

All Electric World Time Attack challenger study

One of the last remaining bastions of technical innovations in motorsport is the Time Attack category. In most categories when an innovative technical solution is presented the first instinct of a regulatory body is to ban said technology. For all it's foibles Time attack, in particular World Time Attack challenge not only encourages technical innovation it embraces it with gusto! In that regard the formula is a positive breath of fresh air and God help our business if this is ever messed with.

However there is one subject that strangely has been very quiet on the Time Attack radar and this is the subject of electric power trains. This is particularly apparent in the World Time attack challenge event. A lot of this is due to the street drag racing/tuner origin of Time Attack. Another aspect has been the technology has not been mature enough. With the emergence of Formula E the latter concern has been dealt with so the question needs to be asked is an all electric time attack challenge contender viable and what would it look like?

Firstly this article will focus our attention on World Time attack challenge that is held at Eastern Creek in October each year in Australia. In particular I'll be focusing our attention on the Open class category. For the last couple of years I've been engineering one of the front runners in this class and not meaning to sound self serving I might now say a thing or two about the cars and what is required!

Before we begin this discussion is an electric power train legal. It's a legitimate question that needs to be asked. In the Open class regulations the section 5.4 section is most enlightening – "Engine modifications are free save for the engine must be based on a production engine from a recognised vehicle manufacturer." Given that Tesla is a vehicle motor manufacturer and it's highly likely they are using a derivative of the Remy HVH 250 motor we should be in the clear. Where things could get a little dicey is "Each vehicle must use a commercial fuel, E85 or unleaded racing fuel in accordance with Schedule G of the CAMS Manual". Technically this could be used to ban an electric vehicle. However what is obvious though is the use of an in production electric motor is within the spirit of the regulations so let's continue the case study.

In order so that we have a frame of reference let's outline some parameters so we have a frame of reference for this. Our base car will be a Lotus Elise. We are choosing the Elise because of its light weight and it gives us considerable weight margin to exploit. The other parameters we will be using is outlined in Table 1,

Table 1 – Parameters for an all electric WTAC vehicle

Parameter	Value/Description
Car	Lotus Elise/Exige
Mass	870 kg/IC , 1000 kg electric
Engine	Remy HVH 250
Power	300 kW @ 8000 rpm
Target Voltage	700 V
C _L A	3
C _D A	1.2

As discussed previously the Remy HVH 250 motor is being used because of its wide availability. Also while Tesla will remain very tight lipped about this given the peak power of a Tesla Model S rear wheel drive is 285 kW you don't need to be a rocket scientist to figure out that Tesla are either using a Remy motor or a close derivative of it. The mass of 870 kg for the IC (Internal combustion) Lotus was used to get us in the ball park. I realise this is heavier then a stock Elise but I'm simulating a worst case scenario. We are modelling a mass of 1000 kg for the electric version. We'll discuss the significance of this later. Lastly in order to be competitive in open class you need to be running a C_LA of about 3. The $C_D A$ has been the appropriately level of drag that goes with this.

The first thing we need to do is to run an internal combustion simulation of an Elise at Eastern Creek at 300 kW so we can size the battery pack we need. The lap time simulated was 84.7s. While this is highly optimistic we did this to get a worst case scenario to see how long you'll be on power for. The break down of lap is summarised in Table 2,

Table 2: Parameters for the Elise lap at Eastern Creek

Lap Segment	Time
Full throttle	48.9s
Part throttle	20s
Full brakes	14.1s

There is a slight discrepancy due to transient braking. However this will get us in the ball park. So our working voltage from Table 1 is 700 V. Consequently for the lap our current draw and Ah consumed for the lap will be,

$$\begin{aligned} I_D &= \frac{P}{V} \\ &= \frac{285 \times 10^3 W}{700 V} \\ &= 407 A \end{aligned} \quad (1)$$

$$\begin{aligned} Ah_{DISC} &= 407 \cdot \frac{58.9}{3600} \\ &= 6.67 Ah \end{aligned}$$

Not the 58.9s figure came from 48.9s at full throttle and approximating the part throttle of 20s at 50%. Let's suppose in Regen we have a max harvest of 150 kW. It is seen,

$$\begin{aligned}
 I_c &= \frac{P}{V} \\
 &= \frac{150 \times 10^3 W}{700V} \\
 &= 214 A
 \end{aligned}
 \tag{2}$$

$$\begin{aligned}
 Ah_{DISC} &= 214 \cdot \frac{14.1}{3600} \\
 &= 0.84 Ah
 \end{aligned}$$

So the total current used in the lap will be,

$$\begin{aligned}
 Ah_{TOT} &= Ah_{DISC} - Ah_{TOT} \\
 &= 5.9 Ah
 \end{aligned}
 \tag{3}$$

So for a flying lap we'll be using 5.9 Ah of battery capacity. What makes WTAC unique is that you get 15 minute sessions. So typically it's an out lap, a flyer and an in lap. So as a rough rule of thumb if on the in and out lap you are using 50% battery capacity each run will set you back 12 Ah and you have to budget for at least 2 runs. So all in all you'll need 24 Ah of capacity. However we don't want to run this down to 0 so we'll need a bit in reserve, say about 40% This will also cover us if we need to double stint on a session. So let's set the pack capacity to 38 Ah.

The question that needs to be asked is what cells shall we use? Remember in my previous articles on electric vehicles that when it comes to cells C rating in both discharge and charge is king. Since we want to maximise our effectiveness we'll choose the Thunder Power Rampage cells. The cell specifications are set below,

Table 3 – ThunderPower Rampage Cell specifications

Parameter	Value
Capacity	3.8Ah
Charge Rating	12 C
Discharge Rating	70 C
Cell mass	0.1 kg
Cell dimensions	8mm x 22mm x 138mm
Price	USD \$30

The big attractiveness of the rampage cell is its C rating in charge. With electric vehicles it is key to harvest all available brake energy. So in terms of what we need from the pack let's say we have a working cell voltage of 3.5V and we need a capacity of 38 Ah. The pack configuration is given below,

$$\begin{aligned} PackConfig &= \frac{700V}{3.5V} S \times \frac{38Ah}{3.8Ah} P \\ &= 200S \times 10P \end{aligned}$$

Bottom line we need 200 Cells in series and 10 cells in parallel.

To refine our choice we put the electrical vehicle parameters into ChassisSim to refine the choice of battery pack. The resultant lap time was 85.9s lap and the relevant parameters are shown in Fig 1,

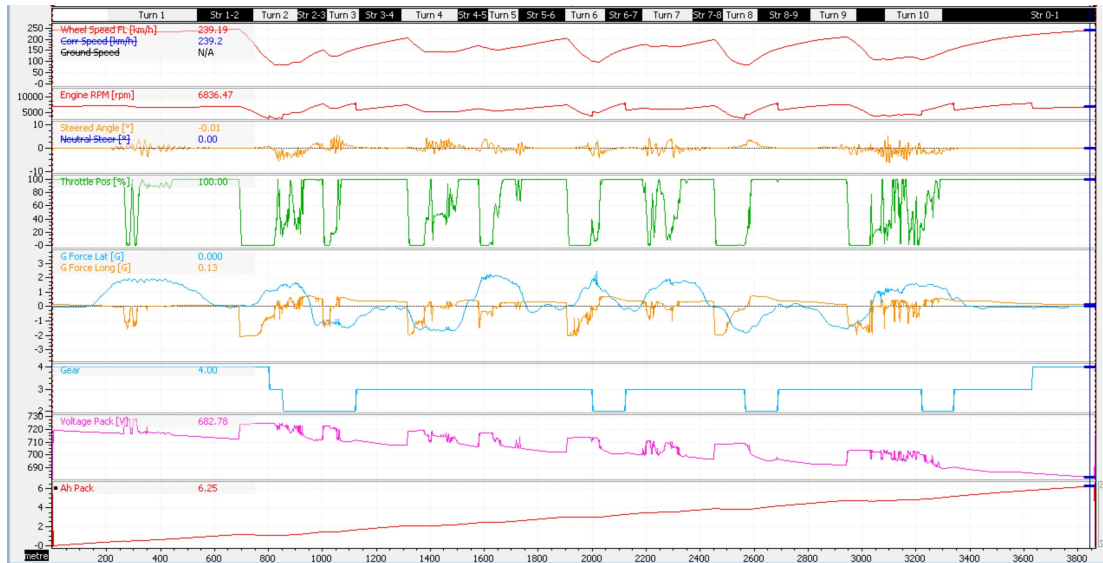


Fig-1 : Electric vehicle parameters.

Two interesting things came out of this analysis. Firstly the discharge estimate of 5.9 Ah was confirmed at 6.25 Ah. Also we could get away with a lower cell count in series. The final pack configuration was confirmed at 170S and 10 P.

Armed with all this information we can now do a mass budget for the electric power train. Firstly for the mass budget we require 170 x 10 cells so 1700 cells in total or 170 kg of cells. The mass budget is outlined in Table 4,

Table 4 – Electric power train mass budget

Item	Total (kg)
Batteries + protective casing	170 + 30 = 200
Remy Motor	57 kg
Electronic Speed Control	10kg
TOTAL	267 kg

Before you all balk at the mass budget just remember a Toyota 2ZZ-GE for an Elise weighs in 120 kg with fluids. By the time you put on an intercooler and turbo to get to 285 kW you'd be looking at 135kg in total. By the time you fuel that is another 15kg. So the net weight penalty here is 110 kg so

while not ideal this is not a show stopper. Note I didn't take cooling into account because whether you are dealing with an IC engine or electric engine you'll need a radiator system anyway.

However where you pay for the electric engine is in price. The cost budget and final price for an electric power train is shown below,

Table 5 – Electric power train cost budget

Item	Total (US Dollars)
Batteries	1700 x 30 = \$51000
Remy Motor	\$10000
Electronic Speed Control	\$5000
Ancillaries	\$5000
TOTAL	\$71000

In contrast a 4 cylinder internal combustion engine brought up to the 300 kW power rating will set the end user back AUD \$30000 or USD \$24000. Clearly this is a significant cost deficit that deleteriously affects the electric power train. However this can be managed in both cost and end weight but we'll discuss this shortly.

So the next question that needs to be asked is which is quicker, the internal combustion engine or its electric equivalent. To resolve this question 135kg was taken off the electric vehicle weight and run back to back in ChassisSim. I should also add where we assuming a very small fuel load. The results are shown in Table 6 and the overlay is presented in Fig -2

Table 6 – Lap time analysis ICE vs Electric

Item	Lap time (s)
Internal combustion	84.72s
Electric	85.9s

Ultimately were the electric engine lost to its internal combustion counterpart was its increased weight and this analysis is illustrated overleaf in Fig-2. The internal combustion car is coloured and the electric car is black. As can be seen the electric car very much pays for its weight in cornering speed and this is all too obvious in the first trace which is speed and the average difference is 4 km/h. However what is most interesting is despite this handicap, down the straight the electric car is up 1 – 2 km/hr. This is due to the flat torque you get from an electric engine.

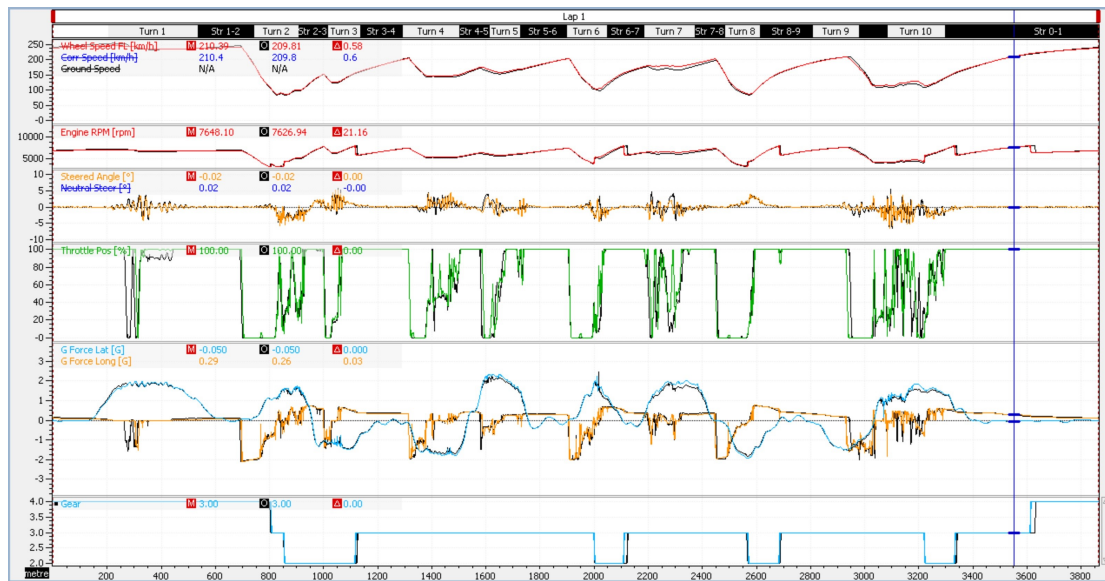


Fig-2 A comparison of an internal combustion car vs an electric car

There is no doubt that right now that the advantage is to the internal combustion engine. The electric engine would give a competitive showing. In 2017 the winning open class time was a 1:27s lap so the electric power train certainly wouldn't disgrace itself. However as straight bolt in option the electric power train would struggle against an internal combustion equivalent. However there is a big but about this matter that we'll discuss shortly.

However there are two key areas where an electric engine offers two huge advantages. Firstly an electric engine offers a completely flat torque curve vs RPM. Consequently it can take off like the proverbial bat out of hell. Also if you run an electric engine within its power and load specifications and if you run a battery pack within its charge and discharge limits they will last forever with zero maintenance. Since World Time attack challenge is predominantly run by small teams this has ongoing saving implications particular if the car is campaigned over a number of years.

One thing that hasn't been stated is the design optimisation that can be done with an electric vehicle. One huge advantage that an electric engine brings to the party is its lack of vibration. Consequently the structural safety factors that you need for an internal combustion engine aren't as critical for an electric power train. Here we have much to learn from the Radio controlled aircraft community. Earlier this year, Extreme Flight a premier manufacturer of high performance aerobatic aircraft released an all electric 95" wingspan unlimited aerobatic aircraft. Since it was designed as an electric aircraft significant savings could be made on the empty weight (in the order of 1 kg). Consequently it's all up flying weight is equivalent to its IC counterparts.

Also continuing on this theme particular with the Elise there is a lot to be gained using the all carbon Elise chassis designed by my UK Dealer Pilbeam racing designs. I don't just say this because Mike and I go way back. The structural and weight advantages offered by the Pilbeam Elise chassis speak for themselves. Also at a cost of 25000 pounds it is outstanding value for money. While strictly speaking this is against the letter of the law of the World Time Attack challenge regulations they are within the spirit of them. What the combination of the carbon chassis and electric power

train does is it enables the WTAC competitor to effectively not have to worry about the chassis and power train and they can focus on the aero and suspension elements of the car.

In terms of where the cross over point is between electric and IC on this analysis it was found the electric weight was 930kg. A number of simulation analysis was run and at 930kg the cornering disadvantages of the increased weight was offset by the superior traction the electric engine offered.

However it would be foolish not to play the devil's advocate. What this analysis has shown is the Achilles heel of an electric power train is its cost and energy density. Even though time attack is a sprint event we still need a battery pack that weighs 200kg. Not to acknowledge this would be borderline delusional. Ditto with the cost of the pack however we are using the Rolls Royce of Lithium Polymer cells so this is a worst case scenario. The other unknown is how CAMS (Confederation of Australian Motorsport), the Australian division of the FIA will react. This is a huge unknown and would affect the car's ability to pass scrutineering.

The other thing to mention is what an electric power train needs. First things first a true crunch point is the radiator design for the battery pack. The radiator to a battery pack is the IC equivalent to having a good coolant system for the engine. You ignore both at your peril. Also if you want to charge the car battery pack at a 1C charge so it can be charged in an hour your going to need a power source that can handle 27kW. This is the equivalent of having ten power points in series with one another. That could present a very serious problem at the race track.

One thing that needs to be discussed is electric power suitable for the Pro-Am and Pro classes. The answer is hell no. The Pro-Am and Pro classes run downforce levels well in excess of DTM cars. That is C_L/A numbers well in excess of 7. Consequently the drag goes up and we are talking peak C_D/A in the order of at least 1.6. Consequently these cars need to produce engine power of at least 500 kW plus. In this case the pack capacity doubles (since you need two motors) and you are talking a battery pack weight of 400kg! There is no way you are going to make up for a weight deficit of 250- 300kg. Also due to its small wheelbase the Elise platform would be hard pressed to make those aero numbers so the discussion is a moot point.

In closing not only is an electric power train viable for Time Attack it can be competitive in the open class. This analysis showed that combined with a Lotus Elise chassis an electric power train offers key advantages in maintenance and packaging. In particular large gains can be made by capitalising on the advantages that can be presented by designing around an exclusive electric power train. However there are risks and not to acknowledge these would be foolish. In particular energy density for an electric power train is still marginal. This is the reason it is not suitable for the Pro-Am and Pro classes. Also charging the battery pack is something that could be a problem and the reaction of event officials is a huge unknown. What will be interesting is to see what happens when someone tries this. This might very well be a matter of when not if.