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Author: Simone Weber, Researcher, Airbus Helicopters UK/Cranfield University
***Co-Author*:** Alastair Cooke, Senior Lecturer, Cranfield University
***Co-Author*:** Mudassir Lone, Lecturer, Cranfield University
Co-Author: Richard Atack, Head of Design Office, Airbus Helicopters UK

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Prediction of in-flight rotor blade deformation using a non-linear Timoshenko beam model

Helicopters operate in many different flight regimes. Often, they are required to perform extreme manoeuvres. Damage on rotor blades can have serious consequences. Due to the wide spectrum of operation, rotor blade designers envisaged a large design envelope. However, the missions flown by many users exercise only a small inner region of this design envelope and they rarely push the blade to its operational limits. The lack of knowledge about the actual loading environment and resulting blade deformation leads to severe limitations of progress in the area of helicopter maintenance, repair and servicing the rotor blades.

This work is motivated by the need for a fast simulation of the aeroelastic behaviour of rotor blades to identify magnitude and location of critical deflections in several flight conditions. This is achieved with the use of a mathematical approach, integrating a non-linear Timoshenko beam model into a non-linear 6-DoF helicopter model (Matlab/Simulink). A linear Timoshenko beam is modelled as a dynamic system, with the equations of motion derived using the Lagrangian method, with Rayleigh damping incorporated, and solved using a state space technique. This model is developed into a non-linear framework in Simulink. For this work data from the bearingless main rotor of an H135 is used, which is part of the Airbus Helicopter family. To replicate the rotor blades, sectional properties are included in the Timoshenko beam model.

The aim of this work is to achieve a 6-DoF model with the capability of a complete aeroelastic rotor model. Its design structure is described as a feedback loop to precisely manage the interactions between aerodynamics on the blades, dynamics and structural mechanics. Control input from the pilot alters the angle of attack at the blade profile which results in the change of blade motion and therefore in the change of flow field and blade loads. The fuselage which is dynamically treated as a rigid body with six degrees of freedom (three translations and three rotations) has a different vibration level than the rotor blade system. Moreover, the frequency and amplitude of the structural blade motion are different to the frequency of the rigid body, where its dynamic mode is described through a phugoid. This difference affects handling and ride qualities of the aircraft. The developed model provides a tool to investigate how the determined blade deformations can be exploited in the overall aircraft design, such as flight control, blade design or other systems.

For verification and validation of the 6-DoF helicopter model, flight test data of several flight conditions is used. This approach is a step away from the conventional approach that only considers a rigid blade following a circular tip path plane.

This knowledge and validation tool is very useful for further research in the area of automated monitoring of rotor blades, such as with the use of fibre-optical instrumentation systems. Furthermore, the results of this study are very beneficial for developing a methodology for optimal fibre-optic instrumentation mapping to formulate the spatial distribution of fibre-optic sensors. The analysis of a deformed rotor blade when the helicopter is IGE (in-ground-effect) and OGE (out-of-ground effect) is part of the future work in this project.