

University of Wales Trinity Saint David

School of Engineering

Real World Analysis

Powertrain and Sustainability

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Ryan James 0751093

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Contents

1	Introduction.....	1
1.1	Aims.....	1
1.2	Objectives	1
2	Part 1 Assessing the Data.....	2
2.1	Issues with DATA.....	2
2.1.1	Data was taken without vehicle moving.....	2
2.1.2	Delta time step	2
2.2	Calculate Distance.....	3
2.3	Align Data	3
2.4	Creating the return Journey.....	4
2.5	GPS Data.....	5
2.6	Calculating the angle	7
2.7	Speed and Acceleration	8
3	Part 2 Comparing Vehicle Types	11
3.1	Constants and MATLAB nomenclature.....	11
3.2	Volumetric Efficiency	11
3.3	Air Density	12
3.3.1	Altitude and density over 60km.....	13
3.4	Drag.....	13
3.5	Lift	13
3.6	Rolling resistance	14
3.7	Total Resistance	14
3.7.1	Resistance Results graphs	14
3.8	Force Required	15
3.8.1	Gear ratio.....	15
3.8.2	Equivalent mass.....	16
3.8.3	Acceleration Force	17

3.8.4	Force Required	17
3.9	Wheel torque.....	18
3.9.1	Wheel torque and available grip	19
3.10	Power	19
3.10.1	Power graph.....	19
3.11	Energy.....	21
3.11.1	Accumulative drive cycle energy Graphs.....	22
3.11.2	Efficiencies.....	22
4	Part 3 Technology for Drive Cycle	24
4.1	The cycle	24
4.2	Technologies to consider.....	24
4.3	Stop Start	24
4.4	Capacitor KERS	25
4.4.1	Super Capacitors	25
4.4.2	Motor efficiencies.....	26
4.4.3	Electric motor efficiency	26
4.4.4	Efficiency per meter	27
4.4.5	Calculating Capacitor Level and energy saved	27
4.4.6	Capacitor selection	28
4.4.7	Capacitor KERS Comparison.....	30
4.4.8	Graph showing limits of 1 capacitor	31
4.5	EV with Capacitor and NMC Battery.....	31
4.5.1	Lithium battery technology.....	31
4.5.2	Battery pack	32
4.5.3	Adding modules to battery	33
4.5.4	Battery level	33
4.5.5	Battery and Capacitor Levels	34

4.6	Flywheels, Fuel Cells, Range extenders, Pneumatic, alternative fuels, and downsizing.....	35
4.6.1	Alternative Fuels.....	35
4.6.2	Hydrogen Fuel Cells.....	36
4.6.3	How Membrane type works	37
4.6.4	Range Extenders and downsizing.....	38
4.6.5	Flywheel KERS	38
4.6.6	Pneumatic KERS.....	38
5	Part 4 Specification	40
5.1	Political policies and criteria.....	40
5.2	Decision Matrixes	40
5.2.1	Decision Matrix overall	41
5.2.2	Decision matrix without political and tail pipe	41
5.2.3	Decision matrix without costs and political.....	42
5.2.4	Specification to Pursue.....	42
6	Conclusion	43
7	References.....	44
8	Appendices.....	45
8.1	Maxwell capacitors	45
8.1.1	Yasa Motors.....	48

1 Introduction

Vehicle efficiency and emissions are currently checked on rolling road drive cycles to decide their tax group and manufactures liabilities with respect to environmental impact. These are not a true representation of real-world driving conditions. To gain a better understanding of a vehicle's behaviour a real-world drive cycle has been provided.

1.1 Aims

- To interpret data and assess the vehicle requirements needed to complete a real world a drive cycle.
- Compare different vehicles across the said drive cycle.
- Explore alternative powertrains.

1.2 Objectives

The following steps must be taken to evaluate the drive cycle checking and calculating the following:

- The validity of data given.
- The elevation and distance travelled (see effect gradient has on force required).
- Speeds and accelerations.
- Power Requirements
- Fuel Consumption
- Efficiencies

2 Part 1 Assessing the Data

The Data Given was split into 3 main groups

	AUX	SAE	CALC
Source	Phone	OBD	Calculated by app
uses	GPS Motion Sensor	Vehicle Sensor Vehicle ECU calculation	AUX and OBD User Constants
Pros	Only Source containing that information	Live Sensor outputs	Makes for quick comparisons
Cons	Doesn't account for phone position (e.g. bike)	Only as reliable as the sensors	Unknown calculations not trustable

2.1 Issues with DATA

2.1.1 Data was taken without vehicle moving

In order to better align data, the start points were all cropped to when the vehicle started moving (the Tiger shed to road was also removed) with the following script.

```
%% 1 remove all Rows before results from VSS gets rid of all pre obd data and gps
T_Data_r(any(isnan(T_Data_r(:,38)), 2), :) = [];
A_Data_r(any(isnan(A_Data_r(:,38)), 2), :) = [];
V_Data_r(any(isnan(V_Data_r(:,38)), 2), :) = [];

T_Data_r(any(isnan(T_Data_r(:,14)), 2), :) = [];
A_Data_r(any(isnan(A_Data_r(:,14)), 2), :) = [];
V_Data_r(any(isnan(V_Data_r(:,14)), 2), :) = [];

T_Data_r(any(isnan(T_Data_r(:,16)), 2), :) = [];
A_Data_r(any(isnan(A_Data_r(:,16)), 2), :) = [];
V_Data_r(any(isnan(V_Data_r(:,16)), 2), :) = [];
```

2.1.2 Delta time step

C	D	E
Time (ms)	Frame Time (delta)	AUX.ACCEL.FORWARD
Time (ms)	Frame Time (delta)	Forward Acceleration
56	56	
1	-55	
225	224	

Figure 1 Negative time step

Figure 1 shows the time frame going back in time for the Aygo. As the frame number was sequential but the time was not the frames I.E. entire rows with a negative timestep were deleted with the following script.

```
%% 2 remove all Rows Where the time step is negative and re calculates time step losses_r for raw

noneg_A = all((A_Data_r(:,4))>0,2);
A_Data = A_Data_r(noneg_A,:);
A_Data(2:end,4) = diff(A_Data(:,3));
noneg_A = all((A_Data(:,4))>0,2);
A_Data = A_Data(noneg_A,:);
A_Data(2:end,4) = diff(A_Data(:,3));

noneg_V = all((V_Data_r(:,4))>0,2);
V_Data = V_Data_r(noneg_V,:);
V_Data(2:end,4) = diff(V_Data(:,3));
noneg_V = all((V_Data(:,4))>0,2);
V_Data = V_Data(noneg_V,:);
V_Data(2:end,4) = diff(V_Data(:,3));

noneg_T = all((T_Data_r(:,4))>0,2);
T_Data = T_Data_r(noneg_T,:);
T_Data(2:end,4) = diff(T_Data(:,3));
noneg_T = all((T_Data(:,4))>0,2);
T_Data = T_Data(noneg_T,:);
T_Data(2:end,4) = diff(T_Data(:,3));
```

2.2 Calculate Distance.

To compare the vehicles the accumulative distance per frame was calculated with the following script replacing 'Not A Number' cells with zero.

```
%% 4 distance per cell VSS
% make any nans = zero for further calculations
A_Data(isnan(A_Data))=0;
V_Data(isnan(V_Data))=0;
T_Data(isnan(T_Data))=0;

% calculates meters travelled accumulative per cell
A_m_VSS = cumsum((((A_Data(:,4))/3.6e6)).*(A_Data(:,38)))/1e-3;%, 'omitnan')/1e-3;
V_m_VSS = cumsum((((V_Data(:,4))/3.6e6)).*(V_Data(:,38)))/1e-3;%, 'omitnan')/1e-3;
T_m_VSS = cumsum((((T_Data(:,4))/3.6e6)).*(T_Data(:,38)))/1e-3;%, 'omitnan')/1e-
```

This illustrates that it was done with vehicle speed sensor and was also done with GPS speed. This showed the inaccuracy of the data, as all three had travelled the same distance, but from the calculations (3 from speeds sensor and 3 from GPS) the results differ. This demonstrates that although all had different distances, these only amounted to a 1% variation at most.

2.3 Align Data

The data came with frame number being the main source of alignment. This gave the following difficulties:

- The time steps were all different lengths
- The vehicles took different amounts of time for the cycle, as velocities varied per vehicle.
- Each vehicle had a different number of time frames
- Negative time frames had been deleted.

As each vehicle travelled the same distance theoretically, this was chosen as the constant to plot all data against. The brief asks for a 60km round trip and, as some results were under and, others over 30km for the one-way trip, all the results were interpolated to 30km at a 1-meter interval using the following script.

```
%% 5 interp all data per m
% Aygo
dist_m = (0:(3e4-1));%max(A_m_VSS)'; % vector of distance travelled accumulative per 1 meter

A_Data_i=zeros(3e4,189); % matrix for results
for i = (1:189)
    Aygo_int(:,1) = (A_Data(:,i)); % puts data to be interpolated into variable
    [A_m_VSSx, index] = unique(A_m_VSS); % finds the points where the vehicle moves and the distance moved at the point
    A_Data_i(:,i) = interp1(A_m_VSSx,Aygo_int(index),dist_m,'pchip');% interpolates all colums by the 1 meter distance
end

% Volvo
dist_m = (0:(3e4-1));%max(V_m_VSS)'; % vector of distance travelled accumulative per 1 meter
V_Data_i=zeros(3e4,187); % matrix for results
for i = (1:187)
    Volvo_int(:,1) = (V_Data(:,i)); % puts data to be interpolated into variable
    [V_m_VSSx, index] = unique(V_m_VSS); % finds the points where the vehicle moves and the distance moved at the point
    V_Data_i(:,i) = interp1(V_m_VSSx,Volvo_int(index),dist_m,'pchip');% interpolates all colums by the 1 meter distance
end

% Tiger
dist_m = (0:(3e4-1));%max(T_m_VSS)'; % vector of distance travelled accumulative per 1 meter
T_Data_i=zeros(3e4,193); % matrix for results
for i = (1:193)
    Tiger_int(:,1) = (T_Data(:,i)); % puts data to be interpolated into variable
    [T_m_VSSx, index] = unique(T_m_VSS); % finds the points where the vehicle moves and the distance moved at the point
    T_Data_i(:,i) = interp1(T_m_VSSx,Tiger_int(index),dist_m,'pchip');% interpolates all colums by the 1 meter distance
end
```

This increased the matrix sizes while keeping the original points where applicable. It also made comparisons between vehicles easier as they all now had 30,000 rows.

The vehicle speed data was used to calculate the distance travelled as it had the least noise even though using the phone GPS would have provided the same source each time.

2.4 Creating the return Journey

Doubling the results would not suffice as the altitude change was the opposite on the return. To calculate the return all the data was flipped and stitched on at the end. This created the reverse inclines necessary to calculate the route but, in places, it would not have realistic speeds as it would be an identical speed to the outbound journey at the same point. This was the best option, even though it would say the vehicles would do the

same speed on hills in each direction, as limiting the acceleration due to incline would mismatch the engine data further.

The return was calculated with the following script:

```
%% There and Back Again by G.O.Williams
dist_m = (0:(max(dist_m)*2)+1)';

V_Data_i(1,4)=0;
V_Data_i(2:end,4) = diff(V_Data_i(:,3));

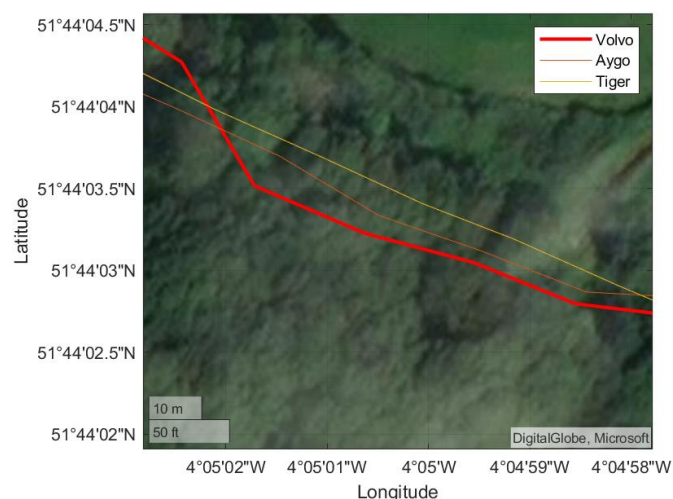
A_Data_i(1,4)=0;
A_Data_i(2:end,4) = diff(A_Data_i(:,3));

T_Data_i(1,4)=0;
T_Data_i(2:end,4) = diff(T_Data_i(:,3));

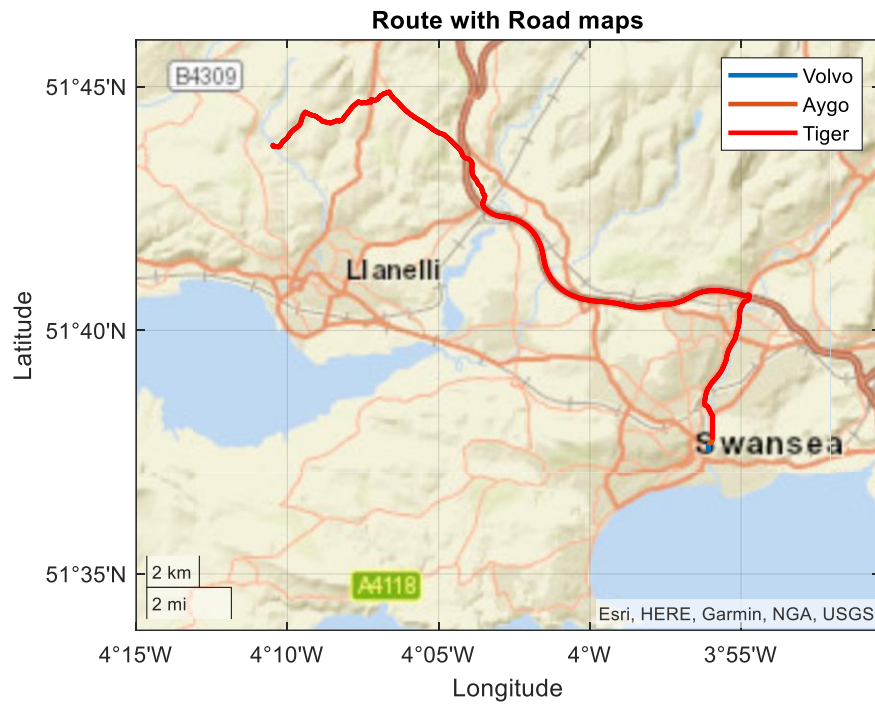
%% turn 30KM too work to 60Km commute
% DONT RUN SECTION REPETATIVLY WILL KEEP DOUBLING
A_Data_i=[A_Data_i; (flip(A_Data_i))];
V_Data_i=[V_Data_i; (flip(V_Data_i))];
T_Data_i=[T_Data_i; (flip(T_Data_i))];
```

2.5 GPS Data

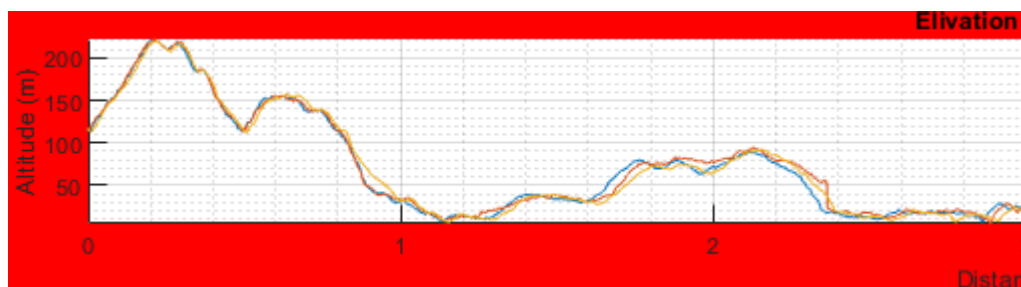
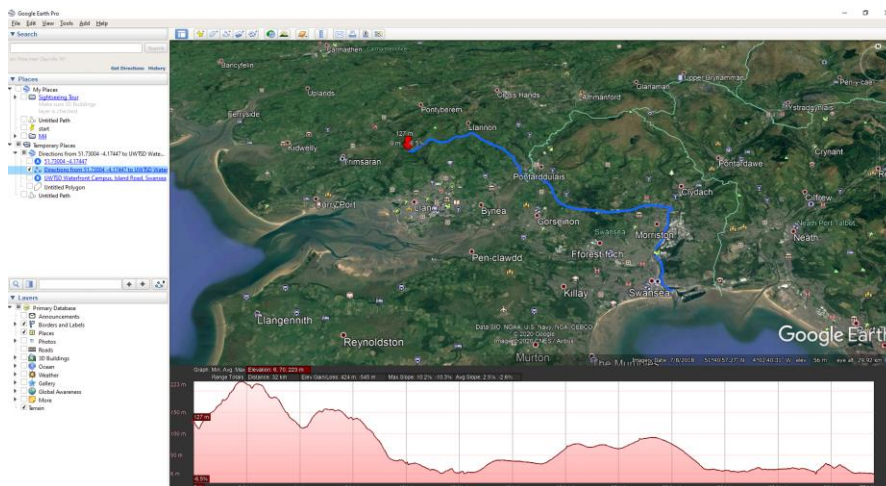
Route Data was obtained from google earth and the actual routes were put into google earth. This showed the vehicles moving “off road” especially around bridges and underpasses.



The data was also put into matlabs map toolbox.



The data elevation profile from the AUX channels correlates to Google Earth's.



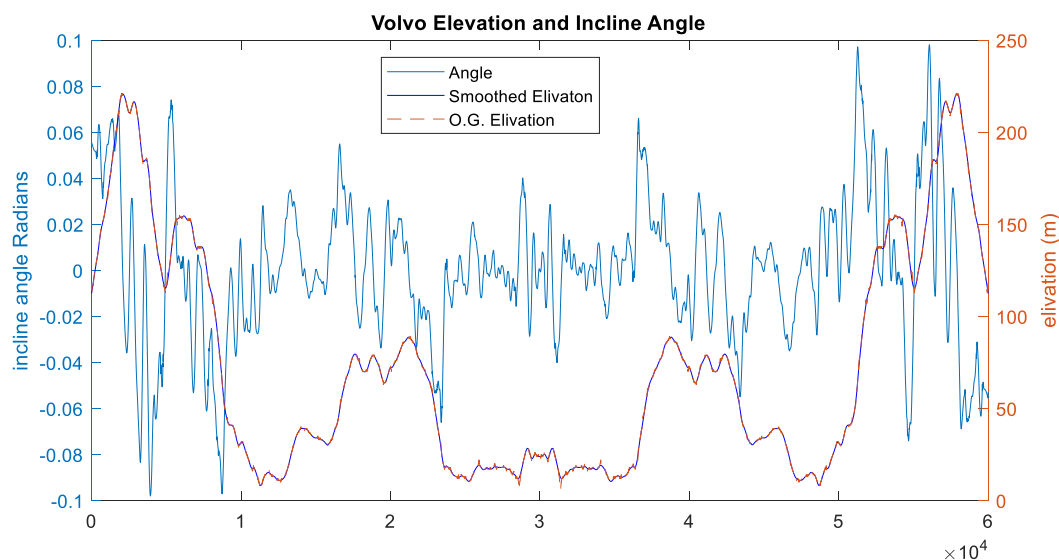
2.6 Calculating the angle

This shows when interpolated to the same distance the elevation matches well. The angle of the slope was calculated to be near 90 degrees this obvious error was due to noise in the elevation data.

The data was smoothed with the following script.

```
%% smoothing elevation
A_El_s =smooth(dist_m,A_El,0.02,'rloess');
V_El_s =smooth(dist_m,V_El,0.01,'rloess');
T_El_s =smooth(dist_m,T_El,0.01,'rloess');
```

This gave the following results.



Results

	Aygo	Volvo	Tiger
Max % Slope	8.5685	9.8342	9.3324
Min Altitude (m)	10.3404	8.1778	7.3152
Max Altitude (m)	220.0119	220.8390	218.9971
Altitude Change (m)	209.6715	212.6612	211.6818

The above figure shows for the full 60km route. The smoothed data kept the same altitude change and gave a similar maximum percentage incline to Google's 10%. The

angle graph shows that, for the return, the incline flips i.e. positive to negative. This is important for calculating the driving force.

The following was used to calculate the angle:

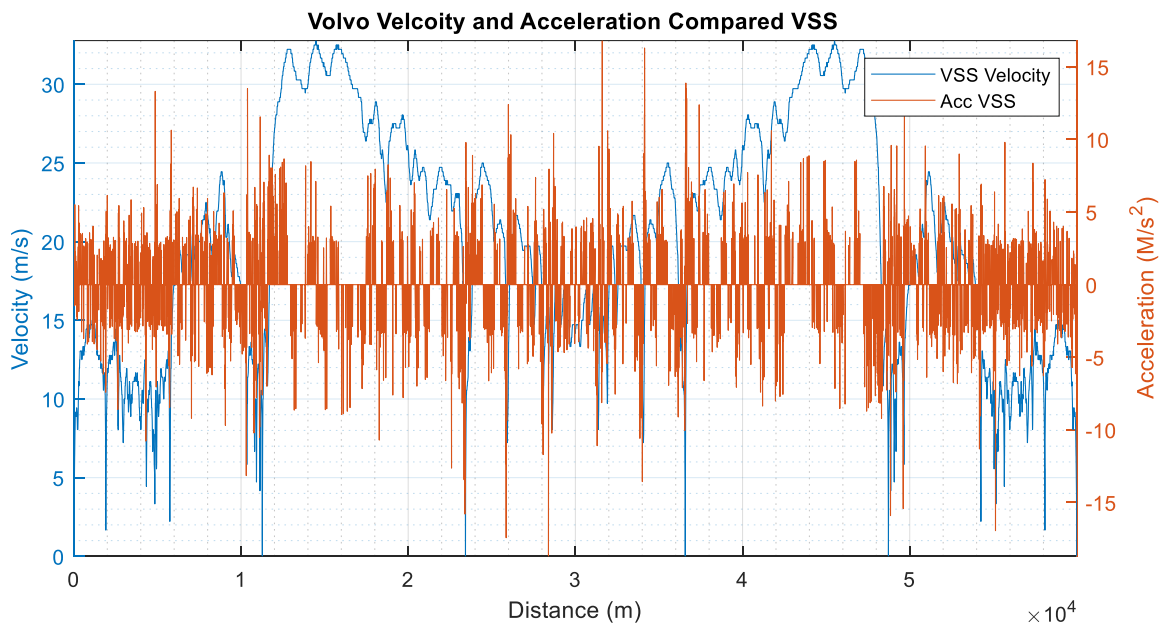
```
%% Calculating angle radians
ang_A = atan((diff(A_El_s))./l);
ang_V = atan((diff(V_El_s))./l);
ang_T = atan((diff(T_El_s))./l);

ang_A(end+1) = ang_A(end);

ang_V(end+1) = ang_A(end);
ang_T(end+1) = ang_A(end);
```

2.7 Speed and Acceleration

The vehicle speed was used to calculate the acceleration. The speed sensor and GPS speed were used and they both gave accelerations which were too high. This is due to the noise in the velocity



Results

	Aygo	Volvo	Tiger
Max acceleration m/s^2	Inf	Inf	Inf
Max deceleration m/s^2	-17.8044	-18.7107	-52.2375
Max Velocity m/s	31.1111	32.7778	33.0556
Average Velocity m/s	20.7623	20.2845	20.0638

The VSS gave the best results but still unrealistic, giving an impressive but useless +5Gs of deceleration on the Tiger and infinite acceleration on all vehicles.

The acceleration was smoothed and recalculated with the following:

```
%% Acceleration
A_KPH_VSS(A_KPH_VSS<3.24)=0;
A_ms_sVSS=(smooth(dist_m, (A_KPH_VSS/3.6), 0.003, 'loess'));%-5.5;

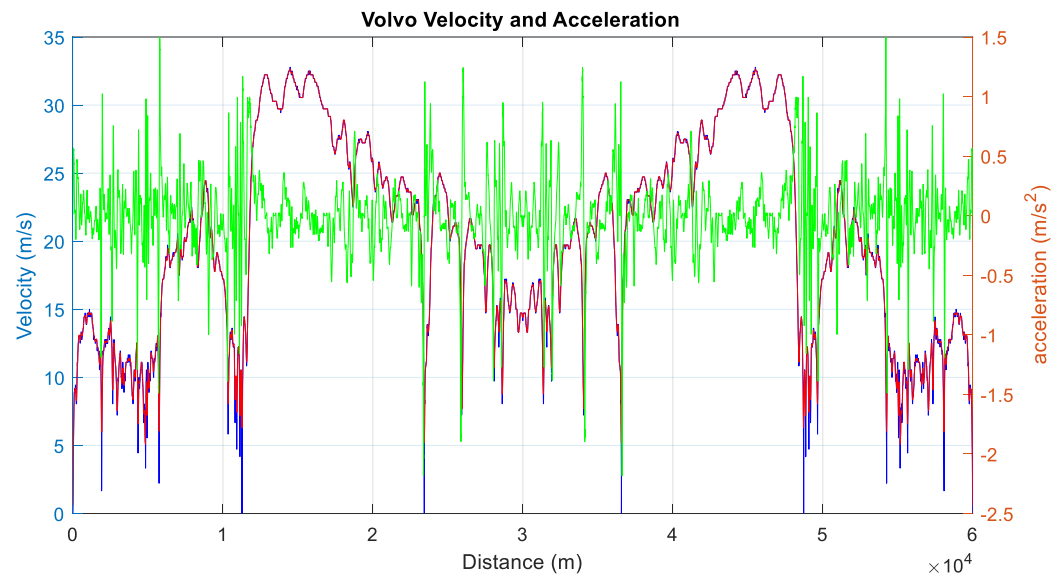
A_sacc_VSS = (diff(A_ms_sVSS))./(diff(A_Data_i(:,3))/1e3);
A_sacc_VSS(end+1)=0;
A_sacc_VSS(~isfinite(A_sacc_VSS)) = 0;

V_KPH_VSS(V_KPH_VSS<3.24)=0;
V_ms_sVSS=smooth(dist_m, (V_KPH_VSS/3.6), 0.003, 'loess');
V_sacc_VSS = (diff(V_ms_sVSS))./(diff(V_Data_i(:,3))/1e3);
V_sacc_VSS(end+1)=0;
V_sacc_VSS(~isfinite(V_sacc_VSS)) = 0;

T_KPH_VSS(T_KPH_VSS<3.24)=0;
T_ms_sVSS=smooth(dist_m, (T_KPH_VSS/3.6), 0.003, 'loess');

T_sacc_VSS = (diff(T_ms_sVSS))./(diff(T_Data_i(:,3))/1e3);
T_sacc_VSS(end+1)=0;
T_sacc_VSS(~isfinite(T_sacc_VSS)) = 0;
```

This was a 0.3% smooth which kept most of the fidelity giving the following results:



Results

	Aygo	Volvo	Tiger
Original Max acceleration m/s^2	Inf	Inf	Inf
Original Max deceleration m/s^2	-17.8044	-18.7107	-52.2375
Original Max Velocity m/s	31.1111	32.7778	33.0556
Original Average Velocity m/s	20.7623	20.2845	20.0638
-	0	0	0
Smooth Max acceleration m/s^2	1.3809	1.4961	3.5781
Smooth Max deceleration m/s^2	-1.9679	-2.1826	-2.2157
Smooth Max Velocity m/s	31.1381	32.6534	32.8735
Smooth Average Velocity m/s	20.7620	20.2845	20.0643

The results give a better representation of the acceleration and therefore, will give better force results.

3 Part 2 Comparing Vehicle Types

3.1 Constants and MATLAB nomenclature

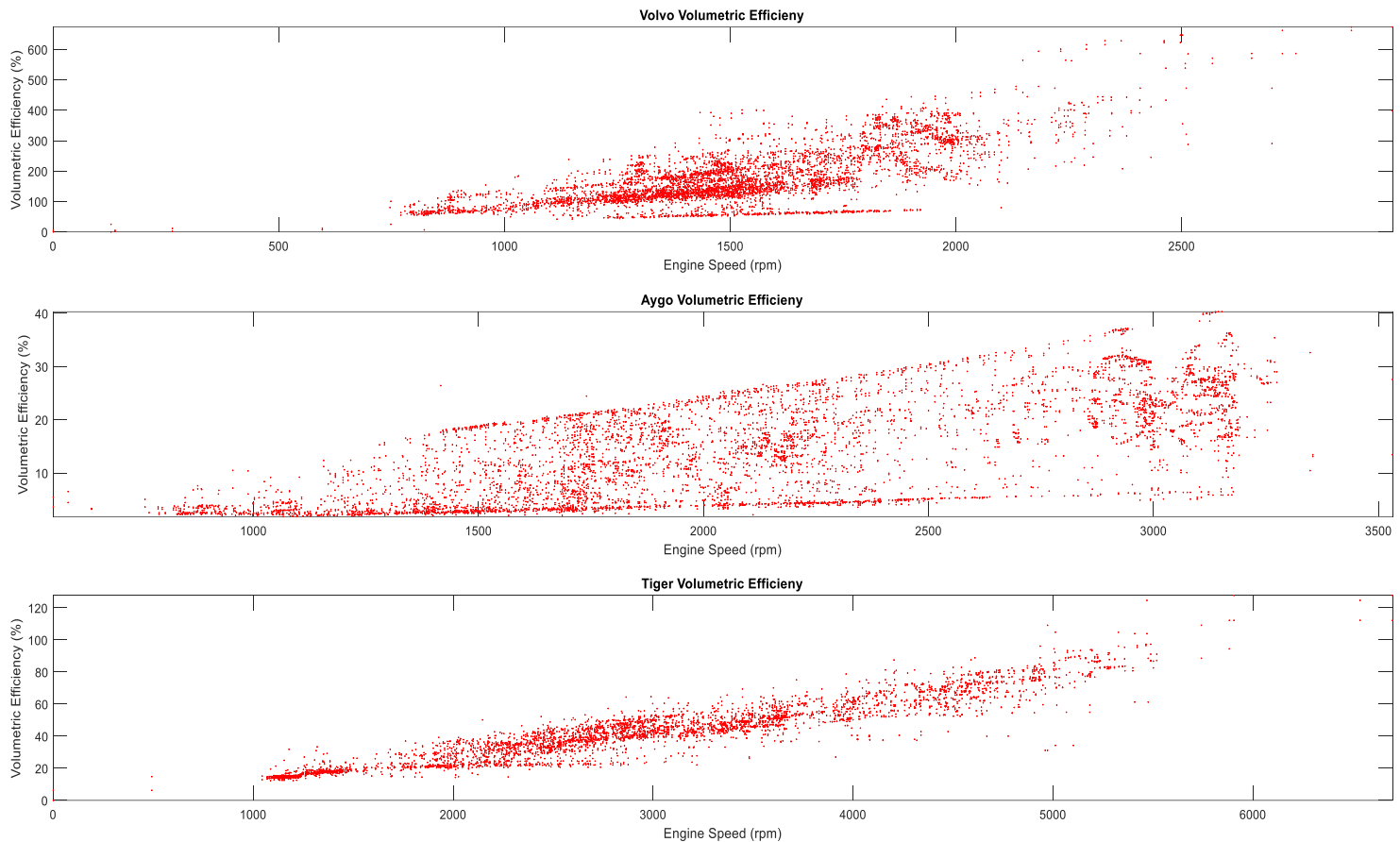
```
%% constants
% frontAL area
T_Front_A = 0.5; % triumph frontal area (m^2)
V_Front_A = 2.2; % volvo frontal area (m^2)
A_Front_A = 2.004215; % Aygo frontal area (m^2)
% Co efficient of Drag
T_CD = 0.9;
V_CD = 0.33;
A_CD = 0.28;
% gas constant
R= 287.05; % j/(kg.K)
co_rr = 0.02; % coefficient of rolling resistance
%masses
M_T = 305; % tiger mass kg
M_V = 1650; % volvo mass kg
M_A = 1070; % mass of aygo
g = 9.81;% acceleration gravity m/s/s
% coefficients Lift
CL_T = 0.09; % tiger lift co
CL_V = 0.099; % volvo lift
CL_A = 0.1; % aygo lift
% wheel radius uncompressed (m)
R_T_T = 0.3209; % tiger wheel radius
R_T_V = 0.33965; % volvo wheel radius
R_T_A = 0.31725; % Aygo wheel radius
% mass of wheels
W_mass_A = 13; % aygo wheel mass kg
W_mass_V = 15; % volvo wheel mass kg
W_mass_T = 7.5; % tiger wheel mass kg
% I of engine
I_A_E = (0.11);
I_V_E = 0.13;
I_T_E = 0.07;
% I of drivetrain
I_A_D = 0.05;
I_V_D = 0.07;
```

3.2 Volumetric Efficiency

As engine speed Mass Air Flow (MAF) and manifold absolute pressure data are given the volumetric efficiency can be calculated. Columns 35 are engine RPM, 33 is MAP and 41,84 and 88 are MAF. Only on the Volvo is this not a calculated channel.

```
%% voleff
```

```
V_v_eff = (V_Data_r(:,41) * 2) / (0.0167*V_Data_r(:,35))*(V_Data_r(:,33)*1e3)*0.000998;  
A_v_eff = (A_Data_r(:,84) * 1.5) / (0.0167*A_Data_r(:,35))*(A_Data_r(:,33)*1e3)*0.000799;  
T_v_eff = (T_Data_r(:,88) * 1.5) / (0.0167*T_Data_r(:,35))*(T_Data_r(:,33)*1e3)*0.001969;
```



The results show the trend for the data but there are anomalies and the inputs are not the most accurate. This shows that the Volvo is turbo charged as there is much over 100%.

3.3 Air Density

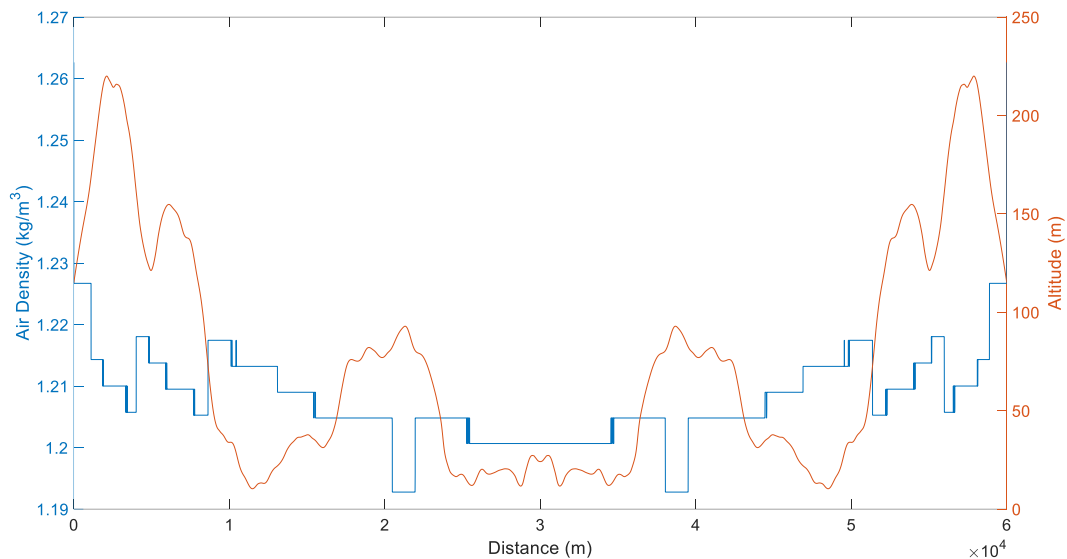
As the Volvo had a barometric sensor and the Tiger had a temperature sensor, the air density for dry air could be calculated for the route. This could be then used for aerodynamic lift and drag.

```
%% Air Density
```

```
pr = (V_Data_i(:,44)); % baromic pressure  
T = T_Data_i(:,41)+273.15; % temp in kelvin from triumph  
p = (pr*1e3)./(R.*T); % density of air Kg/m^3
```

This gave the following results.

3.3.1 Altitude and density over 60km



As there was very little change in pressure the temperature is what drove the change over the route. The lowering density occurred as it warmed closer to Swansea: this may be explained by the sunrise as these were morning commutes. The overall variation is small in density. This is unrepresentative as it was done on different days. However, it is still interesting to calculate.

3.4 Drag

The standard drag formula was used with the calculated air density, where each vehicle's respective velocity frontal area and drag coefficients from the previous constants table to give the drag force per meter. The calculation is shown in the following script:

```
%% drag calc
F_D_T = 0.5.*p.*(T_ms_sVSS.^2)*T_Front_A*T_CD;
F_D_V = 0.5.*p.*(V_ms_sVSS.^2)*V_Front_A*V_CD;
F_D_A = 0.5.*p.*(A_ms_sVSS.^2)*A_Front_A*A_CD;
```

3.5 Lift

The following script shows lift calculation this is identical, except it uses the lift coefficient. When researching, typically, a hatchback, estate, and a motor bike, all produce a very slight positive lift. This positive lift is removed from the calculated

rolling resistance later. As the bike goes through different angles in cornering this may affect the lift coefficient, and this is not accounted for.

```
% lift
L_F_T = 0.5.*p.*(T_ms_sVSS.^2)*T_Front_A*CL_T;
L_F_V = 0.5.*p.*(V_ms_sVSS.^2)*V_Front_A*CL_V;
L_F_A = 0.5.*p.*(A_ms_sVSS.^2)*A_Front_A*CL_A;
```

3.6 Rolling resistance

The rolling resistance is calculated as follows considering the incline.

```
%% Rolling Resistance with incline force parrel
```

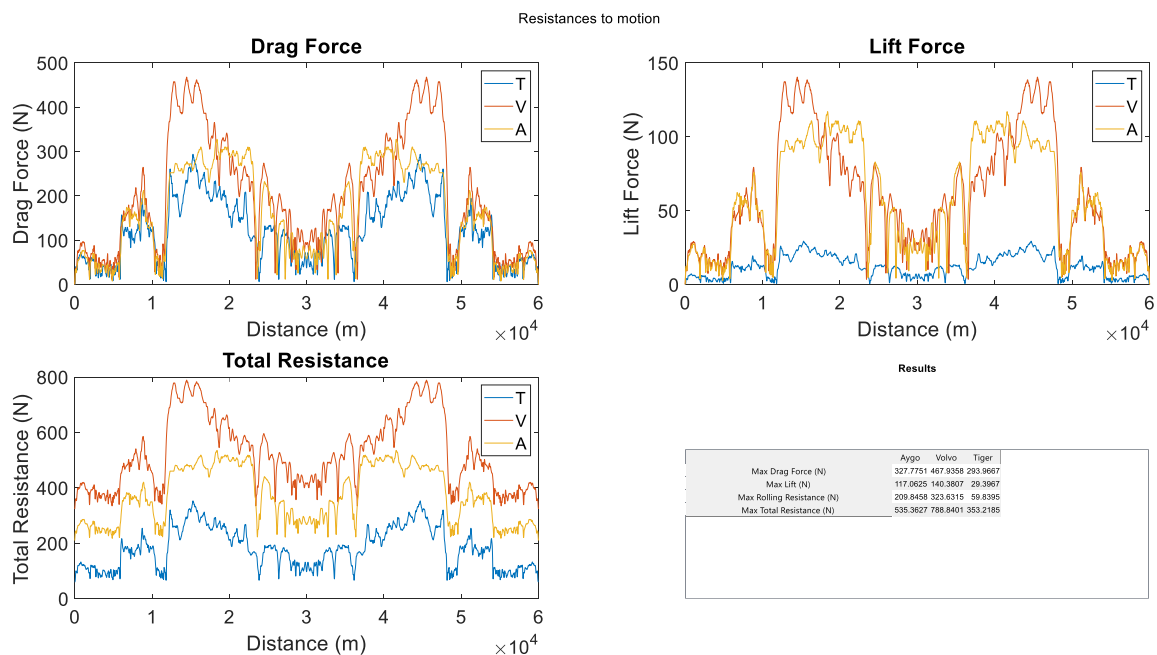
```
RR_A = ((M_A*g)-L_F_A).*(co_rr.*(cos(ang_A)));
RR_V = ((M_V*g)-L_F_V).*(co_rr.*(cos(ang_V)));
RR_T = ((M_T*g)-L_F_T).*(co_rr.*(cos(ang_T)));
```

3.7 Total Resistance

The total resistance is the rolling plus the drag.

```
% total resistance
TR_A = (RR_A+F_D_A);
TR_V = RR_V+F_D_V;
TR_T = RR_T+F_D_T;
```

3.7.1 Resistance Results graphs



- The Drag Force graph shows that even though the Tiger has considerably lower frontal area, the high coefficient of drag means it has nearly the same drag as the Aygo.
- The Lift Force graph splits the forces better with frontal area as they all have similar velocities and lift coefficients.
- As expected, the vehicles total resistance lowers with mass and frontal area.

3.8 Force Required

To calculate the force required to move, the mass and acceleration needs to be calculated with respect to inclines. The mass of rotating parts increases with inertia. To calculate this the gear ratio is needed. The ratios are given but this is also simply output/input.

3.8.1 Gear ratio

The first half of the following script uses the ratios and wheel radius to work out what the gear ratios are. Then the second half works out what ratio each vehicle is in.

```
%% gear calculator

% Gear ratio to wheel from data sheets
GR_A_c = [(3.545*3.55*(0.97*R_T_A)); (1.913*3.55*(0.97*R_T_A)); (1.31*3.55*...
(0.97*R_T_A)); (1.027*3.55*(0.97*R_T_A)); (0.85*3.55*(0.97*R_T_A))];

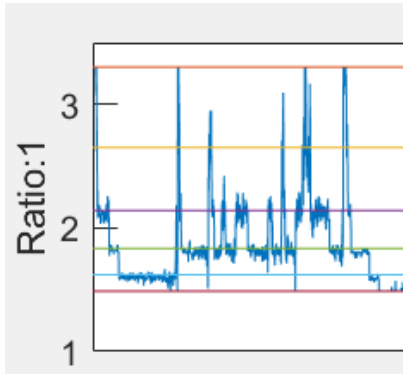
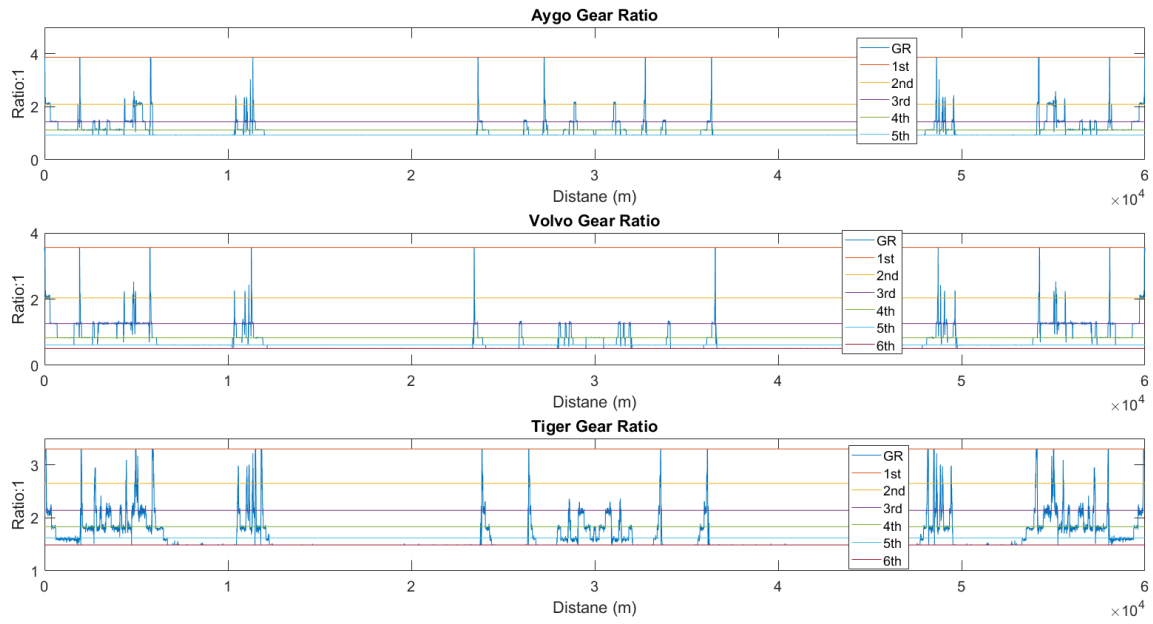
GR_V_c = [(3.583*4*(0.97*R_T_V)); (2.05*4*(0.97*R_T_V)); (1.267*4*(0.97*R_T_V))...
; (0.838*4*(0.97*R_T_V)); (0.617*4*(0.97*R_T_V)); (0.51*4*(0.97*R_T_V))] * 0.75405445;

GR_T_c = [(2.313*3.125*(0.97*R_T_T)); (1.857*3.125*(0.97*R_T_T)); (1.5*3.125*...
(0.97*R_T_T)); (1.285*3.125*(0.97*R_T_T)); (1.136*3.125*(0.97*R_T_T)); ...
(1.043*3.125*(0.97*R_T_T))] * 1.4679802955665024630541871921182;

% gear ratio from output rpm over input rpm
GR_A_r = ((A_Data_i(:,35)./(A_Data_i(:,38).*16.6667)./(2*pi*(R_T_A*0.95))));
GR_A_r(GR_A_r>max(GR_A_c))=max(GR_A_c);
GR_A_r(GR_A_r<min(GR_A_c))=min(GR_A_c);
GR_A_c = repmat(GR_A_c,1,6e4);

GR_V_r = ((V_Data_i(:,35)./(V_Data_i(:,38).*16.6667)./(2*pi*(R_T_V*0.95))));
GR_V_r(GR_V_r>max(GR_V_c))=max(GR_V_c);
GR_V_r(GR_V_r<min(GR_V_c))=min(GR_V_c);
GR_V_c = repmat(GR_V_c,1,6e4);

GR_T_r = ((T_Data_i(:,35)./(T_Data_i(:,38).*16.6667)./(2*pi*(R_T_T*0.95))));
GR_T_r(GR_T_r>max(GR_T_c))=max(GR_T_c);
GR_T_r(GR_T_r<min(GR_T_c))=min(GR_T_c);
GR_T_c = repmat(GR_T_c,1,6e4);
```



The above figures show the actual ratio imposed onto the calculated ratios. As the actual ratio is derived from the vehicle speed there is noise from the sensor sampling.

3.8.2 Equivalent mass

Using the constants and the following formula the equivalent mass per meter was calculated.

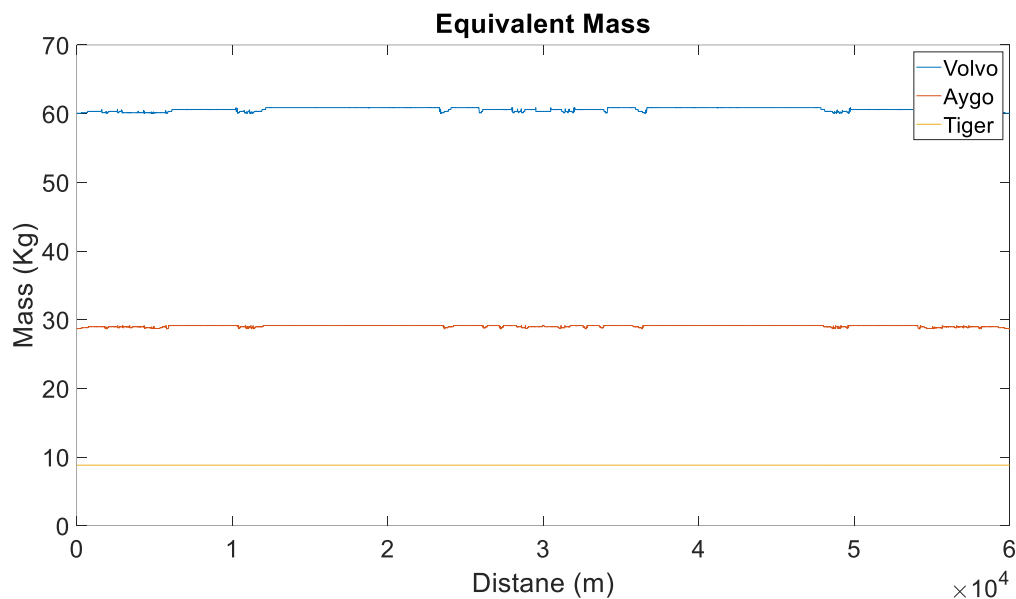
$$M_e = I_{wheel} \left(\frac{1}{r_{wheel}} \right)^2 + \left(I_{engine} \times Eff_{mech} \left(\frac{Ratio_{final} \times Ratio_{gear}}{r_{wheel}} \right)^2 \right)$$

```

%% inertia and Equiv mass
% mass moment of inertia Wheel

I_A_W = (R_T_A^2)*W_mass_A;
I_V_W = (R_T_V^2)*W_mass_V;
I_T_W = (R_T_T^2)*W_mass_T;
% mass moment of inertia Engine and driveline
I_A_E_D = (I_A_E+I_A_D)/(R_T_A^2);
I_V_E_D = I_V_E+I_V_D/(R_T_V^2);
I_T_E_D = I_T_E+I_T_D/(R_T_T^2);
% E_M
T_E_M = ((I_T_W.*(1./R_T_T).^2)+(I_T_E_D.*0.95.*(R_T_T./GR_T_r)).^2)+I_A_W; % 1 driven wheel and 1 rolling
A_E_M = (((I_A_W.*(1./R_T_A).^2)+(I_A_E_D.*0.95.*(R_T_A./GR_A_r)).^2).^2)+(2*I_A_W); % 2 driven 2 rolling
V_E_M = ((I_V_W.*(1./R_T_V).^2)+(I_V_E_D.*0.95.*(R_T_V./GR_V_r)).^2).^4; % 4 driven wheels

```



The greater inertia in the diesel engine and all-wheel drive transmission cause a larger equivalent mass.

3.8.3 Acceleration Force

The acceleration force is the force to change velocity. If this is not accounted for the velocity used in total resistance would not be achieved. This is driven by the acceleration of the vehicle mass and the acceleration and deceleration caused by the slope.

```

%% Acceleration force (N)

AF_A = (A_sacc_VSS.*(A_E_M+M_A))+((A_E_M+M_A.*9.81.*sin(ang_A))-(A_E_M+M_A.*9.81.*cos(ang_A).*0.02));
AF_T = (T_sacc_VSS.*(T_E_M+M_T))+((T_E_M+M_T.*9.81.*sin(ang_T))-(T_E_M+M_T.*9.81.*cos(ang_A).*0.02));
AF_V = (V_sacc_VSS.*(V_E_M+M_V))+((V_E_M+M_V.*9.81.*sin(ang_V))-(V_E_M+M_V.*9.81.*cos(ang_A).*0.02));

```

3.8.4 Force Required

This is the sum of the acceleration force and the total resistance.

```
%% force required  
  
R_F_A = AF_A+TR_A;  
R_F_T = AF_T+TR_T;  
R_F_V = AF_V+TR_V;
```

3.9 Wheel torque

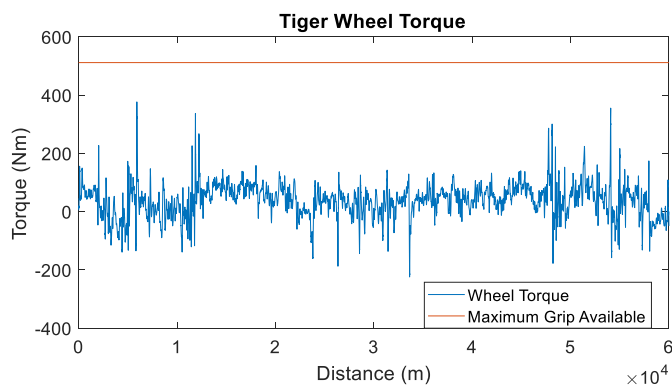
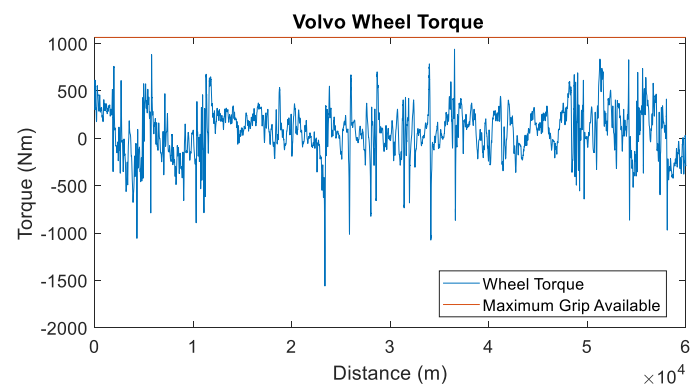
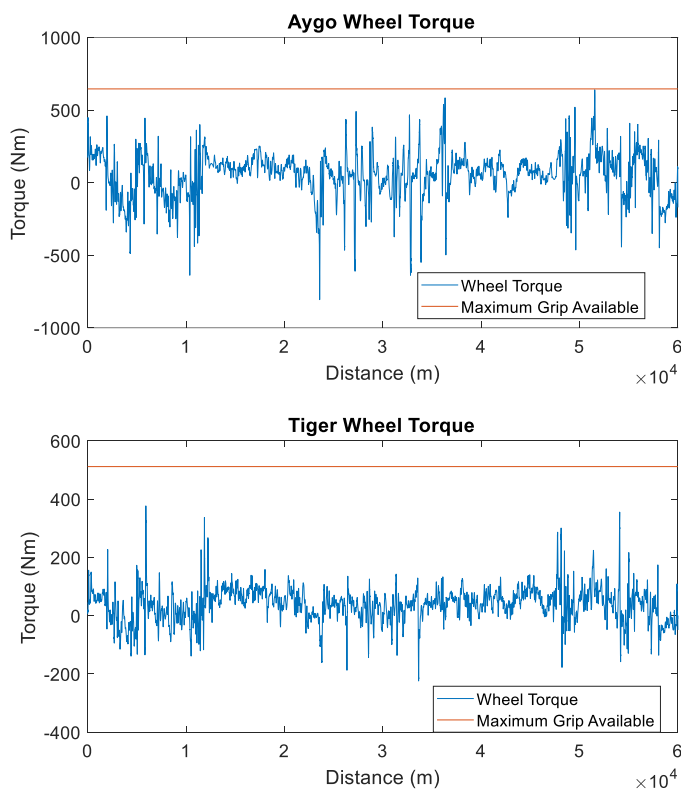
The wheel torque can be calculated by multiplying the force required by the wheel radius (0.97 of the radius is taken due to tyre deformation).

```
%% wheel torque  
T_W_T = R_F_T * R_T_T*0.97;  
A_W_T = R_F_A * R_T_A*0.97;  
V_W_T = R_F_V * R_T_V*0.97;
```

The available grip in a static position can be calculated by multiplying the force on each tyre by the wheel radius.

```
%% grip use  
A_Tmax = 0.8 * ((M_A * 9.8)/4) * R_T_A*0.97;  
V_Tmax = 0.8 * ((M_V * 9.8)/4) * R_T_V*0.97;  
T_Tmax = 1.1 * ((M_T * 9.8)/2) * R_T_T*0.97;
```

3.9.1 Wheel torque and available grip



Results

	Aygo	Volvo	Tiger
Theoretical Torque Before loss of Grip (Nm)	645.3786	1.0655...	511.7172
Max Torque used (Nm)	639.3053	941.2489	376.7654
Percent of Grip Used (%)	99.0593	88.3406	73.6276

- The above figure uses available grip to draw the red line. This does not take into account load transfer from decelerating and accelerating, incline of the road and assumes even weight distribution and tyre size.
- The first 30km is more representative as the second 30km assumes the acceleration up hills can be the same as the deceleration down in the first 30km, as seen just after the 50km mark on the Aygo.

3.10 Power

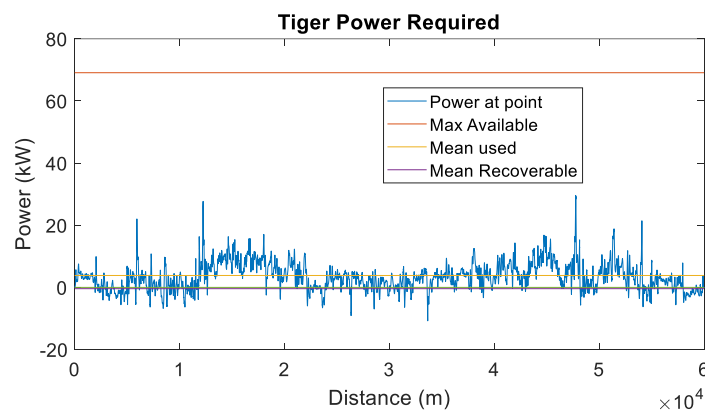
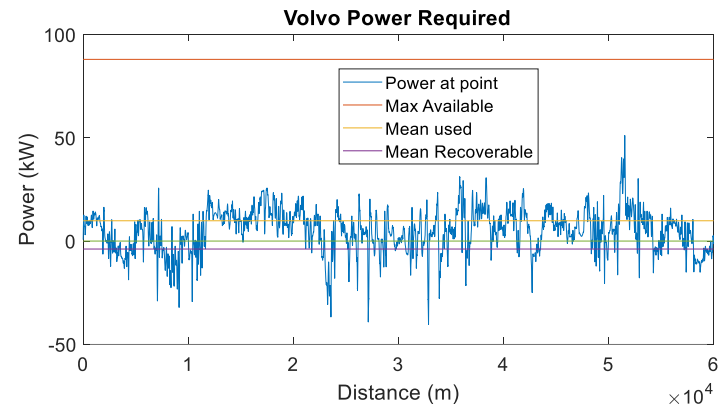
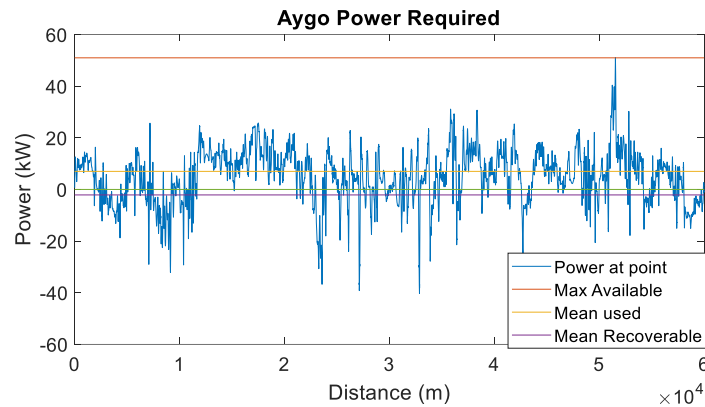
This is the required force in Newtons multiplied by the velocity. $N * m/s = W$. The driveline efficiency is taken to be 85%.

%% Power required KW accel and decel

```
P_R_A = ((R_F_A.*(circshift(A_ms_sVSS,1)))/0.85)./1e3;
P_R_V = ((R_F_V.*(circshift(V_ms_sVSS,1)))/0.85)./1e3;
P_R_T = ((R_F_T.*(circshift(T_ms_sVSS,1)))/0.85)./1e3;
```

3.10.1 Power graph

Power Requirements



Results

	Aygo	Volvo	Tiger
Max Power Available (kW)	51	88	69.1000
Max Power used (kW)	51.1319	70.0060	29.6191
percent of Power used (%)	100.2587	79.5523	42.8641
Mean Power used (KW)	7.0072	9.8298	3.8395
Mean Power Recoverable (KW)	-2.1181	-3.8601	-0.4095

- The above figure again shows, that especially for the Aygo, the return journey has unrealistic accelerations up an incline (using over 100% power listed available in the following table).
- The following table shows that all the vehicles achieved between 40% and 60% in the real-world cycle.
- The true figures may be different as the data has been smoothed. The sampling may have missed peaks. Also, many assumptions have been made with constants and weather, such as head and tail wind, have not been accounted for.
- An over prediction of requirements from the second half of the 60km, gives a factor of safety for any future designs.

	Aygo	Volvo	Tiger
Max Power Available (kW)	51	88	69.1000
30km cycle Max Power used (kW)	25.7083	49.5479	27.6929
30km cycle percent of Power used (%)	50.4084	56.3044	40.0766
30km cycle Mean Power used (KW)	6.7375	9.2100	3.7382
30km cycle Mean Power Recoverable (KW)	-2.5027	-4.0859	-0.4856
-	0	0	0
60km cycle Max Power used (kW)	51.1319	70.0060	29.6191
60km cycle percent of Power used (%)	100.2587	79.5523	42.8641
60km cycle Mean Power used (KW)	7.0072	9.8298	3.8395
60km cycle Mean Power Recoverable (KW)	-2.1181	-3.8601	-0.4095

3.11 Energy

To convert to energy the power per meter is multiplied by the time step per meter. The time step is in milliseconds in `x_Data_i(:,4)`. This energy per meter is accumulated to give the total energy required for acceleration and deceleration for the drive cycle.

```
%% Energy required
%POWER TO ACCEL AND DECCEL
P_R_Aa =P_R_A; % ACCEL POWER
P_R_Ad =P_R_A; % DECCEL POWER
P_R_Aa(P_R_Aa<0)=0;
P_R_Ad(P_R_Ad>0)=0;
%energy needed aygo
a_E_R_A = cumsum((A_Data_i(:,4)/1e3).*P_R_Aa)./1e3;
%energy Recoverable aygo
d_E_R_A = cumsum(abs((A_Data_i(:,4)/1e3).*P_R_Ad))./1e3;

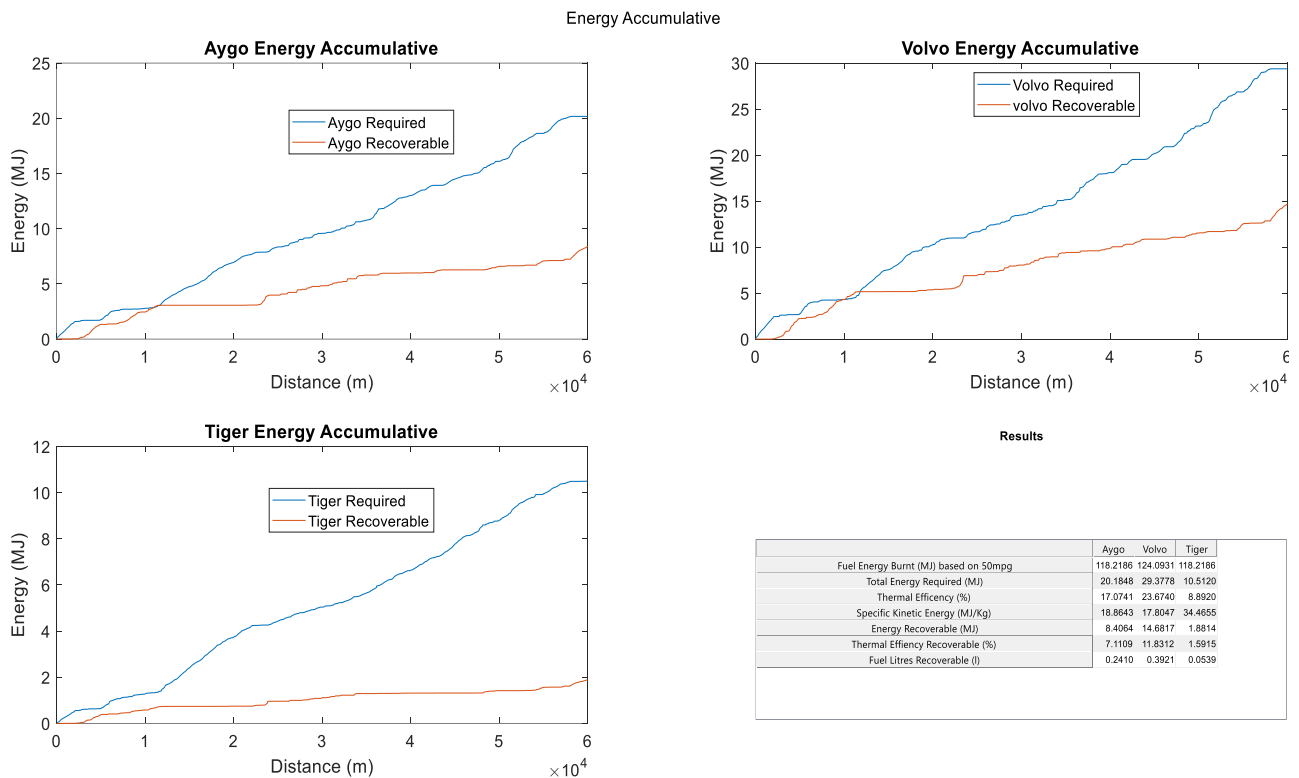
P_R-Ta =P_R_T;
P_R-Td =P_R_T;
P_R-Ta(P_R-Ta<0)=0;
P_R-Td(P_R-Td>0)=0;

a_E_R_T = cumsum((T_Data_i(:,4)/1e3).*P_R-Ta)./1e3;
d_E_R_T = cumsum(abs((T_Data_i(:,4)/1e3).*P_R-Td))./1e3;

P_R-Va =P_R_V;
P_R-Vd =P_R_V;
P_R-Va(P_R-Va<0)=0;
P_R-Vd(P_R-Vd>0)=0;

a_E_R_V = cumsum((V_Data_i(:,4)/1e3).*P_R-Va)./1e3;
d_E_R_V = cumsum(abs((V_Data_i(:,4)/1e3).*P_R-Vd))./1e3;
```

3.11.1 Accumulative drive cycle energy Graphs



- The figure above shows the Volvo has the highest proportion of energy recoverable.
- The Tiger has a very low proportion of energy recoverable, this is due to the high coefficient of drag to overcome and low mass. This means there is less potential energy recoverable which is not lost to drag.

3.11.2 Efficiencies

- The following script works out the total Mega Joules of fuel used presuming 50mpg.
- The thermal efficiency of each vehicle.
- The recoverable thermal energy.
- And the specific kinetic energy of each vehicle.

```

%% 50 mpg

trip_p = ((60/((50*1.60934)/4.54609))*0.775)*45;
trip_d = ((60/((50*1.60934)/4.54609))*0.832)*44; %how many mj in 60km

% calorific conversion efficiency (thermal)

eff_T = max(a_E_R_T)/trip_p;
eff_V = max(a_E_R_V)/trip_d;
eff_A = max(a_E_R_A)/trip_p;

% recoverable calorific conversion efficiency (thermal)
r_eff_T = max(d_E_R_T)/trip_p;
r_eff_V = max(d_E_R_V)/trip_d;
r_eff_A = max(d_E_R_A)/trip_p;

% specific energy (kj)
s_eff_T = (max(a_E_R_T)/M_T)*1e3;
s_eff_V = max(a_E_R_V)/M_V*1e3;
s_eff_A = max(a_E_R_A)/M_A*1e3;

```

	Aygo	Volvo	Tiger
Fuel Energy Burnt (MJ) based on 50mpg	118.2186	124.0931	118.2186
Total Energy Required (MJ)	20.1848	29.3778	10.5120
Thermal Efficiency (%)	17.0741	23.6740	8.8920
Specific Kinetic Energy (MJ/Kg)	18.8643	17.8047	34.4655
Energy Recoverable (MJ)	8.4064	14.6817	1.8814
Thermal Efficiency Recoverable (%)	7.1109	11.8312	1.5915
Fuel Litres Recoverable (l)	0.2410	0.3921	0.0539

- The above table shows the Volvo to be the most efficient at converting fuel energy into usable energy. It has the highest thermal efficiency, lowest specific kinetic energy requirement (energy per kg) and also has the highest percentage of energy recoverable.
- The tiger is the worst on all metrics for the previously described reasons.
- The recoverable percentages and quantities are hypothetical as there would be losses in conversions when recovering.

4 Part 3 Technology for Drive Cycle

4.1 The cycle

The Volvo will be chosen to apply improvements as:

- It has the potential to save the most energy.
- Has the highest initial price (if all had the same profit margin the proportion of consumer budget would be higher and attractive to more affluent customers)
- Largest volume giving more packaging space for alternative drive trains.

Largest mass, meaning any additional parts would have less of a proportionate effect. It also has the heaviest drive train providing more scope to swap

4.2 Technologies to consider

The following will be considered in detail:

- Start stop
- Capacitor KERS
- Full electric with Capacitor KERS

The following will be considered, with reasons for not performing an in-depth investigation given in section 4

- Flywheel KERS
- Hydrogen Fuel Cells
- PHEV Range extenders
- Pneumatic KERS
- Alternative fuels
- Downsizing

4.3 Stop Start

The Volvo was Equipped with start stop but was not selected during the cycle. The following script was used to find the total time stopped (excluding beginning and end) from the original data (as smoothing velocity lost some stops). This was then doubled for the full 60km drive cycle. Using 0.045 litres per hour burnt at idle and using a 288-week working week the potential fuel saving is calculated.

```

%% start stop
i= find(~V_Data_r(:,38)); %finds the stop locations
i(:,2) = gradient(i); % marks the point you come to stop and start moving
c = i(i(:,2)~=1); % GETS THE FRAME NO OF STARTING AND STOPPING
T_STOP = nan((size(c,1)-2)/2,1); % makes answer vector so u dont get orange
for j = 2:2:(size(c,1)-2)
    T_STOP(j-(j/2)) = (sum(V_Data_r(c(j):c(j+1),4)))/1000; % all the times of stops not at start and finish
end
T_T_STOP = (sum(T_STOP)*2); %TOTAL TIME STOPPED FULL 60KM

F_SAVE_P_C = ((2*0.045)/3600)*T_T_STOP;
T_2_SAVE_Y = (1/F_SAVE_P_C)/288; % based on 288 working days in a year

```

	Volvo
Time Stopped (s)	110.2000
Saved 60km Cycle (L)	0.0028
Years to 1L (y)	1.2603

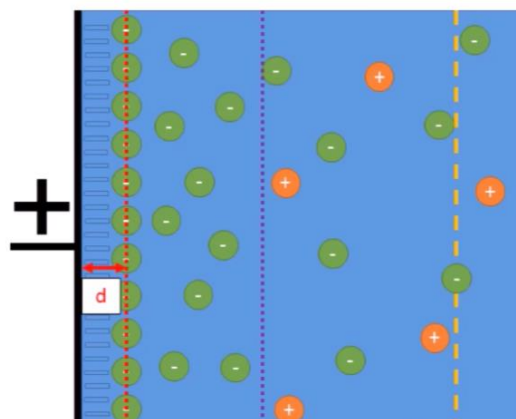
As the table above shows the saving is negligible on a real-world drive cycle. Start stop technology was created to pass the NEDC drive cycle, which has pre-set stops.

4.4 Capacitor KERS

4.4.1 Super Capacitors

Capacitors and batteries work by charging plates (anodes and cathodes). The means by which this is achieved and the advantages for each energy device differ. Both use the principle of only allowing ions to pass through the separator and electrons move through the circuit. Super capacitors have an electrolyte instead of a dielectric and typically use carbon plates to positively and negatively charge. The use of electrolyte and carbon gives an effective double layer to store charge on (Helmholtz layer). This double layer can be thought of as a parallel plate capacitor, the following figure shows how the small thickness of the Helmholtz layer increases capacitance represented by the small d .

Electrical Double Layer



$$C = \frac{\epsilon_o \epsilon_r A}{d}$$

When an electric field is induced across the device, ions are attracted to one plate and electrons are attracted to the other. When the applied field is removed the capacitor maintains its field storing the charge. This is not the most stable store, but the weak field bond allows for rapid discharge (Pipitone and Vitale, 2020).

Super capacitors advantages:

- High power Density
- Rapid Discharge/ Charge times
- Long Cycle Life
- No chemical reactions

Super capacitors disadvantages:

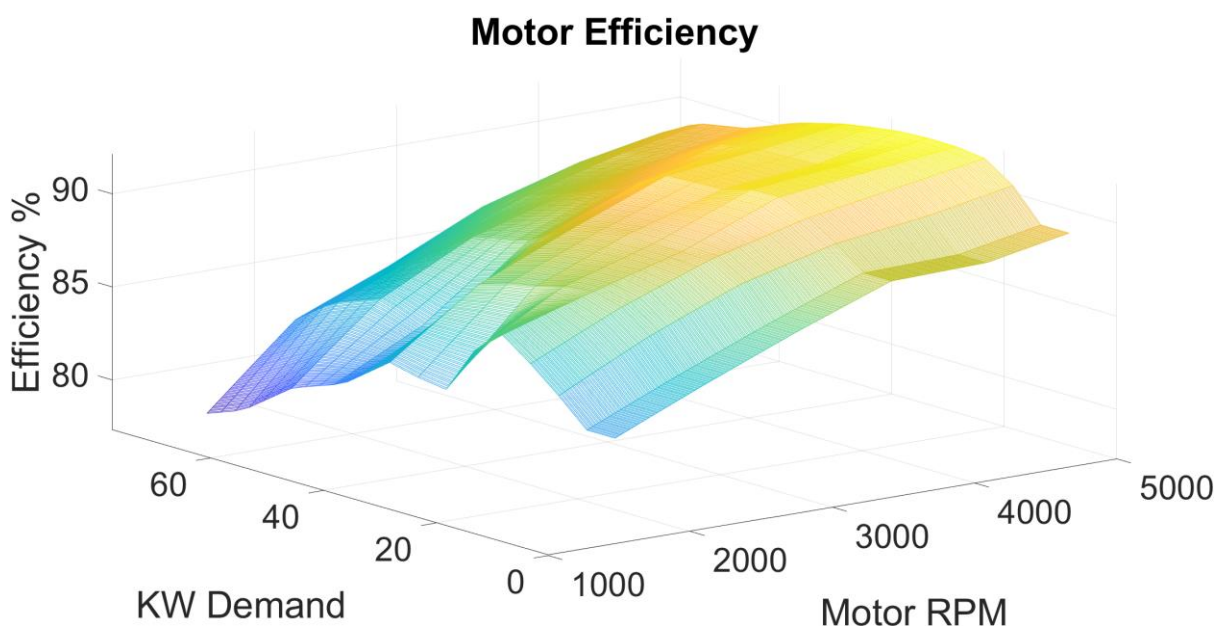
- Poor Charge Retention
- Low Energy density.

As Kinetic energy can only be generated inconsistently depending on driving conditions and driving style the high-power density and the rapid charge and discharge would make capacitors a good option for KERS.

4.4.2 Motor efficiencies

To capture the mechanical energy from the vehicle when decelerating to store in a capacitor an electric motor is needed. The electric motor's efficiency depends on load and rpm. The Yasa motor chosen that meets the requirements has the following efficiencies:

4.4.3 Electric motor efficiency



4.4.4 Efficiency per meter

To calculate the efficiency per meter of the drive cycle the following script was used to interpolate the efficiency table given for the vehicle's respective rpm and load.

```

%% Motor Efficiency at rpm for power input/output
mpef = abs(P_R_V);

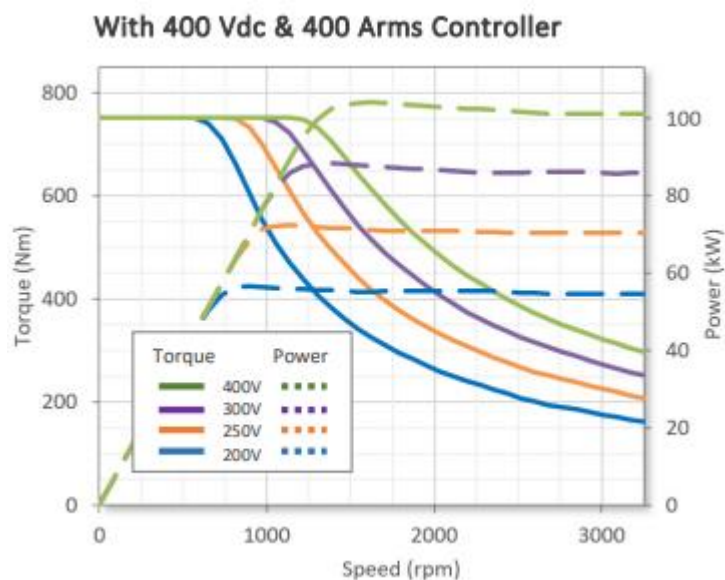
M_EF=zeros(60000,1);
for i=(1:60000)
    xq = V_Data_i(i,35);
    yq = mpef(i);
    M_EF(i) = interp2(mot_eff_RPM,mot_eff_KW,mot_eff,xq,yq);
end

M = min(mot_eff,[],'all');
M_EF(isnan(M_EF))==M;
M_EF=M_EF/100;

```

4.4.5 Calculating Capacitor Level and energy saved

The motor's power and torque are proportional to the voltage. This can be seen in the following graph. At 200 volts the motor would have adequate power for KERS on the Volvo drive cycle.



To reduce the use of a DC to DC converter 1, 2 and 3 capacitors will be evaluated in series. Placing capacitors in series as an energy store increases the voltage but reduces capacitance to an equivalent capacitance. Equivalent capacitance of capacitors in series is calculated similarly to resistors in parallel or springs in series ($1/(1/F+1/F)$). The equivalent capacitance is then put into the energy in capacitor formula (all the

capacitors are the same in series so the simplified formula for equivalent capacitance will be $F/(\text{number of caps})$.

4.4.6 Capacitor selection

Although previously mentioned, the capacitor advantage is in the power, not energy, density to try and capture all the available energy. Large HGV ultracapacitors have been selected from Maxwell.

FEATURES AND BENEFITS*	TYPICAL APPLICATIONS
➤ Up to 1,000,000 duty cycles or 10 year DC life	➤ Buses
➤ 125V DC working voltage	➤ Electric trains and trolleys
➤ Active cell balancing	➤ Heavy duty transportation
➤ Temperature and voltage monitoring	➤ Cranes, RTGS
➤ CAN bus digital monitoring and communications	➤ Utility vehicles
➤ High power density	➤ Mining equipment



These will be tried individually and up to 3 in series. To calculate the full cycle the new mass must be considered and all relevant efficiencies. The capacitors, at worst, have an efficiency of 80% and, when used in series, equivalent series resistance (ESR) degrades the performance due to I^2R losses. The controllers for the motors can work in constant current or voltage and vary the other to obtain the desired power. To simplify the ESR efficiency loss, each capacitor banks' worst case 80% efficiency can be multiplied together to give a worst overall case. As the ESR impedance is given as 18 mΩ at 100A and, as both of these will vary, this is not possible to calculate (so cap $\eta^{\text{number of caps}}$).

The following script shows calculating the capacitor level after considering all the previously discussed parameters and discharging when power is demanded for acceleration.

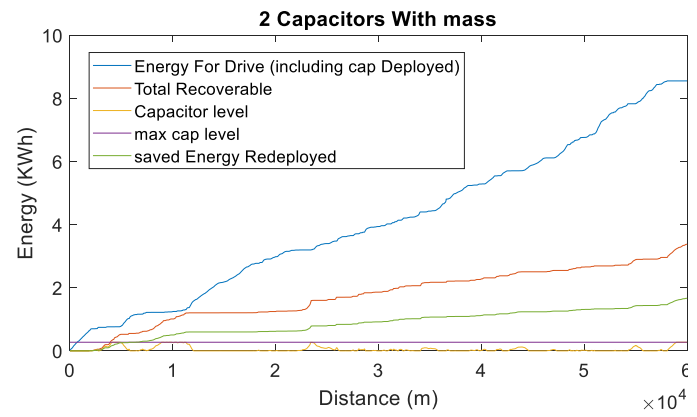
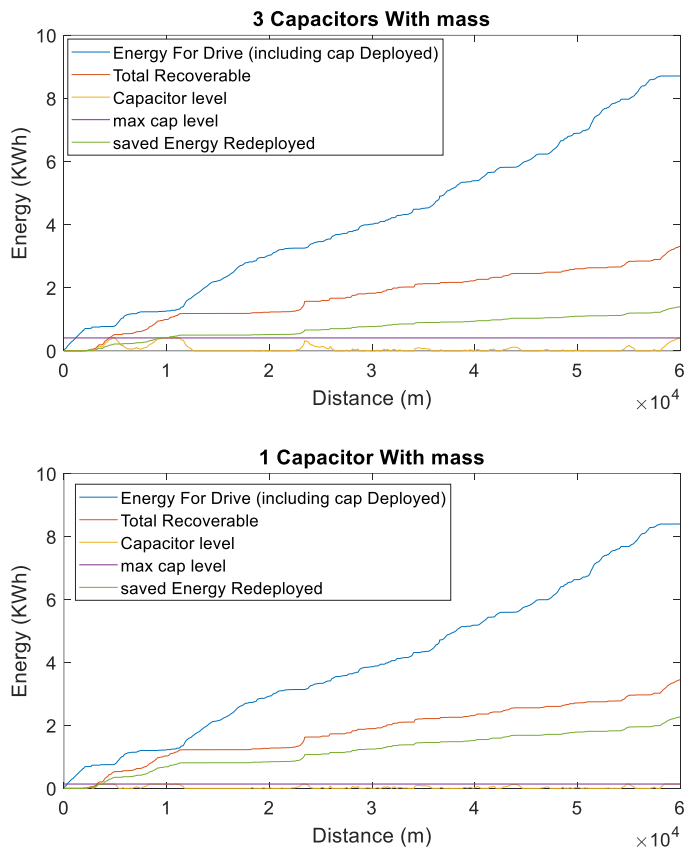
```

%% 1 capacitor + Diesel Engine
CN = 1; % no of caps
S_Add_mass = (61*CN) + 35; % mass of hybrid cap system
S_RR_V = (((M_V+S_Add_mass)*g)-L_F_V).*(co_rr.*(cos(ang_V))); % Rolling resistance with added mass
S_TR_V = S_RR_V+F_D_V; % total resistance with added mass
S_R_F_V = AF_V+S_TR_V; % Required Force is strong with you
S_P_R_V = ((S_R_F_V.*(circshift(V_ms_sVSS,1)))/0.85)./1e3; % Power accel and decel
S_P_R_Va=S_P_R_V;
S_P_R_Vd=S_P_R_V;
S_P_R_Va(S_P_R_Va<0)=0;
S_P_R_Vd(S_P_R_Vd>0)=0;
S_E_R_pm = (((V_Data_i(:,4)/1e3).*S_P_R_Vd)).*-M_EF; % energy in per meter recoverable (delta time * power recover)
S_E_D_pm = (((V_Data_i(:,4)/1e3).*S_P_R_Va)); % energdy to deploy
cap_f = 63;
voltage = 125;
S_cap_max_E = ((0.5*cap_f*(voltage^2))/1000); % wh energy max store of cap
S_cap_level=zeros(60000,1);
S_EN_save=zeros(60000,1);
for i=(1:59999)
    if S_cap_level(i)<0
        S_cap_level(i)=0;
    end
    if S_cap_level(i)>S_cap_max_E
        S_cap_level(i)=S_cap_max_E;
    end
    S_cap_level(i+1) = (S_cap_level(i)+S_E_R_pm(i+1))-S_E_D_pm(i+1);
    S_EN_save(i+1) = (S_E_R_pm(i+1)-S_E_D_pm(i+1)).*M_EF(i).*(cap_eff^CN);
    if S_EN_save(i)<0
        S_EN_save(i)=0;
    end
    if S_EN_save(i)>S_cap_max_E
        S_EN_save(i) = S_cap_max_E;
    end
end

S_max_power_needed = max((cumsum(S_E_D_pm)))-max(cumsum((S_EN_save)));%

```

4.4.7 Capacitor KERS Comparison



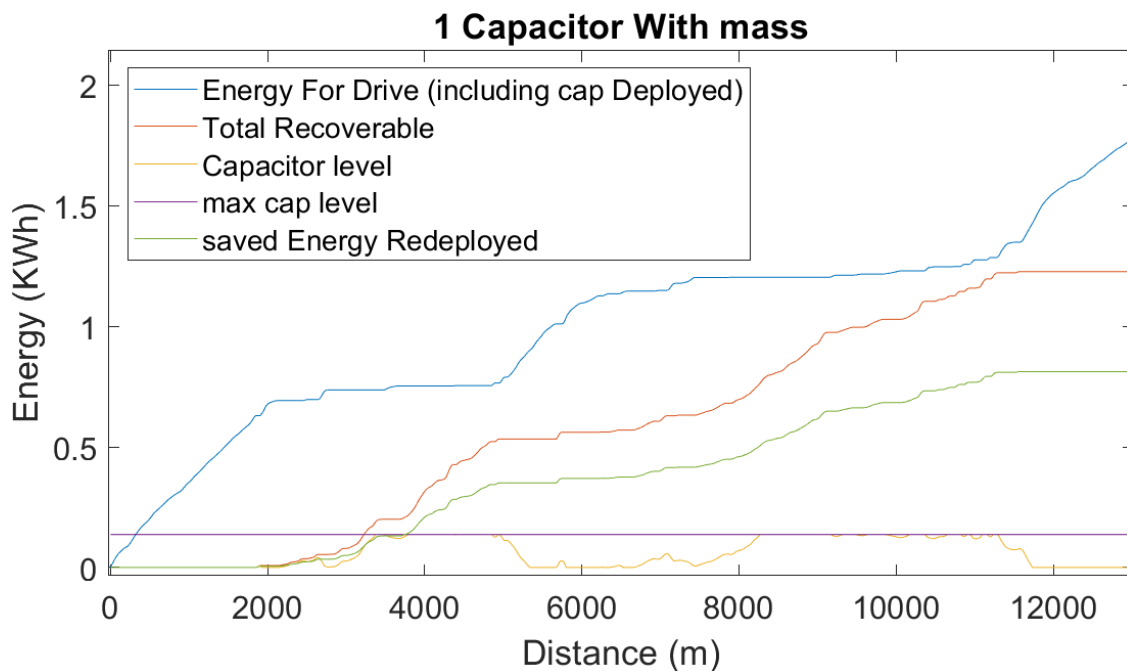
Results

	Drive Energy(MJ)	Fuel Energy Required (MJ)	KERS (MJ)	improvement %
Original	29.3778	29.3778	0	0
1 Cap	30.2412	22.0687	8.1725	24.8797
2 Cap	30.7961	24.7885	6.0076	15.6214
3 Cap	31.3558	26.3224	5.0334	10.4001

The previous figure and following table show that due to taking a worst case for efficiencies and the added mass of each capacitor bank that 1 capacitor is the best option in terms of total improvement (this is more due to the over negative approach to efficiency calculation rather than increased mass).

	Drive Energy(MJ)	Fuel Energy Required (MJ)	KERS (MJ)	improvement %
Original	29.3778	29.3778	0	0
1 Cap	30.2412	22.0687	8.1725	24.8797
2 Cap	30.7961	24.7885	6.0076	15.6214
3 Cap	31.3558	26.3224	5.0334	10.4001

4.4.8 Graph showing limits of 1 capacitor



The previous figure shows zoomed in the 1 capacitor is not capturing all the energy with the purple line (maximum cap level) limiting the cap level. At 4000 meters, if the cap was larger, the energy stored could be higher as there is no demand (blue line is flat at 4000meters) and more recoverable (red line is rising).

4.5 EV with Capacitor and NMC Battery

As the selected Yasa motor and controller has more than enough power and torque to completely replace the ICE it will be used again.

4.5.1 Lithium battery technology

The Cells are made of 5 layers:

- Cathode collector plate (to conduct electrons)
- Cathode active material (to release ions through the electrolyte when charging and receive when discharging)
- Separator (stop short circuit)
- Anode active material (to receive ions and electrons when charging and release when discharging)
- Anode collector plate (to conduct electrons)

There is also an organic electrolyte (carbon based).

During charging electron are pushed to the anode plate (copper) and anode active material (graphite). This attracts lithium ions from the cathode (Lithium oxide) that pass through the electrolyte and separator (polymer). The lithium ions and electrons build up on the anode whilst electrons leave the cathode and cathode plate (aluminium). Discharging is the reverse of this process.

To charge a cell the voltage applied needs to be greater than that of the cell. The capacity of the battery is the number amps it can continuously discharge in one hour. This is known as amp hour or 1C for the battery in question. The maximum and minimum discharge rates are given as C rates of the battery. For example 100Ah battery that has maximum discharge rate of 10C can give out 1000amps for 6 minutes, or a charge rate of 1/2C would take 2 hours to charge at 50amps.

Advantages:

- High energy density (only to other electric battery stores less than 1/50 of hydrocarbons)
- Good charge retention.

Disadvantages:

- Limited life cycle due to the chemical reactions
- Low power density
- Overcharging, high c rate charge or discharge and excessive heat causes growth of solid electrolyte interphase increasing impedance reducing efficiency and total capacity.
- Low charge levels will not hold the electrical potential within the cell to stop chemical breakdown, causing dendrite growth resulting in dangerous and unstable cells.
- When discharging voltage drops increasing current demand to maintain power levels.
- Capacity lowers over time with SEI build up (Myall *et al.*, 2018)

4.5.2 Battery pack

The battery pack will consist of 12 modules in a configuration of 6 series 2 parallel. Each module has a rating of 2.6KWh, a nominal voltage of 60.8volts (16 cells in series with a 3.8 nominal) the maximum continuous current draw of 400 amps and a 10 second peak

of 800amps. The voltage and current changes with configuration selected can be seen with the following script. This does not account for any busbar connection impedance.

4.5.3 Adding modules to battery

```
%% 6 modules in series
module = [ 2.6;60.8;400;800;0;17.2365];
% c rate
module(end-1) = (module(1)*1e3)/module(2);
% bat Kwh 6s2p
Battery = module(1)*12; % total Kwhr a
Battery(2,1) = module(2)*6; % pack voltage s
Battery(3,1) = module(3)*2; % constant current p
Battery(4,1) = module(4)*2; %10s current draw p
Battery(5,1) = module(5)*2; %ah (1 c for charge rate) p
Battery(6,1) = module(6)*12; %mass kg
```

4.5.4 Battery level

The capacitor selected for the full EV option was smaller as it is only needed to capture the peak energy charge and discharge which would raise the C Rate if it had not been utilised. The cap continuously deals with the high demands and the battery stores the excess energy the cap cannot hold. The script can be adjusted so if there is charge in the capacitor, the module will take a percentage of it for recharge. This would free up capacitor float when high in KERS situations, but it is not necessary in the demands seen in this application.

```

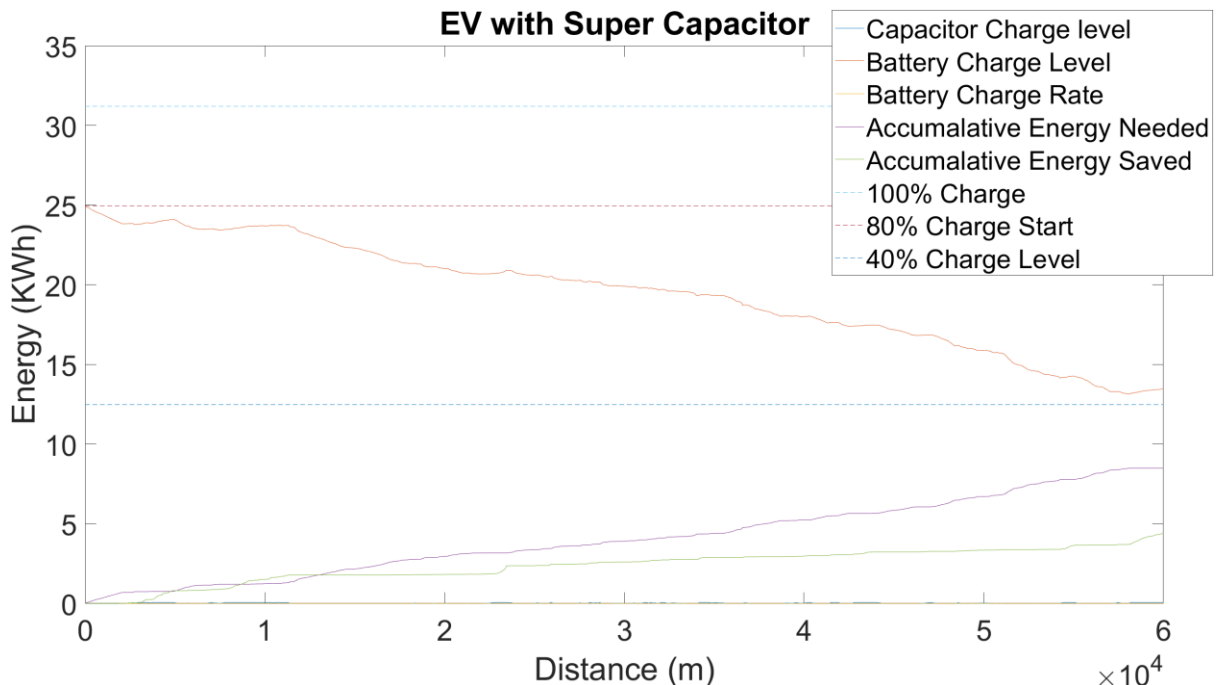
Bat_CR=zeros(60000,1);
E_EN_save=zeros(60000,1);
E_cap_level=zeros(60000,1);
Bat_start = max_SoC*Battery(1)*3600; %K joules
min_SOC = max_DoD*Battery(1)*3600; %K joules
Bat_level(1:6e4,1)=Bat_start;

for i=(1:59999)

    if E_cap_level(i)<0
        E_cap_level(i)=0;
    end
    if E_cap_level(i)>E_cap_max_E
        Bat_CR(i) = (E_cap_level(i)-E_cap_max_E)*M_EF(i+1);
        Bat_level(i+1) = Bat_CR(i)+Bat_level(i); % charges battery with excess
        E_cap_level(i)=E_cap_max_E;
    end
    E_cap_level(i+1) = (E_cap_level(i)+E_E_R_pm(i+1))-E_E_D_pm(i+1);
    E_EN_save(i+1) = (E_E_R_pm(i+1)-E_E_D_pm(i+1)).*M_EF(i+1).*(cap_eff^CN);
    Bat_level(i+1) = (Bat_level(i)-E_E_D_pm(i))+E_EN_save(i+1);
    if E_EN_save(i)<0
        E_EN_save(i)=0;
    end
    if E_EN_save(i)>E_cap_max_E
        E_EN_save(i) = E_cap_max_E;
    end
end
end

```

4.5.5 Battery and Capacitor Levels



To give a safety net each way, the battery was started at 80% state of charge (SoC) and the pack was specified so as to not drop below 40% as can be seen by the dotted lines. Keeping the working level around 60% is ideal as this is the nominal voltage level. The

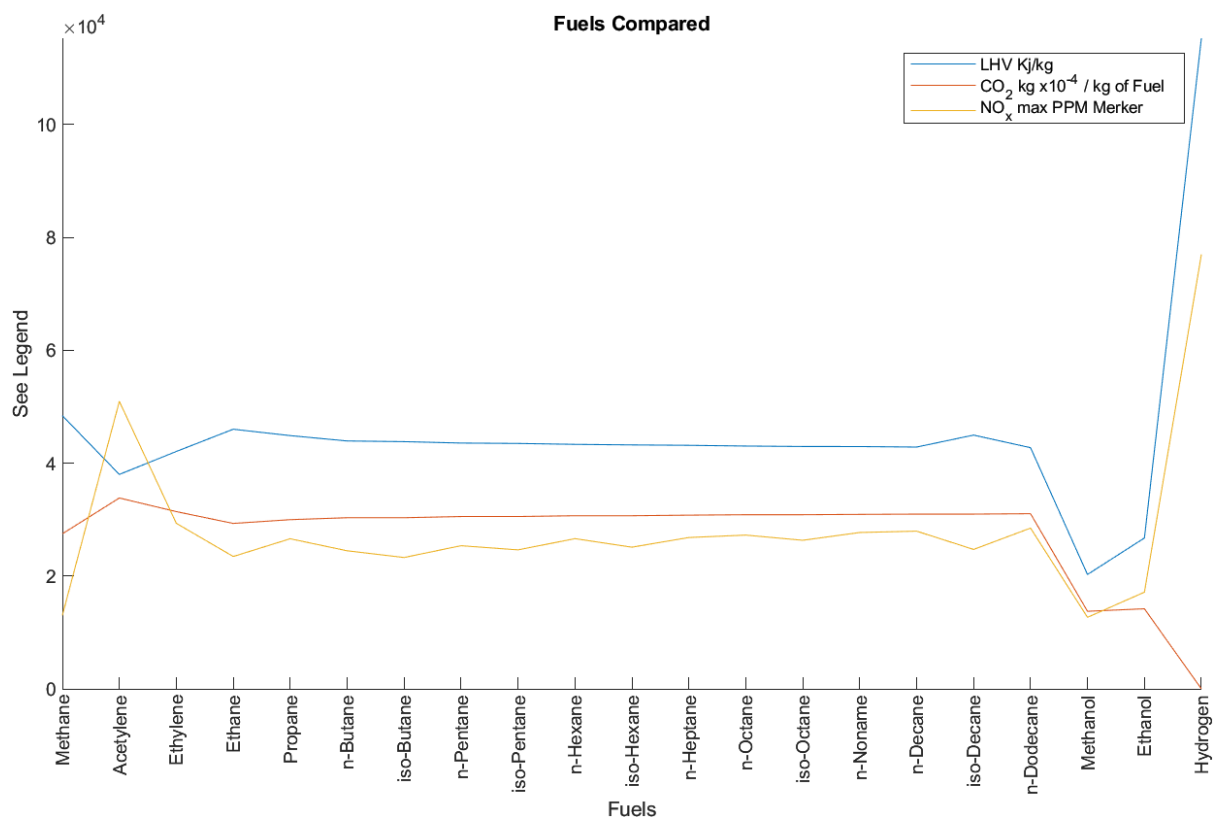
energy from KERS redeployed is approximately 5KWh or 18 mega joules. The energy lost from the battery pack is approximately 12.5KWh or 45 mega joules meaning the total kinetic energy the EV vehicle needs is 17.5KWh or 63 mega joules to drive, which is higher than the ICE as the mass has increased.

The increased mass will influence the vehicle's handling characteristics, especially the height the increased mass is positioned as the higher this is the higher load transfer accelerating, decelerating, and cornering (Ciez and Whitacre, 2016).

For a repeat drive cycle the capacitor already has stored energy, therefore the next cycle will have less drain on the battery, or the battery can be charged from the capacitor after the cycle.

4.6 Flywheels, Fuel Cells, Range extenders, Pneumatic, alternative fuels, and downsizing

4.6.1 Alternative Fuels



- The above graph from the first assignment shows that hydrocarbons always approximately produce triple their weight in carbon dioxide.

- When alcohols are burnt, less carbon dioxide is created, but due to the lower Joules of energy released, more needs to be burnt.
- Using Hydrogen produces no CO₂ but the high heat release increases NO_x Production (Degraeuwe *et al.*, 2016).

4.6.2 Hydrogen Fuel Cells

Hydrogen fuel cells come in many forms the type most suited to automotive use is the proton exchange membrane. This uses air and does not use CO₂ injection to stop CO formation breaking down the electrolyte as in other cell types. This means only 1 fuel tank is needed. It also operates at a temperature that would not require masses of insulation. The electrolyte only consists of proton exchange membrane that is flexible and durable. The main disadvantages are the efficiency and cost of expensive catalyst material (platinum) that is used both sides of the membrane (Tanç *et al.*, 2019).

Below shows various Types with typical efficiency and operation temperatures:

Type	Advantages	Disadvantages
Alkaline	• 70% efficient • 150-200°C	• Needs pure H₂ • Typically uses Compressed O₂ • Expensive platinum catalyst.
Molten carbonate	• 70% efficient • Cheap nickel electrode • Reusable waste heat	• 650°C • Needs CO₂ injection
Phosphoric acid fuel cells	• 60% efficient • 150-200°C	• Platinum electrode • Corrosive internals(Martins <i>et al.</i>, 2020)
Proton exchange membrane	• Polymer sheet electrolyte • 80°C	• 45% efficient • Double platinum catalyst
Solid oxide	• 60% efficient	• 1000°C

4.6.3 How Membrane type works

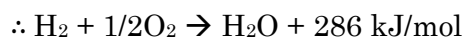
The catalyst at the anode splits the hydrogen into two moles of protons and electrons. The PEM allows the protons to pass through (like ions in a battery) reaching the cathode catalyst layer. The electrons cannot pass through so therefore move to the anode plate generating a current. With a complete circuit from anode to cathode with a load between, electrons flow to the cathode and join the catalyst that side of the PEM. Oxygen flowing in joins with the protons and electrons on the catalyst creating water. Often a capacitor is used as an energy store for high power demand (Liu *et al.*, 2020).

Maximum efficiency at 80°C

Enthalpy of reaction:

$$\Delta H = (h_f)_{H_2O} - (h_f)_{H_2} - 1/2(h_f)_{O_2}$$

$$\Delta H = -286.02 - 0 - 0$$



Gibbs Free Energy

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta S = (s_f)_{H_2O} - (s_f)_{H_2} - 1/2(s_f)_{O_2}$$

$$\Delta S = 0.06996 - 0.13066 - 1/2 \cdot 0.20517 = -0.163285$$

$$\therefore \text{if } T = 353.15K$$

$$\Delta G = -286 - (353.15 \cdot -0.163285) = -228 \text{ kJ/mol}$$

Theoretical maximum Thermal efficiency (not achievable)

$$\eta = \Delta G / \Delta H = -228 / -286.02 = 79\%$$

Presently, most hydrogen is produced from steam reforming of hydrocarbons; it is possible to make from electrolysis, but this will use more grid energy which is still reliant on fossil fuels and wood burning. Hydrogen is not currently readily available at fuel pumps. This makes fuel cells less environmentally friendly than claimed, even though the only tail pipe emission is water.

Tank packaging is a major difficulty as the best shape for a pressure vessel tank to reduce wall thickness and, therefore mass, is a sphere. The next best alternative is a

cylinder but neither of these can be as easy to package as a non-pressured fuel tank or batteries.

4.6.4 Range Extenders and downsizing

The original engine is overpowered for the drive cycle there is scope to downsize the engine, but this would limit its use of the vehicle.

As ICE engines are fuelled with high energy density fuel the EV option explored could increase its range with a 2-stroke engine powering a generator.

4.6.5 Flywheel KERS

The method of application investigated used a CVT box to attach a flywheel KERS system to the final drive. Alternatively, an electric motor generator can be used (Wicki and Hansen, 2017).

Advantages:

- No running emissions in deployment
- High Energy Density
- High efficiencies
- Fast Response

Disadvantages:

- Packaging (Pullen, 2019)
- Expensive design needing magnet bearings and composite disc inners (to keep high mass moment of inertia at lower mass) (Dagnaes-Hansen and Santos, 2018).
- Heavy casing to form protection from exploding Flywheels (Mousavi G *et al.*, 2017).
- Needs vacuum to reduce drag losses
- Self-discharge higher than capacitor or battery
- Gyroscopic forces can affect vehicle handling

4.6.6 Pneumatic KERS

This utilises engine braking to use the engine as an air pump to pump up a pressure vessel during deceleration. When accelerating, the air can be used to drive the engine, pumping compressed air without fuel, or for increasing the volumetric efficiency of the ICE engine. To allow this, the valve timing needs to be adjustable and, fuel and spark need to be adjusted by the system (Gabriel-Buenaventura and Azzopardi, 2015).

.

Advantages:

- No running emissions in deployment
- Lower Cost than Lithium ion batteries in power density
- No need for electric motors

Disadvantages:

- Packaging (pressure vessel)
- Lower power Density than Capacitor
- Adapting valve timing and engine management
- Matching vessel size to use (to large unusable to small wasted capacity)
- During discharge temperature drops reducing pressure reducing effectiveness

5 Part 4 Specification

5.1 Political policies and criteria

The brief asks to consider production for 2028 that will be politically and economically viable. Any proposed design for production will need to have a minimum life cycle of 8 years. This will take it beyond the 2035 petrol diesel ban. Although the ban does not state all internal combustion it is too vague in its current form to pursue them as an alternative powertrain.

5.2 Decision Matrixes

To evaluate all the alternative powertrains investigated different criteria was scored with 5 best 1 worst and put into a decision matrix.

Criteria:

Cost. Fuel cells being the most expensive with platinum catalysts, alternative fuels being the least expensive as some vehicles can already run on higher ethanol content.

Availability: this is how easy it is to obtain the equipment for conversion or how many suppliers of the technology there are.

Energy Density: As carrying mass increases energy consumption.

Power: This is measured if the vehicle proposed needs to perform a more arduous drive cycle in future.

Reliability: This is difficult to define as it varies with quality but as a technology it was assessed with fuel cells coming out top as they have no moving parts but they still rely on an electric motor being the weak link. Biofuel has lowered alternative fuel reliability as it causes high pressure pump problems in diesels.

Safety: Transporting any high energy has danger being chemical/gas combustible fuel or volatile battery chemistry and high voltages with enough current charge to kill.

Tail Pipe Emission: This was weighted as consumers believe that EV or Hydrogen fuel cell are completely green as they are ignorant to manufacturing waste and energy production. This has been double weighted as consumers would benefit and be incentivised to buy through lower tax and manufactures are fined for higher fleet emissions.

Political: with the 2035 petrol diesel ban all ICE engines have been scored low.

Handling Effect: Increasing the mass, packaging a cylinder in positions raising the centre of gravity and carrying a gyro have all lowered the score

Ease of Installation: this is measured as having to redesign an entire vehicle is prohibitive. This is why Jaguar made the mild hybrids which maintain the same body in white (even though their environmental impact was negative compared to traditional ICE as there was negligible efficiency gains at the cost of producing lithium ion batteries and all associated parts).

5.2.1 Decision Matrix overall

Metric	Alternative fuel	Capacitor + ICE	Compressed Air + ICE	Downsize	Range Extender	Start Stop	Hydrogen Fuel Cell	Flywheel + ICE	EV with Capacitor
Cost	5	3	3	4	2	4	1	3	2
Avaliability	4	4	3	5	2	5	1	2	3
Energy Density	5	2	2	5	3	5	4	4	3
Power	5	2	3	4	2	5	3	4	4
Reliability	3	3	2	4	3	4	5	3	3
Safety	4	4	3	4	4	4	4	3	4
Tail Pipe Emissions	1	2	2	1	3	1	5	2	5
Political	1	2	2	1	3	1	5	2	5
Handling effect	5	5	3	3	3	5	3	1	4
Ease of Installation	5	4	4	5	4	4	2	3	3
Sum	39	33	29	37	32	39	38	29	41

The decision matrix shows the best route would be EV Battery with capacitor. This is only due to the 2035 regulations weighing so heavily against ICE engines. Ignoring the double weighted tail pipe emissions and political criteria from an engineering and cost point of view is shown in the following matrix.

5.2.2 Decision matrix without political and tail pipe

Metric	Alternative fuel	Capacitor + ICE	Compressed Air + ICE	Downsize	Range Extender	Start Stop	Hydrogen Fuel Cell	Flywheel + ICE	EV with Capacitor
Cost	5	3	3	4	2	4	1	3	2
Avaliability	4	4	3	5	2	5	1	2	3
Energy Density	5	2	2	5	3	1	4	4	3
Power	5	2	3	4	2	1	3	4	4
Reliability	3	3	2	4	3	4	5	3	3
Safety	4	4	3	4	4	4	4	3	4
Handling effect	5	5	3	3	3	5	3	1	4
Ease of Installation	5	4	4	5	4	4	2	3	3
Sum	36	27	23	34	23	28	23	23	26

This shows that maintaining the century improved ICE unit is the best option from an engineering and cost perspective.

5.2.3 Decision matrix without costs and political

Metric	Alternative fuel	Capacitor + ICE	Compressed Air + ICE	Downsize	Range Extender	Start Stop	Hydrogen Fuel Cell	Flywheel + ICE	EV with Capacitor
Energy Density	5	2	2	5	3	1	4	4	3
Power	5	2	3	4	2	1	3	4	4
Reliability	3	3	2	4	3	4	5	3	3
Safety	4	4	3	4	4	4	4	3	4
Handling effect	5	5	3	3	3	5	3	1	4
Sum	22	16	13	20	15	15	19	15	18

This shows even when the prohibitive cost of fuel cells and EV are removed still ICE powertrains are the best option due to their high energy density, power density and low mass having effect on handling.

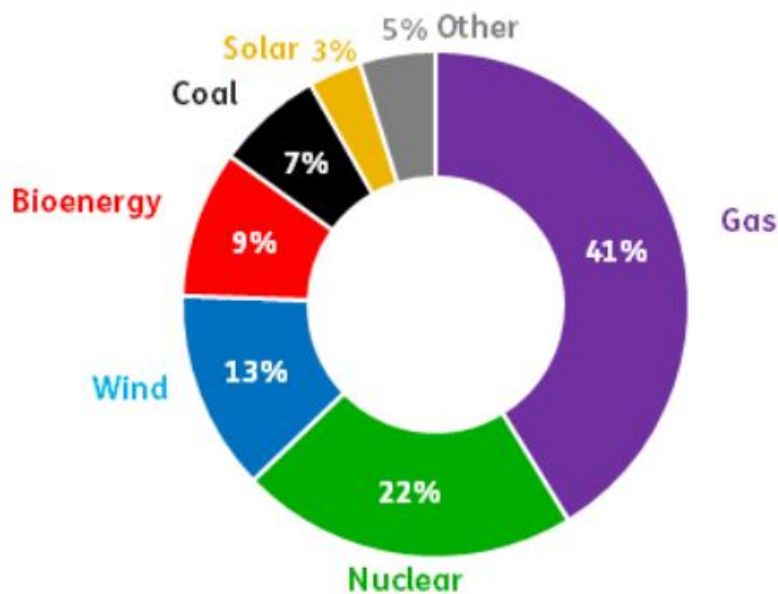
5.2.4 Specification to Pursue

The capacitor EV would be the chosen option as there is too much uncertainty in ICE. As the EV sales have been increasing where other vehicle sales have been decreasing this may make the sector more affordable as companies refine their manufacturing techniques, although extra demand for battery materials could push the price point higher then out of the more profitable high volume market (Ciez and Whitacre, 2016).

EV has the additional problem that consumers must be able to park in locations where charging is available at a reasonable price, ideally at home (Bonges and Lusk, 2016). There is also an electricity supply problem with the cheapest solution to plug the gap being fossil fuels. This shows that the legislative ban on petrol and diesel set for 2035 has not planned to meet the demands of the way the public currently use their vehicles.

6 Conclusion

The following figure shows only 18% of energy currently comes from renewable sources. The 3% solar energy also has a negative impact on the environment with needing allot of energy to create them and large amounts of waste chemicals left from there production (Nunez, 2014). This means that any of the proposed methods will take a large portion of energy from fossil fuels.



Furthermore, when investigating the production of hydrogen, electricity, alternative fuels, battery materials and electric motor components it is found that they all have a massive environmental impact even though they are marketed as clean.

The drive cycle showed that reducing mass, reduces energy consumption which EV vehicles struggle to do with their low energy density which agrees with (Weiss *et al.*, 2020). EV was the chosen path to pursue as its initial costs are less prohibitive than fuel cells but their powertrains are still 3 times the cost of a traditional ICE (Weiss *et al.*, 2015).

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8 Appendices

8.1 Maxwell capacitors

Page 1 Document number: 1014696.7 maxwell.com DATASHEET 125V HEAVY TRANSPORTATION MODULE PRODUCT SPECIFICATIONS ELECTRICAL BMOD0063 P125 B08 Rated Capacitance1 63 F Minimum Capacitance, initial1 63 F Maximum Capacitance, initial1 76 F Maximum ESR DC, initial1 18 mΩ Test Current for Capacitance and ESRDC 1 100 A Rated Voltage 125 V Absolute Maximum Voltage2 136 V Absolute Maximum Current 1900 A Leakage Current at 25o C, maximum 3 10 mA Maximum Series Voltage 1500 V Capacitance of Individual Cells11 3000 F

Maximum Stored Energy, Individual Cell 11 3.0 Wh Number of Cells 48

TEMPERATURE Operating temperature range (Cell case temperature) Minimum -40o C Maximum 65o C Storage temperature range (Stored uncharged) Minimum -40o C Maximum 70o C FEATURES AND BENEFITS* Up to 1,000,000 duty cycles or 10 year DC life 125V DC working voltage Active cell balancing Temperature and voltage monitoring CAN bus digital monitoring and communications High power density

TYPICAL APPLICATIONS Buses Electric trains and trolleys Heavy duty transportation Cranes, RTGS Utility vehicles Mining equipment *Results may vary. Additional terms and conditions, including the limited warranty, apply at the time of purchase. See the warranty details and enclosed information for applicable operating and use requirements. Page 2 Document number: 1014696.7 maxwell.com DATASHEET 125V HEAVY TRANSPORTATION MODULE PRODUCT SPECIFICATIONS (Cont'd)

PHYSICAL BMOD0063 P125 B08 Mass, typical 13 61 kg Power Terminals Radsok® Recommended Torque - Terminal N/A Vibration Specification ISO16750-3 Table 14 Shock Specification SAE J2464 Environmental Protection IP65 Cooling Forced Air

MONITORING / CELL VOLTAGE MANAGEMENT Temperature Interface Serial Data (CAN) Cell Voltage Monitoring Group Voltage (CAN) Connector Deutsch DTM Cell Voltage Management VMS 2.0 POWER & ENERGY Usable Specific Power, Pd 4 1,700 W/kg Impedance Match Specific Power, Pmax 5 3,600 W/kg Specific Energy, Emax 6 2.3 Wh/kg Stored Energy, Estored 7 140 Wh SAFETY Short Circuit Current, typical (Current possible with short circuit from rated voltage. Do not use as an operating current.) 6,900 A Certifications RoHS, eMark High-Pot Capability 12 4,000 VAC Page 3 Document number: 1014696.7 maxwell.com DATASHEET 125V HEAVY TRANSPORTATION MODULE LIFE DC Life at High Temperature 1 (at Rated Voltage & Maximum Operating Temperature) 1,500 hours Capacitance Change (% decrease from minimum initial value) 20% ESR Change (% increase from maximum initial value) 100% Projected DC Life at 25o C 1 (held continuously at Rated Voltage) 10 years Capacitance Change (% decrease from minimum initial value) 20% ESR Change (% increase from maximum initial value) 100% Projected Cycle Life at 25o C 1,9,10 1,000,000 cycles Capacitance Change (% decrease from minimum initial value) 20% ESR Change (% increase from maximum initial value) 100% Test Current 100 A Shelf Life (Stored uncharged at 25o C) 4 years TYPICAL CHARACTERISTICS THERMAL CHARACTERISTICS BMOD0063 P125 B08 Thermal Resistance (Rca, Case to Ambient), typical 8 0.04o C/W Thermal Capacitance (Cth), typical 33,000 J/o C Maximum Continuous Current ($\Delta T = 150$ C) 8 140 ARMS Maximum Continuous Current

($\Delta T = 40^\circ\text{C}$) 8 240 ARMS Page 4 Document number: 1014696.7 maxwell.com

DATASHEET 125V HEAVY TRANSPORTATION MODULE ESR AND CAPACITANCE VS TEMPERATURE NOTES

1. Capacitance and ESRDC measured at 25°C using specified test current per waveform below.
2. Absolute maximum voltage, non-repeated. Not to exceed 1 second.
3. After 72 hours at rated voltage. Initial leakage current can be higher.
4. Per IEC 62391-2, $P_d = 5$.
5. $P_{\max} = 6$.
6. $E_{\max} = 7$.
7. $E_{\text{stored}} = 0.12V^2 \text{ ESRDC} \times \text{mass}$
8. $\Delta T = I_{\text{RMS}}^2 \times \text{ESR} \times R_{\text{ca}}$
9. Cycle using specified test current per waveform below.
10. Cycle life varies depending upon application-specific characteristics. Actual results will vary.
11. Per United Nations material classification UN3499, all Maxwell ultracapacitors have less than 10 Wh capacity to meet the requirements of Special Provisions 361. Both individual ultracapacitors and modules composed of those ultracapacitors shipped by Maxwell can be transported without being treated as dangerous goods (hazardous materials) under transportation regulations.
12. Duration = 60 seconds. Not intended as an operating parameter.
13. Without fan. With fan, mass is 63.4 kg.

$\frac{1}{2} \text{ CV2 } 3,600 \times \text{mass}$

Page 5 Document number: 1014696.7 maxwell.com

DATASHEET 125V HEAVY TRANSPORTATION MODULE

Part Description	Dimensions (mm)	L ($\pm 0.5\text{mm}$)	D ($\pm 0.2\text{mm}$)	H ($\pm 0.7\text{mm}$)
Package Quantity	BCAP0063 P125 B08*	619	33.3	265
	1 BCAP0063 P125 B08			

MOUNTING RECOMMENDATIONS Please refer to the user manual for installation recommendations.

MARKINGS Products are marked with the following information: Rated capacitance, rated voltage, product number, name of manufacturer, positive and negative terminal, warning marking, serial number. *Refer to user manual for product variant details

Page 6 Document number: 1014696.7 maxwell.com

DATASHEET 125V HEAVY TRANSPORTATION MODULE Maxwell Technologies, Inc. Global Headquarters 3888 Calle Fortunada San Diego, CA 92123 USA Tel: +1 858 503 3300 Fax: +1 858 503 3301 Maxwell Technologies SA Route de Montena 65 CH-1728 Rossens Switzerland Tel: +41 (0)26 411 85 00 Fax: +41 (0)26 411 85 05 Maxwell Technologies, GmbH Leopoldstrasse 244 80807 München Germany Tel: +49 (0)89 / 4161403 0 Fax: +49 (0)89 / 4161403 99 Maxwell Technologies Shanghai Trading Co. Ltd. Unit A2,C 12th Floor Huarun Times Square 500 Zhangyang Road, Pudong New Area Shanghai 200122, P.R. China Phone: +86 21 3852 4000 Fax: +86 21 3852 4099 Maxwell Technologies Korea Co., Ltd. Room 1524, D-Cube City Office Tower, 15F #662 Gyeongin-Ro, Guro-Gu, Seoul, 152-706 South Korea Phone: +82 10 4518 9829

Product dimensions are for reference only unless otherwise identified. Product dimensions and specifications may change without notice. Please contact Maxwell Technologies directly for any technical

specifications critical to application. All products featured on this datasheet are covered by the following U.S. patents and their respective foreign counterparts: 6643119, 7295423, 7342770, 7352558, 7384433, 7440258, 7492571, 7508651, 7791860, 7791861, 7816891, 7859826, 7883553, 7935155, 8072734, 8098481, 8279580, and patents pending. MAXWELL TECHNOLOGIES, MAXWELL, MAXWELL CERTIFIED INTEGRATOR, ENABLING ENERGY'S FUTURE, BOOSTCAP, C CELL, D CELL and their respective designs and/or logos are either trademarks or registered trademarks of Maxwell Technologies, Inc. and may not be copied, imitated or used, in whole or in part, without the prior written permission Maxwell Technologies, Inc. All contents copyright © 2013 Maxwell Technologies, Inc. All rights reserved. No portion of these materials may be reproduced in any form, or by any means, without prior written permission from Maxwell Technologies, Inc. ORDERING INFORMATION Base Module 109024B BMOD0063 P125 B08 63F/125V eMark Module with CAN Communication Power Connection Kit 109131 Power Connection Kit, 90 DEG 109132 Power Connection Kit, STRAIGHT Communication Kit 109133 CAN SIGNAL, Deutsch Fan Kit 129036 FAN KIT, 24V, eMark

8.1.1 Yasa Motors

Page 1 Document number: 1014696.7 maxwell.com DATASHEET 125V HEAVY TRANSPORTATION MODULE PRODUCT SPECIFICATIONS ELECTRICAL BMOD0063 P125 B08 Rated Capacitance1 63 F Minimum Capacitance, initial1 63 F Maximum Capacitance, initial1 76 F Maximum ESR DC, initial1 18 mΩ Test Current for Capacitance and ESRDC 1 100 A Rated Voltage 125 V Absolute Maximum Voltage2 136 V Absolute Maximum Current 1900 A Leakage Current at 25o C, maximum 3 10 mA Maximum Series Voltage 1500 V Capacitance of Individual Cells11 3000 F Maximum Stored Energy, Individual Cell11 3.0 Wh Number of Cells 48 TEMPERATURE Operating temperature range (Cell case temperature) Minimum -40o C Maximum 65o C Storage temperature range (Stored uncharged) Minimum -40o C Maximum 70o C FEATURES AND BENEFITS* Up to 1,000,000 duty cycles or 10 year DC life 125V DC working voltage Active cell balancing Temperature and voltage monitoring CAN bus digital monitoring and communications High power density TYPICAL APPLICATIONS Buses Electric trains and trolleys Heavy duty transportation Cranes, RTGS Utility vehicles Mining equipment *Results may vary. Additional terms and conditions, including the limited warranty, apply at the time of purchase. See the warranty details and enclosed information for applicable operating and use requirements. Page 2 Document number: 1014696.7 maxwell.com DATASHEET

125V HEAVY TRANSPORTATION MODULE PRODUCT SPECIFICATIONS (Cont'd)

PHYSICAL BMOD0063 P125 B08 Mass, typical 13.61 kg Power Terminals Radsok®

Recommended Torque - Terminal N/A Vibration Specification ISO16750-3 Table 14

Shock Specification SAE J2464 Environmental Protection IP65 Cooling Forced Air

MONITORING / CELL VOLTAGE MANAGEMENT Temperature Interface Serial Data

(CAN) Cell Voltage Monitoring Group Voltage (CAN) Connector Deutsch DTM Cell

Voltage Management VMS 2.0 POWER & ENERGY Usable Specific Power, P_d 4 1,700

W/kg Impedance Match Specific Power, P_{max} 5 3,600 W/kg Specific Energy, E_{max} 6 2.3

Wh/kg Stored Energy, E_{stored} 7 140 Wh SAFETY Short Circuit Current, typical

(Current possible with short circuit from rated voltage. Do not use as an operating

current.) 6,900 A Certifications RoHS, eMark High-Pot Capability 12 4,000 VAC Page 3

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TRANSPORTATION MODULE LIFE DC Life at High Temperature 1 (at Rated Voltage

& Maximum Operating Temperature) 1,500 hours Capacitance Change (% decrease

from minimum initial value) 20% ESR Change (% increase from maximum initial value)

100% Projected DC Life at 25°C 1 (held continuously at Rated Voltage) 10 years

Capacitance Change (% decrease from minimum initial value) 20% ESR Change (%)

increase from maximum initial value) 100% Projected Cycle Life at 25°C 1,9,10

1,000,000 cycles Capacitance Change (% decrease from minimum initial value) 20% ESR

Change (% increase from maximum initial value) 100% Test Current 100 A Shelf Life

(Stored uncharged at 25°C) 4 years TYPICAL CHARACTERISTICS THERMAL

CHARACTERISTICS BMOD0063 P125 B08 Thermal Resistance (R_{ca} , Case to

Ambient), typical 8 0.04°C/W Thermal Capacitance (C_{th}), typical 33,000 J/°C

Maximum Continuous Current ($\Delta T = 150^\circ\text{C}$) 8 140 ARMS Maximum Continuous Current

($\Delta T = 400^\circ\text{C}$) 8 240 ARMS Page 4 Document number: 1014696.7 maxwell.com

DATASHEET 125V HEAVY TRANSPORTATION MODULE ESR AND CAPACITANCE

VS TEMPERATURE NOTES 1. Capacitance and ESRDC measured at 25°C using

specified test current per waveform below. 2. Absolute maximum voltage, non-repeated.

Not to exceed 1 second. 3. After 72 hours at rated voltage. Initial leakage current can be

higher. 4. Per IEC 62391-2, $P_d = 5$. $P_{max} = 6$. $E_{max} = 7$. $E_{stored} = 0.12V^2 \text{ ESRDC} \times$

mass $V^2 \times 4 \times \text{ESRDC} \times \text{mass} \times \frac{1}{2} \times CV^2 \times 3,600 \times \text{mass}$ 8. $\Delta T = IR_{MS} \times 2 \times \text{ESR} \times R_{ca}$ 9. Cycle

using specified test current per waveform below. 10. Cycle life varies depending upon

application-specific characteristics. Actual results will vary. 11. Per United Nations

material classification UN3499, all Maxwell ultracapacitors have less than 10 Wh

capacity to meet the requirements of Special Provisions 361. Both individual

ultracapacitors and modules composed of those ultracapacitors shipped by Maxwell can be transported without being treated as dangerous goods (hazardous materials) under transportation regulations. 12. Duration = 60 seconds. Not intended as an operating parameter. 13. Without fan. With fan, mass is 63.4 kg. ½ CV2 3,600 Page 5 Document number: 1014696.7 maxwell.com DATASHEET 125V HEAVY TRANSPORTATION MODULE Part Description Dimensions (mm) L (± 0.5mm) D (± 0.2mm) H(±0.7mm) Package Quantity BCAP0063 P125 B08* 619 33.3 265 1 BCAP0063 P125 B08 MOUNTING RECOMMENDATIONS Please refer to the user manual for installation recommendations. MARKINGS Products are marked with the following information: Rated capacitance, rated voltage, product number, name of manufacturer, positive and negative terminal, warning marking, serial number. *Refer to user manual for product variant details Page 6 Document number: 1014696.7 maxwell.com DATASHEET 125V HEAVY TRANSPORTATION MODULE Maxwell Technologies, Inc. Global Headquarters 3888 Calle Fortunada San Diego, CA 92123 USA Tel: +1 858 503 3300 Fax: +1 858 503 3301 Maxwell Technologies SA Route de Montena 65 CH-1728 Rossens Switzerland Tel: +41 (0)26 411 85 00 Fax: +41 (0)26 411 85 05 Maxwell Technologies, GmbH Leopoldstrasse 244 80807 München Germany Tel: +49 (0)89 / 4161403 0 Fax: +49 (0)89 / 4161403 99 Maxwell Technologies Shanghai Trading Co. Ltd. Unit A2,C 12th Floor Huarun Times Square 500 Zhangyang Road, Pudong New Area Shanghai 200122, P.R. China Phone: +86 21 3852 4000 Fax: +86 21 3852 4099 Maxwell Technologies Korea Co., Ltd. Room 1524, D-Cube City Office Tower, 15F #662 Gyeongin-Ro, Guro-Gu, Seoul, 152-706 South Korea Phone: +82 10 4518 9829 Product dimensions are for reference only unless otherwise identified. Product dimensions and specifications may change without notice. Please contact Maxwell Technologies directly for any technical specifications critical to application. All products featured on this datasheet are covered by the following U.S. patents and their respective foreign counterparts: 6643119, 7295423, 7342770, 7352558, 7384433, 7440258, 7492571, 7508651, 7791860, 7791861, 7816891, 7859826, 7883553, 7935155, 8072734, 8098481, 8279580, and patents pending. MAXWELL TECHNOLOGIES, MAXWELL, MAXWELL CERTIFIED INTEGRATOR, ENABLING ENERGY'S FUTURE, BOOSTCAP, C CELL, D CELL and their respective designs and/or logos are either trademarks or registered trademarks of Maxwell Technologies, Inc. and may not be copied, imitated or used, in whole or in part, without the prior written permission Maxwell Technologies, Inc. All contents copyright © 2013 Maxwell Technologies, Inc. All rights reserved. No portion of these materials may be reproduced in any form, or by any means, without prior written permission from

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KIT, 24V, eMark