WT\_Perf User’s Guide

by

Marshall L. Buhl, Jr.

National Wind Technology Center

National Renewable Energy Laboratory

Golden, Colorado

Introduction

WT\_Perf uses blade-element momentum (BEM) theory to predict the performance of wind turbines. It is a descendent of the PROP code originally developed by Oregon State University decades ago. Over the intervening years, many people from many organiza­tions put their marks on the code and it has had several names. More recently, the staff at the NWTC rewrote the program, modernized it, and added new functional­ity and algorithms.

Retrieving Files from the Archive

Create a folder for your WT\_Perf files. You can then download the WT\_Perf archive from our server at [http://wind.nrel.gov/designcodes/simulators/](http://wind.nrel.gov/designcodes/)wtperf. The file is named something such as "wtp\_v300.exe," depending upon the version number. Create a WT\_Perf folder some­where on your file system and put this file there. You can double-click on it from Windows Explorer or by entering the file name (cur­rently "wtp\_v310") at a command prompt, with the WT\_Perf folder as the current directory. This will cre­ate some files and folders.

Distributed Files

The files in the WT\_Perf archive are:

AlphaChangeLog.txt The list of changes to for the various alpha versions.

ArcFiles.txt The list of files that are written to the archive.

Archive.bat The batch file that creates the archive.

ChangeLog.txt The list of changes to .

.exe The WT\_Perf executable file.

.pdf This user’s guide in PDF format.

CertTest\\*.\* Sample input, output, and verification files.

Source\\*.\* The source-code files for WT\_Perf.

Using WT\_Perf

WT\_Perf must be run from the operating system's command prompt. Windows Vista/7 users can access the command prompt by clicking Start, typing "cmd", and pressing enter. In older version of Windows the user will need to click Start, and then click Run before typing the "cmd" command. Once in the command prompt, the syntax for WT\_Perf is

WT\_Perf input file

If you do not enter the input-file argument, WT\_Perf will display the syntax to remind you. All output files use the same root name as the input file, but will have dif­ferent extensions. The extensions are as follows:

bed – the blade-element data  
ech – the echo of the input data  
oup – the primary output file

Creating the WT\_Perf Input File

To create an input file, copy and edit one of the example \*.wtp files from the CertTest folder. Do not add or remove any lines, ex­cept for the variable-length tables, such as the blade layout, the list of airfoil file names, or the list of com­bined cases. Do not depend on the values found in the sample input files to be ac­curate representations of the real turbines—many were modified for convenience. A section-by-section de­scription of an input file fol­lows. In it, variable names use the Letter Gothic typeface. All “flag” vari­ables have values of either true or false.

Header

The first line of the file states the type of file. You may change the line, but do not remove it or add addi­tional lines.

Job Title

You have two lines to describe the turbine model. WT\_Perf copies the first of the two lines in the header to the output files.

Input Configuration

The Echo flag tells WT\_Perf whether or not to echo the input data to the file "echo.out." If you set it to true, WT\_Perf will write out the input values next to their descriptions. If WT\_Perf crashes as a results of an input error, checking this file will help you figure out what caused the crash.

If set to true, the DimenInp flag tells WT\_Perf to ex­pect dimensional input parameters. If set to false, some pa­rameters, such as the chord, are assumed to be nondimensional. If you want to use nondimensional input, di­vide parameters, such as the chord, by the rotor radius. The input-file comments tell you which pa­rameters can be nondimensional. If a parameter can be nor­malized by the rotor radius, the comment states this in the units for the parameter. For example, the units for the hub radius are "[length or div by radius]," where the word "length" means the parameter has units of length if dimensional, or it is divided by the radius of the rotor if normalized.

The Metric flag tells whether or not English units are used or if metric units are used. This parameter does not apply to the wind speed. The setting for wind speed is not affected by the Metric flag. Units used are as follows:

|  |  |  |
| --- | --- | --- |
| **Measurement** | **Metric** | **English** |
| time | seconds | seconds |
| length | meters | feet |
| mass | kilogram | slugs |
| force | newtons | pounds |
| angle | degrees | degrees |

Model Configuration

NumSect is the number of pie-wedge sectors around the rotor disk that are used in the calcula­tions. If you set the Tilt, Yaw, and ShearExp (wind-shear exponent) to zero, you need only one sector. This is true because all cal­cula­tions in all sectors are the same. WT\_Perf ignores this parameter in this situa­tion and analyzes one sector. If any of those three pa­rameters are not zero, WT\_Perf will use a minimum of four sec­tors in the analysis. There is virtually no upper limit for the number of sectors.

MaxIter limits the number of iteration attempts in the BEM induction loop. First, the code assumes there is no induction ef­fect. It then calculates the angle of attack and looks up the lift and drag for that angle. Next, it uses the lift and drag to compute the induced ve­locity. Using the new values for the induction, it re­peats the process. When the induced velocity changes less than a given amount from one iteration to the next, it exits the induction loop. If, after MaxIter itera­tions, the induced veloc­ity changes by more than the given amount, the code terminates the induction loop and sets all output values to a negative num­ber with all nines (for example, the power is given as -999.999 kW).

ATol tells WT\_Perf how little you want the BEM induction factors to change from one iteration to the next in order to consider it converged.

After BEM convergence for each element, WT\_Perf uses the average induction for the entire rotor to compute the skewed wake correction, which it then applies to each element. WT\_Perf will recompute the induction for each element using the newly cor­rected induction values for the initial estimates. It then uses the resulting average induction factor to compute and add the skewed-wake correction to each of those ele­ments. WT\_Perf continues this outer iteration until the correction changes by less than SWTol.

This alpha version of WT\_Perf uses a significantly different iteration algorithm to compute the induction factors. For more information on how the new induction algorithm works in this version of WT\_Perf, please see the paper by (Maniaci 2011): <http://wind.nrel.gov/designcodes/papers/AIAA-2011-150-703.pdf>

Algorithm Configuration

The TipLoss and HubLoss flags tell the code to turn on the Prandtl tip- and hub-loss algorithms. This is usually enabled for non-research work.

The SWIRL flag tells the code to enable the algo­rithms for the calculation of the tangential induction factor (swirl). This is generally set to true.

SkewWake tells the code to correct the induction factor for a skewed wake. It is ignored if the Tilt and Yaw are both zero.

Setting the IndType flag to false eliminates the effects of induction from the algorithm. IndType should almost always be set to true.

AIDrag enables the inclusion of the drag term in the axial-induction algorithm.

TIDrag enables the inclusion of the drag term in the tangential-induction algorithm. If the drag term is included in the tangential-induction algorithm (if TIDrag is true) then a singularity exists in the blade element momentum equations. TISingularity removes this singularity and may improve convergence towards a solution to the blade element momentum equations. Therefore, TISingularity is only used if TIDrag is set to true.

DAWT allows WT\_Perf to analyze a diffuser augmented water turbine. This feature is not fully implemented yet and the DAWT flag is currently ignored.

Cavitation tells WT\_Perf to check for cavitation during analysis of a water turbine. There will be a message in the .oup and .bed output files which indicates if cavitation occurs or not.

PressAtm is the absolute pressure of the atmospheric air. For Stan­dard Temperature and Pressure at sea level, use 101325.0 N/m2 or 2116.2 lb/ft2. PressVapor is the absolute vapor pressure of the water, and for seawater values are approximately 2300 N/m2 or 48 lb/ft2.

CavSF is a safety factor which is multiplied to the vapor pressure (PressVapor), the recommended value is 1.0 or larger.

WatDepth is the distance from the water free surface to the seabed (bottom of tower), it is entered in units of meters or feet if using dimensional data, otherwise divide WatDepth by the rotor radius.

WT\_Perf predicts that cavitation will occur if the following inequality is true:

where CPmin is the minimum pressure coefficient, and σ is the cavitation number defined as

and g is the gravitational accelleration, d is the depth from the free surface of the blade segment being analyzed, and is the total induced velocity at that blade element.

Turbine Data

NumBlade is the number of blades on the turbine. It must be an integer greater than zero.

RotorRad is the rotor radius. It is the distance along the preconed blade, and is therefore a number larger than the swept radius if the precone is not zero.

HubRad is the hub radius entered in either meters or feet if using dimensional data. Otherwise, divide the hub radius by the rotor radius.

The PreCone in degrees should be a posi­tive value regardless of whether the turbine is downwind or upwind.

The shaft Tilt and nacelle Yaw in should be specified in degrees.

HubHt is the hub height entered in either meters or feet if using dimensional data. Otherwise, divide the hub height by the rotor radius..

NumSeg tells WT\_Perf how many analysis points there will be along the blade. The input data should be for the centers of the segments.

The next part of this section contains a header fol­lowed by NumSeg lines defining the distributions of RElm (the distance along the blade of the center of the seg­ment from the center of rotation), Twist, Chord, airfoil file number (AFfile), and a flag (PrntElem) to tell WT\_Perf to print output data for that blade element in the .bed file. If you are entering data in nondimen­sional form, RElm and Chord must be normalized by RotorRad. Enter Twist in degrees.

Aerodynamic Data

The working fluid density (Rho) is always entered as a dimen­sional number. Use either kg/m3 or slugs/ft3. For Stan­dard Temperature and Pressure at sea level, use 1.225 kg/m3 or 0.00238 slugs/ft3 for air. For seawater use 1024 kg/m3 or 1.987 slugs/ft3.

For calculating the Reynolds Number, we added the variable KinVisc, the kinematic viscosity. For Stan­dard Temperature and Pressure at sea level, use 1.464E-05 m2/sec or 1.576E-04 ft2/sec for air. For seawater use 1.05E-06 m2/sec or 1.13E-05 ft2/sec.

ShearExp is the exponent of the power-law wind shear. For the standard 1/7th power law, use 0.143.

The airfoil tables are compatible with AeroDyn. Therefore, they may contain pitching moment coeffi­cient and/or minimum pressure coefficient data. If pitching moment coefficient data is contained in the airfoil filesset UseCm to true. If minimum pressure coefficient data is present in the airfoil files set **UseCpmin** to true. **UseCpmin** must be set to true if checking for cavitation since WT\_Perf predicts cavitation based off of the minimum pressure coefficient.

On the next line, enter the number of unique air­foil-table files (NumAF). After that, enter the NumAF filenames on separate lines and enclose the strings (which may include absolute or relative paths) in quotes or apostro­phes. The next major section describes the format of the airfoil files.

I/O Settings

UnfPower causes the output files to be written in binary format, UnfPower should usually be set to false.

Setting the TabDel flag to true tells WT\_Perf to generate output files with tabs between the columns, instead of using fixed format. Tab-delimited files are best for importing into spreadsheets, while fixed-for­mat files are best for viewing with a text editor or for printing.

OutNines will cause values of nines (for example, power is given as 999.999) to be output in the .bed file if the solution does not converge to the specified tolerances.

**Beep** enables or disables beeps when an error is encountered.

By setting the KFact flag to true, WT\_Perf will output data in the primary results file in “kilo” units. For example, thrust would be in kN or klbf instead of N or lbf, and power would be in kW instead of W.

If WriteBED is true, WT\_Perf will generate a file with the extension .bed containing the blade-element data. Only segments that have their PrntElem flag set in the distributed-data block above will be included in the file. The .bed output file contains the following variables at each blade segment/sector:

Element: The blade element being analyzed

RElm: The radius of the blade element

IncidAng: The incidence angle (twist + pitch)

Azimuth: The angle which bisects the current rotor sectorLoc Vel: The total induced velocity at the rotor plane

Re: Reynolds number

Loss: The loss factor induced by the hub and/or tip loss models

Axial Ind.: The axial induction factor

Tang. Ind.: The tangential induction factor

Airflow Angle: The angle between the cone of rotation and the total induced velocity vector.

AlfaD: The angle of attack

Cl: The lift coefficient

Cd: The drag coefficient

Cm: The pitching moment coefficient

Cpmin: The minimum pressure coefficient

CavNum: The cavitation number

Cav: Cav will equal T if cavitation is predicted to occur, and F otherwise

Thrust Coef: Thrust coefficient within the sector of the annulus

Torque Coef: Torque coefficient within the sector of the annulus

Power Coef: Power coefficient within the sector of the annulus

Thrust/Len: The thrust within the sector of the annulus divided by the span of the blade element

Torque/Len: The torque produced by the sector of the annulus divided by the span of the blade element

Power: The mechanical power produced by the sector of the annulus multiplied by the number of blades

If you enable InputTSR, WT\_Perf will expect the speed data to be tip-speed ratios (TSR) in­stead of actual wind speeds. This applies to both com­bined-case and parametric analyses.

If performing a parametric analysis and OutMaxCp is set to true, WT\_Perf will compute the conditions (wind speed or tip speed ratio, rotor speed, and pitch angle) which resulted in the maximum power coefficient and output these results in the header of the .oup file.

The SpdUnits string tells WT\_Perf what units are used for wind-speed data. Three possible values are valid: "mps" will tell the code that the wind-speed val­ues are in me­ters/second, "fps" will indicate that they are in feet/second, and "mph" will indicate that they are in miles/hour. If InputTSR is true, this parameter is ignored.

Combined-Case Analysis

The first line in the block is the number of com­bined cases (NumCases) to run. If set to zero, WT\_Perf runs no combined cases but performs the old-style parametric analysis.

The second line is the header for the columns in the combined-cases block. It must not be removed from the file.

After that, enter NumCases lines containing a combination of speed (wind speed or TSR), rotor speed (RotSpd) in rpm, and Pitch in degrees.

If NumCases is greater than zero, WT\_Perf will do the performance analysis for each case and generate a single table containing wind speed, TSR, rotor speed, pitch, power, torque, thrust, flap moment, power coefficient, and cavitation flag columns.

Parametric Analysis

If NumCases is zero, WT\_Perf varies as many as three parameters in each run: rotor speed in rpm, blade pitch in de­grees, and wind speed. Enter the wind speed as a tip-speed ratio or an actual wind speed according to the InputTSR flag men­tioned above. The first three parameters in this section are ParRow, ParCol, and ParSht. They determine how the output data are tabulated for output. If all three parameters are varied, WT\_Perf generates multiple tables of data. The ParRow pa­rameter determines variation in the table rows. The ParCol pa­rameter determines column variation in the tables. The ParSht parameter deter­mines which of the parametric values vary from sheet to sheet (table to table).

The next five parameters in this section tell WT\_Perf which of the possible output values should be written to the output file. They are rotor power (kW), power coefficient (CP), rotor torque (N-m or ft-lbf), flap-bending moment at the hub radius (N-m or ft-lbf), and rotor thrust (N or lbf).

This next line tells WT\_Perf how to vary the vari­ous parameters. The PitSt, PitEnd, and PitDel values define the start, end, and delta pitch angles to use. They are input in degrees. The pitch value is added to the local twist at each segment to determine the angle between the chord line and the plane (or cone) of rotation.

The OmgSt, OmgEnd, and OmgDel parameters de­fine the start, end, and delta rotor speed in rpm.

When specifying the parametric wind speeds, you can either input values in tip-speed ratio (speed of the blade tip divided by the wind speed) or actual wind speeds. If you enable the InputTSR flag mentioned above, WT\_Perf will expect the following line to be tip-speed ratios. SpdSt, SpdEnd, and SpdDel de­fine the start, end, and delta speed. If InputTSR is false, enter actual wind speeds. The Units string mentioned above defines the units for actual wind speeds. Three possible values are valid: "mps" will tell the code that the wind-speed values are in me­ters/second, "fps" will indicate that they are in feet/second, and "mph" will indicate that they are in miles/hour. If InputTSR is true, this parameter is ignored.

Creating the Airfoil Data Files

The files containing aerodynamic coefficients are compatible with those used by AeroDyn (http://wind.nrel.gov/designcodes/simulators/aerodyn). WT\_Perf accepts files formatted to the existing AeroDyn v12 style or the newer, slightly modified style. The differences between the styles are minor. Please see the AeroDyn user’s guide for details on the old format of the files.

To tell WT\_Perf to assume the file is in the new format, start the first line with the string AERODYN INPUT FILE. The second and third lines are for comments. The fourth line tells WT\_Perf how many blocks of data there will be for different Reynolds numbers.

For each block, the first value is the Reynolds number. The second value is the control setting. The next seven lines are for AeroDyn’s dy­namic-stall model and are ignored by WT\_Perf, but you must include them.

A multicolumn table follows. The first column is for the angle of attack in degrees. The angle of attack values must increase monotonically and it is recommended that the values span the range -180 to 180 degrees. The second and third columns are for the lift and drag coefficients. The fourth and fifth columns can be used for the pitching moment (Cm) and minimum pressure coefficients (Cpmin). If only using one of these coefficients, either Cm or Cpmin, enter the coefficient data in the fourth column. If using both Cm and Cpmin, enter Cm in the fourth column and Cpmin in the fifth column. At the end of each table, add a line containing the string “EOT”. The new table format allows one to use differ­ent sets of angles of attack for each table. At the very end of the file, after the final "EOT" add a blank line with no text on it.

Known Bugs

None.

Caveats

NREL makes no promises about the usability or ac­curacy of WT\_Perf, which is essentially a beta code. NREL does not have the resources to provide full sup­port for this program. *You may use WT\_Perf for evalua­tion purposes only*.

Acknowledgements

WT\_Perf development was funded by the U.S. Department of Energy.

Feedback

Send your comments or bug reports to

Marshall L. Buhl, Jr.

NWTC/3811

National Renewable Energy Laboratory

1617 Cole Blvd.

Golden, CO 80401-3393

United States of America

Web: <http://wind.nrel.gov/designcodes/>

Email: [marshall.buhl@nrel.gov](mailto:marshall_buhl@nrel.gov)

Voice: (303) 384-6914

Fax: (303) 384-6901