

Vehicle Dynamic

by Zhangwei Guo

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Abstract.

In order to deepen the understanding of vehicle motion and load transfer in the longitudinal steady state and the lateral acceleration state, and to test the use of vehicle behavior analysis and simulation software, this article uses the basic performance simulator to design and run a set of vehicle tests. This paper studies how the roll stiffness distribution affects the steady-state load distribution of the vehicle model, and then demonstrates the correctness and practicability of the vehicle load transfer prediction equation. At the same time, through the study of how the aerodynamic setting affects the load distribution of the vehicle, it can deeper perception of the effects of aerodynamic forces on the overall balance of the vehicle.

Experimental process.

Firstly, it needs to learn the use of the base performance simulator and extensively research data to determine vehicle parameter settings in the simulated environment. After that, group members cooperate to complete the task of designing and running the vehicle test using the basic performance simulator and complete the experimental data collection work. After obtaining the experimental data, combined with the course presentation documents and notes, the experimental principles and experimental formulas will be comprehended to prepare for the subsequent analysis.

For task one, add wheel load channels in the analysis software Motec to read the load changes of each wheel in the whole process of the vehicle for longitudinal comparison, and compare the load changes of each wheel under different settings to evaluate the effect of stiffness distribution on the load condition of each wheel during vehicle travel.

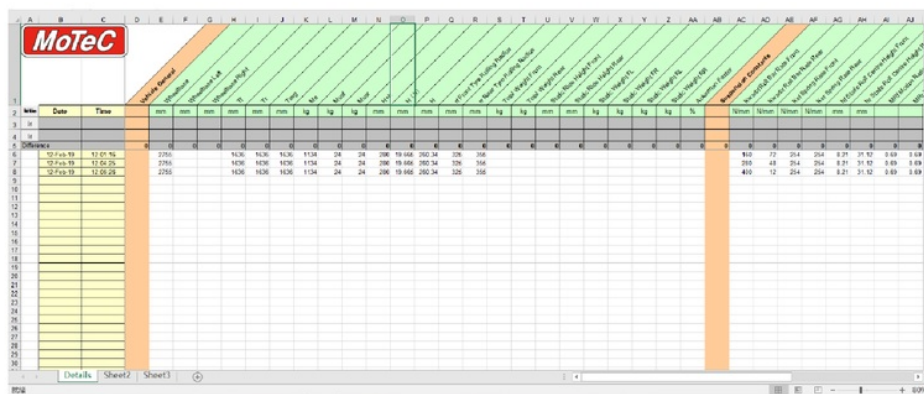


Figure 1.

In order to test the correctness and applicability of the weight transfer prediction equation in the unsteady state, the data points with similar speeds in the acceleration process and the deceleration process of the vehicle are selected. The experimental data read is analyzed and the magic number curves set by the three parameters are compared in these two processes.

For task two, with the calculation formula programmed in Excel, the load distribution of each wheel in nine different settings at constant speed is read in Motec and inputted into Excel. The lift coefficients and resistance coefficients under each setting is calculated. Take a data point at a constant steady state under each setting for the lift coefficients. For the resistance coefficients of the vehicle, two adjacent data points are taken in the high-speed state during the coast down process, and two adjacent data points are taken in the ground speed state, and the calculation formula explained in the classroom is used for calculation.

Experimental principle.

For the task one

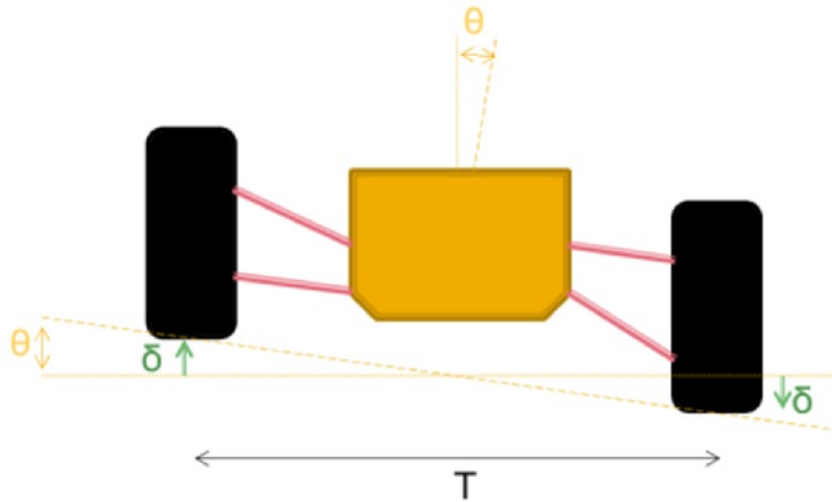


Figure 3

Roll angle(Figure 3) is one of the Euler angles (llang, 2017), it is a very important parameter during the lap process. On the vehicle, it can be expressed according to the picture as:

$$\tan\theta = \frac{O}{A} = \frac{\delta}{0.5T}$$

The roll angle is not too big usually, so with the small angle assumption (baidu, 2016) it can be also expressed as follows:

$$\theta = \frac{\delta}{0.5T}$$

So we can get this for the further calculation.

$$\delta = \frac{T\theta}{2}$$

It is a comprehensive performance parameter related to the roll stiffness and it can be achieved by these formulas:

$$K_{wf} = (K_{sf} \times MR_f^2) + K_{warbf}$$

$$K_{wr} = (K_{sr} \times MR_r^2) + K_{warb}$$

The anti roll moment is the moment produced by the springs and ARM which opposes the body or chassis roll.

$$M_{\theta} = \delta \times K_w \times T$$

$$\delta = \frac{T\theta}{2} \quad \rightarrow \quad M_{\theta} = \frac{T^2\theta K_w}{2}$$

Roll stiffness describes the amount of torque required to roll the chassis through a rad.

$$K_{\theta} = \frac{M_{\theta}}{\theta}$$

$$M_{\theta} = \frac{T^2\theta K_w}{2} \quad \rightarrow \quad K_{\theta} = \frac{T^2 K_w}{2}$$

Which measures in N*m/rad.

Every suspension has its unique roll stiffness and the total roll stiffness is the sum of the front and rear roll stiffness.

$$K_{\theta f} = \frac{T_f^2 K_{wf}}{2}$$

$$K_{\theta r} = \frac{T_r^2 K_{wr}}{2}$$

$$K_{\theta} = K_{\theta f} + K_{\theta r} = \frac{T_f^2 K_{wf}}{2} + \frac{T_r^2 K_{wr}}{2}$$

Overtuning moment is the moment created by the lateral acceleration which tries to rotate the sprung mass about the roll center. It should be equal to the anti roll moment on account of resisted by it on the steady state.

$$M_{ot} = M_s \times a_y \times H$$

H is the distance between the roll center and the gravity center.

Chassis roll angle can be obtained by dividing the overturning moment by the total roll stiffness for the chassis can only have one roll angle.

$$\theta = \frac{\text{Torque}}{\text{Angular Stiffness}} \Rightarrow \theta = \frac{M_{ot}}{K_{\theta}} \Rightarrow \theta = \frac{M_s \times a_y \times H}{\left(\frac{T_f^2 K_{wf}}{2} + \frac{T_r^2 K_{wr}}{2}\right)}$$

The corresponding suspension deflections and wheel load due to the

weight transfer can be obtained after the roll angle being calculated.

$$WT_s = \delta \times K_w \Rightarrow \delta = \frac{T\theta}{2} \Rightarrow WT_s = \frac{K_w T\theta}{2}$$

The elastic weight transfer can be calculated at whichever end of the vehicle.

$$WT_{sf} = \frac{K_{wf}T_f\theta}{2}$$

$$WT_{sr} = \frac{K_{wr}T_r\theta}{2}$$

The sprung mass geometric weight transfer is caused by the sprung mass acting at roll center height.

$$WT_{sRCf} = \frac{M_{sf} \times a_y \times h_f}{T_f}$$

$$WT_{sRC} = \frac{M_{sr} \times a_y \times h_r}{T_r}$$

The unsprung mass acts at wheel center height leads to the unsprung mass geometric weight transfer.

$$WT_{usf} = \frac{M_{usf} \times a_y \times r_f}{T_f}$$

$$WT_{usr} = \frac{M_{usr} \times a_y \times r_r}{T_r}$$

The total weight transfer is the integration of the elastic weight transfer, the sprung mass geometric weight transfer and the unsprung mass geometric weight transfer.

$$WT_f = WT_{sf} + WT_{sRCf} + WT_{usf}$$

$$WT_r = WT_{sr} + WT_{sRCr} + WT_{usr}$$

$$WT_T = WT_f + WT_r$$

The actual weight transfer can be calculated by the formulas introduced within lectures as follows:

$$WT_f = \frac{TireLoadFL - TireLoadFR}{2}$$

$$WT_r = \frac{TireLoadRL - TireLoadRR}{2}$$

$$WT_T = \frac{M_T \times a_y \times (H+h)}{T_{ave}}$$

For the task two

Aerodynamic loads can be achieved by the coefficient of lift which is different on every axle and independent from weight transfer.

$$Lift_{front} = \frac{1}{2} \times CL_f \times \rho \times v^2$$

$$Lift_{rear} = \frac{1}{2} \times CL_r \times \rho \times v^2$$

When we have the load of a constant speed and stopped, we can calculate the aero load through these equations:

$$R_f = FL_0 + FR_0 \quad R_f = (FL_0 + FR_0) + Aero_f$$

$$R_r = RL_0 + RR_0 \quad \text{and} \quad R_r = (RL_0 + RR_0) + Aero_r$$

Then we can calculate the coefficient of lift for both axles and the contribution of the front lift in the total lift as follows:

$$CL_f = \frac{2 \times Aero_{front}}{\rho \times v^2} = \frac{2 \times [(FL + FR) - (FL_0 + FR_0)]}{\rho \times v_{air}^2}$$

$$CL_r = \frac{2 \times Aero_{rear}}{\rho \times v^2} = \frac{2 \times [(RL + RR) - (RL_0 + RR_0)]}{\rho \times v_{air}^2}$$

$$COP(\%) = \frac{CL_f}{CL_f + CL_r} \times 100$$

As for the aerodynamic drag, when it is on a high speed, it can be assumed that the decelerating force is made up of aerodynamic drag and rolling resistance.

$$\text{Aerodynamic Drag} + \text{Rolling Resistance} = ma_1$$

The rolling resistance can be treated as the only decelerating force when in a very low speed.

$$\text{Rolling Resistance} = ma_2$$

So the aerodynamic drag can be calculated by this formula.

$$ma_1 - ma_2 = \text{Aerodynamic Drag} = \frac{1}{2} \rho v_m^2 C_d A$$

Finally, the CD can be calculated by the following formulas:

$$\frac{1}{2} \rho v_m^2 C_d A + RR = ma_1$$

$$RR = ma_2 \quad C_D = C_d * A = \frac{2(ma_1 - ma_2)}{\rho v_m^2}$$

Where $v_m = \frac{v_2 + v_1}{2}$.

Experimental results.

According to the data analysis of the tire load mass channel (Figure 4), it can be seen that with the approximate speed, the contribution to the roll stiffness of the vehicle gradually increases with the increase of the roll stiffness of the front axle, the load on the outer wheel of the front axle increases continuously, and the inner load decreases continuously as the wheel load on the outer side of the rear axle decreases, the load on the inner wheel increases.

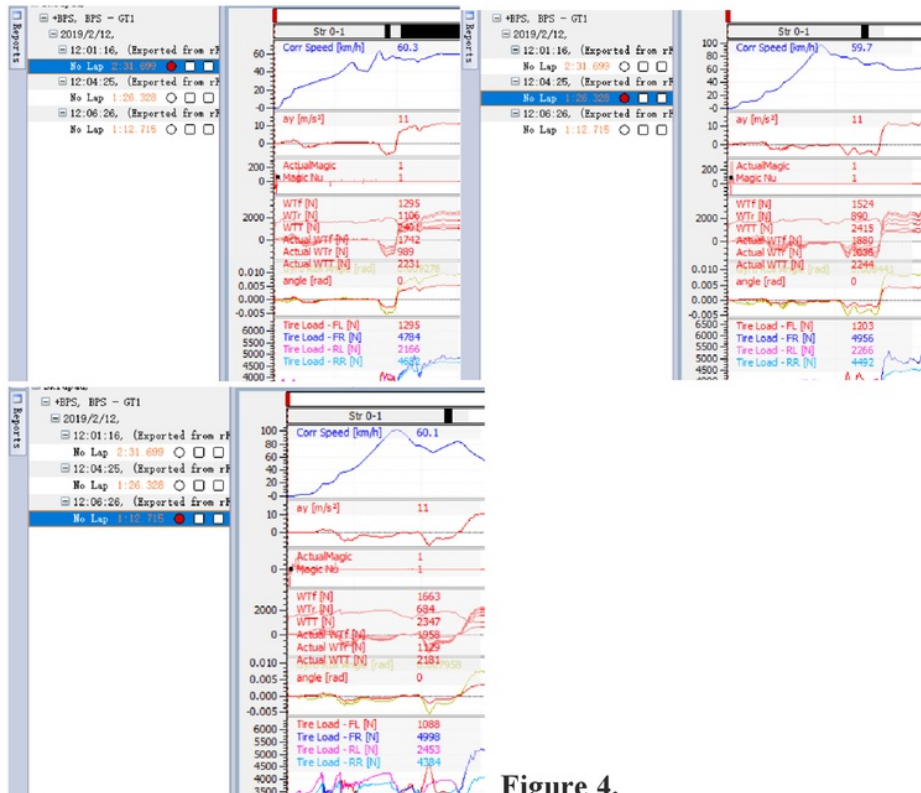


Figure 4.

The mass transfer prediction equation and the actual mass transfer calculation equation are used to create mass channels and select the steady state for the mass transfer amount. The predicted value of the front axle mass transfer amount is smaller than the actual calculated value, and the predicted value of the rear axle mass transfer amount is also smaller than the actual calculated value. But the total mass transfer amount predicted value is greater than the actual calculated value. The front axle, the rear axle and the mass transfer amount of the three settings are inputted into excel, and the ratio of the mass transfer amount of the front axle to the mass transfer amount of the whole vehicle and the contribution of the front axle roll stiffness to the roll stiffness of the vehicle are calculated.

One point(Figure 7) is chosen on which the speeds of three setups are very similar less than 0.1km/h.

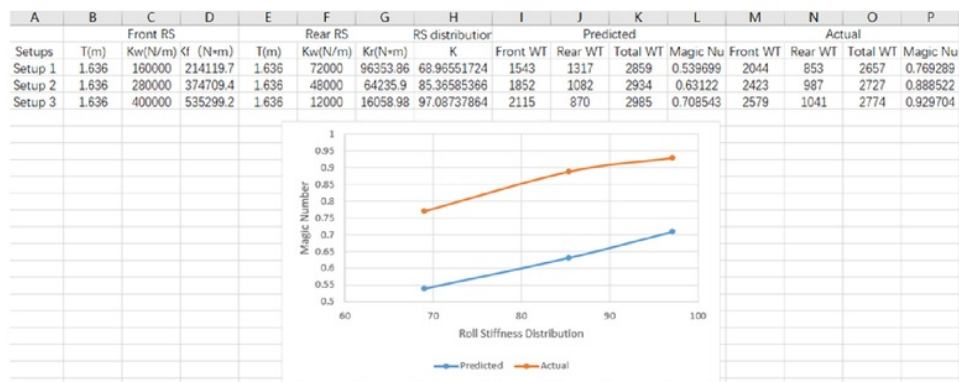


Figure 7.

Times	Setup 1						Setup 2						Setup 3					
	Predicted			Actual			Predicted			Actual			Predicted			Actual		
	Front WT	Rear WT	Total WT	Front WT	Rear WT	Total WT	Front WT	Rear WT	Total WT	Front WT	Rear WT	Total WT	Front WT	Rear WT	Total WT	Front WT	Rear WT	Total WT
0.634	1820	1383	3003	2150	802	2791	1768	1033	2801	2203	957	2903	2057	847	2904	2536	1073	2999
1.399	1537	1312	2849	2054	879	2647	1848	1079	2927	2306	941	2720	2039	839	2878	2527	1091	2975
1.843	1539	1314	2852	2054	875	2651	1797	105	2847	2248	977	2546	2103	865	2968	2562	1042	2759
2.165	1558	1330	2887	2096	873	2683	1811	1058	2870	2276	979	2567	2069	852	2921	2563	1070	2714
2.729	1543	1403	3046	2131	784	2831	1860	1067	2947	2344	961	2739	2036	838	2874	2522	1093	2970
3.374	1592	1359	2952	2131	849	2743	1925	1125	3051	2404	907	2335	2054	845	2099	2546	1000	2994
3.898	1596	1363	2959	2139	853	2750	1791	1046	2837	2240	990	2536	2056	846	2902	2543	1058	2997
4.22	1583	1351	2933	2127	870	2726	1769	1033	2802	2237	1023	2604	2053	845	2897	2563	1079	2993
Average	1583.5	1351.875	2935.125	2115.25	848.125	2777.75	1821.25	945.75	2885.25	2282.25	968.125	2681.25	2058.375	847.125	2905.375	2547.75	1073.25	2700.125

Figure 8.

A section of the steady state data (Figure 8) is taken and the average values over a time period was calculated for the further calculation.

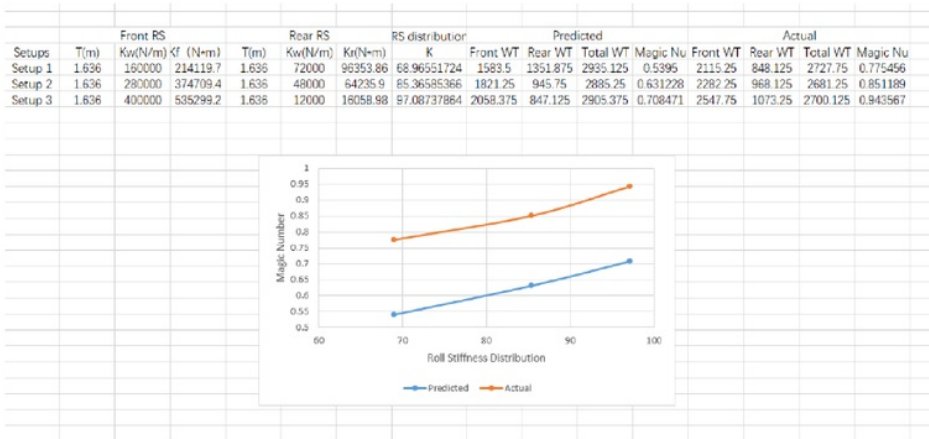


Figure 9.

The curve(Figure 9) drawn by the mean value over a period of time is consistent with the overall trend of the curve drawn by selecting a point with the same velocity, but the curve of the curve drawn by the mean value is more coincident with the predicted curve. The performance of the curve drawn by the selected data points is gradually increasing and the proportion of the front axle roll stiffness in the vehicle roll stiffness is increasing. The mass transfer of the front axle shifts the mass of the vehicle. The impact is also getting bigger and bigger, but the growth trend is gradually slowing down, but the growth trend of the mean value

calculation curve is selected to be gradually accelerated and coincides with the prediction curve. On the one hand, it shows that the correlation calculation over a period of time is more real and accurate. On the other hand, it also explains the theoretical correctness of the vehicle mass transfer prediction equation, but its accuracy needs to be improved.

Aiming at the accuracy and effectiveness of the prediction equation under non-steady state, a certain point with similar speed in the linear acceleration process is selected for data processing to obtain the following curves:

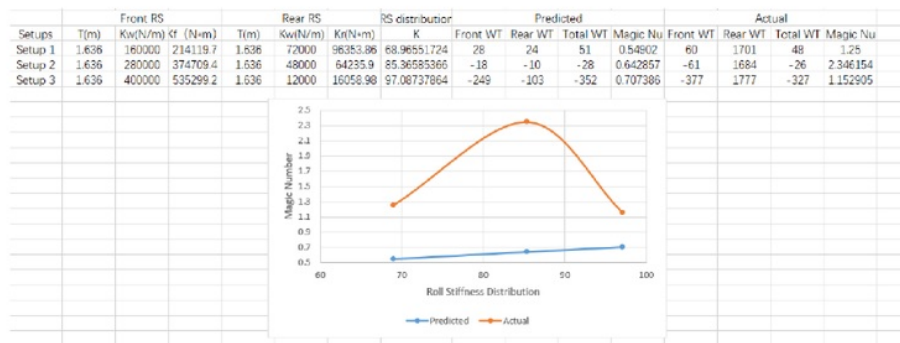


Figure 10.

It can be seen from the figure (Figure 10) that the actual measured value and the predicted value at this time have large errors, and the trends of the two are completely different. In order to prevent accidental errors in individual points, the mass channel of the magic number is compared as shown below:

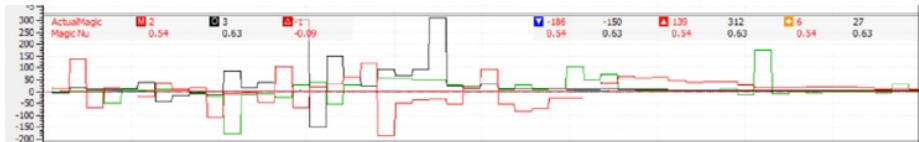


Figure 11.

It can be seen that the mass transfer prediction equation has poor accuracy and applicability in an unstable state.

Most of the computational analysis for aerodynamics is done in excel. The research method uses the control variable method to plot the aero force, CL, CoP, Drag force and CD while the splitter length is the same as the wing angle changes. When the wing angle is the same, the curve changes with the splitter length. As shown below:

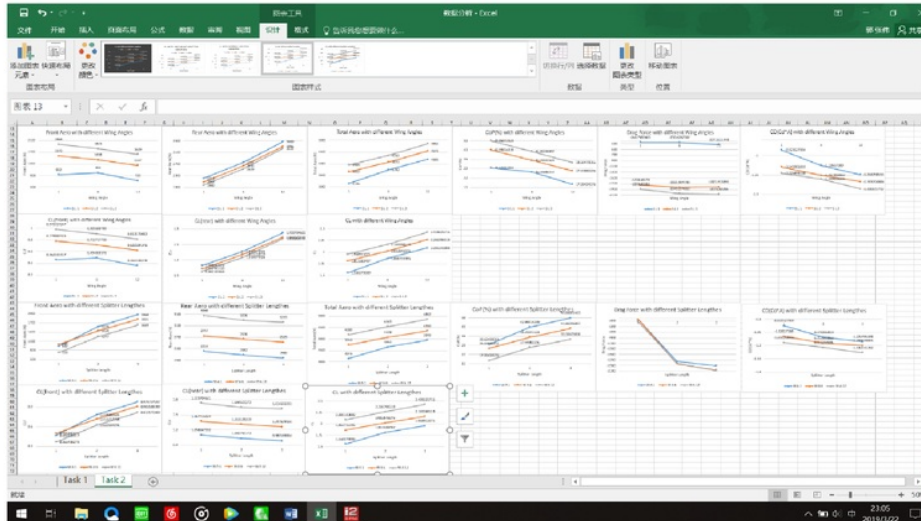


Figure 12.

As we can from the following figure(Figure 13), the front aerodynamic force is decreasing and the rear is increasing as the wing

angle increases and splitter lengthen steady. The total aerodynamic force is increasing. The front aerodynamic force is increasing and the rear is decreasing while the splitter length is increasing. The total aerodynamic force is increasing.

For the coefficient of lift, the front coefficient of lift is decreasing and the rear coefficient of lift is increasing while only the wing angle increases. The total coefficient of lift is increasing.

The front coefficient of lift is increasing and the rear coefficient of lift is decreasing while only the splitter length increases. But the total coefficient of lift is still increasing.

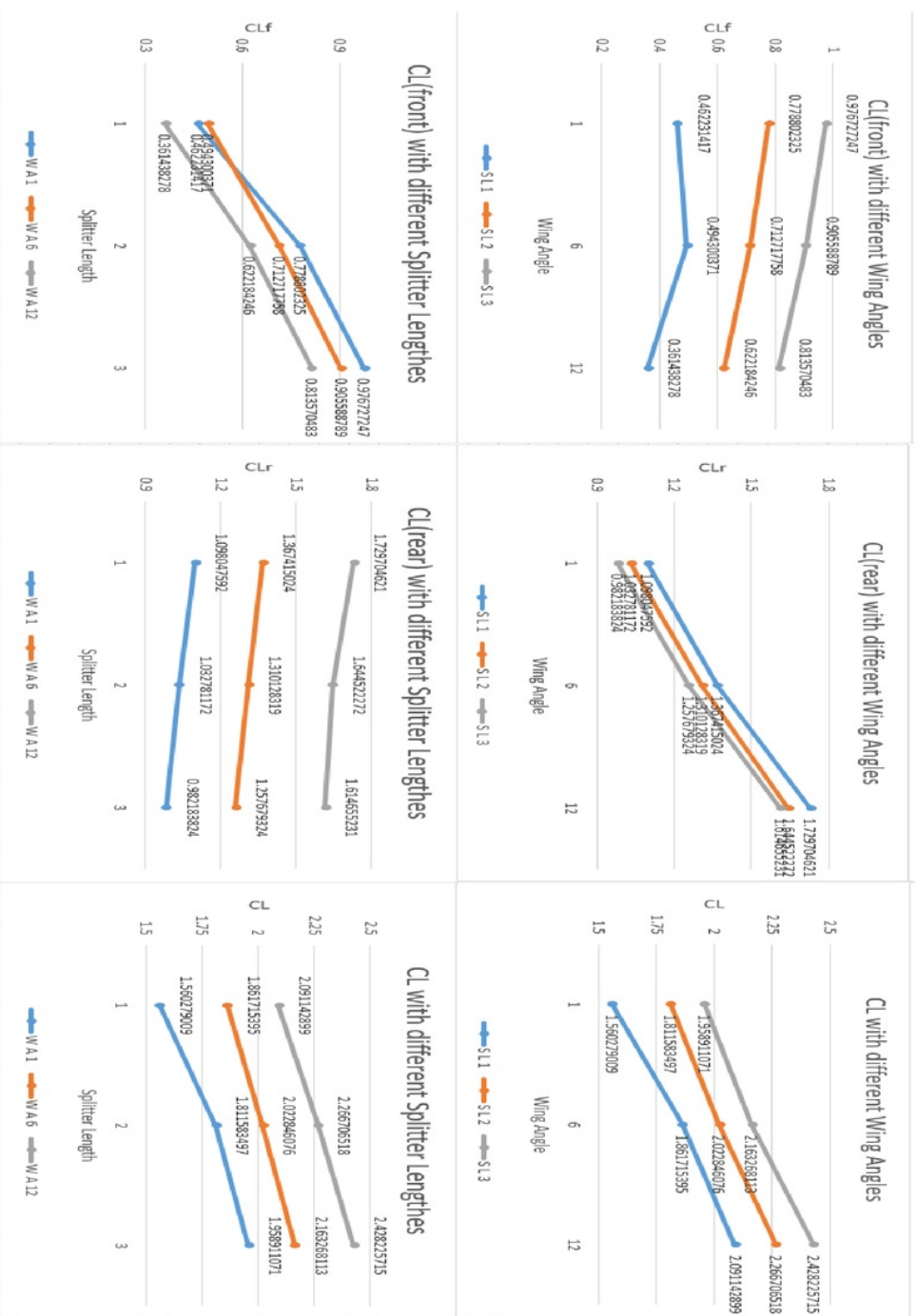


Figure 13.

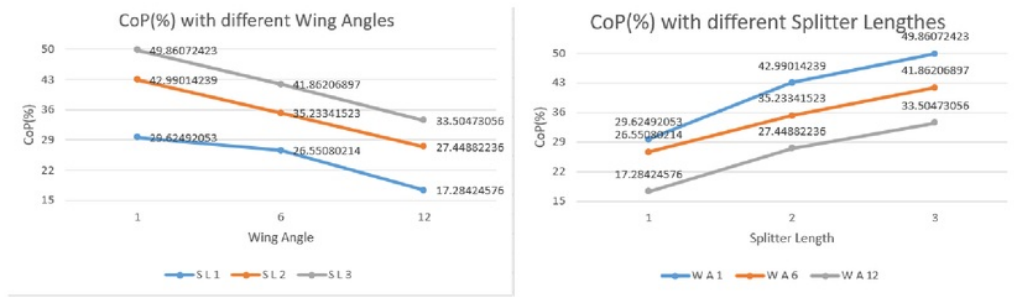


Figure 14

It is easy to understand that as the wing angle increasing, rear load increases and the CoP decreases. But while the splitter length increases, front load increases and the CoP increases.

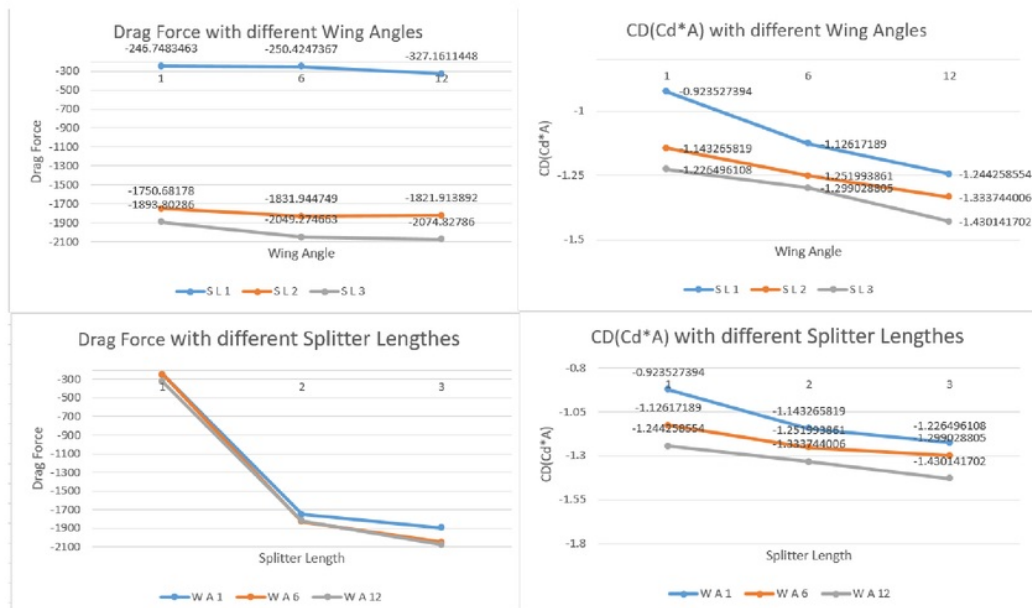


Figure 15.

The drag force decreases whatever as the wing angle or splitter length increase. But there is some problem with one of the coast down

setups, so the data point can only be chosen from a speed which is not so high.

Analysis.

For the weight transfer, even the outer wheels afford more lateral forces with higher loads than the inner wheels, the total weight transfer will increase when the entire roll stiffness increases. The weight transfer of the front axle will be more and more with the front roll stiffness increases which means the front springs become more and more stiff.

Aerodynamic negative lift is caused by the pressure difference which is made from the difference in air velocity around the wing. The air will be divided into two sides around the wings after passes through the leading edge. The lower air flow rate through the upper part will be faster on account of the distance which passed is longer. This special structure leads to a low pressure under the wing and a higher pressure on the wing. Then the down force and negative lift are formed.

Areas of concern.

First, before starting to prepare for the calculation work, pay attention to the consistency of the unit when inputting the basic parameters of the vehicle to simplify the programming of the calculation process.

Secondly, for the calculation of H , the h at the centroid position can be directly calculated using the similar triangle principle, and then H can be obtained by the value of $(H+h)$.

After that, the selection of data points should be fully scientific and rigorous, and efforts should be made to avoid contingency.

Finally, for the part of the team cooperation, it is better to add mutual inspection steps based on your own inspection to avoid data problems similar to this one.

Conclusion.

For the weight transfer, the predicted outcomes are constant with the actual result on the steady state which means the validity of the load transfer prediction equations are useful. The proportion of the front roll stiffness to the entire roll stiffness is bigger, the bigger front weight transfer is. But the weight transfer predict formulas are not quite suitable for the non-steady state.

For the aerodynamic part, the front load decreases while the rear load and total load increases as the wing angle increases which lead to the coefficient of front lift force's decreasing and the increasing of coefficient of rear lift force and total force. As the splitter length increases, the rear load is decreasing and the front load and total load is increasing. The drag force and coefficient of drag are decreasing while the wing angle increasing.

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