SIMULATION OF AIRCRAFT LANDING GEAR DYNAMICS USING FLEXIBLE MULTIBODY DYNAMICS METHODS IN SIMPACK

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Summary

In a variety of mechanical systems friction induced vibrations are a major concern. The aircraft landing gear is by nature a complex multi-degree-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 cooperation between DLR and Liebherr Aerospace.

keywords - Landing gear dynamics, Aircraft ground dynamics, 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 [5]. 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 [16], 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 [18].

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 programmes 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 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 modelling 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 modelled 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 [15]. 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 [7]. 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 (dynamometer 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 in 1981 [10] and Krüger et al [15] in 1997 and one at NASA Langley Research Center by Pritchard [23] are state-of-the-art overviews of aircraft landing gear dynamics. Modeling tires is a science for itself: In 1941, von Schlippe and Dietrich [25], analyzed the shimmy motion of an aircraft tire and described the interaction of tire and landing gear leg stiffness with tire forces analytically. Pacjeka [20] 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 Pacjeka [1], [20] 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 [18] 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 [15] also mention the need of a good model of the antilock braking system dynamics. Yager et al [30] under the FAA/NASA friction programme discuss the evalution of friction measurements for different runway surfaces. General requirements of a good antiskid brake system are described in an SAE paper [32]. Jun [12] in his paper studies ABS control system for automobiles with different control methods and points out that it is difficult for one control system to get optimal control accuracy and robustness under all kinds of braking conditions. Tuney [26] has proposed a novel method of antiskid control for transport aircraft which results in smoother braking and hence improved passenger comfort.

One of the early investigations on brake-induced vibrations was reported by Edman [8]. The report contains both experimental and theoretical studies explaining the basic phenomena and pointing out the importance of design considerations. Only linear solutions were considered in this report, however, it was recommended that non-linear friction characteristics be included in future theoretical studies. The dynamometer tests revealed a connection between the chatter frequencies and the wheel rotation. Theoretically, decrease in chatter amplitudes were noticed for increase in strut damping, rolling radius, and total mass. Biehl [3] during the development of a digital program to simulate the DC-9 aircraft main landing gear found out that brake torque was the primary contributor to chatter and squeal vibrations. J. Enright [9] discusses a simplified technique for laboratory dynamometer simulation of landing gear-brake dynamics which enable it to be used as a matter of routine to study brake dynamics accurately. Hamzeh et al [11] discuss the friction induced instabilities in a simplified aircraft brake model. Denti and Fanteria [6] in their work discuss the effects of different tire models and brake on the longitudinal dynamics of aircraft landing gear. As far as simulation of landing gear dynamics is concerned two reports from the BF Goodrich Aerospace by Rook et al [24] and H. Vinayak et al [28] are state of the art in the area.

1.3 Friction Induced Vibrations in Landing Gear System - Background

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 [9]. 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 [19]. 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 50Hz 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 passanger discomfort.

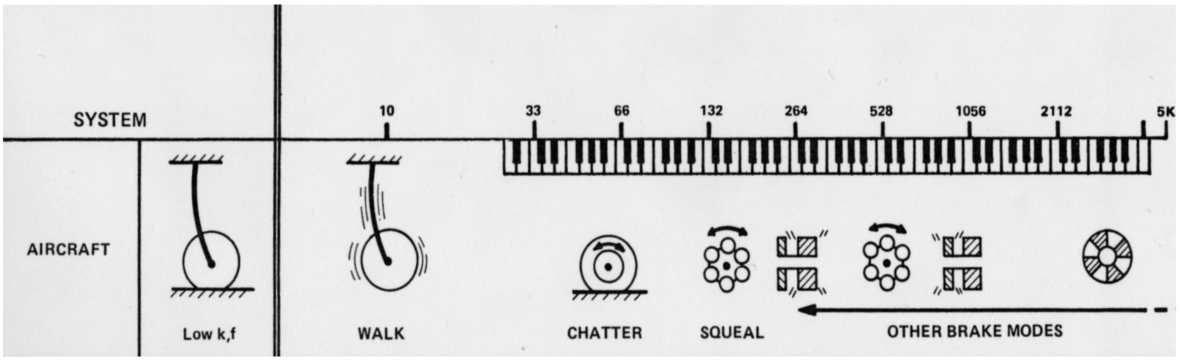

Figure 1: Major Vibration Modes and Frequencies [9]

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 [9]. The traditional way to simulate the gear has been to use alternate structure, a dynamometer 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.

2 Modeling Landing Gear System

2.1 Landing Gear as a Rigid Multibody System

Fig. 1 shows the schematic of a simple form of nose landing gear as a multibody system. In SIMPACK this multibody system is represented by simple body elements such as main fitting, the shock tube, and two or four wheels, respectively. The shock absorbers (oleo) are located between shock tube and main fitting. All landing gears have one translational degree of freedom for the shock absorber and one rotational degree of freedom for each wheel.

The main landing gears include an additional bogie attached to the shock tube with a rotational degree of freedom along the y-axis with 4 wheels attached to it. To model landing gears of large aircraft such as A380 main landing gear which has 6 wheels, a bogie, and a pitch trimmer in addition can be more complex.

To model the system successfully one needs to define proper force elements to simulate the behavior of the whole system. SIMPACK has an in-built library of many force elements and it is also possible to write the so called user-routines which gives additional freedom to user to model different systems.

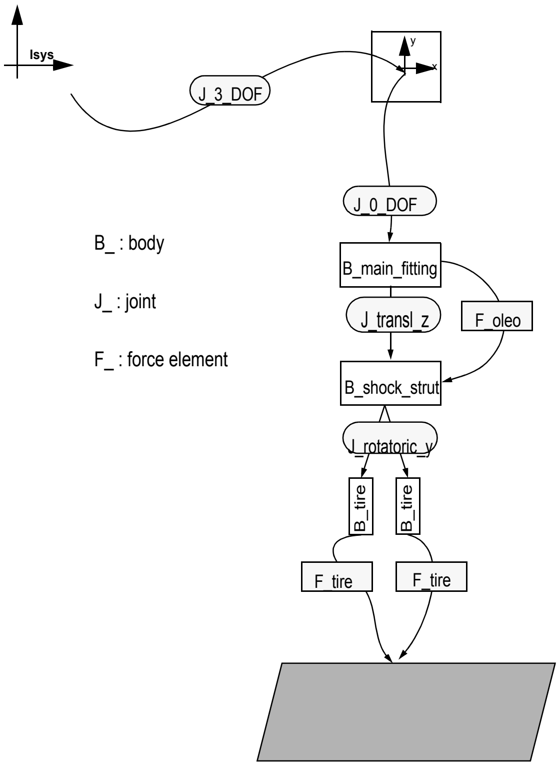

Figure 1: Schematic of a simple nose landing gear

2.2 Force Elements

The force elements describing the landing gear characteristics have been modeled in detail for this work by means of so called user-routines in SIMPACK.

While the equations of the physical phenomena as such are valid independently from the exact aircraft type and can be taken from standard textbooks [5], [22], the parameters for the force elements are usually proprietary. The data used in this work are those which were prepared for the Flexible Aircraft Project [13].

2.2.1 Hydropnematic Oleo

For transport aircraft the main task of vertical energy dissipation is almost exclusively taken over by an oleo-pneumatic shock strut. This device combines a gas spring with oil and additional friction damping [15]. Damping force is provided by oil flow forced through an orifice by vertical strut motion. Often the oil flow is "controlled" by means of metering pin.

The gas spring is represented by a law of polytropic expansion [19]

$$F_f = F_0\left(1-\left(\frac{s}{s_m}\right)\right)^{-n \cdot c_K}$$

with spring force F_f, pre-stress force F_0, oleo stroke s, oleo gas length s_m, polytropic coefficient n ($1 \le n \le \kappa$), and a correction factor c_k. The pre-stress force F_0 can be calculated from the initial pressure in the fully extended oleo. The correction factor c_k, typically between 0.9 and 1.1, allows the adjustment of the curve to measured data. The minimum and maximum stroke limits are modeled by stiff springs. A typical function for a oleo spring is shown in Fig. 2.

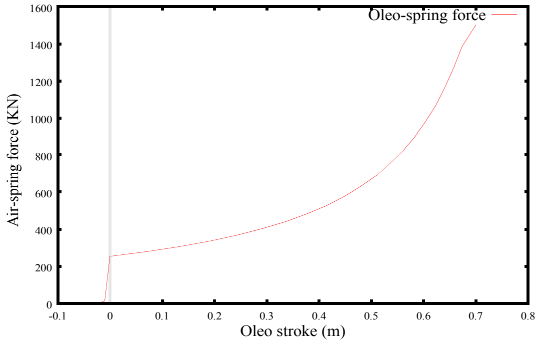

Figure 2: A typical curve set for oleo spring

The properties of the passive damper are determined by the laws describing the flow of a viscous fluid, e.g. oil, through an orifice.

$$F_d = \mathrm{sgn}(\dot{s}) \cdot d \cdot \dot{s}^2$$

with oleo stroke velocity $\dot{s}$, oleo damping force F_d, and damping coefficient d.
A typical function for a damper is as shown in Fig. 3.

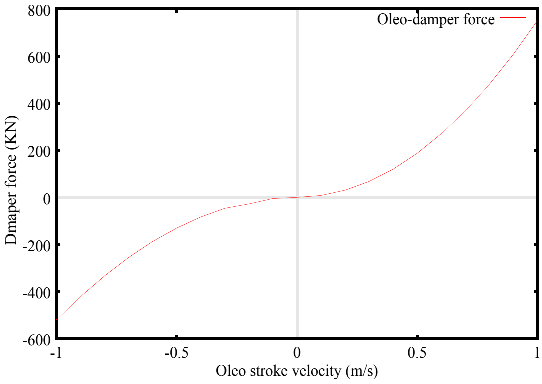

Figure 3: A typical curve set for oleo damper

Stick friction is of great importance especially for the main landing gears. At taxiing, the gears often remain in stick mode for several seconds, leaving the tires as the only flexible suspension element between airframe and runway. This internal friction force results from friction of internal seals in the oleo depends on the internal gas pressure and therefore on the oleo spring characteristics.

$$F_{sf} = -\mu_{sf} \cdot F_s \cdot (s) sign\left(\frac{ds}{dt}\right)$$

where F_{sf} is the seal friction force, μ_{sf} is the seal friction coefficient, F_s is the oleo spring force, and s is the oleo stroke.

2.2.2 Tire

The tire model developed at the DLR takes vertical, longitudinal, and lateral effects into account. The tire connects the wheel to the runway when the aircraft is on the ground. The simulation force element measures the height of the wheel axis with respect to the excitation. This rolling radius r_r is subtracted from the nominal tire radius r_{nom} to determine the tire deflection d_z

$$d_z = r_{nom} - r_r$$

The wheel is modeled as a separate body with a rotational degree of freedom. The longitudinal and lateral motion of the body with respect to the runway is used to calculate tire slip and torque on the wheel.
The vertical force F_z is calculated first. It is a function of the tire deflection d_z. Using a third-order polynomial we find

$$F_z = c_1 d_z + c_2 d_z^2 + c_3 d_z^3$$

where c_1, c_2, and c_3 are selected to match measured tire data. A linear spring can be simulated by setting c_2 and c_3 equal to zero and providing the spring coefficient in c_1.
For longitudinal forces the slip calculated in the main tire element is used. It is defined as the ratio between the horizontal velocity of the wheel contact point and the axle forward velocity,

$$slip_{longitudinal} = \frac{v_x - r_r \Omega}{v_x}$$

where W denotes wheel spin and v_x the wheel axle forward velocity.
The friction coefficient m_{RW} of the runway is a function of slip. An approximation of the functional relation between m_{RW} and slip is displayed in Fig. 4

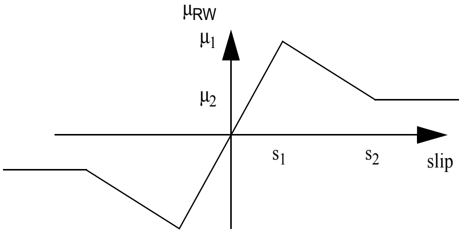

Figure 4: Functional relation between friction coefficient and slip

Typical values for m_1 and m_2 range from 0.4 to 0.9 for dry runways, depending on the runway type.
The friction coefficient m_{RW} is needed to calculate the longitudinal tire force F_x which is a function of the vertical tire force F_z and m_{RW}

$$F_x = \mu_{RW} \cdot F_z$$

The resulting torque T_y on the wheel is calculated using the effective rolling radius $r_{r,eff}$ which can be set to a constant value or, if desired, can be calculated during the simulation using the equation

$$r_{r,\ eff} = r_{nom} - (d_z/\ 3)$$

The torque T_y is then

$$T_y = r_{r,\ eff} \cdot F_x$$

For the asymmetric landing and ground maneuver simulations it becomes necessary to calculate the lateral forces and aligning torque coming on the tires. They are functions of lateral slip. The lateral slip is calculated by the following equation [20],

$$Slip_{lateral} = \frac{v_y}{v_x}$$

The lateral force can be calculated by means of an input function which is a function of the lateral slip and in turn the yaw angle or slip angle. Lateral force and aligning torque as a function of yaw angle is shown in Fig. 5.

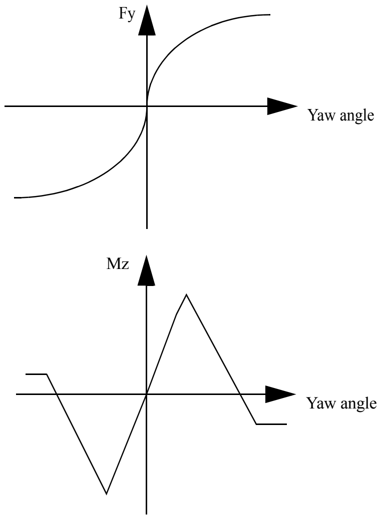

Figure 5: Lateral Force and aligning torque as a function of slip angle respectively

2.3 Modelling Flexible Landing Gear

2.3.1 FEA Interface

Elastic bodies are transferred into SIMPACK using the modal approach. An elastic body is set up in a FEA tool and is there subject to an eigen value/ eigen vector analysis. Mode shapes and nodes are transferred into the MBS model. The resulting deformation is a linear superposition of the mode shapes, Fig. 6.

The spacial motion of an elastic body is divided into a global motion, characterized by the movements of the body reference frame, and its elastic deformation which is expressed by the displacements of all (infinite) body points in relation to the body reference frame, Fig. 7.

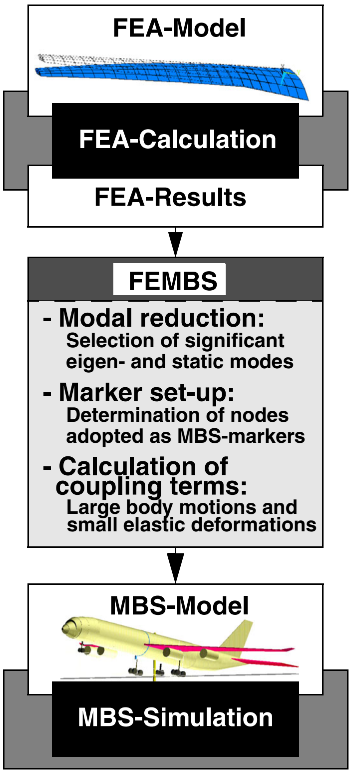

Figure 6: Elastic bodies in SIMPACK

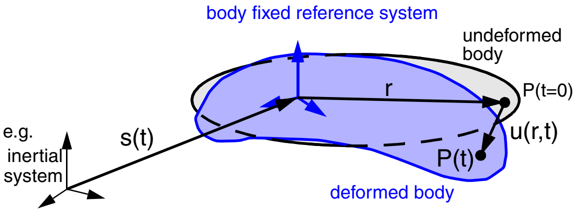

Figure 7: Definition of an elastic body in SIMPACK

The global motion equals the rigid body motion of a classical rigid MBS body. The location and time dependent body deformation vector u(r,t) is split by a separation function often referred to as “Ritz approach” into a location dependent displacement matrix F(r) and the corresponding time dependent so-called *elastic states* q(t):

$$u(r,\ t) = \Phi(r)q(t).$$

Each element of the vector q represents the influence of one eigen mode on the total response. The displacement matrix consists of mode shapes of eigen value and static load analyses. The eigen- and static modes as well as the stiffness matrix are computed in FEA; additionally, geometric stiffening effects, e.g. due to centrifugal forces, can be included.

Depending on the application often a relatively small number of low frequency modes are sufficient to represent, e.g., a static bending shape of an elastic body with sufficient accuracy. During the transfer to SIMPACK, the user is enabled to select only those modes which are necessary to describe the body flexibility for the individual load case. Thus, the full FEA model of system is replaced by a relatively small set of linear equations.

The interface has been implemented for the FEA codes

NASTRAN, ANSYS, ABAQUS and MARC [17], [29].

2.3.2 Modelling Flexible Main Landing Gear for Ebraer190

The landing gear model is prepared in Nastran as a beam model with the help of data exchanged with the industry partner Liebherr for a newly developed regional aircraft. The landing gear is modelled for different strokes and the results of the modal analysis are compared to the model received from the Liebherr and fine tuned to get similar eigen shapes and eigen frequencies.

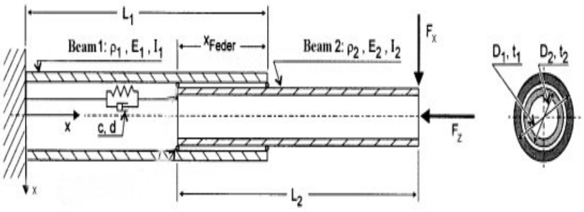

Figure 8: Beam model representation

To create the model in Nastran following data given in Table 1 is used.

Table 1 Geometrical data used for the Landing Gear Nastran model

	BEAM #1	BEAM #2
D1	0.09	0.008
L1	1.469	1.188
t1	0.008	0.008
E1	2.1E+11	2.1E+11

The wheel axle is attached with the rotational degree of freedom around the y-axis at the end of beam number two. The wheels are represented by condensed masses. The results of the modal analysis for zero stroke are given in Table 2.

Table 2 Results of modal analysis in Nastran

MODE NUMBER	EIGEN-FREUENIES HZ	EIGENSHAPE
1	10.10	Torsion, Lateral
2	11.22	Fore-aft, Side stay tangential
3	13.25	Torsion, Side stay radial
4	45.69	Second Lateral
5	62.31	vertical mode of the wheels

The nastran model is then imported in SIMPACK as explained in the Section 2.3.1

3 Aircraft Braking

Stopping of the aircraft being their primary task, brakes are also used to control speed while taxiing, to steer the aircraft through differential action, and to hold the aircraft stationary when parked and during engine run-up. They are generally fixed to the main gears only and add substantial weight to them. Most airplanes use disk brakes in conjunction with an advanced anti-skid control system.

In the work done related to the Flexair project at the DLR, two different braking algorithms have been implemented and tested for different rolling cases.

3.1 Dynamic Braking

Consider the forces and torques on one of the landing gear wheels, as shown in the Fig. 9.

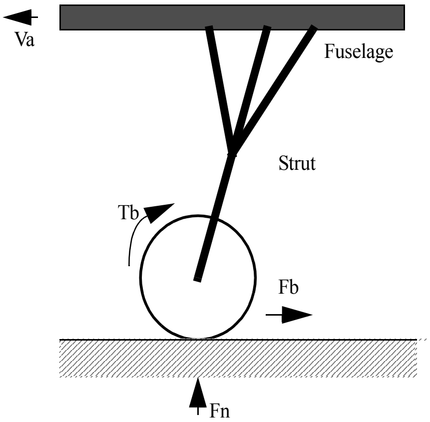

Figure 9: Schematic of one wheel during braking

where Fn is the normal force on the tire, Va is the forward velocity, and Tb is the braking torque. If we write down the general form of force equations they will look like this

$$F_x = F_l \times \cos(\zeta) - F_2 \times \sin(\zeta) - \mu_b \times abs(F_n) \times \cos(\zeta)$$

$$F_y = F_l \times \sin(\zeta) + F_2 \times \cos(\zeta) + \mu_b \times abs(F_n) \times \sin(\zeta)$$

$$M_y = F_l \times r_z - \mu_b \times abs(F_n) \times r_z$$

where μ_b is the braking force coefficient [13], F_x, F_y are the forces in x and y direction respectively, M_y is the moment in y direction, ζ is the yaw angle, r_z is the deformed tire radius. According to JAR standards [31] for dynamic braking the following curve shown in Fig. 10 is used as a constant torque acting between the axle and the inertial system.

3.2 Antilock Braking System

An approximation of functional relation between friction coefficient and the slip ratio is as shown in Fig. 11 [26] which is similar to Fig. 4.

This coefficient depends mainly on the slip ratio,

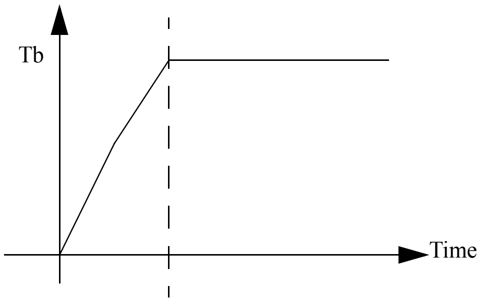

Figure 10: A typical dynamic braking torque curve

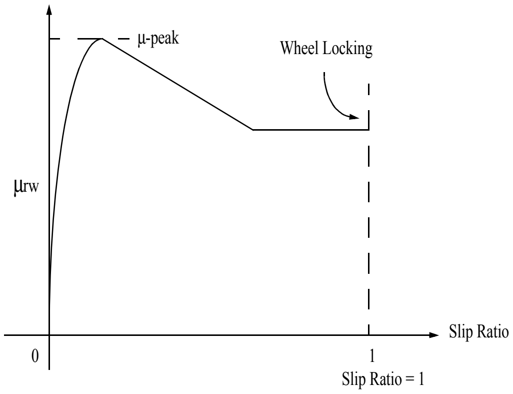

Figure 11: Friction coefficient as a function of slip ratio

normal force, forward velocity, and runway conditions (damp, rain, ice, snow). The nature of this dependence is not well understood even after numerous experiments. If we assume that other factors are fixed the friction coefficient can be represented as a function of slip ratio as shown in Fig. 11 and has a unique maximum. During braking it is possible that the wheels get locked. This occurs when the applied braking torque exceeds the friction torque between the tire and the surface, reducing the wheel angular speed to zero, i.e. the slip ratio becomes equal to one. In such a case the airplane should be equipped with an Antilock Braking System which prevents wheel locking. In addition it should also try to maximize the friction coefficient between the tire and the runway surface, in order to minimize the stopping distance. Achieving a shorter stopping distance becomes critical on wet or icy runways and during rejected take-offs (RTO). It may also be designed to enhance passenger comfort through reducing strut vibrations and improving tire wear through smoother braking, as secondary objectives [26].

For this purpose a simple and somewhat idealized anti-lock braking algorithm has been implemented at the DLR which works as follows:

A sensor at the landing gear wheels measures the actual speed and the slip which is fed to the control system along with the desired velocity and the desired slip. If the actual velocity is greater than the desired velocity and the actual slip is not equal to the desired slip then the antilock braking system is activated. There is a bang bang controller which brings ABS into action when the slip falls below the desired level and releases the brakes when the slip increases. Fig. 12 shows the schematic of an ABS algorithm where v_a and slip_a are actual speed and slip respectively, v_d and slip_d are desired speed and slip respectively, om_a is actual rotational speed of a wheel, and r is the radius of the wheel.

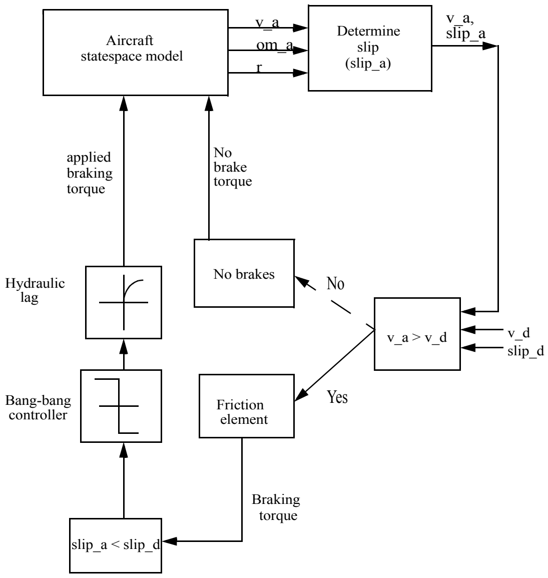

Figure 12: Schematic of an ABS algorithm

4 Main Results

Engineers designing one of the most critical system of an aircraft, the landing gear system, face the daunting task of tracking down and correcting vibration sources in it. In the last decade or so OEMs have cut down the time to deliver the aircraft. So they do not have the luxury of iteratively refine the design by means of experimental testing of the prototype. Dynamic simulation of the entire landing gear system is a faster and very accurate way, thanks to the CAE tools that are available today. It can also be used quickly for different aircraft system as the basic modelling tasks such as brake-algorithm and tire model are ready to use once finished.

To understand the aircraft ground dynamics and to determine realistic ground loads a simulation of operational cases with an accurate model is thus necessary.

In this paper, a ground handling scheme has been examined and has been evaluated by means of various important ground maneuvers. Different modelling tasks included development of a tire model with lateral dynamics to calculate the cornering forces during a curved run, braking system with an ABS algorithm and its effect on the aircraft performance in terms of stopping distance and passenger comfort. The goal of the project is also to study landing gear and brake interaction and the related friction induced vibration. A flexible landing gear was also modelled for that purpose.

4.1 Simulation Cases

For simulating the performance of different braking algorithm complete MBS model of the aircraft and main landing gear are used. The different simulation cases are shown in Table 3.

Table 3 Different Simulation Cases

SIMULATIONS	IMPORTANT RESULTS
Braking	slip optimization, passanger comfort, and stability
Friction-induced vibrations	friction-induced vibrations study, passanger comfort, and stability

4.2 Braking

A good ABS algorithm should avoid locking of the wheel and at the same time maximize the friction coefficient between the tire and runway surface, thus minimizing the stopping distance. It may also take passenger comfort as a secondary objective into consideration. As explained in the Section 3.2, the ABS algorithm implemented in SIMPACK is used for the optimization of the slip value while braking.

Fig. 13 shows how the slip is optimized to get the maximum amount of braking possible without the wheel skidding or locking.

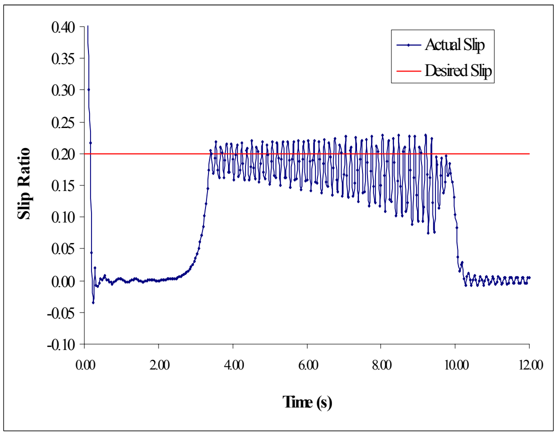

Figure 13: Slip optimization with ABS algorithm

As explained in Section 3.1, dynamic braking has also been examined in the project as an alternative braking algorithm. The following results clearly show that the ABS algorithm is a better alternative for braking as it provides better passenger comfort and reduced friction-induced vibration, and is stable.

Along with the shorter braking distance, as a secondary objective the ABS system may also be designed to improve the passenger comfort. Fig. 14 shows how ABS algorithm reduced forces in x direction at the main landing gear attachment and is stable when it comes to acceleration at the attachment point. It shows that with the ABS algorithm smooth braking is achieved with the reduced strut vibrations and in turn the better passenger comfort.

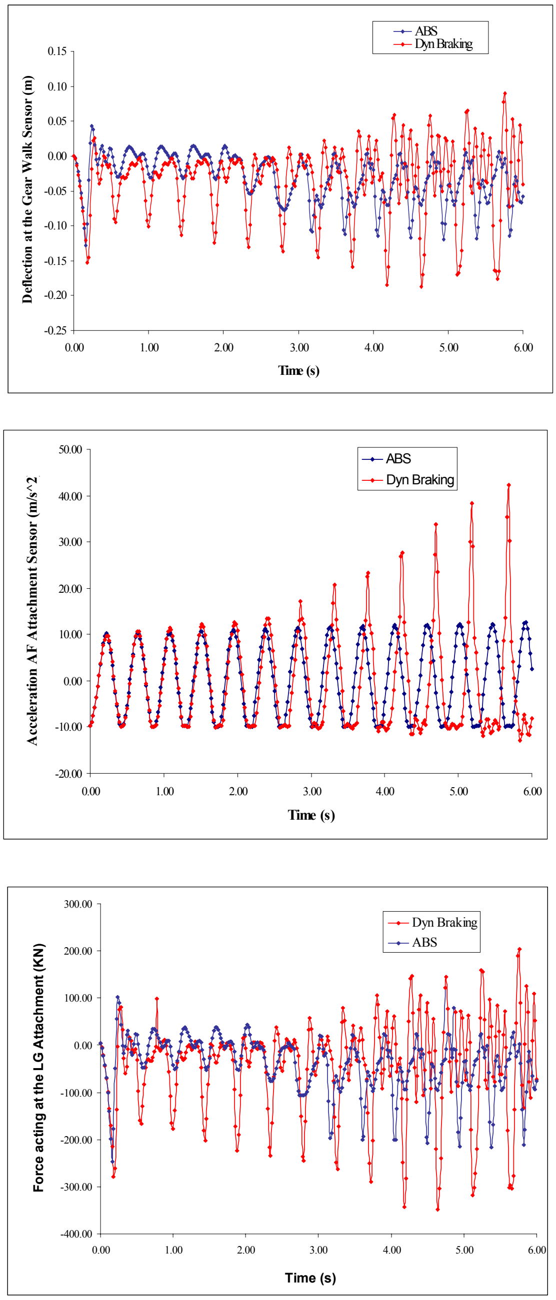

Figure 14: Comparison of ABS and dynamic braking algorithm

4.3 Friction-induced Vibrations

Gear walk, as explained in the Section 1.3, is cyclic fore-aft motion of the landing gear assembly about a normally static vertical strut-center line. Gear walk instability is illustrated by the time histories of gear-deflection, brake torque, and wheel-tire footprint (speed) as shown in Fig. 15.

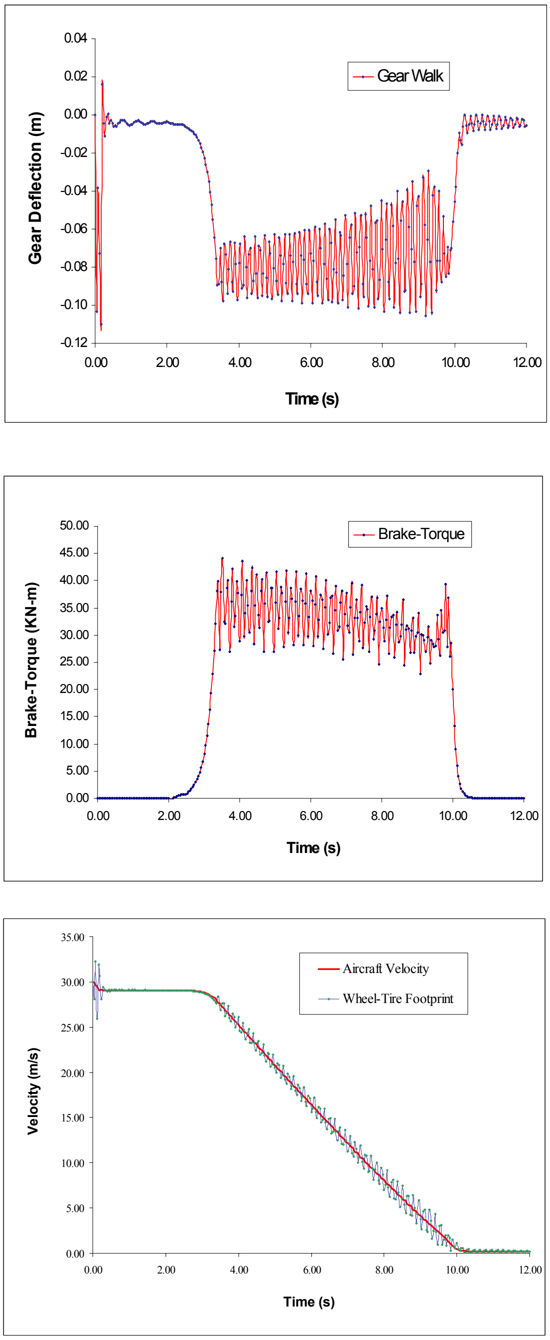

Figure 15: Gear Walk Instability

For this multibody simulation a full aircraft model with flexible landing gear at the attachment point is used. Braking action is initiated at the end of 2 second rolling in forward direction untill the desired speed is achieved. Though initially the gear deflection increases when brakes are applied the amplitude is does not grow as compared to the dynamic braking due to the slip-optimization principle behind the anti-skid algorithm. Once the desired speed is achieved the deflection reduces very fast and is almost zero.

5 Conclusions

In order to simulate important aircraft ground maneuvers and brake-gear interaction different tools such as a tire model with lateral dynamics effects, a simple but effective ABS algorithm are implemented in the commercial multibody simulation code SIMPACK. The simulation comparison shows that antiskid algorithm is more effective in terms passanger comfort, the gear vibrations, and the stability. A flexible landing gear model was developed in order to study the friction-induced vibrations in the landing gear. In future, using the work done as a base, brake gear interaction will be subject to closer studies.

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