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Robust Parametric CAD Models

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Introduction

Complex engineering design problems usually start from a conceptual design phase. In this initial phase, the objective is to find the right combination of product parameters that satisfy all the design constraints and relevant regulations, while at the same time, optimize figures of merit, for example, cost, weight and aerodynamic drag. Essentially, this conceptual design phase is a highly global exploration of the design space. This search process is often carried out in a design optimization framework.

Many of the automated optimization frameworks make use of a central geometry engine which generates parameterized geometrical models that are entirely defined by a set of design variables. The models serve as the starting point for subsequent analysis and evaluation, such as computational fluid dynamics (CFD) or finite element analysis (FEA), the analysis outcome(s) being sent back into the optimization framework, creating a design-evaluate-redesign workflow. In an ideal workflow, the geometry engine is able to deliver a geometry model defined by a given set of design variables as and when required by the optimizer.

One of the most pressing challenges of parametric geometry generation is the control of the trade-off between the desire for robustness and the need for flexibility. The former objective expresses the requirement that the entire design search space can be explored without the geometry failing (or, at least, failing beyond automated repair), while the latter ensures that, at the same time, the design space is large enough for a conceptual level study. Up to now, there is no satisfactory solution to this problem. As a result, bespoke in-house geometry engines still dominate in the conceptual design phase. They are usually more time-consuming, difficult and costly to build up and use than ready-to-use commercial CAD tools. Their applications are usually limited to specific problems. Furthermore, there is no mechanism to guarantee that the precious engineering experience and knowledge that are used in the construction of a bespoke geometry engine can be preserved and further reused. The main objective of this research is to address the above problem by first capturing and synthesizing design knowledge through a support vector regression model and then applying the knowledge base to assist the geometry engine to generate more robust models without limiting its flexibility. In a nutshell, the research aims at reducing the reliance on human design experts in the conceptual design phase and helping speed up the design process.

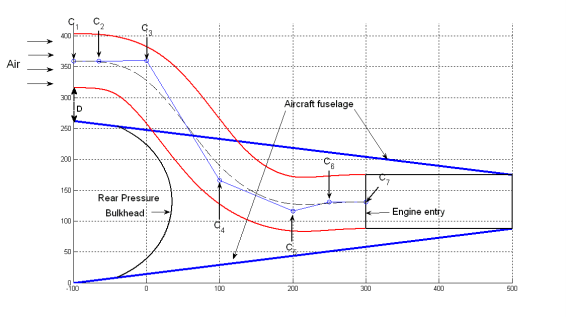

Figure 1 – two dimensional parameterized integrated propulsion model

The automatic geometry repair system

The prototype system that has been built provides the following capabilities so far:

- Capturing design knowledge.
- Integrating this knowledge into a general knowledge base.
- Automatic deployment to recommend a set of repaired geometry alternatives as and when required.
- Production of inferences that the human expert may not be able to devise in a reasonable amount of time.

A 'proof of concept' model has been built based on a two dimensional parameterized integrated propulsion geometric model (Figure 1). Three modes of geometry failure have been identified as illustrated in Figure 2. They are:

- Intake entrance embedded in the fuselage.
- Unphysical loop of the duct.
- Interference with the rear pressure bulkhead.

Each failure mode can be associated with a penalty function. A support vector regression model is then deployed to build a surrogate model of the penalty functions. Support vector regression has been chosen as this type of response surface separates the supplied data into two groups and then builds its model based on the subset considered to be most important in modeling the desired landscape: the so-called support vectors. In this way, a 'health landscape' has been built from these key vectors. This is a function of the design variables and it predicts the regions of the design space where the geometry can be considered to be healthy or failed, depending on the pre-set 'health value' threshold. The slopes of this landscape give an indication as to what repair alterations would bring a failed geometry back to feasibility. A variable resolution search algorithm that homes in on the design featuring the best balance between geometry feasibility and magnitude of repair alteration by successive reductions of the subspace being searched has been developed. As illustrated in Figure 3, a set of repair alternatives can be suggested by the system. In this figure those designs lying along the repair path show a trade-off between increasingly satisfactory geometry and change from the initial design vector (and therefore design intent).

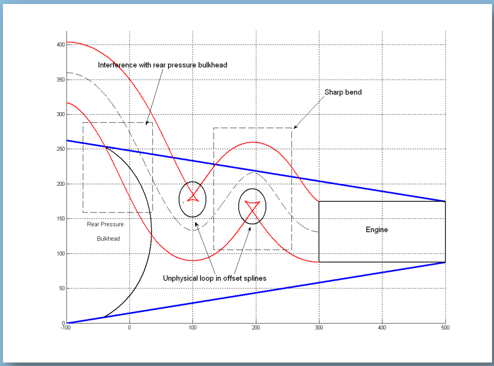

Figure 2 – typical modes of failure in the model

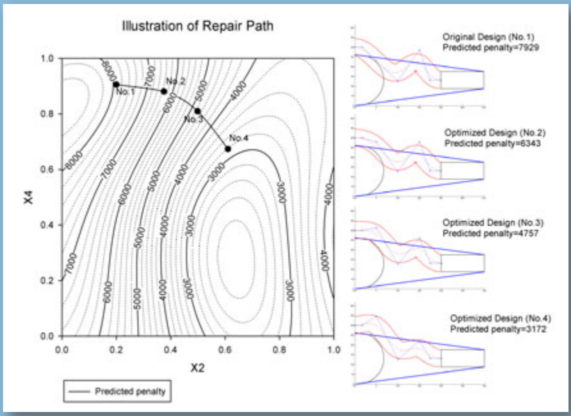

Figure 3 – a range of suggested geometry repairs along with the repair path in the design space.

Future work

Future work aims at:

- Incorporating simulation data into the support vector regression model.

Using the support vector regression tool to identify critical geometries that lie at the tipping point between feasibility and infeasibility.

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