Integrated Approach of Requirements, Mission and Design for Space Launch Vehicle Development

Jin-Wook Kim, Jung-Il Shu*, Seong Jun Cho*, Jae-Woo Lee*, Sangho Kim*, and Joon Chung***

**Aerospace Information Engineering, Konkuk University, 143-701, Seoul, Korea*

***Aerospace Engineering, 350 Victoria Street, Toronto, Ontario, Canada M5B 2K3*

Abstract

In this study, our integrated design process for space launch vehicles (SLV) was developed. The established design process consisted of the 'Requirement Analysis', 'Mission Design', and 'Subsystem Design' stages. In the 'Requirement Analysis' stage, the system requirements and initial points for design optimization are determined and delivered to the 'Mission Design' stage. From the 'Mission Design', users can check the sizing and mission of designed SLV. Based on the results of this stage, the 'Subsystem Design' stage is conducted. Then, the subsystems like the propulsion systems, weight of each sub-system were analysed through it. The entire design stage for SLVs was integrated systematically and performed to show the effectiveness of this process.

1. Introduction

The design for space launch vehicles is based on the system engineering process. The general design process is commonly defined as shown in figure 1.[1] Initially, the requirements analysis starts on a basis of customer's voice. In the phase of the mission design, a sizing analysis for launch vehicles is performed by integrating several disciplines or functional analysis modules as the system using the Multi-Disciplinary Optimization (MDO). The trajectory simulation is required to obtain mission profiles and confirm whether rockets complete missions or not.[2] The baseline configuration of SLVs, which is the essential information for the conceptual design process, can be obtained as results of the mission design.

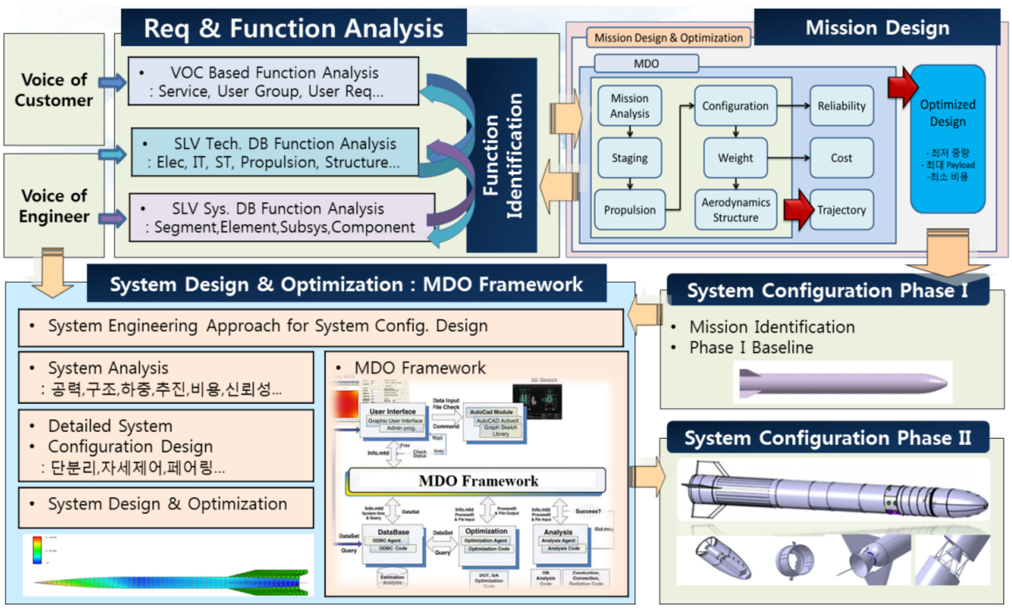

Figure 1: General Design Process for SLVs

2. Design Process for SLVs

The design process for SLVs consists of the 'Requirement Analysis', 'Mission Design', and 'Conceptual Design' as shown in figure 2. Basically, they were placed on a basis of the systems engineering process in order to have a systematic design. As soon as the requirements are established, the 'Subsystem Design' starts after the mission design. If the failure of a design at the final stage occurs, it happens that the requirements analysis is performed from scratch.

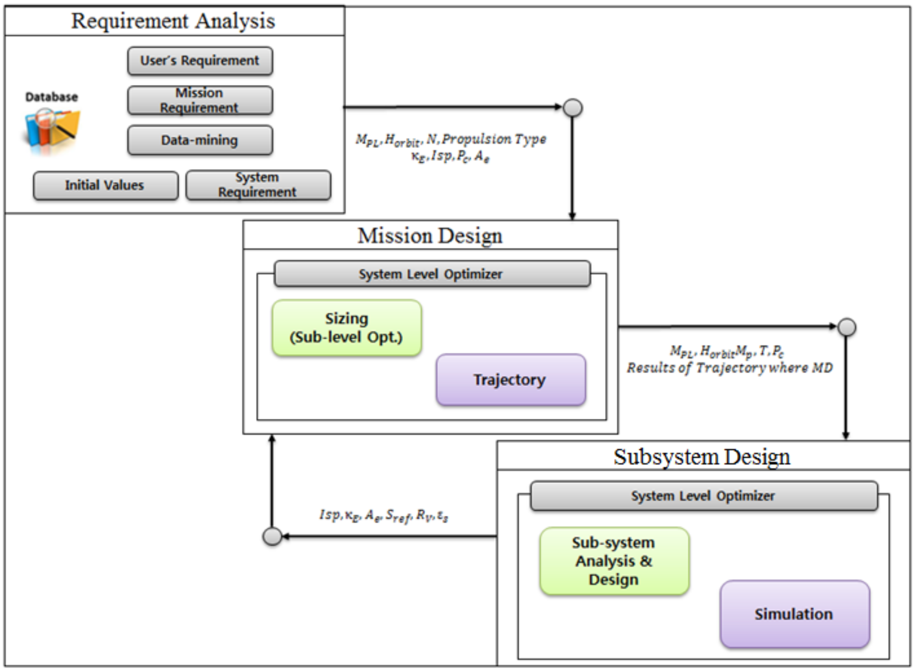

Figure 2: Overall Design Process for SLV

2.1 Requirement Analysis

Database for the world's competitive launch vehicles was built to aid the requirements analysis. The database includes a host of information on the launch vehicle performance, such as the mission performance, configuration, mass, and propulsion. In addition, users can access to the database at which 72 species of launch vehicles in aggregate exist. They are categorized into various items such as nation, rocket families, and number of stages. To embark on the process, the requirements analysis is initially carried out along with the customer's needs. The database provides a great deal of information of the existing launch vehicles selected by the payload and orbit height using data mining techniques. The data-mining is the process that uses a variety of data analysis tools to discover patterns and relationships in data that may be used to make valid predictions. The k-Nearest Neighbor (k-NN) and regression method is selected as our data-mining technique [3]. The k-NN method finds apropos candidates in order of proximity to the target defined by users. Some parameters such as number of stages, diameter, volume ratio, thrust to weight ratio, and propellant type are determined by the first nearest neighbor. The other parameters are obtained through the regression of the system properties from all candidates selected by the k-NN method. Through the 1-NN and k-NN & regression method, several parameters are determined and the others can be obtained to calculate using the results of the data-mining [6].

2.2 Mission Design

Mission design stage is performed after the requirements analysis is completed. This stage consists of two parts: one is the sizing analysis as the sub-system level optimization, and the other is the trajectory analysis as the system level optimization as shown figure 3. The sizing analysis part includes the Mission Velocity, Staging, Propulsion, and Configuration module. System baseline is determined as the result of the sizing analysis so that the trajectory analysis can be well-performed. Such outputs can be obtained via the trajectory optimization: the mission profile, mass, velocity, flight path angle, and dynamic pressure variations over time. Normally, the velocity loss is fed back to the sizing analysis part since it is calculated through the trajectory analysis. The baseline configuration of designed SLV, several specification and mission are drawn from the 'Mission Design' stage. These results are transmitted to the 'Subsystem Design' stage.

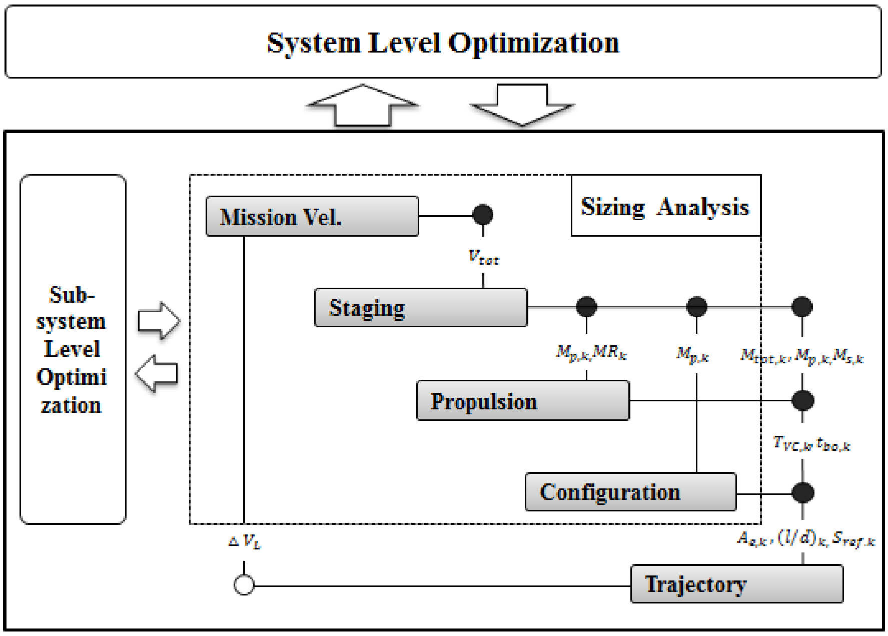

Figure 3: Design Structure Matrix (DSM) for Mission Design

2.3 Subsystem Design

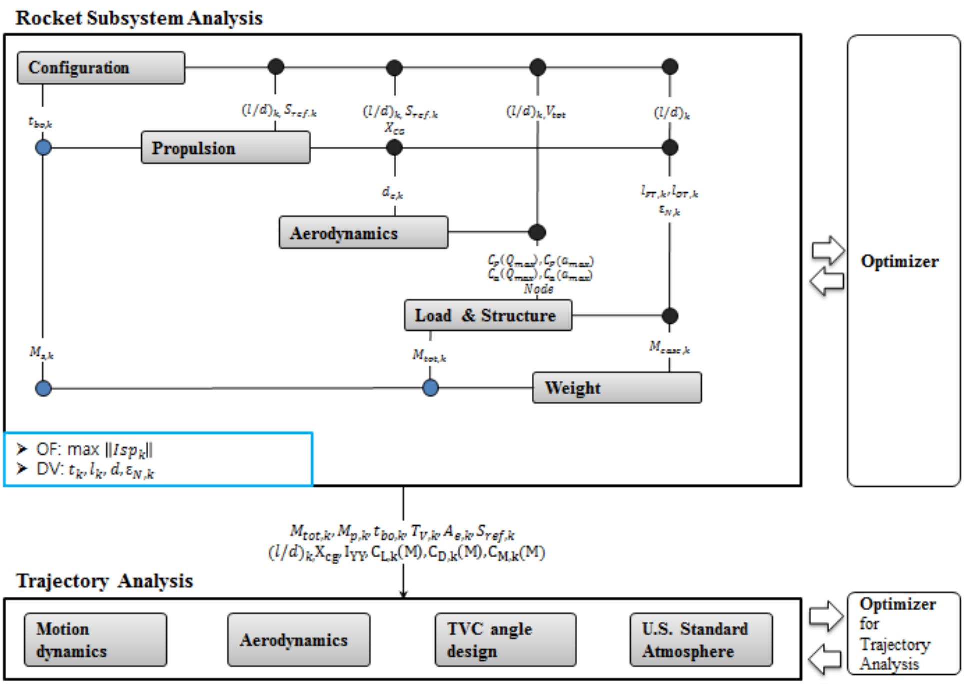

Figure 4: Design Structure Matrix (DSM) for Conceptual Design

The subsystem design stage consists of the Geometric Modelling, Propulsion, Aerodynamics, Load & Structure, Weight, and Trajectory module as shown in figure 4. This stage includes two optimization parts as the mission design stage does: one is the subsystem design part and the other is the trajectory simulation part, and these are

performed sequentially. In the subsystem design part, such variables like the length, diameter, thickness, and nozzle expansion ratio are selected as design variables. As soon as the subsystem design is completed via the optimization, either success or failure depends upon the result of the trajectory simulation.
The Subsystem design stage provides the information such as the configuration including the shape of its exterior and propulsion systems, weight properties, and the performance of propulsion systems. The variables obtained from the subsystem design stage, such as the specific impulse, thrust to weight ratio, engine mass, engine budget, and nozzle exit area are returned to the 'Mission Design' stage. As a systematic process for the launch vehicle design, both mission design and subsystem design stages are combined coupled together. The entire process does not halt until it is converged.

3. Design Results

A design on a basis of Korea Space Launch Vehicle-II (KSLV-II) was successfully completed using the established process. Table 1 represents inputs for the process based on the specification of KSLV-II. Table 2 shows the results of the entire process.

Table 1: Inputs for Integrated Design Based on the KSLV-II

Variables		**Stage 1**	**Stage 2**	**Stage 3**	**Unit**
Requirements	Perigee		700.00		km
	Apogee		700.00		km
	Payload Mass		1500.00		kg
	Fairing Mass		900.00		kg
	Fairing Length		4.0000		m
	Orbit Inclination		98.200		deg
	Longitude		170.00		deg
	Latitude		30.000		deg
	Azimuth Angle		170.00		deg
Configuration	Diameter	3.3000	2.9000	2.6000	m
Propulsion	Propulsion Type	Liquid	Liquid	Liquid	-
	Propellant Type	LOX/RP-1	LOX/RP-1	LOX/RP-1	-

Table 2: Results of Integrated Design

Variables		**Stage 1**	**Stage 2**	**Stage 3**	**Unit**
Mass	Total	214.88	38.811	6.6482	kg
	Propellant	162.61	28.479	2.8507	kg
	Structure	13.455	3.6844	1.3975	kg
	Mass Ratio	4.1112	3.7562	1.7507	-

	Structure Ratio	0.0764	0.1146	0.3290	-
Configu-ration	Length	26.409	6.7404	3.3295	m
	Diameter	3.1296	3.1296	3.1296	m
	Thickness	0.0026	0.0031	0.0026	m
Propulsion	Propulsion Type	Liquid	Liquid	Liquid	-
	Propellant Type	LOX/RP-1	LOX/RP-1	LOX/RP-1	-
	Thrust	2983.2	788.72	68.670	kN
	Specific Impulse	273.53	314.50	322.98	sec
	Chamber Pressure	60.000	60.000	70.000	bar
	Nozzle Expansion Ratio	8.5982	39.616	200.00	-
	Nozzle Exit Area	2.9253	1.9825	0.8588	m^2
	Burning Time	136.20	157.01	150.55	sec

4. Conclusion

A systematic design process was developed, consisting of three stages of analysis: requirements analysis, mission design, and subsystem design. This integrated design process was established based on the systems engineering process. By using data-mining techniques, reasonable values for initial parameters were suggested, and the requirements were established; this promoted the optimization to find the best design solution rapidly.
Based on it, the design process was performed. Additionally, the design results were obtained from the properly developed in-house codes for the Mission Design and Subsystem Design.

Funding

This work was supported by the Space Core Technology Development Program (No. 2012033512) of the National Research Foundation of Korea and the Ministry of Science, ICT & Future Planning.

References

[1] Walter E. Hammond. 2001. Design Methodologies for Space Transportation Systems. AIAA Education Series.
[2] Bum-Seok Oh et. al.. 2004. The Conceptual Design of Launch Vehicle. Journal of the Korean Society for Aeronautical and Space Sciences. Vol. 30. pp. 130-141.
[3] Fayyad, Piatetsky-Shapiro, and Smith. 1996. From Data Mining to Knowledge Discovery: An Overview. in Fayyad, Piatetsky-Shapiro, Smith, Uthurusamy. Advances in Knowledge Discovery and Data Mining. AIAA Press/The MIT Press. Menlo Park. CA. p1-34.
[4] Walter E. Hammond. 1999. Space Transportation: A System Approach to Analysis and Design. AIAA Education Series.
[5] Steven J. Isakowitz, Joshua B. Hopkins, Joseph P. Hopkins Jr. 2004. International Reference Guide to Space Launch Systems. 4th Edition. AIAA.
[6] Jung Il Shu et al., Multidisciplinary mission design optimization for space launch vehicles based on sequential design process, *Proc IMechE Part G: J Aerospace Engineering*, DOI: 10.1177/0954410015586858