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RELIABILITY DEMONSTRATION OF PROPULSION SYSTEM OF SPACE LAUNCH VEHICLE

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ABSTRACT

In executing the large scale national project, such as development of space launch vehicle, it is most important to guarantee the technological reliability. However the reliability analysis of launch vehicle is different from other mass product goods because of the limitation of budget and number of tests. In this study, the reliability analysis technique of the propulsion system, which is one of the major sub-systems of launch vehicle is illustrated and applied to the liquid rocket engine of KSR-III.

Keywords: space launch vehicle, reliability, liquid propulsion system

1. INTRODUCTION

Development of space launch vehicle is important because it is a national project which consumes enormous money, and can show up the technological accomplishment of the nation like the case of Chinese space craft Shenzhou. In fact, number of the countries which successfully launched the satellite are so small to count on your finger. KSLV (Korean Space Launch Vehicle) series which developed by KARI (Korea Aerospace Research Institute) also have to accomplish space mission. They might fly over other nation's territory and should inject the satellite on the orbit accurately. The success of the launch depends on the reliability of the main system as well as sub-systems of the LV (launch vehicle). Among all the sub-systems, propulsion system is the most important one which can affect the mission success (Chang 1996). Almost half of the launch failures are caused by the defect of propulsion system. Therefore, development of reliable propulsion system is the key factor of the successful launch. For that reason, ensuring the reliability of propulsion system including sub-components was needed, and reliability management should be applied through the development program. In this study, reliability demonstration, which is one part of the reliability management, would be explained, and applied to the hot test result of the KSR (Korea Science Rocket)-III propulsion system.

2. RELIABILITY DEMONSTRATION

As part of reliability management, reliability allocation, prediction, verification and demonstration were executed (Christenson et al. 2003). The reliability demonstration is the probabilistic

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estimation of the reliability of propulsion system, which is based on the result of full scale tests. The matter of concern is whether the test is judged as success or failure. From this result, binomial count was performed to calculate the reliability at confidence level of specific number. The significance of the reliability demonstration is that the result of it is based on the solid data rather than supposition. Binomial counting is simple method that successful test number is counted before divided by the whole test number.

$$p = f/n \text{ where } \quad \text{f} = \text{number of successful test,} \tag{1}$$

$$\text{n} = \text{whole number of test} \tag{2}$$

However this estimation has inherent uncertainty caused by the limited size of sample. So, it is desirable to use the lower limit of confidence level which is derived from the statistical concept of confidence interval. The binomial distribution of reliability p % is as follows.

$$\sum_{x=f}^{n} \left(\frac{n!}{(n-x)!x!} \right) L^x (1-L)^{n-x} = \alpha \tag{3}$$

where, L = lower limit of confidence level, $p = 1 - a$

If the whole tests are successful, equation 1 can be simplified as follows.

$$L = (\alpha)^{1/n} \tag{4}$$

There are some difficulties to apply binomial count. At first, the definition of failure can be different among the people concerned, and it has the possibility of intruding the subjective judgement of evaluator. Secondly, the probability of future mission success would be presumed from the results of test executed, which means that small change of production process, launch and flight circumstance can increase the uncertainty. Finally, in order to ensure high reliability, large sample size must be needed, which is impossible to get in the field of launch business. To solve this, previous data using similar engine and integrated test of short duration would be included. Especially, the short duration tests need weighting factor.

3. APPLICATION TO KSR-III

To demonstrate the above contents, engine test data from the development of (KSR) III were used. KSR-III, which developed by KARI, was the first civilian rocket using liquid propulsion system. It was successfully launched on Nov. 28. 2002. In the way of developing liquid rocket engine, propulsion division of KARI established 2 test facilities. One was RETF (rocket engine test facility), which was used for engine test, and the other was PTA (propulsion test article) - II used for integrated performance verification of propulsion system. After PTA-II, SQT (stage qualification test) was performed and finally the flight test was executed. At the beginning of development, the engine of KSR-III had a problem concerning combustion instability, and the problem have been solved by the application of acoustic baffle. It can be said that the design freeze is accomplished after equipment of baffle.

In evaluation of reliability, only the data after design fix were used. The total number of tests used is 19. In detail, total number of tests during the engine development phase is 28, and the number of test after design freeze is 12. The number of test done at the PTA-II is 8, and the number of test after design freeze is 5. During these tests, there were 2 failure due to the facility malfunction and incidental emergency stop. SQT and flight test result are also included. From equation 2 using 50% of the confidence level, reliability is demonstrated as 86.3%.

4. CONCLUSIONS

In this study, reliability demonstration of propulsion system of launch system is illustrated, and applied to the hot test results of KSR-III. In the evaluation of reliability, the most important thing is guarantee of reliable database. Until now, we have difficulties in evaluation of reliability due to the lack of experience. It is hoped that reliable launch system can be acquired through the development of KSLV series.

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