

# Development of logistic support for space equipment on the base of the “Sail-BMSTU” midget spacecraft

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**Abstract.** The paper envisages the application of integrated logistic support conception (ILS) for space equipment on the base of the example of the student's «Sail BMSTU» midget spacecraft (MS). The peculiarities of space equipment logistic support in operation phase are considered. The special focus is done to the problem of decrease in production expenses of spacecrafts. The paper suggests that the solution of this problem has to be based on tools commonly used in engineering fields – functional analysis and FMECA. The fragment of FMECA is presented. Due to FMECA it is clear what products in spacecrafts should be calibrated in accordance with quality requirements of military class and what ones should be calibrated in accordance with quality requirements of commercial and industrial classes. Each failure mode of midget spacecraft, identified within FMECA, is studied by assessing of criticality, severity and probability of emergence. The paper describes the main procedures of integrated logistic support on the base of the student's «Sail MG TU» midget spacecraft. Recommended guidelines providing reliability of electro radio products are elaborated. The practical application of integrated logistic support in aerospace industry is reasonably presented.

## 1 Introduction

The concept of Product Lifecycle Management (PLM) covering all the processes of the life cycle (LC) technology products is actively developed in the last decade. In the field of engineering PLM tools have quite well and successfully developed and in operation of the equipment, the main approach has become an integrated logistics support (ILS) of a product. Integrated Logistics Support presents a methodology to cost optimization of products life cycle, taking into account the best operability of a technological item to exploitation support.

## 2 Main Part

The operability to exploitation support is a correspondence of product design characteristics and its information and logistic system to a demand of permanent readiness to work [1]. Therefore in ILS procedures, methods for monitoring and control of compliance with the actual performance in real operating conditions at various stages of product life cycle design requirement are very relevant. Taking into account the peculiarity of spacecraft the possibility of using ILS technologies in this sector is of undoubted concern, especially in view of the emerging world trend towards the optimization of engineering costs.

The development of midget spacecraft (MS) is a new scientific and technological direction in the satellite industry emerged in the last fifteen years. While the

satellite industry has traditionally been maintained by large, high-performance satellites, the new direction has opened up new opportunities for space missions and its share is growing. Midget spacecrafts provide a drastic reduction of the cost, as the development, production and testing, and start-up: the timing of development projects are reduced from 4-5 years to 1 year, the requirements for test and production equipment are also dramatically reduced due to the reduced dimensions, in connection with this the total cost of the projects is also reduced.

All objects of space systems have common peculiarities that affect the structure of the logistic processes of production and operation:

- the complexity and high cost of production;
- an one-off production, therefore, a unique product;
- the diversity and complexity of processes that require prior experimental and research work;
- continuous improvement of the requirements for quality, reliability, product life cycle;
- the requirement to ensure maximum reliability and quality in the pre-production and production stages without further maintenance and repair work on the next stages of the life cycle;
- as a rule, long service life of equipment (the effective operation of space systems should be provided for a limited period of its useful life). For the moment it ranges from 3 to 20 years for different specimens of space systems;
- limited capacity of utilization that should be carried out by means of space systems themselves.

Thus, the provision of maximum reliability of a device while minimizing the cost of its development is one of the most important tasks of the space industry. The implementation of integrated logistics support can yield tangible results in solving these problems.

### 3 Proposed method

At first sight complete implementation of ILS concept is impossible, as it has been mentioned the possibility of technical maintenance is strongly limited for space systems items. However, the elements of ILS concept can and should be applied to space systems, and one could refer to the Manual «International procedure specification for Logistics Support Analysis», published by the European Association of Aerospace Equipment Manufacturers (ASD) [2].

The appliance of ILS standardized methodologies – functional analysis and FMECA – to space systems items will solve the following tasks:

- Provision of “functional completeness and non-redundant set” in an item;
- Provision of maximum reliability of an item while operating;
- Provision of necessary and sufficient spectrum and amount of material and technical support;
- Provision of mission item performance;
- Provision of product life cycle cost reduction.

Unlike civilian products for space systems items the focus on the value of the product is transferred to its reliability and dependability. The primary task is to ensure trouble-free performance in the active operation of the machine process, only in this case the goal of creating a space vehicle will be made and a scientific experiment will be carried out (in the case of scientific apparatus), the cost of production will be repaid (in the case of a commercial vehicle).

The cost reduction of the product is possible due to implementation of electronic components designed for commercial and industrial use. The foreign space systems manufacturers use more often electronic components designed for commercial and industrial use.

The usage of the electronic components could reduce the production costs increasingly. The fact that up to the 2000s the space systems manufacturers use items designed only for space application. They are characterized by a high degree of reliability. Reliability characteristics of most high-end products (space applications) are different from those in the commercial is about 80-100 times. The difference in electronic components cost for space and commercial application is estimated approximately by the same figures.

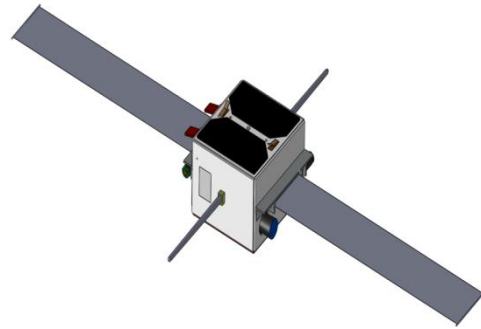
The application of electronic components of industrial class instead of expensive and inaccessible foreign ones in space systems is possible due to the implementation of a vast program of rejected, super rejected and diagnostic tests on the base of non-destructive examination methods, as well as the structural control and physical analysis of representative samples from each batch. [3].

Detailed selection procedure can significantly improve the quality and reduce breakdown rates in batch in 10-30

times on the average due to exclusion of electronic components with hidden defects.

The use of functional analysis and FMECA algorithms for space systems allow to determine where it is possible to use electronic components of industrial class and where one can use more reliable components.

The application of above mentioned algorithms will be shown on the base of student’s “Sail BMSTU” midget spacecraft (fig.1).



**Figure 1.** Sail BMSTU

“Sail BMSTU” was launched in September 2009 in Bauman Moscow State Technical University in academic and research youth space center. The main goal of this center is the elaboration of a midget spacecraft with a solar sail. The main idea of this project is the usage as a light-reflecting surface of the solar sail two narrow strips, which can simply be rolled up on the reel [4].

At the moment the project is adopted by the Federal Space Agency (Roscosmos) to the program of scientific experiments at the International Space Station (ISS). The project team has had to elaborate experimental design of “Sail BMSTU” midget spacecraft.

During the space experiment it is planned firstly to disclose a thin film structure in the form of two strips under the influence of centrifugal forces from the board of the midget spacecraft in the close proximity of the ISS and then test the onboard systems to flight mode for the duration of the active existence of the spacecraft.

This experiment has to achieve the following objectives:

- deploying technology demonstration of the thin film long strips by centrifugal forces;
- demonstration of the on-board equipment based on electronic components designed for non specialized purposes (microcontrollers, temperature sensors, pressure and angular velocity, radios, batteries) in space flight conditions;
- verification of the mathematical model of the thin-film structure dynamics during space flight.

“Sail BMSTU” midget spacecraft has a non-standard way to start - manual start of an astronaut during extravehicular activity on the International Space Station. Therefore, in orbital flight “Sail BMSTU” midget spacecraft is in two states: a state in the storage part of the ISS and the active work of the state, after the launch of the ISS.

### 4 Analysis

Because of the limited scope of the article it is difficult to describe a fully developed procedure for “Sail BMSTU” midget spacecraft – functional analysis and FMECA. In order to present the logic of the conducted work there are fragments in this paper as these procedures are standardized methodologies and the problem is not the algorithms essence but in their application to specific objects. The fragment of functional analysis is presented in Table 1.

**Table 1.** Functional analysis of “Sail BMSTU” midget spacecraft.

Functions	List of subsystems
<b>F0: Deployment of a thin-film structure and downlink</b>	<b>“Sail BMSTU” midget spacecraft</b>
<b>F1: Deployment of studied construction of a solar sail</b>	Deploying system of a frameless thin-film construction
F11: strip storage	Tape reel
F12: deployment of a strip	Stepper engine
F13: midget spacecraft spin-up	Balance-wheel engine
F131: Electric energy conversion into rotation mechanical energy	Brushless engine
F132: Rotation mechanical energy storage	Balance-wheel
F14: generation of commands in experiment management	Micro controller
<b>F2: getting and storing data</b>	Onboard complex control system
F21: rotation sensing of midget spacecraft in three axel groups	MEMS gyro sensor
F22: Photo registration of deployment process	Photo camera
F23: information output about current time	Real-time clock
F24: temperature measuring of component parts of midget spacecraft	Temperature sensor

Taking into account the results of the conducted functional analysis of MS one could have concluded that the optimal product design and the possibility of its further development. The phone is no duplication of functions in different elements, all functions are blocked structural elements. As a result of the functional analysis obtained composition features and design structure of products for FMECA procedure.

Quantitative evaluation of the reliability of the element can be carried out, using as an indicator of the probability of failure-free operation (PFFO). PFFO is calculated by the following formula:

$$P(t) = e^{-\lambda t} \quad (1)$$

where  $\lambda$  – failure rate level of an element; 1/hour;  $t$  – running time of an element, hour. At that the probability

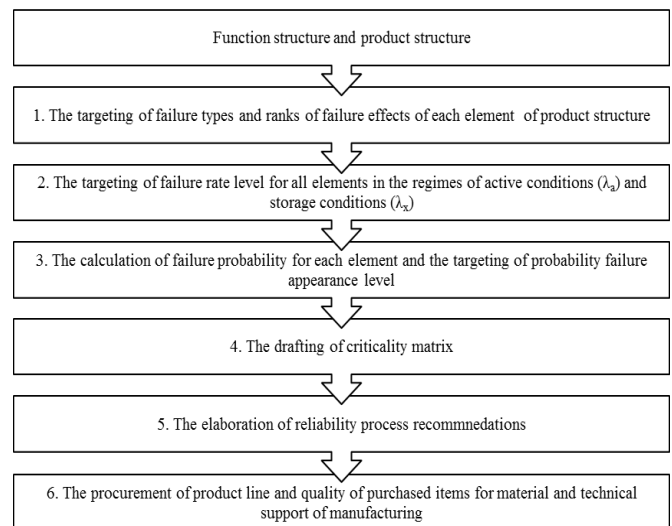
of failure initiation is a reciprocal magnitude of probability of non-failure operation.

In FMECA each structure element has a targeted magnitude of failure rate level. Failure rate is calculated separately for each type of element. The magnitudes of failure rate level for electronic components are given in reference literature and manufacturer’s specifications, so it is reasonable to carry out FMECA up to the level of each separate electronic component. Since MS will be founded in two states, it is necessary to calculate the resulting PFFO. Taking into consideration that successive events are independent, one can use the formula:

$$P(t) = \prod_{i=1}^n P_i(t) \quad (2)$$

where  $n$  - number of states of the system.

The algorithm of FMECA for MS is presented on fig.2.



**Figure 2.** The Algorithm of FMECA

Then for MS the authors of the present article have elaborated the classification of failure critical levels – ranks of failure effects (table 2) and probability level of failure appearance (table 3).

**Table 2.** The classification of failure critical levels.

Critical level	Rank	Failure effects
1	Catastrophic	Element failure leads to the inability of performing two tasks by a satellite
2	Critical	Element failure leads to the inability of performing one task by a satellite
3	Significant	Element failure leads to a decrease in the volume of scientific data obtained

4	Non-significant	Failure element doesn't lead to the lack of system exploitation characteristics, but causes the decrease of a reliability level (reserve rate)
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**Table 3.** Probability level of failure appearance.

Probability level of failure appearance	Description
A	Frequent failure. The probability of failure appearance for a predetermined time exceeds $6 \cdot 10^{-3}$
B	Probable failure. The probability of failure appearance for a predetermined time ranges from $5 \cdot 10^{-3}$ to $6 \cdot 10^{-3}$
C	Possible failure. The probability of failure appearance for a predetermined time ranges from $3 \cdot 10^{-3}$ to $5 \cdot 10^{-3}$
D	Rare failure. The probability of failure appearance for a predetermined time ranges from $1 \cdot 10^{-3}$ to $3 \cdot 10^{-3}$
E	Remote failure. The probability of failure appearance for a predetermined time is lower than $1 \cdot 10^{-3}$

Then MS elements are recorded in the criticality matrix, where they are ranked according to the probability level of failure appearance and ranks of failure effects.

Fig.3 presents the criticality matrix for "Sail-BMSTU" midget spacecraft.

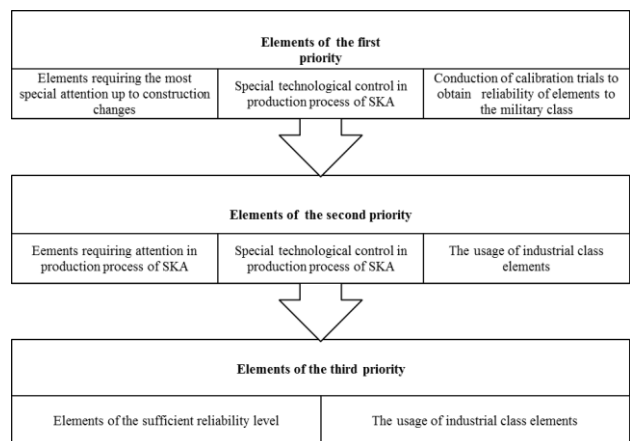
Probability level of failure appearance	Ranks of failure effects			
	4	3	2	1
A	Converter UART-USB	Photocamera	Controller of battery charge/discharge, Micro assembly – receiver/transmitter	Microcontroller
B				Line

				power stabilizer
C		MEMS gyro sensor	USB-connector	
D	Temperature sensor	Real time clock, memory EEPROM	Tape reel, stepper engine, relay switch, body frame	Circuit plate
E	Receiving and technological aerial, light emitted diode		Transmitting dipole aerial, film heater, brushless engine, balance-wheel	Charge battery, solar element, toggle switcher, micro commutator

**Figure 3.** Criticality matrix of "Sail BMSTU" midget spacecraft

The dark grey area indicates the first priority; the light grey area is of the second priority; the white one is the third priority area.

Based on the FMECA results, the recommendations to ensure the reliability of the MS in accordance with the received priority areas have been elaborated (Fig. 4). In case of first priority area it is necessary to conduct calibration trials to obtain reliability of elements to the military class [5]. Electronic components of industrial reliability level have the quality factor  $K = 10$ . They can be brought to the level of quality corresponding to military equipment ( $K = 1$ ), using complex of additional calibration trials (Table 4).



**Figure 4.** Elements of MS in coincidence of priority areas

**Table 4.** Calibration trials.

Recommended additional calibration trials	The expected increase of quality for electronic components
Measurement of electrical parameters for increased severe standards for normal, positive and	1,9

negative temperature	
10 thermo cycles with the measurement of electrical parameters	1,6
Heat test in period of no less than 168 hours. With maximum working temperature for a given element	2
Measurement of informative-bearing parameters after heat test	1,5

The authors have calculated the quality of purchased items of first priority area. We'll use the formula of determining the sample size which would allow to evaluate the rejection proportion in the production lot (10,000 units), up to 2% at a confidence figure  $P = 0,95$ . That is, if the rejection proportion is the  $k\%$ , then with probability of 0,95 we could consider to get rejection share  $k\%$  in the range of  $k\% + 2\% < k' \% < k\% - 2\%$ .

$$n = \frac{t^2 pq}{\Delta^2} = \frac{2^2 * 0,01 * 0,09}{0,02^2} = 9 \quad (3)$$

where  $n$  - elements number in the sample,  
 $t$  – the confidence coefficient. It is determined by the table of the Laplace function  $F(t)$ , in case the confidence figure is known to the researcher  
 $p$  - the rejection proportion in the sample.  
 $q$  - the proportion of qualitative items in the sample.  
 $\Delta$  - given accuracy.

The magnitude of rejection share has been calculated as an average arithmetic mean of rejection shares in electronic components tests for different products. These tests are fulfilled by JSC “Russian Scientific Institute “Elektronstandart”, specializing calibration trials and increasing of electronic components reliability level. For the other elements of the number of items purchased is equal to one piece.

## 5 Conclusion

Thus, having fulfilled the elaborated algorithm of ILS tools application, we get a particular product line and quality of purchased items for material and technical support of manufacturing for spacecraft. Thus it is possible to achieve a significant reduction in product prices due to the use of electronic components of industrial class reliability while ensuring the required level of reliability of the product.

The application of flexible technique such as FMECA has provided the separation of priority elements to military and civil classes. Thus by means of FMECA it is clear what elements should be calibrated. That is the essence of logistic support conception in aerospace industry.

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