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MULTIDISCIPLINARY DESIGN OPTIMIZATION USING RESPONSE SURFACE ANALYSIS

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Aerospace conceptual vehicle design is a complex process which involves multidisciplinary studies of configuration and technology options considering many parameters at many values. NASA Langley's Vehicle Analysis Branch (VAB) has detailed computerized analysis capabilities in most of the key disciplines required by advanced vehicle design. Given a configuration, the capability exists to quickly determine its performance and lifecycle cost. The next step in vehicle design is to determine the best settings of design parameters that optimize the performance characteristics. Typical approach to design optimization is experience based, trial and error variation of many parameters one at a time where possible combinations usually numbering in the thousands. However, this approach can either lead to a very long and expensive design process or to a premature termination of the design process due to budget and/or schedule pressures. Furthermore, one variable at a time approach can not account for the interactions that occur among parts of systems and among disciplines. As a result, vehicle design may be far from optimal.

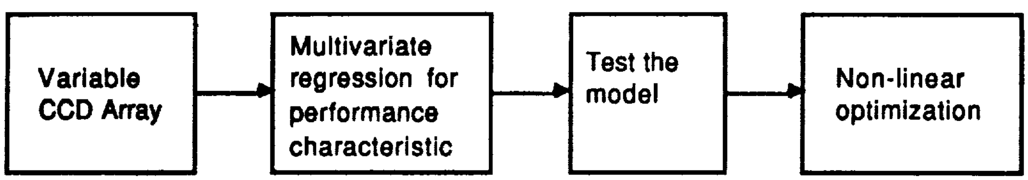
Advanced multidisciplinary design optimization (MDO) methods are needed to direct the search in an efficient and intelligent manner in order to drastically reduce the number of candidate designs to be evaluated. The payoffs in terms of enhanced performance and reduced cost are significant. A literature review yields two such advanced MDO methods used in aerospace design optimization; Taguchi methods and response surface methods.

Taguchi methods provide a systematic and efficient method for design optimization for performance and cost. Using orthogonal arrays (OA) the method explores the entire design space through a significantly small number of point designs than required by a full factorial study. From these data, a first order, linear multiple-regression model representing the performance characteristic in terms of the design parameters is constructed [6]. This linear model is then used to determine parameter sensitivities and predict the best setting of design parameters that optimize the performance characteristic. Taguchi method gains its experimental efficiency by sacrificing some information on parameter interactions. Efficiency diminishes rapidly as more parameter interactions need to be studied.

Taguchi method has been utilized at VAB in structures, propulsion and trajectory analyses [4][5]. In these studies, the Taguchi method provided an efficient, flexible and robust methodology for solving multiparameter vehicle optimization problems. A major advantage of the method is its ability to handle discrete variables. On the limiting side, the Taguchi method locates a near optimum only and must be used repetitively to improve accuracy. It also sacrifices some efficiency when it is necessary to study all interactions. In most vehicle design and analysis problems however, it is very difficult to initially estimate which parameters will tend to interact [4]. Thus, it may become necessary to study all interactions. Finally, the first order linear model may become inadequate as design complexity and response surface non linearity increases.

A more accurate, second order model that can account for all two parameter interactions and capture the curvature (non linearity) on the response surface, could significantly improve the optimization process [1]. A second order model requires that each parameter be studied at three levels (values) as opposed to two [2]. This can not be done efficiently using Taguchi's three-level OA since experimental effort increases exponentially (3^k). However, such a model can be constructed efficiently by using central composite designs (CCD) from design of experiments theory [3]. CCD are first order designs (2^k) augmented by additional points (2k+1) to allow estimation of the coefficients of a second order model [7]. The number of experimental point designs needed for fitting a second order model using CCD is significantly less than required by Taguchi's OA and from full factorial designs. As an example, for a problem involving 5 parameters at three levels and all interactions being considered, CCD requires only 27 experiments, as opposed to 81 required by Taguchi and, 243 required by a full factorial study. Another benefit of CCD is that it can be used sequentially, or "built up" from the first order design.

Response surface method (RSM) leads to a better, more accurate exploration of the parameter space and to estimated optimum conditions with a small expenditure on experimental data. The use of central composite designs, multivariate regression, and a nonlinear optimizer form the basis of response surface methodology. The central composite design element is used to efficiently describe the multivariate combinations needed for analysis. The regression analysis element involves the fitting of multivariate data to create a dependent function of performance characteristics. These generalized estimation equations are then used for rapid multidisciplinary parametric evaluation of the performance characteristics for all combinations of independent variables at system level.



Efficient selection of point designs (Multidisciplinary)	Fitting of second order response surface	Statistical test for lack of fit	Rapid numeric evaluation for all combinations of independent variables

RSM has potential applications at aerospace vehicle design and it can prove to be a very efficient multidisciplinary design optimization tool for systems level design studies.

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