ECCOMAS Thematic Conference on Multibody Dynamics
June 29 - July 2, 2015, Barcelona, Catalonia, Spain

Multibody Modelling of a Novel Two-Bladed Helicopter: Trim Studies

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Abstract

A study on a novel two-blade main rotor conceived for a lightweight helicopter was carried out in [1,2]. This rotor features a complex gimbal mount, based on an innovative constant-speed joint, and a Bell-Hiller type flybar with its mixing mechanism for pitch control. This original design is intended to alleviate some of the drawbacks of teetering rotors, *i.e.* the prevailing architecture among current light helicopters. In particular, it is designed to reduce the considerable 2/rev oscillations in the rotor loads transmitted to the fuselage, which negatively impact on vehicle handling qualities, pilot workload, passenger comfort, and structural fatigue. The highly detailed model of the isolated main rotor (MR) employed in previous studies is here extended to the complete helicopter by adding the fuselage, fins, and tail rotor (TR) models. The tail rotor also involves an original design, with a fixed-pitch, variable-speed configuration. The model is implemented in the nonlinear finite-element multibody code Cp-Lambda, a tool extensively employed in the analysis of rotorcraft and wind-energy industrial systems in recent years (*e.g.* [3]). The resulting multibody representation totals over 2400 degrees of freedom. Figure 1 shows the topological sketches of the complex subsystems composing the main rotor.

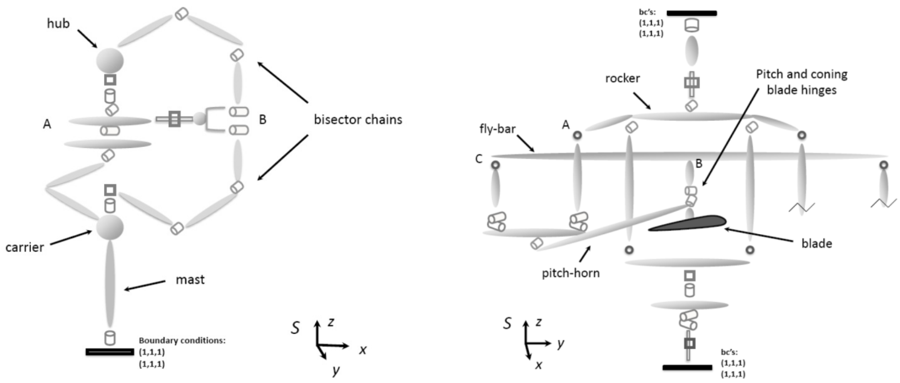

Figure 1: Schematics of the rotor head gimbal and pitch control mechanisms.

This level of fidelity is considered necessary to accurately capture the rotor dynamic behavior when subjected to a cyclic perturbation from periodic conditions, the so-called ‘wobbling’ response. Furthermore a closed-loop multi-channel PID-type control system has been integrated within the multibody model. This system is an autopilot that actuates the helicopter controls, *i.e.* MR collective pitch θ_0, MR lateral and longitudinal cyclic pitches A_1 and B_1 and TR rotational speed N^{TR}, to achieve trimmed straight and level flight at given values of helicopter gross weight, airspeed and altitude. Helicopter trim conditions are broadly defined as those bringing the fuselage in steady state (constant body-axes linear and angular velocities) with constant control inputs, resulting in a periodic motion of the main rotor [4]. Such a condition is computed with relative ease using performance models, such as those based on [5], which adopt drastic simplifications in the main rotor representation. However, such *ad-hoc* approaches allow to capture the global flight mechanics behavior, but lack the ability to determine significant aeroelastic features such as rotor blade deformations, loads and vibrations. Trimming a high-fidelity, fully nonlinear model poses more difficulties, given the complexity of the unsteady motion of virtually all elements within each single revolution. This task is pursued here by constraining first the helicopter to the ground by means of a virtual load cell (a specialized beam element). The autopilot is activated in order to annihilate the vertical force F_z and the three moment components (roll M_x, pitch M_y, yaw M_z) transferred to the ground. Figure 1 shows examples of the results of this process, in terms of load components and control inputs, in a hovering case. As apparent, averaged loads are null, confirming the achievement of a trimmed condition. Subsequently, control values are averaged and input on the uncontrolled, unconstrained model to assess the quality of this solution. A slight drift is obtained, as shown in Figure 2, depicting center-of-mass displacements and fuselage attitude rotation corresponding to the averaged controls of Figure 1. This appears a fairly good estimation for the actual free flight trimmed conditions, since the drift is very limited and does not entail any significant effect on the global vehicle response, nor on rotor dynamics. The results of a number of flight conditions are compared to those obtained by a lower-fidelity performance model of the same helicopter. The paper discusses the related differences, which are relatively limited in hover, but increase with airspeed. Furthermore, the trim solutions have been subjected to cyclic perturbations as previously done for the isolated rotor [2], and the results are compared and discussed.

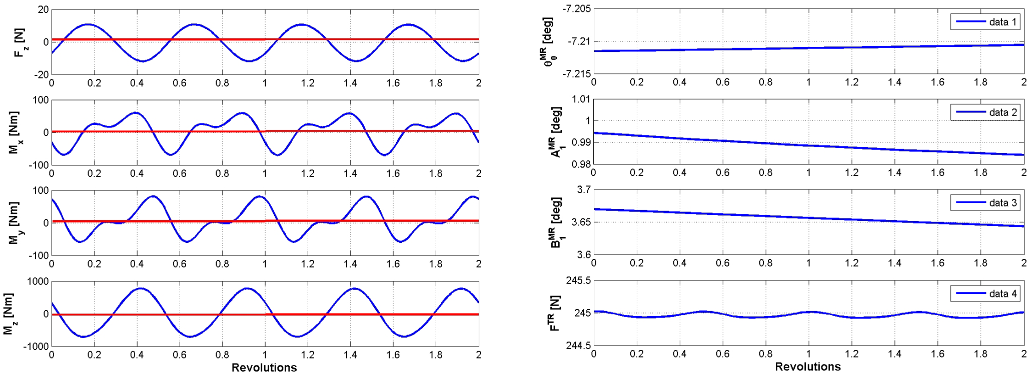

Figure 1: Time histories (blue) and average values (red) of vertical force and roll, pitch, yaw moments (left) and controls (right) for a quasi-trimmed constrained hover condition.

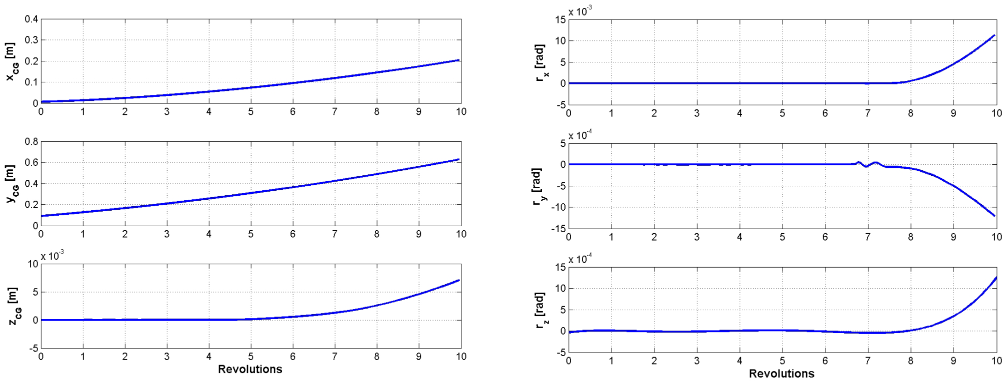

Figure 2: Time histories of center of mass displacement components (left) and fuselage conformal rotation vector components (right) for a quasi-trimmed free hover condition.

References

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