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Time finite element methods for the periodic solution of blade-tip/casing interaction

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Small blade tip running clearances tend to augment both aero engine efficiency and performance. However, small blade tip gaps increase the propensity to blade-tip/casing interactions (blade-tip rubs) that could lead to blade tip or whole aerofoil HCF failures and subsequent secondary damages leading to engine shutdown. The blade-tip/casing interactions have been a subject of research for many years. Experimental results by Batailly et al.[1] on a single blade interacting with a distorted casing coated with an abradable material showed that rub-induced synchronous vibrations of the blade can lead to high-wear patterns in the abradable coating and blade cracks when the rotational speed is close to an engine order (i.e. resonance).

Most numerical models developed to simulate blade-tip/casing interactions and to identify hazardous rotational speeds are based on time integration schemes. In order to reduce the computational time, Salles et al.[2] proposed a frequency-domain approach based on harmonic balance method coupled with parametric continuation for the evaluation of the nonlinear steady-state response of a single blade interacting with a distorted casing.

The harmonic balance method exhibits Gibbs phenomenon at the discontinuities due to the non-smoothness of the problem and may require a high number of harmonics to provide an accurate prediction. In order to avoid this issue, the time finite element method based on weak Hamilton's formulation by Borri et al.[3] is adopted here to evaluate the periodic solution and coupled with parametric continuation to evaluate the forced response over a wide range of rotational speeds. The computational cost compared to the time integration schemes is dramatically reduced and the accuracy and stability compared to the harmonic balance method are significantly enhanced thus making this approach a suitable tool for fast analyses in the preliminary design stage of the blade.

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