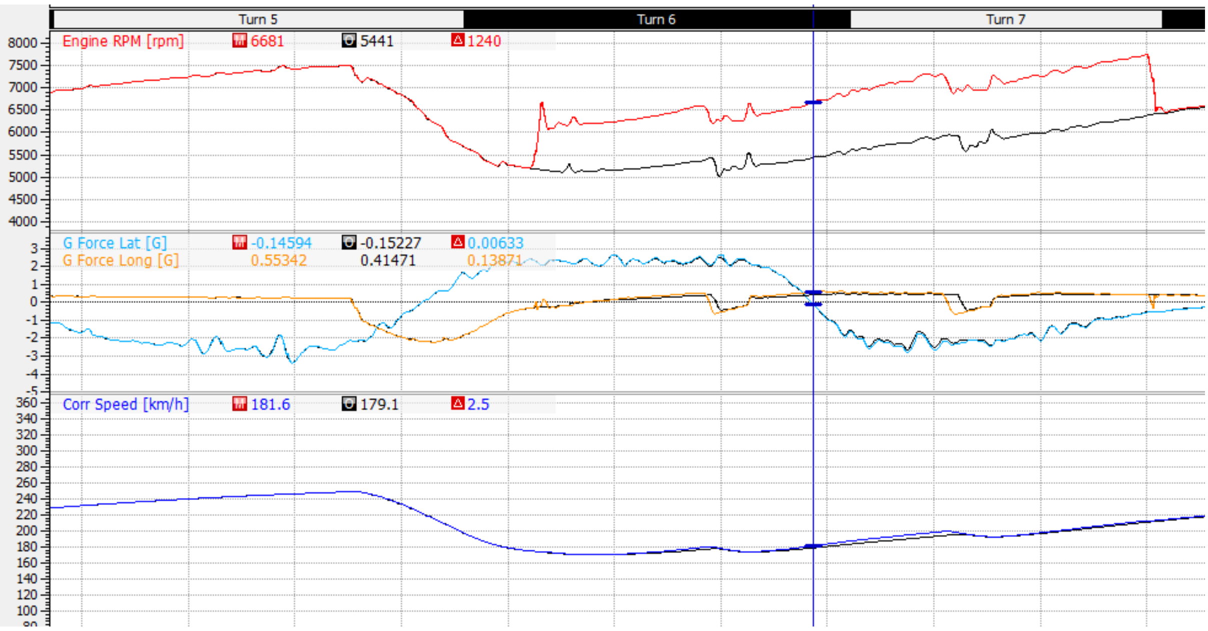
1.0 Qualifying Lap Time - 3.19.970

An assumption made to the required fuel amount is that half the amount of fuel is required for the out-lap and in-lap compared to the flying lap. As a result, by knowing the amount of fuel used per lap - 4.6 litres, then 4.6 litres will be used for the out-lap and in-lap combined, and adding another 1.5 litres for a safety margin brings the qualifying fuel load to 10.7 litres.

The driver model for the qualifying lap differs from the race setup. Both setups run a curvature based model and the option of downshifting in corners is enabled as this gave the best results.

Adjustments were made to the proportional gain of the steering, and was found that the driver's steering inputs were in fact too aggressive, and that after running an optimisation study for steering gain, a lower value of 3% meant that the driver was better able to predict a correct steering input compared to the default gain value 5%.

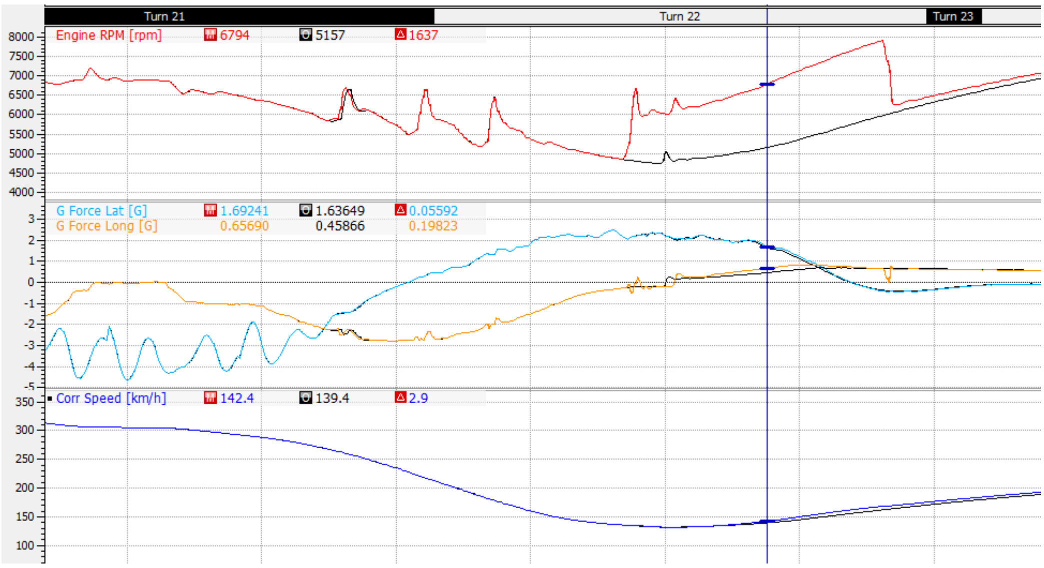
Allowing downshifts in corners resulted in 2 cases on the circuit where the driver opted to go down an extra gear. The first towards the end of the Esses: The black curves indicate the trace of a lap with corner downshifts disabled.



Esses corner section comparison of corner downshift driver model

This extra downshift (seen in the red engine rpm curve) led to a 0.13g increase in longitudinal acceleration, and a higher velocity coming out of the Esses complex.

The second case is at Indianapolis, where again the driver downshifted another time:



Indianapolis corner comparison of corner downshift driver model

This case sees an increase of 0.19g longitudinal at the exit of Indianapolis. These two extra downshifts led to an improvement in lap time of 0.15 seconds.

The qualifying driver model was given increased proportional gain for the throttle pedal to 24% and the driver is more aggressive on the throttle, which will have an inverse effect on wear but does bring the velocity on the straights slightly higher. We have decided to be less aggressive on the race setup to help tyre preservation throughout the stint.

2.0 Performance Analysis

2.1 Aerodynamics

Allowed within the LMP1 regulations is two moveable aerodynamic devices (MADs), which can be used as a drag reduction system (DRS). This allows for one device at the front and on at the rear of the car, each of which, can only have two positions and must be activated at the same time. To allow for a more detailed aerodynamic map setup, an advanced driver aerodynamic map setting was used within VSM.

Max Downforce

For the baseline aerodynamic setup, the vehicle was modeled to generate the maximum allowable downforce. This, from the regulations, is a maximum ClA (coefficient of lift x frontal area) value of 5.2 m^2. To achieve this, the baseline aerodynamic map was modified with an offset to have the maximum ClA for the sum of the front and rear ClA values. This then allowed the offsets needed for each of the front and rear maps to be calculated to change from the baseline map to the maximum downforce map. Once the maps for the maximum ClA is determined, the drag map was modified. This was calculated by ensuring the maximum aerodynamic efficiency does not exceed a value of 4 and from this, an offset was determined to change the baseline aerodynamic map to meet the targeted values.

Min Drag

The technical regulations associated with the drag force of the car outline a minimum CdA (coefficient of drag x frontal area) value of 1 m^2. The baseline aerodynamic setup was modified with an offset so that the CdA map does not go below this minimum value. Once the aerodynamic drag map was set, the downforce map needed to be increased. This was to give a maximum efficiency value of 4, as stated in the regulations. By doing this, a low drag, low downforce setup was created, allowing the car to have a greater top speed.

DRS Activation Points

Once the two aerodynamic maps for the maximum downforce and the minimum drag were developed, each was used in a simulated lap around Le Mans. This allowed the laps to be compared which showed the locations around the track in which each aerodynamic setup was best. The locations where the maps crossed were noted and chosen as the time that the driver was able to activate the DRS. This would then produce the optimum lap as it would allow for the maximum downforce around the slower corners and lower velocity accelerations then reducing the drag allowing for higher top speeds on the straights.

Balance

The aerodynamic balance of the car was modified with the intention of increasing the cars performance. The baseline aerodynamic setup had a balance of 48% to the front. When analysing the track data, the aerodynamic balance was varied in an effort to reduce high speed understeer in the porsche curves. However, the results showed that a balance of 50% proved fastests when looking at a complete lap.

2.2 Vehicle Dynamics

Tyre temperatures revealed large differences between the inside, centre and outside of each tyres and indicated that suspension geometry setup could utilise grip from the tyres more efficiently. A sweep for toe angle was conducted, with 0.19 degrees being the favourable value for the front wheels (increased from the default 0.17). A variation study for front and rear camber angles found the optimal values at -2.8 degrees at the front and -1.8 degrees at the rear.

Ride height had a powerful influence with lap time, and the lower this was, the better the aerodynamics performed, so this was decreased to a value at which the car behaved well, and where stiff (but realistic) springs were still able to prevent the car from bottoming out for too long without compromising driving characteristics negatively. The final ride height of 45mm (front) and 75mm (rear) means that the car is on the limit of scraping at terminal velocity, and will scrape for a short distance under braking.

Understeer was a predominant issue through the chicanes on the Mulsanne straight, and coarse optimisation for front/rear ARB’s gave ballpark figures for the range at which an optimised value can be found, after which, refined optimisation parameters discovered the best case scenario with a front ARB stiffness of 160N/mm and 85N/mm at the rear.

Brake bias was a value that was changed a few times based on the car setup updates relating to straight line speed. The default value was 57%, yet with the new setups that yield higher top speeds, the optimal brake bias shifted to 58.4%.

According to the regulations, there is a maximum allowable wheelbase of 3.15m, and some runs were tested with a few variations of slightly shorter wheelbases, however 3.15m was the best case. Despite the hints of performance improvements from a potentially longer wheelbase, the rules do not allow for it so the team is forced to stick with the value 3.15m.

Heave spring optimisation followed what we expected, that softer would be beneficial for lap time as this would effectively reduce the ride height under aerodynamic load. The default values were sufficiently stiff and the pitch of the car under braking was not an issue.

The braking zone into Indianapolis is rather tricky as it is both bumpy and the car is turning while braking. This resulted in most of the extreme scenarios happening here, the car would be bottoming out, a maximum roll angle of 2.4 degrees happened here and tyre temperatures would peak here.

2.3 Powertrain

The rules for Powertrain suggested to have a Hybrid Powertrain layout with the Engine and Electric motors working in conjunction. The layout used in the car is a 4-Wheel Drive setup in which the Electric motors power the Front Wheels and the Engine drives the rear wheels. Initially, 2019 engine configuration from the previous year was tuned to run for the 2020 Le-Mans Event.

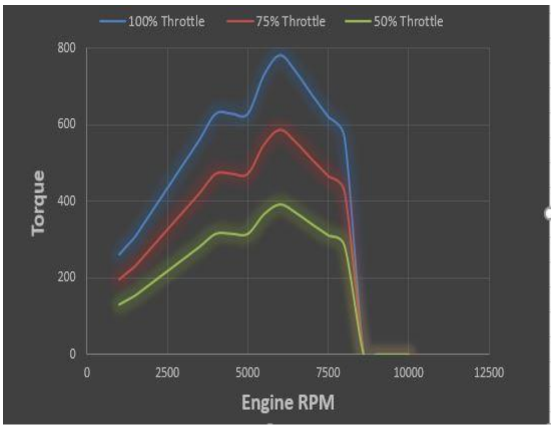
Fuel load, according to the new regulations were increased form 52.9 kgs to 90.7 kgs. This meant increase in weight. The overall vehicle weight was to be kept a minimum of 1040 kg excluding the driver and fuel weight. Engine needed to weigh a minimum of 180 Kg.

Engine power was increased to 508 kW (681 hP) according to the rules, engine power, was therefore increased but could not be increased to the limits because of fuel flow limitations.

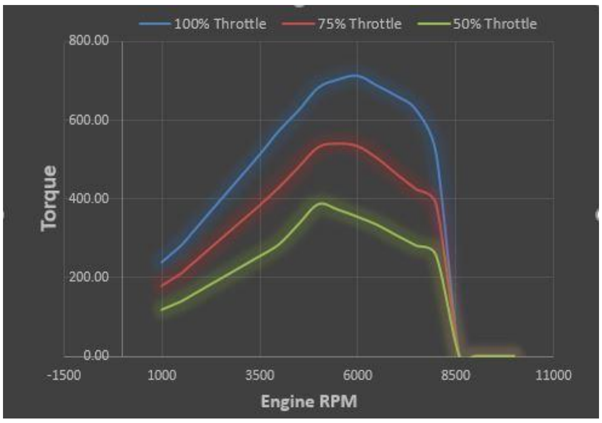
Torque map was found to be too sensitive and required immense driving skill to always run at the limits. The torque map was too peaky and contained a valley between 4500 and 5500 rpm, hence the map was tweaked to achieve a more linear and flatter torque curve. This allows the driver to have a predictable power output while overtaking at top speed.

The BSFC is also tuned for the new setup. This new configuration provided a reduced Fuel Consumption for the race. While fine tuning the engine, BSFC and Fuel Flow rate were given precedence over the power output and aggressive strategy was incorporated to have the minimum BSFC possible for the maximum available Fuel flow which resulted in the engine being around 15HP lower than what the rules allowed. Any further attempt to increase engine horsepower resulted in an increase in fuel flow, making the car illegal as per rules.

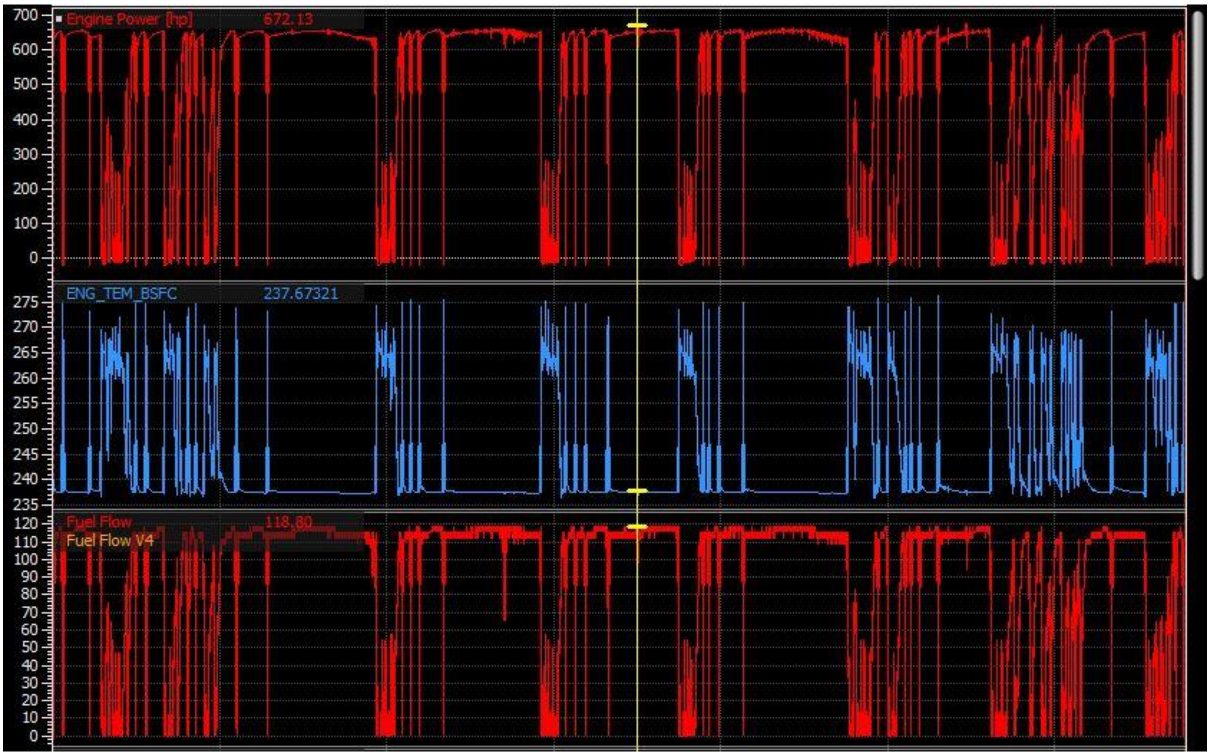
The ERS system had to adhere to rules as well. Maximum electric charge and discharge for the ERS system was limited to 200kW and energy released per lap was limited to 4905kJ. A different ERS strategy was also adopted for straight line, which is discussed in sections below.



Initial Legal Torque Map



Modified Torque Map



Engine Performance for Le-Mans on the Mulsanne Straight

Gearbox settings were altered to best suit our other modifications and the specific track. Multiple simulations were carried out by changing the final drive of the transmission, it was found that 16:42 and 17:41 were the two best ratios on this track. Final drive ratio of 17:41 was chosen based on the Energy recovery and top speed achieved on the straights.

Differential selected for the front and rear is Visco-Mechanical LSD which satisfies the rules and four sets of simulation containing 8 combinations in each set was carried out to obtain the best ramp angle.

It was noticed that a setup with greater emphasis on coasting ramps at the front and accelerating ramps at the rear, provided faster lap times. The differential from Extrac is simulated for various combinations of ramp angles provided and ramp angles of 45/85 at front and 75/30 at rear was found to be the optimum setup for the car in the current track. This setup also utilized the front tyres more effectively and boosted ERS regeneration during braking.

3.0 Straight Line Test Analysis

Simulations were done in order to analyse the straight line performance of the modelled vehicle. The DRS was changed to be fully open from start till the end in order to reduce the drag acting on the vehicle. Other than that, the ERS release map was modified to increase the acceleration till the final gear is achieved. Also, a boost was provided for the last 900 meters.

3.1 Straight Line 170 kph

A baseline lap time of 1:03:850 was achieved in a straight line acceleration run with maximum speed being 170 kph. After the above mentioned changes were made an improvement in the lap time was observed with the final lap time being 1:03:840.

ERS strategy is altered to achieve a faster time. While in the baseline, KERS recuperation occurs, in the faster run, strategy is adjusted as such that to use as much of the available energy from Energy Storage unit.The strategy employed is based on the distance along the track rather than duration of deployment of energy. It is assumed that the battery is fully charged before the run and no recuperation is needed.

3.2 Straight Line 250 kph

A final lap time of 0:44:460 was achieved compared to the baseline value of 0:44:550,when the changes were done to the DRS and the ERS strategy.
Since the only 500 kJ of Energy is released by the KERS unit during acceleration the strategy was similar to the one used in the above section is used to release an additional 400 kJ of energy during acceleration. The strategy employed is based on the distance along the track rather than duration of deployment of energy. It is assumed that the battery is fully charged before the run and no recuperation is needed.

3.3 Straight Line 3000m

The final lap time of 0:35:410 was achieved from a baseline of 0:44:540, when changes to the DRS and ERS control strategy were made.
A perfect balance of acceleration and top speed was required for straight line analysis.
For the straight line acceleration we need the vehicle to reach the final gear in the least amount time, without compromising the acceleration of the vehicle, ERS strategy is adjusted such that the release happens initially while going through the gears and for the last 900
meters. It is assumed that the battery is fully charged before the run and no recuperation is needed. The strategy employed is based on the distance along the track rather than duration of deployment of energy.

The top speed achieved in the event can be increased by changing the Final drive ratio to 18:39 and changing the control strategy of the ERS system, but due to the restrictions in rules this setup cannot be run.

When comparing the aerodynamic balance during each of the straight line simulations, it can be seen that the centre of pressure (CoP) moves rearward as the speed increases. The main reason for this is due to the design of the rear wing and diffuser of the LMP1 car. One reason is due to the relatively large surface area of the rear wing and diffuser. This will cause them to have a greater effect on the CoP at higher speeds, thus, moving the CoP rearwards at higher velocities.

4.0 Skid Pad Test Analysis

The skidpad analysis was run with the baseline vehicle model and a lap time of 0:17.150 was achieved.

The driver model was improved in order to achieve better lap times. The final lap time achieved came out to be 0:15.450s. The curvature based model had significant improvements on the skid pad with adjusted steering gain that was in fact decreased from 5% to 3%. This meant that the driver was better able to input a more correct steering response based on the curvature of the skid pad.

The roll angle of the baseline and the final setup were compared and a lesser roll angle on the baseline model was observed. A similar trend in the understeer oversteer characteristics was observed for both the cases.

For the first 75 meters on the track the mechanical balance of the vehicle appears to be less for the baseline but as soon as the vehicle stabilizes the mechanical balance is almost constant throughout the skidpad run and of the same magnitude for both baseline and final runs.

Inorder obtain better acceleration the ERS strategy has been changed so that the energy is deployed from the start based on the distance for the entire length of the track.

5.0 Tyre Performance Analysis

It was noticed that with the baseline tyre pressures (2 bar) the car was struggling to bring the tyres up to temperature and as a result was not operating in efficient conditions. This was dropped to a value at which the lap times started to converge, and then a variation study with the front/rear tyre pressures revealed the optimum values, 1.18 bar at the fronts, and 1.16 bar at the rears. The temperatures observed with these pressures is still seemingly low, with temperature high's within the range of 80-90°C, and a peak temperature of 110°C however no further lap time reductions came with further reduced pressures.

In cornering tyre saturation seems to be in the 80's which indicates that there should be more available grip from the tyres. It is not certain, yet we do estimate that the tyres are not working in the optimal range, and throughout the process of setting up the car, we have been struggling to bring the tyres up to temperature.

Another reason to believe that there is more grip in the tyres at higher temperatures than in the temperature range we are running at is that in the braking zone to Indianapolis, the tyre temperatures peak at 102°C, and the lateral G-force also peaks here at 2.41g.

6.0 Race Performance

A 24 hour race evaluation was created using a spreadsheet with the user input parameters being fuel used per lap and the lap time in race setup.

Without the ability to accurately model tyre wear, it is difficult to evaluate the change in lap times throughout a stint with the effect of varying fuel load and tyre wear without making major assumptions, thus, the lap times throughout each stint is estimated as constant as well as the fuel used per lap.

With a full tank of fuel, and the fuel per lap known, the amount of laps before the fuel runs out is determined, this is rounded down, and the output value is set to the pit in-lap where 65 seconds is added to represent full refueling and tyre changes. This process is assumed to repeat without interference from traffic and safety cars until the last pitstop is required.

For the last pitstop, a full tank of fuel is not required, but the assumed pitstop minimum time is estimated as half of the average pit stop time (65/2 seconds). Then the proportion of a full tank of fuel necessary to finish the race is multiplied by the other half of the average pit stop time (proportion x 65/2) and the total pit stop time is determined for the final pitstop.

The number of laps for the last stint is then determined based on the race pace lap times until 24 hours is reached, plus one lap. The number of laps per stint also depends on the amount of fuel left in the tank on the lap of the pit stop, such that if this value is less than 1.5 litres then the pitstop will occur on the previous lap.

After the last pit stop, the time taken for the whole race is known and the time left is calculated so that the amount of laps left can be estimated (time left/time per lap) and then 1 lap is added on top to ensure that the last lap occurs after the time has run out.
The spreadsheet screenshot below shows the process of evaluating the stint lengths, pit laps, final pit and stint strategy and finally an evaluation of the finishing time and total number of laps driven.

	A	B	C	D	E	F	G
1	Flying Lap Time (s)	200.39	User Input				
2	Circuit length (km)	13.626					
3	Amount of Fuel (kg)	90.7					
4	ACO Petrol Density (kg/Ltr)	0.756					
5	Amount of Fuel (Ltr)	119.973545					
6	Fuel per lap (Ltr)	4.8	User Input				
7	Number of laps unrounded	24.99448854					
8	Number of laps rounded down	24					
9	Number of laps capable with minimum 1.5 Litres reserve	24					
10	Time per stint (s)	4809.36					
11	Time per stint (min)	80.156					
12	Time per stint (hours)	1.335933333					
13	Pitstop Time (s)	65					
14	Pitstop Time (min)	1.083333333					
15	Stint + Pitstop Time (min)	81.23933333					
16	Stint + Pitstop Time (hours)	1.353988889					
17	Number of Stints Capable	17.72540395					
18	Number of Stints Rounded Down	17					
19	Last stint proportion	0.7254039505					
20	Time until last pitstop (hours)	22.99975556					
21	Final Pitstop time (s)	56.07562839					
22	Final Pitstop time (hours)	0.01557656344					
23	Last run time (hours)	0.984667881					
24	Last Run Laps	19					
25	Last Run Time (hours)	1.057613889					
26	Total Time (hours)	24.07294601					
27	Total Time	24	hours	4	minutes	23	seconds
28	Total Number of Laps	427					
29	Average speed (km/h)	241.6946392					

Race strategy for 24 hours - spreadsheet screenshot

This spreadsheet takes into account how much fuel is left when pitting and ensures that the value is at least 1.5 litres. If the value is below 1.5 litres, then the pit stop is set to occur on the previous lap.

The final time of the race is predicted to being 24 hours, 4 minutes and 23 seconds, after completing 427 laps with an average speed of 242.7km/h.