PHD THESIS SUBJECT

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Title
Launchers multidisciplinary optimization for variable geometry problems

Subject
The context of this thesis is the development of multidisciplinary optimization methods for the design of launchers with consideration of technological choices leading to variable geometry problems.

Multidisciplinary Design Optimization (MDO) is a set of methods aimed at improving the efficiency of the design process. These methods, which involve several disciplines (aerodynamics, propulsion, structure, trajectory, etc.), are particularly used in the preliminary design phases of space vehicles in order to determine the future concepts to be developed [1,13]. Most often, during the preliminary design phases, choices of architecture concepts have to be made (number of engines, type of propulsion, type of propellants, type of materials, number of stages and boosters, etc.). In the case of liquid propulsion in particular, the choice of propellants and the engine cycle are fundamental. In addition to the continuous variables characterizing the system (pressures, quantity of propellants, diameters, etc.), these choices involve a number of categorical and discrete variables within the optimisation process (type of cycle, choice of propellant, etc.). The relevance of a new launcher configuration depends on a judicious choice of the combination of these technological solutions whose assembly constitutes the system.

The categorical and discrete choices during multidisciplinary optimization iteratively have consequences on the "geometry of the optimization problem". Indeed, different design variables and different constraints are successively expressed and must be managed by the optimizer. For example, if we consider an architectural choice concerning the type of propulsion (e.g., liquid, solid, hybrid), depending on the value of the categorical variable "type of propulsion", different continuous variables are present or not (e.g., variables associated with the geometry of the grain which is not present in liquid propulsion). Another example of great interest is the choice of the cycle liquid rocket engines (gas generator, expander, staged combustion, ...). Indeed, this choice can be limited by constraints linked to the mission objectives and has a strong impact on the system as a whole [9,11,12]. Moreover, the physical constraints, that depend on the choice made for the architectures and technologies, will be impacted by these choices. Therefore, this type of optimization problem is called a "variable geometry" problem, as the number and type of optimization variables, and number of constraints, evolve during the iterations of the optimization process.

Recently, metamodel-based approaches (Bayesian optimization) with mixed continuous, discrete and categorical variables, considering "variable geometry" aspects, have been proposed in the literature [2,3,4,5]. However, these approaches quickly reach their limits if the combinatoriality imposed by the presence of technological choices increases. Moreover, these approaches do not consider the particularities of MDO problems in terms of the existence of interdisciplinary couplings. On the other hand, in the present thesis, multidisciplinary optimization strategies for "variable geometry" problems based on the decomposition of the MDO problem, will be developed. This will be done in order to partition the optimization effort into optimization sub-problems with a combinatorial that remains controllable.

Thus, two complementary methodological developments will be carried out. The firstly concerns developments at the level of the decomposition of the MDO problem and the optimization algorithm. Specifically, mathematical formulations of the multidisciplinary design problem, allowing the inclusion of mixed continuous/discrete/categorical variables, will be developed and an adequate organization of the process will be associated to it. This could be achieved, for example, through approaches with several levels of optimization corresponding to different levels of architectures. In addition, the use of "co-evolutionary cooperative" optimization algorithms [6] (based on divide-and-conquer and cooperation mechanisms) could be investigated in an MDO context.
The second track concerns the establishment of surrogate models for the consideration of mixed variables, with the aim of reducing the computational time of MDO processes. We will focus here on the definition of experimental designs for the construction of such mathematical models [7] in order to best distribute the calls to the calculation codes according to the disciplines and the categorical and discrete variables involved. In particular, the best possible use of surrogate models in the MDO formulations developed will be investigated [8]. The methods will be applied to the design of new reusable launch vehicle configurations as well as to the design of innovative rocket engines.

To this end, the thesis will proceed as follows:

- State of the art on multidisciplinary optimization techniques with mixed continuous/discrete/categorical variables as well as on "variable geometry" problems,
- State of the art on propulsion system design approaches and modelling of liquid propellant rocket engine cycles;
- Development of MDO processes to address launch vehicle architecture optimization issues including multiple categorical choices at the propellant system level (propellants, cycle, etc.),
- Implementation of the MDO processes developed for different launcher design cases.

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