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A Study on the Micro Gravity Sloshing Modeling of Propellant Quantity Variation

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Abstract

In this study, the sloshing phenomenon is analyzed for the internal fluid mass change. And the change of the sloshing modeling design variables according to the fluid mass change is also analyzed. First, the sloshing phenomenon for each case is analyzed by CFD when the internal fluid mass is fixed. An appropriate sloshing modeling structure is proposed based on the analyzed results. The PSO method, which is one of the parameter optimization methods, is used as a method for appropriately selecting design variables of proposed sloshing modeling. In the same way, assuming a situation where the internal fluid mass changes in several levels, the sloshing modeling design variables for each internal fluid mass are calculated. The internal fluid varies from 10% to 90% in 10% increments so it is divided into 9 levels. By understanding the relationship between the optimized modeling design variables and the internal fluid mass, a sloshing model can be proposed to respond to the internal fluid mass change.

Keywords: Sloshing Modeling, Second-order system, Parameter Optimization, Parametric Study

1. Introduction

Recently, various missions using spacecraft are increasing globally [1]. Various types of spacecraft are being created and launched, ranging from low Earth orbit to deep space exploration. For low Earth orbits, transports for space station maintenance and satellites to explore the Earth surface and for commercial purposes are being launched. In the case of deep space exploration, preliminary exploration is underway to build a base on the moon and Mars, and spacecraft is being launched or planned [2] for exploration of other solar system planets and outer planets. A common feature for these various explorations is that the size of space launch vehicles, probes and satellites used for

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each mission is required to increase because the cost of escaping the Earth's atmosphere is still very expensive [1]. In order to reduce the launching cost, it is necessary to carry out many missions with a single launch, which requires large-sized space launch vehicles, probes and satellites.

The reason for the increase in the size of spacecraft is to load many exploration equipment, but also to load a lot of fuel. Basically, moving objects in the space gets energy by consuming fuel stored inside rather than supplying energy from the outside. So putting a lot of fuel means that spacecraft can conduct many missions over a long period of time. Many spacecraft uses liquid fuel such as liquid hydrogen or kerosene [3]. The efficiency of the liquid fuel itself is good, and there are advantages such as re-ignition and thrust control. However, there is a problem that the liquid fuel is not fixed in the fuel tank unlike the solid fuel. Unfixed fluids can generate sloshing motion in response to spacecraft motion [4]. In particular, the larger the amount of fuel loaded, the greater the sloshing motion, which must be considered in spacecraft for the accurate operation.

Except spacecraft, sloshing phenomenon is found in tank lorries carrying various types of liquids and in all other transports carrying large quantities of liquids, all of which are affected by the sloshing motion. Therefore, sloshing motion analysis has been analyzed in order to guarantee the stability of such a carrier. However, in most cases, the sloshing analysis is performed mainly for the gravity situation because the gravitational force or similar acceleration is applied to the carrier. In this case, the sloshing motion could be simulated as a pendulum model, and the accuracy of the sloshing motion was verified through various studies [4-5].

Spacecraft, on the other hand, differs from conventional sloshing research in that it should perform maneuvering through attitude control even in the absence of gravity or acceleration. The sloshing motion that occurs in such a micro gravity situation is different from the motion that occurs in the gravity situation [6-9]. And computational fluid dynamics (CFD) study was performed on the sloshing in the micro gravity condition. It focuses on comparing CFD results with experimental results after assuming a specific situation and improving CFD analysis model for CFD's high accuracy [10].

However, it is difficult to directly apply CFD model to the design of spacecraft attitude control because CFD analysis generally requires several minutes to several tens of hours of computation time depending on the model in single process [4]. And a considerable number of simulations are required when designing a controller for a system. In particular, much more computation is required when designing controllers for systems with nonlinear structures that are not expressible as transfer function. Although it is a CFD model that can derive calculation results in a few minutes, it takes an enormous amount of calculation time to design the controller. Therefore, another alternative model for the spacecraft attitude control design is needed. The purpose of this model is to extremely reduce the total calculation time within a few seconds by simplifying the structure of the sloshing motion which occurs in the micro gravity situation [7].

There is also a problem with the internal fluid mass change. General spacecraft consumes fuel to perform its mission, the amount of internal fuel continues to decrease. The amount of internal fuel affects the sloshing motion, which is an important factor regardless of gravity. Therefore, modeling of various fuel quantities should be performed instead of modeling limited to one fuel quantity condition.

In this paper, the sloshing phenomenon that occurs in the micro gravity situation is discussed in Chapter 2. In order to analyze the sloshing phenomenon occurring in the micro gravity situation, the environment is set up and CFD is performed on the defined environment and the result is derived. Analysis of the obtained CFD result data can suggest a suitable type of sloshing alternative model, and design variables to construct the model are defined. Parameter optimization technique is used to select these design variables appropriately. The next Chapter 3 consider change in internal fuel mass for realistic analysis. The sloshing motion, which varies with the amount of internal fuel, is calculated by CFD and the design variable of the alternative model is calculated. It suggests a general alternative model to cope with changes in internal fuel quantity, which is one of the important factors of sloshing motion. Finally, conclusions are presented in Chapter 4.

Nomenclature

a	Acceleration input
d	Magnitude of the input
f	Frequency of the input
L	Second-order system for sloshing modelling