

Vehicle Dynamics with Real Time Damper Systems

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Abstracts

Real Time Damper (RTD) systems are devoted to modify the instantaneous damping characteristics to generally determine increased comfort performance. RTD control strategy conception can moreover support the realization of a strategy oriented to integrate different chassis control systems to carry out a better handling. To cope with the huge problems concerned to those general aims, virtual experimentation appears fundamental to correctly conceive both stand-alone RTD control strategy and its integration with other chassis control systems. The paper presents the methodology adopted to investigate about the vehicle dynamics with RTD, considering as benchmark a step-steer manoeuvre and the stand-alone control strategy robustness to some typical inputs. The vehicle model was carried out with a FIAT customized ADAMS/Car version. The RTD stand-alone and an example of integration with Vehicle Dynamics Control (VDC) was carried out in Matlab/Simulink. Some examples of performance obtained in ADAMS/Car – Matlab/Simulink co-simulation are presented.

Vehicle Model

An analysis using an ADAMS/CAR/Car vehicle model, integrated in co-simulation with MATLAB/Simulink software was conducted. ADAMS/CAR/Car permits the integration with Simulink system blocks, in order to obtain a MATLAB/Simulink full vehicle model for handling manoeuvres. The vehicle model was an Alfa Romeo 166 – 30 super of which a schematic ADAMS/CAR/Car layout is shown in Figure 1.

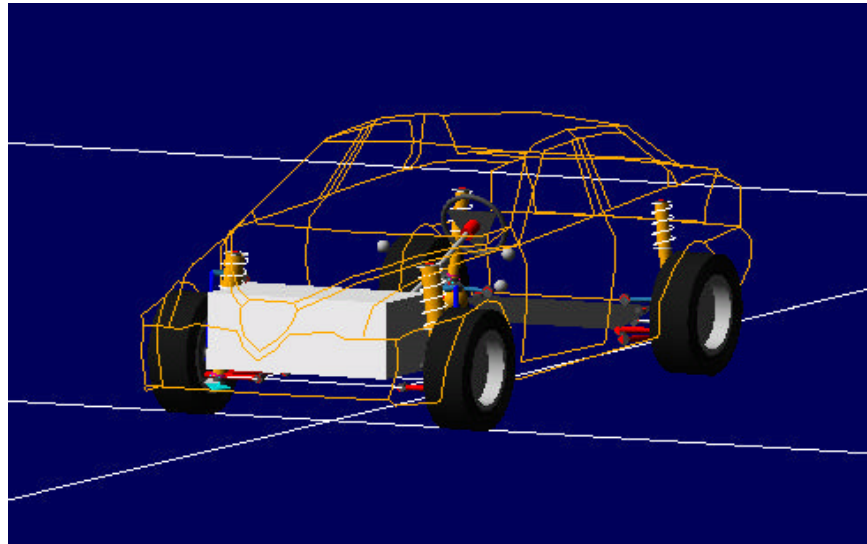


Figure 1. Alfa 166 ADAMS/Car model

Engine is a 3000cc cylinder with 220 CV power and standard 2WD driveline. The vehicle is equipped with Goodyear 205-55-16 tires. Wheel behaviour in ADAMS/Car was described by Pacejka's mathematical model. Alfa 166 tires characteristic curves are shown in Figure 2.

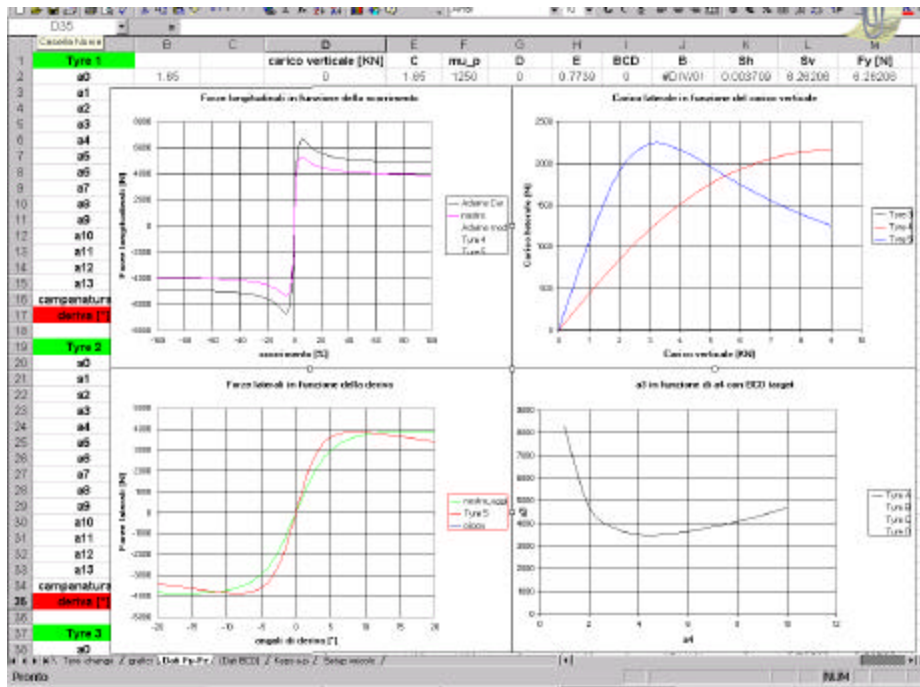


Figure 2. Pacejka's tire forces from Alfa 166 ADAMS/Car model

Vehicle has a front suspension *double wishbone* type, with two attach points in the lower arm, two in the upper, upright with spindle and co-axial springs and dampers. Dampers action in the model was disabled to allow the damper ratio continuous control in MATLAB/Simulink. Rear suspension is a *multi-link* type, with five attach points to the body.

Front and rear roll-bars geometry complicates the direct modeling with ADAMS/Car because it does not allow an accurate description of the physical behaviour, so their influence on vehicle dynamics (deduced from elasto-cinematic curves) was inserted in vehicle model as a conceptual force applied between suspensions and body.

Front anti-roll equivalent stiffness is 34 N/mm considering anti-symmetric jounce. Rear equivalent stiffness was estimated in 21 N/mm. Elasto-cinematic curve for this suspension was validated on experimental data. Validation of ADAMS/Car vehicle model considering steady-state roll behaviour with experimental data was done adjusting bushings and bumpstops stiffness/damping characteristics. Figure 3 shows some examples about the validation work results.

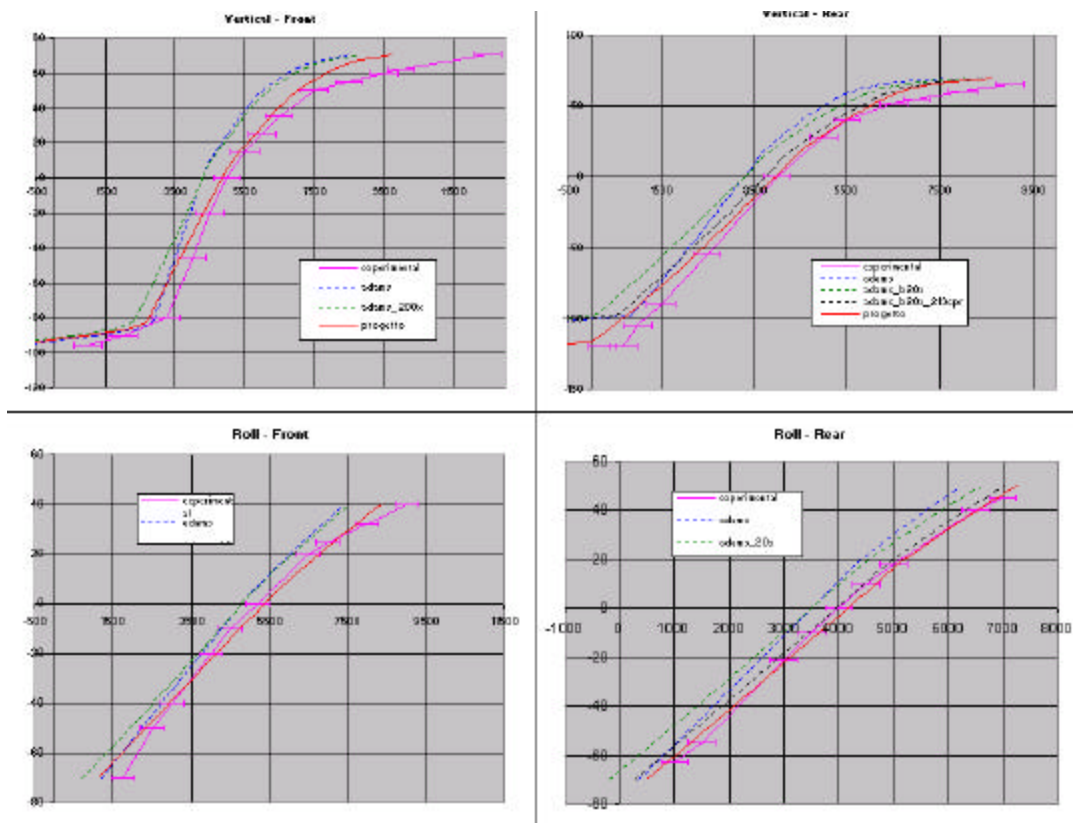


Figure 3. Alfa 166 experimental and modelling elasto-cinematic curves

Manoeuvres

ADAMS/Car permits to generate a large choice of handling and comfort manoeuvres. The more interesting for the present work are briefly resumed in the following:

Step Steer is an abrupt handling manoeuvre. Steering wheel angle (SWA) increases from 0 to 90-100-120 degrees in 0.25-0.3 seconds, then it remains in the same position for the whole simulation time.

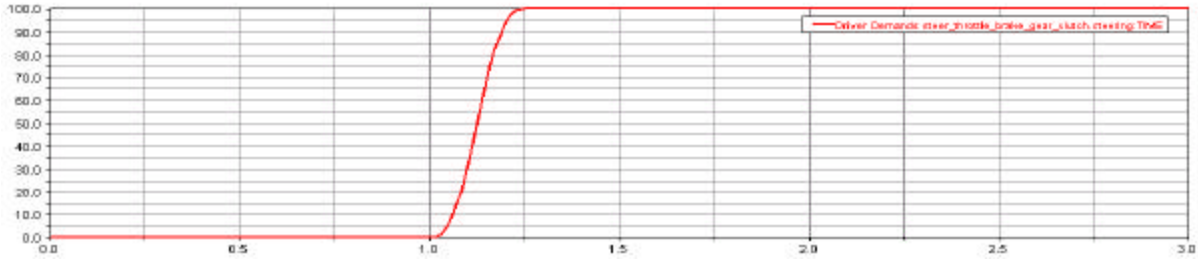


Figure 4. Step Steer (SWA vs time)

Single Line Change is a sinusoidal wave steering input. It simulates for example the driver will on avoiding an obstacle. This manoeuvre points out the vehicle ability on recovering sideslip angle in critical handling conditions.

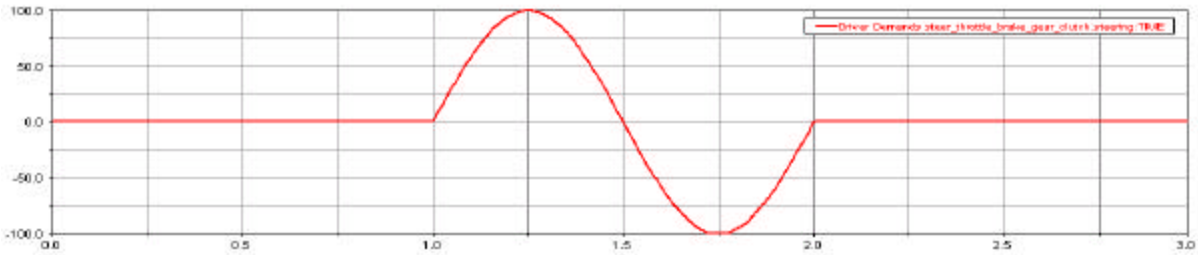


Figure 5. Single Line Change (SWA vs time)

Swept Sine Steer is important for comfort tests, it permits to characterise roll dynamic behaviour and to analyse vehicle frequency response.

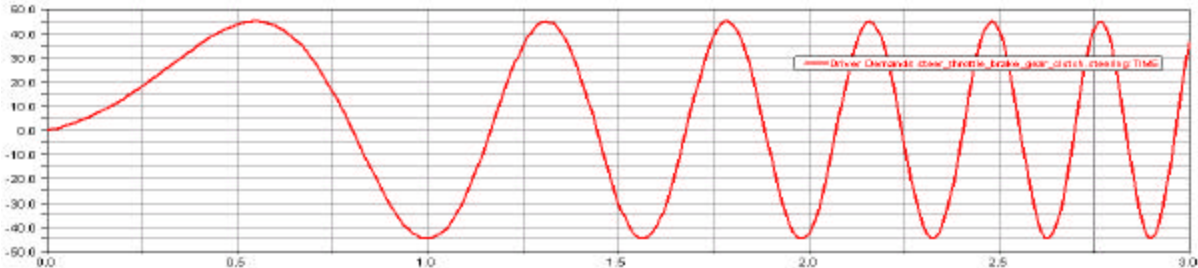


Figure 6. Swept Sine Steer (SWA vs time)

Slow Ramp Steer is a manoeuvre useful to determine the roll stabilized curve (roll angle depending on lateral acceleration), steering wheel angle increases with 15 deg/s rate from 0 to 180° in 12s.

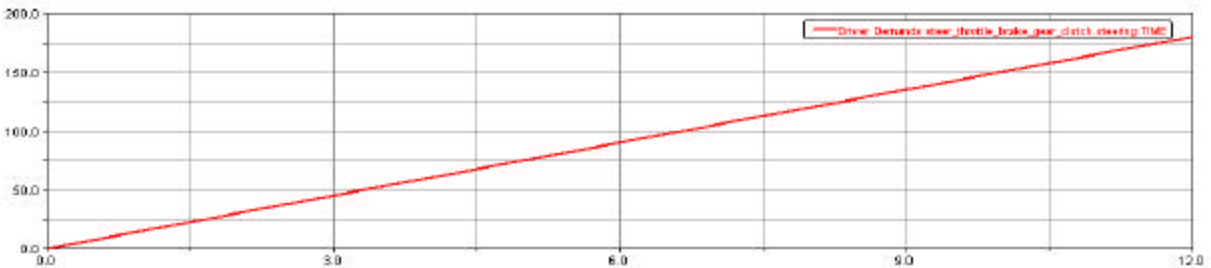


Figure 7. Slow Ramp Steer (SWA vs time)

Real Time Dampers (RTD) control strategy

The general target is to carry out a control strategy elaborated to optimise the vehicle dynamics subjected to a defined handling manoeuvres set. A predictor is devoted to identify the manoeuvre.

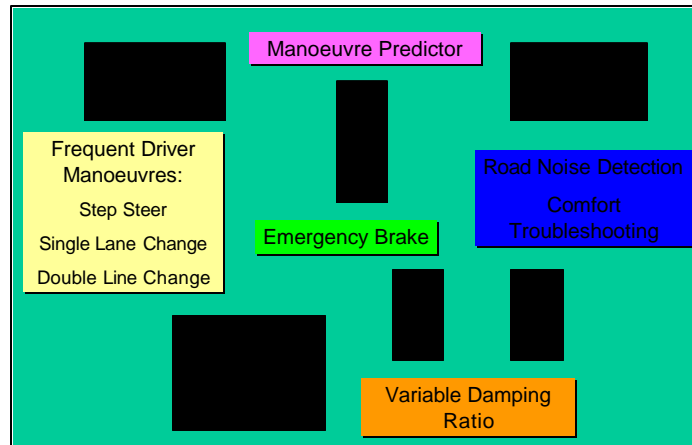


Figure 8. General glance on Real Time Dampers control strategy

Three many targets are mainly important to develop a general Real Time Damping control strategy. The first one concerns handling full vehicle behaviour in the most frequent steering manoeuvres, the second is referred to the brake distance optimisation during emergency braking tests, third is the comfort continuous control. At the moment the first point was developed according to a methodology tested considering a step steer recognizing and a real time roll angle control.

Step steer manoeuvre for a first attempt analysis

The reference manoeuvre was a *step steer 100-120*, (100 km/h, 120 degrees of maximum steering value). Figure 9 presents the variation field expected for damping ratio: *max* curve is obtained multiplying the default one for a 2.5 factor, moreover *min* curve results from a 0.5 multiply factor.

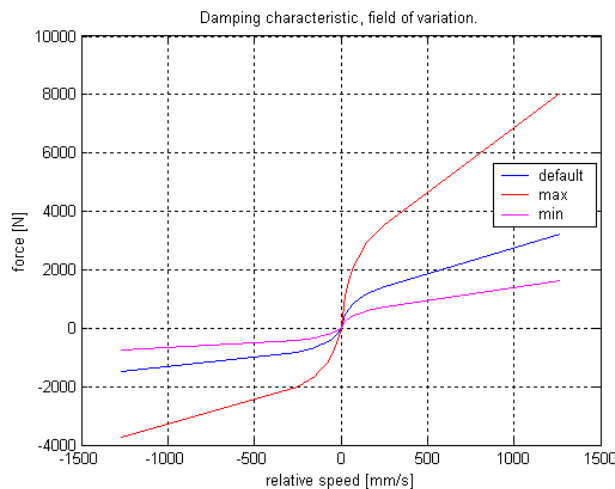


Figure 9. Damping adjustable curves (force vs velocity)

The methodology adopted to optimise damping ratio set considers initially to carry out explorative simulation tests about the *roll/time* diagram, modifying the four damping ratio configuration imposing different set of curves. Figure 10 shows different roll dynamics obtained considering several damper combination setting (numbers in legend are respectively the factors in the order: FL-FR-RL-RR).

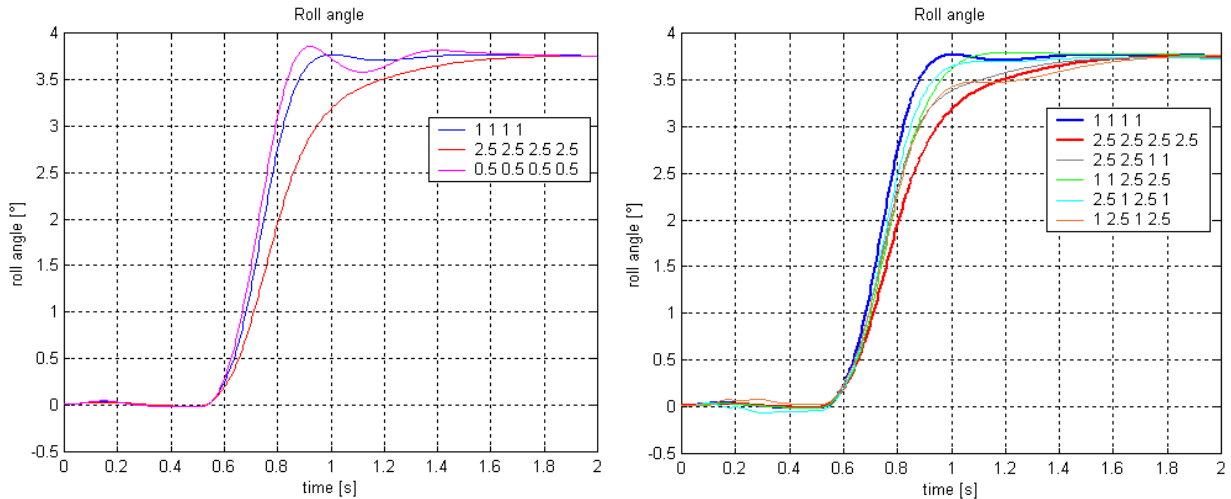


Figure 10. Roll dynamic in different damping configuration, Step Steer 100-100

A control strategy devoted to maximize response velocity of the system (high slope of roll increasing) and to avoid overshooting was chosen. The control strategy was conceived using fuzzy logic. The control was implemented through MATLAB/Simulink fuzzy logic toolbox.

A preliminary control strategy was carried out considering as input roll error, lateral acceleration and the variations of both from one sample to the other. Roll error was calculated as difference between actual roll angle (directly exported from ADAMS/Car model) and the roll angle estimated by roll characteristic curve, according to Figure 11.

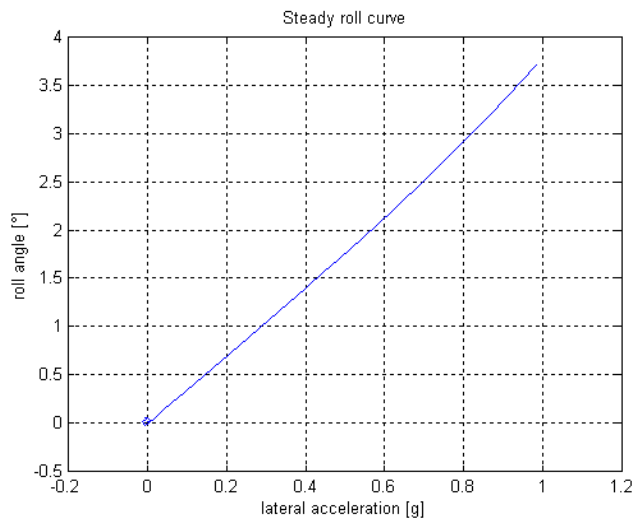


Figure 11. Roll Angle vs Lateral Acceleration, Slow Ramp Steer

Simulation results obtained with such preliminary control strategy are shown in Figure 12. Roll angle behaviour in a 100-120 step steer manoeuvre is efficiently controlled. Progressive degrade of control performances in dependence with velocity and steering wheel angle decreasing are clearly remarkable.

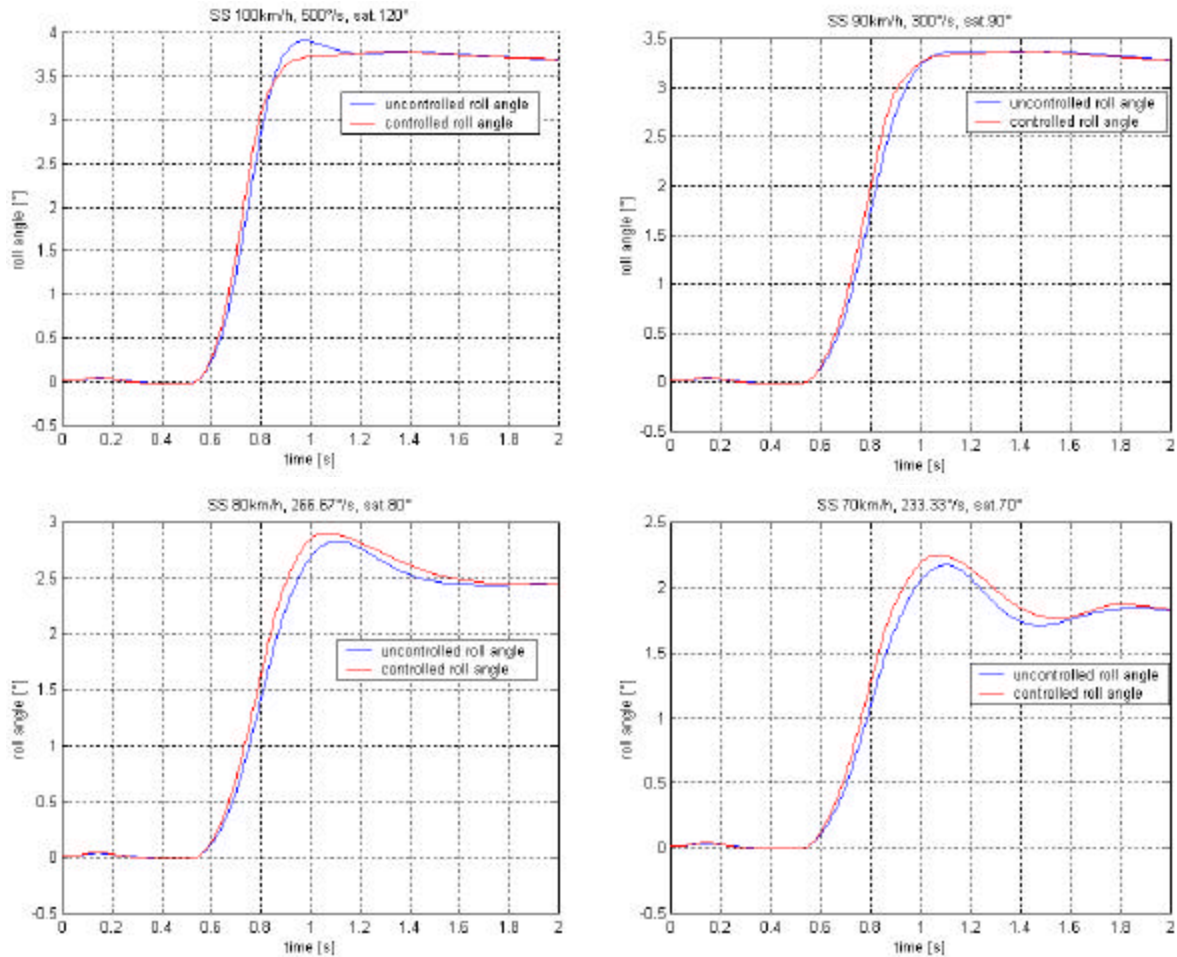


Figure 12. Comparison between RTD controlled and passive vehicle, SWA/velocity decreasing

RTD control works very well in high velocity fields, but its efficiency significantly appears reduced considering less critical manoeuvre conditions, in particular considering vehicle speed, steering wheel angle and steering wheel angle rate lower than those established to optimise performance.

To overcome performance dependence on vehicle and steering wheel angle velocity, a new control input with suitable *membership functions* pointed on vehicle speed was introduced.

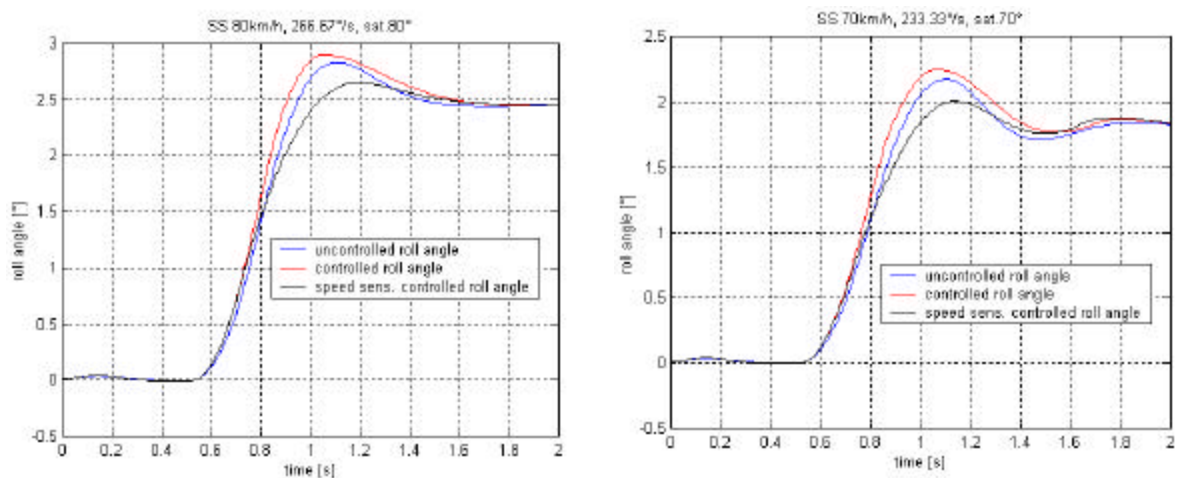


Figure 13. Comparison between speed sensible and simple RTD control, low speed step steer

From the point of view of control strategy flexibility, fuzzy logic appeared very tuneable because permitted to consider the new input not requiring modification to the control strategy formerly conceived. Simulation results obtained with this new *speed sensible roll control* are shown in Figure13.

Functionality of this control switch on for minor speeds than 25 m/s (90 km/h) so. An example of a step steer results analysis obtained considering 80-80 and 70-70 manoeuvres is presented .

Considering diagrams obtained with low vehicle and steering wheel angle velocity it can be observed that it was not possible a complete repealing of the overshooting. For example roll angle in 70-70 step steer manoeuvre reaches a maximum value of 2.2 degrees before stabilising on about 1.8 degrees. Such result depends on the maximum available damping curve limit permitted.

Vehicle Dynamics Control and RTD: an example of integration

A semi-active suspension system modifies the forces exchanged between tire and ground distribution. Moreover, if vehicle is equipped with a Vehicle Dynamic Control (VDC) system, longitudinal forces produced by VDC action are exerted on tires, also. In normal functionality this influence is active mainly in emergency conditions.

By the contrary RTD system points on ride comfort increasing, so a fundamental target for an integration control strategy is to assign each control system priority in particular to optimise the overall performance when driver and operating conditions require a contemporaneous systems' activation.

A general integration strategy could suspend RTD action when the VDC signal is on, so giving a priority to safety (VDC) on comfort (RTD) system. It means that dampers configuration is carried on standard (passive) mode, to avoid that a double action on tire forces could cause an anticipated tire saturation with a following vehicle instability.

The control system switches off RTD action considered by the Authors acts in two different ways: a first strategy turn RTD signal off as soon as VDC overcomes a death-zone limit (*death-zone integration control*), a second strategy implements in RTD Fuzzy control a suitable input which read VDC signal in order to obtain a progressive RTD signal switch off.

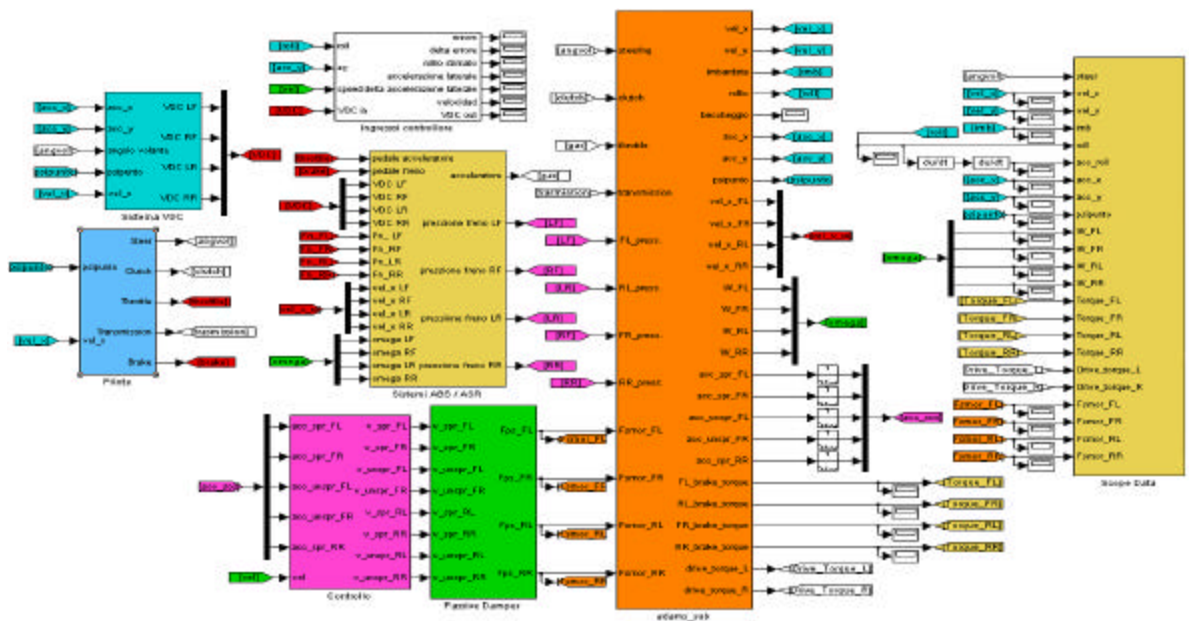


Figure 14. ADAMS/Car vehicle with MATLAB/Simulink control full model

Figure 14 shows the ADAMS/Car and MATLAB/Simulink full model, in which are visible main subsystem blocks: vehicle system ADAMS/Car (orange block), RTD control with dampers MATLAB/Simulink (green block), VDC system MATLAB/Simulink (light blue block).

Integration strategy models were inserted in RTD control subsystem. They are shown in Figure 15, *fuzzy logic* controller block is visible in the centre and the *death-zone* control is located on the right of the field.

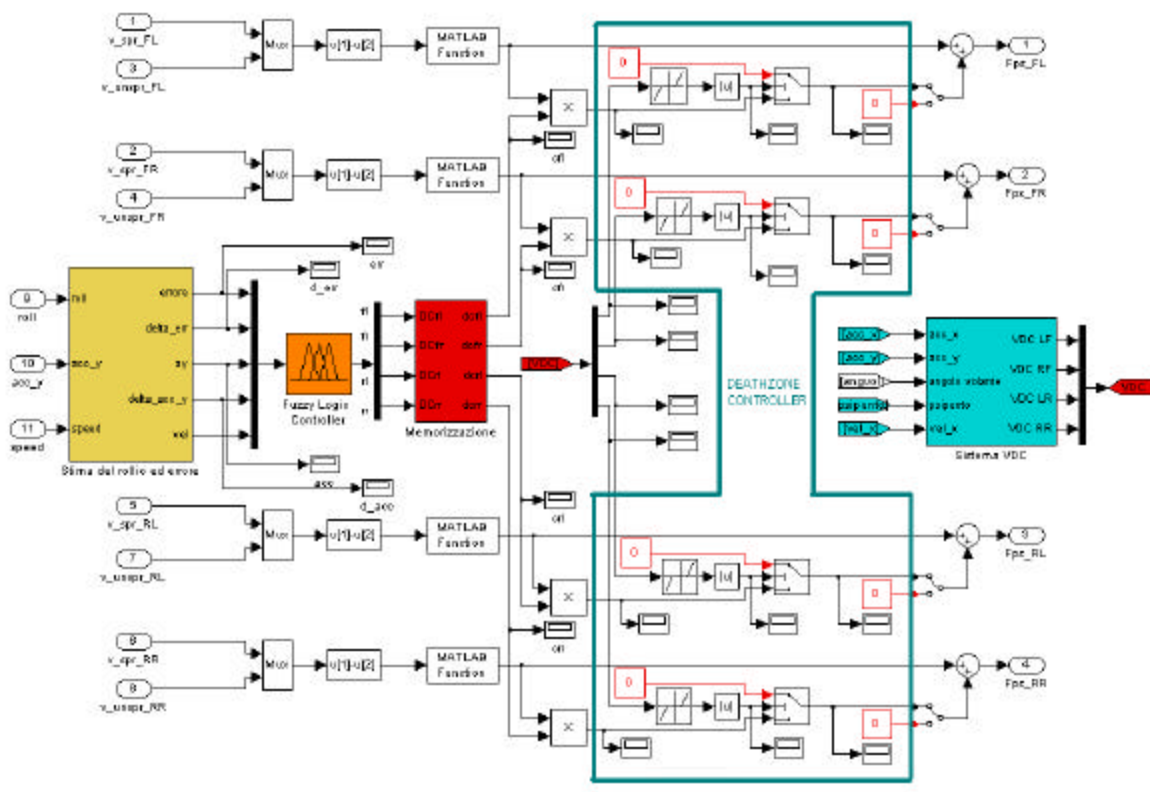


Figure 15. MATLAB/Simulink model, RTD subsystem

Simulation results are reported in Figure 16 and 17. First picture shows the longitudinal tire forces exchanged between ground and wheel in a 100-100 step steer manoeuvre.

In Figure 16 (left) the integration logic effect on tire forces is evident: in critical steering conditions the *stand alone* VDC equipped vehicle feels only one time the stabilizing brake action.

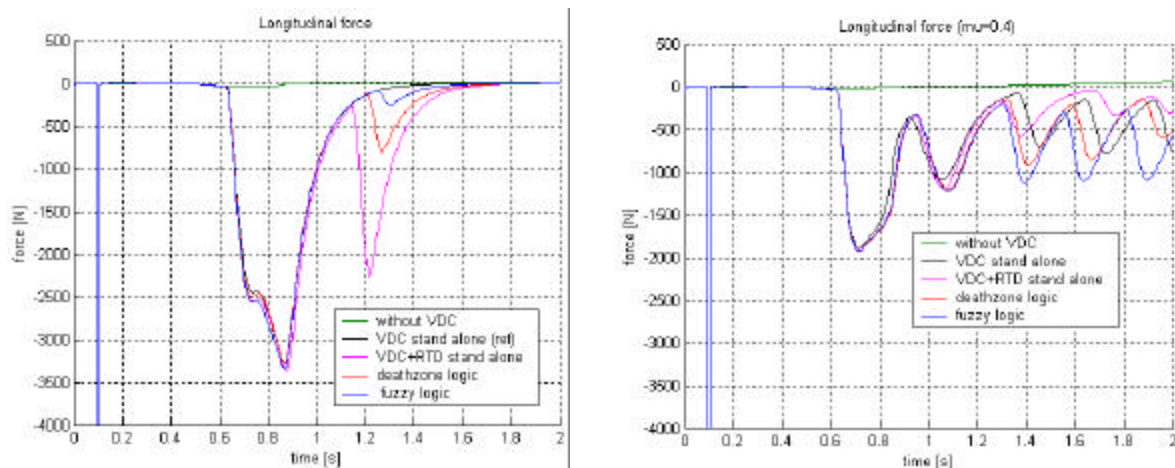


Figure 16. Longitudinal tire forces, $\mu=1$ and $\mu=0.4$

Interaction between stand alone VDC and RTD systems generates a logical conflict that causes a second brake action. This undesired effect can be depressed by *death-zone* and *fuzzy logic* control

RTD system. Moreover right figure shows that two strategies effects are opposite for different adherence conditions: *fuzzy logic* control is better for high adherence, while the *death-zone* strategy works better in low adherence road conditions.

Figure 17 shows RTD/VDC control effect on chassis dynamic.

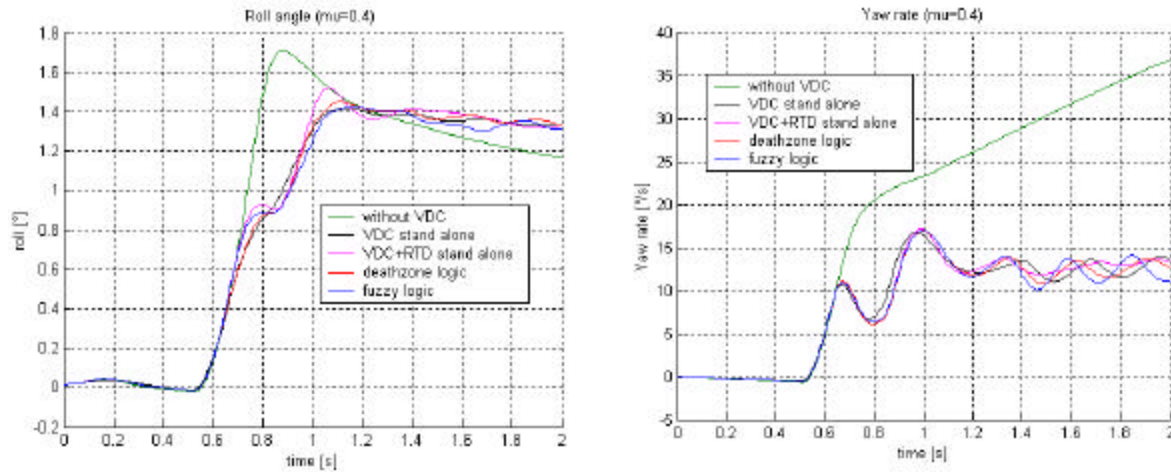


Figure 17. Roll angle and yaw rate curves, 100-100 step steer (low adherence)

In low adherence conditions VDC system succeeds to keeping on control handling behaviour vehicle both with RTD than without it. Anyway oscillations magnitude and quantity around stabilized value give us an important knowledge about goodness of the two different control strategies.

Conclusion

A number of troubles concerning vehicle dynamic and integration between several chassis control system can be numerically predicted by ADAMS/Car. For all the typology of topics that cannot modelled with ADAMS/Car only, co-simulation with MATLAB/Simulink can help the engineers for example in realizing vehicle models with real time controlled parameters.

The activity presented conducted to make an advanced knowledge about vehicle behaviour in continuous damper control and its dynamic dependency from different control strategies, road conditions and suspension parameters setting. In particular it was possible to detect vehicle response in particular conditions of road, manoeuvre and setting. Data results obtained from full vehicle simulations shows the necessity of estimate road adherence coefficient due to choose the best integration strategy for each manoeuvre recognized by the control.

Moreover the paper presented the great versatility of fuzzy logic applied on vehicle dynamic control. Works are in progress to carry on supervision strategies pointed on *advanced general dynamic condition recognizing* for on/off switching of dedicated sub-strategies in Integrated Chassis Control matter. Another next step of this work will be the development of control strategies concerning both the other most common manoeuvres and the analysis considering emergency brake conditions, road noise detection and comfort troubleshooting. Consequently it will be necessary to conceive an integrated supervision control for the management of all sub-strategies on vehicle board.