Assignment 1 - Results

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In this assignment, tyre data from a set of GP2 racing tyres were used to fit the MF96 model proposed by Pacejka. The data was obtained for front and rear wheels, for different road speeds (V_x). By taking as input the slip ratio ($\kappa\,[-]$), the slip angle ($\alpha\,[\text{rad}]$), the camber angle ($\gamma\,[\text{rad}]$) and the load (F_z [N]), it was possible to compute the parameters of the semi-empirical model of the longitudinal force (F_x [N]), the lateral force (F_y [N]) and self-aligning torque (M_z [N·m]).

The results are reported in the following set of tables, in which parameter values were grouped depending on their role within the model and on how they were computed. This is in compliance with the methodology presented in the `Lecture-02-5-DCVR-Tyre- Semiempirical models`. In order to allow an evaluation of the quality of the results of the fitting process, the coefficient of determination R^2 is reported for each fitting procedure. Moreover, some representative *plots* were included, in which the measured forces (F_x and F_y) and the self-aligning torque (M_z) are shown alongside the estimated forces and torques computed with the fitted model. For the sake of brevity, all figures included in this short report regard the case of the front wheel in which the road speed was specified as $V_x = 45$ (m/s).

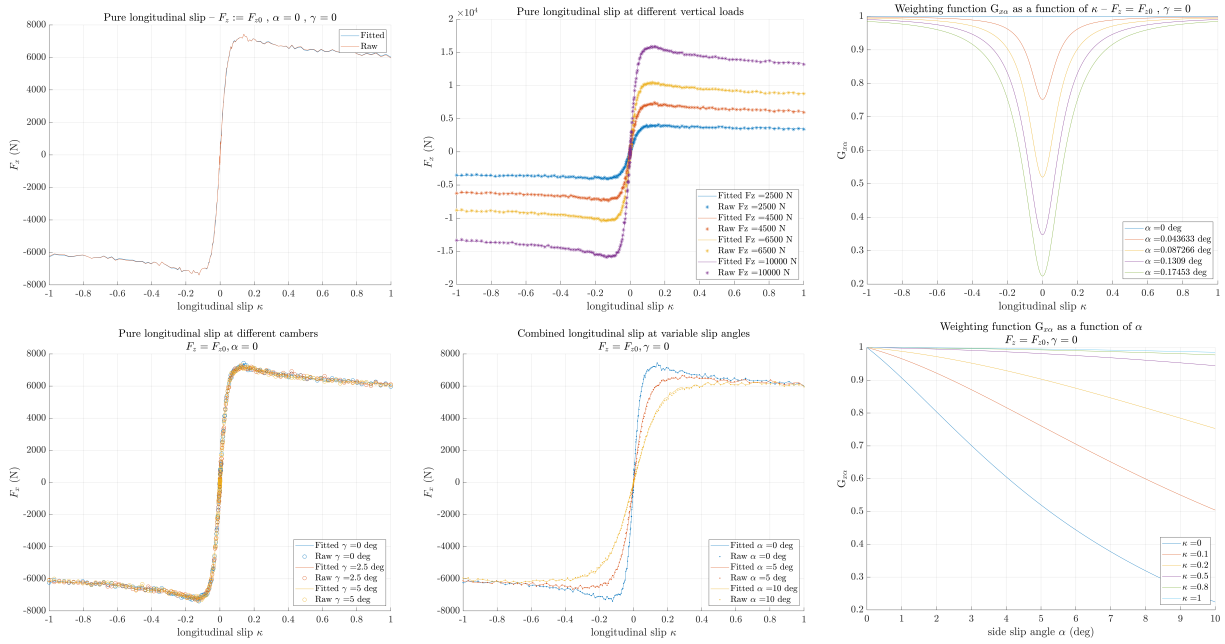
At the end of the document, the results of fitting the tyre deformation as a function of the vertical load (F_z), road speed (V_x) and camber angle (γ) are presented. It was possible to notice that the proposed model in the assignment could describe reasonably well the tyre deformation when the slip ratio κ hasn't changed significantly. Instead, if better accuracy was required, an improvement could be made by adding (for example) a cross term $V_x \cdot \kappa$ in the model expression.

1 Horizontal Force

Longitudinal Force - $F_z = F_{z0}$, γ=0, $\alpha = 0$								
Dataset	dataset/rear_longitudinal_dataset.mat				dataset/front_longitudinal_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
pCx1	1.32	1.3811	1.4078	1.4358	1.3274	1.3803	1.4115	1.4399
pDx1	1.8185	1.7039	1.6274	1.5482	1.7953	1.6828	1.6025	1.5256
pEx1	0.12013	0.24352	0.16795	0.11547	0.21978	0.2108	0.23423	0.14709
pEx4	-0.066116	-0.096971	-0.020144	0.01743	0.014988	-0.026607	0.017631	0.030619
pHx1	-5.61e-05	0.00019072	0.00019795	1.4112e-05	4.0643e-06	0.00019699	0.00013788	-1.4668e-05
pKx1	42.9444	44.2792	42.4861	38.5939	39.2636	39.2853	39.009	34.738
pVx1	-0.000508	-0.0025422	-0.000291	4.5563e-05	0.00020471	-0.00052808	0.00063368	0.00049079
	Metrics				Metrics			
R^2 value	0.99974	0.99967	0.99967	0.99963	0.99975	0.99975	0.99958	0.99966

Longitudinal Force - variable F_z, γ=0, $\alpha = 0$								
Dataset	dataset/rear_longitudinal_dataset.mat				dataset/front_longitudinal_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
pDx2	-0.012959	-0.0052882	-0.0065984	-0.0086446	-0.025251	-0.01966	-0.014954	-0.01053
pEx2	-0.20848	-0.1648	-0.12611	-0.05015	-0.27475	-0.24155	-0.23921	-0.20865
pEx3	0.23481	0.14179	0.1457	0.12661	0.24601	0.18864	0.16965	0.15665
pKx2	0.0033918	0.0029304	0.003313	0.0041694	0.0016842	0.001447	0.0012683	0.0019539
pKx3	-0.14371	-0.12918	-0.13978	-0.15936	-0.065313	-0.056648	-0.04917	-0.067386
pHx2	0.0001729	-0.00017275	-0.00023132	7.6144e-05	-9.5444e-05	-0.00011435	-0.00011772	0.0001633
pVx2	0.00021795	0.00082913	0.00038264	3.6218e-05	4.7838e-06	5.5317e-05	-0.00037282	-0.00049063
	Metrics				Metrics			
R^2 value	0.9996	0.99964	0.99957	0.99956	0.99971	0.9997	0.99961	0.99958

Longitudinal Force - variable F_z, variable γ, $\alpha = 0$								
Dataset	dataset/rear_longitudinal_dataset.mat				dataset/front_longitudinal_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
pDx3	0.15637	0.20001	0.14764	0.10965	0.19029	0.19044	0.19269	0.15956
	Metrics				Metrics			
R^2 value	0.99962	0.99962	0.99957	0.99954	0.99971	0.99968	0.99964	0.99962



2 Lateral Force

Lateral Force - $F_z = F_{z0}$, γ=0, $\kappa = 0$								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
pCy1	1.4823	1.4624	1.5253	1.5047	1.3627	1.379	1.4019	1.4285
pDy1	1.8075	1.6864	1.6043	1.5251	1.7879	1.6661	1.5845	1.5061
pEy1	0.28454	0.11146	0.23042	0.071621	-0.0040282	-0.13259	-0.1642	-0.17722
pHy1	-9.8652e-05	0.00015164	0.00022827	0.00022959	0.00013785	7.106e-05	0.00016306	2.9081e-05
pKy1	38.9278	39.7551	39.7425	39.6608	39.6648	40.9834	40.9367	40.8932
pKy2	2.2222	2.3156	2.2889	2.4745	2.5509	2.6932	2.7284	2.883
pVy1	0.00022666	-0.00086766	-0.00068337	0.0002011	-0.00028701	0.00015256	-0.00017244	0.0002615
	Metrics				Metrics			
R^2 value	0.99996	0.99995	0.99996	0.99996	0.99998	0.99997	0.99998	0.99998

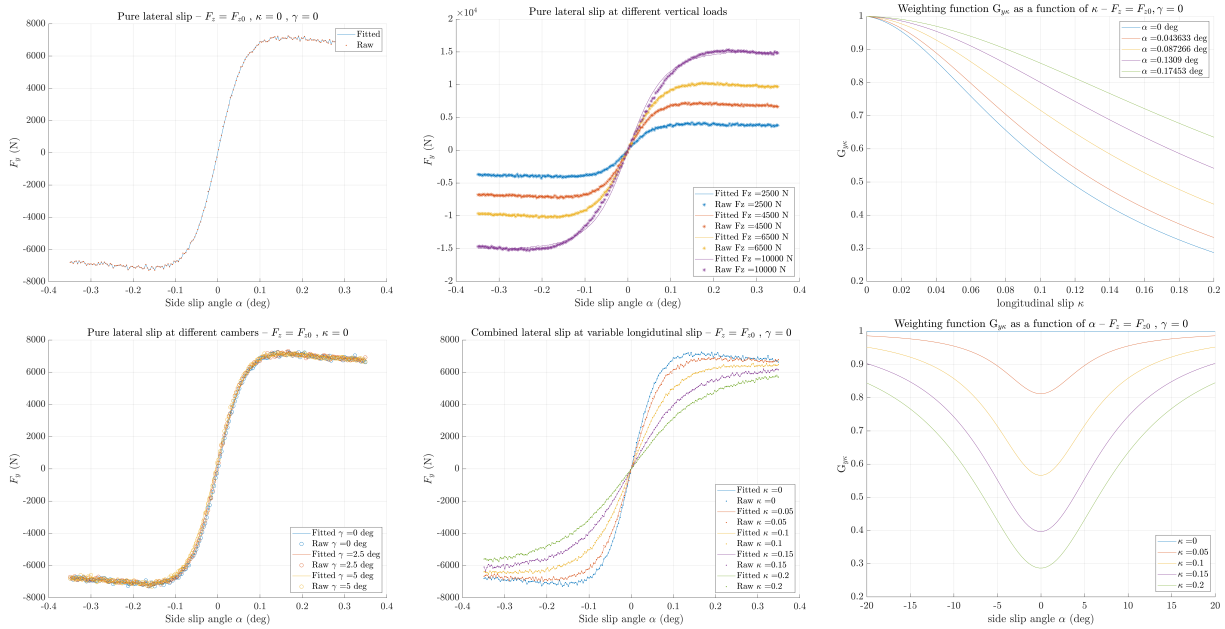
Lateral Force - variable F_z, γ=0, $\kappa = 0$								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
pDy2	-0.0089973	-0.029833	-0.045276	-0.051363	-0.038673	-0.057941	-0.068323	-0.070727
pEy2	0.26415	0.3333	0.22462	0.24359	0.45036	0.53086	0.49531	0.4378
pHy2	1.0186e-05	-0.00010956	-0.00025387	-0.00020988	-8.9032e-05	5.3981e-05	-0.00016208	-8.5623e-05
pVy2	-1.5287e-05	0.00088632	0.00066371	2.7675e-06	-0.00010971	-0.00026901	0.00013939	-0.00013474
	Metrics				Metrics			
R^2 value	0.99959	0.99952	0.99951	0.9996	0.99929	0.99912	0.9992	0.99936

Lateral Force - variable F_z, variable γ, $\kappa = 0$								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
pDy3	-1.7275	-1.3135	-1.0237	-0.62498	-1.3725	-1.0335	-0.64754	-0.32068
pEy3	0.0017262	-0.0009684	-0.0052653	0.00069754	-0.0021823	0.00071965	0.0052201	0.0089071
pEy4	-0.73843	0.44249	2.1928	4.8097	0.29917	1.1825	2.2199	3.3147
pHy3	0.055009	0.056632	0.058089	0.054716	0.058192	0.059386	0.060106	0.058218
pKy3	0.70016	0.73403	0.70594	0.56373	0.92776	0.96618	0.89942	0.81495
pVy3	0.021486	0.0024555	-0.014131	-0.011298	-0.013611	-0.0068485	0.0015501	-0.0089375
pVy4	0.24433	0.17171	0.11685	0.082105	0.14257	0.088328	0.067869	0.077107
	Metrics				Metrics			
R^2 value	0.99965	0.99957	0.99958	0.99964	0.99942	0.99929	0.99934	0.99945

Lateral Force - combined case: $F_z = F_{z0}$, $\gamma = 0$								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
rBy1	11.3639	12.1511	13.2651	13.2749	10.5463	11.3835	11.9603	12.2806
rBy2	11.3029	12.0353	12.8735	12.8889	10.6095	11.3681	11.8486	12.0918
rBy3	0.000278	-0.00033117	-0.00011267	3.3608e-05	-0.00030028	-0.00016836	-0.0006066	-1.9851e-05
rCy1	1.0796	1.0824	1.0714	1.0747	1.0843	1.0867	1.0826	1.081
rHy1	0.0037836	0.0037864	0.0030291	0.0038864	0.0048343	0.0042018	0.004508	0.0046491
rVy1	0.0023034	-0.0010533	-0.00081013	-0.0021479	-0.0015307	-0.0024021	-0.0049043	-0.00059423
rVy4	24.6596	24.6608	24.6599	24.6599	24.6611	24.6607	24.6669	24.6598
rVy5	-3.5624	-3.6318	-3.6261	-3.6241	-3.6729	-3.7844	-3.7805	-3.6789
rVy6	-4.5571	-4.6004	-4.5978	-4.6023	-4.6267	-4.6942	-4.7068	-4.6291
	Metrics				Metrics			
R^2 value	0.99994	0.99993	0.99994	0.99994	0.99996	0.99996	0.99996	0.99996

Lateral Force - combined case: variable F_z , $\gamma = 0$								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
rVy2	-0.0011646	0.00054413	0.00099138	0.0017671	0.0011926	0.00079246	0.0029233	0.0012331
	Metrics				Metrics			
R^2 value	0.99769	0.99795	0.99818	0.99851	0.99857	0.99866	0.99882	0.99904

Lateral Force - Combined case								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
rVy3	-0.64927	-0.61182	-0.60828	-0.58738	-0.29888	-0.26033	-0.2555	-0.28873
	Metrics				Metrics			
R^2 value	0.99727	0.99756	0.99782	0.99828	0.99822	0.99833	0.99853	0.9988

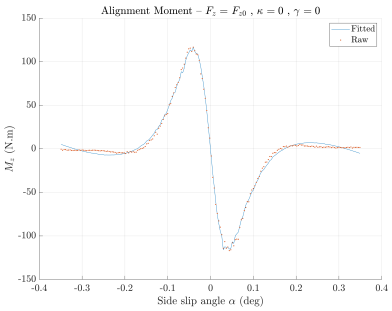


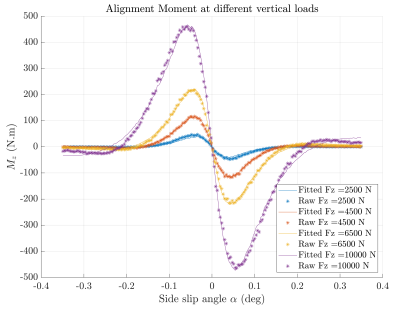
3 Alignment Moment

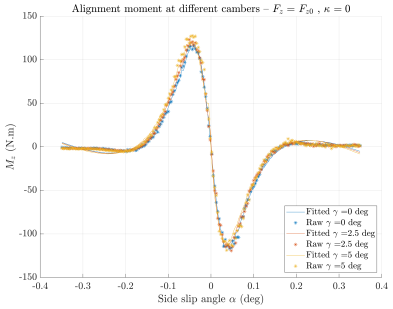
Alignment Moment - $F_z = F_{z0}$ and γ=0, $\kappa = 0$								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s	$V_x = 5$ m/s	$V_x = 20$ m/s	$V_x = 45$ m/s	$V_x = 90$ m/s
qHz1	-0.00015717	-0.00013486	-9.5487e-05	0.00021793	2.1843e-05	0.00013098	2.3057e-05	5.376e-05
qBz1	11.8218	12.463	12.9889	12.0646	12.1653	12.966	13.5653	12.8277
qCz1	2.0182	2.03	2.0334	2.0979	1.9337	1.9369	1.9377	1.9805
qDz1	0.13071	0.13056	0.13081	0.12132	0.13113	0.13223	0.13249	0.12444
qEz1	1.15	1.1519	1.1504	1.1812	1.1022	1.1001	1.0982	1.1148
qEz4	-0.00027628	2.0414e-05	0.00010984	0.00010551	-2.8791e-05	-0.0001229	3.4755e-05	4.6752e-05
qBz9	-500	-500	-500	-500	-500	-500	-500	-500
qBz10	-499.992	-499.9941	-499.9901	-500.0001	-500.0002	-500.0003	-500.0004	-500.0003
qDz6	0.0077593	2.1e-06	0.00036959	0.0093389	-0.0076254	-0.0049466	0.013536	0.016481
	Metrics				Metrics			
R^2 value	0.99909	0.99839	0.99847	0.99861	0.99813	0.99707	0.99551	0.9951

Alignment Moment - variable F_z, γ=0, κ = 0								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	V_x = 5 m/s	V_x = 20 m/s	V_x = 45 m/s	V_x = 90 m/s	V_x = 5 m/s	V_x = 20 m/s	V_x = 45 m/s	V_x = 90 m/s
qHz2	7.9825e-05	0.00026526	6.3658e-05	-0.00020208	-0.00010244	0.00014405	-3.9723e-05	-4.6484e-06
qBz2	-2.2766	-2.225	-2.2809	-1.5509	-2.3697	-2.3377	-2.2909	-1.5574
qBz3	-0.59873	-0.69667	-0.69548	-0.82049	-0.64002	-0.76871	-0.78464	-0.94404
qDz2	-0.0070032	-0.0068164	-0.0084274	-0.0078065	-0.011846	-0.012858	-0.012578	-0.012091
qEz2	0.0087137	0.0083945	0.010316	0.011463	0.0091648	0.009216	0.0076606	0.0076786
qEz3	-0.016981	-0.014221	-0.014715	-0.011727	-0.01286	-0.010991	-0.0078966	-0.0055499
qDz7	0.0035358	-0.012495	-0.014847	-0.0025246	-0.021996	-0.034343	-0.015581	-0.015899
	Metrics				Metrics			
R^2 value	0.99854	0.99828	0.998	0.9981	0.99748	0.99573	0.99456	0.99475

Alignment Moment - variable F_z, variable γ								
Dataset	dataset/rear_lateral_dataset.mat				dataset/front_lateral_dataset.mat			
	Parameters				Parameters			
Parameter Name	V_x = 5 m/s	V_x = 20 m/s	V_x = 45 m/s	V_x = 90 m/s	V_x = 5 m/s	V_x = 20 m/s	V_x = 45 m/s	V_x = 90 m/s
qHz3	0.07471	0.077649	0.073848	0.066776	0.090254	0.083266	0.08154	0.075047
qHz4	0.041064	0.029234	0.028424	0.028721	0.024372	0.025013	0.029528	0.029154
qBz4	0.005759	0.0008041	0.016581	-0.00063095	0.016307	0.0648	0.037741	0.016193
qBz5	0.0057344	0.00081263	0.016575	-0.00059709	0.016276	0.064788	0.037759	0.01627
qDz3	0.42348	0.47993	0.54724	0.26482	0.41784	0.82321	0.65205	0.44631
qDz4	4.186	3.7625	3.9007	5.783	4.6008	1.4536	2.3516	3.8426
qEz5	0.015873	0.013011	0.011066	0.010253	0.0082429	0.0098741	0.0082431	0.0064833
qDz8	4.1928	5.1885	4.995	3.8757	0.20924	0.33433	0.34844	0.087042
qDz9	-2.8948	-1.8914	-0.44408	0.05648	1.6514	1.6357	0.73185	0.4218
	Metrics				Metrics			
R^2 value	0.99478	0.99538	0.99542	0.9958	0.99488	0.99327	0.99158	0.99181







4 Tyre deflection

Tyre deformation				
Dataset	rear_longitudinal_dataset	rear_lateral_dataset.mat	front_longitudinal_dataset.mat	front_lateral_dataset.mat
	Parameters			
a_1	3.6694	3.6694	3.6694	3.6694
a_2	9.1837	9.1837	9.1837	9.1837
a_3	237292.4985	237257.3398	237292.3327	237257.4773
b_1	-7.3335e-08	0	-7.3313e-08	0
b_2	-1.2006e-07	0	-1.2006e-07	0
c_1	44510.0183	44737.3714	44643.2753	44657.167
	Metrics			
R^2 value	0.99888	0.99995	0.99888	0.99995