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VARIABLE SPEED POWER TURBINE PRELIMINARY DESIGN OPTIMIZATION FOR ROTORCRAFT APPLICATIONS

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Variable speed rotor studies represent a promising research field for rotorcraft performance improvement and fuel consumption reduction. The turboshaft engines employed to drive helicopter rotors usually operate at a constant design speed, within a narrow RPM range. The reasons for choosing a constant speed are linked to structural vibrational issues and free power turbine (FPT) performance deterioration in off design conditions. However, in order to minimize helicopter absorbed power, main rotor speed should be adjusted depending on advancing speed, gross weight and altitude [1]. In fact, each different flight condition is characterized by a specific optimal rotor speed; unfortunately, optimal main rotor speed and optimal engine speed, when employing a fixed ratio transmission, represent different goals. The benefits related to optimal main rotor operation may be eventually cancelled by strong deviations from FPT design speed, which lead to higher turbine losses and thus higher fuel consumption. In fact, when FPT speed is far from the design value, the blade incidence angles are far from the optimal values and this implies an increment in blade profile losses. A possible way to overcome this problem is given by an appropriate redesign and optimization of the FPT stages, in order to decrease the stage efficiency sensitivity to RPM variation. Previous studies on this subject can be found in literature; the work carried out by D'Angelo [2] is the first analysis upon the feasibility of a wide speed range turboshaft. Recent activities at the NASA Glenn Research Center related to the development of a variable speed FPT for the Large Civil Tilt-Rotor project are also pointed towards this objective [3],[4].
The present work is focused on the preliminary design and optimization procedure of a variable speed FPT for rotorcraft applications. This task is carried out by employing an in-house 1D meanline analysis code able to predict turbine stages efficiency related to different designs. The stage loss correlation model implemented is a slightly modified version of the well-known model proposed by Craig and Cox; some additional correlations are introduced to increase the accuracy in incidence loss calculations, following suggestions by Moustapha [5] and Bertini et al. [6]. A satisfactory validation of the code has been carried out on different cascade experimental tests, an example of which is represented in fig. 1.
The present study is carried out upon the GE T700 turboshaft engine, mounted on the UH60 Black Hawk helicopter. The redesign of the T700 two-stages axial power turbine is performed with the aim to prevent engine performance deterioration when operating at optimal main rotor speed for different flight conditions. Performance data related to main rotor power and engine fuel consumption are obtained by means of validated numerical simulators. Firstly, using a simple helicopter model (a detailed description and validation of which can be found

in [1]) the optimal main rotor speed minimizing main rotor power is determined for different flight conditions of the rotorcraft. The computed values of main rotor absorbed power and engine RPM are passed as an input to TSHAFT, the gas turbine performance simulator developed at the University of Padova. Overall engine performance can thus be calculated. Instead of using an interpolated FPT map, the previously mentioned 1D code is used to calculate FPT performance in the matching loop inside TSHAFT. In this way different turbine stage designs can be tested using the correct FPT boundary conditions which can only be computed inside the engine matching routine inside TSHAFT. The methodology has been validated, for the T700 design conditions, through comparison against the standard map interpolation procedure and experimental tests, to ensure the 1D code reliability (see fig. 2 for fuel flow comparison). At this point all the simulation tools needed to build an optimization procedure on the turbine stages have been developed. The stages' design variables (such as blade metal angles, solidity, leading edge radius, etc.) are chosen and a multi-point single objective optimization based on genetic algorithms is run. To achieve a FPT design able to perform well at different speeds, three operating points are chosen to be optimized, corresponding to the following flight conditions: hover, cruise and minimum power condition; the objective function to be minimized in every point is fuel consumption.

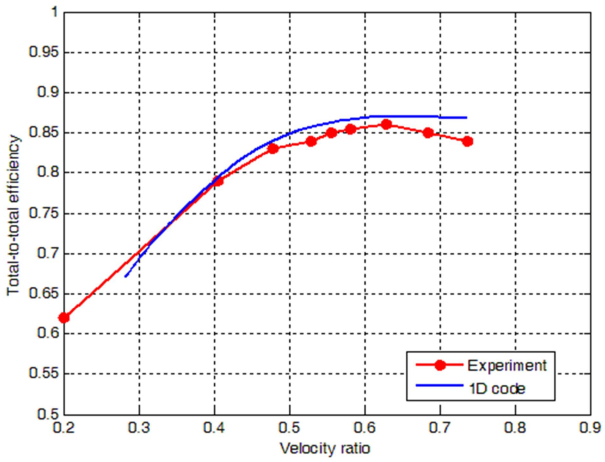

Fig. 2. Validation of meanline 1D code for a turbine stage.

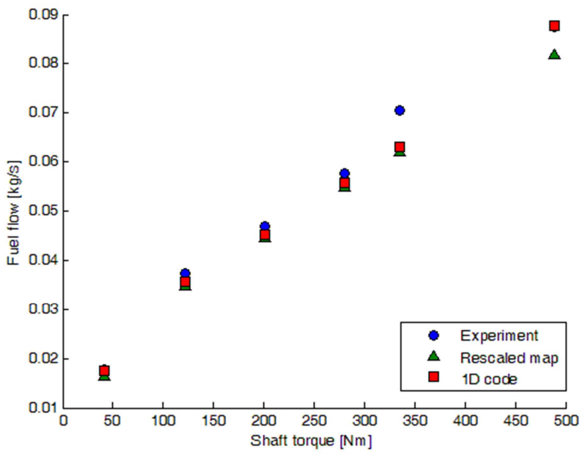

Fig. 1. GE T700 engine model validation: fuel flow.

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