

University of Wales Trinity Saint David

School of Engineering

Steady State Load Transfer and Aerodynamic Loading

Vehicle Dynamics: M5X00407

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1 Introduction

This report is about the characteristics of a vehicle using the Aston Martin DB9 race car as the test. Data was collected from the Base Performance Simulator and MoTeC was used for data evaluation. Aerodynamics, Ackerman steering and weight transfers were tested, also including steady state tests to collect a base reading. Aerodynamics was tested using a top speed test for downforce and a coast down test for drag. The Ackerman steering test was done driving in a circle of radius 25m at a speed of around 2.8m/s. Weight transfers were measured by driving around in a circle with multiple radii and speeds. For weight transfer, predicted calculations were made to compare with the simulated values. The objectives were to collect data from the simulator and use predicted equations to evaluate how accurate these equations are.

2 Methodology

During all tests in the simulator, members of the group each had an individual task of; a driver, a person changing the car setup, another monitoring speed and steering inputs and someone naming the files for later use in MoTeC. One run was done for every setup and the data was saved.

MoTeC with excel were then used for data analysis. Graphs were made from the data gathered and equations to show how values change with setup changes on the vehicle.

3 Results

3.1 Aerodynamic Results

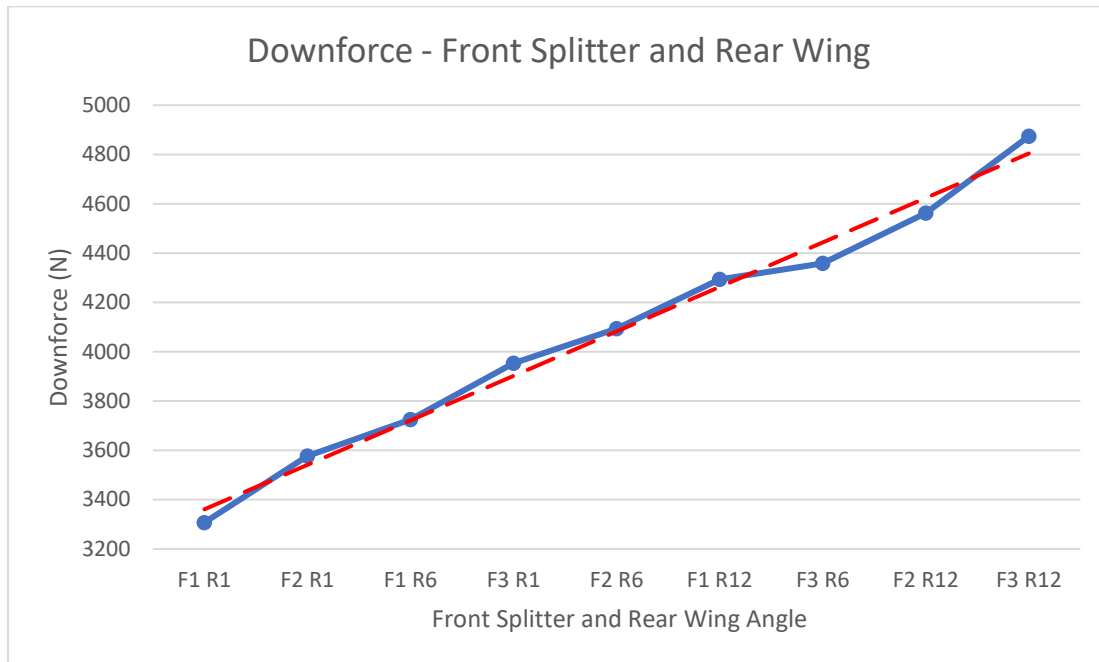


Figure 1 - Graph showing total downforce against front splitter and rear wing angle.

Trendline shows a mostly linear increase. As the angles of front splitter and rear wing increase the downforce increases also.

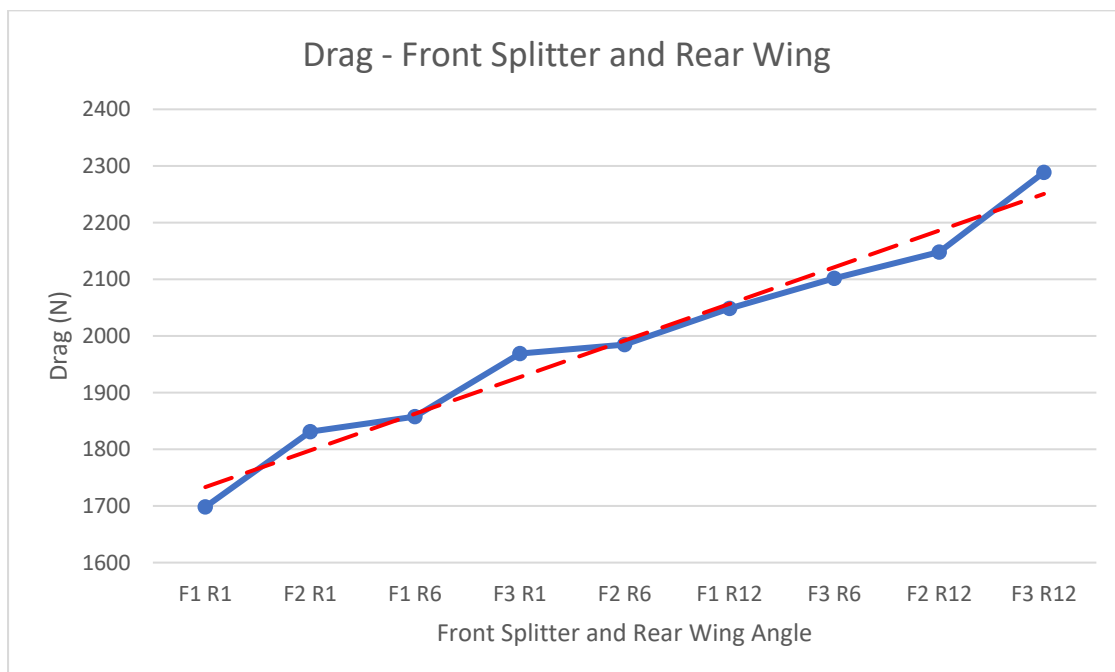


Figure 2 - Graph showing drag against front splitter and rear wing angle.

Trendline shows a mostly linear increase. As the angles of the front splitter and rear wing increase so does the drag.

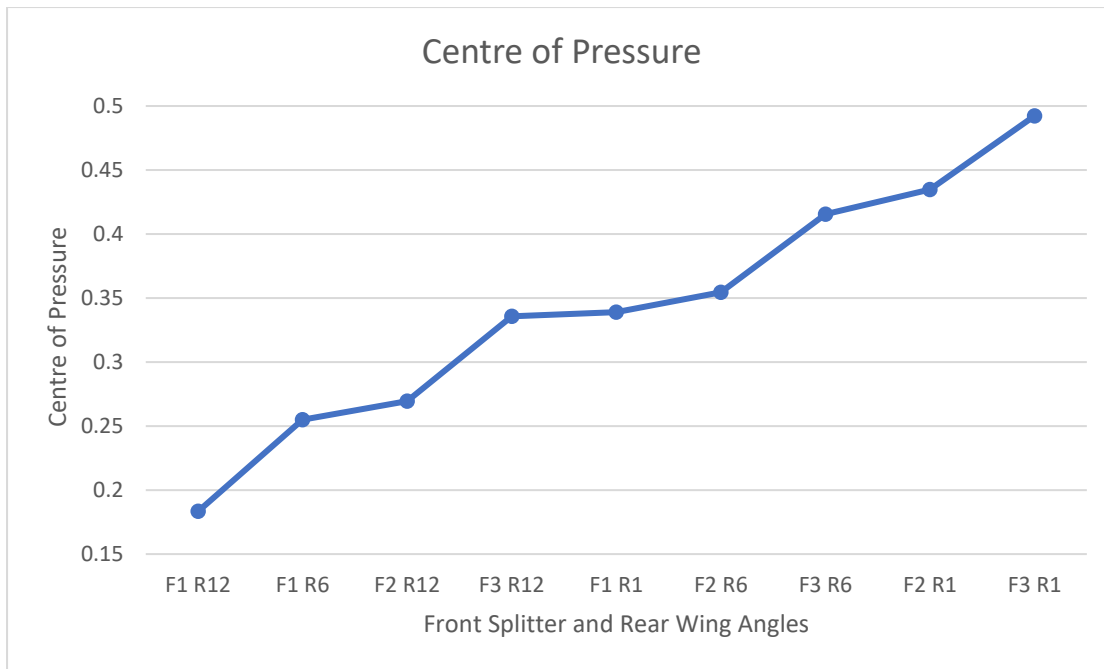


Figure 3 - Graph showing centre of pressure against front splitter and wing angles.

For the test shown in Figure 4 and Figure 5, the front splitter and rear wing angles were set to minimum angle of attack.

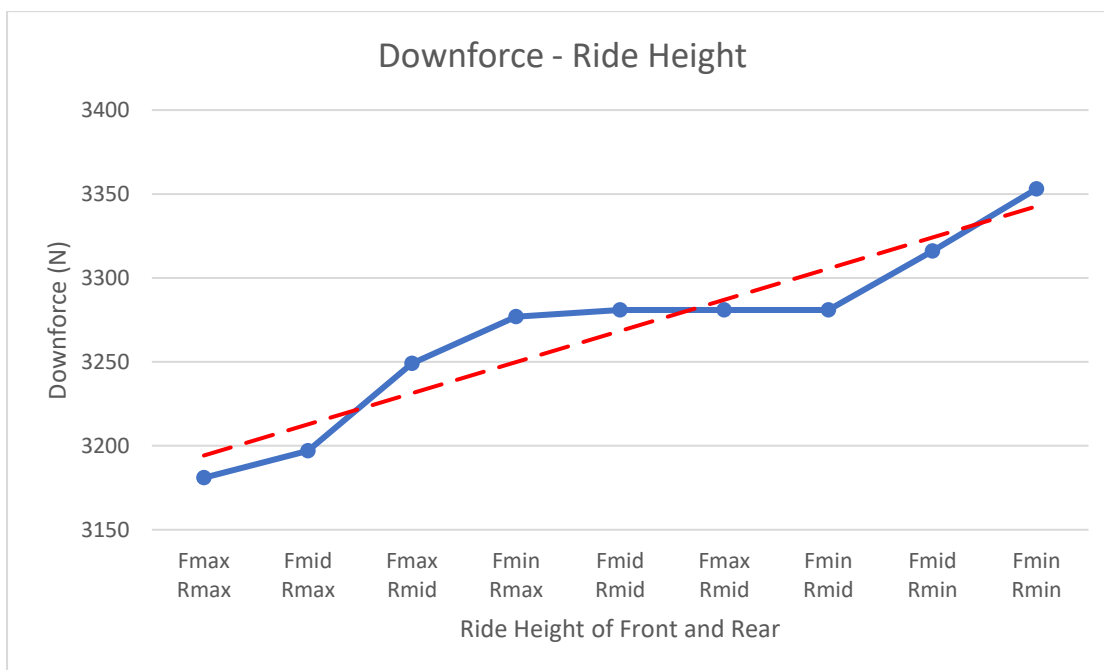


Figure 4 - Graph showing downforce against ride height.

Trendline shows that as the ride height decreases the downforce increases.

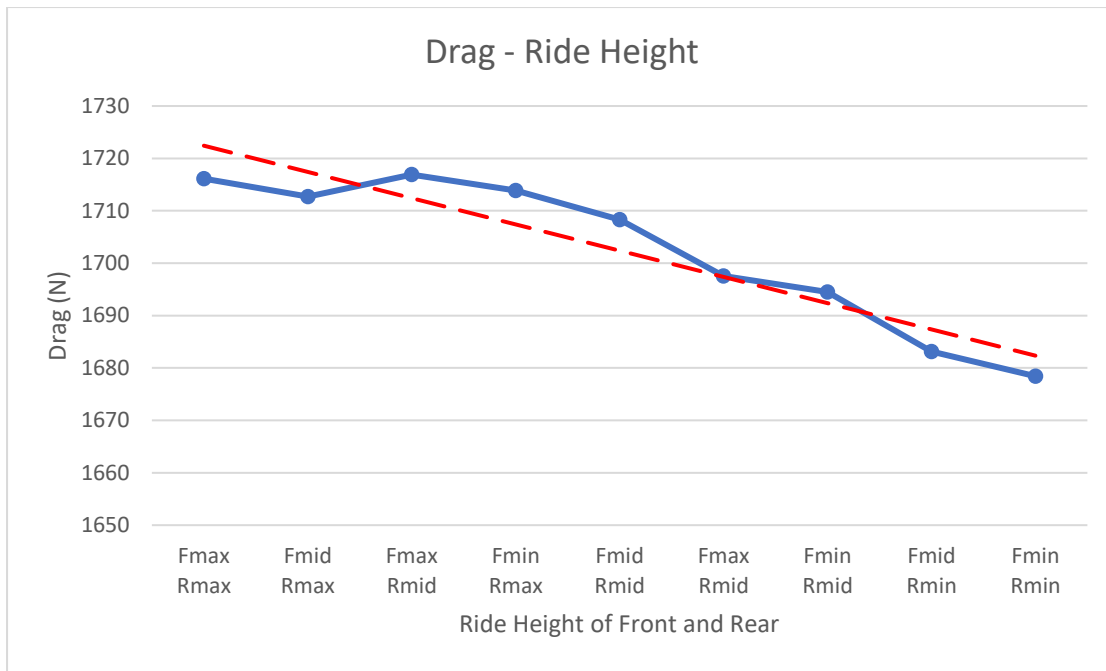


Figure 5 - Graph showing drag against ride height.

Trendline shows that drag decreases when ride height decreases also.

3.2 Weight Transfer Results

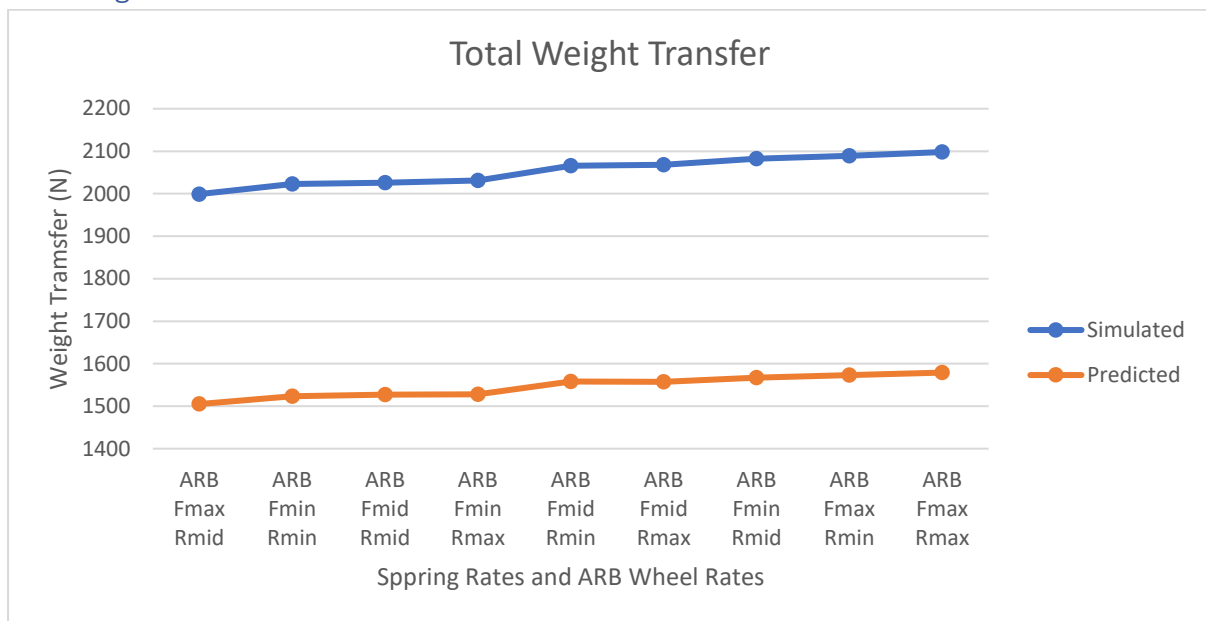


Figure 6 - Graph showing total weight transfer against spring and ARB wheel rates.

Simulated and predicted weight transfers increased linearly as the spring and ARB rates are changed.

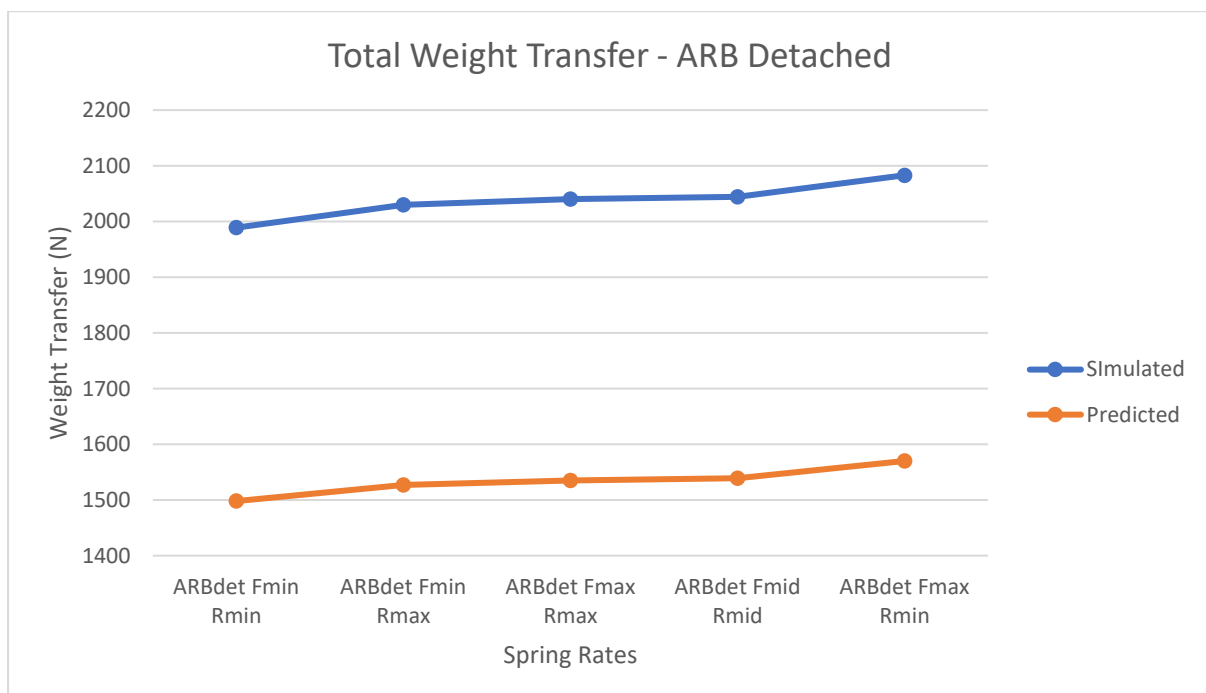


Figure 7 - Graph showing total weight transfer when ARB is detached.

Linear increase of simulated and predicted weight transfers as the spring rates are change with ARB detached.

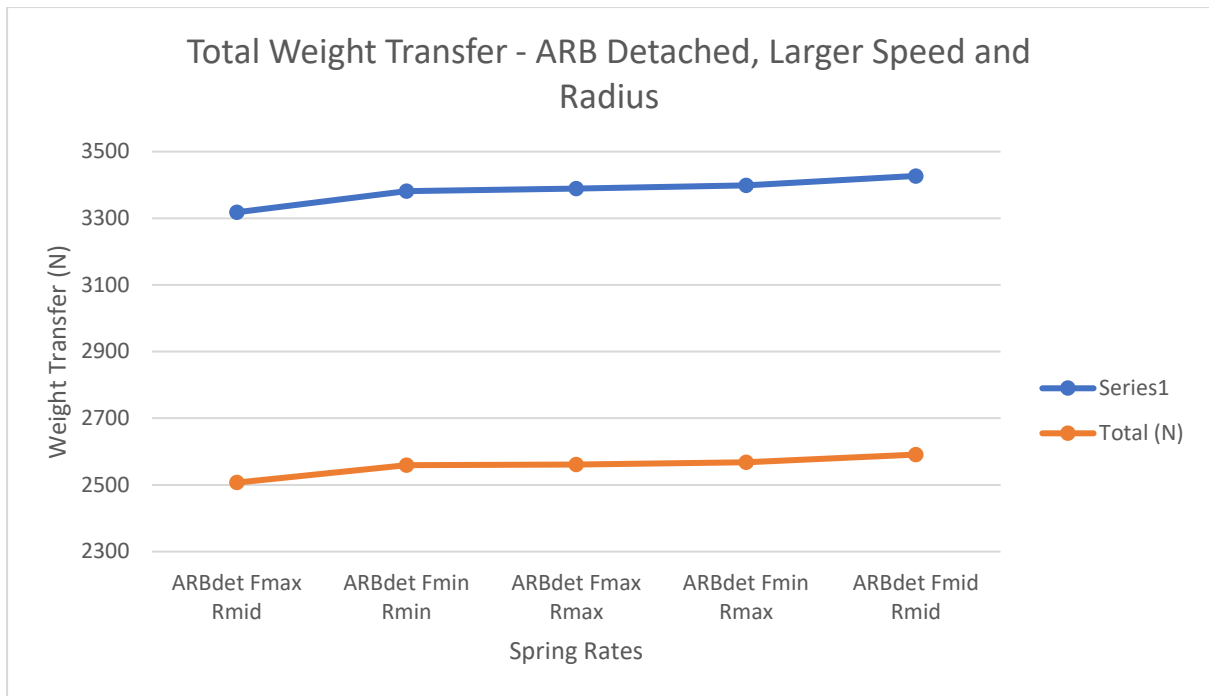


Figure 8 - Graph showing total weight transfer when ARB is detached at a higher speed and larger turning radius.

Linear increase of weight transfer for both simulated and predicted as the spring rates are changed with ARB detached.

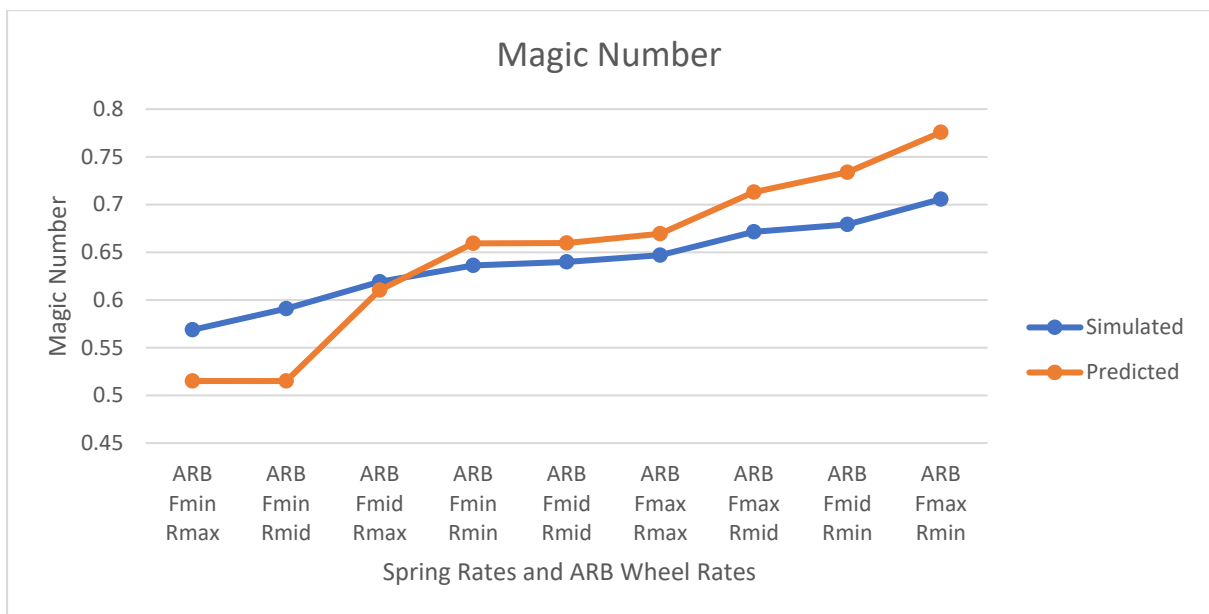


Figure 9 - Graph showing magic number against spring and ARB wheel rates.

Linear increase for the simulated weight transfer, but the predicted weight transfer which also increased was less linear. The predicted crosses over the simulated.

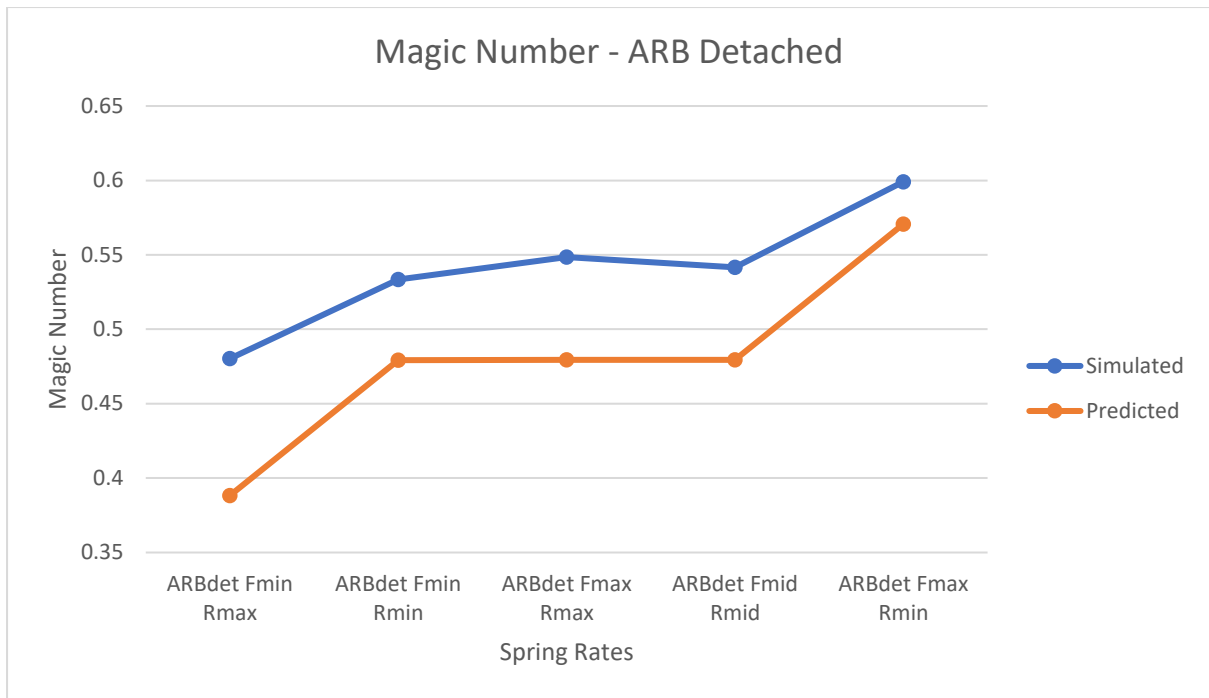


Figure 10 - Graph showing magic number against spring rates with ARB detached.

Simulated weight transfer increases mostly linearly but the predicted weight transfer has a general increase without much trend.

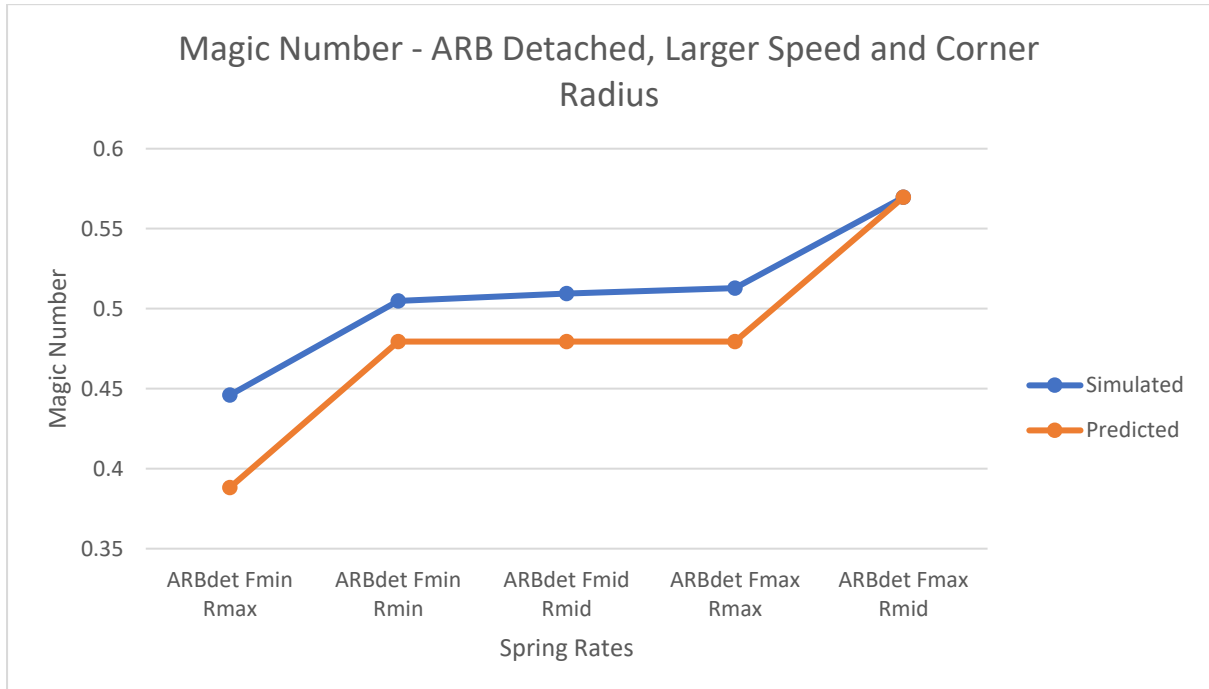


Figure 11 - Graph showing magic number against spring rates with ARB detached at a higher speed and larger turning radius.

Both simulated and predicted weight transfers have a general increase but neither have much of a trend.

4 Analysis

4.1 Aerodynamic Analysis and Ackerman Steering

Figure 1 shows that the increased angle from the diffuser and rear wing also increase the overall downforce of the Aston Martin DB9 race car. Increase in rear wing angle aids to more downforce than the increase of the front splitter. Greater downforce assists the car to corner at higher speeds as $F = \mu R$ and more downforce increases the reaction force, therefore friction is greater. The increase in downforce also increases the drag as there is a greater frontal area due to the wing angles increasing. This is shown in Figure 2. Changing the angles will also change the centre of pressure (CoP) of the vehicle which alters the balance. As shown in Figure 3, the largest difference from front to rear (0.18) is when front splitter is set to the lowest angle and the rear wing set to the highest angle of attack. The most centred setup from front to rear (0.49) is the front splitter set to maximum attack and rear wing set to minimum angle. This balance change affects how the vehicle steers into corners, during the corner, and corner exit. Therefore, the CoP is vital to get it correct in a race car. Furthermore, the CoP is preferred to be behind the centre of mass (more rearward) as it allows more stability during cornering.

Figure 4 shows that the downforce increases linearly as the ride height decreases. This downforce is produced by ground effect. The airflow that flows underneath the car gets compressed, therefore it speeds up, creating negative pressure. This negative pressure causes downforce (McBeath, 2017). As the surface area of the underbody is quite large, the downforce gained due to ground effect adds up to most of the car's downforce. This negative pressure increases when the vehicle is closer to the ground, but if its too close the airflow can stall causing no downforce and a lot of drag. Furthermore, Figure 5 shows that as this downforce increases linearly the drag decreases linearly, which is due to a smaller frontal area. This shows that the most efficient way to create downforce is to use ground effect (Kachare, 2017).

An Ackerman steering angle of 0.11rad was found from the simulation. Ackerman steering angle shows the difference in angle from the inside wheel to the outside wheel when cornering.

4.2 Weight Transfer Analysis

Weight transfer acts on the centre of mass of the vehicle and occurs when the car is accelerating, decelerating or cornering or a combination of these (Pacejka, 2006). Weight transfer of the Aston Martin DB9 race car were simulated when going around corners of a certain radius at a certain speed. Predictions of these weight transfers were also calculated to see how accurate the equations are. Figure 6 shows the total weight transfer of the vehicle traveling at 13.89m/s at a radius of 25m. These values were decided because the car would have to remain in steady state during the test so that accurate data could be measured, as a non-steady state vehicle's weight transfer is unpredictable, therefore giving false results. The simulated and predicted values had a similar trend but the predicted values were a lot smaller than the simulated. There was an error of about 24% which is mainly due to the predicted roll angle, as the equations do not take tyre deformation into account. The predicted values were calculated using math channel equations in MoTeC and a setup sheet. First, the constant centre of gravity height above roll centre axis (H) was calculated with $H = CoG\ Height - x$ where $x = \frac{(h_r - h_f)y}{w} + h_f$ where h_r and h_f are rear and front roll centre heights respectively, y is centre of gravity position and w is wheelbase. Then the front and rear wheel rates were calculated with equations $K_{wf} = (K_{sf} \times MR_f^2) + K_{warbf}$ and $K_{wr} = (K_{sr} \times MR_r^2) + K_{warbr}$ where K_s is spring rate, MR is motion ratio and K_{warb} is anti-roll bar wheel rate. With these wheel rate calculations, roll

angle can be calculated using $\theta = \frac{M_s \times a_y \times H}{\left(\frac{T_f^2 K_{wf}}{2} + \frac{T_r^2 K_{wr}}{2}\right)}$ where M_s is sprung mass, a_y is angular acceleration

and T is track. Weight transfer of front and rear sprung mass with equations $WT_{sf} = \frac{K_{wf} T_f \theta}{2}$ and $WT_{sr} = \frac{K_{wr} T_r \theta}{2}$ respectively. Then the weight transfer of front roll sprung mass calculated with $WT_{sRCf} = \frac{M_{sf} \times a_y \times h_f}{T_f}$ and rear roll sprung mass calculated with $WT_{sRCr} = \frac{M_{sr} \times a_y \times h_r}{T_r}$. Finally, the weight transfer sprung mass front and rear calculated using equations $WT_{usf} = \frac{M_{usf} \times a_y \times h_f}{T_f}$ and $WT_{usr} = \frac{M_{usr} \times a_y \times h_r}{T_r}$ respectively. With these equations the weight transfer front rear and total can be calculated using the equations $WT_f = WT_{sf} + WT_{sRCf} + WT_{usf}$, $WT_r = WT_{sr} + WT_{sRCr} + WT_{usr}$ and $WT_T = WT_f + WT_r$ respectively. Figure 7 shows tests done with the anti-roll bar (ARB) detached to see if only changing spring rates made a difference to the total weight transfer of the vehicle. The results show that there was not much difference when removing the ARBs. In Figure 8 the speed was increased to 25m/s and the radius was increased to 50m. The trend remained the same but the total weight transfer of the vehicle increased. Magic number was then calculated for both simulated and predicted. Magic number was calculated by using the equation $magic\ number = \frac{WT_T}{WT_f}$.

The magic number shows how the car will handle during corners. A value larger than 0.5 means the vehicle will be more prone to understeer and a value less than 0.5 means the vehicle will be more prone to oversteer. As seen in Figure 9, the Aston Martin DB9 race car has more understeer. This is because the race car is based off the road car and road cars are designed to understeer as it is easier for the driver to correct when entering a corner too quickly. When the ARB is detached, the magic number for both predicted and simulated decrease, sometimes below 0.5 which means the car becomes more prone to oversteer as shown in Figure 10. Figure 11 is tested at the higher speed and radius. These values are very similar to the values from Figure 10 which shows that the increase in speed and radius did not change how the vehicle handles. Furthermore, this also shows that the car remained in steady state.

5 Conclusion

Aerodynamic values gave reasonable results which represent the Aston Martin DB9 race car well. The CoP and overall balance of the car gave expected results. The predicted weight transfer equations were not very accurate with a large error between the simulated and predicted weight transfers even though the trends were very similar.

6 Evaluation

With the simulation tests, the car remained in steady state during the weight transfer runs and during the straight line tests, top speed data values were too easy to read off the MoTeC graphs. This allowed for better analysis of the data and no errors were present.

References

Kachare, S. C. (2017) 'A CFD Study of a Multi-Element Front Wing for a Formula One Racing Car', pp. 12–2017.

McBeath, S. (2017) *Competition car aerodynamics : a practical handbook*.

Pacejka, H. B. (2006) *Tyre and vehicle dynamics*. Second. Butterworth-Heinemann.

Appendices

Run #	Setup	Velocity (m/s)	Aerodynamic Loads (N)			Coefficients and pressures				Aerodynamics				Rolling Resistance				Aerodynamic Drag				Efficiency
			Front	Rear	Total	CoP	CLF	CLR	CLT	V1 (m/s)	V2 (m/s)	Time (s)	Deceleration	V1 (m/s)	V2 (m/s)	Time (s)	Deceleration	Deceleration Force (N)	Rolling Resistance (N)	AeroDrag (N)	CD	
1	F1 R1	57.44	1121	2186	3307	0.33898	-0.5547	-1.0817	-1.6364	55.45	53.11	1.264	1.85126582	1.331	0.89	1.252	0.35223642	2099.335443	401.1428571	1698.19259	0.90173255	1.94736453
6	F2 R1	57.38	1555	2022	3577	0.43472	-0.7711	-1.0027	-1.7737	55.99	53.11	1.463	1.96855776					2232.344498	401.1428571	1831.20164	0.9536942	1.95336216
7	F1 R6	57.35	950	2775	3725	0.25503	-0.4716	-1.3775	-1.8491	56.04	53.09	1.481	1.99189737					2258.811614	401.1428571	1857.66876	0.9657527	2.0052014
4	F3 R1	57.31	1946	2007	3953	0.49228	-0.9673	-0.9977	-1.965	56.08	53.07	1.44	2.09027778					2370.375	401.1428571	1969.23214	1.02229165	2.00738141
2	F2 R6	57.33	1451	2643	4094	0.35442	-0.7208	-1.3129	-2.0337	56.1	53.1	1.426	2.10378682	1.56	0.78	2.205	0.3537415	2385.69425	401.1428571	1984.55139	1.02950992	2.06293473
5	F1 R12	57.22	787	3506	4293	0.18332	-0.3924	-1.7483	-2.1407	55.93	53.15	1.287	2.16006216				0.3537415	2449.51049	401.1428571	2048.36763	1.06908484	2.09581519
8	F3 R6	57.3	1811	2547	4358	0.41556	-0.9005	-1.2665	-2.1671	55.86	53.11	1.246	2.2070626					2502.808989	401.1428571	2101.66613	1.09965327	2.07359291
9	F2 R12	57.22	1229	3333	4562	0.2694	-0.6128	-1.662	-2.2749	55.5	53.09	1.072	2.24813433					2549.384328	401.1428571	2148.24147	1.13865206	2.1235974
3	F3 R12	57.22	1636	3238	4874	0.33566	-0.8158	-1.6146	-2.4304	55.83	53.14	1.134	2.37213404	1.36	0.86	1.422	0.35161744	2690	401.1428571	2288.85714	1.19888448	2.12944701
	Ride Height																					
3	Fmax Rmax	57.44	1048	2133	3181	0.32946	-0.5186	-1.0555	-1.5741	55.89	53.39	1.339	1.86706497					2117.25168	401.1428571	1716.10882	0.8969547	1.85361205
6	Fmid Rmax	57.44	1054	2143	3197	0.32968	-0.5216	-1.0604	-1.582	55.13	53.32	0.971	1.86405767					2113.841401	401.1428571	1712.69854	0.92002335	1.8666449
8	Fmax Rmid	57.44	1072	2177	3249	0.32995	-0.5305	-1.0773	-1.6077	56.03	53.77	1.21	1.8677686					2118.049587	401.1428571	1716.90673	0.89289289	1.89235673
5	Fmin Rmax	57.36	1057	2220	3277	0.32255	-0.5245	-1.1016	-1.6261	56.3	51.82	2.402	1.86511241					2115.037469	401.1428571	1713.89461	0.88279778	1.91201955
2	Fmid Rmid	57.42	1079	2202	3281	0.32886	-0.5343	-1.0904	-1.6247	56.13	53.07	1.645	1.86018237					2109.446809	401.1428571	1708.30395	0.88525618	1.9206184
4	Fmax Rmid	57.42	1079	2202	3281	0.32886	-0.5343	-1.0904	-1.6247	56.04	53.09	1.594	1.85069009					2098.68256	401.1428571	1697.5397	0.88250585	1.93279721
7	Fmin Rmid	57.43	1084	2197	3281	0.33039	-0.5366	-1.0875	-1.6241	55.18	53.04	1.158	1.84801382					2095.647668	401.1428571	1694.50481	0.90860123	1.93625889
9	Fmid Rmin	57.46	1108	2208	3316	0.33414	-0.5479	-1.0918	-1.6397	55.85	53.15	1.469	1.83798502					2084.275017	401.1428571	1683.13216	0.88097943	1.97013644
1	Fmin Rmin	57.44	1138	2215	3353	0.3394	-0.5631	-1.0961	-1.6592	55.17	53.36	0.987	1.83383992					2079.574468	401.1428571	1678.43161	0.900309	1.99769831

Figure 12 - Picture showing spreadsheet for aerodynamics.

Run #	Setup	Velocity (m/s)	Radius (m)	Weight Transfer Simulated				Weight Transfer Predicted			
				Front (N)	Rear (N)	Total (N)	Magic Number	Front (N)	Rear (N)	Total (N)	Magic Number
4	ARB Fmin Rmax	13.65	25	1155	876	2031	0.568685377	787	741	1528	0.515052356
3	ARB Fmin Rmid	13.88	25	1230	852	2082	0.590778098	807	760	1567	0.514996809
6	ARB Fmid Rmax	13.73	25	1280	788	2068	0.618955513	950	607	1557	0.61014772
2	ARB Fmin Rmin	13.63	25	1287	736	2023	0.636183885	1004	519	1523	0.659225213
1	ARB Fmid Rmid	13.82	26	1296	730	2026	0.639684107	1007	520	1527	0.659462999
9	ARB Fmax Rmax	13.79	25	1357	741	2098	0.646806482	1057	522	1579	0.66941102
8	ARB Fmax Rmid	13.54	25	1342	657	1999	0.671335668	1073	432	1505	0.712956811
5	ARB Fmid Rmin	13.78	25	1403	663	2066	0.679090029	1143	415	1558	0.733632863
7	ARB Fmax Rmin	13.66	24	1474	615	2089	0.705600766	1220	353	1573	0.775588048
12	ARBdet Fmin Rmax	13.47	24	975	1055	2030	0.480295567	593	934	1527	0.388343157
10	ARBdet Fmin Rmin	13.58	25	1061	928	1989	0.533433886	718	780	1498	0.479305741
18	ARBdet Fmax Rmax	13.67	25	1119	921	2040	0.548529412	736	799	1535	0.479478827
14	ARBdet Fmid Rmid	13.66	25	1107	937	2044	0.541585127	738	801	1539	0.479532164
16	ARBdet Fmax Rmin	13.72	24	1248	835	2083	0.599135862	896	674	1570	0.570700637
20	ARBdet Fmin Rmax	24.88	49	1516	1883	3399	0.446013533	997	1571	2568	0.388239875
19	ARBdet Fmin Rmin	25.23	51	1707	1674	3381	0.504880213	1227	1332	2559	0.479484174
21	ARBdet Fmid Rmid	25.18	50	1746	1681	3427	0.509483513	1242	1349	2591	0.479351602
23	ARBdet Fmax Rmax	24.99	50	1738	1651	3389	0.512835645	1228	1333	2561	0.479500195
22	ARBdet Fmax Rmid	24.88	50	1890	1428	3318	0.569620253	1428	1079	2507	0.569605106

Figure 13 - Picture showing spreadsheet for weight transfer.