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Industrial Design Optimization: From Research to Industry Application

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Micro Abstract
Time effective product development is crucial to success. To obtain viable compromises in aerospace applications, several arrangements with different disciplines have to be made. Those determine the frequency of numerical studies, wherefore time is essential. Starting from a research perspective, general design optimization will be presented. Thereafter, multiple industrial examples will be given, where invested effort returns in performance, robustness and fewer arrangements.

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Introduction

With this conference contribution, a bridge from academic research work to actual industrial application shall be outlined; mutually enrich each other. In industry, time effective product development is often key to success. Project engineers are frequently working on more than one single component, where each component involves multiple disciplines. So as to convergence to feasible compromises in aerospace, several arrangements have to be made with mechanical, design, thermal and even optic engineers. Those arrangements determine the frequency of numerical studies; or in other words, span the period for not only the analysis and post-processing, but also abstraction and model development. For deploying powerful and meaningful optimizations, time is therefore essential. Or in other words, time being sped on optimization is often rare and therefore needs be exploited with highest possible effectiveness. This is where academia comes into play by providing the proper means.

1 Insights gained in academia

Design optimization is of the most use when it is applied as early as possible in the design process. However, in those early design phases, not only mechanical but also others like economical, thermal or techinical requirements have to be adressed as depicted in figure 1.

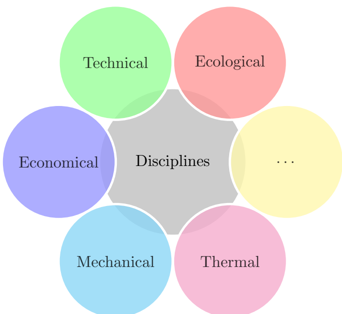

Figure 1. Involved Disciplines in Optimization [1]

This multitude brings forth the two prominently faced challenges: multi-disciplinarity and conflicting goals.

1.1 Multi-disciplinary

There are multiple occasions, where structural optimization involves the consideration of at least another discipline. With the following figure such an example is given. The outlined A pillar not only needed to be as light as possible while being stiff enough and withstanding external loads, but moreover, also needed to be actually producible via braiding. Braiding is a cost effective CFRP manufacturing technique.

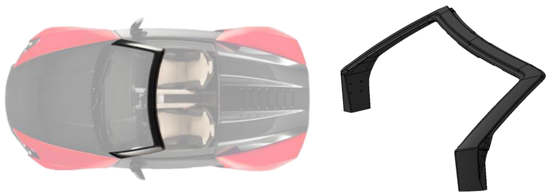

Figure 2. A Pillar of a Roding roadster [1]

Manufacturing effort has been captured by emulating expert knowledge. This was realized by a so called rule-based knowledge basis, which could be comprehended as another model covering manufacturing aspects, i.e. technical discipline (see [3]).

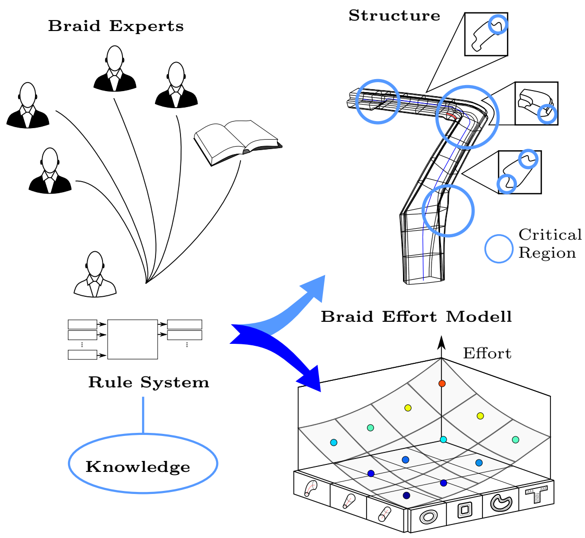

Figure 3. Capturing Expert Knowledge via rule-based systems

The tricky part then is, to actually incorporate this model into an optimization frame. In order to so, the optimization engineer not only has to overcome the actual implementation, i.e. calling of different solvers etc., but also the definition of a proper optimization task; see figure 4. The latter is difficult because of the combination of different responses with different nature and because of the necessity of defining an objective. Hence, which response shall serve as objective or - in case of a combination of multiple responses in the objective function - how to weight them. This is addressed within the field of multi-criteria optimization.

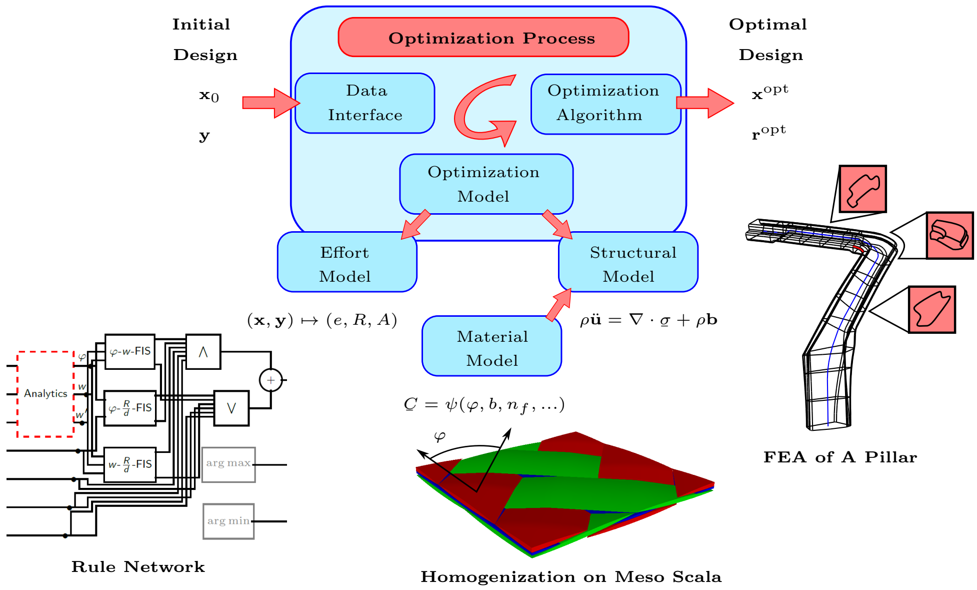

Figure 4. Optimization task involving responses from three models

1.2 Multi-criteria optimization

Multi-criteria optimization addresses the handling of multiple objectives. Figure 5 depicts an example, where a propeller needed to be optimized, such that it sustained all loads (air pressure, deflecting etc.), had a specific modal performance so as to reduce tendency of flutter and of curse, being easy to build along with low cost while still being as lightweight as possible.

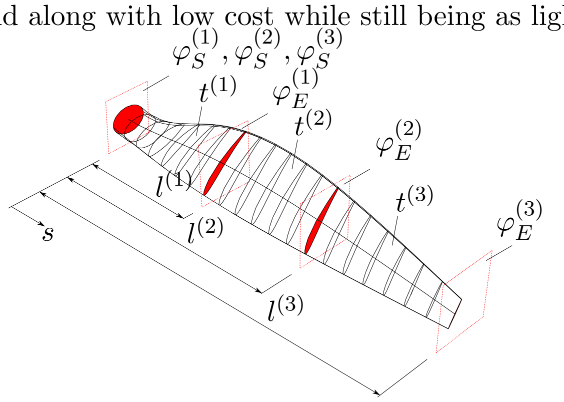

Figure 5. Design space of the propeller optimization task

Evidently, this brings forth a lot of conflicting goals. With the grey surface (Pareto Frontier in figure 6) all optima found for the multi-criteria optimization task of maximizing first Eigenfrequency, minimizing effort and minimizing mass is given. Of course all requirements regarding stiffness, i.e. maximum tip deflection and strength, sustaining air pressure loading are met for each and every optima. The red points in that figure illustrate the result of a sophisticated zero-order algorithm with proper settings and a large number of evaluations (see [4]). This shall just highlight the difficulty in multi-criteria optimization, thus it is not only the design space which exponentially levers the complexity but also the criteria space.

Conclusions and outlook

Within this extended abstract, only two challenges were briefly discussed. In industry, there are more on top of that. This is mainly because, optimization in industry either needs to be applied such that yields huge advantages at low costs and low model development times or it is simply marking a necessity; such as topology optimization for 3D printing or inverse solution finding,

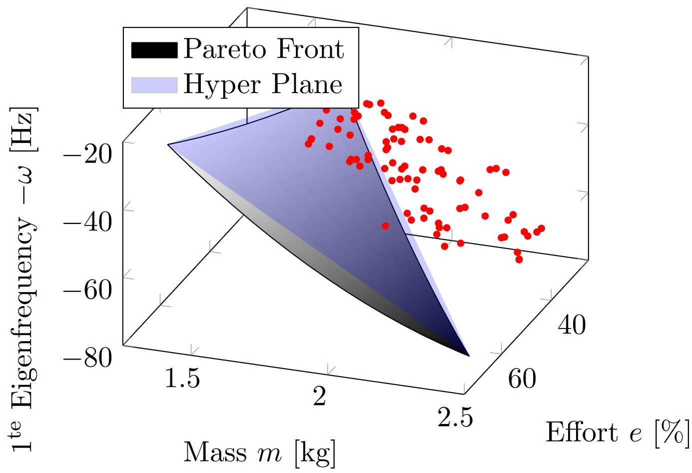

Figure 6. Paretor frontier for the three objectives: mass, Eigenfrequency and manufacturing effort

e.g. mass operator method.

The final presentation will will first outline the challenges mentioned above and how to treat them appropriately. While doing so, fundamental aspects of optimization such as sensitivities and Lagrangian data will be linked to shadow prices and robustness. Those latter two will be picked up in the second part, where industrial application is in focus. It will be shown how those actually help to squeeze most of out a few optimization runs so as to support engineers in early design phases of spacecraft structures.

Apart from that, optimization is gaining pace in industry; and this is partly because of 3D printing. Latest results, as for instance given by [2], will be discussed at the end.

Acknowledgements

At this point of time, i would like to thank three main contributors to my research work and thereby to my future career. Namely, Prof. Dr. Horst Baier for pushing me in the right direction, Dr. Erich Wehrle for having so many fruitful ideas and for supporting me in building a solid fundament. Last but not least, Edwin Schatz for always being there.

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