Assessment cover

OXFORD BROOKES UNIVERSITY

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Module No:	**ENGR7008**	Module title:	**Laptime Simulation and Race Engineering**

Assessment title:	**Assignment 1: Data Analysis**

Due date and time:	**14 March 2023 (Tuesday, S2 Week 7), 1 pm**

Estimated total time to be spent on assignment:	**50 hours**

LEARNING OUTCOMES

On successful completion of this assignment, students will be able to achieve the module following learning outcomes (LOs):
LO 1: Demonstrate a systematic understanding of advanced concepts in motorsport vehicle performance.
LO 2: Apply knowledge base of engineering in order to synthesise racing car performance using computers.
LO 3: Produce computer simulations of racing car lap times by applying subject specific techniques of synthesis and modelling tools.
LO 4: Demonstrate the relative importance of different design parameters and quantify the impact of these variables on different racing formula using modelling evidence to support the analysis.
LO 5: Demonstrate transferable/professional skills such as technical report writing (including effective and concise communication) and problem-solving with complete and incomplete data sets.

Engineering Council AHEP4 LOs assessed (from S2 2022-23)	
M1	Apply a comprehensive knowledge of mathematics, statistics, natural science and engineering principles to the solution of complex problems. Much of the knowledge will be at the forefront of the particular subject of study and informed by a critical awareness of new developments and the wider context of engineering
M2	Formulate and analyse complex problems to reach substantiated conclusions. This will involve evaluating available data using first principles of mathematics, statistics, natural science and engineering principles, and using engineering judgement to work with information that may be uncertain or incomplete, discussing the limitations of the techniques employed
M4	Select and critically evaluate technical literature and other sources of information to solve complex problems
M17	Communicate effectively on complex engineering matters with technical and non-technical audiences, evaluating the effectiveness of the methods used

Statement of Compliance *(please tick to sign)*

x	I declare that the work submitted is my own and that the work I submit is fully in accordance with the University regulations regarding assessments *(www.brookes.ac.uk/uniregulations/current)*

1 FUEL CONSUMPTION

Fuel consumption between both cars is very similar. The LMH car is slightly more economic (0.09kg less of fuel per lap) due to the electric supply deployment at acceleration. However, the engine efficiency is higher by 3% on the LMDh car.

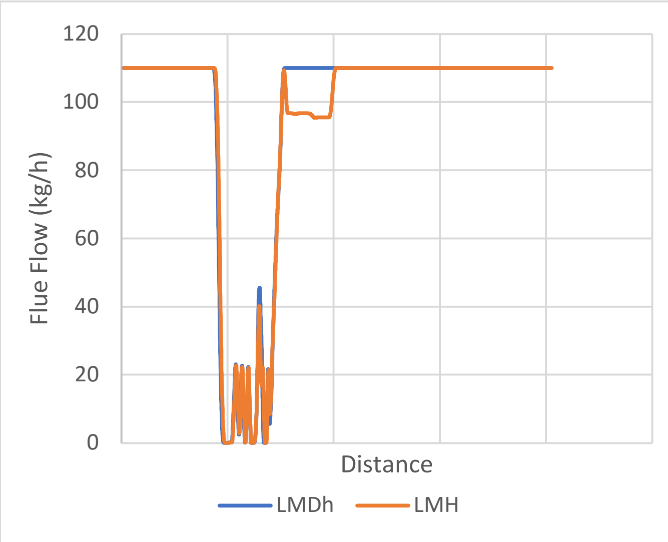

Figure 1. Fuel flow through turn 9 exit.

Regulations limit the power output to 500kW for both cars: in case of the LMDh, the engine power is limited to 470kW, with a supply of 30kW from the electric unit; but in case of the LMH, the engine power has to be limited on electric power deployment, hence the fuel save in acceleration. Figure 1 shows the fuel flow after turn 9, where the electric power is supplied and engine power is cut for the LMH, explaining the fuel saving in the lap, while the LMDh car has no ICE power reduction. (https://a-e.li/, 2023)

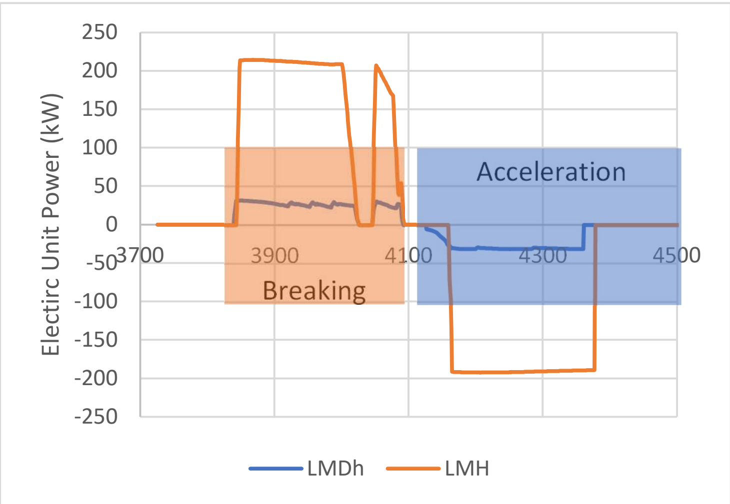

Figure 2. ERS Power during turn 9.

Figure 2 shows breaking and acceleration before and after turn 9. The power limitation of the LMDh class is appreciated, while the LMH class outputs 200KW average, allowing for a higher fuel saving.

2 Power at Drive Shafts

LMDh are restricted to deliver the ERS power to the front wheels while LMH cars do not have any restriction. This limits the LMDh cars to (almost) rear wheel drive, while the LMH cars can benefit from AWD when necessary, as long as they limit the total output power to 500kW.

Figure 4. Shaft power on each wheel through turn 9 for the LMDh car.

Figure 3. Shaft power on each wheel through turn 9 for the LMH car.

Figures 3 and 4 show the wheel shaft power before and after turn 9. For the LMH car, all wheels contribute towards accelerating on the straight, with no limit; while the LMDh car has almost all power delivered to the rear wheels, with a slight contribution of 30kW from the front wheels.

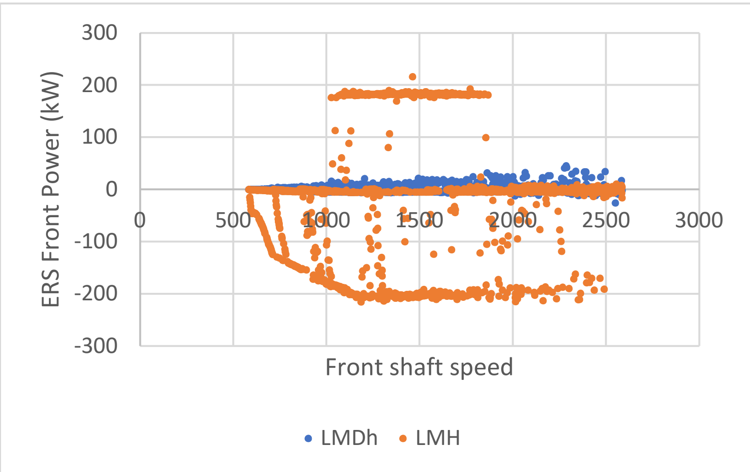

Figure 5. ERS Front shaft powers as a function of the front shaft speed.

If we look at the overall race power distribution of the front wheels, in figure 5, the difference between both cars becomes clear.

No data regarding the differential has been recorded, however, the shaft power graphs suggest a limited slip differential, due to the difference on the left and right curves, usually meaning a corner exit.

3 AERO & MECHANICAL BALANCE

The aero balance measure is 46% for the LMDh and 51% for the LMH. The pitch angle or rake values are -0.22 degrees for the LMDh and -0.28 for the LMH. This is appreciated in the front and rear ride height differences, which are more noticeable for the LMH car. However, the rear downforce is significantly higher for the LMDh, almost 1000N of difference at top speeds, while there is a slight increase of drag as well.

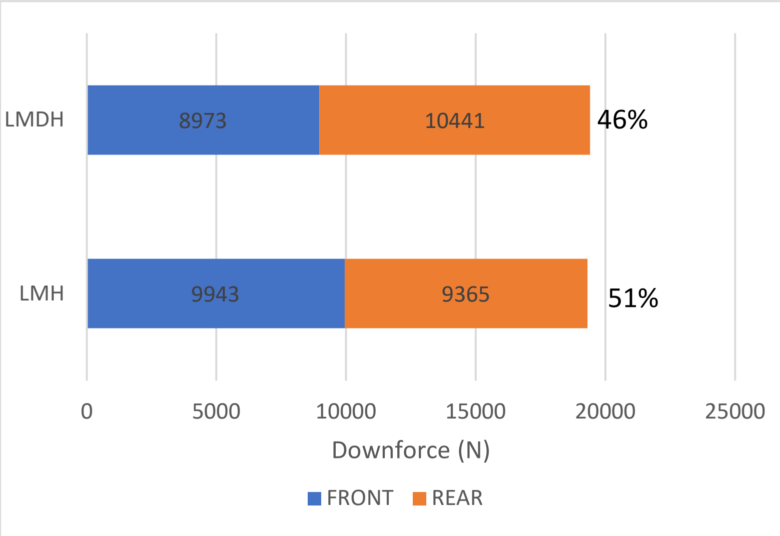

Figure 6. Downforce Distribution front and rear

Figure 6 shows a comparison of both car's aerodynamic balance and forces, where the balance difference is much clearer.

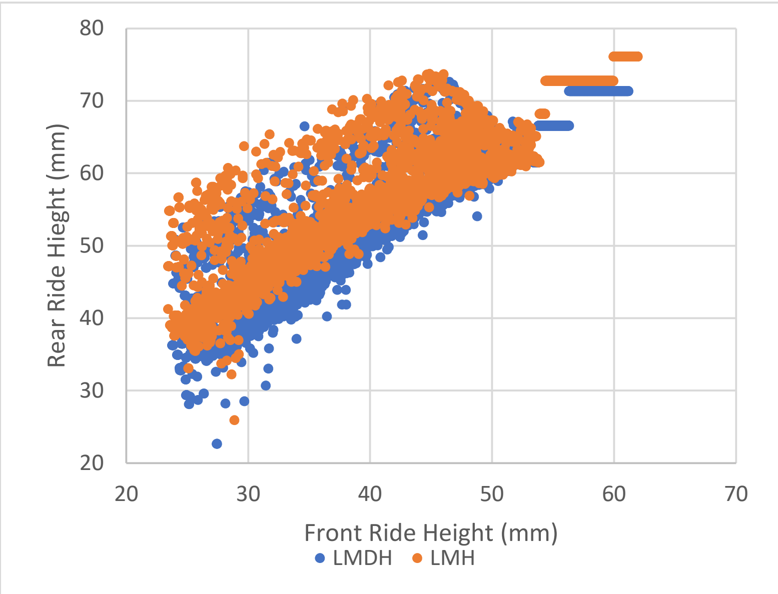

Figure 7. Ride height distribution

Ride height is also significantly different between the two cars. Figure 7 shows the rear ride height with respect to the front. The trend shows how the LMH car has a higher ride height overall.

Mechanical balance refers to the roll bar stiffness distribution between front and rear. Both cars have a very similar distribution. Breaking destabilizes the car, but during cornering the values stay close to 59%. The roll angle during turns 10-11-12 is represented in figure 9, where both cars behave very similarly, and both present very small roll angles.

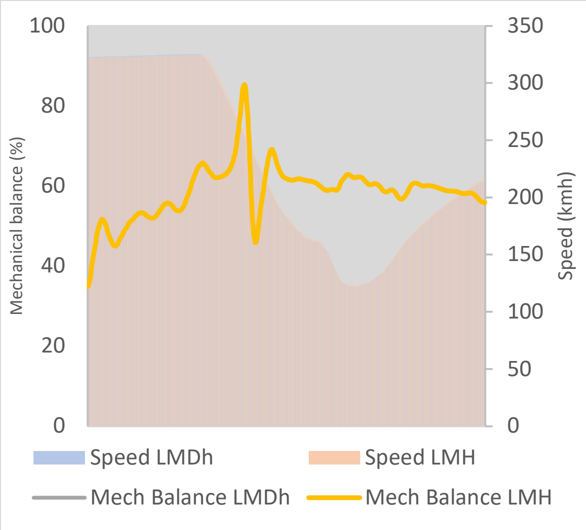

Figure 9. Speed and mechanical balance through turns 10-11-12

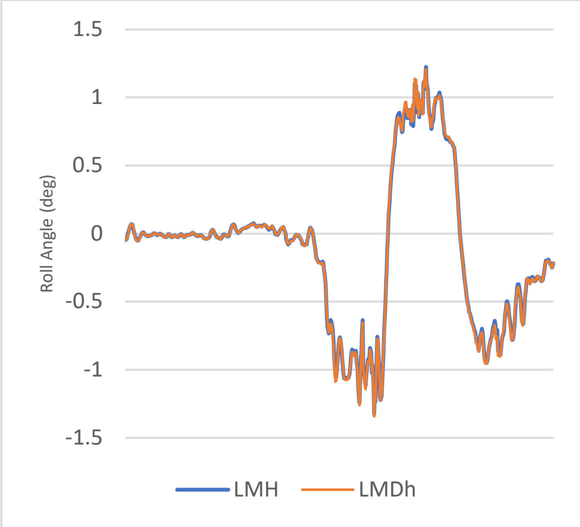

Figure 8. Roll angle variation though turn 10-11-12.

4 Chassis Handling

Observing turn 13 steering dynamics, figure 10 shows the accelerator position, steering angle and understeer gradient for the LMDh car. As soon as the driver steers the wheel rather abruptly, the car understeers, but quickly recovers by oversteering. This induces a reaction in the driver, and the car recovers to understeering throughout the apex of the corner, while the driver starts to accelerate. In the corner exit, the car oversteers slightly as a consequence of throttle.

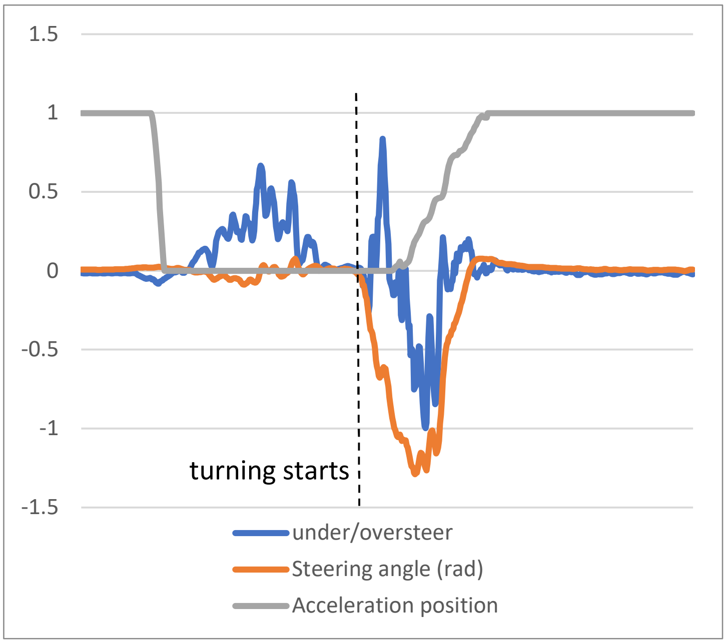

Figure 10. Understeer gradient, steering angle and throttle through turn 13 for the LMDh car.

In case of the LMH, shown in figure 11, the initial understeer response is much less abrupt, and the car understeers along the whole corner, up until the exit.

By comparing the understeer gradient in figure 12, we can appreciate these turning behaviour differences easier.

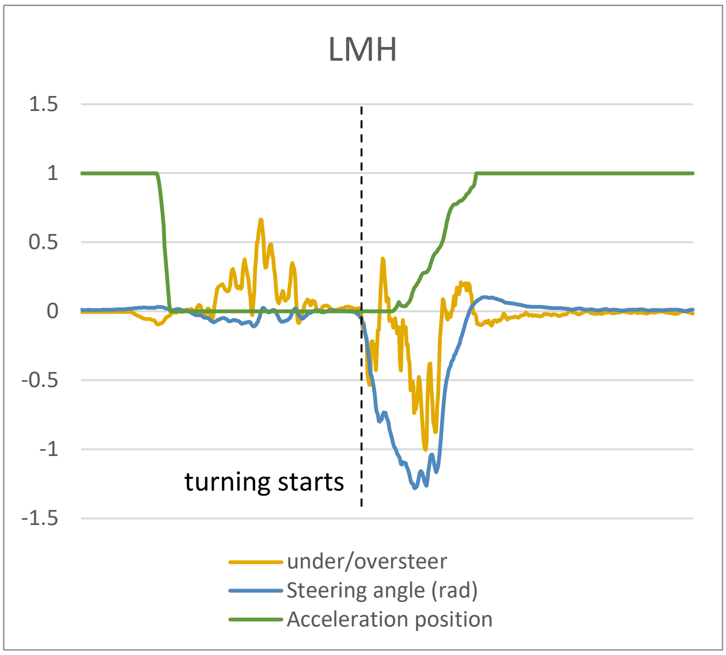

Figure 12. Understeer gradient, steering angle and throttle through turn 13 for the LMH car

The higher oversteering nature of the LMDh car can be caused by the difference in the drive power between front and rear wheels. As explained in part 1, even though the LMDh car has front wheel drive from the electric power system, the amount of power that the front wheels receive compared to the rear is very insignificant, and the car behaves very similar to being rear wheel drive only. At the corner exit, there is a small oversteering spike in the LMDh car which causes the driver to hesitate on the throttle.

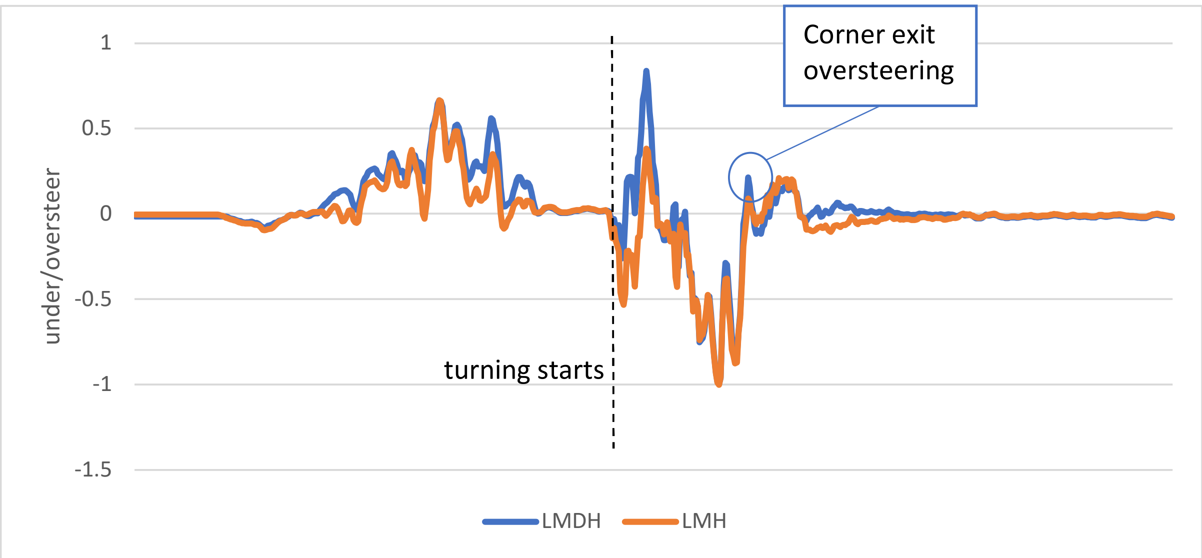

Figure 11. Understeer gradient comparison through turn 13.

5 Tyre Saturation & Tyre Energy

Tyre saturation shows evidence of the electric power distribution differences between both cars. Figure 13 shows tyre saturation for both cars on all 4 wheels for turn 13. During breaking, the LMDh saturates the inside tyre more, while the LMH car braking shows a more balanced approach. However, during the turn both cars saturate the tyres is a similar way up to 80%. The corner shows once again the powertrain differences between both cars.

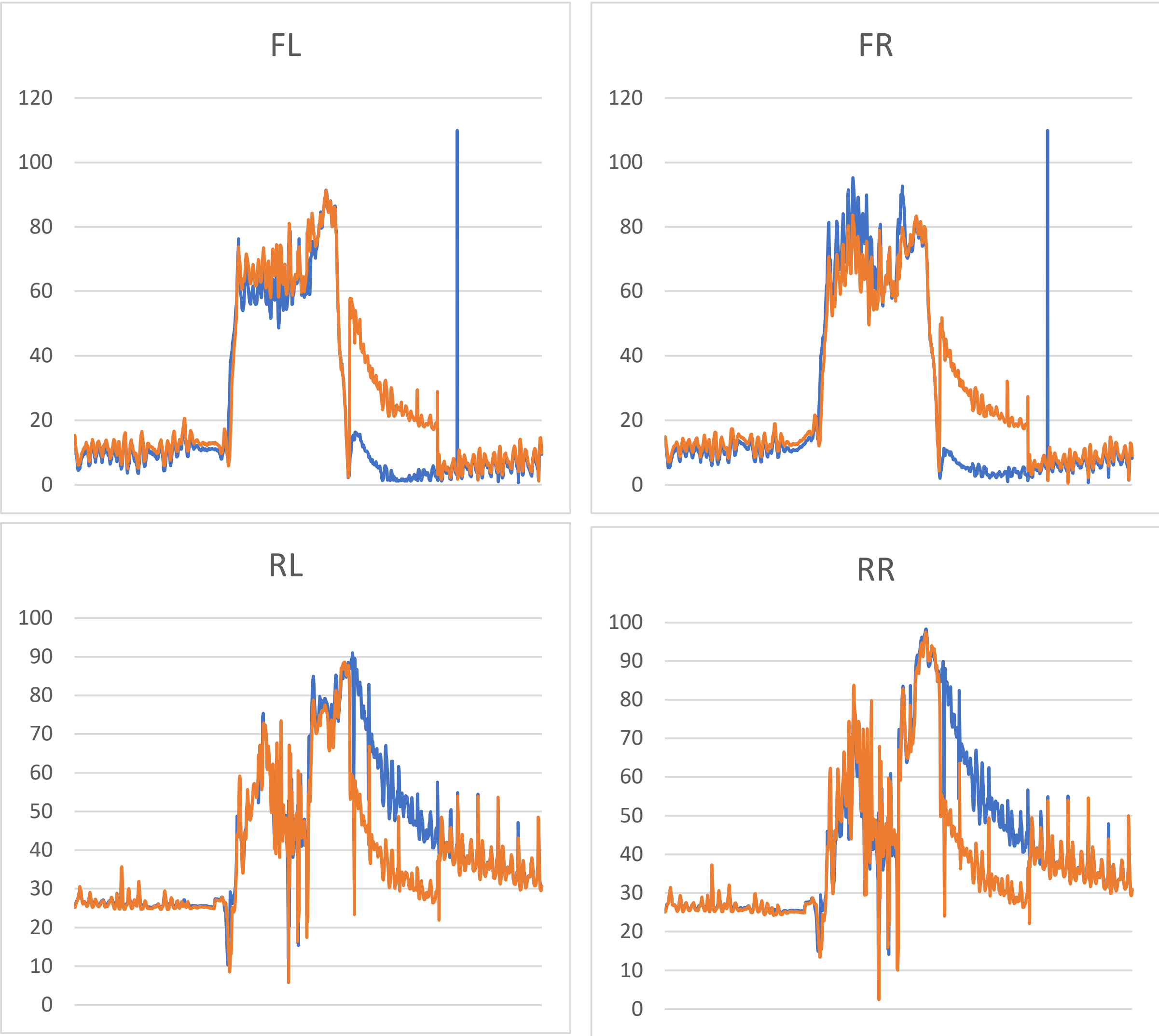

Figure 13. Front and Rear tyre saturations through turn 13. (blue is LMDh, orange is LMH)

Finally, figure 14 shows the front tyre saturation for the sequence of turns 10, 11, and 12. We can see how both front tyres saturate on the chicane. This also happens in turn 1, 8, and 17; and we can see some specific spike points.

It can be seen how the inside tyre saturates over its limit during breaking: the lift tyre before turn 10 (left hand corner), and then the right before turn 11(right hand corner). However, this is only present in the LMDh car. This might be cause by the difference in aerodynamic downforce, where the

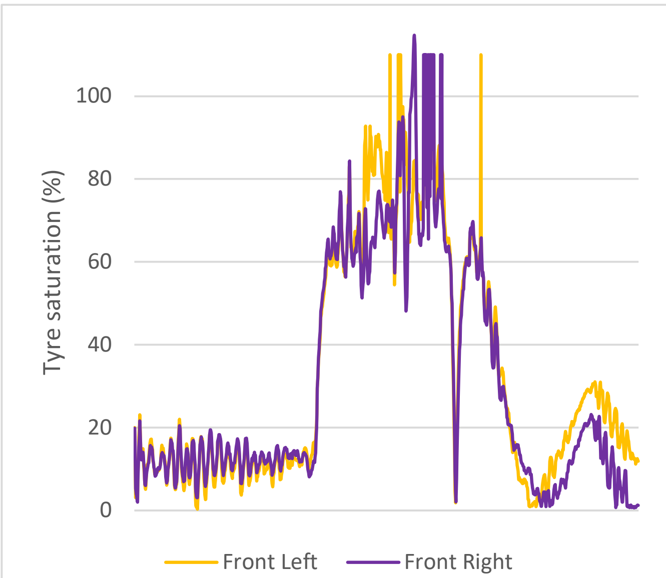

Figure 14. Front tyre saturations in turn 10-11-12 in the LMDh

LMDh has less frontal downforce, and therefore tyres are not able to sustain as much load.

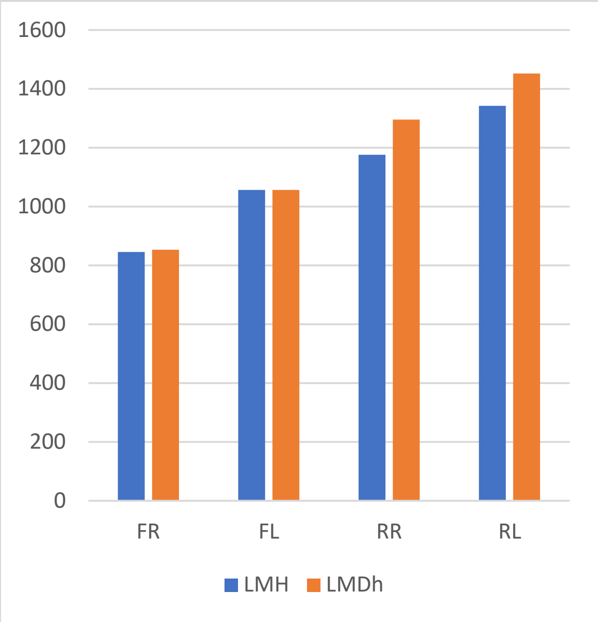

Figure 15. Tyre energy accumulation throughout the lap

In terms of the tyre energy, most noticeable difference is the Rear energy difference, being higher in the LMDh, due to the difference in power distribution once again. Left wheels suffer from a higher energy accumulation, as a consequence of the track layout, but we can appreciate a very small increase in front wheel energies in the LMH.

Figure 16 and 17 shows the tyre lateral force as a function of the slip angle for the front tyres. Both linear trend lines are very close together, on the small slip angle region. The reason for these curves to not mirror along the Y axis is camber. Both cars are setup with -4.5 degrees front left and -3.5 degrees front right of static camber, which induces a higher force when the wheel is turning in the car direction, as a cost of much lower force when turning to the outside. Reason for not having the same camber is that as the track runs clockwise, there are going to be more right turns, and it makes sense to increase tyre capabilities to turn in that direction more efficiently. This higher tyre force accumulation is measured in figure 15.

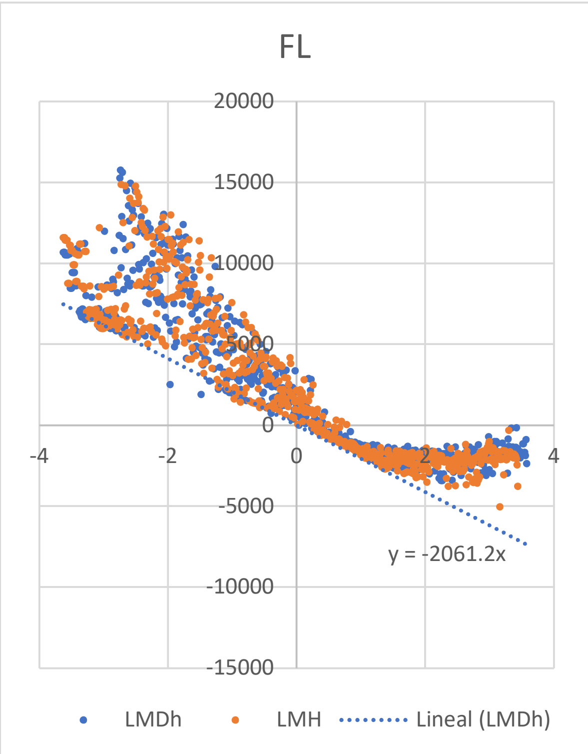

Figure 17. Front left tyre lateral force as a function of slip angle.

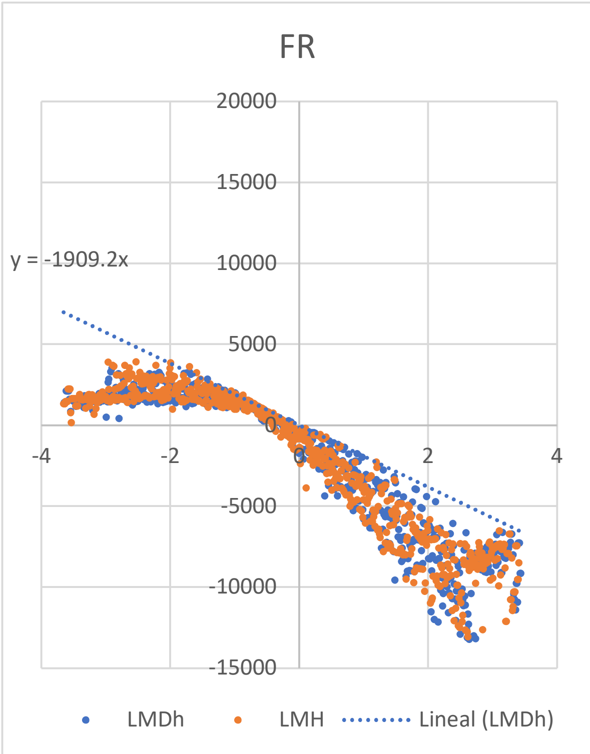

Figure 16. Front right tyre lateral force as a function of slip angle.

6 Driving Style

Figure 18 shows the accelerator and pedal work for turns 3-4-5. The clearest differences are: Firstly, the LMDh car has less throttle and starts to lift-off slightly earlier than the LMH. In terms of the break, the LMDh has significantly higher brake pressure, but this is due to the limitations of the regenerative breaking power, which the LMH does not have, and therefore the break pressure has to be adjusted to account for this system. This is very clear on the entry of turn 3, where the LMDh applies the brakes while the LMH simply lifts the throttle.

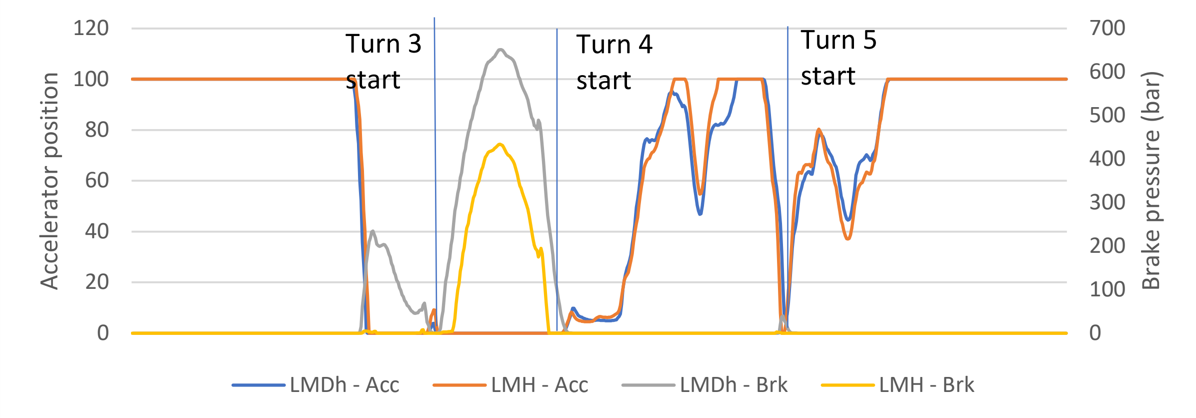

Figure 18. Accelerator and Break inputs through turns 3-4-5

As seen in the other sections, LMDh car can be considered to be rear wheel drive, and its nature tends to oversteer. The car setup is design to counter this behaviour, but some sacrifices in the throttle application have to be made. Nonetheless, the driver loses very little time in comparison to the LMH.

Another noticeable factor is the gear shifting in turn 17: LMH turns in 6th gear and LMDh downshifts to 5th only for this turn. Downshifting is earlier in the LMDh, while upshifting is earlier in the LMH.

Break balance is different as well, which can be addressed to the regenerative system power difference. The LMH car has 53% balance, while LMDh has 67%.

7 Conclusion

All the data gathered in this works presents the LMH as a possible winner. Lap times show that LMH is 0.23 seconds quicker, which in terms of consistency along 24 hours may not mean an absolute win. However, it is the fuel consumption, which is consistently higher in the LMDh car, the key fact for the LMH win. Less fuel consumption may mean less stops overall.

8 REFERENCES

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