A design optimisation course with a focus on industrial applications

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This Design Optimisation course is compulsory for two distinctly different cohorts of students, it is a final year module for Masters of Engineering (MEng) in Aeronautical and Aerospace Engineering, and for Masters of Science (MSc) in Structural Engineering (both full time and part-time), as well as an optional module for MEng students on Civil and Structural, Automotive Engineering, Mechanical Engineering programmes of study. The module contributes as 12.5% of the final year MEng programmes and 8.3% of the total MSc programme. It is requested that the students spend 150 hours of their time on this module, this includes lectures, seminars, coursework completion, reading recommended literature, revision and ending with a 2 hour written examination.

An unusual feature of this module is that the taught part of it is delivered within four days of one week as a “short fat” module. This is particularly attractive to part-time MSc students as well as provides an opportunity of offering it to practicing engineers as part of their Continuous Professional Development (CPD) programme. The module has been attended by engineers from several aerospace companies and research organisations who needed an update on design optimisation, and is regularly taken by new PhD students. The entry requirements are: (i) a first degree in engineering (or equivalent) and some familiarity with the finite element analysis at the user’s level.

The main objectives of the module are:

- Appreciation of a need for design improvement formulated as an optimisation problem.
- Understanding of what the most useful design optimization techniques are.
- Understanding of how these can be used to improve a design focusing on engineering applications.
- This is strengthened by learning how to use professional design optimisation software HyperWorks by Altair Engineering Inc with particular focus on:
  - HyperStudy for solving general optimisation problems,
  - HyperMesh and OptiStruct for solving structural optimisation problems.
- This should broaden the students’ horizons giving them a competitive advantage.

The syllabus can be outlined as follows:

- Motivation for the systematic design improvement. Criteria of design quality. Formulation of an optimisation problem.
- Numerical optimisation techniques. Case studies and applications to practical problems.
- FEA-based design sensitivity analysis.
- Topology, shape and sizing optimisation. Case studies and applications to practical problems.
- Metamodel building and their use in design optimisation.
- Effect of stochastic inputs on an engineering system, robust design, reliability optimisation.

- Case studies and real-life examples of design optimisation. Review of availability of commercial software.

Variants of this course have been delivered at several other universities in Japan, The Netherlands and Egypt. The contents was tailored to the focus of a particular programme, e.g. greater focus on metal forming applications at Hiroshima University. As a shorter version, it was has also been used as the basis for industrial training courses (Altair Engineering, Jaguar Land Rover, offshore industry, etc.) that typically takes two days.

Some of the features of the module:

- The focus is on the problem formulation, there are many examples of how good (or inappropriate) selection of design variables, their limits, formulation of the objective function(s) and constraints affect the solution.
- The theory is secondary to understanding of the main features of the optimization algorithms in order to make an educated choice of the right tools for a particular problem.
- Every major part of the material is accompanied by an industrial case study.
- There are three guest speakers (from Altair Engineering, Arup and EADS Innovation Works) presenting their own case studies, this is particularly appreciated by the students.

A significant minority of the students on the course find it tough to deal with such a large amount of entirely new material in four days. This is rectified by the experience gained while doing the coursework over the next five weeks that includes two major parts:
Part 1:

– solving a structural optimisation problem by several techniques (GA, SQP, etc.) and investigating the effect of the algorithm parameters,
– selecting a Design of Experiments and building metamodels by polynomial regression and the Moving Least Squares method,
– solving an optimisation problem using metamodels,
– formulating and solving a problem with uncertainties in the model inputs,

and Part 2:

– formulating and solving 2-D and 3-D structural topology optimisation problems.

The metamodel-building part of the coursework is particularly relevant to a number of industrial problems as the response functions are highly nonlinear. The students are invited to comment on the accuracy of the metamodels and suggest the ways of improving their quality. They observe that building a metamodel of an intermediate response, and using it for obtaining the final responses leads to a dramatic improvement of the quality of the approximated response. While doing this part of the coursework the students follow the same process as they would see upon graduation in industry, and they develop an appreciation of the importance of the appropriate formulation of the optimisation problem.

The topology optimisation part of the coursework in linked to the programme of their study, and for the part-time students (who are already practicing engineers) it is linked to their professional activity.

Having gone through the short intensive lecture phase followed by a several weeks of working on a large item of coursework the students report that all pieces of information in the course are coming together, and they see an optimisation problem in almost every activity.