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DEVELOPMENT OF FISH TAIL BLADE MODEL USING NACA AIRFOIL PROFILES

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ABSTRACT

The performance of turbine blade depends on the blade geometry and profile. Biomimetic technology indicated that the cross-section of a fish tail has an airfoil-like cross-section. In this study, the concept of the nature of the fish tail was used to develop a fish tail blade model using AutoCAD and CATIA software.

1. INTRODUCTION

The performance of wind turbine depends on the aerodynamics parameters as a function of the blade geometry and shape. The airfoil shape, long and thin with rounded nose and sharp trailing edge is a remarkable geometry that produces a large number of lift force (l) and experiences very low drag (d).This shape works for subsonic high Reynolds number flows. Supersonic airfoils have pointed leading edge to minimize shock produced drag [1].

The observation of human surroundings to enhance life styles applied biomimetic technology ranging from Nano to larger scales. This fact can be seen in the ways birds are flaying and fish swimming using their fins and tails. This concept can be applied in wind turbine blade development.

A marine biologist and researcher observe that fish swim by their lift-base propulsion by coordinated motion of their body and tails like the fast swimmers like Dolphins and Tuna fish [1]. Aquatic animals, insects and birds exibit a different kinetic mechanism in their locomotion. Instead of rotational propellers, these animals utilize oscillatory motions with fins or wings to achieve highly effective propelling and manoeuvring [2].

The thrust from the fluffing tail (the caudal fin) of a fish is very similar to that from a rotating propeller blade. Both are based on the lift force generated by the airfoil type cross sections. The caudal fin oscillates laterally as the fish moves forward. It has two oscillatory motion, lateral motion with amplitude H, and a rotary motion or pitching motion around an axis within the airfoil as indicated in figure 1..

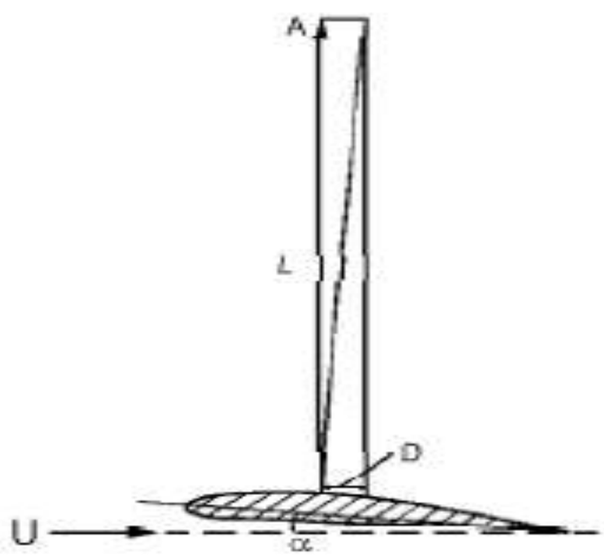

Figure 1.1: The airfoil shape with rounded Leading and sharp trailing edge that gives a larger lift and small drag [1].

The wing of birds, marine propellers, steam turbines and helicopter rotor blades and tails of fish all have cross sections with an airfoil shape as indicated in figure 1.2 [1].

2.0 BLADE GEOMETRY AND CAD MODELLING

The wing is an important parameter of wind turbines (which is the blade). Wind hits the wings and the energy of wind is transformed into mechanical energy. Wings profiles are called airfoils. Airfoil profile is an important parameter for blade design. The blade efficiency depends on airfoil profile, therefore there is a need to study airfoil profile in order to improve the efficiency.

2.1 Air Foil

There are vast number of standard National Advisory Committee on Aeronautics (NACA) air foils database, for example the NACA 0015. The NACA 0015 is a low speed airfoils suitable for low wind speed application. The NACA 0015 airfoil has a maximum thickness of 15% with no camber (symetric).

2.2 Lift-Base Propulsion

The airfoil surfaces are the base for efficient lift and thrust on the airfoil. Wing of an aircraft is one of the visible applications of airfoil. The lift force on an airfoil of plan-form area A moving with velocity U in stationary fluid is usually written as

$$L = C_L (\tfrac{1}{2}) \rho U^2 A \qquad (1)$$

For Symmetrical airfoil of the type found in fish tails, the lift coefficient C_L is given by

$$C_L = 2\pi\alpha \qquad (2)$$

Where α is the angle of attack between the airfoil and the velocity diagram of the fluid.

2.3 Software

Modelling of blade require computer software. CATIA and AutoCAD are examples of modelling software.

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software developed by the French company Dassault Systems and marketed worldwide by IBM. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite [3]

AutoCAD is a software application developed by Autodesk that enables computer-aided design (CAD) and drafting. The software is used to produce 2D and 3D drawings [4]

2.4 Computer

A CAD software require a suitable computer and operating system (OS) to run. CATIA V5 and AutoCAD are both compatible with Windows 8 64 bit Operating System (OS).

3.0 DEVELOPMENT OF FISH TAIL BLADE

3.1. Blade Model Shape

The curves that will determine the leading and trailing edges of the fish tail are parabolic. Therefore, for the purpose of this study, the airfoil section developed were defined by two parabolic curves as shown in figure 3.0 below

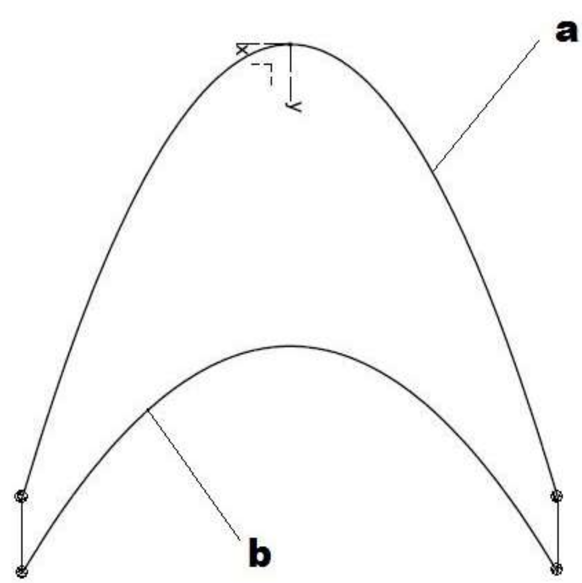

Figure 3.1: Parabolic curve-**a** the leading edge and curve-**b** the trailing edge.

3.2. Blade Model Size

For this work the air foil model has a maximum length of 140mm along the chord i.e. coordinate y = 0mm to y = 120mm taking 20mm as the minimum chord length. The maximum chord length at the center is 80mm.

The span of the fish tail airfoil was limited to 150mm i.e. coordinate x = -75mm to x =75mm.

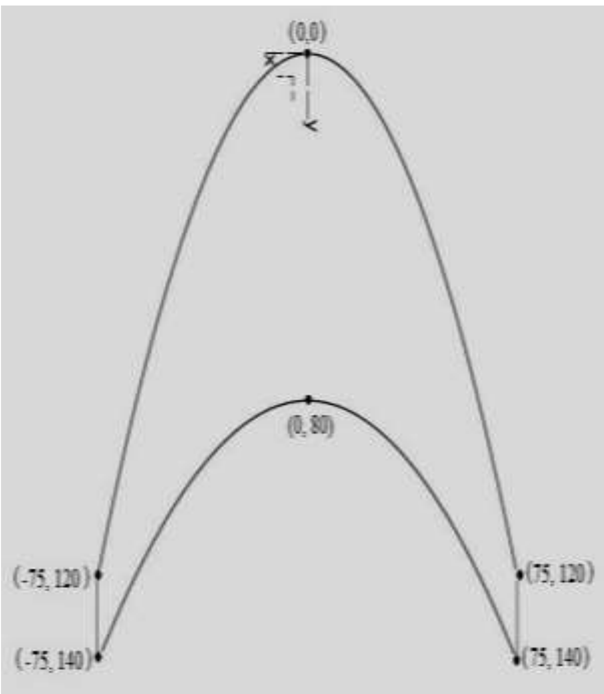

Figure 3.2: Geometrical coordinates of the blade

3.3. Determination of Leading and Trailing Edges Parabolic Curves

Leading Edge (Curve **a)**

Using the equation of the parabola with vertex at (0, 0**)** and focus at $\mathbf{a_1}$ [5].

$$x^2 = 4\mathbf{a_1}y \tag{3}$$

From equation 1 above, when x= 75mm, y = 120mm,

$$\boldsymbol{a_1} = \frac{x^2}{4y} = \frac{75^2}{4 \times 120} = 11.72 \tag{4}$$

Now substituting the value of $\mathbf{a_1}$ in to equation (1) above,

$$x^2 = 4 \times 11.72y = 46.875y \tag{5}$$

Trailing Edges (curve **b)**

$$x^2 = 4a(y - k) \tag{6}$$

For parabola with vertex at (0, k) [5].

$when\ x = 75mm, y = 140mm\ and\ k = 80mm,$

$75^2 = 4\boldsymbol{a_2}(140 - 80)$ which gives

$$a_2 = \frac{75^2}{4x60} = 23.44$$

Therefore, $x^2 = 4 \times 23.44(y - 80)$

$$x^2 = 93.75(y - 80) \tag{4}$$

$\boldsymbol{a_1}$ and $\boldsymbol{a_2}$ will be the focus to be used in drawing the parabolic curves of the leading and trailing edge respectively as indicated above.

3.4. Drawing of the Airfoil

NACA airfoil coordinate data were obtained from UIUC website [6]. AutoCAD was used for the drawing of the NACA airfoil profiles using the coordinate data. The following steps were followed in drawing the NACA airfoil profile;

A new file in AutoCAD was opened and a spline tool was clicked to go to command input. With Notepad text editor the NACA coordinate (e.g NACA 0015.txt) data was copied and pasted on the command input and the Enter Key was then pressed twice and then zoomed for clear view. This file was then saved as dxf format. Now we have NACA airfoil profile in dxf format which was then used in CATIA to draw the blades Model.

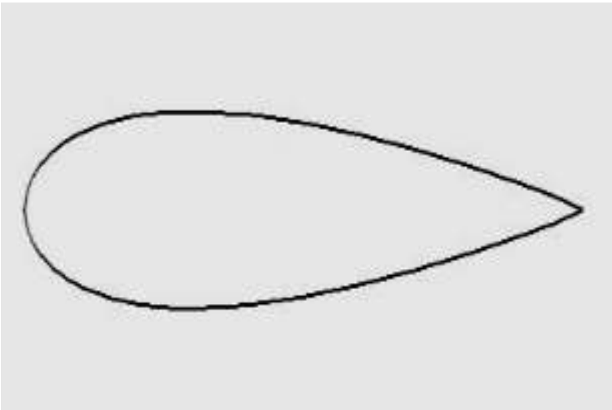

Figure 3.3: The Airfoil cross-section (NACA 0015)

3.5. Importing airfoil profile in to Catia

The airfoil profile in dxf format was imported in to CATIA drafting workbench

The following steps were used in the importation of the airfoil profile

1 Start→ Mechanical design → draftig and then an A4 paper size will be selected.

2 File →open → select the dfx file from the AutoCAD of the NACA profile drawing.

3 The NACA air foil profile imported to CATIA has a chord length of 25.4mm. Therefore, it was scaled according to requirement. For example, to draw a profile with chord length 80mm, it will be scaled by a factor of $\frac{80.0}{25.4}$ = 3.149606299426

and for chord length of 20mm, it will be scaled by a factor of $\frac{20.0}{25.4}$ = 0.7874015748031.

3.6. Blade Profile Design

The blade profile was developed with CATIA part design as follows;

i. Start+mechanical design +part design. This command was used to create a new part file.

ii. A coordinate system was then created by selecting a coordinate system tool.

iii. The x-y plane was then selected and sketch clicked to go to the sketch environment or sketcher workbench.

iv. The parabolic curves that represent the leading and the trailing edges of the crescent airfoil were drawn using the **parabolic tool** in the sketch environment.

In the sketch environment, the leading edge parabolic curve with focus at $\boldsymbol{a_1}$= 11.72 was drawn as follows.

The parabolic **curve too**l was clicked and selected to draw the parabolic leading edge curve with focus at (11.72, 0), vertex at (0, 0), first limit (right) x = 75mm, y = 120mm and second limit (by the left) x = -75mm, y = 120mm.

The leading edge parabolic curve is completed and sketch environment was exited.

v. The x –y plane was also selected to create (0, 80) coordinate and click sketch to go to sketch environment, as before.

vi. To draw the trailing edge parabolic curve with (a_2 =23.44mm) at point (0, 80), step4 (a, b and c) above will be repeated.

vii. Two coordinate systems will also be created at the ends of the curve 1 above and the two parabolic curves have been drawn.

viii. Now the designed airfoil profile will be placed with required position and scaling.as follows;

a. The Dxf NACA airfoil profile file will be open and copied and then go back to part design environment in CATIA.

b. The z-y plane of the first coordinate system was then been selected and the **sketch tool** was clicked to open a sketch environment.

c. The copied profile was then pasted and the profile was selected and scaled to the required factor, to obtain chord length of 80mm, using a **scale tool.**

d. Step 8 was then repeated on coordinate 2 and 3 and this gave 5 sketches(i.e. 2-parabolars and 3-airfoils).

ix. Multi section was then created using a **multi section tool**.

The three air foils where then selected serially in the clock wise direction to generate the air foil model/profile by using the guide curve in the multi section window, then the two parabolic curves will be selected and click ok tool.

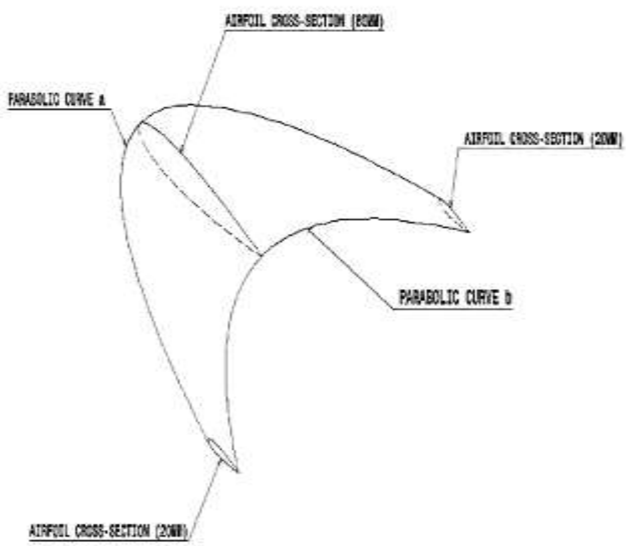

Figure 3.4: The blade profile

4.0 RESULT AND DISCUSSION

4.1 Blade Geometry

Figure 4 below shows the plan and side views of the designed blade.

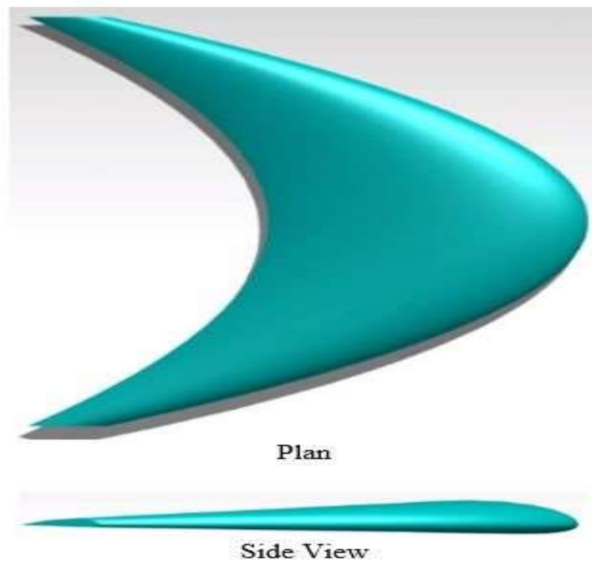

Figure 4.1: The FT blade model

From the blade geometry the plan view shows resemblance with a typical fish tail shape and side view is similar to the cross-section of a typical airfoil.

4.2 Chord length and Span

The chord length and span of the designed fish tail blade were measured using CATIA dimension tool as shown in figure 4.2 below

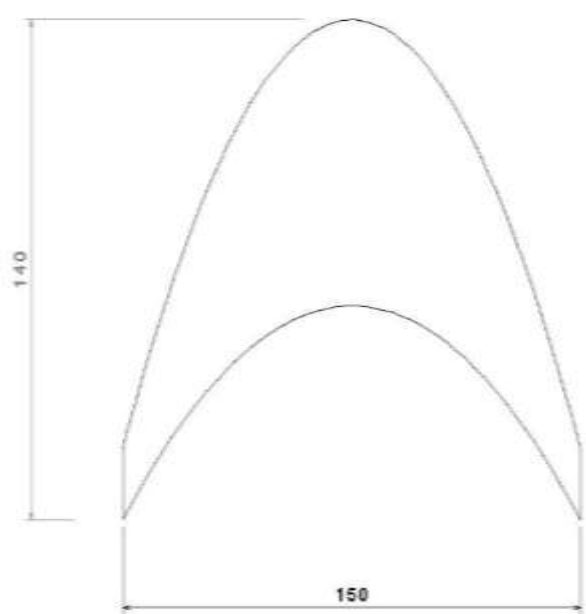

Figure 4.2: The blade dimension

4.3. Blade thickness

The thickness of the blade varies at different location along the blade span and chord length. The maximum thickness of the blade is at the center along the span as shown in the side view in figure 4.3 below

Figure 4.3: The blade thickness

5.0 CONCLUSION

The fishtail blade with NACA 0015 cross-sectional profile was successfully design and model using AutoCAD and CATIA software. The plan view of the FT blade shows resemblance with a typical fish tail. The chord length, span and thickness of the FT blade model were measured using the CATIA dimension tool. The FT blade model was saved as CATIA part file format which can be used to produce a physical model for experimentation using additive or subtracting manufacturing process in either 3D printer or CNC milling machine respectively.

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