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Appendix 1 – Sample wheels dynamic test results summary

Speed : 4 km/h

Tyre	Load (kg)	Time until failure		Standard total run time (Seconds) for 15000 wheel revelutions	Inside		Outside	
		Run Time with out stop cycle (minutes)	Total run time (Seconds)		Center	Rubber	Center	Rubber
					in side C°	in side C°	out side C°	out side C°
Heavy duty wheels								
125x42 Wheel	375	597	47700	7069	164	158	88	65
	400	66	5220	7069	168	155	77	63
	450	36	2820	7069	169	149	68	47
160x42 Wheel	450	216	17220	9048	168	153	99	64
	500	144	11460	9048	149	137	86	55
	550	45	3540	9048	145	135	82	56
180x42 Wheel	450	231	18420	10179	146	142	85	53
	500	171	13620	10179	148	138	83	51
	550	51	4020	10179	140	130	86	43
200x42 Wheel	450	243	19380	11310	114	141	96	52
	500	198	15780	11310	155	142	98	55
	550	72	5700	11310	193	180	105	68
General application wheels								
125 Common Wheel	100	372	29700	7069	134	108	69	57
	125	105	8340	7069	72	103	63	59
100 Common Wheel	80	363	28980	5655	89	88	63	48
	100	36	2820	5655	118	92	66	47

Appendix 2 – Static loading energy calculation case study 1

	m	N	N	Nm	Nm
Increment	**Displacement**	**Force**	**Forcex4**	**Step Energy**	**Sum of Energy**
1	0.0000	0.00	0.00		
2	0.0001	1.19	4.75	0.0005	
3	0.0002	4.08	16.31	0.0017	
4	0.0003	8.58	34.31	0.0035	
5	0.0004	15.27	61.06	0.0062	
6	0.0005	24.22	96.89	0.0099	
7	0.0006	35.10	140.40	0.0143	
8	0.0007	47.57	190.27	0.0194	
9	0.0008	61.61	246.42	0.0251	
10	0.0009	76.97	307.87	0.0314	
11	0.0010	93.81	375.25	0.0383	
12	0.0011	111.94	447.74	0.0457	
13	0.0012	131.47	525.89	0.0537	
14	0.0013	152.54	610.15	0.0623	
15	0.0014	175.10	700.41	0.0715	
16	0.0015	199.04	796.15	0.0812	
17	0.0016	224.06	896.23	0.0915	
18	0.0017	250.59	1002.35	0.1023	
19	0.0018	278.34	1113.37	0.1136	
20	0.0019	307.61	1230.46	0.1256	
21	0.0020	338.24	1352.97	0.1381	
22	0.0021	370.21	1480.83	0.1511	
23	0.0022	403.35	1613.40	0.1646	
24	0.0023	437.93	1751.73	0.1787	
25	0.0024	473.74	1894.97	0.1934	
26	0.0026	511.11	2044.45	0.2086	
27	0.0027	550.26	2201.05	0.2246	
28	0.0028	590.80	2363.20	0.2411	
29	0.0029	632.54	2530.18	0.2582	
30	0.0030	675.68	2702.72	0.2758	
31	0.0031	720.04	2880.15	0.2939	
32	0.0032	765.89	3063.56	0.3126	
33	0.0033	812.98	3251.93	0.3318	
34	0.0034	861.44	3445.77	0.3516	
35	0.0035	911.83	3647.32	0.3722	
36	0.0036	963.51	3854.05	0.3933	
37	0.0037	1016.51	4066.06	0.4149	

38	0.0038	1070.76	4283.06	0.4370	
39	0.0039	1126.46	4505.83	0.4598	6.30
40	0.0040	1183.48	4733.90	0.4830	
41	0.0041	1241.88	4967.51	0.5069	7.29
42	0.0042	1301.61	5206.44	0.5313	
43	0.0043	1362.75	5450.99	0.5562	8.38
44	0.0044	1425.27	5701.07	0.5818	
45	0.0045	1489.68	5958.72	0.6080	
46	0.0046	1555.68	6222.72	0.6350	
47	0.0047	1623.12	6492.47	0.6625	
48	0.0048	1691.83	6767.32	0.6905	
49	0.0049	1762.00	7048.01	0.7192	
50	0.0050	1833.63	7334.53	0.7484	

Appendix 3 – Total energy rate calculation case study 1

	J/mm3	mm3	J		J/s
Element ID	**Energy density**	**Element Volume**	**Element energy**		**Distributed total energy rate**
136	0.000535	27.2	0.014541	7.02%	4.269
121	0.000561	25.1	0.014073	6.80%	4.131
586	0.000432	23.52	0.010157	4.91%	2.982
676	0.000475	20.91	0.009924	4.79%	2.914
106	0.000432	21.17	0.009146	4.42%	2.685
151	0.000357	24.82	0.008864	4.28%	2.602
391	0.000508	16.3	0.008273	4.00%	2.429
601	0.000366	20.86	0.007631	3.69%	2.240
376	0.000386	17.82	0.006878	3.32%	2.019
406	0.000307	20.99	0.006452	3.12%	1.894
616	0.000225	28.02	0.006303	3.04%	1.850
46	0.000181	34.87	0.006300	3.04%	1.850
421	0.000312	18.38	0.005734	2.77%	1.683
706	0.000307	18.52	0.005686	2.75%	1.669
451	0.000447	12.33	0.005510	2.66%	1.618
571	0.000463	11.88	0.005499	2.66%	1.614
61	0.000195	26.53	0.005186	2.51%	1.522
646	0.000333	14.29	0.004761	2.30%	1.398
556	0.000436	10.66	0.004644	2.24%	1.363
241	0.000450	9.68	0.004354	2.10%	1.278
31	0.000158	26.67	0.004210	2.03%	1.236
76	0.000187	21.48	0.004009	1.94%	
166	0.000147	25.46	0.003745	1.81%	
631	0.000341	10.92	0.003727	1.80%	
91	0.000181	20.57	0.003725	1.80%	
436	0.000358	9.46	0.003387	1.64%	
226	0.000509	6.39	0.003251	1.57%	
181	0.000150	20.54	0.003086	1.49%	
196	0.000200	14.41	0.002882	1.39%	
661	0.000514	5.2	0.002671	1.29%	
511	0.000105	23.38	0.002457	1.19%	
496	0.000143	17.15	0.002446	1.18%	
16	0.000140	17.25	0.002420	1.17%	
481	0.000186	12.83	0.002389	1.15%	

211	0.000286	7.15	0.002046	0.99%	
1	0.000110	16.3	0.001790	0.86%	
691	0.000392	4.39	0.001722	0.83%	
526	0.000078	19.96	0.001564	0.76%	
466	0.000221	6.66	0.001472	0.71%	
256	0.000160	6.15	0.000985	0.48%	
541	0.000069	9.83	0.000680	0.33%	
301	0.000033	15.15	0.000503	0.24%	
316	0.000031	16.16	0.000501	0.24%	
331	0.000026	13.72	0.000362	0.17%	
286	0.000033	10.85	0.000361	0.17%	
361	0.000033	9.2	0.000308	0.15%	
271	0.000032	6.13	0.000196	0.09%	
346	0.000022	8.84	0.000191	0.09%	

Appendix 4 – Material property data

Material thermal properties

Material	Mass Density	Specific Heat capacity	Heat conductivity	Forced Convection-Air	Rubber to floor conduction
	kg/mm3	W/kg/k	W/mm/c	W/mm²/ c ◦	W/mm²/ c ◦
PP	0.00000091	1800	0.00018	0.0000060	
Nylon	0.00000125	1700	0.00026	0.0000060	
NR-1	0.0000012	1700	0.000239	0.0000060	0.0001
NR-2	0.0000012	1700	0.000239	0.0000060	0.0001

Nylon

Temperature (°C)	Modulus(MPa)	Yield (MPa)
23	821.2	68.4
140	614.0	19.9

Polypropylene

Temperature (°C)	Modulus(MPa)	Yield (MPa)
23	194.5	24.6
120	152.0	9.2

Appendix 5 – Static load energy calculation case study 2

	m	N	N	Nm	Nm
Increment	**Displacement**	**Force**	**Forcex4**	**Step Energy**	**Sum of Energy**
1	0.00010	0	0.00		
2	0.00020	1.257258	5.03	0.0005	
3	0.00030	3.84284	15.37	0.0015	
4	0.00040	7.206436	28.83	0.0029	
5	0.00050	11.40075	45.60	0.0046	
6	0.00060	16.24889	65.00	0.0065	
7	0.00070	21.98813	87.95	0.0088	
8	0.00080	28.48838	113.95	0.0114	
9	0.00090	35.47014	141.88	0.0142	
10	0.00100	43.02067	172.08	0.0172	
11	0.00110	51.48609	205.94	0.0206	
12	0.00120	60.42285	241.69	0.0242	
13	0.00130	69.90346	279.61	0.0280	
14	0.00140	79.80058	319.20	0.0319	
15	0.00150	90.56133	362.25	0.0362	
16	0.00160	101.9456	407.78	0.0408	
17	0.00170	113.855	455.42	0.0455	
18	0.00180	126.2865	505.15	0.0505	
19	0.00190	139.0828	556.33	0.0556	
20	0.00200	152.2478	608.99	0.0609	
21	0.00210	166.0777	664.31	0.0664	
22	0.00220	180.4575	721.83	0.0722	
23	0.00230	195.2797	781.12	0.0781	
24	0.00240	210.6726	842.69	0.0843	
25	0.00250	226.3694	905.48	0.0905	
26	0.00260	242.4892	969.96	0.0970	
27	0.00270	258.9483	1035.79	0.1036	
28	0.00280	275.9915	1103.97	0.1104	
29	0.00290	293.4132	1173.65	0.1174	
30	0.00300	311.2933	1245.17	0.1245	1.41
31	0.00310	329.5096	1318.04	0.1318	
32	0.00320	348.092	1392.37	0.1392	
33	0.00330	367.0028	1468.01	0.1468	
34	0.00340	386.1508	1544.60	0.1545	
35	0.00350	405.5723	1622.29	0.1622	

36	0.00360	425.4024	1701.61	0.1702	
37	0.00370	445.7278	1782.91	0.1783	
38	0.00380	466.2945	1865.18	0.1865	
39	0.00390	487.0827	1948.33	0.1948	
40	0.00400	508.1855	2032.74	0.2033	
41	0.00410	529.505	2118.02	0.2118	
42	0.00420	550.992	2203.97	0.2204	
43	0.00430	572.9177	2291.67	0.2292	
44	0.00440	595.0815	2380.33	0.2380	
45	0.00450	617.4105	2469.64	0.2470	
46	0.00460	639.9348	2559.74	0.2560	
47	0.00470	662.8398	2651.36	0.2651	
48	0.00480	685.9876	2743.95	0.2744	
49	0.00490	709.2901	2837.16	0.2837	
50	0.00500	732.814	2931.26	0.2931	

Appendix 6 – Total energy rate calculation case study 2

	j/mm3	mm3	j		j/s
Element ID	**Energy density**	**Element Volume**	**Element energy**		**Distributed total energy rate**
316	0.000265870	10.6077	0.002820266	8.11%	1.292
331	0.000252908	9.67325	0.002446438	7.04%	1.121
301	0.000203095	11.7425	0.002384842	6.86%	1.093
1006	0.000192424	12.2099	0.002349472	6.76%	1.076
1021	0.000230018	10.1773	0.002340966	6.73%	1.073
991	0.000149435	13.6587	0.002041084	5.87%	0.935
346	0.000204574	9.3742	0.001917716	5.52%	0.879
1036	0.000209048	8.47719	0.001772136	5.10%	0.812
1111	0.000160948	9.9696	0.001604584	4.62%	0.735
361	0.000137740	9.8194	0.001352526	3.89%	0.620
721	0.000166655	8.02756	0.001337835	3.85%	0.613
271	0.000085904	13.5214	0.001161544	3.34%	0.532
286	0.000087106	12.792	0.001114260	3.21%	0.511
496	0.000111334	9.30384	0.001035835	2.98%	0.475
256	0.000070042	13.6411	0.000955448	2.75%	0.438
1051	0.000143685	6.48561	0.000931886	2.68%	0.427
976	0.000062597	12.9214	0.000808836	2.33%	0.371
736	0.000112505	5.41065	0.000608726	1.75%	
376	0.000058295	10.4366	0.000608400	1.75%	
1081	0.000100734	5.55336	0.000559409	1.61%	
391	0.000046323	9.66751	0.000447824	1.29%	
241	0.000034355	12.2522	0.000420926	1.21%	
586	0.000075645	5.45711	0.000412806	1.19%	
1096	0.000062330	5.46608	0.000340701	0.98%	
1066	0.000090956	3.65384	0.000332339	0.96%	
751	0.000069900	3.05763	0.000213727	0.61%	
406	0.000028449	6.67923	0.000190017	0.55%	
871	0.000068980	2.6912	0.000185640	0.53%	
766	0.000050072	2.857	0.000143057	0.41%	
511	0.000039924	3.28712	0.000131234	0.38%	
886	0.000052473	2.47377	0.000129806	0.37%	
226	0.000012054	9.44255	0.000113816	0.33%	
646	0.000052992	2.08619	0.000110551	0.32%	
856	0.000058347	1.66181	0.000096962	0.28%	
901	0.000025591	3.33241	0.000085278	0.25%	
661	0.000041102	2.07454	0.000085267	0.25%	

421	0.000018083	4.28921	0.000077561	0.22%	
841	0.000044893	1.4802	0.000066451	0.19%	
166	0.000010322	6.13154	0.000063293	0.18%	
781	0.000032610	1.88477	0.000061462	0.18%	
826	0.000031427	1.87331	0.000058873	0.17%	
811	0.000036671	1.48722	0.000054538	0.16%	
526	0.000022276	2.3696	0.000052785	0.15%	
961	0.000005143	8.72056	0.000044851	0.13%	
211	0.000007167	5.92793	0.000042485	0.12%	
181	0.000005758	7.18575	0.000041379	0.12%	
151	0.000007802	5.04791	0.000039383	0.11%	
796	0.000021629	1.7508	0.000037869	0.11%	
631	0.000022445	1.63264	0.000036644	0.11%	
76	0.000033536	1.06177	0.000035607	0.10%	
436	0.000012839	2.74106	0.000035192	0.10%	
676	0.000011942	2.70406	0.000032293	0.09%	
601	0.000014803	2.02524	0.000029979	0.09%	
196	0.000005037	5.58552	0.000028134	0.08%	
916	0.000004477	6.26928	0.000028069	0.08%	
91	0.000022565	1.24036	0.000027989	0.08%	
61	0.000026557	1.02183	0.000027136	0.08%	
106	0.000011736	2.04604	0.000024012	0.07%	
931	0.000003762	5.67673	0.000021357	0.06%	
616	0.000015749	1.31141	0.000020653	0.06%	
946	0.000004227	4.79977	0.000020287	0.06%	
121	0.000005494	3.13512	0.000017223	0.05%	
706	0.000003193	4.97009	0.000015870	0.05%	
451	0.000009152	1.65951	0.000015188	0.04%	
1141	0.000011233	1.32921	0.000014932	0.04%	
541	0.000008620	1.70588	0.000014705	0.04%	
136	0.000003133	4.24859	0.000013311	0.04%	
46	0.000017865	0.711695	0.000012715	0.04%	
466	0.000005754	2.19612	0.000012636	0.04%	
1	0.000004916	1.54294	0.000007585	0.02%	
481	0.000004284	1.76682	0.000007570	0.02%	
556	0.000005440	1.23487	0.000006718	0.02%	
691	0.000001495	4.08363	0.000006104	0.02%	
571	0.000004028	1.36092	0.000005482	0.02%	
16	0.000004377	1.21743	0.000005329	0.02%	
31	0.000006565	0.722598	0.000004744	0.01%	
1126	0.000007526	0.457442	0.000003443	0.01%	

Appendix 7 - Static load energy calculation case study 3

	m	N	N	Nm	Nm
Increment	**Displacement**	**Force**	**Forcex4**	**Step Energy**	**Sum of Energy**
1	0.0000	0.00	0.00		
2	0.0001	1.24	4.95	0.0005	
3	0.0002	3.61	14.43	0.0015	
4	0.0003	6.92	27.69	0.0028	
5	0.0004	10.96	43.84	0.0045	
6	0.0005	15.91	63.63	0.0065	
7	0.0006	21.56	86.24	0.0088	
8	0.0007	27.73	110.93	0.0113	
9	0.0008	34.80	139.20	0.0142	
10	0.0009	42.66	170.65	0.0174	
11	0.0010	50.92	203.66	0.0208	
12	0.0011	60.01	240.05	0.0245	
13	0.0012	69.88	279.53	0.0285	
14	0.0013	80.41	321.64	0.0328	
15	0.0014	91.25	364.99	0.0372	
16	0.0015	102.79	411.15	0.0420	
17	0.0016	115.23	460.91	0.0470	
18	0.0017	128.24	512.95	0.0523	
19	0.0018	141.86	567.43	0.0579	
20	0.0019	155.82	623.27	0.0636	
21	0.0020	170.52	682.10	0.0696	
22	0.0021	185.93	743.71	0.0759	
23	0.0022	201.87	807.46	0.0824	
24	0.0023	218.26	873.05	0.0891	
25	0.0024	235.22	940.88	0.0960	
26	0.0025	252.60	1010.40	0.0516	0.9387
27	0.0026	270.47	1081.89	0.1082	
28	0.0027	288.98	1155.92	0.1156	
29	0.0028	308.11	1232.42	0.1232	

Appendix 8 - Total energy rate calculation case study 3

	mm3	**j/mm3**	**j**		**j/s**
Element ID	**Element Volume**	**Energy density**	**Element energy**		**Distributed total energy rate**
316	7.18371	0.00027528	0.0019776	8.28%	1.083
331	6.6234	0.00026892	0.0017811	7.46%	0.976
631	7.50451	0.00023269	0.0017462	7.31%	0.957
301	7.46889	0.00020512	0.0015320	6.41%	0.839
646	6.7869	0.00021239	0.0014415	6.04%	0.790
616	7.33481	0.00018974	0.0013917	5.83%	0.762
346	5.8648	0.00022742	0.0013338	5.58%	0.731
601	6.47454	0.00015446	0.0010000	4.19%	0.548
661	5.47471	0.00017820	0.0009756	4.08%	0.534
1066	5.32881	0.00016825	0.0008966	3.75%	0.491
361	5.30246	0.00016385	0.0008688	3.64%	0.476
286	7.97832	0.00008470	0.0006757	2.83%	0.370
271	7.92035	0.00008106	0.0006420	2.69%	0.352
676	4.88749	0.00013070	0.0006388	2.67%	0.350
586	6.01317	0.00010380	0.0006242	2.61%	0.342
1186	4.617	0.00013388	0.0006181	2.59%	0.339
256	7.55159	0.00007050	0.0005324	2.23%	0.292
1051	4.49976	0.00011087	0.0004989	2.09%	0.273
871	4.50944	0.00010767	0.0004855	2.03%	0.266
376	4.88574	0.00007644	0.0003735	1.56%	
241	7.21567	0.00004904	0.0003539	1.48%	
691	4.26953	0.00007678	0.0003278	1.37%	
1081	3.01122	0.00009651	0.0002906	1.22%	
391	4.56164	0.00006133	0.0002798	1.17%	

Appendix 9 - Static load energy calculation case study 4

	m	N	N	Nm	Nm
Increment	**Displacement**	**Force**	**Forcex4**	**Step Energy**	**Sum of Energy**
1	0.0000	0.0	0.00		
2	0.0002	2.4	9.73	0.0019	
3	0.0004	7.3	29.03	0.0058	
4	0.0006	15.0	60.17	0.0120	
5	0.0008	24.5	98.15	0.0196	
6	0.0010	36.1	144.37	0.0289	
7	0.0012	50.2	201.00	0.0402	
8	0.0014	65.9	263.52	0.0527	
9	0.0016	82.7	330.63	0.0661	
10	0.0018	100.8	403.32	0.0807	
11	0.0020	119.9	479.73	0.0959	
12	0.0022	140.1	560.34	0.1121	
13	0.0024	161.8	647.03	0.1294	
14	0.0026	184.4	737.49	0.1475	
15	0.0028	207.6	830.40	0.1661	
16	0.0030	231.6	926.36	0.1853	
17	0.0032	257.0	1028.10	0.2056	
18	0.0034	283.3	1133.16	0.2266	
19	0.0036	310.4	1241.59	0.2483	
20	0.0038	338.4	1353.44	0.2707	
21	0.0040	367.1	1468.44	0.2937	
22	0.0042	397.1	1588.45	0.3177	
23	0.0044	428.3	1713.25	0.3426	
24	0.0046	460.2	1840.62	0.3681	
25	0.0048	492.7	1970.88	0.3942	
26	0.0050	525.7	2102.99	0.4206	
27	0.0052	560.1	2240.39	0.4481	
28	0.0054	595.8	2383.01	0.4766	
29	0.0056	632.0	2527.91	0.5056	
30	0.0058	669.0	2675.83	0.5352	
31	0.0060	706.7	2826.63	0.5653	
32	0.0062	744.8	2979.35	0.5959	
33	0.0064	784.3	3137.02	0.6274	
34	0.0066	824.4	3297.67	0.6595	
35	0.0068	866.4	3465.58	0.6931	

36	0.0070	909.3	3637.31	0.7275	
37	0.0072	952.8	3811.24	0.7622	
38	0.0074	996.9	3987.54	0.7975	
39	0.0076	1042.1	4168.26	0.8337	
40	0.0078	1088.2	4352.90	0.8706	
41	0.0080	1135.1	4540.34	0.9081	
42	0.0082	1183.6	4734.42	0.9469	
43	0.0084	1233.1	4932.32	0.9865	
44	0.0086	1283.2	5132.90	1.0266	
45	0.0088	1334.0	5336.15	1.0672	
46	0.0090	1385.5	5542.12	1.1084	19.4
47	0.0092	1438.0	5751.94	1.1504	
48	0.0094	1491.3	5965.39	1.1931	
49	0.0096	1545.5	6182.13	1.2364	
50	0.0098	1600.9	6403.74	1.2807	

Appendix 10 - Total energy rate calculation case study 4

	mm3	j/mm3	j		j/s
Element ID	**Element Volume**	**Energy density**	**Element energy**		**Distributed total energy rate**
354	10.78	0.00063315	0.0068226	8.28%	10.763
351	9.94	0.00061851	0.0061449	7.46%	9.694
631	11.26	0.00053519	0.0060245	7.31%	9.504
620	11.20	0.00047179	0.0052856	6.41%	8.338
646	10.18	0.00048851	0.0049732	6.04%	7.845
433	11.00	0.00043641	0.0048015	5.83%	7.575
349	8.80	0.00052307	0.0046015	5.58%	7.259
604	9.71	0.00035525	0.0034501	4.19%	5.443
664	8.21	0.00040985	0.0033657	4.08%	5.310
1069	7.99	0.00038698	0.0030932	3.75%	4.880
364	7.95	0.00037685	0.0029973	3.64%	4.728
289	11.97	0.00019480	0.0023313	2.83%	3.678
274	11.88	0.00018643	0.0022149	2.69%	3.494
679	7.33	0.00030061	0.0022038	2.67%	3.477
589	9.02	0.00023875	0.0021534	2.61%	3.397
1189	6.93	0.00030792	0.0021325	2.59%	3.364
259	11.33	0.00016215	0.0018368	2.23%	2.898
1054	6.75	0.00025501	0.0017212	2.09%	2.715
874	6.76	0.00024765	0.0016751	2.03%	2.643
379	7.33	0.00017582	0.0012885	1.56%	
244	10.82	0.00011280	0.0012209	1.48%	
694	6.40	0.00017660	0.0011310	1.37%	
1084	4.52	0.00022197	0.0010026	1.22%	
394	6.84	0.00014106	0.0009652	1.17%	