Development of Mission-Design Integrated Framework for Space Launch Vehicles

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Abstract

This study describes multidisciplinary design framework development based on system engineering concept for various space launch vehicles to assist aeronautical engineers to successfully design mission and system analysis process. Design framework is composed of five main stages: Requirements, Mission Analysis and Design, System Synthesis and Simulation, Integrated Mission Design, and Reliability and Cost Evaluation. Two databases are established: one is used in the process of data-mining for requirements and another is in the Graphical User Interface (GUI) development of framework. K-Nearest Neighbors (k-NN) and Regression methods are utilized to make the design optimization performed with fast and successful convergence by processing and estimating the data necessary for design optimization. Framework is mainly developed in VB.Net integrating with all discipline modules separately optimized in Matlab. It is demonstrated that much better design can be obtained by using this framework and considering the important design factors from various disciplines.

1. Introduction

Mission design is a kind of activities to plan and describe a mission that the requirements are satisfied with [1]. It is considered that the mission design is one of the most important phases of design, and the framework focused on the mission design of space launch vehicles based on the systems engineering process. It is possible for users to initially establish the mission requirements using data mining techniques in the framework. In this step, engineers are supposed to perform functional analysis and negotiate with customers in order to satisfy the requirements from both sides. However, there has been insufficient of the mediums or tools to enable users efficiently and easily specify their mission designs. Thus, this system engineering based framework is developed in VB.Net and integrated various disciplines to support users in their performance of analysis and design of missions for launch vehicles.

The paper is organized as follows. Section 2 presents implementation of this framework. System structure of this framework is presented in Section 3; Section 4 describes results after design completion; Section 5 is as to summaries and conclusions.

2. Framework Implementation

The implementation of the framework is based on system engineering concept and includes multidisciplinary design methods for successful mission design process for space launch vehicles. The framework involves different components such as aircraft analysis component, database system component, a Graphical User Interface (GUI) component, data mining, and geometry modeling. Analysis programs are implemented using Matlab programming language, which calculates sizing, aerodynamics, propulsion, mission, configuration, weight and structure, and so on. Rocket database is established in Excel based on hundreds of existing rockets to perform data mining using Excel VBA scripts to determine system requirements and initial values.

Local light-weight database is implemented and used for data integration between different programs and for maintaining data from multiple disciplines. Complete assembled figure of the designed launch vehicle is generated from CATIA.

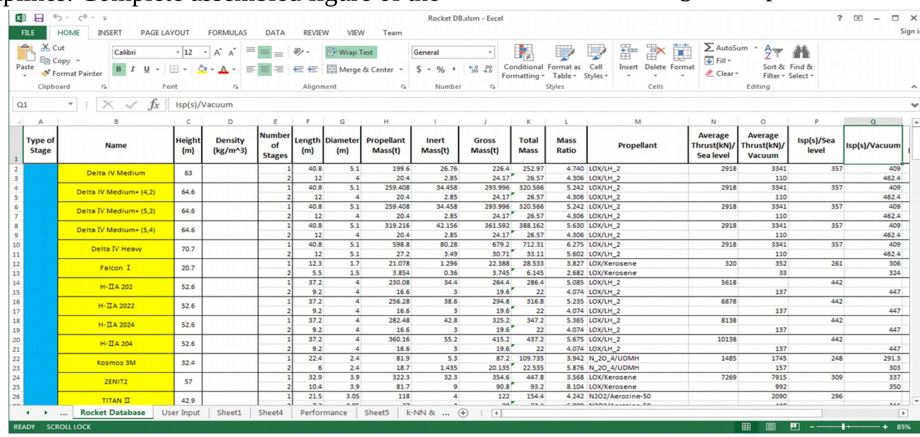
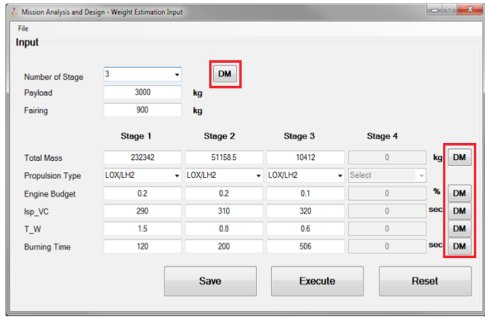


Figure 1. Rocket database

2.1. Data-mining Process

Any variable or parameter that is not specified explicitly in the program must be pre-defined before the program starts. Even running variables or parameters that are updated during the program requires initial reference values with



which to start the program. Those necessary values can be obtained by searching rocket databases as shown in Figure 2. In this study, a database was constructed using Microsoft Excel. The data were then categorized into various items such as nations, rocket families, and stages. To utilize the data for designs, it is recommended to use data-mining process.

Data-mining is the process that uses a variety ...atterns and ...ed to make ...data-mining ...k Nearest ...ods. ...cel VBA. It ...he perigee, ...t, azimuth ...predict and

Figure 2. Accessing data-mining results

values of the design parameters, and to establish system requirements. The results which are obtained can be accessible throughout the whole design process as shown in Figure 2.

2.2. Data Integration Process

The data integration process is divided into three processes: extract, transform, and load. Several different types of file systems (e.g. Flat File, spreadsheet, DB, CATVBA, Matlab and FORTRAN code) are considered for the data integration process. According to the design framework, several data type formats (e.g., design analysis data, aircraft geometry model design data, GUI input/output database, Rocket database) are extracted to be transformed into a uniform data format to be integrated into GUI.

During the transform state, the wrapper program transforms the uniform data format for different types of data from the extract state. The wrapper programs are developed using the Microsoft VB.Net and Matlab language with associated plug-in files, and are based on SQL querying statements. Figure 3 describes the process flow for data integration that is applied in our design framework. wrappers are software modules that manage the interactions between data sources and GUI. The wrappers enable different types of data sources for different database management systems, including CATIA and SQLite as well as document-oriented formats such as spreadsheets or flat text files to be integrated into GUI application. Two wrapper programs are implemented, and are called the database table connector wrapper and the API wrapper. The database table connector (DTC) is database integration program that interacts with GUI and analysis programs' input/output data and the SQLite database for data saving and retrieving processes. Additionally, the DB table connector wrapper provides capabilities, such as view, update, delete, query and export and import of the actual data. The API wrapper manages and controls data transfers between the GUI program and other data sources such as database, Excel, CATIA, Matlab and FORTRAN analysis programs.

3. Framework's System Structure

The

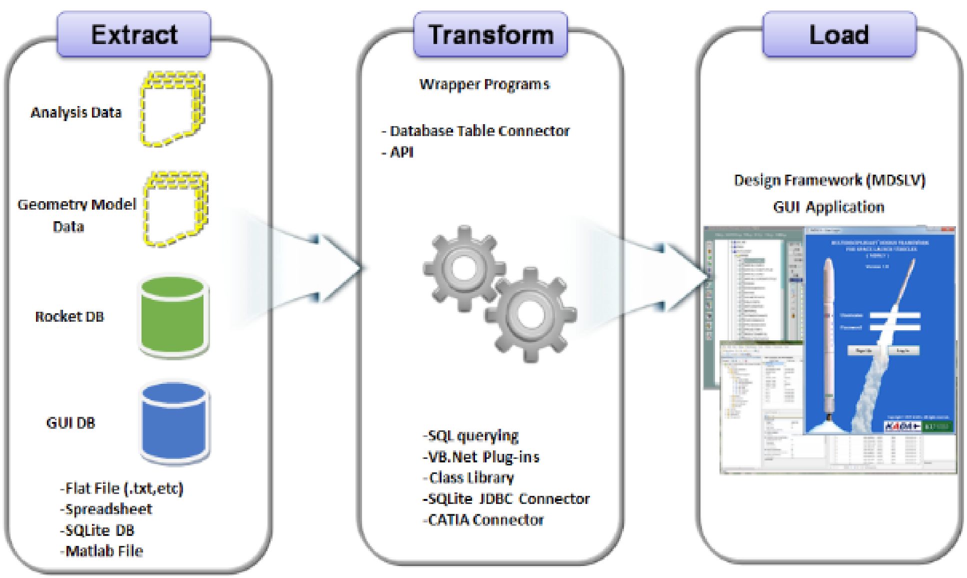


Figure 3. Data integration process for the framework

System architecture of the framework is illustrated in Figure 4. It describes the components of the framework which interact each other. GUI program is designed as a middleware for other components to be connected and interactions between them, and is developed using VB.Net. Excel is used to construct statistics of a variety of existing rockets for data mining of initial value determination and system requirements using k-Nearest Neighbor (k-NN) and Regression methods, and to execute Excel VBA script for automated processing of background data manipulation for data mining methods, and is linked with VB.Net to fetch data mining results back and forth between Excel and VB.Net. SQLite Database is used for storing all input and output data from GUI application since it is a lightweight local database suitable for our framework which is intended to be used locally. All the analysis and optimization codes are developed in Matlab Optimization Module but specifically trajectory analysis in FORTRAN. For the modeling of 3D design of launch vehicle, CATIA v5R18 is used and generates assembled 3D model completing through certain number of stages.

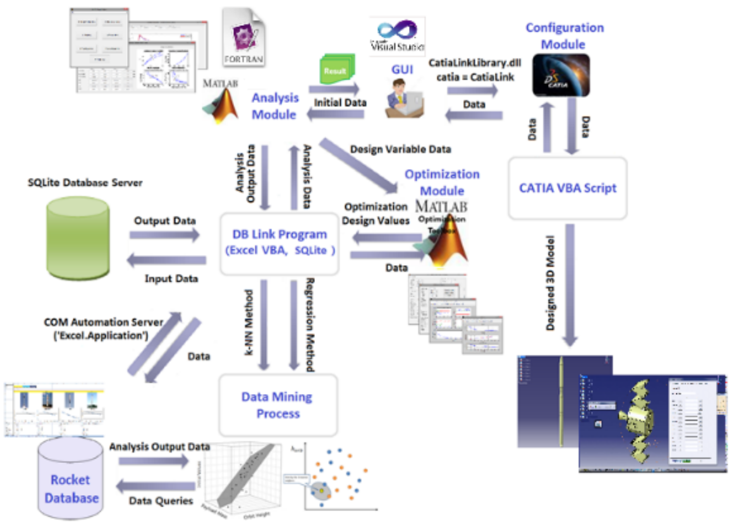


Figure 3. Framework's system structure

The mission-design integrated framework is composed of several dependent stages which interact each other, including requirement analysis module, mission analysis modules, system analysis modules, integrated mission design modules, and geometry modeling. Framework’s data flow is shown in Figure 5.

system baseline for designers. This part is required to solve the MDO (Multi-Disciplinary Optimization) problem in order to obtain system specifications. The information from this stage is provided for next stage, Mission Trajectory. The system weight, propulsion performance, configuration, etc. belong to the information. Based on it, Takeoff Gross Weight Estimation and Trajectory Optimization are performed. Based on the geometry and trajectory data obtained from this stage, partial 3D model of designed launch vehicle is assembled in CATIA.

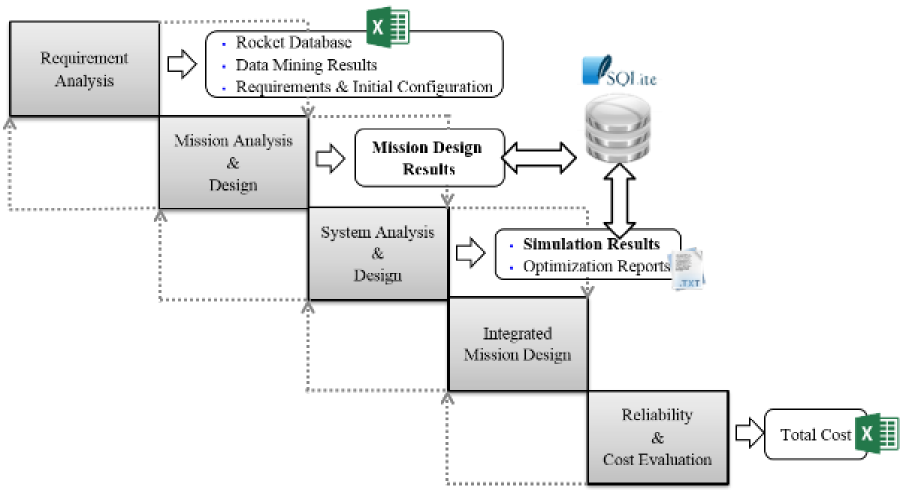


Figure 5. Data flow between each stage of framework

Since the framework is developed based on system engineering concept, it starts from Requirements, determining initial values of design parameters and system requirements for designed launch vehicle based on perigee, apogee, payload mass, and fairing mass provided from user by performing data mining on statistics of the hundreds of existing rockets established in Excel Database.

Mission Analysis and Design stage includes seven sub-modules: Weight Estimation, Mission Velocity, Staging, Propulsion, Configuration, Aerodynamics, and Trajectory which all interact and send coupling data back and forth each other. This process is concentrated on providing the Thus, both the Mission Analysis and the Trajectory Analysis parts are sequentially optimized. Integrated Mission Design combines both mission and conceptual designs into one process, performing them at the same time.

System synthesis and simulation stage is composed of two modules: System Synthesis and Design, and Trajectory Simulation, and Configuration Modeling. System Synthesis and Design consists of five sub-modules: Configuration, Propulsion, Aerodynamics, Load and Structure, and Weight which interact each other with coupling data.

Trajectory Simulation is made up of Sub-system Design and Trajectory which are designed for 2nd and 3rd stage rockets, and is focused on the optimization with the fast convergence in the phase of a mission design. Based on the geometry data obtained from that stage, configuration modeling part is performed, generating the final assembled 3D figure of designed launch vehicle.

Integrated Mission Design is intended to perform both mission and conceptual design analysis of launch vehicle in one stage, yielding mission and conceptual design output variables, optimization report and so on. In the final stage, reliability of the designed launch vehicle, production cost, development cost, and total cost are evaluated.

4. Design Completion

The optimizations for Takeoff Gross Weight and Trajectory are sequentially performed based on the results obtained from the data mining, as shown in the Table 1. Table 2 represents the results of the optimization for the Takeoff Gross Weight.Once mission is successfully designed, trajectory analysis is performed with selected optimization option, mission, specification and flight information.

Table 1. Results of the mission requirements through the analysis [3]

	Name	Unit	Stage		
			1st	2nd	3rd
Requirements	Perigee	km	700		
	Apogee	km	700		
	Payload mass	kg	2100		
	Fairing mass	kg	900		
	Propulsion Type	-	LRE	LRE	SRM
	Propellant Type	-	RP-1	RP-1	HTPB
	Diameter	m	3.0	3.0	2.4
	Mass ratio	-	≤3.2	≤6.2	≤4.1
	Engine mass ratio	-	0.252	0.177	0.094
	T/W(Upper)	-	≤1.600	≤1.500	≤1.900
	T/W (Lower)	-	≥1.367	≥1.359	≥0.448
	Mass flow rate	kg/s	Free	Free	Free
	Nozzle length	m	≤0.6 d	≤0.6 d	≤0.6 d
Initial Condition	Total mass	ton	192.8	66.9	12.2
	Propellant mass	ton	118.2	50.6	6.6
	T/W	-	1.367	1.359	0.448
	Burning Time	-	122	178.6	385
	Chamber Pressure	bar	101.5	64.5	88.2
	Nozzle Expansion R.	-	10.3	32.3	87.9

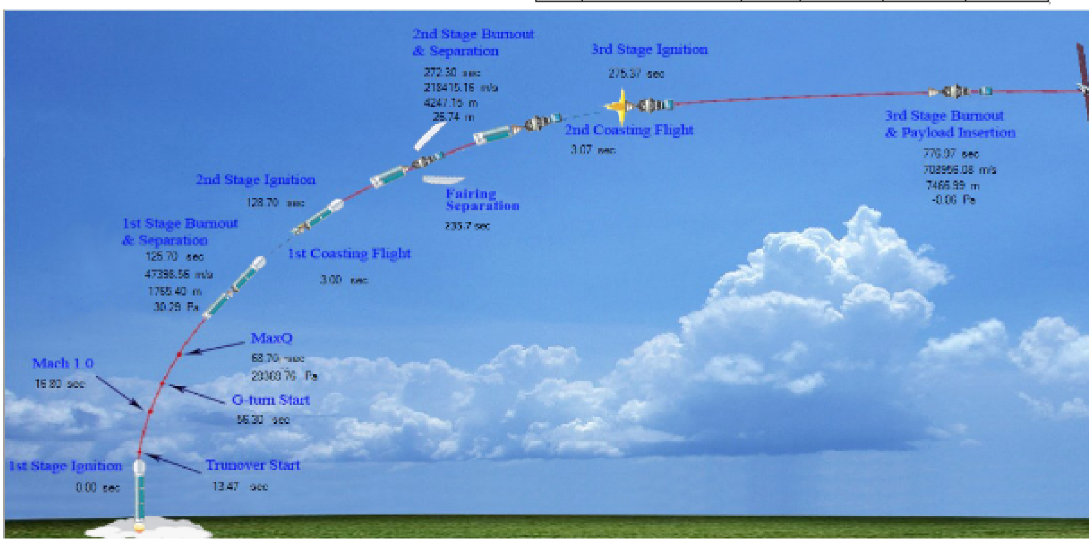


Figure 6. Trajectory analysis output - flight sequence of 3-stage rocket

Table 2. Results of the optimization for the takeoff gross weight [3]

Name		Unit	Stage		
			1st	2nd	3rd
Mass	Total mass	ton	187.33	45.86	8.09
	Propellant mass	ton	128.79	33.62	4.73
	Structure mass	ton	12.689	4.149	0.353
	Structure ratio	-	0.0896	0.1098	0.0694
	Engine mass	ton	3.200	3.748	2.412
Propulsion	T/W	-	1.377	1.361	0.448
	Burning time	sec	112.8	151.7	524.2
	Chamber pressure	bar	142.2	109.8	90.5
	Specific impulse	sec	^{SL}281.0	^{VAC}313.2	^{VAC}329.7
	Thrust	kN	^{SL}2761.3	^{VAC}905.6	^{VAC}73.9
	Nozzle expansion R.	-	18.8	34.1	118.1
	Nozzle exit area	m^2	2.40	1.66	0.54
	Nozzle length	m	2.0	1.8	1.1
Dim.	Length	m	18.4	7.5	3.1
	Length total	m	Total:35.72(Fairing: 6.72)		
	Cross sectional area	m^2	7.069	7.069	4.524
Velocity	Velocity fraction	-	0.2573	0.3347	0.4080
	Velocity distribution	m/s	2357.9	3031.2	4024.0
	Total mission velocity	m/s	9863.0		

As a result, optimization information, decision variables, flight sequence of selected stage of launch vehicle as shown in Figure 6, and report of optimization results are obtained.

5. Conclusion

In the past, design frameworks tend to be text-based which makes engineers debugging and analysis an inconvenient process. This distracts them from focusing on the main task of designing and verifying new designs.

This framework is based on system engineering and designed in GUI so that it can be user-friendly and speed up the user's work. It is more attractive for non-technical people also. In aspects of functions and capabilities, user can simply access data mining results which are more accurate than other existing ones without having to know how it is being processed in the background and see the results at real-time.

Even if the mission fails at certain stage, user can go back to previous stage to perform analysis again until it is successfully designed. In this way, it is time saving that user doesn't need to start from the very beginning of the design process. The database table connector wrapper program plays a role in providing an integration of the analysis programs and database system in a uniform data format.VB.Net programming based on the API wrapper program provides automatic data integration of design analysis data resources from Matlab, FORTRAN, Excel, and CATIA software for geometry modeling. Overall data integration processes to GUI program are described. System and program architecture of the framework is illustrated and explained.

Finally, the mission-design integrated framework for space launch vehicles is established with several distinct aerospace engineering disciplines through efficient database design and data integration and it can be used as a tool for designing a space launch vehicle starting from determining initial requirements to final reliability and cost evaluating in aerospace academia and industry.

Acknowledgements

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References

[1] Walter Edward Hammond, Design Methodologies for Space Transportation Systems, AIAA Education Series, AIAA, 2001

[2] Hwan Seoung Yong, Yeon Muk Na, Jong Soo Park, Hyun Woo Seoung, Min Soo Lee, Sang Joon Lee, Lyn Choi, *Introduction To Data Mining*, Infinity Books.

[3] Thawdar Lwin, "*Efficient Space Rocket Mission Design Framework with Database Integration and Data Mining Automation*", Master Thesis, Department of Aerospace Information

Engineering, Konkuk University, Seoul, Korea, November 2014.

[4] Thawdar Lwin, Jung-Il Shu, Jin-Wook Kim, Jae-Woo Lee*, Sangho Kim, “Interactive Space Launch Vehicle Design Framework Development using Centralized Database Architecture”, Korean Society of Propulsion Engineers (KSPE) Conference, November 2014.

[5] Thawdar Lwin, Jung-Il Shu, Jin-Wook Kim, Jae-Woo Lee*, Sangho Kim, “*Interactive Space Rocket Framework Development for Rapid Mission Design and Analysis*”, Korean Society for Aeronautical & Space Sciences (KSAS) Conference, April 2014.

[6] Jin-Wook Kim, Jung-Il Shu, Thawdar Lwin, Jae-Woo Lee*, Sangho Kim, "Systematic Mission-Design Process and Framework Development for Space Launch Vehicles", CKC, July 2015.

[7] Jin-Wook Kim, Jung-Il Shu, Thawdar Lwin, Jae-Woo Lee*, Sangho Kim, “*Interactive Space Launch Vehicle Design Framework Development using Centralized Database Architecture*”, Korean Society of Propulsion Engineers (KSPE) Conference, May 2015.