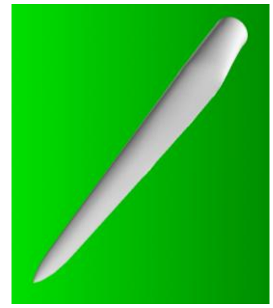
Description of Model Data for SNL100-00: The Sandia 100-meter All-glass Baseline Wind Turbine Blade



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Introduction

This document provides a brief description of model files that are available for the SNL100-00 blade [1]. For each file, codes used to create/read the model files are detailed (e.g. code version and date, description, etc). A summary of the blade model data is also provided from the design report [1]. A Design Scorecard for SNL100-00 [2] is provided at the end of the document, which lists blade design parameters, summarizes blade performance metrics, and lists the bill of materials for the design.

The initial observation is that a 100-meter blade using conventional geometry and all-glass materials is possible. All design requirements are satisfied including maximum strains, tip-tower clearance, buckling resistance, and fatigue life. However, the blade weight for this initial design is very high (and not cost-effective) and the flutter margin is small.

A separate package of model files is available for the associated 13.2 MW turbine model with SNL100-00 blades (FAST code model) [3].

Description of Blade Model File Package

The blade model file package for SNL100-00 includes both the NuMAD [4, 5] blade design files and input files for ANSYS [6]. The blade was designed using NuMAD (version dated 10-30-2009) and analyzed using ANSYS (version 12.0). Table 1 provides a summary of the available model files. Please note that the *.mac files, which are distributed with NuMAD, are also included in this blade file package for convenience as they are needed when reading the *.src files into ANSYS.

Table 1. SNL100-00 Blade Files Summary

Filename	Usage	Description
Sdata1.nmd *Sdata3.nmd* *Sdata3old.nmd*	NuMAD design input files	Contain detailed blade geometry and layup information
MatDBsi.txt	NuMAD materials database	Contains material property information
“Airfoils” folder	NuMAD blade geometry coordinates	Contains a set of files with coordinates for blade cross section geometries
SNL100-00.src	NuMAD output file (original)	Text file formatted for input to ANSYS to generate a finite element model
SNL100-00-mod.src	NuMAD output file (modified)	A modified ANSYS text input file to ensure straight shear webs

The NuMAD input files are useful to investigate blade re-design efforts (e.g. changes in material selection and placement or changes in geometry). NuMAD can produce two types of input files for ANSYS, which include a text input file (*.src) and an ANSYS database file (*.db). A complete set of files for NuMAD and ANSYS is included so that the blade data can be verified by reproduction and also so that modified design solutions can be compared with the provided baseline SNL100-00 design.

Please note that two ANSYS text input files are provided (as indicated in Table 1). When the blade design work started, the most current version of NuMAD was used (version dated 10-30-2009). It was decided to use this version of NuMAD throughout the entire design process for consistency, although updates to the NuMAD code have been implemented during the process. *SNL100-00.src* is the original file produced using NuMAD (version 10-30-2009) with the provided NuMAD input files (*.nmd, etc). During the course of the work, it was learned that this version of NuMAD included a bug that did not permit straight shear webs along their span. Therefore, the original output file was directly modified by adding the following two-line comment and command:

```
!D. Todd Griffith, modification for straight shear web
csys,0
```

and saved as *SNL100-00-mod.src*.

The provided files should provide multiple paths for verification of blade model data. For example, SNL100-00-mod.src can be read directly into ANSYS to produce the SNL100-00 finite element model (correctly with straight shear webs). Also, if a more recent version of NuMAD is utilized, then the NuMAD design input files can be read to produce an entirely new set of ANSYS input files.

Span-wise Properties Summary

Blade span-wise properties were calculated using the PreComp code [7]. As noted in Reference 1 (page 19), an error was discovered in the PreComp code [7] during the course of the Sandia 100-meter blade design work. All calculations that utilized the PreComp code in Reference 1 and those included here were performed using the corrected version of the code. Reference 8 provides a description of the modifications to PreComp (see Appendix B, page 13 of Reference 8).

Table 2 lists the blade span-wise properties including flap- and edge-wise EI, EA, GJ, and mass distributions. Additional span-wise information (e.g. airfoil and chord schedules) can be found in the file package or in Reference 1.

Alternatively, the blade span-wise properties can be computed using the Blade Property Extraction (BPE) code [9], which is a feature of the NuMAD code.

Table 2. Sandia 100-m Baseline Span-wise Properties

(Determined using modified version of PreComp as described in [8])

Station Number	Span Fraction	flp_stff	edge_stff	tor_stff	axial_stff	mass_den	flp_iner	edge_iner
(-)	(-)	(N-m^2)	(N-m^2)	(N-m^2)	(N)	(kg/m)	(kg-m)	(kg-m)
1	0	3.220E+11	3.220E+11	1.678E+11	8.456E+10	5.736E+03	2.183E+04	2.183E+04
2	0.005	2.882E+11	2.877E+11	1.495E+11	7.509E+10	5.094E+03	1.953E+04	1.951E+04
3	0.007	2.495E+11	2.516E+11	1.293E+11	6.537E+10	4.436E+03	1.690E+04	1.706E+04
4	0.009	2.116E+11	2.152E+11	1.093E+11	5.573E+10	3.783E+03	1.433E+04	1.461E+04
5	0.011	1.754E+11	1.801E+11	8.966E+10	4.647E+10	3.148E+03	1.185E+04	1.221E+04
6	0.013	1.620E+11	1.633E+11	7.981E+10	4.278E+10	2.875E+03	1.081E+04	1.105E+04
7	0.024	1.447E+11	1.543E+11	7.223E+10	4.014E+10	2.914E+03	1.017E+04	1.058E+04
8	0.026	1.308E+11	1.409E+11	6.474E+10	3.647E+10	2.682E+03	9.290E+03	9.741E+03
9	0.047	1.040E+11	1.241E+11	5.007E+10	3.082E+10	2.333E+03	7.582E+03	8.748E+03
10	0.068	7.985E+10	1.037E+11	3.532E+10	2.546E+10	1.979E+03	5.846E+03	7.650E+03
11	0.089	7.047E+10	9.368E+10	2.537E+10	2.403E+10	1.838E+03	4.929E+03	7.125E+03
12	0.114	5.575E+10	8.338E+10	1.502E+10	2.206E+10	1.628E+03	3.722E+03	6.317E+03
13	0.146	4.972E+10	8.755E+10	9.273E+09	2.336E+10	1.684E+03	3.143E+03	6.595E+03
14	0.163	4.758E+10	9.845E+10	7.659E+09	2.585E+10	1.736E+03	2.817E+03	6.996E+03
15	0.179	4.171E+10	1.048E+11	5.891E+09	2.679E+10	1.757E+03	2.419E+03	7.241E+03
16	0.195	3.876E+10	1.051E+11	4.411E+09	2.851E+10	1.813E+03	2.173E+03	7.136E+03
17	0.222	3.357E+10	1.032E+11	3.854E+09	2.836E+10	1.791E+03	1.874E+03	6.952E+03
18	0.249	2.851E+10	9.910E+10	3.221E+09	2.812E+10	1.760E+03	1.581E+03	6.618E+03
19	0.276	2.310E+10	6.649E+10	2.672E+09	2.452E+10	1.575E+03	1.284E+03	4.964E+03
20	0.358	1.447E+10	5.483E+10	1.720E+09	2.264E+10	1.434E+03	7.968E+02	3.972E+03
21	0.439	8.956E+09	3.371E+10	1.101E+09	1.996E+10	1.256E+03	4.874E+02	2.612E+03
22	0.52	5.382E+09	2.175E+10	6.900E+08	1.769E+10	1.107E+03	2.915E+02	1.781E+03
23	0.602	3.111E+09	1.444E+10	4.317E+08	1.473E+10	9.346E+02	1.693E+02	1.253E+03
24	0.667	1.799E+09	1.143E+10	2.940E+08	1.223E+10	7.789E+02	9.937E+01	9.610E+02
25	0.683	1.549E+09	1.072E+10	2.635E+08	1.163E+10	7.403E+02	8.566E+01	8.916E+02
26	0.732	1.014E+09	8.719E+09	2.095E+08	9.291E+09	6.065E+02	5.733E+01	7.094E+02
27	0.764	7.357E+08	7.405E+09	1.864E+08	7.526E+09	5.041E+02	4.281E+01	5.895E+02
28	0.846	3.551E+08	4.899E+09	1.286E+08	5.019E+09	3.587E+02	2.224E+01	3.863E+02
29	0.894	2.082E+08	3.663E+09	9.778E+07	3.816E+09	2.895E+02	1.411E+01	2.925E+02
30	0.943	8.095E+07	1.737E+09	4.510E+07	2.724E+09	2.095E+02	5.724E+00	1.392E+02
31	0.957	4.285E+07	9.074E+08	2.579E+07	2.106E+09	1.555E+02	3.066E+00	7.161E+01
32	0.972	1.922E+07	4.187E+08	1.148E+07	1.628E+09	1.202E+02	1.370E+00	3.304E+01
33	0.986	5.125E+06	1.190E+08	3.031E+06	1.071E+09	7.911E+01	3.620E-01	9.382E+00
34	1.000	5.840E+03	6.222E+04	2.573E+03	8.866E+07	6.549E+00	6.332E-04	4.825E-03

References

[1] Griffith, D.T. and Ashwill, T.D., "The Sandia 100-meter All-glass Baseline Wind Turbine Blade: SNL100-00," Sandia National Laboratories Technical Report, SAND2011-3779, June 2011.
[2] "Sandia Large Rotor Design Scorecard (SNL100-00)," Sandia National Laboratories Technical Report, SAND2011-9112P, December 2011.
[3] Griffith, D.T. and Resor, B.R., "Description of Model Data for SNL13.2-00-Land: A 13.2 MW Land-based Turbine Model with SNL100-00 Blades," Sandia National Laboratories Technical Report, SAND2011-9310P, December 2011.
[4] Laird, D. and T. Ashwill, "Introduction to NuMAD: A Numerical Manufacturing and Design Tool," *Proceedings of the ASME/AIAA Wind Energy Symposium*, Reno, NV, 1998, pp. 354-360.
[5] "Wind Turbine Blade Design Tool: NuMAD," http://energy.sandia.gov/?page_id=2238. Last modified 31-October-2011; accessed 06-December-2011.
[6] ANSYS finite element software, http://www.ansys.com. Last accessed 06-December-2011.
[7] NWTC Design Codes (PreComp by Gunjit Bir). http://wind.nrel.gov/designcodes/preprocessors/precomp/. Last modified 26-March-2007; accessed 26-March-2007.
[8] Resor, B. and Paquette, J., "Uncertainties in Prediction of Wind Turbine Blade Flutter," 52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Denver, Colorado, April 4-7, 2011, AIAA-2011-1947.
[9] D.J. Malcolm and D.L. Laird, **"**Modeling Of Blades As Equivalent Beams For Aeroelastic Analysis, " Proceedings of the 2003 ASME Wind Energy Symposium, pp. 293-303.

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Sandia Large Rotor Design Scorecard (SNL100-00)

Completed example for SNL100-00. ***Reference: D.T. Griffith and T.D. Ashwill, "The Sandia 100-meter All-glass Baseline Wind Turbine Blade: SNL100-00," Sandia National Laboratories Technical Report, SAND2011-3779.***

Table 1: Blade Parameters

Parameter	Value
Blade Designation	SNL100-00
Wind Speed Class	IB
Blade Length (m)	100
Blade Weight (kg)	114,172
Span-wise CG location (m)	33.6
# shear webs	3
Maximum chord (m)	7.628 (19.5% span)
Lowest fixed base natural frequency (Hz)	0.42
Control	Variable speed; collective pitch
Special notes:	6% (weight) parasitic resin; all-glass materials

Table 2. Blade Design Performance Metrics Summary

Analysis	Design Load Condition (DLC) designation	Metrics	Notes/method
Fatigue	Turbulent inflow (4 to 24 m/s)	Critical location: Inboard (edge-wise): 1290yrs at 11.1% span	R=0.1 data used; Miners Rule
Ultimate	EWM50; 0 deg pitch	Max strain = 2662 micro-strain Allowable strain = 5139 micro-strain Max/allowable = 48.2%	At max chord (flapwise) FAST, NuMAD/ANSYS
Tip Deflection	ECD-R	Max (11.9 m) vs. allowable (13.67); Clearance = 1.77m = 12.9%	FAST, NuMAD/ANSYS
Buckling	EWM50, 0 deg pitch	Min load factor (2.173) vs. allowable (2.042)	Linear, ANSYS
Flutter	--	Flutter margin (1-1.1)	Beam theory (see SAND2011-3779)

Table 3. Blade Design Bill of Materials

Material performance properties are provided in SNL100-00 Report (SAND2011-3779)

Material	Description	Mass (kg)	Percent Blade Mass
E-LT-5500	Uni-axial Fiberglass	37,647	32.5%
Saertex	Double Bias Fiberglass	10,045	8.7%
EP-3	Resin	51,718	44.7%
Foam	Foam	15,333	13.3%
Gelcoat	Coating	920	0.8%