Bifurcation analysis of landing gear shimmy using flexible multibody models

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One of the key analysis cases in the landing gear design for aircrafts is the so-called shimmy, which manifests itself as self-sustained lateral-yaw oscillations. In severe forms, it can cause discomfort for the pilot/passengers or even damage the safety-critical landing gear structure. Therefore, it is essential to assess the susceptibility of landing gears to shimmy early in the design process. The general strategy employed by the landing gear industry to analyze the shimmy is to perform time-domain simulations to investigate whether instabilities occur during various landing/take-off scenarios, where the model is driven at the corresponding forward velocity and vertical loading. Even though it is a straightforward approach, this procedure is rather time consuming and does not yield the complete shimmy-free operational range for an aircraft but only ensures that shimmy does not occur at the preselected operational conditions. On the other hand, numerical continuation methods are available to analyze the Hopf bifurcations that characterize the onset of shimmy in relatively small analytical models. This study aims to bridge the gap between these approaches by analyzing the shimmy stability properties of a realistic, complex, high-fidelity and flexible landing gear model using numerical continuation software together with multibody analysis.

The general overview of the simulation framework can be seen in Fig. 1. On the left side, the flexible multibody model of the landing gear used in this study is illustrated. This model is a typical fighter aircraft nose landing gear, which contains many of the nonlinear effects typically used in industry models by Fokker Landing Gear, such as tire dynamics, nonlinear shock absorber characteristics and flexible components. Especially the latter aspect is emphasized in this study as including flexibility causes the number of degrees of freedom (DOF) in the model to increase significantly. Subsequently, a Craig-Bampton model reduction approach is applied to efficiently reduce the number of modal coordinates. The reduced model has 33 DOF and and it is similar to an industry model of a typical nose landing gear in terms of structural stiffness, eigenfrequencies, and tire dynamics.

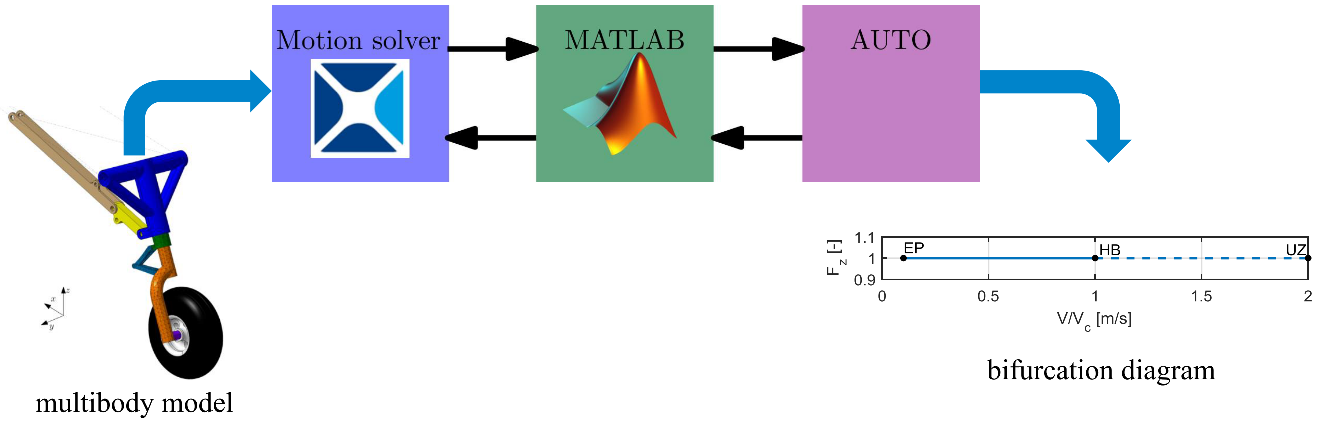
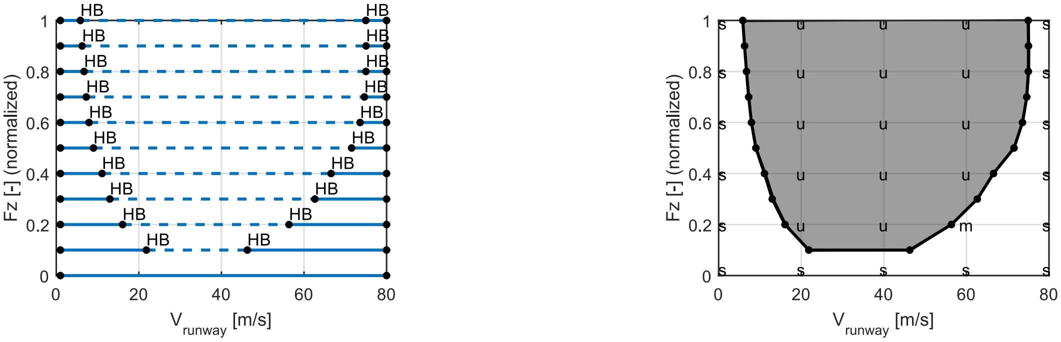


Fig. 1: An overview of the simulation methodology to investigate the onset of shimmy of a nose landing gear with multibody simulations and AUTO.

The software framework which has recently been developed by Siemens PLM [1] is adapted to perform 1-parameter bifurcation analyses of this model. By combining the capabilities of the multibody solver with those of AUTO [2], a continuation analysis is performed to determine the location of supercritical Hopf bifurcations in the parameter space. These bifurcations mark the transition from a stable, quasi-static solution of the system to an oscillatory solution and thus indicate the onset of shimmy. The forward velocity, V, of the aircraft is used as the primary bifurcation parameter and the vertical load on the landing gear, F_z, is used as the secondary bifurcation parameter. Initial investigations indicated that performing a 2-parameter bifurcation analysis, where a locus of Hopf bifurcations is followed in the $V - F_z$ parameter space, is numerically challenging for such large systems with the current software framework. Therefore, quasi-2-parameter bifurcation diagrams are obtained by performing multiple 1-parameter bifurcation analyses in V, where a different value of vertical load F_z is used for each analysis.

The results for the safety-critical case, where the shimmy damper has a leakage, are presented in Fig. 2. For this case, the functionality of the shimmy damper is reduced to 3% of its original value. The result of the bifurcation analyses is illustrated in Fig. 2a, where each horizontal line represents a 1-parameter bifurcation analysis with V as the bifurcation parameter. The solid lines show the stable, quasi-static solutions and the dashed lines show the unstable, quasi-static solutions, which co-exist with oscillatory shimmy solutions. The results show that for the investigated case the stability properties of the landing gear vary significantly as a function of both parameters. The results obtained with bifurcation analyses are compared with 30 conventional time-simulations in Fig. 2b. The shaded area represents the unstable domain enclosed by 20 Hopf bifurcations while the results of the time domain simulations are shown as discrete points on the background grid. The results show that the two methods are in agreement. When the simulation time is considered, both methods require a similar amount of computational time. However, it must be noted that the solutions found with the bifurcation analysis is much denser and yield the exact location of 20 Hopf bifurcation points on the stability boundary. Achieving the same kind of accuracy with the conventional time-domain simulations would require substantially more simulations and computational time.



(a) Multiple 1-parameter bifurcation analyses.

(b) Unstable domain.

Fig. 2: Results of multiple 1-parameter bifurcation analyses (a), where "HB" indicates the supercritical Hopf bifurcations. In (b), the same stability boundary is indicated by a black line and the enclosed unstable domain is shaded. The results of 30 time-domain simulations are indicated by markers: "s" , "u" and "m" denote stable, unstable and marginally stable points, respectively.

A sensitivity study is performed to investigate how much leakage of the shimmy damper is required to impact the stability of the landing gear. It is shown that shimmy will occur within the operational parameter space only if the shimmy damper coefficient is reduced to less than 5% of its original value. Additionally, changing a second fundamental design parameter, i.e., the mechanical trail of the landing gear, indicates that a smaller trail shifts the unstable domain slightly to lower velocities. Lastly, the analysis of a landing gear with the steering actuator enabled shows that the behavior is drastically different as the shimmy oscillations are observed in the high velocity, low vertical load range.

References

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