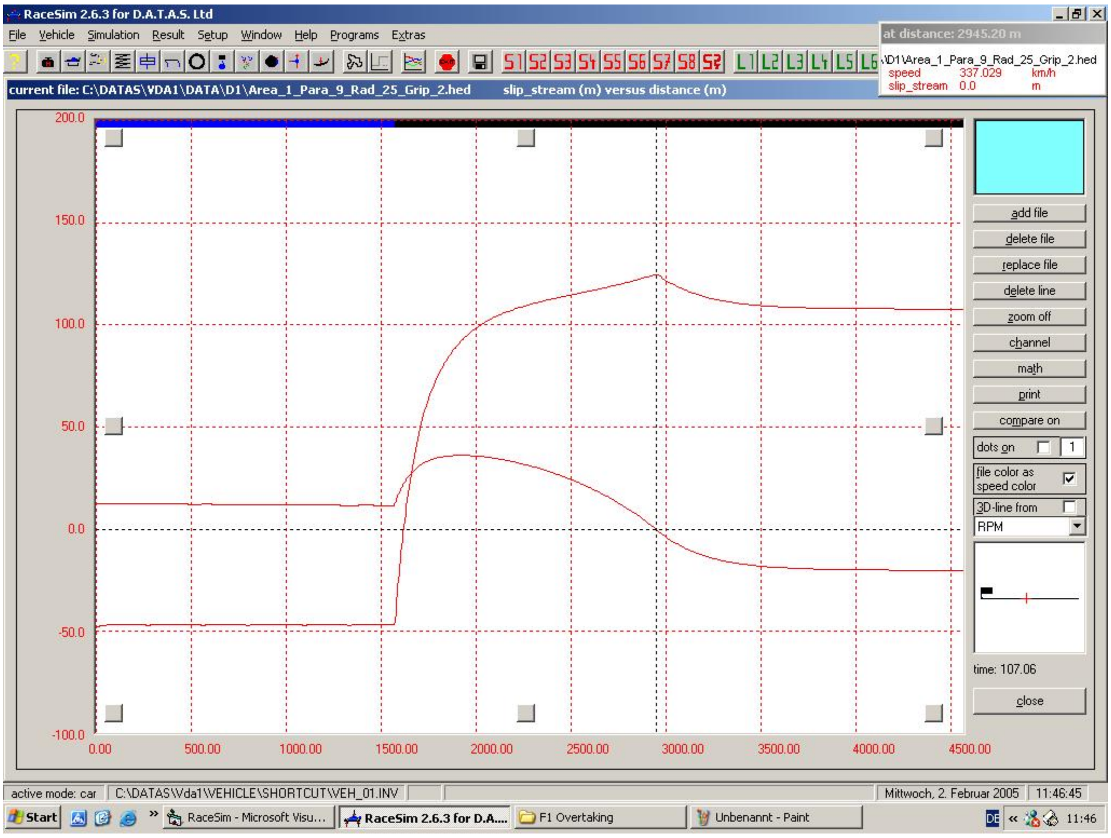
Overtaking in Motorsport

General:

In 2004 started the FIA a research project to analyse the effects of overtaking. The project was split in 3 stages before the F1 OWG (overtaking working group) took it over.

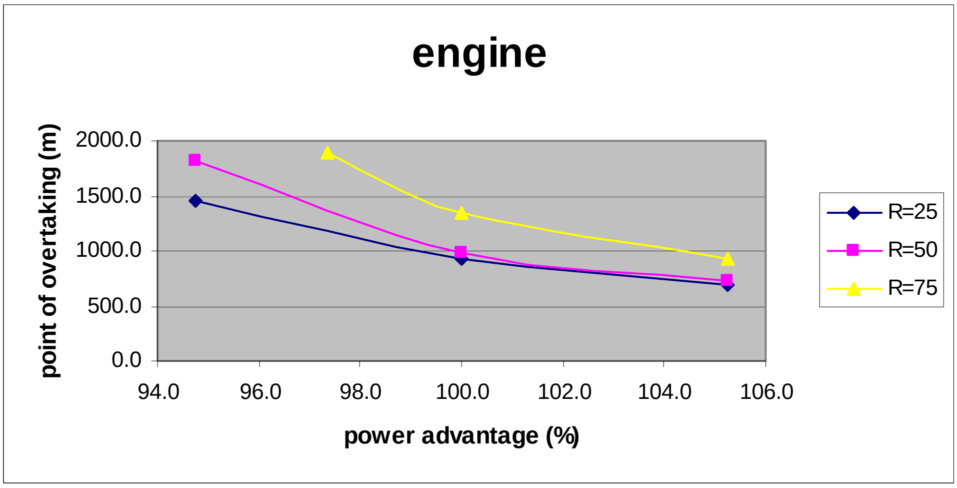
The study was done on various corner radii, always followed by a long straight. Two cars (same car model, unless specified) were put in a start position (speed, gap) and then tried to accelerate as quick as possible. The criteria for overtaking was the distance on the straight line, where the CGs of the two cars were equal. A overtaking was called successful, if this distance was less than 750m.



gap to the leading car and speed of the following car versus distance

Stage 1:

Analysing which advantage the following car needs to have to make a successful overtaking. We analysed tyre grip, downforce, engine power, drag and mass.

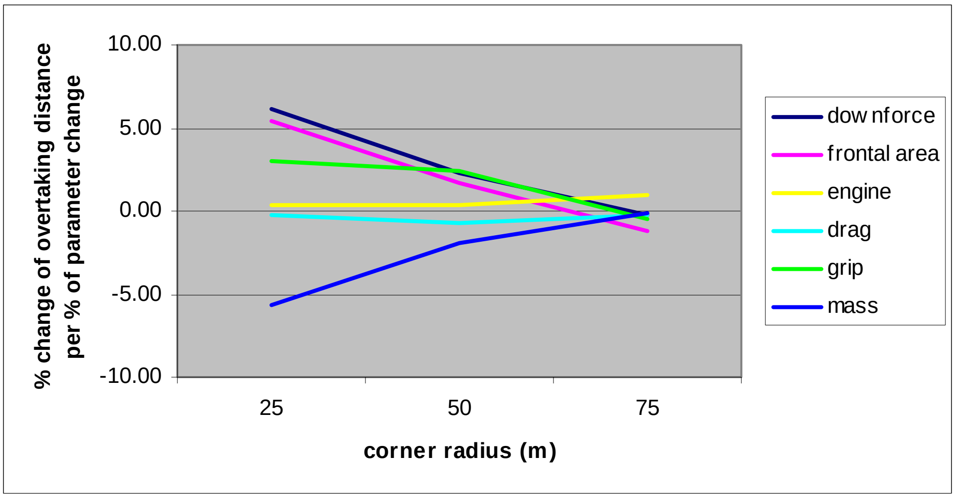


effect of engine power (x-axis) on the point where both cars are leveled (y-axis)

More power, less drag, more downforce helped of course, but we always had to give the following car some extra grip to compensate the lost of downforce in the wake and stay close enough in the corner that it could gain from the advantage once it was on the straight. This corresponded quiet well with the experience of the real F1 races where a top car, once it had to start from the back (e.g. crash in qualy) was able to overtake half of the field till it reached cars which were about 1.5 sec slower that it.

Stage 2:

Analysing the effect on overtaking, if the setup of both cars (leading and following) is changed. We analysed the effect of downforce, overall aero level, engine power, drag, tyre grip and mass.



i.e. 1% more downforce increases the overtaking distance by 6.1% in a 25m radius corner

It became clear that less downforce, more car mass and/or less grip helps the overtaking, while engine power and drag make no significant difference. By far the biggest effect was a reduction of downforce. Mass has as well a big effect, but will not be open to change that much.

Stage 3:

All the simulations of study 1 and 2 used a generic wake model. The definition of the wake is quiet critical to the outcome of the simulation. In stage 3 we analysed the effect of different wake characteristics. One of these wake models was the CDG wing. As a consequence of the sometimes dramatically different wake models different techniques to enter a corner and stay behind the leading car were analysed in stage 3 as well.

Simplified corner model:

All the simulations in stage 1-3 were carried out with RaceSim, a quiet detailed simulation program used by various racing teams in (F1, GP2, DTM, WTCC, GT racing, F3, NASCAR, IRL etc.).

Independent to these simulations is below a formula shown, which uses the first order effects to describe the performance (speed) of a following car in a corner.

$$m*ay = Fy = \mu * Fz$$

$$Fy = \mu * (Fmass + Faero)$$

$$Fy = \mu * (m * g + \frac{Cz * \delta * A * \rho * v^2}{2})$$

$$ay = \mu * (g + \frac{Cz * \delta * A * \rho * v^2}{2 * m})$$

m	:= car mass
ay	:= lateral acceleration
Fy	:= lateral force
Fz	:= vertical force
Fmass	:= car mass force
Faero	:= aero force
g	:= earth acceleration (9.81 m/s2)
Cz	:= downforce coefficient
A	:= frontal area
v	:= car speed
δ	:= reduction of air energy in the wake
μ	:= tyre grip
ρ	:= air density

This formula shows that the performance of the following car is at a similar level if the term $\frac{Cz * \delta * A * \rho * v^2}{2 * m}$ is not much less than the one of the leading car. This can be achieved by:

- having a wake δ that loses only very little behind a car, or
- if this wake is not possible the whole term $\frac{Cz * \delta * A * \rho * v^2}{2 * m}$ needs to be minimized
- in other words reduce the overall downforce Cz and/or increase the mass of the car
- on top of this it becomes obvious that the problem is less the lower the speed corner is
- interesting as well that more grip μ is worse because it increases the car speed v

Different approach:

In all these simulations the following car was using in the corner the same line as the leading car and overtook once it was on the straight. As most of the corners allow only one line (the rest of the track is too dirty), this is currently a realistic scenario. At the moment each lap on the preferred line puts more rubber on this line (increases the grip) and puts the dirt to the side (reduces grip off this line. In other words we have a stable system.

If we would find a solution to create an unstable system, it would immediately generate multi lines. We need to make sure that using a line reduces the grip/performance on this line. With such a system, a following car can use a different line, therefore get almost free air and can stay very close to the leading car, maybe overtook it already in the corner.

There are motorsports where this happens and allows fascinating races. Riding in MotoCross on a line again and again creates in the first laps some banking which helps the performance. But later on bumps come up, which reduces the performance on this line. At the end an alternative line becomes competitive and some riders go for it.

Other positive effects:

- Driver errors
- Car performance differences (not like DTM)
- Strategies
- F1 tyre rule, if it is extreme
- Reversed grid