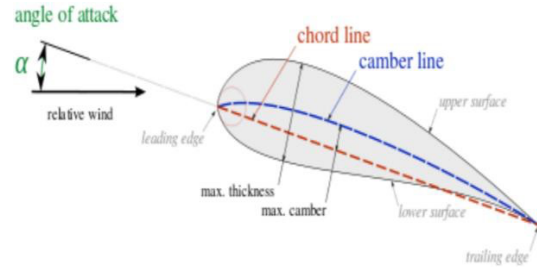

Figure 2. Airfoil Geometry [5]

There are two types of flow over the airfoil, Laminar flow, and Turbulent flow. Laminar flow is a case when the fluid flowing over the airfoil has parallel layers without any separation of flow lines. Turbulent flow is the case where there are rapid variations in the flow of the fluid and flow lines intersect. The diagrammatic view of laminar and turbulent flow is shown in Figures 3(a) and 3(b).
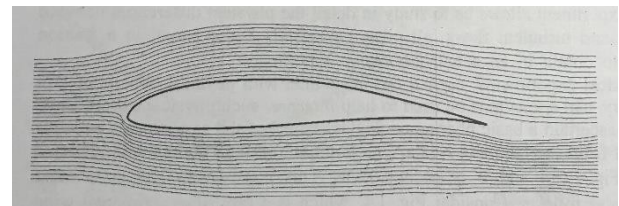

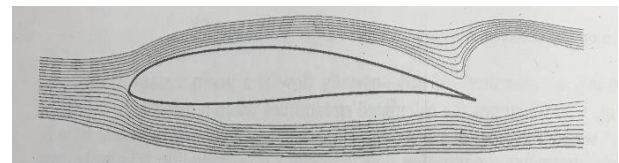**Figure 3(a). Laminar flow over an Airfoil [6]**

Figure 3(b). Turbulent flow over an Airfoil [6]

4. NACA airfoil

The NACA airfoils are the cross-sectional airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA)—the forerunner of NASA (National Aeronautics and Space Administration).

Different airfoils have been identified by NACA with a logical numbering system. The first NACA airfoils are developed in 1930, which was the 4-digit NACA airfoil series [2]. The first digit of the NACA airfoil in 4-digit airfoil indicates the maximum camber in hundredths of the chord, the second digit indicates the location of the maximum camber along the chord from the leading edge in tenths of the chord, and the last two digits indicate the maximum thickness in hundredths of chord [7]. There are many types of NACA airfoil series including, Four-digit series, five-digit series, six-digit series, seven-digit series, and eight-digit series.

The formula of a NACA 00xx airfoil shape is given by an equation. In the equation, "x" is the position along the chord from 0 to 1.00, "y1" is the half-thickness at a given value of x, "t" is the maximum thickness as a fraction of the chord, and here the value of x/c is 1.

5. Program for the NACA 00xx Airfoil

In the program, libraries called NumPy and Matplotlib have been included to simplify the equation and the library called Pandas has been included to export the coordinate file in the form of a CSV document. The values of thickness and chord are given as input in the program where the value of chord remains as 1 in most of the time. The line spacing of the points is given to 100 which can be increased to get more accurate results. The program for the NACA 0012 airfoil is as given below.

Figure 4. Libraries included in the program

The program for generating the coordinates of the airfoil is as given below.

```python
from matplotlib.pyplot import *
from numpy import *
import numpy as np
import matplotlib as plt
import pandas as pd

#initial data to be given
t=0.12
c=1
xc=np.linspace(0,1,100)

#simplifying the equation
y1=(5*t*c)*((0.2969*sqrt(xc/c))-
(0.1260*xc/c)-
(0.3516*(xc/c)**2)+(0.2843*(xc/c)**3)
-(0.1015*(xc/c)**4))
y2=-y1

#to plot results
plot(xc*c,y1,xc*c,y2)

#export to csv document
dict = {'X-coordinate':xc*c, 'Y-
coordinate':y1, 'X-coordinate-
2':xc*c,  'Y-coordinate-2':y2}
df = pd.DataFrame(dict)

#saving the CSV document
df.to_csv(r'C:\Users\Admin\Desktop\NA
CA_coordinates.csv')
```

Figure 5. Python Code for NACA 00XX airfoil

The extracted file will be saved in the given address as "NACA_coordinates" in the form of a CSV document. The graph can be obtained by plotting a graph for the extracted points.

6. Results and Discussion

Here it is shown the program for NACA 0012 airfoil. The coordinates of the airfoil are as given in the below table.

Table 1. Coordinates of NACA 0012 airfoil

X-coordinate	Y-coordinate	X-coordinate-2	Y-coordinate-2
0	0	0	0
0.010101	0.017119	0.010101	-0.01712
0.020202	0.023708	0.020202	-0.02371
0.030303	0.02853	0.030303	-0.02853

0.040404	0.03242	0.040404	-0.03242	0.484848	0.053871	0.484848	-0.05387
0.050505	0.035699	0.050505	-0.0357	0.494949	0.053256	0.494949	-0.05326
0.060606	0.038535	0.060606	-0.03854	0.505051	0.052619	0.505051	-0.05262
0.070707	0.041027	0.070707	-0.04103	0.515152	0.051959	0.515152	-0.05196
0.080808	0.04324	0.080808	-0.04324	0.525253	0.051279	0.525253	-0.05128
0.090909	0.045219	0.090909	-0.04522	0.535354	0.050577	0.535354	-0.05058
0.10101	0.046997	0.10101	-0.047	0.545455	0.049855	0.545455	-0.04986
0.111111	0.0486	0.111111	-0.0486	0.555556	0.049114	0.555556	-0.04911
0.121212	0.050048	0.121212	-0.05005	0.565657	0.048354	0.565657	-0.04835
0.131313	0.051356	0.131313	-0.05136	0.575758	0.047575	0.575758	-0.04758
0.141414	0.052538	0.141414	-0.05254	0.585859	0.046779	0.585859	-0.04678
0.151515	0.053605	0.151515	-0.0536	0.59596	0.045964	0.59596	-0.04596
0.161616	0.054565	0.161616	-0.05457	0.606061	0.045133	0.606061	-0.04513
0.171717	0.055427	0.171717	-0.05543	0.616162	0.044284	0.616162	-0.04428
0.181818	0.056199	0.181818	-0.0562	0.626263	0.04342	0.626263	-0.04342
0.191919	0.056884	0.191919	-0.05688	0.636364	0.042539	0.636364	-0.04254
0.20202	0.05749	0.20202	-0.05749	0.646465	0.041642	0.646465	-0.04164
0.212121	0.058021	0.212121	-0.05802	0.656566	0.04073	0.656566	-0.04073
0.222222	0.058482	0.222222	-0.05848	0.666667	0.039803	0.666667	-0.0398
0.232323	0.058875	0.232323	-0.05887	0.676768	0.038861	0.676768	-0.03886
0.242424	0.059205	0.242424	-0.0592	0.686869	0.037904	0.686869	-0.0379
0.252525	0.059474	0.252525	-0.05947	0.69697	0.036933	0.69697	-0.03693
0.262626	0.059687	0.262626	-0.05969	0.707071	0.035948	0.707071	-0.03595
0.272727	0.059845	0.272727	-0.05984	0.717172	0.034948	0.717172	-0.03495
0.282828	0.05995	0.282828	-0.05995	0.727273	0.033934	0.727273	-0.03393
0.292929	0.060006	0.292929	-0.06001	0.737374	0.032907	0.737374	-0.03291
0.30303	0.060015	0.30303	-0.06001	0.747475	0.031866	0.747475	-0.03187
0.313131	0.059978	0.313131	-0.05998	0.757576	0.030811	0.757576	-0.03081
0.323232	0.059897	0.323232	-0.0599	0.767677	0.029742	0.767677	-0.02974
0.333333	0.059775	0.333333	-0.05978	0.777778	0.02866	0.777778	-0.02866
0.343434	0.059613	0.343434	-0.05961	0.787879	0.027564	0.787879	-0.02756
0.353535	0.059412	0.353535	-0.05941	0.79798	0.026455	0.79798	-0.02645
0.363636	0.059173	0.363636	-0.05917	0.808081	0.025332	0.808081	-0.02533
0.373737	0.0589	0.373737	-0.0589	0.818182	0.024195	0.818182	-0.0242
0.383838	0.058591	0.383838	-0.05859	0.828283	0.023045	0.828283	-0.02305
0.393939	0.05825	0.393939	-0.05825	0.838384	0.021881	0.838384	-0.02188
0.40404	0.057877	0.40404	-0.05788	0.848485	0.020703	0.848485	-0.0207
0.414141	0.057473	0.414141	-0.05747	0.858586	0.019512	0.858586	-0.01951
0.424242	0.05704	0.424242	-0.05704	0.868687	0.018306	0.868687	-0.01831
0.434343	0.056578	0.434343	-0.05658	0.878788	0.017086	0.878788	-0.01709
0.444444	0.056088	0.444444	-0.05609	0.888889	0.015852	0.888889	-0.01585
0.454545	0.055572	0.454545	-0.05557	0.89899	0.014603	0.89899	-0.0146
0.464646	0.05503	0.464646	-0.05503	0.909091	0.013339	0.909091	-0.01334
0.474747	0.054462	0.474747	-0.05446	0.919192	0.012061	0.919192	-0.01206

0.929293	0.010767	0.929293	-0.01077
0.939394	0.009457	0.939394	-0.00946
0.949495	0.008132	0.949495	-0.00813
0.959596	0.006791	0.959596	-0.00679
0.969697	0.005434	0.969697	-0.00543
0.979798	0.00406	0.979798	-0.00406
0.989899	0.002668	0.989899	-0.00267
1	0.00126	1	-0.00126

Using these coordinates graph can be plotted for the NACA 0012 airfoil as shown below in Figure 6. Since the NACA 0012 is an airfoil
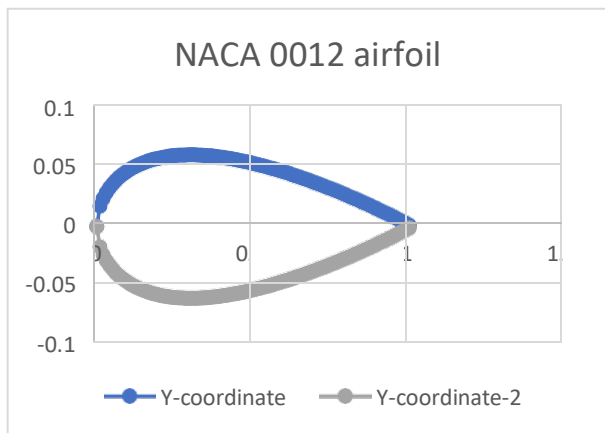

Figure 6. NACA 0012 airfoil coordinates

without any camber, it is symmetrical in shape. Further, the airfoil section can be used to analyze the pressure and velocity contours using the finite element method with help of Computational fluid dynamics. Computational fluid dynamics result is directly obtained in the laboratory from the wind tunnel by varying the values of Reynold's number, Mach number, etc.

Instead of using that giant wind tunnel to plot the results, nowadays researchers and other workers are using some simulation software like Ansys, Hypermesh, and Hyper works.

The slight variations made in the airfoil thickness or camber or chord will give different results of velocity and pressure contours in the simulation software. Each change made to the airfoil will affect the efficiency, speed, and control of the airplane.
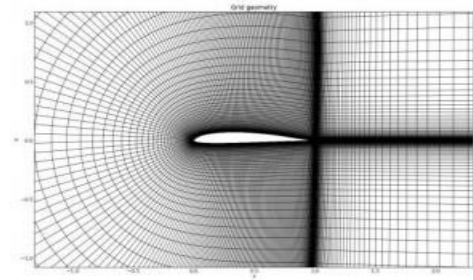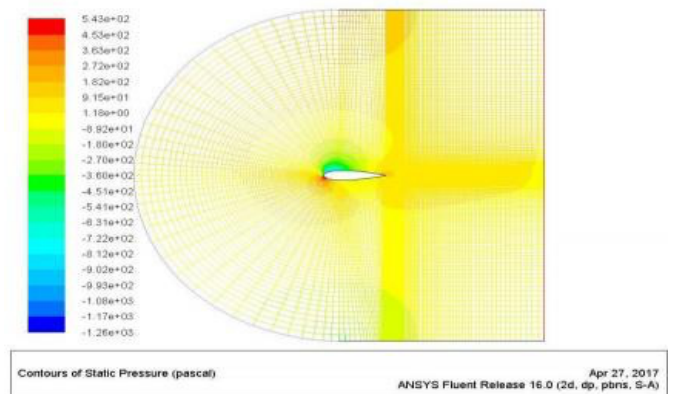

Figure 7. Mesh Generation [5]

Figure 8. Contours of pressure at 16^0 of AOA [5]
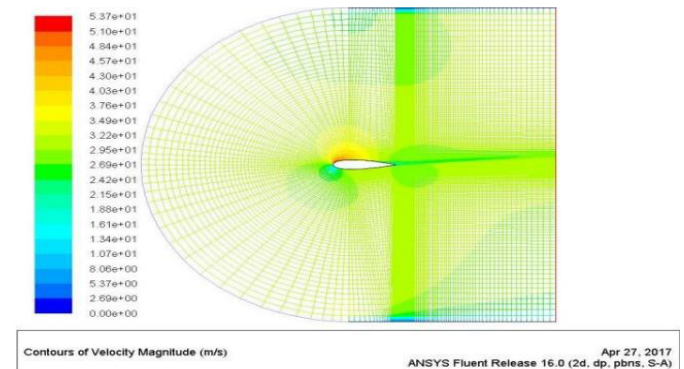

Figure 9. Contour of velocity magnitude at 16° AOA [5]

7. Conclusion

In summary, we can conclude that programming software is a need in all the fields of this rapidly growing technology. By the results obtained from the above program, we can say that it'll also give accurate results and saves a lot of time in calculating, simplifying, and extracting the coordinates than doing it manually.

8. Further recommendation

The program described in this paper is only for 4-digit NACA 00xx airfoils which are camberless. Further work can be carried in the same way on NACA 4-digit cambered airfoils by obtaining the equation for the same and simplifying it by using python programming.

9. References

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