

# Study of Aerofoils of various NACA series and Wing Contour generation using CATIA

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## ABSTRACT

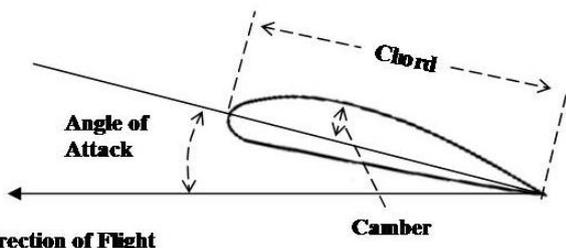
Aerofoil is the basic part to be designed during starting stage of creating a new airplane. It is the part that forms of cross section of the wing. The wing is used to produce lift force that balances the weight which acts downwards. Velocity variation creates pressure difference over top and bottom surface of wing. The pressure difference over top and bottom surface of wing creates lift. In this paper, we studies about aerofoil and its basic types and various NACA series and equation of 4 digit NACA series. In this paper, we come to know how we can export an aerofoil in CATIA from MS EXCEL and how we can design wing contour using CATIA software.

## Keywords

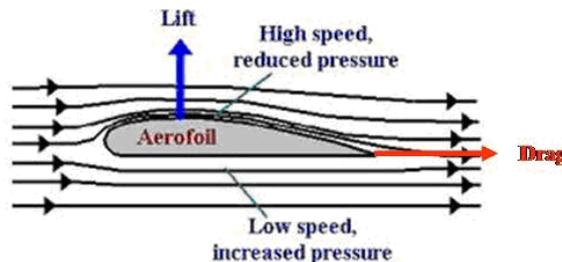
Aerofoil, Lift, Wing Contour, CATIA, MS-EXCEL, NACA Series.

## 1. INTRODUCTION

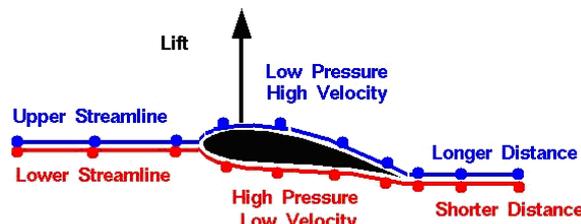
An aerofoil is a shape of an aircraft wing or blade which can produce aerodynamic forces. First patented aerofoil shapes were developed by Horatio F. Phillips in 1884. The standard nomenclature of aerofoil is established by NACA. Consider the aerofoil sketched as



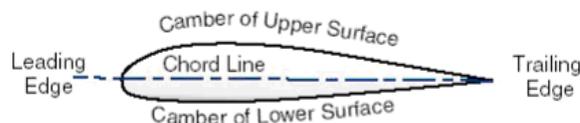
Straight line connecting the leading edge and trailing edge is known as chord line. And precise distance between leading and trailing edge is known as chord. Mean camber is the locus of points halfway between upper and lower surface as measured perpendicular to mean camber line itself. Thickness is the distance between upper and lower surface measured perpendicular to chord line. Force acting upward perpendicular to aerofoil is called lift. Force that acts parallel to an aerofoil, or force acting in opposite direction to line of flight is called drag.



Aerofoil mainly produces lift because of its angle of attack and its cross sectional shape, where angle of attack is defined as an angle formed free-stream air and chord line of airfoil. Most of the aerofoil has positive angle of attack.



On the behave of camber, aerofoil structured into two parts (1) Symmetric aerofoil (2) Cambered aerofoil. Aerofoil whose mean camber line coincides with chord line is known as symmetric aerofoil. In case of symmetric aerofoil, camber is zero.



On other hand, aerofoil whose camber line does not coincide with chord line is known as a cambered aerofoil. For subsonic use the aerofoil section has rounded edge. The depth increases smoothly to a maximum which usually occurs between  $\frac{1}{4}$  and  $\frac{1}{2}$  way along the profile and thereafter tapers off toward rear of section.

## 2. DESIGN

National Advisory Committee for Aeronautics developed many designs of aerofoil. These are known as series or NACA series of aerofoil.

### 2.1 Four Digit NACA Series

4 digit NACA series developed in 1930s. This defines the profile as first digit is the maximum camber in 100<sup>th</sup> of chord. 2<sup>nd</sup> digit is the location of maximum camber along chord from leading edge in 10<sup>th</sup> of chord. Last two digits give maximum thickness in 100<sup>th</sup> of chord. For Example: NACA 2412- Maximum camber is 0.02c located at 0.4c from leading edge and maximum thickness is 0.12c (where c shows chord).

For Symmetrical Aerofoil NACA 00XX, camber is zero. XX indicates aerofoil has a XX thickness to chord length ratio.

#### 2.1.1 Equation for 4 Digit NACA Series

$$y_t = (t/0.2) (0.2969\sqrt{x} - 0.126x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4)$$

Where, c is the chord length.

x is the position along chord from 0 to c.

y is the half thickness at a given value of x.

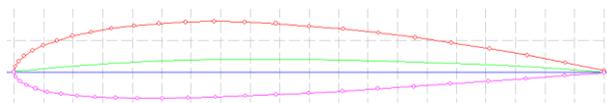
t is the maximum thickness as a fraction of chord.

By putting all these values in equation, we get required points of x and y.

For upper surface {x(U),y(U)} and for lower surface {x(L),y(L)}

$$x(U) = x(L) = x, \quad y(U) = +y(t), \quad y(L) = -y(L)$$

Using these points we can form a profile for aerofoil of 4 digit series.



For Cambered Aerofoil Equation is different from symmetrical aerofoil, given as

$$y_c = (m/p^2) (2px - x^2); \text{ for } x \leq p$$

$$y_c = (m/(1-p)^2) ((1-2p) + 2px - x^2); \text{ for } x > p$$

where m is maximum camber and p is the location of maximum camber. In case of cambered aerofoil, the thickness needs to be perpendicular to camber line.

- The final coordinates for the airfoil upper surface (x<sub>u</sub>, y<sub>u</sub>) and lower surface (x<sub>L</sub>, y<sub>L</sub>) are given by:

$$x_u = x - y_c (\sin\theta)$$

$$y_u = y_c + y_c (\cos\theta)$$

$$x_L = x + y_c (\sin\theta)$$

$$y_L = y_c - y_c (\cos\theta)$$

$$\text{where } \theta = \arctan(\Delta y_c / \Delta x)$$

### 2.2 Five Digit NACA Series

In five digit NACA series, first digit when multiplied by 3/2 it gives the design lift coefficient in tenths. Next two digits when divide with 2 it gives the location of maximum camber from leading edge in 100<sup>th</sup> of chord. Last 2 digits give maximum thickness in 100<sup>th</sup> of chord.

For Example: NACA 23012 is defined as, Design lift coefficient = 2\*(3/2)\*(1/10) =0.3, Maximum camber located at = (30/2)\*(c/100) = 0.15c, Maximum thickness of aerofoil = 12\*c/100 = 0.12c

### 2.3 Six Digit NACA Series

In six digit NACA series, first digit simply identifies the series. Second digit gives the location of minimum pressure in tenths of chord from leading edge. Third digit gives the design lift coefficient in tenths and last two digits give maximum thickness in 100<sup>th</sup> of chord. For Example: NACA 65-218 is defined as follows, 6 show the designation of series, minimum pressure occurs at 0.5c from leading edge of aerofoil. Lift coefficient is 0.2c and maximum thickness of aerofoil is 0.18c.

### 2.4 Seven Digit NACA Series

This series give further advancement in maximizing laminar flow achieved by separately identifying the low pressure zones on upper and lower surfaces of the aerofoil. First digit designates the series. Second digit describes the distance of minimum pressure area on the upper surface in tenths of chord. Third digit gives distance of minimum pressure area on the lower surface in tenths of chord. Fourth letter refers to a standard profile from earlier NACA series. Fifth digit describe lift coefficient in tenths. Last digits two describe maximum thickness as 100<sup>th</sup> of chord. For Example: NACA 712A315 has area of minimum pressure 0.1 of chord back on upper surface and 0.2 of chord back on lower surface, uses standard 'A' profile, has a lift coefficient of 0.3 and has maximum thickness of 0.15of the chord.

## 3. HOW TO EXPORT AEROFOIL IN CATIA?

CATIA is software, which is used to form three dimensional designs of machines, machine parts, tools etc.

To export aerofoil in CATIA, we have to follow following steps:

Step 1: Open the CATIA V5, click on file option and select 'new'. From 'new', select part and part1, then click ok.

Step 2: Minimize the CATIA and open the MS-EXCEL. We make an Excel sheet (having exporter to CATIA) in which we put x and y coordinates calculated from equation of aerofoil, which are discussed above.

Step 3: put z-axis coordinates zero, because aerofoil is a two dimensional profile. For Example, we have 4 digit series aerofoil i.e. NACA 2412



Name Points	X	Y	Z
1	0	0	0
2	1.58915023	8.253879216	0
3	7.89745093	16.54474057	0
4	16.58961763	24.83560207	0
5	31.17913585	33.20106036	0
6	49.51414799	41.79776962	0
7	72.5902314	48.88482507	0
8	99.48442064	55.18846936	0
9	130.3472912	62.20560921	0
10	165.1062584	68.30196807	0
11	203.5849989	72.98935455	0
12	245.0910238	76.42722232	0
13	290.3510323	78.54626064	0
14	339.4153077	79.20888068	0
15	392.7431777	78.52088189	0
16	444.5328869	75.8910389	0
17	500.4247723	72.26299211	0
18	558.452121	67.59914844	0
19	618.236986	61.85310321	0
20	679.420959	54.98916869	0
21	742.2998191	46.0297802	0
22	806.9742603	35.5522646	0
23	870.3574253	25.94533273	0
24	935.1583295	14.18802987	0
25	1000.8170064	1.229504331	0
26	2.8426385	-7.820600918	0
27	13.18289179	-11.8468864	0

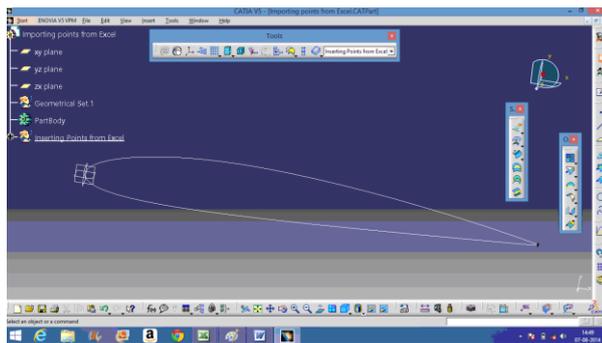
Step 4: Click on 'Exporter a CATIA' box to insert all the points in CATIA from Excel sheet. Click at 'ok'.

Step 5: Progress screen shown at monitor, then click at EXIT. Close the MS-EXCEL.

Step 6: Open the minimized CATIA folder.

Step 7: Click at 'fit in all' option. Now, click at spline command and join all the points one by one in series.

Step 8: Click at 'Tools' and select 'hide all points' option to hide all the points.



Hence aerofoil is created in CATIA.

#### 4. HOW TO DESIGN WING CONTOUR USING CATIA?

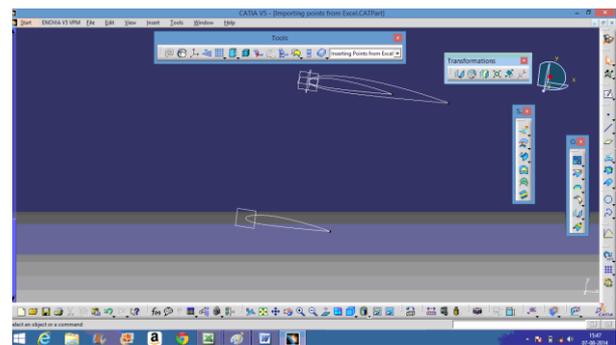
To design a wing contour using CATIA, firstly we repeat all the steps 1 to 8 given above to export an aerofoil in CATIA. Then, follow the steps given below:

Step 9: select plane command to define a plane, click at reference plane (xy) and give offset of 3000 and click at 'ok'.

Step 10: select scaling command, click at aerofoil and then at reference plane zx. After that give ratio 0.6 and click at ok.

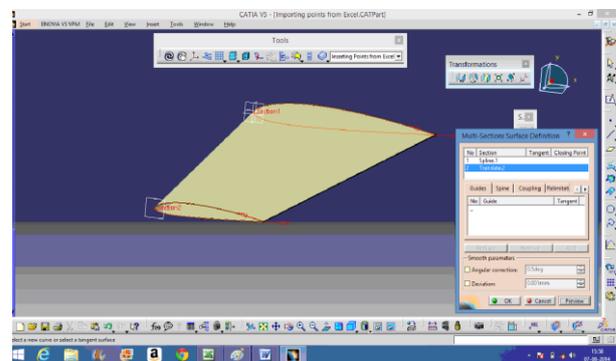
Step 11: Repeat step 10 to scale new aerofoil with reference plane yz having ratio 0.6 and hide the middle aerofoil by right clicking at that aerofoil and click at hide option.

Step 12: select translate command to draw wing tip and click at small aerofoil, select reference plane xy with distance 3000 and click 'ok'.



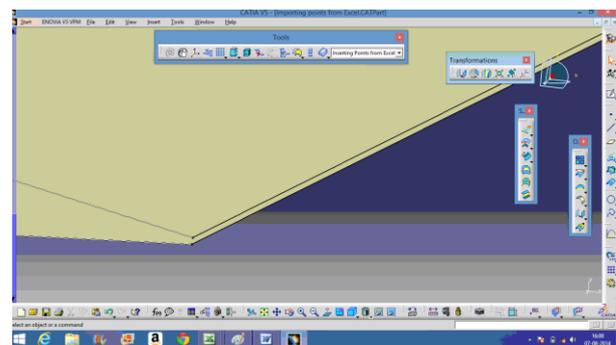
Step 13: Hide the first small aerofoil.

Step 14: Select multi-section command, and click at both aerofoils one by one, then at 'ok'.



Step 15: Select split command, click at wing surface and zx plane. by keeping both sides, click 'ok'.

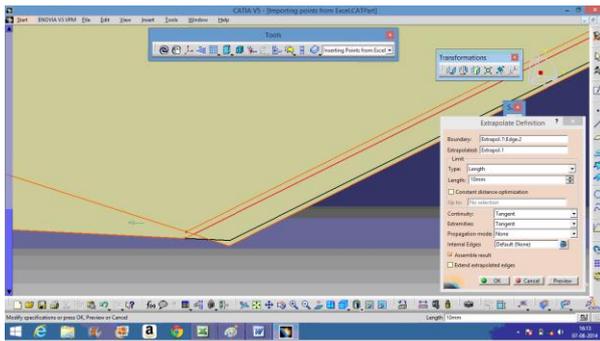
Step 16: Zoom in at trailing edge of wing.



Trailing edge of wing is not closed, to make it close we extrapolate upper and lower surface one by one.

Step 17: To extrapolate, select extrapolate command and click at edge and surface of upper section, then click at 'ok'.

Step 18: repeat the step 17 at lower section of wing.

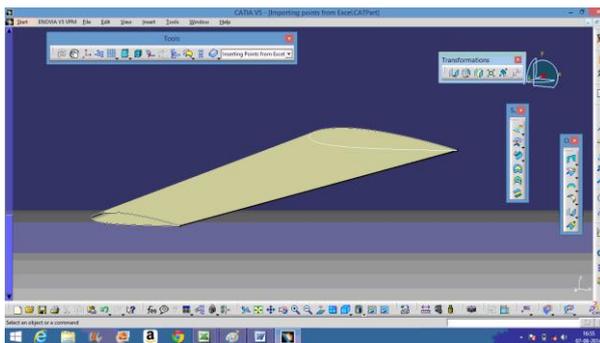


Step 19: choose shape fillet command to put a fillet on intersection of surfaces. For this, select shape fillet. and for support1, click at upper surface and inside arrow direction. For support2, click at lower surface and inside arrow direction. Click 'ok'.

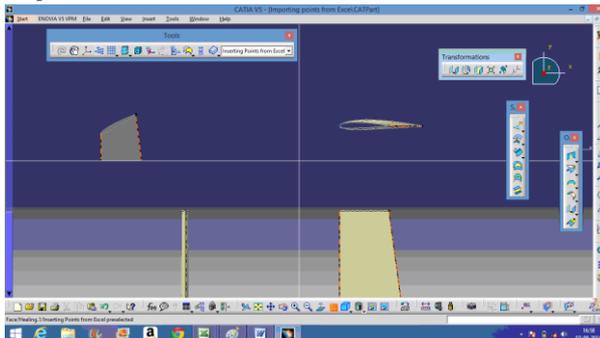
Step 20: Select healing command, click the surface and then click ok.

Step 21: Hide all the planes.

Design of wing contour is completed. Shown as:



Step 22: For multi-view, click at multi-view command.



## 5. CONCLUSION

Here, we have studied about aerofoil and different types and various NACA series of aerofoil including NACA 4 digit, NACA 5 digit, NACA 6 digit and NACA 7 digit series. We come to know how we can export an aerofoil in CATIA. We conclude that we can easily form precise profile of aerofoil with the help of MS EXCEL and CATIA. Aerofoil mainly produces lift because of its angle of attack and its cross sectional shape. In this paper, we have studied how easily we can design a wing with the help of CATIA software. We can design different types of wing using different-different profiles of aerofoil in CATIA.

## 6. FUTURE SCOPES

Using this, further modification can be done to design aerofoils and wings. We can modify different aerofoil profiles and different types of wings. For sonic, super sonic and hyper sonic aircrafts different types of aerofoils and wings are used depending upon lift needs. Aerofoil shapes used to produce maximum lift. So, aerofoil shapes can be modified according to use of lift. From these aerofoils, further different types of wings can be designed to produce maximum lift.

## 7. REFERENCES

- [1] Fundamentals of Aerodynamics (John D Anderson Jr.)
- [2] Aerodynamics For Engineering Students (E.L. Houghton And P.W. Carpenter)