Aerospace Science and Technology ••• (••••) •••–•••

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Automated thermal and stress preliminary analyses applied to a turbine rotor

Maxime Moret [a], Alexandre Delecourt [a], Hany Moustapha [a], Acher-Igal Abenhaim [b], Francois Garnier [a]

[a] *École de Technologie Supérieure, Université du Québec, Montréal, Canada*
[b] *Pratt & Whitney Canada, Montréal, Québec, Canada*

A R T I C L E I N F O

Article history:
Received 21 July 2016
Received in revised form 18 November 2016
Accepted 15 December 2016
Available online xxxx

Keywords:
Preliminary and multidisciplinary design optimization
Tip clearance
Automated analyses

A B S T R A C T

The use of Multidisciplinary Design Optimization (MDO) techniques at the preliminary design phase (PMDO) of a gas turbine engine allows investing more effort at the pre-detailed phase in order to prevent the selection of an unsatisfactory concept early in the design process. Considering the impact of the turbine tip clearance on an engine's efficiency, an accurate tool to predict the tip gap is a mandatory step towards the implementation of a full PMDO system for the turbine design. Tip clearance calculation is a good candidate for PMDO technique implementation considering that it implies various analyses conducted on both the rotor and stator. As a first step to the development of such tip clearance calculator satisfying PMDO principles, the present work explores the automation feasibility of the whole analysis phase of a turbine rotor preliminary design process and the potential increase in the accuracy of results and time gains. The proposed conceptual system integrates a thermal boundary conditions automated calculator and interacts with a simplified air system generator and with several design tools based on parameterized CAD models. Great improvements were found when comparing this work's analysis results with regular pre-detailed level tools, as they revealed to be close to the one generated by the detailed design tools used as target. Moreover, this design process revealed to be faster than a common preliminary design phase while leading to a reduction of time spent at the detailed design phase. By requiring fewer user inputs, this system decreases the risk of human errors while entirely leaving the important decisions to the designer.

1. Introduction

The design of a gas turbine engine is a multidisciplinary and iterative problem in which the best compromise has to be found between the conflicting disciplines involved: thermal, structural, aerodynamics, manufacturing, cost, weight, etc. The design of aero-engines traditionally follows two main stages: preliminary design and detailed design. At the pre-detailed stage, a few groups are involved to design and analyse the turbine concept's components and sub-systems. However, the Science and Technology Organisation of the North Atlantic Treaty Organization (NATO) [1] showed that decisions taken early in the design process are often based on low fidelity models and when only little information (data, requirements, etc.) is available. This may compromise the engineers' ability to select the optimal design. At the detailed design phase, more groups are involved having their own set of specialized tools and methodologies, and the process is thus even more segmented within the groups to form sub-disciplines' specialists. Panchenko et al. [2] explain that even though knowledge increases during the design process, the freedom to modify any part of the design decreases as shown in Fig. 1, and/or induces major delays in the planning and a rise of design costs. It is consequently hard to correct a bad concept at a detailed design phase. To correct this, Panchenko et al. [2] suggest the use of MDO at the preliminary design phase, since it is at that stage that the biggest influence on the final product configuration is made. As explained by Martins and Lambe [3], the concept of MDO has been widely studied during the past 50 years. However, there is a lack of information in the literature about using this methodology during the early stages of design. Panchenko et al. [2] explain that an increase of the efforts and knowledge during the pre-detailed design phase implies involving directly the specialist groups instead of waiting until the design phase. However, it results in significant delays of the concept evolution since many interactions between several groups are then required. This is where PMDO systems come into play in order to automate and ease this iterative process. Referring

E-mail address: mmoret5@gmail.com (M. Moret).

http://dx.doi.org/10.1016/j.ast.2016.12.013

Nomenclature

AO	Axial Overlap rim seal	T_c	Cooling gas temperature
CAD	Computer-aided Design	U	U-shape rim seal
CAE	Computer-aided Engineering	Zone	A zone is defined as a specific location on the surface of the studied geometry
D_h	Hydrolic diameter	$\dot{m}$	Mass flow rate
HTC	Heat Transfer Coefficient	r	Radius at which the calculation is done
L	Length of the conduct	s	Average spacing between the co-rotating disks
Nu	Nusselt number	η_c	Cooling effectiveness
PMDO	Preliminary and Multidisciplinary Design Optimization	Ω	Rotational speed of the disk
Pr	Prandtl number	ρ	Density of the fluid
Re	Reynolds number	ω	Angular velocity of the co-rotating disks
T_{eff}	Effective (or bulk) temperature		
T_h	Hot gas temperature		

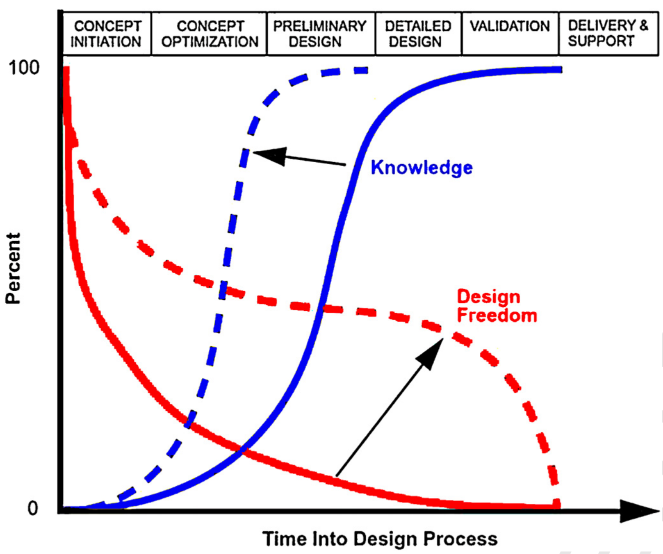
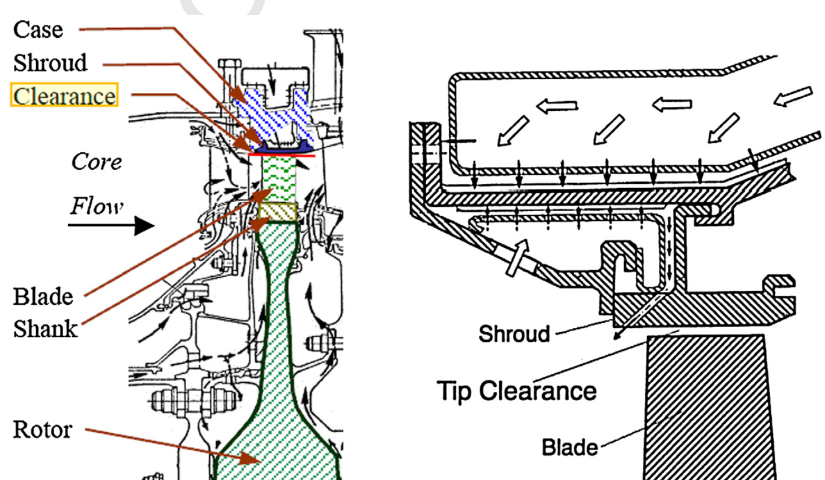


Fig. 1. Knowledge vs. design freedom during the design process [1].

to Panchenko et al. [2], NATO Science and Technology Organisation [1] and Korte et al. [4], the following steps are required to implement a PMDO system:

1. Develop a robust tool base, i.e. design tools based on parametrized CAD models and advanced physics analysis tools;
2. Apply single discipline optimization to individual analytical tools;
3. Create an integration framework, i.e. a software architecture enabling integration, communication and execution of several tools;
4. Implement multidisciplinary optimization with a clear statement of the design objectives, constraints and variables, and an appropriate selection of the algorithms.

A collaborative program was initiated between Pratt and Whitney Canada and the École de Technologie Supérieure to implement an MDO system for designing turbines at the pre-detailed design phase (PMDO). The implementation of a PMDO system generally includes four steps: parameterization of geometric and performance parameters, development or improvement of correlations, integration of disciplines and components, and finally optimization. The present work focuses on the second and third steps. As part of this collaborative program, the development of a tip clearance calculation system is a mandatory step and a perfect example for the implementation of a PMDO methodology considering that it requires the design and analyses (thermal, structural and aerodynamic) of several turbine components as described in Fig. 2. Lattime and Steinetz [5] show that the prediction of a turbine's tip clearance through a typical flight mission is essential in order to maximize an engine's efficiency and its service life. Indeed, an increase of the tip clearance implies that the engine has to augment the turbine inlet temperature to develop the same thrust.



(a) (b)

Fig. 2. (a) Geometry of the E^3 high-pressure turbine [7]; (b) Highlighting of the tip clearance [8].