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Uncertainty Quantification in Computational Fluid Dynamics and Aircraft Engines

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To Manola and Marcello

Preface

It is no wonder that Uncertainty Quantification has become more and more of an actuality in the last decade as the modelling capability jointly with computational power has increased a lot. In the past, the capability to predict flow field and performance in aero engines as well as in turbomachinery was of great support to the design. However, the range of errors in such results was so large as to suggest the use of CFD, mainly to understand the direction of trends and improvements more than the exact evaluation of thermo-fluid-dynamic parameters, which could affect performance, reliability and life of the engine components.

Recently, we have seen two different but relevant matters:

- the improvement of simulation and modelling capabilities, with increasing accuracy and reliability linked as well to the enhanced computing capability offered by massive Parallel Computing architectures;
- the marginal space left to increase the efficiency and reliability of turbomachinery components in aero engines that is approaching the theoretical limits; because of this fact the competition among producers is becoming continuously stronger and critical.

In this environment, the uncertainty on the real configuration of the components both in terms of geometry and real operational conditions becomes a key point and the capability to manage properly these elements both in the design phase and in the monitoring and diagnostic of the engines can be winner elements.

We can only imagine the tremendous impact that this is going to have in the coming years, helping engineers to develop more reliable configurations able to withstand random variations and unexpected failures. Yet, it is strangely difficult to find any book explaining the impact of manufacturing deviations in different components and how UQ should be used to address this problem. It was to supply this need that the present work was written. This monograph represents a valid contribution to the understanding of the methodology that even today can be carried out to control and manage this tough matter.

This book has been written with the support of various academic and industrial actors who provided elements from both real-life experience in the design/production and theoretical and conceptual contest.

This work will provide a wide review of the configuration affected by uncertainty in aero engines as well as of the more up-to-date tools that can be implemented. It is my hope that this book may do something to encourage and direct the reader in studying Uncertainty Quantification and to identify how this will help in the development of future engines.

Firenze, November 2014 Prof. Francesco Martelli

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Introduction

The overall goal of this work is to give an overview of the current research on Uncertainty Quantification applied to aircraft engines. Until 10 years ago the design process of an aircraft engine required 90 % of rig tests and 10 % of computational fluid dynamics simulations. Today, these numbers are almost inverted with CFD playing a major role in the design and certification of aircraft engines.

However, we have reached a level of detail in the simulations where the length scale that is resolved in CFD is comparable to the microscopic errors due to the manufacturing process, although these errors are not accounted for in many simulations. High fidelity CFD for gas turbines requires the simulation of these variations, but in principle these effects are stochastic and we need to move from deterministic simulations to probabilistic CFD.

In this work we show an analysis of the impact of manufacturing/in service degradation on the performance of jet engines, as found in the open literature. Later, we discuss the impact of CFD uncertainty and how different uncertainty quantification techniques have been used to quantify these effects in compressors and turbines. Uncertainty Quantification is a general term that encompasses several different methodologies to carry out stochastic analyses: the last chapter is a guide for beginners through the methods that have been currently applied and explains in detail the mathematical formulation of such methodology.