Exercise 1: Analysis of F-1 racing car telemetry data

The following statement about circuit racing was made by Peter Wright (Lotus):

"Driving a car as fast as possible (in a race) is all about maintaining the highest possible acceleration in the appropriate direction."

A quick racing driver will try to accelerate as fast as possible, brake as hard as possible and maximise the speed through corners. In most cases the tyre is the limiting factor when trying to maximise these accelerations. A good racing driver will try to fully exploit the friction potential of the tyres (obviously without leaving the track…)

To analyse the global vehicle behaviour the racing car may be considered as a point mass, see figure 1. The mass of the vehicle including driver is 650 kg.

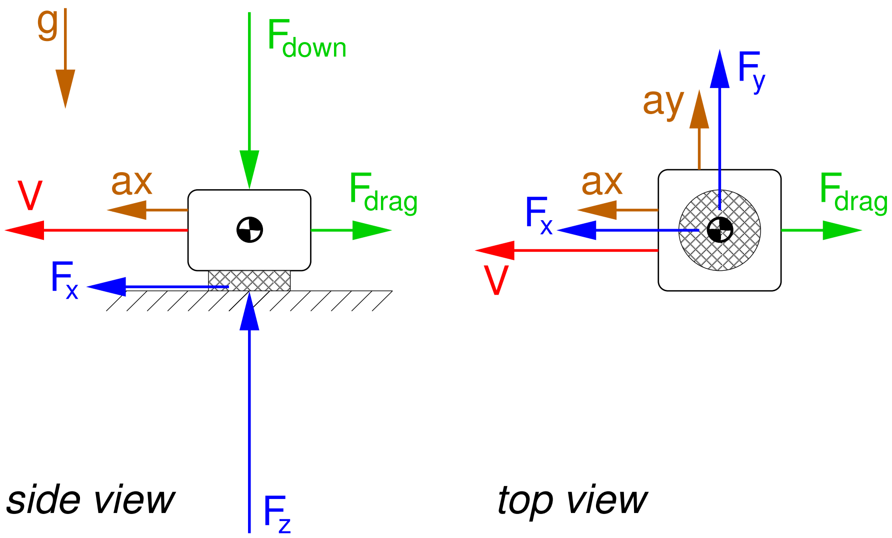

Figure 1 point mass racing car model.

For a F-1 racing car the aerodynamics forces are very important. The following formulae may be used:

- down force: $F_{down} = c_l V^2$, with a lift coefficient $c_l = 2.5$ Ns²/m²
- drag force: $F_{drag} = c_d V^2$, with a drag coefficient $c_d = 0.8$ Ns²/m²

Total rolling resistance of the tyres is 400 N at 300 km/h and may be considered proportional to the vertical load on the tyres F_z.

In figure 2 some telemetry data of a real F-1 racing car during a qualifying lap is shown. The signals are:

- throttle position of the accelerator pedal (100% = full throttle)
- gear selected gear
- V car forward velocity
- ax longitudinal acceleration
- δ_s steering wheel angle
- ay lateral acceleration
- r yaw rate

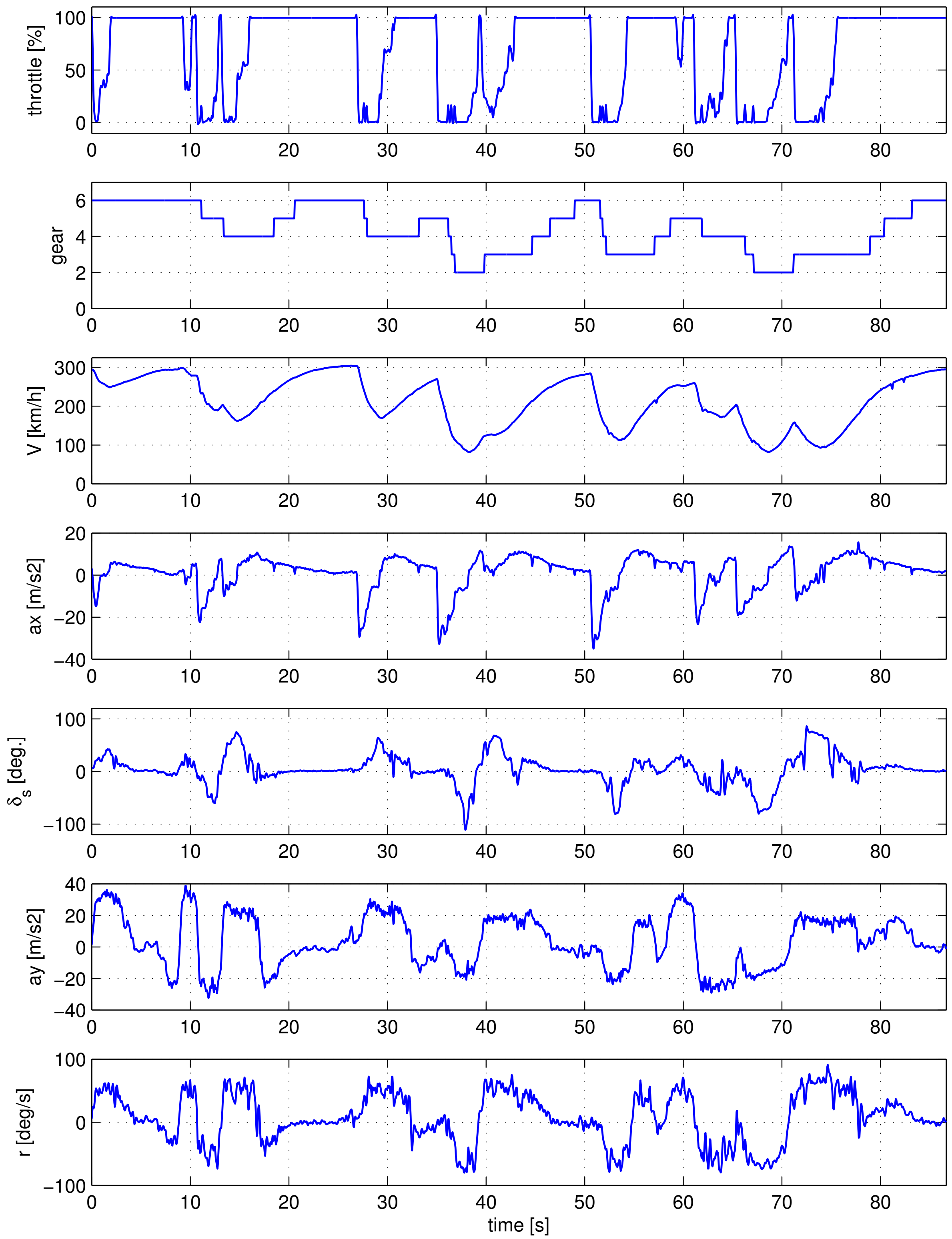

Figure 2 Telemetry data.

Questions

a) Make a plot of the vertical force F_z as a function of the forward velocity (range e.g. 0 - 300 km/h). Is the statement on page 15 of the lecture notes made with respect to the vertical load on the tyres correct? What is the magnitude of the tyre rolling resistance coefficient? (see also page 182 of the lecture notes)

b) Make a plot of the total drag force (both aerodynamic drag and tyre rolling resistance) as a function of the forward velocity. If the car is driving 300 km/h and the driver releases the throttle: what becomes the longitudinal deceleration of the vehicle? For convenience you may assume that engine torque is zero when the throttle is released.

c) In figure 3 the longitudinal and lateral accelerations are plotted as a function of forward velocity. Give a full explanation of the boundaries of the curves. Why does the maximum longitudinal acceleration decrease as a function of forward velocity when the velocity is above approximately 180 km/h? What limits the acceleration below this velocity? Give two reasons why the vehicle decelerates more quickly at high forward velocity compared to low forward velocities. Why does the maximum lateral acceleration increase as a function of the forward velocity?

d) In figure 4 a so called g-g plot is given. Comment on the shape of the curves for the different forward velocities.

e) Make an estimate for the engine power in kW. Given that the maximum engine angular velocity is about 17000 rpm (revolutions per minute), what will approximately be the engine torque? If we would remove the wings from the car ($c_l = 0$, $c_d = 0.2$) and knowing that the tyre rolling resistance is proportional to the vertical force F_z, what would become the theoretical top speed of the car?

f) Using the boundaries of figure 3, make an estimate for the friction coefficient in longitudinal and lateral direction (μ_x, μ_y) at a number of different forward velocities V (e.g. from 100 km/h up to 300 km/h in steps of 50 km/h). Plot the friction coefficients as a function of the vertical force F_z. Is the friction coefficient constant or does it increase/decrease with vertical force F_z? Why does the maximum lateral acceleration increase almost linearly with forward velocity instead of quadratic as you might expect looking at the vertical force F_z (as determined in question a).

g) **Bonus question**
The file `f1_circuit_data.mat` contains the following signals of the F1 car driving on the circuit:

V	forward velocity	[km/h]
ay	lateral acceleration	[m/s^2]
r	yaw rate	[deg/s]
s	travelled distance	[m]
time	time	[s]

Reconstruct the circuit layout from this data. In figure 5 the layout of some circuits is shown, on which circuit did the F1 car drive?

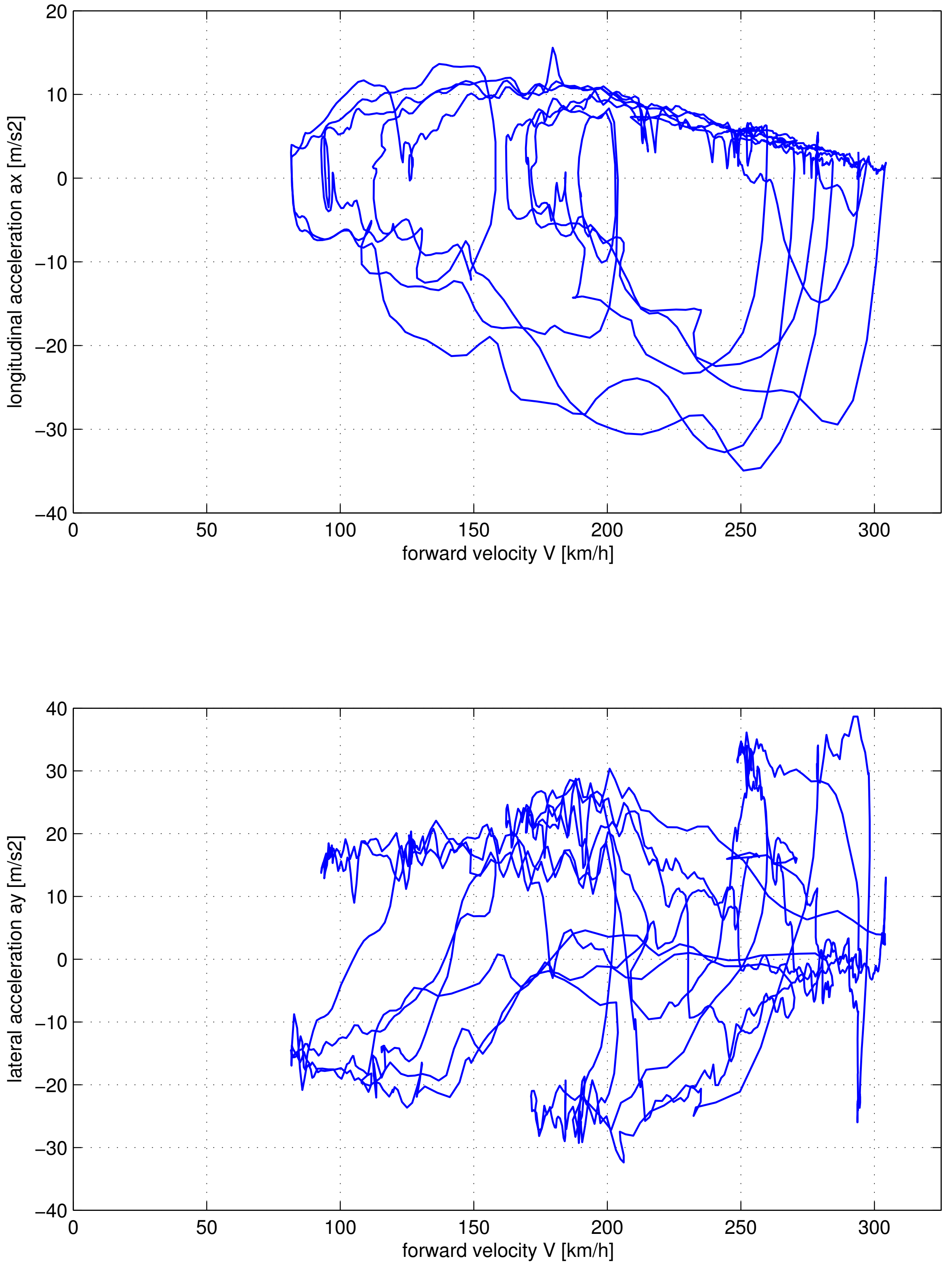

Figure 3 Accelerations as function of forward velocity.

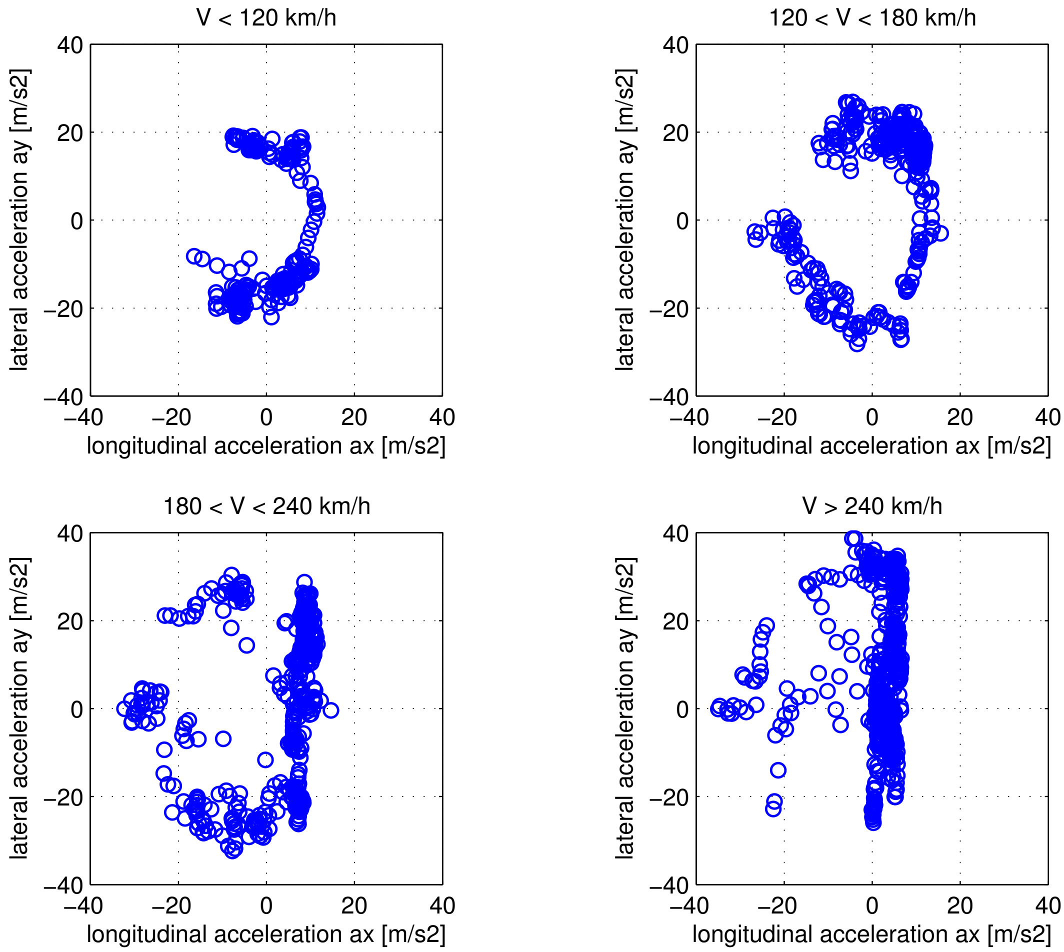

Figure 4 Lateral versus longitudinal acceleration (g-g plot).

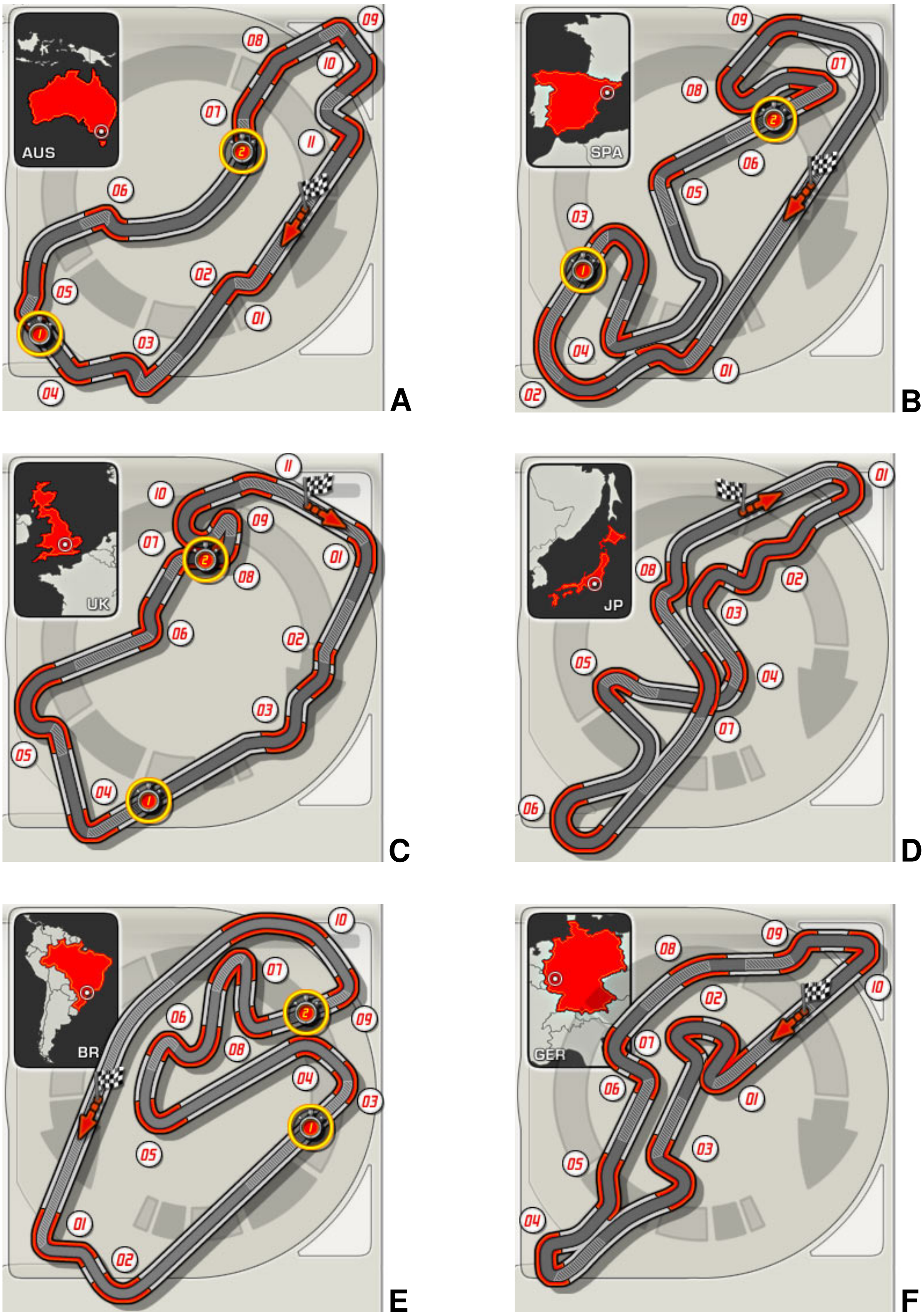

Figure 5 Various F-1 circuits across the globe.