Research on FMEA Application in Assembly Process of Complex Space Probes

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Abstract. The process of developing new spacecraft is time-consuming and task-intensive. This paper analyses various problems existing in the application of spacecraft FMEA, and points out that it is necessary to assure the validity of FMEA work, including normative FMEA work carried out in time, comprehensive identification of failure modes and their causes, correct expression of failure modes and their causes and effects, and the pertinence and maneuverability of measures to be taken. Taking the development of Mars rover as an example and considering the actual situation, the assembly process and FMEA agreement are proposed and formulated. According to the development process, the failure modes, causes and effects (severity) of the main processes are analyzed. The risk sequence number (RPN) is obtained by combining the frequency of occurrence and the difficulty of detection. Finally, through sorting out the assembly work and key points in each stage of AIT, 60 processes and 95 failure modes are analyzed, the possible weaknesses are found out, and the control methods and measures are put forward, so that the RPN values are below 12. Improve the quality and efficiency of product development by strengthening FMEA management, and ensure the smooth development of Mars probe on.

1. Introduction
FMEA (Failure Mode Effects Analysis) is an analysis technology that analyses every potential failure mode in a product and determines its impact on the product and classifies each potential failure mode according to severity level[1]. Since the first application of this method in the Grumman Aircraft Company (USA) development of aircraft control system in the 1950s, many international aerospace companies have taken compulsory measures to vigorously implement the FMEA method. For example, various types of satellites in the United States have stipulated that FMEA must be widely used. FMEA runs through the entire satellite product. The process, including strategy research and implementation, system management and operation, product design, process design, and so on, has achieved good results. FMEA has been gradually implemented in spacecraft design in China, which has played an important role in improving the reliability of spacecraft[2]. However, the reliability analysis of spacecraft assembly process is still in the exploratory stage in China, and there is a big gap compared with the mature reliability management system of spacecraft assembly abroad. Therefore, the research and application of process FMEA should be strengthened.

Functional FMEA, hardware FMEA and process FMEA are involved in spacecraft development. Functional FMEA functional FMEA and hardware FMEA hardware FMEA can be completed in the design stage, eliminating the weak links. Potential failure modes of process FMEA are eliminated...
iteratively along with product implementation process, mainly including processing, assembly, assembly, testing and so on[3].

Aiming at the actual situation of Mars Explorer development process, the standards are formulated and followed. Through sorting out the assembly work and key points in each stage of AIT, the possible weaknesses are found out, and the control methods and measures are put forward to improve the quality and efficiency of product development in management.

2. FMEA Workflow and Conditions

2.1. FMEA Workflow

Spacecraft companies pay more attention to and mostly carry out FMEA work than before, but process FMEA is seldom carried out, and there are various problems at the same time[4].

- FMEA management is not in place, and FMEA work has no closed-loop;
- FMEA lacks systematicness and low effectiveness.
- There are phenomena of "replacing reliability professionals" and "making up afterwards" in FMEA work, and the effect of FMEA is difficult to guarantee.

The FMEA of spacecraft assembly process should be standardized, especially the new process. Process FMEA should be implemented at the beginning of process design and finished before the process is formally applied. Assuming that the product design meets the requirements, identify the possible failure modes, causes and their effects on the product or process in each step of the process, identify the weak links in the process, and propose the possible improvement measures. The FMEA workflow of spacecraft product process is shown in Figure 1.

![Figure 1. The FMEA workflow of spacecraft product](image-url)
2.2. Conditions
According to the assembly technology process, the main processes are analyzed according to the sequence of stages, and the following agreements are made:

- The assembly process FMEA only deals with the important links in the assembly process at all stages starting from the delivery of the product, excluding the production process of the stand-alone product.
- Process FMEA analysis does not involve the installation of separation devices and pyrotechnics, which is reflected in special documents.
- The repetitive work, such as docking, decomposition, deck opening and closing, product hoisting, installation and disassembly of equipment, and cable insertion, is analyzed only once.
- It does not involve obvious and non-technical human factors, such as the instability of the grasp during the transmission of instruments and equipment.
- FMEA analysis does not involve potential hazards caused by force majeure.

3. Technical Scheme
According to the technical status and process of the assembly, the failure modes, causes and effects (severity) of the main processes are analyzed. The risk sequence number (RPN) is obtained by combining the frequency of occurrence and the difficulty of detection. The total risk sequence number (TRPN) is taken as the basis for determining the control measures[5].

3.1. Severity of failure effects
A severity category classification shall be assigned to each identified failure mode analysed. Severity categories are assigned without consideration of existing compensating provisions to provide a qualitative measure of the worst potential consequences resulting from item failure. The agreement on severity is shown in table 1.

| Definition  | Severity category                                                                 | SN |
|------------|----------------------------------------------------------------------------------|----|
| catastrophic | If the product is scrapped and the economic loss is serious, it will have a serious impact on the function of the system product, and will cause harm to people, such as loss of life or permanent disability injury or occupational disease. | 4  |
| critical   | It causes product damage or major overshoot and cannot be repaired; tasks can not be completed; temporary disability but no life-threatening injury or temporary occupational disease. | 3  |
| major      | It causes difficulties in the processing of this or subsequent processes, product overshoot, difficulty in rework and repair, task degradation or process degradation. | 2  |
| negligible | Excess tolerance is acceptable by concession; any other effect.                    | 1  |

3.2. Probability of occurrence
The probability of process FMEA failure mode occurrence is called process FMEA failure mode occurrence degree, which is a qualitative measure of the possibility of process FMEA failure mode occurrence caused by a certain reason. It is usually determined by experience or process statistics.
Only through process design to prevent or control the causes of process failure can the occurrence of process failure modes be reduced. Identify the probability of occurrence of Very likely, Likely, Unlikely, Extremely unlikely are defined as 4, 3, 2, 1.

3.3. probability of detection
Process FMEA fault mode detection degree refers to the qualitative measurement of process fault mode detected, which is divided into four levels. The agreement on the detection level is shown in Table 2.

| Definition                        | Instructions for Degree of Detection                                                                 | DN |
|----------------------------------|------------------------------------------------------------------------------------------------------|----|
| Undetectable                     | There is no known detection method and means to detect the failure mode.                               | 4  |
| Indirect detection or visual measurement | The current detection methods and means are difficult to detect fault modes, or can only be detected by high-level assembly or testing | 3  |
| Direct inspection after completion | In the follow-up process or product, the fault mode can be detected by the current detection methods and means | 2  |
| Direct Inspection of Process     | The fault mode can be detected by the current detection methods and means in the process              | 1  |

3.4. Determination of the criticality number (CN)
Risk Priority Number (RPN) is a measure used when assessing risk to help identify critical failure modes associated with your design or process. The criticality number (CN) shall be defined as the product of the numbers assigned to failure mode severity, probability of occurrence, and probability of detection according to:

\[ \text{RPN} = (SN) \times (PN) \times (DN) \]

The RPN values range from 1 (absolute best) to 64 (absolute worst). The FMEA RPN is commonly used in the automotive industry and it is somewhat similar to the criticality numbers used in Mil-Std-1629A.

3.5. Criticality acceptance criteria
The risk of a potential weak point is regarded as unacceptable and a recommendation for additional preventive or compensatory provisions shall be given if:

- the severity number \( SN \geq 3 \)
- the probability number \( PN = 4 \)
- the detection number \( DN = 4 \)
- the criticality number \( CN \geq 12 \)

Criticality acceptance criteria may be tailored to suit individual projects.

4. Detector assembly process and FMEA results

4.1. Detector assembly process
The general development process of spacecraft is shown in Figure 2. In this paper, process FMEA analysis is carried out according to the flow chart and assembly characteristics of Mars probe development.
Figure 2. The FMEA workflow of spacecraft product

4.2. **FMEA results**

FMEA of MARS-1 detector assembly process has analyzed 60 processes and 95 failure modes. The detailed analysis results are shown in Table 3.

**Table 3.** The detailed analysis results

| Process: Function Requirements | Potential Effects of mode | Potential Effects of Failure | Potential Causes of Mechanisms of Failure | Detection means | Before improvement | Process Control Prevention and Inspection | Improving measures after implementation |
|--------------------------------|--------------------------|-----------------------------|------------------------------------------|----------------|-------------------|------------------------------------------|----------------------------------------|
| Probe packing^3,^ | Structural Collision Damage^3 | Follow-up process^5 | The whole process^3 | Product-(spacecraft)^3 | Y | 4^6 | 1^6 | 2^6 | 16^6 | Strict control of crane speed. Before use, check and confirm that there is no mistake, then connect and install the hanger. |

According to the FMEA analysis results of the assembly process, considering the severity, occurrence, detection and RPN values, the key control links are refined assembly requirements, quantitative indicators are proposed, mandatory checkpoints are set, forms are formed, and tracked in the actual process.

The completed assembly work proves that after the implementation of the improvement measures, the risk priority of the assembly process mainly concentrates in the lower numerical range, and most of the faults are detectable, the ground state can be solved, the severity is low, and the impact on the
detector flight is small. The follow-up assembly work, due to its long cycle, complex tasks and many interface features, is mainly to clarify the overall requirements, improve the quality of personnel, refine process regulations, and strengthen site management is an effective means to prevent and control failures.

5. Conclusions
In the end, taking the development of Mars probe as an example and considering the actual situation, the assembly process and FMEA agreement are proposed and formulated. According to the development process, the failure modes, causes and effects (severity) of the main processes are analyzed, and the risk sequence number (RPN) is obtained by combining the frequency of occurrence and the difficulty of detection as the basis for determining the control measures. By sorting out the assembly work and key points in each stage of AIT, 60 processes and 95 failure modes are analyzed, and possible weaknesses are identified. Process control measures to eliminate these failure modes and their causes or to reduce the risk to an acceptable range (RPN below 12) are proposed. And improve the quality and efficiency of product development by strengthening the management of FMEA.

References
[1] Department of the NAVY Commanding Officer. MILSTD-1629A Failure mode effect analysis[S].Department of Defense, Washington D.C., 1980
[2] YI Wangmin, SUN Gang, LIU Hongyang. Reliability of Spacecraft Assembly, Space Environment Engineering, 2006, 23(3): 161-164
[3] Guidelines for failure modes and effects analysis of spacecraft products, Q/W 1364-2012
[4] LIU Zhiquan, GONG Ying. Consideration about the Validity of Aerospace Product FMEA, Spacecraft Engineering, 2011, 20(1): 142-146
[5] ESA. Space Product Assurance Failure modes, effects and criticality analysis (FMECA), ECSS-Q-30-02A-2001