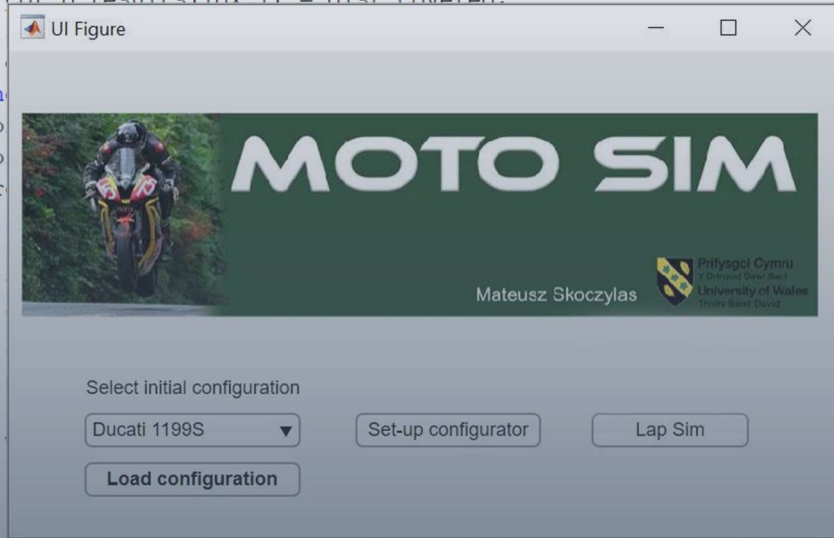


University of Wales Trinity Saint David

School of Engineering

```
988 %>Section B
989 -   idx = 1;
990 -   for i = 1:track_cor_b_dist
991 -       cor_b_results(idx,1) = dist_covered;
992 -
993 -
994 -   en
995 -   co
996 -   co
997 -   if r
998 -
999 -
1000 -
1001 -
1002 -
1003 -
1004 -
1005 -
1006 -
1007 -
1008 -
1009 -   str_a_results(idx,2) = sqrt(str_a_results(idx-1,2)+2*tmp_deaccel);
1010 -   str_a_results(idx,3) = tmp_deaccel;
1011 -   str_a_results(idx,4) = (1/str_a_results(idx,2))+str_a_results(idx-1,4);
1012 -   idx_update = idx;
1013 -   for i = 1:idx_size-idx
1014 -       tmp_idx_vel = find(round(combined_deaccel_limit(:,2),1) == round
1015 -       tmp_deaccel = combined_deaccel_limit(tmp_idx_vel,1);
1016 -       idx_update = idx_update+1;
1017 -       str_a_results(idx_update,2) = sqrt(str_a_results(idx_update-1,2)
1018 -       str_a_results(idx_update,3) = tmp_deaccel;
1019 -       str_a_results(idx_update,4) = (1/str_a_results(idx_update,2))+st
1020 -   end
1021 -   end
```



Motorcycle lap time simulation

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Acknowledgements

Thanks to;

- NS for providing the InterX function for Matlab which I've used to find curve intersection coordinates.
- Vittore Cossalter for providing various typical inertia values and drag coefficients as found in the Motorcycle Dynamics book, which I've used alongside lecture notes to produce a lap time simulator.

1 Introduction

Through the use of MATLAB, I have created a lap time simulator that is fully dynamic. It supports any manual motorcycle that contains up to 7 gears. A power curve (RPM & RWHP) must be provided as well as some other specifications outlined in the 'adding new bike or modifying existing configuration' document. To validate my simulated results, I compare them against real data (Ducati 1199S, ridden by Michael Neeves). I have also included files for a different bike (Yamaha XJ600 restricted to 33RWHP) to test how my code reacts to a vastly different configuration.

I have divided the code into two parts, 'bike sim' and 'lap sim'. The 'bike sim' makes all the prerequisite calculations required for the lap sim to work, such as the optimal RPM the bike needs to shift at as it accelerates in the sim.

2 Bike specifications file



The values below show the figures that I have used for the Ducati 1199S. Geometry values were retrieved through measurement of the Ducati 1199S in the university workshop. The inertia values used are from example data in Motorcycle Dynamics book (Cossalte, 2006) (chapter 3.4.1 example 6). The C_D value used was also from the same book (chapter 3.1.1), a typical value for a faired sports bike. The traction coefficient was set to 1.2 (Richard F. Lambourn, 2010) as that was a value that an SAE research paper suggested, however, I have ended up adjusting it to 1.35 for version 2 of lap sim through experimentation (more on that in the analysis section). Gear ratios were acquired through a motorcycle specifications website (MCS, n.d.).

```
p = 1.167 kg/m3 Density of air - 1.167 @20c & 987 mbar
CD = 0.5 Coefficient of drag
A(tucked in) = 0.7 m2 Frontal area with rider tucked in
A(braking) = 0.8 m2 Frontal area with a rider in a braking position
m = 269 kg Wet mass with a rider
Rolling resistance = 2 % Rolling resistance as a percentage of gravity force
If = 0.6 kgm2 Inertia front wheel
Ir = 0.8 kgm2 Inertia rear wheel
Ip = 0.005 kgm2 Inertia primary shaft
Is = 0.007 kgm2 Inertia secondary shaft
Im = 0.05 kgm2 Inertia engine

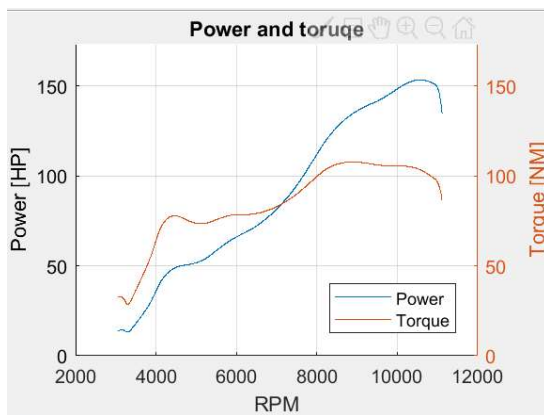
μ = 1.2 Tyre coefficient of friction
p = 1.437 m Wheelbase
b = 0.7 m Rear wheel to COG horizontally
h = 0.65 m Height to COG vertically
RF = 0.32 m Front wheel radius
RR = 0.32 m Rear wheel radius
```

```

Gearbox° = 6 Number of gears
τprimary = 1.77 Primary drive ratio
τ1 = 37/15 1st gear gearbox ratio
τ2 = 30/16 2nd gear gearbox ratio
τ3 = 27/18 3rd gear gearbox ratio
τ4 = 25/20 4th gear gearbox ratio
τ5 = 24/22 5th gear gearbox ratio
τ6 = 23/24 6th gear gearbox ratio
τfinal = 39/15 Final drive ratio

```

3 Dyno file



The dyno file contains power values at the wheel.

Imported from maha dynamometer .csv file.

Torque in Nm is worked out using the formula

$$Torque (Nm) = \left(Power(HP) * \frac{5252}{RPM} \right) * 1.36$$

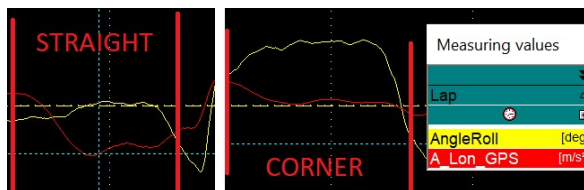
For calculations involving SI units, Horsepower is converted to Watts by multiplying by 745.7. The symbol assigned to power (W) is P

```

Max power = 153 RWHP
Max torque @ wheel = 108 Nm

```

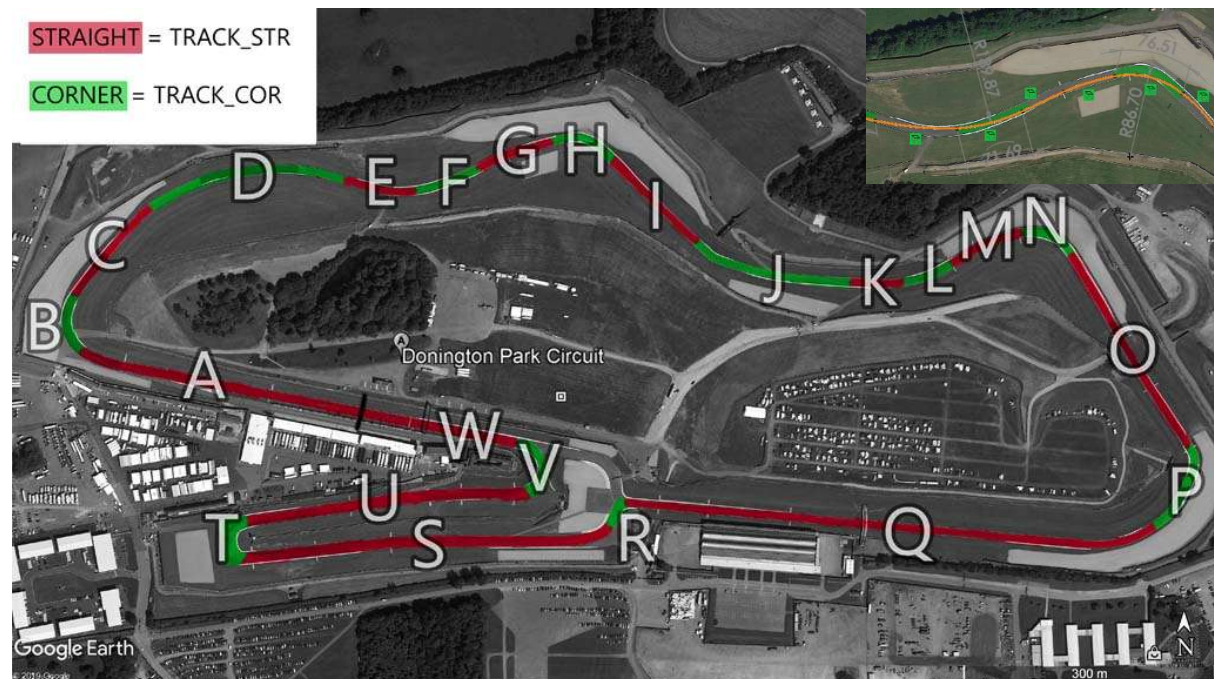
4 Track mapping



I have considered multiple different ways of mapping Donnington Park (GP layout). My final method of deciding whether to treat a segment as a straight or a corner was to analyse real rider

data in 2D Analyzer and use longitudinal acceleration as a guide. In some cases, I saw the rider at close to full acceleration even above 30 degrees of lean angle, and it varied from corner to corner, thus, looking at lean angle alone isn't the best method. Knowing that the ideal lean angle mathematical equation for cornering velocity doesn't factor in acceleration mid-corner, I mapped the areas that had close to no acceleration combined with a lean angle above ~25 degrees as corners. I took the average lean angle per corner individually from the real rider data, and later used this to calculate simulated corner velocity using rearranged ideal lean angle equation

Knowing which sections I could treat as corners, I mapped the track in Solidworks and exported the measurements into a MATLAB readable file.



Corner B = 45°
Corner D = 38°
Corner F = 48°
Corner H = 48°
Corner J = 40°
Corner L = 43°
Corner N = 45°
Corner P = 45°
Corner R = 27°
Corner T = 40°
Corner V = 43°

5 Building the bike sim

```

====Lap Sim====
Acceleration multiplier enabled: 0.85
Deceleration multiplier enabled: 0.67
Real vs sim comparison mode enabled
Corner distance: 1051 m
Straight distance: 2898 m
Total distance: 3949 m

Start line velocity (calculated): 50.7m/s
Start line velocity (real): 56.1m/s
SIM SECTOR A - Time: 7.4s, On throttle: 198.0m (57.4 percent), Avg velocity: 48.9m/s, Min & max accel: -8.7/4.6ms^-2
SIM SECTOR B - Time: 2.7s, Avg velocity: 25.2m/s
SIM SECTOR C - Time: 3.7s, On throttle: 5.0m (3.6 percent), Avg velocity: 38.3m/s, Min & max accel: -7.8/6.8ms^-2
SIM SECTOR D - Time: 5.1s, Avg velocity: 46.3m/s
SIM SECTOR E - Time: 1.8s, On throttle: 35.0m (40.2 percent), Avg velocity: 48.6m/s, Min & max accel: -8.0/4.9ms^-2
SIM SECTOR F - Time: 1.6s, Avg velocity: 45.5m/s
SIM SECTOR G - Time: 3.3s, On throttle: 100.0m (74.6 percent), Avg velocity: 41.8m/s, Min & max accel: -7.9/5.0ms^-2
SIM SECTOR H - Time: 2.5s, Avg velocity: 30.7m/s
SIM SECTOR I - Time: 3.2s, On throttle: 133.0m (100.0 percent), Avg velocity: 41.7m/s, Min & max accel: 4.7/6.8ms^-2
SIM SECTOR J - Time: 4.1s, Avg velocity: 49.6m/s
SIM SECTOR K - Time: 1.4s, On throttle: 34.0m (46.6 percent), Avg velocity: 50.7m/s, Min & max accel: -8.1/4.7ms^-2
SIM SECTOR L - Time: 1.2s, Avg velocity: 47.5m/s
SIM SECTOR M - Time: 2.9s, On throttle: 106.0m (97.2 percent), Avg velocity: 38.2m/s, Min & max accel: -7.8/4.8ms^-2
SIM SECTOR N - Time: 2.4s, Avg velocity: 27.8m/s
SIM SECTOR O - Time: 6.8s, On throttle: 114.0m (42.1 percent), Avg velocity: 40.9m/s, Min & max accel: -7.9/6.8ms^-2
SIM SECTOR P - Time: 3.9s, Avg velocity: 30.0m/s
SIM SECTOR Q - Time: 13.6s, On throttle: 238.0m (37.2 percent), Avg velocity: 49.9m/s, Min & max accel: -8.9/6.8ms^-2
SIM SECTOR R - Time: 1.2s, Avg velocity: 23.0m/s
SIM SECTOR S - Time: 11.7s, On throttle: 198.0m (45.1 percent), Avg velocity: 40.8m/s, Min & max accel: -8.4/6.8ms^-2
SIM SECTOR T - Time: 3.3s, Avg velocity: 15.6m/s
SIM SECTOR U - Time: 10.2s, On throttle: 152.0m (44.8 percent), Avg velocity: 36.0m/s, Min & max accel: -7.9/6.8ms^-2
SIM SECTOR V - Time: 4.1s, Avg velocity: 18.6m/s
SIM SECTOR W - Time: 5.3s, On throttle: 191.0m (100.0 percent), Avg velocity: 38.3m/s, Min & max accel: 4.6/6.8ms^-2
SIM total lap time: 01:43:416
Real total lap time: 01:44:290>>

```

5.1 Velocity per gear

C_R = Circumference rear wheel (m)

R_R = Radius rear wheel (m)

$$C_R = 2 * \pi * R_R$$

$$C_{R\text{Ducati 11992}} = 2.01\text{m}$$

1st gear velocity example (this is repeated for all gearbox ratios):

τ_{PRIMARY} = Primary drive ratio

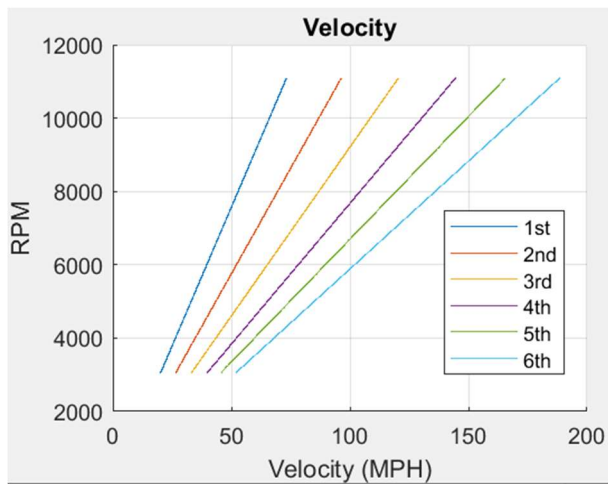
τ_1 = 1st gear ratio (output/input shaft only)

τ_{FINAL} = Final drive ratio (sprockets)

V = Velocity

$$V = \frac{\frac{\text{RPM}}{60} * C_R}{\tau_{\text{PRIMARY}} * \tau_1 * \tau_{\text{FINAL}}}$$

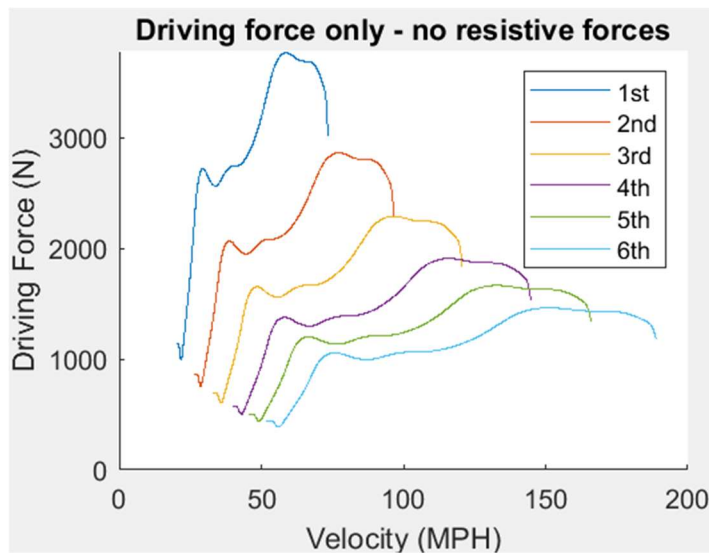
m/s to MPH multiplier: *2.24



Ducati 1199S:

1st gear max: 73 MPH
 2nd gear max: 97 MPH
 3rd gear max: 121 MPH
 4th gear max: 145 MPH
 5th gear max: 166 MPH
 6th gear max: 189 MPH

5.2 Driving force with no resistive forces



S = Driving force (N)

P = Power (W)

V = Velocity (m/s)

$$S = \frac{P}{V}$$

(This is repeated for all gears)

5.3 Net driving force (with resistive forces)

5.3.1 Rolling resistance force

F_R = Rolling friction (N) (assumed to be 2% of gravity force)

m = mass (kg)

$$F_R = \left(\frac{\text{Rolling resistance (\%)}}{100} \right) * m * 9.81$$

$F_{R \text{ Ducati 1199S}} = 52.78 \text{ N}$

5.3.2 Aerodynamic drag force

F_D = Force of drag (N)

ρ = Density of air (kg/m³)

C_D = Coefficient of drag

A = Frontal area (A)

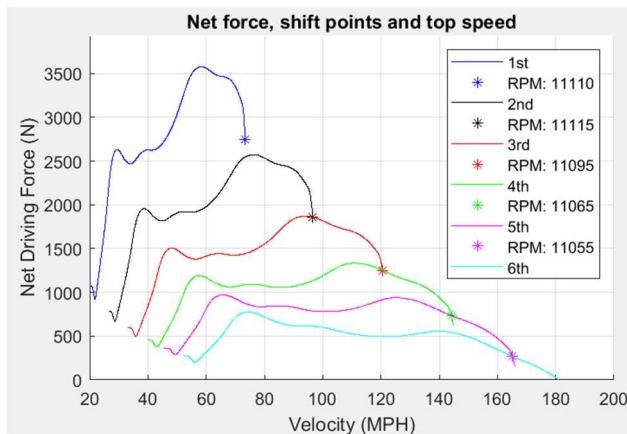
V = Velocity (m/s)

$$F_D = \frac{1}{2} \rho * C_D * A * V^2$$

(The force of drag is calculated twice. 1st calculation is with the frontal area of the rider tucked in (under acceleration), the 2nd calculation is with rider braced under braking.)

Drag force is exponential, thus, the higher the velocity the more increase in power is going to be needed to increase the velocity by 1mph.

5.3.3 Net driving force & shift points



S_{NET} = Net driving force (N)

S = Driving force (N)

F_D = Force of drag (N)

$$S_{NET} = S - F_D$$

The best rpm to shift at for maximum acceleration is where the driving force of one gear crosses over with another. I have used InterX MATLAB function to find the X and Y

coordinates of where driving force lines intercept. My velocity per gear array index is relative to the RPM per gear array index, thus knowing the velocity at the intercept, the script can output the optimal shifting RPM. The Ducati 1199S loses very little power towards the end of its RPM range unlike most other sportbikes like Yamaha R6/R1, and the power-band is fairly flat, thus the driving force lines do not always overlap. In gears where the lines do not intercept, it is assumed that the shift point is at maximum RPM. It is worth to note, that with the stock gearing, it seems that Ducati intended to design the camshaft (peak volumetric efficiency) & the intake/exhaust system (harmonics) so that the driving force is close to its peak after every gear change as long as the gears are shifted at optimum RPM.

The top speed occurs when the driving force and resistive forces are in equilibrium (assuming full throttle).

Ducati 1199S realistic V_{max} : 181 MPH

Optimal gear shift points: 1st 11110 RPM, 2nd 11115 RPM, 3rd 11095 RPM, 4th 11065 RPM, 5th 11055 RPM

5.4 Acceleration & deacceleration

$T\ddot{x}_{pos}$ = Traction limited acceleration (ms^{-2})

$T\ddot{x}_{neg}$ = Traction limited deacceleration (ms^{-2})

$W\ddot{x}$ = Wheelie limited acceleration (ms^{-2})

$E\ddot{x}$ = Endo limited deacceleration

$\ddot{x}_s$ = Driving force limited acceleration (ms^{-2})

μ = Tyre coefficient of friction

m = Mass (kg)

m^* = Reduced mass (kg)

g = Gravity (ms^{-2})

p = Wheelbase (m)

b = Rear wheel to centre of gravity horizontally (m)

h = Height to centre of gravity (m)

F_D = Force of drag (N)

m^* = Reduced mass (kg)

I_f = Inertia front wheel (kgm^2)

I_r = Inertia rear wheel (kgm^2)

I_s = Inertia secondary shaft (kgm^2)

I_p = Inertia primary shaft (kgm^2)

I_m = Inertia engine (kgm^2)

R_F = Radius front wheel (m)

R_R = Radius rear wheel (m)

$\tau_{PRIMARY}$ = Primary drive ratio

$\tau_{GEARBOX}$ = Gearbox ratio for the chosen gear

τ_{FINAL} = Final drive ratio

5.4.1 Reduced mass

$$m^* = m + I_f \left(\frac{1}{R_F}\right)^2 + I_r \left(\frac{1}{R_R}\right)^2 + I_s * \tau_{FINAL} \left(\frac{1}{R_R}\right)^2 + I_p * \tau_{PRIMARY} * \tau_{FINAL} \left(\frac{1}{R_R}\right)^2 \\ + I_m * \tau_{PRIMARY} * \tau_{GEARBOX} * \tau_{FINAL} \left(\frac{1}{R_R}\right)^2$$

1st gear reduced mass: 347.1 kg
 2nd gear reduced mass: 320.5 kg
 3rd gear reduced mass: 307.4 kg
 4th gear reduced mass: 300.3 kg
 5th gear reduced mass: 296.5 kg
 6th gear reduced mass: 293.7 kg

5.4.2 Acceleration equations

Traction limited

$$T\ddot{x}_{pos} = \frac{\mu mg(p-b) - F_D p + \mu F_D h}{pm^* - \mu m^* h}$$

Wheelie limited

$$W\ddot{x} = \frac{m}{m^*} g \frac{b}{h} - \frac{F_D}{m^*}$$

Driving force limited

$$\ddot{x}_s = \frac{s_{net}}{m}$$

5.4.3 Deacceleration Equations

Traction limited

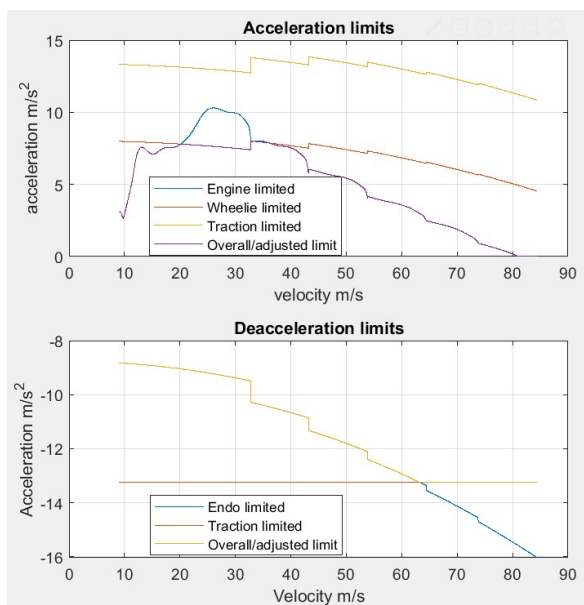
$$T\ddot{x}_{neg} = -(\mu g) \text{ (Cossalte, 2006)}$$

Endo limited

$$E\ddot{x} = \frac{1}{2} p C_D V^2$$

5.4.4 Results

The code is designed to calculate acceleration for each gear separately. This data is then automatically combined, based on the optimal shifting RPM calculated earlier. The 'overall limit' line shows the effective acceleration the bike will have, based on the limiting factor.



For acceleration, the results show that traction with a coefficient of 1.2 is not an issue at any velocity. The acceleration of the Ducati 1199s is mostly engine limited (net driving force). This, however, isn't true at velocities between 20m/s and 33m/s, where 1st gear is engaged, the acceleration will be wheelie limited.

Deacceleration is mostly endo limited (exponential), up to 64m/s where it becomes traction limited (linear).

6 Building the lap sim

```
====Lap Sim====
Acceleration multiplier enabled: 0.85
Deacceleration multiplier enabled: 0.67
Real vs sim comparison mode enabled
Corner distance: 1051 m
Straight distance: 2898 m
Total distance: 3949 m

Start line velocity (calculated): 50.7m/s
Start line velocity (real): 56.1m/s
SIM SECTOR A - Time: 7.4s, On throttle: 198.0m (57.4 percent), Avg velocity: 48.9m/s, Min & max accel: -8.7/4.6ms^-2
SIM SECTOR B - Time: 2.7s, Avg velocity: 25.2m/s
SIM SECTOR C - Time: 3.7s, On throttle: 5.0m (3.6 percent), Avg velocity: 38.3m/s, Min & max accel: -7.8/6.8ms^-2
SIM SECTOR D - Time: 5.1s, Avg velocity: 46.3m/s
SIM SECTOR E - Time: 1.8s, On throttle: 35.0m (40.2 percent), Avg velocity: 48.6m/s, Min & max accel: -8.0/4.9ms^-2
SIM SECTOR F - Time: 1.6s, Avg velocity: 45.5m/s
SIM SECTOR G - Time: 3.3s, On throttle: 100.0m (74.6 percent), Avg velocity: 41.8m/s, Min & max accel: -7.9/5.0ms^-2
SIM SECTOR H - Time: 2.5s, Avg velocity: 30.7m/s
SIM SECTOR I - Time: 3.2s, On throttle: 133.0m (100.0 percent), Avg velocity: 41.7m/s, Min & max accel: 4.7/6.8ms^-2
SIM SECTOR J - Time: 4.1s, Avg velocity: 49.6m/s
SIM SECTOR K - Time: 1.4s, On throttle: 34.0m (46.6 percent), Avg velocity: 50.7m/s, Min & max accel: -8.1/4.7ms^-2
SIM SECTOR L - Time: 1.2s, Avg velocity: 47.5m/s
SIM SECTOR M - Time: 2.9s, On throttle: 106.0m (97.2 percent), Avg velocity: 38.2m/s, Min & max accel: -7.8/4.8ms^-2
SIM SECTOR N - Time: 2.4s, Avg velocity: 27.8m/s
SIM SECTOR O - Time: 6.8s, On throttle: 114.0m (42.1 percent), Avg velocity: 40.9m/s, Min & max accel: -7.9/6.8ms^-2
SIM SECTOR P - Time: 3.9s, Avg velocity: 30.0m/s
SIM SECTOR Q - Time: 13.6s, On throttle: 238.0m (37.2 percent), Avg velocity: 49.9m/s, Min & max accel: -8.9/6.8ms^-2
SIM SECTOR R - Time: 1.2s, Avg velocity: 23.0m/s
SIM SECTOR S - Time: 11.7s, On throttle: 198.0m (45.1 percent), Avg velocity: 40.8m/s, Min & max accel: -8.4/6.8ms^-2
SIM SECTOR T - Time: 3.3s, Avg velocity: 15.6m/s
SIM SECTOR U - Time: 10.2s, On throttle: 152.0m (44.8 percent), Avg velocity: 36.0m/s, Min & max accel: -7.9/6.8ms^-2
SIM SECTOR V - Time: 4.1s, Avg velocity: 18.6m/s
SIM SECTOR W - Time: 5.3s, On throttle: 191.0m (100.0 percent), Avg velocity: 38.3m/s, Min & max accel: 4.6/6.8ms^-2
SIM total lap time: 01:43:416
Real total lap time: 01:44:290>>
```

6.1 Calculating the time taken

The time taken to complete each 1m of the track is calculated by rearranging the velocity formula

$$\text{for time: } T = \frac{d}{v}$$

Where;

T is time (s), d is the distance (m).

The time for every section is added up to produce the final simulated lap time.

6.2 Calculation of straights

The code is designed to recalculate the velocity based on the acceleration array, for every 1 metre of the track. The equation used to calculate velocity is derived from suvat: $v = \sqrt{u^2 + 2\ddot{x}}$

Where;

v is the current velocity (m/s), u is initial velocity (m/s) and $\ddot{x}$ is acceleration (ms^{-2}).

6.3 Calculation of corners

The velocity through a corner is calculated using the ideal lean angle equation rearranged for velocity. The lean angle used for the equation is assumed to be between 27 and 48 degrees as outlined at the beginning of the report.

$$\sqrt{r * g * \tan(\theta)}$$

Where;

r is the radius of the corner (m), g is gravity (ms^{-2}) and θ is the lean angle.

6.4 Corner entry speed lower than ideal

With lower power configurations, the simulator might encounter situations where the bike doesn't reach a speed required for a corner. In such cases, the velocity of the corner will be the entry speed as opposed to the ideal velocity.

```
SIM SECTOR K - Time: 1.7s, On throttle: 73.0m (100.0 percent), Avg velocity: 44.1m/s, Min & max accel: 2.3/2.8ms^-2  
!!!SIM SECTOR L - max possible corner speed of 47.5m/s not reached  
Assuming 46.0m/s through the corner instead!!!
```

6.5 Calculation of start line velocity – flying lap

Corner V (Goddards) is a very tight low-velocity corner, with a relatively long straight before it. It can be assumed that any bike can reach the velocity required for this corner, thus, this is where the run-up begins, ending at the start line.

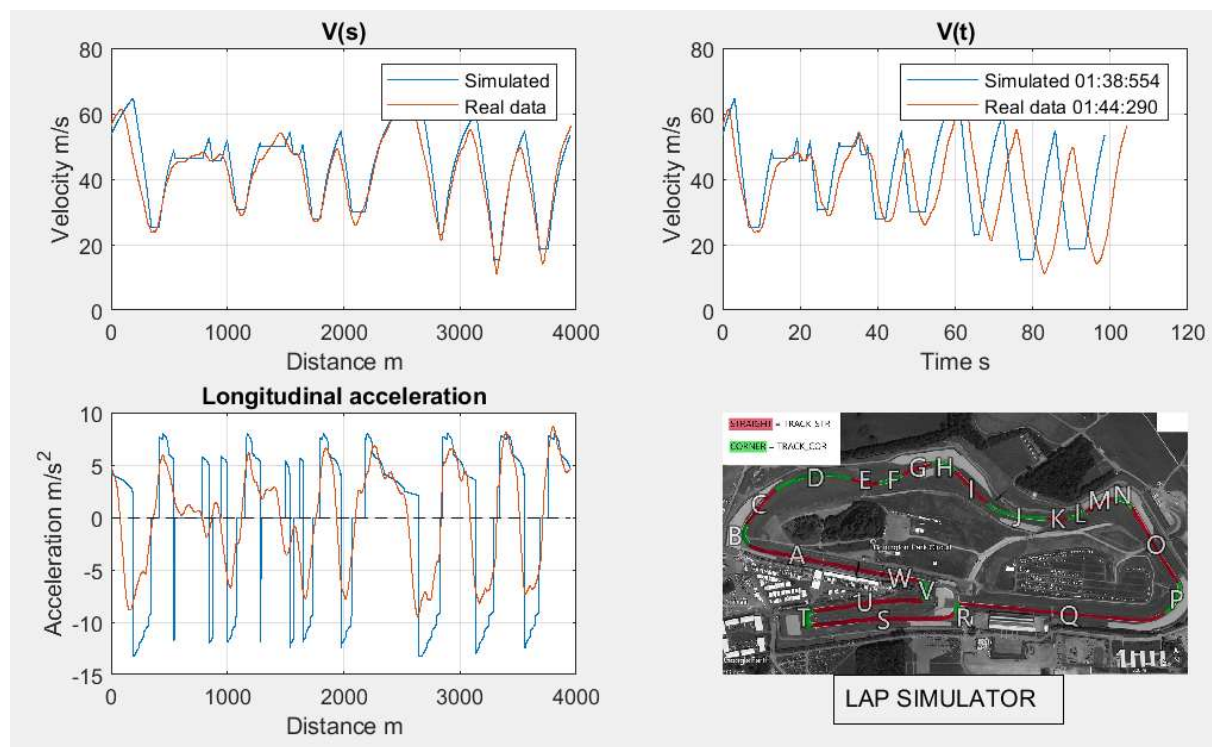
6.6 Calculation of braking points

The braking point of a straight is calculated after the calculation of ideal velocity through the corner. If the entry speed is too high, a series of 'if statements' and 'while'/'for' loops find the optimal braking point for the straight. Upon each iteration of the code, the braking point is moved 1 metre back. The loop is ended when the corner entry speed is the same as the calculated ideal corner velocity.

7 Lap sim results

7.1 Results

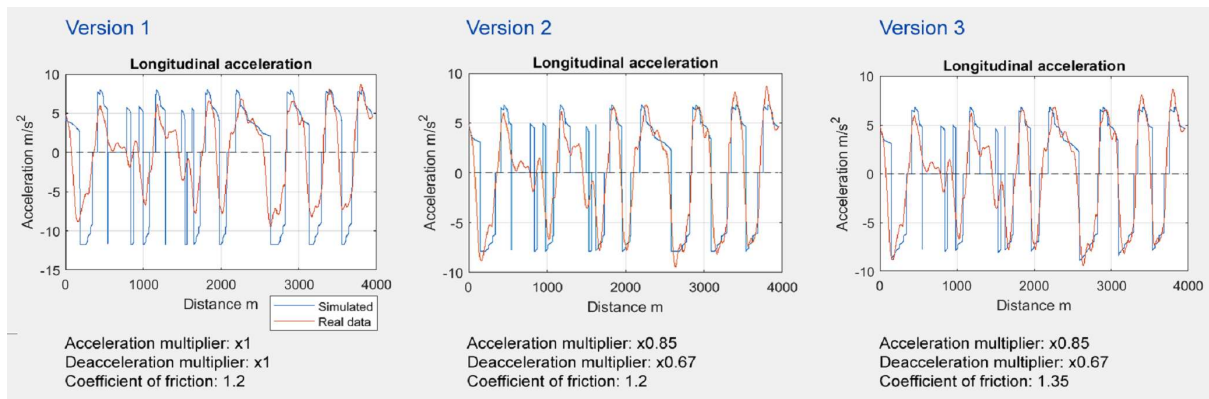
The initial result produced a simulated lap time of 1:38.554. Comparing this to the real lap time of 1:44.29, there is a difference of ~6 seconds. This result can be improved by looking at the reasons for the difference in lap time.



7.2 Analysis & improvements

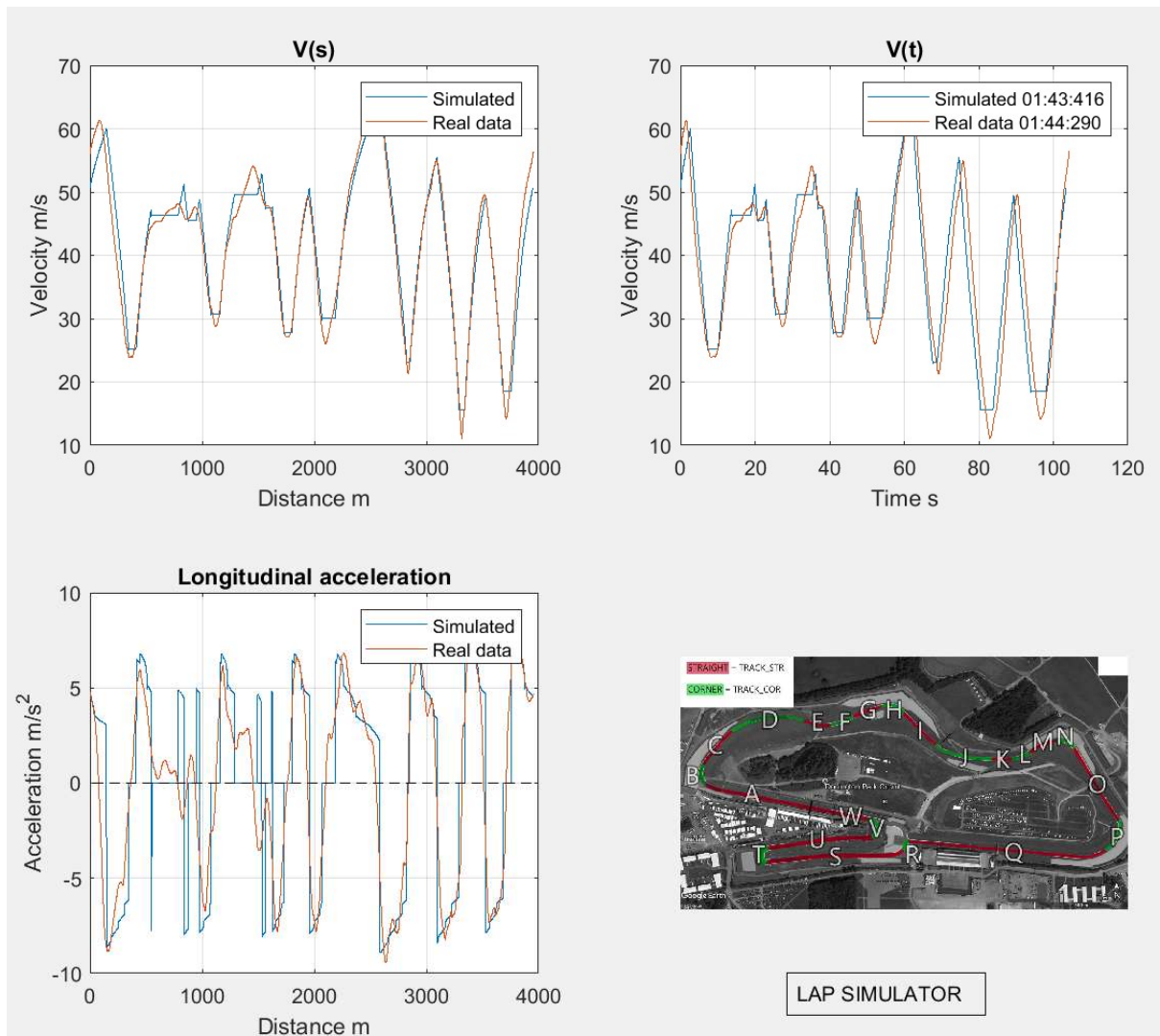
The main reason for the case described above is that the rider is not maximising the performance of the bike, both, under acceleration and braking. For acceleration phases, the rider only uses about 85% of the available acceleration for the vast majority of the track. Only the last two straights see the rider use close to ~95% of the available acceleration. This situation is even more significant when it comes to braking. The rider consistently uses only about 67% of available braking. The motorcycle dynamics book (Cossalte, 2006) mentions that professional riders only use ~1.1g of braking where 1.26g is available (chapter 3.4.5 example 9) – that is 87%. Considering that the Ducati 1199S test day was only a track day, I'm not surprised to find that the rider is only using 67% of available braking.

Using acceleration & deceleration multiplier, I have adjusted the available performance to the rider. I have also adjusted the coefficient of friction from 1.2 to 1.35 (which in effect controls the transition from endo limited to traction limited deceleration), to match the braking profile of the curve found in the real data.

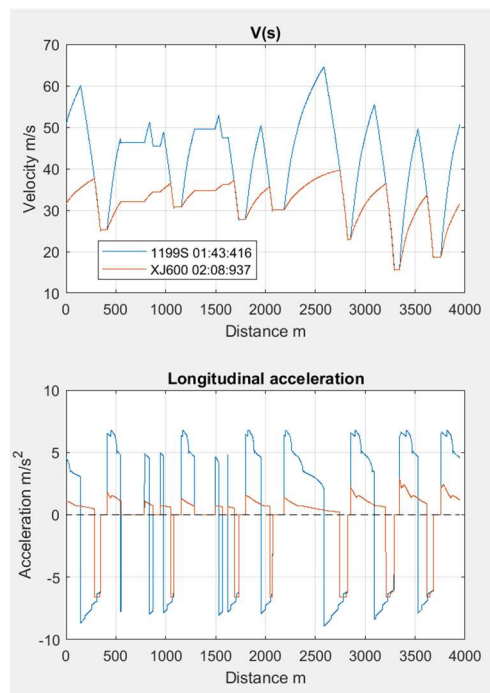


Final result

Simulated: 1:43.42 Real: 1:44.29



7.3 Testing various configurations



I have also included configuration for XJ600 restricted to 33RWHP to test how well my simulator code handles a vastly different configuration. Due to lower power levels, I assume the acceleration multiplier to be higher ($\times 0.95$) than on the Ducati 1199S ($\times 0.85$) as the rider would find it much easier to ride due to the bike being much less on the limit. The deacceleration multiplier, however, remains the same.

While the lack of acceleration through a corner feature in the simulation is not an issue with more powerful bikes, from looking at the $V(s)$ graph, it is visible that less powerful bikes would benefit from that feature. This is especially an issue on long corners (such as Redgate to

Craner Curves) where corner entry speed is well below maximum corner speed threshold.

Ducati 1199S simulated lap time: 1:43.416

Yamaha XJ600 (33RWHP restricted) simulated lap time: 2:08.937

8 Conclusion

The final simulated lap time is only ~1 second away from the real lap time, which I am satisfied with considering the complexity of Donnington Park.

There are several limiting factors and ways in which the simulator could be improved;

- My track mapping and code assumes the rider tips into the corner right away. I could retrace the mapping so that the corner starts when the real data shows the rider tipping into the corner, and end the corner when the real data shows that the bike has a lean angle of 25 degrees or less (where grip available for acceleration is not majorly impacted by cornering forces). I would then adapt the simulation code to reflect those changes. The lean angle would change progressively to reflect real-life behaviour.
- In the real data, it takes the real rider quite a lot of time to come off the throttle and fully onto the brakes, and vice versa. My simulation assumes that this is instantaneous. I could implement a roll-on/off feature in my code.
- It appears that the rider brakes deep into the corner, scrubbing off more speed than needed. I could implement this behaviour into the sim.
- A large majority of the Redgate through to Craner curves section could be remodelled to be a straight rather than a series of very short straights and corners.
- I could implement an acceleration through the corner model, which could improve the lap time accuracy for lower power bikes. I could achieve this by implementing straight section behaviour on corners, but with a multiplier for available power due to a decrease in friction available for acceleration.
- I could implement time loss due to gear shifts. This does not make much difference for bikes with quick shifters, but it could make a noticeable difference for bikes without it.
- I could implement track elevation changes that affect the performance as well as the geometry of a bike.

9 References

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