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Gear walk instability studies using flexible multibody dynamics simulation methods in SIMPACK ☆

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Abstract

In a variety of mechanical systems friction induced vibrations are a major concern. The aircraft landing gear is by nature a complex multidegree-of-freedom dynamic system. It may encounter various vibration modes which can be induced by brake frictional characteristics and design features. These brake induced oscillations can lead to very high loads in the landing gear and brake structure which may result in passenger discomfort and sometimes in component failure. Along with the serious fore and aft oscillations of a landing gear, often referred to as gear walk, chatter, squeal, shimmy and other vibrations in aircraft landing systems are not only annoying and disconcerting but can also affect the stability of the plane during take-off, landing, and rolling. In this paper, simulation of such an unstable and complex phenomenon during aircraft ground maneuvers is done to detect vibrations in aircraft landing gear. A commercial multibody simulation tool SIMPACK is used for this purpose. The article is based on work done in co-operation between DLR and Liebherr Aerospace.

Keywords: Landing gear dynamics; Aircraft ground dynamics simulation; Gear walk and other instabilities

1. Introduction

1.1. Landing gear dynamics – problem definition

The term landing gear indicates one of the main functions of the gear, namely the containment of the landing impact but it fails to describe the other main functions, namely the provision of means for the aircraft to maneuver on the ground, taxi and take off [4]. The predominant task of an airplane is no doubt to fly with the best performance achievable. It must not be forgotten, however, that it will spend a good part of its life on the ground. Landing gear dynamics, especially shimmy and brake-induced vibrations, is one of the problems faced today by the aircraft community. Though they are not catastrophic, can lead to fatal accidents due to excessive wear. It can also shorten the gear life and cause discomfort to the pilot and passengers. Structures of modern aircraft become increasingly flexible. The main reasons are slender fuselages that frequently arise from the stretching of existing aircraft, see [11], and the use of new, light-weight structures and materials that influence the vibrational properties of fuselage and wings. Not only unsuitable combination of structural stiffness, damping, and pneumatic tire characteristics but also an unlucky combination of brake system design with the tire physics can produce a serious vibration problem [14]. Shimmy may be caused by a number of conditions such as low torsional stiffness, excessive free play in the gear, wheel imbalance, or worn parts. Brake-induced vibration includes conditions known as gear walk, squeal and chatter which are caused by the characteristic friction between the brake rotating and non-rotating parts. This will be explained in details later in Section 1.3. Although equations for representing various parts of a landing gear are well established, solving the problems manually with mathematical programs can be slow and laborious. Simplifications made to reduce problem size may introduce inaccuracies such that a design modification to correct a problem in one area causes unforeseen vibration in other parts of the structure. In many cases, vibration problems may not be uncovered until physical prototypes are built and tested, adding considerable time and expense to the product development cycle. However, many commercially available

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computer-aided engineering tools have made it possible to test some of the problems in the design phase by simulating the landing gear impact and rolling. An adequate modeling of tire and brake dynamics is an important issue for the analysis of the behavior of an aircraft during ground maneuvers as potentially unstable phenomenon such as gear walk and shimmy may occur in these phases. At the German Aerospace Center (DLR), simulation of such an unstable and complex phenomenon during aircraft ground maneuvers is done to detect vibrations in aircraft landing gear. A commercial multibody simulation tool SIMPACK is used for this purpose. It allows the import of external models from other codes such as NASTRAN. Landing gear parts modeled in NASTRAN are used to represent the vibration modes accurately. The goal of this project is to study brake and gear interaction and the related vibration phenomena including low frequency gear walk, wheel chatter, and brake squeal.

1.2. Landing gear vibrations – state of the art

Both civil and military organizations have put great effort into optimization of the landing gear and its components. Simulation will play an ever increasing role in further improvement of new aircraft and the introduction of new ideas and systems [13]. There exist some specific publications in the area of landing gear dynamics and simulation. An early overview of computer simulation of aircraft and landing gear is given by Doyle [5]. Shepherd, Catt, and Cowling [3] describe a program funded by British Aerospace for the analysis of aircraft-landing gear interaction with a high level of detail, including brakes and anti-skid, steering control, to simulate standard hardware rig test (dynamo meter and drop tests) as well as flight tests involving ground contact. Barnes and Yager [2] discuss the use of simulators for aircraft research and development. Two publications of the IAVSD (International Association for Vehicle System Dynamics), Hitch [7] in 1981 and Krüger et al. [13] in 1997 and one at NASA Langley Research Center by Pritchard [17] are state-of-the-art overviews of aircraft landing gear dynamics. Modeling tires is a science for itself: In 1941, von Schlippe and Dietrich [19], analyzed the shimmy motion of an aircraft tire and described the interaction of tire and landing gear leg stiffness with tire forces analytically. Pacejka [16] used a similar tire model based on the stretched string concept and developed simple derivatives representing first order lag with a relaxation length and a gyroscopic couple coefficient as parameters. For the description of steady state slip characteristics empirical formula have been developed by Bakker and Pacejka [1], using trigonometric functions, this model is known as Magic Formula. Recently this formulation has been extended to include dynamic tire behavior [21]. The performance of braking system is an important consideration in the design of landing gear system. Luber et al. [14] have shown in their experimental work that adjustable control of brake torque is a sensible way to improve aircraft ground handling and performance. Krüger et al. [13] also mention the need of a good model of the anti-lock braking system dynamics. Yager et al. [25] under the FAA/NASA friction program discuss the evalution of friction measurements for different runway surfaces. General requirements of a good anti-skid brake system are described in an SAE paper [20]. As far as simulation of landing gear dynamics is concerned two reports from the BF Goodrich Aerospace by Rook et al. [18] and H. Vinayak et al. [23] are state of the art in the area.

1.3. Friction induced vibrations in landing gear system – back-ground

The aircraft landing gear, a complex multi-degree-of-freedom dynamic system may encounter vibration modes which can be influenced by brake frictional characteristics and design features [6]. As airplane gross weights are increased, the braking performance requirements have become more severe. The performance requirements include normal landing/refused takeoff braking distance limits, thermal requirements on the landing gear components, durability of friction material and overall weight considerations. Due to superior performance of carbon, increasing numbers of airplanes are using carbon brakes [15]. Although carbon has a higher specific heat capacity, a higher friction coefficient, is lighter in weight and has a better wear rate compared to steel, it is more prone to vibrations. Brake friction acts in the pitch-plane of the landing gear system, and so affects the stability of three pitch-plane modes of vibration as shown in Fig. 1.

Brake Squeal can be defined as torsional vibrations of non-rotating components about the axle in the frequency range of 100–1000 Hz. The root cause of this mode is largely unknown, however, the erratic vibration phenomenon from flight test suggest that this mode is caused by the friction characteristics of brake material, it produces very high oscillatory loads on the landing gear/brake structure and can sometimes cause failure.

Brake Chatter is defined as the torsional motion of the rotating parts of the brake-wheel-tire assembly about the axle and against the elastic restraint of the tire. It is typically above 50 Hz and coupled with the squeal mode.

Gear Walk is defined as the cyclic fore and aft motion of the landing gear strut assembly about a normally static vertical strut center line. This motion is caused by tire-runway interface friction loads which deflect the landing gear. It may be sometimes induced by the anti-skid system and could cause passenger discomfort.

A valid landing gear simulation is one having the same dynamic response to brake torque as the actual gear. This means that the simulated gear must be designed to have the same equation of motion in its walk mode under the action of speed-dependent braking friction [6]. The traditional way to simulate the gear has been to use alternate structure, a dynamo meter fixture such that one of its fundamental modes duplicates the dynamic characteristics of the gear walk mode of interest. In this paper, the flexible multibody dynamics methods are used for the simulation of such an unstable and complex phenomenon during aircraft ground maneuvers to detect friction-induced vibrations in aircraft landing gear.