

Multiple-Point Adaptive Performance Simulation Tuned to Aeroengine Test-Bed Data

Y. G. Li,* L. Marinai,† E. Lo Gatto,‡ V. Pachidis,§ and P. Pilidis¶
Cranfield University, Cranfield, England MK43 0AL, United Kingdom

DOI: 10.2514/1.38823

Adaptive simulation technology enables the calibration of a performance simulation code to a given in-service gas turbine and provides correct prediction of its performance. This is a fundamental prerequisite for reliable gas-path diagnostics and performance health monitoring. In this paper, a new offdesign performance adaptation algorithm is introduced. Cranfield University's consolidated engine performance simulation code PYTHIA is enhanced with the capability of offdesign performance adaptation to model available field data. The software minimizes, via a genetic algorithm, an objective function that measures the error between an initial engine model output and the real engine data by varying some characteristics' scaling factors. In this study, a multiple-point adaptation procedure was applied to a two-shaft aeroengine. This generated an optimized engine model that minimized its deviations from a set of test-bed data. The adapted model was then tested against different real data, resulting in an average error, over 8 measured parameters, of less than 0.35%.

Nomenclature

a	=	weighting factor
ETA	=	isentropic efficiency
K	=	number of measurement
N_1	=	relative low-pressure shaft speed, %
N_2	=	relative high-pressure shaft speed, %
n	=	number of offdesign points
OF	=	objective function
P	=	pressure, atm
\mathbf{P}	=	measurable performance-parameter vector
PR	=	pressure ratio
SF	=	scaling factor
T	=	temperature, K
\mathbf{u}	=	ambient and operating-condition vector
WAC	=	corrected mass flow rate, kg/s
\mathbf{X}	=	component-characteristics vector

Subscripts

amb	=	ambient
DP	=	design point
ETA	=	isentropic efficiency
N	=	relative shaft speed
OD	=	offdesign
PR	=	pressure ratio
WAC	=	corrected mass flow rate, flow capacity
0	=	design point
6	=	low-pressure compressor exit
8	=	high-pressure compressor exit
11	=	high-pressure turbine exit
15	=	outlet fan turbine exit

Superscript

def = default

I. Introduction

THE capability of modeling and accurately predicting aeroengine performance is recognized to be an asset for both engine manufacturers and users. This Introduction discusses how adaptive simulation techniques can be advantageous for both parties, even if from different perspectives.

For original engine manufacturers (OEMs), a reliable performance simulation contributes to a more cost-effective engine development and health monitoring. Although for the purpose of engine development, a generic performance simulation model (representative of a family of engines) is suitable, in the case of performance health monitoring, an engine model (which is tuned to the specific operating engine) is necessary. This allows minimizing the intrinsic deviations between the generic (engine fleet) simulation model and the operating engine that are caused by the not-negligible performance differences that characterize any production line (engine-to-engine variation).

Another point of view can be given for aeroengine operators. The accuracy of the prediction is highly dependent on the quality of engine design data and empirical component information such as component characteristic maps. Such information is normally the exclusive property of engine manufacturers and only partially disclosed to engine users. Consequently, intrinsic deviations between the simulation and the operating engine may exist due to lack of engine component characteristic information.

Equally of interest to both engine manufacturers and operators is the fact that these deviations between the simulation and the operating engine, if not reduced to an acceptable minimum, can result in misleading gas-path diagnostics (GPD) analyses [1,2]. GPD is used in health monitoring to identify the component(s) responsible for performance deterioration and to quantify the deviations of each component performance parameters (typically efficiencies and flow capacities of compressors and turbines) from a baseline condition represented by the simulation model. These deviations, when the engine is clean (not degraded), have to be small; otherwise, these simulation biases will have a disastrous impact on the GPD assessment. As a matter of fact, given that the nonlinear behavior of the thermodynamic performance of a gas turbine varies the component performance parameters, an initial simulation bias or deviation between simulation and operating engine does not result in a constant bias on the GPD assessment, but may produce significant

Presented at the 18th International Symposium of Air Breathing Engines, Beijing, China, 2–7 September 2007; received 29 May 2008; revision received 2 February 2009; accepted for publication 5 February 2009. Copyright © 2009 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved. Copies of this paper may be made for personal or internal use, on condition that the copier pay the \$10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0748-4658/09 \$10.00 in correspondence with the CCC.

*Lecturer, School of Engineering; i.y.li@cranfield.ac.uk.

†Lecturer, School of Engineering; l.marinai@cranfield.ac.uk.

‡Research Student, School of Engineering.

§Lecturer, School of Engineering; v.pachidis@cranfield.ac.uk.

¶Professor, School of Engineering; p.pilidis@cranfield.ac.uk.