Extraction and utilization of satellite products life and reliability data on orbit

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Abstract. Based on the analysis and carding of the reliability and life parameters of satellites, the paper sorted out the on orbit reliability features of various types of satellite products according to the basic concept of reliability. Further, the paper put forward the basic method of reliability feature extraction based on satellite telemetry data. On this basis, the on orbit reliability database of satellite products is designed, which effectively realizes the classified storage and management application of on orbit reliability related information, and provides support for the following on orbit reliability data on orbit life prediction, reliability evaluation and other aspects of utilization.

1. Introduction
For aerospace product reliability, establishing reliability database is a very important work[1]. In order to meet the requirements of reliability research and reliability design, reliability database is a necessary condition for engineers to carry out accurate reliability design[2-3]. Developed countries have always attached great importance to the collection of reliability data[4]. For example, the U.S. government and industry jointly established a non-profit government industry data exchange program (GIDEP) in 1959. The member includes NASA's Department of defense, the armed forces, the Department of energy, the Ministry of Commerce, and the Civil Aviation Administration of China, as well as many companies undertaking military contracts, such as Boeing and Honeywell. Members exchange and share various technical and management information which is constantly updated, such as quality, reliability, maintainability, safety, measurement, electronic components and other technical and management information[5]. In contrast, the construction of domestic aerospace reliability database is still in its infancy.

Space technology and its industry are playing an increasingly important role in the national economic construction. At the same time, higher requirements are put forward for the stable and reliable operation and long life of spacecraft in orbit. The development of small sample satellite products and the special requirements of a successful satellite product determine that it is very difficult to rely on the ground test for the analysis of satellite products on orbit life prediction and reliability evaluation. The effective way to solve this problem is to make full use of a large number of on orbit data to systematically analyze and evaluate the life and reliability of satellite products.

Up to now, there are more than 400 Chinese satellites in orbit, which accumulate a lot of on orbit work information, including all kinds of operation information after the satellite is launched into orbit. At present, it is urgent to analyze and refine the on orbit data of these satellites (especially those in extended service), and establish the collection, management and utilization mechanism of on orbit...
life and reliability information of satellite products in time. Continuously accumulate the on orbit work information of each model is the effective support for the subsequent data utilization.

2. On orbit life and reliability parameter identification
The key to the collection of reliability related data of satellite products in orbit is how to extract the reliability related information from a large number of telemetry data in orbit, and how to store and apply it. In this paper, by analyzing the on orbit working characteristics of different types of products, the life and reliability characteristic information is classified, and the collection and calculation methods are given.

2.1 Analysis of reliability information from the perspective of on working characteristics
First of all, by reviewing the definition of reliability, we analyze which information can be used as the life and reliability data range to be collected in the on orbit work phase. From the characteristics of product reliability, that is, reliability connotation: specified conditions, specified time and specified tasks, the on orbit life and reliability data range are studied.

The specified conditions include the original space environment, product introduction environment and coupling environment of the satellite orbit. From this point of view, it is necessary to collect the original environment data obtained by the heat, force, space environment and other sensors configured and used on the satellite in orbit for a long time, as well as other various environment data obtained through indirect calculation, collectively referred to as environment data.

The specified time, including the operation life, working time, switching times and working cycle times of spacecraft and single machine products, and the on orbit data types of different types of products are also different. For example, if the electronic products correspond to the on orbit operation time, it is necessary to count the startup time of the products after the launch of the spacecraft in combination with the flight program; the mechanism products are the number of on-off and rotation cycles, which are related to their working modes; the battery products are the number of working cycles, etc. These are the on orbit life data of the products.

The specified tasks are directly related to the functional performance of products, and the on orbit data representing various products are also different. Electronic products include output voltage, output power, and mechanism products include output rotation and torque, which is the performance data of products.

For different kinds of products, study the main working mode and the influence of on orbit environment on product performance, analyze the reliability characteristics such as cumulative working characteristics and product degradation characteristics of products, study the relationship between telemetry parameters and product reliability characteristics of products on orbit, and identify on orbit reliability data items of different products.

2.2 Determination of on orbit life parameters for typical classification satellite products
Based on the above understanding and the operability, we determine the range of life and reliability data to be collected according to the specific classification of several typical satellite products.

- Determination of life parameters of electronic products

Electronic products are common product categories on satellite platforms. Most of measurement and control, data tube, power supply, control and other subsystems consist of electronic products. These sub-systems generally work continuously in orbit for a long time, so most of the electronic products in orbit are in a long-term continuous operation mode. The cold backup electronic products, would turn on caused by on orbit test or single particle turnover and other reasons. For electronic products with data transmission and other loads, the on orbit mode is discontinuous, and the machine would be switched on and off several times a day.

Most electronic products follow the exponential distribution, and the time in the middle part of the bathtub curve is very long. That is to say, the working time with stable failure rate and low failure
rate is very long, so the cumulative working characteristics of products mainly depend on the length of working time of products.

Therefore, the main working life parameters of electronic products are working time and switching times.

- **Determination of life parameters of mechanical and electrical products**
  Mechanical and electrical products are mostly mechanical and electrical moving parts, such as gyroscopes. For the active part, the main working life parameters are the accumulated movement times and rotation angle.

- **Determination of life parameters of thruster products**
  The thruster is mainly used to maintain the satellite orbit or assist in attitude maintenance. For the satellite that cannot be directly put into orbit during launch, the thruster will also complete the function of orbit change.
  For the thruster, its working life parameter is the accumulated starting working time.

- **Determination of life parameters of photoelectric products**
  Solar array is a typical photoelectric product. Driven by the driving mechanism of solar array, it always points to the sun and converts sunlight into electrical energy.
  For the low orbit satellite working in the sun synchronous orbit, turning a circle of Junhui around the earth will enter into the shadow. On the one hand, entering and leaving the shadow will cause periodic changes in the light of the solar cell. It will also play a role in the cold and hot alternation of the devices on the solar cell, affecting the working life of the devices.
  Therefore, the main working life parameters of solar array are working time and times of entering the earth shadow.

- **Determination of life parameters of battery products**
  Storage battery is a kind of chemical battery which can charge and discharge repeatedly. At present, the batteries that can be used in orbit for a long time mainly include nickel cadmium batteries, nickel hydrogen batteries and lithium-ion batteries.
  For battery products, the work demand is mainly to supply power for satellites in the shadow period, and each time when entering and leaving the shadow will experience a process of discharging and charging. For the battery, the number of charge and discharge cycles is the main factor restricting its service life.
  Therefore, the main working life parameter of battery products is the cumulative number of cycles.

- **Determination of life parameters of thermal control products**
  For heat pipe, thermal control coating and other products, the main life parameter of the satellite is the working time, because it does not involve the problem of switching on and off, and it works for a long time after the satellite is put into orbit.
  The main working life parameter is working time.

3. On orbit life parameter processing
The premise of obtaining the above life and reliability data is to master the telemetry data of the satellite in orbit.
Telemetry data refers to the data provided to spacecraft engineers and users through sensor transformation, acquisition and arrangement, subcarrier modulation and other processing, and then sent to the ground receiving station through wireless channel[6]. This kind of data reflects the real state of the spacecraft in orbit, including the status information and temperature information of the subsystem equipment, which has the characteristics of fixed data format, slow data change and large amount of data. Telemetry data is the basis of the ground on orbit management platform for satellite on orbit status monitoring, on orbit abnormal alarm and processing, on orbit data analysis, etc[7].
At present, the overall research and development unit of the satellite has mastered and realized the comprehensive storage and management of the satellite in orbit data, which can be used as the basis for analyzing the satellite in orbit working state. This kind of data can be directly used for further data analysis and extraction[8].
3.1 Treatment method of main life parameters

On the basis of on-orbit telemetry information, the on-orbit reliability parameter information can be obtained by processing the telemetry information of satellite products. According to the life parameter information determined above, the calculation process of life parameter information extraction by on-orbit data is given. In this paper, according to the characteristic parameters of various products, the threshold value method and trend analysis method can be used to determine whether the products can work normally in orbit. By referring to the parameter range and index change range specified in the satellite design documents, the life parameter information can be obtained.

Besides, the fault information should include the number of faults, the severity of faults and whether they are completely repaired.

Table 1. Data processing algorithm for typical product life time on orbit.

| No. | Product category | Representative product; | Life time characteristic parameter | Data processing algorithm |
|-----|------------------|-------------------------|------------------------------------|---------------------------|
| 1   | Electronic class | Data management computer | Accumulated working time; Times of switching on and off; Failure data | Mainly used performance parameters such as "voltage" or "current" to judge, and the accumulated working time and switching times are accumulated according to the working state. |
| 2   | Photoelectric class; | Gyroscope | Starting and stopping times of electrode MTTF; Failure data; | Mainly use “rotation angle rate” and other parameters to judge, and the number of motor start and stop and the time without fault are accumulated according to the working state. |
| 3   | Electromechanical class | Solar array | Accumulated working time; Times of entering the earth shadow; Failure data | The number of entering the ground shadow is mainly determined according to the change of output current, mainly use the start-up time or shut-down time to determine, and accumulates the number of air jets and working time according to the on-orbit working state. |
| 4   | Thruster class | Thruster | The number of air jets; Working time; Failure data | Mainly use the start-up time or shut-down time to determine, and accumulates the number of air jets and working time according to the on-orbit working state. |
| 5   | Battery class | Cadmium nickel battery | Number of cycles; Failure data | Use the "voltage" performance parameters to determine, and use the number of periodic changes of voltage to count the number of cycles. Use charging current and discharge point current. The times are accumulated according to the charge discharge cycle. |
### 3.2 Treatment method of degenerate parameters

For on orbit products with degradation performance, such as electromechanical products, batteries, thermal control products, etc., the degradation of on orbit work can be further identified. After extracting telemetry information, the data can be combed again by statistical analysis, big data mining and other methods.

**Table 2.** Data processing algorithm for typical product degenerate characteristic on orbit

| NO | Product category | Representative product; | Degenerate characteristic parameter | Data processing algorithm |
|----|------------------|-------------------------|-------------------------------------|---------------------------|
| 1  | Electromechanical class | Gyroscope | Motor current; Shaft temperature angular velocity output | Wiener process model based on statistical analysis or linear drift |
| 2  | Battery class | Cadmium nickel battery | Battery voltage; Discharge current and charging current; Battery temperature | Fit the battery voltage, discharge current and charging current according to the charge discharge cycle, and record the extreme value; take the extreme value of the final discharge voltage and draw the curve. |
| 3  | Thermal control class | Thermal control material | Degradation rate; Temperature change rate. | The degradation rate is calculated by comparing the sample test value with the reference value, and the temperature change rate is obtained by remote sensing. |

### 4. On orbit life and reliability database design

In order to store and manage the on orbit reliability information more efficiently, the most effective method is to establish a database of on orbit life and reliability which can be directly connected with on orbit telemetry information, to acquire telemetry information directly and to calculate and extract on orbit data. The reliability processing method and the determination of data range in the database are based on the above research.

By fully considering the characteristics of on orbit data and the possibility of future application, on orbit life and reliability database of satellite was designed. The realization is as follows: 1) It can use database to extract, sort and classify the life and reliability data on orbit of satellite products. 2) It can reserve the tool interface for data retrieval, and reserve the interface for product degradation trend analysis, reliability evaluation, life prediction and other calculation and analysis. 3) Data storage function is provided for the analysis results of various on orbit life and reliability data.

#### 4.1 On orbit life and reliability database architecture design
According to the defined database functions, we divide the database architecture into two levels, the basic data layer and the life and reliability data layer. As shown in the figure, the first layer is to sort out all kinds of on orbit information of key products, establish the on orbit basic database of satellite products through automatic data extraction and update, use the mass data storage and management method of on orbit telemetry data to efficiently store and quickly query the satellite telemetry data, and obtain the available reliability telemetry data. In addition, obtain and storage the abnormal cases which will help to analyze reliability data. Further establish spatial environment database for the collection of on orbit operation environment information.

The second layer is to further mine the life and reliability information and establish the life and reliability database on the basis of the on orbit basic database. Through the calculation of the accumulated working time and the times of switching on and off, the information of product on orbit life and reliability parameters is classified and stored; the information obtained on orbit is used to carry out the sorting and standardized storage of reliability assessment, life prediction and other sub-systems to form the reliability information result database.

![Diagram: Architecture design for the on orbit life and reliability database.](image)

**Figure 1.** Architecture design for the on orbit life and reliability database.

### 4.2 Database subsequent application development

Based on the basic meaning of reliability, the paper analyzes the available on orbit data and extracts the on orbit life and reliability information. According to the actual needs of the project, further analyze the development of various reliability design and analysis work. For example, the identification of reliability critical items can refer to on-board fault prone products and fault handling strategies; FMEA and FTA work can use on-board fault mode information; worst case analysis and thermal design can use on-board product end of life degradation data. According to the analysis of the above requirements, we can see that in the future, there are many directions for the database to further classify and store product information and use. 

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6
5. Conclusion
It is a significant and valuable engineering practice to extract and utilization of the on orbit life and reliability data of satellite products. Through the identification and processing of on orbit data, and through the establishment of database for storage, the on orbit life and reliability data information of satellites can be accumulated and managed scientifically and reasonably. Good results have been achieved in understanding the on orbit life and reliability change laws of key products. In the future, with the continuous improvement of the satellite in orbit life and reliability database system, it will not only play an increasingly important role in the reliability evaluation and life prediction of satellite products, but also provide effective support for the reliability design and analysis of satellites, and introduce new concepts for the reliability design of satellites.

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