A New Mission Design Approach for a Multi-disciplinary Space Rocket System Design

Jung-Il Shu, T. J. Kwon*, Jae-Woo Lee*, Sangho Kim*, and Joon Chung***

**Konkuk University*

Konkuk University, Seoul, 143-701, Korea

***Ryerson University*

Ryerson University, Toronto, Ontario, Canada

Informative Abstract

In this study, a new mission design process of a space launching rocket is developed by integrating discipline functions categorized in mission analysis, staging, propulsion analysis, configuration, weight analysis, aerodynamics, and trajectory analysis modules. And a rocket specification database is built to rationally determine initial values of some variables at each module. Through the multidisciplinary optimization method the baseline configuration of the rocket, which is essential information to carry out a conceptual design process, is represented as a result.

This mission design process utilizes the lower fidelity funtional analyses than the conceptual design process does. To be specific, pre-developed in-house programs are adopted with modifications to mission and aerodynamics analysis modules by applying the appropriate empirical equations in the analyses. And Top3D, the in-house trajectory analysis program, is used to analyze the motion of the rocket with the 3 degrees of freedom.

For the optimization problem, rocket sizing, trajectory analysis, and propulsion analysis modules are coupled. First, the two-step mission and trajectory optimization, and MDF, CO problem are formulated. Then the two step mission and trajectory optimization, and MDF approaches are implemented. In this sense, it is demonstrated that much better design can be obtained by simultaneously considering the important design factors from the various disciplines.

A Brief Technical Demonstration

Each module has its own role and feature. In the mission analysis module, the mission velocity at a specific altitude can be calculated by considering the velocity loss due to gravity, drag, and atmospheric pressure change. And these velocity losses can be obtained by using empirical equations which require some variables as inputs, such as specific imulse, thrust to weight ratio, burnout flight path angle, and mass ratio for each stage.

However, these variables are undetermined initially. To be specific, the rocket designer should not arbitrarily choose the values. To solve this problem, the module named Initial Value Calculation, which is connected to the rocket specification database and the mission requirement, are put on the design process. Before the whole mission design process is carreid out, initial values of the specific variables are determined and calculated by using data mining techniques. Some specific data from mission requirements, such as a payload mass and an orbit type are keywords to find the initial values from the database. Thus, the user inputs of each module can be obtained by carrying out this module as well.

In the staging module, given some variables from the mission analysis module as inputs, the variables such as the total mass, propellant mass, structure mass, specific impulse, burning time and required thrust are represented as outputs. To be specific, total required velocity is accordingly distributed to each stage of the rocket by determining the mass ratios, structural coefficients and the velocity fractions of each stage.

The variables from the staging module, such as the payload mass, required thrust, burning time, propellant mass, specific impulse at vaccuum condition, are the inputs to the propulsion analysis module. And with these variables which indicate the required condition to achieve the mission, the propellant mass flux, the specific imulse, and the overall configuration of the rocket engines/motors are calculated. The performance of the engine/motor designed at this module should be satisfied with the required condition above.

Based on the engine/motor geometries, the configuration of the rocket is created in the configuration module. Hence, the total length/diameter of rocket and the geometry of the control fins are determined.

Weights of subsystems like the motor case, control fins, rocket nozzle, fairing, and TVC(Thrust Vectoring Control) are obtained (weight module) and the normal force and axial force coefficients are calculated in the aerodynamic module.

Using data from the previous discipline functions the optimal trajectory of the launch vehicle is calculated at the trajectory module. The required input data include launch information as the initial conidtions of altitude, longitude, latitude, velocity, flight path angle, and azimuth angle. They also require mass fractions such as structure and propellant mass at each stage, and propulsion information like thrust profiles, specific impulses, and nozzle exit areas at each stage. With pre-defined event time and initial guess of control varable, angle of attack (and side slip angle in 3 DOF case), the optimal path is designed in favor of the maximum payload mass or the minimum total mass of the rocket.

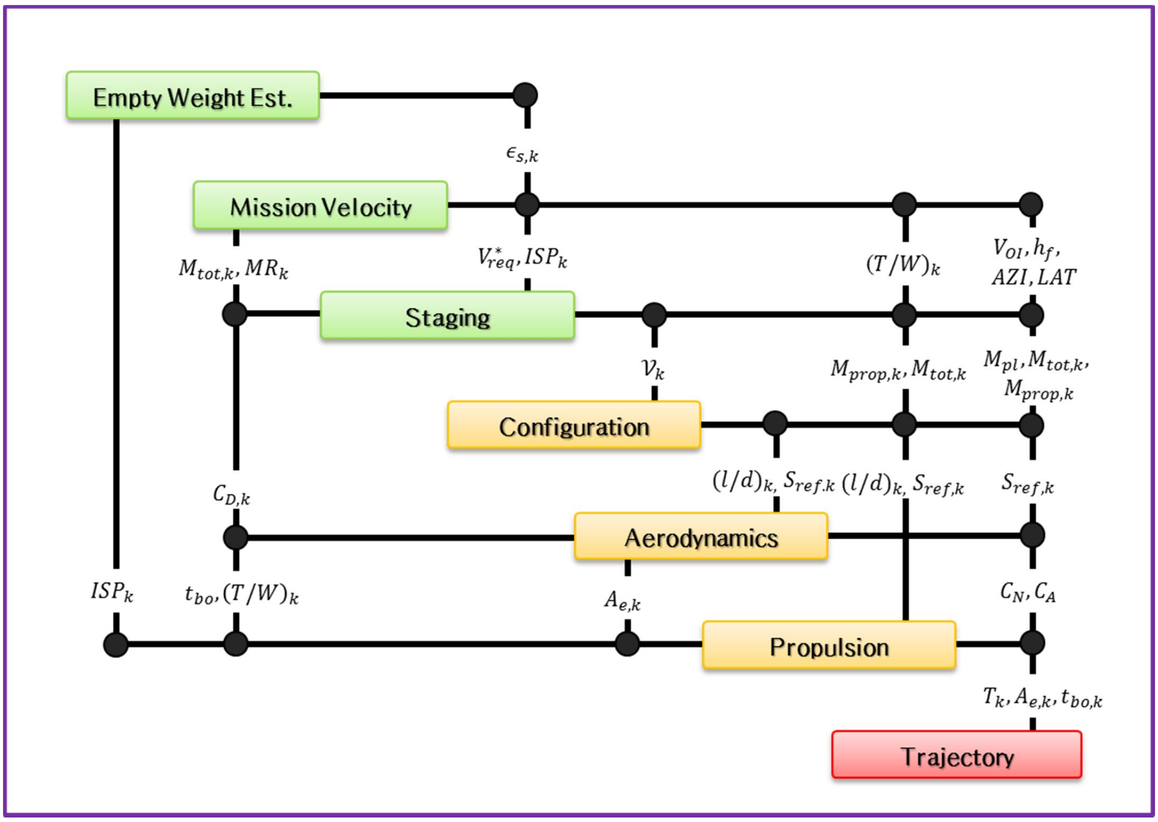

Figure 1: Mission Design Process based on Design Structure Matrix

Description of Variables

LAT = Latitude

AZI = Azimuth

h_f = Vehicle Altitude at Final Position

V_{OI} = Orbit Insertion Velocity

ISP_k = Specific Impulse

$C_{D,k}$ = Drag Coefficient

$\epsilon_{s,k}$ = Structure Coefficient

MR_k = Mass Ratio

M_{pl} = Payload Mass

$(T/W)_k$ = Thrust to Weight Ratio

V^*_{req} = Required Mission Velocity

$M_{prop,k}$ = Propellant Mass

$t_{bo,k}$ = Burning Time

$M_{tot,k}$ =Total Mass of a Vehicle

T_k = Thrust

$\mathcal{V}_k$ = Overall Volume

$(l/d)_k$ = Fineness Ratio

l_k = Length

d_k = Diameter of a Rocket

$A_{e,k}$ = Nozzle Exit Area

S_{ref} = Reference Area of a Rocket

C_N = Normal Force Coefficient

C_A = Axial Force Coefficient

(cf. The symbol, $\boldsymbol{k}$ indicates the *k*th stage of the rocket.)