Abstract #
Preferred Topics: SYSINT / PROPHY
Corresponding author: BARATON Lucas
e-mail of corresponding author: lucas.baraton@isae-supaero.fr
Type: Oral
Status of corresponding author: Student
For student corresponding author: student member of one of the following: None

Title

Comparative review of Multidisciplinary Design Analysis and Optimization architectures for the preliminary design of a liquid rocket engine

Authors

Lucas BARATON [1], Annafederica URBANO [2], Loïc BREVAULT [3], Mathieu BALESDENT [4]*

** Corresponding author*
[1] ISAE SUPAERO, University of Toulouse, France, lucas.baraton@isae-supaero.fr
ONERA DTIS, Université Paris Saclay, France, lucas.baraton@onera.fr
[2] ISAE SUPAERO, University of Toulouse, France, annafederica.urbano@isae-supaero.fr
[3] ONERA DTIS, Université Paris Saclay, France loic.brevault@onera.fr
[4] ONERA DTIS, Université Paris Saclay, France, mathieu.balesdent@onera.fr

Abstract

In the last decade, a trend arose in the space industry: the "New Space" [1]. Historical space actors and young companies participate to develop this economy by working on a growing number of innovative concepts. Within this context, the mission's economical cost and its impact on the environment become the main drivers when designing new projects. The overall architecture of the launch vehicle and its propulsion system are key elements to be optimized to reach an acceptable level of sustainability and profitability. The propulsion system design is a typical multidisciplinary problem involving several disciplines (or subsystems) such as the thrust chamber, the feedsystem and the cooling system.

Besides, in the preliminary design phases, some architectural and technological choices need to be made for the propulsion system (the cycle's choice for instance). These choices strongly impact the overall system behavior. Within the mathematical formulation of the design problem, they can be embedded in a particular type of design variables (called dimensional variables). Depending on their values, the latter modifies the number of variables and constraints of the optimization problem. Such variables generate highly combinatorial, computationally complex problems called variable-size design space problems (VSDSP). The present paper aims at addressing VSDSP by investigating classical approaches.

The Multidisciplinary Design Analysis and Optimization (MDAO) framework is a set of tools for the preliminary design of engineering systems [2] allowing to solve large multidisciplinary problems. Numerous problem decomposition (MDAO architectures) and optimization algorithms have been developed in the last decades [3]. They allow, by innovative mathematical formulations of the problem, to distribute the overall complexity to a series of coordinated less complex optimization problems.

In this work, four MDAO architectures are under focus. They belong to two categories: monolithic and distributed. The members of the first category solve the design problem by formulating it as a single optimization problem. The two monolithic architectures implemented in this paper are *Multidisciplinary Feasible* and *Individual Discipline Feasible* [3]. The methods of the second category divide the problem into several coordinated subproblems optimizations. *Collaborative Optimization* [4] and *Analytical Target Cascading* [5] are studied in this paper. The important focus of this

review is to analyze the capability of the aforementioned MDAO formulations to handle dimensional variables. To evaluate their abilities to deal with VSDSP, the performances of the MDAO architectures are compared in terms of computational efficiency, optimality, scalability, convergence properties, number of variables to optimize and accuracy.

The methods are implemented for a liquid rocket engine (LRE) design problem with three disciplines (thrust chamber, feedsystem and cooling). The model of engine optimized in this study is a LOX-LH2 LRE with a gas generator cycle where the number of turbines is a dimensional variable.

In this paper, the MDAO architectures and their mathematical formulations are described. Numerical simulations are performed on the LRE design problem to compute the parameters of merit useful for comparison purposes. Finally, a discussion about the results is proposed and the most suited generic MDAO formulation to deal with VSDSP is highlighted.

References

[1] Kulu, Erik. (2021). In-Space Economy in 2021 - Statistical Overview and Classification of Commercial Entities.

[2] Martins, J. & Ning, A. (2021). Engineering Design Optimization. Cambridge University Press.

[3] Martins, J. & Lambe, A. (2013). Multidisciplinary Design Optimization: A Survey of Architectures. AIAA Journal. 51. 2049-2075.

[4] Tosserams, S., Etman, L. F. P. & Rooda, J. E. (2009). A classification of methods for distributed system optimization based on formulation structure. Structural and Multidisciplinary Optimization. 39. 503–517.

[5] Kim, H.M. (2001). Target Cascading in Optimal System Design, Ph.D. Dissertation, Department of Mechanical Engineering, University of Michigan, Ann Arbor, Michigan, USA.