16 Lumped Deformations: a Plastic Hinge Approach

Jorge Ambrósio

IDMEC, Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal

16.1 Introduction

The design requirements of advanced mechanical and structural systems exploit the ease of use of the powerful computational resources available today to create virtual prototyping environments. These advanced simulation facilities play a fundamental role in the study of systems that undergo large rigid body motion while their components experience material or geometric nonlinear deformations, such as vehicles, deployable structures, space satellites, machines operating at high speeds or flexible robot manipulators, some exemplified in Figure 16.1.

![Figure 16.1. Natural biological and artificial engineering systems for which multibody dynamics provide good modeling methodologies](image)

If in one hand the nonlinear finite element method is the most powerful and versatile procedure to describe the flexibility of the system components on the other hand the multibody dynamic formulations are the basis for the most efficient computational techniques that deal with large overall motion. Therefore, it is no surprise that many of the most recent formulations on flexible multibody dynamics and on
finite element methods with large rotations share some common features. However, the flexibility of the multibody components can be represented using the finite element method or other lumped approaches, such as the plastic hinge technique, as the models shown in Figure 16.2 exemplify.

Figure 16.2. Vehicle models, for structural impact, using the finite element method (Puppini et al., 2005) and a multibody dynamics approach based on plastic hinges (Ambrósio et al., 2006)

The methodological structure of the equations of motion of the multibody system allows the incorporation of the equilibrium equations associated to a large number of disciplines, and their solution, in a combined form. The description of the structural deformations exhibited by the system components, using linear (Gonçalves and Ambrósio, 2001) or non-linear finite elements (Ambrósio and Nikravesh, 1992) in the framework of multibody dynamics, is an example of the integration of the equations of equilibrium of different specialties. Of particular importance, for the applications pursued with the methodologies proposed here, is the treatment of contact and impact, which is introduced in the multibody systems equations either by using unilateral constraints (Pfeiffer and Glocker, 1996) or by continuous contact force model (Lankarani and Nikravesh, 1994). The availability of the state variables in the multibody formulation allows for the use of different control paradigms in the framework of vehicle dynamics, biomechanics or robotics and their integration with the multibody equations (Valasek and Šika, 2001). The coupling between the fluid and structural dynamics equations allows for the development of applications where the fluid-structure interaction is analyzed, especially for cases with large absolute or relative rotations in the system components are of importance (Møller and Lund, 2000; Møller et al., 2005).

By only involving rigid multibody dynamics, the system deformations can be described using lumped deformations, modeled by spring-damper elements. Due to its simplicity, this approach has found its way into multibody systems where the components are made of slender elements. Methodologies to describe flexibility