A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

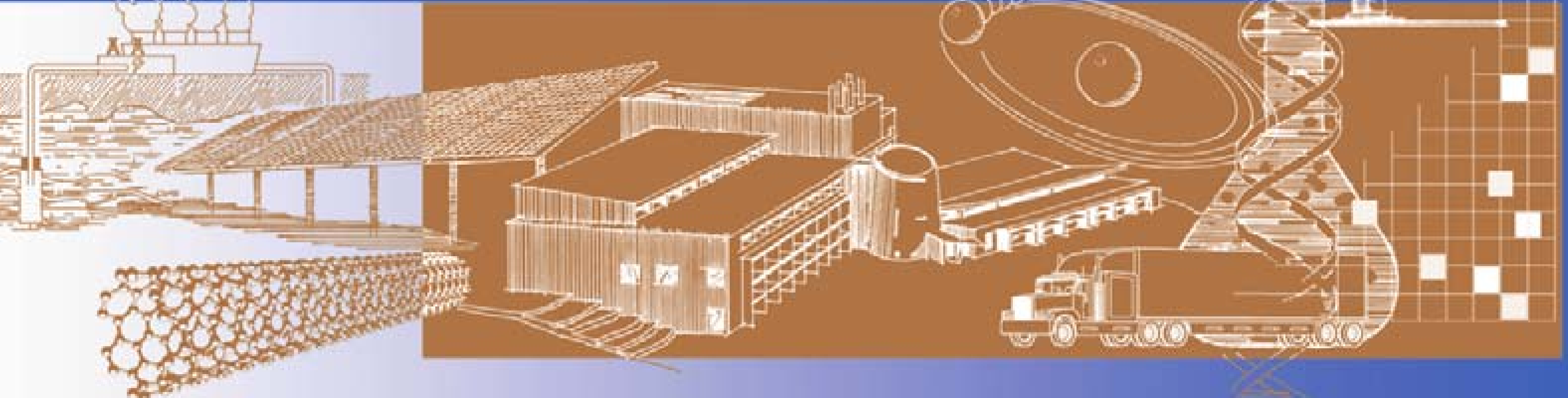
Innovation for Our Energy Future

# TurbSim User's Guide

B.J. Jonkman and M.L. Buhl, Jr.

*Technical Report*
**NREL/TP-500-36970**
**September 2005**

NREL is operated by Midwest Research Institute ● Battelle Contract No. DE-AC36-99-GO10337



# TurbSim User's Guide

B.J. Jonkman and M.L. Buhl, Jr.

*Technical Report*
**NREL/TP-500-36970**
**September 2005**

Prepared under Task No. WER5.3105

**National Renewable Energy Laboratory**
**1617 Cole Boulevard, Golden, Colorado 80401-3393**
**303-275-3000 • www.nrel.gov**

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

## TABLE OF CONTENTS

## List of Abbreviations

| | |
|---|---|
| CoRA | Colorado Research Associates |
| CXML | Compaq Extended Math Library |
| DNS | Direct Numerical Simulation |
| FF | full-field time series |
| FFT | Fast Fourier Transform |
| HH | hub-height |
| IEC | International Electotechnical Commission |
| LES | Large-Eddy Simulation |
| LLLJP | Lamar Low-Level Jet Project |
| NCAR | National Center for Atmospheric Research |
| NREL | National Renewable Energy Laboratory |
| pRNG | pseudorandom number generators |
| TI | Turbulence Intensity |

## Introduction

In 1988, Paul Veers, of Sandia National Laboratories, wrote a program called SNLWIND [1] that could generate full-field turbulent wind for the u component only. In 1992, Neil Kelley of the National Renewable Energy Laboratory (NREL) added several spectral models to SNLWIND and modified it to generate the v and w components [2]. SNLWIND-3D was the result. During the next five years, NREL researchers added further modifications, including the Kaimal and von Karman spectral models specified by the International Electrotechnical Commission (IEC). Gary Desroachers modified it to run on many different platforms by including C-Preprocessor directives for conditional compilation. In 1997, Marshall Buhl added the ability to generate binary files that are compatible with Garrad Hassan's *BLADED* turbine design code.

Both SNLWIND and SNLWIND-3D were written in FORTRAN 77 and required recompilation for different grid densities and run lengths. This made using and supporting the programs difficult.

In January 2000, Neil Kelley removed all of the spectral models except the two defined by the IEC, and Marshall Buhl modernized the remaining code by rewriting all but the Fast Fourier Transform (FFT) routines in Fortran 95 and eliminating the C-Preprocessor directives. This included using dynamic-memory allocation for the big arrays. He found and fixed a few bugs, modified the input and output file format, streamlined processes and added the ability to generate hub-height files in AeroDyn format. Because the changes were substantial, Marshall renamed the program SNwind (Sandia/NREL Wind).

In 2003, NREL researchers updated the code to allow for the addition of coherent turbulent structures and results from the Lamar Low-Level Jet Project (LLLJP). Bonnie Jonkman put the spectral models from SNLWIND-3D back in and replaced the FORTRAN 77 FFT routines with more modern routines from the Compaq Extended Math Library (CXML). She also made changes to the Cholesky factorization algorithm, which sped up the code and allowed for a significant reduction in the memory required to run the program. She eliminated the requirement that the grid be an even number of points in each direction, and allowed the grid height to be different from its width.

Once these enhancements were in place, the researchers modified it to generate coherent structures with realistic temporal and spatial scaling, and coherent turbulence time step files became another output option. The code was then renamed TurbSim (Turbulence Simulator) because of its ability to generate coherent turbulence.

## Retrieving Files from the Archive

Download the TurbSim archive from the NREL web server page at http://wind.nrel.gov/designcodes/. The file will have a name like "TurbSim_v101.exe." Create a TurbSim folder somewhere on your file system and put this file there. You can double click on it from Windows Explorer or type "TurbSim_v101" (or the file name) at a command prompt with the TurbSim folder as the current directory. This will create some files and folders. Please see Marshall Buhl's paper *Installing NWTC Design Codes* for information on how to set up TurbSim to run in any folder.

You will also need to download the coherent structures archive from NREL's web server page if you wish to generate coherent turbulence with TurbSim. The file will have a name like "TSM_structures.exe." Create a folder somewhere on your file system and put this file there. Execute the program by double clicking on it or by typing "TSM_structures" at a command prompt with the folder you created as the current directory. When executed, this archive will create the files and folders used to define coherent structures. You will need to type the name of the path to these folders in TurbSim and AeroDyn input files.

## Distributed Files

See Table 1 for a list of the files included in the TurbSim archive.

**Table 1. Files in the TurbSim Archive.**

| File(s) | Description |
|---|---|
| ArcFiles.txt | The list of files that are written to the archive. |
| ArcFiles.bat | The batch file that creates the archive. |
| ChangeLog.txt | The list of changes to TurbSim. |
| RunTurbSim.pl | A perl script used to run TurbSim, using a different seed each time. |
| TurbSim_AD.ctp | A sample AeroDyn coherent turbulence parameter input file. |
| TurbSim.doc | This user's guide in Word format. |
| TurbSim.exe | The TurbSim program for 32-bit Windows® platforms. |
| TurbSim.inp | A sample input file. |
| TurbSim.pdf | The user's guide in PDF format. |
| TurbSimOverview.pdf | An overview of TurbSim in PDF for-mat. |
| Test*.* | Files used to run and manage the certifica-tion tests. |
| Test\EventData*.* | Files used to run the certification tests with coherent turbulence. |
| Test\TstFiles*.* | My results for the certification tests. |

## Certification Test

Before using TurbSim, run the certification-testing program. It is a batch file called "CertTest.bat" and is located in the "Test" folder. To test the installation, edit "CertTest.bat" and set the environment variables found near the top of the file to settings that are compatible with your system. You will probably have to change only the "Editor" variable. Then, open up a command window, go to the Test folder, and enter "CertTest".

TurbSim will run several times. The test procedure will compare the new results to those stored in the "Test\TstFiles" folder, and it will write the differences between the output files to a file called "CertTest.out." The test procedure will automatically open this file with the editor you specified with the "Editor" variable. Scan through the file; the only differences should be the date and time stamps in the headers of the files and the CPU time in the summary files. If you recompiled TurbSim with another compiler, there may be some slight differences in the last digit of many of the numbers.

## Using TurbSim

To run TurbSim, enter "turbsim [/h] [<RootName.ext>]", where /h and <RootName.ext> are optional. Examples:

`turbsim`

This will start TurbSim and open "turbsim.inp". This is equivalent to entering "turbsim turbsim.inp".

`turbsim myroot.inp`

This will start TurbSim and open "myroot.inp".

All output files will have the specified root file name with different extensions. Wind components are as follows:

u downwind
v to the left when looking downwind
w up

## Input Files

Do not add or remove lines from the sample input files. TurbSim assumes that parameters are located on specific lines.

## Runtime Options

The first two input values tell TurbSim which one of three pseudorandom number generators (pRNGs) to use and how to initialize it. The first input value is a random seed that must be an integer between -2147483648 and 2147483647 (inclusive). The second input value is either a second random seed or the strings "RanLux" or "RNSNLW" which are not case sensitive.

If the second input is a random seed, it must also be an integer between –2147483648 and 2147483647 (inclusive). TurbSim will then use the two seeds to initialize the Compaq Visual Fortran compiler's intrinsic pRNG, which is based on an algorithm by Pierre L'ecuyer [3]. This intrinsic pRNG is identical to the one found in SNwind.

If the second input is the string "RNSNLW," TurbSim will generate random numbers using the algorithm found in SNLWIND and SNLWIND-3D. It will be initialized with only one seed.

Finally, if the second input is the string "RanLux," TurbSim will use Lüscher's level 3 "Luxury Pseudorandom Numbers" [4], [5]. This pRNG will also be initialized with only one seed. We recommend that you use RanLux since our initial tests show that it seems to be the best behaved of the three generators.

The next seven fields tell TurbSim what you want for output. You can use any combination of output types. Valid entries for these flags are the strings "true" and "false." It is not case sensitive.

The first output option is to generate hub-height (HH) time series in GenPro-binary form. It is probably useful only to Neil Kelley. The second file type is a time series of HH wind data and turbulence parameters in formatted (human-readable) form. The third is HH time series in AeroDyn format. The fourth is binary, full-field (FF) time series in AeroDyn and *BLADED* format. The fifth is binary tower time series, containing points in a line at the tower centerline from the bottom of the rectangular grid to the ground. *This feature is still being tested, as using the power law wind profile from the ground to the top of the rotor disk is undesirable. Currently the power law profile is used on the rotor disk while a log profile is used outside of the rotor disk. We expect to make changes to the wind profile in future releases of TurbSim.* The sixth output option is FF time series in SNLWIND-3D human-readable format, and the last output option is coherent turbulence time steps in AeroDyn form. The coherent turbulence feature works only with non-IEC spectral models when the gradient Richardson number is greater than –0.05. TurbSim also creates binary FF time series in AeroDyn form when a coherent turbulence time step file is requested.

The last parameter in this section is a flag to tell whether the turbine rotates in the clockwise direction when looking downwind. This feature is probably useful only if you want to use FF results with *BLADED.* This flag does not have any affect on results when used with AeroDyn.

## Turbine/Model Specifications

The first two parameters are the number of grid points to generate in the vertical and horizontal directions. Unlike SNwind, which accepts only even numbers, TurbSim allows both even and odd grid-point sizes.

The third parameter in this section is the time step. We set it to 0.05 seconds and recommend that you do not change it.

The next parameter is the length in seconds of the data to analyze. This number dictates how many frequencies will be used to generate the output time series. We recommend that this number be at least 600 seconds. In order to speed up the inverse FFT computations, TurbSim may add a few extra time steps to ensure that the number of analysis time steps is a product of small prime numbers.

The usable length of the data to output in seconds comes next. This differs slightly from the actual amount of data that TurbSim will generate. Because AeroDyn requires that there be data both upwind and downwind of the tower in case the turbine is yawed, it insists that there be extra data in the file to shift the data enough to ensure that the turbine will reside entirely within the wind-data domain. If the analysis time is less than the output time, TurbSim will use the length of the output time series as the analysis time.

The hub height of the turbine is the sixth parameter in this section. TurbSim works in the metric system so enter the value in meters.

The next two parameters are the height and width of the grid. TurbSim assumes the diameter of the rotor disk is the smaller of these two values. If the grid height is larger than its width, TurbSim will place the top of the rotor disk at the top of the grid. Otherwise, the hub is centered both vertically and horizontally on the grid. Keep in mind that AeroDyn will test to make sure that the rotor radius plus the shaft length (the distance from the yaw axis to the hub) is less than half the grid width. The height and width must be large enough to ensure that no part of the blade can lie outside the grid.

The vertical mean-flow angle, parameter nine in this section of the input file, allows you to simulate wind blowing uphill or downhill. Enter the angle in degrees and do not exceed 45 degrees in magnitude. A positive value means the wind is blowing uphill.

The last parameter in this section of the input file, the horizontal mean-flow angle, is the wind direction. Positive angles (enter them in degrees) shift the wind to the right when looking downwind.

## Meteorological Boundary Conditions

The first parameter tells TurbSim which spectral model it should use. Valid values are "IECKAI" for the Kaimal model, "IECVKM" for the Von Karman model, “SMOOTH” for the Risø smooth terrain model, “WF_UPW”, “WF_07D”, and “WF_14D” for the NREL Wind Farm upwind, seven rotor-diameters downwind, and 14 rotor-diameters downwind models, and “NWTCUP” for the NREL Wind Farm upwind model modified for NWTC conditions. The values are not case sensitive. For more information on these models, see the section “Spectral Models” in this report.

The second parameter tells TurbSim what turbulence intensity (TI) you want to use with the IEC Kaimal or von Karman models. Input values of “A”, “B”, or “C” correspond to the standard IEC turbulence characteristics, with “A” being the most turbulent. You can also specify the TI in percent instead of choosing the standard turbulence characteristics. If you want to use the scaling parameters from the second edition of the IEC 61400-1 standard, follow your input with the string “-ED2” (i.e. “A-ED2” or “15.2-ED2”). By default, TurbSim will use the scaling from IEC 61400-1, edition 3, for the Kaimal model and scaling from the standard’s second edition for the von Karman model, which is not defined in the newer edition.

If you enter the string “KHTEST” in the second parameter, TurbSim will allow you to test the effects of a KH billow. In order to use this feature, you must specify the “NWTCUP” spectral model. TurbSim will then override the inputs for Richardson number, power law coefficient, and billow type, size, and location. An LES-type billow centered on the rotor disk will be scaled so that the coherent TKE is at least 30 $m^2/s^2$ and the billow achieves a bandwidth of 25 Hz. This billow will last at least half of the usable length of the output time series, and will start a quarter of the way through the time series. This parameter is not used in the other spectral models.

The third parameter in this section specifies the height of the reference wind speed (in meters). This allows you to specify the mean wind speed at a height other than the hub height. If the reference height is above or below the rotor disk, TurbSim uses the logarithmic profile to calculate the mean HH wind speed. Otherwise, TurbSim will use the power law wind profile on the rotor disk to generate the mean HH wind speed.

The fourth parameter in this section is for the mean, u-component wind speed at the reference height. It will be less than the mean, horizontal wind speed, which is the vector sum of the u and v components. Its value must be in meters per second.

The surface roughness length is the last parameter in this section. This length is the extrapolated height at which the mean wind speed becomes zero in a neutral atmosphere, assuming a logarithmic vertical wind profile. Enter the length in meters, or enter the string “default” if you would like TurbSim to use a default value that is based on the specified spectral model.

### Non-IEC Meteorological Boundary Conditions

If you have specified either the Kaimal or von Karman spectral model, TurbSim will stop reading the input file at this point and use the values specified by the IEC standard instead. The other spectral models require these additional meteorological boundary conditions. All of the inputs in this section, with the exception of the gradient Richardson number, can be replaced with the string “default” which is not case sensitive.

The first parameter in this section is the site latitude in degrees. The latitude is used only to calculate the default mixing layer depth.

The first parameter in this section is the site latitude in degrees. The latitude is used only to calculate the default mixing layer depth.

Next is the gradient Richardson number. This parameter is the only one in this section that does not accept the value “default.” Enter zero for neutral conditions, a negative value for unstable conditions, or a positive number for stable atmospheric conditions.

The third parameter is the power law exponent, which is used to compute the mean u-component wind speeds across the rotor disk. Enter a positive number to increase the wind speed with height.

The friction or shear velocity, $u_*$, comes next. Its value must be in meters per second. Following the friction velocity is the depth of the mixing layer. Enter the depth in meters. Next are the cross-correlation coefficients for *u’w’*, *u’v’*, and *v’w’*. TurbSim uses these coefficients to correlate the time series of the three wind components. You may have to adjust these numbers to obtain the desired calculated cross-correlation coefficients in the TurbSim summary file.

The coherence decrements for the three wind components are the next three parameters in this section. They must be positive numbers indicating the degree of coherence between points on the grid.

The coherence exponent is the last parameter in this section.

## Coherent Turbulence Scaling Parameters

The coherent turbulence scaling parameters are used with non-IEC spectral models when the gradient Richardson number is greater than –0.05 and the option to create coherent turbulence time step files has been selected. TurbSim uses empirical values to calculate when and how coherent events should be added to the background turbulence. It uses these values to create a coherent turbulence time step file that AeroDyn will read.

The first parameter in this section is the name of the path that contains the coherent event definition files. This directory should contain files called "Events.les," "Events.dns," and "Events.xtm" as well as one or more files named "Event*xxxxx*.dat" (with the *xxxxx* replaced with digits). These event definition files and the associated binary data files that AeroDyn will read are provided in the coherent structure archive on the TurbSim website (in folder EventData).

The second parameter tells TurbSim which type of coherent event files to use. To have TurbSim randomly choose between the two included types of event files, type the string "Random" here. You may also set this parameter to either of the strings "les" or "dns" to use a specific type of event file. TurbSim will automatically use LES events when the "KHTEST" option is being used.

Set the next parameter to "true" if you wish to randomize the location of the coherent structures in the rotor disk. A value of "true" will override the next three input parameters (the disturbance scale and the location of the wave within the rotor disk). Instead, the coherent structures will be randomly chosen to cover the full rotor disk (75% of the time), only the lower half of the disk (12.5% of the time), or only the upper half (12.5% of the time).

The fourth parameter in this section is the disturbance scale. This parameter determines the size of the coherent event data set relative to the rotor disk. A value of one will make the coherent structures the height of the rotor disk, 0.5 will make them half the height of the rotor disk. If the "KHTEST" option is used, TurbSim automatically sets this parameter to 1.0.

The next two parameters in the input file position the coherent structures on the rotor disk. The first input is the fractional location of the tower centerline from the right to left side (looking downwind) of the coherent event dataset. The coherent structures are periodic in this direction so they will cover the grid horizontally, regardless of the location of the tower centerline. The second parameter is the fractional location of hub height from the bottom of the dataset. To center the events at the hub, use 0.5 for both parameters. TurbSim automatically sets both values to 0.5 when the "KHTEST" option is used.

The last parameter in this section is used to determine where the first coherent structure will be placed in the time step file. TurbSim will make sure that the first event in the coherent time step file will not occur before the time entered here. This feature can be useful if you do not want a turbine to encounter coherent structures during the startup transient of a simulation.

## Spectral Models

TurbSim offers the Kaimal and von Karman spectral models as defined in the IEC standard. Please refer to "IEC 61400-1, Ed. 2: Wind Turbine Generator Systems - Part 1: Safety Requirements" and "IEC 61400-1, Ed. 3: Wind Turbines - Part 1: Design Requirements" for details on these models. Both of these models assume neutral atmospheric conditions.

TurbSim also offers the Risø smooth-terrain model, based on work by Højstrup [6],[7]. This spectral model offers more flexibility in the atmospheric conditions it can model.

The NREL wind farm spectral models are based on measurements taken at a large wind farm in San Gorgonio Pass, California. Please refer to work by Neil Kelley [2] for details on the wind farm models.

The NWTC model is a modified version of the NREL wind farm upwind model. The basic spectra in the two models are identical, but we have made some modifications to the cross-correlation-coefficients, the correlation matrix, the M-O z/L parameter, and $u_*$ in order to reflect more accurately the atmospheric conditions observed at the NWTC

## Output files

TurbSim can generate seven different sets of output files. They take the root name of the TurbSim input file and add extensions that indicate what type of files they are. See the Runtime Options section above to learn how to tell TurbSim which sets to output. TurbSim always generates a summary file.

### Summary Files

TurbSim generates a summary file for all runs. It has a ".sum" extension. The first part of the file tells you what you specified in the input file. After that, TurbSim prints out many statistics for the run. If a coherent event time step file is generated, TurbSim prints the number of events and the total length of those events in the summary file. If you request FF AeroDyn files or tower output, TurbSim will add another section that tells AeroDyn how to convert the normalized data to floating-point form.

### GenPro Binary Files

These files are readable by Neil's GenPro postprocessor and are in machine-readable form. TurbSim gives them a ".bin" extension. See Table 2 for the file format.

### Hub-Height Formatted Files

These files are essentially the same as the GenPro binary files, but they are in human-readable form. They carry a ".dat" extension.

### Hub-Height AeroDyn Formatted Files

These human-readable files are in a format compatible with AeroDyn. They carry the ".hh" extension. See Table 3 for the file format.

### Full-Field AeroDyn Binary Files

These are binary files designed to be read by AeroDyn and *BLADED*. They have a ".wnd" extension. TurbSim normalizes the data and encodes them in two-byte integers. The first part of the file is a header that provides information about the grid and tells AeroDyn and *BLADED* how to convert the integers to floating-point values. The wind speeds for the grids follow that.

When generating these files, TurbSim adds a section to the end of the summary file that tells AeroDyn how to convert the data to floating-point form. TurbSim uses a newer AeroDyn and *BLADED* binary file format than the format SNwind used. In general, this updated format keeps more precision in the normalized two-byte integers than the previous encoding method did.

**Table 2. Format of GenPro Binary Files.**

| | |
|---|---|
| Time | time |
| u | downwind wind speed |
| $u_h$ | horizontal wind speed (u+v) |
| $u_t$ | total wind speed (u+v+w) |
| v | sideways wind speed |
| w | vertical wind speed |
| u' | u fluctuating-velocity component |
| v' | v fluctuating-velocity component |
| w' | w fluctuating-velocity component |
| u'w' | u-w Reynolds stress component |
| u'v' | u-v Reynolds stress component |
| v'w' | v-w Reynolds stress component |
| TKE | Turbulent Kenetic Energy |
| CTKE | Coherent TKE |

### Tower Data Binary Files

These files are similar to the Full-Field AeroDyn Binary Files, except they contain data for points in a single line at the grid center, going from the bottom of the grid to the ground. These files have a ".twr" extension. TurbSim normalizes the data and encodes them in two-byte integers. The first part of the file is a header that provides information about the location of the tower points and size of the file followed by wind speeds. When generating these files, TurbSim adds a section to the end of the summary file that indicates how to convert the data to floating-point form.

**Table 3. Format of Hub-Height AeroDyn Files.**

| |
|---|
| Time |
| Horizontal wind speed |
| Wind direction |
| Vertical wind speed |
| Horizontal wind-shear, linear parameter |
| Vertical power-law, wind-shear exponent |
| Vertical wind-shear, linear parameter |
| Gust speed (not sheared by AeroDyn) |

### Full-Field Formatted Files

These files are the traditional format of SNLWIND-3D FF output. These three files are human readable, but consume five times more storage than the binary files. They are no longer readable by AeroDyn. There is one file for each component. They have ".u," ".v," and ".w" extensions.

The tops of the files have headers with some basic information about the simulation. Blocks of data follow. The first line in each block has the time and the hub-height wind speed. Following that line is a table with the number of rows and columns being the number of grid points specified in the input file.

The tables contain the wind speeds for the different grid points. Their orientation appears as if you are looking downwind.

### Coherent Turbulence Time Step Files

One of the new features of TurbSim is its ability to add coherent turbulence events based on data obtained from numerical simulations of a Kelvin-Helmholtz billow. The data comes from two sources: a Large-Eddy Simulation (LES) from the National Center for Atmospheric Research (NCAR), and a Direct Numerical Simulation (DNS) from Colorado Research Associates (CoRA), both of Boulder, Colorado. Because the grid size of the coherent events is very large (roughly 92 x 92 points), we do not add these events directly to the background turbulence in TurbSim. Instead, we create a file with a ".cts" extension that contains the times and file numbers of the subset of LES or DNS data that define the coherent events. AeroDyn then reads this file along with the background wind file and adds the two wind fields together. As a result, this feature can be used only in programs that use AeroDyn v12.57 or later.

## Using Coherent Turbulence Time Step Files with AeroDyn

To use the coherent time step files that TurbSim generates, you must create a coherent turbulence parameter input file for AeroDyn (or modify the example file included in the archive). This file must have a ".ctp" extension. Enter the name of this file on the WindFile parameter line in AeroDyn v12.57 or later. As with TurbSim, do not add or delete lines from the sample input file because AeroDyn assumes parameters are on specific lines.

### Parameters That Can Vary From One Simulation to Another

The first parameter is the name of the path that contains the binary data files, which you must get from the coherent structure archive on the TurbSim website (in folder x90_i16). This directory must contain files called "Scales.les" and "Scales.dns" which contain scaling parameters for the two event types, and are used to read and convert 16-bit integer binary data to normalized real numbers. There should also be three folders in this directory, named "*u*", "*v*", and "*w*" respectively, containing data for the three wind components. Each of these three directories contains files named something like "u_i16_*xxxxx*.les".

The parameter CTTSfile should be the name of the coherent time step file generated by TurbSim. It will have a ".cts" extension.

The parameter CTbackgr is the name of the background turbulence file. This should be the file with the ".wnd" extension that was generated at the same time the ".cts" file was created. AeroDyn will look for the summary file that goes with this wind file.

The last two parameters in this section are used for decimating the coherent turbulence data. Enter the decimation factors in the y and z directions. Enter "1" on both lines to use the entire grid. *Since this feature has not been sufficiently tested yet, we recommend that you always use the entire grid.*

## Suggestions for Generating Coherent Turbulent Structures

Every effort has been made to randomize the occurrence and scaling of coherent event structures that occur in natural, nocturnal boundary layer flows. Simulations that generate coherent turbulence time step files have up to ten degrees of stochastic freedom and are designed to give some feel of the expected variability in the atmosphere. Because of the degree of variability, we recommend using a minimum of 31 different random seeds for a specific set of boundary conditions.

If you wish to test the effects of a KH billow, we recommend using the "KHTEST" option in the turbulence characteristic input parameter with the NWTCUP spectral model. This test function superimposes one intense coherent event in the middle of the output time series, reducing the number of stochastic degrees of freedom to no more than four. The gradient Richardson number and wind shear of the background flow will be overwritten, and TurbSim will use fixed values to scale the LES-type event. This test function is designed to generate intense turbulence, and does not necessarily reflect the variability for given boundary conditions.

## Warnings

- You must use AeroDyn v12.57 or later in order to read TurbSim files correctly.
- If you compile AeroDyn, you must use the compiler option "/assume:byterecl" to read the TurbSim binary files correctly. If you use ADAMS2AD, be sure to use v12.17 or later so that this compiler option is set.
- HH wind files and FF wind files do not have events happening at the same time because AeroDyn shifts the FF files.
- Because of the way the FFT routine works, we must add extra time to the analysis time to get the FFT to run efficiently. Because of this and the fact that the output time may be less than the analysis time, the mean wind speed for the portion of the run you will actually use may be different from what you specified in the input file.
- TurbSim occasionally cannot perform the spectral matrix factorizations. If this occurs and you believe all of the input values are correct, try modifying the coherence matrix by changing the grid point locations, wind speed, coherence decrements, and/or coherence exponent.

## Limitations

- The SMOOTH spectral model and the coherent turbulence time step files are both considered applicable up to a height of 120 meters at this time.
- The wind farm spectral models (WF_UPW, WF_07D, and WF_14D) and the NWTCUP model are valid up to heights of only about 50 or 60 meters.
- We have not been able to generate a grid larger than 19 x 20 points for a 10-minute run. A larger grid requires more than 2GB of virtual memory, which Windows NT does not permit.

## Possible Future Enhancements

- Extend the applicability of the simulation to a height of 200 meters.
- Add spectral models based on results obtained from LLLJP.
- Instead of specifying a shear exponent for the mean wind profile, add the ability to specify jet wind and direction profiles based on data from LLLJP.

## Known Bugs

- None.

## Caveats

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

## Acknowledgements

TurbSim was written by Bonnie Jonkman under subcontract with the National Wind Technology Center. Funding for TurbSim came from the U.S. Department of Energy under contract No. DE-AC36-99GO10337 to NREL.

Analysis of coherent events was performed by Neil Kelley, Bonnie Jonkman, and George Scott of the National Wind Technology Center, and Professor Jan Bialasiewicz, and Lisa Redmond of the University of Colorado at Denver.

## Feedback

If you have problems with TurbSim, please contact Bonnie Jonkman, Neil Kelley, or Marshall Buhl. If we have time to respond to your needs, we will do so, but please do not expect an immediate response. Send your comments or bug reports to:

**Bonnie J. Jonkman**
NWTC/3811
National Renewable Energy Laboratory
1617 Cole Blvd
Golden, CO 80401-3393
United States of America
E-mail: bonnie_jonkman@nrel.gov
Phone: +1 (303) 384-6907
Fax: +1 (303) 384-6901

**Marshall L. Buhl Jr.**
NWTC/3811
National Renewable Energy Laboratory
1617 Cole Blvd
Golden, CO 80401-3393
United States of America
Web Site: wind.nrel.gov/designcodes/
E-mail: marshall_buhl@nrel.gov
Phone: +1 (303) 384-6914
Fax: +1 (303) 384-6901

# References


[1] Veers, P. S., March 1988, "Three-Dimensional Wind Simulation," SAND88-0152, Sandia National Laboratories, Albuquerque, NM.

[2] Kelley, N.D., November 1992, "Full Vector (3-D) Inflow Simulation in Natural and Wind Farm Environments Using an Expanded Version of the SNLWIND (VEERS) Turbulence Code," NREL/TP-442-5225, National Renewable Energy Laboratory, Golden, CO.

[3] L'ecuyer, P., June 1988, "Efficient and Portable Combined Random Number Generators," *Communications of the ACM*, Vol. 31.

[4] Lüscher, M., February 1994, "A portable high-quality random number generator for lattice field theory simulations," *Computer Physics Communications,* Vol. 79.

[5] James, F., February 1994, "RANLUX: A Fortran implementation of the high-quality pseudorandom number generator of Lüscher," *Computer Physics Communications,* Vol. 79.

[6] Højstrup, J., October 1982, "Velocity Spectra in the Unstable Planetary Boundary Layer," *Journal of the Atmospheric Sciences*, Vol. 39.

[7] Olesen, H.R., Larsen, S.E., and Højstrup, J., 1984, "Modeling Velocity Spectra in the Lower Part of the Planetary Boundary Layer," *Boundary-Layer Meteorology,* Vol. 29.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. REPORT DATE** *(DD-MM-YYYY)*
September 2005

**2. REPORT TYPE**
Technical paper

**3. DATES COVERED** *(From - To)*
August 2005

**4. TITLE AND SUBTITLE**
TurbSim User's Guide

**5a. CONTRACT NUMBER**
DE-AC36-99-GO10337

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
B.J. Jonkman and M.L. Buhl, Jr.

**5d. PROJECT NUMBER**
NREL/TP-500-36970

**5e. TASK NUMBER**
WER5.3105

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

**8. PERFORMING ORGANIZATION REPORT NUMBER**
NREL/TP-500-36970

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSOR/MONITOR'S ACRONYM(S)**
NREL

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**12. DISTRIBUTION AVAILABILITY STATEMENT**
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT** *(Maximum 200 Words)*
The TurbSim stochastic inflow turbulence code was developed to provide a numerical simulation of a full-field flow that contains coherent turbulence structures that reflect the proper spatiotemporal turbulent velocity field relationships seen in instabilities associated with nocturnal boundary layer flows that are not represented well by the IEC Normal Turbulence Models (NTM). Its purpose is to provide the wind turbine designer with the ability to drive design code (FAST or MSC.ADAMS®) simulations of advanced turbine designs with simulated inflow turbulence environments that incorporate many of the important fluid dynamic features known to adversely affect turbine aeroelastic response and loading.

**15. SUBJECT TERMS**
wind turbine design code simulations; inflow turbulence code; TurbSim

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL | | 19b. TELEPHONE NUMBER (*Include area code*) |

**Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

F1147-E(12/2004)