Optimisation methodologies applied to the design of a gas turbine cooling system

Avio - Ing. Daniele Coutandin
Technical Department

Università degli Studi di Firenze - Ing. Simone Taddei
Dipartimento di Energetica

EnginSoft - Ing. Massimo Galbiati – Lorenzo Bucchieri

Universita' degli Studi di Trieste – Ing. Francesco Pinto
DINMA

Introduction

- Design optimisation techniques are a new frontier in engineering planning and can give a relevant improvement to the development time and design quality.

- AVIO Group has began some projects in order to verify the capabilities of modeFRONTIER coupled with its own software and methodologies and applied to turbo-machinery problems.

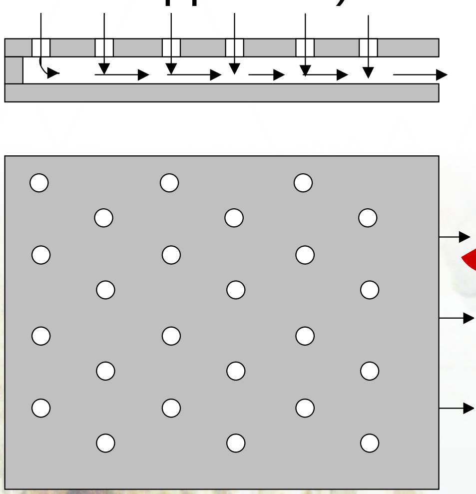
- The cooling systems of turbine blades use a percentage of the compressed air that cannot so be used in the main engine thermodynamic cycle. The reduction of this percentage, without decreasing the cooling effectiveness, would grow up the whole engine performances

Avio project - cooling design optimisation

In the aero-thermal context the project is divided into three steps:

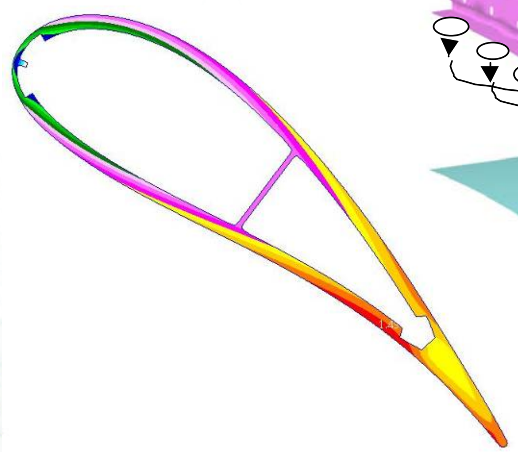
Step 1

Optimisation of an impingement cooling system for a turbine blade (one-dimensional approach)



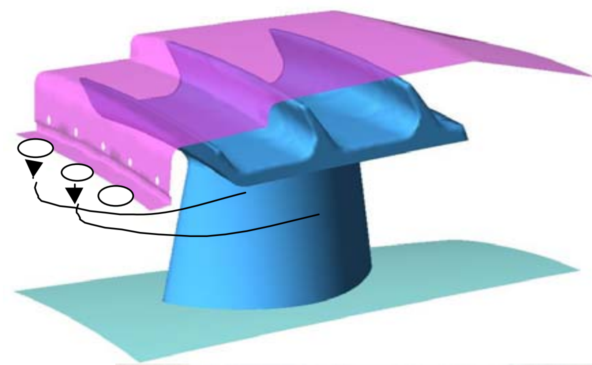
Step 2

Whole turbine blade optimisation and robust design



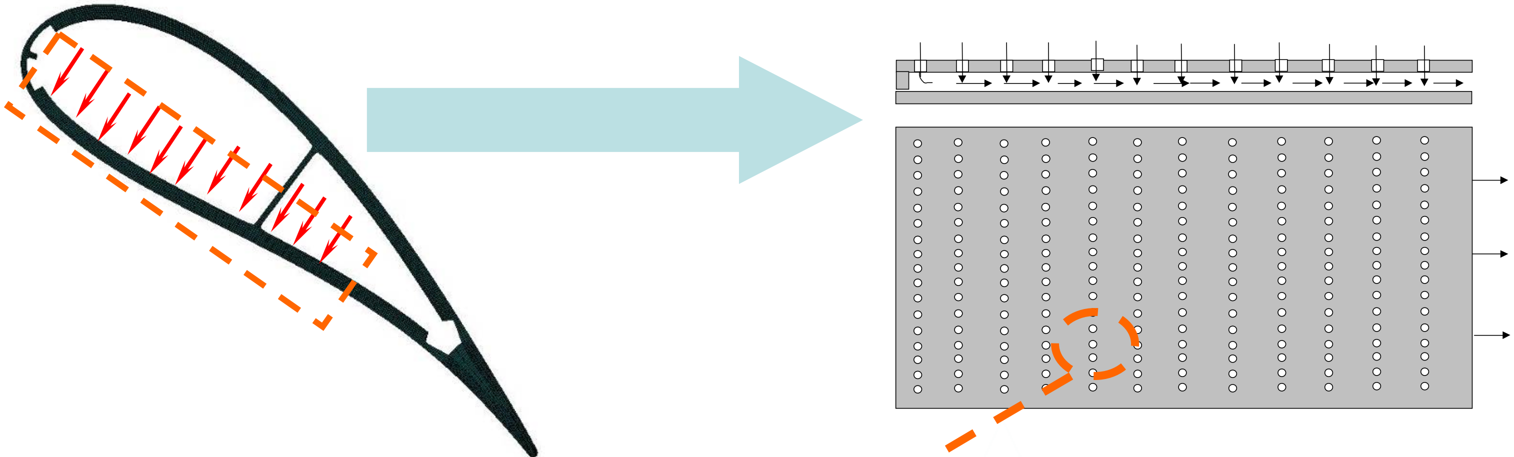
Step 3

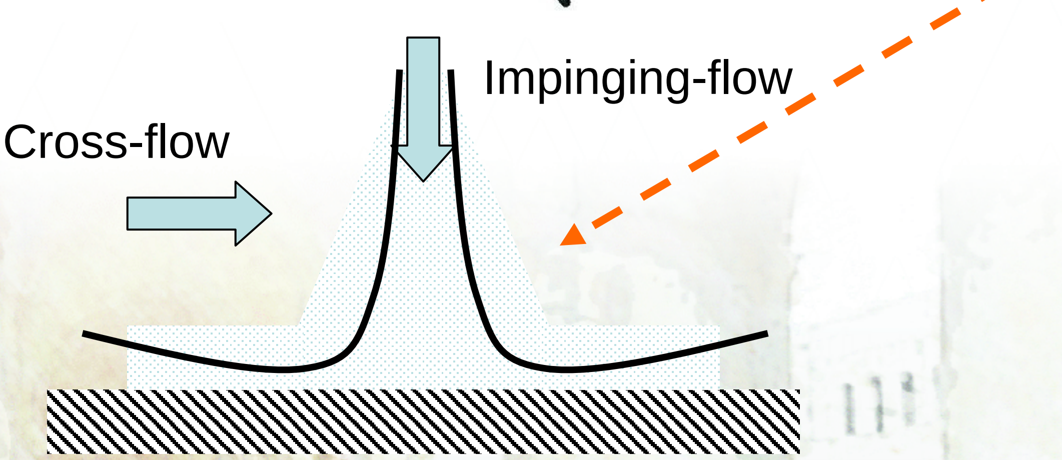
Turbine blade cooling with CFD



Test description

The geometrical configuration of the holes of an impingement cooling system has to be optimised





- Simplified geometry
- Cross flow
- Non linearity

Test description

• The fluid-dynamic behaviour is computed using 1-D correlations (SRBC code developed by the University of Firenze)

INPUT:

• Inlet total pressure

• Inlet total temperature

• Outlet pressure

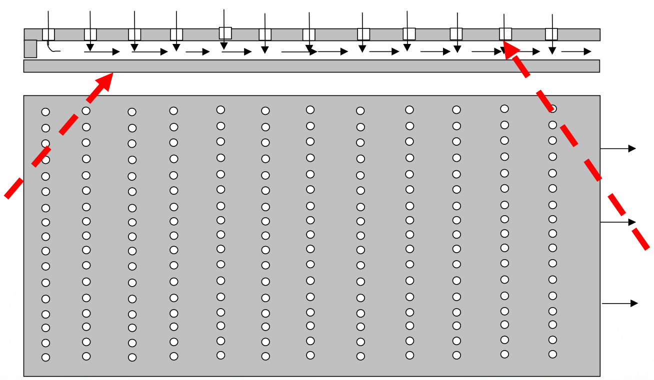
• Geometrical data

OUTPUT:

•Total air mass flow

• HTC distribution on the blade surface

• Pressure distribution on the internal channel



Internal blade surface

Impinging jet

BASE DESIGN:

• D = 0.385mm, constant

• Axial pitch =4.25 mm, constant

Test description

modeFRONTIER project definition

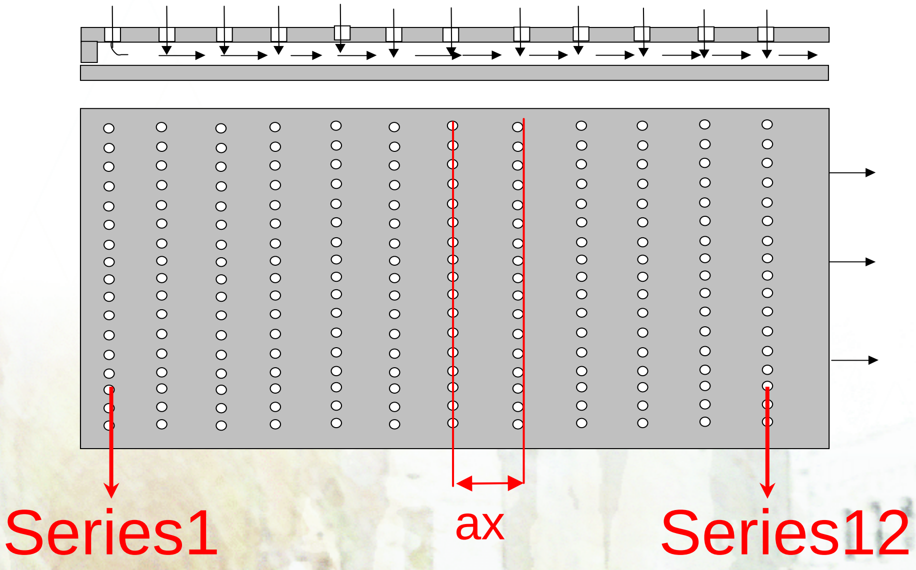
OBJECTIVES:

1. Increase the mean value of the heat transfer coefficient on the blade surface → 1. Improved cooling performance
2. Minimize the total cooling air mass flow → 2. Whole engine performance
3. Reduce the HTC standard deviation on the blade (uniform HTC distribution) → 3. Avoid critical gradients impacting on components life

Test description

INPUT VARIABLES: 12 Series of jets, each series is defined by:

- the diameter of the holes: $$0.3mm \leq D_i \leq 0.47mm \qquad i = 1,\ldots,12$$
- the axial position: $$5 \leq \left(\frac{Axial\_pitch}{Diameter} \right)_i \leq 15 \qquad i = 1,\ldots,12$$



The system is defined by 24 INPUT VARIABLES

Some geometric constraints has to be applied

Methodology

Two different approaches were considered in order to verify the possibility to reduce the number of parameters, with the minimal loss of flexibility.

Approach A:

- 24 input variables
- 12 independent diameters and 12 independent axial positions
- General approach
- Large number of runs to find out the optimal solution

Approach B:

<u>Reduced number of variables:</u>

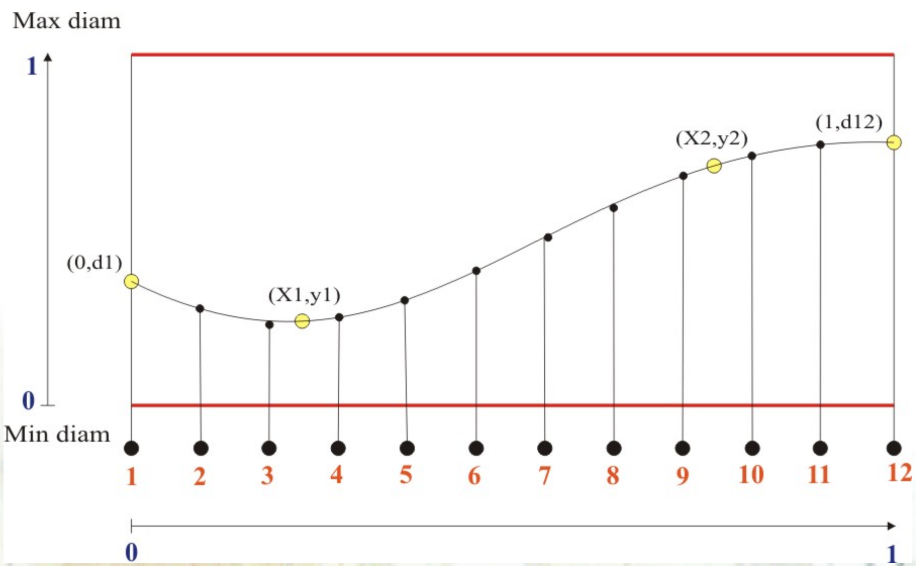
- 10 input variables
- Interpolating functions for the diameters and holes distributions
- Not general approach
- Reduced number of runs

Methodology

Approach B - Variables reduction

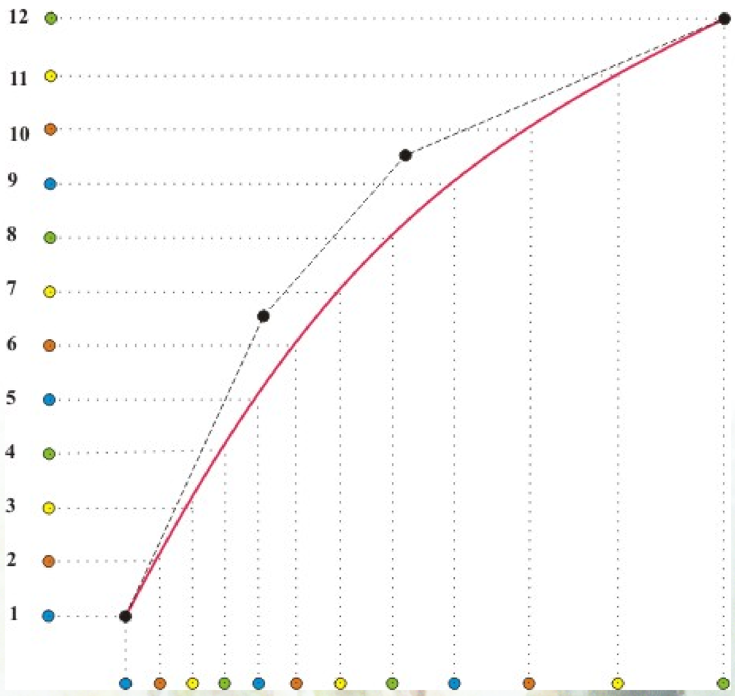
DIAMETERS

- Third degree polynomial interpolation
- Normalized scales
- 6 variables



AXIAL POSITION

- Third degree Bézier curve: Parametric approximation of 4 control points
- 4 variables



Methodology

Approach A

Step 1	DOE Sobol	3000 runs	First investigation of the system
Step 2	Optimisation (3 objectives) • Maximum HTC • Minimum air mass flow • Minimum HTC deviation	5000 runs MOGA	System global response (Pareto frontier)
Step 3	Optimisation (1 objective) • Minimum air mass flow • HTC and its distribution bond to the base design	1500 runs MOGA	Optimal solution
		1000 runs Simplex	Optimal solution

9500 MOGA

We want to reduce the air mass flow without decreasing the cooling effectiveness

Methodology

Approach B

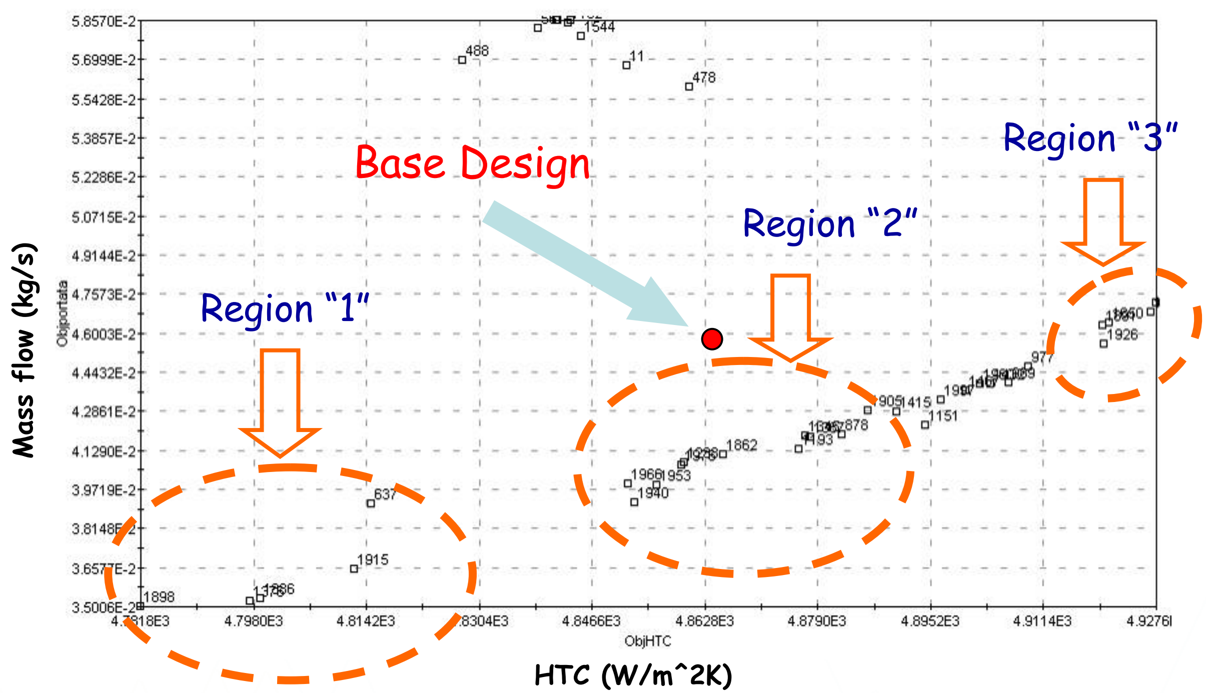
Step 1	DOE Sobol	60 runs	Initial MOGA population
Step 2	Optimisation (3 objectives) • Maximum HTC • Minimum air mass flow • Minimum HTC deviation	3000 runs MOGA	System global response (Pareto frontier)
Step 3	Optimisation (1 objective) • Minimum air mass flow • HTC and its distribution bond to the base design	1500 runs MOGA	Optimal solution

Total 4560 runs

We want to reduce the air mass flow without decreasing the cooling effectiveness

Results

For both the approaches (A and B) the Pareto Frontiers are shown: there are no remarkable differences.



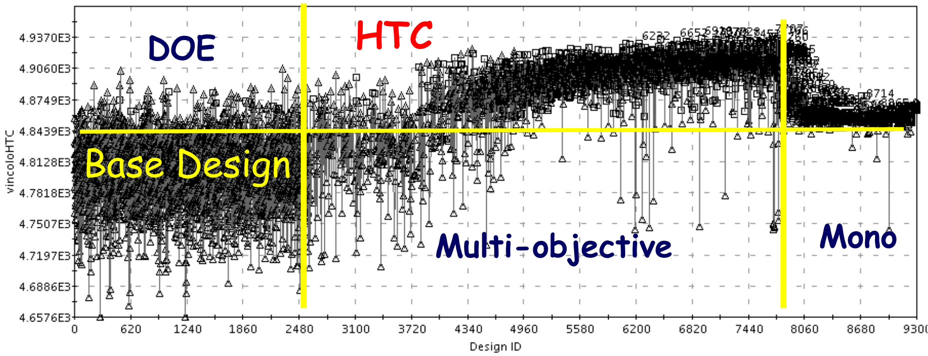
- Region 1: Great mass flow reduction, but HTC decrement
- Region 2: Mass flow reduction and HTC at the same level of the Base Design
- Region 3: Base Design mass flow and increased HTC

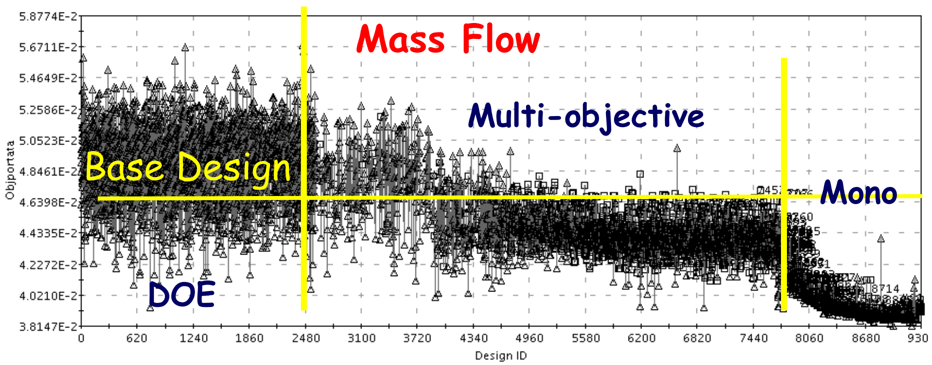
Results

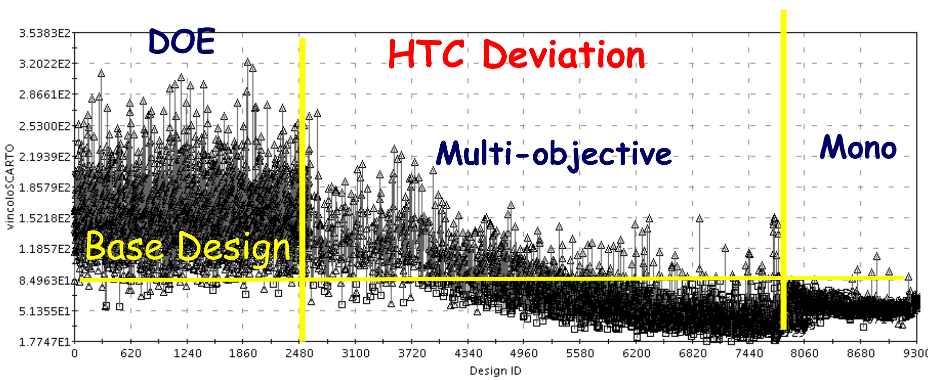
History chart

TCN CAE 2005
International Conference on CAE and Computational Technologies for Industry

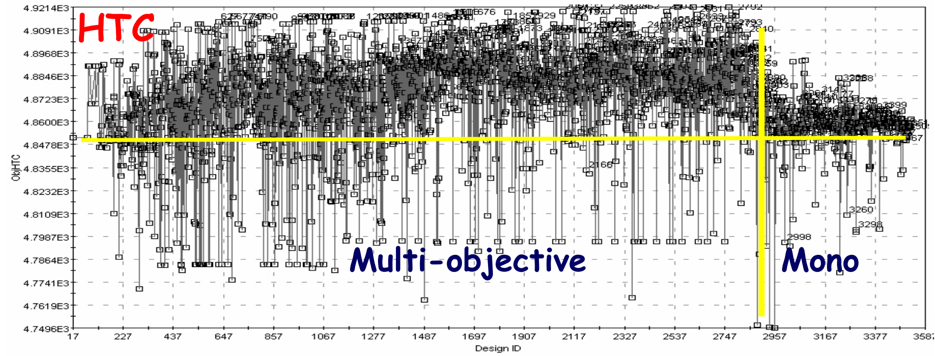
Approach A

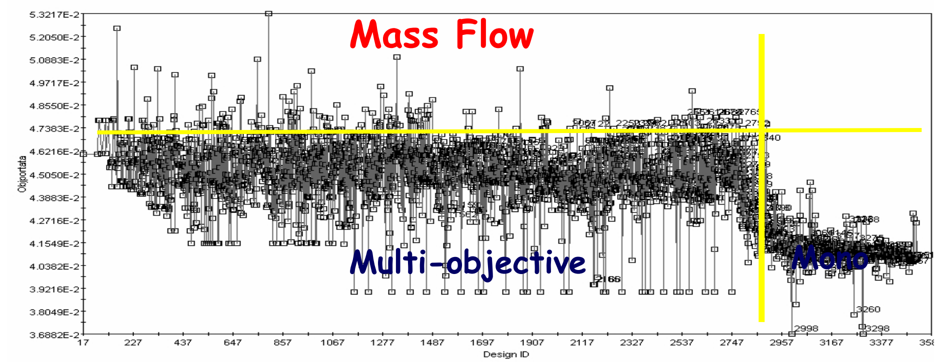


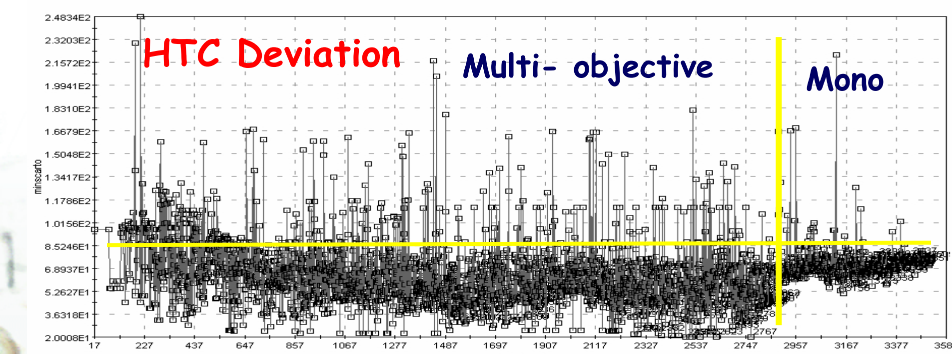




Approach B







Results

	BASE DESIGN	APPROACH A Best design (Moga)	APPROACH B Best design (Moga)
Mass flow [kg/s]	4.6211E-2	3.8635E-2 -16.4 %	3.8048E-2 -17.7 %
HTC [W/m^2/K]	4856.4	4856.6	4857.3
Deviation [W/m^2/K]	83.7	52.7	38.1

- Total Mass Flow: -17%
- No HTC reduction
- More uniform HTC distribution

We have the same cooling effectiveness with a reduced mass flow, hence the whole engine performance has been improved

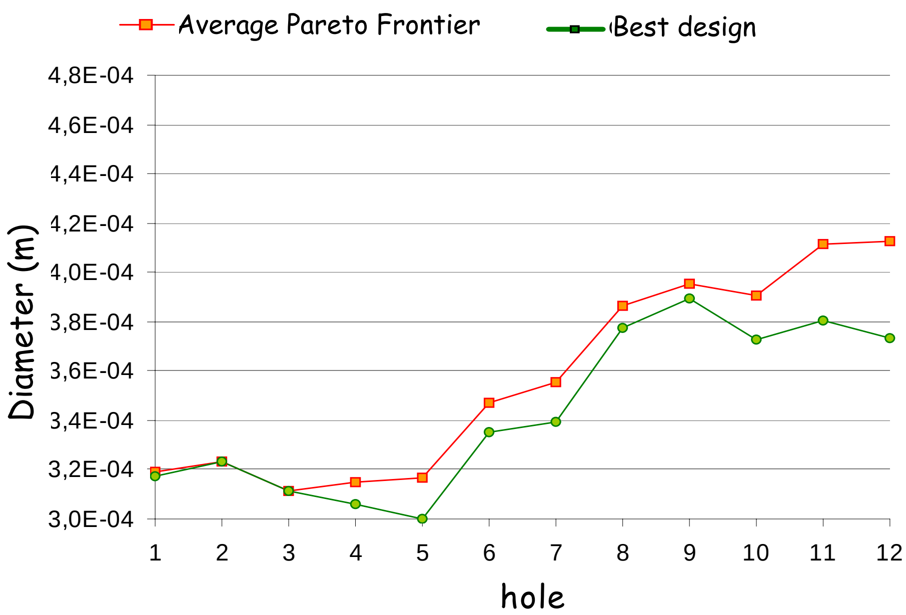
Results

TCN CAE 2005
International Conference on CAE and
Computational Technologies for Industry

Best design: diameter distribution

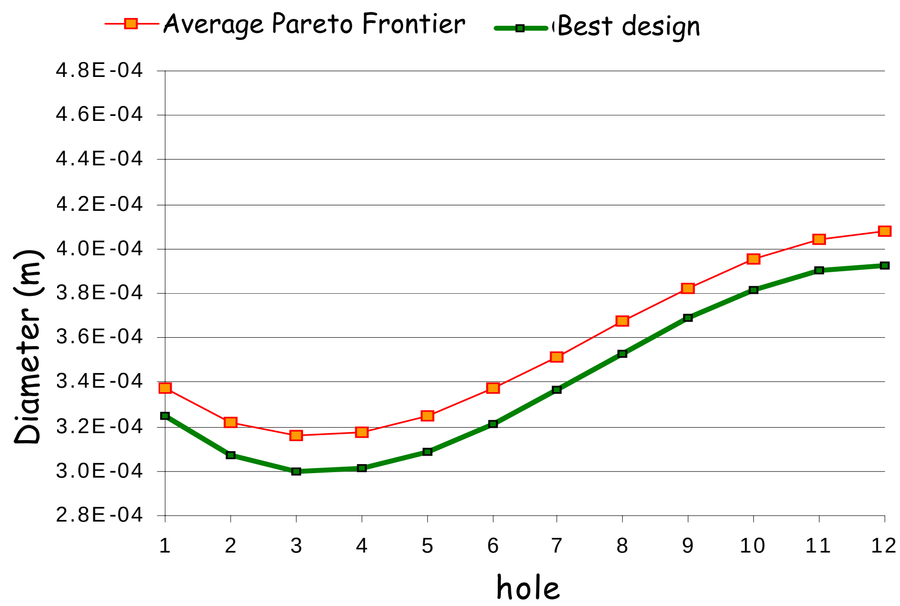
Approach A:

12 independent diameters



Approach B:

Third Degree polynomial interpolation



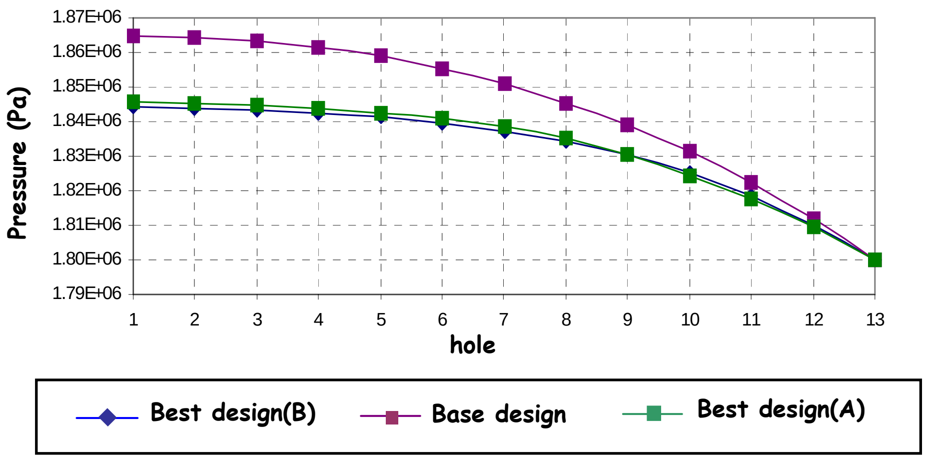
The same behaviour has been found both for the Best Design and for the Designs on the Pareto Frontier with different approaches

Results

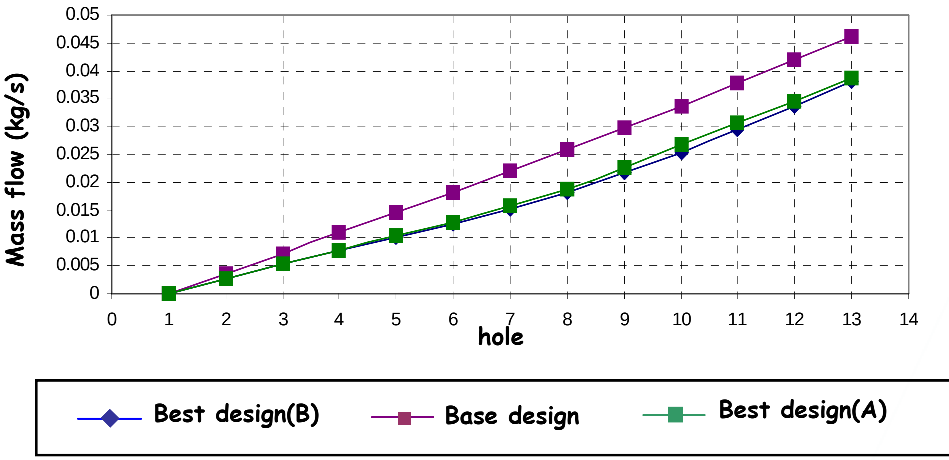
Best design analysis

TCN CAE 2005
International Conference on CAE and Computational Technologies for Industry

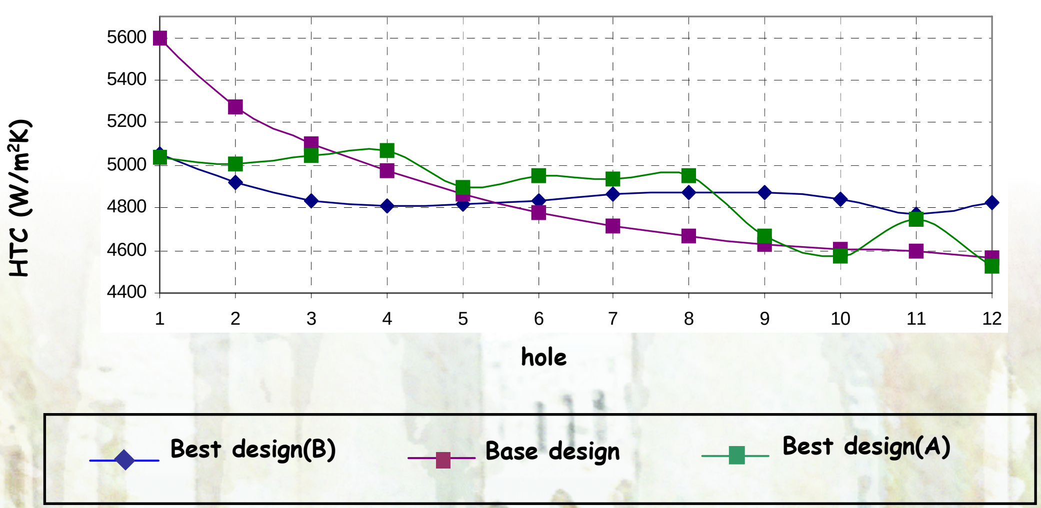
Duct static pressure (Pa)



Duct total mass flow



Duct HTC distribution



Performance of the new design process versus old design process

	old design process	new design process
human work time	2 days	1 day
Analysis time (hardware/software)	0.5 days	5 days
number of configurations compliance to the mandatory limits	10	500
number of configurations compliance to the desirable limits	0	100

Decision for best configuration is easier and automatically driven by the modeFrontier Decision Making Tool

Conclusions and future activities

• Optimisation techniques have been successfully applied to the design of a gas turbine component.

• The efficiency of an impingement cooling system has been considerably improved.

• The test demonstrates a good flexibility of modeFRONTIER linked to Avio computational codes

• Different approaches to the problem have lead to the same type of solution

FUTURE ACTIVITIES:

• The simplified method (with a reduced number of variables) will be applied to the heat transfer optimisation of a complete blade section

•.modeFRONTIER will be tested also for 3-D CFD problems.