TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
MECHANICS | MECHANIKA
3-M/2015

MICHAŁ KLUZIEWICZ*

MODELLING MANOEUVRES THAT MAY INDUCE SIDE SKID IN A FRONT-WHEEL DRIVE CAR

MODELOWANIE MANEWRÓW WYWOŁUJĄCYCH STAN ZARZUCENIA W SAMOCHODZIE PRZEDNIONAPĘDOWYM

A b s t r a c t

The simulation and experimental verification of oversteer inducing manoeuvres are presented. A transient state of oversteering in a front-wheel drive car is initiated only by using steering wheel, throttle and brake inputs. The car's motion is simulated with a single-track dynamic model with a parameterized input that sufficiently reproduces the behaviour of a front-wheel drive Peugeot 106 XSI (group N). The conclusions may be useful in better understanding complex driving techniques and vehicle dynamics that are not commonly described in basic elaborations.

Keywords: vehicle dynamics, car driving techniques, road traffic safety, oversteering, side skid

S t r e s z c z e n i e

Przedstawiono wyniki badań symulacyjnych oraz drogowych dla manewrów wywołujących przejściowy stan nadsterowności przednionapędowego pojazdu o podsterownej charakterystyce w ruchu ustalonym. Do analizy symulacyjnej wykorzystano rowerowy model o nieliniowych charakterystykach samochodu Peugeot 106 XSI (N-grupowy) zweryfikowany podczas prób drogowych. Inicjacja stanu nadsterowności następowała wskutek zadanego wymuszenia kierownicą oraz pedałami przyspiesznika i hamulca. Wyniki pracy mogą być przydatne w zrozumieniu bardziej złożonej dynamiki samochodu i techniki jego prowadzenia, które nie są opisywane w klasycznych opracowaniach.

Słowa kluczowe: dynamika samochodu, techniki prowadzenia, bezpieczeństwo ruchu drogowego, nadsterowność, zarzucenie

DOI: 10.4467/2353737XCT.15.175.4380

* MSc. Michał Kluziewicz, Faculty of Mechanical Engineering, Cracow University of Technology.

1. Introduction and aims

The vast majority of technically fit passenger cars, apart from their construction and drive type, are characterized by understeer steady-state cornering behaviour. Nonetheless almost every understeer car can be forced by the driver to induce a temporary state of oversteering of a various durations. These are the most essential factors for initiating oversteering:

– tyre load change by accelerating/decelerating,
– additional tyre horizontal loads required to change the angular momentum of chassis yaw rotation,
– limitation of tyre friction (tyreforce ellipse) [8].

As a parts of the author's previous investigations the following goals were completed:

– creation of a plain dynamic model of a front-wheel drive car with suitably parametrized inputs that sufficiently simulates states of oversteering [5],
– definition of the manoeuvres that possibly induce oversteering in a nominally understeering front-wheel drive car [4],
– sensitivity analysis of different driving techniques affecting the possibility of oversteering occurrence in manoeuvres considered [5],
– verification of the car model formula and steering methods via comparison to data collected during execution of road tests [5],
– comparison of race and rally cornering techniques efficiency in a front-wheel drive car [6].

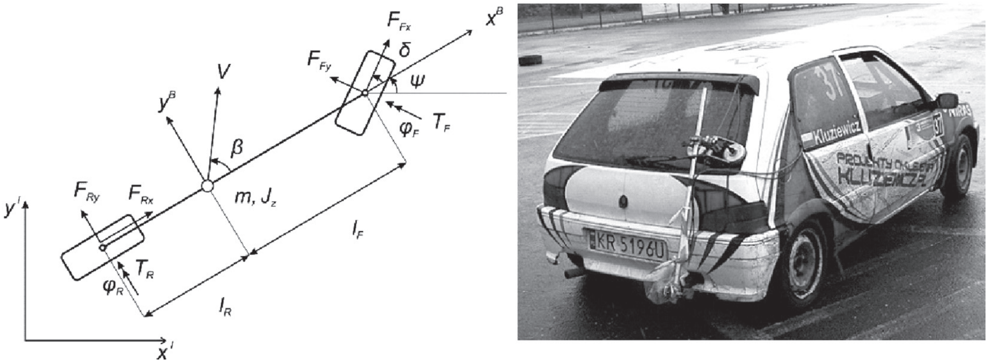
The main goal of this paper was to compare the data obtained during road tests to the modelled oversteer manoeuvres. In addition to previous articles, all simulations were followed by equivalent test drives. The second objective was to present the overlapping timelines for both simulations and trials. The following manoeuvres that could possibly induce oversteering in typical road traffic conditions were taken into consideration:

a) "Scandinavian flick" – slight steering input towards the opposite direction of the corner, then steering into the turn, while sharply lifting off the throttle [11],
b) "Left-foot braking" – braking while the throttle is opened.

In this example a nominally understeering front-wheel drive compact car was considered. Manoeuvres were executed with open-loop steering – no driver model was used. The results may be useful for a better understanding of complex car dynamics and driving techniques that are not widely described in basic elaborations. Some examples of aggressive manoeuver simulations with different drive types and other surfaces can be found in quoted articles [1, 3, 11].

2. Formulation of the rally car model

The car's motion on a flat, plain and non-deformable surface was simulated with a single-track dynamic model [11]. The model consists of three rigid bodies: car chassis and 2 wheels (reduced front and rear axles). Both wheels rotate while the front one swivels. Driving and braking torques are applied to the wheels.



Car parameters	m [kg]	J_z [kgm^2]	l_F [m]	l_R [m]	R_w [m]	J_w [kgm^2]	h_c [m]
Values	810	863	0.75	1.6	0.245	0.75	0.51
Tyre parameters	Tyre size 145/70R13, pressure p_0 =2 .0 bar, tread depth 6 mm						

Fig. 1. Bicycle car model scheme and test vehicle photograph

A physical model with five degrees of freedom, represented by x, y, ψ, φ_F and φ_R coordinates, was formulated according to the following assumptions:
- the suspension travel effects, steering trapeze, differential, stabilizing moment and drivetrain dynamics were neglected;
- the tyres slip characteristics of both axles were reduced to one wheel (one trail);
- the vertical load variations were calculated by a static relation formula;
- the tyre relaxation length was taken into account.

The following values were assumed as parametrized inputs: steering wheel rotation angle, throttle pedal travel and brake pedal travel (dimensionless, range 0 to 1), handbrake acutation, gear change, clutch engagement.

The vehicle movement in accordance with this model [11] is described in a x^i, y^i cartesian coordinate system with following equilibrium of forces and moments equations.

$$m\ddot{x} = F_{Fx}\cos(\psi+\delta) - F_{Fy}\sin(\psi+\delta) + F_{Rx}\cos\psi - F_{Ry}\sin\psi \quad (1)$$

$$m\ddot{y} = F_{Fx}\sin\left(\psi+\delta\right) + F_{Fy}\cos\left(\psi+\delta\right) + F_{Rx}\sin\psi + F_{Ry}\cos\psi \quad (2)$$

$$I_z\ddot{\psi} = \left(F_{Fy}\cos\delta + F_{Fx}\sin\delta\right)l_F - F_{Ry}l_R \quad (3)$$

$$I_i\dot{\omega}_i = T_i - F_{ix}r, \qquad i = F, R \quad (4)$$

The semi-empirical "Magic formula" model was used to imitate the tyre to road interaction in definite motion conditions [9]. This formula allows the calculation of tangent forces values as a function of complex longitudinal slip, lateral slip and tyre vertical load force [1].

Rolling resistance force, air resistance force and functional combustion engine model are included. The quasi-static relation between torque, crankshaft rotational speed and throttle angle is provided by means of an approximating function.

Car model parameters were estimated based on data collected during the execution of stationary and road tests, the author's experience, and similar literature elaborations [4, 5]. The propriety of using a single track model in the states of motion described was experimentally confirmed in essay [5].

3. Simulations and road testing results

Software simulations were performed in order to validate the capability to induce oversteering with various steering inputs. Afterwards simulation results were compared to data collected during the execution of corresponding road tests [1]. The following road experiments were performed in order to verify the single-track vehicle model and validate the capability to induce oversteering in front-wheel drive car.

Road tests were conducted under the following conditions:
- constant car balance, one setup;
- plain, flat tarmac surface;
- light rain providing continuous dampness of surface;
- air temperature around 15°C, no strong wind;
- air pressure in cold tyres 2.0 bar.

3.1. "Pendulum turn" experimental results

The first manoeuvre is defined as a slight steering input in the opposite direction of the turn, then steering into the turn, while sharply lifting off the throttle. Comparison of experimental (dotted line) and simulation (solid line) traces are presented in Fig. 4. The initial vehicle speed was 64 km/h with the throttle opened 34%.

At time t = 0.9 s the throttle pedal was lifted off and simultaneously a sinusoidal input to the steering wheel (approx. 200° to the right) was started. Subsequently step input (approximately 220° to the left) was initiated. The shapes of the road tests and simulation functions are very similar. The tiny differences are in slip angle values. In the simulation timeline the slip angle is delayed (phase shifted) by approximately 0.5 s. Maximum slip angle acquired during the simulation runtime is greater than 40° and still growing.

Due to the simulated vehicle trajectory (Fig. 2) and road test observations, also for the vehicle yaw rate and slip angle values it is noticeable that the car was firmly sideskidding.

3.2. "Left-foot" braking experimental results

The second manoeuvre is defined as a simultaneous pressing of accelerator and brake pedal while executing a turn. Comparison of the experimental (dotted line) and simulation (solid line) time courses are presented in Gig. 3. The initial speed of the vehicle was approximately 63 km/h with the throttle opened 35%.

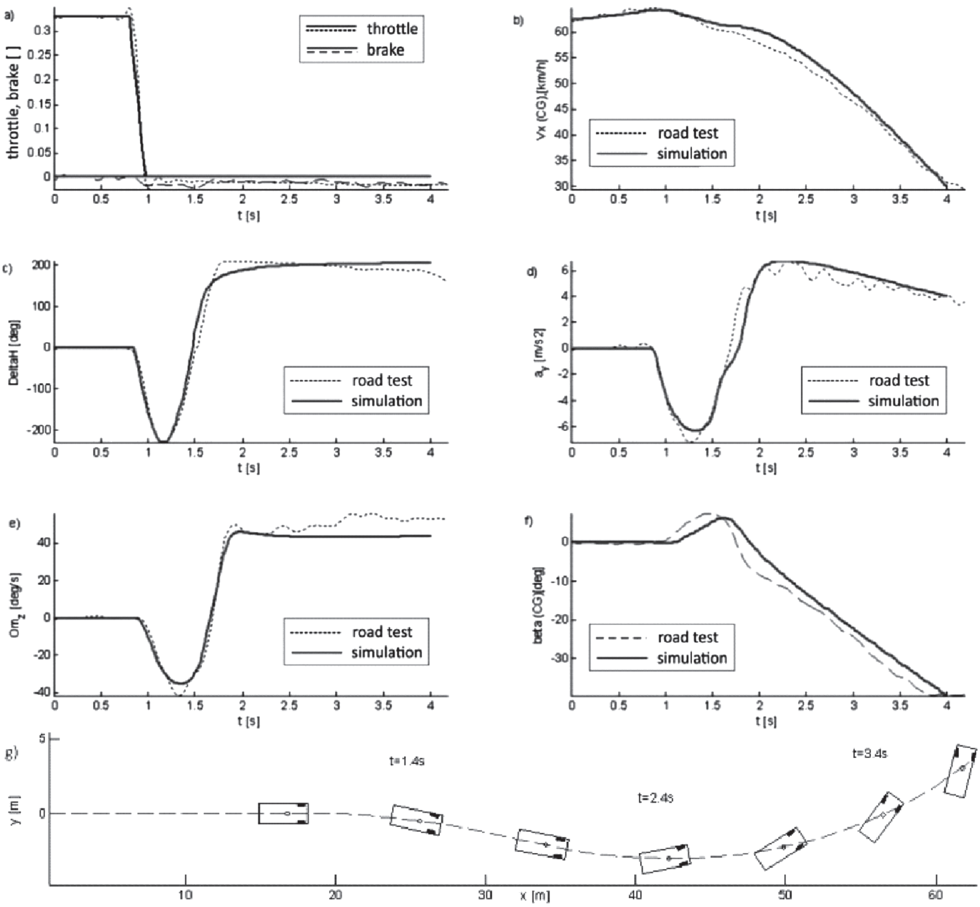


Fig. 2. Experimental and simulation results of "Scandinavian Flick" manoeuvre: a) throttle and brake commands; b) vehicle longitudinal velocity; c) steering wheel control (steering command) d) lateral acceleration; e) vehicle yaw rate; f) slip angle of vehicle's centre of inertia; g) vehicle trajectory

At time of $t = 1.5$ s the throttle pedal was lifted off and a step input to steering wheel (approximately 210° to the left) was started. Subsequently at time $t = 2.8$–4.5 s both accelerator and brake pedal were pressed and held. In the simulation timeline throttle liftoff was omitted as an irrelevant factor towards the car's behaviour. In order to correct the shorter acceleration time, initial speed in the simulation was increased.

The shapes of the signals from road tests and simulations are very similar. The tiny differences are in the vehicle's yaw rate. Due to the simulated vehicle trajectory (Fig. 3), road test observations, also from the vehicle yaw rate and slip angle values it is noticeable that the car was sideskidding intensely.

The maximum slip angle achieved during the simulation runtime is greater than 90° and car is moving backwards to a full stop in further simulations.

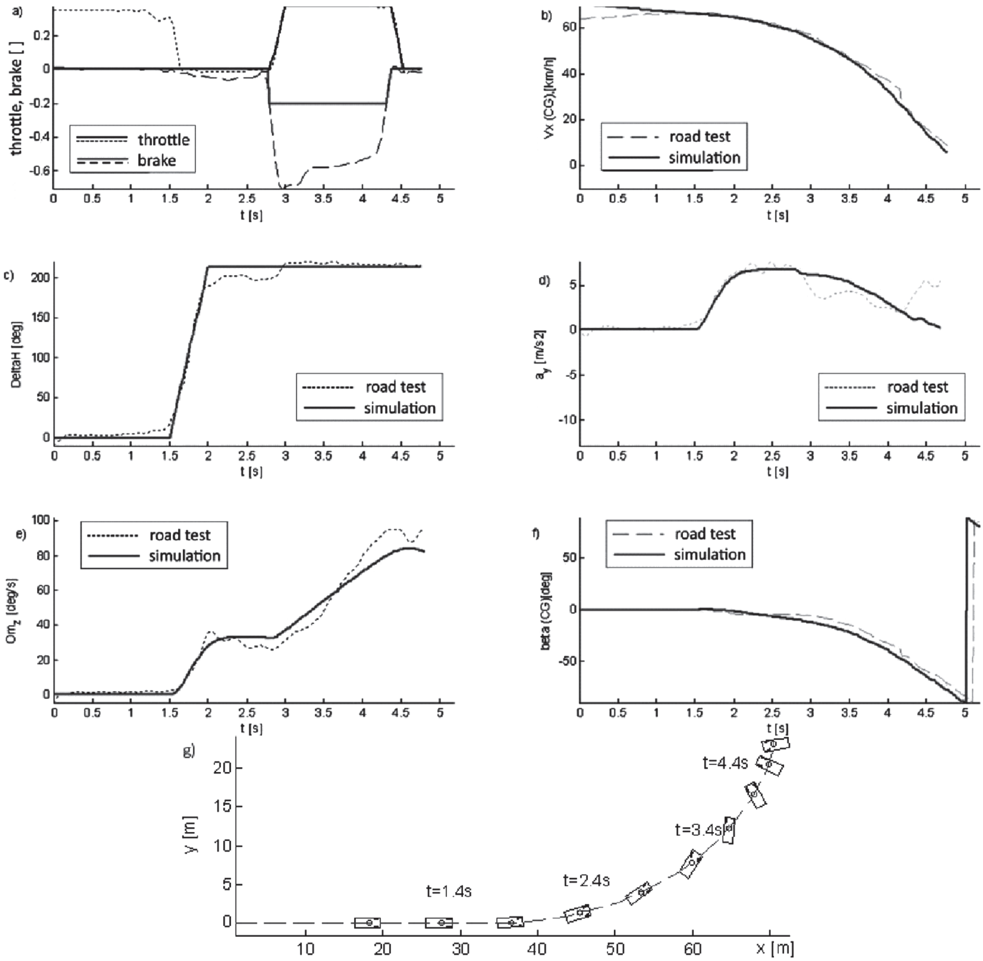


Fig. 3. Experimental and simulation results of "left-foot braking" manoeuvre: a) throttle and brake commands; b) vehicle longitudinal velocity; c) steering wheel control (steering command) d) lateral acceleration; e) vehicle yaw rate; f) slip angle of vehicle's centre of inertia; g) vehicle trajectory

4. Conclusion

Two methods of inducing oversteering in a nominally understeer front-wheel drive car were presented. The results of simulations were verified qualitatively and quantitatively based on road tests and the author's experience. No driver reaction (feedback) was assumed.

According to road experiments results of more than 90% of model accuracy were obtained (for constant car setup) in all runs. Both manoeuvres induced significant side-skid (slip angles over 40° during runtime). In real life driver reactions may both strengthen or weaken the oversteering tendency.

References

[1] Abdulrahim M., *On the Dynamics of Automobile Drifting,* SAE 1019, 2006.
[2] Bogdanow O. A., Cyganow E. S., *Sportowa Jazda Samochodem*, WKiŁ, Warszawa 1989.
[3] Hindiyeh Y., Gerdes Ch., *Driftkeeping: path tracking at the friction limits using high sideslip cornering*, International Association of Vehicle System Dynamics, Manchester 2011.
[4] Kluziewicz M., Maniowski M., *Stany nadsterowności podsterownego samochodu z przednim napędem.* Zeszyty Naukowe Instytutu Pojazdów Politechniki Warszawskiej, z.1(77), 2010, 169–177.
[5] Kluziewicz M., *Przejściowe stany nadsterowności podsterownego samochodu z przednim napędem*, praca dyplomowa-magisterska, Wydział Mechaniczny, Politechnika Krakowska, 2010.
[6] Kluziewicz M., Maniowski M., *Porównanie wyścigowej i rajdowej techniki pokonania łuku samochodem przednionapędowym*, Czasopismo Techniczne, 5-M/2012, 51–62.
[7] Maniowski M., Materiały z koła naukowego „Inżynier Ścigant", Kraków 2011.
[8] Mitschke M., *Dynamik der Kraftfahrzeuge, Band B*, Springer-Verlag, 1984.
[9] Pacejka H.B., *Tyre and Vehicle Dynamics*, Butterworth-Heinemann, SAE, 2002/2006.
[10] Velenis E., Tsiotras P., *Minimum Time vs Maximum Exit Velocity Path Optimization During Cornering*, 2005 IEEE International Symposium on Industrial Electronics, Dubrovnic, Croatia, June 2005
[11] Velenis E., Tsiotras P., Lu J., *Modeling Aggressive Maneuvers on Loose Surfaces: The Cases of Trail-Braking and Pendulum-Turn.* Proceedings of the 2007 European Control Conference, Kos, Greece, July 2–5, 2007.