7th International Conference on Nonlinear Vibrations, Localization and Energy Transfer
July 1-4, 2019 - Marseille, France

Nonlinear Vibration in Aircraft Engines

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Abstract Several component of turbomachinery operate in nonlinear regime of vibration during operation. We present in this work the state of the art techniques for analysing nonlinear vibration of turbomachinery. Most of the vibration anlayses are performed using frequency response for forced response problem. It is possible to use the concept of nonlinear normal modes and their adaptation for non conservative system. The periodic response are calculated using boundary value problem (BVP) solvers. We will present results using harmonic balance method and finite element in time techniques for non smooth dynamic problem. The work will conclude with presentation of challenge for the future in turbomachinery vibration analysis.

Turbomachinery are very complicated systems and undergo a large level of vibration during operation that leads to nonlinear behavior. Several kinds of nonlinearity are present in an aircraft engine as shown in Figure 1.

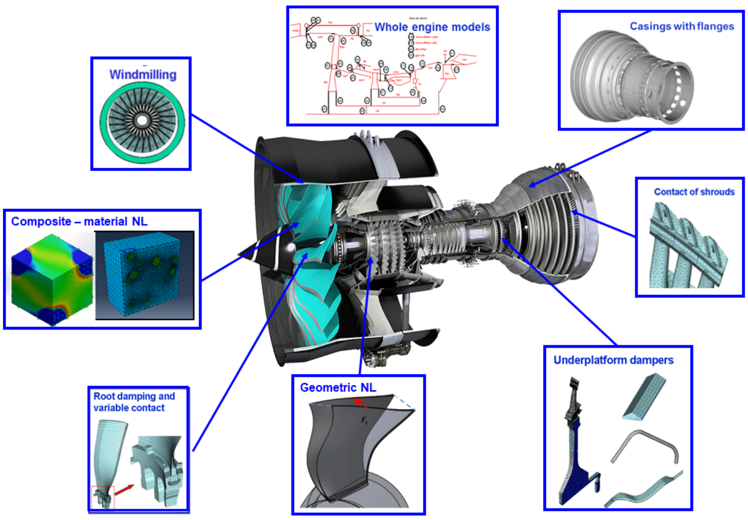
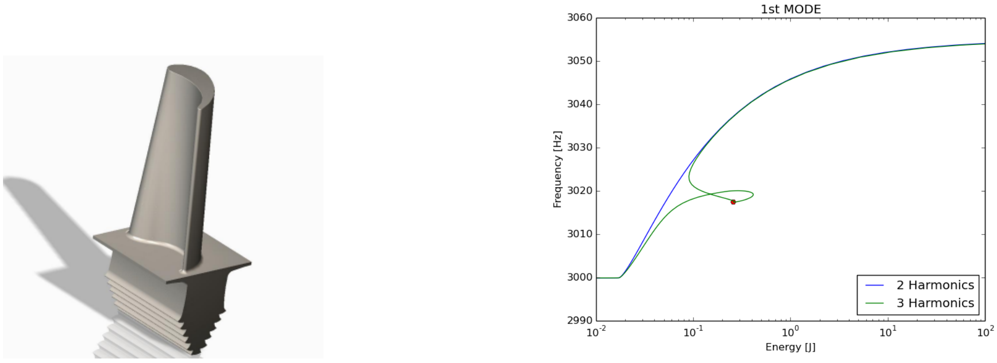


Figure 1: Nonlinearities in aircraft engine (pictures courtesy Rolls-Royce Plc)

An in-house code named FORSE has been developed at Imperial College for twenty years to deal with nonlinear vibration and different types of nonlinearity. The code was first designed to treat localized nonlinearities: contact, friction, impact, bearings. . . and was recently extended to distributed nonlinearities: material nonlinearities and geometric nonlinearities. FORSE is based on harmonic balance method coupled with continuation method and permits to compute frequency response, (complex) nonlinear normal modes and limit cycle oscillation. The software is based on object oriented programming using Modern Fortran. Some feature of the code are presented in this work and results for different applications. FORSE permit to solve boundary value problem in time defined by the following equation

$$\mathbf{M}\ddot{\mathbf{U}} + \mathbf{C}\dot{\mathbf{U}} + \mathbf{F}_{\text{int}}(\mathbf{U}) = \mathbf{F}_{\text{nl}}(\mathbf{U}, \dot{\mathbf{U}}) + \alpha\mathbf{F}_{ex}(t) \tag{1}$$

where $\mathbf{M}$ and $\mathbf{C}$ are the mass and damping matrices, $\mathbf{U}$ is the vector of displacement, $\mathbf{F}_{\text{int}}$ represents the internal forces due to large deformation or material nonlinearities, $\mathbf{F}_{\text{nl}}$ is the vector of localized nonlinearities, $\alpha \mathbf{F}_{ex}(t)$ are the excitation forces and α is a cefficient used to switch between autonomous and non-autonomous system. The ordinary differential equation Eq. 1 is transformed to nonlinear algeabric system using Fourier Galerkin method and reduced order modelling (ROM) based on Component Mode Synthesis. The proposed ROM depends on the nonlinearities [2, 7]. The proposed techniques permits to calculate frequency response with detection and path following of bifurcated branches [4]. The code has been modified to calculate (complex) nonlinear normal modes for different applications [5, 6]. It is possible to extend the technique for analysing stability of rotating system [1]. Figure 2 shows results for a blade tip rub application [3].



(a) turbine blade (b) FEP

Figure 2: Nonlinear Normal Mode of blade of first bending mode due to tip rub

Acknowledgment The first and second authors are grateful EPRSC and Rolls-Royce Plc for providing the financial support through prosperity partnerships Cornerstone (EP/R004951/1). The third author is grateful to China Scholarship Council (File NO. 201708060239) for providing the financial support for this project.

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