Stabilizing aircraft during takeoff and landing using math

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This is an example of runway marks left after a shimmy event. Credit: C.I.A.I.A.C., Madrid, Spain.

One of the lesser known concerns about commercial aircraft is their stability on the ground during taxiing, takeoff, and landing. During these processes, planes must maintain stability under various operating conditions. However, in some situations, the aircraft landing gear displays unwanted oscillations, which are referred to as shimmy oscillations.

In a paper published last month in the *SIAM Journal on Applied Dynamical Systems*, authors Chris Howcroft, Bernd Krauskopf, Mark Lowenberg, and Simon Neild study the dynamics of aircraft landing gear using nonlinear models. The dynamics of landing gear shimmy and the wheel-ground interaction are fundamentally nonlinear.

"Shimmy oscillations of aircraft landing gear have long been a problem, and their prediction and prevention remains an ongoing challenge in landing gear design," explains author Chris Howcroft. "The issue is that a landing gear may display the desired behavior during ground take-off/landing manoeuvres over several hundred or so flights, but then suddenly oscillate given just the right—or rather, the wrong—conditions."

Fortunately, mathematical models provide cost-effective ways to study the dynamics of the main landing gear (MLG) and determine the types of oscillations that may occur under different conditions. "The work we conducted clarifies under which conditions shimmy oscillations can be encountered in the MLG of a representative midsize passenger aircraft. We identified different types of shimmy oscillations and showed where they occur," says Howcroft.

"Having the right mathematical model is really the key," he adds. "Actual testing is extremely expensive; however, nonlinear analysis methods are very well suited to identifying these hard-to-find dynamics. They may also be employed to determine the shimmy characteristics before the aircraft has actually been built."

The model can provide insights not only into aircraft operation, but also design features, and can aid in adjusting both for optimum stability.

Aircraft landing gear supports the weight of the aircraft during landing and ground operations. In addition to their wheels, landing gear also have shock absorbing equipment or "shock struts" as well as brakes, retraction mechanisms, controls, and structural entities that attach the gear to the aircraft.

The model in the paper takes into account tire-contact dynamics and the orientation of the side-stay, the part of the aircraft that supports the shock strut. It characterizes the motion of the system in terms of dynamics of the MLG, which are expressed as three degrees of freedom: rotation about the main strut, and in-plane and out-of-plane motion with respect to the plane of main strut and side-stay. After determining the dynamics for the simplest geometric case, where the side-stay is perpendicular to the direction of travel, the authors use the model to study different side-stay orientations.

"For the specific case of MLG, we developed a nonlinear and fully parameterised model that allowed us to map out how its dynamics depends on operational parameters, such as aircraft velocity and loading, and design parameters describing the geometry of the landing gear," explains Howcroft. "In contrast to the more traditional approach of performing large numbers of simulations, this was achieved by employing advanced tools from dynamical systems that track solutions and stability changes in parameters directly."

Moreover, other parameters could be incorporated into the model further down the road, such as runway conditions or tire pressure, or physical effects such as the dynamics of the shock absorber.

"Future directions of this research will focus on the incorporation and assessment of additional nonlinear effects," says Howcroft. "For example, mechanical joints loosen over the lifespan of an aircraft landing gear, and this may have a dramatic effect on dynamic performance, service life and maintenance requirements of the landing gear."

"Nonlinear modeling and analysis are now being introduced as tools into industrial practice, via the recent development of a MATLAB toolbox," says author Simon Neild. "This is exciting to see, and has allowed our group to tackle not only the problem of landing gear shimmy, but of aircraft ground manoeuvres and airliner loss-of-control in flight."

Author Bernd Krauskopf adds, "This project is part of a larger research effort in collaboration with Airbus into aircraft ground dynamics via the bifurcation analysis of nonlinear models. Related work concerns shimmy in nose landing gears and its interplay with the dynamics of the fuselage."

Future work would integrate many different aspects into a unifying model. "Ultimately our current research is moving towards the integration of landing gear and airframe into an overall model that allows us to create a full dynamic picture of aircraft ground dynamics," says author Mark Lowenberg.

More information: Influence of Variable Side-Stay Geometry on the Shimmy Dynamics of an Aircraft Dual-Wheel Main Landing Gear, Chris Howcroft, Bernd Krauskopf, Mark H. Lowenberg, and Simon A. Neild, *SIAM Journal on Applied Dynamical Systems*, 12(3), 1181–1209. (Online publish date: July 23, 2013) epubs.siam.org/doi/abs/10.1137/120887643

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