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Aerodynamic Analysis of Aircraft Wing

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Abstract—*Aerodynamics plays an important role in the performance of an Airplane during flight as well as during take-off and landing. Aerodynamics problems in general are often difficult to solve by analytics analysis. However, due to the large expenses required in the experimental method, the numerical method is more preferred. This paper presents the modeling and simulating processes of computational fluid dynamic (CFD) problem on aircraft wing model. AUTODESK CFD used to analyse the pressure and velocity distribution of different shapes of wing.*

Keywords*: Aerodynamic, airfoil, wing model, pressure coefficient, CFD analysis.*

1. INTRODUCTION

It is a fact of common experience that a body in motion through a fluid experience a resultant force which, in most cases is mainly a resistance to the motion, patel *et al* [1]. A class of body exists, However for which the component of the resultant force normal to the direction to the motion is many time greater than the component resisting the motion, and the possibility of the flight of an airplane depends on the use of the body of this class for wing structure. Airfoil is such an aerodynamic shape that when it moves through air, the air is split and passes above and below the wing. The wing's upper surface is shaped so the air rushing over the top speeds up and stretches out. This decreases the air pressure above the wing. The air flowing below the wing moves in a comparatively straighter line, so its speed and air pressure remains the same. Since high air pressure always moves toward low air pressure, the air below the wing pushes upward toward the air above the wing. The wing is in the middle, and the whole wing is "lifted." The faster an airplane moves, the more lift there is. And when the force of lift is greater than the force of gravity, the airplane is able to fly.

2. NOMENCLATURE OF AN AIRFOIL

The suction surface (upper surface) is generally associated with higher velocity and lower static pressure. The pressure surface (lower surface) has a comparatively higher static pressure than the suction surface. The pressure gradient between these two surfaces contributes to the lift force generated for a given airfoil. The **leading edge** is the point at the front of the airfoil that has maximum curvature. The **trailing edge** is defined similarly as the point of maximum curvature at the rear of the airfoil. The **chord line** is the straight line connecting leading and trailing edges. The chord length, or simply chord, is the length of the chord line. That is the reference dimension of the airfoil section [1]. The basic nomenclature of an airfoil is shown in Fig. 1.

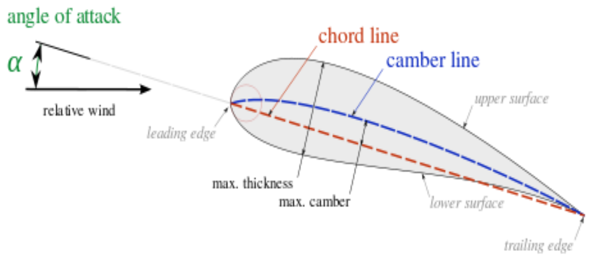


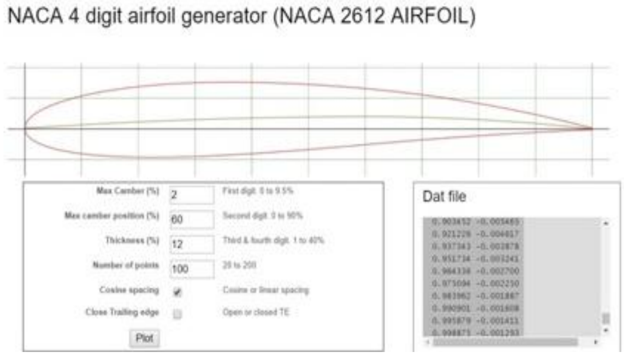
Figure 1: Basic nomenclature of an airfoil

3. APPLICATONS OF SYNTHETIC CURVES TO AIRFOIL PROFILES

Many shapes in real life applications such as aircraft bodies, automobile body shapes, moulds and die profiles, horse saddle, ship hulls, etc., are difficult to represent by analytical curves. For this purpose free-form synthetic curves are developed [2]. Applications of such synthetic curves like B-spline, Bezier, and Lagrange have been implemented in this section.

3.1 B-Spline Curve

B-spline curve have the flexibility of choosing the degree of the curve irrespective of the number of control points using the software available for standard airfoil generator by 'National Advisory Committee for Aeronautics' (NACA), the resultant co-ordinate data is produced as shown in Figure 2.



NACA 4 digit airfoil generator (NACA 2612 AIRFOIL)

Max Camber (%)	2	First digit 0 to 9.5%
Max camber position (%)	60	Second digit 0 to 90%
Thickness (%)	12	Third & fourth digit 1 to 40%
Number of points	100	20 to 200
Cosine spacing	☑	Cosine or linear spacing
Close Trailing edge	☐	Open or closed TE

Dat file

```
0.903452 -0.005465
0.921226 -0.004617
0.937343 -0.003878
0.951734 -0.003241
0.964336 -0.002700
0.975094 -0.002250
0.983962 -0.001887
0.990901 -0.001608
0.995879 -0.001411
0.998875 -0.001293
```

Fig. 2: NACA airfoil by B-spline

Using this data, B-spline curve for airfoil is plotted as shown in Figure 3 using AUTOCAD software considering following parameters of the curve, Patel *et al* [1]:

1. Maximum camber=2%
2. Maximum camber position = 60%
3. Thickness =12%
4. Number of points =100
5. Initial velocity =51 m/s
6. Initial pressure=101325 pa

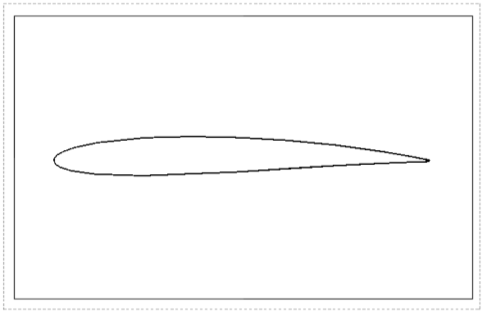


Fig. 3: B-spline airfoil by AutoCAD

Aerodynamic analysis of this curve is carried out using CFD module of Autodesk software. The result of analysis is shown in Figure 4.

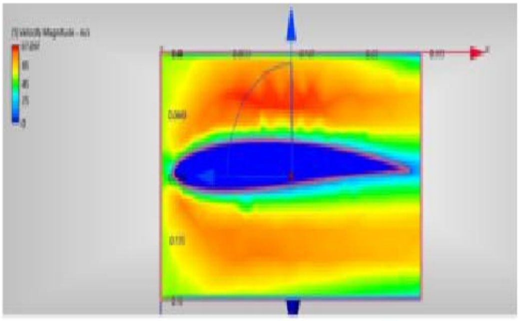


Fig. 4: CFD analysis of B-spline profile for airfoil

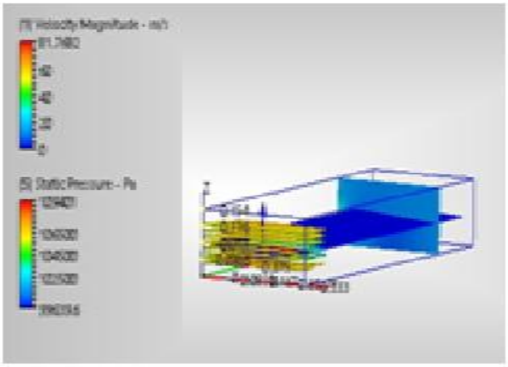


Fig. 5: CFD results analysis of B-spline profile for airfoil

As shown in above figure 5, the grid is generated on the surface of airfoil which is indicated by yellow colour lines and the blue colour is indicated as the surface of airfoil. Pressure is higher on the upper surface of airfoil and reaches its maximum at the point of attack. Meanwhile, the flow velocity on the upper surface is faster than the lower surface of airfoil. Therefore, lift generation theory was demonstrated to be consistent by simulation method.

3.2 Bezier Curve

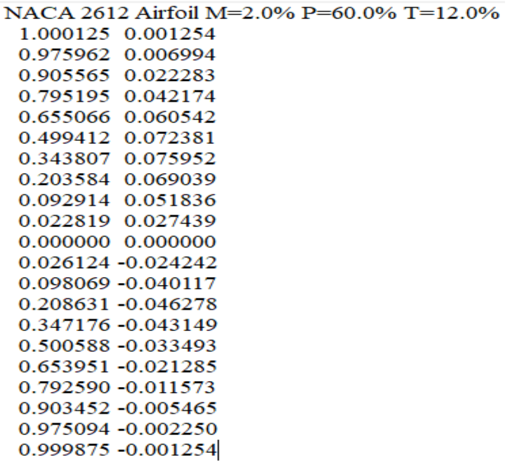
Bernestein polynomials are simply defined, can be calculated quickly on computer system and represent a tremendous variety of functions. They can be differentiated and integrated easily, and can be pieced together to form spline curves that can approximate any function to any accuracy desired, [3].

$$p(u) = a_0 + a_1 u + a_2 u^2 + \ldots + a_{n-1} u^{n-1} + a_n u^n \qquad \text{(i)}$$

Where,

$$\binom{n}{i} = \frac{n!}{i!(n-i)!} \ldots\ldots\ldots \qquad \text{(ii)}$$

Entering above value in NACA , get the 20 points for Bezier curve using this points the equation for curve is develop, as shown in figure 6



NACA 2612 Airfoil M=2.0% P=60.0% T=12.0%

```
1.000125  0.001254
0.975962  0.006994
0.905565  0.022283
0.795195  0.042174
0.655066  0.060542
0.499412  0.072381
0.343807  0.075952
0.203584  0.069039
0.092914  0.051836
0.022819  0.027439
0.000000  0.000000
0.026124 -0.024242
0.098069 -0.040117
0.208631 -0.046278
0.347176 -0.043149
0.500588 -0.033493
0.653951 -0.021285
0.792590 -0.011573
0.903452 -0.005465
0.975094 -0.002250
0.999875 -0.001254
```

Fig. 6: Points from online generator

$$= (1-t)^{20}t^{0} + 20(1-t)^{19}t^{1} + 190(1-t)^{18}t^{2} + 1140(1-t)^{17}t^{3} + 4845(1-t)^{16}t^{4}$$
$$+ 15504(1-t)^{15}t^{5} + 38760(1-t)^{14}t^{6} + 77520(1-t)^{13}t^{7} + 125970(1-t)^{12}t^{8}$$
$$+ 167960(1-t)^{11}t^{9} + 184756(1-t)^{10}t^{10} + 167960(1-t)^{9}t^{11}$$
$$+ 125970(1-t)^{8}t^{12} + 77520(1-t)^{7}t^{13} + 38760(1-t)^{6}t^{14} + 15504(1-t)^{5}t^{15}$$
$$+ 4845(1-t)^{4}t^{16} + 1140(1-t)^{3}t^{17} + 190(1-t)^{2}t^{18} + 20(1-t)t^{19} + t^{20}$$

Using this data, Bezier curve for airfoil is plotted as shown in Figure 7 using AUTOCAD software

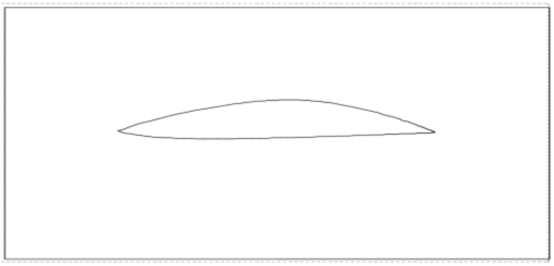


Fig. 7: Bezier curve by AutoCAD

The result of analysis as shown in figure 8

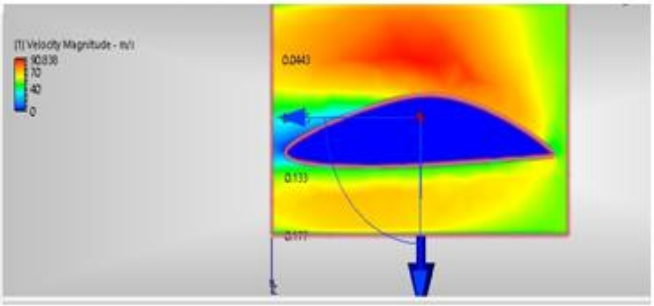


Fig. 8: CFD analysis of Bezier curve profile for airfoil

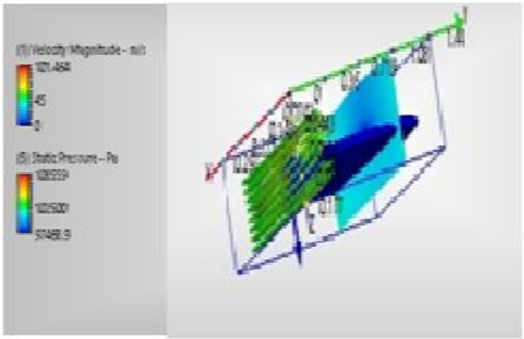


Fig. 9: CFD results analysis of Bezier curve profile for airfoil

As shown in figure 8 and figure 9, Pressure is lower on the upper surface of airfoil and, the flow velocity on the lower surface is faster than the upper surface of airfoil reaches its minimum at the point of attack Meanwhile Therefore, lift generation theory was not demonstrated to be consistent by simulation method.

3.3 LAGRANGE INTERPOLATION CURVE

This is again an N^{th} degree polynomial approximation formula to the function f(x), which is known at discrete points x_i, i = 0, 1, 2 . . . N^{th}. The formula can be derived from the Vandermonds determinant but a much simpler way of deriving this is from Newton's divided difference formula,[4].If f(x) is approximated with an N^{th} degree polynomial then the N^{th} divided difference of f(x) constant and $(N+1)^{th}$ divided difference is zero,[5]. That is

$$f\,[x_0, x_1, \ldots x_n, x] = 0$$

$$L = \prod_{\substack{j=0 \\ j \neq 0}}^{n} \frac{x - x_i}{x_i - x_j}$$

The result of analysis as shown in figure 10

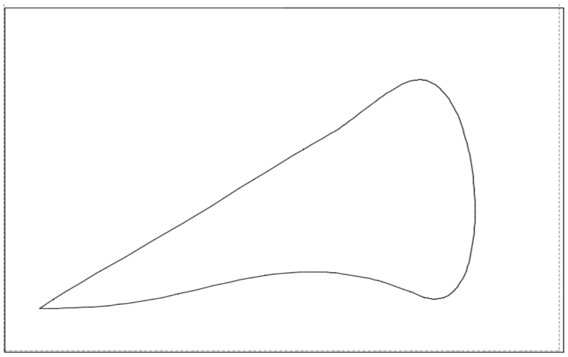


Fig. 10: Lagrange curve in AutoCAD

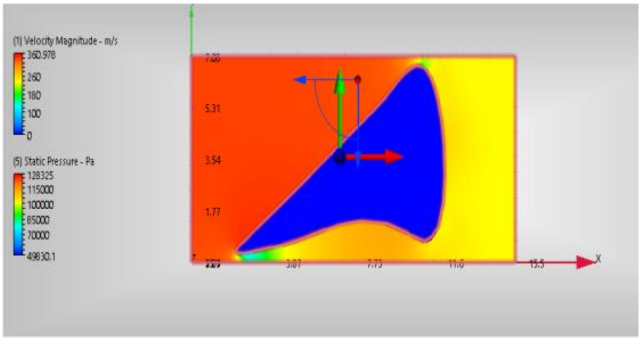


Fig. 11: CFD analysis of Lagrange curve profile for airfoil

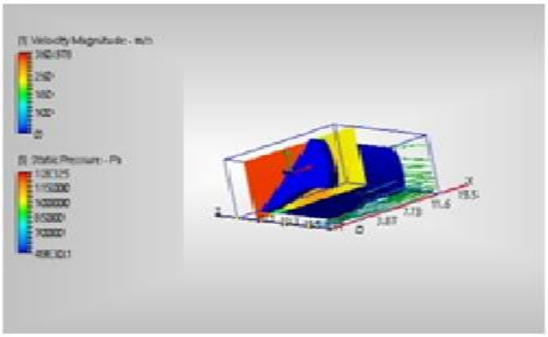


Fig. 12: CFD results of Lagrange curve profile for airfoil

As shown in figure 11 and figure 12, Pressure is higher on the upper surface of airfoil and reaches its minimum at the point of attack. Meanwhile, the flow velocity on the upper surface is faster than the lower surface of airfoil. Therefore, lift generation theory was not demonstrated to be consistent by simulation method. In this paper, the aircraft wing model using NACA 2612 airfoil was chosen to be analyzed. Fluent and Structural packages of AUTODESK Software were used to simulate the model, Ng**uy**en Minh Triet *et al* [6]

4. RESULT AND COMPARISON

Table 1: Resultant data from the analysis of three curves

Sr. No	Parameters	B-spline curve	Bezier curve	Lagrange curve
1	Velocity(m/s) (maximum)	81.7682	101.464	1690575
	(initial velocity)	51	51	51
2	Pressure(pa) (maximum)	109401	108559	126617
	(initial pressure)	101325	101325	101325

From above mentioned table no 1, the B-spline curve has maximum velocity as compared to Bezier curve and langrage curve, and the Lagrange curve has maximum pressure according to the Bezier curve and B-spline curve so going to the next step, Consider the B-spline curve velocity as 1 and others curve velocity are divided by B-spline curve velocity, similarly Lagrange curve pressure as 1 and curve pressure divided by Lagrange curve pressure as shown in table 2

Table 2: Normalization of data shown in Table 1

	Velocity	pressure	Score
B-Spline curve	1	0.86	1.86
Bezier curve	0.80	0.85	1.65
Lagrange Interpolation Curve	0.48	1	1.48

5. CONCLUSION

From table no 2 conclude that the score of B-spline curve is more than Bezier curve and Lagrange interpolation curve. For lifting the airplane the pressure in lower side of the wing is higher and the velocity is low so therefore the pressure in upper side of wing is less and velocity is more according to this criteria velocity is low and pressure is high in lower side of wing is B-spline curve. Therefore according to analysis of three curves the B-spline curve is more preferable than the Bezier curve and Lagrange interpolation curve for Aircraft Wing

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