Collaborative engineering process for multidisciplinary optimization of a gas turbine component

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1. Abstract

Today manufacturing companies are more and more often characterized by a growing product and processes complexity. Projects needs the participation of a pool of companies that have to collaborate in a multidisciplinary and integrated way following a defined PLM strategy.

These challenges are meant to introduce a new way of working, based on innovation and global collaboration, both internally among different disciplines and externally between operations, administration, and maintenance and its suppliers. The development engineering department works with a know-how based on models algorithms and data coming from different key-disciplines as aerodynamics, heat transfer, mechanical integrity, combustion, materials, etc. For this reason the use of these topics in a multi-disciplinary process is often difficult due to the incompatibility of notation, informatics languages and IT platforms.

Here-hence the need of defining and managing the simulation processes and associated data so that they can always be tracked, traced, referred to the product requirements and available by all the users operating in network on different disciplines involved in the product design.

The target for the introduction of a collaborative engineering process is to manage, improve and accelerate the multidisciplinary simulation analysis, in order to obtain the best product in terms of technological innovation, performance and quality since the early design conception. The introduction of collaborative engineering process is the key to meet the targets of a competitive market like the energy field.

This paper is focused on a gas-turbine blade where both thermal and the mechanical disciplines are involved. The model of the complete process, implemented in SEE-Fiper environment and involving all the calculation tools is described. The results obtained considering many optimization variables are reported.

2. Introduction

Ansaldo Energia (AEN), company of Finmeccanica Group, is the Italy's leading producer of thermoelectric power plants including process, mechanical, civil, installation and start-up engineering. The production centre is split into three product lines: gas turbines, steam turbines and generators.

The Product Lifecycle Management is a strategic approach aimed to the management of the information, processes and resources in order to support the product life cycle, beginning from its conception, through the design, manufacturing, until sales and service.

Through the years the company has dealt topics on PLM Solution starting from design, to configuration management, classification and product configuration, document management with the future goal of extension of PLM platform on MRO and In-Service management. If all applications and business areas were based on a single platform, they would give with many benefits in terms of economic and organizational efficiency: managing 3D CAD data with related product structure and product configuration, integrated with change and configuration management, CAM data integrated with engineering data bringing to the production area all relevant information to operators through "totem" data visualization 2D, 3D, notes, production information etc.

One of the most important phase of the PLM Project is the implementation of the manufacturing data management and the integration with ERP.
One of most relevant requirement of turbomachinery industry is the issue of having to cope with manufacturing technical data spread in non-integrated multiple systems resulting in difficulty in the reuse of data and lack of structured validation processes. After the implementation a controlled and structured management system for data and related processes has been delivered to Manufacturing: Routing cycles, Methods, Documents, Tapes, Tools, Tool assemblies, Equipments, Work Places, Specs are now all integrated and interrelated into a single source of managed knowledge.

Another important task in PLM project is the simulation data and design results management.
With this in place AEN has now a truly collaborative managed environment to control and distribute knowledge across the entire enterprise.
Then this involves an integrated approach based on a methodology of collaborative work and team organization starting from the engineering processes definition.

The role of the Engineering during the conception phase of a new product is crucial to achieve success over the whole lifecycle process.

The AEN PLM project is started in Development Engineering Dpt. since it has gone from the engineering's organization structured in disciplines, e,g. Centres of Excellence, to one where the teams operate in a multidisciplinary context and the turbomachinery components are the focus of the process design.

In general, there are two aspects that characterize the engineering's:

- the know-how in the form of models, algorithms, tools for the simulations, data coming from the various disciplines: aerodynamic, heat transfer, materials, mechanical integrity, combustion, etc. Often, the exchange of data is not agile because of the incompatibility of the concepts, differences in notations, implementation languages, platforms and sometimes the conflicts among the operators.
- the processes: generating a large amount of information/data/simulations and for this reason there is the need to improve and accelerate the exchange of data, that is able to operate in an environment of Collaborative Engineering.

Hence the need to define and to manage the processes and the design data so that they can always be reachable, secure, accessible to all the users operating in the network on various disciplines, in order to obtain the best product in terms of upgrade, performance and quality.

To define this new methodology three pilot projects on the data and processes management and optimization have been carried out. This project consists of introducing:

- A **process management** system, that will allow to all the multidisciplinary team experts to work using shared design procedures, following an established design activities flow, applying shared tools and simulation database. It makes also possible the automation of the design processes and, subsequently, carrying out **multidisciplinary & multi-objective optimization**.
- A **simulation data management** system, that will allow to ensure the basic properties, such as:
  - *Uniqueness*: data are reliable, unique and officially issued
  - *Traceability*: data are located in the simulation process. Every user knows anytime the data road map bottom-up or top-down, who produced the data, the creation date, the used software tools and the issued release.
  - *Sharing in real time*: data are available in the last version at anytime.

3. Project Description

The introduction of the PLM allows the Engineering to gather and manage reliable simulation data and processes of all the key disciplines in the design activities and to use them in best way.
Thereby, this methodology enables to improve the effectiveness in the whole design process as well as to ease the knowledge communication in the work teams among who have issued the data and who have to use them.

The aim of the proposal is to bring in Engineering a high degree of innovation through the PLM in order, on the one hand, to manage, upgrade and speed-up the multidisciplinary design processes focused on the product innovation while, on the other hand, to make the best use of the synergies amongst the team works, the experiences and the skills of the users.

So, in order to achieve the previous results the following few specific requirements have been specified:

- the capitalization of the technical know-how and know-why on the key-disciplines
- the development of an ICT environment for the collaborative engineering processes
- the simulation data management
- the management and automation of the process flows
- the mono- and multi-objective optimization of the design solutions

The introduction of the PLM in Development Engineering must be considered useful in order to meet the competitive marketing in the energy field.
To do it in the energy industry, and in particular in **Ansaldo Energia**, three pilot projects have been launched on the gas turbine product development, each of which committed to a multidisciplinary team and focused to a benchmark of the design in collaborative environment.

The outline of the three pilot projects is shown in Fig.1.

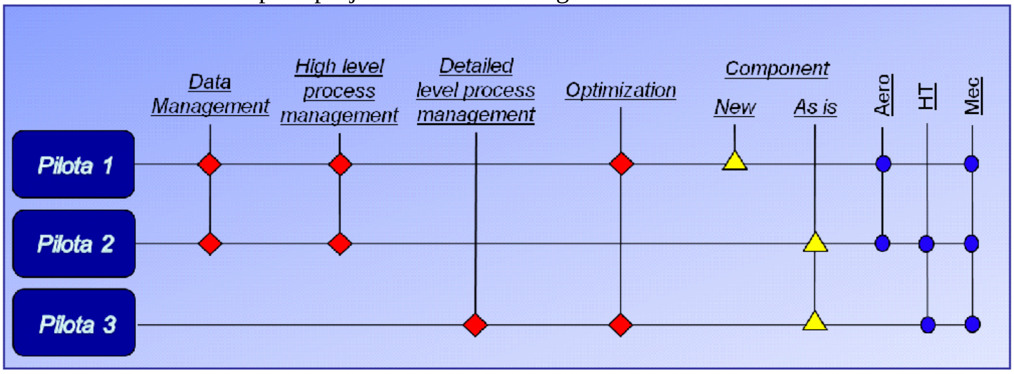

Fig. 1 - Outline of the Pilot Projects

The pilot projects are planned in order to cover all the topics of interest, in terms of data and process management, optimization, and to include both the existing components (*as is*), on which the *re-engineering* is performed, and new design components *(new).* The involved components are compressor and turbine blades.

The pilot projects are:

– **Pilot 1**: data management and optimization process on airfoil of a 'new design' of a compressor blade
  Involved disciplines: aerodynamics and mechanical integrity
  Target: process and data management of a compressor blade
– **Pilot 2**: data management of an existing turbine blade 'as is'(CAD 3D models already available in the repository area)
  Involved disciplines: aerodynamics, heat transfer and mechanical integrity
  Target: data management of a gas turbine cooled blade
– **Pilot 3**: optimization of an existing turbine blade 'as is'
  Involved disciplines: heat transfer and mechanical integrity
  Target: optimization of the internal cooling design

On the current stage the main phases of this initiative are here below listed:

- investigation in literature and analysis of proposed methods
- capitalization of the knowledge through the drafting of the Design Practices
- design software tools census and their interaction
- installation of a high performance hardware environment
- acquisition and installation of commercial software tools for the collaborative engineering
- training on the job of the multidisciplinary working teams
- development of design real cases in the collaborative engineering environment (pilot projects)

This paper is focused on the description of the activities carried out for the pilot project 3 (multidisciplinary optimization of a gas turbine component).

3.1 Multidisciplinary optimization of a gas turbine component

The project concerns a multidisciplinary process aimed to a multi-objective optimization of a gas-turbine blade.

The blade configuration is characterized by an air-cooled airfoil protected by a thermal barrier coating (TBC) over the outer side.

The internal side of the airfoil is done of three channels along all its length to feed-up by the cooling air in order to reduce the metal temperature. Special provisions (ribs) are applied on the surface of these channels in order to increase the heat transfer.

A special calibrated plate at the bottom of the blade governs the air mass flow inside the airfoil.

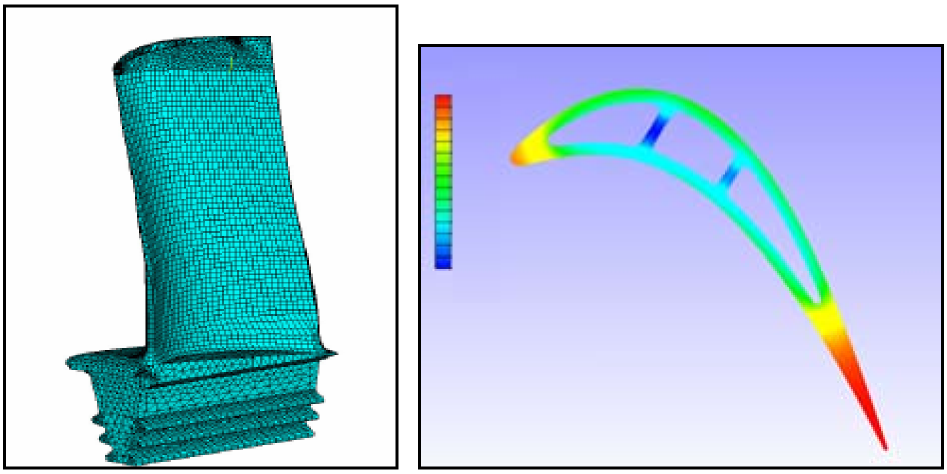

Fig. 2 – Blade & Section Blade

The disciplines involved in the analysis are the heat transfer and mechanical integrity.

The activities carried out are:

- ✓ The creation of a automated and repeatable procedure for the thermo-mechanical calculation.
- ✓ The implementation of macro for the calculation and the post-processing of the FEM results.
- ✓ Identification of the optimizated solutions.
- ✓ An approach to the distributed calculation.

The following an example of process done:

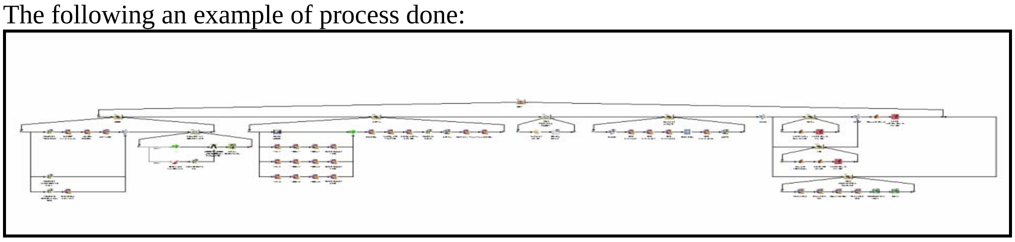

Fig. 3 – Process Flow

The process is divided in four parts:

- 2D thermal analysis
- 3D thermal analysis
- 3D thermo-structural analysis
- Post-processing of results

With this automated procedure was launched in a single run the thermal calculation 2D, the thermal calculation 3D, the structural calculation and make the post-processing of the results, varying in a simple way some parameters at the beginning of the process.

This project provides the integration of more processes iSight distributed on more machines; in order to optimize not only the result (to find a blade more efficient) but also the resources company avoiding so overloading a single machine.

On this process has been carried a DOE (design of experiment) analysis, composed of 256 run and, subsequently, was made an optimization from an response surface obtained from the DOE analysis.

To make these analyses has been identified input parameters in order to change them and to see their influence on the parameters of output and to make an optimization on these parameters.

The following table show the input/output parameters:

INPUT PARAMETERS	***OUTPUT PARAMETERS***
- Cooling air mass flow	- 2D thermal maps
- TBC thickness	- 3D thermal maps
- Position Rib (channel 1) (R1)	- 2D stress maps
- Position Rib (channel 2) (R2)	- 3D stress maps
- Position Rib (channel 3) (R3)	- Safety margin
- Height Rib	- Creep time
- Footstep Rib	- Damage to LCF
- Inclination Rib	

Tab. 1 - Input/Output parameters

3.1.1 2D Thermal Analysis

In this process is carried out the 2D thermal analysis, obtaining the thermal maps of sections of the blade.

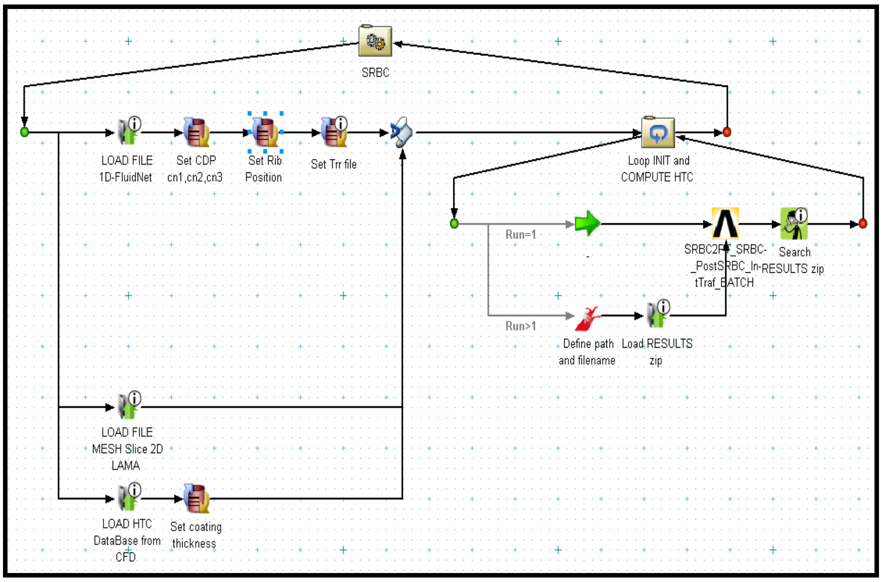

Fig. 4 - 2D Thermal Analysis

INPUT	***OUTPUT***
- Mesh slices 2D	- 2D thermal maps
- HTC values	- Flow network result
- Boundary temperatures	- 2D HTC distribution
- Thermal material properties	
- TBC thickness	
- Plates section	
- Cooling flow network	

Tab. 2 – I/O 2D thermal Process

3.1.2 3D Thermal Analysis

This process is carried out 3D thermal analysis, obtaining the 3D thermal map of the blade. The boundary conditions are passed by 2D thermal analysis.

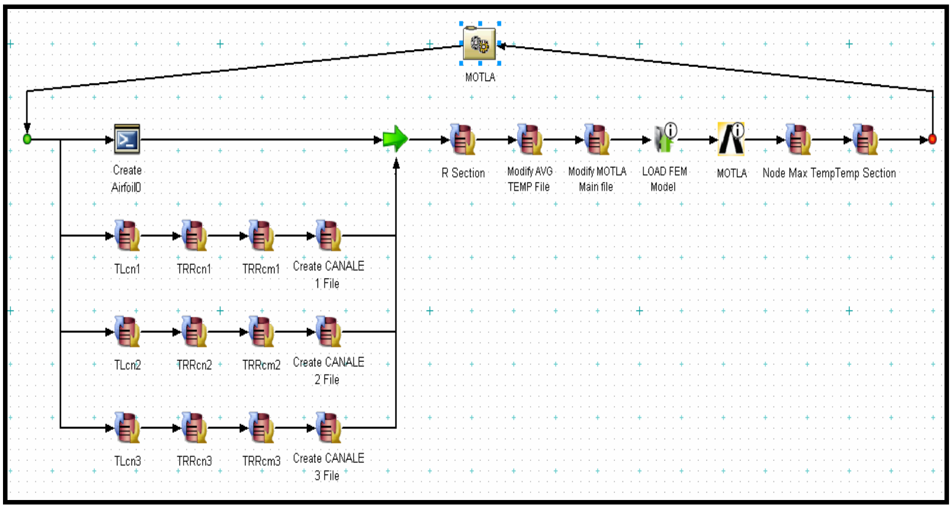

Fig. 5 - 3D Thermal Analysis

INPUT	***OUTPUT***
- 3D mesh - HTC on cooling cannel from 2D analysis - HTC values on external profile - Temperature on cooling cannel from 2D analysis - Temperature on external profile - Fixed HTC on platform and fir tree - Cooling flow network	- 3D temperature maps

Tab. 3 – I/O 3D thermal Process

3.1.3 3D thermo-structural analysis

This process is carried out 3D thermo-structural analysis of the blade, applying various structural loads (pressure, centrifugal force, etc.) and the map of the temperatures obtained with 3D thermal analysis, obtaining the 3D map of stress on the blade.

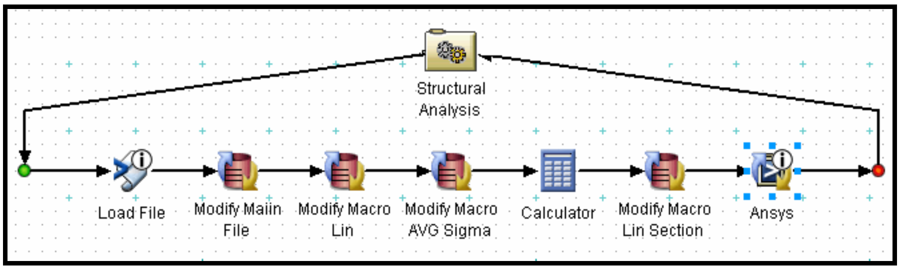

Fig. 6 - 3D Thermo-Structural Analysis

INPUT	***OUTPUT***
- 3D mesh - 3D thermal Map (Thermal Load) - Structural material properties - Pressure load - Centrifugal load - Constraints	- Stress distribution

Tab. 4 – I/O 3D thermo-structural analysis

3.1.4 Thermo-structural post-processing

The thermo-structural post-processing is divided into three parts:
- calculation of the margin of safety
- calculation of the creep time
- calculation of the fatigue damage

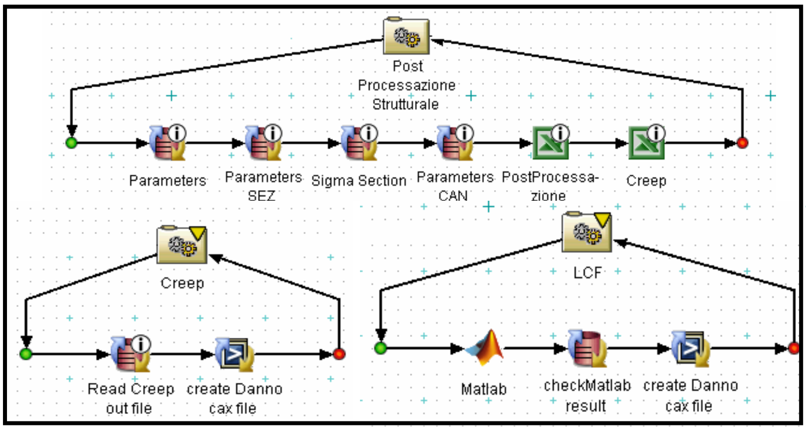

Fig. 7 - Thermo-structural post-processing

3.1.5 DOE analysis

The DOE analysis was achieved by varying the input parameters and combing them, thus obtaining an analysis composed of 256 run of the entire process.

The following shows examples of the results obtained from the analysis DOE:

- Sensibility analisys: percentage of individual variables of input on the variables output

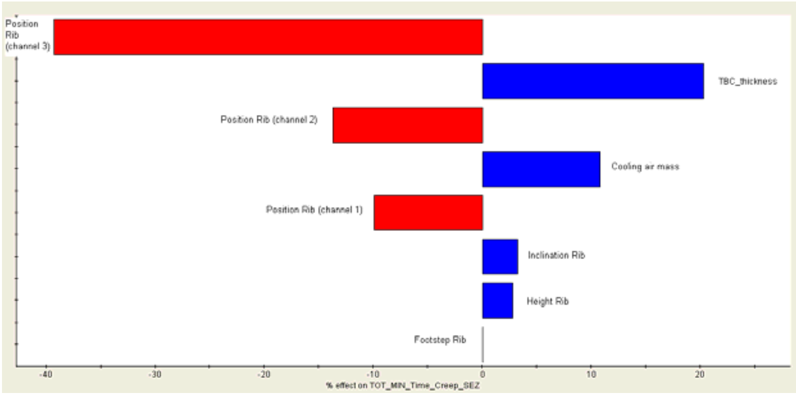

Fig. 8 – Creep sensibility analisys

- Response surface

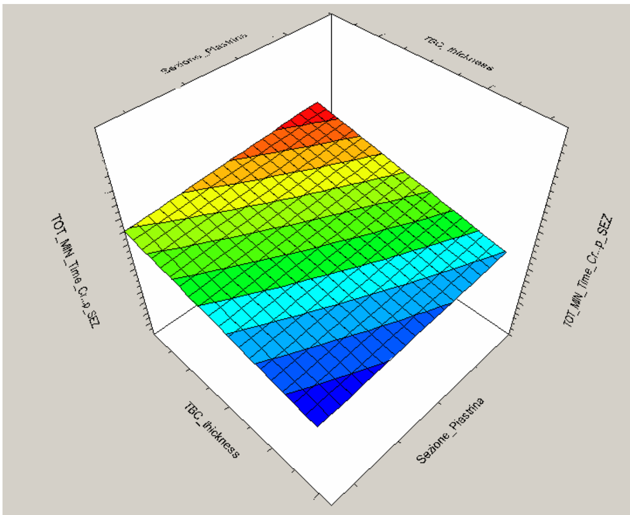

Fig. 9 - Creep response surface

3.1.6 Optimization and Results obtained

Consequence DOE analysis has been carried out an optimization with a genetic multi objective algorithm.

Following a table with the goals and constraints of the optimization and some image whit Pareto's front.

GOALS	***CONSTRAINS***
- Max. creep time - Min. fatigue damage - Min. Cooling air mass flow	- Safety margin > n

Tab. 5 – Goals/Constrains optimization

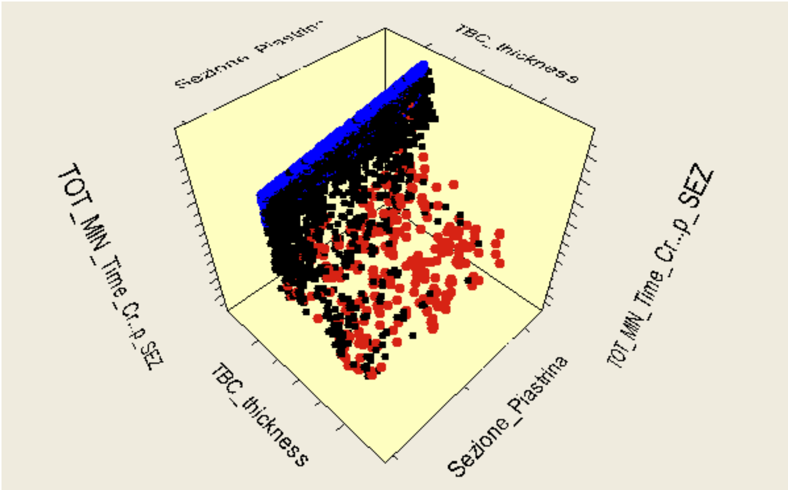

Fig. 10 - Optimization

The figure above represent with blue points the excellent cases that are part of the Pareto's front, with red points the cases that do not comply with the constraints and with black points the cases which are not part of the Pareto's front but comply with the constraints.

Observation of the front of Pareto were chosen some cases excellent and on them was carried out a new rigorous analysis to validate the results.
In figures following view the position of nominal case compared to the Pareto's front.

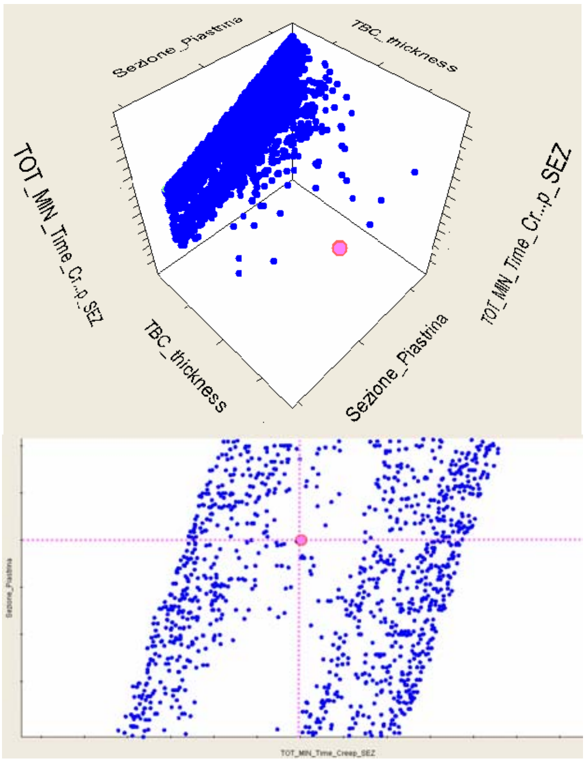

Fig. 11 - Pareto's front and nominal case

4. Conclusion

The implementation of the project leads to remarkable benefits in tangible and intangible assets.
The most observable profits are here in after listed:

- **Sharing of the Company Know-how:** This outcome is not easily measurable in terms of return of investment, even though it is definitely a key factor in a Company ever-growing. In particular, in the Development Engineering the know-how spreading is a crucial point in order to release rapidly new optimized design solutions.
- **Data Generation, Management, Traceability:** Be able to gather easily and clearly the information concerning analysis and reports previously carried out gives undoubtedly a relevant profit in terms of times reduction even in the future works. Essentially this benefit involves the adopted practices by the reusing both the design processes already implemented and the results already obtained.
- **Design Processes Standardization:** The generation of standard processes, made official and shared amongst the users, gives a profit in terms of time reduction due to their repeatability by the side of the users operating in network.
- **Optimization of the Design Process:** Tangible reduction in the computing times of the design processes is achieved by the improvement of the hardware platform, through a computing cluster driven by the standard processes, and by the implementation of optimization tools, based on the most updated optimization techniques.

Whereas then the blade's optimization were reached configurations in which, in the light of changes in the system of internal cooling and the TBC's thickness, you diminish the Cooling air mass flow and improving the blade's response to creep and fatigue.

5. References

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