Optimization-driven set-based design for dynamic design requirements

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Abstract

This thesis presents novel design methods for obtaining a set of design solutions to address design requirements that may change during the design process or over a system's lifetime. These methods aim at supporting design engineers quantitatively so they can make informed decisions in the early phases of product development when uncertainty is high. The applications used in this thesis demonstrate the efficacy of these methods and are centered around product remanufacturing by means of directed energy deposition, an additive manufacturing technique. Specifically, they aim at providing design solutions in the form of geometry of the deposit and the remanufacturing process parameters. The first method considers remanufacturing as a strategy to address changing requirements in optimal design problems. Sets of optimal design solutions, as opposed to single-point designs, are obtained using numerical optimization. The optimization objective is to maximize structural performance subject to design and process constraints. Since optimality and feasibility depend on varying design parameters, parametric studies are conducted to obtain optimal solutions for different parameter values. A response surface of the optimization solutions captures the effect of changing one or more parameters on the optimal solution and provides a method to map designs from the design space to the parameter space. A manufacturing transition rule is formulated in the parameter space to identify sets of design solutions that are scalable by additive manufacturing. The transition rule is based on the physical limitations of the manufacturing method. Scalable design solutions are mapped back to the design space to obtain the corresponding design variable values. This method draws inspiration from set-based design principles used to generate sets of

design solutions rather than converging to a single design solution early in the product development process. The first method focuses on making decisions using information that is available to the designer. Since product development involves several design iterations and stages, a second method for making decisions based on information from past iterations is presented in this thesis. It focuses on additive manufacturing problems where design requirements remain constant throughout a time interval referred to as an epoch and only change at discrete times in between epochs. This results in a series of design decisions that must be made at the end of each epoch referred to as a decision arc. This method considers selecting the best combination of design decisions from a set of discrete design choices. A combinatorial optimization problem is formulated to minimize the level of overdesign subject to reliability constraints. The reliability constraints are computed by evaluating the probability that a design will satisfy a design requirement given by a joint probability density function. Several design requirements are chained together and defined at the end of each epoch to form a requirement arc. Several requirement arc samples are generated using importance sampling. The optimization problem is solved for each requirement arc to obtain a set of corresponding decision arcs. This set of optimal decision arcs is compared against sets of robust and flexible design arcs. A tradespace is used to visualize the design sets and identify the relative degree of flexibility and robustness in the set of optimal decision arcs. The remanufacturing of a turbine rear structure, an aeroengine structural component is used to test the proposed methods. A stiffener is deposited on the outer casing of the turbine rear structure to increase its stiffness when subjected to thermal loads due to the exhaust gases. The first method is used to determine the sets of optimal and scalable stiffener designs by optimizing the geometry and laser power used to deposit the stiffener. The second method is used to identify the set of optimal design arcs by chaining together several discrete stiffener designs to minimize the overall level of overdesign while maintaining a threshold reliability throughout the design process or the product's lifecycle. The two methods form a complete set-based design framework for addressing changing requirements in design problems featuring continuous and discrete design variables for instantaneous or progressive change in the design requirements.