JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 49, No. 2, March–April 2012

Aerodynamic Shape Optimization System of a Canard-Controlled Missile Using Trajectory-Dependent Aerodynamic Coefficients

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DOI: 10.2514/1.A32064

This paper describes a shape optimization study to maximize the range of a guided missile. To design a guided missile having maximum range, a shape optimization system is incorporated with a trajectory analysis program and an optimization technique. In particular, trajectory-dependent aerodynamic coefficients are fully considered. In the trajectory analysis step, a component buildup method is directly connected to the equation of motion to calculate aerodynamic coefficients at every time step. In the optimization step, a real-coded adaptive range genetic algorithm is adopted to determine the optimal shape of the global maximum range. The shape optimization system of a guided missile can maximize the range of the missile and yield the optimal shapes of canards and tailfins. Finally, the effects of trajectory-dependent aerodynamic coefficients, guidance, and control on the range of a missile are illustrated.

Nomenclature

C_A	=	axial force coefficient
C_L/C_D	=	lift to drag ratio
C_M	=	pitching moment coefficient
C_N	=	normal force coefficient
h	=	altitude, m
M	=	Mach number
α	=	angle of attack, rad
δ_c	=	canards deflection angle, rad

I. Introduction

THE typical conceptual design process for missiles is an iterative process, requiring a number of design iterations to achieve balanced emphasis from the diverse inputs and outputs. Figure 1 shows the representative iterative process used for conceptual design synthesis. Based on mission requirements, an initial baseline from an existing missile with a similar mission is established. This baseline is used as a starting point to expedite the missile design convergence. The new conceptual design is evaluated against its flight performance requirements. If the design does not meet the requirements, it is changed and resized for the next iteration and evaluation. If the new missile design meets the requirements, the design is finalized [1].

This series of iterative steps is repeated, and the design of each subsystem (aerodynamics, propulsion, weight, and trajectory) involves a similar series of iterative steps. Typically, the entire process of the missile design requires considerable time and cost. Although a missile design may meet the flight performance and other requirements pertaining to measures of merit and constraints, it nevertheless may not be an optimal missile design [2]. To achieve an optimal missile design, researchers have developed optimization techniques, and research is actively being conducted on possible optimization methods for each area involved in missile design [3–9]. For many years, researchers have applied gradient-based optimization schemes to aerodynamic shape optimization [3]. Also, there has been growing interest in the use of global optimization methods in a wide range of design problems, as well as aerodynamic shape optimization. Hybrid optimization methods based on genetic and gradient search algorithms have been applied to three-dimensional shape optimization of ogive shapes, star shapes, spiked projectiles, and lifting bodies in a hypersonic flow [4]. Anderson et al. [5] applied Pareto genetic algorithms (GAs) to the multiobjective optimization of missile aerodynamic shape design. Tekinalp and Bingol [6] have developed a simulated annealing method for missile trajectory optimization. Al-Garni et al. [7] presented a fast and reliable technique for aerodynamic shape optimization of supersonic missiles using a Monte Carlo optimization method. Through the optimization studies undertaken by previous researchers, it has become possible to design guided missiles more efficiently.

However, in the case of aerial vehicles such as ground-to-ground missiles, shape optimization has proved difficult due to aerodynamic characteristics such as rapid changes in the Mach and Reynolds numbers. Ground-to-ground missiles primarily use solid fuel; hence, velocity and altitude change rapidly after launch, resulting in correspondingly rapid changes in the Mach and Reynolds numbers. The Mach and Reynolds numbers are the most important variables determining the aerodynamic characteristics of guided missiles. As such, their rapid variation makes it difficult to predict the missile's aerodynamic characteristics. In shape optimization for guided missiles, the Mach number and the Reynolds number are particularly important determinants of aerodynamic characteristics [10–14]. For this reason, optimizing the external shape of aerial vehicles such as ground-to-ground missiles brings about the problem of having to derive a shape that takes the entire range of flight into account. In this case, repeated calculations of trajectory-dependent aerodynamic coefficients are required. However, a simpler approach in which onetime calculation of optimization is defined at a particular flight condition has been employed in the past. In this simpler approach, the effects of guidance and control, as well as the Mach and Reynolds numbers, cannot be described fully. To remove this weakness, full consideration of trajectory-dependent aerodynamic coefficients in missile aerodynamic shape optimization is made in the present study. By doing so, the effects of trajectory-dependent aerodynamic coefficients, guidance, and control on the range of a missile are illustrated.

II. Aerodynamic Shape Optimization System

This study addresses the issue of aerodynamic shape optimization for maximizing the range of ground-to-ground missiles, such as the

Received 10 March 2011; revision received 15 September 2011; accepted for publication 26 September 2011.

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