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User Manual for Sandia Blade Manufacturing Cost Tool: Version 1.0

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Abstract

This document provides a description of usage for the Sandia Blade Manufacturing Cost Tool (Version 1.0). This cost tool is comprised of two spreadsheet files that are linked together to perform an analysis of total blade cost based on a detailed design specification. The cost components in the version 1.0 model are limited to those that are most strongly are affected by blade design decisions. These include blade costs in materials, labor content, and capital equipment. The tool can be used to estimate these individual cost components as well as scaling these cost components to larger blade lengths. The basis for the labor content analysis is a detailed conceptual labor process defined for an example 40-meter blade. The usage of the tool is described for each of the major cost components.

CONTENTS

Introduction

This document is intended to provide a brief overview of usage for the Sandia Blade Manufacturing Cost Tool (version 1.0) spreadsheets. The Blade Cost Estimator is located in two files: (1) the main file called "SNL_Blade_Cost_Estimator.xlxs" and (2) a secondary file that contains the labor process description "Blade_Labor_Cost.xlsx".

The costs in this initial version of the tool are divided into three components: Materials, Labor, and Equipment which have their own tabs in "SNL_Blade_Cost_Estimator". There are additional tabs for Total, Pie Charts, and Sensitivity Analysis. Only the Labor tab relies on data from "Blade_Labor_Cost".

This report describes the means to compute the required blade component geometric design information (e.g. ply lengths and areas) based on a detailed layup specification. However, in the future it is anticipated that the Sandia NuMAD blade modeling software (Reference 1) will be updated to automatically provide such information so that the intermediate calculations that are required and described below may not be necessary.

A companion report to this user guide that provides an analysis of large blade manufacturing costs and cost trends using this cost tool is provided in Reference 2.

Materials Tab

In the Materials tab there are tables to input material prices and material content ("bill of materials") for specific blades. Examples are included for baseline comparisons (the example 40m All-glass blade, Sandia 100m All-glass blade ("SNL100-00" in Reference 3), Sandia100m Carbon Spar with Foam Blade, and Sandia 100m Carbon Spar Blade ("SNL100-01" in Reference 4).

Material Weights

Figure 1 describes the inputs to the Materials Tab including some example material prices. If mass data is not available for specific types of fiberglass fabric then just one of Uni-axial or Double Bias may be used generically for all fiberglass content. Epoxy resin and exterior coating may also be input based on weight.

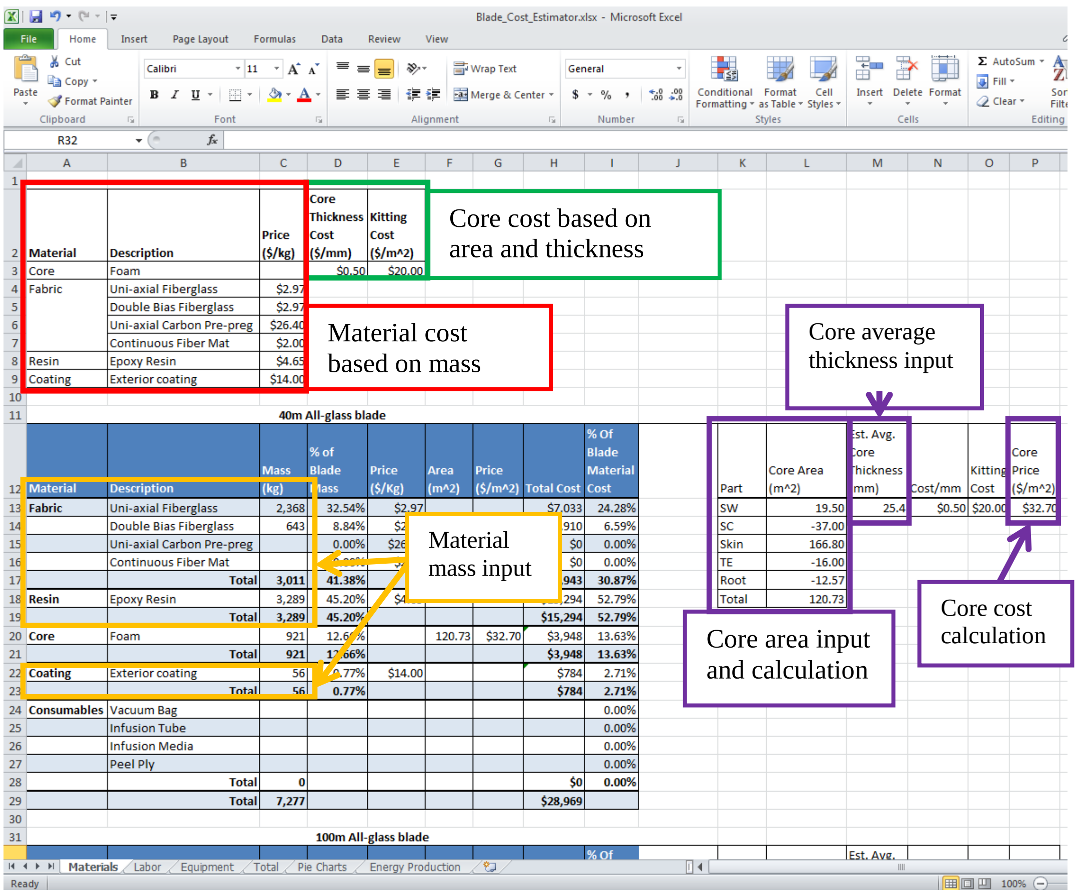
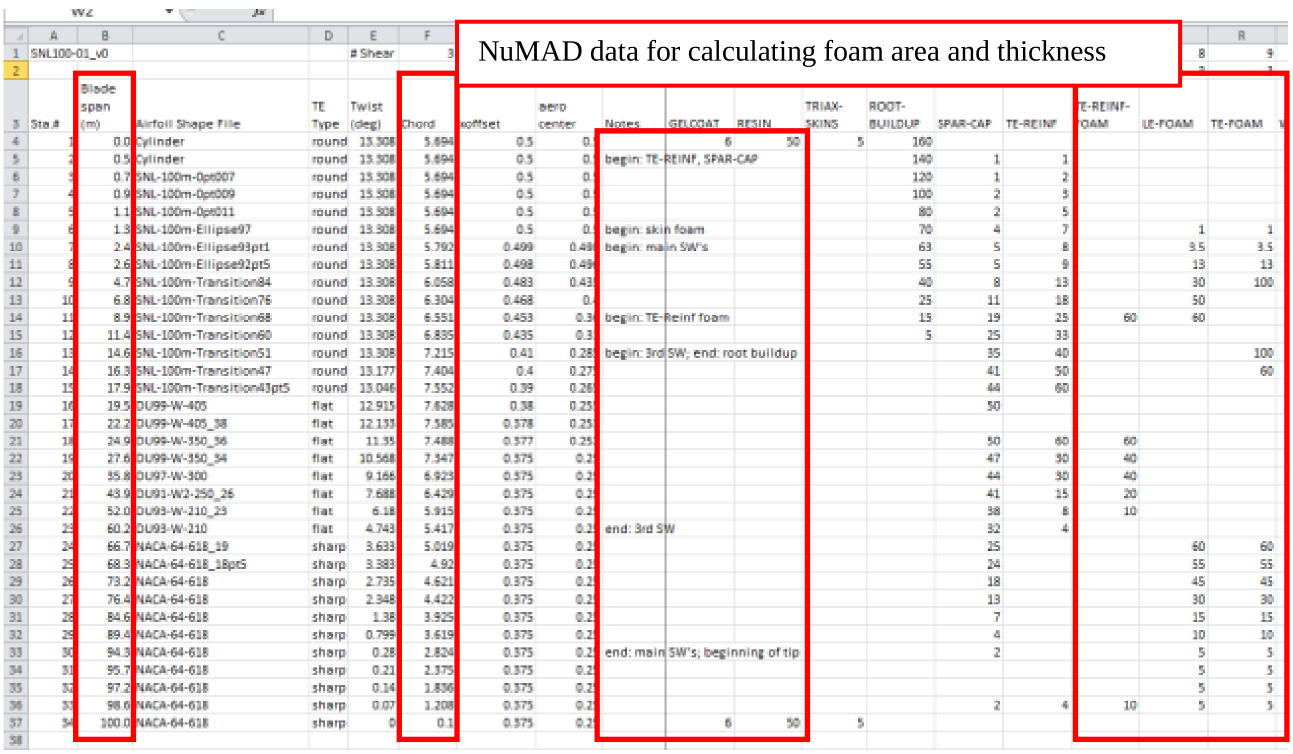


Figure 1. Screenshot of Materials Tab with Highlights of Inputs/Outputs of the Module

Core area, thickness, and cost calculation

The cost of core material is computed in a different way in this modoel as it is derived from the area and thickness of the foam (not by weight). First the average thickness of all foam needs to be calculated from the NuMAD data. Then the surface area of the foam is found by taking the total skin surface area from ANSYS and subtracting areas that have no foam and adding additional areas of foam. The non-foam areas are: the spar cap, some parts of the trailing edge, and the root. The additional foam area is the shear-web(s). Because the spar cap and trailing edge have constant width, their surface areas may be determined by multipling their lengths by their widths.

For example, the width can be found in the "Parameters" tab of the "NuMAD.xlsx" worksheet [1]. The length of the foam in the TE is shown in the "TE-Foam" column where the initial span and final span of the TE-foam can be seen. The root surface area can be found by finding the circumference from the "Chord" column at 0.0m span and multipling by the length of root without foam which is found at the span of "begin: skin foam" in the "Notes" column (Figure 2). The shear web(s) area must be found using ANSYS area calulations. This method could potentially be used for the other components.



	A	B	C	D	E	F												
1	SNL100-01_v0				# Shear	3											8	9
2																		
3	Sta.#	Blade span (m)	Airfoil Shape File	TE Type	Twist (deg)	Chord	xoffset	aero center	Notes	GELCOAT	RESIN	TRIAX-SKINS	ROOT-BUILDUP	SPAR-CAP	TE-REINF	TE-REINF-FOAM	LE-FOAM	TE-FOAM
4	1	0.0	Cylinder	round	13.308	5.694	0.5	0.5		6	50	5	160					
5	2	0.5	Cylinder	round	13.308	5.694	0.5	0.5	begin: TE-REINF, SPAR-CAP				140	1	1			
6	3	0.7	SNL-100m-0pt007	round	13.308	5.694	0.5	0.5					120	1	2			
7	4	0.9	SNL-100m-0pt009	round	13.308	5.694	0.5	0.5					100	2	3			
8	5	1.1	SNL-100m-0pt011	round	13.308	5.694	0.5	0.5					80	2	5			
9	6	1.3	SNL-100m-Ellipse97	round	13.308	5.694	0.5	0.5	begin: skin foam				70	4	7		1	1
10	7	2.4	SNL-100m-Ellipse93pt1	round	13.308	5.792	0.499	0.49	begin: main SW's				63	5	8		3.5	3.5
11	8	2.6	SNL-100m-Ellipse92pt5	round	13.308	5.811	0.498	0.49					55	5	9		13	13
12	9	4.7	SNL-100m-Transition84	round	13.308	6.058	0.483	0.43					40	8	13		30	100
13	10	6.8	SNL-100m-Transition76	round	13.308	6.304	0.468	0.4					25	11	18		50	
14	11	8.9	SNL-100m-Transition68	round	13.308	6.551	0.453	0.3	begin: TE-Reinf foam				15	19	25	60	60	
15	12	11.4	SNL-100m-Transition60	round	13.308	6.835	0.435	0.3					5	25	33			
16	13	14.6	SNL-100m-Transition51	round	13.308	7.215	0.41	0.28	begin: 3rd SW; end: root buildup					35	40			100
17	14	16.3	SNL-100m-Transition47	round	13.177	7.404	0.4	0.27						41	50			60
18	15	17.9	SNL-100m-Transition43pt5	round	13.046	7.552	0.39	0.26						44	60			
19	16	19.5	DU99-W-405	flat	12.915	7.628	0.38	0.25						50				
20	17	22.2	DU99-W-405_38	flat	12.133	7.585	0.378	0.25										
21	18	24.9	DU99-W-350_36	flat	11.35	7.488	0.377	0.25						50	60	60		
22	19	27.6	DU99-W-350_34	flat	10.568	7.347	0.375	0.2						47	30	40		
23	20	35.8	DU97-W-300	flat	9.166	6.923	0.375	0.2						44	30	40		
24	21	43.9	DU91-W2-250_26	flat	7.688	6.429	0.375	0.2						41	15	20		
25	22	52.0	DU93-W-210_23	flat	6.18	5.915	0.375	0.2						38	8	10		
26	23	60.2	DU93-W-210	flat	4.743	5.417	0.375	0.2	end: 3rd SW					32	4			
27	24	66.7	NACA-64-618_19	sharp	3.633	5.019	0.375	0.2						25			60	60
28	25	68.3	NACA-64-618_18pt5	sharp	3.383	4.92	0.375	0.2						24			55	55
29	26	73.2	NACA-64-618	sharp	2.735	4.621	0.375	0.2						18			45	45
30	27	76.4	NACA-64-618	sharp	2.348	4.422	0.375	0.2						13			30	30
31	28	84.6	NACA-64-618	sharp	1.38	3.925	0.375	0.2						7			15	15
32	29	89.4	NACA-64-618	sharp	0.799	3.619	0.375	0.2						4			10	10
33	30	94.3	NACA-64-618	sharp	0.28	2.824	0.375	0.2	end: main SW's; beginning of tip					2			5	5
34	31	95.7	NACA-64-618	sharp	0.21	2.375	0.375	0.2									5	5
35	32	97.2	NACA-64-618	sharp	0.14	1.836	0.375	0.2									5	5
36	33	98.6	NACA-64-618	sharp	0.07	1.208	0.375	0.2						2	4	10	5	5
37	34	100.0	NACA-64-618	sharp	0	0.1	0.375	0.2		6	50	5						
38																		

Figure 2. Screenshot of NuMAD Blade Design Data Needed for this Cost Model

Once the area of the components are determined they may be input into the table to the right of the blade table being analyzed as shown in Figure 1. There are cells for shear web (SW), spar cap (SC), skin, trailing edge (TE), and root. Remember that there are two spar caps and two trailing edges. The areas are summed as positive or negative core areas and totaled at the bottom.

The average core thickness is input in the adjacent cell to the area input column. Cost of the core is calculated from its thickness a base price for kitting. The cost/mm thickness and the kitting cost can be changed in the material cost table at the top of the sheet.

Consumables

Consumable prices (e.g. vacuum bags, infusion media, etc.) may be added to the material cost table and weights added into the tables below as indicated in Figure 3. However, when comparing blades of the same length, it is not necessary to know the consumables cost because it will be the same unless major component additions or subtractions take place.

40m All-glass blade

Material	Description	Mass (kg)	% of Blade Mass	Price ($/Kg)	Area (m^2)	Price ($/m^2)	Total Cost	% Of Blade Material Cost
Fabric	Uni-axial Fiberglass	2,368	32.54%	$2.97			$7,033	24.28%
	Double Bias Fiberglass	643	8.84%	$2.97			$1,910	6.59%
	Uni-axial Carbon Pre-preg		0.00%	$26.40			$0	0.00%
	Continuous Fiber Mat		0.00%	$2.00			$0	0.00%
	Total	**3,011**	**41.38%**				**$8,943**	**30.87%**
Resin	Epoxy Resin	3,289	45.20%	$4.65			$15,294	52.79%
	Total	**3,289**	**45.20%**				**$15,294**	**52.79%**
Core	Foam	921	12.66%		120.73	$32.70	$3,948	13.63%
	Total	**921**	**12.66%**				**$3,948**	**13.63%**
Coating	Exterior coating	56	0.77%	$14.00			$784	2.71%
	Total	**56**	**0.77%**				**$784**	**2.71%**
Consumables	Vacuum Bag							0.00%
	Infusion Tube							0.00%
	Infusion Media							0.00%
	Peel Ply							0.00%
	Total	**0**					**$0**	**0.00%**
	Total	**7,277**					**$28,969**	

Consumables mass input

Part	Core Area (m^2)	Est. Avg. Core Thickness (mm)	Cost/mm	Kitting Cost	Core Price ($/m^2)
SW	19.50	25.4	$0.50	$20.00	$32.70
SC	-37.00				
Skin	166.80				
TE	-16.00				
Root	-12.57				
Total	120.73				

Core area input and calculation, average thickness input, and cost calculation

Figure 3. Screenshot of Materials Tab Highlighting Consumables and Core Inputs

Labor Tab

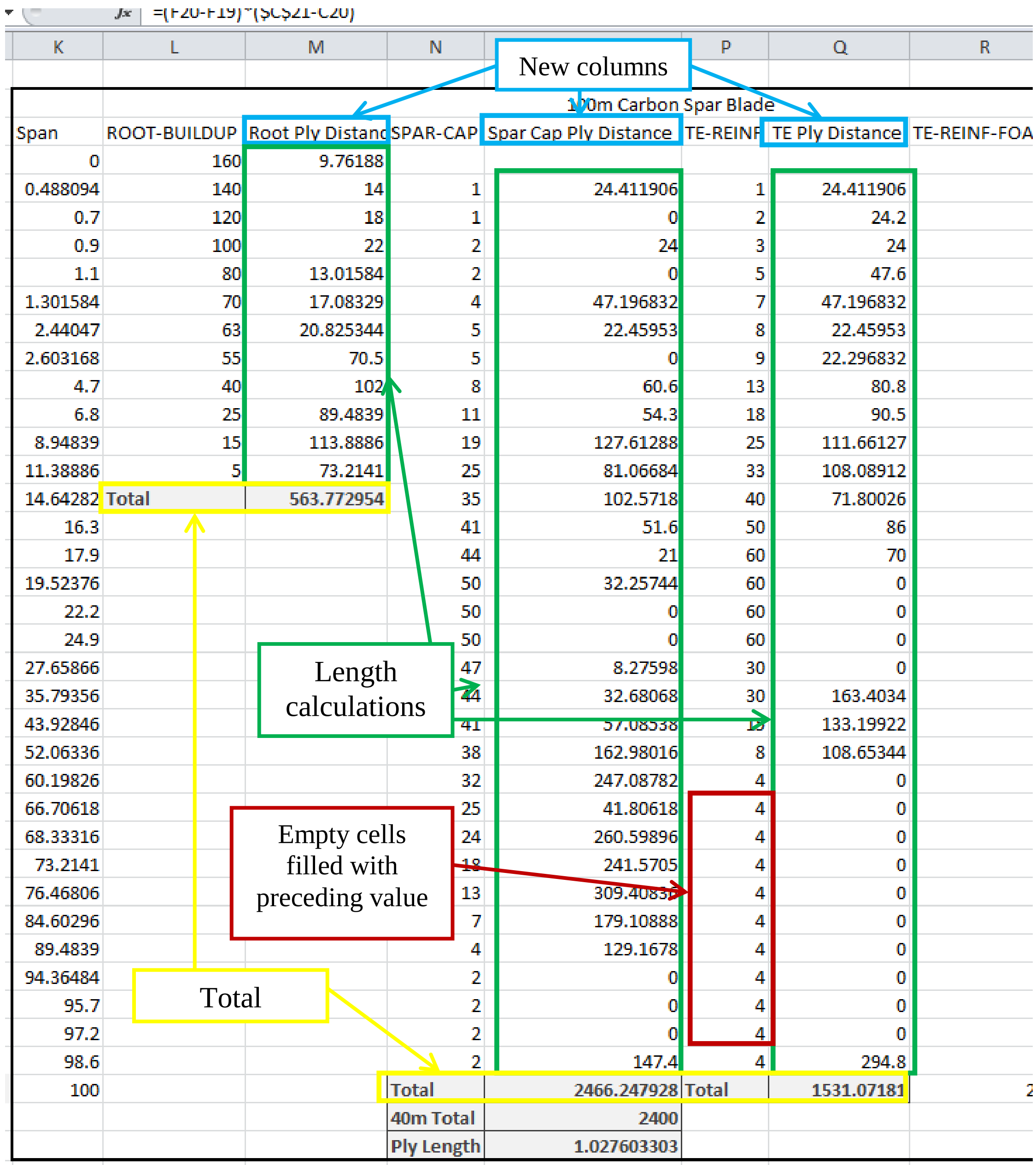
To calculate the labor content the “Blade_Labor_Cost” worksheet must be opened. The output labor hours in that worksheet are linked to the tables in the “Labor” tab of the “SNL_Blade_Cost_Estimator” worksheet. The labor calculations require blade design information from NuMAD and ANSYS, which can be found in the “Geometry” tab of the NuMAD output. The NuMAD information is transferred to the “Blade_Labor_Cost” spreadsheet. Specifically the NuMAD columns: Span, Root-Buildup, Spar-cap, and TE-Reinf are copied to the “NuMAD” tab of “Blade_Labor_Cost”.

As mentioned in the Introduction, it is anticipated that these intermediate calculations for the blade geometry may be added as a future feature in NuMAD version 2.0 [1].

Ply Lengths

Ply length is an important factor for the labor operations associated with the root, spar cap, and trailing edge preform because the lay-up sub tasks are driven by ply length in these cases. To estimate the ply length, two methods are considered. The first is very fast, but the accuracy is not as good as the second. This method assumes that the ply drops result in a triangular longitudinal cross section. To find the ply length multiply the spar cap length by the number of plies at the thickest location and divide by two.

The second method is more involved, but is more accurate. For this method new columns are added for: Root Ply Distance, Spar Cap Ply Distance, and TE Ply Distance (see Figure 4). These are created to compute an estimate of the length of fabric used in each lay-up by estimating the length of fabric in each NuMAD ply drop. All empty ply number cells must be filled to equal the value of the preceding cell in the column. Unnecessary columns have been deleted.



=(F20-F19)*(C21-C20)

Span	ROOT-BUILDUP	Root Ply Distanc	SPAR-CAP	Spar Cap Ply Distance	TE-REINF	TE Ply Distance	TE-REINF-FOA
0	160	9.76188					
0.488094	140	14	1	24.411906	1	24.411906	
0.7	120	18	1	0	2	24.2	
0.9	100	22	2	24	3	24	
1.1	80	13.01584	2	0	5	47.6	
1.301584	70	17.08329	4	47.196832	7	47.196832	
2.44047	63	20.825344	5	22.45953	8	22.45953	
2.603168	55	70.5	5	0	9	22.296832	
4.7	40	102	8	60.6	13	80.8	
6.8	25	89.4839	11	54.3	18	90.5	
8.94839	15	113.8886	19	127.61288	25	111.66127	
11.38886	5	73.2141	25	81.06684	33	108.08912	
14.64282	Total	563.772954	35	102.5718	40	71.80026	
16.3			41	51.6	50	86	
17.9			44	21	60	70	
19.52376			50	32.25744	60	0	
22.2			50	0	60	0	
24.9			50	0	60	0	
27.65866			47	8.27598	30	0	
35.79356			44	32.68068	30	163.4034	
43.92846			41	57.08538	[illegible]	133.19922	
52.06336			38	162.98016	8	108.65344	
60.19826			32	247.08782	4	0	
66.70618			25	41.80618	4	0	
68.33316			24	260.59896	4	0	
73.2141			18	241.5705	4	0	
76.46806			13	309.4083[illegible]	4	0	
84.60296			7	179.10888	4	0	
89.4839			4	129.1678	4	0	
94.36484			2	0	4	0	
95.7			2	0	4	0	
97.2			2	0	4	0	
98.6			2	147.4	4	294.8	
100			Total	2466.247928	Total	1531.07181	2
			40m Total	2400			
			Ply Length	1.027603303			

Figure 4. Ply Length Calculation for Labor Content Tab Based on NuMAD Layup Schedule

The ply length estimation is done by calculating the length of a ply or group of plies from their origin to the end of the thickest section and multiplying that by the number of plies in the group. For example: in the column "Spar Cap Ply Distance" the first ply length is found by the number of plies at that span (1-0) multiplied by the span distance of that group to the end of thickest section(24.9-0.488). This estimates one ply at 24.4m for the protion up to the thick section. The remaining portion will be calculated from the other end. This process is followed for all ply groups descending until the thickest section is reached. After the thickest section is reached the process is reversed from the bottom up. The first and last cells in the column subtract 0 from the ply number. For another example: If we skip down to 19 plies, we find the number of plies for that group to be (19 - 11), the end to be at 50 plies because that is the thickest section, and the span distance to be (24.9 - 8.95). See Figure 5. This estimates 8 plies at 15.95m long for a total length of 127.6m of material to be placed in the mold for this task. For the other side of the ply drops, the opposite process is used. For example: at 13 plies the number of plies is (13 - 7) and the distance is (76.4 - 24.9). This estimates 6 plies at 51.5m long for a total of 309m. The same method can be used for the “TE Ply Distance” and “Root Ply Distance” columns. The totals are linked to cells in the first tab “Summary and Scaling”.

K	L	M	N	O	P	Q	R
				100m Carbon Spar Blade			
Span	ROOT-BUILDUP	Root Ply Distanc	SPAR-CAP	Spar Cap Ply Distance	TE-REINF	TE Ply Distance	TE-REINF-FOA
0	160	9.76188					
0.488094	140	14	1	24.411906	1	24.411906	
0.7	120	18	1	0	2	24.2	
0.9	100	22	2	24	3	24	
1.1	80				5	47.6	
1.301584	70				7	47.196832	
2.44047	63	20.825344	5	22.45953	8	22.45953	
2.603168	55	70.5	5	0	9	22.296832	
4.7	40	102	8	60.6	13	80.8	
6.8	25	89.4839	11	54.3	18	90.5	
8.94839	15	113.8886	19	127.61288	25	111.66127	
11.38886	5	73.2141	25	81.06684	33	108.08912	
14.64282	Total	563.772954	35	102.5718	40	71.80026	
16.3			41	51.6	50	86	
17.9			44	21	60	70	
19.52376			50	32.25744	60	0	
22.2			50	0	60	0	
24.9			50	0	60	0	
27.65866			47	8.27598	30	0	
35.79356			44	32.68068	30	163.4034	
43.92846			41	57.08538	15	133.19922	
52.06336			38	162.98016	8	108.65344	
60.19826			32	247.08782	4	0	
66.70618					4	0	
68.33316					4	0	
73.2141			18	241.5705	4	0	
76.46806			13	309.40836	4	0	
84.60296			7	179.10888	4	0	
89.4839			4	129.1678	4	0	
94.36484			2	0	4	0	
95.7			2	0	4	0	
97.2			2	0	4	0	
98.6			2	147.4	4	294.8	
100			Total	2466.247928	Total	1531.07181	2
			40m Total	2400			
			Ply Length	1.027603303			

(19 - 11)*(24.9 - 8.95) =

(47 - 44)*(27.7 - 24.9) = 8.28

Figure 5. Example Ply Length Calculation for Labor Content Tab

Scaling

The labor content scaling takes place in the first tab "Summary and Scaling" of "Blade_Labor_Cost" in tables next to each blade design. The type of input is described in the "Variable Legend" table at the top of the sheet. The first two blade design tables are reserved for comparison. Results from previous new designs can be saved in a new tab or spreadsheet. It is not recommended to add more blade design tables because a new table must be added in all subsequent tabs.

In the scaling table are components that will be scaled, the baseline values from the example 40m blade, the values for the blade to be considered, a description of the effects of the scaling process, and the scaling factor for that particular operation or component. See Figure 6.

The table to the right of the scaling table contains non-scaled additional hours that can be added to specific operations where the scaling is either not known, where no scaling is possible, or simply to make adjustments to the model. The operations of infusion and curing may be able to be scaled if a relationship between component thickness, mass, length, etc. and infusion and curing times could be established.

	Man Hours	% fabrication time	% of toal time
23			
24	Man Hours	% fabrication time	% of toal time
25	146.2	10.3%	5.1%
26	136.2	9.6%	4.7%
27	77.4	5.5%	2.7%
28	103.45	7.3%	3.6%
29	615.4	43.5%	21.3%
30	98	6.9%	3.4%
31	238.2	16.8%	8.3%
32	1414.85		49.1%
33			
34	Man Hours	% finishing time	% of total time
35	185.25	12.6%	6.4%
36	23.175	1.6%	0.8%
37	16.1	1.1%	0.6%
38	64.2	4.4%	2.2%
39	1135.65	77.3%	39.4%
40	44.15	3.0%	1.5%
41	1468.53		50.9%

Component	40m All-Glass Blade	100m All-Glass Blade	Description	Factor
Spar Cap Ply Length (m)	1000.0	6612.6	Total estimated length of all plies for lay-up	6.6
Spar Cap Length (m)	37.0	92.0	Length from design(NuMAD) for consumable lay-up	2.5
Spar Cap Laminate Thickness (mm)	50.0	136.0	Thickest section from design(NuMAD) for infusion time	2.7
Fore and Center SW Length (m)	37.0	92.0	Shear web length from design(NuMAD) for lay-up and consumable lay-up	2.5
Aft SW Mold Length (m)	37.0	45.0	Shear web length from design(NuMAD) for lay-up and consumable lay-up	1.2
TE Reinforcement Ply Length (m)	1000.0	1531.1	Total estimated length of all plies for lay-up, 40m values based off of the spar cap because there is no comparable TE operation	1.5
TE Reinforcement Length (m)	37.0	98.0	Length from design(NuMAD) for consumable lay-up, 40m values based on spar cap	2.6
TE Reinforcement Laminate Thickness (mm)	50.0	60.0	Thickest section from design(NuMAD) for infusion time, 40m values based on spar cap	1.2
Root Ply Length (m)	100.0	563.8	Total estimated length of all plies for lay-up	5.6
Root Preform Length (m)	2.0	2.6	Length from design(NuMAD) for consumable lay-up	1.3
Final Root Length (m)	3.0	11.4	Length of root in the skin mold including additional ply overlays from design(NuMAD) for root build-up	3.8
Number of Root Bolts	62.0	157	Total number of root bolts, for T-bolt operations	2.5
Blade Surface Area (m^2)	166.8	1251.5	Total surface area from design for skin plies, foam, finishing operations, and certain blade inspections	7.5
Blade Total Length (m)	40.0	100.0	Length from design for consumable lay-up, edge triming, and certain blade inspections	2.5
Web Bond Line Length (m)	37.0	229.6	Total length of the bond line for all shear webs based on design for bond pasting prior to shear web attachment	6.2
Close Bond Line Length (m)	117.0	429.6	Total length of the bond line for all shear webs and perimeter based on design for bond pasting prior to final close	3.7

Operation	Componenet	Step	Additional Time (hrs)
Spar Cap	LP and HP Spar Caps	Cure	1
	LP and HP Spar Caps	Infusion	0.5
Shear Webs	Fore and Aft Shear Webs	Cure	0.25
	Fore and Aft Shear Webs	Infusion	0.25
TE Prefabs	LP and HP TE Reinforcements	Cure	-0.5
	LP and HP TE Reinforcements	Infusion	-0.5
Root Prefabs	LP and HP Root Prefabs	Cure	1
	LP and HP Root Prefabs	Infusion	0.5
Infusion	HP and LP Molds	Cure	0.5
	HP and LP Molds	Infusion	0.5

Figure 6. Labor Content Scaling in "Blade_Labor_Cost.xlsx"

Ply lengths are linked to the totals from the "NuMAD" tab that were described previously. Component lengths, mold lengths, and component thicknesses are input from NuMAD or may be calculated from the span distances in the "NuMAD" tab by subtracting the starting span of the component from the ending span.

In the "Fabrication Scaling" and "Finishing Scaling" tabs there are tables that mark which scaling factors are used in which operation tab. This is useful to know where to see the sub task *effects of a scaling factor change as applied in this version 1.0 of the manufacturing cost analysis.*

Individual Operations – By Component

The remaining tabs in the worksheet contain the individual sub tasks for different blade components. At the top of each (e.g. the “Spar Caps” tab) is the 40m baseline operations which is referenced by all new blade design tables below it. The values for the 40m baseline operation and subtask times are located in the “Data” tab near the end of the worksheet. In the new blade design tables are the same subtasks—sometimes duplicated for multiple similar components like shear webs—where the “# people” column is unchanged, the “Process Time” is scaled by multiplying the 40m value by the scaling factor, and the “Man hours” is calculated by multiplying the “# people” by the “Process Time”. *The underlying assumption is that if a subtask man hours are derived from primarily component length then a component of twice the length will take twice as long to be finished by the same number of people.* See Figure 7.

To the right of the subtask tables are the scaling factor legends that are color-coded to their associated subtasks. Subtasks that are not colored are not affected by scaling. Subtasks that are repeated for components in operations with two halves like the HP and LP spar caps are linked to the man hours value of the first components subtasks so that they are always the same.

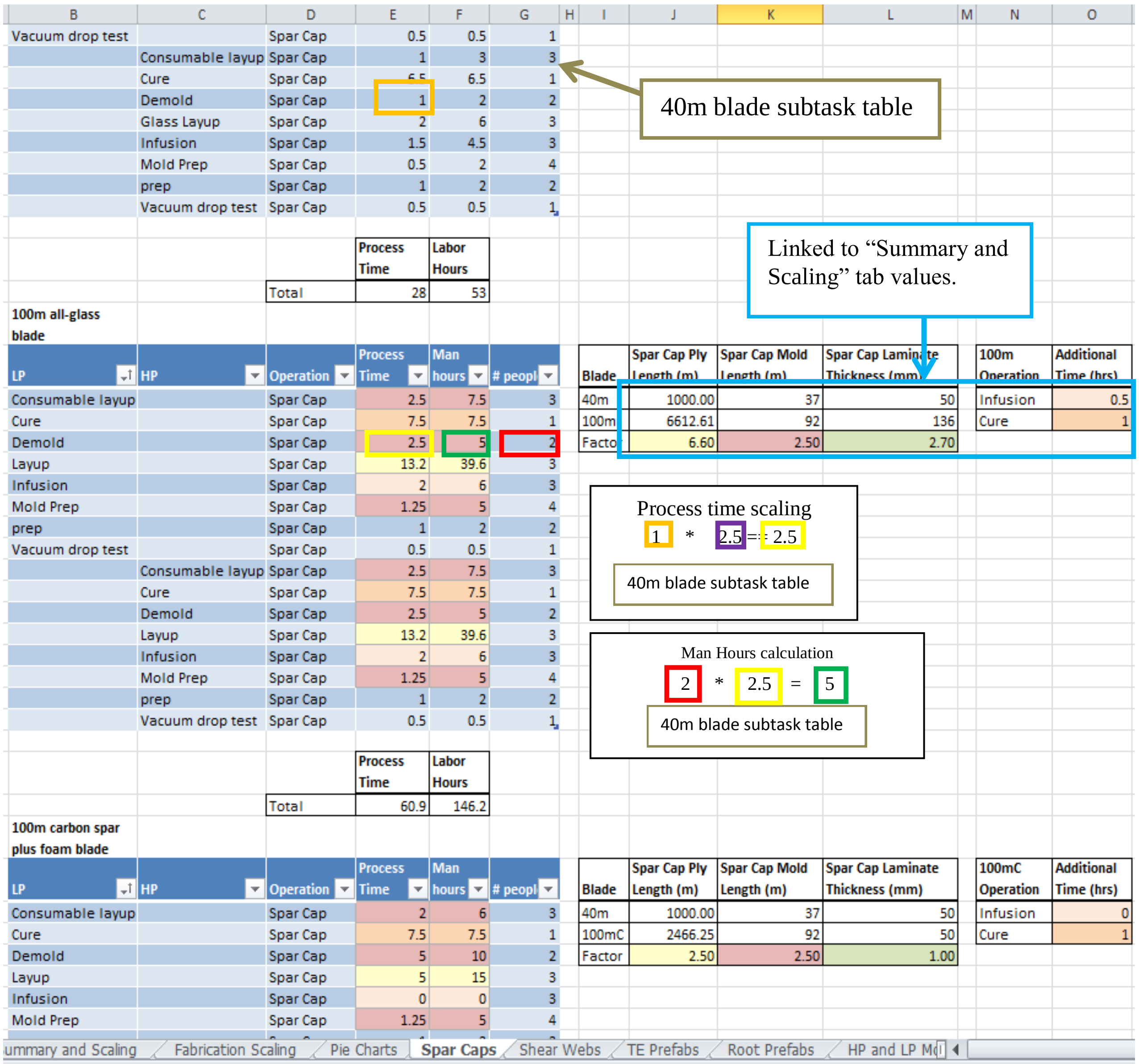


Figure 7. Example Labor Content Scaling for Individual Operations: Spar Cap Construction

In the "TE Prefabs" tab the 40m blade has no comparable TE preform so the operation and subtasks from the 40m spar cap are used for scaling. This was chosen because the 40m spar cap is of comparable size and shape to the larger TE preforms.

To study the effects of automation on a specific subtask, the user must go into the tab of the operation of the subtask and manually alter the value in the table. For instance, if an automated lay-up process were desired for the spar caps then the lay-up subtask would need to be changed. If the automation would only require a single person to monitor it then the "people #" would be reduced to 1. If the process time would be faster that value could be changed to reflect the time savings. It may make sense to create an additional column in the scaling table for automation and link it to the "Summary and Scaling" tab.

Totals

At the end of the fabrication step tabs is the “Summary Fabrication” tab. All of the previous tabs’ man hours are totaled for each blade design. The same tab exists for the finishing operations in the “Summary Finishing” tab. The summary tables on these tabs are linked to the tables on the “Summary and Scaling” tab. These tables show the percent time of either fabrication or finishing for each operation and the percent time of total blade construction time for each operation. Below the fabrication and finishing operation tables is the man hour grand total for the blade.

The tables from the “Summary and Scaling” tab are directly linked to the “Labor” tab of the “SNL_Blade_Cost_Estimator” worksheet. In this tab the labor hour grand total is multiplied by a user inputted average wage rate to yield the labor cost per blade. To the right of the labor tables are aggregate labor hour calculations for more generalized operations. Individual operations are combined to simplify the resulting pie charts.

Equipment Tab

In the capital equipment calculation table there are power scaling equations to determine the value of equipment needed for a specific blade design. The costs are divided into two parts: “Master and Molds” and “Tooling”. Both values are derived from a power law equation based on the blade length. This power law increases the cost of equipment at an exponent of 2.09. This value is from the 2003 WindPACT “Cost Study for Large Wind Turbine Blades" (Reference 5). The table allows the user to change the exponent if desired. Surface area is also included because it is likely that some of the costs would be driven by surface area, especially the master and molds, whereas other equipment like preform molds would be driven by blade length instead.

The values for capital equipment are not necessary for a comparison of blades of the same size. Design changes may result in slightly different surface areas, but the cost for capital equipment will remain largely the same. This tool is primarily useful for comparing blades of different sizes.

Total Tab

The totals are given in two identical tables. It is duplicated so that formatting can be tailored to the specific use of the tables in a document.

Pie Charts Tab

The pie charts in this tab reflect all of the percentage of total calculation from the previous tabs as examples for analysis and comparison of the reference blade designs.

Sensitivity Analysis Tab

This section includes some example sensitivity analysis to examine cost trade-offs in the design and manufacturing process between Materials, Labor, and Equipment. These types of analysis will likely be an important use of this tool; for example, to examine the effect of manufacturing operations changes such as automation on labor content and equipment costs.

References

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