# Computational Approaches for the Aerodynamic Design and Optimization

Jae-Woo Lee*

* Department of Aerospace Engineering, Konkuk University, Seoul, Korea
Tel : +82-2-450-3461; E-mail: jwlee@konkuk.ac.kr

**Abstract**: Computational approaches for the aerodynamic design and optimization are introduced. In this paper the aerodynamic design methods and applications, which have been applied to various aerospace vehicles at Konkuk University, are introduced. It is shown that system approximation technique reduces computational cost for CFD analysis and improves efficiency for the design optimization process.

**Keywords:** Computational Fluid Dynamics, Aerodynamic Design, Optimization, Missile, Ram jet

## 1. INTRODUCTION

Aerodynamic analysis methods have progressed very rapidly with the development of computational fluid dynamics (CFD). With the rapid increase of the computing power and memory, practical aerodynamic optimization methods are required for the efficient aerospace vehicle design. However, design methods have not received the same level of attention that analysis methods have received. In this paper the aerodynamic design methods and applications, which have been applied to various aerospace vehicles at Konkuk University, are introduced.

## 2. DESIGN AND OPTIMIZATION METHODS

A three dimensional compressible Navier-Stokes code, AADL3D, has been developed to perform the aerodynamic design and optimization based on CFD. Roe's Flux Difference Splitting (FDS) scheme is implemented for the inviscid spatial discretization with the Monotonic Upstream-Centered Scheme for Conservation Laws (MUSCL). And a fully implicit Lower-Upper symmetric Gauss-Seidel scheme (LUSGS) is employed for time integration. To account for nonequilibrium chemical reaction for mixtures involving hydrogen, oxygen, and nitrogen, Moretti's eight-step and seven species chemical reactions model is employed.

By applying the high fidelity methods to the specific analyses, for instance, Navier-Stokes code application for the aerodynamic analysis, the accuracy of the analysis can be improved, but the computational efforts and cost are big obstacles during the optimization process which requires repetitive analysis calculations. The repetitive response surface enhancement technique (RRSET) [1] is proposed as a new system approximation method for the efficient aerodynamic design and optimization. In order to represent the highly nonlinear behavior of the response with second order polynomials, RRSET introduces a design space transformation using stretching functions and repetitive response surface improvement.

## 3. AERODYNAMIC DESIGN APPLICATIONS

### 3.1 Air-launching rocket

A study of a supersonic separation of air-launching rocket from the mother plane is performed. Influential factors during the rocket separation from the mother plane are extracted through comprehensive analyses. By the presence of the properly designed fins, the pitch-up motion is stabilized and safe separation is guaranteed. Through the investigation of the shock interaction effect between the rocket and the mother plane, a guideline for the safe separation is proposed.

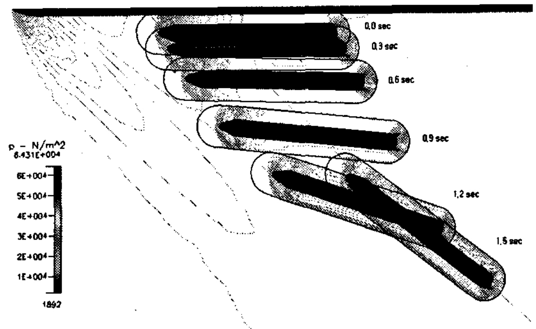
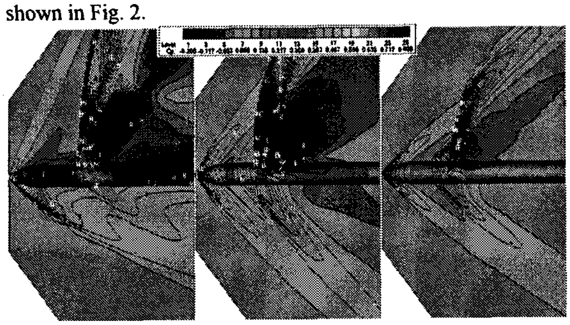



Fig. 1 The supersonic separation of air-launching rocket

### 3.2 Lateral jet controlled missile

The behavior of the normal force and the pitching moment characteristics have been investigated for the different jet flow conditions, angle of attacks, circumferential jet nozzle locations and spouting jet angles [2]. Based on results of the aerodynamic analyses around lateral jet controlled missile for various conditions, pitching moment and normal force are selected as the objective and constraint functions, and the Mach number, the angle of attack and the spouting lateral jet angle are chosen as design variables. The design optimization of the lateral jet controlled missile is performed to find out the most effective flight conditions for the missile control, as shown in Fig. 2.



(a) Baseline 1 (b) Optimum

Fig. 2 $C_p$ contour on the symmetry plane

### 3.3 Optimization of space launcher [3]

To effectively reduce the computational loads during the optimization process, RRSET[1] is implemented as a refined response surface method for the nose fairing design of a space launcher. Sub-optimization for the design space parameters and the iterative regression model construction technique are proposed in order to build response surface with high confidence level using minimum number of experiment points.

The result shows that an optimum nose fairing shape is obtained with four times less analysis calculations compared with the sensitivity-based optimization method. The techniques can be directly applied to the multidisciplinary design and optimization problems with many design variables.

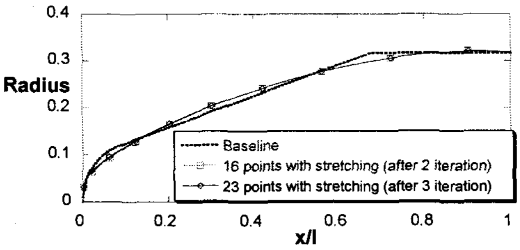



Fig. 3 Results of nose faring configurations

A multi-point optimization technique has been implemented to improve the performance over a wide operating range for the shape design of a nose fairing to a space launcher. The key flight events are simplified for efficient multi-point design and separate response surfaces have been constructed for each design point. The response surfaces are combined together with a weighting factor to construct an objective function. The shape function approach and the Nonuniform Rational B-Spline (NURBS) curve approach are implemented and compared for modeling the nose geometry. The optimization approach proposed in this study results in a nose fairing shape of the launcher that has a 24% improved drag characteristic when compared to the baseline shape.

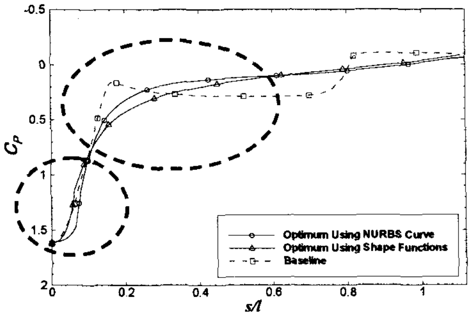



Fig. 4 Surface pressure distributions (Design point 2)

### 3.4 Supersonic diffuser design of rocket ramjet engine

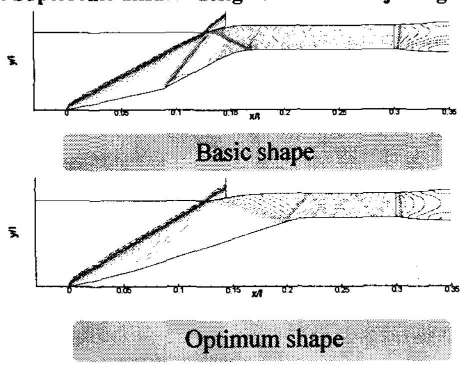



Fig. 5 Comparison of basic and optimum shape (Mach Contour)

Optimal supersonic diffuser shape of integrated rocket ramjet engine was derived which maximizes the total pressure recovery. Mass flux is considered as a design constraint and the second oblique shock angle of the external ramp, the cowl-lip angle and the throat area are selected as design variables. Virtual nozzle was located at the end of throat to adjust the back pressure. With only 20 aerodynamic analyses, optimal diffuser shape which has 14% improved total pressure recovery characteristics was successfully designed.

### 3.5 Premixture optimization of ram accelerator

This problem [4] is to find the minimum ram tube length required to accelerate projectile from initial velocity $V_0$ to target velocity $V_e$. The premixture is composed of $H_2$, $O_2$, $N_2$ and the mole numbers of these species are selected as design variables. The objective function and the constraints are linearized during the optimization process and the gradient based SLP (sequential linear programming) has been employed. RSM with design space stretching technique approximates the response surface accurately near the highly nonlinear region and results in a good optimum value, hence it is demonstrated that the RSM can be applied efficiently to the design problems which requires huge computational time like ram accelerator analysis.

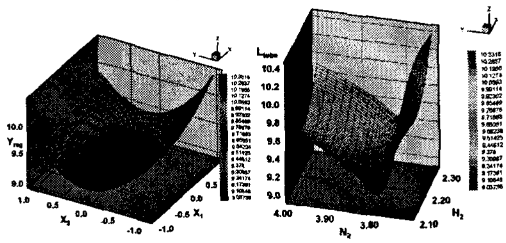


*Fig. 6 response surface (left) coded variable space, (right) natural variable space (at β=7 )*

## 4. CONCLUDING REMARKS

Computational approaches for aerodynamic design and optimization are presented. Several optimization problems are analyzed by using CFD and recent design methods. It is shown that the present system approximation technique reduces computational cost of CFD analysis and improves efficiency of the design optimization process.

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