Horizontal Axis Wind Turbine Free Wake Model for AeroDyn

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Existing Models

As a turbine's rotor extracts energy from the wind, that wind flow is slowed. T
between the energy removed by the turbine and the resulting change in flow. Sev
have been used to analyze this interaction. One of the simplest, and most widely
Element Momentum (BEM) model. Here a static balance between the blade loa
the flow is maintained. The balance involves a radial portion of the blade and th
that blade element. Two problems surface using this approach. First, each blad
flow, has no a ect on adjacent elements. This is inadequate for prediction ofiu.
forces and flow ne
lacking for many
and dynamic flov
However, it conta
Another way
from the flow is

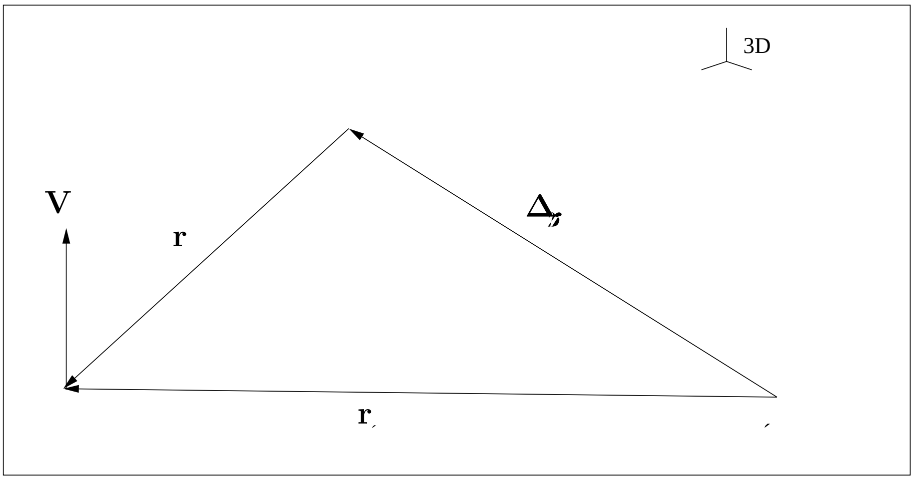

Figure 3: Biot-Savart Vectors

With this form of the Biot-Savart Law we can determine the induced velocity, generated by a particular straight vortex segment, anywhere in the flow field. To find the overall induced velocity from the wake the individual contributions from all vortex segments are summed. Thus the Biot-Savart Law is repeatedly applied to find the induced velocity at each blade element, the local flow at the blade is determined.

The vortices in the wake will move over time. A free wake model determines the motion of each vortex, or vortex end, through Biot-Savart calculations. The induced velocity at each wake point, vortex end, is determined by summing contributions from each wake vortex. This is done for each wake point each time step. This calculation of induced velocity at each wake point is the computationally expensive portion of a free vortex wake model.

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- OMP Private
- OMP Reduction

This placement allows multiple threads to increase the overall simulation run-time performance.

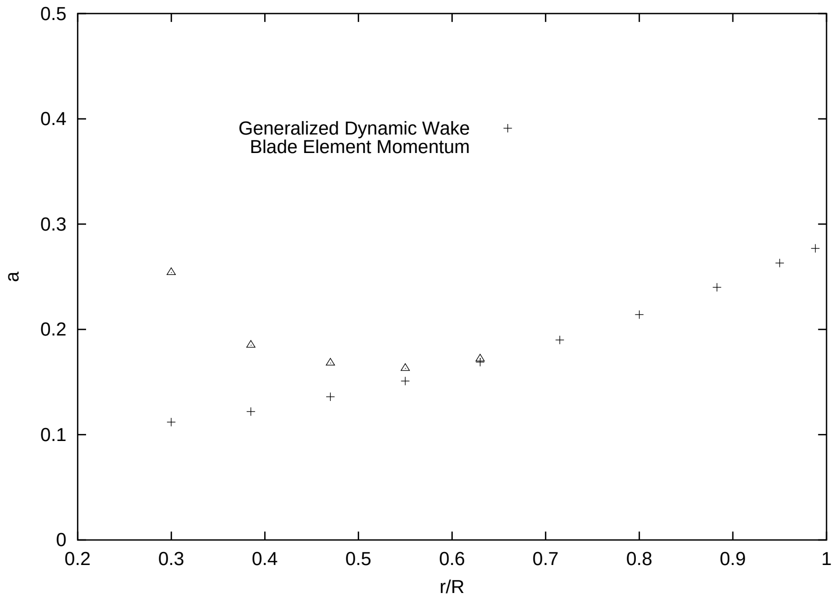
Results

Very few runs have been done to validate the new Free Vortex Wake Model. The goal of the work was to develop the basic code. Runs which have been done model the UAE turbine. This was a highly instrumented wind tunnel test of a thirty foot turbine. [10] Computer runs modeled operation at 8 m/s using four available models, BEM, GDW, Prescribed Vortex Wake and the new Free Vortex Wake. This model assumed a rigid structure and steady head on wind. The results from each model are shown in Table 1. Each run used the same input data.

Table 1: Power Calculations

ow c on		
Model	Power (kW)	Rotor Torque (Nm)
Blade Element Momentum	8.06	1070
Generalized Dynamic Wake	8.55	1140
Dynamic Prescribed Wake	8.08	1070
Free Vortex Wake	8.21	1090

For this same model axial inductions were plotted at each blade element. This is a good way to determine steady state characteristics giving an indication of performance radially along the blade.



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0.3
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0.2
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0.4
0.5
0.6
0.7
0.8
0.9
1
r/R
Generalized Dynamic Wake
Blade Element Momentum

Table 3: Dual Core Run Times

n	
Threading Mode	Time (s)
1 Thread	420.774
2 Threads	250.226
3 Threads	356.241
4 Threads	353.227
5 Threads	401.778
6 Threads	418.205
7 Threads	476.424
8 Threads	526.703

Future Development

A Free Vortex Wake model linked to AeroDyn is a powerful tool on which to base future research. The first carry on work will be to better validate the code, both statically and dynamically. The code, as well as AeroDyn and its structural code FAST are open source. A validated code will be an attractive vehicle for ourselves and other researchers to investigate turbine operation. Two areas of such research are anticipated to be yawed flow and dynamic flow. The new model should give insight into these regimes of operation.

The main hurdle to using such free wake models is the computational expense they entail. The multi-core work done is anticipated to make this, and similar codes, more attractive. There is a research opportunity to improve execution times through mo

Expenses

The project budget was for faculty time only, no equipment funds. A multi-core processor is now on loan from Intel.

The times expended on the project by Hugh Currin and Jim Long exceeded those proposed though this was anticipated from the start. The expenses were as follows:

Faculty Time and Cost		
Prof. Currin	169.5 hours @ $49/hr	$ 8306.
Prof. Long	162.5 hours @ $40/hr	$ 6500.
Indirect Costs		
OIT federally approved indirect rate of 58.5% on $14,806 in salaries		$ 8622.
Total Project Cost		$ 23,468.

Dr. Jason Jonkman from the National Wind Technology Center at the National Renewable Energy Lab assisted on the project. However his time was paid directly by NREL.

Prof. Coton consulted on the project but was not able to contribute the 17 -e r

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References

[1] Laino, D. J., and Hansen, A. C., 2002. User's guide to the aerodynamics computer software aerodyn. Tech. rep., NREL, Golden CO.

[2] Moriarty, P. J., and Hansen, A. C., 2005. Aerodyn theory manual. Tech. rep., NREL, Golden CO.