BLADE/CASING CONTACTS IN TURBOMACHINERY: STATE OF THE ART AND RECENT DEVELOPMENTS

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OBJECTIVE

This tutorial aims at providing an overview of past and on-going research related to the field of rotor/stator interactions within turbomachines, with a focus on the blade tip/casing contact interface. The growing significance of this interface in the design of modern aircraft engines and gas turbines has indeed motivated a vast amount of both applied and theoretical research work—in a variety of engineering domains—over the past decade. This tutorial also intends to detail practical outcomes of these works for manufacturers.

ABSTRACT

The notion of rotor/stator interactions covers a wide variety of physical phenomena that are detrimental to aircraft engines operation. This tutorial focuses on rotor/stator interactions specifically related to the blade-tip/casing contact interface with an emphasis on structural dynamics considerations. The lack of a comprehensive theoretical framework for the analysis of mechanical systems featuring contact interfaces is a major issue for engineers and designers. They must prevent these interactions while ensuring a maximal efficiency of the engine with ad-hoc methodologies and often rely on empirical linear criteria. For this reason, the understanding and simulation of rotor/stator interactions subsequent to contact events have generated a large amount of research work over the past decade, both from a numerical and an experimental point of view. The extremely high cost for full scale experimental observations has motivated the design of simplified experimental setups as well as the development of predictive numerical tools. This tutorial will provide a brief overview of the main strategies employed by a variety of research teams worldwide to tackle this issue. In particular, a highly competitive context combined with the analysis of proprietary bladed components has led to very distinct numerical strategies that are extremely difficult to compare. Various solution techniques, featuring distinct contact treatment algorithms with no standard benchmark make it almost impossible to compare numerical predictions from a publication to another. Accordingly, particular attention will be paid in this tutorial to give a detailed presentation of the state of the art in the field of rotor/stator interactions looking at various researchers' groundwork. The prediction of rotor/stator interactions could yield significant improvements for modern aircraft engines with great industrial implications, therefore, research on the prediction of rotor/stator interactions is still a much invested area in aerospace engineering. In this tutorial, on-going research topics of rotor/stator interactions as well as some of the most promising outcomes that are expected in a near future will be discussed.

TUTORIAL OUTLINE

The tutorial outline will be as follows:

I - Rotor/stator interactions [The notion of rotor/stator interaction covers a wide range of physicial phenomena. This section provides insight on these distinct phenomena. It focuses on the blade tip/casing contact interface and the subsequent interactions that may arise—namely rubbing, modal and whirl interactions. The specificity of each application (aircraft engines, gas turbines and helicopter engines) is also underlined. Finally, in this field dominated by industry-led research activities, the challenges posed by confidentiality and proprietary data for comparison and confrontation of proposed methodologies are also addressed.]

I.1 - Historical overview

I.2 - Blade tip/casing contacts

I.2.1 - Importance of the issue

a - A safety concern

b - Contextual factors

- new environmental norms
- a highly competitive market
- development of lighter materials

I.2.2 - Today's engineering challenges

a - Gas turbines

- can the abradable layer be removed ?
- high maintenance costs due to failure

b - Aircraft engines

- prevent early maintenance operations
- wear of blades in turbine stages

c - Other applications

- helicopter engines (impellers)
- link to other industrial issues

I.2.3 - Academia/industry collaborations

a - A particular context

b - Confidentiality and proprietary data

- difficult confrontation of developed methodologies
- experimental/numerical comparison is limited

II - Research investigations: state of the art [Research activities on blade tip/casing contacts cover experimental, theoretical and numerical aspects. From an experimental standpoint, the complexity of abradable coatings microstructure and the intricacy to obtain equivalent mechanical properties have driven numerous research works. The contact interface itself, with or without abradable coating, has also been the focus of many investigations: academic research mostly focused on simplified setups while some manufacturers pushed for the development of full-scale setups. Theoretical and numerical developments are motivated by the lack of unified framework for the analysis of mechanical systems undergoing structural contacts.]

II.1 - Experimental investigations

II.1.1 - Abradable coatings mechanical properties

- microstructure analysis
- wear mechanisms

II.1.2 - Simplified setups

- thermomechanics and contact
- rigid and flexible components

II.1.3 - Full-scale setups

- fan stages
- compressor and turbine stages
- engine-like conditions

II.2 - Theoretical and numerical developments

II.2.1 - Contact mechanics

- improvement of existing methodologies
- nonsmooth modal analysis
- alternatives to the finite element method

II.2.2 - Model reduction

- accounting for inertial effects
- thermomechanical reduced basis

II.2.3 - Nonlinear vibrations

a - Frequency methods

- use of nonlinear normal modes
- linear complementarity problem
- harmonic balance method

b - Time integration

- improvement of existing techniques
- development of new contact algorithms

III - Industrial applications: state of the art

[It can be difficult to assess the state of the art for industrial applications as publication policies significantly vary from a manufacturer to another. Nonetheless, the degree of maturity reached by numerical developments now allows to incorporate those within manufacturers software environments. Recent publications underline that these nuemrical tools provide important results for the design of both compressor and turbine stages.]

III.1 - Predictive numerical strategies

- numerical/experimental confrontations
- multiphysics analysis

III.2 - Design specifications

III.2.1 - Bladed components

- redesign operations
- definition of design criteria

III.2.2 - Stator components

- numerical tools for stress levels estimation
- influence of stator shape and manufacturing precision

IV - Going forward...

[The definition of a unified framework for the analysis of mechanical systems undergoing contacts is still today an open question. While recent developments are promising, they are still far from any industrial application. Going further implies a thorough comparison of existing numerical strategies which calls for a more open approach. In particular, the definition of standardized benchmarks is required. Modern numerical tools will have to combine advances made in distinct research areas: mistuning, geometric nonlinearities, multi-stage vibration analysis...]

IV.1 - Need for more open strategies

IV.2 - Definition of new design guidelines

IV.2.1 - Blades robust to contact

IV.2.2 - Safe integration of lighter materials

IV.3 - Combining various types of nonlinearities

IV.3.1 - Bladed components

IV.3.2 - Multi-stage analysis

IV.4 - Stochastic modelling

V - Concluding remarks

REFERENCES

The complete list of bibliographic references will be provided with the presentation.