A Tool for Lap Time Simulation

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A Tool for Lap Time Simulation

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ABSTRACT

The top Formula 1 and Indycar teams make large use of computer simulation to improve the performance of their cars and make the set-up process quicker on the circuit.
The paper aims to present a lap time simulation software dedicated to racing cars. It is based on the background of vehicle dynamics research developed at the University of Brescia, Italy (see [1]).
It should be stated that racecar dynamics is strongly non-linear due to the fact that tyres are always very near the limit of adhesion. Moreover this makes the effect of lateral load transfer fundamental for the general balance of the car.
Therefore Pacejka's Magic Formula has been used for lateral force/slip while longitudinal force computation is based on the assumption of a maximum longitudinal coefficient of friction μ. This is not only for simplicity but it is also due to lack of available data. The combined case is then based on the so-called "traction circle". Lateral and longitudinal load transfer and downforce as well as their effects on tyre load are taken into account.
The vehicle model is capable of following a trajectory acquired with the on-board instrumentation. Also, the use of genetic algorithms enables the program to find the optimum cornering line for any given track. Some results are shown and compared with real world data.

INTRODUCTION

Simulation has become one of the most involving engineering subjects. Modern computers enable the transformation of real life into the so-called virtual reality, which offers many advantages to the development engineer.
The racing world has always been very keen on simulation because of high testing costs involved in the development of a new car. Modern racing cars are complex devices, and both designers and race engineers can hardly control all the variables they can play with.
A computer model can help when choosing gear ratios, aerodynamic configuration, engine power characteristics and in general where a compromise must be reached to suit a peculiar circuit morphology. The simulation of a complete lap on a given circuit is one of the most interesting possibilities for this purpose. Data acquisition also enables quick and successful tuning and verification of the math models.

THE LAP SIMULATION SOFTWARE

Many computer programs have been written in the past for the above purpose. This paper aims to present a lap simulation software which goes deep into vehicle dynamics theory.
A first phase of the work was the accurate study of the cornering line the drivers commonly follow in the average corner. At this stage data acquired on various circuits with different cars were analysed. Subsequently an algorithm was tested which tries to reproduce the cornering line for any corner with the help of the genetic method. An introduction to the genetic method is presented in “Semi-Active Strategies for Racing Car Suspension Control” by the same authors [2].
The vehicle model allows for aerodynamic forces, non-linear tyre load sensitivity, lateral load transfer distribution due to roll stiffness as well as spring and tyre stiffnesses. Chassis rigidity can be taken into account as well.

COMPUTATION OF THE OPTIMUM CORNERING LINE

When pursuing the best performance on a given track the first step is usually the search for the optimum cornering line. The subject is very well-known in the racing community, nevertheless the analysis of data acquired on various circuits with different cars was very helpful to go "back to basics". The cornering radius is easily computed from data acquisition with the following math channel:

$$R=V^2/a_y$$

where R=cornering radius, V=vehicle speed and a_y=lateral acceleration. As a convention R can be set to 0 (and not ∞) in the straightline.
We would like to point out that, usually:

- the turn-in point (1, Fig. 1) is on the outer side of the road (car still braking)
- after the brake release point (2) no longitudinal acceleration is applied to the vehicle
- point (3) -where throttle is applied- is placed on the inside around the mid corner zone.
- the corner exit/zero steer angle point (4) is again placed on the outside
- the cornering radius function gets a parabolic shape (Fig. 2); in detail the radius is larger in exit then in turn-in to maximize the exit speed.

Due to the nature of the problem an interpolation approach was fairly straightforward. The restrained cubic splines have been chosen because:

- if compared to polynomials -whose oscillatory behaviour can not be easily controlled- splines behave in a smoother way
- cubic splines are characterized by the lowest curvature in the spline family
- the restrained cubic splines can be particularly effective in this case, the slope being known at each end. The slope is actually given by the straightline direction before and after the corner.

The optimization is carried out with the use of a genetic algorithm [2]. Optimization means finding the combination of the four points -turn-in, brake release, throttle application, exit- which actually maximize the minimum cornering radius. This has a direct effect on cornering speed. Moreover, the spline computation must always result in a parabolic line shape.

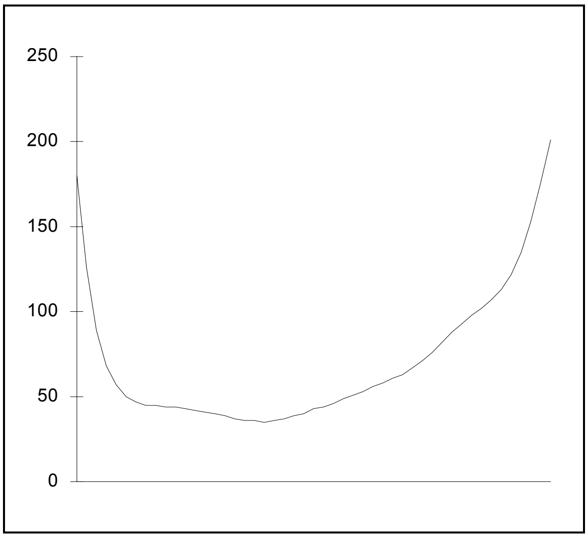
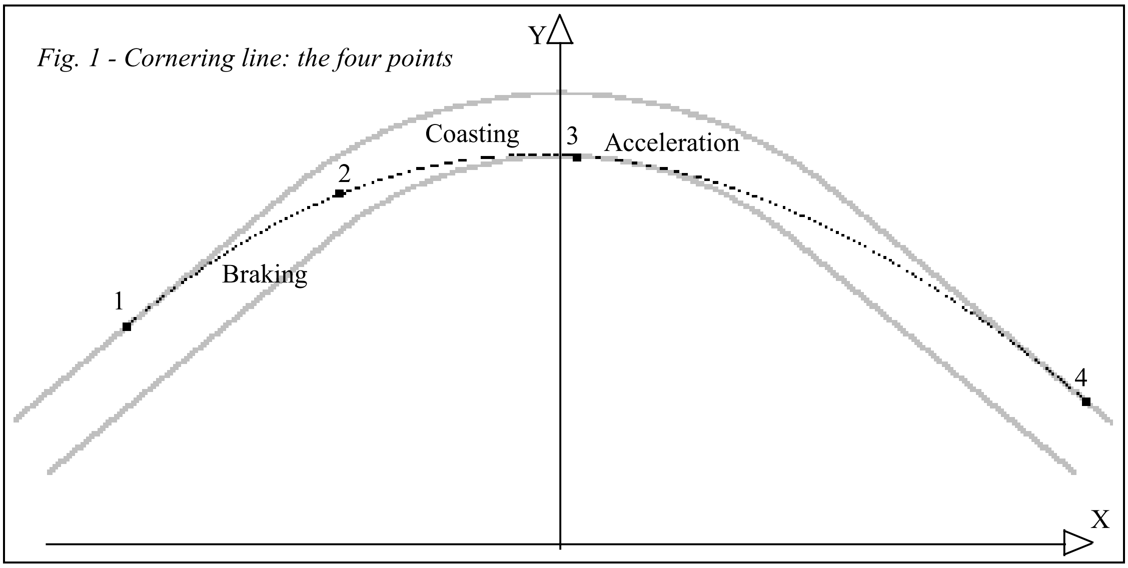


Fig. 2 - Cornering radius along a turn (from data acquisition)

This means that corner geometry characteristics (radius, angle and track width) are the main factors in computing the theoretical cornering line. Nevertheless the spline computation could be tuned to suit the type of car (front or rear wheel drive, high or low power, high or low downforce) or a peculiar driving style. Also, it should be noticed that genetic algorithms do not offer a unique solution to the problem. Figure 1 shows a 50 m radius, 80° corner. The four typical points are also shown. Figure 3 shows the cornering radius function for the same corner.
Once the theoretical cornering line is computed for every corner the whole circuit can be written on a file with the use of relative coordinates.

Fig. 1 - Cornering line: the four points



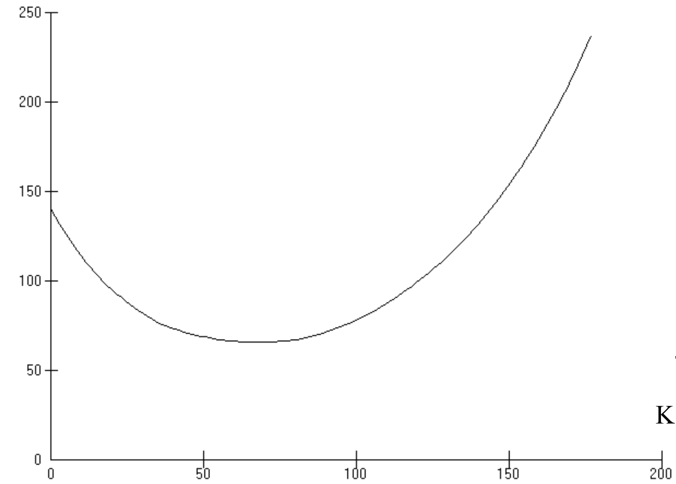


Fig. 3 - Cornering radius along a turn (computed)

THE TYRE MODEL

According to “The Milliken” [3], “Racing is all about driving the vehicle at its limits, near the boundary of the g-g diagram”. Therefore tyres are -or should be- always working near the limit of adhesion i.e. where the sideslip function is strongly non linear and load sensitivity is extremely marked. This means that a racecar model needs to run on a comprehensive, non-linear tyre model.
Unfortunately it is very difficult to get up to date tyre test data from tyre manufacturers, and this is particularly true for racing tyres. Moreover, even when some data are available they usually regard sideforce only -no longitudinal slip and absolutely no combined slip data.
This can be overcome by analysing negative acceleration data in pure braking. An average μ coefficient can be easily computed for the longitudinal slip case, and such μ can be assumed as a basis for a pure longitudinal slip linear model. Any of the most common, non-linear tyre models can be used for pure sideforce/sideslip, while the combined slip model can be based on the good old friction ellipse theory. The classic 1989 Pacejka Magic Formula [4] was chosen as a sideslip model in our program.

CORNER-TO-CORNER PERFORMANCE EVALUATION

Engine power curve, transmission ratios and efficiency, braking power and aerodynamic coefficients (Cx, cross section area, Cz front, Cz rear) are needed to assess the performance between corners with traditional dynamics formulae. Also longitudinal load transfer is taken into account to determine the longitudinal adhesion limits either in braking and under power.
For cornering performance the vehicle model (Fig. 4) is based on the above combined tyre model and on a simple linear chassis model with springs, anti-roll bars, radial tyre stiffnesses, and chassis torsion flexibility. The lateral load transfer distribution (LLTD) due to front and rear roll stiffnesses and the consequent tyre side forces are computed to determine the maximum lateral acceleration in the mid corner point for a given turn.

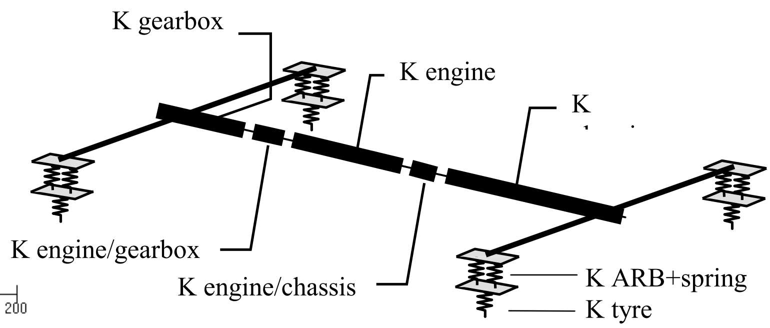


Fig. 4 - Single-seater vehicle model

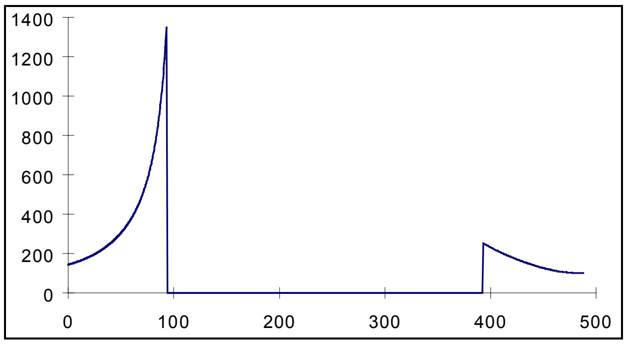


Fig. 5 - Cornering radius along a circuit section

The whole circuit is then split into sections from a mid-corner point to the following mid-corner point through the straight line in between. The maximum speed in the middle of each corner can be assessed as above by considering pure coasting (no longitudinal acceleration, i.e. pure tyre sideslip). Hence a section is composed by a first known-speed point, an acceleration zone, eventually a top speed zone, a braking zone and a second known-speed point.
The combined tyre model is used to keep the car on the boundary of the g-g diagram between points 1 and 2 (cornering under braking) and between points 3 and 4 (cornering under power). If the straight is too short to reach the top speed an iterative process is used to match the speed at the end of the acceleration zone i.e. the beginning of the braking zone.
The model is quasi-static, hence transient effects on lateral load transfer distribution due to dampers are neglected. Also, a driver model was not built into the program, the aim being to assess the best possible lap time for a given car on a given circuit.

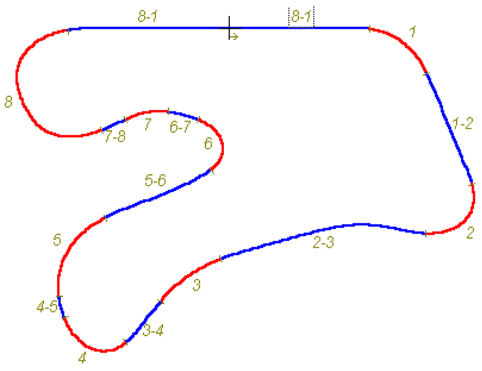


Fig. 6 - Hockenheimring (short circuit): the real cornering line

VALIDATION

The results of a lap simulation on the Hockenheimring (short circuit) are shown ; the car is a FWD, D2 Super Touring saloon.
As one could expect, actually the simulation is slightly quicker than the real car when running on the real cornering line (i.e. the line computed with the help of data acquisition, see Fig. 6 and case *b*) while the line computed with the use of the genetic algorithm makes the simulation slower (case *c*)

a) Real lap time 1'06"31
b) Simulated lap, real line 1'05"61 *(-1.05%)*
c) Simulated lap, computed line 1'07"84 *(+2.31%)*

Case *b* is compared with reality in Fig. 7 (speed), Fig. 8 (lateral acceleration), Fig. 9 (longitudinal acceleration), Fig. 10 (gear position) and Fig. 11 (time difference).
The computation of an "optimum line" with the use of the genetic algorithms needs further developments.

THE INTERFACE

The program was then completed with a user-friendly windows interface which provides easy data input and processing as shown in Figs. 12 and 13. No built-in post-processing is provided yet.

CONCLUSION

A lap simulation software has been presented. It is based on a simplified vehicle model and on a non-linear tyre model. The program is aimed to be a tool for the race engineer when optimising the car setup. It can be particularly useful where a compromise is needed: choice of gear ratios, aerodynamics, and so on.
The results show that the model is reliable at least with the type of car considered in this example. Improvements should be made to the gearshift strategy and also when two corners are separated by a very short straight (or not separated at all).
The genetic algorithm computation for the optimum cornering line needs to be tested further and improved; also, the model should be tested with different types of cars (e.g. a RWD car with lots of downforce) and a post-processing module should be added.

Many thanks to Riccardo Bonetti & Marco Rossato

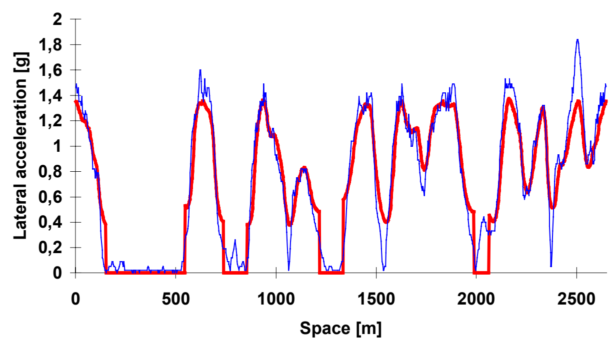


Fig. 8 - Lateral acceleration vs space

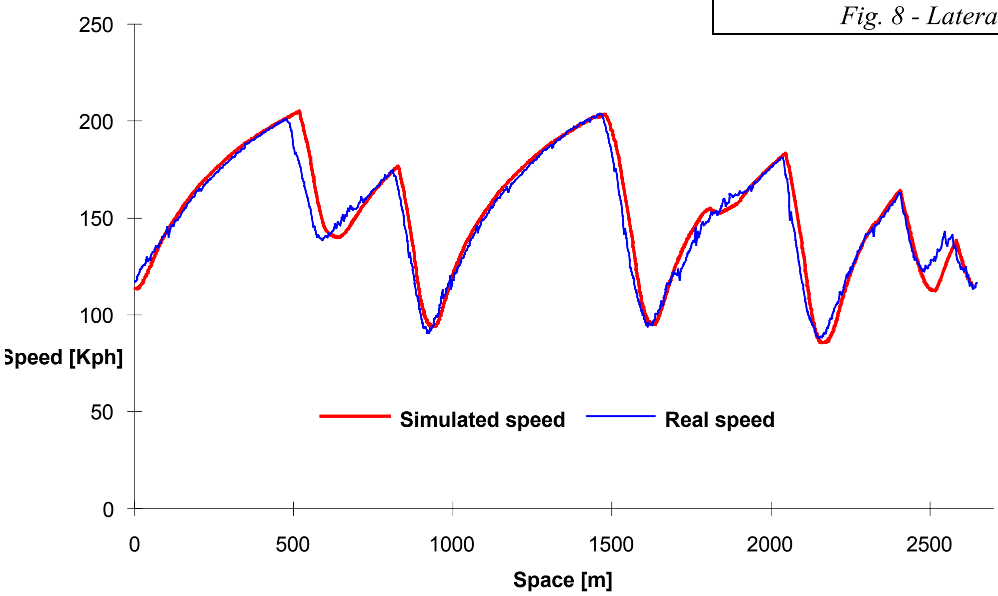


Fig. 7 - Hockenheim ring simulation : speed vs space

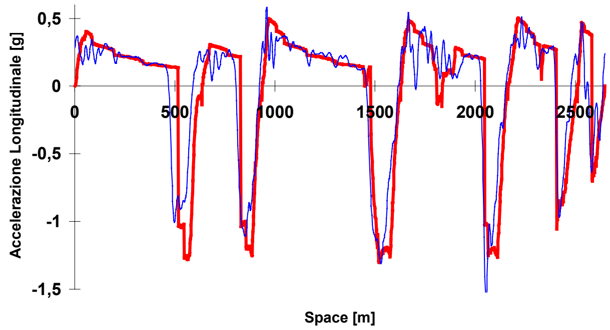


Fig. 9 - Longitudinal acceleration vs space

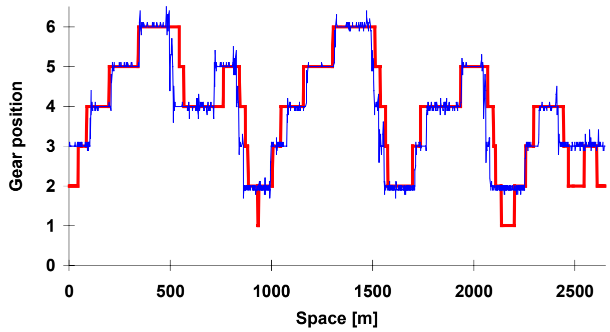


Fig. 10 - Gear position vs space

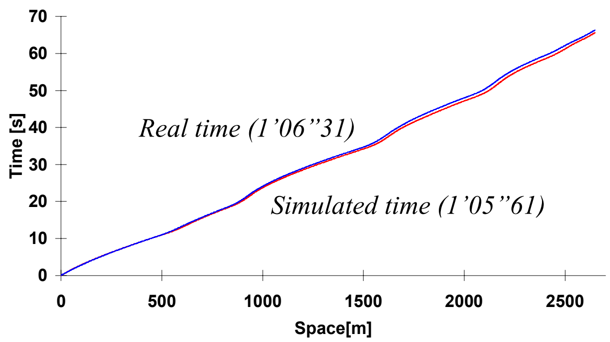


Fig. 11 - Time difference vs space

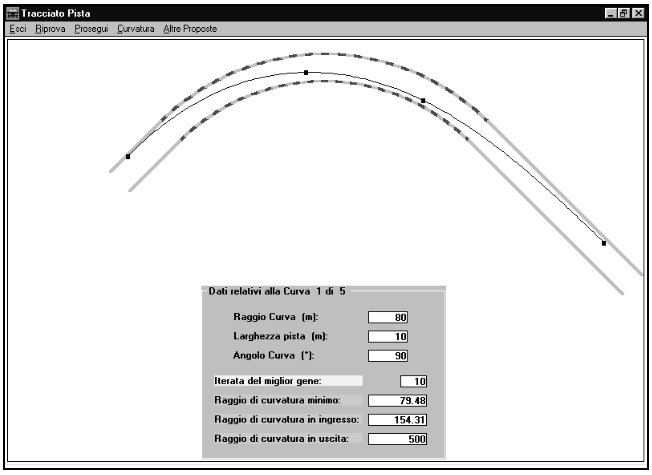


Fig. 12 - Cornering line interface

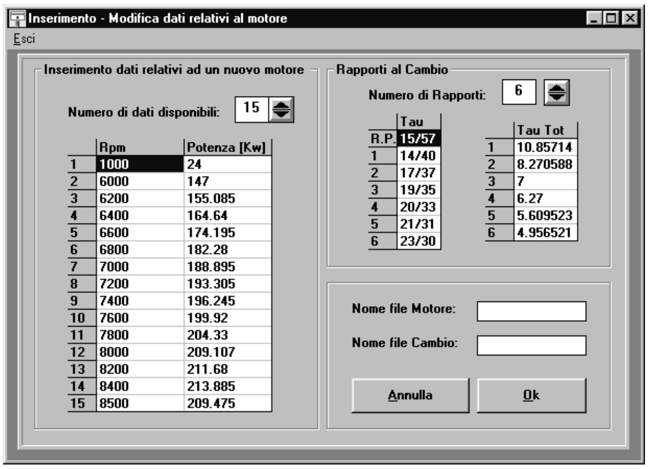


Fig. 13 - Engine power curve and gear ratio input

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