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# Reliability evaluation methods for unmanned aircraft systems with multi-rotors

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# Reliability evaluation methods for unmanned aircraft systems with multi-rotors

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**Abstract**: According to the characteristics of unmanned aircraft systems (UASs) with multi-rotors, this paper realizes the reliability evaluation. Referring to the relevant standards and specifications for reliability evaluation of electronic products and communication products, the methods of sampling, test plan, test conditions and index evaluation related to reliability evaluation of Referring to are proposed. Based on the exponential distribution, the reliability index and its calculation method are put forward, and the evaluation method for non-failure data is also studied. The method is applied and the reliability level of UASs with multi-rotors is obtained. This method meets the actual market demand and provides a practical method for UASs reliability evaluation.

## 1. INTRODUCTION

With the progress of aviation technology and wireless transmission, the application of multi rotor UASs has increased significantly, and the development and dealers of UASs with international cutting-edge have emerged in China. Drones are used more and more, and they are changing from professional level to consumer level. It can be seen that the UASs industry has entered a period of vigorous development.

However, with the development of UASs, some safety accidents have gradually occurred, so the reliability of multi rotor UASs has become a hot spot. Lv et al. Studied the system reliability of UASs and proposed an estimation method for the reliability test of samples [1]. Zhang Rui et al. Studied the reliability allocation method of UASs system [2]. Zhou Jinniu judged the reliability of UASs Based on fuzzy comprehensive evaluation method [3]. Based on the data used by domestic UASs in the outfield, Zhang Wenjin and others used the method of establishing mission reliability block diagram to successively establish the mission reliability models of subsystems and systems, and completed the prediction of mission success probability (MCP) [4]. But this method requires the accumulation of a large amount of data. Prescott D.R. et al. Proposed the method of using BDD for task planning of multi-stage mission system taking UASs as an example [5]. Therefore, most of the current reliability evaluation methods rely on the failure data of the underlying parts, and the evaluation is based on the reliability analysis method. Some reliability evaluation methods for sample tests also rely on a large number of samples, and a large number of failures are required. Most of them focus on the data analysis method, lacking a systematic test design method.

Therefore, this paper presents a reliability evaluation method for multi rotor UASs, determines the sampling, test scheme, test conditions and index evaluation methods, and puts forward the non-failure data processing method.

## 2. TEST METHODS

The goal of the reliability evaluation methods is to describe the reliability level of the system operation of UASs with multi-rotors as a whole, namely the mean operating time between failures (MTBF) and the mean operating time to first failures (MTTF). According to the life test method, UASs with multi-rotors reliability evaluation test adopts the sampling test method. Sampling from qualified batches of drone products produced within the last two years. The number of samples should be no less than 3 units. The censoring time of the test should be no less than 10 times the battery life of the product.

The test conditions are as follows:

a) Generally, the reliability field tracking test should be carried out after the UAS works for 3 endurance times. If it is necessary to track early failures and failures during normal use, the reliability field tracking test can be carried out after the UAS product is put into operation;

b) The mission profile and environmental profile should be determined in advance according to various information of the UAS life cycle;

c) One or a series of typical programs can be compiled according to the information of the mission profile, so as to simulate the mission profile in the test field test;

d) The test environment should be arranged according to the environmental profile of the UAS;

e) During the test, the simulation program of the task profile and the simulation environment of the environment profile shall be applied at the same time to fully expose the system failure;

f) If the accelerated method is used for the test, the following requirements should be met: 1) The accelerated method should have obvious acceleration; 2) The accelerated method should not change the failure mode and failure mechanism; 3) The acceleration factor should be determined.

## 3. RELIABILITY INDEX EVALUATION

The reliability indexes of UASs with multi-rotors include MTTF and MTBF.

### *3.1 Point estimation of MTTF*

The calculation formula for the point estimation of MTTF is as follows:

$$m = \frac{T_0}{N} \quad (1)$$

Where $T_0$ is the sum of working time before the first failure of all samples, in hours (H); N is the total number of samples.

### *3.2 Point estimation of MTBF*

The calculation formula for the point estimation of MTBF is as follows:

$$\mathrm{m} = \frac{\sum_{i=1}^{N} t_i}{r} = \frac{\sum_{i=1}^{N} t_i}{\sum_{i=1}^{N} r_i} \quad (2)$$

Where r is the total number of failures; $t_i$ is the accumulated working time of the ith UAS in the evaluation period, in hours (h); $r_i$ is the cumulative failure number of the ith UAS in the evaluation period.

### *3.3 Non-failure data analysis of MTBF*

If the UASs products do not failure in the fixed time test, the lower confidence limit of MTBF is:

$$m_L = \frac{T}{-ln(1-\alpha)} \quad (3)$$

Where T is the total test time of all samples for the fixed time test, in hours (h); α is the confidence level.

### *3.4 Interval estimation of MTBF*

The interval estimation method of MTBF is as follows:

$$m_L = mC_L \tag{4}$$

$$m_U = \mathrm{m}C_U \tag{5}$$

Where $m_L$ is the lower confidence limit of MTBF; $m_U$ is the upper confidence limit of MTBF; $C_L$ is the lower confidence limit coefficient of MTBF for the fixed time test (see Table 1); $C_U$ is the upper confidence limit coefficient of MTBF for the fixed time test (see Table 1).

Table 1. Confidence coefficient of two sides (or one side) when MTBF is calculated in the fixed time test

| r | 40% (two sides) | | 60% (two sides) | | 80% (two sides) | | 90% (two sides) | |
|---|---|---|---|---|---|---|---|---|
| | 70% (one-sided confidence lower limit) | 70% (one-sided confidence upper limit) | 80% (one-sided confidence lower limit) | 80% (one-sided confidence upper limit) | 90% (one-sided confidence lower limit) | 90% (one-sided confidence upper limit) | 95% (one-sided confidence lower limit) | 95% (one-sided confidence upper limit) |
| 1 | 0.410 | 2.804 | 0.334 | 4.481 | 0.257 | 9.491 | 0.211 | 19.417 |
| 2 | 0.553 | 1.803 | 0.467 | 2.426 | 0.376 | 3.761 | 0.317 | 5.658 |
| 3 | 0.630 | 1.568 | 0.544 | 1.955 | 0.499 | 2.722 | 0.387 | 3.659 |
| 4 | 0.679 | 1.447 | 0.595 | 1,742 | 0.500 | 2.293 | 0.437 | 2.930 |

## 4. APPLICATION

In this application, three sets of UAS are used, which have been processed and passed the appearance acceptance and functional performance test. The test adopts the timed censoring test scheme, and the cumulative relevant test time of each sample should be 10 times the product endurance time.

### *4.1 Test profile*

Make the UAS fly circularly according to the following eight stages until the UAS reaches the endurance time and returns when the power is insufficient , as shown in Figure 1.

Stage 1: take off the UAS from the ground and reach a vertical height of 10m above the ground in about 20 seconds;

Stage 2: hover the UAS at a height of 10m above the ground for 20s;

Stage 3: test the maximum ascent speed of UAS, and fly the UAS at the maximum ascent speed;

Stage 4: test the maximum horizontal speed of UAS, and fly the UAS at the maximum horizontal speed;

Stage 5: raise the UAS to a vertical height of 100m above the ground;

Stage 6: hover the UAS at a height of 100m above the ground for 10s;

Stage 7: test the maximum descent speed of UAS, and land the UAS at the maximum descent speed;

Stage 8: UAS landing flight.

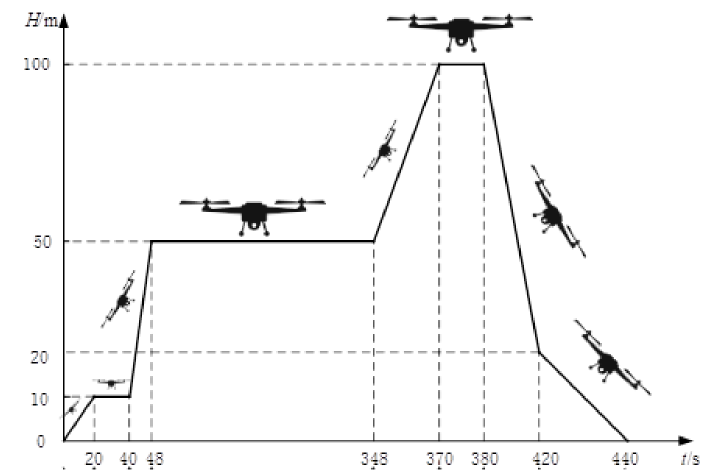


Figure 1. Test profile of the UASs

*4.2 Test data*

From October 12, 2021 to June 2, 2022, field flight test will be carried out in Mohe. There are 3 test samples, and each UAS has been tested for 12 times the endurance time. The operation process is recorded as follows:

Table 2. Reliability test operation record of UAS 01

| No. | Date | Runtime | | Downtime | Recovery time |
|---|---|---|---|---|---|
| | | Start time | End time | | |
| 1 | 2021.10.22 | 9：00 | 9：25 | | |
| 2 | 2021.10.25 | 9：00 | 9：22 | | |
| 3 | 2022.01.26 | 9：00 | 9：10 | | |
| 4 | 2022.05.05 | 9：00 | 9：03 | 9：03 | 9：30 |
| 5 | 2022.05.07 | 9：00 | 9：30 | | |
| 6 | 2022.05.10 | 9：00 | 9：25 | | |
| 7 | 2022.05.13 | 9：00 | 9：25 | | |
| 8 | 2022.05.17 | 9：00 | 9：30 | | |
| 9 | 2022.05.21 | 9：00 | 9：25 | | |
| 10 | 2022.05.26 | 9：00 | 9：25 | | |
| 11 | 2022.05.30 | 9：00 | 9：30 | | |
| 12 | 2022.06.02 | 9：00 | 9：30 | | |

Table 3. Reliability test operation record of UAS 02

| No. | Date | Runtime | | Downtime | Recovery time |
|---|---|---|---|---|---|
| | | Start time | End time | | |
| 13 | 2021.10.22 | 9：00 | 9：30 | | |
| 14 | 2021.10.25 | 9：00 | 9：30 | | |
| 15 | 2022.01.26 | 9：00 | 9：30 | | |
| 16 | 2022.05.05 | 9：00 | 9：30 | | |
| 17 | 2022.05.07 | 9：00 | 9：28 | | |
| 18 | 2022.05.10 | 9：00 | 9：30 | | |
| 19 | 2022.05.13 | 9：00 | 9：25 | | |
| 20 | 2022.05.17 | 9：00 | 9：25 | | |
| 21 | 2022.05.21 | 9：00 | 9：30 | | |
| 22 | 2022.05.26 | 9：00 | 9：25 | | |
| 23 | 2022.05.30 | 9：00 | 9：23 | | |
| 24 | 2022.06.02 | 9：00 | 9：30 | 9:20 | 9:22 |

Table 4. Reliability test operation record of UAS 03

| No. | Date | Runtime | | Downtime | Recovery time |
|---|---|---|---|---|---|
| | | Start time | End time | | |
| 25 | 2021.10.22 | 9：00 | 9：25 | 9:22 | 9:24 |
| 26 | 2021.10.25 | 9：00 | 9：26 | | |
| 27 | 2022.01.26 | 9：00 | 9：25 | | |
| 28 | 2022.05.05 | 9：00 | 9：25 | | |
| 29 | 2022.05.07 | 9：00 | 9：26 | | |
| 30 | 2022.05.10 | 9：00 | 9：25 | | |
| 31 | 2022.05.13 | 9：00 | 9：23 | | |
| 32 | 2022.05.17 | 9：00 | 9：22 | | |
| 33 | 2022.05.21 | 9：00 | 9：20 | | |
| 34 | 2022.05.26 | 9：00 | 9：22 | | |
| 35 | 2022.05.30 | 9：00 | 9：20 | | |
| 36 | 2022.06.02 | 9：00 | 9：23 | | |

*4.3 Failure conditions and treatments*

During this test, the tested product has three failures , as shown in Table 5.

Table 5. Summary of failure conditions and treatments

| Sample No. | Date of failure | Failure phenomenon | failure cause | treatment |
|---|---|---|---|---|
| 01 | 2022.05.05 | UAS out of control, causing blade damage. | Failed to receive GPS signal | Replace the damaged blades, and the UAV flight test is normal |
| 02 | 2022.06.02 | When the UAV rises to 100m, the prompt of the remote controller drops and the signal is weak. | Signal link disturbed | After returning home, the UAV conducted flight test again, and there was no abnormality |
| 03 | 2021.10.22 | When the UAV flies to 50m, the flight data is not displayed, indicating that the aircraft loses control and starts to return | Signal link interruption | After returning home, the UAV conducted flight test again, and there was no abnormality |

All faults are caused by external factors, and the UAS itself has no relevant faults, so all the three failures are not counted.

*4.4 Reliability evaluation index calculation*

Since the samples are new products and do not require preventive maintenance, only the MTBF is evaluated. Since there is no fault in the UAV product at the time of the timed censoring test, the point of the mean time between failures is estimated as follows when the confidence is 80%:

$$m_L = \frac{T}{-ln(1-\alpha)} = \frac{15.02}{-ln(1-0.8)} = 9.33h$$

## 5. CONCLUSION

This paper presents a reliability evaluation method for multi rotor UAV. Based on the relevant standards and specifications of reliability evaluation of electronic products and communication products, this method puts forward the methods of sampling, conditions, schemes, data analysis and so on. It gives the process and method of reliability evaluation applicable to UASs with multi-rotors in an engineering manner, and realizes the reliability evaluation under limited sample size. At the same time, the MTBF estimation method under fault free data is proposed, which effectively realizes the reliability evaluation of UASs with multi-rotors in practical engineering application.

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