High dimensional multidisciplinary design optimization with Gaussian process for eco-design aircraft

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Abstract:

The European project AGILE 4.0 (https://www.agile4.eu/) is developing methodologies to optimize complex aeronautical systems addressing the entire life cycle. It will provide aircraft industry with solutions to reduce significantly the cost and the quantity of energy expended by aircraft, moving towards cheaper and greener solutions.

Aeronautics design is especially multidisciplinary and, in this context, some integer or categorical variables could arise such as the number of engines, the shape of the tail or the type of the wingtip devices. To tackle this class of problems, new mixed integer multidisciplinary efficient global optimization algorithms have recently been developed [10]. We propose to tackle mixed integer optimization and its application to aeronautic design. The problem will be treated as an expensive black-box that we try to optimize with as few evaluations as possible and with both a large number of design variables (∼700) and many constraints (∼20). The constraints can be inequalities or equalities and we will consider no convexity assumption.

This work follows the PhD thesis of R.Priem (2017-2020) in which an adaptative efficient global optimization method under constraint (enrichment algorithm) was developed. The latter extends the stochastic efficient optimization to both equality and inequality constraints [2]. This approach was evaluated on a large battery of academic tests and validated at an industrial scale on the BRAC test case of Bombardier Aviation, Canada [8].

Bayesian optimizers that handle both continuous and categorical inputs are of high interest, yet pose significant challenges. Current approaches, like one-hot encoding, severely increase the dimension of the covariance matrix related to the Kriging model, also known as Gaussian Process [5]. In this context, the construction of the Kriging model may not be scalable to practical applications involving multiple categorical variables. In fact, using the surrogate model in the standard way is computationally expensive due the the large number of hyperparameters to estimate in the covariance matrix.

To begin with, in this PhD thesis (2020-2023), we address this issue by constructing a covariance kernel for the Kriging model that depends on only a few hyper-parameters. The new kernel is constructed using continuous relaxation [4] and based on information obtained from the Partial Least Squares method [3]. In the classical approach the mixed problem is modeled by a Multi-Arm Bandit where every arm is a discrete category and corresponds to a continuous space evaluate via conditional probabilities [6].

A benchmark of functions was proposed to validate the method and new results were obtained on a reference model of a A320 aircraft design problem. The obtained numerical results lead to

a significant computational gain without jeopardizing the performance of the regarded Bayesian optimization solver [1].

Regarding the approaches, many ways of improvement are being considered. A possible improvement for optimization is to correctly estimate mixed probability distributions [10]. In addition, the thesis of J. Pelamatti (2017-2020) made it possible to explore many variants of Gaussian process models using covariance kernels adapted to mixed integer variables.

Two direct applications of this thesis are the optimization of a flexible wing aircraft [9] and that of a hybrid propulsion aircraft [7] which will serve as test cases for developed algorithms. Taking into account mixed variables in aeronautical design optimization will allow to obtain more efficient aircraft configurations, such as in the aircraft concept DRAGON aiming at reducing fuel consumption through distributed electric propulsion.

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Short biography – This thesis is a collaboration between ISAE-SUPAERO and ONERA and is follow a master's thesis for a M. Sc. in Operational Research at the Ecole Nationale de l'Aviation Civile (ENAC) and a MEng in Applied Mathematics and Models at the Institut National des Sciences Appliquées (INSA).