modeFRONTIER: Successful technologies for PIDO

The acronym PIDO stands for Process Integration and Design Optimization. In few words, a PIDO can be described as a tool that allows the effective management of the design process and orienting it to the optimum. This kind of tool is becoming more and more important when designing a product as it assists engineers in overcoming the common error of giving priority directly to the product, rather than to the entire process. Although this is unfortunately a common problem, it has been recognized that anything that shortens the time from basic research through product test, process design and production will have an important influence on the overall project quality.

Moreover, many companies today take advantage of virtual prototyping rather than physical testing for the former is usually faster and less expensive. The combination between virtual prototyping and design process makes PIDO an emerging class of tools with the ability to revolutionize product development. The most complete and user-friendly PIDO tool available on the market today, is provided through modeFRONTIER and developed by ESTECO.

Multi-disciplinary design optimization

A multi-disciplinary design process is characterized by subsequent transformations and additions of details. A complete multi-disciplinary design process can be divided into several phases while receiving the contributions of many professional staff and different departments, trying to meet conflicting requirements at the same time. Each phase can be defined as a single module and each single module can be described as a finite group of tightly coupled relationships. These relationships can be under the responsibility of a particular individual or department and may have some variables representing independent inputs or dependent outputs. The single module of a design process usually appears as a “black-box” to other individuals or departments.

Engineers and other specialists are more inclined to push towards improvements of objectives relating to variables of their own discipline which they are able to control directly. In doing so, they usually generate unexpected side effects that other departments and disciplines have to take into account. In most cases, a side effect caused by another discipline generates a decrease of the overall performance. In short, this means that the optimal decision of a single department does not necessarily produce the global optimum of the design process. Roughly speaking, we can say that determining an optimal design within a complex engineering system requires analysis that accounts for interactions between several disciplines. A PIDO system may indeed support the design of complex engineering systems and of all subsystems. Moreover, a good PIDO tool such as modeFRONTIER, can help engineers in identifying all the relationships between mutually interacting phenomena. modeFRONTIER assists engineers to quickly investigate several design options, to analyze the influence of several reciprocally conflicting goals, and finally, to identify the most robust designs.

A software which really implements PIDO, has to face several complementary aspects globally:

1. The formalization and management of the workflow to treat in a flexible and dynamic way, processes of any complexity grade

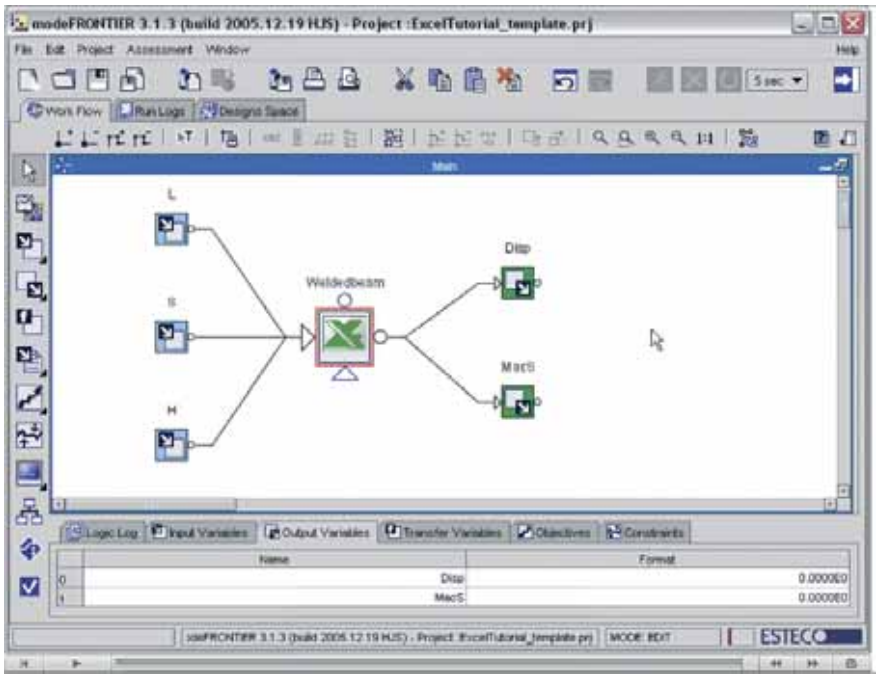

Figure 1: A movie frame from the website, describing direct integration between modeFRONTIER and EXCEL

2. A set of design of experiments and statistical tools to identify which parameters contribute most to the global performance
3. The set of methods, technologies and strategies for multi-objective and multi-disciplinary optimization
4. Meta-modeling and response surface methodologies (RSM)
5. Charts for visualizing the results for easy interpretation
6. The set of the so-called techniques for decision support which allow the orientation and the documentation of choices. From all of the optimal options, the design team must formulate a number of plausible designs.
7. Advanced probability and statistical methods for reliability and uncertainties (design for six sigma)

As this list reflects, a PIDO tool is more a collection of technologies rather than a single software. modeFRONTIER provides all these technologies within an excellent and modern graphical user interface.

modeFRONTIER: a collection of technologies

This section illustrates the technologies involved in a complete PIDO and describes how the same are implemented in modeFRONTIER.

The workflow

The formalization and management of the logic is well guaranteed by modeFRONTIER that allows easy coupling to almost any computer aided engineering (CAE) tool whether commercial or in-house. The formalization of the logic and its workflow cannot be set aside from the integration of the required tools and should be associated with information technology aspects. Indeed, modeFRONTIER is able to deal with processes of any complexity and network organization in a flexible and dynamic way, in the context of distributed and parallel engineering and in presence of local subsystems. modeFRONTIER provides an easy-to-use environment which allows product engineers and designers to integrate and drive their various CAE tools, such as CAD, finite element structural analysis, computational fluid dynamics (CFD) software as well as other multi-disciplinary software. For this purpose, ESTECO has established partnerships with different independent software and hardware vendors. Through these alliances, ESTECO always delivers state of the art industry applications and solutions for multidisciplinary design optimization and system integration. The partnerships include, among others, the ABAQUS Software Alliance, AMESim Partner, ANSYS ESP Program, CD-adapco Software Partner, CST Cooperation Partner, Flowmaster Partner, Linux Networx (LNXI) Partner, as well as the MathWorks Connection Program. By providing a seamless integration with many programs, modeFRONTIER assists in embedding its optimization technology easily in daily work performing both multiple repetitive and concurrent simulations.

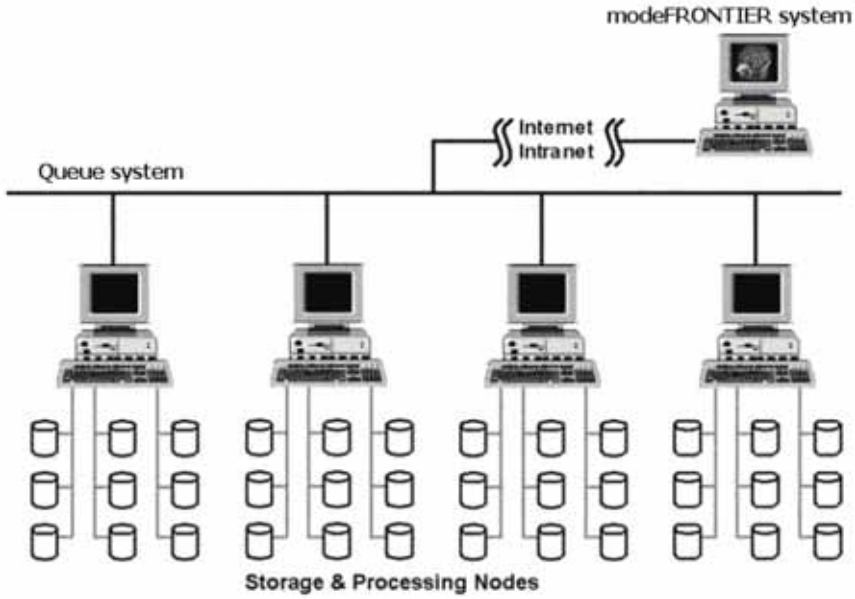

Figure 2: modeFRONTIER coupled with a queuing system, a mixed architecture computer pool can be used to run in parallel several analyses and exploit distributed computing resources

The link "http://www.esteco.com/direct_integration.jsp" provides several examples of how to directly integrate software within modeFRONTIER. Particularly, two interesting animated samples demonstrate how to construct a direct integration with EXCEL and MATLAB in a few steps.

The link http://www.esteco.com/software/queue.jsp shows an example of how to integrate the most famous queuing systems (e.g. Condor) in the modeFRONTIER environment. When using a queuing system, the workflow describes the operation necessary to evaluate a single design. Actually, the whole analysis, or a part of it, can be submitted to a queuing system to be executed in a remote computer. Whenever more than just one computer or CPU is available in the queuing system, more than one design can be executed simultaneously. Moreover, by using a queuing system together with modeFRONTIER, a mixed architecture computer pool can be used to run in

parallel several analyses exploiting a large collection of distributed computing resources thus helping scientists and engineers to increase their computing throughput.
modeFRONTIER does support engineers in managing the IT infrastructure. modeFRONTIER can run software regardless of whether or not it is installed on links together with all CAE tools in a reliable chain-tool.

Design of experiments and statistical tools

The design of experiment (DOE) tool provided in modeFRONTIER can assist in preparing and executing a given number of experiments in order to maximize knowledge acquisition.

When using modeFRONTIER and its methods, users can find several statistical charts and tests, such as, the analysis of variance (ANOVA), Hartley and Bartlett test, Box-Whiskers chart, the multi-range test that shows which means are significantly different from others, a table of means displaying the mean of each along with its uncertainty intervals.
modeFRONTIER provides a "statistics summary" which contains uni-variate descriptive statistics of a parameter along with simple statistical charts and tables. Among others, it contains a frequency plot, probability density and cumulative distribution function charts, as well as a quantile-quantile plot and distribution fitting.

MDO tools

The third item in the list is the element that distinguishes modeFRONTIER from all the other PIDO tools. This element refers to multi-objective and multi-disciplinary optimization (MDO). It is very important to understand the peculiarity of this approach. As the concept of MDO is of great importance, we provide following a brief summary for the completeness of this article.
It is important to recall that the optimum in multidisciplinary contexts with several and often conflicting objectives is not limited to the search for a single absolute extreme of a utility function. This is due to the fact that no utility function is usually able to synthesize a complex phenomenon. With a multi-objective problem, the notion of "optimum" changes as the aim is to find good compromises rather than a single solution. Hence, a multi-objective optimization does not produce a unique solution but a set of solutions. These solutions are called Pareto solutions, the set of solutions can be called both "trade-off surface" or Pareto frontier (named after the economist Vilfredo Pareto).

The first step for a real-world multidisciplinary design optimization is the identification of this frontier. In order to identify the set of good solutions, it is necessary to use the proper algorithms that starting from tentative solutions, allow the evolution towards the optimum. There is not only a single method to solve this problem. The appropriate strategy though has to be verified and applied on a case by case basis, also in connection with the kind of variables considered. For this reason, modeFRONTIER provides a wide range of possible algorithms to choose from for solving different problems.

Moreover, it is possible to combine different algorithms to obtain some hybrid methods. With a hybrid method, we can try to exploit the specific

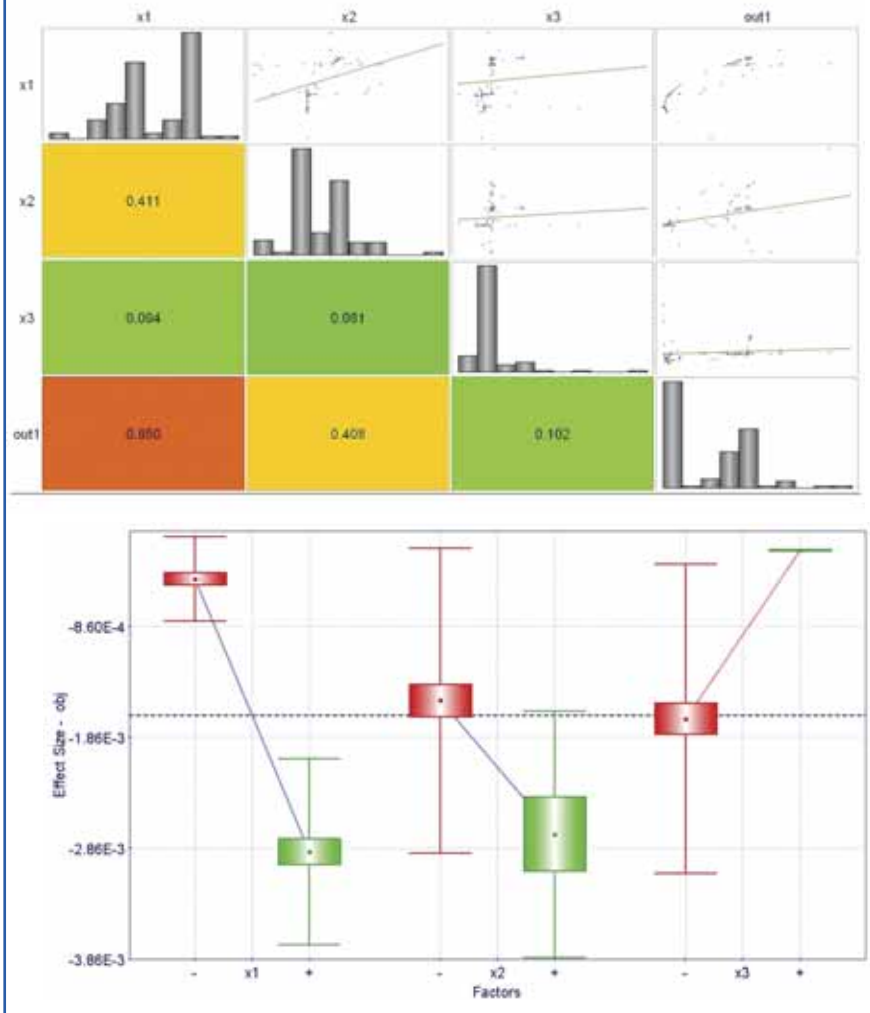

Figure 3: modeFRONTIER statistical chart

advantages of different approaches by linking more than one together. The most common used algorithms for MDO are metaheuristic methods for single and multi-objective optimizations. Metaheuristic methods represent a new type of methods that have been developed since 1980 and are now widely used due to their robustness. These methods have the ability to solve even difficult optimization problems in the best possible way.

Meta-modeling

When considering the advantages and perspectives of interpolation and regression methods and their use in modeFRONTIER, it is important to recall that the use of mathematical and statistical tools to approximate, analyze and simulate complex real world systems is now widely applied in many scientific domains.

These kinds of interpolation and regression methodologies are becoming common even in engineering where they are also known as Response Surface Methods (RSMs). RSMs are becoming very popular as they offer a surrogated model to be used when the original simulation is computationally heavy. A meta-model offers a second generation of improvements in speed and accuracy in computer aided engineering even in cases in which the intensive use of distributed computing resources is not helpful.

Visualizing the results

All PIDOs deal with the problems of visualizing results obtained from multi-disciplinary optimizations. These kinds of problems are usually linked to several dimensions of both, the input parameters and the objectives. modeFRONTIER contains methodologies and charts that simplify and reduce linear and non-linear multidimensional data to much more easy to read charts. Among the most modern tools for this purpose are the so-called Self-Organizing Maps (SOMs) which provide a simplified view of the complex high-dimensional data set. SOMs are particularly useful for data visualization and the classification of databases that appear to be excessively large for human evaluations. Based on the power of such data visualization methods, a new tool has been included into the new release of modeFRONTIER.

Furthermore, modeFRONTIER contains tools for hierarchical and partitive clustering, multi-dimensional scaling, principal component analysis as well as other tools and charts for multi-variate analysis.

Decision support tools

As any good MDO, modeFRONTIER has the ability to look for a complete set of non-dominated solutions. After having found some solutions for the multi-objective optimization problem, engineers obviously find it difficult to select from a given list of choices. Although many efficient solutions exist, only one or a reduced number of final solutions must be finally selected. Multi-Criteria Decision Making (MCDM) refers to the solving of decision problems that involve multiple and conflicting goals. MCDM provides a final solution which represents a good compromise acceptable to everybody involved. The Multi Criteria Decision Making tool provided in modeFRONTIER assists the Decision Maker in finding the best solution from a set of reasonable alternatives. It allows the correct grouping of outputs into a single utility function which is coherent with the preferences expressed by the user without the drawbacks of a weighted function.

Reliability and uncertainties

In real problems, the presence of uncertainties makes the traditional approaches for multi-disciplinary design optimization insufficient. The importance of controlling variability as opposed to just optimizing the expected value has recently started to gain attention within the engineering and scientific communities. Uncertainties in real problems are due to errors in measuring, or difficulties in sampling, or may depend on events and effects in the future that cannot be known with certainty (uncontrollable disturbances

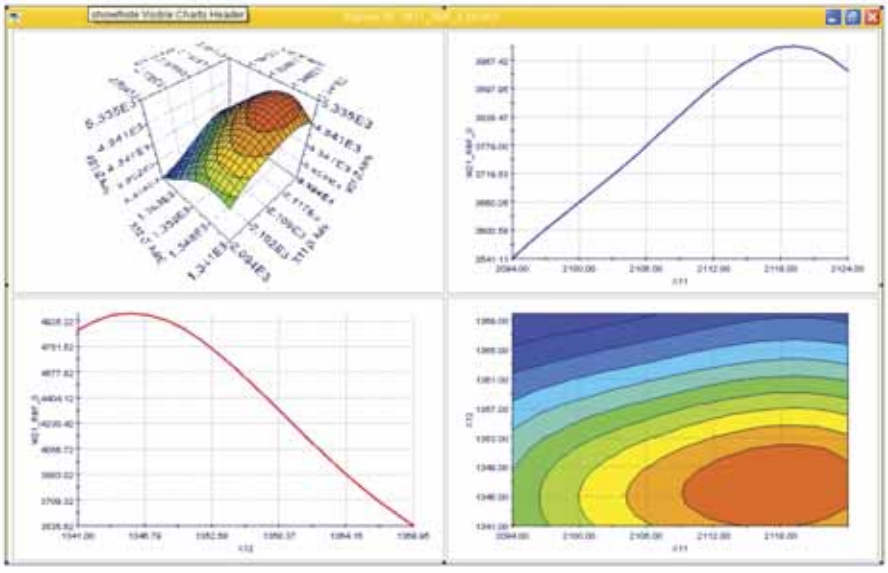

Figure 4: modeFRONTIER tool for meta-models 3D-exploration

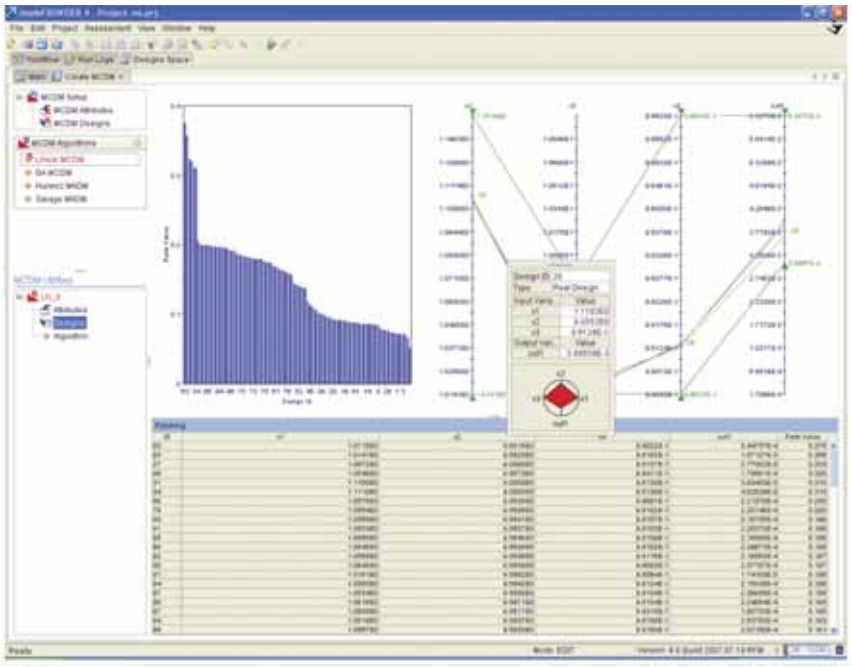

Figure 5: modeFRONTIER tool for supporting Multi-Criteria Decision Making

and forecasting errors). modeFRONTIER covers even these topics. It contains dedicated sampling methods based on Monte Carlo and Latin Hypercube and special statistical charts to verify the reliability of solutions. Moreover, it has a special optimization module named MORDO (multi-objective robust design optimization) that allows the user to perform a robust design analysis to check the system's sensitivity for manufacturing tolerances or small changes in operating conditions.

Conclusions

Nowadays computer technologies have been challenging the environment of engineering design by enabling software tools such as PIDO and MDO systems. This is due to the advances in processor speeds, runtime reduction strategies (parallel computation), powerful disciplinary analyses and simulation programs. The advantages of modeFRONTIER and other PIDOs may be summarized as follows:

- Reduction in design time
- Systematic, logical design procedure. This ensures the launching of innovative quality products to the market thus improving the brand images of all companies using these technologies
- Ability to handle wide ranges of design variables and constraints
- Not biased by intuition or experience

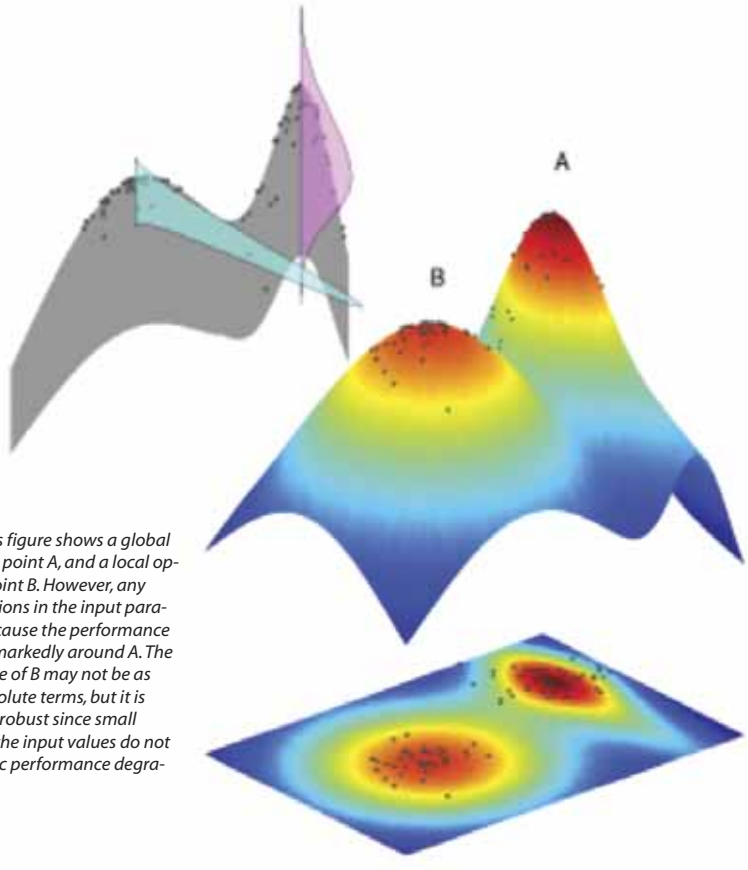

Figure 6: this figure shows a global optimum at point A, and a local optimum at point B. However, any small variations in the input parameters will cause the performance to drop off markedly around A. The performance of B may not be as good in absolute terms, but it is much more robust since small changes in the input values do not cause drastic performance degradation.

References

[1] Design of Experiments – EnginSoft Newsletter – Anno 3 – n. 4 – Inverno/winter 2006

[2] Multi-objective Optimization and Decision Making Process in Engineering Design – EnginSoft Newsletter – Anno 4 – n. 1 – Primavera/spring 2007

[3] Meta-modeling with modeFRONTIER: Advantages and Perspectives – EnginSoft Newsletter – Anno 4 – n. 2 – Estate/summer 2007

The websites, www.esteco.com and www.network.modefrontier.eu provide several examples of how to apply PIDO technologies in Engineering Design. For any questions on this article or to request further examples or information, please email the author:

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