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Definition and updating of simplified models of joint stiffness

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ABSTRACT

The objective of this work is to define a simple linear model of joints used in aeronautics and to update this model efficiently.

Industrial designers usually resort to semi-empirical linear joint models to represent the behavior of the joints of a large aeronautical structure. Here, we propose to develop a one-dimensional linear joint model which is capable of representing the behavior of every joint of a large structure globally while enabling local nonlinear reanalysis of the most highly loaded joints. Work on nonlinear reanalysis is not considered in this paper.

In order to solve the numerical difficulties encountered in some of modeling situations, an updating strategy based on the constitutive relation error is proposed. Since the updating efficiency is significantly affected by the ratios of the stiffnesses of the different parts of the model, the strategy consists in rigidifying some parts of the model in order to control the updating accuracy and the rate of convergence. The numerical results of a standard model and a rigidified model illustrate the updating improvements allowed by the strategy.

1. Introduction

Joints are often used in aeronautics because they make the assembly and maintenance tasks easier for the manufacturers. However, joint properties such as machining quality, friction or preloading are hard to control during manufacturing and lead to differences in behavior from one fastener to another. These irregularities can induce overloading and failure at joint locations during the global loading of the structure.

Therefore, the representation of the actual behavior of a single joint or a set of joints is a real issue in structural mechanics. From a computational mechanics point of view, joints create a dilemma. When dealing with large structures such as aircraft, the joints are too small and too numerous for each to be modeled with a detailed 3D geometry: an Airbus aircraft uses more than one million bolts and several million rivets. However, no realistic simulation can be undertaken without taking them into account. Due to these computational limits, industrial design is usually carried out employing a two-scale method. First, simulations using a linear representation of the global structural level are performed. The linear modeling consists of shell or plate elements (representing the structural parts of the aircraft) connected by various types of springs (representing the joints). Most of the joint representations are based on semi-empirical models (Huth, 1986; Tate and Rosenfeld, 1946). This first simulation provides an estimation of the distribution of the joint loads in the structure. Finally, the most loaded joints are identified and local reanalyses are performed with 3D nonlinear modelings in order to verify damage criteria. Fig. 1 illustrates the design method. Usually, uncertain representation and sensitivity analysis are also carried out. At the global levels, an important effort on the quality of the estimated distribution of the joint loads must be made. In the present paper, only the first part of the design, *i.e.* the estimation of a reliable distribution of loads employing a linear modeling, is considered.

The earliest works on joint modeling in aeronautics were developed for static loading using semi-empirical models based on springs (Huth, 1986; Tate and Rosenfeld, 1946). Simple analytical joint models were developed (McCarthy et al., 2006; Yen, 1978) along with one-dimensional FEM models (Baumann, 1982; Ekh and Schön, 2008) and multi-dimensional representations (Bortman and Szabó, 1992; Champaney et al., 2008; Chen et al., 1995; Ingvar Eriksson, 1986; Izumi et al., 2005; Kelly, 2005; McCarthy et al., 2005). A comparison of 4 types of FEM joint models was presented in (Kim et al., 2007). Techniques have also been developed for dynamics (Segalman et al., 2003), where joints play a crucial role as dampening elements of the structure.

When many fasteners are used, industrial designers usually prefer 1D joint representations on the global structural level. One of the main objectives is to obtain the loading conditions (Wei-Xun

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