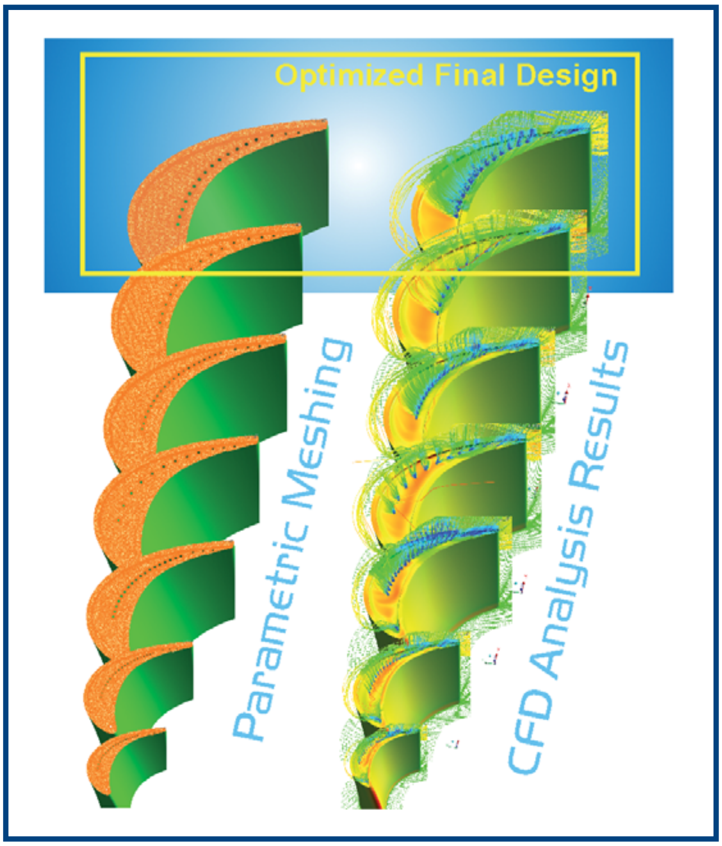
Optimization of Gas Turbine Blades

Tip Cooling Holes Layout Design via Multiobjective Genetic Algoritms And Artificial Neural Network Expert System

A novel methodology has been used to design the layout of the tip cooling nozzles of a high pressure rotor blade turbine.
The methodology used is through a complete CAE approach, by means of a parametric CFD model which is run many times for the exploration of several designs by an optimizer.
Hence the design is carried out automatically by parallel computations, with the optimization algorithms taking the decisions rather than the design engineer. The engineer instead takes decision regarding the physical settings of the CFD model to employ, the number and the extension of the geometrical parameters of the blade tip holes and the optimization algorithms to be employed.
The final design of the tip cooling geometry found by the optimizer proved to be better than the base design (which used mean values of all input parameters) and also better than the design proposed by an experienced heat transfer AVIO engineer, who used standard best practice methods.
Furthermore the large number of experiences gained by the several simulations run by the optimizer generated a virtual database of tip cooling configurations, allowing the designer to find laws, functions and correlation between input parameters and performance output, with a further and deeper insight on this specific design blade cooling problem.



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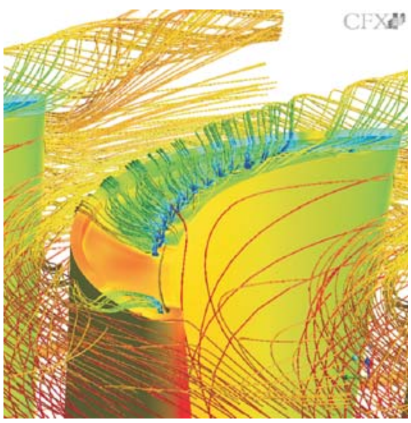
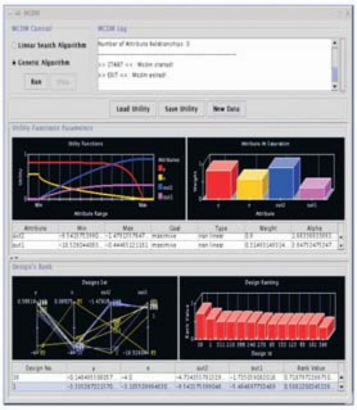
Methodology

This study is part of an AVIO project concerning the development of High Pressure Turbine blades with advanced cooling systems. Due to the high gas temperatures entering the turbine of the most recent aero-engines in general up to 2000 K at the turbine inlet at 40 bars, a very efficient cooling system is required in order to maintain the metal temperatures below the allowable limits. This means to use a certain amount of "cold" air directly extracted from the compressor, with a significant negative impact on the engine performance.
One of the most critical area, from a thermal point of view, is the tip region of the unshrouded rotor blades. Tip regions are generally cooled using rotor internal air ejected in the flow path through a series of small holes located in the tip surfaces. The ejected air must cover all the surfaces in order to create a cold film between the hot gas and the metal. As the tip region is characterized by a very complex 3D flow field, it is very difficult to optimize the cooling system using the standard design methodologies, also considering the other blade tip requirements such as minimizing the



hot leakage air from pressure to suction side, which has a negative impact on turbine aerodynamic efficiency.
For these reasons the area of the tip is investigated with a parametric CFD approach: a parametric model is run several times guided by an optimization algorithm, such that an optimal solution in terms of performance can be found.
This kind of approach requires to link an optimization software (modeFRONTIER) to a 3-D CFD code (ICEM-CFX5) with the goal to find the optimal values of some geometrical parameters of the tip area of the high pressure rotor blade, such that certain performance objectives are reached. As a consequence of the geometrical complexity of the problem and of the high computational time, the use of the interpolators or expert system techniques becomes compulsory if a 3-D fluid-dynamic optimisation has to be approached.



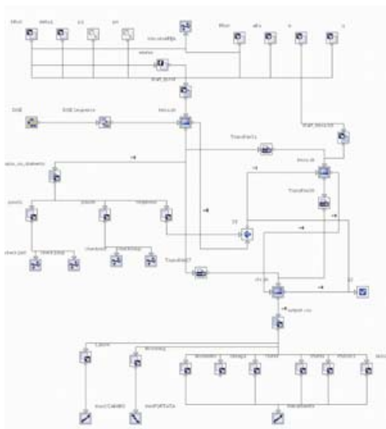
Several methods are generally available within optimization software: RSM, ANN, etc. In this case a ANN method was chosen because of the nonlinearity of the system.

Blade Cascade

This way, after a preliminary series of CFD analyses and after the estimation of ANN, the 3-D CFD model can be substituted by a series of mathematical functions and the computational time is considerably reduced. The expert system, represented by a ANN, must be introduced after a fair number of analysis are run, such that the expert system is reliable.

The error of the expert system is a known value and is the parameter which yields the accuracy of the interpolator relative to the database of real experiments so far acquired. It is up to the designer to chose the threshold error value of his expert system. Basically more CFD analysis we run, the more trained and the more accurate the expert system becomes, but with an increase of the CPU effort, and viceversa.

A parametric batch procedure allows the creation of different geometrical models, the mesh generation and the CFD analyses of the blades in an automatic way.
A series of preliminary CFD simulations is planned and a screening is performed in order to build an input-output database.
ANN coefficients for the two layers are calculated by the optimizer. A MOGA algorithm investigates runs with further CFD "Virtual" analysis, exploring the space of possible solutions on the ANN. Basically a virtual optimization of the cooling system is carried out without further CPU expensive CFD analysis.
The best virtual solutions are selected and the ANN virtual solutions are validated by a "real" CFD analysis.



More accurate Neural Nets can now be estimated with a larger database. The virtual optimization can be executed again and new and more performing designs can be found. This procedure is repeated till the desired convergence to the set of optimal solutions is achieved.

Finally a layout of tip cooling nozzles is found by the optimizer and validated by a CFD analysis. The final design chosen proved to yield the same heat transfer performance with a reduction of approximated 16% of the cooling air required. Hence we can conclude that a remarkable increase of performance of 16% is obtained thanks to an innovative complete CAE design process with CFD parametic models evolved by optimization algorithms.

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