# ADAMS/WT Advanced Development - Version 1.4 and Beyond

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## Abstract

ADAMS/WT is an wind-turbine-specific shell for the general-purpose mechanical system simulation package ADAMS®. It was developed under the guidance of the National Renewable Energy Laboratory to give engineers and analysts in the wind turbine community access to the analytical power of ADAMS, without having to become expert in its particular technology. The 1.4 version of ADAMS/WT is the most recent upgrade to the package, incorporating the most up-to-date version of the AeroDyn aerodynamic forcing subroutines from the University of Utah. It is also the first version to be made available on the Windows/NT platform.

In version 1.4, ADAMS/WT has been significantly improved throughout and runs much faster than previous versions. Automatic generation of standardized output has been added. The documentation has been extensively augmented with more detailed descriptions, more figures and many more examples. Along with the other enhancements described in this paper, ADAMS/WT remains the most powerful analytical tool available for horizontal-axis wind turbine development. Planned enhancements in the next release include yaw control, parametric design capabilities and easier exchange of subassemblies.


## Introduction

ADAMS/WT (Wind Turbine) is an application-specific version of the well known, general-purpose mechanical system simulation package ADAMS® (Automated Dynamic Analysis of Mechanical Systems). It consists of two main components:

1. a set of ADAMS/View macros and panels which create a customized, highly automated preprocessor for horizontal-axis wind turbine modeling
2. a set of ADAMS/Solver FORTRAN subroutines for computing the highly nonlinear unsteady airloads on the turbine blades.

The package also includes various utility programs used in both pre- and postprocessing, and a complete set of documentation.

## Usage

Over the past five years, ADAMS/WT has been delivered to about 20 sites, including universities, laboratories and commercial wind turbine manufacturers, both in the United States and overseas. Due to the recent elimination of most energy credits for renewable resources, usage in the U.S. is now limited to just a few companies and various laboratories. Usage in Europe, where "carbon taxes" are more common, is fairly widespread.

History

In early 1991, the Solar Energy Research Institute (SERI) contacted Mechanical Dynamics after seeing an article in Mechanical Engineering magazine about the use of ADAMS for modeling helicopter rotors. A demonstration contract was arranged and in the summer of 1991, Dr. Elliott visited the laboratory in Golden, Colorado. Over the course of two weeks, working together with the SERI engineers, he constructed an ADAMS model of the ESI-80 horizontal-axis wind turbine using version 6.0 of ADAMS. This model was validated using existing test data and other, simpler codes.

While SERI was pleased with the results, they believed that turbine modeling in ADAMS was much too complicated for the typical wind turbine company to invest in, and would only be useful if access to ADAMS' power could be made easier. They then contracted with MDI to create a customized interface to ADAMS which would simplify and automate much of the turbine modeling process. At the same time, they contracted with Dr. Craig Hansen at the University of Utah to create a set of nonlinear aerodynamic forcing routines, called AeroDyn, which could be used with models created by the new ADAMS interface. The result of these efforts was ADAMS/WT 1.0, released in the summer of 1993. This version reduced the two-week initial modeling effort to about two days.

Over the next year, the users of WT found various capabilities missing and SERI, which had since changed its name to the National Renewable Energy Laboratory, decided to upgrade the program. NREL also believed that although they distributed ADAMS/WT free-of-charge, the base ADAMS product on a workstation was too expensive for most turbine industry users. Therefore version 1.2 was made compatible with ADAMS 7.1, then available on the PC under Extended-DOS. This version was released in the summer of 1994 and was widely distributed. Under WT 1.2, it took about a day to build and run a complete turbine model.

The list of additional capabilities desired for WT continued to grow, along with a call to make it even simpler to use and faster. Version 1.3 was released in July 1995 for ADAMS 8.1. It was the first version to run under Windows-NT. Because of the structural changes to ADAMS between versions 7.x and 8.x, the 1.3 version was not backwardly compatible with 1.2 models and code. However, with more and more automation in the View macros, the modeling process was now down to about 2 hours once the data files were ready.

NREL has continued to support the code and version 1.4, the current release, was made available in January of 1996. In addition to continued improvements to automation and run times, version 1.4 includes the latest upgrade to the AeroDyn and a greatly enhanced set of documentation including many more examples and details. Currently a turbine model can be built in under 15 minutes, and the amount of real ADAMS expertise required is very minimal.

## ADAMS/WT Features

As mentioned above, ADAMS/WT consists mainly of a set of View macros and panel command files and a set of aerodynamics subroutines for Solver. The View command files create a complete wind-turbine-specific preprocessor overlay. They are all loaded automatically from a single, overseer file called *wt_main.cmd.* The resulting preprocessor contains a variety of new low-level and aggregate elements which greatly simply model development. The aerodynamics subroutines are linked right into the base ADAMS/Solver program to create a special-purpose executable version of the code. This is done using the normal ADAMS commands. Standardized output request creation and plotting are also included.

## Preprocessor

When the WT macro and panel files are read into ADAMS/View, the menu structure is enhanced by adding additional elements to some of the standard menus and by adding a complete supplemental hierarchy specifically dedicated to wind turbine modeling. For example, the standard force menus now include a set of special elements, as shown here:

| | | | |
|---|---|---|---|
| MODEL | CREATE | DIRECT | TAPERED BEAM |
| PART | MODIFY | BODY | MOTOR-GENERATOR |
| MARKER | DELETE | ELEMENT_LIKE | SIMPLE AERO FORCE |
| GEOMETRY | COPY | WT | WIND DUMMY VFORCE |
| CONSTRAINT | ATTRIBUTES | | GUY WIRE |
| FORCE | | | |
| DATA_ELEMENT | | | |
| WT | | | |

Selecting "WT" on the main preprocessing menu puts the user into the WT menu structure, but does not remove any of the underlying functionality, power and flexibility of the View interface. The main WT menu, which includes options for all the major turbine subsystems, is shown here:

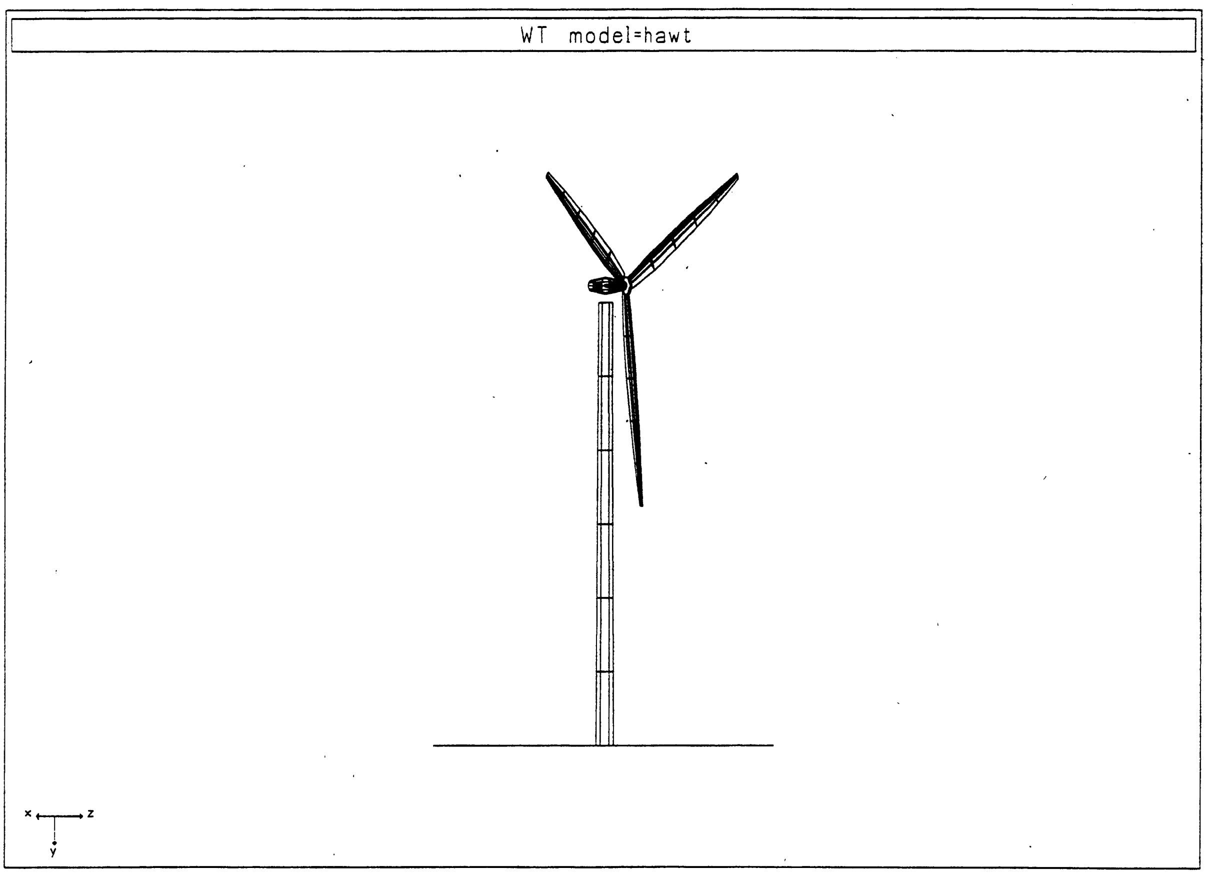
| |
|---|
| TOWER |
| NACELLE |
| POWER TRAIN |
| ROTOR HUB |
| ROTOR BLADE |
| AERODYNAMICS |
| MAIN MENU |
| ABOUT WT |

Most of these aggregate elements make use of the new low-level elements, as will be shown below.

Turbine Modeling with ADAMS/WT

Instead of going into detail about each of the low-level and aggregate elements in WT, it is probably more useful to discuss the overall organization of the model and to get a feel for how it goes together. The sections that follow describe some of the basic approaches used in WT, as well as the design of the flexible tower and rotor blades, and how the aerodynamics are set up. For more detail on the aggregate entities or the added low-level elements, refer to the ADAMS/WT User's Guide[1]

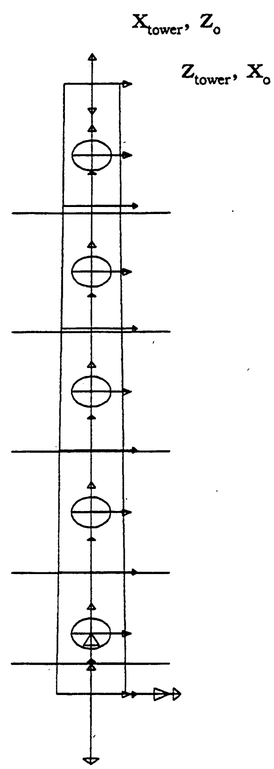
Basically, a horizontal-axis wind turbine system consists of a tall support tower, a rotating nacelle housing the motor-generator and drive train, some kind of rotor hub and a set of long, thin rotor blades. Optionally, there may be tower guy wires, blade tip brakes, nacelle yawing and pitching mechanisms, etc.




[1] Elliott, A..S., ADAMS/WT User's Guide, Version 1.4, January 1996. Mechanical Dynamics, Inc., Ann Arbor, Michigan.

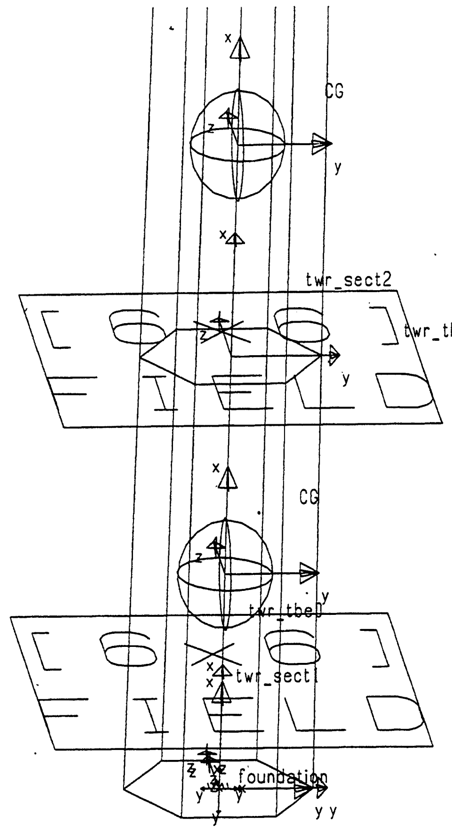
Tower Construction

In ADAMS/WT, the support tower is an aggregate element which is modeled as a beam-like structure using the tapered beam and tapered part low-level elements. Details of those elements can be found in WT manual. Like the ADAMS BEAM element, the tower long axis is along the local +x direction of the tower PARTs and FIELDs.



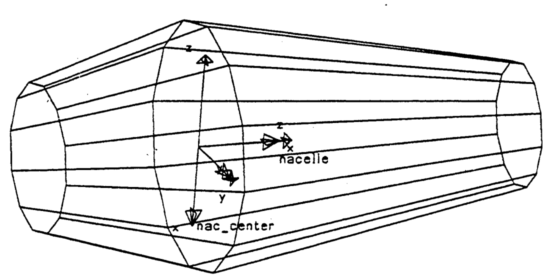

Each pair of parts in the tower is connected by one of the special WT tapered beam FIELD elements, running between the part centers-of gravity. The bottom-most part is connected to ground using a half-length tapered beam element. This is shown in the following figure.

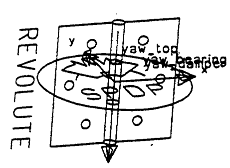
The automation methodology used in ADAMS/WT is based on a standardized naming hierarchy for pieces of the turbine. For example, tower parts are named *twr_sect#*, numbered from the bottom up starting with 1. The special tapered beam FIELD elements are named *twr_tbe#*, again numbered from the bottom up, starting with 0. Each of these is arranged with the J marker for the FIELD on the bottom and the I marker on the top. For example, for *twr_tbe0*, the J marker is *ground.foundation* and the I marker is *twr_sect1.CG*. For *twr_tbe1*, the J marker is *twr_sect1.CG* and the I marker is *twr_sect2.CG*, etc.



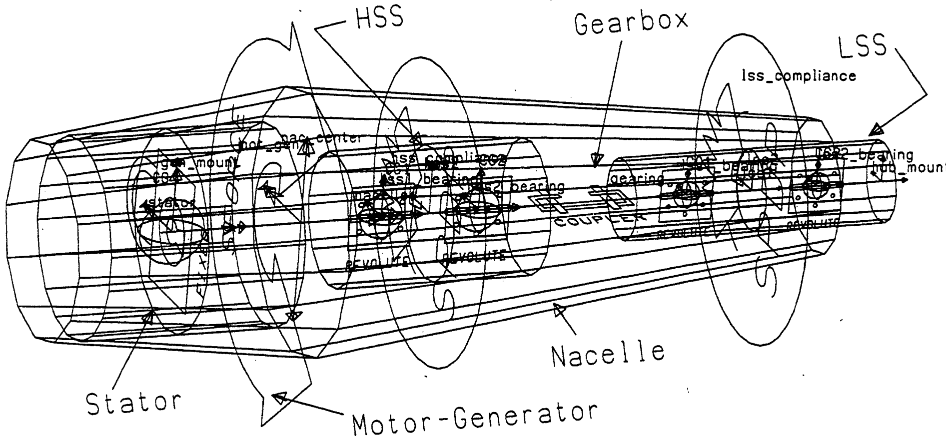

Nacelle and Power Train Construction

The nacelle is treated rather simply in ADAMS/WT. It basically serves as a platform on which to mount the power train and to connect to the tower. It consists of only one part, *nacelle*, which is connected to the tower with a revolute JOINT called *yaw_bearing* and a rotational SPRING-DAMPER called *yaw_damper*. This is shown in the figure below.



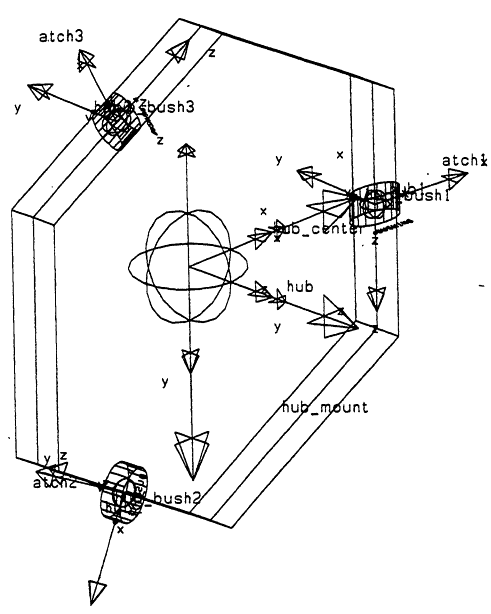
The power train consists of multiple ADAMS entities, including the generator body (a PART), the motor-generator (a rotational SFORCE), high-speed and low-speed shafts (multiple PARTs) and the gearing, if any (a coupler). Depending on the configuration of a particular rotor, some of these components may not be needed in the model.




Hub Construction

WT allows for six different hub variations to cover most of the existing and proposed hub designs. You can chose between 2-bladed teetering and 3- or 4-bladed rigid hubs, and can optionally add limited flexibility (at the blade attachment point) to any of the choices.

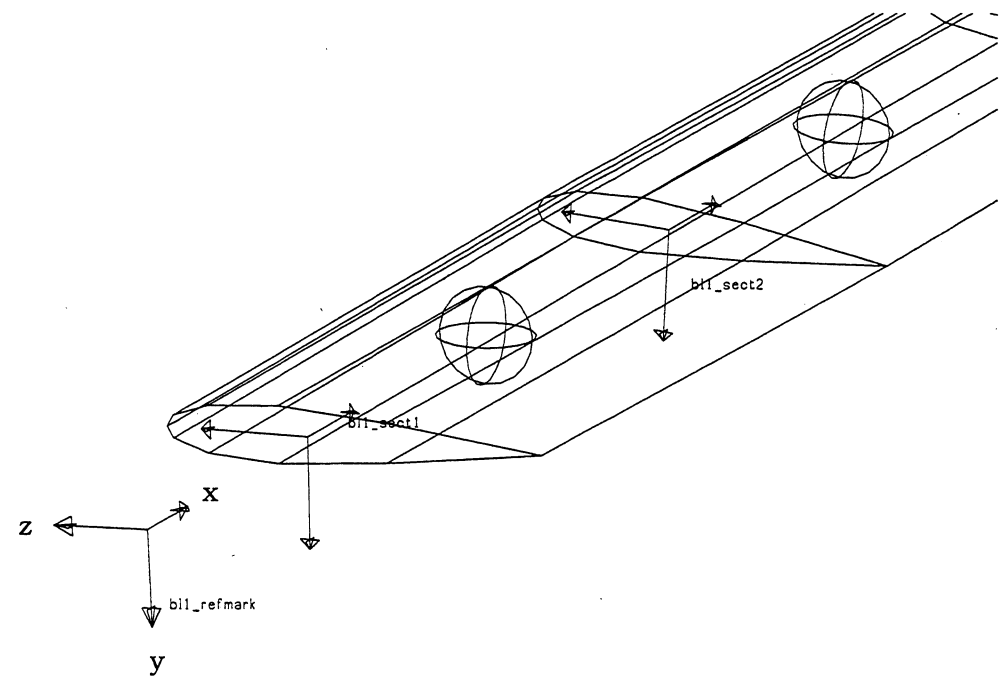
An example 3-bladed, flexible hub is shown below.



Blade Construction

In WT there are two different types of rotor blades, fully flexible and rigid/hinged. The fully flexible blade is an aggregate element, much like the tower, and is also modeled as a beam-like structure using the tapered beam and tapered part low-level elements. The rigid/hinged blade is a one- or two-part aggregate element with an optional hinge and spring-damper between the parts. This corresponds to the classic rigid flap-only blade that is often used in simpler analytical approximations in other codes.

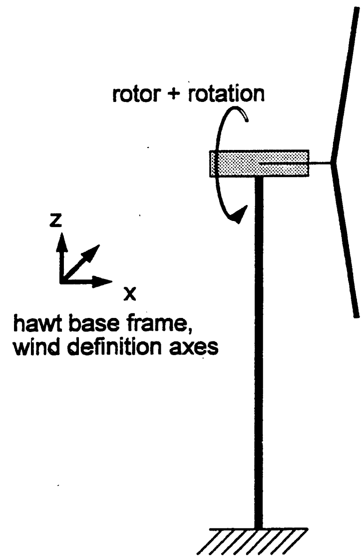
Regardless of which type of blade is used, the blade's long axis (i.e. radial axis) is along the local x direction of the blade PARTs. The +z direction is toward the leading edge and the +y direction is toward the pressure side (nominally upwind) for a rotor which rotates counterclockwise looking upwind (which is the WT default).



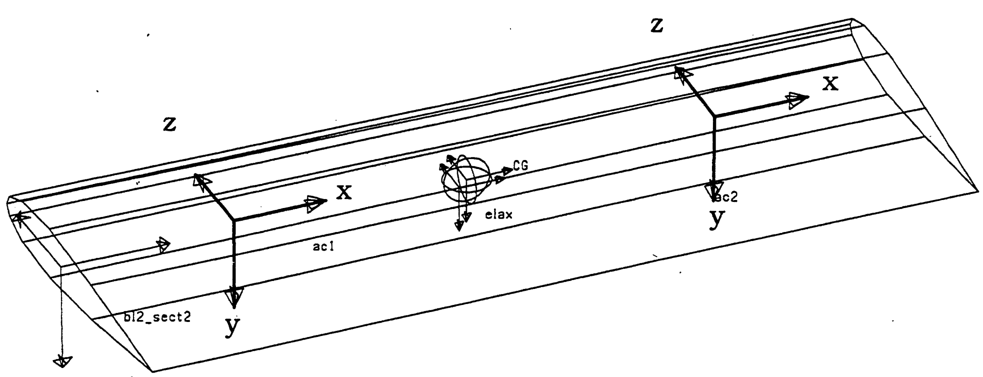

Aerodynamics

Two options are offered for aerodynamics in ADAMS/WT. The first is a very simple, linear, steady aerodynamics algorithm implemented directly as ADAMS functions. The second is the complete 2-D, nonlinear, unsteady aerodynamics from the associated AeroDyn package. Either approach can be automatically added to a blade in WT very simply, basically with one click of the mouse. The automation, however, hides very strict rules for the orientation and placement of the aerodynamic control point markers and the wind definition coordinates.

In version 1.4 of ADAMS/WT, the default rotor configuration is downwind with counter-clockwise rotor rotation looking upwind, i.e. positive about the base frame x-axis..

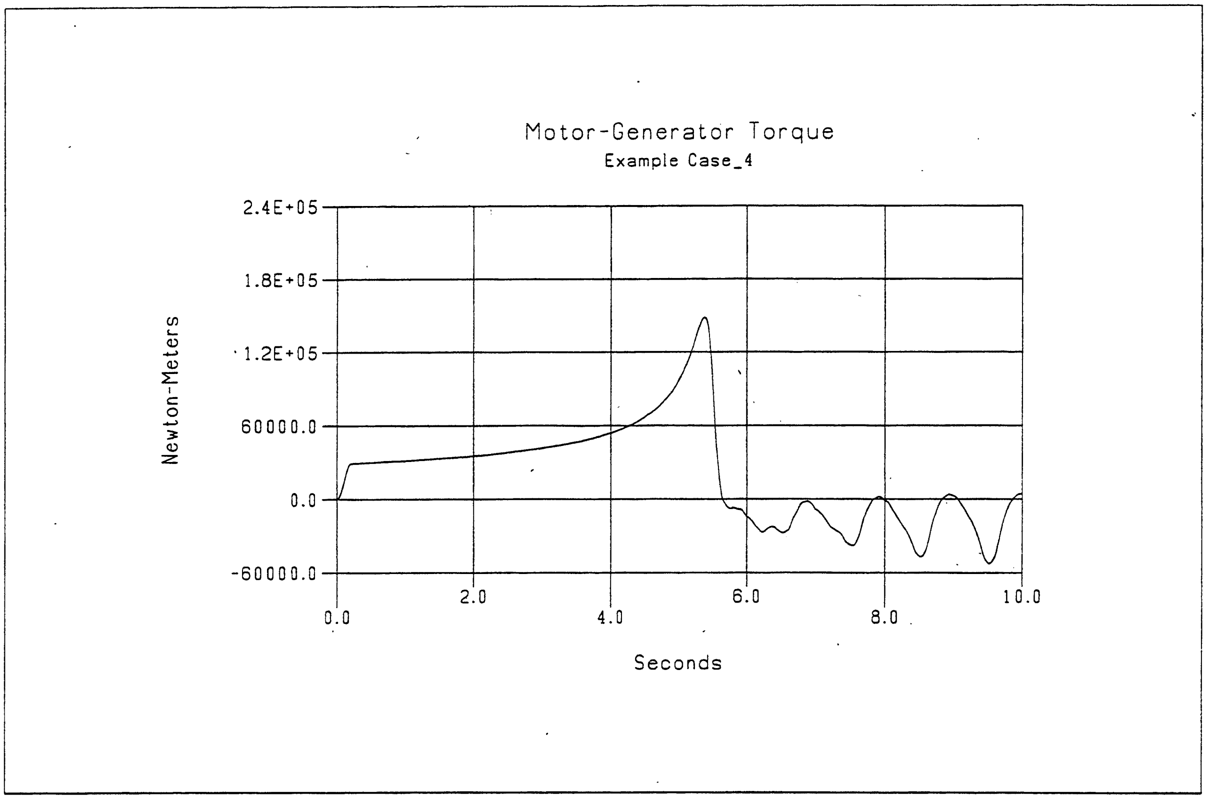



With WT, you have a choice of putting 0, 1 or 2 aerodynamics control points on each blade section. Also, you can define the number of aero markers per section either once for the whole blade or individually on a section-by-section basis. When WT adds aerodynamic control markers to a rotor blade section, it automatically puts them at the Gaussian integration points and orients them correctly, as shown in the two-point blade section here.




<u>Postprocessing</u>

ADAMS/WT adds a set of pre-defined REQUESTs to the normal ANALYSIS OUTPUT_CONTROL CREATE REQUEST menu. These requests cover all the normally instrumented parts of a wind turbine, and additionally include many things that turbine engineers *wish* they could instrument. In addition, a template plotting command file for View is included to automatically plot and format the results from these requests. This allows easy comparison of run-to-run differences. An example of this automatic plotting is shown here:




Example Cases

As an aid to new users, a series of four example rotors of increasing complexity are included with the ADAMS/WT package and are very completely documented, from staring View and loading WT to what goes into every input field to running the analyses to plotting the results. At each step, screen shots are used to ensure that the user is going the right way. The following cases are included, all using the full, nonlinear AeroDyn aerodynamics:

1. 2-bladed, teetering rotor with rigid blades and rigid drive shaft, but with flexible tower.
2. Same as #1, but with flexible blades and a torsion-only shaft.
3. Same as #2, but with a fully flexible drive train.
4. 3-bladed, rigid hub rotor with flexible blades, shaft and tower.

Availability and Support of ADAMS/WT

WT is supplied by MDI completely free-of-charge to interested users, after they have been approved for distribution by the National Renewable Energy Laboratory. To get approval, contact

Mr. Alan D. Wright
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393
Phone: 303/384-6928
e-mail: alan_wright@nrel.gov

ADAMS/WT support is provided by MDI under contract to NREL. For WT-specific problems, contact the author,

Dr. Andrew Elliott
MDI Professional Services
6530 E. Virginia Street
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Phone: 602/985-1557
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## Future Enhancements

NREL is committed to supporting ADAMS/WT, so that regular enhancements and improvements are being made to the product. In the near future, depending on user requirements, we expect to add the following features to WT:

1. Compatibility with the new 9.0 View interface
2. Different machine configurations
3. Partial DOF lockouts for blades and tower
4. Composite blades
5. Aggregate entity “swapping”
6. Parametric variation capability