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NuMAD Structural Optimization and Blade Model Discussion

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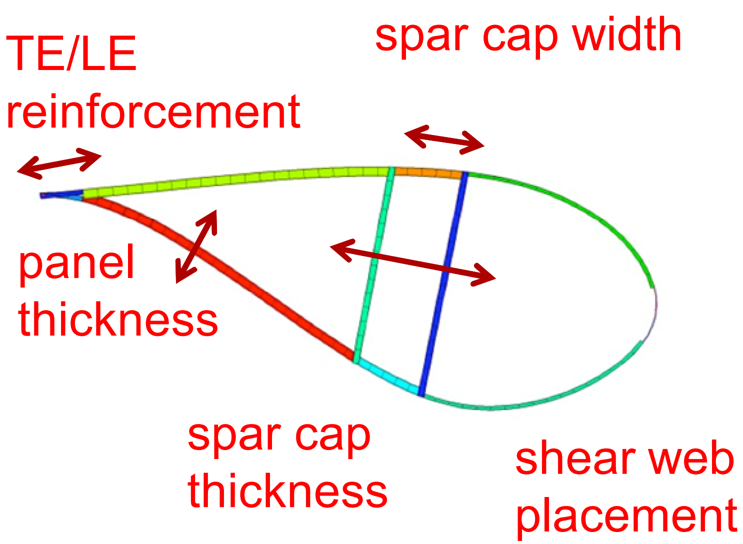
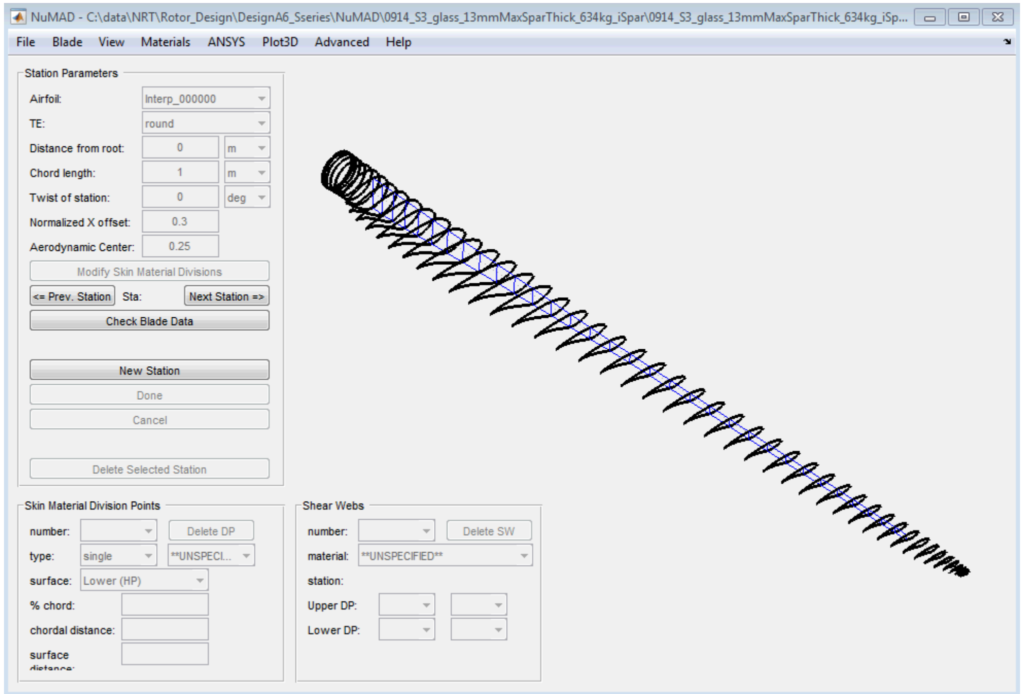
Structural Optimization

- Structural optimization performed using NuMAD to manage the material and structural changes and PreComp and BModes to estimate the blade structural properties
- IEC wind turbine design standard load cases are analyzed using FAST aeroelastic wind turbine simulator with the structural blade representation





Design Load Cases

- IEC analysis currently employs DLC's 1.x, 6.x
  - These DLC's are historically known to be most critical
  - Other DLC's test the turbine control system and fault loads
- The size of wind turbines and different site atmospheric conditions result in different design drivers
  - Important in this project to represent these differences in the optimization analysis

Table 2 – Design load cases

Design situation	DLC	Wind condition		Other conditions	Type of analysis	Partial safety factors
1) Power production						
2) Power production plus occurrence of fault	2.1	NTM	$V_{in} < V_{hub} < V_{out}$	Control system fault or loss of electrical network	U	N
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	Protection system or preceding internal electrical fault	U	A
	2.3	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM	$V_{in} < V_{hub} < V_{out}$	Control, protection, or electrical system faults including loss of electrical network	F	*
3) Start up	3.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG	$V_{hub} = V_{in}$, $V_r \pm$ 2m/s and V_{out}		U	N
	3.3	EDC	$V_{hub} = V_{in}$, $V_r \pm$ 2m/s and V_{out}		U	N
4) Normal shut down	4.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
5) Emergency shut down	5.1	NTM	$V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
6) Parked (standing still or idling)						
	6.4	NTM	$V_{hub} < 0{,}7\ V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM	1-year recurrence period		U	A
8) Transport, assembly, maintenance and repair	8.1	NTM	V_{maint} to be stated by the manufacturer		U	T

Wind Turbine Design Classification

- Turbine classification defined in terms of wind speed and turbulence level at the installation site.

Wind Turbine Class	I	II	III
V_{avg} (m/s):	10	8.5	7.5
A	$I_{ref\ @\ 15\ m/s}$: 0.16		
B	$I_{ref\ @\ 15\ m/s}$: 0.14		
C	$I_{ref\ @\ 15\ m/s}$: 0.12		

- Representative 3 MW designs will be developed as part of this project to analyze the potential benefits of carbon fiber development in low and high wind speed sites representative of much of the U.S.
  - **Class III-A, low wind speed blade design**
  - **Class I-B, high wind speed blade design**

NuMAD Structural Inputs

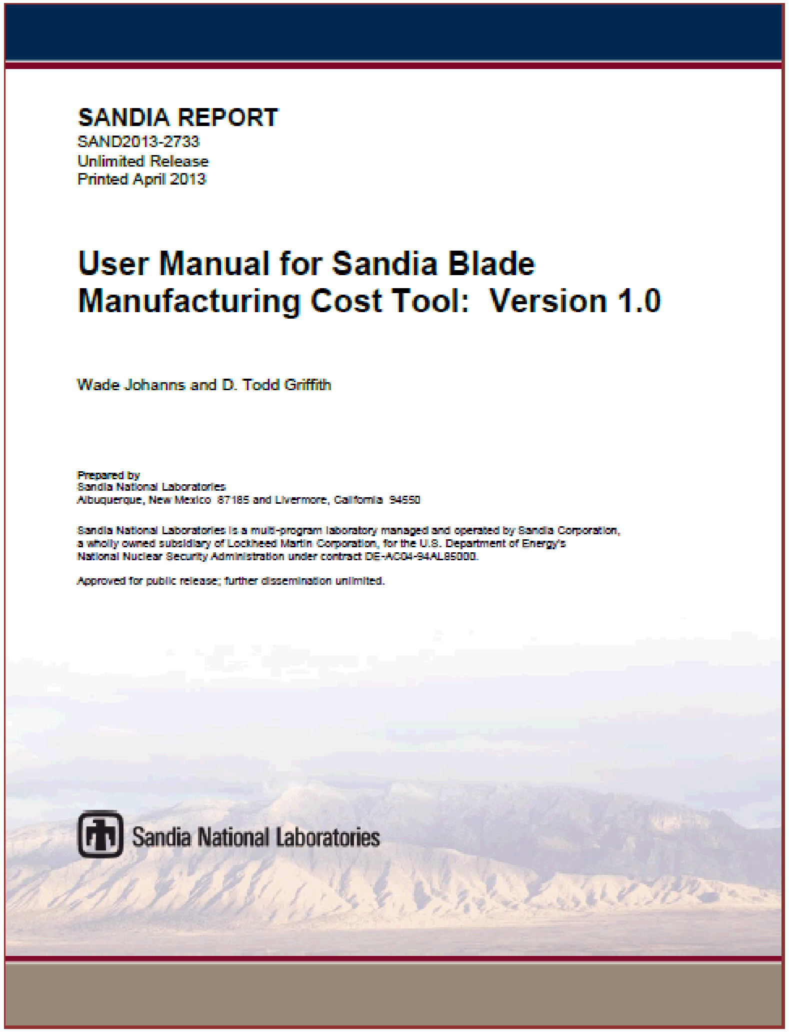
	A	B	C	D	E	F	G	H	I
1	Compatible with version v2013-07-25						do not delete ==>	0	<==
2		Spar cap width	300	[mm]					
3		LE band width	76	[mm]		Component Group = 0:blade, 1:sw1, 2:sw2, etc...			
4		TE band width	125	[mm]					
5									
6	Component Group	Component Name	Material ID	Fabric Angle	HP Extents	LP Extents	CP span	CP nLayers	Layer Interp
7	0	gelcoat	5	0	le,te	le,te	[0, 1]	[1, 1]	linear
8	0	outershell-01	2	0	le,te	le,te	[0, 1]	[1, 1]	linear
9	0	outershell-02	2	0	le,te	le,te	[0, 1]	[1, 1]	linear
10	0	outershell-03	1	0	le,te	le,te	[0, 0.192]	[1, 1]	linear
11	0	outershell-04	1	0	le,te	le,te	[0, 0.142]	[1, 1]	linear
18	0	core-le02	4	0	a,b	a,b	[0.455, 0.853]	[1, 1]	linear
19	0	core-te02	4	0	c,d	c,d	[0.455, 0.853]	[1, 1]	linear
20	0	core-03	4	0	a,d	a,d	[0.853, 0.947]	[1, 1]	linear
21	0	spar-01	1	0	b,c	b,c	[0.069, 0.924]	[1, 1]	linear
22	0	spar-02	1	0	b,c	b,c	[0.089, 0.885]	[1, 1]	linear
23	0	spar-03	1	0	b,c	b,c	[0.104, 0.847]	[1, 1]	linear
24	0	spar-04	1	0	b,c	b,c	[0.116, 0.804]	[1, 1]	linear
38	0	innershell-05	1	0	le,te	le,te	[0, 0.139]	[1, 1]	linear
39	0	innershell-06	1	0	le,te	le,te	[0, 0.189]	[1, 1]	linear
40	0	innershell-07	2	0	le,te	le,te	[0, 0.995]	[1, 1]	linear
41	0	innershell-08	2	0	le,te	le,te	[0, 0.995]	[1, 1]	linear
42	0	root	3	0	le,te	le,te	[0, 0.019, 0.052]	[39, 39, 0]	linear
43	0	ter-01	1	0	d,te	d,te	[0.162, 0.808]	[1, 1]	linear
44	1	sw1-01	2	0	b+15	b+165	[0.077, 0.846]	[3, 3]	linear
45	1	sw1core-02	4	0	b+15	b+165	[0.077, 0.846]	[2, 2]	linear
46	1	sw1-03	2	0	b+15	b+165	[0.077, 0.846]	[3, 3]	linear

Any of the structural or material properties used in NuMAD can be variables in the optimization routine

Sandia Blade Cost Model

Sandia National Laboratories

- Using NuMAD input, calculates blade cost as a combination of:
  - Material Costs
  - Labor Costs
  - Capital Costs
- Based on blade manufacturing data from 40 m blades
- Integrating this tool into the structural optimization enables optimization fitness functions that minimize cost



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User Manual for Sandia Blade Manufacturing Cost Tool: Version 1.0

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