Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 29 (2018) 289–302

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th CEAS AIR & SPACE CONFERENCE AEROSPACE EUROPE 2017, CEAS 2017, 16-20 October 2017, Bucharest, Romania

Uncertainty quantification and robust design optimization applied to aircraft propulsion systems

Marco Panzeri[a,*], Andrey Savelyev[b], Kirill Anisimov[b], Roberto d'Ippolito[a], Artur Mirzoyan[c]

[a]Noesis Solutions, Gaston Geenslaan, 11, 3001 Leuven - Belgium
[b]Central Aerohydrodynamic Institute (TsAGI), Zhukovsky 140180, Moscow Region, Russian Federation
[c]Central Institute of Aviation Motors (CIAM), Moscow, Russian Federation

Abstract

The standard way of formulating optimization problems applied to aircraft design is based on the assumption that the underlying system is deterministic, i.e., that the knowledge associated with the design variables and with the system dynamic is not characterized by uncertainty. However, in real conditions randomness impacts the formulation of the design process in multiple ways and the system outputs (i.e., the key performance indicators and the design constraints) are also affected by uncertainty. A system designed under deterministic assumptions may therefore have an unreliable behavior due to the fluctuations associated with the input random variables. This problem can be tackled by adopting a probabilistic approach and re-formulating the design optimization problem with an additional set of constraints associated with the robustness / reliability of the target system. This work addresses the problem of optimizing the geometry of a turbofan engine nacelle subject on reliability constraints. An advanced, machine-learning based framework is adopted in order to (a) investigate the system behavior through an adaptive design of experiments technique and (b) build accurate surrogate models of the system dynamics. These surrogate models are then employed to run a set of probabilistic studies at an affordable computational cost. The results of these investigations include (a) an extensive suite of analyses aimed at characterizing the uncertainty associated with the output quantities of interest; (b) a robust optimization of the engine nacelle geometry and (c) an assessment of the reliability of the optimized design. The improved performance and reliability of the design, together with the limited number of overall system evaluations required to run the analyses, demonstrate the effectiveness and the engineering applicability of the proposed approach.

Peer-review under responsibility of the scientific committee of the 6th CEAS Air & Space Conference Aerospace Europe 2017.

* Corresponding author. Tel.: +39-334-806-4246.
E-mail address: marco.panzeri@noesissolutions.com

2352-1465 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 6th CEAS Air & Space Conference Aerospace Europe 2017.
10.1016/j.trpro.2018.02.026

*Keywords:*Uncertainty Quantification; Computation Fluid Dynamics; Robust Design Optimization; Reliability Assessment; Propulsion System

1. Introduction

In a typical design process developed under a deterministic paradigm, all input parameters are considered to be known without uncertainty. In this context, all manufacturing processes are assumed to produce identical structures that will operate at the same environmental conditions. This is typically not true because the presence of non-predictable effects associated, for example, with imperfections occurring in the manufacturing process or with the non-exact definition of the target operating conditions, have a considerable impact on the reliability of the system in terms of structural instabilities.

The aim of this study is to optimize the geometry of a turbofan engine nacelle by adopting a probabilistic approach, according to which the input system parameters are considered as random quantities and therefore also all the output quantities are associated with probability density functions. This approach allows re-formulating the optimization problem by introducing a new set of robustness / reliability constraints that are directly associated with the probability of failure or with the robustness of the target system instead of being inferred from implicit knowledge or experience.

The advantages of adopting this approach are multi-fold: it enables the possibility to assess the reliability of the target system in terms of quantities defined in a rigorous probabilistic context instead of handling subjective, experience-based and heuristic values; as a consequence, the approach can yield an optimized system that is sufficiently reliable but is typically associated with increased performances.

Uncertainty quantification techniques are well-known to be computationally demanding because an accurate characterization of the uncertainty associated with the output quantities of interest requires a large number of system evaluations. In this study, these burdens are circumvented by adopting an approach based on surrogate models, according to which a machine learning-based, adaptive Design of Experiments technique is used to build a dataset of system results together with the corresponding surrogate models. The latter are then employed to run the system evaluations associated with the uncertainty analyses and the reliability optimization.

This study is developed within the context of the European AGILE project. AGILE targets a significant reduction (i.e., 40%) of the time required to implement and solve realistic multidisciplinary design optimization studies. The key enablers are provided by (a) a suite of advanced optimization techniques and strategies; (b) a framework that supports the collaboration aspects between the involved partners and (c) a knowledge-based information technology [Ciampa et al. (2017a, 2017b), Lefebvre et al. (2017), van Gent et al. (2017)]. In the context of AGILE, a key target of the current work consists on assessing the effectiveness and the suitability of the uncertainty analyses techniques on conventional multi-disciplinary design problems. These methodologies will then be applied to novel aircraft configurations during the upcoming phases of the project.

The remainder of this manuscript is organized as follows. Section 2 provides the theoretical framework and the methodologies adopted to optimize the geometry of a turbofan engine nacelle under reliability constraints. These techniques have been applied to the test case described in Section 3, while Sections 4 and 5 present the results and main conclusions, respectively.

Nomenclature

ADOE	Adaptive Design of Experiments
CFD	Computational Fluid Dynamics
DOE	Design of Experiments
FOSM	First Order Second Moment
FORM	First Order Reliability Method
IGES	Initial Graphics Exchange Specification
LES	Large Eddy Simulation
MC	Monte Carlo
MPP	Most Probable Point