2ND INTERNATIONAL COLLOQUIUM ON VEHICLE TYRE ROAD INTERACTION

"FRICTION POTENTIAL AND SAFETY : PREDICTION OF HANDLING BEHAVIOR"

EXTERNAL EXPERT CONTRIBUTION

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Title : Vehicle Dynamics and tyre road friction performance models

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ABSTRACT
The use of vehicle dynamic model is becoming common in the framework of safety analysis of roads. Investigations using simulations can be very helpful in the definition of different road design modifications to avoid accidents or reduce the gravity in accident prone areas.
Investigation can be conducted from accident reconstruction when all relevant information are known, from simulation with different vehicle types with typical commands leading to loss of control (typical scenarios in "out of road accidents").
Key points of these simulations are the pertinence of the dynamic parameters (of the simulated vehicles) and the tyre road friction model.
Agreement between computed dynamic responses and test values is mainly dependent upon vehicle dynamic parameters validity for low solicitation level, for high level solicitation (emergency manoeuvres and lost of control) the agreement is strongly dependent upon the rele vance of the tyre/friction performances model with regard to the local friction potential and tyre road contact condition (dry, damp, wet,…).

The two following questions will be dealt with in the paper:
- Vehicle dynamic parameters sensitivity analysis
- Estimation of tyre road friction model

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INTRODUCTION

The Road Surface and Vehicle Dynamics (SCDV in French) Group of the "Laboratoire Central des Ponts et Chaussées" has been engaged on road vehicle interaction modelling for 6 years. The targeted goal is to improve interpretation of road geometric features (slope, curves radius, cross slope,…) and road surface characteristics (evenness, adherence, texture etc,), with regard to vehicle dynamic potential and consequently to road safety. It is expected that a parametric investigation realised with a vehicle dynamic model including a realistic road description and an interactive driver model would bring along a better understanding of the interactions between driver, vehicle and road factors.

According to these objectives and within this framework two stages have to be considered to describe progress on this research:

- stage 1 : test and complementary development of a vehicle dynamics program developed by SERA-CD
- stage 2 : application of the road/vehicle/driver interaction model to run-off- the road (wet or damp) accidents which represent more than 60% of single vehicle accidents on curves.

N.B.: The wet road accidents programme launched end of 1998 is financially supported by the French Ministry of Research (PREDIT programme) and by the French Directorate of Road Safety and Road Traffic (Direction de la Sécurité et de la Circulation Routière)

The first part of this paper summarizes the main results obtained in the first stage. The second part is concerned with tyre friction performance model estimates.

MODEL FOR ROAD/VEHICLE/DRIVER INTERACTION

SERA-CD has developed a package called CALLAS for 3D road vehicles dynamics simulation with 16 DoF and a special attention to the handling limit on any road. A working group was created including SERA-CD Paris, INRETS-MA (French National Institute for Transport and Safety Research, Department of Accident Mechanisms Analysis) of Salon de Provence, LCPC - SCDV (Road and Bridges Central Laboratory) of Nantes, DGA-ETAS (Military Technical Testing Centre) at Angers, to establish the validity of this package. The principle of validation is to compare simulation results to ground tests data.

Comparison between simulation and data measured during ground tests were made for four different types of light vehicle. About 200 tests of pure longitudinal, lateral, vertical dynamics and various combinations of these, from low solicitation up to and beyond the limit of tyre adherence, on two different test tracks under dry and wet conditions, were performed.

Agreement between computed dynamic responses and test values proved to be mainly dependent upon vehicle dynamic parameters validity for low solicitation level : for lateral manoeuvre, primary parameters are steering ratio, cornering stiffness balance, elasto-kinematics steer.

For high level solicitation (emergency manoeuvres and lost of control) the agreement is strongly dependant upon the relevance of the tyre/friction performances model with regard to the local friction potential and tyre road contact condition (dry, damp, wet,…) : for lateral manoeuvres, the decisive factor is the maximum friction coefficient on the most solicited outer wheel .[1][2][3][4]

Figures 1 and 2 illustrate typical validation results for typical lateral solicitations. On these figures dotted lines correspond to measured values, continuous lines correspond to simulation. Good correlation is obtained between measured and computed data as shown in these examples for lateral acceleration.

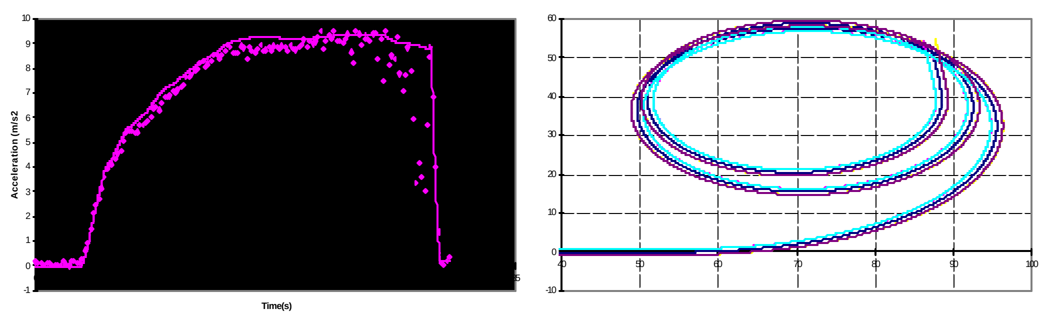

Figure 1: spiral curve, Peugeot 605 SR, 50 km/h,
lateral acceleration (left) and centre of gravity and tires trajectories (right)

Figure 2: ISO chicane Citroën BX 110 km/h (maximum possible speed)
lateral acceleration (left) and centre of gravity and tires trajectories (right)
(simulation : continuous line – measurements : dotted line)

A sensitivity analysis on vehicle parameters given on table 1 for a light vehicle was performed by ETAS (Military Technical Testing Centre) [5] [2].

Parameter	variation
Center of gravity height	± 50 %
Yaw inertia Izz	± 50 %
Roll inertia Ixx	± 50 %
Front spring stiffness Kr(av)	± 50 %
Rear suspension spring stiffness Kr(ar)	± 50 %
Front suspension roll stiffness Ka(av)	± 50 %

[2] the study includes a heavy vehicle

Rear suspension roll stiffness Ka(ar)	± 50 %
Front suspension damping ratio D(av)	± 100 %
Rear suspension damping ratio D(ar)	± 100 %
Front tyres cornering stiffness Kd(av)	± 40 %
Rear tyres cornering stiffness Kd(ar)	± 40 %

Sensitivity of the variation on these parameters were interpreted with regard to different vehicle dynamic response parameters for 4 ground tests: steady state turn, J turn, braking in a bend, random alternative cornering.
This study showed that the height of the gravity centre, suspension stiffness, yaw inertia and tyre cornering stiffness are very sensitive parameters.
At high speed and high dynamic demand, the need of a relevant tyre model is proved to be of primordial importance. In this condition, if the tire model is not appropriate for the operating conditions even a very good vehicle model would lead to invalid results.

THE RELEVANCE OF THE TYRE/FRICTION PERFORMANCES MODEL

Problem to be worked out :

For a given tyre, the basic tyre/road performance model is adjusted on experimental data. These data are either obtained on an internal flat track or on section on a test track. Tyre friction performances and consequently parameters of the model are strongly dependent on micro and macro 3D irregularities in the contact patch. This is true for dry friction but more when hydrodynamic is involved (damp and wet road). There is a need to adapt this basic tyre model to local sites, that means various surfacings and various tyre contact conditions (dry, wet, damp,..).

Methods investigated.

Two methods are currently been tested:

- the first one is based upon a fully validated vehicle dynamic model. In this case some parameters of the model are evaluated from pure longitudinal and lateral dynamic tests then the general model is set up and corrected until good results are obtained between simulation and measurement for a set of dynamic tests. This method is called the white box method.

- the second solution is based upon a simplified model from which system state will be estimated and then relevant information regarding tyre/road forces will be evaluated. This method is called the grey box method.

This paragraph is concerned with the first method. Works on the second method are under way at the “Laboratoire de Robotique de Paris” (Robotics Laboratory of Paris). Information on this work can be found in paper [9] and [10].

Longitudinal performances model estimation

At the beginning of this study, the advanced hypothesis was: a model adapted to local conditions can be obtained from the following elements : longitudinal stiffness and estimates of peak (μ_{max}) and 100% slip (μ_{locked}) friction coefficients.
The longitudinal stiffness is obtained from tire manufacturer data and estimates of μ_{max} and μ_{locked} (figure 3) can be obtained from on site measurement.

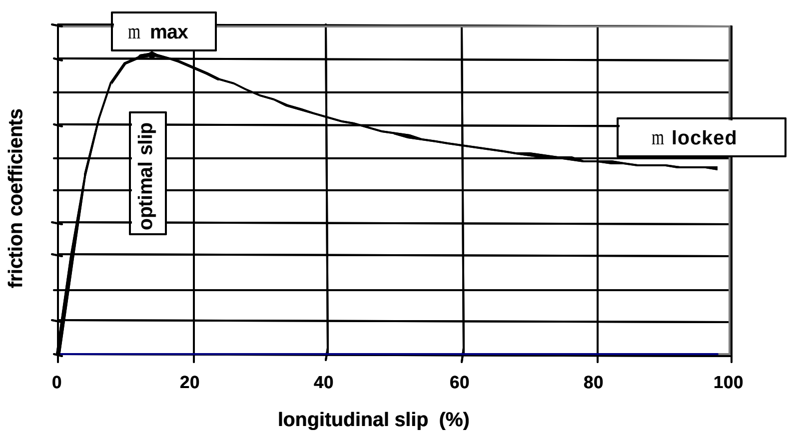

Figure 3 : typical longitudinal friction curve

The front wheel braking method (known since the sixties) has been tried out regarding estimation of the two friction coefficients. This method, easily applied on trafficked road proved to give acceptable results. Table 1 gives an example of results.

Table 1 comparison of friction coefficient obtained
from front wheel braking measurements and from tyre manufacturer measurements

	Dry open grade friction course		Wet open grade friction course		Wet bituminous concrete		Wet polished bituminous concrete	
	μ_{max}	μ_{locked}	μ_{max}	μ_{locked}	μ_{max}	μ_{locked}	μ_{max}	μ_{locked}
Front braking measurements		0,69	0,88	0,67	0,84	0,60	0,51	0,43
Tyre manufacturer Measurements	1,02	0,75	0,92	0,69	0,87	0,64	0,55	0,39

So the problem to be worked out is the estimation of the tire model coefficient (Magic formulae) from the longitudinal stiffness and μ_{max} and μ_{ocked} estimates

The formulae used is:

$$m(G) = D\sin\left(C\arctan\left(BG - E\left(BG - \arctan(BG)\right)\right)\right) \quad (1)$$

Taking into account special features regarding « arctan (*BG*- *E(BG* - arctan (*BG*)) » (almost linear and almost crossing O(0,0)

Formulea (1) can be simplified as

$$m(G) = C_1 \sin(C_3 \arctan(C_7 G))$$

With

$$D \to C_1$$
$$C \to C_3$$
$$BG - E\left(BG - \arctan(BG)\right) \to C_7 G$$

C1, C3 et C7 are estimated from μ_{max} μ_{locked} estimates

Figure 4 shows examples of curves obtained with the estimated models (red curves) and with a closely fitted (parametric model [6][7]) model on measurement with continuous longitudinal slip variation (blue curves)

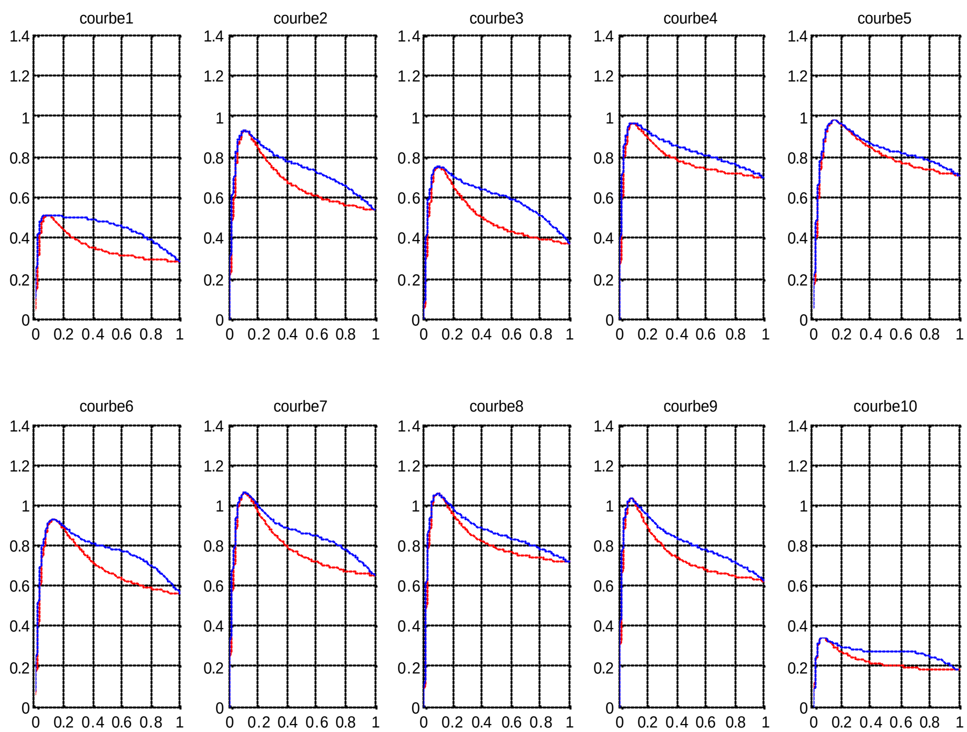

Figure 4 : comparison between performances curves adjusted on tire measurement data (blue) and identified model from longitudinal slip stiffness and μ_{max} μ_{locked}

Longitudinal friction coefficients are dependent on speed and vertical force. With regard to speed, front braking measurement can be carried out at different speed but μ_{max} and μ_{locked} are estimated for one vertical force. Figure 5 shows an example of the influence of these forces on the longitudinal friction coefficient. This dependence have to be taken account in the tyre longitudinal friction forces model.

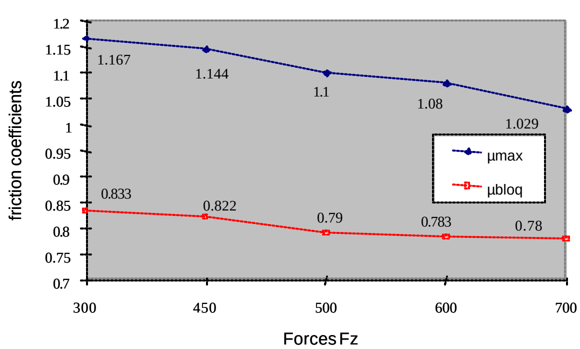

Figure 5 influence of the vertical forces on the longitudinal friction coefficients

Finally on site measurement have to be performed at different speeds in the relevant condition regarding tyre/road contact condition.

Lateral performances model estimation

This case is much more difficult to tackle because on site reliable lateral performances values are very difficult to get.
The European TIME programme [8] recently conducted was concerned with the development of a tyre measurement for steady state. This programme proved the difficulties to get reliable and consistent tyre performance with realistic driving conditions. The "TIME procedure" defined in this programme cannot be applied on trafficked road.

On figures 6 and 7 are shown longitudinal and lateral friction performances for a 185/70 R14 tyre on two wet sections : figure 6 corresponds to a new laid surfacing, figure 7 corresponds to a worn surfacing.

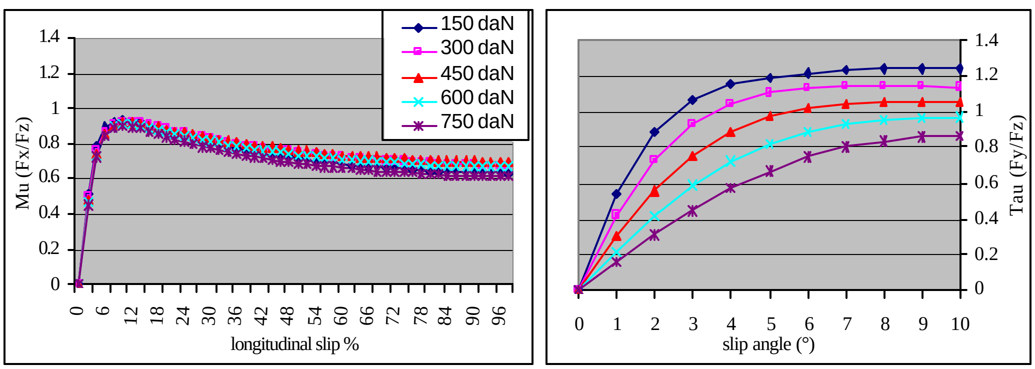

Figure 6: μ = F(longitudinal slip%) and τ = F(slip angle δ)
on a high skip resistant section

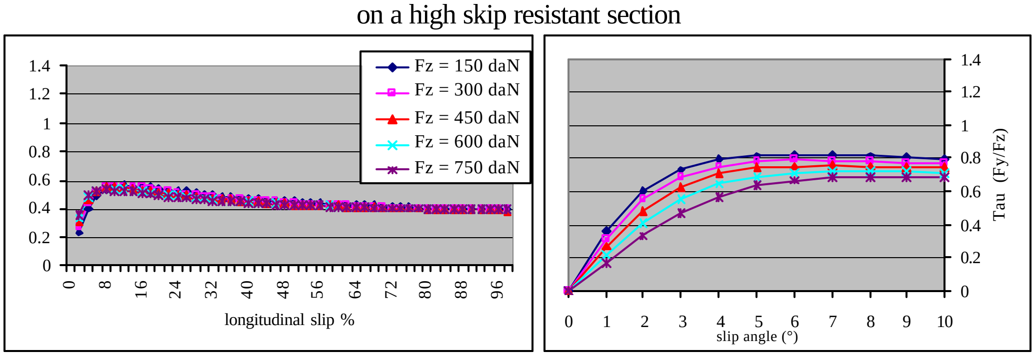

Figure 7: μ = F(longitudinal slip%) and τ = F(slip angle δ)
on a low skip resistant section

Longitudinal performances (μ = F(longitudinal slip %), on the left side are slightly dependent on vertical load (almost negligible except for high loads on figure 6).

Lateral performances are strongly dependent upon vertical loads and more sensitively for high grip section (figure 6 right hand side) .

Figure 8 shows differences for longitudinal and transversal friction coefficients for the two sections. For longitudinal performances, one can notice two cases:

case 1:loads 150 daN, 750 daN

case 2 loads 300,450,600 daN

Despite this difference, obtaining values μ_{max} and μ_{locked} with an instrumented car seems to be an acceptable solution to adjust tyre model for a local condition (surfacing and condition of tyre/road contact)

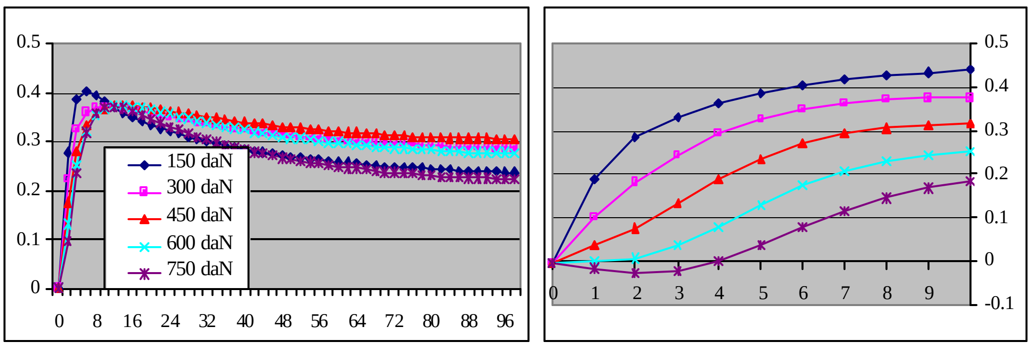

Figure 8 : differences for longitudinal (left side) and transversal (right side) friction coefficients for the two sections

For lateral friction getting a single point value (F_z and δ given) is not sufficient to build up an acceptable and a relevant model. This is a strong limit for accidents reconstruction when emergency manoeuvre involving large slip angles at high speeds have to be simulated. For example, for an emergency avoidance manoeuvre, depending whether the solicitation exceeds or not the friction potential, the car response will be totally different, so there is a need to know tyre lateral performance for slip angle up to 7° and vertical forces variation from 200daN to 700daN for a light car. So a complete model is needed.

Possibilities to get elements from longitudinal model to set up the lateral model were investigated. Friction coefficient values versus actual sliding speed were computed. An example of result is shown on figure 9. Significant differences between longitudinal and lateral friction coefficients can be noticed. These differences are increasing with the load.

All investigations conducted on possible links between longitudinal and lateral performances were not really fruitful.

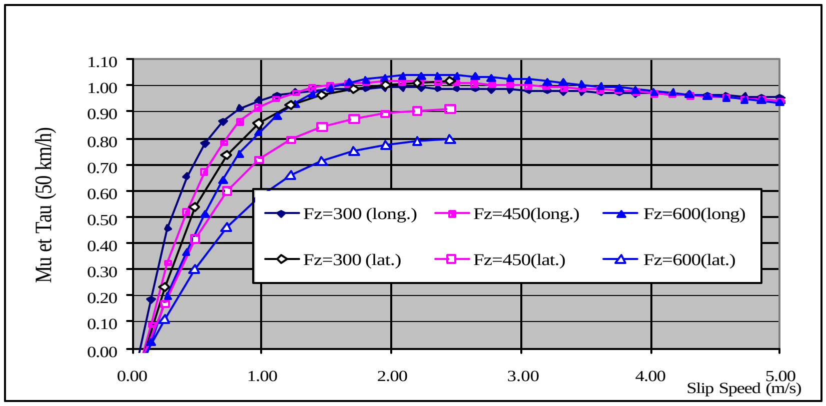

Figure 9 : Friction coefficients values versus actual sliding speed
(Lateral performance friction curves are those plotted from 0 to 2.5 m/s)

Simulations carried out with both tyres for a double change of lane driver command are only slightly different for low solicitation. On the contrary good adjustment of tyre model is necessary condition to get good results at higher speed. This conclusion is crucial regarding accident reconstruction. Evaluation of a relevant lateral friction force model for a given road section remains a problem to be solved.

CONCLUSION

In the state of the work an acceptable solution was found to adapt a relevant longitudinal tire friction model. It was found that obtaining values μ_{max} and μ_{locked} with an instrumented car is an acceptable solution to adjust tyre model through parameters identification for a local condition (surfacing and condition of tyre/road contact). In this case correction coefficients related to vertical load must be applied to build up a relevant model.

No satisfactory solution was found regarding side friction performances. Iterative adjustments were successfully tested but this method is not scientifically based.

ACKNOWLEDGMENTS

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The objective of this programme regarding road safety is to define all possible actions (vehicle, driver, road characteristics and road environment) which could reduce number and gravity of wet road accidents.

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REFERENCES

[1] SERA-CD (Gilles Schaefer)
CALLAS non linear coupled model for vehicle dynamics
[2] D. Lechner, Y. Delanne, G. Schaefer, V. Schmitt,
Méthodologie de validation du logiciel de dynamique automobile CALLAS.
Papier SIA 970202. Congrès SIA International "La dynamique du véhicule automobile et ferroviaire" Ecole Centrale de Lyon, Avril 1997.
Reprint in "Ingénieurs de l'Automobile" N°713, Mai 1997.
[3] G. Schaefer, D. Lechner, Y. Delanne, V. Schmitt,
CALLAS: a decisive step toward validity for 3d vehicle dynamics.
ISATA Paper 97SAF005. 30th ISATA Conference, Florence June 1997.
[4] D. Lechner, Y. Delanne, G. Schaefer, Influence of road and vehicle factors on accidents: what can be gained from driver/road/vehicle interaction model.
FISITA 98, Paris Septembre 1998.
[5] V.Schmitt, F. Vangraefschèpe
Contribution of digital simulation on the analysis of the design parameters of light and heavy vehicle. - AUTOTEST - Barcelona June 1998
[6] Y. Delanne, G. Beurier
Evaluation of tire/road friction performance models from on site measurements.
SURF 2000 Juin Nantes France
[7] G. Beurier, Y. Delanne
Méthode de recherche statistique de relations entre les paramètres de modèles en vue de l'identification de ces paramètres. - CIFA 2000 Juillet, Lille France
[8] J.J.M. van Oosten, C.Savi, M.Agustin, O.Bouhet, J.-P. Colinot
Time, Tyre Measurements, Forces and Moments EAEC Barcelona June 1999
[9] A.El Hadry, J.-C. Cadiou, K.N.M'Sirdi, Y. Delanne
Wheel-Slip Regulation based on Sliding mode approach SAE paper 01PC-152
[10] A.El Hadry, G. Beurier, J.-C. Cadiou, K.N.M'Sirdi, J.-C. Cadiou, Y.Delanne
Simulation et observateurs pour l'estimation des performances dynamiques d'un véhicule; - CIFA 2000 Lille France