A Rapid 3D-Modeling Method for Impeller of Wind Turbine

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Abstract. It is a very important fundamental work that 3D-model of impeller for wind turbine can be achieved precisely, in order to enhance the credibility of CFD analysis in subsequent calculations. However, the current studies do not emphasize closely on the modeling with time-saving and high efficient. Therefore, one high efficient approach for geometric modeling of wind turbine impeller is proposed by this study, and the validity of logical framework and pseudo-code of each part correspondingly is confirmed through several applications upon modeling of impeller, with time-efficient to shape in the process-designed. Moreover, the validity concerning CFD solution is verified by CFD computations of wake of a wind turbine. Additionally, the high efficient approach is also suit for a wider spectrum in fluid machinery for the modeling of relevant entities, and especially for performing such optimal modeling associated with high efficiency, in terms of concise readjustment to grammar and related modeling operations in the logical framework proposed by this paper.

Keywords: 3D-rapid-modeling, time-saving, impeller, pseudo-code, chord length, torsional angle, airfoil, high efficient, verification, wind turbine.

1. Introduction

The wind power generation has become the proven technology and emerging industry in recent years, which is one of the fields of most commercial prospects and large-scale exploited value. The impeller of wind turbine is one key part of wind power generation equipment, especially for aerodynamic aspects [1]. Furthermore, the geometric modeling of wind turbine impeller is very complicated for that torsion angle and chord length of cross-sectional shapes of impeller are both varied along the direction of radius, and is also very time-consuming for traditional approaches [2]. Therefore, the efficiency and accuracy of geometric modeling of wind turbine impeller are both matters of cardinal significance and should be researched further, particularly in CFD studies to engineering application, often relating to complicated turbulence and varied boundary conditions.

There has been a series of correlative research work which has been carried out in recent years. Yan et al. [3] introduced the method for 3D-modeling of wind turbine blade using UG and GAMBIT, and proposed the principles of blade modeling which was illustrated in details by one relative example of...
3D-modeling. Ren et al. [4] investigated the method of 3D-modeling with parameterized for wind turbine employing UG. The strategy that utilized the data handling functions of EXCEL to realize coordinate transformation of nodes belonging to local airfoil and adopted the application of cubic quasi-interpolation to shape the three-dimensional model of wind turbine blade was shown to be effective by surface inspection of blade example. Yang et al. [5] proposed three-dimensional modeling method of wind turbine blade based on the design of aerodynamic shape of 1.2 MW wind turbine blade, and the Pro-ENGINEER has been applied to achieve the entity modeling of blade and proved the effectiveness of modeling method above. Zhang et al. [6] built one model of 15 kW wind turbine blade in three-dimension field choosing airfoils in the types of NACA 63-421, NACA 64-418 and NACA 64-415, in which Pro-ENGINEER was used to satisfy the requirement of geometric modeling in order to carry out the subsequent analysis for structure modality characteristics. Chen et al. [7] investigated the geometric model of parametrization for wind turbine blade through MATLAB and ANSYS. The flapping and shimmy frequency which was consistent with the corresponding measured data was studied based on blade element theory (BET) and illustrated that blade modeling was validated. Wu et al. [8] modified the conventional design algorithm of Willson for wind turbine blade and relative geometric model of blade was realized using CATIA with a series of airfoils of NACA 63, for which the modeling of blade can provide relevantly accurate foundation to aerodynamics and structural dynamics of research.

However, the lots of correlative research above do not pay sufficiently close attention to the key point that efficiency of geometric modeling of impeller should be greatly enhanced in order to improve the overall progress of research and development for wind turbine. Therefore, one rapid method of geometric modeling is proposed taking the advantage of MATLAB and GAMBIT by the study in this paper. The core-points of realization of this method are stated in subsequent section, including pseudo-codes of coordinate conversion of nodes, input file generation for GAMBIT and relative command stream of modeling, etc.

2. Theory for aerodynamic shape of wind turbine

It is an essential part to aerodynamics characteristics of wind turbine for the assessment of power generation performance. In the most general sense, the aerodynamics theory to wind turbine mainly includes these aspects of relevant geometric parameters of impeller, types of airfoils associated with lift-drag ratio, crucial aerodynamic parameters for tip speed ratio and Reynolds number on airfoil, and optimization design method, etc.

2.1. Relevant Geometric Parameters for Impeller

The geometric parameters of wind turbine ties up with corresponding aerodynamics are regarded as those items including the coordinates of rotating shaft, diameter size of swept surface of impeller, the definition of blade axis of impeller, local pitch angles of characteristic cross-sections, the blade number of wind turbine and the elevation of impeller, etc. The representation of illustrative for geometric parameters of wind turbine is shown in Table 1.

| Parameter name               | Illustration                                                                 |
|------------------------------|------------------------------------------------------------------------------|
| Rotating shaft               | Rotatory central line of impeller                                            |
| Swept surface                | Rotating plane for impeller                                                  |
| Blade axis                   | Axis of rotation in the direction of span-wise for blade of impeller         |
| Pitch angle                  | Included angle between the cord of airfoil profile at local radius r and rotating plane of wind turbine |
| Blade number                 | Number of blade of wind turbine                                              |
| Impeller elevation           | Included angle between rotational axis of impeller and reference level of horizontal |
| Types of wind turbine        | Classification in the light of the relative position of rotating axis for impeller and of tip speed ratio interrelated |

Table 1. Geometric parameters mainly for impeller of wind turbine
The essential process of blade modeling for wind turbine is the combinations of actually applied parts of differently local airfoil profile in the radial direction from the root to the tip of blade, which is subject to the layout including the actually different installation angle and chord length.

2.2. Types of Airfoils
The selection and research of airfoils are both core work for aerodynamics designs of blade of wind turbine. The design of blade to wind turbine is applied by the conventional aviation airfoils until the 1990s, for instance, the NACA 44 series and NACA 63 series both shown in Figure 1, etc. However, the performance for aerodynamics of impeller is dropped considerably with widely used general airfoils as a result of the linear amplification of coordinates of thin airfoils to satisfy the requirement of profile thickness on the root of blade.

![Conventional aviation airfoils for NACA 44 series](image1)

(a) Conventional aviation airfoils for NACA 44 series

![Conventional aviation airfoils for NACA 63 series](image2)

(b) Conventional aviation airfoils for NACA 63 series

**Figure 1.** Conventional typical airfoils for NACA series in design

Therefore, the special airfoils for wind turbine are investigated and designed by European countries and the United States from 1980s. It has been formed such items series currently that is insensitive to
surface roughness with high ratio of lift over drag and the different demands for airfoils of wind turbine in positions of blade of tip, mid and root respectively are satisfied, including NREL S series of United States, RISΦ series of Denmark, FFA series of Sweden and DU series of Netherlands. The typically dedicated airfoils of wind turbine to those series of NREL S and FFA are both displayed in Figure 2.

2.3. Crucial Aerodynamic Parameters

There are two most important parameters for aerodynamic performance of wind turbine, which are tip speed ratio \( \kappa \) and Reynolds number over airfoil \( Re \) respectively. The definition of tip speed ratio of wind turbine refers to the ratio of tip speed for impeller over correspondingly designing wind velocity, which is closely associated with the energy conversion efficiency of impeller. The relationship between tip speed ratio and impeller efficiency is positively correlated in the light of the rotating speed without exceeding limit. The appropriate expression can be described below,

\[
\kappa = \frac{v}{V} = \frac{\pi n R}{30V}
\]  

(1)

Where \( v \) is the linear velocity of tip for wind blade, and \( V \) is designed wind speed. The \( n \) refers to angular velocity and the \( R \) indicates radius of impeller.
The Reynolds number over airfoils of wind turbine is another critical parameter for aerodynamics, for which the range of attack angle including high lift coefficient is progressively widening with increase of Reynolds number based on dedicated airfoils of wind impeller, and is especially important to the stall control. The representation of $Re$ is as follows,

$$Re = \frac{\bar{V}C}{\nu}$$  

Where $C$ is the chord length of local airfoil on impeller and $\nu$ is the kinematic viscosity, as well as $\bar{V}$ represents the relative velocity for airflow.

### 2.4. Optimization Design Method on Aerodynamics

It is the most widely applied theoretical approach to the blade element-momentum theory (BEM) in aerodynamic optimization design for wind turbine, which can obtain a good trade-off between computational accuracy and efficiency and considers the probability distribution of wind speed in local farm. The BEM theory originated from the disk theory in the 19th century, which was mainly developed by several physical scientists including Joukowki, Betz, Prandtl, Glauert and Wilson, etc. The relatively integrated theoretic system for such theory above was formed by Wilson method which elaborated systematically to the application of BEM theory in modern wind turbines.

The correlative modified algorithms [9,10] for Wilson method as well as some of the advanced intelligent algorithms including genetic algorithms (GA), particle swarm optimization algorithms (PSO) and multiple-objective evolutionary algorithms (MOEA), etc [11,12], are indeed employed in currently studies for aerodynamic optimization design of wind impeller.

### 3. Implementation of one rapid 3D-modeling for wind impeller

The rapid 3D-modeling of designated series for impeller is mainly based upon the geometric parameters of necessary and crucial, and coordinate transformation of characteristic cross-sections, as well as the appropriate coding combined with employment of proprietary software for instance, MATLAB and GAMBIT.

#### 3.1. Necessary Geometric Parameters for Modeling

The blade of wind impeller is often a very irregular surface in three-dimension for the aerodynamic requirements, which is taken shape through the necessary parameters composed of such distance between specified blade profiles with radius varied along span-wise and rotating shaft of impeller, local chord lengths and torsional angles associated with standard airfoils. It has been shown in Table 2 for details of formulation to those parameters.

#### Table 2. Formulation for details of necessary parameters on blade

| Number for profile | Distance (m) | Chord length (m) | Torsional angle (deg) | Type of airfoil          |
|-------------------|-------------|------------------|-----------------------|--------------------------|
| 1                 | D_1         | C_1              | T_1                   | airfoil-type             |
| 2                 | D_2         | C_2              | T_2                   | airfoil-type             |
| 3                 | D_3         | C_3              | T_3                   | airfoil-type             |
| 4                 | D_4         | C_4              | T_4                   | airfoil-type             |
| 5                 | D_5         | C_5              | T_5                   | airfoil-type             |
| 6                 | D_6         | C_6              | T_6                   | airfoil-type             |
| ...               | ...         | ...              | ...                   | ...                      |
| n                 | D_n         | C_n              | T_n                   | airfoil-type             |
| ...               | ...         | ...              | ...                   | ...                      |
| N-2               | D_{N-2}     | C_{N-2}          | T_{N-2}               | airfoil-type             |
| N-1               | D_{N-1}     | C_{N-1}          | T_{N-1}               | airfoil-type             |
| N                 | D_N         | C_N              | T_N                   | airfoil-type             |
The N in Table 2 is the quantity of specified cross-sections, which can be determined by complexity of surface for blade and demands of accuracy for modeling. The airfoil-type correspondingly for each profile number can be uniform or different types according to the practical applications.

3.2. Coordinate Transformation for Characteristic Profiles
The standard airfoil data for requirements can be obtained through the platform of airfoil investigation database (AID). Then the airfoil data acquired for each feature profile can be able to transformed into the actually local data for designated airfoil by mainly 3 steps, including the translation of aerodynamic center and coordinate conversion for discrete points of feature profile correspondingly through chord length and torsional angle respectively. The first step can be described as following,

\[
(X_1, Y_1) = (X_0, Y_0) - (X_c, Y_c)
\]

(3)

Where the \((X_c, Y_c)\) is the coordinate of aerodynamic center for airfoil in the light of setting that chord-wise direction is horizontal axis and the origin is leading edge stagnation point, and the \((X_0, Y_0)\) and \((X_c, Y_c)\) are the coordinates respectively for each discrete point of feature profile before and after translation. Additionally, it is noteworthy that the aerodynamic center is generally at the local point chord length from leading edge. The next 2 steps are expressed as follows,

\[
(X_2, Y_2) = (X_1, Y_1) \cdot C_i
\]

(4)

Where \(C_i\) is the chord length for designated characteristic cross-section of blade on impeller, in which \(i\) is in the range of 1 to \(N\). The \((X_3, Y_3)\) stands for the transformation of coordinate in each involved cross-section airfoil by \(C_i\).

\[
\begin{align*}
X_3 &= \sqrt{X_2^2 + Y_2^2} \cdot \cos \left( \arctan \frac{Y_2}{X_2} + T_i \right) \\
Y_3 &= \sqrt{X_2^2 + Y_2^2} \cdot \sin \left( \arctan \frac{Y_2}{X_2} + T_i \right)
\end{align*}
\]

(5)

Where \((X_3, Y_3)\) is the transforming to coordinate of airfoil correspondingly through \(T_i\) that refers to the torsional angle of such cross-sections above individually, and \(i\) also with the range from 1 to \(N\). Besides that, the Z values of coordinate for three dimension is determined by \(r_i\) which is the local radius for each of the airfoil sections employed.

3.3. Appropriate Coding and Employment of Software for Modeling
The flexible adjustability and adaptability to application software are both the pivotal items upon such coding for a high efficiency modeling. The command statements which should be identified properly by customized software for geometric modeling in flow and structure fields, such as GAMBIT, are processed through MATLAB in the form of correspondingly logical data structure and deterministic grammars. The pseudo-code globally composed of several sections mainly here for the high efficient modeling, including coordinate transformation of nodes on local cross-sections, subsequent operations based on nodes imported in modeling software and preservation and examination for the generated model, is shown in Figure 3.
The implementation of the coordinate transformation and subsequent operations in GAMBIT by appropriate coding with MATLAB.

### Essential parameters setting

**Airfoil_types = M; Aerofoil_sections = N;**

where **M** and **N** represent the number of types for airfoil and cross-sections on blade respectively.

```matlab
Specified_airfoil(:,:,1) = importdata('airfoil-type_1.txt');
:
Specified_airfoil(:,:,Aerofoil_types) = importdata('airfoil-type_M.txt');
```

where `Specified_airfoil(:,:,i)` is standard airfoil data for each type used here and `i` can be ranged from `1` to `M`. Additionally, the sequence of `Specified_airfoil(:,:,i)` should rely on layout about `Airfoil_types` on blade.

**Chord_length = importdata('The design of the chords for modeling.txt');**

**Torsional_angle = importdata('The design of the torsional angles for modeling.txt');**

where `Chord_length(i,1)` and corresponding `Torsional_angle(i,1)` are both in the sequence from root to tip, and `i` is changing accordingly from `1` to `N`.

#### (a) The part of essential parameters setting for wind impeller modeling

**The implementation of this section for coordinate transformation.**

**Coordinate transformation**

```matlab
sequence(:,:,1) = importdata('The information of layout for airfoil-type upon blade.txt');
```

where `sequence(j,1)` is the vector of order information to layout of type of airfoil, in which the value stored in position of `sequence(j,1)` is variable `i` that can represent the type in `Specified_airfoil`, and it is varying from `1` to `M`, additionally, the range of `j` is from `1` to `N`.

**Dimension Coord_trans = zeros(total_size,Dimension);**

**accumulate = 0; setting = [1,0];**

for `count = 1:1: Aerofoil_sections`

```matlab
type_info = sequence(count,1);
each_size = size(Specified_airfoil(:,:,type_info),1);
total_size = total_size + each_size;
end for
```

where `total_size` is the total number of rows for data of all aerofoil sections.

**Dimension = 3; Coord_trans = zeros(total_size,Dimension);**

**accumulate = 0; setting = [1,0];**

for `count = 1:1: Aerofoil_sections`

```matlab
type_info = sequence(count,1);
each_size = size(Specified_airfoil(:,:,type_info),1);
for `tally = 1:1:each_size`

```matlab
C_1 = Specified_airfoil(tally,1,type_info) - Chord_length(count,1)/4 * setting(1,1);
C_2 = Specified_airfoil(tally,2,type_info) - Chord_length(count,1)/4 * setting(1,2);
Coord_trans(tally + accumulate,3) = Delta * count;
C_1 = Chord_length(count,1) * sqrt(C_1^2 + C_2^2) .
- cos(arctan(C_2/C_1) + Torsional_angle(count,1));
C_2 = Chord_length(count,1) * sqrt(C_1^2 + C_2^2) .
- sin(arctan(C_2/C_1) + Torsional_angle(count,1));
Coord_trans(tally + accumulate,1) = C_1; Coord_trans(tally + accumulate,2) = C_2;
end for
accumulate = accumulate + each_size;
end for
```

where `Delta` is the fixed interval between adjacent cross sections along radial direction on blade.

#### (b) The part of coordinate transformation for wind impeller modeling
The implementation of this section for subsequent operations of modeling in GAMBIT.

Modeling operations ⇒ Creation of blade

```
Fid_modeling = fopen('D:\Wind Turbine\Modeling data for wind turbine.txt','w');
for count = 1:1:total_size
    for tally = 1:1:Dimension
        fprintf (Fid_modeling, '%9.7e     ', Coord_trans(count,tally));
    end for
    fprintf (Fid_modeling, '\r\n');
end for
fclose(Fid_modeling);
```

% where operations such above is for the generating file of modeling data by node coordinates, in which the file can be identified into the GAMBIT.

```
Fid_modeling = fopen('D:\Wind Turbine\Operations for modeling in proper grammar.jou','w');
fprintf (Fid_modeling, '/ Journal File for GAMBIT 2.4.6, modeling operations \r\n');
fprintf (Fid_modeling, 'import vertxdata "D:\\\Wind Turbine\\Modeling data for wind turbine.txt" \r\n');
```

\]\] Modeling data for wind turbine.txt"\r\n% Reading for modeling data.
accumulate_plus = 0; subtraction = 2;
```
for count = 1:1:Aerofoil_sections – subtraction
    type_info = sequence(count,1);
    each_size = size(Specified_airfoil(:,:,type_info),1);
    Curve_fitting_airfoil_profiles(accumulate_plus,median,K);
    accumulate_plus = accumulate_plus + each_size;
end for
```

% where the variable subtraction is associated with correction of root of impeller and median and K can ensure validity of grammar with regard to GAMBIT in an appropriate range.
```
fprintf (Fid_modeling,'vertex delete');
vertex_create_onedge(Aerofoil_sections,subtraction,percentarc-length);
```
```
fprintf (Fid_modeling,'save name "Checking number of vertex.dbs"');
close(Fid_modeling);
```
```
Fid_modeling = fopen('D:\Wind Turbine\Operations for modeling in following 1.jou','w');
start_vertex = Q; end_vertex = Q + Aerofoil_sections – subtraction – 1;
edge_split(start_vertex,end_vertex); edge_create_nurbs(Aerofoil_sections,start_vertex);
```
```
face_create_wireframe(Aerofoil_sections,subtraction);
```
```
fprintf (Fid_modeling,dge delete lowertopology\r\n');
```

% The creation of face and entity for blade is done by here.

(c) The part of modeling operations for creation of blade
The implementation of this section for subsequent operations of modeling in GAMBIT.

Modeling operations ⇒ Creation of rest part for impeller

Hub_ generating (height, radius, height_plus, fairing_distance);
% where height, radius, height_plus and fairing_distance are used to determine the size and shape of hub for impeller.

Root_treatment (vertex_angle, ...);
% where the controlling parameters can be modified and extended to suit for various applications.

Impeller_assembling (number_blade, rotating_angle);
% The fast geometric modeling of wind turbine impeller is completely done, in which the command mode of Journal in GAMBIT is employed.

(d) The part of modeling operations for creation of rest part for impeller

The implementation of this section for subsequent operations of modeling in GAMBIT.

Preservation and examination for generated entity of impeller

fprintf (Fid_modeling,’window modify shade\r\n’);
fprintf (Fid_modeling,’volume modify ”volume.1” color “cyan”\r\n’);
fprintf (Fid_modeling,’volume modify ”volume.1” scolor “grey”\r\n’);
fprintf (Fid_modeling,’default set...
 ”GRAPHICS.GENERAL.WINDOWS_BACKGROUND_COLOR” string “white”\r\n’);
fprintf (Fid_modeling,’save name ”Target_impeller.dbs”\r\n’);
fclose (Fid_modeling);
% where the end of the command with mode of Journal and corresponding result data can be found in file Target_impeller.trn.

(e) The part of preservation and examination

Figure 3. Pseudo-code for high efficiency modeling of impeller of wind turbine

The process of rapid 3D-modeling for impeller of wind turbine is displayed succinctly in Figure 4, in order to better understanding to the procedure and relevant pseudo-code of each part, in which essential parameters setting and coordinate transformation are preparatory phases, and modeling operations composed of blade and rest is execution phase in GAMBIT, and the last part is checking and saving operations correspondingly.

Figure 4. Procedure of high efficient modeling for impeller of wind turbine
4. Results of rapid 3D-modeling for impeller

The results of high efficiency modeling for impeller of wind turbine, with extendable and adaptable codes, corresponding to one of the CFD preprocessing software GAMBIT, are displayed below from Figure 5 to Figure 8. The wind turbine impeller of S series new aerofoil, installed on small generator system at the roof of a building, is shown in Figure 5, for which power rating is 300 W, and the designing wind speed and start-up air speed are 10 m/s and 3 m/s, individually.

Figure 5. Impeller of wind turbine for small generator system at the roof of a building

The impeller of one vertical axis in Figure 6 can be generated high efficiently, in terms of appropriate modifications, with which the coding of creation of blade is simplified and the part upon creation of rest part for impeller is extended, comparing with the employment original in Figure 5.

Figure 6. Impeller of wind turbine for routine and small-scale with vertical-axis

The impeller of one vertical axis in Figure 6 can be generated high efficiently, in terms of appropriate modifications, with which the coding of creation of blade is simplified and the part upon creation of rest part for impeller is extended, comparing with the employment original in Figure 5.

Figure 7. Blade of wind turbine for 1.5 MW large-scale with designated airfoil NACA 63-415
It is also very time saving that the geometric modeling for blade of wind turbine with designated airfoil NACA 63-415 and impeller of NREL S809 can be performed accurately and rapidly, which have been clearly manifested in Figure 7 and Figure 8, especially for impeller of S809, the modeling of root of entity has been simply adjusted to suit for the specific application.

The last part of preservation and examination to the examples upon impeller and blade of wind turbine above are performed, respectively, in which the results of output file for each application above should be preserved ultimately by the extension of the file name correspondingly, avoiding overwriting the previous output file. The more details of the description for high efficient geometric modeling can be obtained in functional plate Transcript in GAMBIT, including the descriptions upon validity for topology.

In order to test and verify the validity and accuracy of such geometric modeling to CFD computations, the investigation of wake of wind turbine was performed based on the entity model of impeller of S-series. The appropriate discussions of wake flow will be given in the subsequent section, in which the CFD model of wake of wind turbine will be also illustrated in detail.

### 5. Verification of such 3D-modeling via cfd study

In this section, the regional division and grid layout, specification of definite solution condition, and selection of characteristic plane, with regard to the CFD model of wind turbine, will be correspondingly described, respectively. Then, the results of such CFD solution will subsequently manifested and discussed in the last part of this section.

#### 5.1. Regional Division and Grid Layout for the Wake Model of Wind Turbine

According to the considerations to the compute resources and requirement of calculation precision [13-15], the CFD model of numerical calculation of wind turbine chosen above was generated by means of a series of independent verifications. The visualization of the CFD model is shown in Figure 9.

The radius of the domain of CFD model is set to 5 times the swept surface radius of the wind impeller, set to 3.5 m, in order to avoid the influence of non-physical interface at the peripheral border of wake model. The length of the overall cylindrical domain to the CFD model is 9 m, and the length and radius of grid encryption area in the central part of the wake are 6.25 m and 1.1 m, respectively. The encrypted area of impeller nearby employed the tetrahedral mesh subjecting to the control of topological size.
function prescribed, and the central region of the wake applied the prismatic grid to improve capture accuracy while administered the quantity of grid generation in the discrete process. The total number of grid cells is approximately 3.89 million under the above division strategy.

The sliding grid algorithm was adopted to achieve such transmission of information of flow field flux between body-fitted rotating area and peripheral stationary region.

![Discrete grid block using the tetrahedron and prism](image)

**Figure 9.** The visualization of CFD model of wake of wind turbine to S-series airfoil

5.2. Specification of Definite Solution Condition

The transient implicit algorithm of SIMPLEC method was employed to advance the time domain, based on the incompressible Navier-Stokes equation. The pressure term was discretized through an implicit Second-order finite difference scheme, and such convection and diffusion term were translated into the discretization by means of central differencing scheme. The turbulence model of large eddy simulation (LES) was used by the testable investigation in CFD, associating with sub-grid model of Smagorinsky. In consideration of the complexity to such engineering numerical computation, the under-relaxation factor for pressure term was set to 0.28, and other associated under-relaxation factors maintained regular levels.

The left side of overall cylindrical domain was set to the inflow boundary of velocity inlet, and the right side was specified as the outflow boundary of pressure outlet, manifested in Figure 9. The flow medium is the actual air, which temperature maintains at 300 K as the same as the wall temperature all included in the CFD model. The value of velocity inlet was 10 m/s, and the reference pressure fixed at 1 atm. The tip speed ratio for design is 5.5, and the lower tip speed ratios are respectively 4.0, 4.5, and 5.0. In the contrast of lower conditions, the corresponding high working conditions of tip speed ratio were defined as 6.0, 6.5, and 7.0 in the computation. The size of time step in the unsteady situation was corresponding to 1 degree in each working condition of tip speed ratio, which can be obtained by means of the formula (1). In order to acquire the steady calculation results, the early period of computation was performed by the advancement on up to 10 circles of rotation in each working condition for tip speed ratio.

5.3. Selection of Characteristic Plane

In the light of evolution patterns to vortex structure, especially for the central eddy and tip vortexes in the wake domain, it was selected finally to the characteristic plane of the coordinate $Z_0$ equaled to zero to obtain those visual calculating results, for which such characteristic plane was displayed in Figure 10.

It is noteworthy that such characteristic plane was defined in the relative coordinate system which can be propitious to the visualization of CFD solutions, particularly in a rotating flow. The correlative
interpolation for the results, to project the CFD numerical solutions on to such plane, was also involved in the verification.

![Figure 10. The characteristic plane in the CFD model of wake](image)

5.4. Results of the CFD Solution at the Characteristic Plane

In view of the considerations about the resolution ratio of grid of spatio-temporal in the domain and the complicated physics of the wake, the CFD solution of radial velocity was chosen to manifest the evolution characteristics within the downstream of impeller. Those flows at different working conditions of tip speed ratio were investigated, and were correspondingly exhibited in Figure 11, separately.

The distribution of radial velocity for the working condition of tip speed ratio of design at the characteristic plane was expressed in Figure 11(a) distinctly. The results of lower working conditions for tip speed ratio were also calculated, corresponding to Figure 11(b), (c), and (d) at different lower levels of tip speed ratio. In the contrast of working conditions, the information to the higher values of tip speed ratio were displayed in Figure 11(e), (f), and (g), respectively.

For the analysis of Figure 11(a), the feature of eddies-structure of radial migration outward can be observed clearly within the region of tip vortex in the downstream at the condition of design. The fusions between tip vortex and central vortices occurred in far field of the wake, with the diffusing of large-scale vortexes in the central area of the domain. It is very significant that the diffusing described above dose affect the characteristics of acoustic radiation, and reflect the efficiency of energy conversion in the flows of wind turbine.
Figure 11. Radial-V distribution at characteristic plane for different tip speed ratios
For the analysis of lower tip speed ratios, showing in Figure 11(b) to (d), such extent of radial migration of tip vortex and of fusions in the far field was weaker than the situation of design. Furthermore, the tip vortex structure manifested a longer visual wake-flow in identical criterion of visualization. It is therefore indicates that the energy flow carried by tip vortex is stronger than the designed condition, for which it is a harmful performance to improve the energy conversion efficiency.

With regard to the higher values of tip speed ratios, the strength and influence of fusions in far field are both in a higher level, evidently in Figure 11(e) to (g), which suggests that the a stronger sound decibels of the surrounding environment will be generated, making against the goal for low noise performance.

According to the above analysis, demonstrated that the situation of design is the best wake physics to performance of high efficiency and low noise upon wind impeller, which is accordance with the aims of design. Thus, these results illustrates that the CFD model of wake of impeller is reasonable and effective, especially for the validity of geometry of impeller, using the rapid 3D modeling method in this paper.

6. Conclusion

The high efficient approach of geometric modeling upon impeller of wind turbine is introduced in this paper, in which the relevant procedure for modeling steps is manifested and corresponding pseudo-code of each part has also been summarized in detail, incorporating essential parameters setting, coordinate transformation, modeling operations, preservation and examination.

The validity of precision and efficiency to model the impeller of wind turbine has been confirmed by several applications of different types of wind turbine, including kinds of horizontal axis, vertical axis and of small-scale, large-scale, and medium-scale. Moreover, the verification of the efficient modeling method concerning CFD solution was also performed by the investigation of wake of wind impeller at different working conditions of tip speed ratio. The results shows that the validity of geometry of impeller, using the rapid 3D modeling method, dose satisfy the requirements for that the CFD model of impeller is reasonable and effective.

Furthermore, the high efficient approach not only can be able to apply to modeling of wind turbine, but suit for a wider spectrum in fluid machinery to efficiently generate entity of impeller and other parts, especially for performing optimal modeling with such high efficiency, in terms of readjustment to grammar and related operations for each step in this logical framework proposed by the study.

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