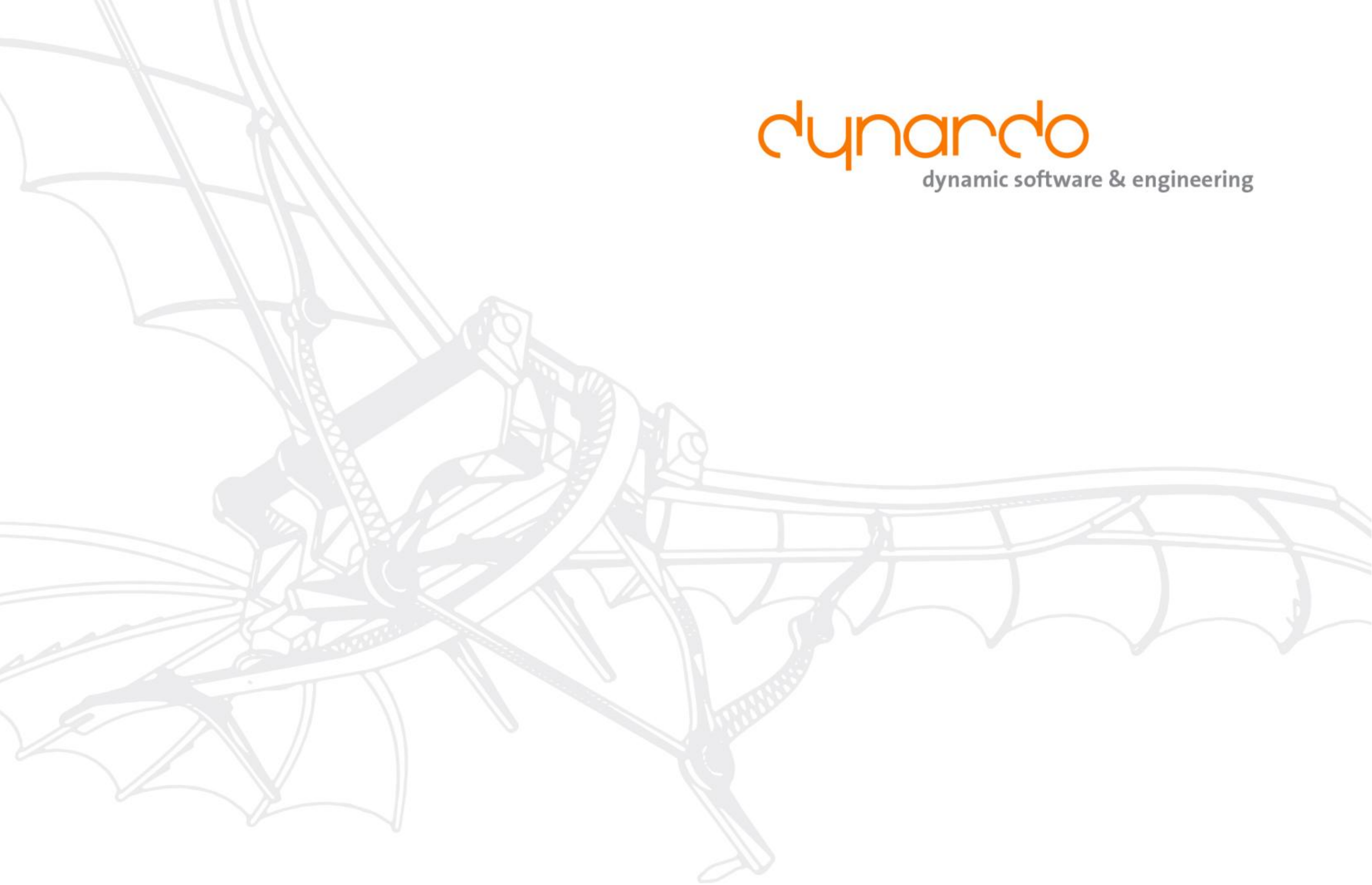

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Lectures

CAE-based Robust Design Optimization (RDO) in the virtual product development

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presented at the NAFEMS Conference 2012
Source: www.dynardo.de/en/library

CAE-based Robust Design Optimization (RDO) in the virtual product development

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1 Introduction

The speed of development and introduction of technical innovations as well as the requirements for the optimization of products demands more than ever a virtual product development. A distinction has to be made between the construction of designs (Computer Aided Design-CAD) and the calculation or the detection of functionality by simulation methods (Computer Aided Engineering CAE). Here, CAE-based optimization and stochastic analysis are key technologies to improve product performance while proving the quality requirements of reliability and robustness. At the same time, efficient strategies of robust design optimization (RDO) are required to secure the optimization results and robustness evaluations.

1.1 Variant studies, parametrics, and process automation

For 20 years, CAE-based optimization strategies, ranging from manually generated variant studies of DOE techniques, topology and design optimization to multi-disciplinary optimization of parameters, have been gradually integrated into the product development and the production process. In addition to stand-alone solutions for the optimization of individual disciplines and product requirements, there is now a trend using parametric modeling environments that open up the potential to combine CAD and CAE parametric calculation connecting several disciplines and product requirements to each other. Thus, products can be optimized automatically by intelligent variant calculations across multiple disciplines and simulation considering CAD and CAE constraints. Therefore, consistent parametrics, integration and automation of simulation processes are a necessity of modern parametric RDO processes leading to an increased number of parameters that have to be considered. Tasks with a dozen or a few hundred parameters become normal and represent both parameters to be optimized and scatters to be considered.

1.2 Optimization and robustness in conflict?

Optimization goals, such as weight reduction and performance optimization, are frequently in conflict with robustness and reliability of products. This is nothing new. Of course, at all times, engineers have been concerned about the balance between optimization and reliability. This is illustrated in the example of the Dombauhütten during the Middle Ages. In the Romanesque time, window openings were narrow and arched in a semi-circle shape. From a static point of view, this was very safe. Later, facades became more and more sophisticated and the arcs more risky. Step by step, the master builder exceeded the known limits of feasible static structures and many churches remained unfinished or simply collapsed. From these experiences, design rules were derived for masonry structures, some of which are still popular today. These safety margins have been established to realise the most sophisticated church buildings containing sufficient safety margins considering subsoil uncertainties, geometrical tolerances of the church buildings or material scatters.

2 RDO in the virtual product development

In the past, product robustness and reliability were secured either by real experiments or with conservative safety margins in the global design. Because real-scale tests are to be minimized under cost and time constraints of today's product development cycles and conservative safety margins lead to inefficient product designs, it is a logical trend to shift the validation of robustness and reliability to the virtual product development. Real-scale of components has to be reduced to a minimum. The proof of robustness and reliability in robust design optimization can be done either by global or local safety factors as well as by methods of stochastic analysis. In the RDO strategies which connect the optimization objectives and the validation of robustness and reliability, both methods will be found.

Here, the term of robustness refers to the applied standard deviation or sigma-derived properties. The term reliability analysis is used if small probabilities (<1 in 1000) are used for validation.

2.1 What are the challenges of integrating RDO in the virtual product development?

The implementation of CAE-based optimization follows in many aspects the previous operation methods of engineering to compare different design variants. Of course, the definition of the optimization task (transferring design requirements into objective functions and constraints), the variation space (parameterization of the design space) and the optimization strategy (optimization methods) strongly affect the optimization potential. However, an improvement of 0.5% or 10% is a valid result in both cases. This usability and validity being independent towards the variation of space definition within an optimization problem and the optimization algorithm is no longer valid in stochastic analysis.

The introduction of CAE-based stochastic optimization methods requires significant extensions of previous "deterministic" calculation processes and the maintenance of a balance between the definition of the input scatter, the method of stochastic analysis and the estimation of variation and correlation measures for the evaluation of robustness and reliability.

In order to obtain reliable estimations of outcome variations as a basis of any evaluation of robustness and reliability, all relevant input scatters are to be considered in an appropriate manner. This is an issue concerning the implementation of RDO strategies. It is understood that a detailed knowledge of all potentially effective variables and an adequate parametric determination of all input scatters appear to be an almost insurmountable obstacle in stochastic analysis. Waiting for a perfect knowledge will probably lead to no development at all. Therefore, a pragmatic approach is to start with conservative assumptions about all potentially relevant scattering input variables. Thus, for important scattering input variables, the knowledge and the discretization of the definition of scattering input variables can be gradually increased.

Another obstacle for the introduction of stochastic analysis is the fact that a standard deviation or a probability can only be estimated and not (deterministically) calculated. Therefore, the outcome for the user will be an estimation, not a real numerical result. In order to obtain a trustworthy and, thus, a firm estimation which can be used to evaluate product features, often more than one stochastic calculation is necessary.

Basically, it must be accepted that the introduction of stochastic analysis for firm evaluation of robustness and reliability within a RDO process demands a significantly large number of nodes (samples of a stochastic analysis) in the region of several hundred or several thousand. Since a single design evaluation already requires a high amount of CPU capacity, it represents a significant challenge to the hardware, and if necessary, to the licenses conducting parallel calculation of designs. Therefore, the challenge in choosing a robust design optimization methodology is to keep a balance between the number of solver calls and the trustworthiness of the robustness and reliability measures.

Therefore, in all RDO methods, for an estimation of robustness measures it is worthwhile to reduce the amount of real design nodes to a minimum. After a robust design optimization, a final evaluation of the presumptive optimal and robust design with appropriate methods of a reliability analysis is mandatory.

Due to the large number of sampling nodes in a stochastic analysis, RDO algorithms primarily use meta-models (response surface models) to estimate value variation. The usability of meta-models for robustness evaluation and reliability analysis is discussed controversially in literature. The amount of effort to generate appropriate meta-models depends strongly on the number of important scattering input variables, the non-linearity of the result spaces and the probability level of a robust design. In any case, there must be a final reliability analysis using real design nodes proving the robust design which was generated by meta-models.

2.2 Integration status of Robust Design Optimization (RDO) in the virtual product development

The first important step is to implement a trustworthy robustness evaluation of the most important result values regarding the influence of uncertainties and scatters. By this sensitivity analysis of the uncertainties and tolerances potentially effecting all important result values, a first estimation of variation and variable importance can be conducted. In order to reduce the number of scattering variables to those being important for the result value variation and to prove the reliability of the estimation of variation values, an iterating approach is often necessary.

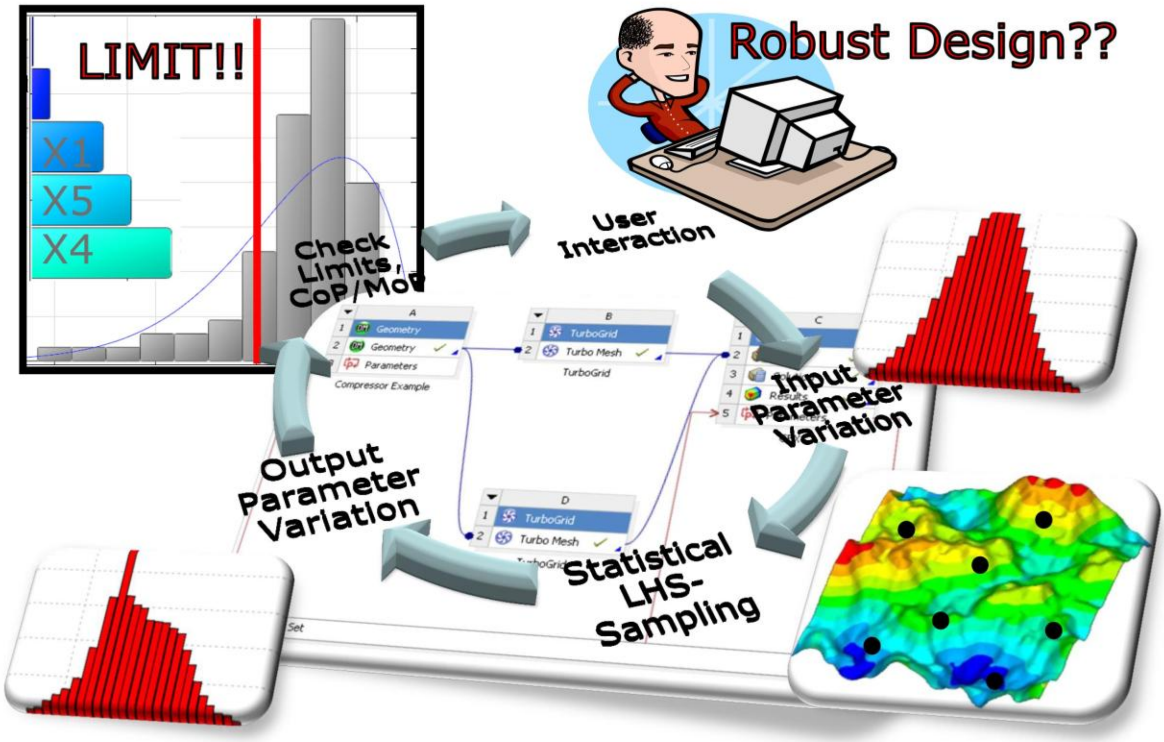

Figure 1 process chart robustness evaluation

In the next step, safety margins are estimated to be considered in the implementation of a deterministic optimization. The generation of an optimized design using preset safety margins is followed by a stochastic analysis proofing robustness or reliability. If the safety margins were not sufficient, optimization and robustness steps have to be repeated. This procedure (iterative RDO) is effective if the necessary safety margins are fairly constant in the optimization space.

If The safety margins for proofing a robust design vary greatly in different areas of the optimization space, it might be necessary to determine the variation of each design in the optimization space. These variation values are used to set constraints and objective functions of a robust design optimization. After that, methods of optimization and stochastic analysis can be automated and combined (automatic RDO). Usually, the effort of an automatic RDO compared to an iterative RDO increases significantly in the course of an analysis.

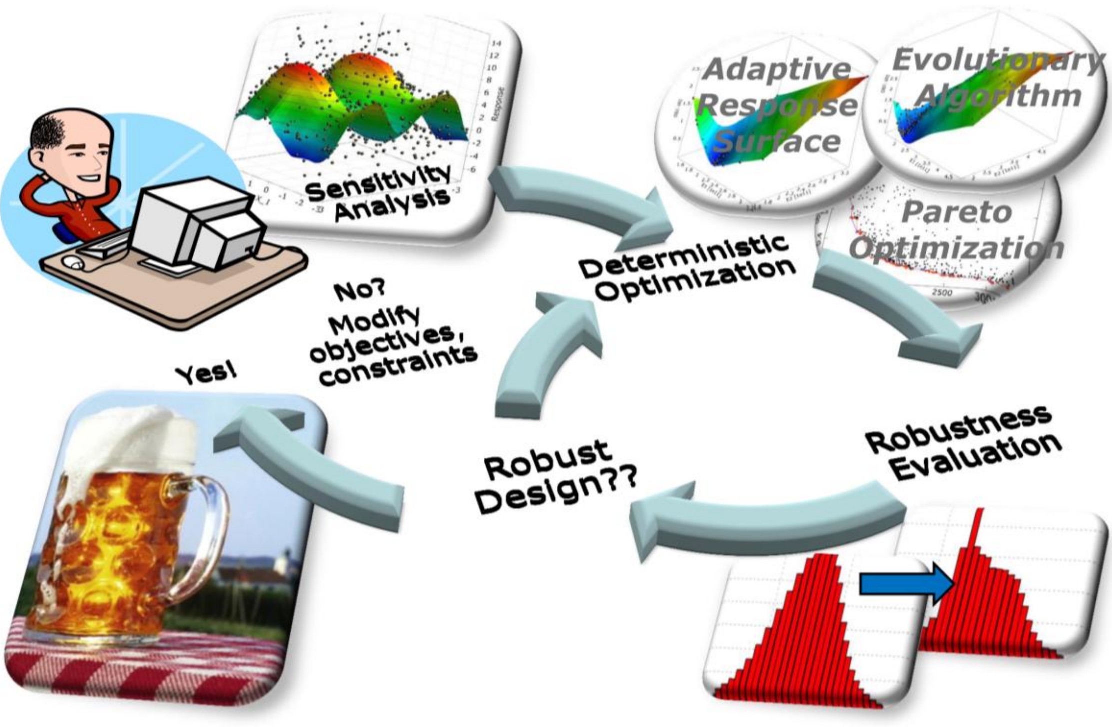

Figure 2 process chart iterative Robust Design Optimization

2.3 Requirements for RDO software solutions

From the above discussion about the challenge of integrating RDO methods in virtual product development, we can define the following requirements for software solutions:

- All potentially important scattering input variables referring to the best knowledge of the variations (in case of doubt also with conservative assumptions about the scattering) have to be considered at least at the beginning of a robustness analysis. This leads to real-life tasks with many stochastic parameters. The software solutions must be capable of fulfilling these tasks and provide technologies to determine safely the importance and unimportance of scattering variables. This is the basis to reduce the number of stochastic variables to those being important for the robustness evaluation, to choose an appropriate method of stochastic analysis and to define appropriate safety margins and constraints of an RDO task.
- For the best possible application of the knowledge about variations, the software solution must find suitable distribution functions in experimental data, identify correlations between different scattering values and consider spatial correlations of scattering values.
- Efficient methods of reliability analysis have to be applicable for the final proof of robustness and reliability.
- When integrating RDO in the process chain of virtual product development, the user might not possess special knowledge about methods of optimization, stochastic analysis and statistical evaluation. Therefore, the need of user input has to be minimized and preset modules of sensitivity analysis, optimization, robustness and robust design optimization have to be made available.
- The trustworthiness of variation and correlation measures should be displayed to the user with easy-to-understand values. Statistically insignificant information is filtered out automatically and post processing should minimize the number of statistical result values for evaluating the stochastic analysis to important and firm measures.

As a conclusion, the methods of Robust Design Optimization should be applicable easily even without special knowledge. At the same time, the user should be made aware that the definition of scattering values is the essential basis of a stochastic analysis. The verification and development of the definition and discretization of scattering input parameters is an essential key to the success of Robust Design Optimization.

2.4 Dynardo's optiSLang

In Dynardo's software optiSLang, the most efficient methods of optimization and stochastic analysis are integrated for the solution of RDO tasks. Customers have successfully implemented RDO in their virtual product development. Also, the lectures at Dynardo's RDO Conference - the Weimar Optimization and Stochastic Days - confirm this development. In order to implement even more RDO applications as an integral part of product development and to provide this methodology also for customers without expertise in optimization and stochastic analysis, we have currently developed our "best practice" modular system. In the new software version "optiSLang inside ANSYS Workbench" and "optiSLang v4.0", necessary user input was minimized and automated defaults for variable reduction and the automatic generation of the best possible meta-model were implemented.

2.5 Minimizing application obstacles

A successful integration of RDO methods in the virtual product development make high demands on the user. Parts of the application obstacles can be minimized in commercial software solutions by easy and safe to use RDO modules. However, if the assumptions on the input scattering for a chosen method of stochastic analysis and the reliability of the estimated variation are not in balance, the results of the RDO calculations are unusable. Therefore, it is recommended to introduce CAE-based RDO methods step by step in the virtual product development and to establish the verification of a trustworthy robustness evaluation as the basis of a reliable estimation of the variation of important output variables. The adjustment of the variation values with measurements and experience, as well as the verification of assumptions about scatters, should be permanently reviewed, verified and refined.

3 References

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