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SIMULTANEOUS OPTIMIZATION OF SPACE MISSION CONCEPT OF OPERATIONS WITH NONLINEAR SYSTEMS DESIGN VIA MIXED-INTEGER NONLINEAR PROGRAMMING

Abstract

Designing and optimizing architectures for space exploration campaigns introduces multifaceted challenges. The task simultaneously demands the selection of concepts of operations (CONOPS) in the architecture and also the assurance of technical feasibility across various components and disciplines. The multidisciplinary aspect in space systems has been studied extensively as system-of-systems design or multidisciplinary design optimization (MDO) problems; however, the selection process of CONOPS is often considered separately and lacks quantitative strategies. For example, the Advanced Concept Office (ACO) at NASA Marshall Space Flight Center currently approaches this problem by solving an MDO problem for every possible combination of CONOPS in the architecture. Such brute-force methods can become computationally intractable when faced with a vast number of potential CONOPS. This computational expense naturally entails slow design processes, which are further hampered if the design must be revised due to, for example, the correction of model parameters.

In order to improve the efficiency and automate the process, this work develops mathematical methods capable of integrating discrete variables into the modeling, optimization, and synthesis of space exploration campaign architectures coupled with systems design. The inherent discreteness in CONOPS (e.g., using a high- or low-thrust engine can be expressed as a 0-1 variable) creates a nonconvex mixed-integer nonlinear program (MINLP), which is known as the most challenging class of optimization problem. To tackle this challenge, we have developed a novel and convergent method for nonconvex MINLP which decomposes the problem into convex mixed-integer and nonconvex nonlinear subproblems.

In collaboration with NASA's ACO, our method was applied to a case study problem in which the CONOPS and system-of-systems design must be optimized simultaneously, thus formulating a nonconvex MINLP. Our method converged in a reasonable time, and our solution closely matched the solution obtained by ACO via brute-forcing. The remainder of this work will investigate our method's scalability in problem size and complexity as well as techniques to further improve computational efficiency. In addition, we will study our method's performance when black-box system design components are introduced. As suggested by our initial case study result, our method has the potential to greatly reduce the process time of designing space mission and campaign architectures coupled with complex space systems.