Effects of Non-Steady Aerodynamic Forces on Car Handling: Implementation in ADAMS of a New Experimental-Numerical Model for Longitudinal and Lateral Wind

F. Cheli, P. Dellachà, P. Mandelli, A. Zasso
Politecnico di Milano, Milano, Italia

1. INTRODUCTION

Many researches have been carried on in order to develop the modelling of a vehicle in its several parts (chassis, suspensions, tyres, steering wheel) for comfort and handling simulations in specific programs for dynamic analysis such as ADAMS.
The object of this work is to create a particular software which is able to reproduce the effects of aerodynamic steady and non-steady forces on a vehicle as well as the effects of lateral wind and which is intended to be compatible with the model of the vehicle itself implemented in ADAMS or with the models of its parts implemented in other softwares (CAE, FEM, etc). In particular, this software represents in the ADAMS environment a user-application tool to add the aerodynamic effects to the generic custom vehicle model.

2. THE MODELLING OF THE AERODYNAMIC FORCES

2.1 The aerodynamic field

Aerodynamic forces acting on a vehicle depend by the instantaneous asset of the vehicle itself. The effects of these forces can be consequently classified in:
1) steady effects
2) non-steady effects

the former being caused by aerodynamic steady forces which are influenced exclusively by the average position of the vehicle; the latter caused by non-steady forces which derive from the variations of the asset around the steady position (due, for examples, to moving on an irregular road). The main result of the depending of these forces on the non-steady motion of the vehicle consists in the influence on its overall stiffness and damping characteristics.

2.2 Experimental analyses in wind tunnel

Wind tunnel tests are performed on the vehicle, or on its scale model, in order to obtain its complete aerodynamic definition.
These tests can be:
1) static tests
2) dynamic tests

Through the first type of tests the aerodynamic coefficients of the aerodynamic field components are identified for different assets of the vehicle, which is varied by changing the values of parameters such as ground clearance and pitch angle (roll angle and angle of incidence of the windcan be varied as well).

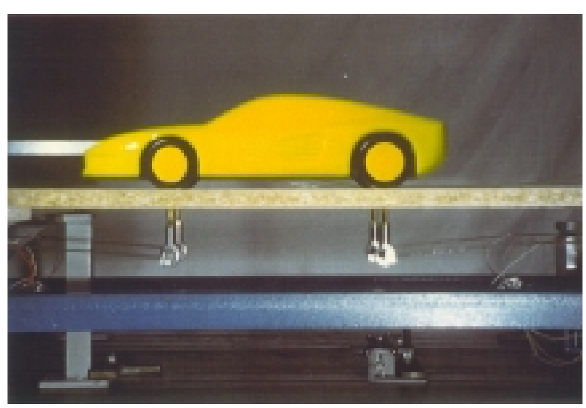

Fig. 1: Experimental model for dynamic wind tunnel tests.

In these tests the vehicle remains still. On the contrary in the second type of tests the vehicle is moving: their purpose is to define the aeroelastic characteristics of the vehicle with a special set of coefficients, called aeroelastic coefficients, through the measurement of time decays consequent to system excitation and through appropriate techniques of parametric identification.
Fig. 1 shows the experimental set up in the wind tunnel for non-steady coefficients identification.

2.3 Aerodynamic non-steady forces models and lateral wind models

Experimental data obtained from wind tunnel tests need to be correctly inserted in appropriate models for the evaluation of aerodynamic forces.
For this purpose specific models have been developed in order to consider the contemporary effects of non-steady aerodynamic forces and lateral wind. In order to reproduce correctly the former, the Quasi-Steady Model and the Aeroelastic Coefficients Model have been implemented, accounting not only for the effects of translational and rotational displacements $\{\underline{x}\}$ (asset variations of the chassis), but also for the effects of velocities $\{\dot{\underline{x}}\}$ (vertical velocity and pitch rotational velocity). Thus the aerodynamic force field on the vehicle has the following generic expression:

$$\underline{F}_a = \underline{F}_a\,(\,\underline{x}\,,\,\dot{\underline{x}}\,,\,\underline{V}(t)\,,\,t\,)$$

Lateral wind is reproduced considering also roll angle and yaw angle of the vehicle.
These models have then been implemented in ADAMS for the simulation of a high speed vehicle handling subjected to the aerodynamic field.

3. APPLICATION OF THE MODELS IN ADAMS

3.1 The implementing of the models

The models mentioned above are implemented through the application to the vehicle of a particular field of forces, depending instantly by the system status conditions: displacements, velocities and eventually side wind. The fundamental input of these numerical models are the aerodynamic steady and non-steady coefficients given by wind tunnel tests.
In order to reconstruct aerodynamic steady and non-steady forces, specific user-written subroutines allow to separate the steady motion of the system, which influences only steady forces, from its non steady motion, which influences the non-steady ones.

3.2 Results

Several simulations have been conducted in order to:
1) evaluate the effects of aerodynamic non-steady forces on vehicle dynamic characteristics;
2) analyse side wind effects during car handling simulations.

The first type of analyses shows a significant influence of aerodynamic stiffness and damping terms on the dynamic characteristics of the vehicle.
System frequencies and damping critical ratios are modified by the aerodynamic field, as it can be seen in Fig. 2, where the curves of frequency and damping ratio, varying with vehicle speed, relative to rotational pitch mode of the chassis are reported.
The analysis shows a decrease of frequency as velocity increases which is due to a decrease of the total torsion stiffness, given by structural stiffness plus aerodynamic stiffness. It must be stressed that the trend of rotational pitch stiffness reduction might

be very dangerous due to the possible reaching of instability (static divergence). On the contrary overall damping increases.
These changes in frequency and damping ratio caused by the aerodynamic field are expected to affect deeply comfort and handling characteristics of the vehicle in a considerable interval of vehicle speeds.
Other analyses have been conducted in order to simulate the handling of the vehicle under lateral wind conditions.

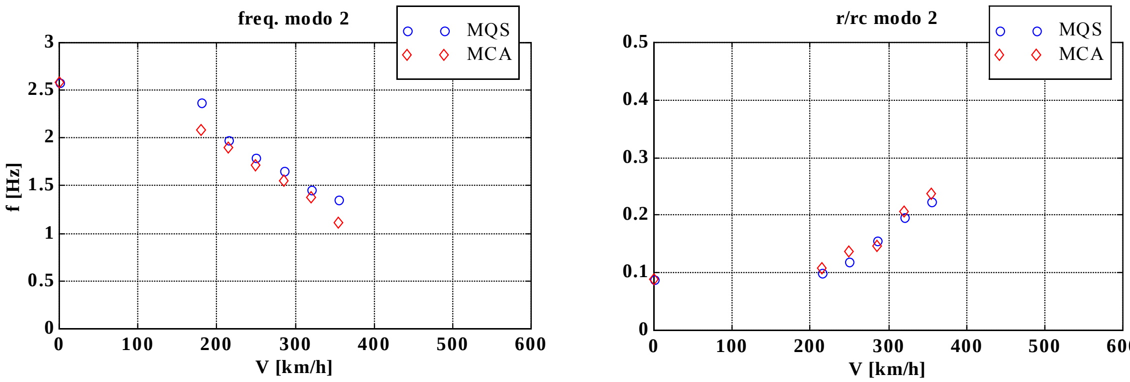

Fig. 2: frequency and damping ratio of pitch torsion mode varying with vehicle speed obtained with Quasi-Steady Analysis (MQS) and Aeroelastic Coefficients Analysis (MCA).

Side wind models have been developed with the intent to reproduce any environmental condition in which the vehicle might be set: in this way it is possible to simulate wind coming from any direction and also gusts of wind.

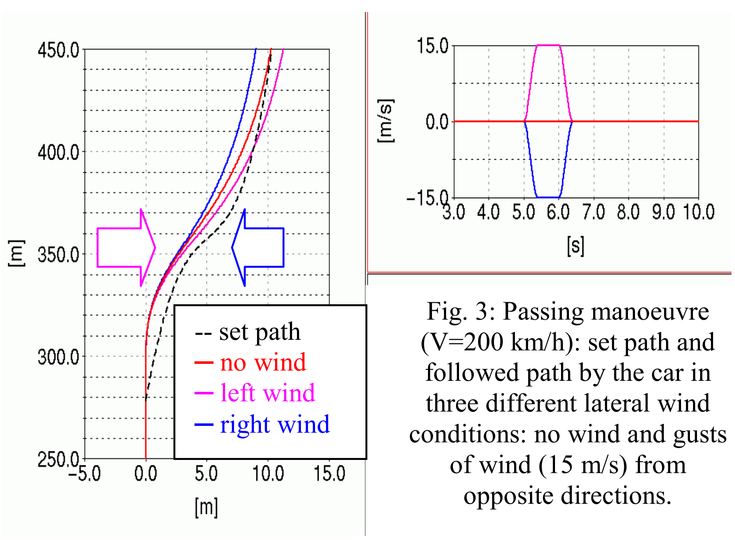

Fig. 3: Passing manoeuvre (V=200 km/h): set path and followed path by the car in three different lateral wind conditions: no wind and gusts of wind (15 m/s) from opposite directions.

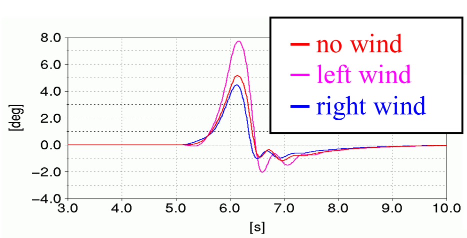

Fig.4: Slip angle of bacwward left tyre in the three cases

Fig. 3 shows a passing manoeuvre executed by the vehicle (endowed with a simple driver model) in three different conditions (no side wind and gusts of wind coming from opposite directions). As an example of the relevant wind effects on the car handling, Fig. 4 shows the slip of the backward left tyre in the three cases. Effects of aerodynamic non-steady forces and lateral wind forces play an important role in defining vehicle handling characteristics.
As it can be seen, wind effects appear really critical in affecting the vehicle behaviour.
The model of the aerodynamic field which has been developed and implemented in ADAMS provides an instrument to account for all these effects, by giving a comprehensive formulation for steady and non-steady forces depending on the instantaneous full status of the system: asset (described in terms of ground clearance,

pitch angle and roll angle), velocity of variation of the asset, angle of incidence of the wind.

4. CONCLUSIONS

The application tool developed represents a satisfactory approach to the reproduction of aerodynamic forces, steady and non-steady, acting on a vehicle, allowing also to simulate the effects of side wind.

The first analyses performed have shown that both aerodynamic non-steady and lateral wind forces have considerable effects on vehicle overall comfort and handling characteristics and that the use of ADAMS seems very suitable for this purpose since it allows to integrate any vehicle model with the model of the aerodynamic field acting on it.

The software implemented might be developed in the future as a complete separate user-tool which can be attached to the main vehicle model implemented in ADAMS/View or ADAMS/Car: its input is given by the aerodynamic characteristics of the vehicle determined in the wind tunnel and by the instantaneous system status generated by the integration of the motion equations; its output is the forcing given by the aerodynamic field which then affects the system dynamics, as shown in Fig. 5.

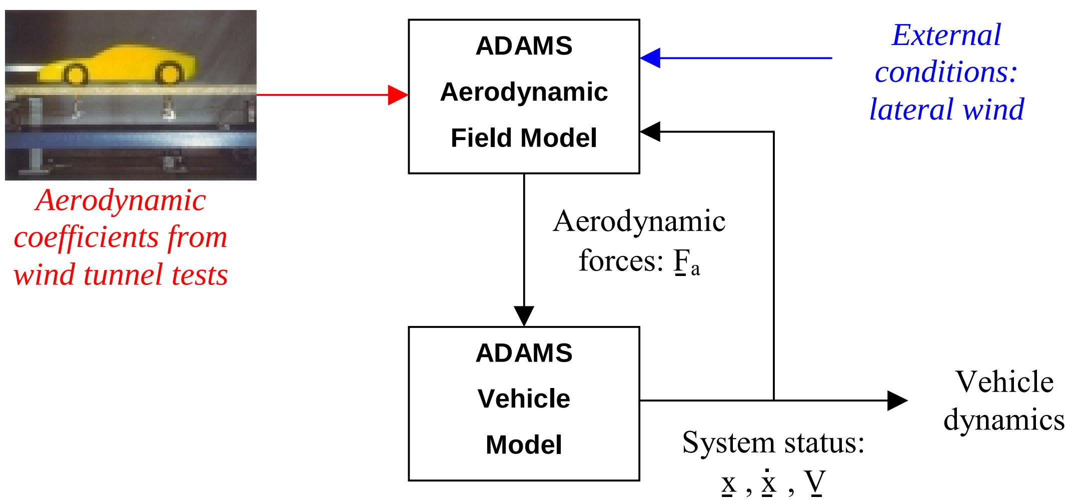

Fig. 5: Representation of the scheme adopted for the analyses in ADAMS.

5. REFERENCES

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