Dynamic Analysis of a Two-spool Aero-engine Model Undergoing Multi-disk Rub-impact using a Semi-analytical Method

A Thesis submitted

in partial fulfilment for the degree of

Doctor of Philosophy

by

Prabith K

Department of Aerospace Engineering

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

THIRUVANANTHAPURAM - 695 547

May 2022

Abstract

Fan blade-out event and windmilling of the turbofan engine, generated as a consequence of bird strike, is a potential threat to the aircraft during its flight. The tight clearance between the blades and casing can cause the multi-disk rub-impact in the engine whenever the rotor deflection exceeds the clearance. As a result, the Federal Aviation Administration has introduced some stringent rules and regulations in testing aircraft engines so that the engine can contain damages without catching fire. However, the conduction of tests to prove the engine's safety is costly and sometimes leads to severe injuries to the test personnel. In this work, a numerical model of the aero-engine dual-rotor similar to the CFM56-5B engine is utilized to analyze the response characteristics of the engine under multi-disk rub-impact. The rotor system is modelled using the tapered Timoshenko beam elements, including rotary inertia, gyroscopic moments and shearing effects. A modified model reduction technique based on component mode synthesis is utilized to reduce the size of the finite element model in which the whole model is divided into primary and secondary components. The primary component consists of all the nonlinear degrees of freedoms, while the secondary component is reduced using the Craig-Bampton substructuring technique based on the quadratic eigenvalue decomposition. The proposed method is effective in the model reduction of systems involving asymmetric global matrices. The steady-state response of the model under multi-disk rub impact is investigated using a semi-analytic technique called the approximate time variational method. It is a time-domain method and is suitable for solving multi-frequency excitation problems. Moreover, a hypersphere based continuation technique is also incorporated to trace the solution branches beyond bifurcation points. The type of bifurcations is determined by monitoring the Floquet exponents. While analyzing the results, it is observed that the nonlinearities are intensified, and the rightward bending of the response curve is increased during the multi-disk rub-impact. Limit point and Neimark-Sacker bifurcations are observed, and their onset points are dependent on the multi-disk rub-impact. The responses such as period-5, quasi-periodic, and dry friction backward whirl motions are noticed for different values of the rub parameters. As a result, a parametric analysis is also performed to understand the effects of rub and squeeze film damper parameters.