Development of a complete FSUM car multibody model to study the influence of friction on automotive suspension systems

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Abstract

The development of accurate multibody dynamics models is fundamental for understanding, predicting, and improving the dynamic behavior of automotive vehicles. Such models can be applied to a wide range of applications, from passenger cars to racing vehicles, and require a detailed representation of all vehicle subsystems, including tire-road interaction, suspension, and steering systems. This work presents the development and application of a detailed multibody dynamics model of the Formula Student of the University of Minho (FSUM) single-seater vehicle, as illustrated in Fig. 1a, intended to support the analysis of vehicle handling and suspension performance under dynamic operating conditions.

The complete multibody model of the car comprises 30 rigid bodies interconnected by 41 mechanical joints, including spherical, translational, revolute, universal and cylindrical types. Detailed representation of the front and rear suspension subsystems is provided in Fig. 1b-c. This results in a vehicle model with a total of 18 degrees of freedom, of which 14 are active degrees of freedom.

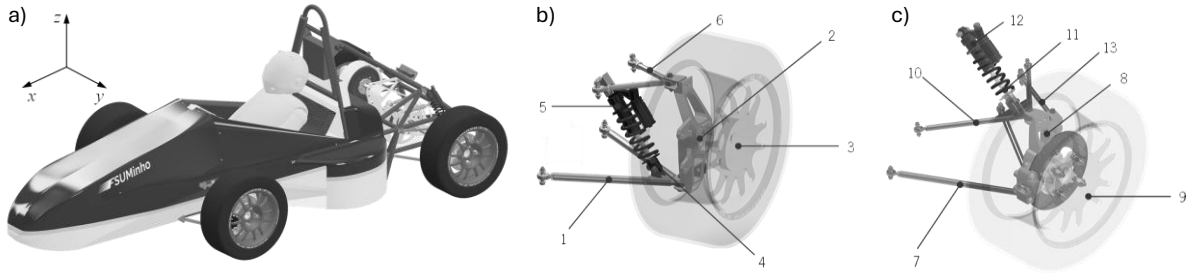


Figure 1: Vehicle model: (a) CAD representation, (b) front left and (c) rear left suspension subsystems.

Special attention is devoted to the modeling of suspension systems, which can help assess or improve passenger comfort or vehicle handling performance. Shock absorbers play a key role in maintaining tire-road contact by suppressing oscillation and controlling the motion of the sprung mass [1]. In most studies, they are modeled as perfect cylindrical joints, typically represented by spring-damper elements acting in parallel, without accounting for dissipative effects generated at the damper seals during shock absorber actuation due to dry friction phenomena.

Friction is a highly nonlinear and complex phenomenon that manifests as a tangential resistive force between contacting surfaces [2, 3]. It often has prejudicial effects on the dynamic performance of a wide variety of multibody mechanical systems, contributing to energy dissipation, increased noise, and reduced reliability. To account for these effects, a novel cylindrical joint model incorporating friction is proposed, based on the perfect kinematic joint formulation, in which the friction forces are estimated from the computed joint reaction forces and moments and included in the equations of motion as external generalized forces. The joint formulation relies on four constraint equations that restrain translational and rotational motion normal to the joint axis. Accordingly, four generalized reaction forces are obtained, which allows the effective estimate of real contact forces and, together with the joint kinematics, the evaluation of the resulting friction forces.

To numerically represent the frictional phenomena, several friction force models have been proposed and discussed in the literature [2]. These models are generally divided into two main categories, the static and dynamic models. Static models are more limited, as they represent only the steady-state behavior of the friction force as a function the sliding velocity, possibly including viscous friction and the Stribeck effect. Dynamic models, on the other hand, take advantage of an additional state variable to capture phenomena such as presliding displacement, hysteresis, and frictional lag. Bearing that in

mind, the present work analyzes and compares the utilization of two static friction models, Rooney and Deravi [4] and Bengisu-Akay [5], and two dynamic friction models, Dahl [6] and LuGre [7].

The developed multibody model of the car has been built in MUBODYNA, an in-house code for spatial multibody dynamics simulation using Cartesian coordinates [8]. The verification of the implemented methodology was performed through two simulation scenarios, namely an obstacle avoidance dynamic test and suspension excitation through a four-poster rig. For running the first scenario, the Magic Formula Tire Model [9] was implemented to simulate the tire-road interaction. The vehicle was subjected to a lane-change maneuver for the initial speed of 72 km/h. Figure 2a exhibits the trajectory of the vehicle's center of gravity during the evasive maneuver executed, while Fig. 2b presents a comparison of the total shock absorber force calculated within the spring-damper force element for the left front wheel, both without considering friction and using the four friction models under analysis. The results indicate that the introduction of friction forces in the shock absorbers leads to a reduction in the physically allowable compression and rebound motions.

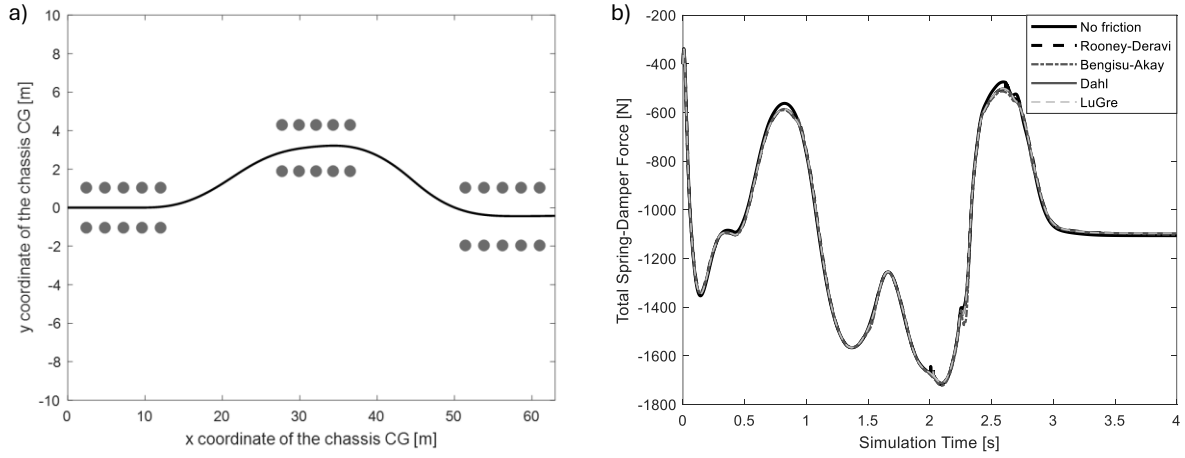


Figure 2: (a)Trajectory of the car's center of gravity during the maneuver, and (b) the total force exerted on the front left shock absorber considering different friction forces models.

To sum up, this work provides a complete multibody model for the FSUM vehicle, suitable for vehicle dynamics analysis, while demonstrating the relevance of friction modeling in the accurate representation of suspension systems. The application examples demonstrate the impact of accounting for these effects and highlight the influence of each friction force model on the vehicle's dynamic response.

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