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SPACECRAFT PRELIMINARY SIZING FORMULATION METHODS

Abstract

A spectrum of various formulations can encode the same set of sizing equations and relationships used during the preliminary or conceptual design phase of a spacecraft. Such formulations include spreadsheet calculations, executable scripts in different programming languages, process integration software, and declarative equation specification languages. This paper describes a minimal abstract representation for any formulation: a nested directed graph encoding the data flow connecting sizing variables, computational elements encoding the sizing relationships, and solvers. Although regular directed graphs have been used ubiquitously in the literature, the hierarchical property of the nested directed graphs provides the generality needed to encode the different formulation methods. The nested property introduces the possibility of describing formulations involving solvers, such as fixed-point iteration solvers that can converge a subset of the sizing relationships. We compare and contrast formulation methods, including the earlier four examples, based on their representation in the nested directed graph format and pay special attention to inherent structural problems that come with the different formulations. Such problems include circular dependencies, design variable dimensionality explosion, providing an initial design point, and correctness problems, i.e., whether a formulation could hide feasible design points. Given a formulation, we also describe the computational properties of the process to generate candidate feasible designs: convergence properties and computational performance. We also present a set of operators that can convert between different formulations. We discuss the advantages and disadvantages such reformulations can introduce, like increasing or decreasing the dimensionality of the problem. Finally, the paper compares and contrasts different formulations of the same set of sizing equations for a satellite constellation design problem. We compare the different formulations in terms of the number of initial design values required, the convergence as a function of different formulations and different solvers, based on Newton's method and fixed-point iteration methods like Gauss-Seidel or Jacobi iteration.